EVOLUTION OF LAKE ERIE BASED ON THE POSTGLACIAL SEDIMENTARY RECORD BELOW THE LONG POINT, POINT PELEE, AND POINTE-AUX-PINS FORELANDS

by

John Phillip Coakley, M.Sc.

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Earth Sciences

Waterloo, Ontario 1985

I hereby declare that I am the sole author of this thesis.

I authorize the University of Waterloo to lend this thesis to other institutions or individuals for the purpose of scholarly research.

Signature

I further authorize the University of Waterloo to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Signature

The University of Waterloo requires the signatures of all persons using or photocopying this thesis. Please sign below, and give address and date.

I dedicate this thesis to my parents

Wilfred Stanley Coakley

Naomi M. Coakley

"The tale of the question is not exhausted, but no more are needed if only it has been shown that the subject is not in reality simple, as many have assumed, but highly complex.......It is a problem of nature, and like other natural problems demands the patient gathering of many facts, of facts of many kinds, of categories of facts suggested by the tentative theories of today, and of the new categories of facts to be suggested by new theories."

Grove Karl Gilbert, on the
evolution of the Niagara River.
(The Toronto Lecture, 1889, in:
Davis, 1922, p. 159)

ABSTRACT

The postglacial geological history of Lake Erie was interpreted primarily on the basis of borehole sedimentary sequences below the major accretionary forelands: Long Point, Point Pelee, and Pointe-aux-Pins. These data were complemented by a number of sedimentary profiles from other boreholes in and around the lake, radiocarbon and pollen-based dating of postglacial sediments, relict geomorphological features, and geometrical and sedimentary data from inflowing streams.

Trends in sediment properties in the basal portion of the sequences consistently show an abrupt change from glacial sediments (Unit 1), topped by an eroded surface, possibly sub-aerially exposed, to postglacial silty clays deposited in deep- or quiet-water environments (Unit 2). As topographic lows were infilled and water depths decreased, the mean grain size increased, reflected in an increasing frequency of sandy laminations (Unit 3). This transitional unit is usually topped by an erosional unconformity, suggesting non-deposition and reworking prior to the deposition of well-sorted, medium sand (Unit 4) at the top of the sequence. Deposition of the top unit began around 5000 years B.P., and clearly occurred in an upper shoreface setting where saltation and bottom traction were the predominant transport modes. This change probably marks the initiation of spit formation at the sites. All boreholes exhibit a clear coarsening-upward

textural trend, suggestive of lateral migration of the higher-energy upper shoreface (spit) facies over lower shoreface and lagoonal facies.

Combined with the radiocarbon dates and other data, the above sediment interpretation suggests important revisions to earlier interpretations of postglacial lake levels in the Lake Erie basin. Moreover, the lake level curve presented here confirms glacioisostatic rebound of the lake outlet as a major factor in the initial lake level trend, but it also suggests that other processes (such as the changing pattern of inflows from the Upper Great Lakes, the nature and postglacial tectonics of the lake outlet, and paleoclimatic influences) could have become important in the later stages.

The above data were used in a hypothetical reconstruction of Lake Erie paleogeography, including the three major forelands of the north shore. The inferred form of the contemporary shoreline, and the evolutionary trends indicated by beach-ridge patterns on the forelands themselves, suggest that these forelands did not result from conventional spit formation. Rather, their origin is due priamrily to the effectiveness of cross-lake moraines in Lake Erie as sand-accumulation sites. The evolution of the forelands over the past 3000 years involves persistent erosion and shoreward transgression under the influence of rising lake levels, in a manner analogous to the ongoing retreat of barrier islands on marine coasts.

ACKNOWLEDGEMENTS

This work could not have been accomplished without the financial and logistical support of the National Water Research Institute (NWRI) of Environment Canada where the author is presently employed. The support of the proposal from the beginning by Drs. T.M. Dick (Chief, Hydraulics Division) and M.G. Skafel (Head, Shore Processes Section) is especially appreciated. Among the support staff, special thanks are due to G.A. Duncan, for his able assistance in the field and laboratory; G. Winter, for logging the Pelee Shoal cores; and Mrs. Norma Snelling and Dianne's Word Processing (Burlington, Ontario) for typing most of the manuscript. Pollen analysis of borehole samples at Long Point and Point Pelee was done partly by C.E. Winn of Barnett-Winn Palynological Consultants (Stoney Creek, Ontario), and partly by N. Harper of NWRI.

A number of people, both at NWRI and elsewhere, were helpful in many ways. Dr. N.A. Rukavina (NWRI) provided unpublished technical reports of nearshore coring and jetting surveys around Long Point and Pointe-aux-Pins, as well as useful discussion on nearshore sediments. A.J. Zeman (NWRI) and P.J. Barnett (Ontario Geological Survey) read portions of the manuscript and gave constructive criticism and advice. B.H. Feenstra (Ontario Ministry of Natural Resources) and Dr. J. Terasmae (Brock University) also provided useful advice and information. A.J. Cooper (Gartner Lee Associates) made available the borehole data and radiocarbon dates on Pointe-aux-Pins he collected for O.G.S. in 1977.

Drs. T.W. Anderson and C.F.M. Lewis of the Geological Survey of Canada generously supplied the author with pollen profiles, borehole and nearshore core data, as well as constructive and useful advice. D.E. Guy, Jr., D. Buchanan, Dr. C.H. Carter, and J.A. Fuller (Ohio Department of Natural Resources) allowed the use of radiocarbon dates from the Ohio side of Lake Erie. Joan Pope of the Buffalo District of the U.S. Army Corps of Engineers provided borehole data for sites along the U.S. side of the lake. Valuable subsurface information and samples were kindly provided by Drs. S.J. Williams (U.S. Geological Survey) and C.M. Carmichael (University of Western Ontario).

The assistance of staff of Ontario Hydro and the Ontario Ministry of Transportation and Communication in making seismic profile and borehole data available to the author is acknowledged with gratitude. Access to seismic profiles of the eastern part of the lake was granted by the Transcontinental Gas Pipe Line Corporation, Houston, Texas. This was much appreciated. In addition, staff of the Ministry of Citizenship and Culture forwarded archaeological reports on Long Point, Turkey Point, and Pointe-aux-Pins to the author.

At the University of Waterloo, D. Desaulniers kindly carried out X-ray diffraction analyses on clay minerals, and stable isotope ratio determination on porewaters from one of the Long Point cores. Discussions and criticism of the project by my thesis committee members: Drs. J.A. Cherry, and D.E. Lawson (Department of Earth Sciences) and R.L. Thomas (Great Lakes Fisheries Research Branch, Fisheries and Oceans Canada) are acknowledged with gratitude.

Finally, I thank my Supervisor, Dr. P.F. Karrow, whose patient encouragement and incisive comments were necessary ingredients in this work.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

1.0 INTRODUCTION

The issue of the long-term evolution of Lake Erie has important implications, especially for coastal land use. In addition to being the oldest and shallowest of the Great Lakes, Lake Erie is located in the most densely populated of all the Great Lakes' basins (Dobson, 1981). Furthermore, projected trends show that population here is rising at higher rates than in the other basins. This situation is expected to become even more critical in the future when large-scale, expensive, and long-life engineering projects are contemplated for the coastal zone. Examples which come to mind are: the coastal industrial complex at Nanticoke, land resources management and planning at Long Point and Point Pelee, possible siting of toxic waste disposal sites, and proposed lake level regulation schemes for Lake Erie. In all of these some insight into natural long-term processes and cycles would be desirable.

The work described here is aimed at defining such evolutionary trends in the Lake Erie basin through an interpretation of the postglacial geological record. The focus of the research will be on the Canadian side of the lake, where samples of the postglacial sedimentary deposits could be obtained with relatively little logistical difficulty.

1.1 Geographical Setting

The northern shoreline of Lake Erie (Figure 1-1) extends some 600 km from the Detroit River in the west, to the Niagara River in the east. Composed almost entirely of unconsolidated glacial sediments, this shoreline shows considerable morphological variety. The most striking shoreline features comprise the three large forelands occurring at intervals along the shore. They all consist of a sandy, dune-covered area fronting on the open lake, with a sheltered bay or marsh behind. Because of their location at or near the southernmost point on the Canadian mainland (Point Pelee is the southernmost point), the adjacent waters are relatively warm in summer, making them popular as bathing beaches and visiting sites. In addition, the forelands lie on major bird migration routes. The forelands of Lake Erie thus represent a valuable wildlife and recreational resource to the many urban centres located in the area. Largely for this reason, ownership of large portions of all three landforms is in public hands, Point Pelee and Long Point being administered by the Government of Canada (Parks Canada and the Canadian Wildlife Service, respectively), and Pointe-aux-Pins by the Government of Ontario (Ministry of Natural Resources). Another common feature is the prevalent concern at all three sites over shore erosion and its effect on long-term land use of these areas.

The remainder of the shoreline is almost entirely in private ownership (Boulden, 1975). Much of it consists of high (up to 50 m) bluffs made up of glacial sediments. In places, these bluffs are also experiencing recession at high rates that are of concern. For instance, in the central portions of the lake shoreline between Long Point and Pointe-aux-Pins, long-term recession rates have been measured as high as 3 m/y (150-year average) (Gelinas, 1974). Short-term (10-year average) rates in excess of 5 m/y are not uncommon. These rates are the highest measured anywhere in the Great Lakes. Although most of the areas concerned are primarily agricultural, the economic losses attributed to erosion are considerable (Boulden, 1975).

1.2 Thesis Problem and Objectives

The specific objectives of this study are as follows:

1. To analyze sediment and other physical data from boreholes through the major forelands along the north shore of Lake Erie (Long Point, Point Pelee and Pointe-aux-Pins) and apply this analysis to interpreting the postglacial sedimentation history of the lake.

2. To assemble recently obtained geological information on other relevant aspects of lake history, such as radiocarbon dates, borehole stratigraphy, and shoreline geomorphology, in order to produce a synthesis of postglacial lake levels and paleogeography in the Erie basin. In addition to providing a useful constraint and independent check on the conclusions resulting from the sedimentary analysis, such a synthesis would be a desirable updating of our understanding on a subject that has not been closely examined since the 1960's.

3. To examine the formation of the three forelands occurring along the north shore of the lake whose age and mode of origin have long aroused curiosity and speculation.

1.3 Previous Work

The postglacial evolution of the Lake Erie shoreline is a topic which has only recently begun to receive attention. In most work prior to 1976, the emphasis was placed either on bedrock geology, modern bottom sediments, or most recently, on recession rates and dynamic coastal processes. One of the few early studies on shoreline evolution in this lake was that of Moseley (1904) on the origin of

Sandusky Bay and Cedar Point on the Ohio shore of the lake. Wilson (1908) made the first attempt at a regional review of the shorelines of Lakes Ontario and Erie, paying special attention to the four large cuspate and "flying" spits (he included Presque Isle, a foreland on the Pennsylvania shore in this group) occurring along the shore. He attributed these features to systematic deposition of longshore drifted material at suitable sites. Another early effort in explaining the presence of these large shoreline features was that of Kindle (1933), who investigated shoreline processes at Point Pelee, the most westerly of these features. In this report, Kindle, like Wilson, proposed a simple littoral-drift mode of formation for Point Pelee. Neither took into consideration the age of the forelands nor examined the possibility of different lake levels and shoreline geometry prevailing at the time of their formation.

Coinciding with a period of high lake levels in the 1950's, studies of shore erosion in the central shore segment from Pointe-aux-Pins to Long Point were carried out by Wood (1951), who went on to link these eroded materials to the origin and growth of Long Point in a manner similar to that proposed by Wilson (1908).

However, during this time, most of the work being done on Lake Erie was on the American side. Ross (1950) studied the Quaternary sediments in the western basin of the lake, with emphasis on the chronological classification of the proglacial lake deposits found below the modern sediments. In the 1950's, the Ohio Division of Geological Survey began publishing their investigations into shore processes and bottom materials in this area of the lake (Pincus, 1953). More detailed geological studies of the unconsolidated deposits continued into the 1960's (Hartley, 1961; Herdendorf, 1968).

Lake geology studies on the Canadian side of the lake were greatly accelerated when the University of Toronto Great Lakes Institute began such studies in the Lower Great Lakes. The pioneering work by Lewis (1966) and his colleagues (Lewis et al., 1966) represented the first attempt to study the sediments of the lake as a whole, and to tie these unconsolidated materials into the glacial and post-glacial history of the lake. It was Lewis who assigned an age of approximately 12,600 years Before Present (B.P.) for the initial low-lèvel stage, Early Lake Erie, and who devised a history of lake levels from that time to the present (Lewis, 1969). He identified the three cross-lake underwater ridges which subdivide the lake into sub-basins as glacial moraines (Lewis, 1966), and recognized that these features could form the sites of residual sand and gravel accumulation which could be linked to the location of the four large forelands (Sly and Lewis, 1972). In addition, Lewis's work on the central basin (Lewis et al., 1973) attracted others into the investigation of geotechnical, stratigraphic (pollen and paleomagnetic), as well as the paleoenvironmental (isotopic analysis) aspects of the central basin (Lewis et al., 1966; Creer et al., 1976; Fritz et al., 1975). Lewis (1966) also described the sedimentary sequence in a deep borehole drilled at Long Point, on which pollen stratigraphical analysis was carried out (T.W. Anderson, Geological Survey of Canada, 1983, pers. comm.).

In addition to Lewis, others at the University of Toronto carried out important baseline studies into Lake Erie sub-bottom sediments. Among these was Wall (1968), who identified seismic reflectors at various depths below the bottom, and interpreted their significance to the geologic history of the lake. Hobson et al. (1969) conducted more detailed seismic work in the western basin, and inferred pre-glacial drainage systems and glacial features in the area. At around this time, Terasmae (1970) published the results of stratigraphic drilling at Point Pelee, including some radiocarbon dates on basal organics below the Point.

With the opening of the Canada Centre for Inland Waters in 1968, the need for regional bottom sediment mapping for baseline purposes resulted in large-scale sediment distribution studies by Thomas et al. (1976) in the offshore areas of Lake Erie, and by Rukavina and St. Jacques (1971, 1978), and St. Jacques and Rukavina (1973) in the nearshore zone. Coakley (1977) initiated investigations into nearshore sediments and modern processes at Point Pelee while recognizing the importance of postglacial history. He also recognized that Point Pelee, and perhaps the other large forelands in the lake, could thus be seen as basically relict features now being shifted and altered by modern processes. This hypothesis also focussed attention on the possibility of a more complex lake level history in the basin during postglacial time than that proposed by Lewis (1969).

Finally, the recent (still largely uninterpreted) borehole and seismic surveys carried out by the U.S. Army Corps of Engineers (Williams and Meisburger, 1982; Williams et al., 1980; Carter et al., 1982) in the vicinity of the shoal area north of Presque Isle, and along the Ohio nearshore zone, have provided much interesting data on the nature and probable ages of these deposits. Additional Corps of Engineers' data on boreholes drilled in river mouths and harbours on the U.S. side of the lake (though unpublished) were made available and proved useful in the analysis of past lake levels. Borehole logs and a radiocarbon date, collected by the Ohio Department of Natural Resources, also proved useful.

Similar borehole data in Ontario exist in unpublished form in many public agencies, including the Ontario Geological Survey (O.G.S.), which made available unpublished borehole logs and radiocarbon dates obtained in the Pointe-aux-Pins area. An unpublished O.G.S. report on the Quaternary geology of the Niagara area of the basin has been prepared by Feenstra (1981), while land-based Quaternary geology surveys of parts of the central and eastern portions of the shoreline are presently in progress (P.J. Barnett, O.G.S., 1983, pers. comm.).

Because many of the data held by private firms were collected for other than geologic purposes, they are rarely indicated in the normal geologic literature. For instance, water well records containing descriptive sediment logs are kept for all wells drilled in Ontario in the files of the Water Resources Commission (Ontario Ministry of the Environment). Borehole logs and geotechnical reports of footings for all major construction (such as roads, bridges) are also kept on record either by the Ontario Ministry of Transportation and Communications or by Public Works Canada. Other agencies, both private and public, are often repositories of data potentially valuable to such studies as this. However, although similar data bases exist on the U.S. side of the lake, the search was restricted to Canadian agencies, with a few exceptions (U.S. Army Corps of Engineers and the Ohio Department of Natural Resources). This was done primarily for reasons of accessibility.

Detailed seismic and borehole records collected by Ontario Hydro along a narrow corridor stretching from Nanticoke, Ontario, to Coho, Ohio (Figure 1-1), were also made available (Ontario Hydro, 1981). The author was allowed access to similar seismic profiles taken between Port Colbourne, Ontario, and Sturgeon Point, New York, for the Transcontinental Gas Pipe Line Corporation. The excellent seismographs obtained showed a number of sub-bottom features and sediment data which contributed greatly to the goals of this study. Finally, much useful subsurface information was gleaned from the files of private engineering firms working in the Lake Erie area.

1.4 Study Methodology and General Procedure

As outlined in Section 1.1, the need exists for an examination of the shoreline evolution of Lake Erie over the long-term in order to respond to questions basic to present and future land use in the basin. Such an examination must necessarily begin in the geologic past when Lake Erie was formed. It is difficult to obtain a full sediment record covering the entire period of Lake Erie's existence because the net rising trend in lake levels since the lake's formation results in a record that is, in most places, either obliterated, obscured, or truncated by erosion or non-deposition. Another difficulty is that in those places where considerable portions of the sedimentary record is expected to exist (i.e., beneath the three major sandy forelands (Section 1.1) where net deposition has predominated), it is accessible only through expensive and difficult drilling operations.

1.4.1 Study approach and thesis organization

The initial phase of the study involved extensive literature search into the sequence of late glacial and postglacial events in the Lake Erie area of Ontario and the U.S. Because much of the interpreted glacial history in this area is still being debated, the review included as Chapter 2 is intended only to outline the present state-of-the-art.

The subsurface sedimentary record in Chapters 3 and 4 forms the principal data on which the study is based, and is discussed in the above glacial geological context. The aim of the sediment data-gathering phase was to characterize and highlight the postglacial portion of the sedimentary record. For this reason, emphasis was placed on borehole information - in particular, sampled boreholes. Of necessity, most of the scientific boreholes drilled were located in areas where a thick postglacial record had presumably been preserved, namely below three major depositional forelands. Although thick postglacial sedimentary sequences probably also exist in the deeper offshore areas of the lake, it was believed that such deposits would be less sensitive indicators of changes in the physical lake environment than nearshore areas. Moreover, such areas would be more difficult and costly to sample adequately.

The intention of using such data was that by careful granulometric, geotechnical, and other measurements and analysis, important trends and changes in the Lake Erie depositional environment would be documented. Supplementary examination of the stratigraphic relationships associated with the above trends would be provided by radiocarbon dates on organic matter and by contained fossils (pollen, mollusks). There are obvious limitations to this approach, however. The adequate definition of the above postglacial depositional trends would require subsurface investigations of regional scope, involving dozens of boreholes, with a correspondingly large number of radiocarbon dates and sedimentological analyses. In addition, a more exact knowledge than exists at present of ongoing physical processes in the basin (such as uplift rates, sediment transport volumes and pathways) would be required. The cost of such an effort and the scope of such an investigation would far exceed the resources of one student.

For this reason, although a limited drilling program was undertaken, much effort was also devoted in the study to uncovering and applying subsurface information collected by other agencies as outlined in Section 1.3.

The conclusions derived from the sedimentological analysis must then be verified, in this case, by comparing the inferred depositional environments with those indicated by postglacial lake history and evolution derived from other independent sources. This is attempted in Chapter 5, and culminates in a reconstruction of the lake evolution under the combined effects of the lake level rise, postglacial neotectonics, and dynamic shore-related lake processes (erosion and deposition). The procedure used is generally deductive, since direct evidence of these effects is difficult to isolate. In the reconstruction, the original lake bottom surface elevation and topography and that of the lake borderlands are reconstructed, then a shoreline position is defined by the intersection of the water plane with this topographic surface. If the original surface and lake level is known (or inferred), and the rate of rise of the lake level is also known or inferred, then hypothetical shoreline positions with time can readily be defined.

Such a simple model of shoreline development through submergence and emergence alone would be, at best, only a crude approximation since it clearly ignores two important factors in shoreline development, namely coastal erosion and, to a lesser extent, deposition. In a basin composed almost entirely of unconsolidated materials, shoreline recession due to erosion would be considerable even if lake levels were stable. Furthermore, the rates of such recession would not be uniform spatially, and would depend to a large extent on shoreline geometry (open-water wave exposure, or fetch), shoreline orientation with respect to the incoming wave climate, offshore slope, and bathymetry) and composition. The temporal non-uniformity would also be considerable, although by averaging the recession over a long enough time period, this effect could be reduced to insignificance. Net deposition could also affect the shoreline position (leading to a regressive trend) despite the net rise in lake levels over postglacial time.

Apart from a progressive infilling and smoothing of the bottom topography, however, deposition is expected to have only a local effect on shoreline evolution. Sites of major deposition are manifested in the three large forelands occurring along the Lake Erie north shore. These structures are of additional importance in view of their preserved record of shoreline positions (beach ridge patterns) and depositional environments (sediment profiles). In spite of the difficulties involved, it is important that an attempt be made to include both long-term shore erosion and depositional landforms into our model of shoreline evolution.

Another factor that must be re-evaluated in our reconstruction of shoreline positions is the assumption that lake levels rose in a uniform fashion from Early Lake Erie to the present. The question of whether all the sub-basins of the lake were always confluent (i.e., at the same level), and if not, the history of levels in each, must also be taken into account. Other questions must be addressed, namely, how quickly did levels rise to their present elevations? Was there another low level stage when drainage from the upper lakes bypassed Lake Erie (between the Lake Algonquin and Nipissing phases)? Were postglacial lake levels ever higher than at present? These questions could be approached by the collection of as large a body of dated lake level (shoreline) references as possible. Sites where such features may be preserved or otherwise indicated include buried lake-bottom surfaces, elevations to which river mouths are cut, and possibly, terraces in major stream valleys. All these will be examined in the study.

Once realistic hypotheses of shoreline positions and lake level trends are in hand, then suitable models of the probable origin and subsequent evolution of the three major forelands of the Lake Erie north shore can also be developed. Because they are sites of net deposition and sediment accumulation, they represent prime sites to search for datable materials, such as organic matter or fossil pollen profiles, which bear directly on lake history. If such materials exist, then their analysis should provide valuable time control on the above shoreline evolution model. In addition, the sedimentary record beneath these landforms could yield insights into the postglacial depositional environment, including important factors such as water depths.

1.4.2 Field work

Six vibratory cores to depths of 11 to 18 m below datum were drilled on the shoal south of Point Pelee in 1974. Three of these penetrated to till. The cores yielded a total of four radiocarbon dates. In 1980, two boreholes (to depths of 40 and 59 m below lake datum) were drilled at Long Point. These ended in fine clayey silt, of postglacial age. In 1981, a single borehole was drilled in the western portion of Long Point to a depth of 38 m below lake datum. This hole encountered material apparently of glacial origin. No datable quantities of organic matter were obtained in any of these three boreholes, but samples for a pollen profile were collected.

In addition to the above boreholes, a series of gravity cores was collected in 1982 on the underwater ridge trending south from Pointe-aux-Pins; these cores ended in sandy silt with abundant shells. In one case a large wood fragment occurred at the core base. Samples from both types of organic materials were dated at the University of Waterloo and are reported in this study.

Other field work consisted of numerous visits to sites of interest along the study shoreline in which observations and sampling of depositional sequences were sometimes carried out. These data are described in detail in the relevant thesis sections.

2.0 GEOLOGICAL BACKGROUND OF LAKE ERIE

2.1 Preglacial History

The Lake Erie basin lies within a tectonically stable region of Paleozoic sedimentary rocks draped over and around the Precambrian Canadian Shield. Although the bedrock is masked to a great extent by the lake itself and by thick sequences of glacial deposits, scattered oil and gas well data and land-based mapping allow a fairly detailed picture of the local bedrock geology (Figure 2-1). The lake is underlain primarily by shales and carbonates of Devonian age (Table 2-1) except for the shallower western part where carbonate rocks of Silurian age are important. Carbonate bedrock crops out in the nearshore and shoreline areas in the extreme eastern end of the lake (Haras and Tsui, 1976). Along the northern part of this segment, these rocks form two prominent escarpments: the Onondaga and the Niagara Escarpments. The latter serves in most places as the drainage divide between Lake Erie and Lake Ontario. Outcrops of carbonate rocks also occur in the Islands area of the western sub-basin, and as headlands occasionally along the southwestern shoreline.

Over most of the area, the rock strata dip gently southward at around 5 m/km (Sanford, 1961; Straw, 1968) except near the western end of the lake where the dip changes direction to reflect the presence of the northeast-trending basement arch (the Findlay Arch) and the major structural depression just west of the lake (the Michigan Basin). The generally east-west regional strike of the bedrock formations is also affected by the above structural features. Apart from the slow vertical movements associated with these basement features, tectonic activity is minimal, and confirmed major faults are limited to the extreme east of the basin (the Clarendon-Linden fault east of Buffalo; Figure 2-1). Minor faults, some mineralized, have been noted in the

Niagara Peninsula north of Lake Erie, and low-level seismic events are common (Basham et al., 1979). Faulting has also been suggested in the northwestern and western part of the basin (Sanford, 1961).

Over the long interval between the deposition of the youngest rocks in the area (Carboniferous) more than 270 million years ago, and that of the Quaternary (1 to 2 million years ago) glacial drift which covers it now, the Lake Erie region must have been weathered and eroded to a very mature state, characterized by a low-to-moderate relief. The predominant east-west trend of the rock formations and their contrasting resistance to weathering probably resulted in a pattern of alternating escarpments (formed by the harder carbonate rocks) and valleys (underlain by shales), of similar trend. The latter low areas are believed to have been the focus of drainage of a mature river system which flowed into the Ontario basin, and thence to the Atlantic Ocean, via the St. Lawrence Lowlands (Spencer, 1891; Hobson et al., 1969; Straw, 1968).

2.2 Glacial History

As the Laurentide ice-sheets overrode the Niagara Escarpment and entered the Lake Erie basin during the Pleistocene Epoch, their flow was apparently deflected southwestward by the Appalachian highlands to follow the trend of the above-mentioned pre-existing valleys. In this way, the less resistant bedrock formations underlying the valleys were further excavated to form the elongated northeast-southwest-trending depression in which Lake Erie eventually developed.

The southeastern limit of North American glaciation is located just beyond the lake (at Salamanca, New York, it is less than 50 km from Lake Erie). The sequence of deposits associated with the various glacial stages in this area is thus spatially compressed, and therefore difficult to resolve with confidence. This, in addition to the lack of detailed knowledge of glacial deposits beneath the lake itself, and the present limits on radiocarbon dating, makes regional correlation of glacial events somewhat uncertain. In any event, the oldest glacial deposits identified to date in the Lake Erie area are tills in southern Ohio, believed to be of Illinoian age (Goldthwait et al., 1965). However, the glacial stage best represented is the most recent, or Wisconsinan Stage.

The stratigraphic classification of the Wisconsinan Stage, devised by Dreimanis and Karrow (1972) particularly for the eastern Great Lakes and St. Lawrence region, has replaced earlier schemes developed by Frye and Willman (1960) and Leighton (1958) in Canadian usage. This classification scheme, shown in Table 1, is based on major glacial events in the Great Lakes area expressed in terms of ice advances (stadials) and retreats (interstadials). Although some of the events noted are still controversial, or are not represented in the Lake Erie area proper, the generally accepted picture of events leading up to the present-day Lake Erie can be summarized as shown below. For a more thorough treatment, the reader is referred to Goldthwait et al. (1965), Dreimanis and Karrow (1972), and Dreimanis and Goldthwait (1973).

2.2.1 Early Wisconsinan

The first ice incursion of the Wisconsinan stage in the area is represented by the Bradtville Till, assigned by Dreimanis and Karrow (1972) to the Guildwood Stadial (ca. 70,000 years Before Present (B.P.)). This silty till was found directly overlying bedrock in borings taken near Port Talbot (Dreimanis, 1963). Two Bradtville tills, an upper and a lower, were identified by Dreimanis et al. (1966) in the Port Talbot areas, separated by glaciolacustrine clay.

2.2.2 Middle Wisconsinan

After the glacial advance responsible for the Bradtville deposits had retreated from the area, a relatively long, cool, non-glacial interval prevailed. This period comprises the Port Talbot and Plum Point Interstadials (or Port Talbot Interstadial Complex), extending from ca. 65,000 to 25,000 years B.P. Because no till was found between these two non-glacial deposits in the type area, Dreimanis et al. (1966) concluded that central Lake Erie was not covered by an ice sheet during this interval. However, their tentative correlation of the small exposure of Dunwich Till (occurring near Port Talbot) with varved glaciolacustrine sediments remains the only indication of glacial ice in the Erie basin during the mid-Wisconsinan. This corresponds to the Cherrytree Stadial in Table 1.

The Port Talbot and Plum Point interstadial deposits are characteristically lacustrine silts and clays containing organic material probably deposited in a marsh environment. The Port Talbot Interstadial has been correlated with a prominent paleosol, the Sidney Soil, while the Plum Point corresponds to the Farmdale Soil in the southern (U.S.) part of the basin.

2.2.3 Late Wisconsinan

Outside the Port Talbot area, glacial deposits within the Lake Erie basin are predominantly of Late (or classical) Wisconsinan age (24,000 to 10,000 years B.P). Directly overlying the Plum Point deposits is a yellowish-brown coarse-textured till, the Catfish Creek Till. It has been correlated with the Kent and Navarre Tills in Ohio (Goldthwait et al., 1965). These tills represent an extensive glacial advance which overrode the area at the beginning of the Nissouri Stadial (Dreimanis and Karrow, 1972), dated at approximately 24,000 years B.P.

Little direct evidence exists in the Lake Erie area for the Erie Interstadial, a period of ice retreat which follows the Nissouri Stadial in the classification of Dreimanis and Karrow (1972). This interstadial is thought to have lasted approximately from 16,000 to 14,500 years B.P. (Fullerton, 1980). However, several pieces of indirect evidence support its existence. The most persuasive is related to indications that the retreat of the glacier created a glacial lake in the Erie basin (Lake Leverett), discussed in Section 2.3. The fine, clayey texture of tills deposited during the next glacial advance is a strong indication of the incorporation of pre-existing glaciolacustrine clays (probably deposited during the Erie Interstadial) into the base of the glacier.

Outside the area, Sigleo and Karrow (1977) described lacustrine silts of Erie Interstadial age (the Wildwood Silts) overlying Catfish Creek Till north of London, Ontario. Pollen assemblages indicate a non-glacial (forest-tundra) interval.

The next period of glacial advance, the Port Bruce (or Cary) Stadial has been assigned an age of between 14,500 and 13,500 years B.P. (Fullarton, 1980). In order to accommodate subsequent events (Port Huron advance) the former age appears more reasonable. As it advanced, the glacier apparently incorporated and reworked glaciolacustrine clays deposited during the Erie Interstadial, producing fine-textured tills (the Port Stanley Drift of Ontario and the Hiram

Till of Ohio) (Dreimanis and Goldthwait, 1973). The retreat of this glacier during the Mackinaw Interstadial has been suggested as being responsible for the deposition of the cross-lake Pelee and Erieau recessional moraines (Sly and Lewis, 1972). This event also ushered in a period in which the basin was repeatedly covered by glacial and non-glacial lakes culminating in the present Lake Erie (see Section 2.3).

The last glacial advance in the Lake Erie area occurred during the Port Huron Stadial, for which Fullerton (1980) gives a date of 13,000 years B.P.. Fullerton (1980) and Sly and Lewis (1972) inferred that the first Port Huron maximum (or outer Port Huron) corresponded to an ice-front position at the Paris and Galt moraines. The cross-lake Norfolk Moraine (Figure 1-1) is believed to mark this maximum as well, being widely interpreted as an extension of the Paris Moraine (Sly and Lewis, 1972). This advance has also been credited with the deposition of the Wentworth till, a brownish sandy-silt till which forms the core of the above moraines and is spread thinly over the northeastern Lake Erie basin. Recent work (P.J. Barnett, O.G.S., 1982, pers. comm.) has cast considerable doubt on the above interpretation. Careful mapping of the area to the northeast of the lake indicates that the Paris and Galt Moraines (and by extension, the Norfolk Moraine) are related to the Port Bruce Stadial (Barnett, 1979). Thus the Wentworth Till is probably also of Port Bruce age.

According to Barnett, the final ice advance in the Erie basin, the Port Huron advance, only reached as far as the extreme northeastern part of the lake, probably in the area of the Port Maitland Moraine (Figure 1-1). The Halton Till, confined to this area of the basin, was deposited during this phase, and is correlated with the glaciolacustrine sediments of Lake Whittlesey (Barnett, 1979).

This proposed revision does not change the previously mentioned date of 13,000 years B.P. for the Port Huron stage.

It is clear that controversy still persists in the interpretation of the late Wisconsinan record in the Erie basin. The short interval between the Port Bruce and Port Huron advances (1000 years or so) favours Barnett's interpretation of ice positions, in that the Port Huron ice would not have to advance twice (over a considerable distance) to deposit first the Wentworth Till (and build the large Paris and Galt moraine systems), and then the Halton Till after it. Also the thick glaciolacustrine deposits in the eastern sub-basin suggest a long period of open-water conditions, rather than glacial cover as far west as the Norfolk moraine.

2.3 Glacial Lakes in the Erie Basin

Glacial lakes (or more precisely, proglacial lakes) are formed when glacial ice blocks normal outlets for drainage of waters ponded between the ice-front and the basin divide. So, except for times when ice completely filled the Erie basin, it is conceivable that glacial lakes occupied the basin on many occasions during the Pleistocene Epoch. However, because the readvancing ice often drastically altered, removed, or obliterated all traces of previous lake phases, little trace remains of the older glacial lakes. The case for glacial lakes in the basin before the Port Bruce Stadial (Table 1) is based, for the most part, on indirect evidence (i.e., not related to either shoreline indications or sedimentary deposits) such as the presence of the buried St. Davids Gorge at Niagara (Hobson and Terasmae, 1969).

Dreimanis (1969) suggests that glacial lake phases existed in the Erie basin during early stages of the Wisconsinan, such as during the Middle Wisconsinan Plum Point and Port Talbot Interstadials, as indicated by the lacustrine sediments characteristic of these periods. Similarly, he contends that the glaciolacustrine deposits between the Upper and Lower Bradtville tills must correspond to an Early Wisconsinan glacial lake.

The evidence is clearer, however, for Late Wisconsinan glacial lakes in the Erie basin. Between the time of the Port Bruce stadial and the final departure of the ice about 12,500 years B.P., the retreating ice gave way to a series of proglacial lakes, most of which were at higher elevations than the present lake. As it retreated, the ice margin fluctuated considerably, resulting in changing lake levels as outlets at various elevations were opened or closed. The complex sequence of these glacial lakes is well described in Hough (1966), Sly and Lewis (1972), Barnett (1978, 1979), Prest (1970), and Fullerton (1980). They are summarized below.

2.3.1 Glacial Lake Maumee and its successors

The retreat of the Port Bruce glacier led to the creation of a series of glacial lakes in the Erie basin. They were: Lake Maumee (244 m above sea level), followed by lower level Lakes Arkona (around 216 m a.s.l.), and Ypsilanti (around 165 m a.s.l.) (Fullerton, 1980). The two former stages drained westward into glacial Lake Chicago (in the Michigan basin), while Lake Ypsilanti probably drained eastward either into the Lake Ontario basin (Fullerton, 1980), and to the Mohawk River system of New York. The raised shorelines of most of these lakes are clearly identifiable, especially in the western portions of the Erie basin.

2.3.2 Glacial Lakes Whittlesey and Warren and their successors

The Port Huron ice advance around 13,000 years B.P. closed off the lower outlets creating Lake Whittlesey at an elevation of around 225 m a.s.l. (Barnett, 1979). Subseqent ice retreat and the uncovering of lower outlets led to the glacial Lake Warren stages at around 207 m a.s.l., followed in succession by Lakes Grassmere (195 m), Lundy (189 m), and Dana (158 m a.s.l.). Lakes Whittlesey and Warren drained westward across the Michigan Peninsula, while Lakes Grassmere, Lundy, and Dana are generally believed to have drained eastward, eventually into glacial Lake Iroquois (Ontario basin).

2.3.3 Glacial lake shorelines and sediments

The two major lakes of this series, Whittlesey and Warren, left strongly developed shorelines on the flanks of moraines and highlands in Ontario and in the bordering United States (Figure 1-1). Leverett and Taylor (1915) and more recently Calkin (1970) mapped these shorelines south of Lake Erie and confirmed their tilted attitude (upward to the northeast). The zero isobase for these lakes (i.e., the line west of which no tilt was noted in the attitude of these shorelines) was also placed across the central basin of the lake (Figure 1-1). Comparable raised shoreline data were published on the Ontario side by Barnett (1979) for Lake Whittlesey, Karrow (1963) for Lakes Whittlesey and Warren, and Feenstra (1981) for Lake Warren and lower stages in the Niagara area. In this portion of the basin, evidence was noted of other identifiable low-level phases such as Lake Dunnville (Feenstra, 1981) and Lake Tonawanda (Calkin and Brett, 1978).

Over their relatively short existence, the glacial lakes in the Erie basin were the recipients of large amounts of sediments both from glacial meltwater and from erosion of the virtually unvegetated shores of these lakes. Thick (up to 30 m) deposits of firm, laminated, gray to reddish-brown clay constitute the characteristic sediment for this interval, exposed along the shore and below the lake (Lewis, 1966).

2.4 Early Lake Erie

When the retreating Port Huron ice finally exposed the Niagara River outlet, the glacial phase ended in the Lake Erie basin, and the last of the glacial lakes, Lake Dana, drained into the Ontario basin. This event resulted in a low-level, non-glacial lake phase in the Erie basin, which Hough (1966) termed Early Lake Erie. Using plant detritus collected in sediment cores from the western and central basin of the lake, Lewis et al. (1966) were able to assign radiocarbon ages to this low-level phase of between 12,370 and 12,790 years B.P. An Early Lake Erie age of 12,500 years B.P. is given more recently in Sly and Lewis (1972).

Sly and Lewis (1972) estimate that when Early Lake Erie came into existence the outlet and part of the eastern basin were still depressed approximately 35 m below their present levels. They infer that Early Lake Erie began at around this level. Since this work, much additional information related to this initial phase of the lake has come to light. In the review and re-interpretation of the postglacial lake level history of Lake Erie (Chapter 5), the initial conditions of Early Lake Erie will be examined in some detail.

2.5 Present-day Lake Erie

A summary of averaged physical data on present-day Lake Erie that are relevant to this research work is presented in Table 2.2. Sources of the data tabulated are given in the table.

The basin of the lake is subdivided by north-south trending submerged ridge-like features into three major sub-basins (Figure 1.1). The deepest (eastern) sub-basin is cone-shaped, with steeper bottom slopes than the others. Maximum depths are around 60 m. The central and most of the western sub-basins are characterized by a uniformly flat bottom topography, at around 24 and 12 m, respectively. The central sub-basin is the largest, while the western sub-basin, interrupted by bedrock islands, is the smallest. The so-called Sandusky Basin (Thomas et al., 1976) is here included in the western sub-basin.

The ridges separating the sub-basins have been interpreted as recessional moraines marking the progressive retreat of the Port Bruce glacial lobe (Sly and Lewis, 1972). It is therefore somewhat puzzling that these ridges are not clearly expressed on shore. This could be explained by subsequent erosion or sediment cover associated with the high-level glacial lakes that succeeded the ice retreat. Similar effects could result from erosion or sediment cover by channelized flows along the ice-land boundary, if the ice-lobe was confined to the lake basin. In fact, the western sides of these cross-lake features are characterized by thick stratified sand deposits suggestive of large ice-margin deltas or kames in the Point Pelee and Long Point areas (Leamington sand deposits, Sand Hills of Norfolk County, respectively) (E.V. Sado and P.J. Barnett, O.G.S., 1983, pers. comm.).

2.5.1 Surficial sediments

The surficial sediments of the Lake Erie basin have been described by Lewis (1966) and Thomas et al. (1976) for the offshore areas, and by Rukavina and St. Jacques (1971, 1978) and St. Jacques and Rukavina (1973) for the nearshore portions (water depths less than 20 m) of the Canadian side (Figure 2-2). Similar nearshore measurements and surveys were carried out on the U.S. side by Ross (1950), Hartley (1961), Herdendorf (1968) and by Williams et al. (1980).

Although the offshore areas are covered almost exclusively by soft Lake Erie muds, scattered sand bodies occur, generally associated with the large forelands and with the cross-lake morainal ridges (Figure 2-2). In the nearshore zone, wave-eroded platforms of glacial materials crop out over large portions of the Canadian side.

2.5.2 Sub-bottom sediments

Vertical sediment sections have been published for the western sub-basin by Herdendorf (1968), and by Lewis (1966) for the entire basin. Additional subsurface information has recently been obtained from seismic profiles run for Ontario Hydro and Transcontinental Gas Pipe Line Corp. across the eastern sub-basin of the lake (Figure 1-1).

In most of the areas receiving sediment, the Quaternary sedimentary sequence is almost always firm, clayey glacial material overlain by soft Lake Erie muds. The contact between these deposits is often erosional, and associated with a sandy or shelly lag concentrate layer. The glacial materials consist either of glaciolacustrine clays (mainly in the central and eastern basins) or till, and because of their frequent textural similarity, it is often difficult to differentiate between them in core samples. The top mud unit is generally uniform texturally, although an abrupt change to coarser material (silt) has been noted at mid-depths within this unit (Creer et al., 1976) in the central sub-basin. These sediments will be discussed further in the next two chapters.

2.5.3 Erosional coastal features

The prime erosional features observed along the Lake Erie shoreline fall into two categories:

- the bluff shorelines
- the gently-sloping wave-eroded platforms occurring over most of the nearshore zone.

The former, which comprise steep cliffs up to 50 m in height, are composed of glacial sediments (mostly till or glaciolacustrine deposits), and are presently receding at rates of up to 5.6 m/y (Boulden, 1975; Haras and Tsui, 1976). Long-term recession rates for the central shoreline of the lake were calculated by Wood (1951) using comparisons of the original nineteenth century surveys with present-day maps; and by Gelinas (1974) who compared the above surveys with recent aerial photographs of the shoreline. Gelinas' study showed rates ranging from 0.25 to 3.0 m/y. A summary of published long-term recession rates for the Lake Erie north shore is given in Figure 2-3. Gelinas also obtained a good correlation between recession rates and the calculated wave energy impact at the shoreline site in question.

Although other factors such as bluff composition, height, and shoreline orientation with respect to dominant waves have been linked to the recession rate, high or rising lake levels are most often cited as the major causal factor. This relationship, often referred to as the Bruun Rule, was formulated (Bruun, 1962) to link the chronic recession noted in Florida beaches to ongoing Holocene sea-level rise. Since then, it has achieved wide acceptance, and confirmatory evidence of its effect has been put forward, notably by Schwartz (1965, 1967), Hands (1977), Dubois (1976) and Weggel (1979). The inherent weakness in applying the above concept generally lies in the fact that the research cited deals only with recession on sandy coasts. To date, the author is aware of no research that has been published on the application of the Bruun Rule to unconsolidated clayey bluff shorelines, such as those typical of the lower Great Lakes. A relevant study in this regard is that by Seibel (1972) on shore erosion along Lakes Michigan and Huron. From recession measurements taken from aerial photographs for the period 1938 to 1970, Seibel concluded that "a definite relationship exists between the average lake levels and the average rates of erosion; this relationship, moreoever, as a result of the present study has been quantitatively established." A similar conclusion was reached by Matyas et al. (1976) for shorelines along the Niagara Peninsula of Lake Ontario.

Other researchers differ from this view. In the Lake Erie bluff shoreline near Port Bruce recession rate was concluded to be independent of lake levels (Packer, 1976). In fact, some types of bluff failure mechanisms might become more frequent in periods of low lake levels (Quigley et al., 1977). However, Quigley recognized the comparable importance of other factors, such as shore slope and shore material texture and geotechnical properties in the recession process. From the above, one can conclude that while lake level rise might not always be the predominant factor leading to higher recession in bluff shorelines, the impact of waters at a shore elevation normally affected only by subaerial processes could lead to a temporary increase in the recession of the shoreline, until the shore profile adjusts to the new level.

Insofar as erosion mechanisms and rates for nearshore platforms are concerned, no results of ongoing research have as yet been published (R. Davidson-Arnott, University of Guelph, 1983, pers. comm.).

2.5.4 Depositional coastal features

The three large sandy forelands occurring at more or less regular intervals along the Lake Erie north shore (Figure 1-1) are now recognized to be related to the glacial geology and postglacial regime of the lake basin, rather than to simple accidents of erosion and deposition. These features are apparently complex genetically, and their mode of origin has provoked much attention (see Section 1.3). Although that aspect of the features will be discussed in detail in later sections, some comments on their physiography will be given here.

1. Point Pelee. Point Pelee is a cuspate foreland extending southward for more than 12 km from the northwestern portion of the Lake Erie shoreline of Essex County (Figure 2-4). Its location and orientation corresponds with that of the cross-lake Pelee moraine (Sly and Lewis, 1972) which continues on to meet the U.S. shore near Lorain, Ohio. Point Pelee comprises roughly 80 km 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.

In an earlier work (Coakley, 1980), the author concluded that while the east side of the Point is eroding steadily (marsh peat outcropping on the submerged beach slope, truncation of marsh ponds and beach ridges), the west side shows a net accretion. This is indicated by a well-developed sand plain with a series of sub-parallel dune ridges up to 10 m in height, occupying the sites of storm beach ridges and indicating the successive progradation of the western shoreline since the formation of the Point. Another noteworthy feature is the progressive change in orientation of these ridges to trend more and more north-south.

Radiocarbon dates averaging approximately 3500 years B.P. (Terasmae, 1970) were obtained for basal marsh peat below the present ponds, indicating a probable time of origin of the landform.

South of Point Pelee, a broad, sandy shoal continues south for 9 km. Water depths over the shoal average around 6 m, and judging from the coarse texture of the surface sediments there, and the long fetch toward the east (140 km), sediment transport processes are often intense.

2. Pointe-aux-Pins. Pointe-aux-Pins, or Rondeau Peninsula, is a rounded cuspate foreland protruding some 7 km southward from the north shore of Lake Erie (Figure 2-5). From its junction with the shoreline, the eastern arm of the cuspate foreland widens from approximately 0.5 km to 2 km near its southern extremity. The southwestern arm, however, is much narrower (less than 100 m in places), and is occupied in part by the town of Erieau. The entire foreland covers approximately 50 km^2, 60% of which (30 km^2) comprises an enclosed area of pond and marsh, Rondeau Harbour. The harbour averages less than 4 m in depth, and much of the marsh along its northern side has been drained for agricultural purposes.

The broader eastern limb of the foreland comprises a wooded beach-dune complex, made up of a large number of sub-parallel ridges, alternating with marshy swales, well-defined on aerial photographs. These ridges are usually less than 5 m in height, and as at Point Pelee, correspond to prior positions of the shoreline. This feature, in addition to the relative widths of the beaches, make it clear that the east limb of the peninsula is prograding lakeward, while the west side is steadily eroding. It is noteworthy that this is the reverse of the situation at Point Pelee.

A radiocarbon date of around 5200 years B.P. on basal organic material from the -9 m (below lake datum) level of a borehole drilled on the Point (A.J. Cooper, formerly of O.G.S., 1982, pers. comm.) was obtained, giving a minimum estimate of the age of formation of the beach ridge-lagoon complex.

3. Long Point. Long Point is a large (100 km^2) foreland extending 35 km in an east-west direction from the north shore of Lake Erie near its eastern end (Figure 2-6). Long Point is composed basically of four physiographic types: a) an active, high-energy sand beach zone along its southern shore; b) a densely wooded series of longitudinal sand dunes and beach ridges up to 10 m in height, c) low meadow and grassland to the north of the wooded dunes; d) wetlands occupying most of the western portion of the northern shoreline. The curving form of the dune ridges indicates that they were originally storm beach ridges deposited at the shoreline. Thus their pattern of orientation (Figure 2-6) reflects progressive changes in the shoreline position as the foreland evolved. The principal tree cover ranges from red oak and white pine in the more mature areas, to cottonwood in the southern, more dynamic areas. The wetland area is contiguous with the large marsh formed where Big Creek enters Inner Bay, to the north of Long Point.

Recent research on Long Point has been aimed primarily at coastal processes. Wood (1960) used hindcasted wave energy reaching various locations along the shore of the Point to calculate an annual transport index. Linking this with the calculated annual volumetric growth of the tip, he estimated an annual littoral transport of 1,140,000 m^3.

Liard (1973) refined the above wave calculations to derive a wave energy/longshore transport relationship for Long Point and arrived at a transport rate of 510,000 m^3/y. His work was the first to include a computer simulation of the growth of Long Point.

In a subsequent chapter, a reexamination of the postulated modes of origin of these forelands will be made in the light of a reinterpretation of lake level history. This reinterpretation will rely heavily on postglacial sediment stratigraphy, described in the next two chapters.

3.0 THE POSTGLACIAL SEDIMENTARY RECORD (LONG POINT)

The use of vertical sedimentary sequences and horizontal lithofacies relationships in interpreting the depositional history of an area has been demonstrated by many sedimentologists (Pettijohn, 1957; Visher, 1965; Walther, 1894). As stated by Pettijohn, a sediment deposit is basically a product of its source and its environment of deposition. If we assume, in such a restricted study area as the north shore of Lake Erie, and over such a limited period of time as the post-glacial interval, that sediment sources would not change significantly, then the deposits under study should predominantly reflect trends in the environment of deposition. Important parameters in this regard are depth of water (or lake level), intensity of wave or current action, distance from the shoreline, and biological and chemical diagenesis. In the analysis of the sediments which follows, most attention will be given to evidence supplied by grain-size distributions and vertical textural trends. Chronologic control will be provided by radiocarbon dating (where obtainable) and palynology.

The sediments studied in this and subsequent chapters are all from boreholes and cores collected on or near the three major forelands of the Lake Erie north shore. This was done because these are the only sites (apart from the almost inaccessible deeper offshore areas of the lake) where a considerable part of the postglacial sedimentary record is expected to have been preserved. Most of the information collected was from Long Point and Point Pelee, so these areas will be highlighted in the analysis. For Pointe-aux-Pins, the data base is more limited, so the existing uninterpreted data on the subsurface deposits (collected and made available by others) will be analyzed and interpreted.

3.1 Sediment Data Base and Analytical Procedures

3.1.1 Long Point

Two boreholes were drilled at Long Point in the summer of 1980 using a wash-boring technique (Figure 3-1). These boreholes, labelled BH1 and BH2 on Figure 2-6, were sampled to depths of 40 and 59 m below IGLD*, respectively. Split-spoon samples, collected at 1 to 1.5 m intervals, were described in the field, then bulk-stored in glass jars. One Shelby tube sample was collected from BH1 for geotechnical testing.

Another borehole, BH3, was drilled to a depth of 38 m below IGLD in the fall of 1981 using a hollow-stem auger rig (Figure 3-2). Split-spoon samples and Shelby tubes were taken almost continuously down the hole. The split-spoon samples were first described in the field, then placed in tightly sealed plastic sleeves for transportation and storage. A total of seven Shelby tubes was taken for geotechnical and other purposes. Prior to logging, each split spoon sample and Shelby tube sample was X-rayed while still in its liner and the X-radiograph developed. This non-destructive process is useful in determining the presence of internal sedimentary structures and objects such as pebbles, shell and wood fragments, that may not be so easily noticed when the sample is split and logged. After this, the sample was split longitudinally and qualitative physical properties such as colour, texture, internal structures, bedding and contact planes, and fossil content were recorded.

---

* International Great Lakes Datum (Lake Erie - 173.3 m above sea level).

Particle size analysis (0.5 phi (∅) intervals) was carried out on all samples collected from representative sections of the borehole profile using the combined sieve - settling tube - pipette - Sedigraph procedure (Duncan and Lahaie, 1979). Other analyses, such as X-ray diffractometry (for clay and other mineral identification), the determination of oxygen isotope ratios on interstitial waters, and carbon analyses were carried out on selected samples from BH3.

During the logging of BH3, measurements of undrained shear strength of the cohesive sediments were taken using a fall-cone apparatus (Hansbo, 1957) at approximately 15 cm intervals. In addition, a total of five Shelby tube samples (one from BH1 and four from BH3) were subjected to one-dimensional consolidation testing, using the technique outlined in Terzaghi and Peck (1967). The Shelby tubes were 5 cm (2 inches) in diameter. Other standard soil tests were conducted including moisture content, Atterberg limits, and bulk density determination.

3.1.2 Point Pelee

Six cores, 9 cm in diameter and ranging from 4.1 to 12.2 m in length, were collected from the Pelee Shoal in 1974 (Figure 2-4, Table 4-1) using a Vibracore apparatus mounted on a barge (Figure 3-3). Because of the inability of other coring techniques to penetrate more than a few centimeters into sand and gravel deposits, these cores represent the first set of long cores taken on the Pelee Shoal.

In the laboratory, each core section was X-rayed and an X-radiograph of the core developed prior to opening. Later, qualitative physical properties of the core were logged. During the logging of Cores 1 and 2, the undisturbed and remolded shear strength of the cohesive sediments were measured at 30 cm intervals using a Wykeham Farrance laboratory vane. Samples for particle size analysis and natural water content were taken at 30 cm intervals from all cores; those for Atterberg limits every 30 cm in the areas of cohesive sediments. Grain size analysis was carried out as previously described. Carbonate percentages were determined at 90 cm intervals using the Chittick apparatus procedure developed by Dreimanis (1962). Atterberg limits and natural water content were determined using standard ASTM procedures (D-423/424 and D-2216, respectively). Qualitative X-ray diffraction analyses were carried out on the $<2\mu m$ fraction of 37 samples representing all sediment types, using a Philips X-ray diffractometer.

One-dimensional consolidation tests were performed on samples from two positions in each core, using standard ASTM procedures. The pre-consolidation pressure, P_C, was estimated by Casagrande's graphical construction (Casagrande, 1936). Four samples of organic material (plant detritus and shells) were collected from various levels in some of the cores and radiocarbon dated at Brock University, St. Catherines, Ontario. These dates (numbered 18 to 21) are listed in Table 3-1.

3.1.3 Pointe-aux-Pins

Figure 2-5 shows the location of 23 boreholes drilled on Pointe-aux-Pins. Twenty-two of these boreholes were for either water-supply purposes or to provide geotechnical support data for construction projects. The logs were generously made available by Trow, Ltd. and Golder Associates of London, Ontario, and by the Ontario Ministry of the Environment. Two boreholes drilled at one site, labelled OGS-1, formed part of the geological mapping and research work carried out by the Ontario Geological Survey (Cooper, 1977).

The above data included only a limited number of granulometric analyses, and the sediment descriptions in the logs are less detailed than those at the other two forelands. Nevertheless, the gross trends in sediment type are clearly discernible. In addition, two radiocarbon dates on peat from OGS-1 were made available and these are included as nos. 35 and 36 in Table 3-1.

3.1.4 Sediment data from other sources

The location of four other land-based boreholes drilled on Long Point are shown also in Figure 2-6. Near the tip is a 120 m borehole drilled in 1963 (Lewis, 1966) hereafter referred to as the Lewis borehole or LBH. Near the western end of the point are four water wells whose logs were obtained from the files of the Ontario Ministry of the Environment.

Figure 2-6 also shows the locations of lake-bottom cores and water-jetting probes which supplied information on the nature and thickness of surficial sediments near Long Point. The sites shown are only a small proportion of the sub-bottom cores and probes taken in the area (St. Jacques and Rukavina, 1973; Rukavina, 1981; Lewis, 1966), but were selected because they apparently penetrated the cover of recent muds that now cover most of the area. The vertical position and character of the sediments encountered in the cores are shown in Table 3-2. Table 3-2 also summarizes comparable jetting probe data close to Long Point. The jetting sites selected comprised only those in which signs of a possible glacial sediment base (probe bouncing, very slow penetration, glacial clay on tip), were present.

Data from three boreholes drilled in Point Pelee National Park (Terasmae, 1970) were also utilized in this study. In the

Pointe-aux-Pins area, the series of seven offshore boreholes drilled by the Consumers Gas Company (Creer et al., 1976; Lewis et al., 1973) also proved useful for background purposes. These are shown in Figure 1-1. In addition, gravity and piston core data collected from the lake bottom immediately south of Pointe-aux-Pins by the author and others (C.M. Carmichael, University of Western Ontario) provided useful data, including two radiocarbon dates (37 and 38 in Table 3-1).

3.2 Subsurface Sediments, Long Point

Summary logs of the three boreholes drilled on Long Point in 1980 and 1981 are presented in Appendix 1. Tables showing the results of grain-size analysis on a total of 183 samples from these boreholes are presented in Appendix 5. Summary profiles of sediment textural properties and other measured parameters are presented in Figures 3-4 and 3-5. These profiles are plotted to horizontal scale in Figure 3-6 to illustrate spatial relationships, and along with stratigraphic controls (described in later sections), they provide a preliminary overview of the continuity of sedimentary facies under Long Point. Although there are minor differences between boreholes, the sedimentary sequences making up the boreholes sampled are consistent enough to be readily differentiated visually into distinct lithological units. Preliminary boundaries between the units were based on visual appraisal, but when less defined, the units were separated on the basis of breaks in the vertical textural properties, especially sand-silt-clay ratios and mean grain size (Figures 3-4, 3-5). This classification is not meant to imply that the various units are correlated or were formed under similar process conditions. Differentiation on this basis will be attempted in a later section when grain size distributions and structural features observed in the cores will be examined for clues as to depositional processes.

Rather, the classification used below serves mainly as a convenient means of describing the gross lithological sequences making up the postglacial sedimentary record below Long Point.

3.2.1 Compacted uniform clay (Unit 1)

This unit appears to be the oldest encountered, and was sampled only in BH3 (below -20 m) and LBH (below -80 m). Over the entire length sampled, the unit consists of a uniform, fine clay (Figure 3-7). The colour is grayish brown (2.5Y 5/2), and characteristically has a reddish cast when fresh. It is firm to stiff in consistency (see Section 3.5.3). Structural details are very indistinct, and occur as very faint colour laminations throughout, which when enhanced by drying, often exhibit contorted or inclined attitudes. X-radiographs of selected cores (LP50, Figure 3-12) show vague rhythmic laminations (varves?) several millimetres thick. Reddish spots and irregular silt patches and lenses are also common near the base of the section sampled. Isolated pebbles (up to 5 cm in diameter) are occasionally present.

The low variability in the plotted grain-size distributions for samples from this unit (Figure 3-5) confirms the remarkable textural uniformity of these sediments. Mean grain size ranges from 8.7 to 9.5 phi, and standard deviation is fairly consistent at around 1.5 phi. There is a slight trend toward finer sizes upward in the unit. The size distribution is usually unimodal, negatively skewed, and platykurtic in shape. The clay-sized component is consistently above 80% (Appendix 5). The contact with the unit above is abrupt and irregular, with infilled grooves visible (Figure 3-7).

3.2.2 Interface between Unit 1 and Unit 2

Disconformably overlying the Unit 1 clay sediments is an 8 cm thick zone of polymict material containing abundant well-preserved pelecypod and gastropod shells (Figure 3-7). The shells are described and interpreted in a later section (3.4.2). The sediment contained in this zone (see samples LP24-4A and 4B in Appendix 5, and corresponding size distributions in Figure 3-5) may be characterized as a muddy sand. Mean size is around 4 phi and sorting is poor (standard deviation 2.3 to 3.0 phi). Samples from this zone are strongly bimodal, with the dominant sand mode (3.25 phi) showing good to moderate sorting, as indicated by the slope of the cumulative curve in Figure 3-17. The silt and clay components together comprise approximately 30%.

Efforts to obtain thin sections of this zone were unsuccessful due mainly to the fine, clayey matrix. However, close-up photographs (Figure 3-11) show that the coarser (sand- to granule-sized) material and larger shell fragments were distributed fairly uniformly throughout the zone, although some patchy concentrations occurred as vague lenses and irregular bands. Most of the coarse material appeared to be suspended in the clayey silt matrix, and clear signs of graded structures were absent.

3.2.3 Soft clayey silt (Unit 2)

The unit directly overlying (and grading downward into) the above-described interface zone in BH3 is best described as a uniform clayey silt, dark gray (10Y 4/1) in colour (Figure 3-8). Consistency is much softer than Unit 1. Faint darker laminations and almost black (sulphide) streaks and patches occur frequently. Organic matter and shells are rare.

In contrast to the underlying Unit 1, silt predominates over clay in Unit 2, and ranges from 50 to 70% (Appendix 5, Figure 3-5). Clay content ranges between 32 and 46%, and sand is virtually absent. Mean grain size is consistently within a narrow range of 6 to 8 phi, and sorting (standard deviation) improves upward from around 2.2 phi near the base to 1.6 phi elsewhere in the unit. Unlike Unit 1, this unit generally shows positive skewness, although kurtosis values are comparable. In BH3, the only one in which the entire unit was sampled, Unit 2 is slightly more than 5 m thick.

Apparently similar material (see Section 3.3.5) occurs in the lower 12 and 20 m of BH1 and 2, respectively. However, irregular lenses and thin (2 to 5 cm) layers of fine sand and sandy silt are occasionally observed in these cores, bringing the sand content to between 5 and 12%.

3.2.4 Interlaminated sand and silt (Unit 3)

This unit forms the basal 30 and 40 m (approximately) of BH1 and 2. The unit can be subdivided into two sub-units (a, b) on the basis of texture (breaks in sand, silt, clay proportions and mean grain size; Figure 3-4). Unit 3a is predominantly a sandy clayey silt, becoming gradually more sandy upward. Unit 3b consists predominantly of silt and sand interlaminations.

In BH3, where more detailed descriptions were possible, there is no such division. The contact between the base of this unit and the predominantly silt unit (Unit 2) below is gradational, and is indicated mainly by the significant appearance and increasing frequency of coarser (fine sand) material. The unit is characteristically dark gray (10YR 5/2) to grayish brown in colour (Figure 3-9), with the coarser sections being more brownish gray. The dominant structural feature of the unit is the upward-increasing frequency of thin sandy laminations, usually less than 5 mm in thickness, which, in effect, result in a gradual change upward in the unit from a clayey silt with minor sand laminations, to a fine sand with minor silt laminations. The sand/silt ratio thus increases from less than 0.2 in the basal portions to as high as 8 near the top. Clay content declines steadily from around 30% to less than 10% (Appendix 5, Figure 3-5). Structures noted in this unit include small-scale cross-stratification (wavelength: 2 to 5 cm; height: around 1 cm), which is clearly visible only in X-radiographs. These structures are most pronounced in the middle portions of the unit in BH3, e.g., samples LP9, 10, and 11 (Figure 3-13). The small diameter of the core and the lack of satisfactory control on core orientation during the X-radiography make reliable interpretation of these structures difficult. However, they appear to be almost equally divided between types suggestive of wavy- or flaser-bedding (Reineck and Singh, 1975), or "starved" sand ripples. More detailed study than is feasible in this thesis is required for further interpretation, but the above combination suggests dominant mud deposition alternating with episodic fine sand inputs.

The total thickness of Unit 3 ranges from approximately 10 m in BH3 to more than 40 m in BH2 (Figures 3-4 and 3-5, respectively). However, in BH3, the unit contains an anomalous 2.5 m thick fine-grained upper section which ranges in texture from sandy silt (top) to clayey silt at the base (Figure 3-5). The change from normal Unit 3 sediments to this finer section is abrupt. Organic matter (wood and plant fragments, leaves, and leached shell fragments) were frequently noted both in this finer section and in the top portions of the unit in the other boreholes. The contact with Unit 4 above is sharply defined in all cases, but with no definite sign of erosion.

Excluding the fine-grained upper sub-unit in BH3, the mean sediment size of this unit increases upward from around 6 phi at the base, to around 3 phi in the upper section. Though generally unimodal, bimodal and polymodal samples were noted frequently, especially in the coarser portion of the distribution. Thus sorting was noted to be very variable, but generally poor (standard deviation of around 2.0 phi). In BH1 and 3, sorting shows an overall improving-upward trend from poorly sorted basal sections (standard deviation of around 2.0 phi) to moderate sorting near the top (standard deviation of around 1.5 phi). Skewness is usually positive, reflecting the significant silt component.

3.2.5 Sorted sand (Unit 4)

The well-defined top unit in all the boreholes is a clean, medium-textured sand, gray to brownish-gray in colour (Figure 3-10). Heavy mineral concentrations form occasional thin (less than 1 mm) dark laminations, which are highlighted on the X-radiographs from the lower portion of the unit in BH3. Coarse granule layers (1 to 5 mm thick) occur throughout the unit in BH1 and 2, and often contain dark oxidized wood or charcoal fragments (BH2-48). Other organic matter is generally scarce, and is restricted to occasional shell fragments, except at the base of the unit in BH3, where plant detritus is observed at the sharp contact with the silt unit below. Midway through the unit in BH3 (sample LP2), a 40 cm thick deposit of interbedded sand and olive-gray silty clay occurs abruptly. This fine-grained sub-unit contains visible organic detritus (leaves, roots, twigs). Overall thickness of Unit 4 ranges from 6.5 m (BH3) to 20.0 m (BH2).

Excluding the thin coarser layers and the silty clay sub-unit in BH3, characteristic mean grain-size values range from 2.0 to 2.7 phi, and sorting is relatively good (standard deviation: 0.4 to 1.50 phi). All boreholes, however, show cases of anomalous transient poorer sorting (standard deviation as high as 2.5 phi) usually associated with randomly-occurring coarse or fine layers. The unit is generally unimodal although minor coarser modes are common. The size distribution is almost always negatively skewed and leptokurtic in shape (Figure 3-5, Appendix 5).

3.2.6 Sedimentary sequences from other Long Point boreholes

Apart from the three drilled by the author, the only other borehole drilled on Long Point for scientific purposes was by Lewis (1966). This borehole, whose location is shown on Figure 2-6 , was completed in April 1963, and reached bedrock at 120 m below mean lake level. The sediments traversed are described in Lewis' (1966) core log (reproduced here as Appendix 2) and are shown plotted in Figure 3-6. The subdivision of the sequence into lithologic units was performed as described earlier although Lewis used graphic measures of grain-size rather than the moment measures used in this study. The upper portion of this borehole showed sedimentary units comparable to those encountered in BH1, 2, and 3, and paraphrasing Lewis' core log, the sediments may be summarized as follows:

0 to 20 m : Clean medium-textured sand (Unit 4)

20 to 60 m : Fine sand grading downward to sandy silt and silty clay. Sorted fine-to-coarse sand interbeds

are common in the upper section; silt and clay beds occur in the lower section. Wood and coal fragments are common down to 25 m. (Unit 3)

60 to 80 m : Soft gray silty clay (8.5 to 10.1 phi median diameter) with faint dark laminations common. A few thin sand and silt seams occur in the upper few metres. (Unit 2)

80 to 114 m : Reddish-gray to brown clay, faintly laminated (alternating clay and silt) or, less often, massive. Median diameter averages around 10.5 phi. (Unit 1)

114 to 118 m : Layered complex consisting of reddish gray clay with sand partings, massive stiff clay, silt and sorted sands, and basal gravel (possible till unit).

118 to 120 m : Limestone bedrock with striated surface.

Two other boreholes were drilled on Long Point (Figure 2-6), but these were for water supply purposes only and the descriptions contained in the logs (Ontario Water Resources Commission water well records) are of limited value for geological interpretation purposes. As an example, well 44-2386 was drilled in 1969 and the log is reproduced below:

0 to 7.6 m	:	Sand
7.6 to 51.8 m	:	Wet soupy clay
51.8 to 82 m	:	Hard clay
82 to 94 m	:	Limestone

It is obvious that the most that can be extracted from such information is the thickness of the top sand (probably similar to Unit 4) overlying the clay and the depth to bedrock. The other water well on Long Point showed 4 m of sand over clay, and in the others to the west (Figure 3-6), "clay" was recorded at the surface.

3.3 Grain-size Analysis

Analysis of grain-size statistics and size-frequency plots in the interpretation of sedimentary environments has long been a widely-used tool in sedimentological investigations. The literature on the subject is too voluminous to review adequately here. Good summaries are presented, however, in Visher (1969) and Glaister and Nelson (1974). Broadly speaking, two approaches are represented. One involves the use of grain-size moment statistics and their plotted inter-relationships to determine visually where sediments from various known depositional environments tend to cluster on the plot. The empirical inferences thus obtained can then be applied to data from sediments of unknown depositional origin (Friedman, 1961; Folk and Ward, 1957; and Mason and Folk, 1958). This approach was elaborated on by Klovan (1966), who used statistics provided by factor analysis of the original size frequencies.

The other approach, originally proposed by Doeglas (1946) and more recently by Visher (1969) and Spencer (1963), uses a similar empirical technique, but is based on the shape of the cumulative size-distribution curve (plotted in phi units and on probability paper). Characteristic curve shapes were identified which showed distinct (sometimes truncated) straight-line segments. Visher (1969) and Middleton (1976) associated these segments with separate log-normal grain-size populations, denoting different modes of sediment transport and deposition: traction (coarse sand, gravel), saltation or intermittent suspension (sand), and suspension (fine sand and silt). Although Visher and Middleton restricted their interpretations to sand-sized materials, the plotted cumulative trends of the fine (silt + clay) tail in the Lake Erie samples are visually continuous with their "suspension-mode" fine sand segment. This is the main justification for extending their approach to the finer sediments in this study. When these populations are mixed together in a sediment, the relative importance of each serves to define various depositional environments.

For all cases, the slope of the segments is taken as a direct indicator of the degree of sorting, and the various size modes are recognized by the intervening flatter sections of the curve. In addition, the curve may be used to provide specific size percentiles, such as "C" (the 1st percentile) and "M" (the median, or 50th percentile), which when plotted on log paper, have been used empirically to define various depositional environments (Passega, 1957, 1964; Schlee, 1973).

The analysis presented below relies mainly on the latter approach. The main reason for this is that the inherent inadequacies of borehole sampling and standard grain-size analysis do not, in the writer's opinion, warrant the level of sophistication implied by the former approach, particularly insofar as the higher moment statistics are concerned. Furthermore, using the grain-size cumulative curves provides a more visual and complete presentation of the size data.

Cumulative curves were plotted for 150 grain-size distributions from the Long Point boreholes. In addition, C-M values for the distributions were plotted and are summarized in Figure 3-18. The characteristic curves identified and their inferred associated depositional environments are outlined below.

3.3.1 Dominant suspension (Type 1)

These curves (Figure 3-14) are characterized by a regular, convex-upward trend of relatively low slope, which flattens gradually at the fine end. Although minor amounts of fine sand might be present, there is no well-defined saltation or traction population. These curves are associated with fine mean size, moderate to poor sorting, positive skewness, and marked platykurtosis. Schlee (1973) correlates such curves with gravity settling of sediments from a turbid suspension. Wave and bottom current action is very low, suggesting either a sheltered depositional environment or relatively deep water below wave base. On the C-M diagram (Figure 3-18), these curve types all plotted within the region of "pelagic suspension" (Passega, 1964), denoting gravity settling in quiet water. Curves of similar shape are presently associated with surface sediments in the deeper parts of Lake Erie (Figure 4-17), so a deep-water lacustrine environment is the most likely interpretation for these sediments.

In the Long Point boreholes, Type 1 curves are found only in BH3, from sample LP18-6B (15.3 m below datum) down to the end of the borehole, and in the interval LP7-2 (-5.0 m) to Shel.-1B (-7.1 m). A clear shift in curve position toward the finer end, but with identical shape, occurs below sample LP24-7B (-20.2 m). The break is also reflected in a marked displacement toward higher M-values in the C-M diagram (Figure 3-18). This separation forms the basis for an arbitrary division of Group 1 into two sub-groups (A, B). The finer (1A) group was likely deposited in deeper (more quiet) water than the other group (1B), or possibly in water with a stable ice-cover, which kept wave agitation to a minimum.

3.3.2 Mixed saltation/suspension (Type 2)

Characteristic curves associated with this mode of deposition are shown in Figure 3-15. The identifying feature is the higher-sloped coarse end, forming a clear straight-line segment (saltation population). This component can form up to 50% of the distribution. The saltation population is evidently truncated at its fine end by a suspension population, roughly similar in shape and slope to that of the Type 1 curve. A minor traction population (up to 1%) is often present.

Type 2 curves are associated with poorly-sorted sand/silt+clay mixtures, and show moderate sorting, positive skewness, and mesokurtosis. Schlee (1973) correlated these curves with a fluctuating or episodic bottom current regime, which was able occasionally to sort the fine sand component. This curve shape thus represents an increase in the level of wave and bottom current activity from that associated with Type 1 curves. Although not discussed in the literature, the sand component could also represent occasional inputs of sand by storm or wind processes being deposited into a sheltered bay which at other times received mainly suspended sediments. The size distributions of these Type 2 samples are almost always bimodal, with modes at around 4 phi and from 5 to 6 phi. It is not clear whether the first mode reflects such occasional inputs, or is due to the size deficiency gap commonly noted in the 4 to 4.5 phi fraction and linked by a number of investigators to either a break between bed load and suspended load components, or to the type of grain size analysis used (see Shea (1974)) for a review of these interpretations). The question of whether the sand and silt+clay were deposited at the same time is important in this regard. Apart from the upper sections of Unit 3, where alternating sand and clayey silt laminae could sometimes be sampled separately, the samples analyzed consisted of bulk samples, possibly combining these separate laminae. Curves of similar shape are found in sediments from present-day Long Point Bay (Figure 2-6) taken from water depths of around 14 m. These curves tend to fall into the C-M region of "graded suspension" (Passega, 1964), where tractive currents are beginning to have a noticeable effect (Figure 3-18), and may thus be correlated with lower shoreface sediments (outer nearshore), or shallow protected (lagoon, bay) environments.

Long Point borehole samples characterized by this type of curve include most of the section in BH3 between samples LP11-2 (-10.0 m) and LP18-3 (-15.0 m); in BH1, from BH1-26 (-22.4 m) to BHG1-40B (end of the borehole, -39.6 m) and between BH1-20A (-16.7 m) and BH1-23 (-19.6 m); and in BH2, from BH2-54M (-20.9 m) to BH2-74B (end of the borehole, -59.1 m). Other BH3 sections showing this curve shape are LP4A-3B (-4.6 m) to LP5-3B (-5.2 m). In BH3 samples, the saltation segment has a higher slope (better sorting) than in the other boreholes and also shows a definite traction segment (up to 1%). A noteworthy feature is that the inferred saltation population in this group shows little variation in modal size (between 3 and 4 phi). This could be due to the analysis-related considerations discussed previously, however. In spite of the size uniformity in this saltation component, the mean (and median) grain size of this group increases upward in the sampled section of all boreholes, mainly through increases in the silt at the expense of the clay fractions.

3.3.3 Dominant saltation (Type 3)

The characteristic feature of this group of curves is a high-slope saltation segment, comprising most of the curve (Figure 3-16). This saltation population is associated with a well-sorted sand sub-population. Less sorted coarse (traction) and fine (suspension) tail segments are usually present, but one or the other may be absent. In general, sorting is good to very good and skewness is negative, except where the suspension population increases in importance. The distribution is usually unimodal and leptokurtic.

Visher (1969) associated this type of curve with energetic sorting processes, indicating upper shoreface (beach, foreshore), stream channel, or dune environments. Distinguishing between these environments on the basis of curve shape alone is tenuous, but generally speaking, the lack of a traction segment usually indicates one of the latter two (in our case, a dune interpretation appears more realistic), while the lack of a suspension, and the presence of a significant traction population indicates a wave-agitated, beach environment. Sources of the sand sampled and transportation history are also factors which could affect the shape of the curve. For instance, in glaciated areas such as Lake Erie, source materials may be eroded and reworked in place to produce concentrates of coarser materials (lag) which would tend to skew the shape of the curve. Ice-rafting of coarse beach material could also have a similar effect. All these processes are associated with the high-energy wave-active zone (beach, surf zone). Samples showing curves of this type cluster well in the C-M region of bottom supsension and rolling as defined in Passega (1964). They are common in modern nearshore sediments on Long Point (Figure 2-6).

Long Point borehole samples characterized by this type of curve include the top portions of all the boreholes, in particular:

BH1 : BH1-1 (+0.2 m) to BH1-20 (-17.0 m), and BH1-24 to 25 (-21.0 m). High traction samples occur between sample 1-5 (-3.3 m) and 1-7A (-4.7 m) and between 1-13 (-10.5 m) and 1-16B (-12.9 m).

BH2 : BH2-45 (-7.1 m), 2-47 (-10.2 m), and 2-48 (-12.0 m).

BH3 : LP1-2 (+0.2 m) to LP10-4 (-9.8 m); samples with high traction populations occur at many (9) locations, especially between LP2-5B (1.1 m) and LP4A-1T (-4.1 m); and between LP8-1T (-7.5 m) and LP12-1T (-10.6 m).

Type 3 curves showing good sorting with no traction population and only minor suspension population (suggesting aeolian deposits) include:

BH1 : At scattered positions (BH1-3, -1.0 m; and BH1-12, -9.0 m).

BH2 : At two positions (BH2-41, -1.3 m; and BH2-53T, -18.7 m).

BH3 : At a number of positions in the top portion including: LP1-5B (+0.2 m); LP6-2 and 6-6B (-5.6 m); and LP8A-3B (-8.6 m) to LP10-4 (-9.8 m).

3.3.4 Deviant or transitional curves (Type 4)

Almost all the size distribution curves fit into one or the other of the three types described above. However, there are a few that do not, and representatives of this group are shown in Figure 3-17. Interpretation of these curves is more tenuous, as they could represent complex interactions of the three main types.

BH3 shows more of this group than the other boreholes. For instance, curves from samples LP2-1T and 2-3 (-0.9 m) exhibit a well-sorted saltation population, but are sharply truncated by a large, poorly-sorted suspension population. No traction population is present. The saltation population is as well-sorted as the Type 3 high-energy sands, but the high silt+clay fraction indicates (periodic) sheltering and low energy (gravity settling) deposition from a turbid suspension. Such a situation is most compatible with a lagoonal environment that is subject to occasional inputs of well-sorted beach sand through storm inlets or washover fans across a low barrier ridge.

