BARRIER ISLANDS OF KOUCHIBOUGUAC BAY -
NEW BRUNSWICK

THE BARRIER ISLANDS OF
KOUCHIBOUGUAC BAY
NEW BRUNSWICK

by

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SCOPE AND CONTENTS:

This study examines a barrier island system in the Southern Gulf of St. Lawrence with the objective of comparing it to other systems in North America and of examining indicators of the processes responsible for its formation. Like most barrier island systems, this one is undergoing shoreward retreat and dissection by wind and wave action. A study of sediment size and shape reveals that wind and wave processes are constantly overlapping each other in depositing sediments on the beaches. Since wave action dominates over the barrier island configuration, simulation of the distribution of wave energy to the islands after refraction was undertaken to show that many of the areas of the barrier undergoing change are areas of heavy wave attack. A cursory study of the stability of the inlets between the islands reveals that the change in island configuration at these points may also be due to the inability of the inlets to flush longshore drifted material out of the inlet during a normal tidal cycle.

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And with a little help from my friends.

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ABSTRACT

This study is concerned with a 29 km long barrier island system along the New Brunswick coast of Kouchibouguac Bay. Over the past 150 years these islands have been retreating shorewards and have been affected by storm wave action. The changes in the island configuration, the characteristics of the island topography and the seasonal variations in the beach profile suggests that these islands are similar to better known ones along the Unites States coastline.

The sediment characteristics of these islands reveal that there is an interplay of wind and wave processes on the islands,--an interplay that is constantly mixing beach, dune and lagoon sands. The dominant southwest winds in summer cause most of the beach and dune sands to take on the characteristics of wind affected sands while the fall and spring storms impart characteristics of wave deposition to the beach sands at these times.

The sediment characteristics revealed seasonal changes in the islands but simulation modelling of the

energy distribution of waves in the bay after wave refraction accounts for most of the long term change in the island configuration. This modelling emphasizes field work which revealed that not all parts of the islands are affected by the same storm waves. North-northeast waves have a better chance of affecting the southern part of the bay while more easterly approaching waves will only influence the northern part. Over a period of time from 1894 to 1964, wave refraction modelling also shows that much of the change in the configuration of South Beach can be accounted for by wave refraction over a changing offshore bathymetry.

Storm wave action thus accounts for most of the change in island configuration but the change around the inlets is most likely dependent upon the ability of these inlets to maintain stability at all times. Richibucto Inlet has achieved a stable equilibrium between the strength of the tidal currents passing through the inlet and the amount of incoming longshore drift, so that its position has remained static over the last 30 years. It is unlikely that Blacklands Gully or Little Gully have achieved this stability.

CHAPTER 1

INTRODUCTION

The barrier islands of Kouchibouguac Bay, New Brunswick (Fig. 1:1) offer a unique area of study in the Canadian Maritimes in that they are simplified representations of the barrier island complexes of the Southern Gulf of St. Lawrence. The earliest paper on these barrier islands was written by Ganong (1908), but his descriptions of Kouchibouguac Bay are very brief. Johnson (1925, p. 342) only mentions the Kouchibouguac Bay barrier islands in passing, although his description of the coastline of the Southern Gulf of St. Lawrence remains one of the most complete works attempted. The most recent paper on this area is by Kranck (1967), who deals with the sediments of Kouchibouguac Bay. Her brief description of the beaches and shoreline represents the only significant work on these barrier islands. One of the main purposes of this thesis is to provide a full description of this barrier island system and its associated environment. To this end Chapter 2 presents a detailed topographic description of these islands based on field work carried out August 1970 and May to June 1971.