Almost invariably occurring below either the above or Type 2 curves in sequences from BH1 and 2, are sediments with unusual distributions, and which have all three populations represented (Figure 3-16 Right). The traction population, however, is unusually high. These are strongly bimodal, poorly-sorted distributions. Examples of such curves are found in BH1-16B (-12.9 m) and frequently from BH1-20A (-16.7 m) to BH1-22 (-18.2 m). Similar curves occur in BH2 at 2-47 (-10.2 m) to 2-48 (-12.0 m). All these curves are most likely a variant of Type 3 (high-energy deposition) curves, but with the unusual addition of a large suspension population. They thus also might represent storm inlet or washover inputs of coarse beach materials into normal suspension-mode environments (lagoon). Similar coarse, poorly-sorted sediments were interpreted by Moslow and Heron (1981) as an inlet channel facies. This interpretation for the Long Point curves is supported by the presence, almost without exception, of overlying sediments characterized by Type 2 (or the finer Type 4 example described above) curves. Such a sequence is highly suggestive of inlet erosion followed by closing and return to typical lagoonal sedimentation.

Another such unusual type of curve was noted in samples LP18-1T (-14.8 m) and from LP24-1T to 24-4B (-20.0 m). Though shifted somewhat toward the coarse end, the curves had a similar shape, but with a much sharper truncation between the two populations. The suspension population was also less sorted. No example of these curves was found in present Lake Erie sediments, although similar distributions occurred at depth in LE81-19 south of Pointe-aux-Pins (Figure 4-16). However, they resemble those attributed by Visher (1969) to turbidity current deposits. Their abrupt entry (over an eroded contact) into a fine-sediment environment, and their anomalously high shell and shallow-water pollen content (Section 3.4.1) are compatible with such a depositional mode.

3.3.5 Summary of sediment physical properties

The discrimination of different sediment types on the basis of grain-size distribution curves and C-M diagrams is in general agreement with the classification based on visual characteristics (see Section 3.2). One notable exception, however, is the inclusion into Type 1 curves of Unit 2 in BH3. Though Units 1 and 2 are readily differentiated visually, the size-distribution curves and C-M data are comparable, indicating that they were deposited under similar conditions. This means that BH3 is actually the only one in which Unit 2 was sampled, and so its presumed occurrence in BH1 and 2 (Section 3.2.3) must be modified accordingly. The basal sediments in these latter boreholes are characterized by Type 2 curves, and so are correlated with Unit 3. Furthermore, the upper and lower portions of these sediments in BH1 and 2 show sufficient visual, structural and textural differences that they can be sub-divided into two units: 3a and b, as shown in Figure 3-4. This sub-division highlights Sub-unit 3b as a transition facies between Units 3 and 4.

The above interpretation is greatly aided by the information on internal structures provided by the X-radiograph prints. Using these prints, structural details invisible in the logging process were resolved clearly. For instance, what appear to be true varves (rhythmic laminations diagnostic of glaciolacustrine deposition) became visible in portions of Unit 1 in BH3. Also, the ripple cross-lamination structures resolved in Unit 3 by the X-radiographs provide strong support for a transitional environment, where occasional high-energy events were the key agent in the alternating sediment textural changes (silty clay to sandy silt) noted.

The borehole sequences are all characterized by a clear coarsening-upward trend, from quiet-water clays (Unit 1) upward to shoreface sands (Unit 4). Such sequences have been widely used elsewhere to define depositional trends in areas of sea-level change. This aspect will be examined further in later sections.

3.4 Borehole Chronology

In recent years, sophisticated techniques have been developed for obtaining chronologic control on vertical sediment sequences covering the postglacial period in cases where radiocarbon dating is not possible (usually due to insufficient organic material). These efforts have focussed primarily on dated events occurring within certain pollen species (Lewis _et al_., 1966), paleomagnetic profiles (Creer _et al_., 1976), and vertical trends in the ratios of certain stable isotopes (Fritz _et al_., 1975). Other recent work by Kalas (1980) has demonstrated the use of molluscan fauna in stratigraphic correlation and paleoclimate analysis. Some of these, as well as inferences from geotechnical studies, will be discussed in this section.

3.4.1 Palynology

Fossil pollen profiles were obtained from all four boreholes drilled on Long Point. Partial pollen analyses on BH1 and BH2 were carried out at the National Water Research Institute (Harper, 1982), aimed primarily at identifying diagnostic trends in spruce, pine, hemlock, and Ambrosia. More comprehensive analysis of samples from BH3 was performed under contract by Barnett-Winn Palynological Consultants, Stoney Creek, Ontario. Pollen species frequencies from BH3 are presented in Table 3-3. Frequency profiles of selected species from all of these analyses are shown graphically in Figures 3-19 and 3-20. The pollen diagram for LBH at the tip of Long Point was kindly made available to the author by T.W. Anderson of the Geological Survey of Canada, and is included in Figure 3-19.

The stratigraphic interpretation of these profiles was based on the following established events in the postglacial pollen record of northeastern North America (Mott and Farley-Gill, 1978; Ogden, 1967; Davis, 1981; Winn, 1977; and Anderson, 1971):

Spruce (Picea) maximum	-	11,700 years B.P.
Spruce-Pine (Pinus) transition	-	10,600 years B.P.
Pine maximum	-	9,000 years B.P.
Pine - Oak (Quercus) transition	-	7,600 years B.P.
(Closed boreal forest - Hardwood)		to 8,000 years B.P.
Hemlock (Tsuga) rise	-	6,700 years B.P.
Hemlock decline	-	4,800 years B.P.
Hemlock return	-	3,500 years B.P.
Ambrosia rise	-	120 years B.P.

The record in LBH is the longest of all, extending beyond the spruce maximum. Anderson's interpreted pollen zones and time horizons are shown in Figure 3-19.

The pollen data obtained from BH1 and BH2 (Figure 3-20) contained large (up to 50%) unidentified pollen fractions.

Furthermore, they were based on samples spaced 1.0 to 1.5 m apart. As a result, they did not permit the fine resolution of pollen zones obtainable from BH3 and LBH. However, some minimal chronological inferences can be drawn. Neither borehole intersected the spruce maximum or decline, so the holes both presumably bottomed in sediments younger than 10,500 years B.P. Anderson (1982, pers. comm.) tentatively interpreted the pollen profiles for BH1 and BH2 on the basis of trends in hemlock and grass pollen as indicating a 3500 to 4000 years B.P. age for the basal sediments in BH1 and 5000 to 6000 years B.P. for similar sediments in BH2.

The interpretation of the comprehensive pollen profile in BH3 was complicated by the low pollen counts encountered in most of the samples analyzed. Figure 3-19 and Table 3-3 show that the number of pollen grains per slide was almost always less than 50, and often less than 20. This would also be expected to have an effect on the accuracy of the statistics obtained, and, together with the usual overrepresentation of the pine component, could explain the spikiness and irregularity of the pollen diagram (Figure 3-19).

The glaciolacustrine unit (Unit 1) was found to be virtually devoid of pollen in BH3. In LBH, however, sufficient pollen was found in comparable sediments to enable the definition of both the spruce maximum (11,700 years B.P.), and decline (10,600 B.P.) as shown in Figure 3-19. Although it is clear that Unit 1 correlates stratigraphically with these older sediments in LBH, the lack of sufficient pollen made verification impossible in BH3. Such very low pollen counts could also be an indication of sheltering of the deposits from the pollen rain by a semi-permanent ice cover at the time.

Meaningful pollen counts began in BH3 only at the base of Unit 2 (20 m below lake datum). These basal sediments, comprising the interface zone, contained abundant pollen ($\geq$120 grains/slide) showing good to fair preservation. The assemblage was dominated by pine, closely followed by oak and maple. Surprisingly, non-arboreal pollen species (NAP) were also very abundant at approximately 20%. Dominant NAP species were grasses (Gramineae), sedges (Cyperaceae), cat-tails (*Typha*), and weeds (Compositae). Such a high NAP count, and its composition, suggest strongly a very shallow-water, marshy environment. However, the smooth transition to uniform fine sediments suggests deep water, and so adds support for the turbidity-flow depositional mode interpreted for these deposits in Section 3.3.4. The species composition also suggests that it was deposited during the transition from closed boreal (coniferous) to mixed hardwood forests in southern Ontario, dated at between 8000 and 7600 years B.P. (Anderson, 1971; Winn, 1977). The assemblage is definitely younger than 10,500 years B.P. (the approximate age of the spruce-pine transition) as no samples dominated by these species were found. T.W. Anderson (1982, pers. comm.) assigned similar sediments in LBH (just above the contact with the glaciolacustrine sediments) an age of 7700 years B.P.. Furthermore, although some doubt has been cast on the accuracy of the radiocarbon dates obtained from whole core samples (Section 3.4.3), one such section at -19 m yielded a date (8490 years B.P.) comparable to that inferred above.

Higher up the core (at around -11 m), the percentage of pine pollen declines sharply, while the hardwoods show a steady rise (Figure 3-19). This is interpreted as corresponding to the onset of true mixed hardwood forests, i.e., whose dated occurrence was earlier given as around 7600 years B.P. (see LBH, Figure 3-19). The borehole interval between -11 and -20 m therefore appears to have been deposited during the above vegetational transition phase. The available data do not permit further time resolution within the section.

The younger established palynological markers, namely the hemlock decline and recovery (around 4800 years B.P.) and the *Ambrosia* rise (around 120 years B.P.), are also not very clearly defined in BH3, although they were resolved in LBH. Although hemlock percentages were very low at -13, -10 and -6 m, the latter was the only one where overall pollen abundances were satisfactory (308 grains/slide). This position (-6 m) could possibly represent the 4800 years B.P. marker. The *Ambrosia* peak was not resolved and so must be assumed to lie above the first sample level (-1 m) in the high-energy sands traditionally barren of pollen. It is noteworthy that all the markers identified in BH3 occurred much higher in the sequence than they did in LBH. For instance, the *Ambrosia* peak was identified in LBH at close to -20 m, at the base of the apparently shoreface sand unit (Unit 4), and the hemlock marker occurred at close to -70 m.

3.4.2 Molluscan fauna

The interface zone between units 1 and 2 in BH3, is represented by a 5 cm thick, well defined zone, containing muddy sand and abundant, well-preserved shells. The dominant mollusk species and their relative abundance (identified by L.L. Kalas of the Aquatic Ecology Division of NWRI) are shown below. Taxonomic sources are similar to those given in Kalas (1980).

Gastropoda:	*Valvata tricarinata*	-	4 (specimens)
	Nasonia modicella	-	2
	Goniobasis livescens	-	1
	Pyrgulopsis letsoni	-	1
	Pleurocera acuta	-	1
Pelecypoda:	*Sphaerium striatinum*	-	3 specimens

The above list provides information of limited value for stratigraphic or ecological zonation. All the species represented have existed in the Lake Erie area from deglaciation to present (L.L. Kalas, 1982, pers. comm.; see also Section 4.3.2). Goniobasis (Oxytrema) livescens was thought by Miller et al. (1979) to be a characteristic species of Nipissing or younger sediments in the Huron basin (5000 years ago to present). However, the species was noted in 9000-year old sediments from both the Niagara River area (Calkin and Brett, 1978) and the Cuyahoga River area of Ohio (Miller, 1983). The species in the above assemblage also have a wide temperature tolerance. Nevertheless, Kalas believes that they indicate water temperatures somewhat cooler than those of today. This suggests that the assemblage is definitely pre-Hypsithermal (a period of relatively warm climate which occurred about 4000 years ago), and possibly as old as 9000 years B.P.. Such an age is more compatible with the pollen-derived date of around 8000 years B.P., cited in the previous section (3.4.1).

Kalas also interpreted the ecological preferences of the assemblage to include water depths above the thermocline (i.e., normally 6 to 15 m). No terrestrial species were noted, nor were there any that are normally associated with aquatic vegetation. A fairly open-water nearshore environment is therefore indicated.

3.4.3 Radiocarbon dating

Although organic detritus was commonly noted in the upper portions of the Long Point cores, such material did not occur in sufficient quantities to permit normal radiocarbon dating. An attempt was therefore made to use whole core sections whose organic carbon content appeared to be high enough to allow dating (Table 3-1). This procedure has been used with apparent success in lake sediment studies (R.A. Bourbonniere, National Water Research Institute, 1982, pers. comm.).

The results are included in Table 3-1 (Nos. 47 to 49). The resulting age in one case (LP7-3, 11,280 ± 380 years B.P., WAT-1080) is clearly too old. The date is around 3000 years older than that of sample LP23 (WAT-1083), several metres below, and 4000 years older than that of LP7-1 (WAT-1079), 20 cm above it in the core. Because the core sections used contained abundant inorganic (carbonate) carbon (Table 3-4), such an overestimation could be explained by contamination by older, isotopically-dead carbon, and so these values are deemed unreliable. Because the other sediment sections dated (LP7-1, LP23) also contain significant carbonate, these results, though more in line with the pollen data, must be regarded with suspicion as well. The results are included here nonetheless, but they are assigned second place to the pollen profiles as chronological markers.

3.5 Other Sediment Properties

3.5.1 Clay mineralogy

Qualitative mineral determination by X-ray diffraction was carried out on the clay-sized fraction from selected borehole samples. Two samples from the basal portions of BH1 and BH2 were analyzed at NWRI using an abbreviated pre-treatment procedure (high temperature treatment of the sample was omitted). Six samples, including a re-analysis of one of the above, were analyzed for the author at the University of Waterloo, Department of Earth Sciences (D. Desaulniers, 1982, pers. comm.) using standard procedures (pre-treatment:

air-dried, treated with glycerol, heated to 350°C, and HCl digestion of some samples).

The clay minerals identified in the borehole samples (Figure 3-21) were predominantly illite and chlorite, with lesser amounts of mixed-layer clays (smectite, montmorillonite, and swelling chlorite). In the Unit 1 clay sample (LP25, BH3), these latter were very minor in occurrence, suggesting a very low level of mineral weathering. Samples from younger units showed a slightly higher incidence of mixed layer clays. Also present in all samples were considerable amounts of quartz, feldspar (both plagioclase and orthoclase), and carbonates (calcite and dolomite).

3.5.2 Stable isotope ratios of porewaters

Determination of stable isotope ratios of porewaters from various depths in BH3 are presented in Table 3-5 (D. Desaulniers, University of Waterloo, 1983, pers. comm.). According to Desaulniers, the values indicate a level of enrichment in ^{18}O greater than that expected for glacial lakes or meltwaters. Normal $\delta\ ^{18}O$ (SMOW)* values for glacial waters are quite low (around $-25^{0}/_{00}$); modern meteoric water and groundwaters are around $-10^{0}/_{00}$; while evaporated waters could be even higher. The measured $\delta\ ^{18}O$ value in the upper sample (LP3 at 3.5 m depth) was close to normal meteoric water composition. However, the isotopic concentrations measured in lower units of the Long Point core were abnormal in that they appear to belong to the evaporated category. Desaulniers (1983, pers. comm.) favours the explanation that the porewaters of the identified glaciolacustrine

* Standard Mean Ocean Water.

sediments are not of glacial origin, but were probably introduced to the sediments from a small shallow lake in which evaporation was significant. This suggests that either climatic conditions (and isotopic composition of surface waters) at the time were quite different from those of today, or that lake hydrology was such that evaporation was relatively higher.

If we assume that the porewaters in the sediments originally were of a composition characteristic of glacial lake water ($-25^{0}/_{00}$ $\delta\,^{18}O$), and were later covered by an evaporative lake of concentration, $-5^{0}/_{00}$ $\delta\,^{18}O$, a rough estimate can be made of the time necessary for such an evolution. The estimate was made based on the analytical solution of the well-known advective-dispersive equation for solute transport through a saturated porous medium of low permeability (Bear, 1972). Values for the necessary medium parameters were taken from results for comparable glacial sediments at Wainfleet, Ontario (Desaulniers et al., 1981), and are as follows:

Diffusion coefficient - 10^{-6} cm^2/s (10^{-3} cm^2/y, 10^{-10} m^2/s)
Hydraulic conductivity - 10^{-8} cm/s

Assuming that downward linear groundwater velocities in such a situation would be much less significant than diffusion, it was calculated that it would take more than 10^8 years for the concentration of glacial porewaters ($-25^{0}/_{00}$ $\delta\,^{18}O$) to reach -5%. Such an explanation is clearly not valid in this case. The low isotopic porewater concentration then most likely reflects dry climatic conditions (involving some evaporation of the porewaters at depth), probably during the period of subaerial exposure of the area suggested in the next section.

3.5.3 Geotechnical properties

The approach used in this study makes use of one-dimensional consolidation testing (Casagrande, 1936) to estimate the original maximum overburden thickness (or effective pre-consolidation pressure, P_c) at the same position in the borehole. When this figure is compared with the present overburden pressure (P_o'), calculated by totalling the buoyant unit weight of the overlying sediment units, the amount of any over-consolidation ($P_c/P_o' \geq 1.0$) can be interpreted in terms of the removal by erosion of a definite overburden thickness, or a post-depositional period of desiccation under subaerial conditions.

The prime objective of the testing was to produce a means of further characterizing the sediments for stratigraphic purposes, and possibly to differentiate between deposits of different origins, e.g., glacial versus postglacial. This was necessary because it was not clear on visual criteria whether BH1 and BH2 had crossed the glacial/postglacial boundary. In addition, it was hoped that measured differences between P_c (the pre-consolidation pressure) and P_o' (the present overburden pressure) could be used to determine the magnitude of overlying material subsequently removed by erosion.

The details of the consolidation testing procedure are outlined in most basic geotechnical texts, such as Terzaghi and Peck (1967), and Craig (1978). The use of the technique (more generally associated with engineering construction soil mechanics and foundations) in interpreting the post-depositional history of glacial deposits has been demonstrated by Rominger and Rutledge (1952). Others, such as Harrison (1958) and White (1961), have used consolidation testing to estimate the original thickness of the ice-sheet overlying the sediments tested. Geotechnical testing has been used to identify erosional breaks in the sedimentary record elsewhere in Lake Erie (Zeman, 1976; Lewis _et al._, 1973).

Consolidation tests were carried out on one sample from BH1 and four samples from BH3. The vertical location of the samples is shown in Figures 3-4 and 3-5. The former was tested by Trow, Ltd. (Hamilton) under contract to NWRI; the latter were tested at the Soil Mechanics Laboratory, University of Waterloo by the author and Mr. W. Rodych. The samples were collected in 2 inch (5 cm) Shelby tubes.

The test results for the Long Point boreholes are summarized in Table 3-6. Also shown are other measurements such as initial water content (w), initial void ratio (e_0), sediment type and texture, and others that could be useful in characterizing the sediments and interpreting the results. Figure 3-5 shows the vertical profiles of moisture content and undrained shear stength measured on BH3 samples.

Only three of the samples produced reliable results. The flattened, rounded form of the e-Log P curve of two of the five samples tested showed they were probably disturbed (Shelby 7 from BH3 and the sample from BH1), so these were not used in the interpretation. The other three, whose P_c and P_0' values are shown in Table 3-6 (and plotted in Figure 3-5), show a definite change downward from slightly under-consolidated sediment ($P_c < P_0'$) to definitely over-consolidated ($P_c > P_0'$) across the contact between Units 1 and 2. The pre-consolidation pressure near the top of Unit 1 (i.e., 370 kPa), corresponds to an original vertical section of about 20 m of sediment of unit weight around 19 kN/m^3 (the figure measured for Unit 1 sediments). All this material then must have been eroded from the site of Shelby 5 prior to postglacial deposition. This assessment is confirmed by the almost identical P_c value at Shelby 6 (5 m below).

The above evidence of a significant break in sedimentation (or even erosion) at the observed contact is supported further by the profiles of grain-size, moisture content, and shear strength (Figure 3-5). For instance, the latter shows a local increase near the contact which suggests that desiccation (i.e., an interval over which the sediments stood above the water table) might have been a factor in the increase in shear strength and the over-consolidation. However, the possibility of local compaction through a more rapid drainage via the zone of coarser sediment above cannot be completely discounted.

Other geotechnical properties of sediments, such as bulk density, have been demonstrated to be correlated to sedimentation history. This is especially true for fine-grained sediments where post-depositional compaction and settlement are relatively slow. These processes occur in direct response to the time-dependent reduction of void space as excess porewater is expelled. Excess porewater pressures result from the increasing weight of overlying sediment units (Zeman, 1979; Yamamoto et al., 1974). By measuring the in situ bulk density of a sediment, and estimating its original value, the total thickness of the original newly-sedimented deposit may be calculated. An important assumption is that deposition was relatively rapid.

In the BH3 sediment units, only Unit 2 was suitable for this approach. Unit 1 was found to have been already over-consolidated with respect to its existing overburden pressure prior to postglacial sedimentation, so no further compaction is to be expected. Units 3 and 4 contain sufficient sand layers for rapid drainage of excess pore pressures to have occurred as these sediments accumulated, with no appreciable reduction in thickness.

In the silty clay Unit 2, however, large compaction settlement could be expected, primarily because of its apparently rapid accumulation (Section 3.4.1), and the lack of any boundary or internal sand layer for rapid dewatering. From the geotechnical test measurements (Shelby 4 in Table 3-6) and extrapolation from measurements on comparable sediments in the area, we have:

ρ^*	=	present bulk density Unit 2	1940 kg/m^3
ρ_S, G_S	=	grain (solids) density	2600 kg/m^3
ρ	=	density of water	1000 kg/m^3
ρ_0^*	=	est. bulk density of freshly deposited sediments (Zeman, 1979)	1300 kg/m^3

Relating the increase in bulk density to the loss of porewater and reduction of void space during compaction, we can make use of the standard relationship between bulk density and void ratio (e) of saturated sediments:

$$\rho^*_{saturated} = \left(\frac{G_S + e}{1 - e}\right) \rho$$

The computed pre- and post-compaction values of (e) are:

e_0	:	original void ratio	4.0
e	:	present *in situ* void ratio	0.7

In other words, pore volume can be expected to have undergone an estimated six-fold reduction as a result of post-depositional compaction.

Adjusting the present thickness of Unit 2 (5 m) to reflect this change, and bearing in mind that the volume of solids remain unchanged during compaction, we obtain a figure of 14.7 m for the original thickness of Unit 2. Because compaction of sediments is a time-dependent process (sediments compact as they accumulate, and not as an entire unit as assumed above), the above value is admittedly an overestimation. A more accurate model, taking time-dependency into account, would require more data than are presently available (more detailed bulk density profiles and more accurate sedimentation rates in Unit 2, for instance). In any event, a conservative estimate of the original thickness of the unit would fall somewhere between 8 and 12 m. Even an accumulation of this magnitude at the site would have serious implications, in particular on the estimation of probable lake levels at the time. If water depths were as interpreted by analogy with comparable present-day sediments as greater than 20 m (Section 3.3.1), then lake levels around 8000 years B.P. (the pollen-derived age of the unit) must have been between 15 and 25 m above the glacial sediment surface (-20 m), i.e., close to the present lake datum. This aspect will be discussed further in later sections on postglacial lake level history.

Of the other parameters measured, Atterberg limits show a noticeable decrease from Unit 1 to Unit 2. The number of points is insufficient to resolve any consistent internal trend in these parameters near the Unit 1 surface, although the plastic limit declines slightly at the top of Unit 1. No further interpretation of these data will be attempted here.

3.6 Synthesis of Results

The data presented in the preceding sections comprise several lines of evidence bearing on the nature and timing of sedimentary events at Long Point. The level of sedimentological insight provided by three 5 cm diameter borehole samples of unconsolidated sediments is necessarily limited in comparison to more extensive surface exposures, bluff or road-cut sections, for instance. In addition, key information on depositional structures (such as bioturbation and cross-stratification) is often not readily identifiable or may have been destroyed in the drilling process. The net result is that the data are often less than conclusive, and inference must play a significant role in the interpretation. Nevertheless, the lines of evidence provide sufficient information to attempt an interpretation of the broader trends in postglacial sedimentation in the area.

3.6.1 Depositional history

1. Unit 1

On textural and C-M evidence, supported by structures defined on X-radiographs, Unit 1 is interpreted to have been deposited from suspension in very quiet water (below wave base). Water depths at the time cannot be estimated with confidence in such fine, cohesive sediments, as other factors such as reduced fetch distances due to shoreline morphology and possible stable ice cover, might also have played a role; however the water was likely relatively deep (>30 m). The scarcity of drop-stones and other ice-rafted debris indicates that the ice-front ponding the lake was located at some distance from the area. The presence of contorted laminations at intervals within the unit could be due to one of several processes, namely disturbance of the sediments by grounded ice, effects of melting permafrost or ice masses below the sediments, dewatering, wave loading, or periodic down-slope mass movement. Also, because these contorted zones were more common in the upper portions of the unit, they could be associated with dewatering during the period of subaerial desiccation inferred earlier (Section 3.5.3). No means of dating the deposit were available (pollen counts in the unit were all very low), but the presence of varve-like structures and its overall similarity with other deposits in the area conclusively identified as glaciolacustrine deposits (LBH) leads to the conclusion that the setting was likely one of the high-level glacial lakes which occupied the Lake Erie basin as the last glacier retreated (see Section 2.3). This would place the time of deposition at prior to 12,000 years B.P. (Lewis, 1969).

2. Interface zone between Units 1 and 2

The first postglacial depositional event discernible in the sediment record is the change from Unit 1 to Unit 2 sedimentation, observed in the lower portion of BH3 (change from Type 1A to 1B curves). Both these units are uniform, fine-grained deposits, whose major point of difference is a tendency toward higher silt percentages (coarser texture) in Unit 2. Nevertheless, depositional processes, as inferred from the grain-size distribution data, are very similar. The tendency toward a coarser sediment in Unit 2 is especially evident in the separation of the two units on the C-M diagram. The importance of the change from Unit 1 to Unit 2 sedimentation is emphasized by the abrupt change to the sandy, shelly interface zone (LP24-4A,B) between the units.

The change to Unit 2 (clayey silt) sediments apparently was complex. The visual, geotechnical, and porewater geochemistry data imply strongly that the change was preceded by a period of non-deposition, or even subaerial exposure and erosion. The presence of abundant hardwood pollen and the lack of clear dominance of either spruce or pine in the samples from this zone, however, suggests that sedimentation at BH3 did not resume until close to 8000 years B.P. This estimate thus suggests a hiatus of around 4000 years; strong evidence for an extended period of low lake levels in the area, i.e., 20 m or more below present datum.

The origin of the coarse, shelly layer between Units 1 and 2 is not clearly indicated by the sediment data. Initially interpreted as a shallow-water lag concentrate on the eroded glaciolacustrine surface, its grain-size composition and curve shape include a large, poorly-sorted suspension population that does not fit such a high energy depositional mode. In addition, the good sorting noted in the sand (saltation population; see LP24-4A,B in Figure 3-17) is a clear indication of transport rather than of residual concentration. The truncated curve shape, together with the unusual association of apparently shallow-water (non-marsh) shells with marsh-type pollen in generally unbroken condition, support the hypothesis of chaotic transport downslope, and deposition offshore by turbidity currents (Visher, 1969). This view is supported by the fabric of the unit (as shown in the close-up photographs, Figure 3-11) in which the coarser grains and shell fragments are matrix-supported (Section 3.2.2). The patchy sand concentrations noted, however, could indicate some limited reworking. Such a mode of deposition suggests that contemporary water depths at the site were again relatively deep. Such deep-water conditions would be more compatible with the observed gradational change to the non-fossiliferous, soft Unit 2 sediments occurring above this zone. The obvious irregularity of the Unit 1 surface thus might either predate the deposition of the coarse layer, or might have resulted from such a turbidity flow. On the basis of the irregularity of the surface (Figure 3-11), the former explanation is more likely.

3. Unit 2

The first definitely postglacial sediments occurring in BH3 above the erosional disconformity are the soft clayey silts labelled Unit 2. These sediments are almost identical in texture and appearance to the sediments presently being deposited in the deeper portions of the lake (see C-M positions in Figure 3-18). The texture and C-M position of the unit indicate that it is an open-water shelf-facies deposit (in the terminology of Reineck and Singh, 1975), laid down below wave base in fairly deep water (but not as deep as in the case of Unit 1). In spite of its fine grain size, water depths could have been less than 15 m or so since the area was possibly sheltered from the prevailing wind and wave impact by the Norfolk moraine ridge close by to the west. In any event, the abruptness of the change from non-deposition, to coarse turbidity deposits, to fine-grained silts suggests that the initial submergence of the site was rapid.

Unit 2 sediments, characterized by Type 1B curves, were noted only in BH3 between -15.3 and -20.0 m, but probably occur below the terminations of BH1 and 2. A comparable grain-size analysis could not be carried out on LBH sediments, but the textural similarity of sediments there (between 60 and 80 m below datum) with Unit 2 sediments in BH3 suggest a similar depositional environment. The low organic carbon content (0.4%) of selected samples from the unit in BH3 are usually indicative of well-circulated, open-water depositional conditions, with rather low sedimentation rates. This inference is contradicted by the pollen data, however. On pollen evidence, the 5 m thick unit in BH3 was deposited approximately between 8000 and 7000 years B.P., giving a sediment accumulation rate (uncorrected for compaction) of close to 0.5 cm/y. In LBH, the 20 m thick unit was apparently deposited between 10,500 and 3500 years B.P. (Figure 3-19), for an accumulation rate of 0.3 cm/y. If the measured moisture content for the unit in BH3 is used (30%), with a solids specific gravity of 2.7, these figures translate to sedimentation rates of 7370 and 4260 g/m /y, respectively, i.e., equal to, or greater than, the maximum present-day rates for the eastern sub-basin of Lake Erie (1500 to 4310 g/m /y) published in Kemp et al. (1977). It must then be concluded that sedimentation rates were exceptionally high at the time of Unit 2 deposition, and that the low organic carbon levels measured must be due to other factors. Possible explanations could be the low level of primary productivity in the cold, eutrophic waters of the lake at the time, or to dilution by high inputs of allochthonous (land-derived) sediment low in organic matter. This latter is deemed more likely in view of the close proximity of the BH3 site to a major stream, Big Creek (Figure 2-6).

4. Unit 3

The onset of Unit 3 sedimentation indicates another important step in the evolution of the local depositional environment in the Long Point area. At the BH3 site, relatively deep-water fine-grained sediments gradually gave way to coarser (Unit 3) sediments, characterized by upward-increasing frequency of fine sand laminations. The characteristic presence of wavy or flaser-type bedding has been interpreted elsewhere as an indication of environments where transport energy oscillates periodically, such as tidal-flats (Reineck and Wunderlich, 1968). In this case, tides are negligible, so another mechanism must be invoked. The most likely is periodic oscillation of water depths (or lake levels), either in the short-term (seiche, storm set-up and set-down) or long-term (hydrological changes). In addition, the increasing incidence of sandy beds indicate an overall shoaling trend in the area.

Concurrent sedimentation patterns at BH1 and 2 reflect a similar shoaling trend, although initial water depths were presumably somewhat greater. Unit 3a represents the initial fairly deep-water sediments, whose textural uniformity indicates a stable low-energy environment. This environment gradually changed, by shoaling, to permit coarser sedimentation (Unit 3b). Further shoaling is indicated by the increasing frequency of sandy laminations upward in 3b.

The maximum size transported (as indicated by the C-value of Unit 3 sediments; see Figure 3-18) provides a means of estimating likely water depth ranges at the BH3 site. The estimate assumes that wave orbital currents were the main transporting agent. The maximum C-value (300 μm) would require a minimum bottom current velocity of about 10 cm/s to initiate motion (Inman, 1957). Assuming maximum significant wave periods of 3 to 4 s, fetch-limited at around 50 km, estimated maximum water depths would be between 10 and 15 m (Coastal Engineering Research Centre, 1973, p. 4-67). Water depths could be less if the actual fetch was shorter, i.e., in a lagoonal or bay setting. In any event, Unit 3 may be interpreted as a transitional deposit, intermediate between shelf (Unit 2) and shoreface (Unit 4) deposition.

The fine, olive gray, silty sub-unit noted in BH3 at the top of Unit 3 is anomalous, however. The lithologic change was not observed in any of the other boreholes, so this sub-unit could represent an abrupt, but local change toward a more isolated type of depositional environment. Because little organic debris (plant fragments or molluscs) was observed in the sub-unit, and organic carbon values were lower than expected in a restricted environment (where aquatic vegetation and organic matter should be plentiful), the change could also be due to an abrupt increase in water depths. The decline in hemlock pollen dates this sub-unit at around 4800 years B.P., i.e., around the time of the postulated Nipissing drainage resumption (Lewis, 1969). A similar correspondence of signs in the pollen record with the Nipissing event was concluded at LBH (T.W. Anderson, 1982, pers. comm.). Another reason why a similar change in sediment type was not found in the other boreholes could be that the sub-unit was a local deposit, and could mark the beginning phases of spit development at Long Point, wherein recurved portions of the spit could abruptly cut off and partly isolate portions of the leeside nearshore zone (lagoons). Either or both of the above hypotheses might well be compatible with such a situation.

From the pollen record at LBH, Unit 3 deposition (47 m thick) occurred between 3500 years B.P. and less than 120 years ago, or at an average accumulation rate of 1.4 cm/y. On the other hand, the rate for the middle portion of the unit in BH3 (between the less well-defined hemlock decline and the major forest transition) was around 0.17 cm/y; in other words, an order of magnitude less.

5. Unit 4

The transition from Sub-unit 3b to the top unit, Unit 4 in BH3 is sharp. Unit 4 is clearly a high-energy upper shoreface or foreshore deposit similar to present-day deposits at the site, whose good sorting shows the dominant effect of direct wave and wind action. This is confirmed by the common heavy mineral laminations and the presence of planar stratification as well as the medium-to-coarse texture of the unit. By analogy with present Lake Erie deposits, the overlying water depths would have been less than 5 m. These sands are presently associated with the progradation of the Long Point spit over the eastern sub-basin and Long Point Bay sediments, so the transition from silty sands (Unit 3) to Unit 4 sands is likely an extension of this modern trend.

On the basis of the cumulative size distribution curves, a variety of sub-environments in the upper shoreface zone could be identified, e.g., very well sorted dune and coarser inlet channel deposits. Minor fine-grained, sheltered deposits also identified in the unit attest to periods of inter-recurve ponding and quiet-water sedimentation, usually associated with inlet closing.

The unit is clearly transgressive, and apparently began to be deposited at the BH3 site around 4800 years B.P., while at the LBH, the pollen record shows that deposition of Unit 4 did not begin until after the Ambrosia peak (dated at around 120 years ago). This yields an accumulation rate for BH3 of around 1.2 cm/y and around 14 cm/y at LBH. The latter rate is extremely high and can best be accounted for by lateral migration of a large sand bedform (such as a spit), rather than conventional vertical deposition.

3.6.2 Vertical and spatial lithologic trends

The most striking feature noted consistently in the post-glacial sequence of all the boreholes was the distinct coarsening-upward in mean grain size (see mean size profiles Figures 3-4 and 3-5). This pattern, in which clays are overlain by silts, which in turn are overlain by sands, can be used as a diagnostic feature of the sedimentary history of an area, since it is indicative of lateral facies migration caused by progressive changes in the depositional environment. The pattern has been associated by several authors with a prograding coastal sequence, in which coarse shoreface (sand) deposits migrate over deeper water (or more sheltered bay or lagoonal) finer-grained deposits. Typical examples are the barrier islands of the eastern U.S. (Moslow and Heron, 1981) and Italy (Reineck and Singh, 1975, p. 316). In both cases, rising sea-level during Holocene time was the cause, leading to the spit (or barrier island) growing or being pushed laterally (prograding) over the finer lagoonal or back-bay deposits. Postglacial trends in lake levels and modern processes such as over-wash and large-scale erosional trends on Long Point (Boulden, 1975) lend support to this hypothesis of lateral spit migration under the effect of rising lake levels.

Using the boreholes and the limited offshore coring and jetting data, the spatial continuity and distribution of the sedimentary units can be examined. The best stratigraphic data obviously pertain to the line of boreholes along the length of Long Point. These data are combined into the longitudinal section shown in Figure 3-6. It is clear that the water well data can be used only for indicating the thickness of the clean sand unit west of BH3. Furthermore, because of the considerable distance between the boreholes (around 10 km or more), the inter-borehole projection of unit boundaries is open to question.

It was possible to construct only a general picture of transverse spatial relationships. This was due to the sparse and limited nature of data available on adjacent lake bottom materials (Figure 2-6). Reliable identification of the glaciolacustrine surface was obtained only in scattered areas (more than 20 km south, and in the extreme west) of the lake bottom off Long Point. No such information was available for the Inner Bay and Long Point Bay areas to the north. The shallow refusal depths obtained by the jetting probe in these areas (compared to the position of glacial materials in on-land borehole sections) suggest that the jet did not bottom in glacial materials. It is possible that depth of penetration of the jet is limited by factors other than substrate, such as side-wall friction in sticky cohesive materials.

Figure 3-22 therefore presents only an hypothesized model of spatial relationships of lithologic units compatible with their position in the boreholes at the few additional reliable reference points (noted on the abscissa). The model clearly interprets the data to suggest a lateral shift of the facies units, i.e., a northward shift at the site of BH1 and 3 and a southward shift at BH2. Such a progressive shift in the landform over the time since its formation is in keeping with the evidence from the vertical trend described at the beginning of this section, and with the trends noted in the orientation and accretion of beach ridges visible on the Point, as discussed in Section 2.5.4.

The above model of the geometry of the Long Point sand deposits can also be used in estimating the total (sand) volume contained in the foreland. The detailed estimate is outlined in Table 3-7, and yields a figure of between 4 and 7 billion cubic metres.

3.6.3 Summary of the depositional sequence

In summary, while the vertical sediment profiles in the boreholes do not provide unequivocal time-controlled evidence of trends in postglacial processes, the following general inferences are possible:

1. Consolidation tests indicate that a considerable thickness (around 20 m) of the glaciolacustrine sediment surface was eroded prior to the deposition of the postglacial sequence. Such a thick layer could only have been eroded as a shoreline trangressed through the

area. This supports geotechnical and porewater isotopic evidence that the area occupied by BH3 was probably subaerially exposed for some time during and after the low-level Early Lake Erie stage (ca. 12,500 years B.P.).

2. The area of BH3 passed abruptly from being subaerially exposed to receiving fairly deep-water, fine-grained sediments (Unit 2). The lack of an intermediate shallow-water deposit or transitional sequences between the glacial and postglacial sediments suggests that the initial transgression was relatively rapid. Pollen data and mollusc assemblages suggest this transition occurred around 8000 years B.P. and lasted until around 7000 years B.P. Similar sediments were being deposited at LBH until around 3500 years B.P.

3. After this stage, interpreting the correspondence between lake levels and sediment lithology becomes more ambiguous. The change to interlaminated silt and fine sand deposits (Unit 3) overlying Unit 2 is compatible with either an oscillating, but definite lowering trend in lake levels, leading to a gradual increase in wave effect on bottom sediments of the area, or represents the initial signs of the progradation of an updrift shoreline in the form of a spit, or both.

4. Abrupt fine-grained sedimentation returning above Unit 3 in BH3 could indicate either a sharp increase in water depths (Nipissing rise in lake levels), or a sudden sheltering of the area by a recurve from an approaching foreland. It is possible that the fine material represents allochthonous deposition primarily, probably from an ancestral Big Creek.

5. Abrupt entry of the well-sorted sand facies (Unit 4) into the profile is associated with the northward and eastward progradation

of the Long Point spit as lake levels rose. The migration process is interpreted as being analogous to that which characterizes barrier islands along ocean coasts experiencing Holocene transgression of sea-levels.

6. Deposition of the various sediment facies occurred at different times, with the eastern areas lagging behind those to the west. For instance, the site of LBH did not begin to receive Unit 4 sediments until less than 120 years ago, according to pollen data interpretations, compared to around 4000 years B.P. in BH3. Similarly, Unit 3 deposition did not begin there until after 3500 years ago, probably long after it had begun at the site of BH3.

7. Sedimentation rates for Unit 2 are much higher than present-day rates in eastern Lake Erie. Rates for Unit 3 are generally lower and more variable, ranging from high (1.4 cm/y in LBH) to moderate (0.17 cm/y in BH3). The rapid sediment accumulation rates inferred for Units 4 and 3 from the pollen profile in LBH is best explained by the hypothesis of lateral spit migration (or progradation) rather than vertical accumulation of coarse sediment inputs from shore erosion or other sources.

4.0 THE SEDIMENT RECORD AT POINT PELEE AND POINTE-AUX-PINS

Although the sedimentary record at Long Point described in the previous chapter is the most recent sampled, and was collected specifically for this study, useful sediment profiles exist from the other forelands on the Lake Erie north shore. The offshore cores in the Pelee Shoal area were collected by the author, while those from elsewhere in the coastal and nearshore areas were collected by others, and were generously made available for this study. These data are combined below and are used to complement the sediment record at Long Point.

4.1 Subsurface Sediments, Point Pelee Area

General information on core collection, sample preparation, and sample analysis techniques used for the six lake-bottom cores collected by the author in the Point Pelee area were outlined previously in Section 3.1.2. Summary logs of the cores collected from the Pelee Shoal are presented in Appendix 3 (detailed logs are found in Coakley et al., 1977). Core location and other background information are summarized in Table 4-1 and Figure 2-4. The results of grain-size analyses are tabulated in Appendix 5. Summary plots of the vertical lithology and profiles of other measurements made on the cores are shown in Figures 4-1 to 4-3. The boundaries of the lithologic groupings shown were based primarily on perceived breaks in vertical trends in grain-size parameters (mainly sand-silt-clay percentages and mean grain size), as well as on diagnostic sediment structures, both logged visually and from X-radiographs. This classification was largely confirmed by more comprehensive grain-size analyses discussed later in Section 4.2. It should be borne in mind that some of the structural characteristics, such as massive structure in the upper sand sub-unit, could have been induced to some extent by the Vibracore technique of boring.

Nevertheless, the major lithological units defined are, for the most part, laterally continuous and can be traced from core to core. These units are described below.

4.1.1 Till (Unit 1)

This unit forms the base of Cores 1, 3, and 4, and represents the oldest sediment encountered. It is usually dark grayish brown (10YR 4/2) in colour, with occasional reddish and gray mottling. In composition, it is characteristically a sandy silty clay till, in which sand averages around 20% (maximum 40%), silt, 30% (maximum 50%) and clay, 50%. Mean size averages around 6.5 phi, and sorting is very poor (standard deviation of around 3 phi). Pebbles are primarily local Paleozoic rock types (gray limestone, buff siltstone, and black shale) with a minor granitic component. All are sub-angular to subrounded in shape. In Cores 1 and 4, a thin (15 cm) lag gravel layer separates the till from the overlying units, but in all cases, the contact is sharp. Internal structures are absent. No direct evidence of soil formation or in-place plant remains was observed at the contact, although the reddish mottling observed could represent leaching and the incipient development of a soil profile, especially in Core 3. The surface elevation of the till appears to have considerable relief, ranging from around -8 m (165 m a.s.l.) in Cores 1 and 3, to somewhere below -18 m (155 m a.s.l.) in Cores 2, 5, and 6.

4.1.2 Clay/silt complex (Unit 2)

This unit forms the base of Cores 2 and 5, occurring below the -14 m level in both. The unit in Core 2 is uniform clayey silt, free of pebbles, while that in Core 5 shows considerable and abrupt changes in texture. Silt occurs predominantly in the upper portion of the unit, grading downward to silty clay at the bottom. Mean grain size is fairly constant at around 7 phi, and sorting is moderate (st. dev. of around 2 phi). Structure may be either laminated or massive. The upper contact with the overlying Unit 3 was found to be either gradational or sharp, and was often associated with a gravel concentrate. The colour of the unit varies downward from olive gray to dark olive gray. Apart from the dark colour, there are other indications of reducing conditions during or after deposition. These consist of black streaks (probably iron sulphide), well-preserved plant fragments, and relatively high levels of organic carbon, compared to the upper units. In all cores, no sign of bioturbation of this fine-grained unit was detected. The interpreted top of this unit varies in elevation from less than -18 m (Core 6) to around -14 m (Cores 2 and 5).

4.1.3 Interlaminated sand/silt (Unit 3)

This unit occurs in all cores except Cores 1 and 3, but reaches its maximum thickness in Core 6, forming the basal 6 m. The unit consists, at the top, of fine-to-medium sand with minor interfingering lenses of silt, but sand content decreases gradually downward as silt increases. Mean grain size shows a corresponding downward decline from around 4 to 6 phi approximately, and sorting is comparable to that of Unit 2. Colour also changes downward from olive gray (5Y 4/2) to dark olive gray (5YR 5/1). Internal structures, where present, range from laminations (both planar and contorted) to irregular lenses of clay and sand, predominantly in the lower and upper sections, respectively. Lenses and laminations are fairly thick, on the order of 1 to 3 cm. In the lower sections, dark laminations of varying thickness composed of iron sulphide and plant detritus also occur. Wood chips and mollusk shells are common throughout the unit.

The top surface of this unit, in the cores in which it is present, is apparently quite regular and rises gently northward from around -12 m in Core 2 and -10 m in Core 5, to around -8 m in Core 4 (Figure 4-4). In cores where Unit 3 is not present, the till surface (top of Unit 1) also lies approximately in this plane (e.g., at around -8 m in Cores 1 and 3). This surface uniformity over the area suggests that Unit 3 deposition culminated in a period of surface infilling and erosion of the subaqueous portions of the area to local wave base prior to the deposition of Unit 4.

4.1.4 Sorted clean sand (Unit 4)

This is the top unit in all cores, and comprises the dominant surficial sediment on the Pelee Shoal. It usually consists of an upper (massive) and a lower (laminated) sub-unit, and is readily identifiable visually. Below the Pelee Shoal, it ranges in thickness from about 1 m (Core 1) to more than 5 m (Core 6). It overlies the till directly in Cores 1 and 3. The boundary between the two sub-units is consistently sharp, and is marked by the above change in structure, and by the upward change from finer to coarser texture. The colour of the unit grades from brown (2.5Y 4/4) to olive gray (5Y 3/2) in the lower sub-unit. The unit is generally medium in texture, with mean phi values averaging around 2.0 in the upper, fining downward to around 3.0 to 4.0 in the lower sub-unit. Sorting is moderate to good (phi standard deviation usually less than 1.5 phi), but coarser particles ranging from granule to cobble size occur sparsely throughout, or are concentrated in sharply-defined layers within the unit. Although heavy mineral laminae are virtually absent from the upper sub-unit, they are common in the lower sub-unit. The heavy mineral concentrations serve to highlight the wide-spread planar cross-stratification and inclined laminations occurring within the unit. Pelecypod shells and shell hash are common in the lower sub-unit.

4.1.5 Sediments in other boreholes

Figures 4-5 and 4-6 show plotted logs for two of the three sites drilled in Point Pelee National Park (Terasmae, 1970). Borehole locations are shown in Figure 2-4. Because neither grain-size data nor more detailed descriptions (than those given in the figure) were available, only the broader aspects of the relationship of these sediments to those on the Shoal can be discussed. The above borehole sequences might still be of importance in casting additional light on late glacial and postglacial sedimentation events in the area.

Several features are worth noting in Figures 4-5 and 4-6:

1. The till surface occurs at a much higher elevation than below the Shoal, sloping southward from about -4 m (BH1T), to about -6 m (BH2T), to lower than -10 m (BH3T). What appear to be multiple till sheets (separated in two cases by a laminated silty clay (glaciolacustrine?)) occur below Point Pelee (BH1T and 3T, Figure 4-5).

2. Except for a thin silty layer (1 m thick) in some cases, the sand unit rests directly on the till without any of the intermediate units noted in the Shoal boreholes. The sand thickens southward from less than 3 m in BH1 to more than 10 m in BH2. Like the sand unit on the Shoal, there is also a clear coarsening-upward textural trend, from fine, silty sand at the base to coarse, pebbly sand at the top.

4.2 Grain-size Analysis

Cumulative curves were plotted for the 160 sediment samples collected from the six Pelee Shoal boreholes. Representative curve types are shown in Figures 4-7 to 4-9. From these curves, C-M values were extracted and plotted as summarized in Figure 4-10. In spite of the much closer borehole coverage, the curves and C-M diagram show considerable scatter compared to those from Long Point, for instance. However, the curves exhibit some consistent features that might be related to the overall trends in local depositional conditions.

4.2.1 Unsorted deposits, or till (Type 1)

These curves (Figure 4-7), though highly variable, are generally characterized by a low-sloping, almost linear trend, which extends from pebble-sized to clay-sized fractions, indicating minimal sorting. Skewness is almost invariably negative (Appendix 5). None of Visher's three major populations (traction, saltation, and suspension) are identifiable. These samples are all from core sections identified visually as till, and their pattern on the C-M diagram supports this classification (Schlee, 1973). Samples showing this curve and C-M pattern are found in the bottom sections of Cores 1, 3, and 4.

4.2.2 Dominant suspension (Type 2)

These curves are characterized by an ill-defined saltation segment of moderate slope, merging smoothly into a dominant suspension segment. The overall shape of these curves is thus linear to convex-upward, with no clear break between segments (Figure 4-8). Skewness is usually positive, and sorting is moderate to poor (standard deviation:

1.5 to 2.3 phi). These curves are similar in shape to others at Long Point (see Section 3.3.1) interpreted as indicative of gravity settling from a turbid suspension. The relatively high C-values of the group (compared with similar sediments at Long Point), combined with the virtual absence of any definite traction or saltation population, is suggestive of minor, random inputs of coarser material, most likely from seasonal ice-rafting, or storm-related or aeolian processes.

Three sub-groups of this type are resolved on the C-M diagram (Figure 4-10). Type 2a samples, found almost entirely in the basal sections of Cores 2 and 5, are characterized by median (M) values less than 8 micrometres (>7phi). The shape of the cumulative curve is more linear than convex. Skewness is usually negative, and sorting is moderate to poor.

Type 2b samples comprise mainly the sample 4-240 to 4-540 section of Core 4 (overlying the till unit), and most of the basal portion of Core 6 (below 6-600). This sub-group is coarser than 2a, with M-values ranging between 10 and 40 micrometres (4.6 to 6.6 phi). Curve shape was the standard convex-upward type. Skewness is usually positive, and sorting is slightly better than that of 2a.

Type 2c differs from 2b only in its much larger C-values. This sub-group is restricted almost entirely to samples from Core 5 (section 5-420 to 510). These samples show linear curve shapes comparable to those of type 2a, but are shifted considerably toward the coarser end. Although indistinct saltation segments can sometimes be discerned, no clear break occurs between the populations. Sorting is relatively poor (st. dev. around 2.0 phi), and skewness is variable.

In summary, this group, though representing a dominant suspension-settling mode of deposition, exhibits strong spatial variation. Samples in this group from Core 5, for instance, differ considerably from those from the other cores. This spatial non-uniformity is a clear reflection of a rather restricted or sheltered sedimentary basin, probably with an irregular bottom topography, where depositional processes responded primarily to local conditions (see Section 6.2). Reliable estimation of water depths could not be made in this case, as the coarser material was probably not water-transported, and thus bore no relationship to wave climate and the resulting orbital (tractive) currents. However, the fine texture of the sediments represented suggests they were probably deposited below local wave base.

4.2.3 Dominant saltation (Type 3)

These curves are characterized by a high-sloped saltation population, comprising most of the curve (Figure 4-9). The group corresponds closely in occurrence to that of the well-sorted Unit 4 sands. Variable (but generally minor) traction and suspension populations are usually present, but sorting is generally good (st. dev. of around 1.0). Skewness is strongly positive, in marked contrast to the comparable unit at Long Point where negative skewness was the rule. On the CM diagram (Figure 4-10), samples having this type of distribution all tend to cluster within the area labelled 3; however, some samples (especially from Cores 5 and 6) were consistently shifted slightly to the left (finer) side of this main group. This deviant group is labelled 3b in the C-M diagram. Both curve types are associated with energetic sorting by waves and currents (Visher, 1969), conditions characterizing the upper shoreface (foreshore, beach) environment.

The good sorting indicated by the relatively high slope of the saltation segment, and the virtual lack of a significant traction population in sections of Cores 4 (30 - 210) and 3 (270, 300), suggest a nearshore bar or dune environment. The relative importance of the traction population in the upper portions of Cores 2, 5, and 6 is compatible with either a higher-energy surf-zone or inlet channel environment, or with subsequent reworking of existing sediments in such an environment. The shape of curves from the middle portion of Cores 2, 5, and 6, and from all of the sand unit in Core 1 is remarkably consistent. These curves are all very positively skewed, with a significant, but unsorted (flat) suspension segment (approximately 5%). The traction population is usually less than 1%. It is possible to trace the evolution of these curves upward (into the high-traction examples described above) and downward into the high-suspension Type 3a (Core 5) and 2c curves, depending on whether the coarser or finer components were being concentrated. This is further support for the explanation of the high-traction distributions in the upper portion of Unit 4 as being caused by reworking.

In summary, the sediments comprising this group show a discernible trend from a relatively sheltered shallow-water environment, characterized by an important suspension component (lagoon or back-bay environment), to higher-energy, saltation-dominated environments (shoreface zone). In some cases, the trend apparently is continued into still higher energy environments involving higher traction deposition, indicating more intense reworking of the above deposit types (surf-zone or inlet channel environments).

4.3 Borehole Chronology, Point Pelee

The stratigraphically important data discussed below comprise a number of radiocarbon dates from both the Pelee Shoal and Point Pelee, as well as pollen profiles, molluscan faunal studies, and geotechnical test results from cores on the Shoal. These studies were carried out by collaborators with the author in a study of Point Pelee Shoal sediments and are outlined in full in Coakley et al. (1977) and partially in Kalas (1980). In the sections below, salient points of these studies will be summarized and updated with more recent data obtained by the author.

4.3.1 Radiocarbon dating and pollen chronology

Conventional radiocarbon dates obtained from the Point Pelee area are summarized in Table 3-1 (dates no. 16-21). The only dates below Point Pelee itself were on basal gyttja in the marsh ponds in Point Pelee National Park (dates no. 16 and 17). Materials dated in the Pelee Shoal cores consisted of disseminated organic debris and shells.

Practical problems in using radiocarbon dates from such materials for stratigraphic purposes are discussed in some detail later on in Chapter 5. In short, with the exception of the two dates from below Point Pelee, all the dates obtained have to be treated with some caution, as is indicated in Table 3-1. Of the Pelee Shoal dates, dates no. 18 and 19 (from Cores 6 and 5, respectively), though apparently from transported material, appear to be the most reliable chronologic markers.

A detailed pollen profile from Core 2, prepared for the author under contract by Barnett-Winn Palynological Consultants, is presented in Figure 4-11. Percentage counts of selected pollen species are summarized in Table 4-2.

In general, pollen abundance was considerably higher than in BH3 at Long Point, although here again, pollen counts dropped sharply in the sandy upper 6 m of the core. The profile is characterized by low counts of spruce in the core segment above -17 m, but with a significant rise in the basal 1 m of the core. This trend indicates that even though the 10,500 B.P. spruce decline horizon was not reached, it was apparently not far below the bottom of the core. C.E. Winn (1983, pers. comm.) noted a similarity between this trend and basal trends at sites elsewhere in southwestern Ontario dated at between 9500 and 10,000 B.P.

Another pollen chronological marker is provided by the distinct change at around -16 m from pine-dominated (closed boreal forest) assemblages to those of mixed hardwood species (note the fall in pine and the rise in birch, oak and maple). This transition, also noted at Long Point, was assigned an age of between 7600 and 8000 B.P. (Winn, 1977). This inferred age is in marked conflict with the radiocarbon age of 10,260 BP (date no. 21, BGS-254) on disseminated organics near this horizon. However, its relatively high position and the likelihood that these organic materials were eroded and transported from an older deposit, suggest that the pollen age is more reliable.

Younger pollen markers, such as the hemlock "double-peak", are indistinct or non-existent. A hemlock peak occurs at around -13 m, followed by a decline to uncountable levels. This could represent the initial hemlock maximum dated by Winn (1977) at around 6000 B.P.

4.3.2 Molluscan fauna

This section was compiled from extracts taken directly from an unpublished report by Kalas (1980) documenting a very detailed study of late Quaternary paleoclimatic trends in molluscan fauna in one core from the Shoal site (Core 2). For details on techniques, procedures, and units used, the reader is referred to the above report. Kalas' species list is reproduced here in Table 4-3, and an overview of species diversity and abundance is presented in Figure 4-12.

On the basis of species identification and counts from 370 core sub-samples equally spaced over the 11 m length of Core 2, Kalas was able to compile a list of 25,000 mollusk specimens. These specimens corresponded to 40 genera and 65 separate species, including both aquatic and terrestrial groups. Although almost all are still living in the Pelee area, the trends in species diversity and abundance provide further insights into changes in the physical environment in the area.

All species noted at the Unit 1 - 2 interface at Long Point (Section 3.4.2) were represented, except Nasonia modicella. Goniobasis (Oxytrema) livescens was present down to elevations of -16 m, with a peak at around -10 m.

Associated with the separated molluscan material were other organic remains: crustacean carapaces, coleopteran fragments, chironomid head capsules, and fish scales. The floral remains included charcoal, coniferous leaves and their casts, twigs of deciduous trees, a hazel nut (Coryllus americana), and Potamogeton seeds.

Peaks in mollusk species diversity and abundance are related primarily to favourable changes in habitat conditions, such as higher temperatures, shallower water, abundant supplies of nutrients, and favourable substrate conditions, including low sedimentation. The peaks could also be related to dilution and concentration effects as well, e.g., high sedimentation results in lower shell densities due to dilution, and low sedimentation with surface winnowing results in higher concentrations of shells). In addition, the presence of terrestrial species in lake sediments could be a significant indicator of extremely high surface runoff or of the inundation of nearby previously emergent areas.

On examination of the diversity profile in Figure 4-12, it is clear that species diversity in the lower portion of the core (below -14 m) is relatively low, increasing upward from around 3 - 6 species, to around 11 species per 9 cm core increment. In the middle portion (-11 to -14 m), diversity is higher, and rarely falls below the level of 12 species per increment. The top portion (-7 to -11 m) is characterized by highest levels of diversity and total species abundance, although an important decline is recorded above -9 m, apparently corresponding to the onset of high-energy sand deposition. The top portion is also characterized by sharp peaks in both parameters, some of which correspond in position to core sections where winnowing and coarse sediment concentration obviously occurred (e.g., at -10 m). The overall trend in most of the top portion, however, is interpreted by Kalas as representing optimal habitat conditions beginning at around the time of the warmer Hypsithermal episode some 4000 years ago, as the in-phase trend of peaks in both diversity and abundance cannot be explained by winnowing and shell concentration alone. The extremely sharp peak in abundance at -10 m probably marks the onset of such an important period of climatic improvement. Furthermore, the sharp drop in both at around -9 m could be explained by the change from shallow-water, but sheltered habitat, to one characterized by higher energy conditions (see Section 4.2). Although they appear periodically in lower core sections, terrestrial mollusks show an abrupt peak in abundance at between the -8 and -9 m depths (Kalas, 1980; Table 1). This is probably related to the initial flooding and submergence of the Pelee moraine to the east (see Section 5.2.1).

Superimposed on this long-term trend to increased species diversity, Kalas noted a cyclicity in species abundance in which he concluded climatic amelioration had played a major role:

> "Rather brief events occur in the record with regularity in which mollusk populations were eliminated and decimated, concurrently with the occurrence of terrestrial snails. These events are shown as sharp lows in species abundance centred around -12.3, -11.3, and to a lesser degree, around -10.5 and -10.3 m. These events represent, for aquatic mollusks, periods of habitat deprivation".

The author believes that much of the above cyclicity may also be related to the sedimentary environment as well. The cyclicity of species abundance during the above-mentioned period, -12.3 to -10.3 m, might be related to instability in lake levels as well as to climatic fluctuations. Periodic changes in depth could apply stress to benthic communities by causing increases in wave and current action on the bottom, thus resulting in higher levels of water turbidity and habitat siltation. This core section corresponds closely to Unit 3 (Section 4.1.3), where alternating sand and silt deposition could be interpreted as indicative of oscillating water depths. This notion is further supported by the periodic increase of terrestrial species in the record, suggesting that shells were being washed from nearby previously emergent areas during high lake phases. However, the shells could have also been washed in from the land during high-intensity runoff events.

Based on normalized values for species diversity and abundance, and using as control the radiocarbon date in the lower portion of Core 2, Kalas devised a chart linking the trends in these to sedimentation rate (Figure 4-12). Putting aside, for the moment, the questions raised regarding the validity of the above radiocarbon date (Section 4.3.1), it can be inferred that average sediment accumulation rates were initially high (0.4 cm/y) from around 12,500 to 11,000 B.P., then declined considerably to an average of less than 0.1 cm/y from then up to the present. Allowing for the normal time-dependent compaction, the corresponding initial rates could have reached as high as 1.4 and 0.7 cm/y for the early and later core sections, respectively (Zeman, 1979). If the radiocarbon date in Core 2 (10,260 B.P.) overestimates the age of the sediments at the -13 m level, as suggested in Section 4.3.1, i.e., if these sediments are in fact 8000-9000 years old (as indicated by the pollen data), then the sedimentation rates shown above would have to be adjusted accordingly. In other words, rates for the earlier units would be almost halved, while those of the upper units would have to be doubled. The extremely high specimen abundance values noted at various intervals (e.g., around -10 m depth) were probably accentuated by increases in winnowing at these levels and are thus indicative of low accumulation rates. However, if the larger peaks beginning at around -11 m are, in fact, related mainly to sharply warmer climates during the Hypsithermal episode (ca. 5000 years ago), then average accumulation rates since then can be estimated at approximately 0.1 cm/y.

In summary, trends in mollusk populations in Core 2 were found to be related either to climatic factors, to physical changes in the sedimentary environment, or both. The species are characterized by a wide environmental tolerance, and while some species with more boreal affinities were found in the basal portions of the core, most are similar to species inhabiting the area today. Trends in species diversity are most sensitive to climate, and indicate a general warming trend upward in the core. Sharp peaks, suggesting climatic maxima, occur in the upper portions, with the most pronounced beginning around

-11 m. This latter peak could correlate with the time of the relatively warm Hypsithermal episode in North America and Europe.

Species abundance trends, on the other hand, could reflect shell dilution and concentration, that are related more to sedimentation rates than to climate. Their use to estimate sedimentation rates in Core 2, however, is compromised by the questionable nature of the only radiocarbon date obtained on the core. For this reason, the sedimentation rates obtained, based on mollusk data, are seen as only rough estimates at best.

The presence of terrestrial mollusks, however, is seen as a clear indicator of relatively sharp variations in lake levels, although possible allocthonous transport to the area during exceptionally high run-off events cannot be ruled out. The position of the peak in terrestrial species abundance at around -9 m could thus be correlated with a major rise in lake levels, such as that believed to have resulted when inflow from the Upper Lakes (Lake Nipissing) returned to the Erie basin around 5000 B.P.

4.4 Other Sediment Properties

4.4.1 X-ray mineralogy

The mineral assemblages determined on the clay-sized (2 micrometres or less) fraction of the core samples comprise two broad groups. Within the till samples, illite and chlorite are well crystallized, as indicated by distinct diffractogram peaks at 14 Å, 10 Å, and 7 Å. The unweathered character of the till is confirmed by the general absence of mixed-layered and expandible clay minerals. Among non-clay minerals, quartz, calcite and dolomite are most abundant, followed by minor amounts of plagioclase. Potash feldspar and amphibole are usually not detectable. Two sub-samples taken from the upper 5 cm of the till in Cores 1 and 3 proved to be slightly weathered, as indicated by relatively poorer crystallization of illite, chlorite, and calcite, but there were no signs that the surface had been intensely leached.

The clay-sized fraction of the postglacial clays and silts (Unit 2) also contains fresh mineral particles of potash feldspar, plagioclase and amphibole. Clay minerals are generally poorly crystallized, however. The sub-samples comprising silty and massive sand (Unit 3 and lower Unit 4) were found to be mineralogically similar to the underlying sediments. Small amounts of expandible and interlayered minerals were detected in all the postglacial sediment samples.

In summary, the X-ray diffraction results show that a significant mineralogical difference exists between the postglacial sediments and the unweathered glacial till. The postglacial sediments consistently show more signs of prior weathering of clays by the presence of mixed-layer and expandible clay minerals. This is evidently a result of general climatic improvement after deglaciation, and the increasing pace of soil formation in the basin as a whole.

4.4.2 Inorganic and organic carbon

Results of inorganic and organic carbon analyses on 56 sub-samples taken at regular intervals down the cores are shown plotted in the core-diagrams (Figures 4-1 to 4-3). The inorganic (carbonate) carbon content ranges from 1.48 to 3.8%. With the exception of the maximum value (3.8%) obtained for the coarse gravel in Core 2 (1.8 m depth), the values in the massive and laminated sands were generally lower than those for the postglacial silts and clays. The values obtained on the till samples were fairly uniform with depth, ranging from 2.22 to 2.84%.

Organic carbon content was found to range from 0.45 to 2.41%. In general, the lowest values were obtained on samples of glacial till and on the upper sandy units. The highest concentration of organic carbon was determined on samples of the silt and clay units occurring at the base of Cores 2, 5, and 6.

4.4.3 Geotechnical properties

The following outline was taken from the section of the report by Coakley et al., (1977) written by co-author A.J. Zeman (NWRI). The results of the more relevant geotechnical tests are plotted along with the other core measurements in Figures 4-1 to 4-3.

1. Laboratory shear vane tests (undrained shear strength). Shear vane testing was carried out only on Cores 1 and 2, and are plotted in Figure 4-1. The shear strength values of the postglacial silts and clays in Core 2 range from 5 to 30 kN/m^2, i.e., they can be described as being of soft to medium consistency (Terzaghi and Peck, 1967). The shear strength of the till ranges from 130 kN/m^2 at the surface to a minimum value of 40 kN/m^2 at a depth of -10 m in Core 1 (i.e., stiff to very stiff consistency). In both cases, the shear strength decreases with depth. In the case of the postglacial silts and clays, this decrease may be linked to a corresponding increase in clay and natural moisture content (Figure 4-1).

2. One-dimensional consolidation tests. The results for 5 of the 12 samples tested are shown in Table 3-6. These samples were found to be the least disturbed. The till samples from Cores 1, 3, and 4 are characterized by rather low values for natural moisture content (w = approx. 20%) and initial void ratio (e less than 0.6). In addition, all are over-consolidated, as indicated by P_c being higher than P_o' (P_c /P_o' ratio ranging from 2.21 to 8.57). This is to be expected in such ice-contact (possibly sub-glacial) deposits. As a result, unlike the case of the glaciolacustrine sediment surface at Long Point, no interpretation can be made regarding overconsolidation caused by possible subaerial exposure, desiccation, or erosion.

The remaining eight samples tested were of postglacial sediments. The silt samples from Cores 2, 5, and 6 (Table 3-6) have rather high water content and void ratios (w = approx. 44%, and e greater than 0.6), and are clearly under-consolidated (P_c/P_o' ratios of between 0.65 and 0.78). The upper portions of the silt unit, however, showed lower (w) and (e) values, and are either normally consolidated (P_c/P_o' = ~1), or slightly over-consolidated (consolidation ratios of 1.4 to 2.9)

Compared with present-day silts in Lake Erie, these samples show up to a 50% reduction in water content and void ratio (see Section 3.5.3). The core sediments have thus apparently undergone (and are probably still undergoing) considerable post-depositional compaction. Estimates of the total amount of compaction are difficult, as the complete postglacial sediment column was not sampled. Depending on sedimentation rate and total thickness, compaction amounts could reach between 4 and 8 m.

Although it is certain that Vibracoring and sampling caused some sample disturbance, the predominant under-consolidation noted in the bottom portions of Cores 2 and 6 is strongly suggestive of rapid sedimentation or resedimentation of slumped materials.

4.5 Stratigraphic Relationships and Depositional History, Point Pelee

4.5.1 Interpretation and correlation of lithologic units

1. Unit 1. The till encountered in some of the cores is obviously the base on which subsequent deposits were laid down. Although it was not possible to determine the age of the till, its fine-grained texture and spatial affinity to similar tills in nearby Essex County, Ontario (Vagners, 1972) and Ohio (C.H. Carter, 1983, pers. comm.) suggest a correlation with the Port Stanley - Hiram Tills of Port Bruce age (ca. 14,000 B.P.). These tills are noted for fine texture and flow structures indicating a possible water-lain origin. However, the till in the Pelee Shoal cores shows no such structures and is apparently more stoney than the on-shore tills. This factor, together with the considerable degree of over-consolidation noted, suggests a lodgement facies. The bathymetric preservation of the lobate form of the feature, however, is more consistent with the moraine interpretation of Sly and Lewis (1972). Unidentified, but older, tills appear to lie below the till exposed on the lake bottom (or the uppermost till below Point Pelee) in the Point Pelee area.

   The till surface as shown in Figures 4-4 and 4-5 exhibits considerable relief, providing further support for the morainal origin cited previously. Where encountered in the cores, there were indications of a surface erosional interval, as suggested by the usual association with a surface lag gravel layer. In addition, there are indications that the till at higher elevations was subaerially exposed for an undetermined period of time. The most conspicuous surface topographic feature is a depression of over 8 m relief in the vicinity of Cores 2, 5, and 6 below the Shoal, none of which reached the till surface. Due to insufficient core coverage to the south, the extent or shape of the closure could not be defined. However, the identification of till lake-bottom a few kilometres to the south (Coakley, et al., 1977; Rukavina and St. Jacques (1978) at elevations of 161 to 165 m a.s.l. (8 to 12 m below lake datum), and the presence of till and bedrock to the west at comparable elevations indicate that the closure of till surface contours below its average elevation in the area (-10 to -12 m below datum) was rather limited in area. In other words, the local sedimentary basin for the initial sediment deposits was initially much more restricted than at present. Another noteworthy feature is the decrease in elevation of the till surface in the direction: from Core 1 to 3, to 4, (and even lower elevations in 2, 5, and 6) suggesting a local paleoslope downward toward the south or southwest.

2. Unit 2. Unit 2 is characterized by considerable lithologic variability, comprising both massive and laminated sections. Judging from the till surface elevation discussion above, initial water depths were probably less than 10 m, and the body of water was small in area. Deposition in fairly shallow water of limited area is also suggested by the presence of detrital wood and plant fragments and the relatively high carbon values. All these signs, in addition to the facies variability mentioned above, point to a protected nearshore environment of deposition, similar to a shallow embayment, pond, or lagoon. The grain-size curves for this

fine-textured unit suggest deposition via gravity settling from suspension in quiet water. The quiet water conditions were probably due mainly to topographic sheltering from wave action rather than deep water. In addition, the relatively high till surface relief is expected to have contributed to periodic slumping and resedimentation of the local unconsolidated glacial and postglacial sediments, resulting in the alternating massive and laminated sections noted.

In Core 2, the unit lies below the position of the oldest radiocarbon date obtained on local postglacial sediments (10,260 ± 325 B.P., BGS-254). However, the more reliable pollen chronology suggests that deposition took place approximately between 10,000 and 7000 B.P. This estimation is in better agreement with the radiocarbon dates in Cores 5 and 6. Deposition of the unit therefore probably began some time after the initial stages of Early Lake Erie, when lake levels in the western sub-basin were rising from their minimum position, and ended when levels were about 5 m below present datum, or higher.

Sedimentation rates can only be roughly estimated, as the base of the unit was not reached in any of the cores. The ca. 10,000 yr. age (pollen-based) of the basal sediments in Core 2, however, suggests that the base of the unit was not far below this level. Estimating, then, that the overall thickness of the unit in Core 2 was 7 m means that prior to the end of Unit 2 deposition around 7000 B.P., the averaged sediment accumulation rate can be calculated at approximately 0.2 cm/y (uncorrected for compaction). When conservative estimates of post-depositional compaction are taken into account, the unit could have been originally as much as 8 m thicker, and thus accumulation rates could have been even more rapid. Such a rapid sedimentation might account for the lack of bioturbation noted in the unit. Using the average water content of 40% obtained for this unit (Section 4.4.3), and a solids specific gravity of 2.7, a sedimentation rate of 2340 $g/m^2/y$ is obtained. While this figure is considerably less than that for the initial depositional units at Long Point, it is still relatively high (see Section 3.6.1) compared with present rates in Lake Erie.

3. Unit 3. This unit is interpreted as a transitional unit between the low-energy silty clay unit below and the high-energy sandy unit above. At some sites, e.g., Cores 2 and 5, a coarse gravelly layer (lag deposit) separates Units 2 and 3, indicating a period of non-deposition or erosion prior to Unit 3 deposition. The periodic but increasing entry of sandy laminations upward in the Unit 3 sequence could be interpreted either as a response to increasing sand inputs from nearby sources (eroding sandy shorelines to the west or an approaching sandy foreland to the east) as at Long Point, or to periodic exposure to higher energy waves (increasing lake area and greater fetch distances), or to fluctuating, but decreasing water depths. Support for the latter possibility (i.e., a general shoaling trend) is provided by the smooth, apparently infilled surface of Unit 3 in all cores in which it was encountered, and a truncation to comparable elevations of the till in cores where the unit was absent. This pattern is highly suggestive of a period of surface infilling and erosion to wave base levels prior to Unit 4 deposition. Therefore, while it is also possible that all the above factors were active in the depositional trends noted in this unit, the latter alternative, namely deposition under progressive shoaling conditions, seems to be the overriding factor. From the pollen profile in Core 2, and the few radiocarbon dates available, the unit was apparently being deposited approximately between 7000 and 4000 B.P.

4. Unit 4. The top sand unit was clearly deposited in a shoreface or nearshore environment, dominated by wave action. The laminated lower sub-unit, being significantly finer, most likely represents a lower-energy environment than the top (massive) sub-unit. It was probably deposited in a west-facing nearshore zone where it was sheltered by some geomorphic feature from the large waves of the central sub-basin. The western sub-basin was most likely still too small and restricted to generate large waves. The sheltering feature could have been the Pelee moraine ridge or the ancestral Point Pelee foreland to the east (see Section 6.3.2). The massive upper sub-unit is interpreted as indicating the initiation of the effect of larger waves from the east, resulting in a reworking of the lower, laminated sand sub-unit. Such a reworking would occur as the high-energy east-facing shoreface and beach transgressed westward up the local slope as lake levels rose.

   The above interpretation is supported by the pattern in grain-size curves and the "lag" gravel layers common in the unit. Sediment accumulation rates, calculated on the basis of the radiocarbon date in Core 6, averaged around 0.13 cm/y.

4.5.2 Vertical and spatial lithologic trends

In contrast to the Long Point borehole samples, considerable inter-core variability was noted in the lithological sequences from the Pelee Shoal cores. In addition, no recognizable glaciolacustrine facies was identified at the base of the postglacial sediment sequence. With the exception of Cores 1, 3, and 4, where Unit 4 (or Unit 3) overlies the till (Unit 1) directly, all the others show major lithological inconsistencies, especially in Unit 2. This unit is characterized by both massive and laminated sections (Cores 2 and 5). In Core 6, the basal silty unit at comparable elevations shows abrupt transitions to interlaminated sand sections associated more with Unit 3. This non-uniformity suggests that the environment of deposition was, initially at least, subject to abrupt facies changes, most likely due to restricted geographic area.

Despite the above variability, consistent vertical trends are still apparent. Like the Long Point sequences, there is again a clearly-defined coarsening-upward trend, probably caused by lateral facies migration associated with a westward transgression of higher-energy sediments. A definite break in sedimentation (either non-deposition or erosion) generally occurs between Units 2 and 3.

Spatially, the sequence thickens toward the southwest and south, with the lower units pinching out as the till surface rises toward the north. This trend is shown graphically in the cross sections through the cores and boreholes (Figures 4-4 and 4-5). From Core 3 to below Point Pelee and in the Pelee Passage to the west, the till surface and that of Unit 3 is planed almost flat at around 165 m a.s.l., suggesting sediment infilling and wave abrasion to that level. In all cases, Unit 4 sediments overlie this surface, and pinch out toward the north as the till rises to above 170 m a.s.l.

4.5.3 Summary of the postglacial depositional sequence at Point Pelee

The glacial till surface marking the base on which postglacial sediments accumulated, is characterized by considerable relief (almost 20 m). This, together with indications of an ice-contact origin, strongly supports the moraine designation of the feature by Lewis (1966). The oldest postglacial sediments were deposited in surface depressions on the west slope of the moraine. The depression in which most of the cores lie deepened toward the southwest and south (to less than 153 m a.s.l.), confirming the placement of the area within the western sub-basin.

The core data indicate that the till surface was subjected to an interval of desiccation probably due to subaerial exposure, prior to the deposition of the postglacial sediments. Similar desiccation of the top of the Pleistocene deposits was encountered in BH3 drilled below Long Point (Section 3.5.3).

Initial postglacial sedimentation (Unit 2) began around 10,000 to 9500 B.P. in a restricted nearshore environment interpreted as a small embayment or lagoon facing southwest. Despite the fineness of the sediments in this unit, water depths could have been less than 10 m. Slumping of the unconsolidated deposits surrounding the area apparently alternated with normal sedimentation and resulted in a mixture of laminated and massive facies. This might also account for the anomalously coarse texture of the basal unit in Core 6. Sediment accumulation was probably rapid (at least 0.2 cm/y). Unit 2 deposition apparently kept pace with rising lake levels but most of the bathymetrically low areas apparently filled in by 7000 B.P. During this interval, the bathymetric highs to the north (e.g., Cores 1, 3, and possibly 4) received no sediment and were likely subaerially or subaqueously eroded.

The transition to Unit 3 sedimentation was preceded by an interval of non-deposition or erosion, suggesting either a drop in lake levels or shoaling due to sediment accumulation. This would account for the signs of reworking of the unit's surface noted in Section 4.5.1. Average sediment accumulation declined accordingly to less than 0.1 cm/y.

The uniformity of the Unit 3 surface also suggests a period of infilling and erosion of the local lake bottom, indicating shoaling conditions and fairly stable lake levels. The radiocarbon date in Core 6 indicates that such conditions prevailed prior to 5000 years ago. However, the increasingly frequent sandy laminations in the silt could suggest oscillation in these lake levels. However, the increasing input of fine sand to Unit 3 could reflect periodic coarser sediment inputs from nearby sources. Water depths are estimated at less than 5 m, but the area was apparently still sheltered from intense wave action from the east. This suggests a more open, but still restricted western sub-basin. The three lower units thus reflect the initial semi-isolated conditions then prevailing in the western sub-basin west of the Pelee moraine.

Unit 4 deposition indicates the initiation of open lake conditions, with corresponding exposure to more intense easterly wave action. The lower laminated sub-unit likely represents deposition in a partially sheltered (lee-side) environment such as a back beach or lee-side shoreface area, subjected to frequent overwash of beach sand from the windward (east-facing) side of a narrow foreland or barrier. The top massive* sub-unit is interpreted as a high-energy upper shoreface facies which, with time, either migrated westward over the laminated sub-unit, or incorporated it through intense reworking. Water depths are still estimated at less than 5 m during deposition of this unit, and sediment accumulation rates are estimated (based on the 3600 B.P. radiocarbon date in Core 6) at slightly more than 0.1 cm/y.

The spatial distribution of lithologic facies and the gradual coarsening-upward trend noted in the Point Pelee cores add further support for lateral migration westward of the higher energy facies. As at Long Point, such a pattern is compatible with the westward

---

* Massive structure might be an artifact of Vibrocoring, see Section 4.1, p. 80.

transgression of a linear, sandy feature, such as a spit or barrier, as lake levels rose.

4.6 Subsurface Sediments, Pointe-aux-Pins Area

Figure 4.13 shows the logged sedimentary sequences in one borehole on, and two cores offshore from, Pointe-aux-Pins (see Sections 3.1.3, and 3.1.4 for further details). Detailed logs and descriptions of boreholes drilled by Consumers Gas Ltd. are presented in Creer et al. (1976) and in Lewis et al. (1973); their respective positions are shown in Figures 1-1 and 2-5. No borehole data on the foreland itself were collected by the author, but a total of 23 boreholes drilled for other purposes were compiled. These borehole data contained only limited grain-size information, mainly in the form of cumulative frequency curves. A relatively small number of apparently reliable grain-size data were derived from cumulative curves included in some of the geotechnical reports (particularly for the western limb of the Point). Therefore, detailed discussion and interpretation of borehole sediments comparable to those at the other forelands was not possible. The sparse grain-size and other analytical data restrict the conclusions drawn below to the grosser lithological and geometrical relationships, and for that reason, the interpretations will be more general than at the other sites.

4.6.1 Sediment lithology

1. Sediments in land-based boreholes. Of the over 25 land-based boreholes logged in the Point-aux-Pins area, only one site was drilled for geologic purposes. The others were either for water wells or drilled for geotechnical purposes.

The two boreholes drilled by the Ontario Geological Survey (the most complete of which is included here as OGS-1) contain the most reliable and well-documented record of sediments below the eastern limb of the Point. The logs of both boreholes taken from the original field notes (provided courtesy of A.J. Cooper, formerly of O.G.S.) are reproduced as Appendix 4. The sediment sequence is plotted in Figure 4-13. Cross-sections through the eastern and western limbs of the Point, including all the useful borehole data are shown in Figure 4-14. Grain size statistics were computed from the cumulative grain-size curves included in the geotechnical reports (Appendix 5), and these were used to generate the cumulative curves shown in Figure 4-15.

Figure 4-13 shows that the sequence begins at the base with sediments identified visually by Cooper as fine-textured Port Stanley Till. The reference to contorted laminations in Cooper's description suggests that this sediment might, in fact, be a glaciolacustrine deposit, analogous to Unit 1 below Long Point, rather than merely a water-lain phase of the Port Stanley Till as Cooper suggested. This unit is overlain by a 3 m thick organic silt/peat complex, which begins with an interlaminated silt and fine sand layer containing wood fragments (up to 2 cm). The upper part of the complex consists of alternating peat and dark grey silt. The predominant peat layers occur at between -5 and -7 m (referred to lake datum). Above -5 m, the sequence changes abruptly to a coarse sand with gravel-sized particles (up to 2 cm in diameter). The top 6 m of the profile consists of sorted medium sand.

Below the western limb, most of the boreholes terminate in a more pebbly stiff to hard glacial sediment (labelled till on the geotechnical logs), and some of the boreholes reached limestone bedrock at around -30 m. A till interpretation is supported by the poorly-sorted but fine-grained nature of the cumulative curve (73245-3-10, 73245-1-3 in Figure 4-15) for these samples. Commonly overlying the till is a silty clay layer, up to 3 m thick, whose description in the logs as "firm to stiff" suggests a glaciolacustrine sediment. The coarser grain size (median size 8 to 10 phi) and the linear, rather than convex, shape of the cumulative curve (Figure 4-15), however, is more compatible with a compressed, fine-grained postglacial mud (Type 1B, Figure 3-14). Peat occurs above this unit in several discrete layers, ranging in elevation from -5 to the lake datum level. Some of the upper layers are enclosed within the topmost sand unit, while the lowest layers generally directly overlie glacial sediments. The lateral extent of the peat layers could not be defined beyond the area of borehole coverage, but they appear to terminate abruptly in the lakeward direction (Figure 4-14). The sequence is capped by a thin layer (less than 3 m) of medium sand and fill. The sand has the cumulative curve signature of a high-energy shoreface, with a significant traction component (Figure 4-15).

2. Sediments in nearby lake-bottom cores. At the site of the Consumers Gas boreholes (Figure 1-1, Table 4-1), the sub-bottom sequence typically consists of glacial materials (glacial till overlain by glaciolacustrine clay) in the bottom section of the cores, disconformably overlain by 9 m or less of postglacial materials, generally lacustrine mud (Lewis et al., 1973). At the glacial/postglacial contact where it occurred above -28 m (or 145.3 m a.s.l.), Lewis et al. (1973) noted a thin zone of coarse sand and shells (which they identified as a lag concentrate) capping the eroded glacial sediment surface. In the areas of uneroded glacial sediment surface further offshore, around -37 m, Lewis et al. (1973) also noted a brown, oxidized crust on the

uneroded glaciolacustrine clay surface. The reduced water content and local high shear strength values in this zone were interpreted as being possibly due to a period of subaerial exposure and desiccation. Shoreward and toward the west, the postglacial sequence thins considerably as the till surface rises, accompanied by an erosional truncation of the glaciolacustrine clay unit. Beyond these areas, the postglacial sequence lies directly on till.

The postglacial sequence at the site of these boreholes was described briefly in Creer et al. (1976). Of special note was an abrupt increase in silt-sized particles and decrease in carbonate at around the 6 m depth in the core (-30 m referred to lake datum). Creer et al. (1976) used pollen profiles to date this position at around 6000 B.P., and correlated it to the onset of Nipissing drainage into the lake (see Section 6.1). The initial sedimentation was dated at around 8000 B.P.

Detailed grain-size analysis and visual logging (aided by colour photographs and X-radiographs) were carried out on the 1 m long Benthos core (LE81-19, Figure 4-13), collected in 23 m of water (Appendix 5). At the base of the core, a sharply-defined 10 cm thick layer composed of coarser materials (sand, fine gravel, shells, and oxidized wood fragments) occurs. Some of the material was also coated with a brownish, oxidized (manganese?) material. Coarse sediments such as these are unexpected in waters of this depth, especially since the top of the core comprised more typical soft lacustrine silty clay (mud).

A close-up photograph of the anomalous bottom layer is shown in Figure 4-18. Combined sand and gravel averaged 70%, and fines, 30%. Cumulative grain-size curves for the coarse basal layer (Figure 4-16) were remarkably similar to those from the basal postglacial layer in BH3 below Long Point (Type 4, Figure 3-17). The shape of the curve, and the apparent matrix-supported fabric visible in the photograph suggest deposition from a density current, rather than as a lag deposit. Subsequent reworking and removal of some of the fines are also possible factors in the sharp truncation of the suspension and saltation components of the curve. The transition to the uniform fine, soft muds making up the top part of the core is gradational. Cumulative curves for this section (Figure 4-16) show the usual linear to convex-upward shape associated with deposition from a suspension.

Although there is no indication of the underlying materials, the position of the core atop the south-trending bathymetric high, together with echo-sounder data in the area, suggest that the base of the core is not far above the glacial sediment surface.

Grain-size analysis was also carried out on the 9.2 m piston core collected in the central sub-basin south of Pointe-aux-Pins (UWO F-15, Figures 4-13, 4-17) in 25 m of water (Appendix 5). This core apparently covered only the upper portion of the postglacial record, and it comprised typical soft lacustrine silty clay (mud). However, as in the Consumer Gas boreholes to the north, an abrupt zone of anomalously siltier sediments occurs at between -32 and -33 m (Figure 4-13). The bottom contact of this zone with the normal soft, fine, silty clay below is irregular, indicating that the change was rapid and accompanied by some erosion. Representative cumulative curves from the samples from this core are shown in Figure 4-17. Although the median grain size increase, due to increased silt content, between -32 and -33 m is clearly visible, the convex-upward shape of the curve, and the smooth transition between its various sub-populations still suggests settling out from a suspension. This supports the notion of inputs of coarser source materials, rather than in-situ reworking as the explanation of the abrupt textural change.

4.6.2 Deposit geometry

The glacial sediment surface below Point-aux-Pins clearly shows the abrupt rise of the till surface below the town of Erieau (Figure 4-14). The till surface rises from lower that -10 m in the eastern portion of the cross-section to -5 m or higher below Erieau and Rondeau Bay. This supports the designation by Sly and Lewis (1972) of this feature as the topographic expression of the cross-lake Erieau moraine. The feature is also continuous with bathymetric highs to the south, including the sub-surface glacial sediment high interpreted at the site of Core LE81-19 (Figure 1-1). The feature is also apparently linked with the sand-capped bathymetric high mapped by Carter et al. (1982) off Fairport, Ohio (Figure 1-1). The glacial sediment surface down to -40 m offshore from Pointe-aux-Pins rises gently shoreward, and this, together with the thin lag concentrate which characterizes it in the shallower areas, is a clear indication of a history of wave abrasion in waters less than 10 m deep. It is noteworthy that the glacial sediment surface in the nearshore zone to the east and south of the foreland also shows a sharp break in slope at around -15 m (Rukavina and St. Jacques, 1978), indicative of a possible relict shoreline profile. Below Pointe-aux-Pins, the glacial sediment surface is noticeably flattened at an elevation of around -10 m and also at -5 m (Figure 4-14).

4.6.3 Chronology

1. Radiocarbon dating. A total of four credible radiocarbon dates (two from borehole OGS-1, and two from the Benthos core LE81-19) were obtained (dates no. 35 to 39, Table 3-1). The two OGS-1 dates (averaging around 5250 B.P.) were on the peat layer below the eastern limb of the Point (Figure 4-13). Date no. 38 (3140±110 B.P., WAT-946) was from a large (10 cm long) wood fragment collected in the coarse, shelly layer at the base of Core LE81-19 (Figure 4-13). However, shells from the same horizon were dated at 7000±370 B.P. (date no. 39, WAT-970). As discussed in Section 5.1.1, the difference between these dates could be due to contamination of the shells by "old", isotopically-depleted carbon (the silty matrix was highly calcareous). However, if the dates are valid, the difference could also represent the time (or times) that the initial deposition or reworking was taking place.

2. Pollen stratigraphy. Next to the radiocarbon dates described above, the most useful stratigraphic references consist of pollen profiles from Core 13194 (Creer *et al*., 1976; Fritz *et al*., 1975). Figure 4-19 shows an unpublished pollen diagram from that core (courtesy T.W. Anderson, Geol. Surv. Canada). Inferred time markers based on established pollen zones and events (see Section 3.4.1) are also shown. The very sharp transition from high spruce levels, and the thinness of the pine peak in this diagram support the conclusion, presented earlier, of a major erosional unconformity at the glacial sediment surface.

3. Mollusks. Mollusks from the shelly layer at the base of Core LE81-19 were examined by L.L. Kalas (National Water Research Institute). He identified the following species (and their abundance) in the sample:

Sphaerium striatinum	2
Oxytrema livescens	3
Pisidium nitidum	6
Valvata tricarinata	3
Pyrgulopsis letsoni	1
Valvata sincera	1
Gyraulus parvus	1

The shells were generally well-preserved, suggesting minimal transport. The assemblage identified was interpreted as indicative of a normal shallow-water (above the thermocline) assemblage, comparable in make-up to the Pelee Shoal fauna (see Section 4.3.2). An open-lake environment, with water depths less than 15 m (some species were characteristic of depths of 2 to 6 m) was inferred (L.L. Kalas, 1982, pers. comm.). These inferred depths contrast considerably with the present shell layer elevation of -24 m.

4. _Other stratigraphic data_. Stable isotopes of oxygen and carbon measured on mollusk and ostracode shells from Core 13194 were analyzed by Fritz _et al_. (1975) for trends in local paleoclimate. The base of the postglacial sequence (around -32 m) is marked by high values of $\delta^{18}O$ concurrent with the pollen-defined transition from pine to oak forest (7000-8000 B.P.). They interpreted these high values as indicative of climatic improvement rather than increased rates of evaporation in the lake. This interpretation, however, is being reappraised (P. Fritz, 1983, pers. comm.).

Attempts to develop a paleomagnetic stratigraphy for cores from the same area (Cores 13193 and 13194) were made by Creer _et al_. (1976). Apart from a geomagnetic excursion beginning at around 14,000 B.P., no postglacial events could be interpreted with confidence.

4.6.4 Interpretation of depositional history, Pointe-aux-Pins

Although it is probable that sedimentation continued without a break from the Early Lake Erie phase to the present in the deeper offshore areas (such as UWO F-15), there are signs that it did not begin in the area covered by the Consumers Gas boreholes until around 8000 B.P. (Creer *et al*., 1976). From the initiation of Early Lake Erie until then, the entire nearshore area was non-depositional, or even erosional, as suggested by the apparent major unconformity at the glacial sediment surface. Water depths were probably less than 10 m. If the desiccated crust noted on the glaciolacustrine surface is indeed a result of subaerial exposure, then the initial lake level could have been as low as -30 m or lower.

The initial postglacial sediments, dated by Creer *et al*. (1976) at around 8000 B.P., consisted of typical lacustrine muds, deposited in waters more than 10 m deep. This would place the lake level at that time at about 10 m or less below present datum. In the shallower areas closer to the moraine ridge, coarser, reworked turbidity deposits with concentrated shells were accumulating on the glacial sediment surface.

This phase lasted until around 6000 B.P., when abruptly higher percentages of coarser materials (silt) mark a sharp change in the depositional environment. The presence of this horizon even in widely spaced cores signifies that the change affected at least the entire central sub-basin. Pollen dates suggest a time of around 6000 B.P. for this event. The time of this change coincides approximately with the return of drainage into Lake Erie during the Nipissing I phase (Hough, 1966; Lewis, 1969). The silt is probably related to increased inputs of coarser sediment eroded from the shores as lake levels rose more rapidly than before, or winnowed out of more shoreward deposits (offlap sequence) when lake levels fell some time afterward to below their previous levels. The sediment data base is too limited to resolve this matter any further. However, it will be examined from other viewpoints in a later section when the lake level history is discussed.

The absence of early postglacial sediments below Pointe-aux-Pins, and the relatively high glacial sediment surface, indicate that prior to about 5250 B.P. (the age of the peat layer in OGS-1), depositional conditions were very different from those of the overlying sediments. The organic silt layer occurring below the peat at this site (see Section 4.6.1) is suggestive of sheltered, quiet-water deposition at the site prior to the peat deposition, a situation more compatible with relatively high lake levels. Such a conclusion is inconsistent with the offshore sediment record, which suggests lowered levels (and increased winnowing) at this time. Here again, more data are required in order to resolve this apparent conflict.

Following the deposition of the silt/peat complex, the OGS-1 site changed fairly abruptly to high-energy shoreface (sandy foreland) conditions, comparable to those of today. This is indicated by the coarse-grained, well-sorted sediments making up the upper sand unit. The gravelly basal section overlain by medium sand could indicate shoreface facies changes such as inlet closure or storm/post-storm deposits. Further interpretation of these sediments would require grain-size data from the site. Nevertheless, it appears that, unlike the western limb, there is no clear indication of a coarsening-upward trend in the postglacial sediments.

The upper sand unit below the western limb of the foreland is not as thick as that below the eastern limb, as the glacial sediment surface slopes toward the east. The presence of repeated layers of peat in the sand sequence is indicative of fluctuations between marsh and more open-water conditions. This could have been caused by periodic overwash events or breaches in the beach barrier (then located further offshore than it is at present). Both of these processes still dominate in the area today. No dates were obtained for these western peats, but their higher vertical position, compared to that of the dated peats in OGS-1, suggests they are younger than those below the eastern limb. The lack of grain-size data rules out any more detailed inferences regarding changes in depositional conditions for the sand unit.

The return, and persistence, of uniform, finer-material deposition above the silt layer in the cores offshore, and the replacement of the marsh conditions at Pointe-aux-Pins by sandy shoreface sediments after 5250 B.P. are interpreted as indicative of the resumption of a steady rise in lake levels (and shoreline transgression) up to the present.

5.0 DATA FROM OTHER SOURCES RELATED TO LAKE ERIE HISTORY

In addition to the evidence from sediment profiles, other data sources could be of some use in indicating aspects of postglacial lake history. The data presented in this chapter summarize recently acquired information (mostly of a geomorphological nature) that possibly relate to postglacial lake levels and paleogeography. In addition, since Lewis' interpretation of lake levels in the Erie Basin (Lewis, 1969), a large number of additional radiocarbon dates and elevations have come to light. These data, a number of which were collected by the author, are also presented in this chapter.

5.1 Data Base for Lake Level Interpretation

The first step in the data analysis will be to review the data presently available including that on which the earlier lake level model was based. Because radiocarbon dates, on samples whose elevation with respect to the lake level existing at the time is known (or can be reliably estimated), play a major role in reconstructing lake levels, these data should first be critically appraised and, if necessary, screened. The nature and magnitude of possible errors in radiocarbon dates/elevation sets in glaciated, carbonate terrains such as the Erie basin will be briefly discussed, and a subjective assessment of the data sets will be given. An attempt will then be made to interpret the surviving data set in the context of Lake Erie postglacial history. Finally, an updated version of lake level history will be presented and discussed.

5.1.1 Radiocarbon dates and elevations

A total of 50 postglacial radiocarbon dates (below or close to Lake Erie) obtained or compiled by the author are presented in Table 3-1. The locations of the dated samples are plotted in Figure 1-1. Note that all sample elevations have been referred to International Great Lakes Datum (IGLD) for Lake Erie (173.3 m a.s.l.). A brief description of the material dated and its sediment matrix, as presented in the source reports, is also included. A number of factors which could impair the reliability of these data in interpreting the history of lake levels in the Erie basin are discussed briefly below.

1. Sampling errors. Virtually all the dates were obtained on plant material (wood, gyttja, peat) collected using a variety of coring techniques. Some of these techniques could lead to sample disturbance and contamination by organics from above the zone sampled. For this reason, dates no. 1 to 14, which were collected using a technique of water-jetting (to remove the overlying sediments) followed by coring of the target area, must be treated with caution. Sampling contamination might explain why date no. 11, though stratigraphically equivalent to date no. 12, shows a considerably younger age. Dates where sampling errors are a real possibility are designated (S) in the Comments column of Table 3-1.

2. Allochthonous or transported organic material. The Pleistocene glacial sediments exposed along much of the shoreline in the Erie basin have long been subjected to erosion and redeposition elsewhere in the basin. Organic matter incorporated in these older deposits have also been reworked and may occur as detrital organic matter included within relatively younger deposits. Clues to such older, detrital organics are usually provided by the character of the organic matter (disseminated organics, or broken and eroded

fragments), or by the nature of the sediment/organic matter association. For instance, wood fragments, or plant detritus in a lacustrine mud matrix are sure indications of redeposition or of transport downslope (or slumping) from an original subaerial position. Stratigraphic inferences based on such materials are thus subject to considerable inaccuracy, both insofar as the age of the deposits is concerned, as well as in the associated lake level existing at the time.

Wood in sand deposits, however, is expected to date these deposits and their corresponding lake level fairly accurately, because older wood is more likely to be destroyed in high-energy environments characterized by sand deposition. Furthermore, the deposition of the wood as driftwood on or near the strand-line (beach), or in shallow alluvial environments close to the lake is a more natural and likely possibility.

In general, dates obtained from wood samples that are apparently in growth position are most reliable of all. Date no. 27, on wood fragments in firm (glacial) clay was believed by the collector (S.J. Williams, U.S. Geological Survey, 1982, pers. comm.) to be on _in situ_ root material. This date is seen as being reasonably reliable, although the "roots" could have extended several metres below the contemporary lake level. Dates on wood in peaty sequences also are generally reliable, as transport after death is judged to be minimal in such environments.

Dates on material probably transported to the sampling site are labelled (T) in the Comments column in Table 3-1.

3. In-situ contamination and isotopic fractionation. The anomalously old ages commonly obtained on fresh-water mollusk shells and

humified plant detritus have been discussed by a number of workers (Mott, 1975; Karrow and Anderson, 1975; Keith and Anderson, 1963; and Rubin and Taylor, 1963). Silt-sized detritus from inorganic carbonate terrains such as the Lake Erie watershed could introduce significant inaccuracy to shell dates as it is very difficult to remove these isotopically-depleted particles completely from the shell samples. This could account for the anomalously older shell date (date no. 39), compared with the stratigraphically equivalent wood sample (date no. 38). Date no. 50, on shallow alluvial organics, could be either too old (humified modern organics) or too young (older organics contaminated by modern roots).

4. Post-depositional compaction. This process was described in some detail earlier in Sections 3.5.3 and 4.4.3. Depending on the texture and original water content of the sediments, their rate of sedimentation, and the time following deposition, sediment column reductions might easily exceed 50%. Similar compaction effects are also common in peat deposits. The main effect of this process would be the overestimation of the sample depth below datum, especially for those samples overlying compressible sediments in the lower portion of the column. Thus, the estimated lake level range stated in Table 3-1 for peat samples and those from organic matter in cohesive materials (silty clays) has been broadened to reflect this possibility. Samples probably affected to an undetermined degree by this process are labelled (C) in Table 3-1.

5. Other factors. In reviewing the reliability of the radiocarbon dates, other indicative factors were considered where relevant. One crude indicator of reasonable dates is the existence of a proper younging-upward relationship in cases where a vertical sequence of dates was involved (dates no. 3 to 5, 31 to 34, 43 to 45). Another is the existence of confirmatory pollen data from the

sampled borehole (dates no. 31 to 34). Such pollen examination resulted in the revisions to dates no. 1 to 7 noted in Table 3-1. Consideration was given, when using dates and elevations from streams now located close to the lake shoreline, to the fact that the elevations refer to the river channel, and not the base (lake) level at the time. Because the distances from the lake and the stream gradient at the time are imprecisely known, lake levels inferred from such data must be regarded as maximum values only.

Taking all these factors into account, the perceived reliability of the dates and elevations presented in Table 3-1 were subjectively appraised. This appraisal is included in the Table in the form of estimated lake level ranges, as well as notations regarding possible sources of error. Some dates are clearly spurious, especially those on whole sediment samples, and date no. 21 where pollen profile data indicate an age of around 6000 to 7000 for this horizon. Such dates are indicated by an (X) in Table 3-1, and were disregarded in subsequent analyses. Fairly definitive date/ elevation sets, i.e., those with higher perceived reliability, are indicated with an asterisk in Table 3-1. Those that were rejected or deemed overly questionable are indicated by a (?). Of the original 50 dates, only 30 were eventually used.

5.1.2 Geomorphological indicators

Relict geomorphologic features indicative of previous lake levels both below and above the present lake datum (173.3 m a.s.l.) were interpreted from subsurface records and topographic maps. In view of the general scarcity of absolute dates for these features, their ages can be approximated only by superposition. In the discussion below, they will be grouped as follows:

1) Subsurface lake-level indicators (from acoustical profiling and boreholes);
2) Lake level indicators provided by shoreline topographical features and stream-downcutting maxima. The location of the features discussed is given in Figure 1-1.

1. Subsurface indicators. The most definitive indicators include truncated erosion terraces or platforms cut into the pre-Lake Erie glacial sediments, and sharply-defined slope breaks beneath modern sediments offshore (suggestive of an earlier shore-bluff or nearshore profile). Due to coverage bias and possibly better preservation prospects, most of these features were identified in the more sheltered eastern sub-basin of the lake. The features were resolved by extensive echosounding surveys in the area (C.F.M. Lewis, Geol. Surv. of Canada, 1983, pers. comm.) and by seismic profiles made available to the author by private firms (Ontario Hydro and Trans Continental Pipe Line, Inc.) (for survey locations, see Figure 1-1). A sub-bottom seismic and borehole survey of the U.S. side of the lake south of Long Point was reported in Williams and Meisburger (1982), and shows a distinct east-west trending channel cut into glacial sediments and now infilled with more recent sediment. The channel has a maximum depth of more than 45 m, with a higher (more recent) channel at around 30 m below datum. Borehole BH3 on Long Point and the Consumer Gas boreholes in the central sub-basin near Pointe-Aux-Pins (Lewis *et al.*, 1973) were also used to record diagnostic erosional features at these sites. These consisted of signs of overconsolidation and erosion of the glacial sediment surface, and the presence of a lag sediment cover.

A total of 26 measurements of the lowest limits of eroded (truncated) glacial sediment surfaces were made from the eastern sub-basin echograms. These values rose in an eastward direction from around 39 m below datum in the west (Long Point Bay), to 25 m below datum in the east (off Port Colborne). In addition, abrupt slope breaks were noted in the Ontario Hydro seismic profiles off Nanticoke (Shoreline I in Figure 5-1) at between 30 and 35 m below datum. A representative seismic record for the feature is shown in Figure 5.2. Less defined shoreline indications were noted also at 20 to 22 and 10 to 15 m b.d. in the same area. Comparable features were noted along the TCGPL seismic profile between Port Colborne and Sturgeon Point, N.Y. at depths of 25 to 30 m below datum. Other such features were resolved from the echograms in the Long Point Bay area at depths of 28 to 32 m b.d. In the borehole section on Long Point (Figure 3-6), a scarp-like feature was inferred in the eroded glacial sediment surface at around 20 m b.d. Comparable slope changes were also noted in subsurface echograms east of the Pelee Shoal and Pointe-aux-Pins (Rukavina and St. Jacques, 1978; locations plotted in Figure 1-1). The erosion limit in the Erieau boreholes and echograms was recorded at around 30 m b.d. The locations of these points are shown in Figure 1-1.

Figure 5-3 shows the elevations of these features (and the estimated lake level to which they refer) plotted against distance from a point west of the presumed zero isobase for the Port Huron glacial lakes (along the line of maximum tilt, N24E, according to Leverett and Taylor, 1915; and Calkin and Brett, 1978). When compared to similar plots of corresponding raised and tilted shorelines in the eastern part of the basin (based on various sources), it is clear that they fall considerably below the extension of the raised features that Feenstra (1981) linked to Early Lake Erie. Furthermore, no reasonable line fitted to all or combinations of these features was able to intersect or pass above either the bedrock sill across the Niagara River at Fort Erie -

Buffalo, the crest of the Fort Erie Moraine (180 m), or that of the Niagara Falls Moraine (183 m a.s.l.), all of which were potential outlet controls for Early Lake Erie. Neither could any correlation of these features be made with the established Lake Tonawanda stage (178.3 m a.s.l. at Niagara Falls (Kindle and Taylor, 1913; Calkin and Brett, 1978)). This suggests that the geomorphologic features noted were not created by the initial low-level stage of Early Lake Erie except under an unusual combination of circumstances (Section 5.2). From the relatively high slope of the Long Point Bay - Port Colborne reconstructed section (Figure 5-3), it is possible that the sub-bottom features might predate the Port Huron glacial lakes phase (i.e., Lakes Whittlesey to Dana), and have either been preserved near the surface since then, or were uncovered intact by recent bottom erosion. However, because the Point-aux-Pins - Long Point section shows no apparent tilting, these features most likely postdate the isostatic rebound of the area, i.e., they are probably younger than around 11,000 B.P. This is inferred from the fact that the zero isobase for glacial Lake Iroquois (in the Ontario basin, whose shorelines have been dated at more than 12,000 B.P. (Karrow et al., 1961)) occurs to the east of Long Point, placing the reconstructed section within the zone of horizontality of water planes. Nevertheless, the suggestion of low levels persisting in the central and eastern sub-basins for some time after Early Lake Erie differs from earlier publications (Lewis, 1969), and will be discussed further in later sections of this paper.

2. Shoreline topography and stream-downcutting indicators. Raised shorelines below the Lake Warren level were identified mainly in the eastern portion of the basin (Feenstra, 1981; Leverett and Taylor, 1915) (Figure 1-1). Feenstra reported three slightly raised shoreline features (between 177 and 180 m a.s.l.) in the

Niagara River area which he linked to Early Lake Erie. Kindle and Taylor (1913) and Calkin (1970) identified low, raised shorelines in the Niagara Falls area as vestiges of Lake Tonawanda. In the Long Point area, a slightly raised bluff shoreline, now separated from the lake, extends from the western end of Long Point to its truncation by the modern shoreline east of Turkey Point (Figures 1-1 and 2-6). The base elevation of the bluff is estimated from topographic maps at between 175 and 180 m a.s.l. Lobate features (suggestive of small deltas) extending from stream valleys cut into this bluff are clearly identified (Barnett and Zilans, 1983) in the area west of Turkey Point (Figure 2-6). The flattened surface of one of these features was hand-leveled at around 5 m above the level of the bordering marsh, i.e., about 6 m above datum (P.J. Barnett, 1983, pers. comm.). Assuming that this feature is comparable to a Gilbert-type delta, then the above elevation is a reasonable estimate of the level of the lake into which the stream flowed, i.e., 5 - 10 m above datum. Alluvial organic matter from a terrace associated with one of these features yielded a radiocarbon date of 960 ± 80 B.P. (BGS-908, date no. 50, Table 3-1), but for reasons outlined in Section 5.1.1, Item 3, this date needs further confirmation before it can be accepted as a reliable age for these deltoid features.

Similar suggestions of an abandoned shoreline above that of the present are found landward of the Point Pelee and Pointe-aux-Pins forelands, and along the north shoreline of the western sub-basin at identical elevations. The lack of any apparent tilting indicates that this shoreline trace is more recent than Early Lake Erie, although no other dates are presently available.

The vertical channel geometry and sedimentation patterns of streams entering the lake can also provide useful information regarding stream base-level changes, and thus indirectly, the contemporaneous lake level. A total of 10 measurements and descriptions of sediment sequences was taken from borehole records associated with bridge construction over some major streams flowing into Lake Erie (Figure 1-1). These data were provided by the Ontario Ministry of Transportation and Communication, the U.S. Army Corps of Engineers, and the Ohio Department of Natural Resources, and are summarized in Table 5-1.

The lowest down-cutting (>11 m b.d.) was found in the eastern sub-basin at the mouths of the Grand River and Big Creek (Figure 1-1), neither of which was bedrock-controlled. In Big Creek, the original alluvial deposits are apparently being re-channelled again, indicating a more recent change to lower base levels, or a reduction in the distance to the creek mouth.

The only stream whose sedimentation sequence was accurately dated was Clear Creek, (Figure 1-1), where pollen profiles, controlled by four radiocarbon dates (dates no. 31 to 34) were obtained (Barnett et al., 1985, in press). The stream channel was cut to a depth of 5 m b.d., and basal sandy sediments were pollen-dated at around 9500 B.P. Because the distance to the lake and the stream gradient at the time are unknown, the above channel elevation represents an upper limit for lake levels at the time. The sedimentary sequence shows a steady upward change from fluvial to marsh conditions, which became established at around 7000 B.P. (date no. 34). Arboreal vegetation was apparently drowned by high water levels at around 4000 B.P. (date no. 31 on an in-situ log layer at the top of the section), indicating lake levels 2 m or more above present datum. Assuming that base level changes in the lake were the underlying cause for this sequence, the pattern suggests a rising trend from at least around 9500 B.P. Lake levels apparently approached their present elevation by around 4000 to 5000 B.P. and continued rising until shortly after 4000 B.P.

Miller (1983) noted the presence of alluvial channel sands (up to an elevation of 181 m a.s.l., or 8 m above datum) at a site in the lower reaches of the present Cuyahoga River valley, Ohio, now approximately 5 km from the lake (Figure 1-1). The minimum elevation of previous stream channels at the site was 165 m a.s.l. (or 8 m b.d.), a definite indication of lake levels below this value. Using radiocarbon dates on wood from the upper portion of the sand unit (dates no. 43 to 45), he interpreted these deposits as indicative of river aggradation around 8540 B.P. to a base level higher than present levels. The present river bed at the site is at 174 m a.s.l. Any attempt to correlate this base level to Lake Erie must be tempered by references in Miller's paper to local controls (landslide dams) on river aggradation levels at that time. Assuming uniform stream gradients, however, this sequence does add support for a rising trend in lake levels from below 8 m b.d., beginning prior to 9000 B.P. Sometime afterward, lake levels then fell to their present elevations (or shore erosion increased the stream gradient), as is indicated by the later re-entrenchment of the river to 174 m a.s.l. This trend, though not documented in similar detail (only three radiocarbon dates were obtained, all between 8500 and 8800 B.P.) is in general agreement with the early developments at Clear Creek.

5.1.3 Additional borehole sediment indicators

Postglacial sediments in boreholes below Long Point, Pointe-aux-Pins, and Point Pelee have been described and interpreted in earlier chapters. What will be added here are estimates of original deposit thickness (and thus minimum lake levels) based on consolidation tests carried out at selected horizons in the cores.

It is important to note that, unlike the stream data described above, the elevations of sediment horizons provide only a minimum estimate of lake levels, and that the pollen dates are approximate (an error band of plus/minus 500 years is not an unreasonable assumption).

The sediment data indicate that at the site of BH3 on Long Point, sediment accumulation began around 8000 B.P. on an over-consolidated glaciolacustrine clay surface (surface elevation: 20 m b.d., Figure 3-6). Consolidation tests and shear strength profiles indicate that prior to this time, the surface might have even been subjected to subaerial or subaqueous erosion sometime after deposition. Pollen assemblages at the base of the initial postglacial sequence indicate a closed boreal/mixed hardwood forest environment, suggesting a minimum age of between 7500 and 9000 B.P. for this horizon (Section 3.4.1).

Five metres of uniform, quiet-water sediments (silty clays) were deposited at the site up to around 7000 B.P. (Unit 2 in Figure 3-5). Making approximate allowance for post-depositional compaction (discussed in an earlier section of this paper), the original sedimentation column thickness may be conservatively estimated at 10 to 15 m. Assuming, therefore, a water depth of at least 10 m (reasonable for such fine sediments) would place the lake level around 7000 B.P. at between 20 and 25 m above the glacial sediment surface, i.e., within 5 m of the present datum. Water depth inferences from the more recent interlaminated sands and silts and the sorted sands which cap the sequence could not be made with confidence due to possible spit progradation and aeolian deposition into the area, rather than changes in the lake level.

At Point Pelee (Figure 4-1), the situation is strikingly similar, except that the base of the silty clay unit was not reached (Section 4.1.2). Therefore no accurate figure for the total sediment thickness was possible. However, the unit in Core 2 is more than 6 m thick, so it could be estimated to have undergone a compaction similar to that at Long Point. In other words, the unit surface (pollen-dated at around 7000 B.P. and at an elevation of 13 m b.d.) could also have been originally at least 5 m higher, providing further support for the idea of lake levels at the time being close to the present datum. The bottom of Core 2 (18 m b.d. in silty clay) was pollen-dated at around 10,000 B.P., indicating lake levels somewhere above that elevation, possibly as high as 10 m b.d. at that time.

5.2 Definition of the Original Postglacial Surface

It follows from Section 2.5.2 that the original surface onto which Lake Erie was initially ponded would coincide, in the deeper areas at least, with the glacial sediment surface occurring below the postglacial muds. This surface was defined by Lewis (1969), using seismic data collected by Wall (1968) and Morgan (1964), and a large personal data base of echograms and cores. For this study, Lewis' map was revised to accommodate the more recent data on this surface provided by Coakley _et al_. (1977), Williams and Meisburger (1982), and the borehole and seismic data mentioned earlier in this thesis. The revised glacial surface topography is presented in Figure 5-4.

Another important consideration in defining this surface is to allow for the significant amounts of erosion that have taken place in the shallower areas, where the glacial sediments now are exposed on (or just below) the present lake bottom, or on the shallow cross-lake morainal ridges. On cross-sections constructed from the revised glacial surface map, a clear change is sometimes noted between the slope of the contact preserved below the offshore muds and the exposed glacial sediment platform exposed further inshore (Figures 5-5 and 5-6). If we assume, first, that the buried contact offshore represents the original (i.e., Early Lake Erie) surface slope, and secondly, that the land surface from the top of the shore-bluff inland has not been greatly altered by surface erosion, then the original glacial sediment profile can be estimated by joining these two segments. The vertical displacement between the reconstructed and the present profile then represents the eroded section, and this amount can be added to the present elevation of the glacial surface to approximate the original lake bottom elevation. In a similar fashion, the truncated flanks of the eroded cross-lake ridges can be projected to their intersection to obtain an approximation of the original profile and elevations of these morainal features. Figure 5-4 takes these adjustments into account.

5.2.1 Computer-assisted technique for compensating for postglacial uplift

The first step in reconstructing the initial paleogeography of Early Lake Erie and its successive stages (Section 6.2.1) is to compensate for the differential uplift that has occurred east of the Lake Warren zero isobase (Figure 1-1) since around 12,800 years B.P. The technique involved superimposing a 10 kilometre square reference grid system over the revised postglacial surface in the lake basin and surroundings east of the zero isobase. One side of the grid was aligned to coincide with this isobase. A large matrix of surface elevations and spatial coordinates was then extracted and entered into a computer program specifically designed for this purpose. The total uplift figures obtained from the amount of tilt of the Warren shoreline with respect to distance from the zero isobase (Figure 5-3) increased in a non-linear fashion from zero at the zero isobase, to around 50 m at the Niagara sill. These values were used in the combined linear/exponential model (described later in Section 6.1.2) to estimate the elevation of the depressed surface at any given time. The matrix of elevations and coordinates was then adjusted accordingly, and the revised matrix was subsequently passed to another computer program for plotting and contouring.

Figure 5-7 (top) illustrates the net result of the non-linear compensation for isostatic uplift along the axis of the lake (cross-section x-x' in Figure 5-4). At around 12,500 years B.P., the total uplift remaining at the Niagara River sill was approximately 40 m. This figure is based on an original sill depression of 50 m at the time of Lake Whittlesey (Figure 5-3; Calkin, 1970). The profile taken from the computer-assisted contour map is seen to be in good agreement with the postglacial surface, and the compensation program simulates satisfactorily the original depressed state of the surface. The importance of the transverse moraines in the Niagara River area (Figure 5-7) on outlet elevation is still poorly understood. This will be discussed further in Section 6.1.2.

6.0 POSTGLACIAL LAKE LEVELS AND PALEOGEOGRAPHY OF LAKE ERIE

This chapter presents a synthesis of all the data presented in earlier chapters that have a bearing on the postglacial history of Lake Erie. The aim is to present a hypothetical reconstruction of the evolution of lake levels and paleogeography for Lake Erie that is most compatible with the interpreted sediment record and with the geomorphological indicators noted previously.

6.1 Postglacial Lake Level History

Published views on the transition from the post-Port-Huron glacial lakes to Early Lake Erie have been discussed previously (Section 2.4). The 12,500 years B.P. date for this event was based on the oldest radiocarbon date for marsh-related plant debris collected in lake-bottom cores from the western sub-basin of the lake. Lewis (1969) placed the initial elevation of Early Lake Erie at "about 40 m below present level".

Lewis (1969) and Sly and Lewis (1972) concluded that from about 12,500 B.P. to the present, lake levels followed a fairly uniform upward trend, responding primarily to the crustal rebound of the outlet. The only attempt made as yet to interpret the actual time-history of the lake level rise was by Lewis (1969), based primarily on 17 radiocarbon dates and inferred elevations of samples collected below the lake basin (dates no. 1 to 17, Table 3-1). Almost all these samples were located in the shallow western sub-basin of the lake (Figure 6-2). The placement of the initial lake elevation by Lewis was based only on estimates of uplift after the Whittlesey and Warren proglacial lake stages. The tilted and upraised shorelines of these lakes are clearly defined in the basin and have been studied by

Leverett and Taylor (1915), Calkin (1970), Feenstra (1981), and Barnett (1979). Lewis' interpretation of lake level history was based on limited data, though the best available at the time.

6.1.1 Revised lake level curve for Lake Erie

The inferences resulting from the data base presented in the preceding chapter were synthesized to create the revised postglacial history of lake levels in the Erie basin shown in Figure 6.1. No attempt was made to have the curve pass through all data points. Rather, I attempted to fit as smooth a curve as possible to the points used, with more weight given to stream geometry and sedimentation constraints and to dates judged to be definitive (dates no. 15 and 27, in particular). Sharp trend changes were avoided as much as possible in order to avoid undue speculation.

The oldest published date for Early Lake Erie (12,650 B.P.; date no. 3) was adjusted as a result of later pollen analysis on Core 68-6 (T.W. Anderson, 1984, pers. comm.) to a value of approximately 12,000 B.P. All the older dates on marsh detritus in Western Lake Erie (also subsequently verified by pollen studies) now fall between 10,000 and 12,000 B.P. These dates thus define the range for Early Lake Erie as contemporaneous, in part, with the Two Creeks Interstadial (around 11,800 B.P., Table 2-1).

The lake level corresponding to Early Lake Erie appears to have been rather complex. Levels in Western Lake Erie appear to have been controlled at levels above 10 m b.d. by local sills between the sub-basins (Figure 6-2). In Central Lake Erie, no radiocarbon dates of comparable age were available, so the original lake elevation must be inferred, paying special attention to the depth of the buried channel through the Norfolk Moraine, and the lower limit of the wave-eroded glacial sediment surface. These suggest minimum levels of approximately 30 m or more below present datum (Lewis, 1969).

Undated indications of a low-level stage in Eastern Lake Erie at around 30 to 36 m b.d., interpreted from geomorphological features in the sub-bottom, however, do not appear to be related to Early Lake Erie raised shoreline traces and outlet controls mapped onshore by Feenstra (1981) (Figure 5-3). Furthermore, their geometric relationship with erosion limits in Central Lake Erie does not accommodate the necessary differential tilting expected for Early Lake Erie shorelines. Such discrepancies could possibly be explained by non-confluence between these sub-basins, especially if lake levels were temporarily free of outlet controls in the initial stages. The possibility of a period of minimal outflow caused by rapid uplift of the outlet is discussed later. However, for now, the discussion will assume that initially, levels in the central and eastern sub-basins were more or less confluent at around 30 m b.d. or lower, while initial levels in the western sub-basins were at the elevation of the relevant sills (i.e., 10 to 15 m b.d.).

From the above minimum at around 12,000 up to 10,000 B.P., the lake level apparently rose rapidly (approximately 80 cm/century) from elevations of at least 30 m below datum, to around 15 m b.d. This trend is in agreement with the erosion limits for glacial sediments occurring on the periphery of the central sub-basin and below Long Point. The curve was deliberately drawn to pass close to date no. 27, judged to be a definitive date.

From around 10,000 up to 7000 B.P., the trend slope declines noticeably to accommodate minima imposed by the postglacial sediment columns below Long Point and Point Pelee (pollen-dated), and maxima imposed by channel elevations of major inflowing streams. Four factors might have contributed to this slope change:

1. Back-flooding of the topographically-higher Western Lake Erie; the resulting increased surface area and storage volume would result in a slower rise in levels for unchanged inflow and outflow volumes.

2. The opening of northern outlets for glacial Lake Algonquin at around 10,500 B.P. (Karrow et al., 1975) would greatly reduce inflows into Lake Erie.

3. Down-cutting of the lake outlet through the Fort Erie Moraine to bedrock would result in increased outflows.

4. The gradual onset of a period of climatic improvement (warmer, drier), as suggested by the contemporaneous vegetational change in the basin (pine-dominated closed boreal to mixed hardwood forests), could increase evaporation losses.

From around 7000 to 5000 B.P., the interpreted trend in lake level is almost flat at around 5 m b.d., to accommodate maximum values provided by the Clear Creek dated sequence (dates no. 31 to 34), and minima imposed by the marsh peat at Pointe-aux-Pins (dates no. 35 and 36) and deep-water pollen-calibrated dates (date no. 5). The stability of levels during this interval agrees well with the earlier curve (Lewis, 1969), except that the lake level is placed some 10 m higher in this interpretation. Such a stable interval could be linked to a climatic optimum, perhaps the mid-Holocene Hypsithermal interval, and is consistent with the fact that trees grew to maturity on marsh sediments at Clear Creek at that time.

Between around 5000 and 3900 B.P., the curve shows an abrupt rise (approximately 90 cm/century) to levels as high as 5 m above datum. The most direct evidence for this is date no. 31 on the "drowned forest" bed at Clear Creek. Topographic contours and deltoid features along the north shore of the lake suggest a relatively recent shoreline position compatible with such a level. Although the deltoid features are geographically linked with the 960 B.P. date (no. 50), they could possibly correlate with the above rise in levels, given the potential for contamination of the dated material by younger organics, as discussed in Section 5.1.1. The time interval of this rise coincides with the onset of the single-outlet Nipissing II phase in the Upper Great Lakes (Lewis, 1969), when full drainage, via the St. Clair River, returned to the Erie basin.

From 3900 B.P. to present, the lake level trend is not fully resolved, and the curve can be interpreted in two distinct ways. If the deltoid features are assumed to be around 1000 years old, then the curve must pass through them, and a gradually lowering trend is suggested from 3900 B.P. to the present. If date no. 50 is discounted and the deltas linked chronologically with the Nipissing event, then the lake level trend must undergo a sharp drop in order to have it conform with dates no. 15, 16, and 17, all of which are judged reliable dates. Until further confirmation of the single radiocarbon date on the deltoid features is obtained, this latter option is favoured.

The inferred sharp drop can best be explained by the widening of the Niagara outlet to carry higher post-Nipissing outflow volumes. Because it is bedrock-bound, sufficient deepening of the outlet is inconceivable in such a short time. The possibility that other outlet pathways could have been temporarily activated, such as the Low Banks site suggested by B.H. Feenstra (1982, pers. comm.) cannot be entirely ruled out. This site, whose location is shown in Figure 1-1, corresponds with low points both in the northeast Lake Erie shoreline, as well as in the Onondaga Escarpment. Moreover, its location is just south of the Welland (Wainfleet) Marsh. If this were indeed the case, then it would explain the presence of the Wainfleet Bog linked to an earlier lake stage by Feenstra, and the persistence of Lake Tonawanda features to the present (Calkin and Brett, 1978).

The slow rise in levels (approximately 10 cm/century) from around 3000 B.P. to the present is difficult to explain in terms of hydrological changes. With the outlet in apparent equilibrium with even maximum outflows, levels should be stable over the long term. One possible explanation involves steady neotectonic uplift of the outlet. Comparable vertical differential movements over historical time have been reported based on water-level comparisons between Lake Erie long-term gauges (Kite, 1972; the Co-ordinating Committee on Great Lakes Basic Hydraulic and Hydrological Data, 1977), and on regional geodetic re-levelling (Hands, 1977). Rates of differential movement obtained range from 6 cm/century (gauge comparison; Buffalo rising with respect to Cleveland) to 30 cm/century (geodetic re-levelling; north shore rising with respect to the south). These results are in agreement with the trend in Figure 6-1, and suggest that differential crustal movements are continuing long after postglacial isostatic adjustments have ended. Further confirmation is required to document and confirm these processes.

6.1.2 Outlet control of Lake Erie levels

Earlier publications on Lake Erie levels consistently assumed that the elevation of the rebounding outlet was the only controlling factor at all times, and that inflows were always sufficient to fill the lake to this level. Figure 5-7 shows that discounting the end-moraine ridges that lie across the outlet channel (and probably initially added several metres to the outlet elevation), the bedrock sill is presently only 5 m or so below lake datum. Figure 6-3 shows two variations of the conservative exponential model of postglacial rebound of the outlet (of the form presented in Andrews (1970, p.31) and in Washburn and Stuiver (1962) which were compared to the empirical lake-level curve. These models were based, respectively, on half-response times (the time for the uplift remaining to be reduced to half of its initial value on unloading) of 700 years, proposed for parts of Greenland by Washburn and Stuiver (1962) and by Broecker (1966) for Lake Algonquin, and of 1800 years suggested by Andrews (1970, Table III-4, p.34). The shorter 700-year figure was included to accommodate the fact that, based on the rate of migration of zero isobases of the post-Port Huron lakes (Figure 1-1), postglacial isostatic adjustment in the Erie basin must have been complete by around 8000 B.P.

When superimposed on the lake level curve (Figure 6-1), these exponential models of sill rebound clearly did not fit well, as they both place the sill above the lake level up until around 7000 B.P., an improbable situation at best. A much better fit to the lake-level curve was obtained by using a composite model of sill uplift, in which a concurrent linear uplift component was added to the above exponential component, using the 700 year half-response value (Figure 6-3). Similar composite models for postglacial uplift have been proposed for Fennoscandia by Morner (1980), and for New Quebec by Hilaire-Marcel (1980). In addition, Lewis (1970) applied a linear trend to uplift data (covering the past 5000 years) for Manitoulin Island. The equation for the linear component used here was obtained by visually fitting a straight line from the origin (present) through dates 15, 16, and 17 in Figure 6-1.

Even using this non-conventional model of outlet rebound, it appears that the sill lay above the empirical lake-level curve for considerable periods of time prior to around 8500 B.P. Two possible explanations for this come to mind. The first is that neither the exponential nor the composite model provide anything but a crude approximation of the actual uplift process. Such a view is supported by Walcott (1970), who predicted oscillatory uplift processes following glacial unloading. This view is attractive in that it explains why the raised shorelines of the Port Huron glacial lakes are still horizontal west of their zero isobases, in spite of the measured modern uplift. This test might not be so conclusive, however, if the uplift is localized to the vicinity of the outlet, where raised shorelines are quite tilted, and are sparse and discontinuous in the relatively low-lying topography. Second, lower outlets might have existed west of the Niagara River, which even during the initial period of rapid uplift could have maintained lake outflow. B.H. Feenstra (1981, pers. comm.) speculated on such outlets in the Lowbanks area. This idea was prompted by topographic considerations alone, and no confirmation in the field has been reported.

If either of the above uplift models for the present outlet is accepted, then the conclusion follows that a period of minimal outflows via the Niagara River occurred until at least around 8500 B.P. The notion of variable outflow volumes through the Niagara outlet during postglacial time was previously put forward by Gilbert (in Davis (1926), p.158) and Kindle and Taylor (1913). Such periods of minimal outflow would have been further enhanced by the loss of Upper Great Lakes (Algonquin) drainage to Lake Erie around 10,500 B.P. (Karrow _et al._, 1975) due to the opening of northern outlets. In any event, this question of the underlying causes of lake level trends, and the possible association with the neotectonics of the lake outlet after glacial unloading, are areas where further research is definitely needed.

6.2 Lake Erie Paleogeography

As was shown in the above discussion on lake level indicators, previous shoreline positions below the present position are few and often inconclusive. The reconstruction which follows will therefore be based largely on the combination of interpretations of sediment data and the above lake level trends. The geomorphologic indicators, where they are most conclusive, will be used as constraints on the resulting reconstruction.

Basically, the approach used consists of tracing the intersection of the changing water surface plane with the also-changing lake bottom elevation. Changes affecting the bottom elevation are caused primarily by isostatic uplift in the eastern half of the lake and by erosion/deposition in the nearshore areas. A model for differential isostatic and neotectonic uplift of the lake outlet area has already been outlined (see Sections 5.2.1 and 5.2.2). Because the western half of the lake was apparently unaffected by the former process, no adjustment of the bottom elevation there for uplift was necessary.

6.2.1 Reconstructed paleogeography of Lake Erie: 12,500 years B.P. to present

1. Early Lake Erie. Figure 6-4 shows the reconstructed paleogeography of Early Lake Erie at around 12,500 years B.P. The lake apparently comprised two main water-bodies, with smaller, semi-isolated ponds occupying lows in the western sub-basin. The Pelee Moraine (west) and the Norfolk Moraine (east) formed broad, subaerially exposed barriers between the three major sub-basins.

As discussed in Section 6.1.1, the original lake levels in these sub-basins can be estimated only through inference. If it is assumed that the Niagara River sill acted like a weir in controlling lake levels (as it does at present), then from Figure 5-7 (bottom), the suggestion is clear that the level in the eastern sub-basin was probably lower than that suggested by erosional indications in the central sub-basin (i.e., minimum level of 30 m below datum). However, if the topographically-higher Fort Erie Moraine was the initial outlet control (as suggested in an earlier section), then levels in the eastern sub-basin could have been several metres higher, and the two sub-basins might have been confluent at around 30 m b.d. The former option (i.e., lower eastern sub-basin) is more compatible with the presence of the channel cut through the Norfolk Moraine to around 30 m b.d., which, allowing several metres for isostatic rebound, would indicate a hydraulic gradient between the two sub-basins.

In the central sub-basin, the original shoreline was apparently several tens of kilometres lakeward of its present position, and the sites of both the Consumers Gas boreholes and BH3 at Long Point were presumably subaerially exposed.

In western Lake Erie, the levels of the individual bodies of water were kept higher by the sills between the individual depressions (Figure 6-2), and by the Pelee Moraine, at between 10 and 15 m b.d. These bodies of water, and hypothetical drainage links, are shown schematically in Figure 6-4. Given the expected high flows from the contemporary glacial Lake Algonquin then occupying the Huron Basin, it is difficult to visualize how such shallow (and apparently stagnant and organic-rich (see Section 5.1.1)) ponds could be maintained. C.F.M. Lewis (1985, pers. comm.) suggests that the organic deposition could correspond to the low-water

Kirkfield phase of Lake Algonquin (Karrow *et al*., 1975). The present data base is inadequate to resolve this question, however.

2. Lake Erie, 10,000 years B.P. The next reconstruction (Figure 6-4, bottom) shows the lake at around 10,000 years B.P. Lake levels in the central and eastern sub-basins are assumed to be confluent by this time and were around 20 m b.d., and both water bodies had apparently expanded considerably, mainly at the expense of the Norfolk and Pelee moraine ridges. The former feature was probably then expressed as a north-south-trending peninsula, on which trees and other vegetation were growing (see date no. 27, Section 5.1.1). The expanded area of the sub-basins suggest that shore erosion might have begun to play an important role in the paleogeographic evolution of the lake, with sand deposits accumulating at the extreme down-drift shorelines.

   Figure 6-1 suggests that the Niagara River outlet was not operational at this time, leaving the conclusion that either no outflow existed for a time, or that outflow was via another topographically-lower site (such as the Lowbanks area indicated by an arrow and question mark in Figure 6-4, bottom).

   The Pelee Moraine was still high enough to maintain the water bodies in the western sub-basin separate from (and at a higher elevation than) the other sub-basins. The ponds in the western sub-basin had also expanded significantly in area.

3. Lake Erie, 8000 to 6000 years B.P. These reconstructions, shown in Figure 6-5, illustrate the evolution of the lake paleogeography over this interval. Lake levels had by now stabilized somewhat at an estimated elevation of 5 to 8 m b.d., approximately. All sub-basins (including the western) were now confluent, and the

major shoreline changes were now related more to shore-platform and shoreline erosion and deposition, than to inundation by rising lake levels. The largest sub-basin (central) presumably showed the most change, and the moraine-related forelands bounding it had probably become foci for major sand accumulation. The Norfolk Moraine ridge, facing the direction of longest wave fetch, must have experienced the most intense erosion, resulting in a steady narrowing and planing-down of the ridge, and the deposition of considerable coarse material, eventually in the form of dune-backed beaches and recurved spits (Figure 6-5, bottom).

4. Lake Erie, Nipissing phase. This phase which corresponded to the return of Upper Great Lakes drainage to the Erie basin, is estimated to have occurred between 5500 and 4000 years B.P. The increased inflows to the lake probably raised levels to 5 m or more above present levels. The reconstructed paleogeography of Lake Erie at this time is presented in Figure 6-6, top. The reconstruction assumes that all the cross-lake forelands and sandy spits were inundated, and their sand deposits dispersed to form submerged sandy shoals and platforms. The sharply increased lake outflows are presumed to have occurred via low points in the Onondaga Escarpment, including the Niagara River.

5. Lake Erie, 3500 years B.P. to present. When levels in Lake Erie fell again to approximately 3 m b.d., the expected result would be the re-exposure of much of the previously-inundated nearshore areas, especially the shoals over the cross-lake ridges and along the southern shore of the western sub-basin. The reconstructed paleogeography of the lake at around 3500 years B.P. is presented in Figure 6-6, bottom. The most noteworthy development at this time would be the mobilization of the above sandy shoals to form the ancestral Long Point, Point Pelee, and Pointe-aux-Pins spits.

Much of the shoreline in the central and western sub-basins was probably still located several kilometres lakeward, while in the bedrock-dominated eastern sub-basin, the shoreline was likely close to its present position.

6. Summary. The paleogeographic evolution presented above is based mainly on hypotheses that still need confirmation. Indications of prior shoreline positions (described in Section 5.1.2) are scarce and not conclusive, and much of this record has been obliterated by shore erosion. Nevertheless, the reconstructed trends in the evolution of the lake are consistent with sedimentation patterns described in earlier sections (such patterns were used as input data for the lake level history) and are, for the most part, compatible with generally-accepted views on hydrological trends in the Great Lakes area following deglaciation.

6.3 Evolution of Long Point, Point Pelee, and Pointe-aux-Pins

The final step in this thesis is to fit the major forelands of the Lake Erie north shore into the above evolutionary model. For this task, additional information, such as trends in the patterns of beach ridges on these features (see Section 2.5.4, Figures 2-4, 2-5, and 2-6), and distribution patterns of relict sediment bodies in the nearshore zone, will be utilized. The vertical trends in sedimentation in boreholes from the sites will also provide useful clues on the evolution of these landforms. Unfortunately, this study includes no dating of the ridge sequence (used effectively in Moslow and Heron, 1981; and Hester and Fraser, 1973). Only at Long Point were there any archaeological time-references available. At Point Pelee and Pointe-aux-Pins, radiocarbon dates obtained on basal marsh organics provided minimum ages for these forelands.

6.3.1 Long Point

1. Ancestral Long Point (12,500 to around 8000 years B.P.). The paleogeographic reconstruction (Figure 6-4) places the initial sandy foreland development in the Long Point area at around 10,000 years B.P. Prior to this time, the area comprised a broad ridge spanning the lake. The ridge evolved into a peninsula due to rising lake levels and the expansion of the inter-basin drainage channelway to the south. Though presumably a site for sand accumulation, the peninsula at 10,000 years B.P. was still essentially a till-cored moraine feature. It was probably not until levels stabilized between 8000 and 6000 years B.P. that sand accumulation and ridge planation reached a level to suggest a conventional sandy foreland. The form was that of a pointed cuspate foreland oriented almost north-south (Figures 6-5 and 6-7).

2. Cuspate foreland with recurves (8000 to 5000 years B.P.). Due to its position at the end of a long fetch distance for the prevailing winds and waves, the peninsula transgressed eastward up the glacial sediment slope. Longshore-drifted sand would be carried around the southern tip to be eventually deposited on the east (lee) side. The net result would be that by 6000 years B.P., the foreland would have assumed a more rounded form, with spit recurves extending northeastward from the lee-side (Figure 6-7). These recurves, concave toward the longest local fetch distance in the eastern sub-basin (i.e., southeast), are believed to be preserved in the low, concave-lakeward beach ridges still discernible in the west and central parts of Long Point today (designated "A" in Figure 2-6). With time, these recurves assumed a more NE-SW orientation (numbers 1 to 4), as the foreland retreated landward. This stage in the Long Point evolution is believed to be associated first with the fine-grained (sheltered) sediments in Unit 2, and

later with the inter-laminated sand/silt (Unit 3) sediments in BH3.

Modern examples of such a rounded cuspate foreland are Presque Ile spit across the lake in Pennsylvania, the Toronto Islands in Lake Ontario, and the La Coubre spit on the Atlantic coast of France. The rounded form and the length of the recurves would be expected to become more accentuated as lake levels rose to their Nipissing peaks, and as the foreland, as a result, retreated northward up the plunge slope of the moraine.

3. Modern Long Point (3500 years B.P. to present). The transfer of Lake Nipissing drainage waters to the Erie Basin around 5000 years B.P. likely had a dramatic effect on Lake Erie shoreline features. By raising lake levels by more than 10 m, this event probably led to the submergence of the north-south trending cuspate foreland then existing in the Long Point area (Figure 6-6). Massive amounts of sand were probably dispersed to the northeast by wave action, creating a broad, sandy shoal which later would serve as the spit platform (Meistrell, 1966) for the radically changed Long Point foreland that was to follow. The previous form is still preserved in the shape of the offshore relict sand deposit south of Long Point (Figure 6-7D).

When lake levels again fell some 8 m to approximately 3 m b.d. about 3500 years B.P., the sediments making up the spit platform were reworked by shallow-water wave action to initiate the present eastward-trending "flying" spit described in Wilson (1908) (Figure 6-7B). The spit was attached at the shoreline salient formed by the moraine, and was nourished by littoral drift from eroding shores to the west. This change to a more conventional evolutionary pattern (Zenkovich, 1967) is reflected in the change from concave- to convex-lakeward observed in the beach ridge pattern (designated 'B' in Figure 2-6). At the same time, the rising lake level trend over this period led to the northward migration (transgression) of the spit as a whole, in a manner analogous to the Holocene retreat of barrier islands on marine coasts. The barrier transgression is believed to account for the increasing sand deposition (Unit 4) in BH3. The orientation of the more distal (younger) beach ridges (C) has also shifted from northeasterly to easterly. This indicates that the distal portion of the spit is rotating clockwise, i.e., toward the south, with time.

The north-facing spit components (trending northwest-southeast) shown in the reconstruction (Figure 6-7C) are located further north of their present positions at around 1000 years B.P. This hypothesis is based on projections of the truncated ridges on land. These components are interpreted as originating as baymouth bars (across the recurve extremities) that were subsequently pushed shoreward by easterly storm waves.

Assuming that the present foreland dates back to the post-Nipissing stage (i.e., 4000 years ago), then the average growth of the spit is approximately 9 m/y. Preliminary archaeological surveys near the site of BH2 (Figure 2-6) indicate human visitations dating back to 700 A.D. (i.e., 1250 years B.P.) (Bill Fox, Ontario Ministry of Citizenship and Culture, 1983, pers. comm.). Assuming that these sites were associated with the tip of the Point, then in 1250 years, the spit apparently has extended close to 7 km, for an average growth rate of about 5 m/y. Modern rates (1951 to 1979) indicate no net extension, which suggests that the growth of the spit has declined sharply with time.

6.3.2 Point Pelee

This section represents an updated version of an earlier interpretation of Point Pelee origin and evolution by the author (Coakley, 1976).

1. Ancestral Point Pelee (12,500 to 8000 years B.P.). Early developments at Point Pelee were generally similar to those at Long Point. Most of the area was subaerially exposed as a broad cross-lake ridge (Figure 6-4) during this period. Sedimentation prior to 8000 years B.P. was taking place only in depressions on the west flank of the ridge (Cores 2, 4, and 6 described in Section 4.3). No doubt the ridge served as a focus for deposition of sand eroded from adjacent sandy bluffs to the east and west. However, because the Pelee Moraine ridge was originally at a higher elevation, and much broader than the Norfolk ridge (Figure 5-4), such deposition probably did not cover the Pelee ridge until much later. Also, because of its greater exposure to long-fetch, energetic waves, the east-facing side of the ridge was probably the site where sand deposition was greatest.

   After confluent lake levels reached about 10 m b.d. around 9000 years B.P., the ridge evolved into a peninsula, with fringing beaches developing predominantly on the eastern side. As lake levels rose slowly these deposits grew in size and probably supplied inland dune fields in the Shoal area. The Point Pelee area was still exposed above lake level, and sedimentation at the Shoal core sites still consisted of silts and clays typical of sheltered conditions.

2. Large cuspate foreland stage (8000 to 5000 years B.P.). The main development up until the Nipissing phase was the gradual reduction

in the area of the peninsula, and the slow migration of the sandy barrier westward into the Shoal area. This trend is indicated by the increasing occurrence of interlaminated sand/silt deposition at the site of the Pelee Shoal cores. By 6000 years B.P., the Shoal area was probably dune-coverd and the sand beaches on both sides had coalesced to form a large cuspate foreland (Figure 6-8).

3. Modern Point Pelee (5000 years B.P. to present). As was the case at Long Point, the Nipissing drainage event resulted in a general submergence of the low-lying peninsula, including the area to the north now occupied by Point Pelee. The sand deposits were then dispersed over the area, particularly over the Shoal area to the west (Figure 6-6).

When lake levels fell again around 3500 years B.P., the above dispersed sand deposits could be rapidly reworked into fringing barrier ridges, with flooded (lagoonal) areas behind. The oldest date for basal Point Pelee marsh peat (3250 years B.P.; date no. 16) provides a minimum age for this development. Judging from the projection of the innermost of the truncated beach ridges (Figure 2-4), the barrier beaches on both sides of the ridge would likely meet at the southern end to form a cuspate foreland much larger than the present feature, and having an elongated, low, sandy tip (Figure 6-8) analogous to the present spit.

The present truncated form of the beach ridges and marsh ponds adjacent to the east barrier indicates clearly that relatively rapid westward migration of the east barrier represents the main evolutionary trend (Figure 6-10). This would also account for the diminishing area of the foreland with time, the sharp cuspate form, and the abandonment of the Shoal deposits as relict spit elements. Unlike Long Point, however, Point Pelee is retreating over the long term, as the present accretion on the west side is more than balanced by recession on the east.

6.3.3 Point-aux-Pins

The data base on Pointe-aux-Pins has the least amount of first-hand, detailed information on subsurface sediments. Stratigraphic data also are limited, and comprise radiocarbon dates at two sites on and offshore from the Point (date nos. 35 to 38, Table 3-1). The treatment which follows is therefore based largely on sediment sequences and glacial sediment surface topography in the land-based and offshore boreholes, nearshore echograms, and patterns of marsh peat deposition.

1. Ancestral Pointe-aux-Pins (12,500 to 5000 years B.P.). The cross-lake moraine ridge which underlies Pointe-aux-Pins occurs at a much lower elevation (more than 30 m b.d. in offshore areas) than at Pointe Pelee and Long Points. Therefore, during the Early Lake Erie stage, it never formed a land-bridge across the lake. Rather, judging from the glacial sediment surface (Figure 5-4), the original shoreline feature at the site consisted of a broad promontory located some 20 kilometres to the south of the present landform (Figure 6-4). Such a feature would still serve as a focus for the accumulation of longshore-drifted sand. However, because of the fairly rapid lake level rise, the overall evolutionary trend until around 8000 years B.P. (when levels stabilized) was probably a reduction in foreland area and net shoreward retreat. Thereafter, until the Nipissing phase, major sand accumulation along both sides of the promontory probably occurred, eventually converting the promontory into an asymmetrical cuspate foreland (Figure 6-9A). Due to the longer easterly fetch lengths, the predominant littoral drift direction was likely from the

east-facing side around the tip to the south-facing side. By around 6000 years B.P., marsh vegetation was apparently growing at the site of borehole OGS-1.

2. Modern Pointe-aux-Pins. As was hypothesized for Point Pelee and Long Point, the increased inflows which characterized the Nipissing phase resulted in a submergence of the low-lying cuspate foreland. As lake levels rose soon thereafter, wave action was able to abrade the distinctive nearshore platform noted at around 8 to 10 m b.d. (Figure 4-14). The sand making up the foreland was also dispersed over this platform in the form of a shoal. Rising lake levels apparently killed the marsh vegetation at the OGS-1 site as well, resulting in its preservation as peat below deeper water, or more sheltered, silty sediments.

   Later (around 3500 to 4000 years B.P.) when lake levels fell to their post-Nipissing low, beach barriers were likely formed by wave action on the exposed or shallow shoal deposits (Figure 6-9B). It appears that Pointe-aux-Pins originally consisted of a major, straight-to-convex-lakeward beach barrier, trending northeast - southwest, facing the long east and southeast wave directions, with a lower, concave-lakeward barrier trending northwest - southeast, facing the shorter-fetch southwest wave direction. A contributory factor to the barrier development is probably the change in orientation and position of the Long Point foreland, increasing fetch distances (and shore erosion) affecting the shoreline to the east of Pointe-aux-Pins. this stage is reconstructed in Figure 6-9B,C, and corresponds to the innermost beach ridges (stage A) in Figure 2-5.

   From around 3500 years B.P. to present, the main morphological development at Point-aux-Pins consisted of a gradual shift in the orientation of both sides to accommodate progressive changes in the directions of greatest fetch. The east-facing barrier, is becoming oriented more north-south in response to changing shoreline patterns to the east. Likewise, the south-facing barrier is now experiencing longer-fetch waves from the south to south-southwest as Sandusky Bay (Ohio) increases in area, and is becoming aligned more east-west. Littoral supplies appear to have declined in recent times, and although the east-facing barrier is still accreting lakeward, the accretion appears to be more at the expense of the low, rapidly-retreating south-facing barrier than of the adjacent bluff shorelines. This is illustrated in the sharply-defined southern truncation of the beach ridges on the Point, the more rapid accretion of the south end of the foreland, and in the more convex-lakeward form of the more recent additions to the system (designated 'C' in Figure 2-5).

6.3.4 Summary and discussion

The preceding sections demonstrate clearly that prior to the Nipissing-related peak in lake levels (5000 to 4000 years B.P.), the forelands were all of the cuspate type, oriented roughly north-south along the axes of the cross-lake moraines. However, the forelands were apparently not formed in the manner proposed by Gulliver (1895) or Gilbert (1885), i.e., by deposition of littoral drift from opposing currents. Their formation was linked to the location of the three cross-lake moraines. During the period of stable lake levels which preceded the Nipissing rise, these cross-lake features had served as foci for the accumulation of large amounts of sand eroded from shorelines located updrift. These sand features were then reworked by wave and current action into large cuspate forelands. Eventually submerged during the above lake level rise, these forelands were reactivated when lake levels fell soon after.

The Point Pelee and Pointe-aux-Pins forelands resumed their predominantly cuspate form, while Long Point, affected to a greater extent by long-fetch waves and very high sediment supply, assumed a free-form (anchored at one end) growth mode (Zenkovitch, 1967). Over the past 4000 years, Long Point has steadily migrated northward as it grew eastward. The northward retreat has been due to sediment transfer processes such as wind deflation and washover through the low-lying areas during storms or high-level periods. Washover processes have in historical times resulted in major breaches across the Long Point spit, some of which were large enough to permit the passage of ships. Some material is also being transferred from the south to the north shore around the tip of the Point. So, in many respects, the modern and long-term processes acting on Long Point are analogous to those active on barrier islands on marine coasts (Hoyt, 1967; Kraft, 1971).

The barrier island analogy is even more fitting for the evolution of the eastern side of Point Pelee. The mode of origin proposed by Kindle (1933), invoking a similar accident of littoral drift deposition as that cited above for Long Point, does not fit well with the scenario of rising lake levels and changing paleogeography in the western portion of the lake. Rather, the coincidence with the Pelee Moraine and the clear signs of westward retreat (Figure 6-10), support our hypothesis of its reactivation (following the fall from peak levels) into a cuspate form (much larger than at present), consisting of a fringing barrier enclosing a marshy lagoon. This feature gradually decreased in area in response to the slow recent rise in levels.

Although there is less basis for reconstructions of the origin and evolution of Pointe-aux-Pins, it appears that developments there followed the pattern at Point Pelee. Its relatively broad and rounded cuspate form could reflect its greater exposure to wave action on both sides, or the lower elevation of the underlying moraine surface. In addition, the age of its basal peat layer is much older than that of the Point Pelee gyttja, so the form of Pointe-aux-Pins could represent a more mature stage in the development of these forelands.

7.0 SUMMARY

In Section 1.2, the thesis problem and objectives were outlined. These may be repeated in summarized form as follows:

1. To use sediment and other physical data collected from subsurface borings to interpret the postglacial depositional evolution of Lake Erie.

2. To update the general perception of lake level trends since the inception of Lake Erie, and to use this in reconstructing the paleogeography of the Erie basin.

3. To present a mode of origin for the three major forelands of the north shore forelands of the lake based on the above insights, and reconstruct their evolution up to the present.

In this chapter, the extent to which these objectives were met will be discussed, and the conclusions summarized.

7.1 Postglacial Sedimentation in Lake Erie

Interpreting postglacial trends in sedimentation in the 10 boreholes drilled by the author (and, where possible, in those drilled by others) was limited by several factors. The coverage of the area, especially insofar as detailed logging and sampling were concerned, was rather sparse. Complete vertical records of postglacial sedimentation were rarely collected, and only a few boreholes covered the glacial/ postglacial boundary. Chronology of the sedimentary sequences was mainly limited to pollen profile interpretations, and radiocarbon dates were rare. Appraisal of spatial variations and sediment structures was limited by the borehole spacing and diameter.

In spite of these shortcomings, a readily interpretable pattern was observed in sediments from the two major areas sampled (Long Point and Point Pelee).

7.1.1 Glacial sediment surface

East-west cross-sections through all the forelands sampled show a local rise in the elevation of the glacial sediment surface. The slope of the surface indicates that the areas were located near the tops of large cross-lake ridges. The glacial sediments encountered consisted of till in the Point Pelee and Pointe-aux-Pins areas, and glaciolacustrine clay at Long Point (Unit 1). Till, however, rises to form the shoreline immediately west of Long Point (Barnett and Zilans, 1983). This confirms the earlier interpretation of the original sites as recessional moraine features (Sly and Lewis, 1972).

In all the boreholes drilled by the author which encountered the glacial/postglacial boundary, there were clear signs of a period of non-deposition. Consolidation tests on the glaciolacustrine sediment surface at Long Point indicate that some erosion (either subaerial or subaqueous) of the glacial sediments took place during this initial postglacial period.

7.1.2 Initial postglacial sedimentation

The earliest postglacial sediments encountered in the two major areas (excluding Pointe-aux-Pins) consisted of fine mud (Unit 2).

Texturally, these sediments are indicative of slow, quiet-water sedimentation, suggesting either deep, or sheltered, water bodies. Deep water can be ruled out because of the relatively high elevation of the areas (less than 20 m below present datum) and the low position of the lake level at the time. So it is concluded that these areas were topographically sheltered from wave action, either by some form of barrier (e.g., at Long Point), or were located in areas characterized by embayments and islands (Pelee Shoal).

7.1.3 More recent sedimentation trends

From that time to the present, these areas have all experienced similar trends in deposition. The units overlying the basal muds, in almost all cases, show a consistent coarsening-upward textural pattern, with mud grading into sandy silt, then silty sand (Unit 3), and finally clean, medium sand at the top (Unit 4). The timing of this trend appears to be related to water depth, and it occurs later in the more offshore areas (e.g., in LBH at Long Point, the sand unit begins much later than in BH3).

On open (marine) coasts, such a coarsening-upward trend is most often associated with regressive (or seaward-advancing) shorelines, associated either with accretionary features like spits or deltas (if water levels are stable), or with offlap deposition (if levels are falling). It is clear from the other data that Lake Erie levels have followed a generally rising trend. Therefore, the coarsening-upward trend in the borehole sediments can best be explained as indicative of a shoreward transgression of a barrier-island-type coastal feature over a more sheltered lagoonal or back-bay environment located on its landward side. Analysis of textural properties using grain-size curves and C-M diagrams provide some support for this conclusion.

7.1.4 Chronology of postglacial sediments

The association of sedimentary changes in these three widely separated locations in the lake with the overall lake history requires dependable chronologic control. It was originally hoped that sufficient radiocarbon-datable materials would be collected in the cores for this purpose. However, this was not the case, and most of the chronological inferences made in the analysis had to be based on pollen profiles. These suffered from limitations, such as low pollen counts in the upper sandy portion of the column, and a lack of clear definition of established pollen time-markers. For example, the spruce decline at around 10,000 B.P. was generally absent in the postglacial sequences sampled, and the hemlock decline (around 5000 B.P.) was difficult to define with confidence in most cases. As a result, chronologic control was deemed adequate in only two boreholes (BH3 on Long Point and Core 2 at the Pelee Shoal).

Using inferred pollen markers in these cores, a similar pattern in sediment accumulation rates (uncorrected for compaction) was noted. Accumulation rates were relatively high initially in the basal units of the cores (Unit 2), and declined considerably thereafter in the upper portions. The initial rapid accumulation is consistent with the rapidly rising trend in lake levels at that time, and the separated, relatively small sub-basins then characterizing the two sites. In addition, stream erosion and slumping of the poorly-vegetated unconsolidated glacial sediments would probably lead to increased sediment inputs. Lower accumulation in the coarser units comprising the upper portions of the cores most likely reflects the eventual infilling of these depositional areas to wave base, followed by increased sediment by-passing.

7.2 Lake Erie Levels and Paleogeography

7.2.1 Lake level history

The postglacial history of lake levels in the Erie basin is clearly not as uniform as indicated by previous models (Lewis, 1969). A variety of factors, hydrological, physiological, and tectonic, were apparently important.

Radiocarbon-dated elevations are still the prime sources for data on such developments, although in the Erie basin, a variety of processes are apparently active in reducing their reliability. Examples of these processes are detrital transport, hardwater and inorganic carbon contamination, sampling procedures, and post-depositional compaction. Supplementary data from stream geometry and depositional history, preserved geomorphological features below the lake, and the pollen-dated history of sedimentation below accretionary features in the lake were valuable in our re-interpretation of postglacial lake level trends. The trend presented in this thesis is the one which best fits these diverse data sources.

The lake level curve shows a relatively steep initial rise from more than 30 m below datum prior to 12,000 B.P., to around 15 m b.d. at around 10,000 B.P., i.e., roughly 80 cm/century. It appears that initially, the sub-basins were at different elevations. Levels in the eastern sub-basin probably lagged several metres behind those in the central sub-basin due to the presence of the Norfolk Moraine ridge. Levels in the western sub-basin were kept at higher that 15 m b.d. due to local sills. The initial rise could have been associated with rapid glacio-isostatic rebound of the lake outlet at Niagara and to high inflow volumes from Glacial Lake Algonquin, then occupying the Upper Great Lakes. From 10,000 to 7000 B.P., the rate of rise declined, primarily due to loss of Lake Algonquin drainage, and back-flooding of the topographically higher western sub-basin of the lake. From 7000 to 5000 B.P., average lake levels appear to have stabilized at around 5 m b.d.

The main departure from previous interpretations is associated with the period between 5000 and 3900 B.P., when lake levels are believed to have risen sharply to about 5 m above datum. This could correspond to the initiation of drainage into the Erie basin from Lake Nipissing, then occupying the upper lake basins. However, by 3500 B.P., levels appear to have declined again to around 4 m b.d. From then to the present, the trend showed a slow rise (10 cm/century) in what appears to be a linear fashion.

This latest inferred rise in lake levels is too recent to be explained by accepted glacioisostatic models. However, it can be fitted to a composite model, combining an initial exponential (isostatic) and a linear (neotectonic) component. Such an interpretation is empirical only, and would require further verification before it is accepted.

For a more accurate resolution of lake levels in the Erie Basin, further work or data are required on the critical periods, 12,800 to 12,000 B.P. and 4000 B.P. to the present. In the case of the latter, such further work should also include a better definition of the role of neotectonics in the vicinity of the outlet.

7.2.2 Paleogeographic reconstructions

The reconstruction of the paleogeographical evolution of Lake Erie, based on all the data presented, is still, to a large extent, hypothetical. Such an exercise nevertheless represents the logical extension of the thesis effort. Furthermore, by attempting to compensate for non-linear postglacial rebound of the eastern half of the basin, these reconstructions present a more realistic picture of lake/outlet relationships and possible shoreline positions in this part of the lake. Nevertheless, this aspect of the study is definitely one where more information, especially from the U.S. side, would be welcome.

Initially (i.e., prior to 12,000 B.P.) the lake basin was occupied by a number of small, separate pondings, whose elevations were controlled by inter-basin sills. The largest were in the central and eastern sub-basins, while the higher western sub-basin was predominantly dry land. Shallow ponds there served mainly to by-pass inflow waters to the central sub-basin. The lake outlet at this time is uncertain. As long as the Fort Erie moraine still blocked the entrance of the Niagara River, then it is possible that outflow was through low-lying parts of the Onondaga Escarpment to the west, and thus into Lake Tonawanda.

Areal expansion of the bodies of water was likely most rapid in the central sub-basin, leading first to a confluence with the eastern sub-basin, and then backflooding the western. It is estimated that all sub-basins became confluent between 10,000 and 8000 B.P.

During this period, the major cross-lake moraines were emergent to a greater or lesser extent, and evolved from broad isthmuses to cuspate peninsulas as lake levels rose. The low-lying Erieau Moraine was expressed only as a minor promontory, however. Because of their location at the extremities of the sub-basins, these sites rapidly became the focus for sand accumulation on both sides as the open-water area of the lake became larger. As wave energy levels increased, this sand was mobilized into dune fields, cuspate spits, and sandy shoals associated with the morainal promontories. This development characterized the stable lake-level period between 8000 and 5000 B.P.

The rise in levels between 5000 and 3900 B.P. (Nipissing drainage into Lake Erie) resulted in wide-spread and dramatic shoreline changes. The inter-escarpment lowland located in the extreme northeastern part of the lake basin was again occupied by an outlet lake, and the low-lying sand spits associated with the cross-lake moraines were inundated. Because the shoreline was composed otherwise of bluffs, shoreline traces surviving the subsequent erosion are scarce.

It was this event that set the stage for the development of the three major forelands (Long Point, Pointe-aux-Pins, and Point Pelee) as we know them today. The above-mentioned inundation served to distribute and shape the previous spit deposits into submerged shoals (spit platforms). When lake levels subsequently fell around 3500 B.P. to close to their former elevations, these deposits were reworked by wave action to form the precursors of the above forelands. While Point Pelee and Pointe-aux-Pins retained their cuspate form, Long Point developed thereafter as an east-west-trending free-form spit, attached to the mainland at only one end. The evolutionary trends since this point are reflected in the changing orientation and form of the beach ridges preserved on the forelands.

In summary, these forelands were formed and later evolved in a manner analogous to the barrier islands of the U.S. east and south coasts. These latter were initiated during the sea-level minimum related to the last glaciation, and during the subsequent rise known as the Holocene transgression, they migrated landward over their adjacent lagoons. From the sediment profile data and relict geomorphological features (shoals, elongated relict sand deposits, and beach ridge trends), evidence of a similar migration is observed at the three Lake Erie forelands. The hypothetical reconstructions thus appear to be compatible with the existing data base, and should serve as useful guides in directing future research efforts into this subject.

7.3 Suggestions for Future Research

The preceding chapters have illustrated some of the uncertainties which result from the present data base. In order to resolve some of these uncertainties, research into the following areas would be useful:

1. Long cores from the deeper portions of the lake. Such cores should penetrate the 30 m (or more) of continuous postglacial sedimentation in the central and eastern sub-basins. The stratigraphy of the lower part of the sediment column would conceivably cast useful light on the initial transition from proglacial lake to Early Lake Erie. Because cores of such length are beyond the capability of present-day piston and gravity coring techniques, and might be too expensive for normal research funding, their collection will probably have to be done opportunistically with commercial drilling operations (e.g., hydrocarbon exploraion) offshore in Lake Erie.

2. Oriented cores from sand-rich units below the forelands. One major limitation in the data base for this thesis was the lack of directional information on internal structures, such as inclined laminations and cross-stratification, noted in the upper core units (Units 3 and 4). The technology exists for such coring operations, but this would result in slower and more laborious progress in the field. Nevertheless, any future borehole drilling at these sites should make an attempt to collect this type of information.

3. Improved chronological control of borehole sediments. Radiocarbon dating generally provides better stratigraphic control than does palynology, but occurrences of suitable organic matter in the cores were either too haphazard or in insufficient quantity for positive interpretation. Recent developments in dating minute quantities of

organic matter (less than 1 gram) using direct counting of C-14 offer promise for improved borehole sediment chronology. The cores used in this thesis have been preserved in anticipation of such techniques becoming available.

Furthermore, a longitudinal series of radiocarbon dates on basal organic matter in the inter-ridge ponds on Long Point and Point-aux-Pins would also be useful in fine-tuning the rates of evolution of these forelands. Similarly, greater use should be made of recent archaeological findings in these areas to provide checks on interpretations of foreland development.

4. Additional stratigraphic boreholes in the coastal zone. Other areas (apart from the forelands) where signficant postglacial sediment columns might be preserved include the coastal lowland areas on the U.S. side of the western sub-basin of Lake Erie. These areas are more sheltered from the prevailing winds and waves than the more easterly shorelines. Therefore gaps in the sediment record due to erosion might be less significant. Promising sites are the Sandusky River and Maumee River estuaries in Ohio, and that of Cedar Creek on the Canadian side.

5. Assessment of regional neotectonics. The thesis argued that differential crustal movements are continuing in the Erie Basin, especially in the Niagara outlet area. Further investigations into this phenomenon would be useful in providing constraints and mechanisms related to the postglacial lake level history presented.

6. Niagara River history. The Niagara River, the main controlling factor in lake level evolution, is intimately linked to Lake Erie history. Investigations into river deposit stratigraphy, such as those of Calkin (1970), should be resumed and expanded to include

river paleohydrology and valley geomorphology. Though subject also to record obliteration through erosion, relict alluvial features and sediment records related to the past regime of the river (and indirectly that of Lake Erie) might still exist, especially in the delta into Lake Ontario. This work should include investigations into former Niagara River tributaries that might have been used as Lake Erie outlets in the initial stages. Subsurface profiles in the Lowbanks area and to the east would serve to test the hypothesis of a possible outlet at that site.

REFERENCES CITED

ANDREWS, J.T. 1970. A geomorphological study of postglacial uplift with particular reference to Arctic Canada. Inst. Brit. Geographers (Publ.), London, 156 p.

ANDERSON, T.W. 1971. Postglacial vegetative changes in the Lake Huron - Lake Simcoe District, Ontario with special reference to glacial Lake Algonquin. Unpubl. Ph.D. Thesis, Dept. of Geology, University of Waterloo, 245 p.

BARNETT, P.J. 1978. Quaternary geology of the Simcoe area, southern Ontario. Ont. Div. Mines, Geoscience Report 162, 74 p.

BARNETT, P.J. 1979. Glacial Lake Whittlesey: the probable ice-frontal position in the eastern end of the Erie basin. Can. Jour. Earth Sci. 16, pp. 568-574.

BARNETT, P.J., and Zilans, A. 1983. Quaternary geology of the Long Point area, southern Ontario. Ont. Geol. Survey, Map P. 2616, Geological Series Prelim. Map.

BARNETT, P.J., COAKLEY, J.P., TERASMAE, J., and WINN, C.E. In press. Chronology and significance of a Holocene sedimentary profile from Clear Creek, Lake Erie shoreline, Ontario. (Submitted to Can. Jur. Earth Sci.)

BASHAM, P.N., WEICHERT, D.H. and BERRY, M.J. 1979. Regional assessment of seismic risk in eastern Canada. Seismological Society of America Bull. 69, pp. 1567-1602.

BEAR, J. 1972. Dynamics of fluids in porous media. American Elsevier, New York, 764 p.

BOULDEN, R.S. 1975. Canada - Ontario Great Lakes Shore Damage Survey. Tech. Report. Environment Canada and Ontario Ministry of Natural Resources. 97 p.

BROECKER, W.S. 1966. Glacial rebound and the deformation of the shorelines of proglacial lakes. Jour. Geophys. Res. 71, pp. 4777-4783.

BRUUN, P. 1962. Sea level rise as a cause of shore erosion. Jour. Waterways and Harbours Div., ASCE, 88 (WW1), pp. 117-130.

CALKIN, P.E. 1970. Strand lines and chronology of the glacial Great Lakes in northwestern New York. Ohio Jour. Sci. 70, pp. 78-96.

CALKIN, P.E., and BRETT, C.E. 1978. Ancestral Niagara River drainage: stratigraphic and paleontologic setting. Geol. Soc. Am. Bull. 89, pp. 1140-1154.

CARTER, C.H. 1984. An early Lake Erie delta: the Fairport Harbour, Ohio, sand deposit. Abstr. 27 Conf. Great Lakes Research, IAGLR, Brock Univ., St. Catharines, Ontario, p. 32.

CARTER, C.H., WILLIAMS, S.J., FULLER, J.A., and MEISBURGER, E.P. 1982. Regional geology of the southern Lake Erie (Ohio) bottom: a seismic reflection and vibracore study. U.S. Army Corps of Engineers Coastal Eng. Res. Center, Misc. Report 82-15, 109 p.

CASAGRANDE, A. 1936. The determination of the preconsolidation load and its practical significance. Proc. 1st Int. Conf. Soil Mech. Found Eng., Cambridge, Mass., pp. 60-64.

COAKLEY, J.P. 1976. The formation and evolution of Point Pelee, western Lake Erie. Can. Jour. Earth Sci. 13 (1), pp. 136-144.

______________________. 1977. Processes in sediment deposition and shoreline changes in the Point Pelee area, Ontario. Inland Waters Directorate, Environment Canada, Sci. Series No. 79, 76 p.

______________________. 1980. Postglacial evolution and modern processes at Point Pelee, Lake Erie. In: "The Coastline of Canada", S.B. McCann, (Ed.), Geol. Surv. Can. Paper 80-10, pp. 429-437.

COAKLEY, J.P., ZEMAN, A.J., and KALAS, L.L. 1977. Lithology and geotechnical properties as indicators of the depositional history of late Quaternary sediments from the Pelee Shoal, western Lake Erie. Unpubl. Report, Hydraulics Res. Div., National Water Research Institute, Burlington, Ontario, 47 p.

COASTAL ENGINEERING RESEARCH CENTER. 1973. Shore Protection Manual. U.S. Army Corps of Engineers, Volume 1, 180 p.

THE COORDINATING COMMITTEE on Great Lakes basic hydraulic and hydrological data. 1977. Apparent vertical movement over the Great Lakes. Detroit District, U.S. Army Corps of Engineers, 70 p.

COOPER, A.J. 1977. Quaternary geology of the Strathroy (401/13), Bothwell (401/12), and Ridgetown (401/5) areas, Middlesex, Lambton, Kent, and Elgin counties. Ont. Geol. Survey Summary of Field Work, 1977, pp. 139-140.

CRAIG, R.F. 1978. Soil Mechanics. Van Nostrand Reinhold, New York, 318 p.

CREER, K.M., ANDERSON, T.W., and LEWIS, C.F.M. 1976. Late Quaternary geomagnetic stratigraphy recorded in Lake Erie sediments. Earth and Planetary Science Letters 31, pp. 37-47.

DAVIS, M.B. 1981. Outbreaks of forest pathogens in Quaternary history. Proc. IV Int. Palynological Conf., Lucknow (1976-77), pp. 216-227.

DAVIS, W.M. 1926. Biographical memoir - Grove Karl Gilbert, 1843-1918. Nat. Acad. Sci. Vol. XXI, 5th Memoir, pp. 1-303.

DESAULNIERS, D.E., CHERRY, J.A., and FRITZ, P. 1981. Origin, age, and movement of pore water in argillaceous Quaternary deposits at four sites in southwestern Ontario. Journal of Hydrology 50, pp. 231-257.

DOBSON, H.F.H. 1981. Trophic conditions and trends in the Laurentian Great Lakes. Water Quality Bulletin (WHO) 6 (4), pp. 146-151.

DOEGLAS, D.J. 1946. Interpretation of the results of mechanical analysis. Jour. Sed. Petr. 16, pp. 19-40.

DREIMANIS, A. 1962. Quantitative gasometric determination of calcite and dolomite by using Chittick apparatus. Jour. Sed. Petr. 32, pp. 520-529.

DREIMANIS, A. 1963. New test drillings in Lower Wisconsin deposits at Port Talbot, Ontario. Geol. Soc. Am. Spec. Paper 76, p. 51.

DREIMANIS, A. 1969. Late Pleistocene lakes in the Ontario and Erie basins. Proc. 12th Conf. Gt. Lakes Res., IAGLR, pp. 170-180.

DREIMANIS, A., and GOLDTHWAIT, R.P. 1973. Wisconsin glaciation in the Huron, Erie, and Ontario lobes. In: "The Wisconsinan Stage", R.F. Black, R.P. Goldthwait, and H.B. Willman (Eds.), Geol. Soc. Am. Mem. 136, pp. 71-106.

DREIMANIS, A., and KARROW, P.F. 1972. Glacial history in the Great Lakes - St. Lawrence region and the classification of the Wisconsinan Stage. XXIV Int. Geol. Congr. Proc. Sect. 12, pp. 5-15.

DREIMANIS, A., TERASMAE, J., and McKENZIE, G.D. 1966. The Port Talbot Interstade of the Wisconsin glaciation. Can. Jour. Earth Sci. 3, pp. 305-325.

DUBOIS, R.N. 1976. Nearshore evidence in support of the Bruun rule on shore erosion. Jour. Geology 80 (4), pp. 485-491.

DUNCAN, G.A., and LAHAIE, G.G. 1979. Size analysis procedures used in the Sedimentary Laboratory. Hydraulics Div. Manual, National Water Research Institute, Burlington, Ontario, 23 p.

FEENSTRA, B.H. 1981. Quaternary geology and industrial minerals of the Niagara - Welland area, southern Ontario. Ont. Geol. Surv. Open File Report 5361, 260 p.

FOLK, R.L., and WARD, W.C. 1957. Brazos River bar: a study of the significance of grain-size parameters. Jour. Sed. Petr. 27, pp. 3-26.

FRIEDMAN, G.M. 1961. Distinction between dune, beach, and river sands from the textural characteristics. Jour. Sed. Petr. 31, pp. 514-529.

FRITZ, P., ANDERSON, T.W., and LEWIS, C.F.M. 1975. Late Quaternary climatic trends and history of Lake Erie from stable isotope studies. Science 190, pp. 267-269.

FRYE, J.C., and WILLMAN, H.B. 1960. Classification of the Wisconsinan Stage in the Lake Michigan glacial lobe. Ill. Geol. Survey Circ. 285, 16 p.

FULLERTON, D.S. 1980. Preliminary correlation of post Erie Interstadial events (16,000 - 10,000 radiocarbon years Before Present), central and eastern Great Lakes region, and Hudson, Champlain, and St. Lawrence Lowlands, United States and Canada. U.S. Geol. Survey Prof. Paper 1089, 51 p.

GELINAS, P.-J. 1974. Contributions to the study of erosion along the north shore of Lake Erie. Unpubl. Ph.D. Thesis, University of Western Ontario, 264 p.

GILBERT, G.K. 1885. The topographic features of lake shores. Papers accompanying the 5th Ann. Report, U.S. Geol. Surv., pp. 71-123.

GLAISTER, R.P., and NELSON, H.W. 1974. Grain-size distributions, an aid to facies identification. Can. Petr. Geologists Bull. 22, 203-240.

GOLDTHWAIT, R.P., DREIMANIS, A., FORSYTH, J.L., KARROW, P.F., and WHITE, G.W. 1965. Pleistocene deposits of the Erie lobe. In: "The Quaternary of the United States", H.E. Wright, Jr. and D.G. Frey (Ed.), Princeton University Press, pp. 85-97.

GULLIVER, F.P. 1895. Cuspate forelands. Geol. Soc. Am. Bull. 7, pp. 399-422.

GUTENBERG, Beno. 1933. Changes in sea-level, postglacial uplift, and mobility of the earth's interior. Geol. Soc. Am. Bull. 52, pp. 721-772.

GUY, D.E., Jr. 1983. Origin and evolution of Bay Point sand spit, Lake Erie, Ohio. Unpubl. M.Sc. Thesis, Bowling Green State University, 205 p.

HANDS, E.B. 1977. Implications of submergence for coastal engineers. Proc. Coastal Sediments '77, ASCE, Charleston, S.C., pp. 149-166.

HANSBO, S. 1957. A new approach to the determination of the shear strength of clay by the fall-cone test. Proc. Royal Swedish Geotech. Inst. 14, 46 p.

HARAS, W.S. and TSUI, K.K. 1976. Canada-Ontario Great Lakes Shore Damage Survey - Coastal Zone Atlas. Environment Canada, Ontario Ministry of Natural Resources publ., 95 p.

HARPER, N.S. 1982. Palynology of samples from three boreholes at Long Point. National Water Research Institute Report of Study H-4309, Burlington, Ontario, 4 p.

HARRISON, W. 1958. Marginal zones of vanished glaciers reconstructed from the preconsolidation-pressure values of overridden silts. Jour. Geology 66, pp. 72-95.

HARTLEY, R.P. 1961. Bottom sediments in the Island area of Lake Erie. Div. Shore Erosion, Ohio Dept. Nat. Res., Tech. Report 9, 22 p.

HERDENDORF, C.E. 1968. Sedimentation studies in the South Shore Reef area of western Lake Erie. Proc. 11th Conf. Gt. Lakes Res., IAGLR, pp. 188-205.

HERDENDORF, C.E. and BRAIDECH, L.L. 1972. Physical characteristics of the reef area of western Lake Erie. Ohio Division of Geological Survey, Report of Investigations 82, 90 p.

HESTER, N.C. and FRASER, G.S. 1973. Sedimentology of a beach ridge complex and its significance in land-use planning. Illinois Geol. Surv. Environmental Geology Notes 63, 24 p.

HILAIRE-MARCEL, Claude. 1980. Multiple component postglacial emergence, eastern Hudson Bay, Canada. In: "Earth Rheology, Isostasy, and Eustasy", N.-A. Morner, (Ed.), IUGS Geodynamics Project, Report No. 49, p. 215-230.

HOBSON, G.D., HERDENDORF, C.E., and LEWIS, C.F.M. 1969. High-resolution reflection seismic survey in western Lake Erie. Proc. 12th Conf. Gt. Lakes Res., IAGLR, pp. 210-224.

__________________, and TERASMAE, J. 1969. Pleistocene geology of the buried St. Davids Gorge, Niagara Falls, Ontario: Geophysical and palynological studies. Geol. Surv. Can. Paper 68-67, 16 p.

HOUGH, J.L. 1958. Geology of the Great Lakes. Univ. of Illinois Press, Urbana, 313 p.

HOUGH, J.L. 1966. Correlation of glacial stages in the Huron - Erie and Michigan basins. Jour. Geology, 74, pp. 62-67.

HOYT, J.H. 1967. Barrier island formation. Geol. Soc. Am. Bull. 78, pp. 1125-1136.

INMAN, D.L. 1957. Wave-generated ripples in nearshore sands. Tech. Memo. 100, U.S. Army Corps of Engineers, Beach Erosion Board, Washington, D.C., 42 p.

INTERNATIONAL GREAT LAKES LEVELS BOARD. 1973. Regulation of Great Lakes water levels. Report to International Joint Commission, Dec. 7, 1973, 294 p.

KALAS, L.L. 1980. Climatic oscillations and their impact on taxonomic diversity and specimen abundance fluctuation of late Quaternary mollusca from the Pelee Shoal, Canada. Nat. Water Res. Inst., Unpubl. Rep., 59 p.

KARROW, P.F. 1963. Pleistocene geology of the Hamilton - Galt area. Ont. Dept. of Mines Geol. Report 16, 68 p.

KARROW, P.F. and ANDERSON, T.W. 1975. Palynological study of lake sediment profiles from southwestern New Brunswick: discussion. Can. Jour. Earth Sci. 12, pp. 1808-1812.

KARROW, P.F., ANDERSON, T.W., CLARKE, A.H., DELORME, L.D., and SREENIVASA, M.R. 1975. Stratigraphy, paleontology, and age of Lake Algonquin sediments in southwestern Ontario, Canada. Quaternary Res. 5 (1), pp. 49-87.

KARROW, P.F., CLARK, J.R., and TERASMAE, J. 1961. The age of Lake Iroquois and Lake Ontario. Jour. Geology 69, pp. 659-667.

KEITH, M.L. and ANDERSON, G.M. 1963. Radiocarbon dating: fictitious results from mollusk shells. Science 141, p. 634-636.

KEMP, A.L.W., MacINNIS, G.A., and HARPER, N.S. 1977. Sedimentation rates and a revised sediment budget for Lake Erie. Jour. Great Lakes Res. 3 (3-4), pp. 221-233.

KINDLE, E.M. 1933. Erosion and sedimentation at Point Pelee. Ontario Dept. of Mines, 42nd Ann. Report, pt. 2, 22 p.

KINDLE, E.M. and TAYLOR, F.B. 1913. U.S. Geological Survey Geological Atlas, Niagara Folio 190.

KITE, G.E. 1972. An engineering study of crustal movements around the Great Lakes. Environ. Canada, Inland Waters Br. Tech. Bull. 63, 57 p.

KLOVAN, J.E. 1966. The use of factor analysis in determining depositional environments from grain-size distributions. Jour. Sed. Petr. 36, pp. 115-125.

KORKIGIAN, I.M. 1972. Effects of gauge relocation and changes in harbour configuration on crustal movement rates and water level transfers. Unpubl. Report, U.S. Army Corps of Engineers, Detroit, 10 p.

KRAFT, J.A. 1971. Sedimentary facies patterns and geologic history of a Holocene marine transgression. Geol. Soc. Am. Bull. 82, pp. 2131-2158.

LEIGHTON, M.M. 1958. Important elements in the classification of the Wisconsin glacial stage. Jour. Geology 66, pp. 288-309.

LEVERETT, F., and TAYLOR, F.B. 1915. The Pleistocene of Indiana and Michigan and the history of the Great Lakes. U.S. Geol. Surv. Mon. 53, 529 p.

LEWIS, C.F.M. 1966. Sedimentation studies of unconsolidated deposits in the Erie basin. Unpubl. Ph.D. Thesis, University of Toronto, 135 p.

__________________. 1969. Lake Quaternary history of lake levels in the Huron and Erie basins. Proc. 12th Conf. Great Lakes Res., IAGLR, pp. 250-270.

__________________. 1970. Recent uplift of Manitoulin Island, Ontario. Can. Jour. Earth Sci. 7, pp. 665-675.

__________________, ANDERSON, T.W., and BERTI, A.A. 1966. Geological and palynological studies of early Lake Erie deposits. Proc. 9th Conf. Gt. Lakes Res., Univ. of Michigan Gt. Lakes Res. Div., pp. 176-191.

_______________, WOOTON, A.E., and DAVIS, J.B. 1973. Stratigraphic and engineering studies of unconsolidated sediments in central Lake Erie near Erieau, Ontario. Geol. Surv. of Canada Report of Activities, Part A: April to October 1972. GSC Paper 73-1, pp. 205-209.

LIARD, A.C. 1973. A study of the energy - transport relationship and a simulation of Long Point, Lake Erie. Unpubl. M.Sc. Thesis, Dept. of Earth Sciences, University of Waterloo, 51 p.

MASON, C.C., and FOLK, R.L. 1958. Differentiation of beach, dune, and aeolian flat environments by size analysis, Mustang Island, Texas. Jour. Sed. Petr. 28, pp. 211-226.

MATYAS, E.L., WHITE, O.L., HEGLER, D.P. and RUTKA, R.N. 1976. Shoreline erosion in western Lake Ontario. Contract Report by Dept. of Civil Engineering, University of Waterloo to the Geological Survey of Canada, Vol. III, 61 p.

MEISTRELL, F.J. 1966. The spit-platform concept: laboratory observation of spit development. In "Spits and Bars", M.L. Schwartz (Ed.), pp. 225-284.

MIDDLETON, G.V. 1976. Hydraulic interpretation of sand size distributions. Jour. Geology 84, pp. 405-426.

MILLER, B.B. 1983. Late Quaternary fluvial history of the Lower Cuyahoga River in northeastern Ohio. Jour. Great Lakes Res. 9 (1), pp. 97-105.

MILLER, B.B., KARROW, P.F., and KALAS, L.L. 1979. Late Quaternary mollusks from glacial Lake Algonquin, Nipissing, and transitional sediments from southwestern Ontario, Canada. Quaternary Research 11, pp. 93-112.

MORGAN, N.A. 1964. Geophysical studies in Lake Erie by shallow marine seismic methods. Unpubl. Ph.D. Thesis, University of Toronto, 170 p.

MORNER, Nils-Axel. 1980. The Fennoscandian uplift: geological data and their geodynamic implications. In: "Earth Rheology, Isostasy and Eustasy", N.-A. Morner, (Ed.), IUGS Geodynamics Project, Report No. 49, p. 251-284.

MOSLOW, T.F., and HERON, S.D., Jr. 1981. Holocene depositional history of a microtidal cuspate foreland cape: Cape Lookout, North Carolina. Marine Geology 41, pp. 251-270.

MOSELEY, E.L. 1904. Formation of Sandusky Bay and Cedar Point. Proc. Ohio State Acad. of Sci. 4, pt. 5, pp. 179-238.

MOTT, R.J. 1975. Palynological studies of lake sediment profiles from southwestern New Brunswick. Can. Jour. Earth Sci. 12, pp. 273-288.

MOTT, R.J., and FARLEY-GILL, L.D. 1978. A late Quaternary pollen profile from Woodstock, Ontario. Can. Jour. Earth Sci. 15, pp. 1101-1111.

OGDEN, J.G. 1967. Radiocarbon and pollen evidence for a sudden change in climate in the Great Lakes region approximately 10,000 years ago. In: "Quarternary Paleoecology", E.J. Cushing, and H.E. Wright, Jr. (Eds.), Yale University Press, pp. 117-127.

OGDEN, J.G., III, and HAY, R.J. 1965. Ohio Weslyan University Natural Radiocarbon Measurements, II. Radiocarbon 7, pp. 166-173.

OGDEN, J.G., III, and HAY, R.J. 1969. Ohio Weslyan University Natural Radiocarbon Measurements, IV: Radiocarbon 11, pp. 137-149.

ONTARIO HYDRO. 1981. Lake Erie marine cable crossing. Geotechnical Investigation - 1980 Program. Unpubl. Report 81169 (plus uninterpreted seismic profiler records).

PACKER, R.W. 1976. University of Western Ontario coastal research activities. Proc. 1st Workshop on Great Lakes Coastal Erosion and Sedimentation, Canada Centre for Inland Waters, Burlington, pp. 85-88.

PASSEGA, R. 1957. Texture as characteristic of clastic deposition. Am. Assoc. Petrol. Geologists Bull. 41 (9), pp. 1952-1984.

PASSEGA, R. 1964. Grain size representation by CM patterns as a geological tool. Jour. Sed. Petr. 34 (4), pp. 830-847.

PETTIJOHN, F.J. 1957. Sedimentary Rocks. Harper's Geoscience Series, 718 p.

PINCUS, H.J. 1953. Investigations into Lake Erie sediments, vicinity of Sandusky, Ohio. Div. Geol. Survey, Ohio Dept. Nat. Res., Report of Investigations No. 18, 37 p.

PREST, V.K. 1970. Quaternary geology of Canada. In: "Geology and Economic Minerals of Canada", R.W. Douglas (Ed.), Geol. Surv. Can. Econ. Geol. Report No. 1, 5th edition, pp. 675-764.

QUIGLEY, R.M., GELINAS, P.-J., BOU, W.T., and PACKER, R.W. 1977. Cyclic erosion - instability relationships; Lake Erie north shore bluffs. Can. Geotech. Jour. 14, pp. 310-323.

REINECK, H.-E., and SINGH, I.B. 1975. Depositional sedimentary environments. Springer-Verlag, 439 p.

REINECK, H.-E., and WUNDERLICH, F. 1968. Classification and origin of flaser and lenticular bedding. Sedimentology 11, pp. 99-104.

ROMINGER, J.F., and RUTLEDGE, P.C. 1952. Use of soil mechanics data in correlation and interpretation of Lake Agassiz sediments. Jour. Geology 60, pp. 160-180.

ROSS, A.R. 1950. Pleistocene and recent sediments in western Lake Erie. Unpubl. Ph.D. Thesis, University of Michigan, 57 p.

RUBIN, M., and TAYLOR, F.B. 1963. Radiocarbon activity of shells from living clams and snails. Science 141, p. 637.

RUKAVINA, N.A. 1976. Nearshore sediments of Lakes Ontario and Erie. Geoscience Canada 3, pp. 185-190.

__________________. 1981. Lake Erie nearshore sediment and acoustic data, Long Point area. Hydraulics Div., National Water Research Institute Techn. Note 81-02, 4 p.

__________________. 1983. Nearshore acoustic and subsurface geological data, Pointe-aux-Pins, Lake Erie. Hydraulics Div., National Water Research Institute Techn. Note 83-01, 5 p. (plus Appendices).

RUKAVINA, N.A., and ST. JACQUES, D.A. 1971. Lake Erie nearshore sediments, Fort Erie to Mohawk Point, Ontario. Proc. 14th Conf. Great Lakes Res., IAGLR, pp. 387-393.

______________________, and ST. JACQUES, D.A. 1978. Lake Erie nearshore sediments, Point Pelee to Port Burwell, Ontario. Inland Waters Directorate, Environment Canada, Scientific Series No. 99, 44 p.

SANFORD, B.G. 1961. Subsurface stratigraphy of Ordovician rocks in southwestern Ontario. Geol. Surv. Can. Paper 60-26, 54 p.

ST. JACQUES, D.A., and RUKAVINA, N.A., 1973. Lake Erie nearshore sediments, Mohawk Point to Port Burwell, Ontario. Proc. 16th Conf. Gt. Lakes Res., IAGLR, pp. 454-467.

SCHLEE, J. 1973. Atlantic continental shelf and slope of the United States - sediment texture of the northeastern part. U.S. Geol. Survey Prof. Paper 529-L, 64 p.

SCHWARTZ, M.L. 1965. Laboratory study of sea level rise as a cause of shore erosion. Jour. Geology 73 (3), pp. 528-534.

SCHWARTZ, M.L. 1967. The Bruun theory of sea level rise as a cause of shore erosion. Jour. Geology 75 (1), pp. 76-92.

SEIBEL, E. 1972. Shore erosion at selected sites along Lakes Michigan and Huron. Unpubl. Ph.D. Thesis, University of Michigan, Ann Arbor, 175 p.

SHEA, J.H. 1974. Deficiencies of clastic particles of certain sizes. Jour. Sed. Petr. 44, 985-1003.

SIGLEO, W.R., and KARROW, P.F. 1977. Pollen-bearing Erie Interstadial sediments from near St. Mary's, Ontario. Can. Jour. Earth Sci., 14, pp. 1888-1896.

SLY, P.G., and LEWIS, C.F.M. 1972. The Great Lakes of Canada - Quaternary geology and limnology. Guidebook, Excursion A43, XXIV Int. Geol. Congr., Montreal, 92 p.

SPENCER, D.W. 1963. The interpretation of grain size distribution curves of clastic sediments. Jour. Sed. Petr. 33 (1), pp. 180-190.

SPENCER, J.W. 1891. Origin of the basins of the Great Lakes of America. Am. Geologist, 7, pp. 86-97.

STEVENSON, A.L., and BENNINGHOFF, W.S. 1969. Late postglacial rise of Lake Erie and changes in vegetation of the Maumee Lake Plain. Proceedings 12th Conf. Gt. Lakes Res., IAGLR, pp. 347-350.

STOTHERS, D.M. 1972. A preliminary investigation into the archaeology of Rondeau Provincial Park. Unpubl. Report, Ontario Ministry of Culture and Recreation, unpag.

STRAW, A. 1968. Late Pleistocene glacial erosion along the Niagara Escarpment of southern Ontario. Geol. Soc. Am. Bull. 79, pp. 889-910.

TERASMAE, J. 1970. Report on stratigraphic drilling in Point Pelee National Park, Ontario. Contract Report 68-200, National and Historic Parks Br., Dept. Ind. and North. Affairs, 6 p.

TERZAGHI, K., and PECK, R.B. 1967. Soil mechanics in engineering practice. John Wiley and Sons, 729 p.

THOMAS, R.L., JAQUET, J.-M., KEMP, A.L.W., and LEWIS, C.F.M. 1976. Surficial sediments of Lake Erie. Jour. Fish. Res. Board of Canada 33, pp. 385-403.

VAGNERS, U.J. 1972. Quaternary geology of the Windsor-Essex area (eastern part), southern Ontario. Ont. Dept. Mines and Northern Affairs, Prelim. Map P.750, Geol. Series.

VASSOYEVICH, N.B. 1959. Bedding in the light of sedimentary differentiation: Translated by P.F. Moore. Int. Geol. Review, 1, pp. 59-71.

VISHER, G.S. 1965. Use of vertical profile in environmental reconstruction. Am. Assoc. Petrol. Geologists Bull. 49, pp. 41-61.

VISHER, G.S. 1969. Grain size distributions and depositional processes. Jour. Sed. Petr. 39 (3), pp. 1074-1106.

WALCOTT, R.I. 1970. Isostatic response to loading of the Crust in Canada. Can. Jour. Earth Sci. 7, pp. 716-727.

WALL, R.E. 1968. A sub-bottom reflection survey in the central basin of Lake Erie. Geol. Soc. Am. Bull. 79, pp. 91-106.

WALTHER, J. 1894. Einleitung die Geologie als historische Wissenschaft; Beobachtungen über die Bildung der Gesteine und ihre organischen Einschlusse, bd. 1: Jena, G. Fischer.

WASHBURN, A.L., and STUIVER, M. 1962. Radio-carbon-dated postglacial develling in northeast Greenland and its implications. Artic 15, pp. 66-73.

WEGGEL, J.R. 1979. A method for estimating long-term erosion rates from a long-term rise in water level. Coastal Eng. Res. Centre, Tech. Aid 79-2, 16 p.

WHITE, O.L. 1961. Application of soil consolidation tests to the determination of Wisconsin ice thickness in the Toronto region. Unpubl. M.A.Sc. Thesis, University of Toronto, 95 p.

WILLIAMS, S.J., and MEISBURGER, E.P. 1982. Geological character and mineral resources of south central Lake Erie. U.S. Army Corps of Engineers Coastal Engineering Research Center, Misc. Rep. 82-9, 62 p.

WILLIAMS, S.J., CARTER, C.H., MEISBURGER, E.P., and FULLER, J.A. 1980. Sand resources of southern Lake Erie, Conneault to Toledo, Ohio - A seismic reflection and vibracore study. U.S. Army Corps of Engineers, Coastal Eng. Res. Centre, Misc. Report 80-10, 83 p.

WILSON, A.W.G. 1908. Shoreline studies on Lakes Ontario and Erie. Geol. Soc. Am. Bull. 19, pp. 471-500.

WINN, C.E. 1977. Vegetational history and geochronology of several sites in south southwestern Ontario. Unpubl. M.Sc. Thesis, Brock University, 374 p.

WITHERSPOON, D.F. 1971. General hydrology of the Great Lakes and reliability of component phases. Environment Canada Inland Waters Br. Tech. Bull. 50, 14 p.

WOOD, H.A.H. 1951. Erosion of the shore of Lake Erie, Pointe-aux-Pins to Long Point. Unpubl. M.A. Thesis, McMaster University, 209 p.

____________. 1960. Wave transport of beach materials on Long Point, Lake Erie. Can. Geographer 16, pp. 27-35.

YAMAMOTO, A., KANARI, S., FUKUO, Y., and HORIE, S. 1974. Consolidation and dating of the sediments in core samples from Lake Biwa. p. 135-144 In: "Paleolimnology of Lake Biwa and the Japanese Pleistocene," Second Issue, Shoji Horie (Ed.), pp. 135-144.

ZEMAN, A.J. 1976. Geotechnical properties of Lake Erie clays. Unpubl. M.Sc. Thesis, McGill University, 133 p.

____________________. 1979. Reconstruction of sedimentation rates from geotechnical properties of offshore sediments. Proc. 1st Can. Conf. on Marine Geotechnical Engineering, Calgary, Alberta, pp. 47-54.

ZENKOVICH, V.P. 1967. Processes of Coastal Development. Interscience Publishers, New York, 738 p.

APPENDICES

APPENDIX 1

Summary log of Long Point boreholes

Summary Log L.P. BH #1 (July/80)

0 = 175.3 m asl	(Ground Level).
0 - 1510 cm	Gray to grayish brown medium (2.0 - 2.9 Ø) sand; generally well-sorted, except for pebbly layers (470, 550, 600, 1070 cm). Shells often associated with coarse layers. Wood rare (1280 cm). Gravelly layer (1310 - 1510 at base of unit.
1510 - 2680 cm	Below gravelly layer, material changes to gray, fine sand (3.8 Ø) with silt interlaminations and lenses becoming more common with depth. Bottom material is classified as sandy silt (5.4 Ø). Scattered plant fragments, wood pieces, and shells present.
2680 - 4180 cm	Dark gray soft clayey silt with occasional sandy interlaminations in upper portion, becoming more clayey and less sandy with depth. Rare wood and organic matter. (3570 cm:artesian flow).
4180 - 5395 cm	Drilled down but no sample taken. Material on bit - soft gray clay (Glaciolacustrine?).

Summary Log L.P. BH #2 (July 1980)

0 = 175.4 m asl	(Ground Level).
0 - 2080 cm	Brownish-gray (grading to gray 10 YR 5/1 at bottom), well sorted medium sand (2.0Ø to 2.6 Ø) with occasional pebble bands and siltier layers. Wood fragments within pebbly sand layer at 1350 cm.
2080 - 3000 cm	At 2080 - 2090 and 2408 - 2424, bands of gray coarser sand and shells are present. Remainder of unit composed of gray fine-medium sand interlaminated with silty and clayey layers. Black plant fragments common.
3000 - 6130 cm	3000 - 4100 cm: Gray to dark gray (10.5 YR 4/1) sandy silt to silt (5.5 to 5.9 Ø), firm to stiff in consistency. Sand layers occur at 3964 and 4830. Material gets finer from 4100 on down (6.1 Ø) but sand fraction still around 10%. Silty clay material shows almost a "fissile" cleavage property and an apparently low moisture content. Interlaminations and lenses of coarser material persist to EOH. (Artesian flow at 3810, 4270 cm).

Summary Log L.P. BH #3 (October 1981)

0 = 175.7 m asl	(Ground Level).
0 - 650 cm	Brown to brownish-gray well-sorted medium sand (2.1 - 2.7 Ø) uniform except for common darker laminations (heavy minerals in bottom section) and occasional ice-rafted (?) pebbles. Organic debris (twigs, leaves, root fragments) common and occasionally form thin layers.
650 - 899	Sharp contact separates sand unit above from Unit 2. Dark olive gray silt to clayey silt characterized by faint inclined laminations, scattered shell hash and organic debris, and partly dissolved bivalve shells. Rare indications of worm burrowing (fibres, mottling).
899 - 1740	Contact not sampled. Unit grades slowly from grayish brown fine silty sand (2.8 Ø) at top to dark gray clayey silt (6.6 Ø) at the bottom. Sand layers and lenses interfinger regularly with silty layers, with silt layers more frequent in downward direction. Inclined contacts, vague low angle cross-laminations. Organic matter common and usually associated with sediment contacts and in sand layers.
1740 - 2263	Dark gray clayey silt, ranging in mean size from 7.1 to 7.9 Ø . Very uniform, with faint dark subhorizontal laminations. Gas bubbles common throughout. Rate shells, silt or fine sand lenses. Effervesces in HCl.

2263 - EOH (4054 cm) (Unit 4)	Grayish brown (2.5 and 5/2) clay; stiff to firm in consistency. Plastic and greasy feel. Uniform in texture, although vague colour banding and laminations common. Laminations often contorted and inclined. Rare dark gray and reddish clay balls and flecks, no shells. Rare "ice-rafted" pebble. Siltier laminations and lenses become more common near base of borehole.

APPENDIX 2

Plotted log of LBH reproduced from Lewis (1966). Lithological units shown were interpreted by the author (Lewis' facies interpretations are included, labelled A to D). Note that size parameters used are different from those used in the other Long Point borehole samples (moment measures).

Metres below datum (174.0m a.s.l.): 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120

Litho-logical Units	Lewis' Sediment Description	Median	Dev.	Skewness	Kurtosis	Facies
Unit 4	Stratified buff to brown fine and coarse sand with rounded pebbles and cobbles.	1.60	1.37	-0.81	0.31	D
		0.41				
		-1.49	1.21	0.21	0.25	
		2.59	0.37	0.02	0.21	
	Stratified buff to brown fine and medium sand with occasional thin silt interbeds. Fine sand is calcareous and loosely cemented in places. Detrital shell fragments throughout. Grass stems at 8 m. Charcoal at 9 m. Wood fragments at 14 and 15 m.	2.70	0.54	0.12	0.28	
Unit 3	Stratified buff to brown fine sand grading down to sandy silt and silty clay. Some shell fragments and sorted fine to coarse sand interbeds common in upper section. Grey silt and clay beds in lower section commonly contain black reduced (organic?) matter. Wood fragments common from 20-25 m and from 33-39 m. Coal fragments at 23 and 25 m.	4.64	0.99	0.17	0.25	
		4.40	0.96	0.29	0.25	
		4.58	1.18	0.18	0.24	
		5.70	1.15	0.09	0.23	
Unit 2	Soft grey silty clay, commonly faintly laminated with a few uniform sections. Clay oxidizes rapidly to brown colour when exposed to air. Water contents range between 35 and 45% of dry weight. Laminae caused by horizontal alignment of specks of black reduced (organic?) matter. Occasional thin sand and silt seams and lenses in upper few metres. H2S odour in places. Decreasing reduced matter.	8.53	1.38	0.39	0.24	C
		10.00	1.62	0.30	0.31	
		10.10	1.64	0.26	0.31	
		10.17	1.70	0.17	0.29	
Unit 1	Soft reddish-grey to brown clay. No colour change with exposure to air. Water cont. 41 - 48% (dry weight). Faintly laminated; in places varve-like, with alt. beds 1mm to 5 mm thick of clay and silt. Toward base, beds reach 3 cm in thickness and contain pebbles, sandballs, siltballs rarely.	10.74	1.87	-0.24	0.27	B
		10.75	1.64	-0.02	0.31	
		11.33	1.40	-0.12	0.48	
		11.04	1.42	0.06	0.29	
	Reddish-grey clay, firmer than above. Water cont. 30 - 36%. Faintly laminated; in places massive. Some alternating clay and silt zones. Siltballs, seams, and sand grains common. Occas. limestone pebble.	10.91	1.48	0.06	0.30	
		10.82	1.57	0.03	0.29	
		10.23	1.65	0.24	0.31	
		9.89	1.84	0.22	0.30	
Till	Layered complex of variable texture incl. reddish grey clay with sand partings, clay with sand- and silt-balls, massive stiff clay and silt, sorted sand and pebbles, and basal gravel.	6.90	1.97	1.07	0.29	A
		9.37	2.08	0.20	0.30	
		7.04	2.59	0.80	0.31	
		9.17	2.22	0.18	0.31	
		4.70	1.00	0.18	0.18	
		8.67	2.44	0.25	0.32	
		8.69	2.41	0.23	0.32	
b.r.	Bluish-grey crystalline limestone with striated surface.					

Lewis' facies interpretation: A - Ice-contact deposits; B - glaciolacustrine deposits;
C - Postglacial lacustrine deposits; D - Recent spit deposits.

APPENDIX 3

Summary logs of Cores 1 to 6 from the Pelee Shoal.

(The logs shown were summarized from the original comprehensive logs of the cores done by Gary Winter, a summer student at NWRI, under the author's supervision. These original logs appear as an appendix in Coakley *et al* (1977))

Summary log of Core 1, Pelee Shoal

0 = 166.5 m a.s.l	Lake bottom level
0 - 1.2 m (Unit 4)	Dark grayish-brown (2.5 Y, 4/2), sorted fine to medium sand; massive with scattered pebbles. Gravel layer at 0.8 to 0.9 m. Shell fragments scattered throughout the unit, with maximum concentration in the gravel layer. From 0.9 to 1.1 m, the unit grades into fine sand at the base. A poorly-sorted coarse, sub-rounded pebble layer occurs at 1.1 to 1.2 m (lag deposit?).
1.2 - 4.1 m (Unit 1)	Silty clay till, dark grayish-brown in colour (10YR, 4/2), with numerous pebbles and granules scattered randomly throughout. Slight mottling of reddish and grayish patches, increasing with depth. Sharp contact with sand above. At around 2.7 m, till colour becomes more dark brown (7.5Y, 4/2).

Summary log of Core 2, Pelee Shoal

0 = 166.5 m a.s.l.	Lake bottom level
0 - 5.2 m (Unit 4)	From 0 to 1.3 m, well-sorted, medium sand, light olive gray (5Y, 6/2) in colour becoming slightly darker with depth (more heavy minerals?). Top portion is massive, but below 0.4 m faint laminations are visible. Gravel layer occurs at 0.7 to 0.8 m. 1.3 to 5.1 m, colour becomes dark grayish-brown (2.5 Y, 3/2), although texture is same as above. Thin gravel layers at 1.3 m, 1.6 - 1.9 m, and 5.1 to 5.2 m. From 3.8 to 5.1 m silty interlaminations begin to appear.
5.2 - 6.9 m (Unit 3)	Predominantly fine sand with minor silt laminations (2.5Y 4/2 dark grayish-brown). Below 5.7 m gradual change occurs to olive gray (5Y, 4/2) silt with minor fine sand and clay laminations. Both textural and colour banding (the latter dark in colour and probably sulphide) 0.1 to 2 cm in thickness. No shell fragments, but abundant plant detritus (wood chips, stems (partially decayed) are present, especially between 6.0 and 6.1 m (sampled for C-14 dating).
6.9 - 11.8 m (Unit 2)	Clayey laminations have increased until this unit is now predominantly a silty clay, ranging from gray (5Y, 5/1) to olive gray (5Y 4/2), to dark gray (5Y 4/1) in colour with depth, with black (Fe sulphide) laminations more frequent with depth. Pebbles and shells present, but rare.

Summary log of Core 3, Pelee Shoal

0 = 167.7 m a.s.l.	Lake bottom level
0 - 2.3 m (Unit 4)	Predominantly massive, medium sand, moderately well sorted, olive brown (2.5Y 4/4) in colour. Heavy mineral laminations present as contorted and irregular laminations (Vibracoring process. Shell fragments, random pebbles throughout.
2.3 - 3.4 m (Unit 4)	Sharp, inclined contact separates this section from that above. Texture is similar, medium to fine sand. Structure of this section, however, is predominantly laminated, with clearly-defined heavy mineral laminations, sometimes inclined like cross-laminations (planar), in the portion above 3.1 m. Below this point, laminations become more sub-horizontal and parallel. Overall colour is 2.5Y 4/2 dark grayish-brown. Wood and plant fragments, and some whole gastropod shells are scattered throughout this section.
3.4 - 9.6 m (Unit 1)	Dark brown (7.5 YR 4/2) pebbly silty clay till. Slight mottling (reddish-brown and olive gray) occurs. Structure is uniformly massive.

Summary log of Core 4, Pelee Shoal

0 = 167.4 m a.s.l. Lake bottom level

0 - 1.2 m (Unit 4)	Well-sorted, medium sand with occasional rounded granules. Colour is generally olive brown (2.5Y 4/4). Structure is massive, with a few vague heavy mineral concentrations.
1.2 - 2.4 m (Unit 4)	Well-sorted medium sand, same as above, but more very dark grayish-brown (2.5Y 3/2) in colour. Structure also changed thinly laminated (less tham 0.5 cm) sub-parallel and cross-laminations. Contact with the section above is sharply defined by colour and change in structure.
2.4 - 5.5 m (Unit 3)	Below sharp textural change contact, materials change to interlaminated sand, silt and clay. Colour is generally dark gray (5Y 4/1) to olive gray (5Y 4/2). Interlaminations are usually less than 0.5 cm thick, and are often irregular and contorted into lens-like structures. Clay content increases noticeably with depth, and becomes dominant (silty clay laminations) by 4.2 m depth. Laminations become more regular below this level.
5.5 - 5.7 m	Sharp contact between this section and that above. Material changes abruptly to poorly-sorted gravelly coarse sand. Shells present. Material changes at 5.6 m back to sandy, clayey silt, and by 5.7 m, it has become a silty clay again. Colour is dark gray (5Y 4/1).
5.7 - 7.2 m (Unit 1)	Dark brown (7.5YR 4/2) sandy, silty clay, pebbly till. Some of pebbles are partially decomposed. Faint mottling (dark gray, 5Y 4/1) occurs to 6.8 m depth. In one instance, the mottling (at 6.4 m) appears to radiate downward from a partially decomposed limestone pebble (leaching under subaerial conditions?). Upper portion of till feels stiffer than lower portion.

Summary log of Core 5, Pelee Shoal

0 = 164.9 m a.s.l.	Lake bottom level
0 - 1.3 m (Unit 4)	Well sorted, medium sand, dark brown (10YR 3/3) to very dark grayish brown (2.5Y 3/2) to dark olive gray (5Y 3/2) in colour with increasing depth. Pebble concentrations, shells, and heavy mineral laminations occur randomly, but structure is generally massive.
1.3 - 1.8 m (Unit 4)	Dark olive gray fine silty sand, massive with scattered fossil molluscs and organic matter. Interlaminations of silt and clay begin to appear.
1.8 - 5.4 m (Unit 3)	Complexly interlaminated silty fine sand with silty clay; colour is still dark olive gray, but changes with depth to olive gray (5Y 4/2). Silt and clay components increase also with depth and by 4.8 m, the material could be termed a sandy clayey silt, although sand lenses still occur. At the base of this section, a coarse, poorly-sorted layer (3 cm thick) occurs.
5.4 - 7.5 m (Unit 2)	Dark olive gray (5Y 3/2) laminated silty clay. Laminae (0.5 cm) are sub-parallel and sub-horizontal, resembling lenses at times. Shells and small wood fragments present. At base of the section, and separated from the portion above by a sharp contact, is a 6 cm thick (lag) gravel layer. Some pebbles coated by a carbonate material. Mollusk and wood fragments common.
7.5 - 9.1 m (Unit 2)	Silty clay, ranging from gray (5Y 5/1) to olive gray (5Y 4/2). Subangular pebbles sparsely scattered throughout. Silt content and pebble frequency increase downward (ice-rafting?). Structure is faintly laminated to 8.2, and thereafter becomes massive. Shells and occasional wood present throughout. Some black sulphide streaks also noted in more clay-rich zones.

Summary log of Core 6, Pelee Shoal

0 = 167.4 m a.s.l. Lake bottom level

0 - 0.5 m (Unit 4)
Olive brown (2.5 Y 4/4) coarse to medium sand with abundant granules and pebbles. Structure is massive. Mullusk shells abundant.

0.5 - 5.6 m (Unit 4)
Well-sorted medium sand, very dark grayish brown (2.5Y 3/2) in colour. Structure is laminated, due either to heavy mineral segregations or to textural changes. Heavy-mineral-rich bands (0.5 cm) are generally sub-parallel and inclined (cross-laminations?) or convoluted. Coarse bands occur frequently at 0.6, 1.0, 1.5, 2.2, 2.6, 3.6, and 5.4 m depth.Gastropod shells are most common in coarse zones, but occur throughout. Organic material in the form of wood (at 4.2 m, collected for C-14 dating) and a seed was also noted.

Silt content show marked increase from 5.0 m down, in the form of lenses interfingering with the still dominant sand phase.

5.6 - 11.9 m (Unit 3?)
Texturally complex section consisting of massive sandy clayey silt. Upper contact is gradational. Numerous small cracks in the core (gas release?). Colour is olive gray (5Y 3/2). Shell fragments and wood chips common in upper portion above 8.8 m, and only occasionally thereafter. Shells are usually unbroken. Clay lenses (convoluted) become more frequent between 8.1 and 9.0 m, while sand lenses (sub-horizontal) are present to the end of the core.

APPENDIX 4

Field notes and logs of two boreholes drilled at one site in Rondeau Provincial Park (Pointe-aux-Pins) in December, 1977 by A.J. Cooper of the Ontario Geological Survey. The second (1b) was the most complete and was used in this study (as OGS-1)

A.J. Cooper's Field notes and logs of BH 1a and 1b
Pointe-aux-Pins

BH 1a

0 = 176.8 m a.s.l. Ground level

0 - 0.3 m	Sandy topsoil
0.3 - 1.5 m	Dark, medium sand
1.5 - 3.0 m	Medium brown sand, med. - fine in texture, saturated No pebbles, some fines (10-15%, eolian?0
3.0 - 6.1 m	N = 32, 42 - Occas. pbl., shell (beach?)
6.0 - 7.6 m	N = 2, 3, 5; Plastic greenish gray lacustrine clay; non-calcareous, lam.; with pbls (2) and organics - grits.
7.6 - 10.7 m	N = 5, 6, 7; Similar to above; somewhat more brownish in colour; massive, non-calc. clay - softer.

BH 1b

0 - 6.1 m	Largely med. sand as before
6.1 - 6.5 m	Fine, med. and coarse sand and fine gravel (quartz, sed. rock fragments, etc.) subangular to subrounded. N = 16, 26, 28.
6.5 - 7.0 m	N = 5, 26, 36; Same as above with gravel up to 4 cm, sub-angular.
8.5 - 9.0 m	Slightly clayey silt to fine sand; calcareous, dark gray (5Y 4/1), with some light to dark reddish brown organic debris in small amounts.
9.0 - 9.3 m	Top 6" (15 cm): Clayey silt and silty fine sand; calcareous, dark gray, with some organic detritus. Bottom 6" (15 cm): Gray silt with med. brown organic debris, dark brown to black finely disseminated organic material;

BH 1b (Continued)

9.0 - 9.3 m (continued)	silt is calcareous.
9.3 - 9.7 m	Gray calcareous silt, fine and med. sand, silt and sandy silt contains some dark brown inclusions of organic material. Bottom: Mostly med. to dark brown organic material, some silt.
9.7 - 10.2 m	Top: Dark brown to gray organic material, fairly finely divided; silt included and silt lams. Bottom: Very dark gray weakly to moderately calcareous silt and clayey silt; brown and dark brown organic debris - not as plentiful as in previous samples.
10.7 - 11.1 m	Top: V. dark gray silt, weakly to moderately calcareous; brown to very dark brown organic material, disseminated, similar in appearance to material at 9.3 - 9.7 m (bottom). Bottom: Laminated greenish gray (5Y 4/1) silty clay and silty fine sand with some large (up to 5 cm) woody, organic fragments; non-calcareous.
12.2 - 12.6 m	Dark grayish brown (10YR 4/2) mod. calcareous clay and silty clay; laminations apparent, rather mottled, contorted; N = 6, 9, 14.

APPENDIX 5

Moment statistics and other textural data for samples from cores and boreholes used in this study, taken from Long Point (BH1, BH2, LP), Pelee Shoal (Cores 1 to 6), and Pointe-aux-Pins area. Sample elevations are referred to International Great Lakes Datum (IGLD for Lake Erie is 173.3 m above sea-level at Father Point, Quebec), and are in metres.

Long Point

Sample Ident.	Elev. below IGLD*	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	%clay
BH1-1	+0.2	1.95	2.06	0.49	-0.25	2.83	93.50	5.14	1.36
BH1-2	0.3	2.02	2.11	0.45	-0.80	5.82	97.36	1.92	0.72
BH1-3	1.0	2.20	2.23	0.36	-0.28	0.70	98.39	1.06	0.55
BH1-4	2.6	2.09	2.18	0.56	-0.66	4.81	97.75	1.73	0.52
BH1-5	3.3	0.41	1.74	2.61	-0.48	-0.80	96.42	2.77	0.81
BH1-6	4.1	1.91	2.10	0.74	-0.68	3.98	92.33	6.42	1.25
BH1-7A	4.7	0.87	1.11	1.27	-0.74	2.22	97.45	1.90	0.64
BH1-7B	5.0	2.23	2.42	0.78	-0.78	5.68	86.77	10.96	2.27
BH1-8	5.8	2.24	2.36	0.58	-0.80	2.80	98.24	1.42	0.33
BH1-9	6.7	2.65	2.72	0.37	-1.33	12.58	98,26	1.01	0.73
BH1-10	7.6	2.73	2.77	0.36	-1.17	9.63	97.76	1.14	1.10
BH1-11	8.5	1.67	2.51	1.41	-0.60	0.85	96.41	2.67	0.92
BH1-12	9.0	2.82	2.81	0.30	-0.06	1.53	98.09	1.12	0.78
BH1-13	10.5	2.28	3.05	1.69	-0.96	2.55	83.26	14.38	2.36
BH1-14	10.9	2.20	2.72	1.42	-1.05	3.43	97.44	2.03	0.54
BH1-15	12.0	1.95	2.79	1.91	-0.82	1.27	95.29	3.43	1.28
BH1-16T	12.6	3.07	3.20	0.48	-1.03	8.08	88.45	9.60	1.95
BH1-16B	12.9	-0.70	-0.75	2.32	+0.25	-0.94	92.24	S+C: 7.76	
BH1-17	13.7	3.83	3.30	1.74	+0.96	4.15	79.23	19.02	1.75
BH1-18A	14.7	5.83	5.82	1.78	+0.27	1.09	18.93	71.77	9.30
BH1-18	15.1	4.37	3.89	2.08	+0.24	0.86	53.84	41.08	5.08
BH1-19	15.5	4.01	3.44	1.54	+1.03	4.05	78.96	19.72	1.32
BH1-20A	16.7	5.45	5.82	2.51	-0.38	2.07	25.94	61.56	12.50
BH1-20	17.0	4.10	3.48	1.62	+1.09	4.70	76.38	21.90	1.72
BH1-21	17.8	4.30	3.58	1.68	+0.72	1.11	67.40	28.92	3.68
BH1-22	18.7	5.24	5.13	2.16	+0.14	1.14	34.96	56.61	8.43
BH1-23	19.6	5.07	4.82	1.71	+0.54	0.71	32.61	60.29	7.11
BH1-24	20.6	5.02	3.97	2.31	+0.56	0.48	50.55	41.52	8.93

*In metres below International Great Lakes Datum

Sample Ident.	Elev. below IGLD*	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	%clay
BH1-25	21.3	4.22	3.35	1.97	+0.86	2.11	71.17	22.27	6.56
BH1-25A	21.6	6.45	6.63	2.26	-0.11	0.87	15.76	60.79	23.45
BH1-26	22.4	5.22	5.11	1.74	+0.66	1.81	29.60	60.33	10.07
BH1-27	23.3	5.44	5.65	2.01	+0.38	-0.03	37.41	54.00	8.58
BH1-28	24.5	5.98	6.00	1.87	+0.30	0.12	21.74	65.85	12.41
BH1-29T	25.3	5.88	5.97	1.65	+0.22	0.08	18.51	68.85	12.64
BH1-29B	25.6	6.57	6.27	2.04	+0.37	-0.02	12.05	73.67	12.28
BH1-30T	26.2	6.67	6.66	2.22	+0.20	-0.39	18.03	69.84	12.13
BH1-30B	26.5	6.06	6.11	1.90	+0.29	0.11	18.79	65.54	15.67
BH1-31T	27.4	5.76	5.45	1.67	+0.45	0.45	12.60	74.75	12.65
BH1-31B	27.7	6.05	5.83	1.93	+0.45	0.71	16.95	72.30	10.75
BH1-32T	28.6	5.68	5.03	1.73	+0.88	2.76	5.52	82.69	11.80
BH1-32B	28.8	6.29	6.05	2.05	+0.43	0.56	12.45	71.61	15.94
BH1-33T	29.5	6.19	5.82	1.91	+0.59	1.74	8.08	77.41	14.51
BH1-33B	29.8	6.06	5.48	1.87	+0.62	1.28	7.20	77.64	15.16
BH1-34	30.3	6.35	6.33	1.80	+0.32	0.75	11.72	73.42	14.87
BH1-35	30.9	6.59	6.42	2.07	+0.35	0.24	10.90	71.11	17.99
BH1-36T	32.7	6.47	6.41	2.00	+0.30	0.46	11.36	69.55	19.09
BH1-36B	33.0	6.42	6.24	1.92	+0.50	0.74	9.29	73.71	17.00
BH1-37T	34.1	6.90	6.80	1.90	+0.35	0.33	5.50	71.61	22.88
BH1-37B	34.4	6.47	6.17	1.89	+0.50	0.95	5.92	79.87	14.21
BH1-38	36.1	6.69	6.59	1.67	+0.35	0.38	5.22	75.47	19.30
BH1-38B	36.4	6.45	6.31	1.83	+0.34	0.62	9.75	72.33	17.92
Shel-39	37.3	6.76	6.50	1.70	+0.47	0.48	1.00	75.0 S	24.0S
BH1-40T	39.3	6.99	6.90	1.81	+0.35	0.25	4.01	72.27	23.72
BH1-40B	39.6	6.81	6.29	1.89	+0.50	0.43	4.08	69.19	26.73

Sample Ident.	Elev. below IGLD*	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	%clay
BH2-41	1.3	2.01	2.10	0.38	-0.54	1.40	98.49	1.38	0.19
BH2-42	2.6	2.16	2.20	0.29	-0.22	1.61	98.85	0.76	0.39
BH2-43	4.1	2.36	2.36	0.33	-0.14	-0.63	98.02	1.78	0.20
BH2-44	5.6	2.47	2.57	0.37	-0.79	4.74	94.60	4.50	0.90
BH2-45	7.1	2.08	2.35	0.93	-1.07	4.40	97.20	2.36	0.44
BH2-46	8.7	2.54	2.61	0.33	-0.29	1.31	97.56	1.23	1.21
BH2-47	10.2	3.23	2.75	2.17	+0.52	2.72	79.21	17.97	2.81
BH2-48	12.0	2.31	2.57	0.84	-1.64	11.93	95.37	13.43	1.21
BH2-49	13.2	3.46	2.77	1.94	+1.01	3.13	78.67	19.63	1.69
BH2-50	15.4	2.62	2.67	0.25	-0.55	1.14	98.46	1.02	0.52
BH2-51	16.0	2.55	2.62	0.35	-0.14	1.83	95.11	4.21	0.68
BH2-52	17.5	3.14	2.73	1.58	+1.40	7.55	87.50	11.17	1.33
BH2-53T	18.7	3.82	2.97	1.83	+0.74	2.11	67.44	29.59	2.97
BH2-53M	19.0	4.52	4.85	2.40	+0.26	-0.02	41.64	50.70	7.66
BH2-53B	19.2	4.78	3.85	2.40	+0.52	0.38	53.56	40.35	6.09
BH2-54T	20.6	5.38	5.49	2.23	+0.19	0.63	27.14	64.65	8.21
BH2-54M	20.9	4.86	4.80	1.35	+0.36	0.96	24.76	73.08	2.16
BH2-54B	21.0	5.30	5.20	1.59	+0.47	1.55	19.64	74.89	5.47
BH2-55T	22.2	3.06	2.36	2.10	+0.83	2.02	77.73	18.05	4.22
BH2-55B	22.5	5.46	5.39	1.67	+0.26	0.82	20.57	74.19	5.24
BH2-56B	22.8	6.08	6.07	1.98	+0.32	0.80	16.30	70.39	13.31
BH2-57B	25.6	5.68	5.51	1.99	+0.30	0.71	18.96	70.99	10.04
BH2-58B	27.1	3.09	2.57	2.37	+0.57	1.13	73.88	22.94	3.19
BH2-59B	28.6	5.00	4.95	2.18	-0.14	4.24	24.16	68.30	7.54
BH2-60B	30.2	5.53	5.27	1.86	+0.45	1.16	19.16	68.56	12.28
BH2-61B	31.7	5.62	5.36	1.67	+0.42	1.54	14.97	73.21	11.83
BH2-62B	33.2	5.72	5.32	1.66	+0.62	1.76	10.71	73.56	15.74
BH2-63B	34.7	5.89	5.65	2.05	+0.48	0.66	20.25	67.66	12.09

Sample Ident.	Elev. below IGLD*	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	%clay
BH2-64B	36.2	5.78	5.29	2.02	+0.60	1.13	18.22	70.14	11.64
BH2-65T	37.2	3.19	2.86	1.28	+1.29	6.68	87.67	11.21	1.12
BH2-65B	37.5	5.96	5.99	1.72	+0.21	0.32	14.70	72.42	12.88
BH2-66B	39.0	5.44	5.20	2.24	+0.56	0.96	29.75	59.63	10.62
BH2-67T	40.2	6.22	5.50	2.09	+0.47	0.33	11.62	69.46	18.92
BH2-67B	40.5	6.13	5.50	1.93	+0.43	0.16	11.71	70.66	17.64
BH2-68T	42.7	6.09	5.40	1.90	+0.55	0.66	8.93	73.49	17.59
BH2-68B	43.0	6.52	6.36	2.01	+0.36	0.42	11.12	72.21	16.67
BH2-69	44.5	6.22	6.08	1.71	+0.29	0.19	9.63	74.60	15.77
BH2-70	47.5	6.63	6.68	1.95	+0.17	-0.15	10.16	66.73	23.11
BH2-72	52.9	6.50	6.49	2.01	+0.19	0.03	14.15	61.60	24.25
BH2-73	55.9	7.45	7.26	2.15	+0.14	-0.26	8.64	62.93	28.43
BH2-74T	58.8	6.28	6.08	1.87	+0.32	0.24	6.96	69.01	24.03
BH2-74B	59.1	6.69	6.57	1.84	+0.27	-0.05	8.83	70.97	20.20

BH 3 Long Point (LP)

Sample Ident.	Metres below IGLD*	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand +grav.	% silt (Pipette)	%clay
LP1-2	+0.7	2.15	2.16	0.42	-0.01	2.18	99.69	S+C: 0.31	
LP1-5B	+0.2	2.28	2.27	0.44	+0.27	1.34	97.41	2.59	
LP2-1T	0.8	6.30	6.14	2.00	+0.22	0.51	8.78	70.80	20.42
LP2-3	0.9	4.83	5.33	1.94	+0.11	-1.18	36.97	49.24	13.78
LP2-5B	1.1	2.39	2.52	0.75	-0.89	6.18	92.89	S+C: 7.11	
LP3-2	1.5	2.39	2.42	0.56	-0.36	3.99	95.62	S+C: 4.38	
LP3-5	1.7	2.26	2.29	0.71	-2.84[+]	45.30	98.85	S+C: 1.15	
LP3-7B	2.0	2.07	1.98	0.56	+0.28	4.24	99.95	S+C: 0.05	
LP4-1T	2.6	2.63	2.91	1.09	-1.60	12.0	90.87	S+C: 9.13	
LP4-3B	3.1	2.73	2.75	0.35	-0.28	9.01	95.66	S+C: 4.34	
LP4A-1T	4.1	2.62	2.69	0.51	-1.29	16.29	96.37	S+C: 3.63	
LP4A-3B	4.6	5.13	5.13	1.32	+0.30	0.18	23.41	69.45	7.14
LP5-1T	4.7	5.77	5.94	1.42	+0.02	-0.27	10.21	78.10	11.70
LP5-3B	5.2	5.53	5.66	1.47	+0.07	-0.23	13.72	70.05	16.24
LP6-2	5.4	5.89	5.75	0.94	+0.58	1.04	0.0	87.53	12.47
LP6-4	5.7	6.10	6.13	1.19	+0.01	1.25	3.05	81.62	15.33
LP6-6B	5.9	6.46	5.98	1.64	+0.72	1.45	0.0	83.80	16.20
LP7-2	6.0	7.21	7.18	1.66	+0.40	0.02	0.0	70.71	29.29
LP7-5B	6.5	7.17	7.00	1.65	+0.47	0.36	0.0	73.71	26.29
Shel-1T	6.6	7.36	7.26	1.65	+0.35	0.20	0.50	66.0 S	33.5 S
Shel-1B	7.1	7.62	7.53	1.64	+0.22	-0.11	1.00	58.5 S	40.5 S
LP8-1T	7.5	2.83	3.04	0.80	-1.25	8.79	89.28	S+C:10.72	
LP8-3B	8.0	2.97	3.22	0.81	-1.17	6.15	89.26	S+C:10.74	
LP8A-1T	8.1	2.97	3.06	0.88	-0.89	5.16	88.93	S+C:11.07	
LP8A-3B	8.6	3.94	3.39	1.50	+0.81	1.58	73.06	21.42	5.52
LP9-2	8.8	4.42	3.68	1.74	+0.47	-0.41	60.58	32.82	6.60
LP9-3	8.9	3.16	3.36	0.71	-1.65	13.01	83.73	S+C: 16.27	
LP9-5B	9.2	2.84	3.31	1.15	-0.90	2.06	85.41	S+C: 14.59	

Sample Ident.	Metres below IGLD*	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	%clay
LP10-2	9.5	3.22	3.35	0.57	-2.01	20.60	84.46	S+C: 5.43	
LP10-4	9.8	4.50	3.83	1.71	+0.96	3.74	62.28	31.32	6.40
LP11-2	10.0	4.68	4.53	1.25	+0.61	1.31	38.86	58.21	2.94
LP11-4	10.2	4.61	4.51	1.28	+0.57	1.24	41.05	56.19	2.76
LP11-6B	10.5	5.20	5.19	1.22	+0.34	0.47	16.85	74.46	8.69
LP12-1T	10.6	2.77	3.16	1.05	-1.08	4.92	87.81	S+C: 12.19	
LP12-2	10.7	4.72	4.52	1.54	+0.46	0.07	43.98	49.59	6.44
LP12-3	11.1	4.81	4.58	1.50	+0.43	-0.15	41.61	50.44	7.95
LP13-2	11.3	5.08	5.20	1.60	+0.23	-0.61	31.37	58.42	10.21
LP13-3	11.4	4.58	4.40	1.30	+0.54	0.86	43.70	51.51	4.79
LP13-5B	11.6	5.18	5.25	1.63	+0.21	-0.90	35.13	57.16	7.72
LP14-1T	11.7	4.30	3.80	1.52	+0.62	0.89	58.49	35.79	5.72
LP14-2	11.9	5.28	5.32	1.55	+0.22	-0.72	27.61	59.97	12.42
LP14-4B	12.3	5.35	5.34	1.47	+0.21	-0.61	25.21	65.53	9.26
LP15-2	12.5	6.25	6.34	2.33	+0.24	-0.70	24.91	56.30	18.79
LP15-4	13.0	5.43	6.12	1.48	-0.09	-1.22	23.25	61.55	15.20
LP16-1T	13.1	5.26	4.84	2.03	+0.55	0.69	38.72	51.38	9.89
LP16-3B	13.5	6.62	6.57	2.00	+0.19	0	10.87	65.91	23.22
LP17-2	14.3	5.86	6.20	1.48	-0.07	-0.47	13.86	66.70	19.44
LP17-4	14.4	6.53	6.80	1.94	+0.12	-0.11	13.25	62.88	23.87
LP17-6B	14.7	6.03	6.14	1.06	-0.17	1.19	5.67	87.10	7.23
LP18-1T	14.8	4.94	4.93	2.16	+0.38	0.28	44.95	45.72	9.32
LP18-3	15.0	6.65	6.64	1.84	+0.27	0.42	5.49	71.42	23.09
LP18-6	15.3	7.29	7.21	1.57	+0.43	0.32	0	67.58	32.42
Shel-3B	15.6	7.23	7.15	1.85	+0.29	-0.14	2.0	64.0 S	34.0 S
LP19-2	16.0	7.48	7.45	1.60	+0.33	0.15	0	63.27	36.73
LP20-2T	16.7	7.50	7.50	1.60	+0.40	0.18	0	67.51	32.49
LP20-2B	17.0	7.62	7.50	1.58	+0.39	0.17	0	64.18	35.82

Sample Ident.	Metres below IGLD*	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness (+)	Kurt-osis (+)	% sand	% silt	%clay
Shel-4B	17.7	7.55	7.40	1.73	+0.32	-0.09	0.50	61.5 S	38.0 S
LP21-2	17.9	7.70	7.73	1.56	+0.34	0.07	0	58.35	41.65
LP21-5	18.3	7.82	7.72	1.58	+0.38	-0.10	0	55.05	44.95
LP22-3	18.7	7.58	7.56	1.59	+0.33	0.16	0	61.07	38.93
LP23-2	19.2	7.91	7.93	1.67	+0.24	-0.26	0	56.49	43.51
LP23-4B	19.6	7.83	7.84	1.65	+0.29	-0.28	0	53.78	46.22
LP24-1T	19.7	7.12	7.57	2.29	-0.14	-0.35	13.14	48.43	38.43
LP24-2	19.8	7.37	7.59	2.13	-0.10	0.05	8.61	50.36	41.03
LP24-3	19.9	6.69	7.24	2.63	-0.06	-0.88	22.19	39.68	38.12S
LP24-4A	19.95	4.36	3.16	2.98	+0.51	-0.30	66.94	18.04	15.02
LP24-4B	20.0	3.85	3.06	2.64	+0.72	1.00	71.85	13.48	14.67
LP24-5	20.1	9.55	10.12	1.43	-0.40	1.39	0.79	11.02	88.19S
LP24-6	20.1	7.18	7.14	1.77	+0.38	-0.06	0	23.89	76.11
LP24-7B	20.2	9.42	10.58	1.48	-0.24	-0.18	0	11.32	88.68
LP25-3	20.5	9.42	10.34	1.53	-0.21	-0.58	0	14.46	85.54
Shel-5B	21.4	9.78	10.79	1.45	-0.53	1.60	0.25	7.25	92.50S
LP26-3	21.8	9.16	10.06	1.48	-0.11	-0.28	0	14.69	85.31
LP27-3	22.4	9.28	10.71	1.77	-0.21	-0.73	0	16.85	83.15
LP28-3	23.0	9.22	9.72	1.36	+0.04	-0.75	0	17.35	82.65
LP29-3	23.6	9.30	10.38	1.43	-0.22	0.11	0	8.33	91.67
LP30-3	24.2	9.52	10.75	1.37	-0.23	-0.05	0	9.70	90.30
LP31-3	24.8	9.39	10.54	1.49	-0.13	-0.70	0	11.67	88.33
LP32-3	26.6	9.31	10.22	1.48	-0.25	0.30	0	10.46	89.54
LP33-3	27.3	9.17	9.93	1.43	-0.02	-0.81	0	14.44	85.56
LP34-3	27.8	9.11	9.89	1.48	-0.03	-0.72	0	15.48	84.52
LP35-3	28.4	8.97	9.61	1.48	-0.08	-0.15	0	16.64	83.36
LP36-3	29.1	9.12	9.68	1.49	-0.07	-0.22	0	15.46	84.54
LP37-3B	29.7	9.05	9.58	1.43	+0.07	-0.83	0	15.35	84.65
Shel-7M	33.2	9.16	9.49	1.43	-0.01	-0.68	0	18.9 S	81.1 S
LP46 B	36.1	8.74	9.11	1.70	-0.10	-0.45	0	29.5 S	70.5 S
LP50 B	38.5	8.71	8.91	1.48	+0.05	-0.39	0	29.2 S	70.8 S

Pelee Shoal

Sample ident.	Elev. below IGLD*	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	%clay
PP1-30	7.10	2.80	2.67	1.23	+1.36	9.92	93.57	3.73	2.70
PP1-60	7.40	2.89	2.70	1.21	+1.67	11.89	94.00	2.54	3.46
PP1-90	7.70	2.53	2.42	1.15	+1.19	10.72	95.10	3.97	0.93
PP1-120	8.00	6.56	7.79	3.22	-0.32	-0.53	19.88	32.82	47.30
PP1-150	8.30	6.44	7.84	3.26	-0.45	0.06	18.92	32.66	48.42
PP1-210	8.90	6.51	7.41	3.48	-0.35	-0.20	22.16	35.76	42.08
PP1-240	9.20	6.61	7.46	2.92	-0.34	-0.14	17.69	40.25	42.06
PP1-270	9.50	6.26	7.34	2.89	-0.29	-0.51	21.12	37.08	41.09
PP1-300		7.49	8.29	2.92	-0.60	1.79	8.65	36.65	54.70
PP1-330	10.10	6.09	7.46	3.67	-0.27	-0.58	25.97	30.32	43.70
PP1-360	10.40	6.81	8.12	3.19	-0.34	-0.18	16.12	32.43	51.45
PP1-390	10.70	6.80	8.01	3.07	-0.45	0.29	15.28	34.54	50.19
PP2-30	7.10	2.39	2.43	1.15	+0.23	10.97	96.69	2.78	0.53
PP2-60	7.40	2.42	2.60	1.14	+0.07	10.16	97.76	1.63	0.61
PP2-90	7.70	1.60	1.94	1.08	-0.70	3.31	99.81	0.14	0.15
PP2-120	8.00	1.90	2.10	0.77	-0.67	12.88	99.66	0.24	0.11
PP2-150	8.30	2.62	2.54	1.16	+1.44	13.34	95.56	2.69	1.74
PP2-180	8.60	0.76	0.42	1.86	+0.22	0.80	98.83	0.63	0.54
PP2-210	8.90	2.92	2.79	1.66	+1.66	16.54	95.92	2.21	1.87
PP2-240	9.20	3.08	2.85	1.10	+1.88	14.41	93.43	2.82	3.76
PP2-270	9.50	3.17	2.97	1.06	+1.89	15.12	93.45	3.18	3.37
PP2-300	9.80	2.99	2.83	0.87	+2.31	22.77	96.12	2.17	1.72
PP2-330	10.10	3.32	3.17	1.03	+1.74	12.85	94.06	3.20	2.74
PP2-360	10.40	3.31	2.89	1.61	+1.19	5.64	87.80	6.42	5.78
PP2-390	10.70	2.91	2.68	1.22	+1.56	9.53	91.90	5.51	2.59
PP2-420	11.00	3.39	3.07	1.46	+1.65	10.28	91.95	3.16	4.89
PP2-450	11.30	3.68	2.99	1.83	+0.96	2.91	76.68	14.68	8.64
PP2-480	11.60	3.67	3.17	1.64	+0.99	3.21	78.91	12.98	8.11

Sample Ident.	Metres below IGLD	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	% clay
PP2-510	11.90	4.14	3.11	2.84	+0.43	0.59	69.33	15.23	11.18
PP2-540	12.20	4.21	3.07	2.52	+0.58	0.05	63.14	17.93	18.93
PP2-570	12.50	5.05	5.08	2.50	+0.24	-1.5	44.41	34.41	21.18
PP2-600	12.80	5.70	6.02	2.80	+0.20	-1.24	43.85	28.07	28.07
PP2-630	13.10	6.52	6.58	2.33	+0.14	-0.83	20.21	48.99	30.80
PP2-660	13.40	5.98	6.07	1.76	+0.16	0.12	13.11	61.67	25.22
PP2-720	14.00	6.34	6.44	1.56	+0.15	-0.29	5.82	67.27	26.91
PP2-750	14.30	6.73	6.86	1.86	-0.16	1.17	7.14	59.43	33.43
PP2-780	14.60	6.81	7.07	1.76	-0.14	1.52	4.26	60.22	35.52
PP2-810	14.90	6.86	7.03	1.67	+0.06	-0.40	4.51	60.66	34.82
PP2-840	15.20	6.83	7.04	2.14	-0.35	1.75	8.67	56.21	35.13
PP2-870	15.50	6.99	7.22	1.85	-0.07	-0.18	6.99	55.49	37.51
PP2-900	15.80	7.16	7.41	1.86	-0.17	0.95	4.53	56.13	39.35
PP2-930	16.10	7.67	7.90	1.93	-0.23	0.76	2.39	48.81	48.81
PP2-960	16.40	7.57	7.99	2.01	-0.02	-0.67	5.61	44.55	49.85
PP2-990	16.70	7.98	8.38	1.94	-0.13	-0.15	3.82	38.57	57.61
PP2-1020	17.00	7.46	7.77	1.73	-0.04	-0.42	3.04	51.39	45.57
PP2-1050	17.30	7.64	8.04	1.64	-0.09	-0.02	2.49	46.80	50.70
PP2-1080	17.60	7.58	7.85	1.73	-0.16	0.21	3.19	49.47	47.34
PP3-30	5.90	2.29	2.22	1.39	+1.23	8.96	95.30	2.62	2.07
PP3-60	6.20	1.89	1.99	1.84	+0.53	4.25	93.97	2.66	3.38
PP3-90	6.50	1.98	1.78	1.49	+1.21	7.69	95.36	2.60	2.04
PP3-120	6.80	2.22	2.30	1.46	+0.38	6.52	96.41	2.36	1.23
PP3-150	7.10	2.05	2.12	1.32	+0.70	8.03	96.91	1.99	1.10
PP3-180	7.40	2.32	2.28	1.01	+1.44	15.78	97.04	1.45	1.50
PP3-210	7.70	1.82	1.84	1.41	+0.80	7.35	96.91	2.19	0.90
PP3-240	8.00	2.31	2.36	1.50	0.69	5.00	95.14	4.86	0.00

Sample Ident.	Metres below IGLD	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	% clay
PP3-270	8.30	2.82	2.64	1.26	+1.57	10.20	93.92	3.13	2.95
PP3-300	8.60	2.79	2.60	1.14	+1.60	10.81	94.96	4.62	0.42
PP3-330	8.90	3.32	2.85	2.00	+0.83	2.19	84.06	8.32	7.62
PP3-360	9.20	6.41	7.24	2.73	-0.46	0.60	14.33	48.04	37.62
PP3-450	10.10	6.71	7.88	3.13	-0.31	-0.23	16.98	34.38	48.64
PP3-540	11.00	6.92	8.09	2.83	-0.56	1.32	9.57	39.32	51.11
PP3-630	11.90	6.52	7.68	3.05	-0.36	-0.04	17.00	35.77	47.22
PP3-720	12.80	6.56	8.17	3.44	-0.47	0.22	17.21	30.73	52.07
PP3-810	13.70	6.62	7.90	2.98	-0.39	0.13	14.97	36.44	48.59
PP3-900	14.60	6.66	7.99	3.13	-0.41	0.03	15.81	34.30	49.89
PP4-30	6.20	2.13	1.86	1.18	+1.70	12.60	95.53	4.47	0.00
PP4-60	6.50	1.70	1.76	0.54	-0.40	1.34	98.56	1.44	0.00
PP4-90	6.80	2.14	2.01	1.03	+2.01	18.12	96.61	2.90	0.50
PP4-120	7.10	1.90	1.88	0.77	+1.79	26.24	98.59	1.41	0.00
PP4-150	7.40	2.18	2.12	0.89	+1.97	20.32	97.59	2.41	0.00
PP4-180	7.70	2.55	2.35	1.10	+2.00	16.33	95.83	2.95	1.23
PP4-210	8.00	2.52	2.36	1.00	+2.03	17.11	96.32	3.68	0.00
PP4-240	8.30	5.25	4.75	2.30	+0.38	-0.43	39.81	44.55	15.65
PP4-270	8.60	5.48	5.18	2.03	+0.40	0.18	25.59	56.37	18.04
PP4-300	8.90	5.32	5.23	1.79	+0.33	-0.27	26.58	55.89	17.53
PP4-335	9.20	5.74	5.71	1.69	+0.31	-0.30	13.81	63.84	22.35
PP4-360	9.50	5.78	5.49	1.76	+0.42	0.11	13.62	66.03	20.35
PP4-390	9.80	5.98	6.05	1.93	+0.25	-0.33	17.50	58.04	24.46
PP4-420	10.10	6.23	6.30	1.95	+0.27	-0.07	11.60	61.06	27.33
PP4-450	10.40	5.77	5.83	1.81	+0.30	-0.35	19.58	54.73	25.69
PP4-480	10.70	6.62	6.84	1.94	+0.23	-0.36	8.27	57.57	34.15
PP4-510	11.00	6.33	6.51	2.02	+0.18	-0.44	13.10	56.91	29.99

Sample Ident.	Metres below IGLD	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	% clay
PP4-540	11.30	5.10	5.24	2.18	+0.22	-0.77	35.29	44.22	20.49
PP4-570	11.60	4.60	4.89	2.56	+0.16	-0.66	42.21	38.53	19.26
PP4-600	11.90	6.56	7.80	2.91	-0.30	-0.29	15.97	36.70	47.33
PP4-630	12.20	6.04	7.61	3.15	-0.41	0.01	18.37	36.33	45.29
PP4-660	12.50	6.54	7.56	3.26	-0.34	-0.44	20.62	35.62	43.76
PP4-690	12.80	6.33	7.29	3.04	-0.32	-0.30	19.79	39.08	41.13
PP5-30	8.70	1.96	2.26	1.42	-0.28	5.82	97.79	1.00	1.22
PP5-60	9.00	2.33	2.45	1.11	+0.15	12.21	97.88	0.95	1.18
PP5-90	9.30	1.91	1.94	2.69	+0.45	1.34	88.48	4.24	7.27
PP5-120	9.60	2.52	2.59	1.66	+0.20	1.62	89.46	10.54	0.00
PP5-150	9.90	3.61	3.21	2.03	-0.11	-0.09	70.26	29.74	0.00
PP5-180	10.20	4.81	4.71	1.81	+0.13	-0.09	46.87	43.97	9.16
PP5-210	10.50	4.40	3.87	1.86	-0.05	-0.89	52.57	47.43	0.00
PP5-240	10.80	4.28	3.58	1.64	+0.11	-0.83	62.32	37.68	0.00
PP5-270	11.10	3.38	2.83	1.99	+0.21	-0.35	75.44	24.56	0.00
PP5-300	11.40	4.44	3.90	1.71	+0.11	-1.22	51.67	48.33	0.00
PP5-329	11.70	4.43	3.99	2.03	+0.13	-0.89	50.27	37.47	12.27
PP5-360	12.00	4.05	3.59	1.81	+0.19	-1.17	56.04	35.16	8.79
PP5-390	12.30	4.97	5.27	1.60	-0.06	-0.99	39.34	58.16	2.50
PP5-420	12.60	5.03	5.24	2.01	+0.17	-0.46	35.73	46.27	18.00
PP5-450	12.90	5.11	5.52	1.82	-0.14	0.69	24.97	60.31	14.73
PP5-480	13.20	4.53	5.30	2.19	-0.22	-0.82	40.23	54.06	5.71
PP5-510	13.50	5.45	5.61	1.95	0.00	0.37	23.83	57.37	18.79
PP5-540	13.80	6.87	7.12	1.93	+0.03	0.04	5.03	58.01	36.96
PP5-570	14.10	7.14	7.15	1.92	+0.28	-0.48	1.78	59.53	38.69
PP5-600	14.40	6.33	6.38	1.80	+0.22	0.43	6.69	63.95	29.37
PP5-630	14.70	6.64	6.49	2.10	+0.30	-0.06	7.73	57.80	34.48

Sample Ident.	Metres below IGLD	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	% clay
PP5-660	15.00	6.92	7.10	2.04	+0.22	-0.49	6.45	56.54	37.01
PP5-690	15.30	7.09	7.42	2.00	+0.12	-0.70	4.68	52.65	42.67
PP5-720	15.60	6.96	7.47	2.02	+0.08	-0.66	6.36	50.59	43.05
PP5-750	15.90	2.44	2.10	4.11	+0.19	-0.95	62.66	20.45	16.89
PP5-780	16.20	7.80	8.21	1.62	-0.14	1.54	1.56	44.74	53.69
PP5-810	16.50	7.08	7.68	2.44	-0.54	2.31	8.38	47.84	43.77
PP5-840	16.80	6.48	7.22	2.40	-0.06	-0.97	20.40	41.84	37.76
PP5-870	17.10	6.33	6.82	2.24	-0.04	-0.40	15.40	51.49	33.10
PP5-900	17.40	6.48	6.88	1.92	-0.34	1.92	5.46	63.03	31.51
PP6-30	6.20	0.30	0.37	0.70	-0.23	6.15	99.17	0.83	0.00
PP6-90	6.80	1.83	1.94	0.66	-0.77	6.22	98.79	1.21	0.00
PP6-120	7.10	2.14	2.22	0.91	+0.83	12.19	96.90	1.20	1.90
PP6-150	7.40	2.10	2.17	1.19	+0.89	12.85	95.78	1.18	3.05
PP6-180	7.70	2.45	1.92	2.59	+0.66	1.01	81.38	8.50	10.12
PP6-210	8.00	2.19	2.16	0.91	+2.98	42.85	97.66	0.75	1.59
PP6-240	8.30	2.01	1.93	1.05	+2.16	24.21	96.71	1.17	2.12
PP6-270	8.60	1.90	2.01	0.96	-0.03	16.48	98.46	0.89	0.65
PP6-300	8.90	2.01	1.94	1.00	+2.04	26.56	97.55	0.85	1.60
PP6-330	9.20	2.26	1.91	1.77	+1.32	7.32	90.40	3.57	6.03
PP6-360	9.50	2.32	2.20	1.36	+1.96	20.50	96.37	1.17	2.46
PP6-390	9.80	2.80	2.74	1.33	+0.89	8.37	94.76	1.75	3.49
PP6-420	10.10	2.85	2.66	1.72	+0.89	6.00	89.48	5.59	4.93
PP6-450	10.40	3.17	2.72	1.84	+1.46	8.32	88.61	5.72	5.67
PP6-480	10.70	3.39	2.98	1.34	+0.82	2.94	78.19	16.78	5.03
PP6-510	11.00	3.77	2.97	1.80	+0.36	-0.26	68.00	25.19	6.81
PP6-540	11.30	3.54	3.13	1.65	+0.16	1.03	67.25	24.34	8.42
PP6-570	11.60	4.40	4.06	1.63	-0.18	-0.76	49.73	43.66	6.62
PP6-600	11.90	4.88	5.06	1.67	+0.24	-0.25	33.13	51.01	15.87

Sample Ident.	Metres below IGLD	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	% clay
PP6-630	12.20	4.54	4.01	1.67	+0.32	-0.73	49.90	41.34	8.76
PP6-660	12.50	5.10	4.89	1.84	+0.65	1.31	26.36	51.70	21.86
PP6-690	12.80	5.78	5.84	2.06	+0.17	-0.33	18.77	57.43	23.80
PP6-720	13.10	5.53	5.50	2.13	+0.34	-0.23	28.28	49.99	21.73
PP6-750	13.40	5.67	5.49	1.96	+0.48	0.48	17.61	56.52	25.87
PP6-780	13.70	5.85	5.91	2.18	+0.17	0.07	18.40	54.40	27.20
PP6-810	14.00	5.49	5.50	2.08	+0.23	-0.36	27.77	49.53	22.70
PP6-840	14.30	5.43	5.82	2.41	+0.21	-0.76	34.03	38.14	27.83
PP6-862	14.52	4.40	3.96	1.23	+0.55	0.48	52.20	44.48	3.23
PP6-870	14.60	5.91	5.83	2.05	+0.27	-0.21	15.60	55.93	28.47
PP6-900	14.90	6.15	5.98	2.10	+0.27	-0.15	13.00	59.69	27.31
PP6-930	15.20	6.87	6.91	1.88	+0.22	0.04	3.49	60.03	36.49
PP6-960	15.50	5.93	6.34	2.04	+0.15	-0.81	21.74	47.69	30.57
PP6-990	15.80	5.93	5.95	1.83	+0.23	0.08	10.98	63.06	25.96
PP6-1020	16.10	4.86	3.95	2.29	+0.42	-0.33	52.06	26.89	21.05
PP6-1050	16.40	4.68	3.86	2.23	+0.55	0.35	57.47	25.74	16.79
PP6-1080	16.70	5.64	5.97	2.36	+0.22	-0.68	29.19	41.68	29.12
PP6-1113	17.00	6.79	6.91	1.92	+0.29	-0.37	3.06	61.69	35.25
PP6-1140	17.30	6.15	6.32	2.51	+0.18	-0.71	24.66	44.98	30.36
PP6-1170	17.60	5.97	6.12	2.52	+0.17	-0.71	24.89	45.29	29.82

Pointe-aux-Pins area, land-based data from geotechnical reports (curves).

Sample Ident.	Metres below IGLD	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	% clay
WT4-5*	ca. 0	-0.71	-0.33	2.47	-0.13	-1.06	95	Silt + clay: 5	
WT4-30	8	3.09	3.22	0.48	-0.39	1.61	85	S+C: 15	
WT5-5	0	1.27	1.29	0.93	-0.02	0.37	97.5	S+c: 2.5	
GA73399									
1-3	2	2.04	2.18	0.77	-1.09	9.23	98	S+C: 2	
2-6	8	8.26	9.88	2.28	-0.10	-1.08	2	32	66
GA73245									
1-6	2	4.07	4.22	1.20	0.05	0.94	25	65	10
1-9	4	7.24	8.23	1.38	-0.29	-0.28	2	41	57
1-13	7	4.66	7.26	3.45	-0.33	-0.49	23	28	49
3-6	3	3.97	4.16	0.90	0	5.50	20	69	11
3-8	5	7.35	8.75	1.53	-0.33	0.07	4	37	59
3-10	6	4.26	6.34	3.76	-0.30	-0.67	27	31	42

* WT = William Trow, Assoc.

GA = Golder Assoc.

Core locations given in Figure 4-14, selected grain-size cumulative curves shown in Figure 4-15

Pointe-aux-Pins area, offshore borehole and core samples

Sample Ident.	Metres below IGLD	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	% clay
LE81-19									
1	23.0	8.61	8.90	1.46	0.12	-0.72	0	31	69
2	23.3	8.58	9.33	1.86	-0.18	-0.33	2	28	70
3	23.4	8.72	9.56	1.71	-0.11	-0.26	1	26	73
4	23.5	8.20	8.89	1.83	-0.16	-0.17	2	33	65
5	23.5	2.87	2.50	2.60	0.59	0.73	72	14	14
6	23.6	3.59	2.70	2.98	0.68	0.70	72	6	22
7A	23.6	3.43	2.76	2.13	0.84	1.63	72	11	16
7B	23.6	3.06	2.58	2.18	1.24	5.60	84	5	11
7C	23.6	3.42	2.68	2.40	0.89	2.05	75	8	17
UWO-F15									
1	25.5	8.81	9.64	1.70	0.01	-1.01	0	27	73
2	26.5	8.51	9.44	1.74	-0.02	-0.59	0	30	70
3	27.3	8.94	9.94	1.60	0.06	-0.96	0	24	76
4	28.2	9.28	10.17	1.46	-0.02	-0.96	0	16	84
5	29.6	8.92	9.90	1.62	0.05	-1.06	0	24	76
6	30.5	9.04	10.04	1.41	0.01	-0.83	0	18	82
7A	31.0	8.64	9.60	1.60	0.10	-0.91	0	28	72
7C	31.2	8.40	9.27	1.76	0.02	-0.84	0	32	68
7D	31.3	7.90	8.66	1.89	0.21	-0.83	0	44	56
7E	31.4	7.89	8.50	1.72	0.28	-0.64	0	45	55
7F	31.5	8.17	8.79	1.83	0.11	-0.80	0	40	60
8A	31.8	8.21	8.92	1.76	0.17	-0.81	0	38	62
8B	31.9	7.64	7.67	1.68	0.35	-0.19	0	56	44
8C	32.0	7.81	7.75	1.92	0.23	-0.73	0	54	46
8D	32.1	7.16	7.22	1.81	0.43	-0.04	0	60	40
8E	32.2	7.18	7.09	1.59	0.54	0.74	0	68	32
8F	32.4	6.90	6.36	1.71	0.63	0.71	0	76	24
8G	32.6	8.82	10.13	1.88	0.01	-1.13	0	27	73

Pointe-aux-Pins area, offshore (continued)

Sample Ident.	Metres below IGLD	Mean Ø	Median Ø	Ø St. Dev.	Skew-ness	Kurt-osis	% sand	% silt	% clay
UWO-F15									
9	33.3	9.41	10.50	1.45	-0.15	-0.51	0	12	88
10	34.2	9.35	10.58	1.37	-0.09	-0.35	0	10	90

TABLES AND FIGURES

TABLES

TABLE 2-1. Summary of stratigraphy and age relationships of Lake Erie basin deposits.

Approx. Age (Ma)	Period	Epoch	Glacial/Intergl. Stage	Substage	Stadial/Interstad.	C^{14} Age yr. B.P.	Lake Erie Basin Deposits	
	QUATERNARY	Holocene	Postglacial		Driftwood			Postglacial Lake Erie
					North Bay	10,000		
1-2		Pleistocene	Wisconsinan	Late Wisconsinan	Valders			
					Two Creeks	11,800		
			Sangamonian			12,500		Early Lake Erie
						12,800		Lake Warren
	TERTIARY	Pliocene Miocene Oligocene Eocene Paleocene	Illinoian		Port Huron	13,000	Halton Till	Lake Whittlesey
			Yarmouthian		Mackinaw	13,500		Lake Maumee to Ypsilanti
			Kansan		Port Bruce	14,000	Wentworth T. Port Stanley T. Hiram T. (U.S.)	
60-70			Aftonian		Erie	16,000		Lake Leverett (?)
	CRETACEOUS		Nebraskan (?)		Nissouri	20,000	Catfish Creek T. Kent, Navarre T. (U.S.)	
	JURASSIC							
	TRIASSIC			Middle Wisconsinan	Plum Point	25,000		Glacial Lake
230	PERMIAN				Cherrytree	35,000	Dunwich T.	
	CARBONIFEROUS				Port Talbot	65,000		Glacial Lake
	DEVONIAN			Early Wisconsinan	Guildwood	70,000	Bradtville T.	
	SILURIAN				St. Pierre	75,000		
	ORDOVICIAN				Nicolet			
	CAMBRIAN							
600	PRE-CAMBRIAN							

Table 2-2. Physical and hydrological data, Lake Erie.

Physical data*

Drainage area of basin		58,800 km^2
Surface area of lake		25,700 km^2
Maximum length		388 km
Maximum depth		92 m
Shoreline length:	Canada	640 km
	U.S.	763 km
Volume		484×10^9 m^3

Hydrological data**

Inflow (Detroit River)	5292 $m^3.s^{-1}$	(187,000 cfs)
Surface runoff	708 $m^3.s^{-1}$	(25,000 cfs)
Precipitation	736 $m^3.s^{-1}$	(26,000 cfs)
Evaporation	736 $m^3.s^{-1}$	(26,000 cfs)
Outflow (Niagara River, Welland Canal)	6000 $m^3.s^{-1}$	(212,000 cfs)

*Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (1977).

**International Great Lakes Levels Board (1973). Data refer to the lake alone. Lake St. Clair hydrology reflected only in "inflow" figures.

Table 3-1. Comprehensive listing of radiocarbon dates from the Erie basin near or below the lake. Description of organic materials used, sources, and a subjective appraisal of the reliability of the date are also given. Date numbers are keyed to similar numbers in the location map (Figure 1-1).

No.	Location	Metres below datum: Sample	Metres below datum: Est. lake level	C-14 age (yrs. B.P.)	C-14 age Lab. No.	Comments	Source
1 *	Central sub-basin (Core 2226)	28.5	above 18	10,200 ± 180	GSC-330	DRIFTWOOD at base of offshore muds (T)	Lewis et al (1966), Lewis (1969)
2 *	Sister sub-basin (Core 1240)	14.0	below 13	11,300 ± 160	GSC-382	BASAL PLANT DETRITUS in local ponding (C,P)	-
3 *	Pelee sub-basin (Core 66-6)	16.7	below 12	12,650 ± 170	I-4040	BASAL PLANT DETRITUS in local ponding (C,O,P) Note: Pollen stratigraphy suggests age of around 12,000 years B.P. for this level.	Lewis (1969), T.W. Anderson (1983, pers. comm.)
4 *	Pelee sub-basin (Core 68-6)	16.3	below 12	11,140 ± 160	I-4041	TOP OF PLANT DETRITUS in local ponding (C,O,P) Note: Pollen strat. suggests 10,600 B.P.	-
5 *	Pelee sub-basin (Core 68-6)	13.4	3 to 11	5,750 ± 180	GSC-1165	DISSEM. ORGANIC MATTER at upward transition from clay to clayey silt (T,O,C,P) Note: Pollen age - 4000 to 5000 B.P.	-
6 *	Sister sub-basin (Core 68-16)	13.6	below 13	11,430 ± 150	I-4035	BASAL PLANT DETRITUS in local ponding (repl. of (2)) (C,P)	Lewis (1969)
7 *	Sister sub-basin (Core 68-20)	9.1	below 13	11,200 ± 180	GSC-1136	BASAL PLANT DETRITUS in fringing marsh of local pond (C)	-
8 *	Kelley-Bass sub-basin (Core 67-10)	14.0	below 10	10,370 ± 150	I-4034	BASAL PLANT DETRITUS in local pond open to Sandusky sub-basin (C)	-
9 *	Kelley-Bass sub-basin (Core 67-10)	13.8	below 10	10,340 ± 150	I-4033	TOP OF PLANT DETRITUS in local pond open to Sandusky s.b. (C)	-
10 ?	Portage River mouth (Core I-57)	9.2	?	6,550 ± 134	OWU-110	WOOD (oak) at base of plant detritus layer (T,S)	Ogden and Hay (1965), Herdendorf and Braidech (1972), Lewis (1969)
11 ?	Sister sub-basin (Core WR-31)	12.5	?	4,335 ± 135	OWU-318	FRAGMENTED PLANT DETRITUS (T,C,S)	Ogden and Hay (1969), Herdendorf and Braidech (1972), Lewis (1969)
12 ?	Sister sub-basin (Core WR-32)	12.5	?	9,115 ± 210	OWU-319	FRAGMENTED PLANT DETRITUS (T,S)	-
13 ?	Sister sub-basin (Core WR-33)	12.6	?	9,440 ± 315	OWU-350	FRAGMENTED PLANT DETRITUS (T,S)	Herdendorf and Braidech (1972), Lewis (1969)
14 ?	Sister sub-basin (Core WR-34)	12.5	?	5,097 ± 175	OWU-351	FRAGMENTED PLANT DETRITUS (T,S)	-
15 *	Terwilliger's Pond Bass Island	3.0	close to 3	2,500 ± 270	OWU-275	WOOD in subaerial swampy soil overlain by marsh deposits (P)	Ogden and Hay (1969), Lewis (1969), Stevenson and Benninghoff (1969)
16 *	Rednead Pond Point Pelee	3.5	above 3	3,520 ± 100	I-3992	BASAL GYTTJA (C,O)	Terasmae (1970), Lewis (1969)
17 *	Big Pond Point Pelee	3.5	above 3	3,310 ± 100	I-3993	BASAL GYTTJA (C,O)	-
18 *	Point Pelee Shoal (Core 6)	10.5	above 2	3,600 ± 140	BGS-256	WOOD FRAGMENTS near base of transgressive sequence (T)	Coakley et al (1977)
19 *	Point Pelee Shoal (Core 5)	12.3	above 2	6,600 ± 180	BGS-252	WOOD FRAGMENTS near base of transgressive sequence (T)	-
20 ?	Point Pelee Shoal (Core 5)	16.0	?	8,100 ± 300	BGS-255	SHELLS in lag gravel layer over silt at base of transgressive sequence (O,X)	-
21 ?	Point Pelee Shoal (Core 2)	12.6	?	10,260 ± 325	BGS-254	PLANT DETRITUS in fine sand/silt sequence (T,X) Note: pollen strat. suggests age of less than 7000 yrs.	-
22 ?	Sandusky sub-basin (Core 85)	18.6	above 18	12,180 ± 400	BGS-608	PLANT DETRITUS within sandy silt 3 m below lake bed (T,X)	Guy (1983), C.H. Carter (1983, pers. comm.) J.A. Fuller (1983, pers. comm.)
23 ?	Sandusky sub-basin (Core 86)	17.4	?	10,330 ± 560	BGS-610	WOOD in surficial sandy silt 1.5 m below lake bed (T,X)	-
24 ?	Sandusky sub-basin (Core 91)	15.9	?	6,490 ± 140	BGS-612	SHELL LAYER in sandy silt (C,O,T,X)	-
25 ?	Sandusky sub-basin (Core 101)	7.4	?	7,730 ± 400	BGS-609	WOOD in surficial sand (T,X)	-
26 *	Old Woman Creek Estuary, Ohio	5.2	below 5	7,690 ± 210	DIC-1134	WOOD in coarse sand / silt alluvial complex (T)	D. Buchanan (1981, pers. comm.)

Table 3-1. (Continued)

No.	Location	Metres below datum: Sample	Metres below datum: Est. lake level	C-14 age (yrs. B.P.)	C-14 age: Lab. No.	Comments	Source
27 *	Norfolk Moraine (Core 28)	22	close to 22	10,800 ± 190	UM-1706	WOOD in firm silty clay over till. Believed to be in situ root fragments	Williams and Meisburger (1982) Williams et al (1980)
28 *	Norfolk Moraine (Core 23)	21	11-16	8,545 ± 150	UM-1705	WOOD at base of clean medium sand with clay layers (T)	"
29 *	Norfolk Moraine (Core 4)	21	11-16	8,240 ± 210	UM-1703	WOOD in interbedded sand/clay unit (T)	"
30 *	Norfolk Moraine (Core 18)	22	above 17	6,870 ± 150	UM-1704	WOOD at the base of massive fine - medium sand (T)	"
31 *	Clear Creek, Ontario	-1.8	above 2	3,900 ± 100	BGS-898	LARGE WOOD FRAGMENT, in situ in well preserved forest bed.	Coakley, this study Barnett et al (1984, in prep.)
32 *	"	-0.5	below 0	5,975 ± 150	BGS-899	PEAT layers in silt	"
33 *	"	-0.3	below 0	6,460 ± 125	BGS-900	"	"
34 *	"	0.7	below 1	6,980 ± 120	BGS-901	"	"
35 *	Rondeau Prov. Park, Pointe-aux-Pins	6.3	0-5	5,330 ± 250	WAT-378	PEAT with shells and silt above silty clay layer (C,O)	A.J. Cooper, Ontario Geological Survey (1982, pers. comm.)
36 *				5,180 ± 370	WAT-379		
37 ?	S. of Pointe-aux Pins (Core LE81-19)	23.2	?	5,420 ± 150	WAT-1081	Whole silty clay sample (O,X)	Coakley, this study
38 *	S. of Pointe-aux Pins (Core LE81-19)	23.5	above 13	3,140 ± 110	WAT-946	WOOD FRAGMENT in shelly, gravelly layer with silt and clay (T)	"
39 ?	"	23.5	?	7,000 ± 370	WAT-970	SHELLS picked from the above layer (T,O)	"
40 *	Central sub-basin (Core 62)	20.8	above 15	8,250 ± 145	DIC-1329	WOOD FRAGMENTS in muddy sand (T)	Carter (1984)
41 ?	Central sub-basin (Core 62)	18.9	above 14	4,020 ± 190	DIC-1328	WOOD FRAGMENTS in sandy silt 2 m below lake bed (T)	"
42 ?	Central sub-basin (Core 61)	17.4	above 12	3,360 ± 160	BGS-611	WOOD AND ORGANICS in surficial sandy silt (T)	
43 *	Lower Cuyahoga River, Ohio	-4.7	below -4.7	8,540 ± 70	DIC-1137	WOOD from vegetation-rich layers in top section of cross-bedded alluvial sand	Miller (1983)
44 *	Lower Cuyahoga River	-1.7	below -1.7	8,760 ± 90	DIC-1136	(Same as above)	"
45 *	Lower Cuyahoga River	-0.7	below -0.7	8,780 ± 80	DIC-1135	(Same as above)	"
46 ?	Eastern sub-basin south of Long Point	18.5	?	4,100±100	BGS-363	WOOD at base of silty clay / fine sand surficial deposit (T)	Rukavina (1981)
47 ?	Long Point (Borehole 3)	-6.0	?	7,420±280	WAT-1079	WHOLE ORGANIC SILT sample (O,X) Note: Pollen strat. suggests an age of less than 5000 B.P.	Coakley, this study
48 ?	Long Point (Borehole 3)	6.4	?	11,280±380	WAT-1080	WHOLE ORGANIC SILT sample, same as above (O,X)	"
49 ?	Long Point (Borehole 3)	19.5	?	8,490±330	WAT-1083	WHOLE SILTY CLAY sample (O,P)	
50 ?	Small unnamed stream flowing into Long Point Bay	-4	?	960 ± 80	BGS-908	ORGANIC MATTER in silt and sand alluvium (T,O)	P.J. Barnett, Ontario Geol. Survey (1983, pers. comm.)

LEGEND:
T - Probably transported
O - Possibly contaminated by "old" carbon
C - Probably underwent some compaction
S - Possibly contaminated during sampling
P - Pollen stratigraphy exists as a check on date
X - Date judged unreasonable, rejected
? - Age or elevation cannot be assessed with confidence
* - Age/elevation are definitive, or can be deduced with confidence

Table 3-2. Summary of short core (top) and water-jetting data (bottom) in the Long Point area. Jetting data and all cores with CE prefix are from Rukavina (1981); the remaining cores are from C.F.M. Lewis, (Geol. Surv. Can., 1982, pers. comm.). For core and jetting locations see Fig. 2-6.

Core I.D.	Water Depth (m)	Penetration (cm)	Interval (m below IGLD)	Sediment Description (Paraphrased from Above Sources)
CE 3	10.3	52.5	8.9 - 9.4	Thin silty fine sand (1.5 cm) over silty clay
CE 4	9.6	36.5	8.2 - 8.6	Thin silty sand over stiff silty clay with black sulphide patches.
CE 7	11.6	38.0	10.2 - 10.6	Thin soupy mud over stiff silty clay with black sulphide patches.
CE 28	12.1	114	11.1 - 12.2	Clean, medium sand (20.5 cm) over sand/silt interbedded unit, abundant organic matter
CE 29	14.6	49	13.5 -14.0	Clean medium-coarse sand over fine sand/silt interbedded unit, scattered organic matter
CE 30	14.6	33	13.5 - 13.8	Clean medium sand over clean fine sand
CE 31	17.7	101	16.5 - 17.6	Clean fine-medium sand over sandy silt
CE 32	18.9	70	17.8 - 18.5	Fine sand over fine sand/silt unit. Wood fragment at base of core
CE 33	3.6	99	2.5 - 3.5	Fine-medium sand
CE 34	13.7	34	12.6 - 12.9	Stiff silty clay (glaciolacustrine)
CE 35	12.8	94	11.7 - 12.6	Soft mud over silt/fine sand unit. Irregular lenses predominate; rare shells, wood.
CE 36	10.9	82.5	9.8 - 10.6	Clean coarse to fine sand with heavy minerals, shells abundant.
CE 81	12.0	49.5	10.9 - 11.4	Soft mud over silt/fine sand unit.
1219 g	20.4	35	20.2 - 20.6	Very dense (glaciolacustrine) laminated clay
1085 g	41.5	175	41.3 - 43.0	Soft mud
1214 g	28.3	306	28.1 - 31.2	Soft mud
1221 g	30.4	241	30.2 - 32.6	Soft mud
1212 g	17.7	109	17.5 - 18.6	Thin sand and gravel over interbedded silt-fine sand unit plant detritus, shell
906 p	14.0	198	13.8 - 15.8	Thin gravel over interbedded fine sand-silt unit
1074 g	17.2	50	16.9 - 17.4	Fine silty sand over laminated silt-clay unit

Probe I.D.	Water Depth (m)	Refusal (cm)	Interval (m below IGLD)	Sediment Description (Paraphrased from Above Sources)
102	10.3	3.7	8.8 - 12.5	Very stiff sediment
107	8.7	8.2	7.2 - 15.4	Fast penetration (sticky clay) at first
108	4.0	8.5	2.5 - 11.0	(Same as 107)
113	7.5	11.2	6.0 - 17.2	Gravelly at top, slow penetration (stiff sediment) near base
114	4.9	9.5	3.4 - 12.9	"Bottomed on glacial sediment"
116	14.1	4.5	12.6 - 17.1	(Same as 114)
117	12.2	5.0	10.7 - 15.7	"Bottomed on firm sediment (glacial?)"
120	14.8	3.7	13.3 - 17.0	Fast (2.25 m), then slow, penetration (1.5 m) Stiff sediments at base
124	15.8	3.7	14.3 - 18.0	Firm bottom; probe bounced during penetration
126	6.2	6.7	4.9 - 11.4	Alternating cohesive/loose sediment, very resistant sediment base
127	16.5	2.5	15.0 - 17.5	"Firm bottom. Glacial (?) sediment"
130	12.1	2.2	10.6 - 12.8	Penetration slowed with depth. Probe bounced in stiff sediment near base of hole. Glacial sediment
131	17.4	2.7	15.9 - 18.6	Slow penetration. Bottomed in glacial sediment
137	8.6	3.7	7.1 - 10.8	Smear of glacial sediment on probe tip
138	17.5	3.5	16.0 - 19.5	Smear of glacial sediment on probe tip
144	6.9	3.2	5.4 - 8.6	Top 2 m - coarse sediment, stiff below. Glacial sediment
142	18,5	2,5	17.0 - 20.5	Last metre of jet pipe shows smear of glacial sediment

Table 3-3. Tabulated pollen data for borehole BH3 samples, Long Point. Species percentages shown refer to total pollen grains (both AP and NAP).

Sample Ident.	Metres below datum	Number grains count.	Grains per slide	% ARBOREAL POLLEN (AP)							% GRASSES & HERBS (NAP)			Total NAP	Comments
				Picea	Pinus	Tsuga	Betula	Quercus	Fagus	Acer	Grasses	Rumex	Ambrosia		
BH3:															
LP2-1	0.8	166	24	9.6	36.1	1.8	7.8	7.2	1.2	7.6	3.6	3.0	0.4	22	Spores and charcoal present, preservation good.
2-3	0.9	243	81	5.3	22.6	6.6	4.1	31.7	10.3	7.8	0.8	-	0.4	4	
4A-2	4.3	223	56	7.2	26.0	3.1	7.6	16.1	17.9	5.3	2.2	1.3	0.4	7	Preservation excellent; material highly organic.
6-3	5.6	308	308	2.6	25.6	0.6	2.9	25.3	16.9	6.2	1.2	3.8	0.3	11	Preservation good; highest pollen abundance.
Shel.1	7.0	17	8	Not counted										16	Minor fine organics.
8A-3	8.7	23	11												Preservation very good
10-4	9.6	155	26	7.1	22.5	5.2	3.9	16.8	7.1	8.3	1.9	3.2	0.6	17	Preservation good
11-4	10.2	211	30	7.1	22.3	-	10.9	17.1	21.3	4.3	0.5	0.9	-		
12-17	10.6	24	12	Not counted											
12-2	10.7	13	4	Not counted										8	Preservation good, organics oxidized slightly.
13-58	11.6	137	17	13.9	54.7	6.6	1.4	8.0	5.1	0.7	-	-	-		
14-2	11.9	241	40	18.2	34.0	5.8	2.1	12.8	5.4	3.3	0.8	3.3	-	12	Pres. good.
15-2	12.5	279	40	14.7	26.9	3.2	2.1	13.6	1.8	2.9	3.2	1.8	1.8	24	Typha (cat-tail) pollen pres.
16-2	13.2	145	18	12.4	56.5	-	2.7	12.4	1.4	3.4	2.0	1.4	-	10	Preservation good; one reworked spore.
17-1	14.2	237	79	10.1	36.7	7.6	2.9	12.6	5.0	2.1	1.7	8.0	-	18	Pres. good; 1 cat-tail pollen counted.
18-2	14.9	57	11	Not counted										12	Pres. fair to good, some breakage and oxidation
19-1	15.9	147	16	7.5	57.8	10.2	2.7	6.1	0.7	2.7	-	1.3	-	10	Pre. good, pine somewhat oxidized.
19-4B	16.5	211	35	18.0	48.3	9.0	1.9	6.8	0.5	1.4	-	2.8	-		
20-4B	16.9	228	57	8.8	59.6	12.7	8.7	7.9	-	3.0	0.4	2.8	-		
21-1	17.8	8	8	Not counted										25	Reworked spore; much fine organics present.
23-2	19.2	202*	-	13.9	35.6	5.4	3.5	3.0	7.9	2.5	7.9	2.5	0.5		* Done by N.S. Harper.
24-3	19.9	5	5	Not counted										60	Organics abundant, fine to coarse (roots?), well pres.
24-4A	19.95	255	177	2.7	20.0	3.5	1.2	20.8	3.9	19.2	2.3	0.4	0.8	20	Pollen abundant, fair pres., much organics, charcoal. Cat-tail pollen (1.6%) + others.
24-4B	20.0	230	230	1.3	29.1	5.2	0.9	17.4	1.7	20.0	3.9	0.4	1.7	17	Pollen abundant, fair pres. Some broken; charcoal, spores pres.
24-5	20.1	1	0.5	Not counted											No pollen, minor fine organics.
24-6	20.1			Not counted											"
25-1	20.3	3	1.5	Not counted											Pine pollen broken, NAP squashed.
30-1	23.9	2	1	Not counted											Broken half of spruce and pine pollen.

Table 3-4. Determinations of carbon content in selected fine-grained sediments from Long Point boreholes and from cores from the central sub-basin, south of Pointe-aux-Pins. Similar data for the Pelee Shoal cores are plotted in Figures 4-1 to 4-3.

Sample	Elev. (m) below datum (173.3 m a.s.l.	Percent	
		Total Carbon	Organic Carbon
BH 3 Long Point:			
LP 7	-6.0	4.13	0.20
LP 23	-19.2	4.21	0.44
Core LE81-19:			
Samp. 1	-23.4	1.66	1.46
2	-23.3	2.61	2.53
3	-23.1	2.85	2.72

Table 3-5. Determinations of $\delta^{18}O$ and $\delta^{2}H$ stable isotope ratios in pore waters from samples from BH3, Long Point.

Sample	Elev. (m) below datum	$\delta^{18}O$ ‰ (SMOW)	$\delta^{2}H$ ‰ (SMOW)
LP 3	-1.5	-7.2	-68
LP 19	-16.5	-4.3	-43
LP 23	-19.5	-3.1	-46
LP 27	-22.5	-4.3	-51
LP 32	-26.7	-3.9	
LP 44	-34.3	-3.6	
LP 50	-38.0	-4.3	

Table 3-6. Results of geotechnical testing on subsurface samples from Long Point, Point Pelee Shoal, and the central sub-basin of Lake Erie south of Pointe-aux-Pins.

Sample I.D.	Depth* (m)	Elevation (m, IGLD)	Sediment type	Moisture content (w) %	Void ratio (test) (e)	Consolidation tests			Unit weight kN/m^3	Atterberg limits	
						C_c	P_c (kPa)	P_o		Liquid	Plastic
Long Point											
BH 3											
Shelby 4	-17.2	156.1	Postglacial clayey silt	30.3	0.93	0.21	160	187	18.8	27.6	18.0
5	-20.8	152.5	Glaciolacustrine clay	36.2	1.46	0.63	370	224	19.1	44.0	22.7
6	-25.7	147.6	Glaciolac. clay	38.8	1.37	0.54	350	270	17.2	46.0	25.0
7	-33.0	140.3	"	46.0	1.39	0.45	125	350	20.0	42.0	24.0
BH 1 *	-36.9	137.5	Postglacial clayey silt	28.9	0.76	0.11	370	185	19.2	26.9	21.7
Pelee Shoal**											
Core 2	-17.0	156.0	Laminated clayey silt	44.1	1.23	0.32	55	84	16.87		
Core 5	-16.6	156.4	"	38.9	1.15	0.29	51	66	17.6		
Core 6	-16.7	156.3	Massive clayey silt	37.2	1.09	0.26	62	90	17.7		
Core 1	-10.3	163.0	Massive till	22.0	0.68	0.14	107.9	23.5	19.6		
Core 4	-17.5	155.8	Massive till	20.9	0.61	0.12	136.3	61.8	20.3		
Centr. s.-b.***											
13193	-39.8	133.5	Postglacial silty clay	68.2	-	0.63	11-59	59	15.6	68	25
13193	-47.6	125.7	Glaciolacustrine clay	40.3	-	0.45	123	123	17.5	47	23

* Tested by Trow, Ltd. (sample sat for almost a year prior to testing, so it could have dried out despite waxing. This could explain anonalously high (w) and (P_c)).

** From Coakley et al (1977) *** From Zeman (1976)

Table 3-7. Estimation of total sand volume contained in the Long Point foreland (including offshore extensions), based on the interpretive cross-sections shown in Figure 3-22.

Unit	Cross-Section	Average % sand (0.06 mm)	Area of Unit (m^2)	Area of Sand (A) (m^2)	Interval Length (L) (m)	Volume A x L (m^3)
1	A - A' (BH2)	95	min. 83,820 max. 100.584	79,629 95,554	15,000	1,194,435,000 1,433,322,000
	B - B' (BH1)	95	min. 70,104 max. 152,400	66,599 144,780	9,000	599,389,200 1,303,020,000
	C - C' (BH3)	95	min. 9,140 max. 22,860	8,683 21,707	18,000	156,294,000 390,906,000
						min.1,950,118,200 max.3,127,248,000
2	A - A'	20	min. 182,880 max. 304,800	36,576 60,960	15,000	548,640,000 914,400,000
	B - B'	40	min. 83,820 max. 152,400	33,528 60,960	9,000	301,752,000 548,640,000
	C - C'	40	min. 190,500 max. 381,000	76,200 152,400	18,000	1,371,600,000 2,743,200,000
						min.2,221,992,000 max.4,206,240,000

Total sand volume in both units = 4×10^9 m^3 (min.); 7×10^9 m^3 (max.)

= 5.5×10^9 m^3 (Arith. average)

Table 4-1. Location and other descriptive data on offshore cores and boreholes referred to in this study (shown in Figure 1-1).

Location	Core I.D.	Coring date	Latitude (North.)*	Longitude (East.)	Core length (m)	Elevation of top of core** (Water depth, m)
Pelee Shoal						
Pelee Shoal	Core 1	8/74	N41°54'05" (N4639650)	W82°29'20" (E376544)	4.11	166.5 (6.8)
	Core 2	"	N41°53'00" (N4637655)	W82°28'25" (E377755)	11.08	166.5 (6.8)
	Core 3	"	N41°53'05" (N4637871)	W82°29'40" (E375960)	9.56	167.7 (5.6)
	Core 4	"	N41°53'10" (N4638080)	W82°30'40" (E374580)	7.16	167.4 (5.9)
	Core 5	"	N41°52'25" (N4636626)	W82°30'30" (E374831)	9.19	164.9 (8.4)
	Core 6	"	N41°52'20" (N4644030)	W82°29'10" (E376627)	11.95	167.4 (5.9)
S.E. of Pointe-aux-Pins	13156		N42°10'12"	W81°30'48"		149.3 (24.0)
(Consumers Gas boreholes)	13160		N42°02'00"	W81°53'54"		149.7 (23.6)
	13161		N42°14'00"	W81°38'00"		150.0 (23.3)
	13163		N42°09'12"	W81°47'24"		151.5 (21.8)
	13189		N42°15'30"	W81°36'06"		149.7 (23.6)
	13193		N42°14'30"	W81°28'42"		150.0 (23.3)
	13194		N42°04'48"	W81°39'48"		149.05 (24.3)
S. of Pointe-aux-Pins (Central sub-basin)	LE81-19	5/82	N42°02'23"	W81°58'40"	0.6	150.3 (23.0)
	UWO-F-15	10/79	N41°54'44"	W81°43'41"	9.24	148.3 (25.0)

Table 4-2. Tabulated pollen data for Core 2 samples, Pelee Shoal. Species percentages shown refer to total pollen grains (both AP and NAP).

Sample Ident.	Metres below datum	Number grains counted	Grains per slide	% ARBOREAL POLLEN (AP)							% GRASSES & HERBS (NAP)			Total NAP	Comments
				Picea	Pinus	Tsuga	Betula	Quercus	Fagus	Acer	Grasses	Rumex	Ambrosia		
CORE 2:															
2-354	10.4	0	0	Not counted										0	Coarse organics and reworked Paleozoic spores
2-385	10.7	3	3											33	Fine organics
2-415	11.0	4	4											25	
2-435	11.1	0	0											0	
2-480	11.6	16	16											19	Sphagnum present, preservation good
2-512	11.9	29	29											14	Sphagnum, Typha (cattail) present
2-570	12.5	42	21											9	
2-598	12.8	195	97	0.5	25.1	-	12.3	32.8	1.0	0.5	4.6	-	0.5	16	Typha and Sphagnum present; bundant organics & charcoal
2-608	12.9	168	168	7.7	44.6	1.2	7.1	11.9	-	1.8	1.8	0.6	-	11	Typha, coarse organics, and charcoal present
2-620	13.0	249	83	6.8	30.1	0.4	4.0	18.5	-	0.4	2.4	1.6	0.4	19	Preserv. good; organics, Typha, and Sphag. present
2-650	13.3	241	80	9.1	36.0	0.4	4.1	14.5	-	2.1	3.7	0.4	-	16	Same as above; no Sphag.
2-680	13.6	166	42	8.4	47.5	-	2.4	16.3	0.6	0.6	4.8	-	-	11	
2-710	13.9	156	52	3.8	52.6	-	3.8	18.6	0.6	3.8	0.6	-	-	10	
2-740	14.2	225	225	4.9	64.4	-	1.3	14.2	0.4	-	-	-	-	9	Sphag., Typha, reworked spores present
2-770	14.5	241	241	4.6	65.6	1.0	2.1	12.0	-	-	-	-	-	6	Same as above
2-800	14.8	264	264	7.6	66.3	0.4	0.7	11.4	0.4	2.3	-	-	-	4	Organics, charcoal, Typha present
2-848	15.3	286	143	8.0	66.4	0.3	2.4	7.3	-	0.6	1.7	-	-	8	Same as above; Sphag. present
2-880	15.6	250	250	8.0	68.0	-	2.0	7.2	0.4	0.8	-	-	-	7	Sphag., Typha present
2-910	15.9	302	302	6.3	67.5	0.3	1.6	8.2	-	0.3	0.3	0.3	-	7	Same as above; no Sphag.
2-940	16.2	277	277	8.6	59.9	0.7	1.8	10.5	0.3	-	1.4	-	-	12	Sphag. and Typha present
2-972	16.5	242	121	7.8	73.5	2.0	1.2	4.5	-	-	0.4	-	-	4	Sphag. present; no Typha
2-1002	16.8	248	248	11.5	74.1	-	0.8	4.4	-	0.4	-	-	-	3	1 Typha grain; no Sphag.
2-1032	17.1	241	121	21.9	66.8	-	1.6	2.1	-	0.4	-	-	-	3	Sphag., Typha present
2-1062	17.4	225	75	16.9	77.8	-	-	3.5	-	-	-	-	-	0	
2-1092	17.7	222	222	20.7	69.3	0.4	-	4.95	-	0.4	-	-	-	0	1 Sphag. grain present
2-1108	17.9	207	103	8.2	62.3	-	1.4	5.8	-	0.4	-	-	-	5	Fine organics; reworked spores; 1 Sphag. present

Table 4-3. Dominant molluscan species from Core 2, Pelee Shoal, reproduced with permission from Kalas (1980).

DOMINANT FORMS

Pelecypoda (Unionacean and Sphaeriacean clams):

Unionacea (various species)

Pisidium spp.

Sphaerium striatinum

Musculium lacustre

Prosobranchiate Gastropods:

Valvata tricarinata

Valvata perdepressa

Valvata sincera helicoidea

Cincinnatia cincinnatiensis

Probythinella lacustris

Pyrgulopsis letsoni

Pleurocera acuta

Oxytrema livescens

Freshwater Pulmonate Gastropods:

Gyraulus parvus

Succinea ovalis

Catinella vermeta

Discus cronkhitei

Helicodiscus parallelus

Punctum minutissimum

Zonitoides arboreus

Zonitoides nitidus

Striatura milium

Table 5-1. Vertical sedimentary relationships and channel geometry of stream mouths along the shore of Lake Erie. Location of sites is given in Figure 1-1.

STREAM	Distance from mouth (km)	Water elev.(m)	Water depth /Bott. elev. IGLD	Sed. materials below channel (glac/postgl. contact)	Contact elevation	Bedrock elevation	COMMENTS
Grand River: Port Maitland	0	173	7.6m/166.4	Alluvial sand over lacustrine clay (glacial)	162.4	160.8	Stream apparently cut into glaciolacustrine clay deposit. Change of stream regime apparent in upward transition from loose, fine to coarse sand with shells, to soft silty clay with organic matter. Stream not bedrock-controlled.
	0 - 0.5 offsh.	173	7.9 / 166.4	Loose sand and gravel over clay	161.5	154	
Dunnville	6.0 (upstream)	176	2 / 173.7	"Marly" loose sand over reddish gray clay (glac.) Broad (500 m) valley cut in clay.	161.5	152	
Lynn River: Port Dover	0.8 (upstream)	174	3.3 / 170.7	Thin layer of loose to compact alluvial sand over firm (glac.?) clay.	170	170	Stream has apparently cut down into soft surficial silty clay and then into loose sand and glac. clay. Stream not bedrock-controlled
Big Creek (vic. Port Rowan)	2.0 (upstr.)	175	1 / 173	Alluvial sand, gray silty and organic, over reddish gray stiff clay.	unknown; below 165	not observed	Channel originally cut into glac. clay to around 160m or less. Sands originally laid down now being channelled again.
Cattaraugus Creek New York	0.2 (offsh.)	174	2.5 / 171.5	Sand and gravel over glacial till and glac. clay.	167.3	-	Channel cut through glaciolacustrine clay down to till.
Clear Creek:	at shoreline	174.5	175.6	Glacial till	168.9	-	Narrow channel silted up and abandoned. Sediments grade down from a 1 m thick surface layer of logs and peat, through coarsening-downward series of silt, sand, and gravel, to pinkish till.
Otter Creek: Port Burwell	0.5 (upstream)	173.8	-	Loose to compact gray silty fine sand with wood over stiff clay (till?)	168.5	-	Port entrance dredged often so relationships might be disturbed. Stream probably cut in till to 165.7m. Top loose organic sediment represents modern deposits while loose sands repr. aggradation phase as lake rose.
	"	"	6.3 / 167.5	(same as above)	165.7	-	
Catfish Creek: Port Bruce	0.5 (upstream)	174	1.2 / 172.8	Fine to coarse sand with fine gravel and organic matter over very stiff, truncated silty clay surface (till?)	169.5 to 170	-	Stream cut into sand layer of alluvial or nearshore origin
Cedar Creek	4.8 (upstream)	173.9	Borehole on land	Peat over compact to very dense silty fine to coarse sand. Glacial sed. base not encountered.	lower than 168.5	-	Borehole stopped in sand at 168.5. Sand probably laid down at a high lake stage.
Old Woman Creek Ohio	0.3 (upstream)	-	174	Silty clay layers with organic matter over undetermined substrate. Coarse pebbly layer at base probably alluvial.	lower than 167.8	-	Contact could be lower than that noted, as B.H. did not reach glacial substrate.

FIGURES

Figure 1-1

General location map of Lake Erie, showing place names and physiographic features of importance to the local glacial history (cross-lake and other moraines, raised shorelines of glacial Lake Warren, zero iso-bases (hinge-lines) for the post-Port-Huron glacial lakes). Also shown are the locations of boreholes which yielded useful stratigraphic data: 4 land-based boreholes on Long Point; 7 offshore boreholes south of Pointe-aux-Pins drilled by the Consumers Gas Co.; and 6 south of Point Pelee. Shaded area along the southern side of the lake marks the area covered by Vibracore and seismic surveys by the U.S.Army Corps of Engineers and the Ohio Division of Geological Survey.

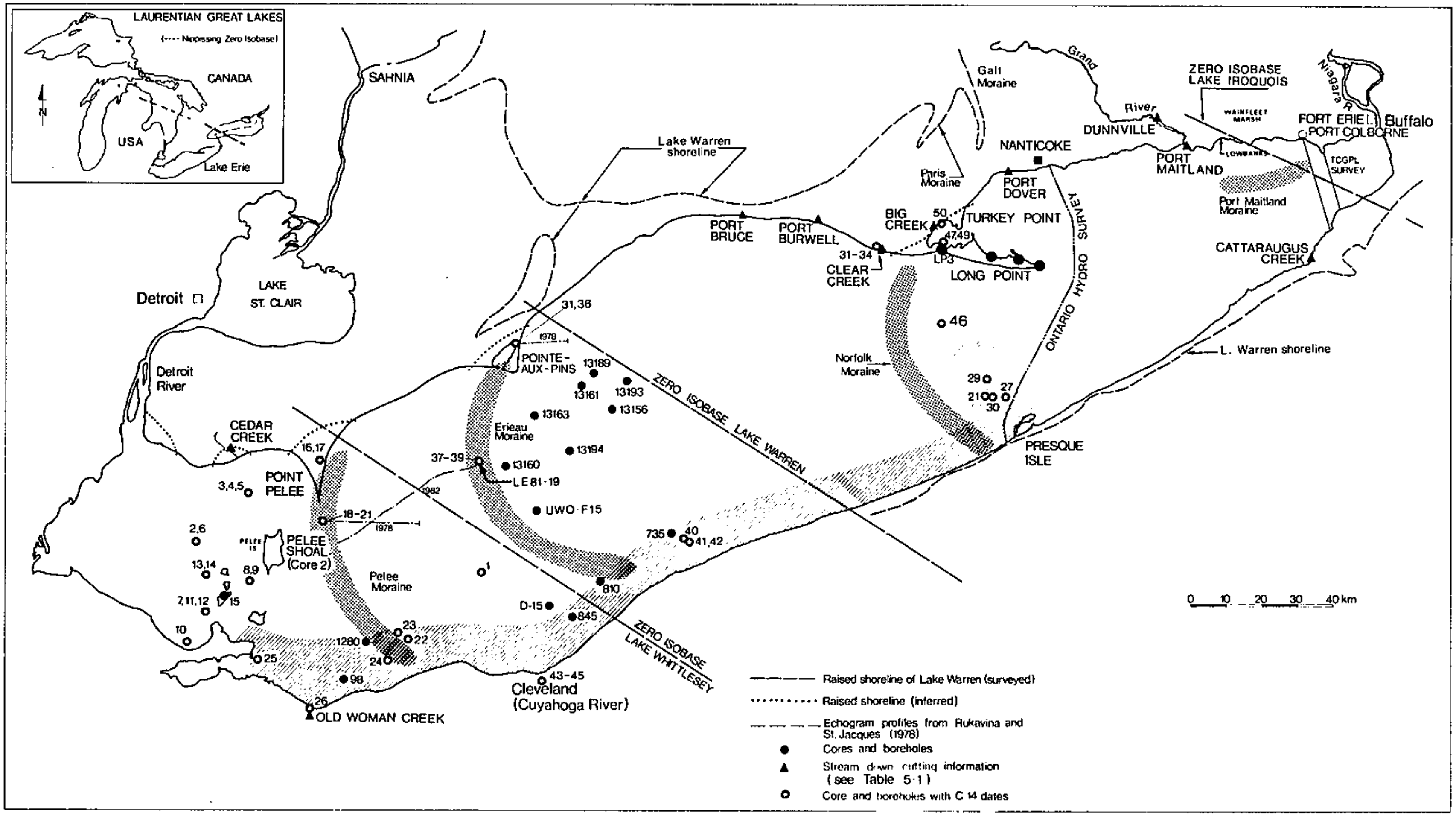
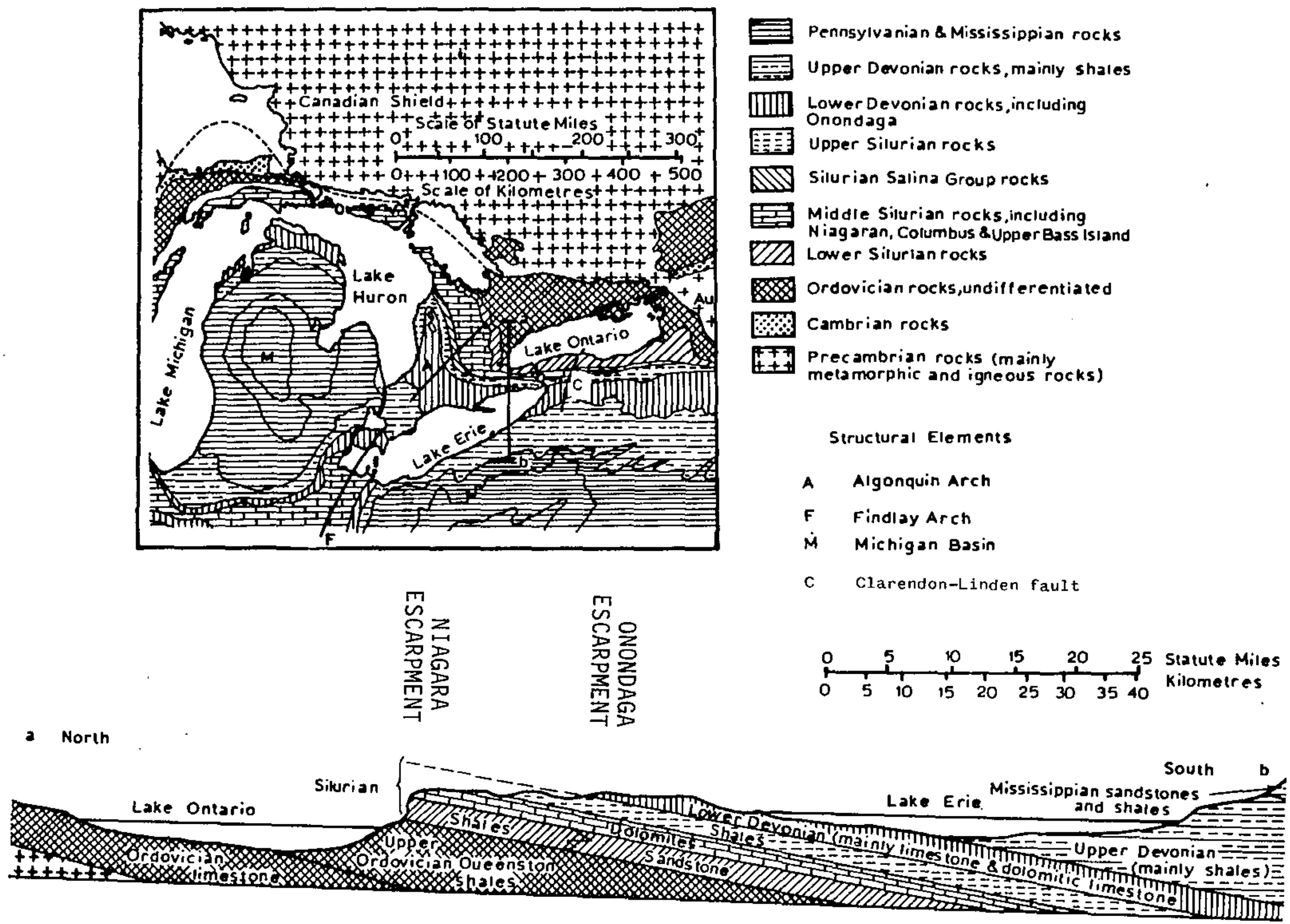

LAURENTIAN GREAT LAKES
(---- Nipissing Zero Isobase)
CANADA
USA
Lake Erie
N
SAHNIA
Detroit
LAKE ST. CLAIR
Detroit River
CEDAR CREEK
POINT PELEE
PELEE SHOAL (Core 2)
Pelee Moraine
Erieau Moraine
POINTE-AUX-PINS
Lake Warren shoreline
PORT BRUCE
PORT BURWELL
CLEAR CREEK
BIG CREEK
TURKEY POINT
LONG POINT
PORT DOVER
NANTICOKE
Paris Moraine
Galt Moraine
Grand River
DUNNVILLE
PORT MAITLAND
Port Maitland Moraine
ZERO ISOBASE LAKE IROQUOIS
WAINFLEET MARSH
LOWBANKS
FORT ERIE
PORT COLBORNE
Buffalo
Niagara R.
TCGPL SURVEY
CATTARAUGUS CREEK
ONTARIO HYDRO SURVEY
Norfolk Moraine
L. Warren shoreline
PRESQUE ISLE
ZERO ISOBASE LAKE WARREN
ZERO ISOBASE LAKE WHITTLESEY
Cleveland (Cuyahoga River)
OLD WOMAN CREEK
LE 81-19
UWO-F15
D-15
0 10 20 30 40 km
Raised shoreline of Lake Warren (surveyed)
Raised shoreline (inferred)
Echogram profiles from Rukavina and St. Jacques (1978)
Cores and boreholes
Stream down cutting information (see Table 5-1)
Core and boreholes with C 14 dates

Figure 2-1

Generalized bedrock geology of the Lower Great Lakes region (adapted from Hough, 1958). Also shown are geological and physiographic features that played a role in the location of the Lake Erie Basin and its glacial evolution.



Canadian Shield
Scale of Statute Miles
0 100 200 300
0 100 200 300 400 500
Scale of Kilometres
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
Au
M
A
C
b
F
Pennsylvanian & Mississippian rocks
Upper Devonian rocks, mainly shales
Lower Devonian rocks, including Onondaga
Upper Silurian rocks
Silurian Salina Group rocks
Middle Silurian rocks, including Niagaran, Columbus & Upper Bass Island
Lower Silurian rocks
Ordovician rocks, undifferentiated
Cambrian rocks
Precambrian rocks (mainly metamorphic and igneous rocks)
Structural Elements
A Algonquin Arch
F Findlay Arch
M Michigan Basin
C Clarendon-Linden fault
NIAGARA ESCARPMENT
ONONDAGA ESCARPMENT
0 5 10 15 20 25 Statute Miles
0 5 10 15 20 25 30 35 40 Kilometres
a North
South b
Silurian
Lake Ontario
Lake Erie
Mississippian sandstones and shales
Ordovician limestone
Upper Ordovician Queenston shales
Shales
Dolomites
Shales
Sandstone
Lower Devonian (mainly limestone & dolomitic limestone)
Upper Devonian (mainly shales)

- 236 -

Figure 2-2

Distribution of bottom sediment types in the nearshore zone of Lake Erie (north side), from Rukavina (1976). Note the sand bodies transverse to the shore, associated with the three major forelands and major morainal features.

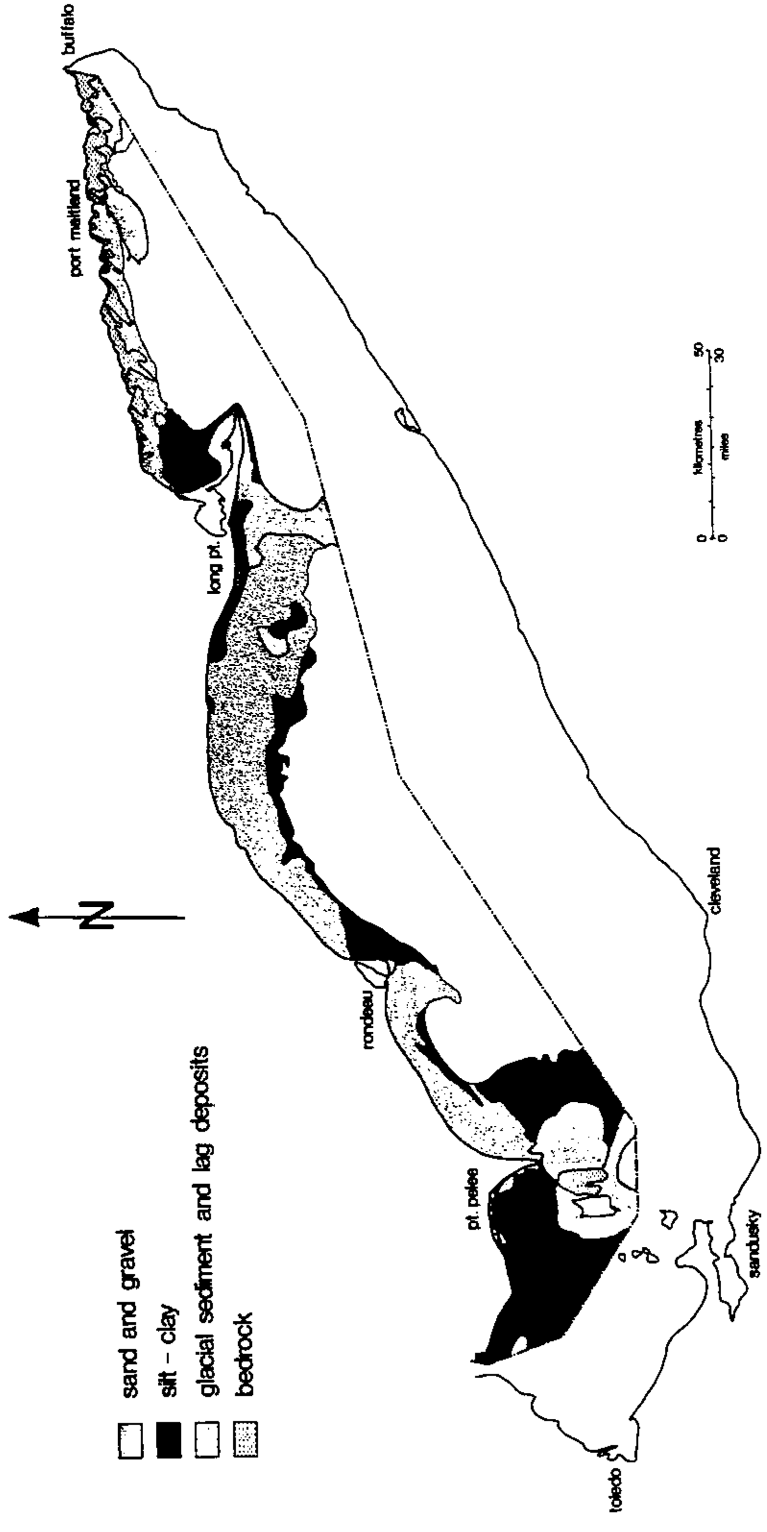

buffalo
port maitland
long pt.
rondeau
pt. pelee
toledo
sandusky
cleveland
N
kilometres
miles
0
50
30
sand and gravel
silt - clay
glacial sediment and lag deposits
bedrock

Figure 2-3

(Top): Average recession rates (1810 to 1964) for the central portion of the north shore of Lake Erie (from Gelinas, 1974)

(Bottom): Average recession rates (approximately 1936 to 1970) for the remaining shoreline segments of the north shore of Lake Erie. Basic data plotted were taken from Haras and Tsui (1976).

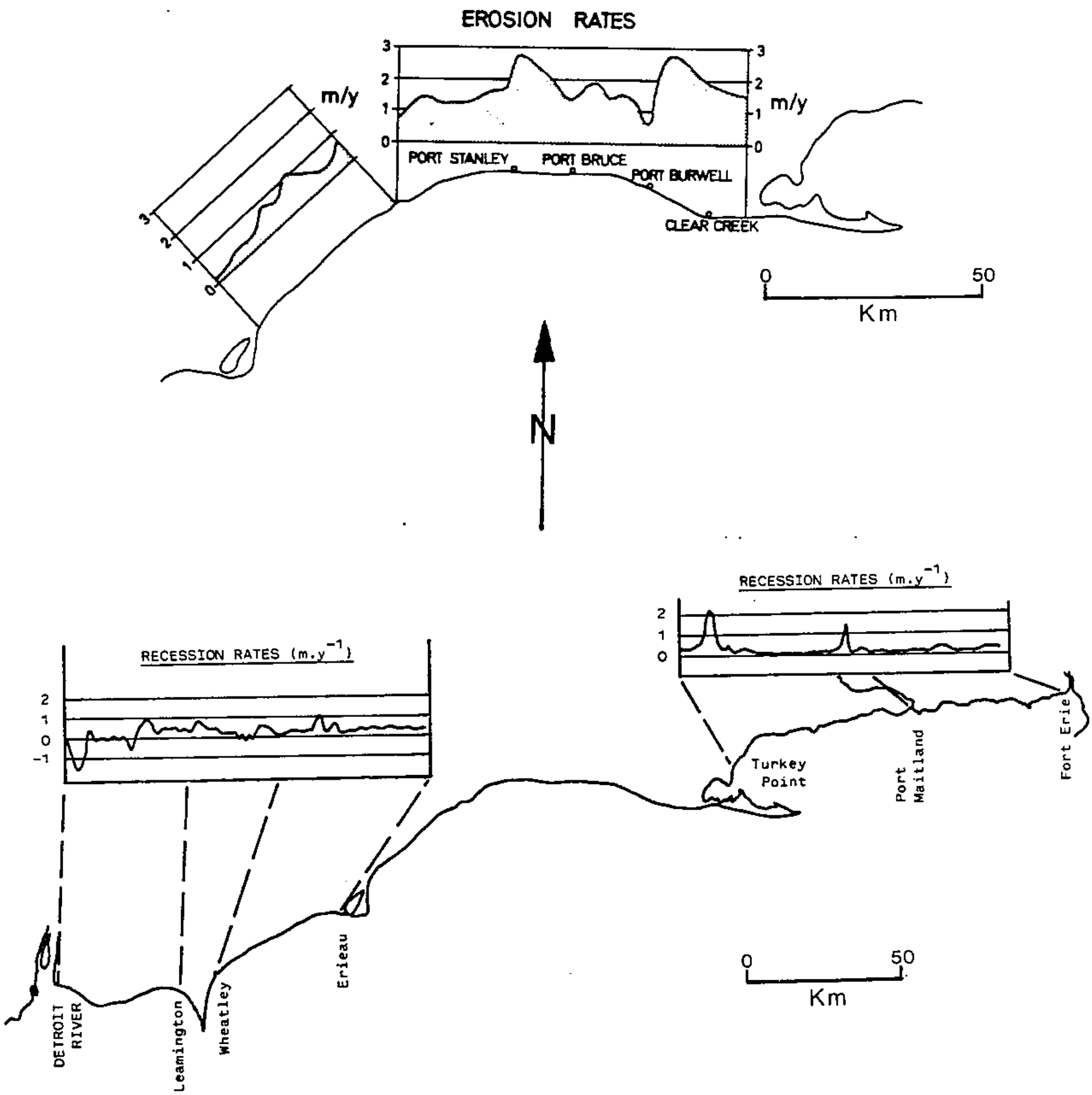

EROSION RATES
m/y
m/y
PORT STANLEY
PORT BRUCE
PORT BURWELL
CLEAR CREEK
0 50
Km
N
RECESSION RATES (m.y^{-1})
RECESSION RATES (m.y^{-1})
Turkey Point
Port Maitland
Fort Erie
DETROIT RIVER
Leamington
Wheatley
Erieau
0 50
Km

Figure 2-4

Physiographic elements and borehole locations in Point Pelee National Park and on the Pelee Shoal. Position and orientation of beach ridges and dunes were traced from aerial photographs taken in 1972. Note the clear truncation of ponds and beach ridges on the eastern side and the accretion of such ridges on the western side. Numbers 1T, 2T, and 3T refer to boreholes drilled by Terasmae (1970) and reproduced in part in Figure 4-6. Cores 1 to 6 were drilled by the author in 1974. Details of radiocarbon dating are presented in Table 3-1. Cross-sections AB and CD are shown in Figure 4-5.

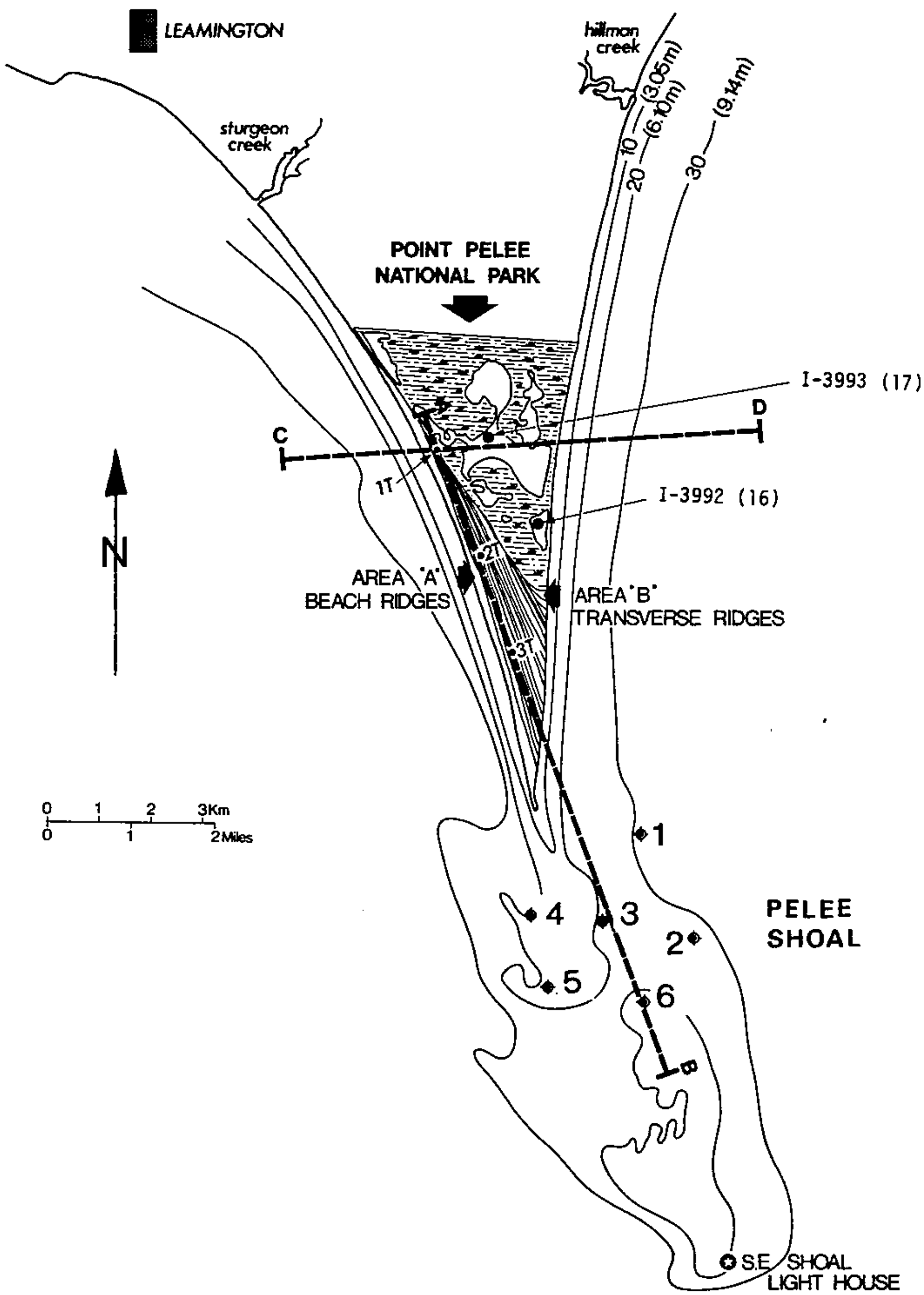

LEAMINGTON
hillman creek
sturgeon creek
10 (3.05m)
20 (6.10m)
30 (9.14m)
POINT PELEE NATIONAL PARK
I-3993 (17)
C
D
1T
I-3992 (16)
N
2T
AREA 'A' BEACH RIDGES
AREA 'B' TRANSVERSE RIDGES
3T
0 1 2 3Km
0 1 2Miles
1
4
3
2
5
6
B
PELEE SHOAL
S.E. SHOAL LIGHT HOUSE

Figure 2-5

Physiographic features and changing pattern of beach and dune ridge orientation at Pointe-aux-Pins. The only borehole drilled for geologic purposes (OGS-1) by the Ontario Geological Survey is also shown near the entrance to the Rondeau Provincial Park, which occupies the eastern limb of the foreland. Inset (top) shows the location of 22 other land-based boreholes drilled for other purposes. The location of cross-sections plotted in Figure 4-14 is also shown.

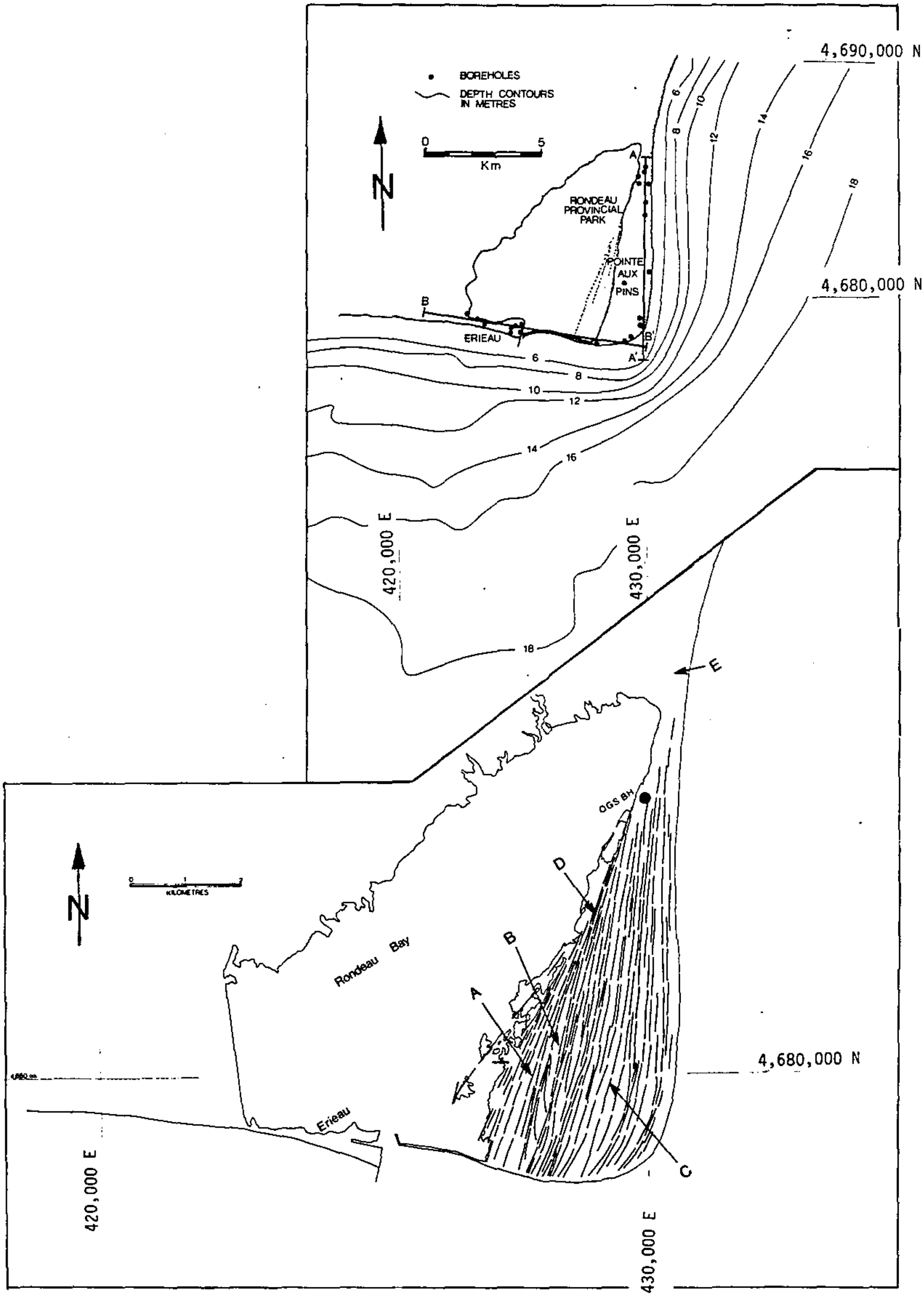

4,690,000 N
BOREHOLES
DEPTH CONTOURS IN METRES
0
5
Km
N
RONDEAU PROVINCIAL PARK
POINTE AUX PINS
ERIEAU
A
A'
B
B'
6
8
10
12
14
16
18
4,680,000 N
420,000 E
430,000 E
E
OGS BH
D
B
A
C
Rondeau Bay
Erieau
N
KILOMETRES
4,680,000 N
420,000 E
430,000 E

Figure 2-6

Physiographic features, land ownership, and changing patterns of beach ridge and dune orientation at Long Point. The distinct abandoned shoreline to the west and northwest of the Point is shown, as well as small delta-like features between Long Point and Turkey Point. The inset (upper right) shows the location of land-based boreholes drilled on Long Point, and nearshore probes and cores taken in the area (Rukavina, 1983; C.F.M. Lewis, 1982, pers. comm.). For more details on these data refer to Table 3-2. Cross-sections A-A', B-B', and C-C' are plotted in Figure 3-22.

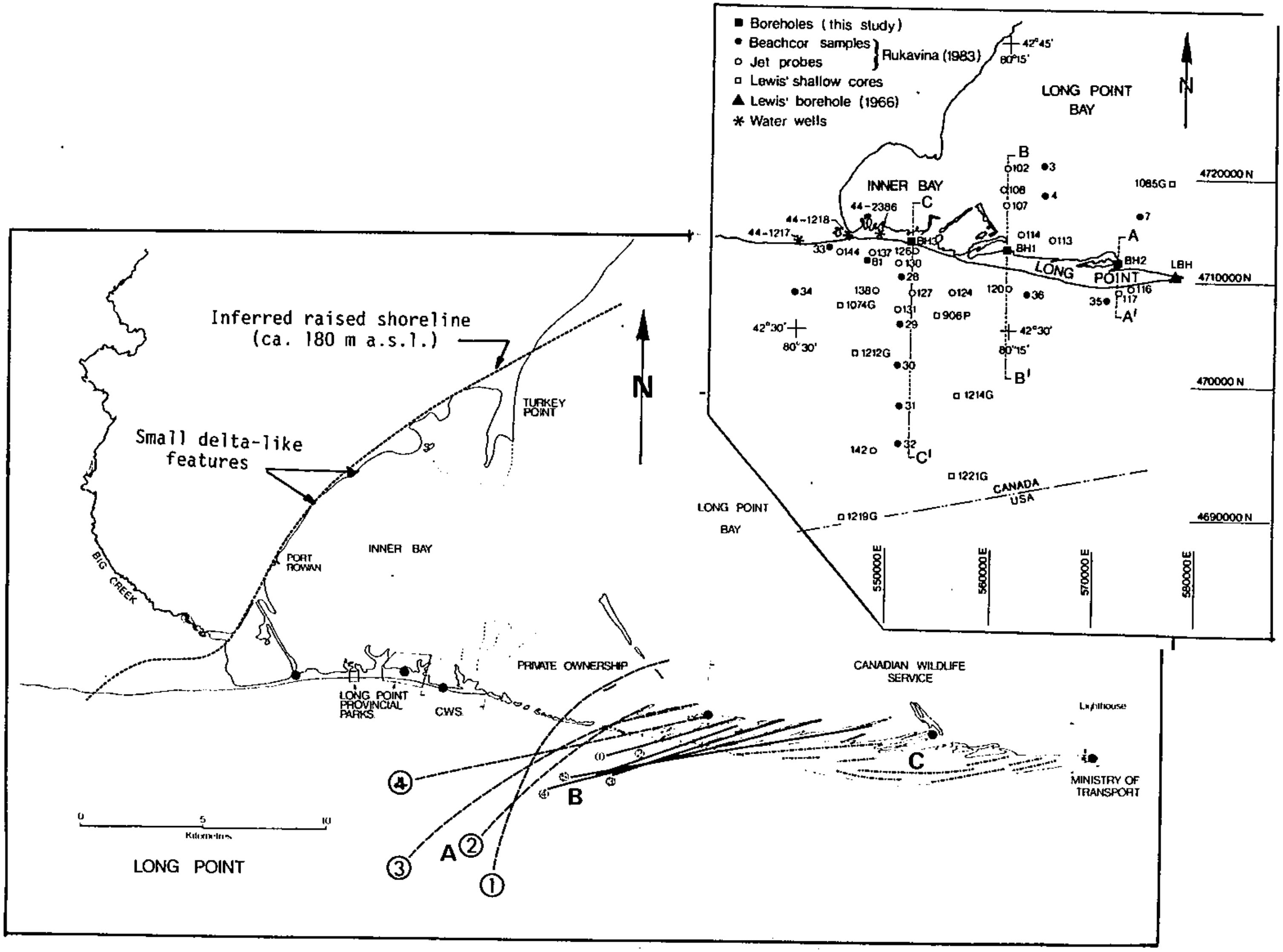

Boreholes (this study)
Beachcor samples
Jet probes
Rukavina (1983)
Lewis' shallow cores
Lewis' borehole (1966)
Water wells
42°45'
80°15'
LONG POINT
BAY
N
INNER BAY
4720000 N
4710000 N
4700000 N
4690000 N
550000 E
560000 E
570000 E
580000 E
LONG POINT
BH1
BH2
BH3
LBH
42°30'
80°30'
80°15'
CANADA
USA
LONG POINT
BAY
Inferred raised shoreline
(ca. 180 m a.s.l.)
Small delta-like
features
N
TURKEY
POINT
INNER BAY
PORT
ROWAN
BIG CREEK
LONG POINT
PROVINCIAL
PARKS
CWS
PRIVATE OWNERSHIP
CANADIAN WILDLIFE
SERVICE
Lighthouse
MINISTRY OF
TRANSPORT
0
5
10
Kilometres
LONG POINT

Figure 3-1

Borehole drilling on Long Point in 1980 using a wash-boring rig.

Figure 3-2

Borehole drilling on Long Point in 1981 using the truck-mounted, hollow-stem auger rig owned by the University of Waterloo.

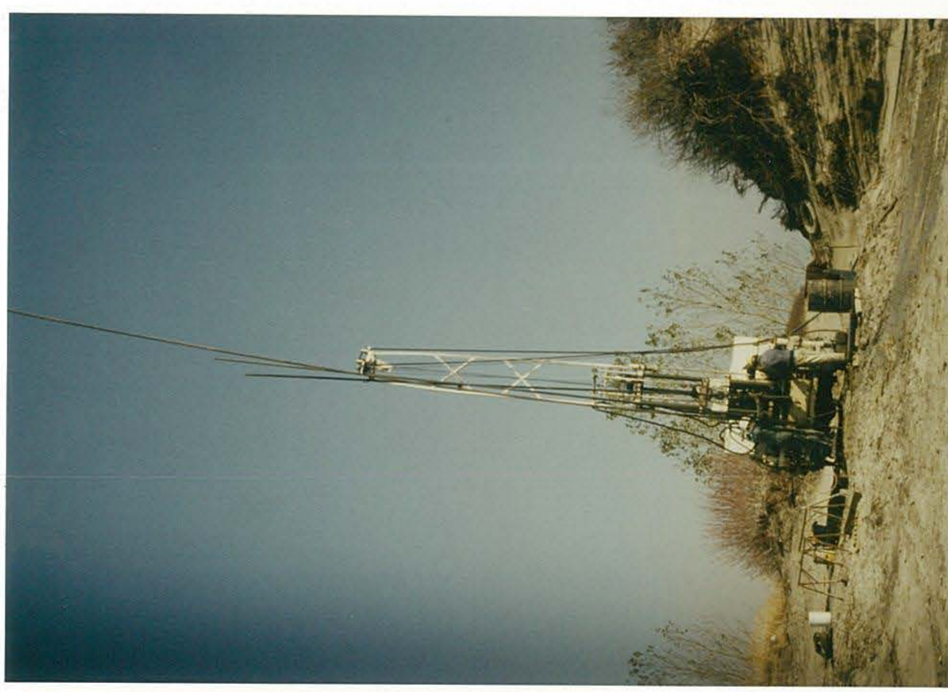


Figure 3-3

(Top) Alpine Vibracorer, with auxiliary 15 m crane and compressor, being loaded onto barge at Kingsville Harbour, prior to leaving for the Pelee Shoal study area in 1974.

(Bottom) Vibracorer in operation on the Pelee Shoal.

Both photographs by W.G. Booth, National Water Research Institute.

Figure 3-4

Lithology and selected grain-size parameters plotted against depth in BH1 and BH2, Long Point (see Figure 2-6 for location).

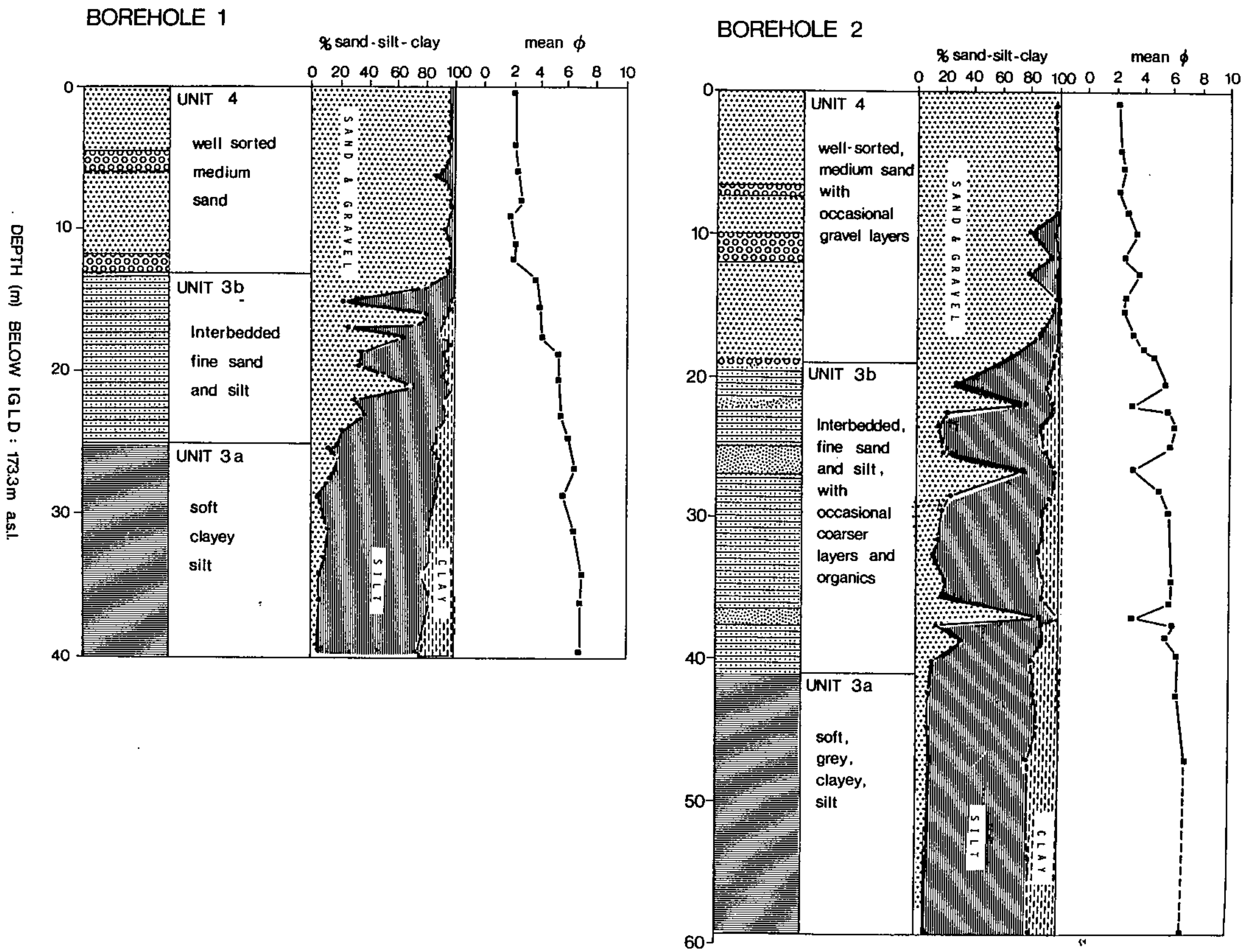

BOREHOLE 1
% sand - silt - clay
mean φ
0 20 40 60 80 100
0 2 4 6 8 10
DEPTH (m) BELOW IGLD : 173.3m a.s.l.
0
10
20
30
40
UNIT 4
well sorted
medium
sand
UNIT 3b
Interbedded
fine sand
and silt
UNIT 3a
soft
clayey
silt
SAND & GRAVEL
SILT
CLAY
BOREHOLE 2
% sand-silt-clay
mean φ
0 20 40 60 80 100
0 2 4 6 8 10
0
10
20
30
40
50
60
UNIT 4
well-sorted,
medium sand
with
occasional
gravel layers
UNIT 3b
Interbedded,
fine sand
and silt,
with
occasional
coarser
layers and
organics
UNIT 3a
soft,
grey,
clayey,
silt
SAND & GRAVEL
SILT
CLAY

Figure 3-5

Lithology, selected grain-size parameters, and geotechnical measurements plotted against depth in BH3, Long Point. Borehole location is shown in Figure 2-6.

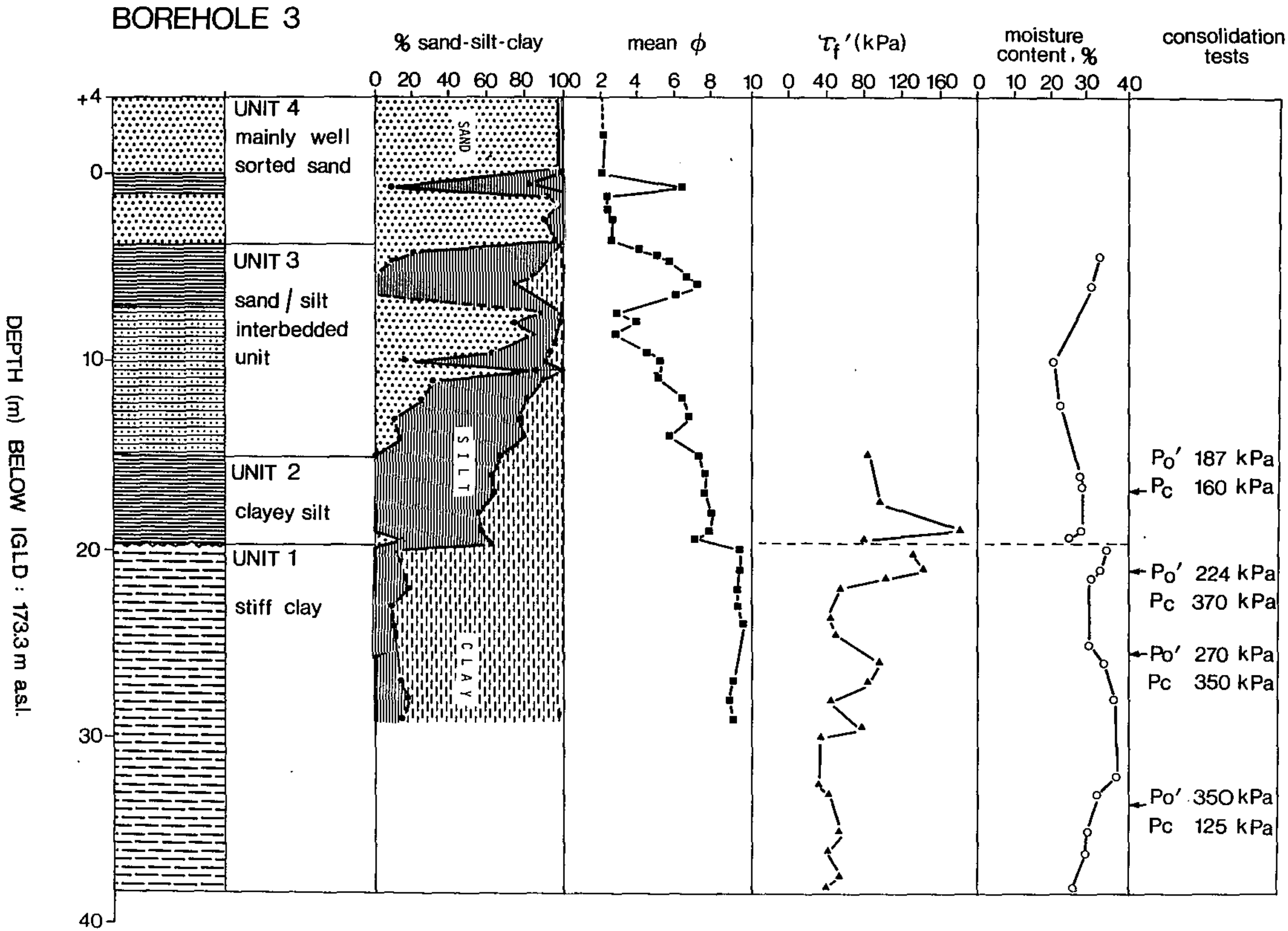
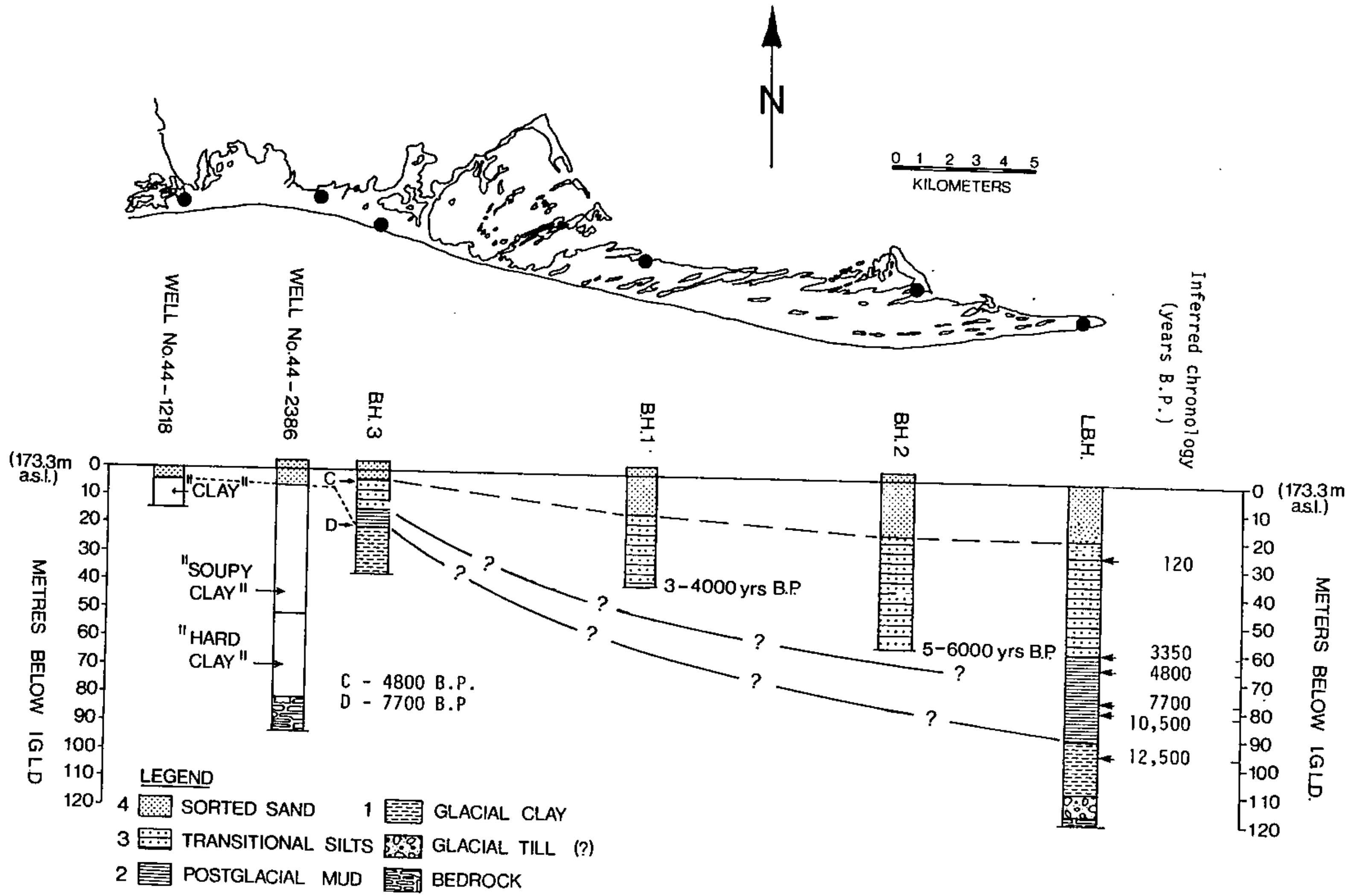

BOREHOLE 3
% sand-silt-clay
mean φ
τf′ (kPa)
moisture content, %
consolidation tests
DEPTH (m) BELOW IGLD : 173.3 m a.s.l.
UNIT 4
mainly well sorted sand
UNIT 3
sand / silt interbedded unit
UNIT 2
clayey silt
UNIT 1
stiff clay
SAND
SILT
CLAY
Po′ 187 kPa
Pc 160 kPa
Po′ 224 kPa
Pc 370 kPa
Po′ 270 kPa
Pc 350 kPa
Po′ 350 kPa
Pc 125 kPa

Figure 3-6

Longitudinal section through boreholes on Long Point, including inferred lithological boundaries. These boundaries are clearly time-transgressive as shown by the inferred chronological markers based on pollen profiles that are also included (see Figure 3-19 and 3-20 for details on pollen profiles).



N
0 1 2 3 4 5
KILOMETERS
WELL No.44-1218
WELL No.44-2386
BH. 3
BH.1
BH.2
LBH.
Inferred chronology (years B.P.)
(173.3m a.s.l.)
METRES BELOW IGLD
METERS BELOW IGLD.
"CLAY"
"SOUPY CLAY"
"HARD CLAY"
C
D
C - 4800 B.P.
D - 7700 B.P
3-4000 yrs B.P
5-6000 yrs B.P
120
3350
4800
7700
10,500
12,500
LEGEND
4 SORTED SAND
3 TRANSITIONAL SILTS
2 POSTGLACIAL MUD
1 GLACIAL CLAY
GLACIAL TILL (?)
BEDROCK

Figure 3-7

Colour photographs of core sections from BH3 on Long Point classified as Unit 1 (glaciolacustrine clay). Sections from left to right are: LP26 (21.6 to 22.2 m b.d.); LP39 (30.7 to 31.3 m b.d.); and LP49 (37.4 to 38.0 m b.d.). Arrow points to hole left by 400 g fall-cone testing for shear strength. Note very stiff consistency and very faint laminations which characterize these samples. (Photograph by Keith Salisbury, National Water Research Institute).


LP 26
LP 39
LP 49

Figure 3-8

Colour photographs of core sections from BH3 on Long Point classified predominantly as Unit 2 (lacustrine clayey silt). The extremely irregular contact between Units 1 and 2 is readily visible in the lower portion of the section at the far right (black arrow). Whitish specks in that area are shell fragments. Red arrow points to a small wood fragment. Note the alternating silty and clayey layers in the two cores on the left, especially at the far left. Sections from left to right are: LP19 (16.1 to 16.7 m b.d.*); LP21 (17.9 to 18.5 m b.d.); and LP24 (19.7 to 20.3 m b.d.). (Photograph by Keith Salisbury, NWRI).

(* below lake datum: 173.3 m above sealevel)


LP 19
LP 21
LP 24

Figure 3-9

Colour photographs of core sections from BH3, Long Point.

Right: (Top) Unit 3 (interlaminated sand, silt, and clay unit), showing colour changes associated with textural variations. Red arrow indicates plant fragments common in this unit. Sections shown (left to right) are: LP9 (8.8 to 9.4 m b.d.); LP11 (10.0 to 10.6 m b.d.); LP13 (11.2 to 11.8 m b.d.); and LP17 (14.3 to 14.9 m b.d.).

Left: Photograph of unusually silty, clayey sections of Unit 4 (sand). Sections shown are: LP4a (4.2 to 4.8 m b.d.) and LP6 (5.3 to 6.0 m b.d.).

(Photograph by Keith Salisbury, NWRI).


LP 17
LP 13
LP 11
LP 9


LP 6
LP 4a
20'-22'

Figure 3-10

Colour photographs of core sections from BH3, Long Point, showing top predominantly sand unit (Unit 4). Sections shown (left to right) are: LP2 (0.9 to 1.5 m b.d.) showing the anomalous silty clay bed occurring within the top section of the unit; LP3 (1.5 to 2.1 m b.d.); and LP4 (2.7 to 3.3 m b.d.). (Photograph by Keith Salisbury, NWRI).


LP 2
275 - 335 cm
LP 3
335 - 396 cm
LP 4
457 - 518 cm
LONG POINT
BH 3

Figure 3-11

Close-up colour photograph of contact area between Units 1 (bottom) and 2 in BH3, Long Point (enlarged from that shown in Figure 3-8). Dark line crossing the upper portion of the core is a desiccation crack in a sandier segment. Shells and sand granules are scattered throughout the irregular, 6 cm thick, sandy contact zone. (Photograph by Peter Fisher, University of Waterloo).

(Top)

Figure 3-12

X-radiography prints of sediment core sections from BH3, Long Point. Sections shown (left to right) are: LP24 (19.7 to 20.3 m b.d.), note contrast change between the denser (less exposed) Unit 1 and the overlying Unit 2; and LP50 (38.5 to 39.3 m b.d.), note the faint inclined rhythmic laminations visible especially at the base of this section. Core on left is 7 cm wide, that on right is 5 cm wide. (X-radiography prints made by Daniel Mackenzie, Canada Centre for Inland Waters).

24

50

Figure 3-13

X-radiography print of sediment core sections from the central portion of BH3, Long Point, showing well-defined small-scale planar and cross-laminations (note bottom portion of second core from right). Sections shown (left to right) are: LP9 (9.3 to 9.9 m b.d.); LP10 (9.9 to 10.5 m b.d.); LP11 (10.5 to 11.2 m b.d.); and LP13 (11.8 to 12.5 m b.d.). Contrast on X-ray transmission of silty and sandy laminations is clearly shown in the alternating density of the image.

9

10

11

13

Figure 3-14

Representative cumulative grain-size curves for samples from BH3, Long Point deposited from gravity settling (Type 1 on C-M diagram, Figure 3-18).

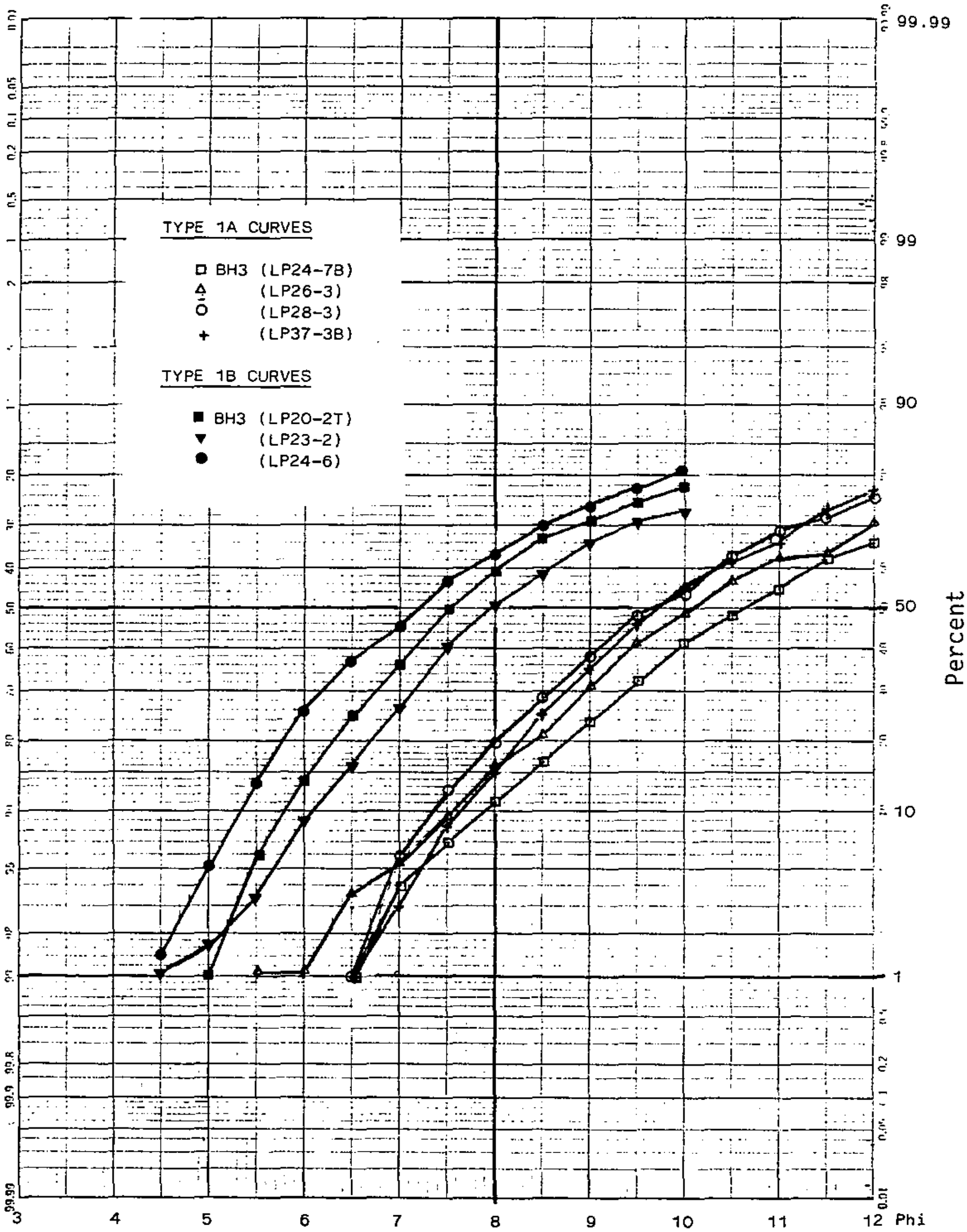

TYPE 1A CURVES
BH3 (LP24-7B)
(LP26-3)
(LP28-3)
(LP37-3B)
TYPE 1B CURVES
BH3 (LP20-2T)
(LP23-2)
(LP24-6)
99.99
99
90
50
10
1
0.01
Percent
3
4
5
6
7
8
9
10
11
12 Phi

Figure 3-15

Representative cumulative grain-size curves from boreholes on Long Point, indicating deposition from a mixture of gravity-settling and saltation processes (Type 2).

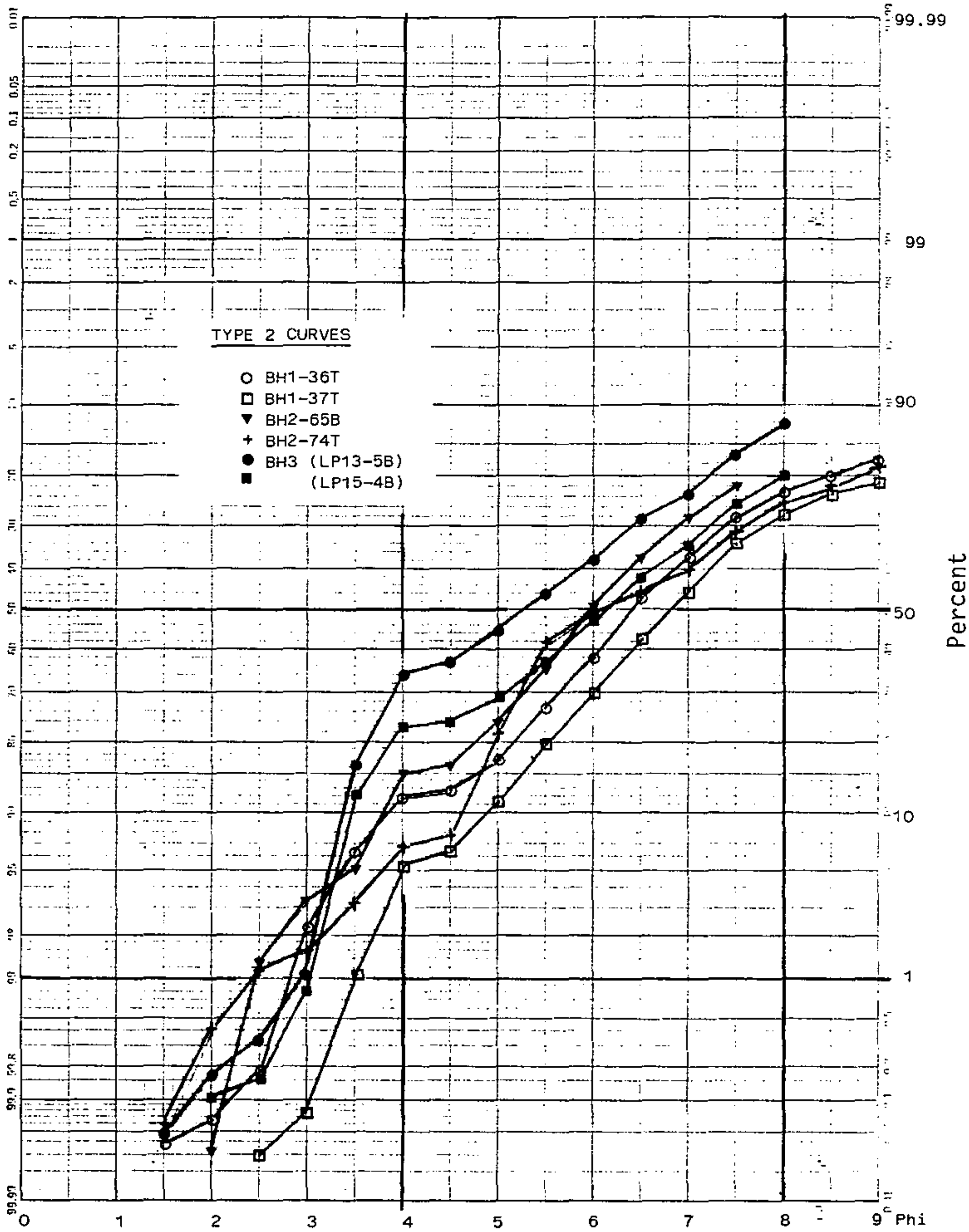

TYPE 2 CURVES
BH1-36T
BH1-37T
BH2-65B
BH2-74T
BH3 (LP13-5B)
(LP15-4B)
Percent
Phi
99.99
99
90
50
10
1
0
1
2
3
4
5
6
7
8
9

Figure 3-16

Representative cumulative grain-size curves from borehole samples taken from Long Point, indicating deposition predominantly from saltation processes (wind or water) on left; and a mixture of saltation and bottom traction on the right.(Type 3 in C-M diagram, Figure 3-18).

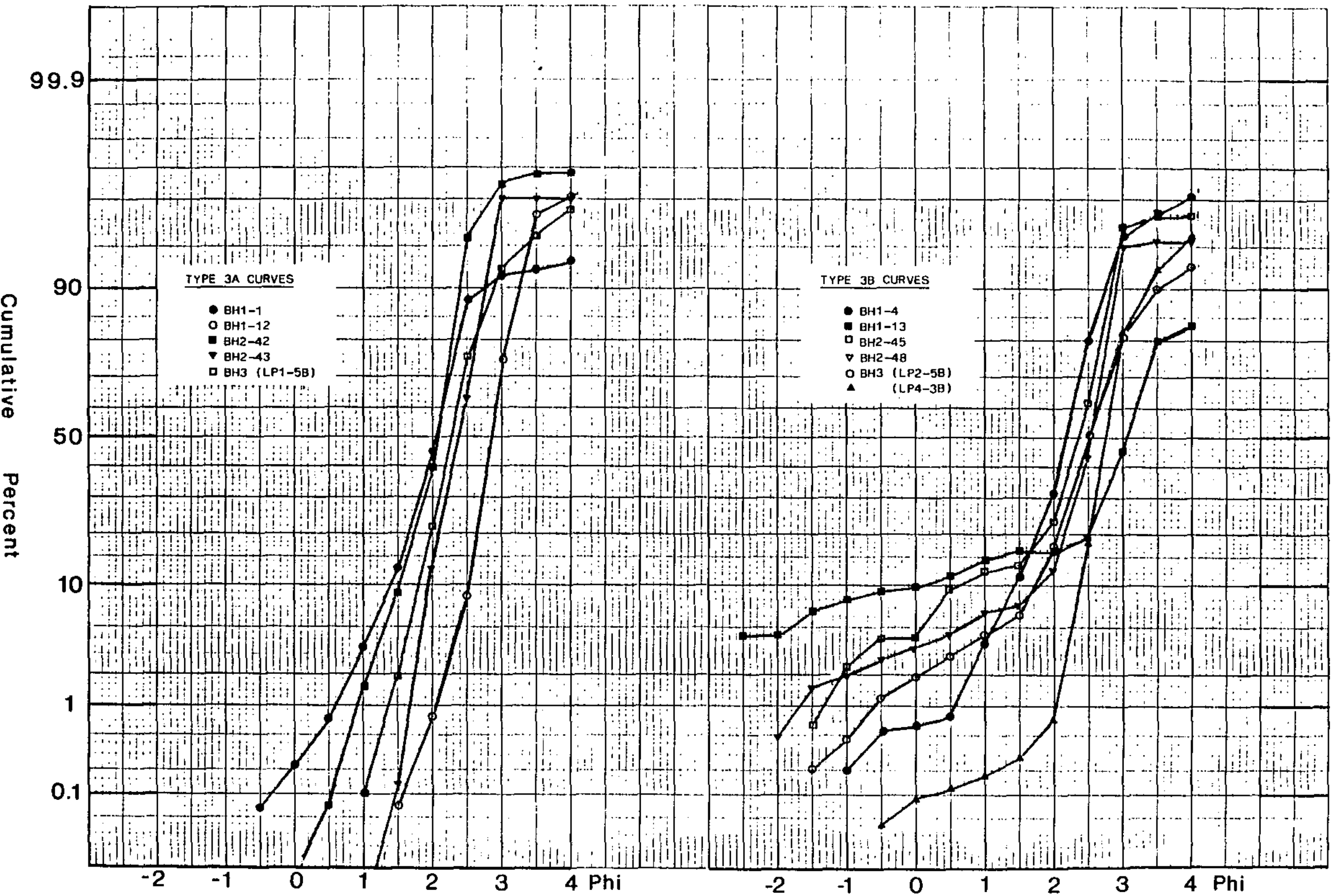

Cumulative Percent
99.9
90
50
10
1
0.1
TYPE 3A CURVES
● BH1-1
○ BH1-12
■ BH2-42
▼ BH2-43
□ BH3 (LP1-5B)
TYPE 3B CURVES
● BH1-4
■ BH1-13
□ BH2-45
▽ BH2-48
○ BH3 (LP2-5B)
▲ (LP4-3B)
-2 -1 0 1 2 3 4 Phi
-2 -1 0 1 2 3 4 Phi

Figure 3-17

Cumulative grain-size curves from borehole samples on Long Point that do not fit easily into any of the previously mentioned three types (Type 4). Note the similarity in form of some of these curves with those from the coarse layer at Pointe-aux-Pins (Figure 4-15).

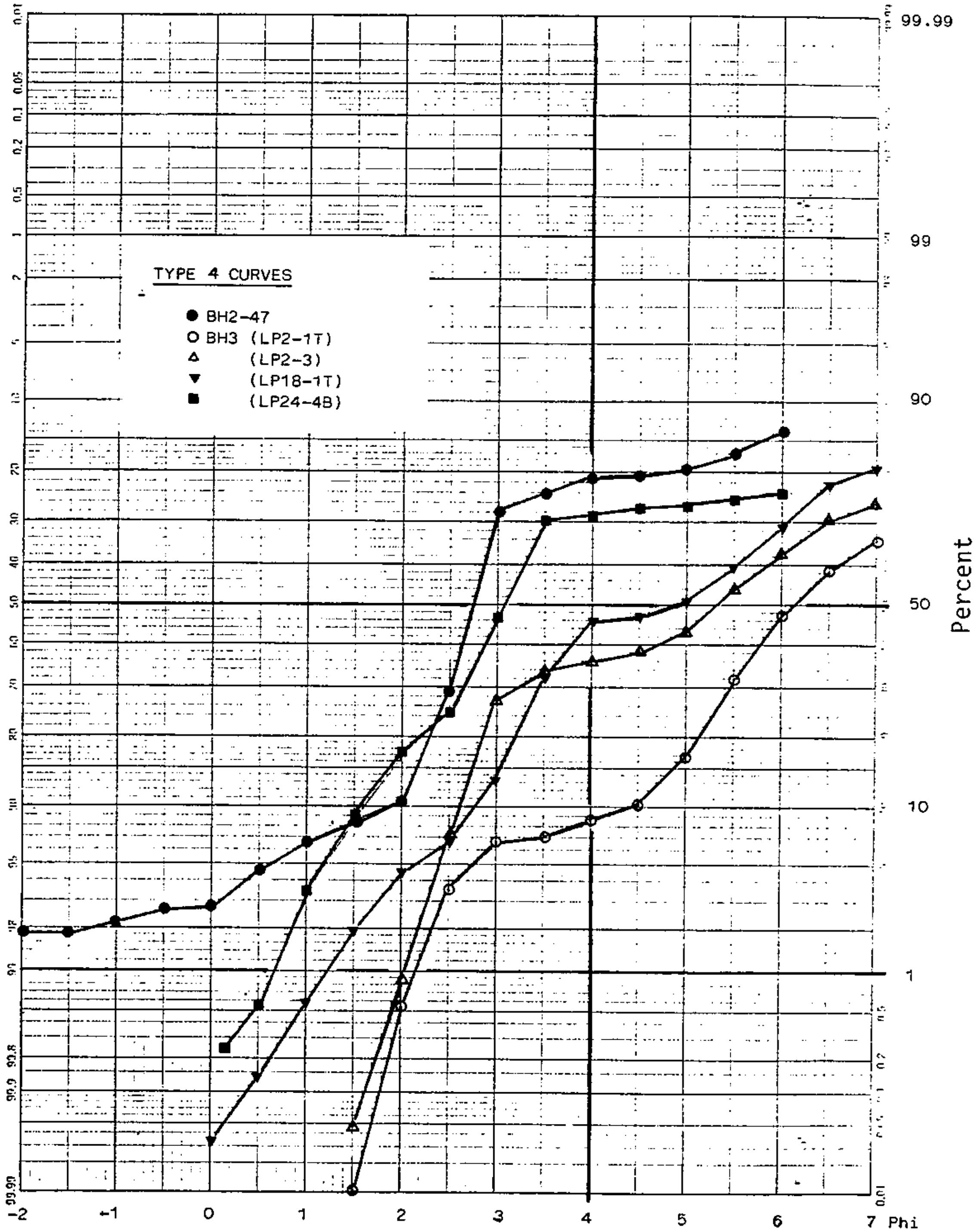

TYPE 4 CURVES
BH2-47
BH3 (LP2-1T)
(LP2-3)
(LP18-1T)
(LP24-4B)
99.99
99
90
50
10
1
Percent
-2
-1
0
1
2
3
4
5
6
7 Phi

Figure 3-18

C-M diagram for sediment samples from Long Point boreholes, with selected samples from surficial deposits in the area for comparison. Circumscribed fields (labelled 1 to 3) were drawn on the basis of natural clustering of the plotted points, and serve as the criteria for classifying depositional processes.

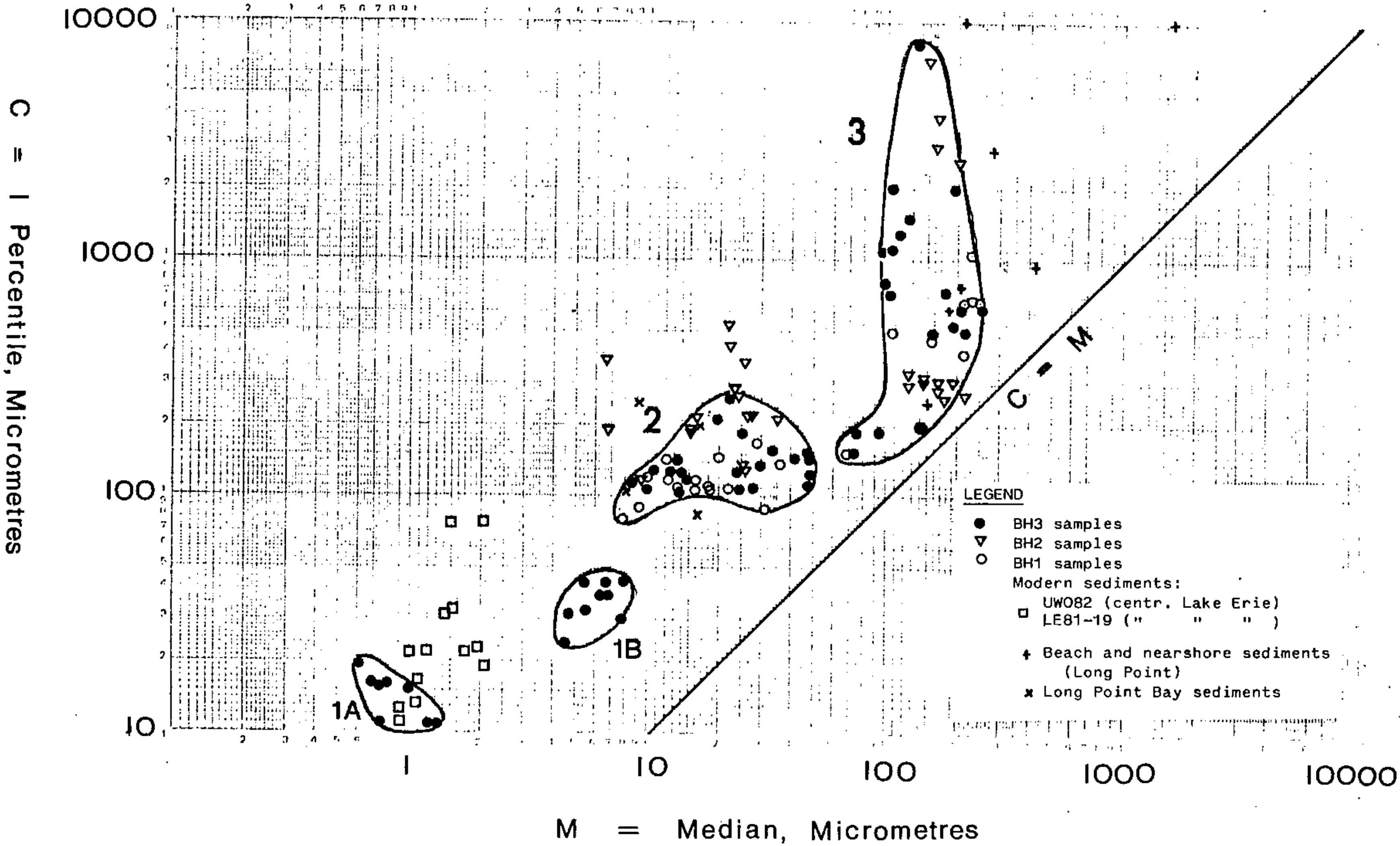
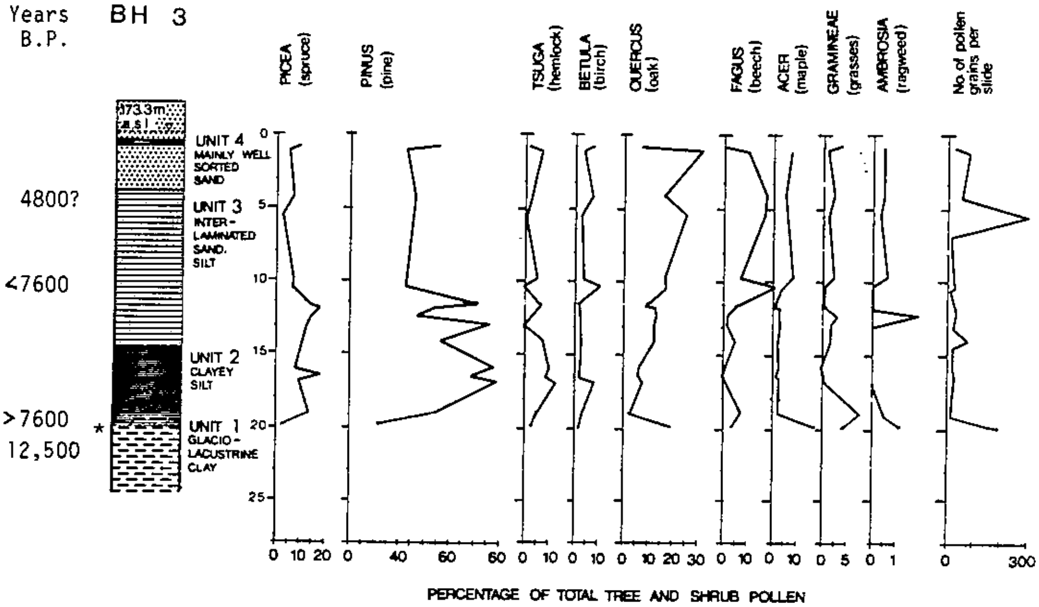

C = I Percentile, Micrometres
10000
1000
100
10
M = Median, Micrometres
1
10
100
1000
10000
1A
1B
2
3
C = M
LEGEND
BH3 samples
BH2 samples
BH1 samples
Modern sediments:
UWO82 (centr. Lake Erie)
LE81-19 (" " ")
Beach and nearshore sediments
(Long Point)
Long Point Bay sediments

Figure 3-19

Pollen diagrams (percentage of selected species with respect to the total tree and shrub pollen, plotted against depth in the core) for BH3 and LBH on Long Point. Note the disparity in vertical scales. Interpreted chronological markers (top: by the author and C.E. Winn; bottom: by T.W. Anderson, who supplied the diagram) are shown in the left-hand margin.



*8490 ± 300 (WAT-1083), no. 49, Table 3-1.

LONG POINT CORE (LBH)

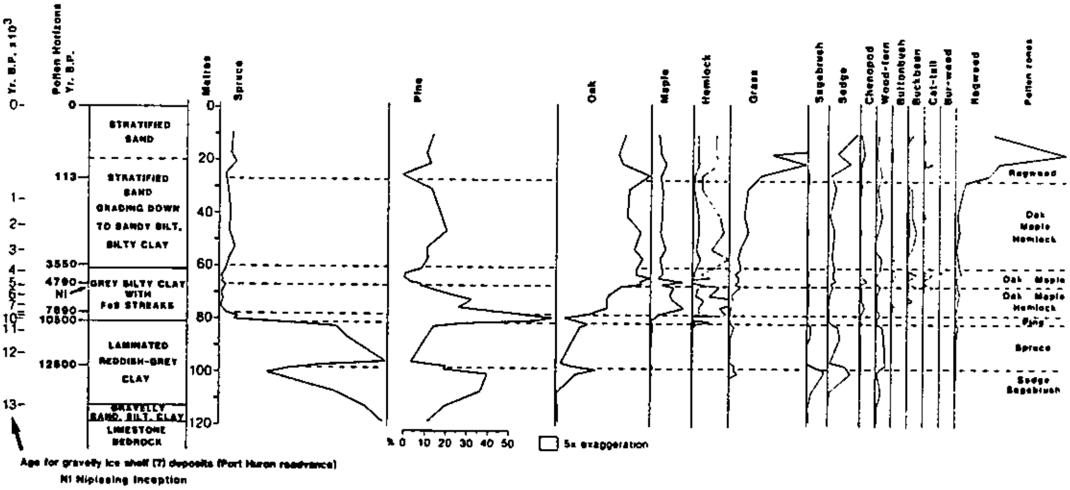


Figure 3-20

Pollen diagram for BH1 and BH2, Long Point. Samples for pollen analysis were taken at larger intervals than those for Figure 3-19 (1 to 1.5 m), so resolution of major pollen markers is limited. Interpreted chronological markers (T.W. Anderson, pers. comm.,1982) are shown at right.

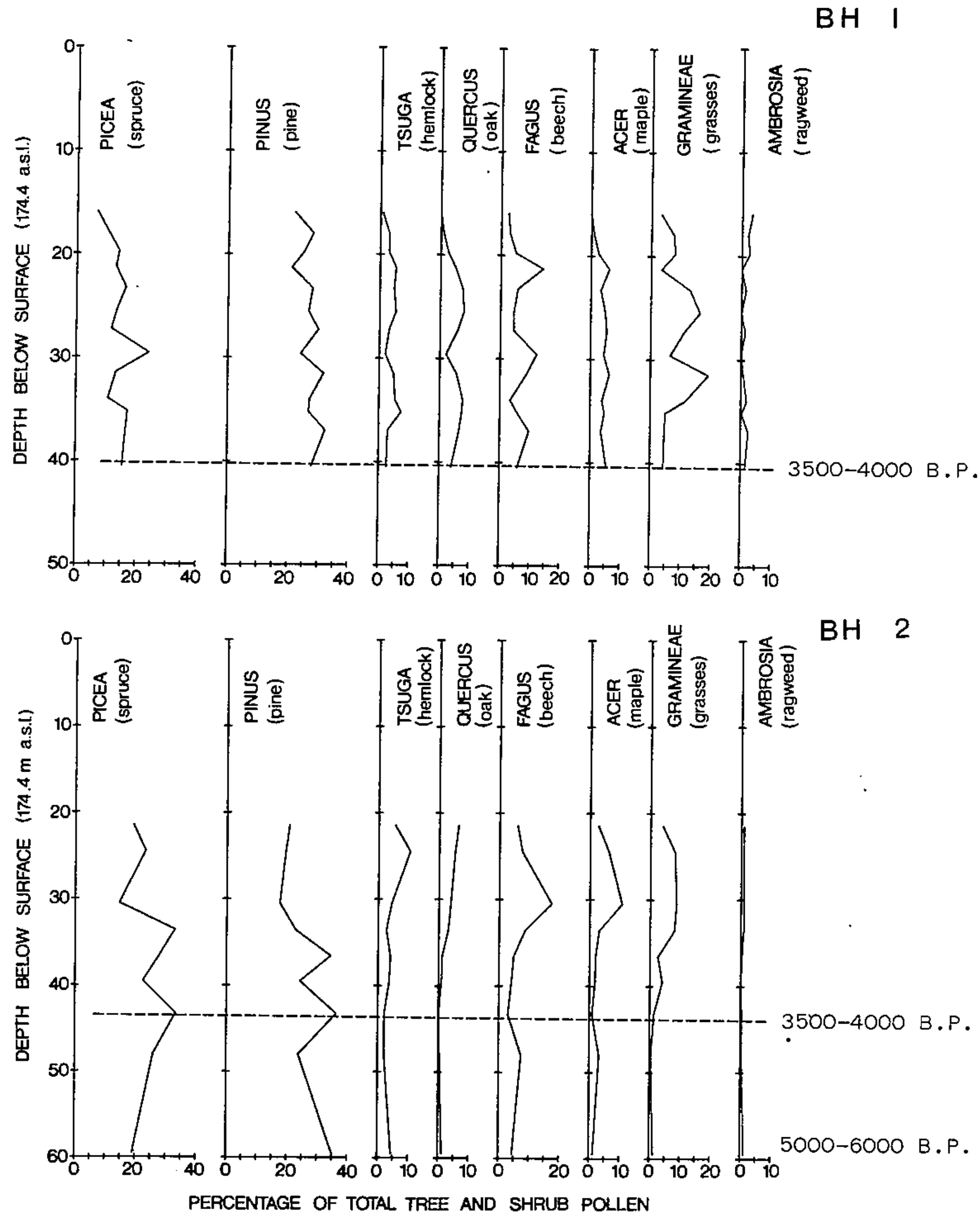

BH I
DEPTH BELOW SURFACE (174.4 a.s.l.)
PICEA (spruce)
PINUS (pine)
TSUGA (hemlock)
QUERCUS (oak)
FAGUS (beech)
ACER (maple)
GRAMINEAE (grasses)
AMBROSIA (ragweed)
3500–4000 B.P.
BH 2
DEPTH BELOW SURFACE (174.4 m a.s.l.)
PICEA (spruce)
PINUS (pine)
TSUGA (hemlock)
QUERCUS (oak)
FAGUS (beech)
ACER (maple)
GRAMINEAE (grasses)
AMBROSIA (ragweed)
3500–4000 B.P.
5000–6000 B.P.
PERCENTAGE OF TOTAL TREE AND SHRUB POLLEN

Figure 3-21

Representative X-ray diffractograms from samples from BH3, Long Point (analysis carried out by D. Desaulniers, University of Waterloo). Top section is from core section LP19 (see Appendix 5 for elevation) representing postglacial sediments; the two lower records are from LP25 and LP44, in sediments interpreted as glaciolacustrine in origin. Identification of peaks are shown in the top record. The letters A, H, and G refer to Air-dried, Heated to 350°C, and Glycolated for 1 hour at 60°C. A.D. refers to Acid-digestion in concentrated HCl for 8 hrs. at 60°C. Minerals identified are calcite (CAL), plagioclase feldspar (PLAG), quartz (QTZ), chlorite (CHL), montmorillonite (MML), and illite (ILL).

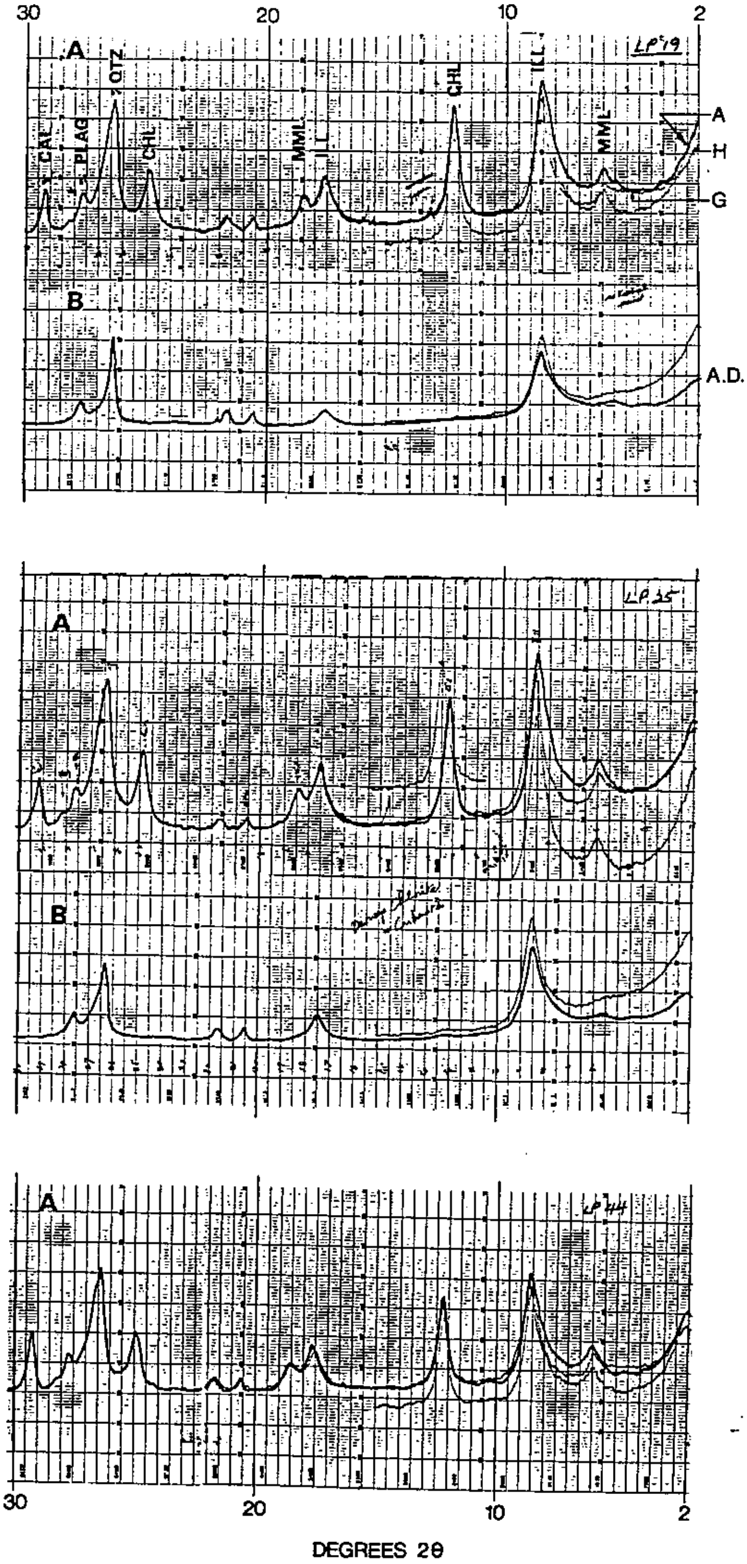
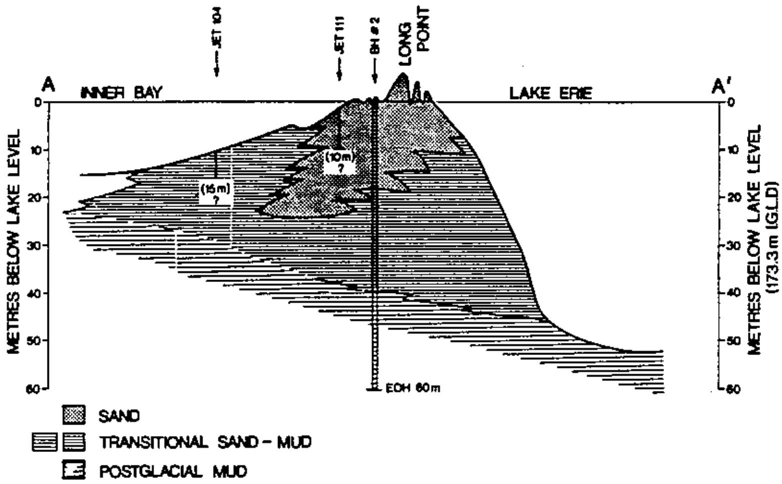
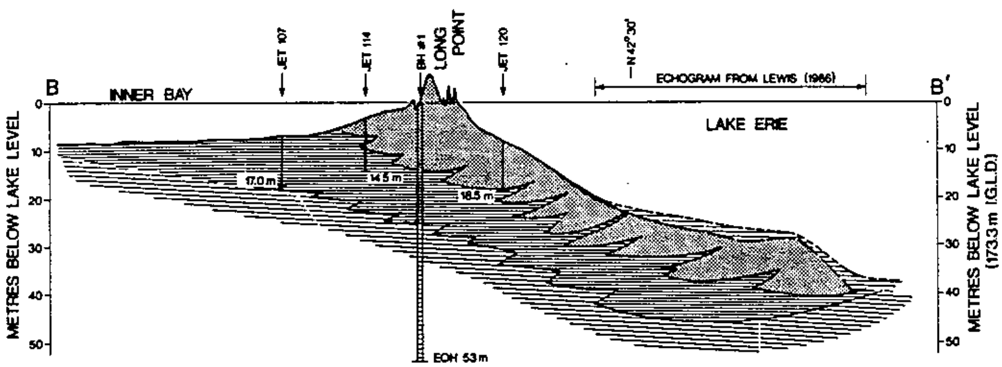

30
20
10
2
A
CAL
PLAG
QTZ
CHL
MML
ILL
CHL
ILL
MML
A
H
G
B
A.D.
A
B
A
30
20
10
2
DEGREES 2θ

Figure 3-22

Transverse cross-sections through Long Point boreholes BH1, 2, and 3, showing interpreted facies relationships. Jetting and short core data also used in this diagram are described in Table 3-2. Locations of sections are given in Figure 2-6 (inset). Interpretation of transgressive migration at BH1 and 3, and regressive shoreline migration at BH2 is based in part on pattern of beach ridges preserved on Long Point.


A
A'
INNER BAY
LAKE ERIE
JET 104
JET 111
BH # 2
LONG POINT
(10m) ?
(15m) ?
EOH 60m
METRES BELOW LAKE LEVEL
METRES BELOW LAKE LEVEL (173.3m I.G.L.D)
SAND
TRANSITIONAL SAND - MUD
POSTGLACIAL MUD


B
B'
INNER BAY
LAKE ERIE
JET 107
JET 114
BH #1
LONG POINT
JET 120
N 42° 30'
ECHOGRAM FROM LEWIS (1966)
17.0m
14.5m
18.5m
EOH 53m
METRES BELOW LAKE LEVEL
METRES BELOW LAKE LEVEL (173.3m I.G.L.D.)

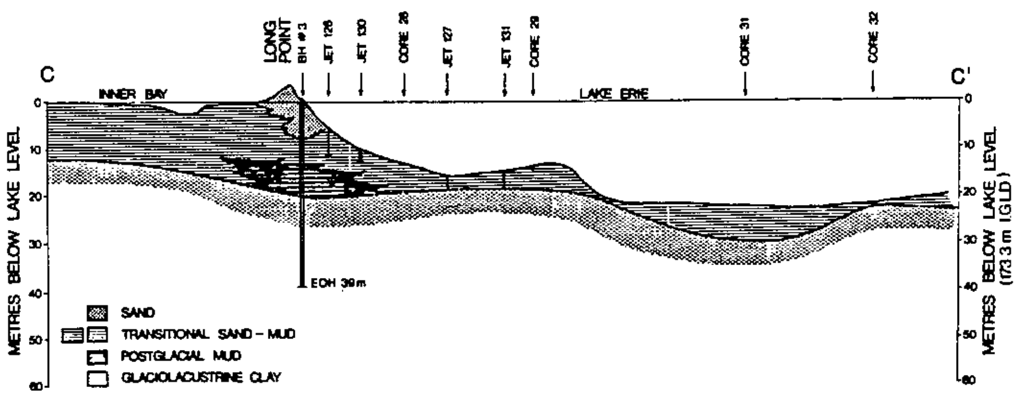
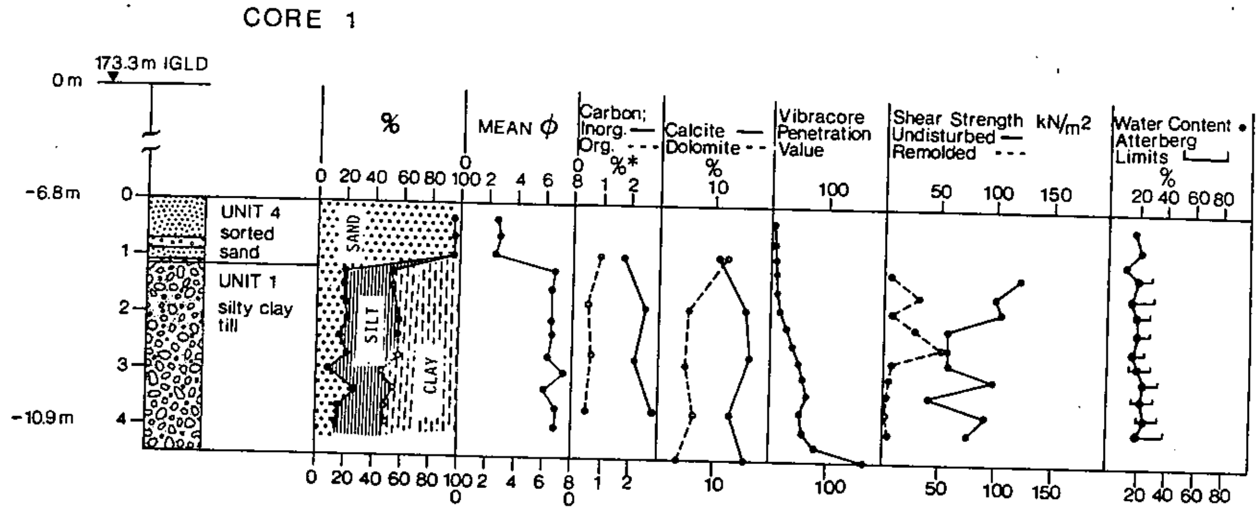
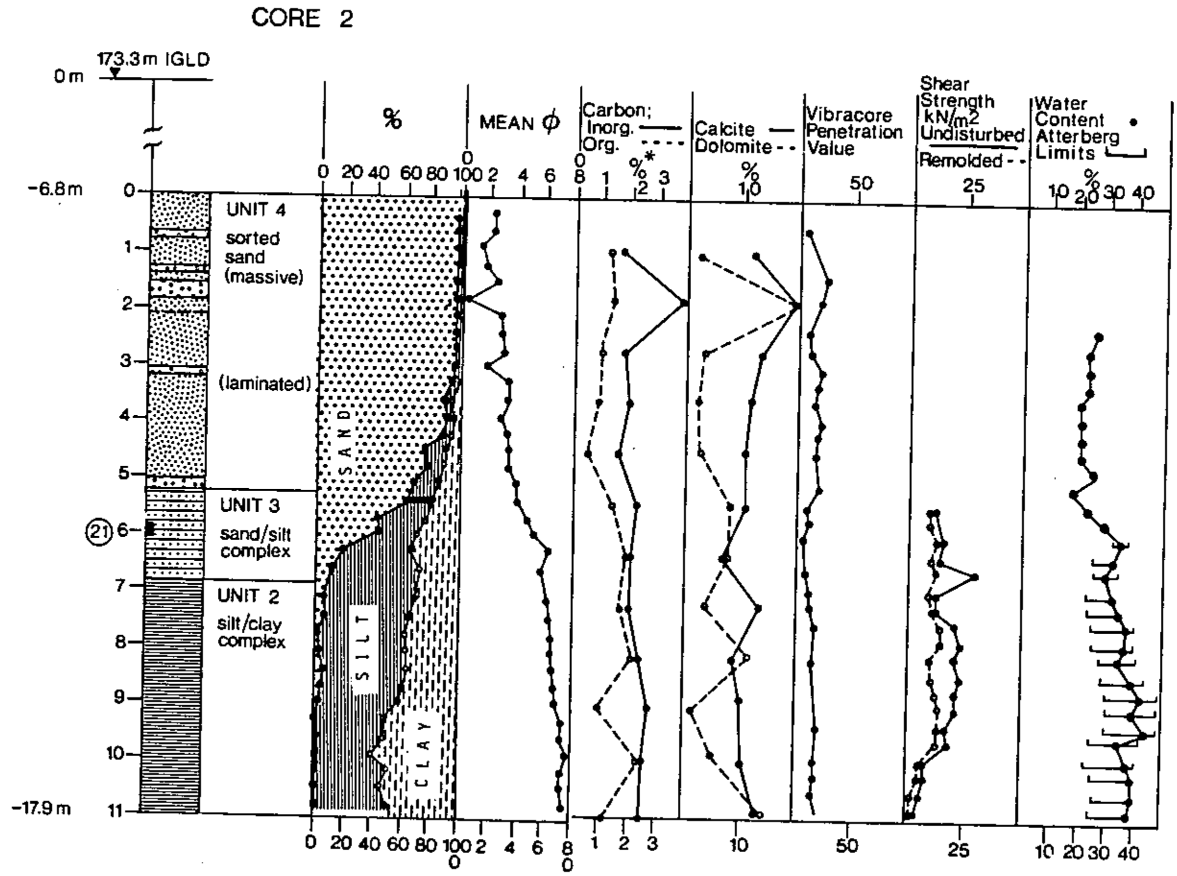

C
C'
INNER BAY
LAKE ERIE
LONG POINT
BH #3
JET 126
JET 130
CORE 28
JET 127
JET 131
CORE 29
CORE 31
CORE 32
EOH 39m
METRES BELOW LAKE LEVEL
METRES BELOW LAKE LEVEL (173.3m I.G.L.D.)
SAND
TRANSITIONAL SAND - MUD
POSTGLACIAL MUD
GLACIOLACUSTRINE CLAY

Figure 4-1

Lithology, grain-size parameters, selected chemical analyses, and geotechnical properties of Vibracores 1 (top) and 2 (bottom), Pelee Shoal. Circled numbers in the left margin refer to radiocarbon dates obtained from the cores (corresponding to numbers in Table 3-1). (modified from Coakley *et al*, 1977)



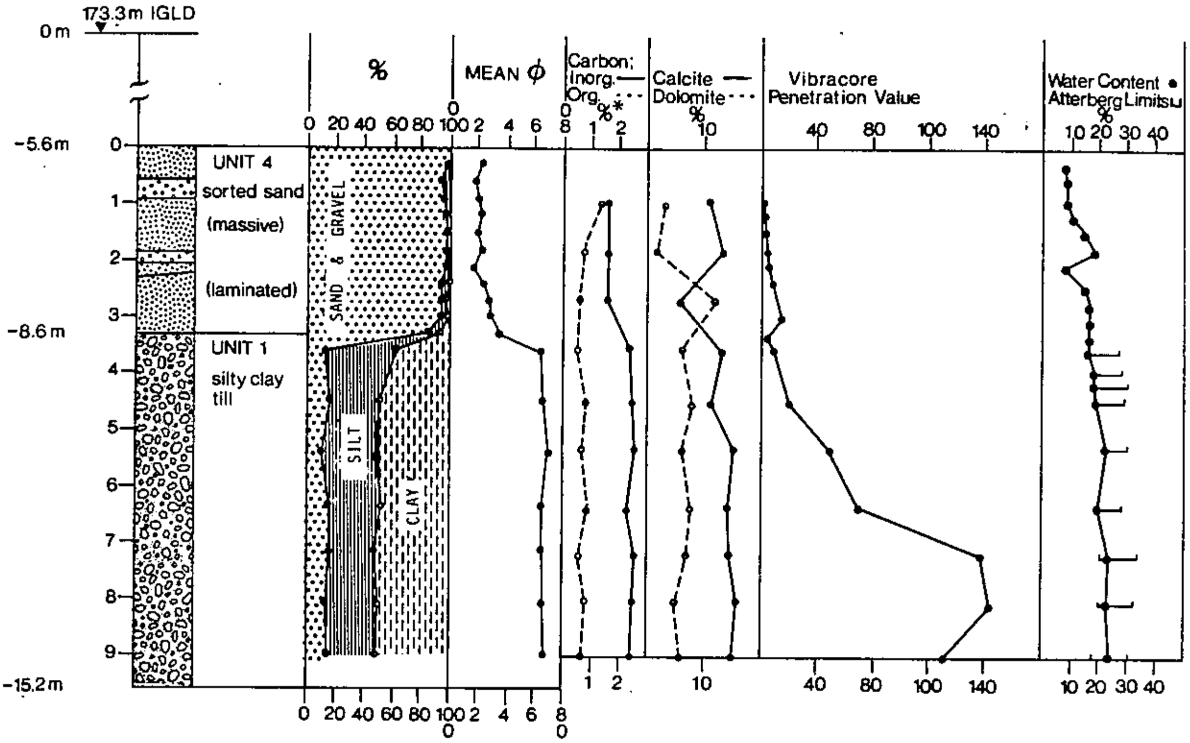


21 : 10,260±325 BP (BGS-254)

Figure 4-2

Lithology, grain-size selected grain-size parameters, chemical analyses, and geotechnical properties of Vibracores 3 and 4, Pelee Shoal. (Modified from Coakley et al, 1977).

CORE 3


173.3m IGLD
0 m
-5.6m
-8.6 m
-15.2m
UNIT 4
sorted sand
(massive)
(laminated)
UNIT 1
silty clay
till
SAND & GRAVEL
SILT
CLAY
%
MEAN φ
Carbon;
Inorg. —
Org. - - -
%*
Calcite —
Dolomite - - -
%
Vibracore
Penetration Value
Water Content •
Atterberg Limits
%

CORE 4

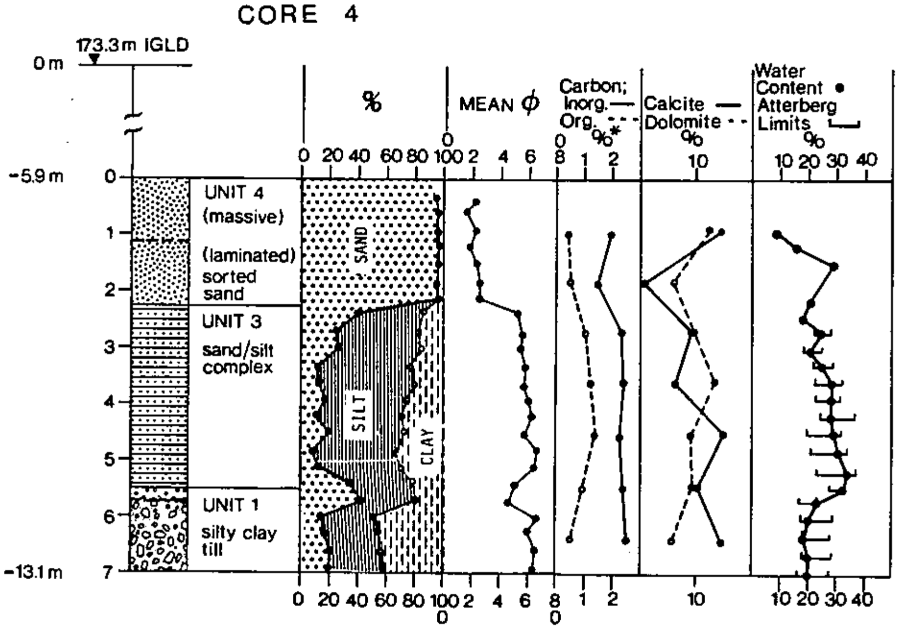
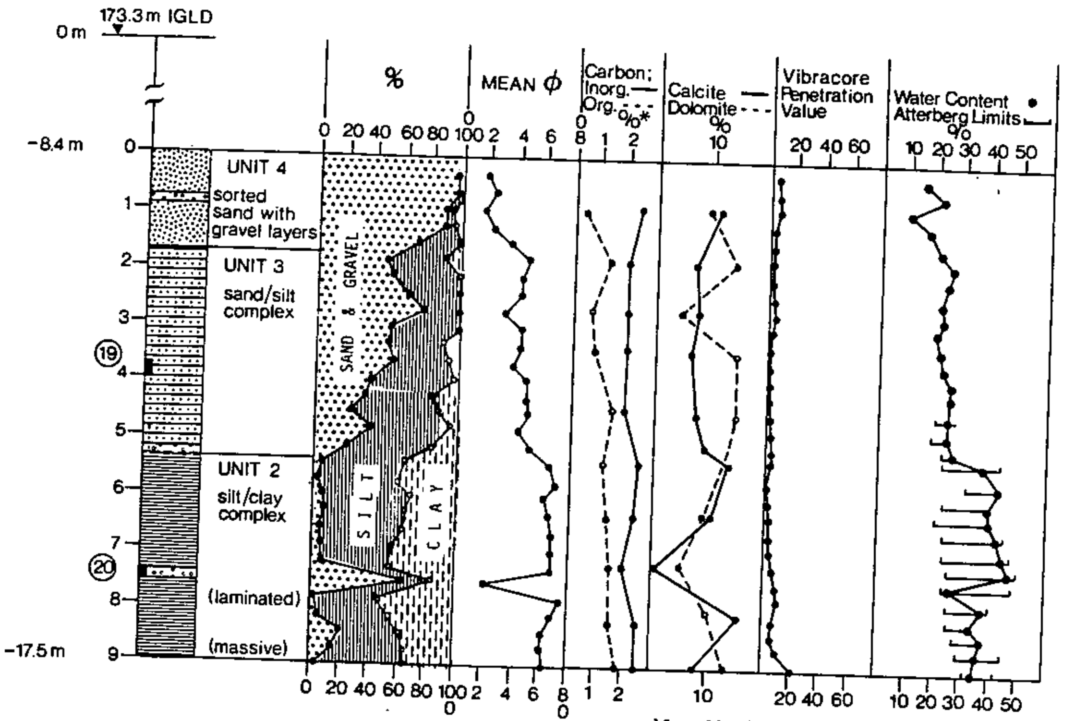

173.3m IGLD
0 m
-5.9 m
-13.1 m
UNIT 4
(massive)
(laminated)
sorted
sand
UNIT 3
sand/silt
complex
UNIT 1
silty clay
till
SAND
SILT
CLAY
%
MEAN φ
Carbon;
Inorg. —
Org. - - -
%*
Calcite —
Dolomite - - -
%
Water
Content •
Atterberg
Limits
%

Figure 4-3

Lithology, grain-size parameters, selected chemical analyses, and geotechnical properties of Vibracores 5 and 6, Pelee Shoal. Circled numbers in the left margin refer to radiocarbon dates obtained at that position in the core (corresponding to numbers in Table 3-1). (Modified from Coakley et al, 1977).

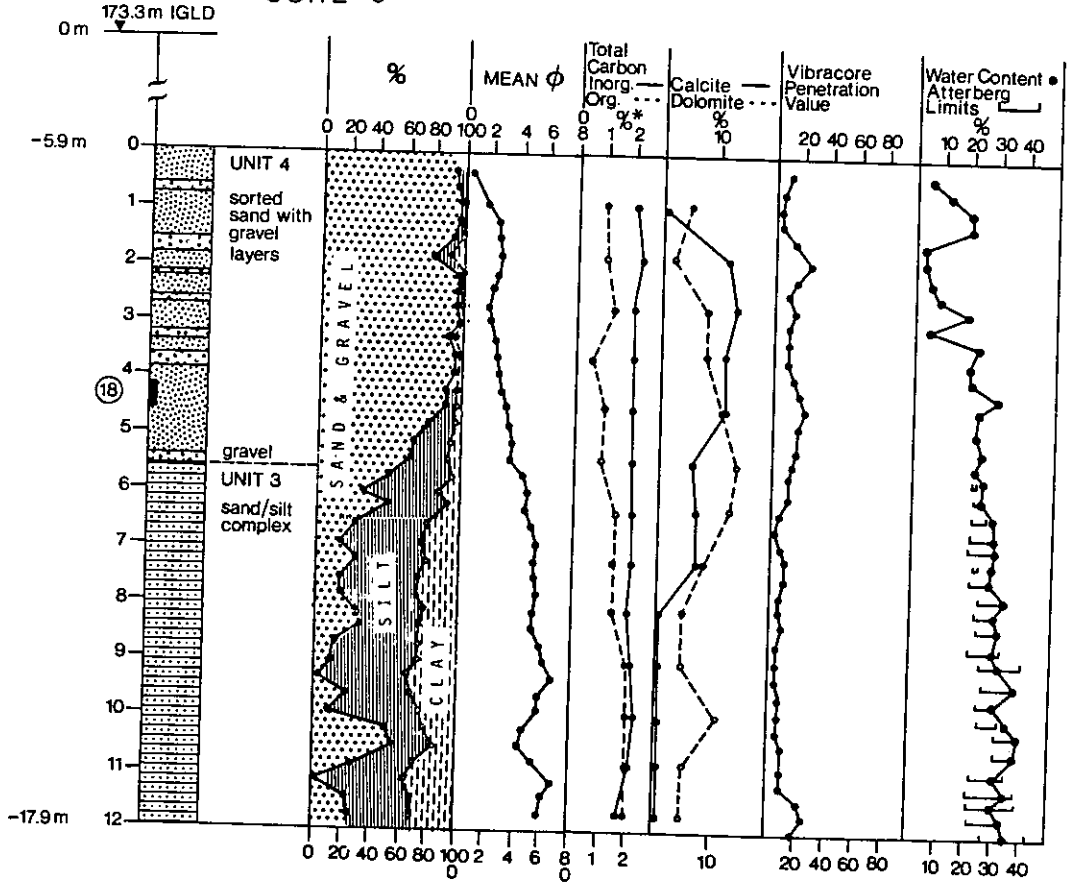
CORE 5



19 : 6600±180 BP (BGS-252)

20 : 8100±300 BP (BGS-255)

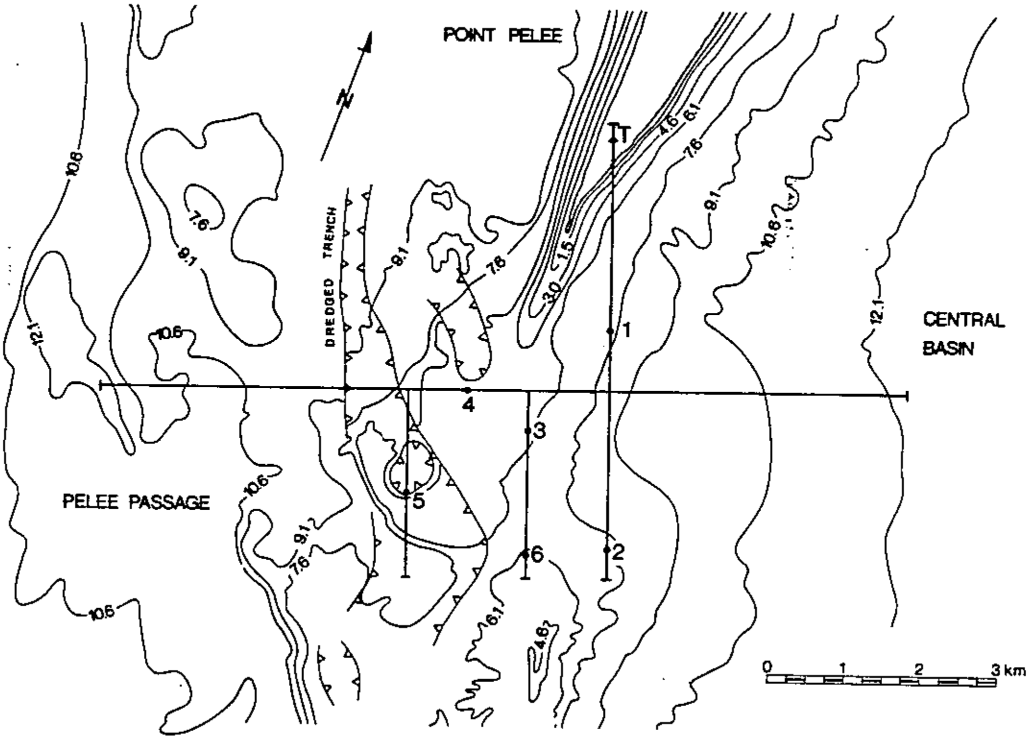
CORE 6

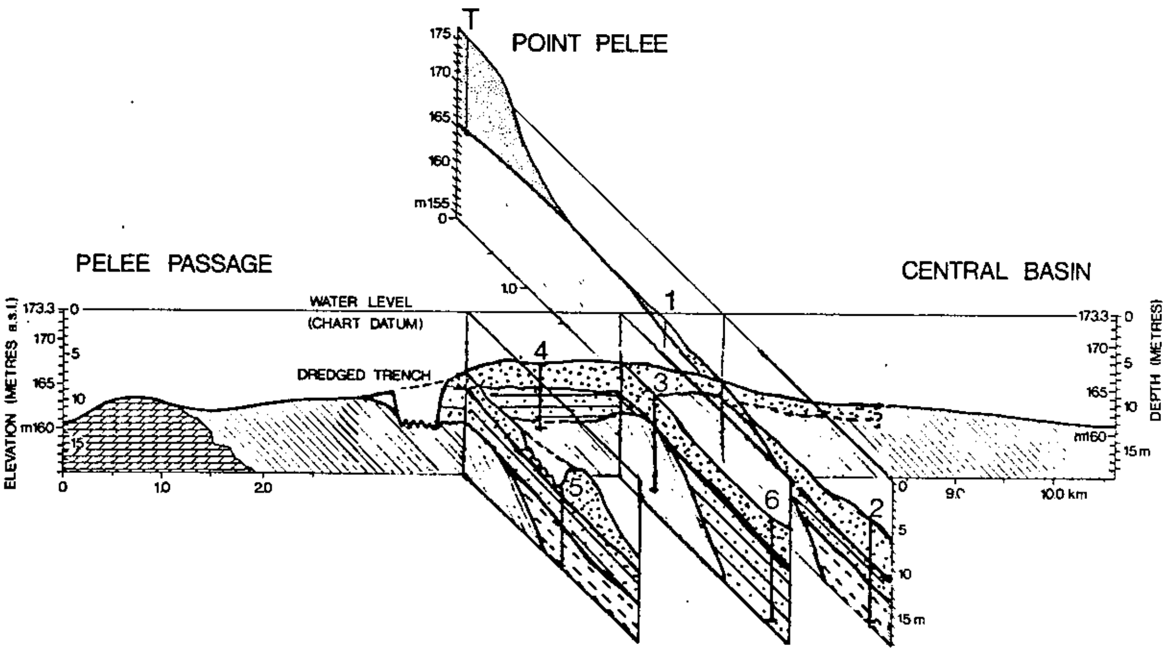


18 : 3600±140 BP (BGS-256)

Figure 4-4

Fence diagram showing sections through Vibracore sites on the Pelee Shoal, and including one land-based borehole 3T (Figure 2-4). Figure modified from that in Coakley *et al* (1977). Units refer to inferred stratigraphic classification in Section 4.1.





LEGEND

Carbonate bedrock

Till (Unit 1)

Unit 2

Unit 3

Unit 4

Figure 4-5

Longitudinal (top) and transverse (bottom) cross-sections through boreholes and Vibracores in the Point Pelee area. BH 1, 2, and 3T were drilled by Terasmae (1970) and two of them are described in detail in Figure 4-6. Borehole 2T was plotted from written logs (J. Terasmae, pers. comm. 1981). Location of cross-sections is given in Figure 2-6.

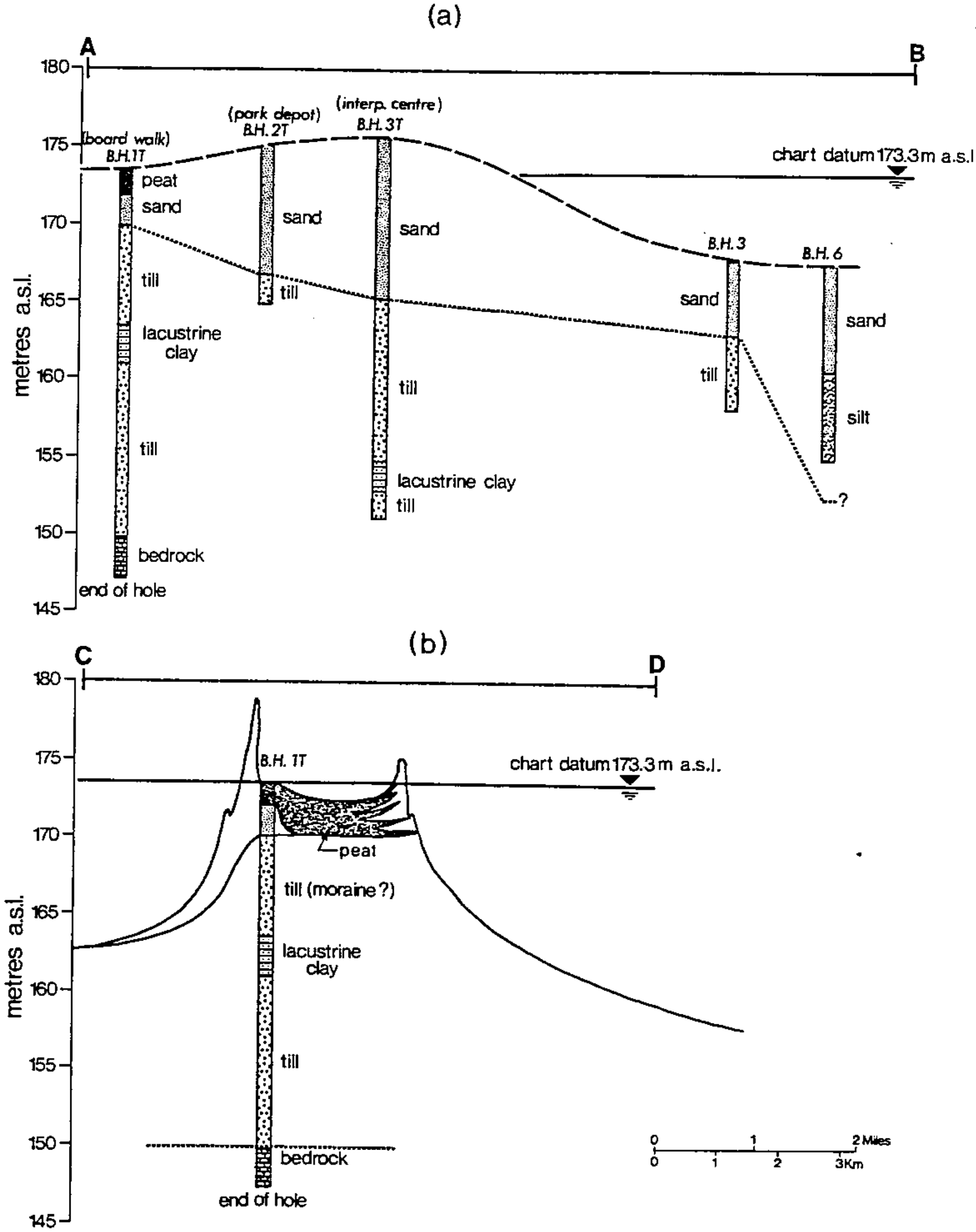

(a)
A
B
180
175
170
165
160
155
150
145
metres a.s.l.
(board walk)
B.H. 1T
(park depot)
B.H. 2T
(interp. centre)
B.H. 3T
chart datum 173.3 m a.s.l
peat
sand
till
lacustrine clay
till
bedrock
end of hole
sand
till
sand
till
lacustrine clay
till
B.H. 3
sand
till
B.H. 6
sand
silt
?
(b)
C
D
180
175
170
165
160
155
150
145
metres a.s.l.
B.H. 1T
chart datum 173.3 m a.s.l.
peat
till (moraine?)
lacustrine clay
till
bedrock
end of hole
0
1
2 Miles
0
1
2
3Km

Figure 4-6

Lithology of boreholes (1T and 3T in Figure 2-4) drilled in Point Pelee National Park (from Terasmae, 1970). Profiles A, B, etc. represent other boreholes drilled on the same site (within 200 m of the main borehole (A).

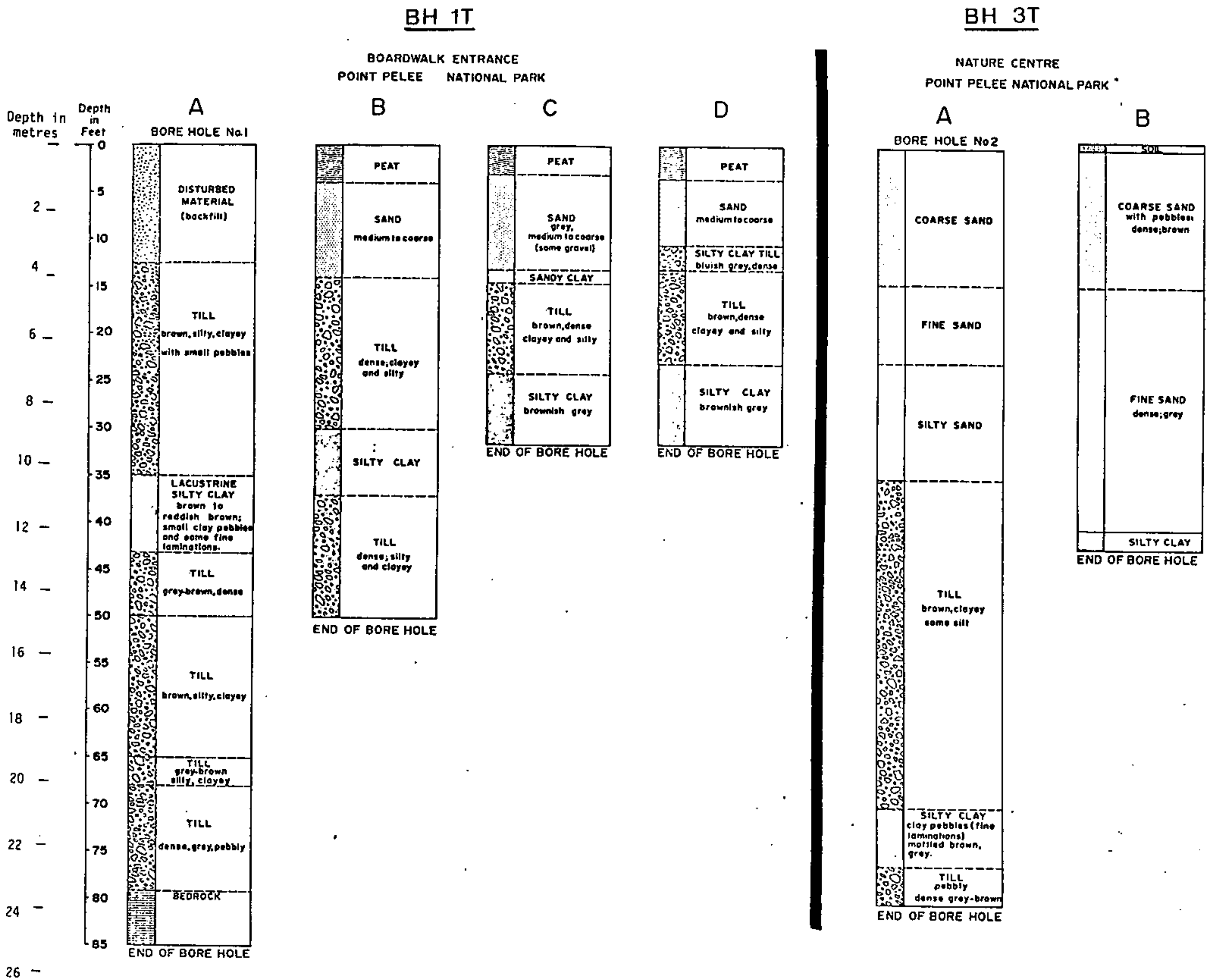

BH 1T
BOARDWALK ENTRANCE
POINT PELEE NATIONAL PARK
BH 3T
NATURE CENTRE
POINT PELEE NATIONAL PARK
Depth in metres
Depth in Feet
A
BORE HOLE No.1
DISTURBED MATERIAL (backfill)
TILL brown, silty, clayey with small pebbles
LACUSTRINE SILTY CLAY brown to reddish brown; small clay pebbles and some fine laminations.
TILL grey-brown, dense
TILL brown, silty, clayey
TILL grey-brown silty, clayey
TILL dense, grey, pebbly
BEDROCK
END OF BORE HOLE
B
PEAT
SAND medium to coarse
TILL dense; clayey and silty
SILTY CLAY
TILL dense; silty and clayey
END OF BORE HOLE
C
PEAT
SAND grey, medium to coarse (some gravel)
SANDY CLAY
TILL brown, dense clayey and silty
SILTY CLAY brownish grey
END OF BORE HOLE
D
PEAT
SAND medium to coarse
SILTY CLAY TILL bluish grey, dense
TILL brown, dense clayey and silty
SILTY CLAY brownish grey
END OF BORE HOLE
A
BORE HOLE No2
COARSE SAND
FINE SAND
SILTY SAND
TILL brown, clayey some silt
SILTY CLAY clay pebbles (fine laminations) mottled brown, grey.
TILL pebbly dense grey-brown
END OF BORE HOLE
B
SOIL
COARSE SAND with pebbles dense; brown
FINE SAND dense; grey
SILTY CLAY
END OF BORE HOLE

Figure 4-7

Representative cumulative grain-size curves from Pelee Shoal borehole samples classified as Group 1 (Figure 4-10). Note the very poor sorting (low slope of curves), with particle sizes ranging from pebble to fine clay, typical of glacial till.

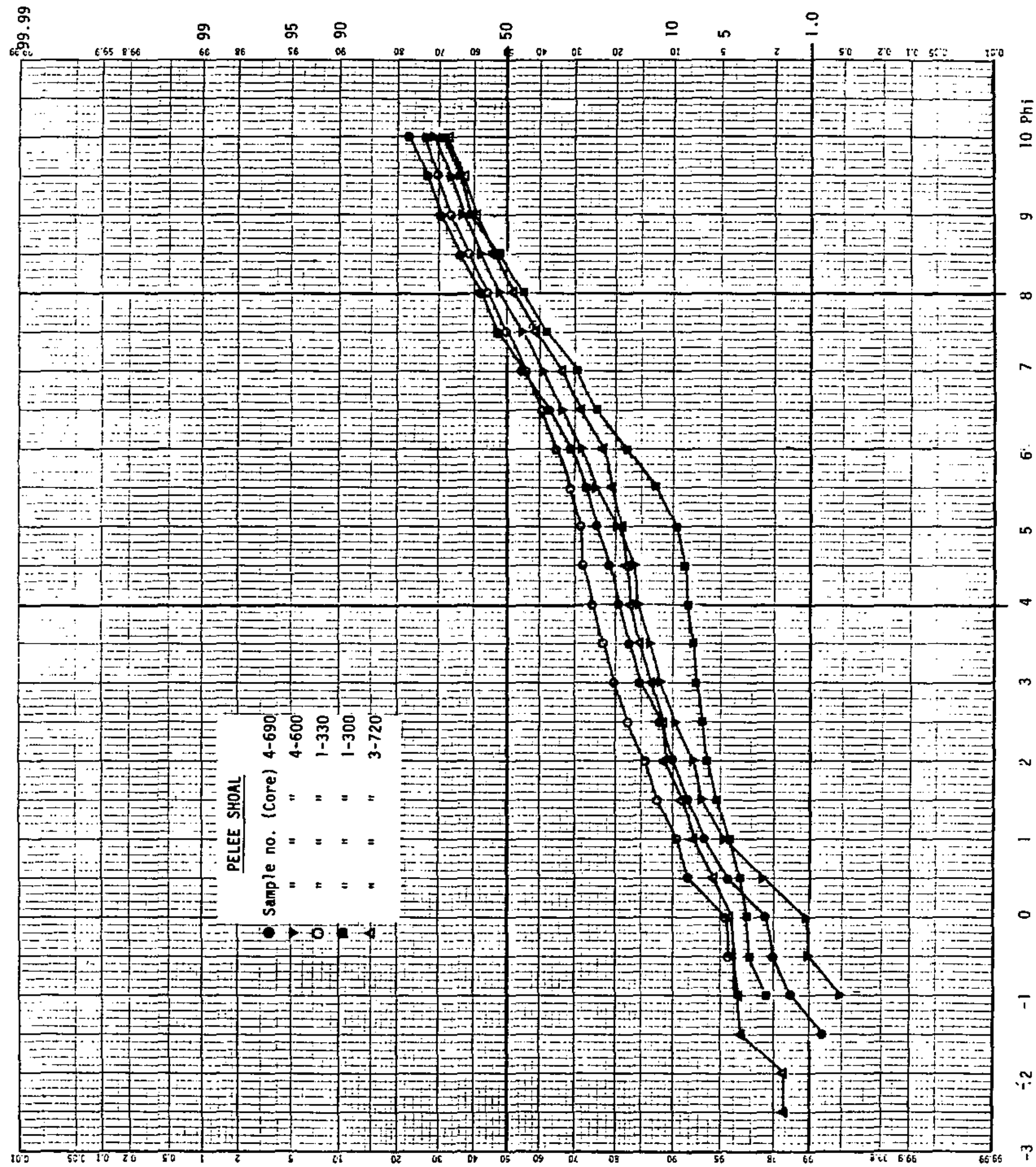

PELEE SHOAL
Sample no. (Core) 4-690
" " " 4-600
" " " 1-330
" " " 1-300
" " " 3-720
10 Phi
99.99
99
95
90
50
10
5
1.0

Figure 4-8

Representative cumulative grain-size curves from Pelee Shoal samples classified as Group 2 (Figure 4-10). Note the low slope, ranging from linear, to convex-upward in shape, indicative of gravity settling from a turbid suspension. Though showing the same overall shape, the group can be sub-divided into three on the basis of coarsening texture from 2a to 2c.

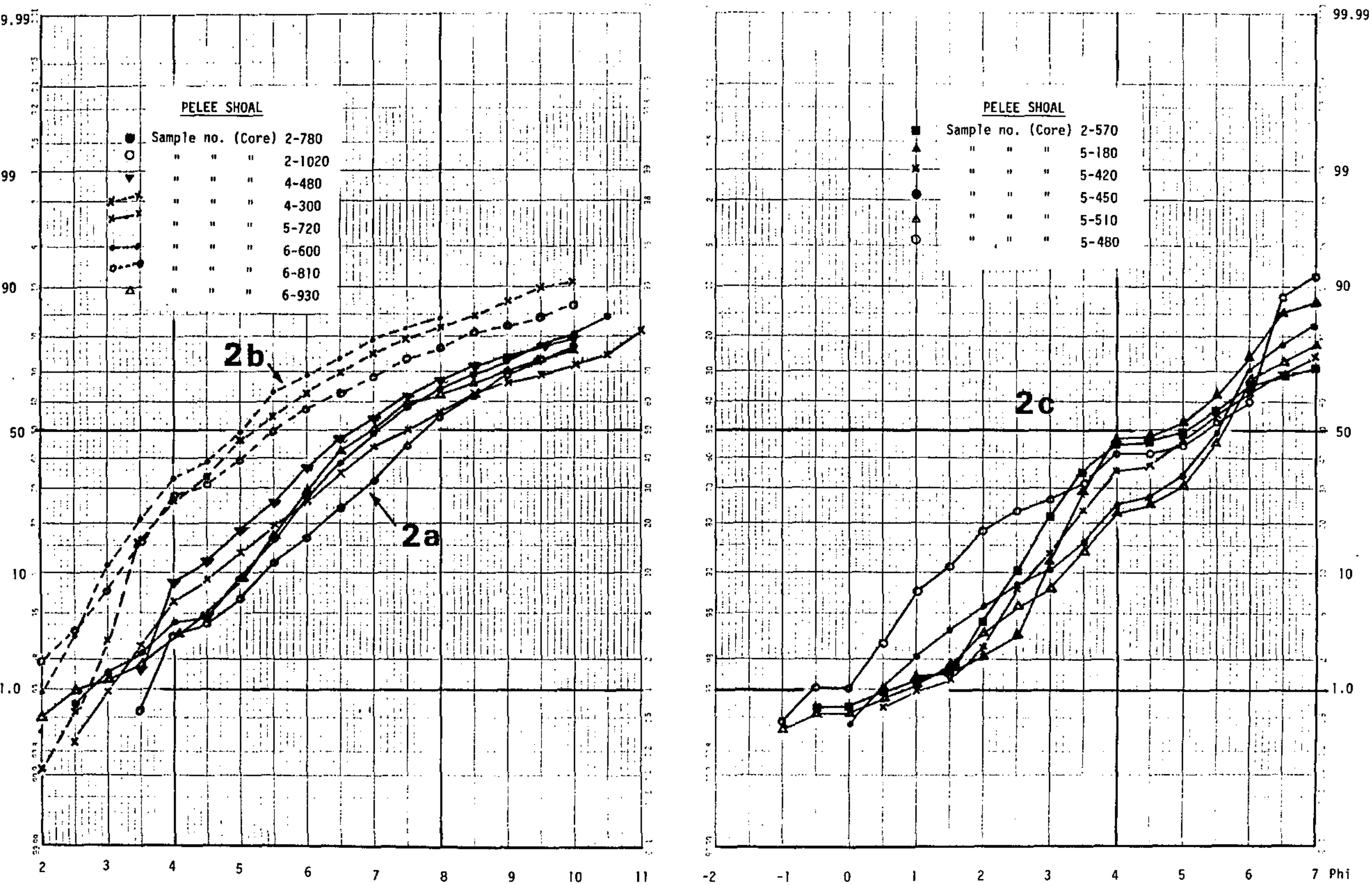

PELEE SHOAL
Sample no. (Core) 2-780
" " " 2-1020
" " " 4-480
" " " 4-300
" " " 5-720
" " " 6-600
" " " 6-810
" " " 6-930
2b
2a
PELEE SHOAL
Sample no. (Core) 2-570
" " " 5-180
" " " 5-420
" " " 5-450
" " " 5-510
" " " 5-480
2c
99.99
99
90
50
10
1.0
Phi

Figure 4-9

Representative cumulative grain-size curves from Pelee Shoal samples classified as Group 3 (Figure 4-10). Main group 3 ranges from samples having a relatively large traction (coarse) component (left) to very well sorted sands, transported predominantly by saltation (middle). The curves, 3a, on the right are anomalous, and show a second mode in the clay fraction. On Figure 4-10, this sub-group falls between Groups 2 and 3.

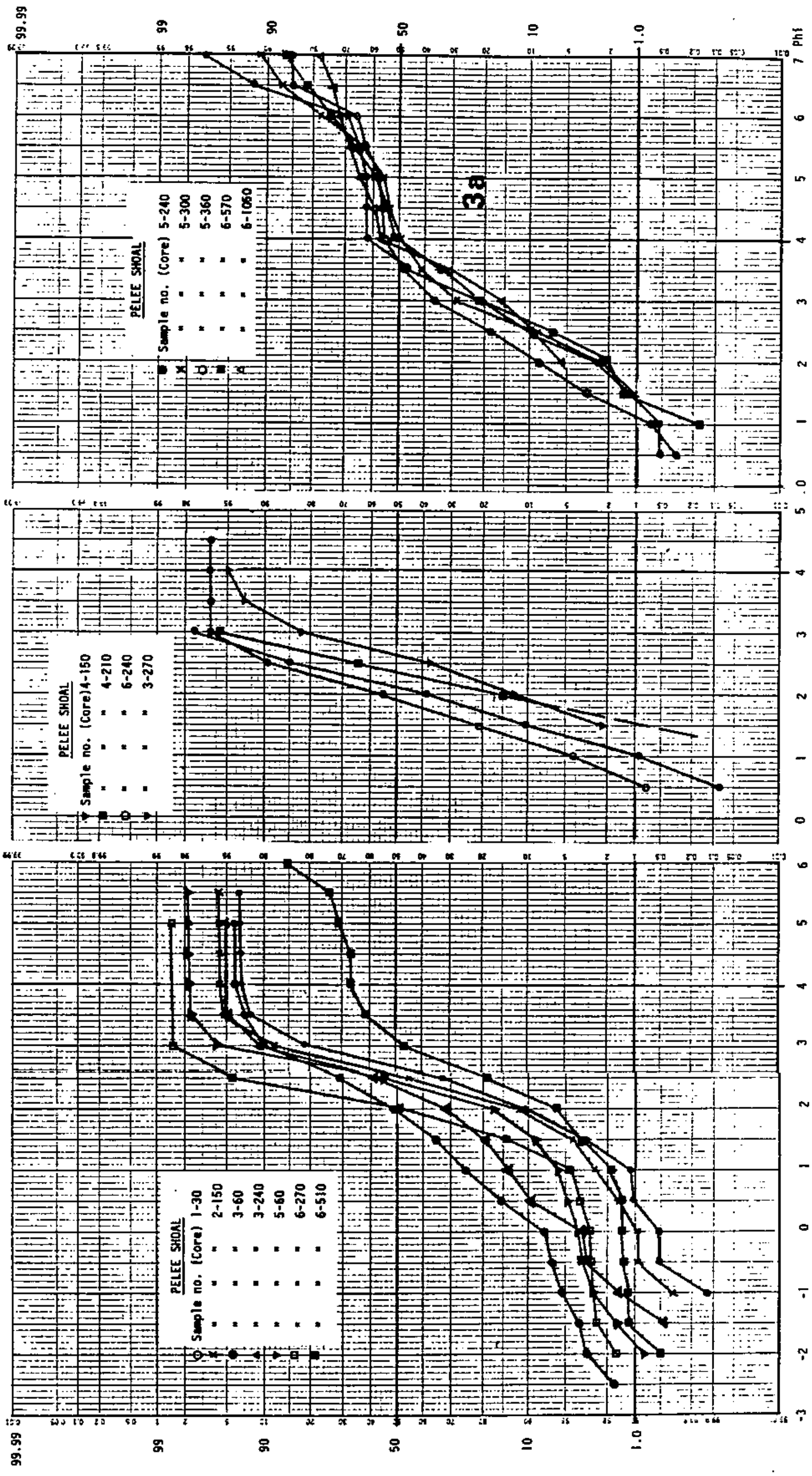
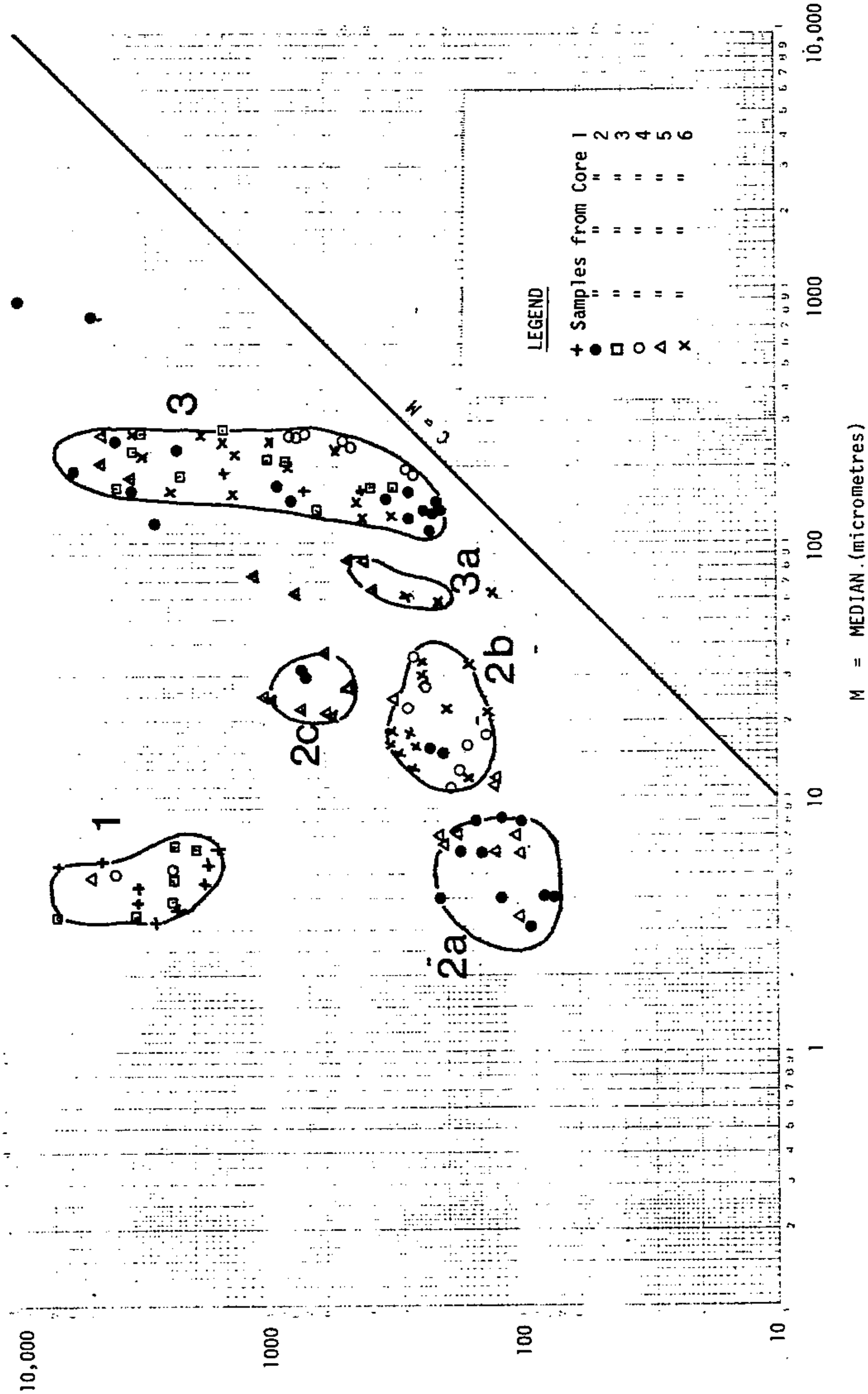

PELEE SHOAL
Sample no. (Core) 5-240
5-300
5-360
6-570
6-1050
38
PELEE SHOAL
Sample no. (Core)4-150
4-210
6-240
3-270
PELEE SHOAL
Sample no. (Core) 1-30
2-150
3-60
3-240
5-60
6-270
6-510
99.99
99
90
50
10
1.0
Phi

Figure 4-10

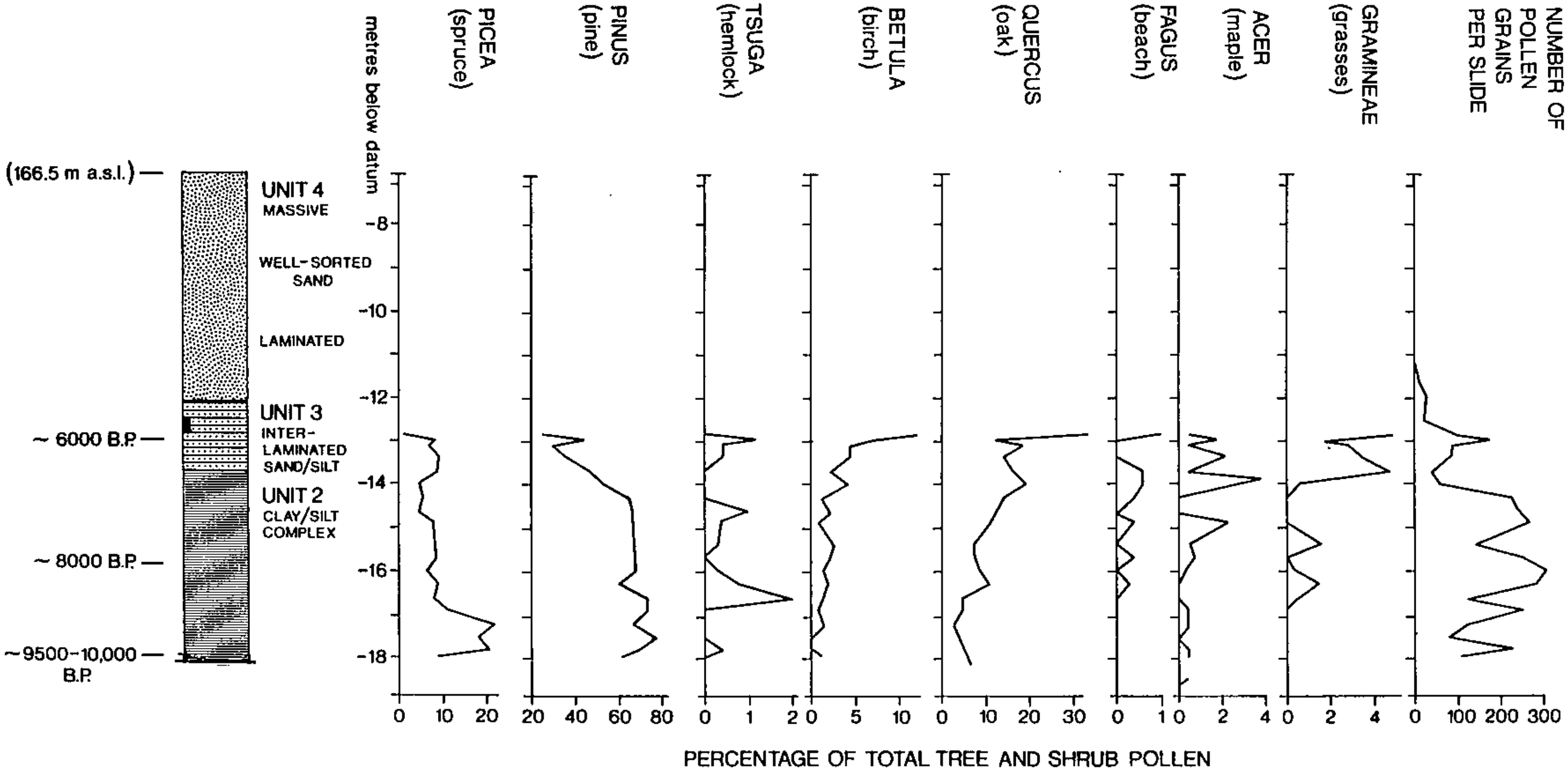
C-M diagram for selected sediment samples from the Pelee Shoal. Circumscribed fields were drawn on the basis of natural clustering of the full plotted data set.



C = 1 Percentile (micrometres)

Figure 4-11

Pollen diagram for Core 2, Pelee Shoal, showing selected pollen species distribution versus depth in the core. Chronological markers shown to left of core were inferred from pollen species trends. Pollen analysis was carried out by Barnett-Winn Palynological Consultants, Stoney Creek, Ontario.



■ Date no. 21 (Table 3-1) 10,260 ± 325 B.P. (BGS-254)

Figure 4-12

Figure (reproduced from Kalas, 1980) showing vertical profile of molluscan species abundance and species diversity (left). The mollusk data were used to produce the interpreted curve of sediment accumulation rate shown on the right. Asterisks represent the occurrence of terrestrial mollusk species in significant numbers.

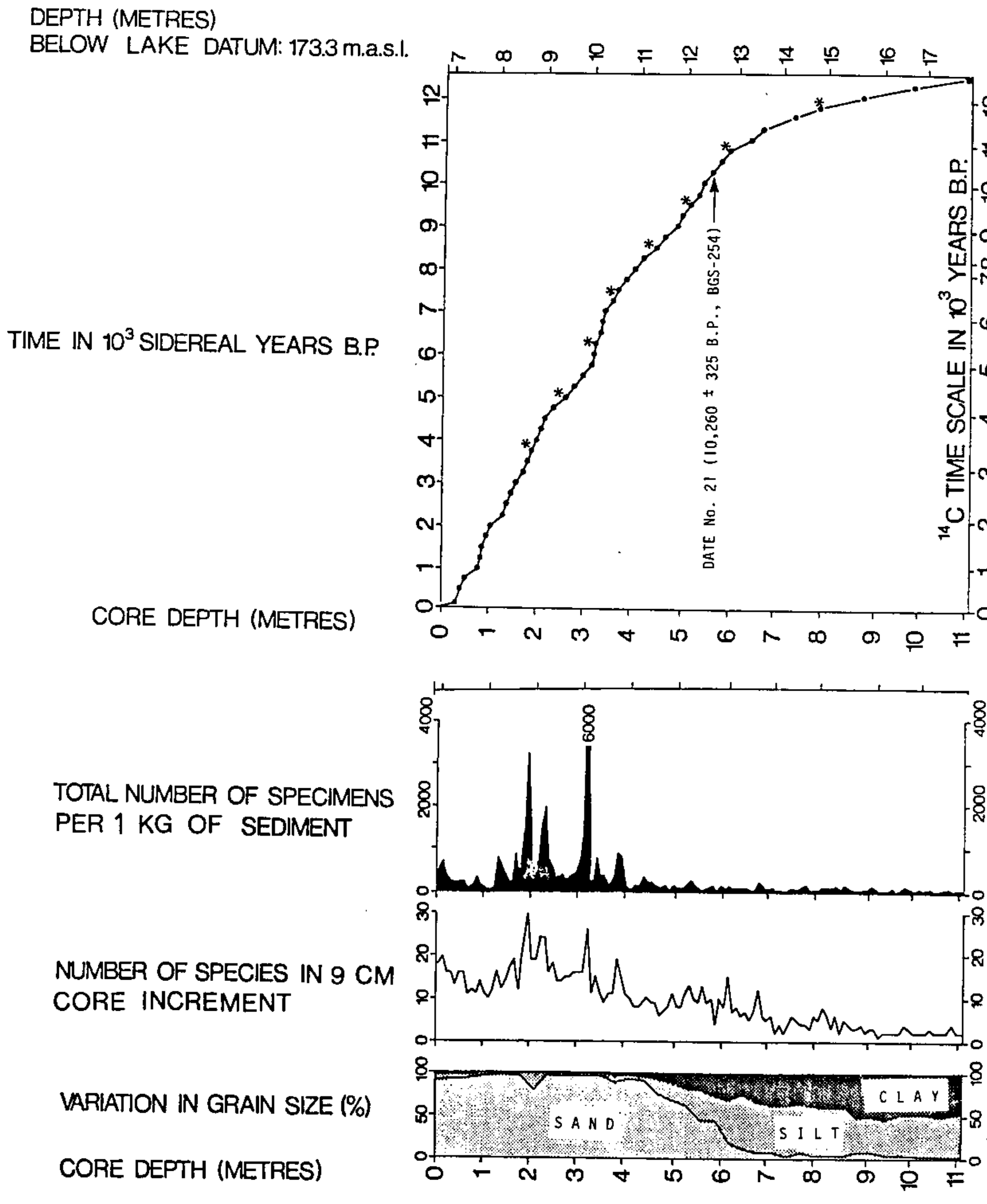
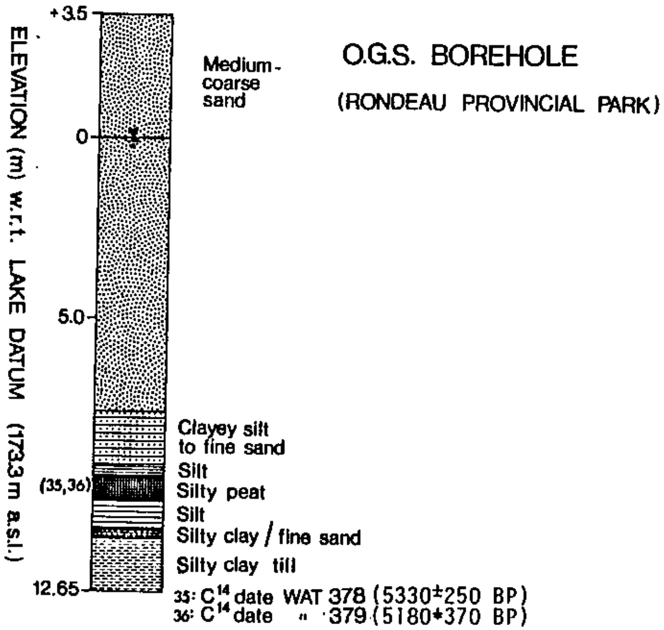
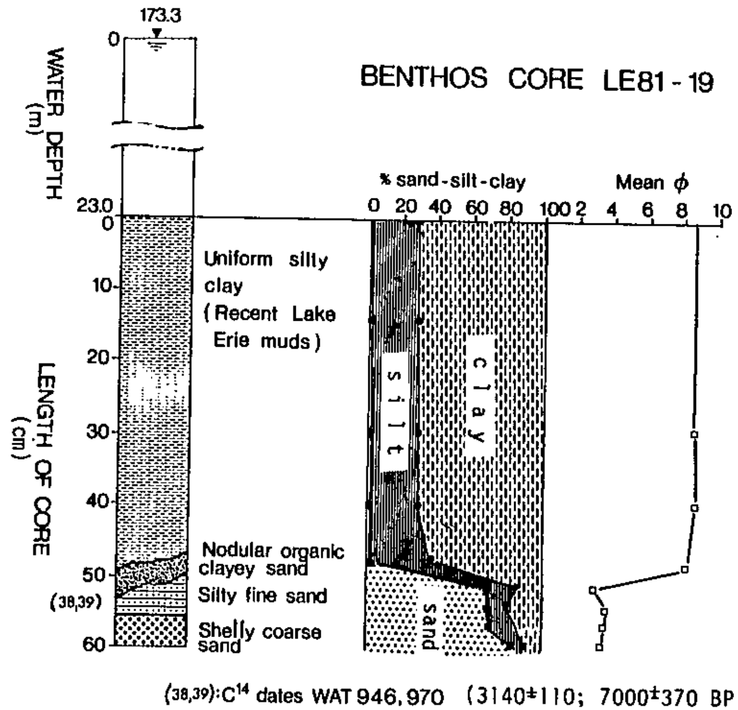

DEPTH (METRES)
BELOW LAKE DATUM: 173.3 m.a.s.l.
TIME IN 10³ SIDEREAL YEARS B.P.
CORE DEPTH (METRES)
DATE No. 21 (10,260 ± 325 B.P., BGS-254)
¹⁴C TIME SCALE IN 10³ YEARS B.P.
TOTAL NUMBER OF SPECIMENS
PER 1 KG OF SEDIMENT
6000
NUMBER OF SPECIES IN 9 CM
CORE INCREMENT
VARIATION IN GRAIN SIZE (%)
SAND
SILT
CLAY
CORE DEPTH (METRES)

Figure 4-13

Plotted log of a geological borehole (OGS-1) drilled on Pointe-aux-Pins (Rondeau Provincial Park) by the Ontario Geological Survey, showing also the location of two radiocarbon dates (Table 3-1) at top left. Figures at top right and bottom left show sediment profile of two lake-bottom cores from the central sub-basin south of the Point. Also shown are grain-size parameters and radiocarbon dates (where obtained). Location of lake-bottom cores is given in Figure 1-1. Location of OGS-1 is given in Figure 2-5. Note vertical scale change in core plots.


O.G.S. BOREHOLE
(RONDEAU PROVINCIAL PARK)
ELEVATION (m) w.r.t. LAKE DATUM (173.3m a.s.l.)
+3.5
0
5.0
12.65
Medium-coarse sand
Clayey silt to fine sand
Silt
(35,36)
Silty peat
Silt
Silty clay / fine sand
Silty clay till
35: C14 date WAT 378 (5330±250 BP)
36: C14 date " 379 (5180±370 BP)


BENTHOS CORE LE81-19
173.3
WATER DEPTH (m)
0
23.0
LENGTH OF CORE (cm)
0
10
20
30
40
50
60
Uniform silty clay
(Recent Lake Erie muds)
Nodular organic clayey sand
(38,39)
Silty fine sand
Shelly coarse sand
% sand-silt-clay
0 20 40 60 80 100
silt
clay
sand
Mean ϕ
2 4 6 8 10
(38,39): C14 dates WAT 946, 970 (3140±110; 7000±370 BP)

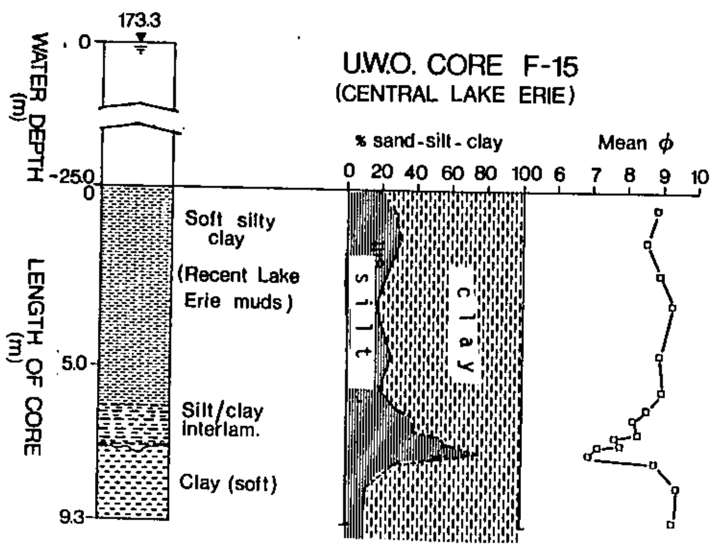
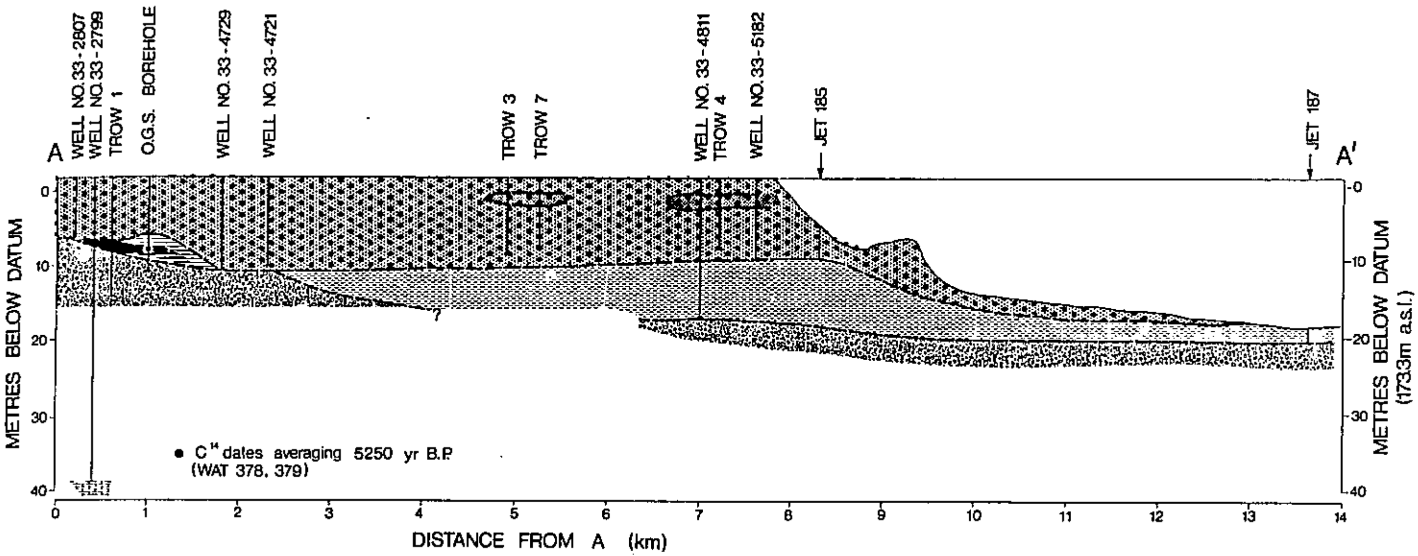
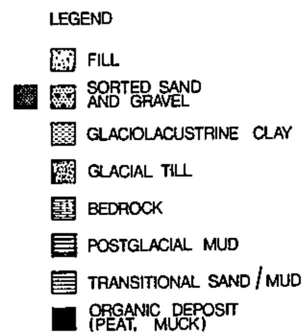

U.W.O. CORE F-15
(CENTRAL LAKE ERIE)
173.3
WATER DEPTH (m)
0
-25.0
LENGTH OF CORE (m)
0
5.0
9.3
Soft silty clay
(Recent Lake Erie muds)
Silt/clay interlam.
Clay (soft)
% sand-silt-clay
0 20 40 60 80 100
silt
clay
Mean ϕ
6 7 8 9 10

Figure 4-14

Longitudinal cross-sections through the east (top) and west (bottom) limbs of Pointe-aux-Pins (see Figure 2-5 for location). Also shown are borehole sequences obtained from a variety of borehole sources, and interpreted glacial surface topography.


A
A′
WELL NO.33-2807
WELL NO.33-2799
TROW 1
O.G.S. BOREHOLE
WELL NO. 33-4729
WELL NO. 33-4721
TROW 3
TROW 7
WELL NO. 33-4811
TROW 4
WELL NO.33-5182
JET 185
JET 187
● C[14] dates averaging 5250 yr B.P.
(WAT 378, 379)
METRES BELOW DATUM
METRES BELOW DATUM
(173.3m a.s.l.)
DISTANCE FROM A (km)


LEGEND
FILL
SORTED SAND AND GRAVEL
GLACIOLACUSTRINE CLAY
GLACIAL TILL
BEDROCK
POSTGLACIAL MUD
TRANSITIONAL SAND / MUD
ORGANIC DEPOSIT (PEAT, MUCK)

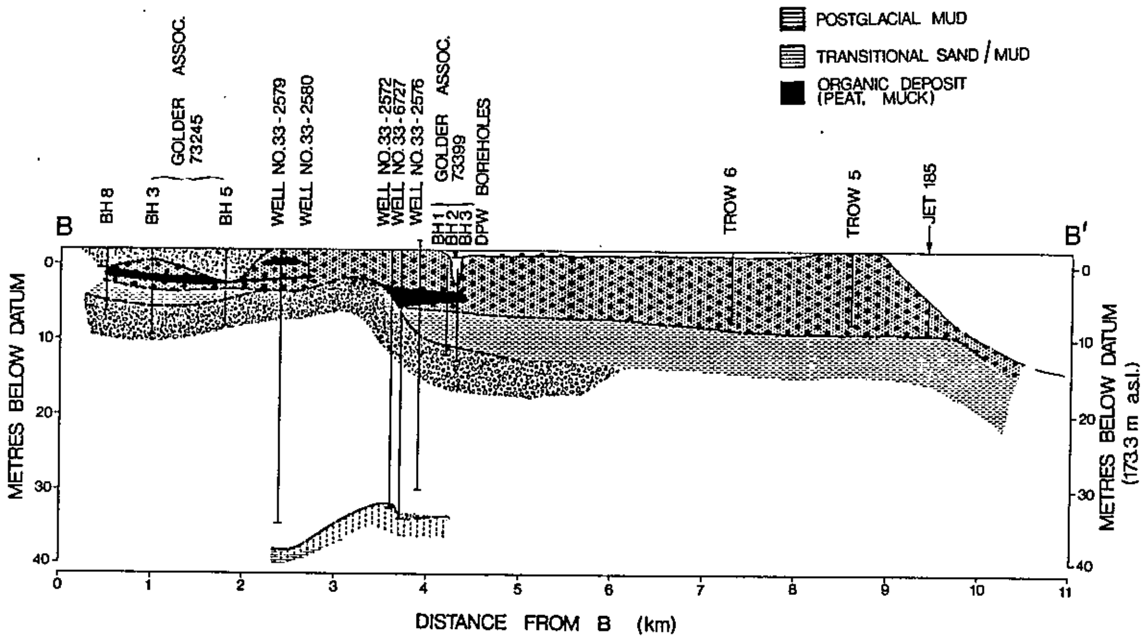
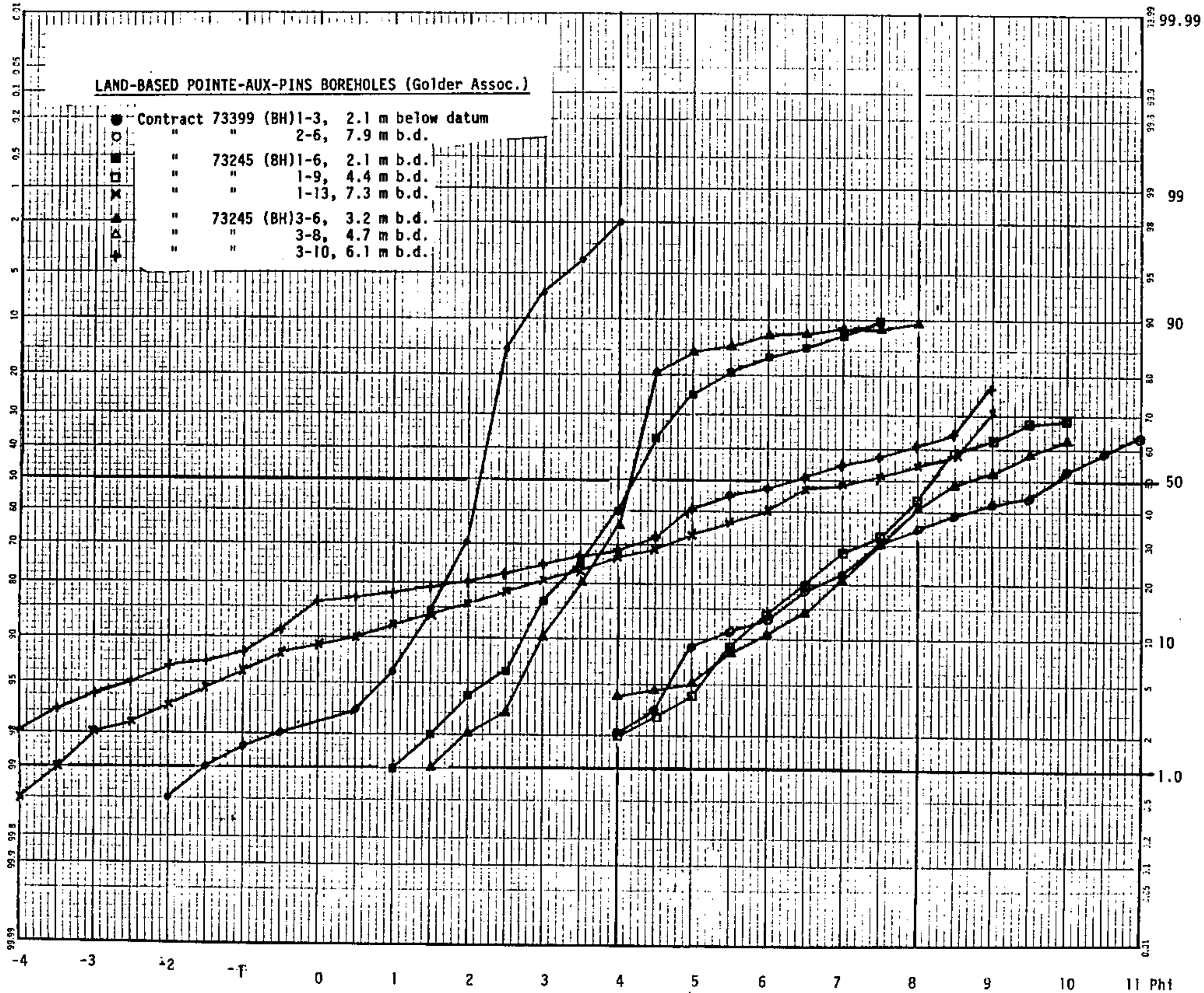

B
B′
BH 8
BH 3
BH 5
GOLDER ASSOC. 73245
WELL NO.33-2579
WELL NO.33-2580
WELL NO.33-2572
WELL NO.33-6727
WELL NO.33-2576
BH1
BH2
BH3
GOLDER ASSOC. 73399
DPW BOREHOLES
TROW 6
TROW 5
JET 185
METRES BELOW DATUM
METRES BELOW DATUM
(173.3 m a.s.l.)
DISTANCE FROM B (km)

Figure 4-15

Representative cumulative grain-size curves from boreholes on Pointe-aux-Pins, collected by Golder Assoc. . Location of boreholes is in the vicinity of Erieau (western limb, see Figure 4-14). Curve types appear similar to Group 1 (samples 1-13, 3-10 above); Group 2 (1-9, 2-6, 3-8); and Group 3 (1-3, 1-6, 3-6) curves from the Pelee Shoal sections (see Figures 4-7 to 4-9).



LAND-BASED POINTE-AUX-PINS BOREHOLES (Golder Assoc.)
● Contract 73399 (BH)1-3, 2.1 m below datum
○ " " 2-6, 7.9 m b.d.
■ " 73245 (BH)1-6, 2.1 m b.d.
□ " " 1-9, 4.4 m b.d.
✕ " " 1-13, 7.3 m b.d.
▲ " 73245 (BH)3-6, 3.2 m b.d.
△ " " 3-8, 4.7 m b.d.
✚ " " 3-10, 6.1 m b.d.
99.99
99
90
50
10
1.0
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11 Phi

Figure 4-16

Representative cumulative grain-size curves for samples from Benthos core LE81-19, to the south of Pointe-aux-Pins. Curves with solid symbols (nos. 5 to 7B) correspond to the coarse basal layer (containing wood and shells shown in Figure 4-18. Note similarity in form of these curves with those in the basal layer in BH3 on Long Point (Figure 3-17). Curves with open symbols, typical of the upper silty clay section, are similar to Group 1B curves at Long Point (Figure 3-14).

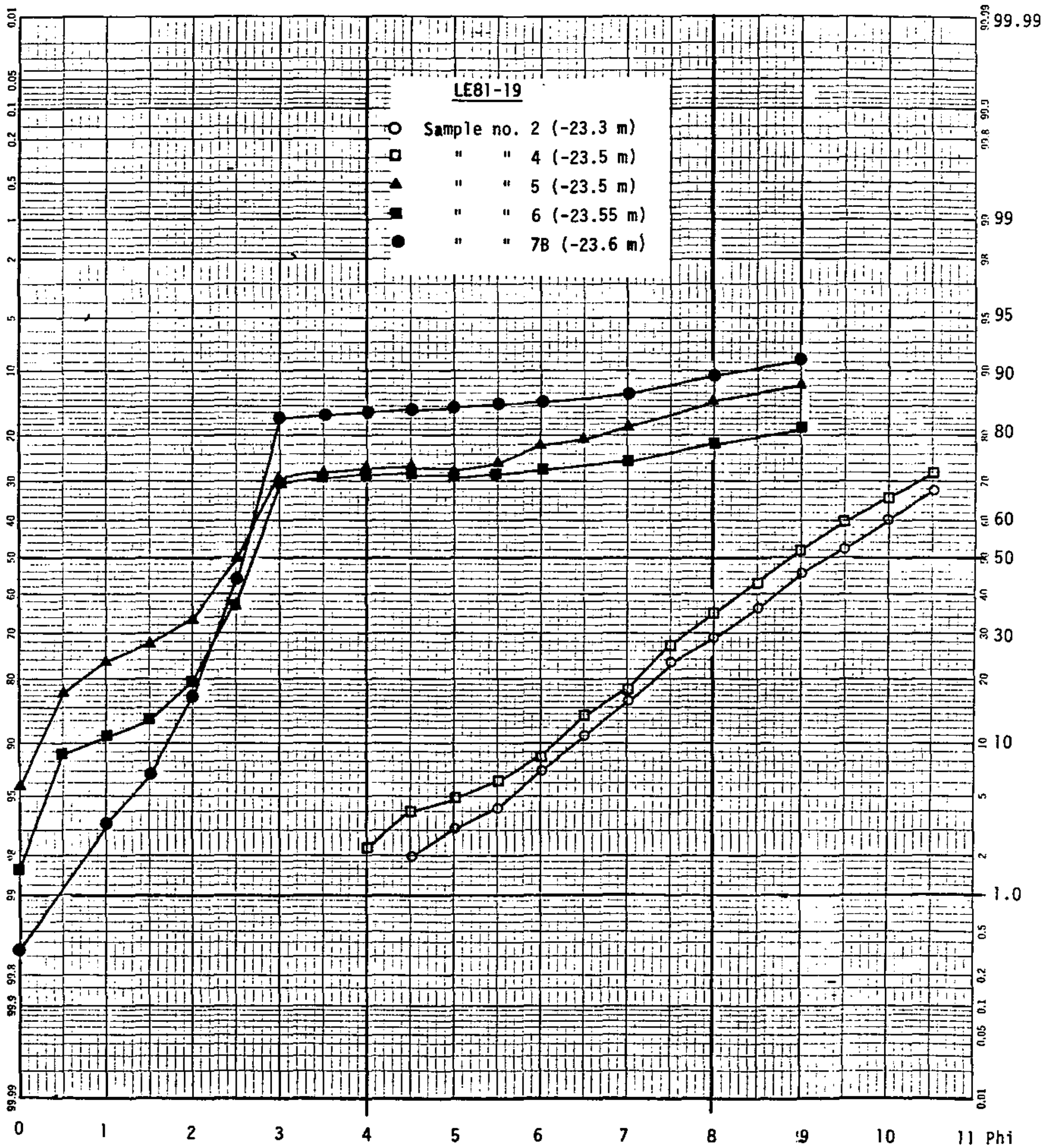

LE81-19
Sample no. 2 (-23.3 m)
" " 4 (-23.5 m)
" " 5 (-23.5 m)
" " 6 (-23.55 m)
" " 7B (-23.6 m)
99.99
99
95
90
80
60
50
30
10
1.0
0
1
2
3
4
5
6
7
8
9
10
11 Phi

Figure 4-17

Representative cumulative grain-size curves for samples from piston core UWO F-15, in the central sub-basin. Curves with solid symbols (nos. 8B, E, and F) correspond to samples from the high-silt layer noted at depth in the core (Figure 4-13). Note similarity in form to Group 1B curves at Long Point ánd LE81-19 off Pointe-aux-Pins.

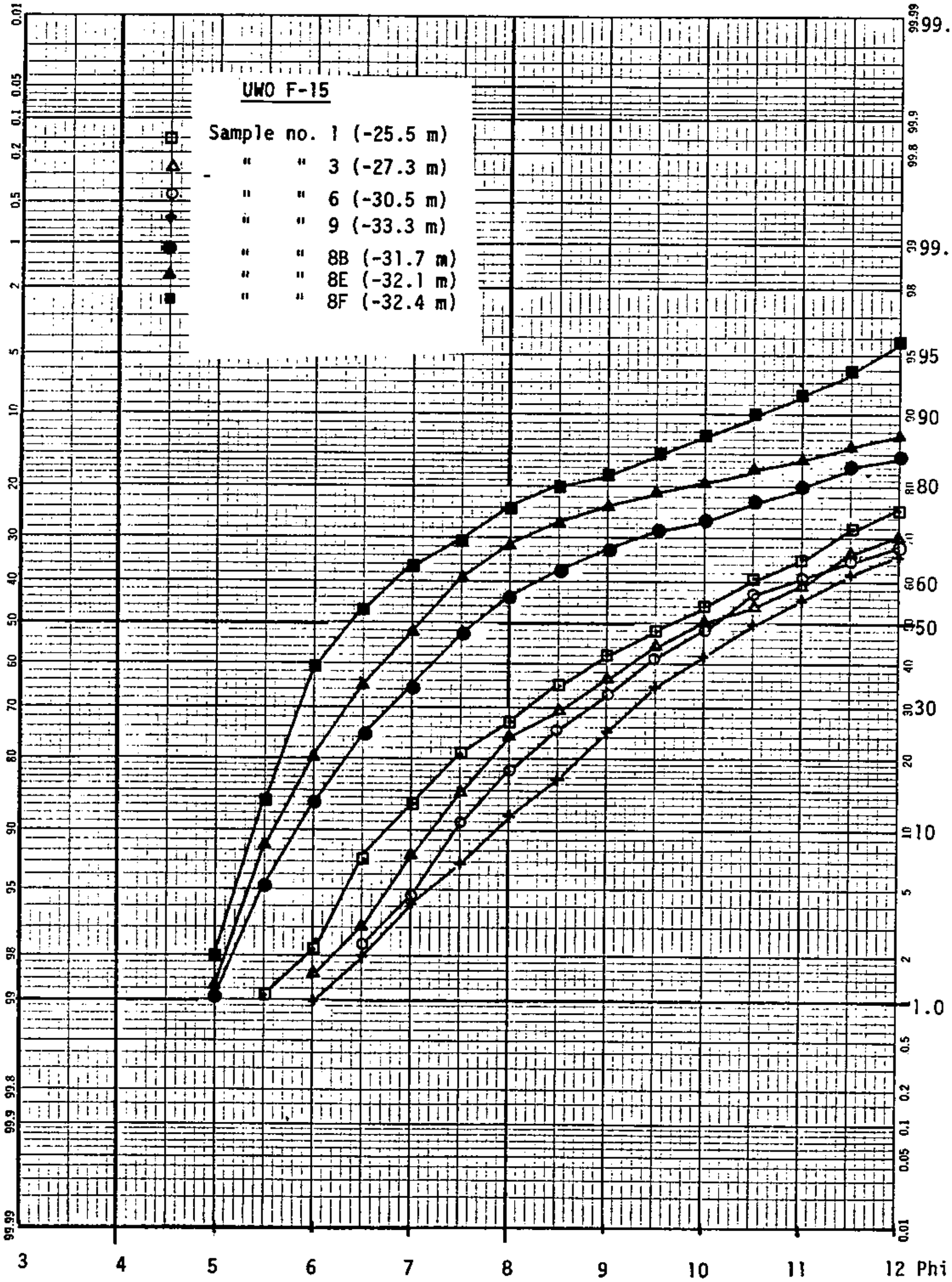

UWO F-15
Sample no. 1 (-25.5 m)
" " 3 (-27.3 m)
" " 6 (-30.5 m)
" " 9 (-33.3 m)
" " 8B (-31.7 m)
" " 8E (-32.1 m)
" " 8F (-32.4 m)
99.99
99.0
95
90
80
60
50
30
10
1.0
3
4
5
6
7
8
9
10
11
12 Phi

Figure 4-18

Close-up colour photograph of the contact zone between coarse-grained basal sediments and the overlying fine, uniform silty clay unit at the bottom of Benthos core LE81-19, south of Pointe-aux-Pins. Note the oxidized, nodular appearance of the basal layer. Photograph taken by Peter Fisher, University of Waterloo. Photograph width is 6.6 cm.

Uniform silty clay

Nodular organic clayey sand

Silty, fine sand

Shelly coarse sand

Figure 4-19

Pollen diagram from BH 13194 (drilled by Consumers Gas; see Figure 1-1 for location) to the southeast of Pointe-aux-Pins. The diagram was prepared by T.W. Anderson, Geological Survey of Canada, and his interpreted chronology is presented in the left margin.

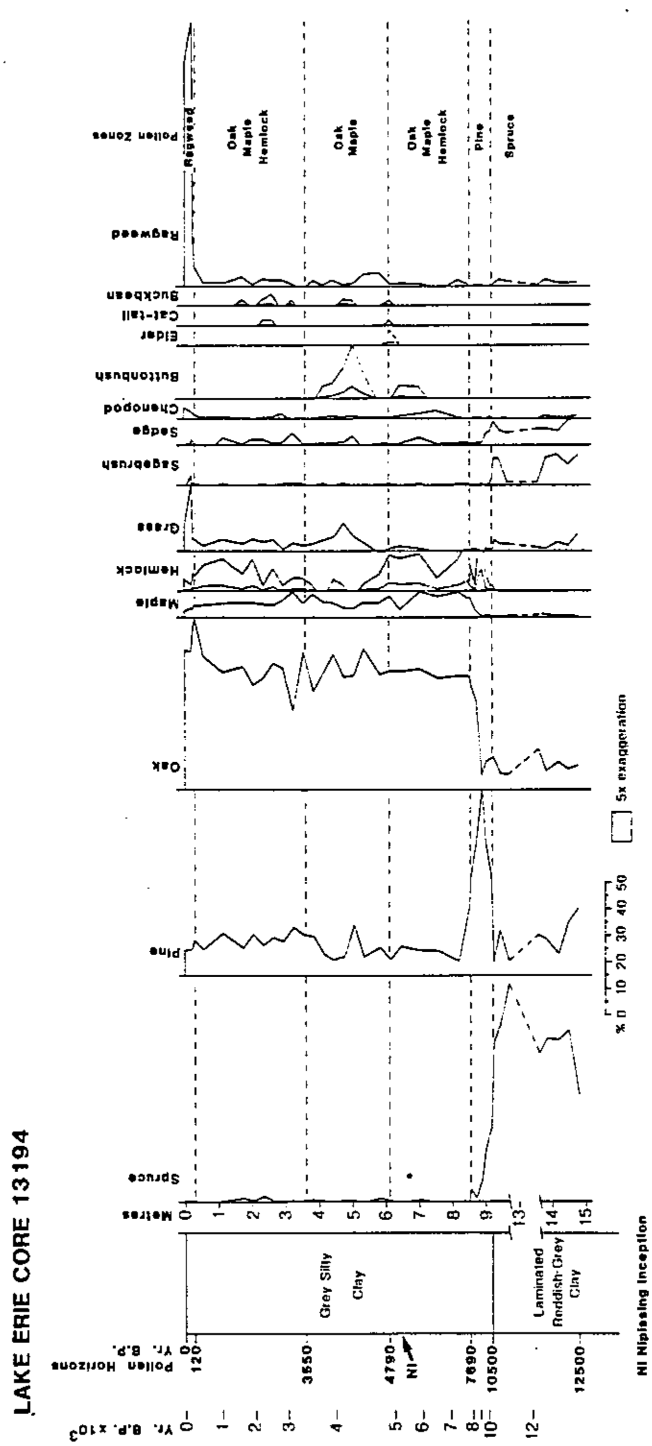

LAKE ERIE CORE 13194
Yr. B.P. x10³
Pollen Horizons Yr. B.P.
Metres
Spruce
Pine
Oak
Maple
Hemlock
Grass
Sagebrush
Sedge
Chenopod
Buttonbush
Elder
Cat-tail
Buckbean
Ragweed
Pollen Zones
Ragweed
Oak Maple Hemlock
Oak Maple
Oak Maple Hemlock
Pine
Spruce
Grey Silty Clay
Laminated Reddish-Grey Clay
NI Nipissing Inception
5x exaggeration
% 0 10 20 30 40 50

Figure 5-1

Interpreted geological cross-section through Quaternary deposits along a seismic reflection segment offshore from Nanticoke, Ontario. The entire survey track (from Nanticoke to Coho, Ohio) is shown in Figure 1-1. The uninterpreted seismic records on which the section was based (see Figure 5-2)were made available courtesy of Ontario Hydro. Morphological features and deposit geometrical characteristics were interpreted to define previous shoreline positions I, II, and III.

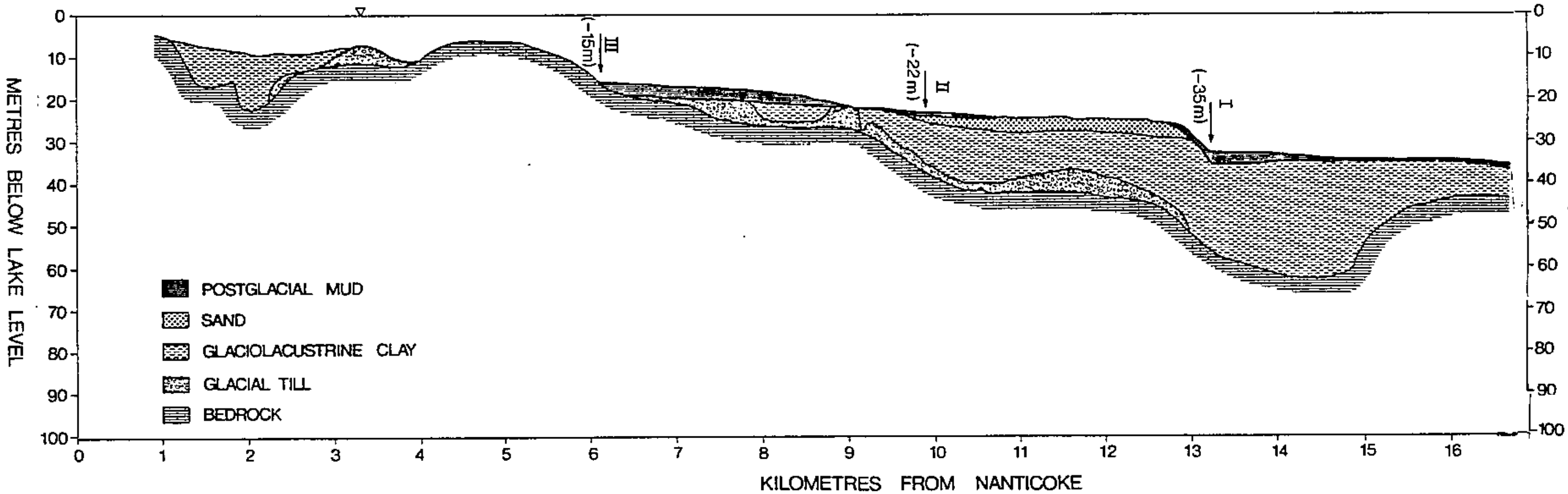

METRES BELOW LAKE LEVEL
0
10
20
30
40
50
60
70
80
90
100
III
(-15m)
II
(-22 m)
I
(-35m)
POSTGLACIAL MUD
SAND
GLACIOLACUSTRINE CLAY
GLACIAL TILL
BEDROCK
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
KILOMETRES FROM NANTICOKE

Figure 5-2

Example of a seismogram from the Ontario Hydro survey, showing the geomorphological feature interpreted in Figure 4 as a relict shoreline (I), cut into laminated glaciolacustrine deposits at 30 m b.d.. The vertical black line is a distance fix marker. Seismogram reproduced with permission of Ontario Hydro (J. Godawa, 1984).

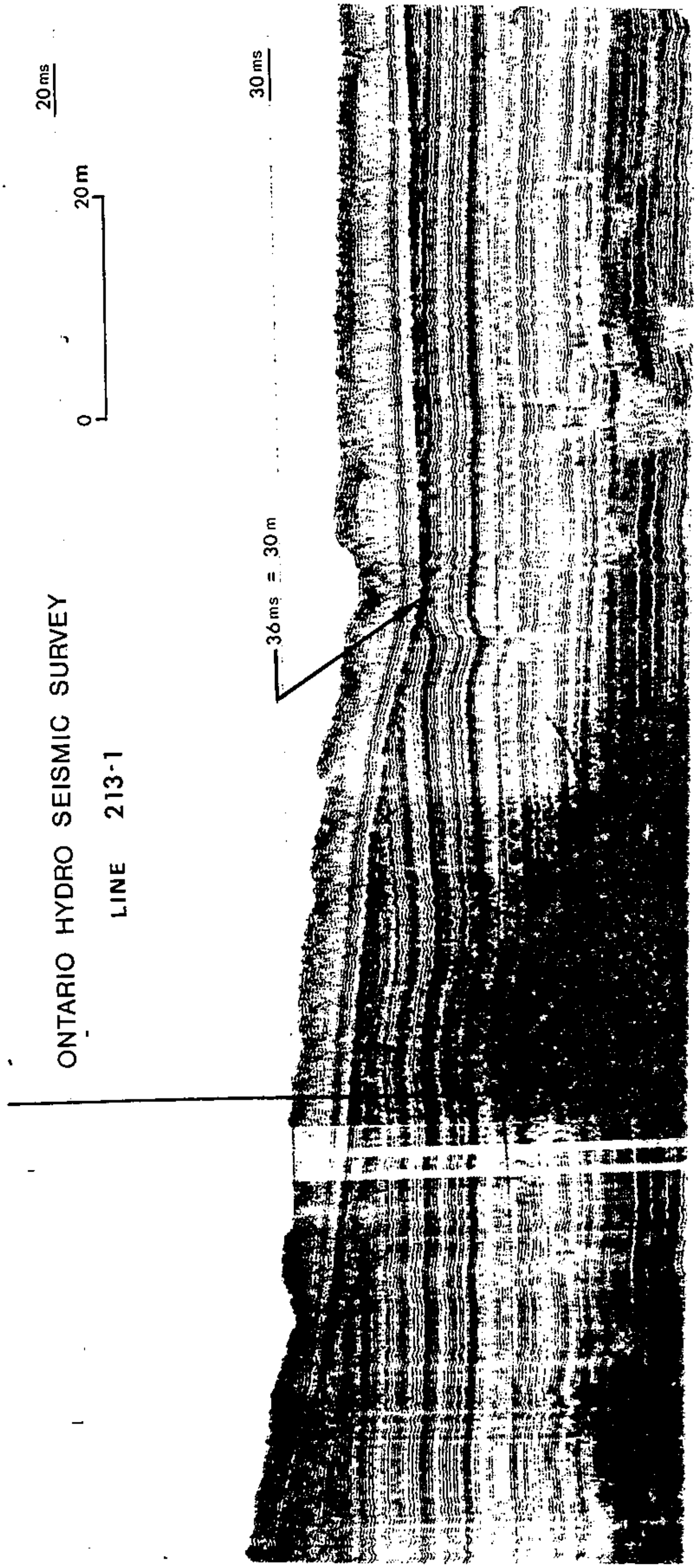
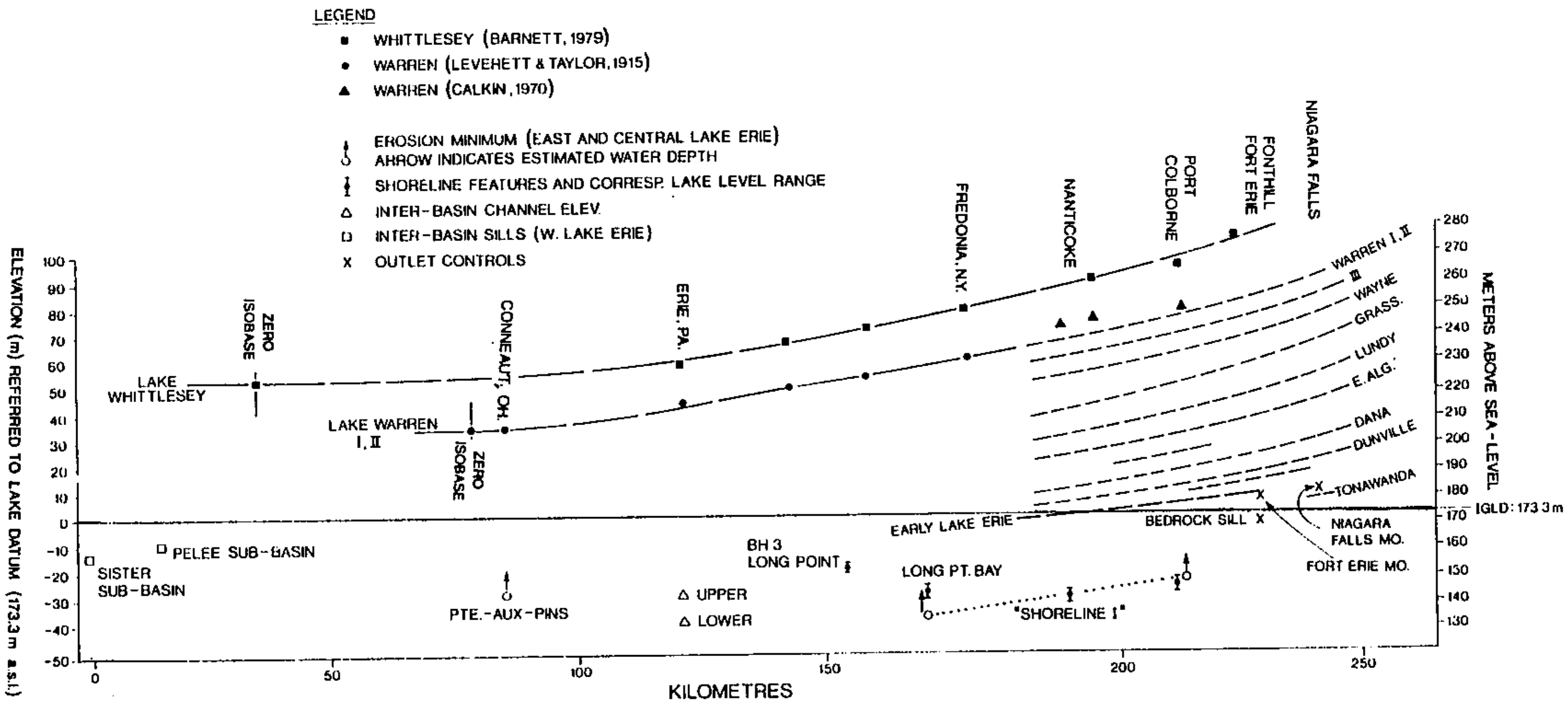

ONTARIO HYDRO SEISMIC SURVEY
LINE 213-1
20 ms
0
20 m
30 ms
36 ms = 30 m

Figure 5-3

Elevation versus distance (from an arbitrary point in the western part of the lake basin) of raised and uptilted shorelines of the Whittlesey and subsequent lake phases in the central and eastern parts of the Erie basin (modified after Feenstra, 1981 and Leverett and Taylor, 1915). Also plotted are submerged geomorphological features noted on or below the lake bottom, and the relationship of these features to possible outlet controls at the Niagara River (see Figure 5-7).



LEGEND
WHITTLESEY (BARNETT, 1979)
WARREN (LEVERETT & TAYLOR, 1915)
WARREN (CALKIN, 1970)
EROSION MINIMUM (EAST AND CENTRAL LAKE ERIE)
ARROW INDICATES ESTIMATED WATER DEPTH
SHORELINE FEATURES AND CORRESP. LAKE LEVEL RANGE
INTER-BASIN CHANNEL ELEV.
INTER-BASIN SILLS (W. LAKE ERIE)
OUTLET CONTROLS
ELEVATION (m) REFERRED TO LAKE DATUM (173.3 m a.s.l.)
METERS ABOVE SEA-LEVEL
KILOMETRES
ZERO ISOBASE
LAKE WHITTLESEY
LAKE WARREN I, II
CONNEAUT, OH.
ERIE, PA.
FREDONIA, N.Y.
NANTICOKE
PORT COLBORNE
FONTHILL
FORT ERIE
NIAGARA FALLS
WARREN I, II
III
WAYNE
GRASS.
LUNDY
E. ALG.
DANA
DUNVILLE
TONAWANDA
IGLD: 173.3 m
EARLY LAKE ERIE
BEDROCK SILL
NIAGARA FALLS MO.
FORT ERIE MO.
SISTER SUB-BASIN
PELEE SUB-BASIN
PTE.-AUX-PINS
UPPER
LOWER
BH 3 LONG POINT
LONG PT. BAY
"SHORELINE I"

Figure 5-4

Reconstructed postglacial surface below Lake Erie (uncorrected for postglacial isostatic rebound) prior to the Early Lake Erie phase. The figure is modified after Lewis (1969), using the additional data that are presently available (boreholes postdating Lewis' interpretation are included in the figure, as well as seismic traverses across the eastern sub-basin, shown in Figure 1-1). Reconstruction also attempts to compensate for postglacial shoreline erosion, as indicated in the cross-sections shown (Figures 5-5 and 5-6). Present outline of the lake is shown dashed, and contours are referenced both to sealevel and to present lake datum. Solid circles refer to borehole and core sample sites used as control (see Figure 1-1).

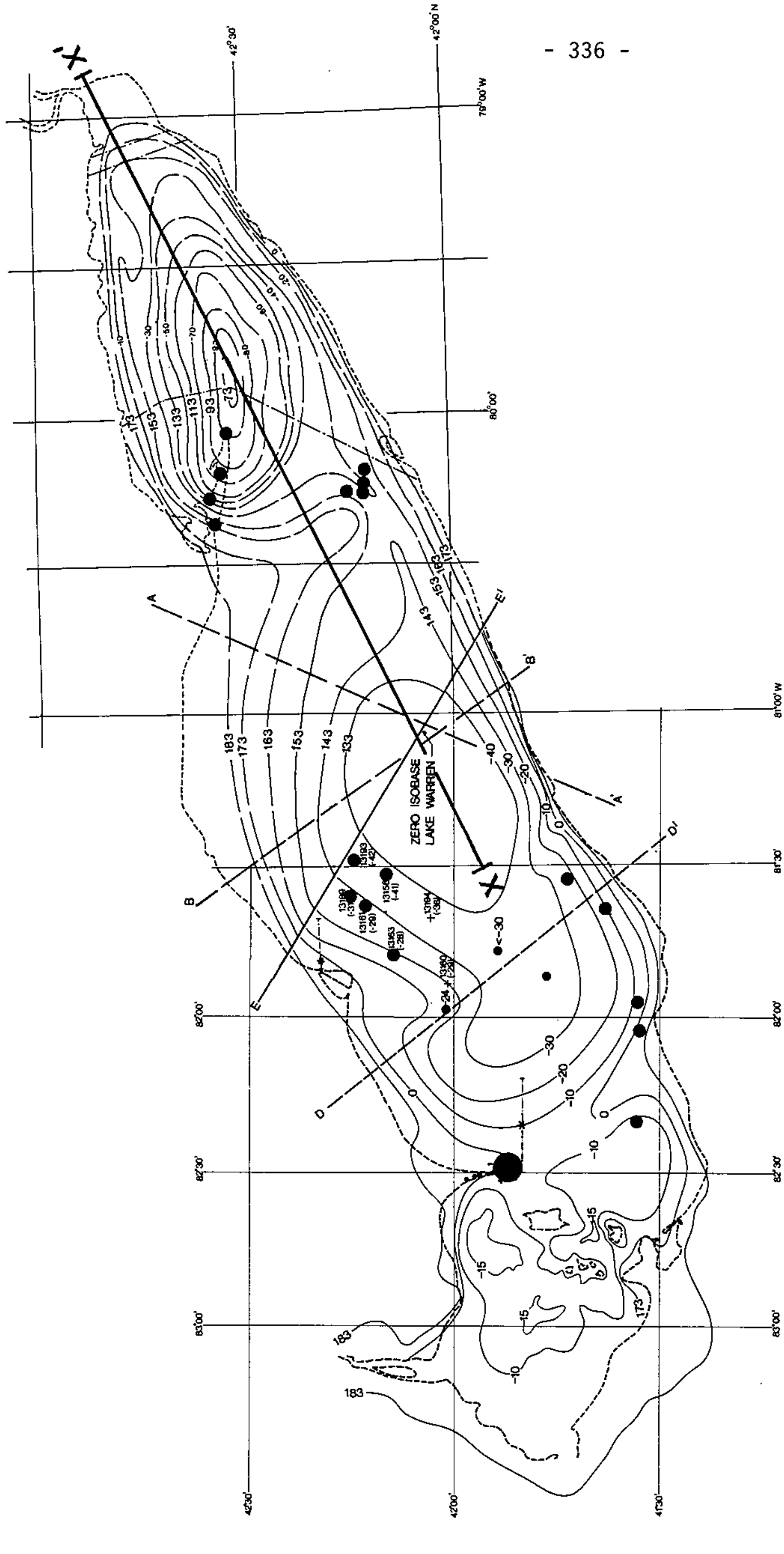
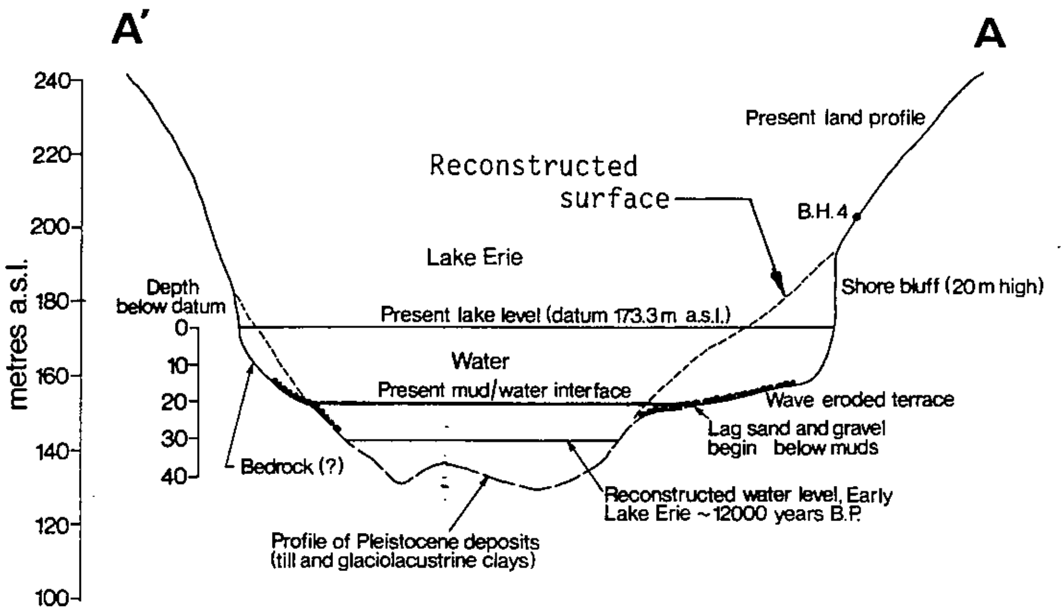

ZERO ISOBASE
LAKE WARREN
X
X'
A
A'
B
B'
D
D'
E
E'
42°30'
42°00'N
78°00'W
80°00'
81°00'W
81°30'
82°00'
82°30'
83°00'
42°00'
41°30'
183
173
163
153
143
133
113
93
73
0
-10
-20
-30
-40
-15
15

Figure 5-5

Cross-sections A'-A (top) and B'-B (bottom) through the central sub-basin of Lake Erie, showing the approach used to reconstruct the original postglacial profile immediately prior to Early Lake Erie. Cross-section locations are given in Figure 5-4.


A′
A
240
220
200
180
160
140
120
100
metres a.s.l.
Present land profile
Reconstructed surface
B.H.4
Lake Erie
Depth below datum
0
10
20
30
40
Shore bluff (20 m high)
Present lake level (datum 173.3 m a.s.l.)
Water
Present mud/water interface
Wave eroded terrace
Lag sand and gravel begin below muds
Bedrock (?)
Reconstructed water level, Early Lake Erie ~12000 years B.P.
Profile of Pleistocene deposits (till and glaciolacustrine clays)

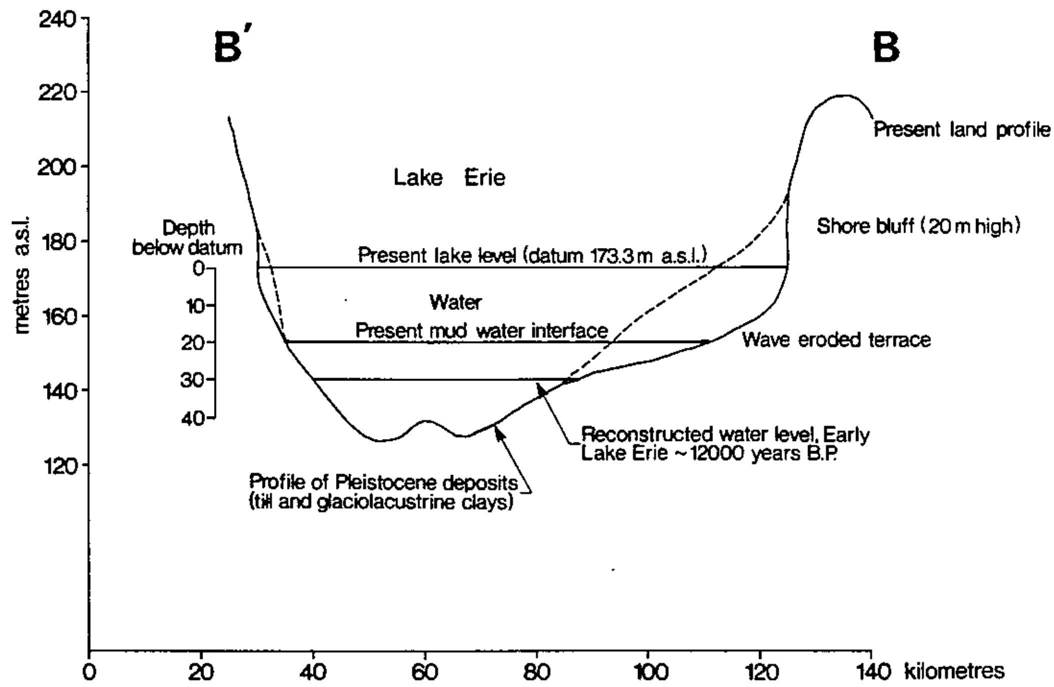
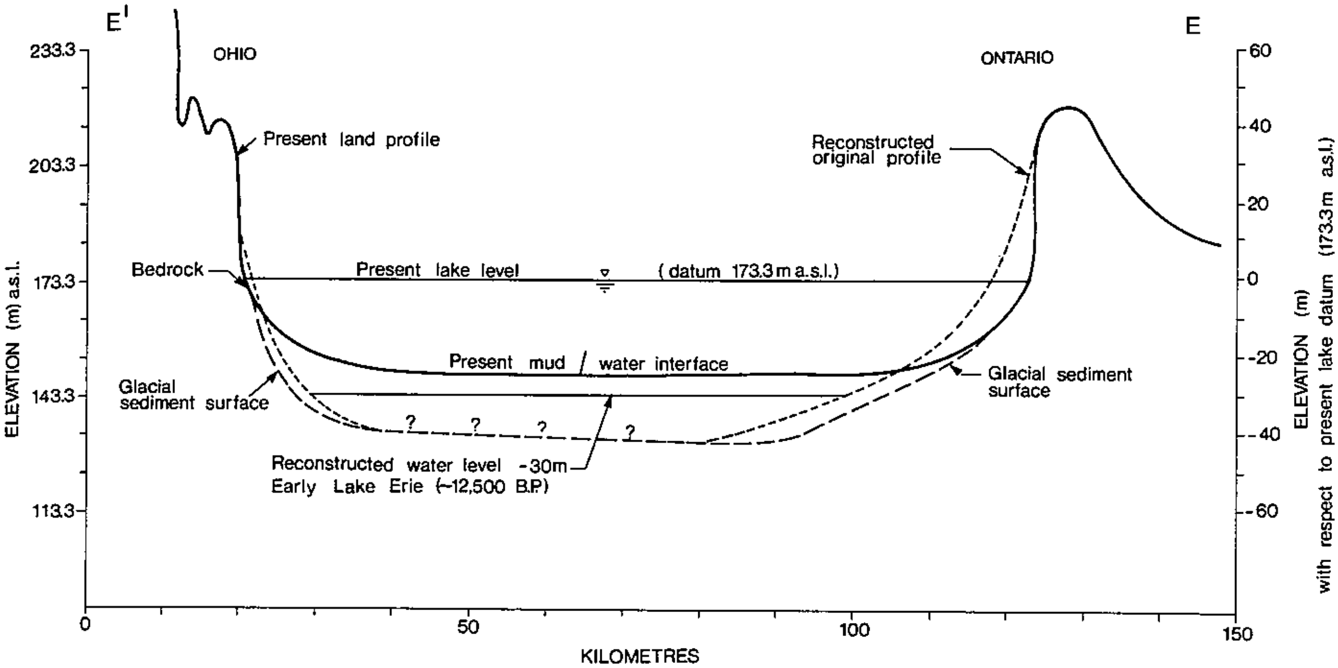

240
220
200
180
160
140
120
metres a.s.l.
B′
B
Present land profile
Lake Erie
Depth below datum
0
10
20
30
40
Shore bluff (20 m high)
Present lake level (datum 173.3 m a.s.l.)
Water
Present mud water interface
Wave eroded terrace
Reconstructed water level, Early Lake Erie ~12000 years B.P.
Profile of Pleistocene deposits (till and glaciolacustrine clays)
0
20
40
60
80
100
120
140 kilometres

Figure 5-6

Cross-sections D'-D (bottom) and E'-E (top) through the central sub-basin of Lake Erie, used to reconstruct the original postglacial profile immediately prior to Early Lake Erie. Cross-section locations are given in Figure 5-4.


E'
E
OHIO
ONTARIO
233.3
203.3
173.3
143.3
113.3
ELEVATION (m) a.s.l.
60
40
20
0
-20
-40
-60
ELEVATION (m) with respect to present lake datum (173.3m a.s.l.)
Present land profile
Reconstructed original profile
Bedrock
Present lake level
(datum 173.3 m a.s.l.)
Present mud / water interface
Glacial sediment surface
Glacial sediment surface
? ? ? ?
Reconstructed water level -30m Early Lake Erie (~12,500 B.P.)
0
50
100
150
KILOMETRES

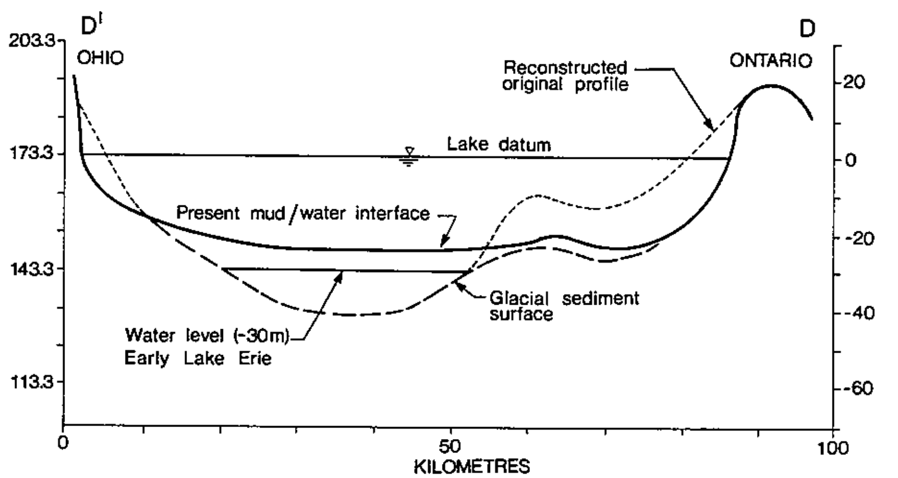
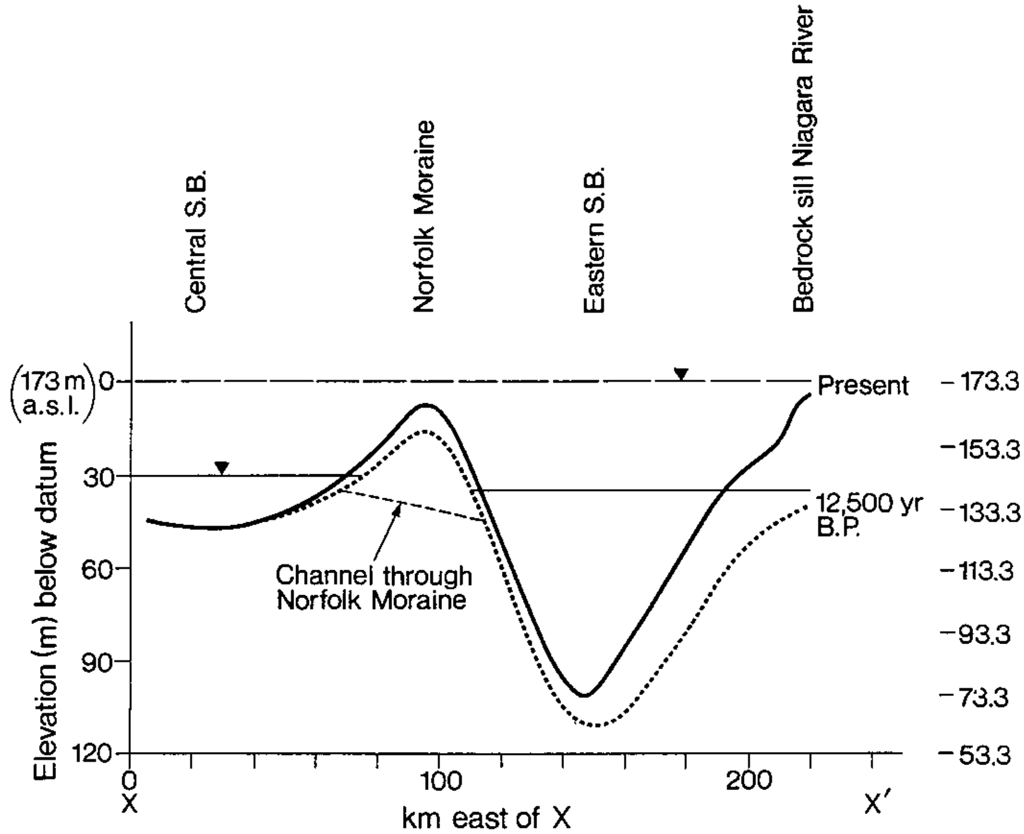

D'
D
OHIO
ONTARIO
203.3
173.3
143.3
113.3
20
0
-20
-40
-60
Reconstructed original profile
Lake datum
Present mud/water interface
Glacial sediment surface
Water level (-30m) Early Lake Erie
0
50
100
KILOMETRES

Figure 5-7

(Top): Cross-section through the central and eastern sub-basin of Lake Erie (see Figure 5-4 for location) showing the present lake-bottom profile compared to the reconstructed original profile prior to postglacial isostatic rebound. Positions of the lake level in the two sub-basins are hypothesized based on the elevation of the channel through the Norfolk Moraine.

(Bottom): Detailed cross-section through the lake outlet at the Niagara River, showing the relationship between the bedrock sill and the two transverse moraines, based on present topography. Estimated heights of the moraines are sketched in, as well as their possible relationship to Lake Tonawanda (see Figure 5-3).


Central S.B.
Norfolk Moraine
Eastern S.B.
Bedrock sill Niagara River
(173 m a.s.l.) 0
30
60
90
120
Elevation (m) below datum
Present
12,500 yr B.P.
Channel through Norfolk Moraine
- 173.3
-153.3
-133.3
-113.3
-93.3
-73.3
-53.3
0
100
200
X
X′
km east of X

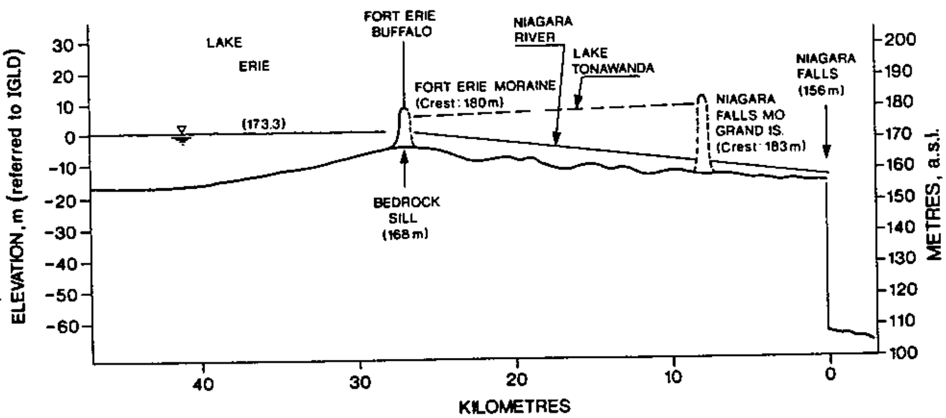

LAKE
ERIE
FORT ERIE
BUFFALO
NIAGARA
RIVER
LAKE
TONAWANDA
FORT ERIE MORAINE
(Crest: 180m)
NIAGARA FALLS MO
GRAND IS.
(Crest: 183m)
NIAGARA
FALLS
(156m)
(173.3)
BEDROCK
SILL
(168m)
ELEVATION, m (referred to IGLD)
METRES, a.s.l.
KILOMETRES

Figure 6-1

Interpreted history of postglacial lake levels in the Erie basin, based on the various data sources presented in Chapter 5 (solid line). The dashed line represents the theoretical lake level at the outlet sill (assuming an overlying depth of water similar to that at present; see Figure 5-7) based on a composite model of sill rebound since deglaciation. The arrows indicate the direction ane estimated distance to the contemporary lake level (the base of the solid portion of the arrow represents estimated minimum water depth over the organic sample). The small triangle (upper right) indicates the position of date no. 50, and the arrow shows its probable link with the peak at around 4000 BP. The dotted line represents an earlier interpretation of Lake Erie levels by Lewis (1969).

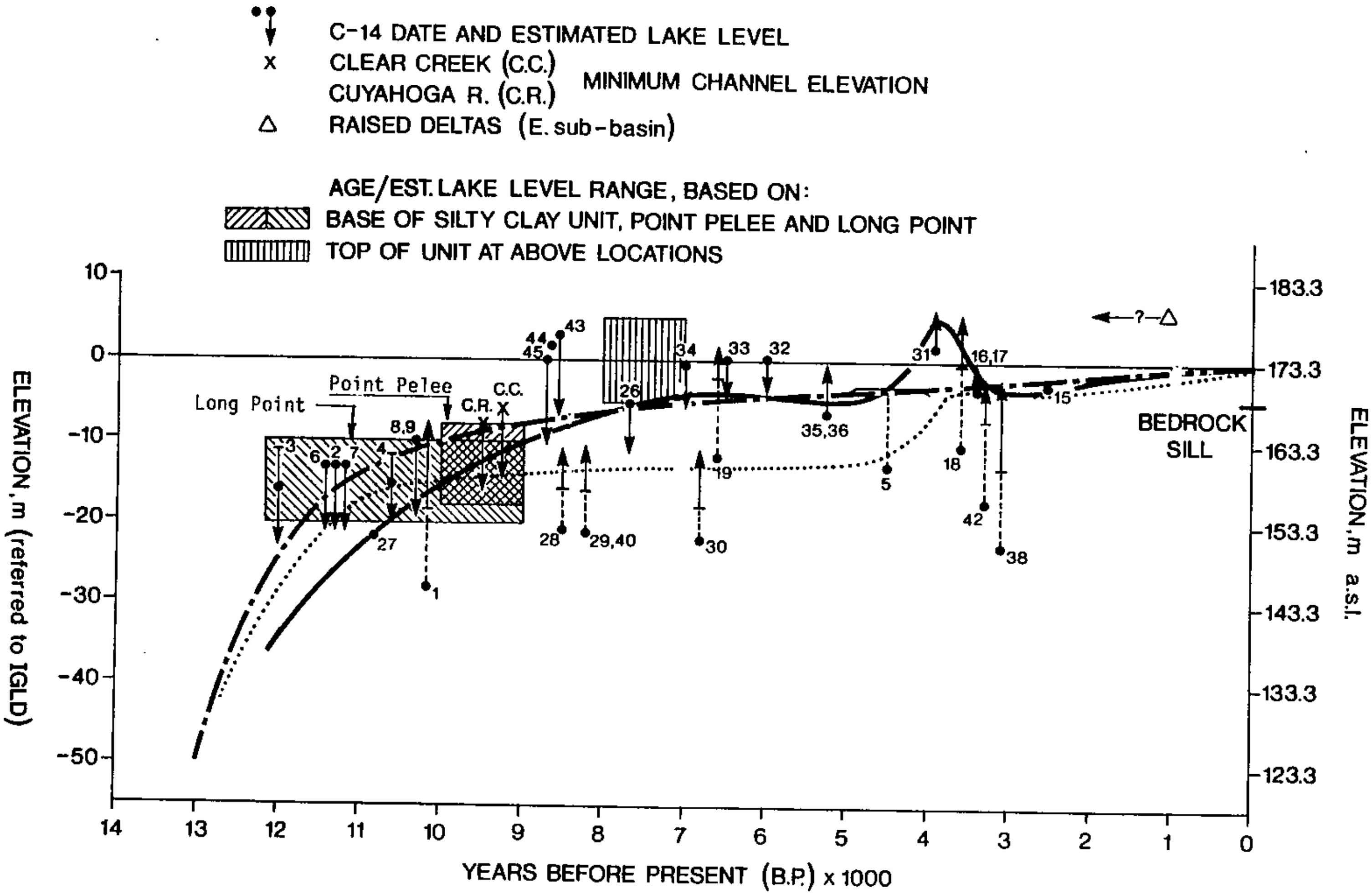

C-14 DATE AND ESTIMATED LAKE LEVEL
x CLEAR CREEK (C.C.)
CUYAHOGA R. (C.R.)
MINIMUM CHANNEL ELEVATION
△ RAISED DELTAS (E. sub-basin)
AGE/EST. LAKE LEVEL RANGE, BASED ON:
BASE OF SILTY CLAY UNIT, POINT PELEE AND LONG POINT
TOP OF UNIT AT ABOVE LOCATIONS
Long Point
Point Pelee
C.R.
C.C.
BEDROCK SILL
ELEVATION, m (referred to IGLD)
ELEVATION, m a.s.l.
YEARS BEFORE PRESENT (B.P.) x 1000
10
0
-10
-20
-30
-40
-50
183.3
173.3
163.3
153.3
143.3
133.3
123.3
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8,9
15
16,17
18
19
26
27
28
29,40
30
31
32
33
34
35,36
38
42
43
44
45
←?–△

Figure 6-2

Component sub-basins in Western Lake Erie, interpreted from the inferred topography of the glacial sediment and bedrock surface (modified after Lewis, 1969). Names of the sub-basins and numbered dots are keyed to radiocarbon dating sites in Table 3-1.

SUB-BASINS WESTERN LAKE ERIE

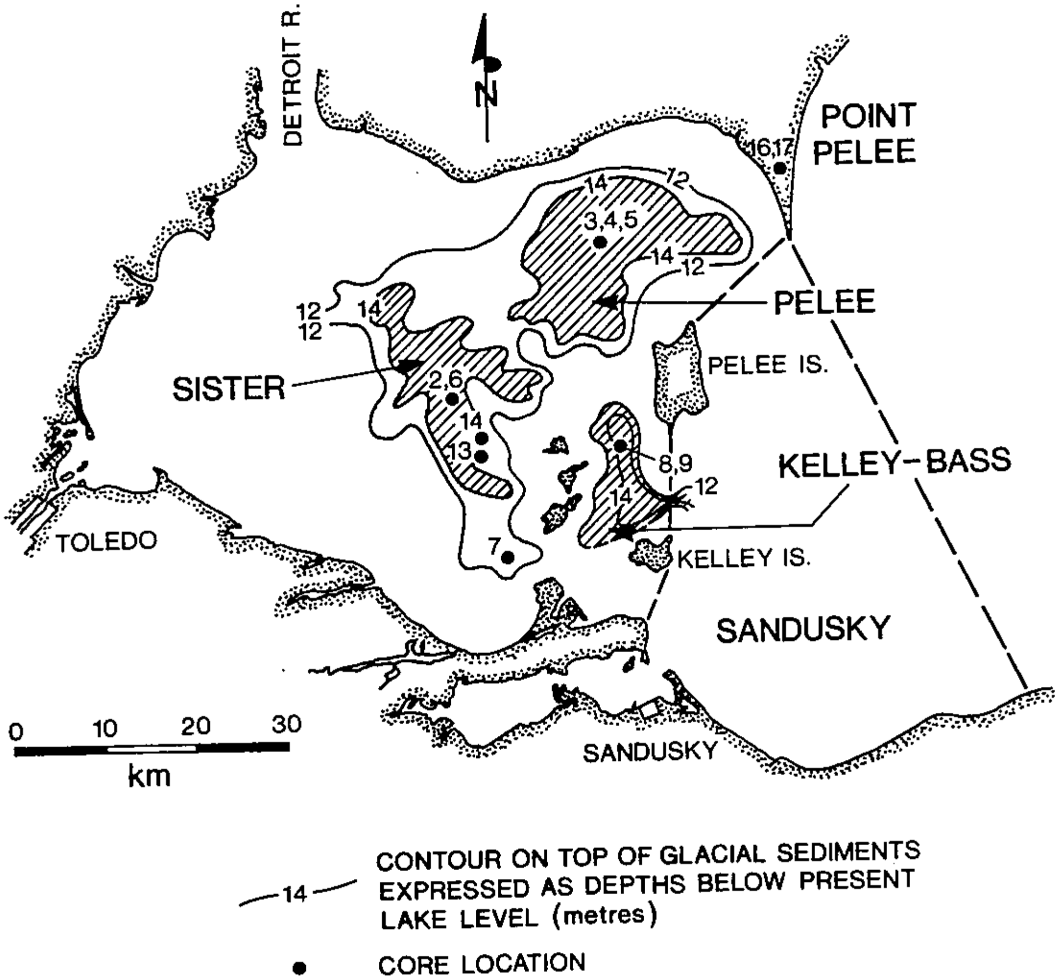
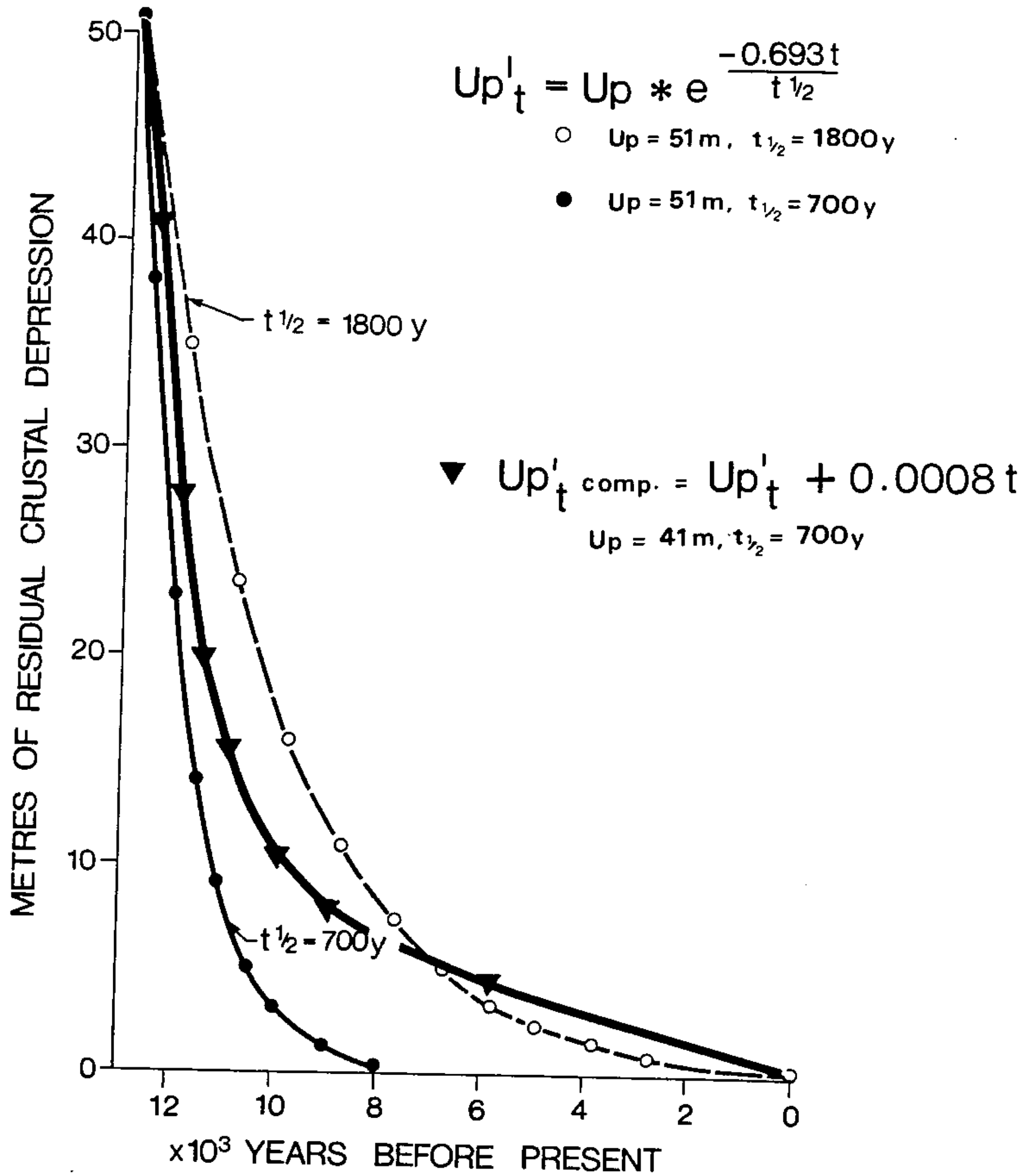


Figure 6-3

Plots of residual crustal depression (or uplift remaining) at the Lake Erie outlet at Niagara versus time before present. Plots are based on three separate theoretical models for postglacial crustal rebound, two of which are exponential (with different relaxation times) and one is a composite of exponential and linear components. Exponential model is based on that in Andrews (1970), as is the $t_{1/2}$ value of 1800 years. The half-time value of 700 years was taken from Washburn and Stuiver (1962) and Broecker (1966).



$Up'_t = Up * e^{\frac{-0.693t}{t\,1/2}}$
○ Up = 51 m, t ½ = 1800 y
● Up = 51 m, t ½ = 700 y
▼ $Up'_{t\ comp.} = Up'_t + 0.0008\,t$
Up = 41 m, t ½ = 700 y
t ½ = 1800 y
t ½ = 700 y
METRES OF RESIDUAL CRUSTAL DEPRESSION
x10³ YEARS BEFORE PRESENT
50
40
30
20
10
0
12
10
8
6
4
2
0

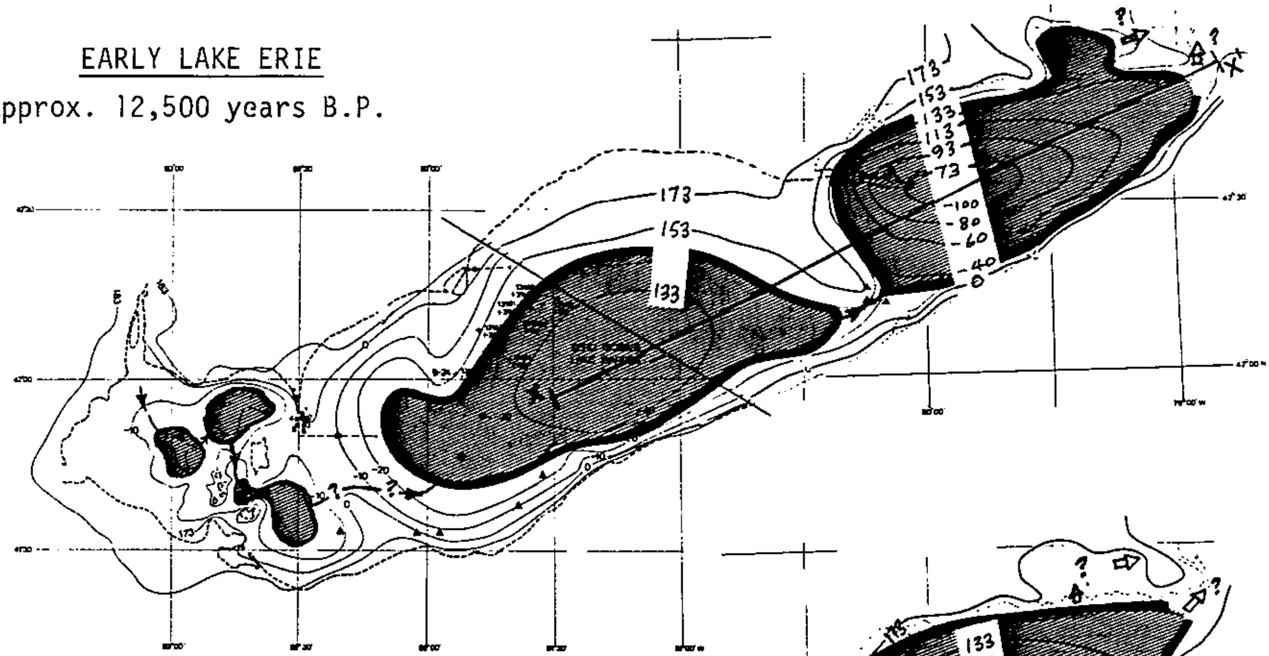
Figure 6-4

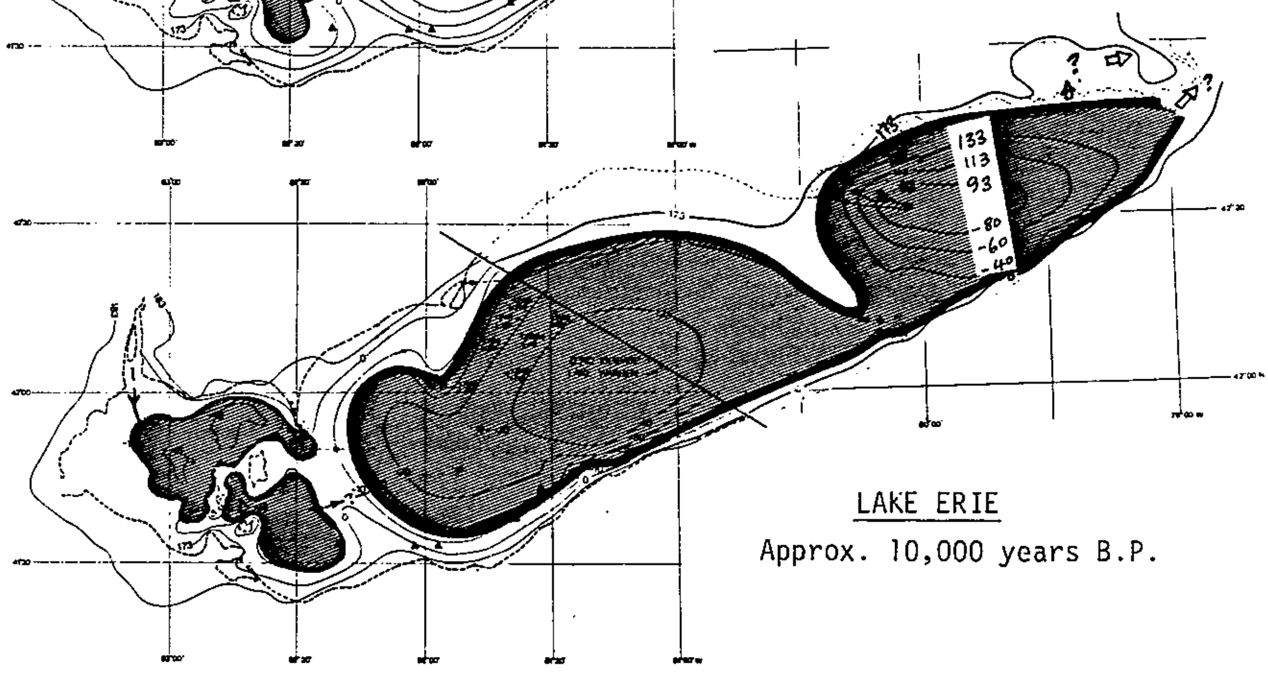
(Top): Reconstruction of the paleogeography of Early Lake Erie at approximately 12,500 years B.P.. Lake levels are estimated at between 10 and 15 m below present datum for the western sub-basin, and 30 and 35 m b.d. for the central and eastern sub-basins respectively. Note that at this time, the eastern half of the lake was glacio-isostatically depressed (Figure 5-7) and the lake levels take this into account.

(Bottom): Lake Erie at approximately 10,000 years B.P.. The eastern and central sub-basins are presumed to be confluent at this time (lake level approximately 20 m b.d.), with the western sub-basin still slightly higher.

EARLY LAKE ERIE

Approx. 12,500 years B.P.





LAKE ERIE

Approx. 10,000 years B.P.

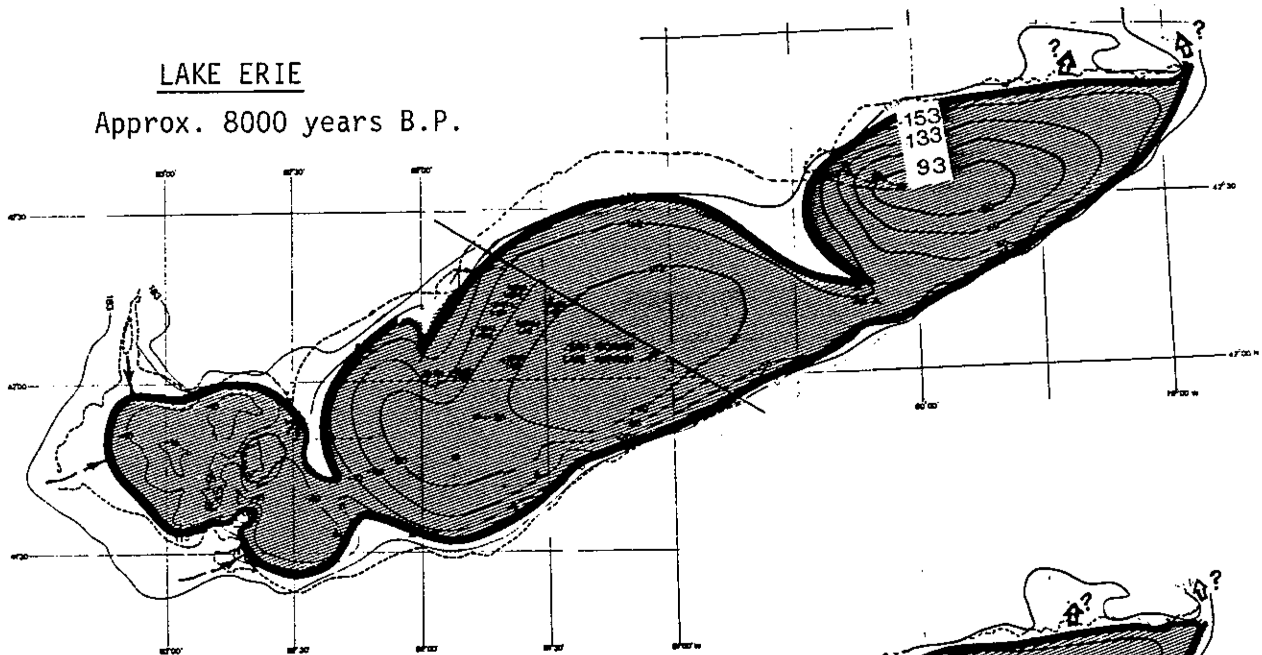
Figure 6-5

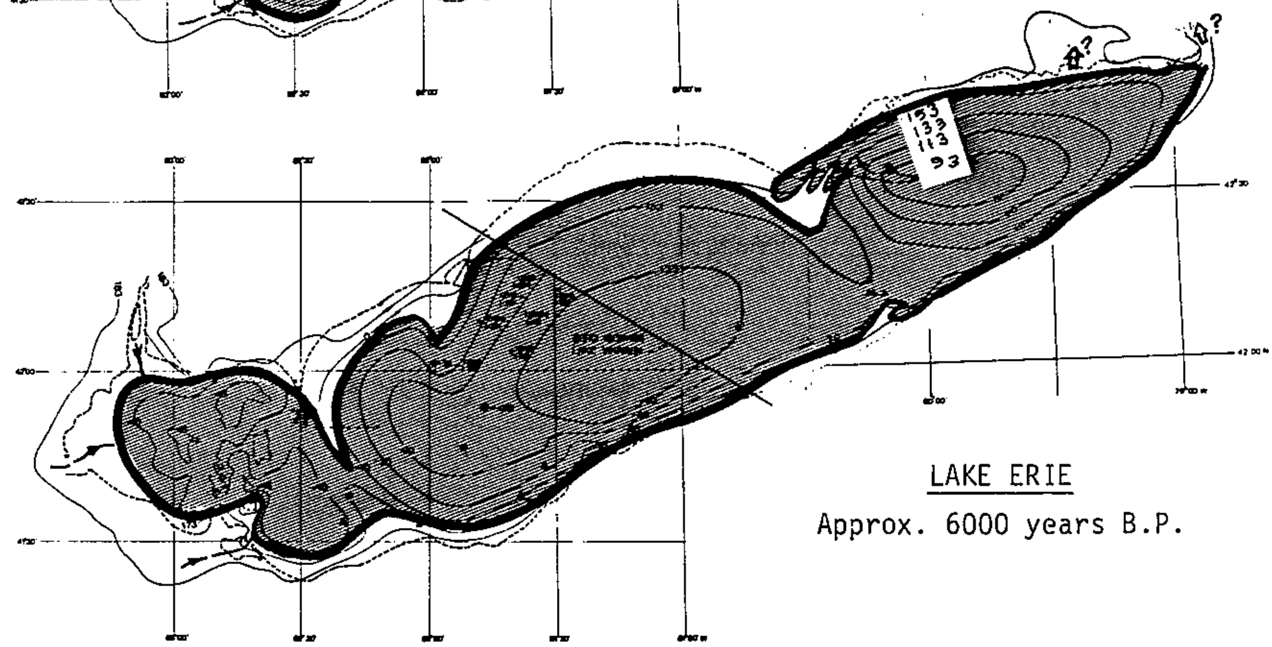
(Top): Paleogeographic reconstruction of Lake Erie at approximately 8000 years B.P. (lake level at approx. 8 m b.d.). Shoreline position in the central sub-basin has been adjusted to reflect estimated erosion amount due to coastal processes in the expanding lake.

(Bottom): Lake Erie at approx. 6000 years B.P. (lake level: approx. 5 m b.d.). Note changes to the three major forelands, shown in more detail in Figures 6-7 to 6-9.

LAKE ERIE

Approx. 8000 years B.P.





LAKE ERIE

Approx. 6000 years B.P.

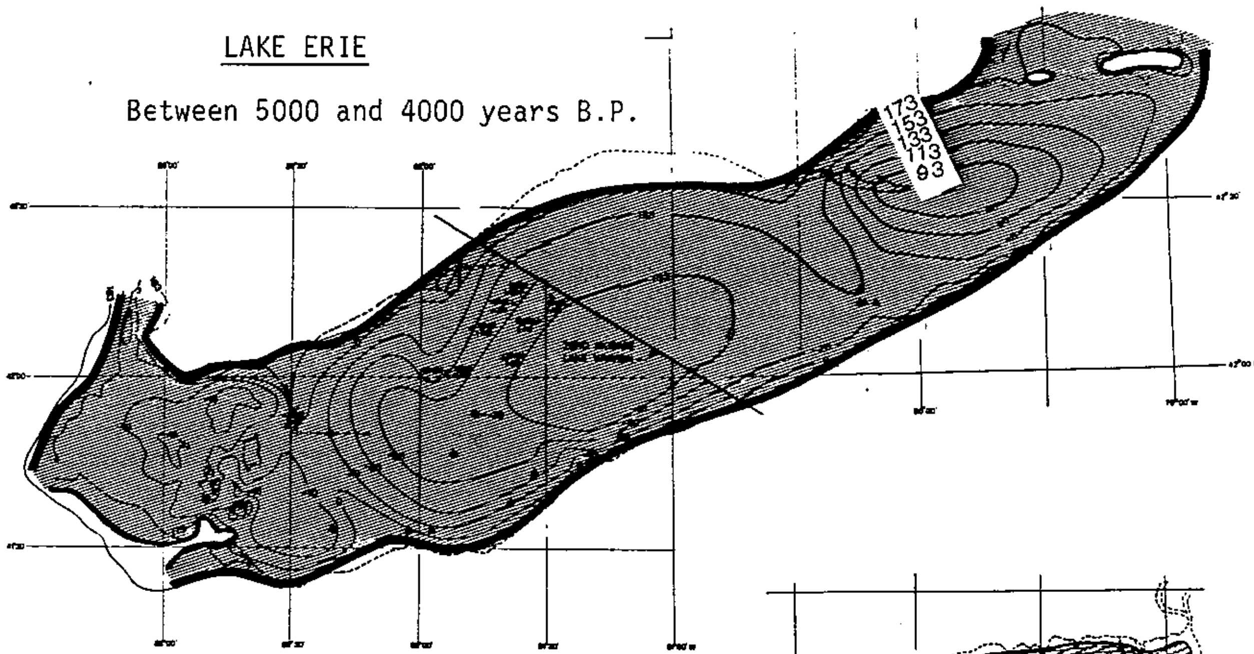
Figure 6-6

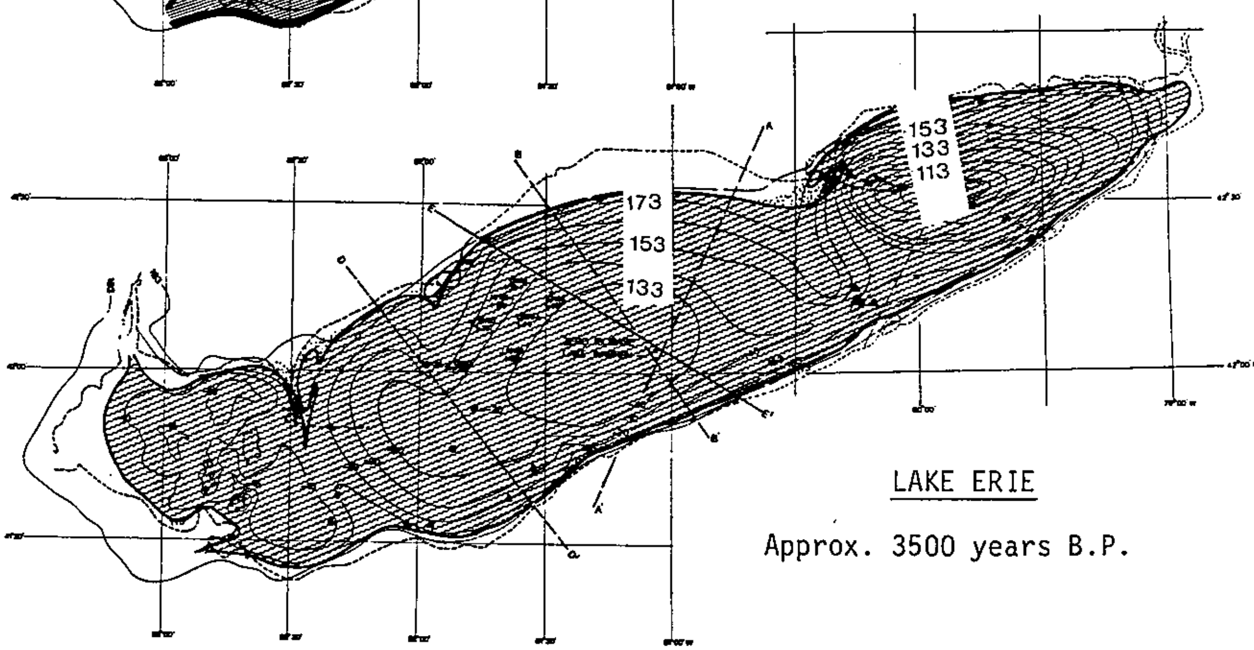
(Top): Paleogeographic reconstruction of Lake Erie at the time of the Nipissing phase, when drainage from the upper Great Lakes was resumed, râising lake levels to an estimated 5 m above present datum or higher.

(Bottom): Lake Erie at approximately 3500 years B.P. (lake levels at approx. 3 m b.d.). Reactivation of spit and barrier ridge growth is schematically shown.

LAKE ERIE

Between 5000 and 4000 years B.P.





LAKE ERIE

Approx. 3500 years B.P.

Figure 6-7

Reconstruction of the evolution of Long Point, based primarily on beach ridge orientation patterns and interpretations of borehole sedimentary sequences (boreholes on Long Point shown circled). The reconstruction shows Long Point originating as a north-south cuspate foreland, with recurves (A). After the inundation associated with the Nipissing event, the Point then developed as a more conventional free-form spit, transgressing northward as lake levels rose (B, C).

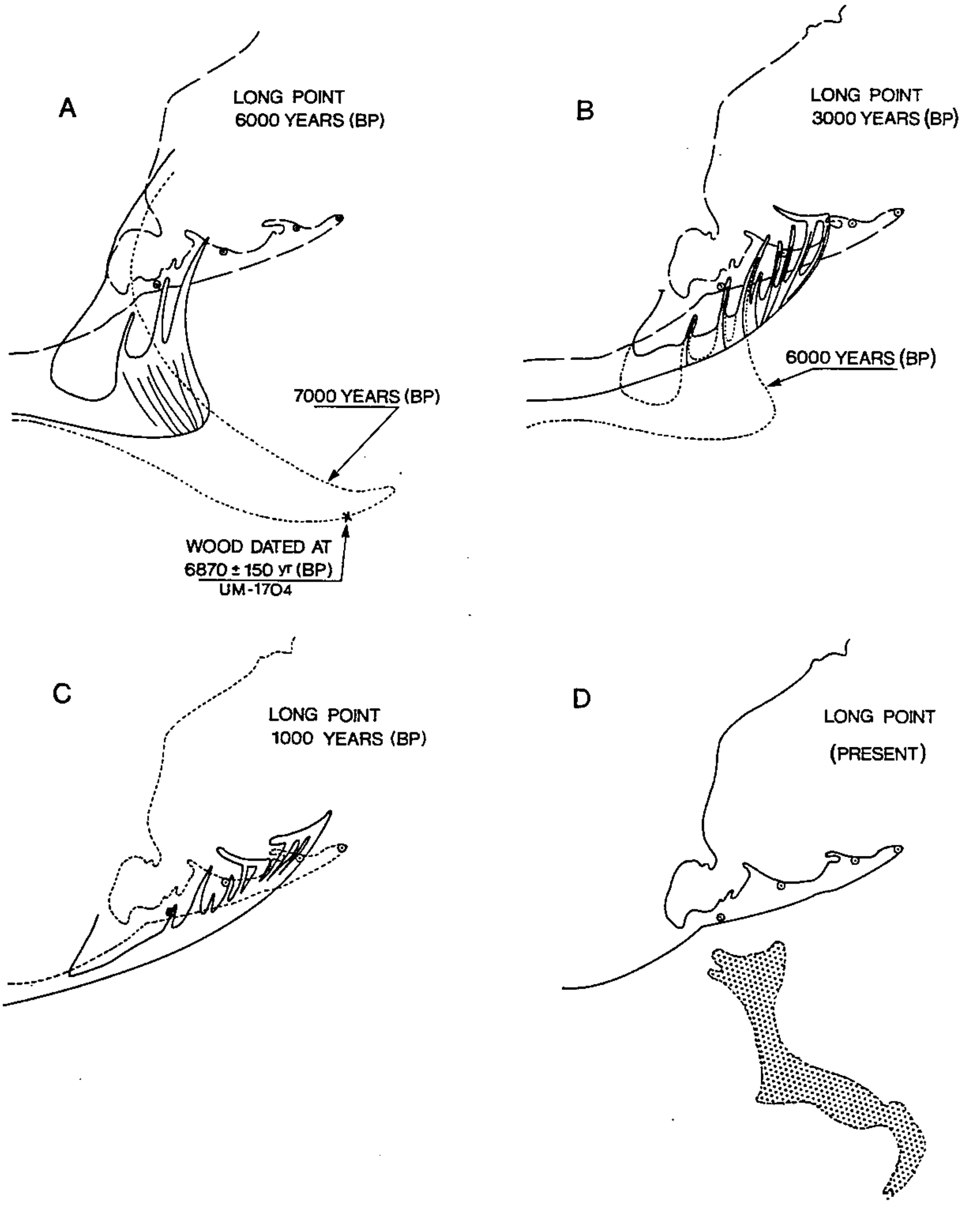

A
LONG POINT
6000 YEARS (BP)
7000 YEARS (BP)
WOOD DATED AT
6870 ± 150 yr (BP)
UM-1704
B
LONG POINT
3000 YEARS (BP)
6000 YEARS (BP)
C
LONG POINT
1000 YEARS (BP)
D
LONG POINT
(PRESENT)

Figure 6-8

Reconstruction of the evolution of Point Pelee, based primarily on beach ridge orientation patterns, radiocarbon-dated marsh stages, and interpretation of borehole sediments. The evolution of the transgressing eastern side is clearly analogous with that of barrier islands on marine coasts.

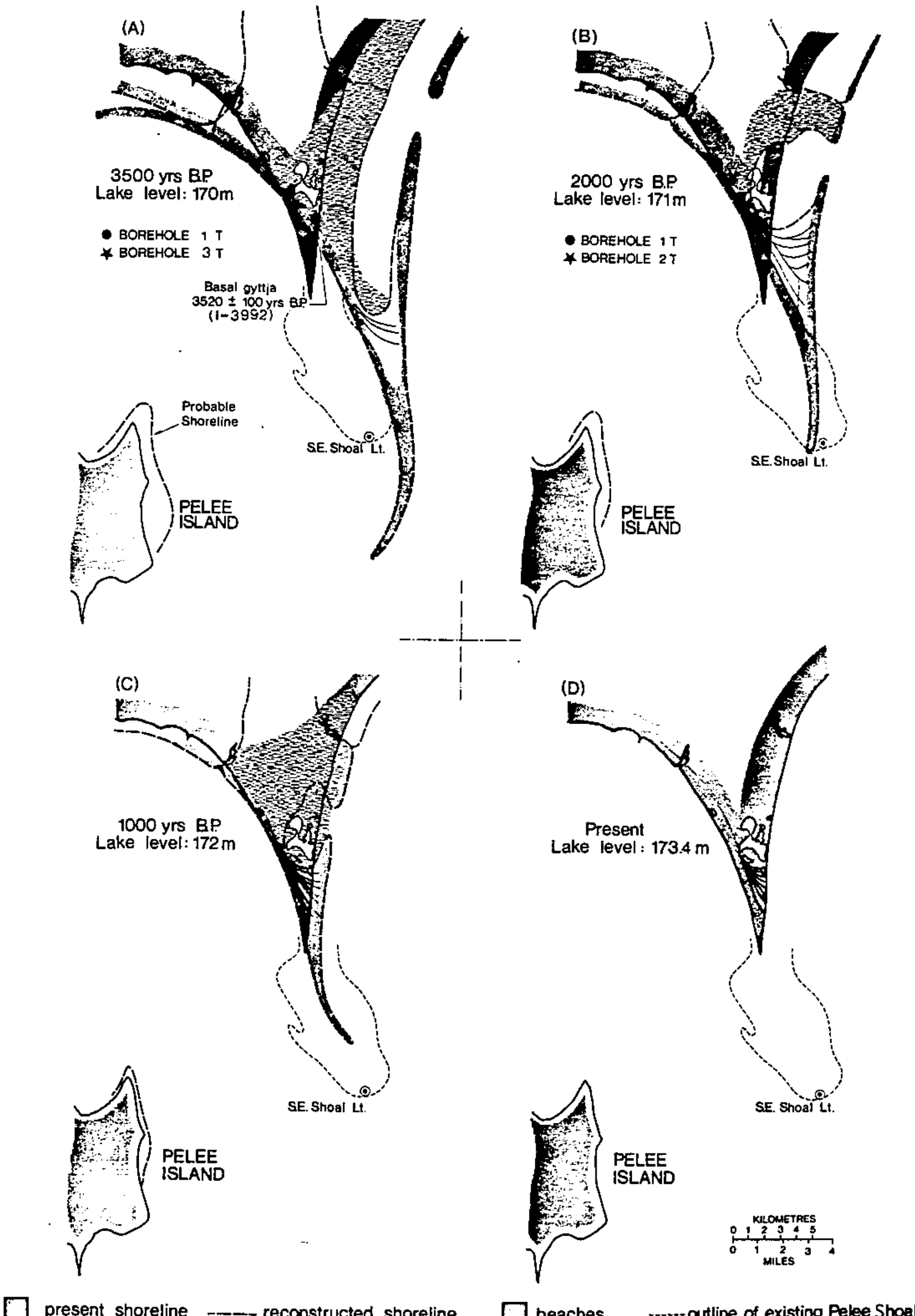

(A)
3500 yrs B.P.
Lake level: 170m
● BOREHOLE 1 T
✱ BOREHOLE 3 T
Basal gyttja
3520 ± 100 yrs B.P.
(I-3992)
Probable
Shoreline
S.E. Shoal Lt.
PELEE
ISLAND
(B)
2000 yrs B.P.
Lake level: 171m
● BOREHOLE 1 T
✱ BOREHOLE 2 T
S.E. Shoal Lt.
PELEE
ISLAND
(C)
1000 yrs B.P.
Lake level: 172 m
S.E. Shoal Lt.
PELEE
ISLAND
(D)
Present
Lake level: 173.4 m
S.E. Shoal Lt.
PELEE
ISLAND
KILOMETRES
0 1 2 3 4 5
0 1 2 3 4
MILES
present shoreline
reconstructed shoreline
beaches
outline of existing Pelee Shoal

Figure 6-9

Reconstruction of the evolution of Pointe-aux-Pins, based primarily on beach ridge orientation patterns, interpreted prior shoreline positions (asterisks mark these positions on nearshore echosounder traverses shown as dashed lines), limited sediment profiles, and radiocarbon-dated basal organics (solid dots).

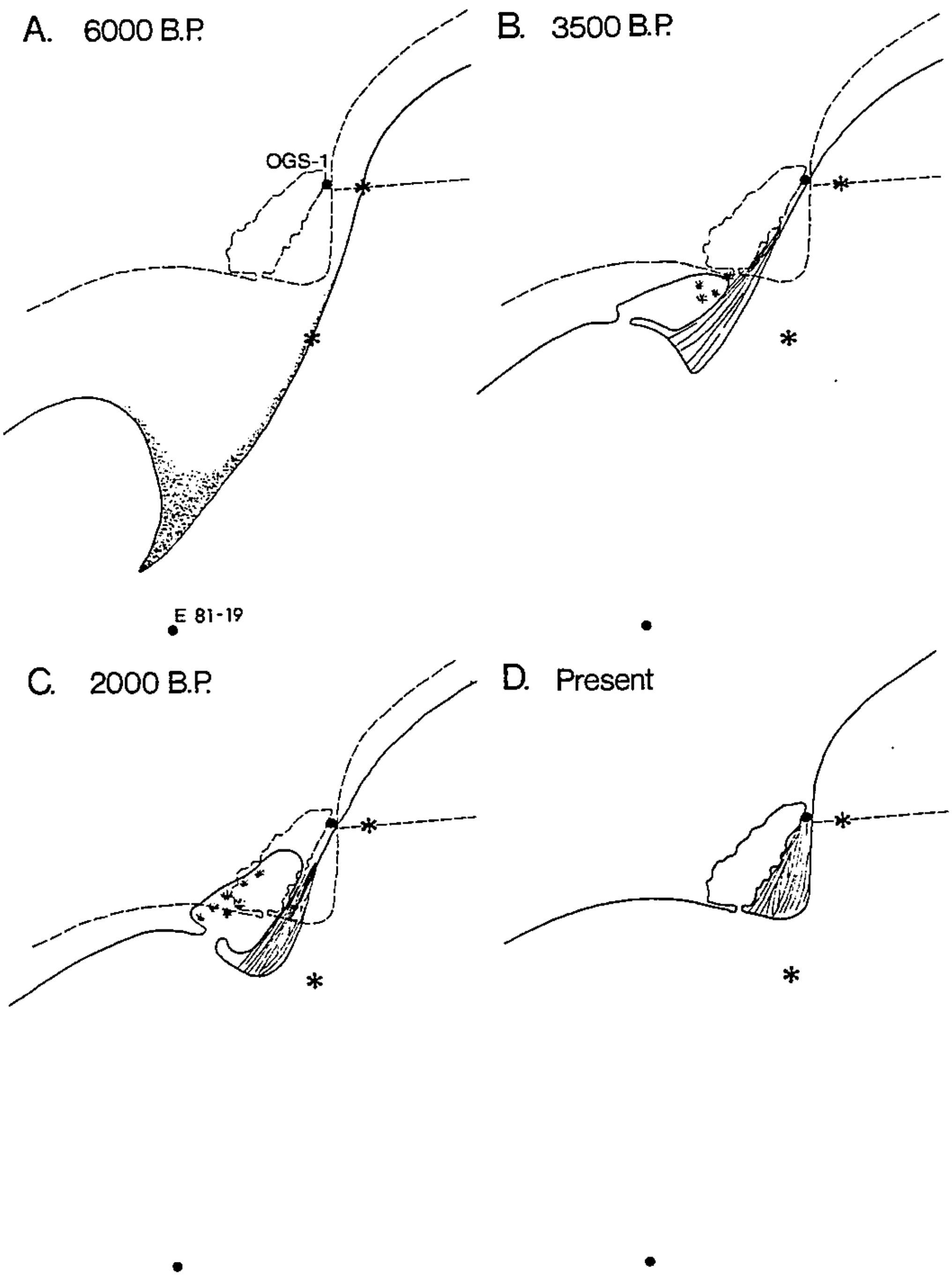

A. 6000 B.P.
OGS-1
E 81-19
B. 3500 B.P.
C. 2000 B.P.
D. Present

Figure 6-10

Oblique aerial photograph showing evolutionary processes at work along the east "barrier" of Point Pelee (looking south toward the tip). The picture was taken in 1976, and the preceeding years of record high lake levels have seen the shoreline recede several tens of metres in places (note the gap between the groyne field and the shore, and the large washover breach into the marshes in the central portion of the photograph). The canal (centre right) marks the northern boundary of Point Pelee National Park.