With these descriptions it is thus possible to

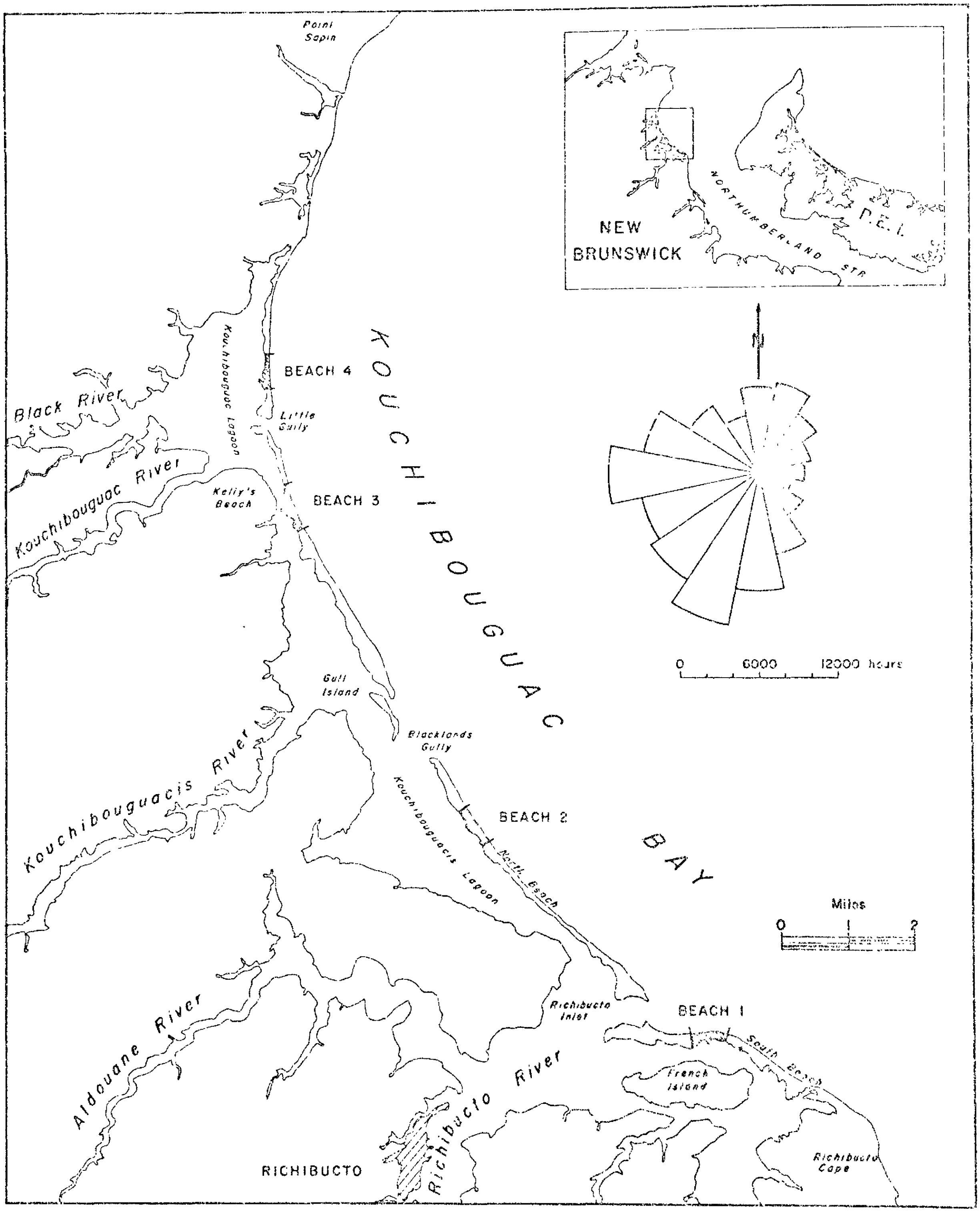


Fig. 1:1 General map of Kouchibouguac Bay with study locations.

to examine the theme of this thesis--the nature and causes of changes on the Kouchibouguac Bay barriers. It is the purpose of Chapter 3 to outline these changes using map, air photographic, surveyed and field evidence and to set these islands within the context of the literature for barrier islands in the United States section of the Eastern North American barrier island system. With this setting of the Kouchibouguac Bay barriers, it is then possible using the bay's unique protected situation in the Gulf of St. Lawrence to describe simply the processes responsible for the change occurring here.

The presence of barrier islands offshore from a coast has posed intriguing questions as to genesis. Johnson (1919) presented the idea that barrier islands were characteristic of emergent coasts and upward building offshore bars. The former idea has been regarded as an obvious misconception since many barrier islands are found on submergent coasts, but the latter point has been widely accepted in North America and is still upheld in the Russian literature (Leontyev, 1965). King (1959, pp. 181-185) has shown that an offshore bar cannot grow above still water level or above water level in a tidal environment and thus Johnson's complete explanation of barrier island genesis must be regarded as incorrect.

Beaumont (1845) originally put forward the now accepted idea that barrier islands form as the result of landward movement of material from offshore. Ganong (1908) independently came up with similar ideas as to the genesis of barrier islands in the Southern Gulf of St. Lawrence but it wasn't until Hoyt's paper (1967) that the genesis was outlined fully. The present barrier island systems originated at the lower sea levels of the Holocene as coastal beaches and spits which were able to build up significant dunes and beach deposits. As sea level rose the land behind these dunes was flooded forming lagoons. The beaches and dunes then underwent shoreward retreat as sea level continued to rise. The barrier island thus represents a dynamic equilibrium between the slope of the land, the rise of sea level, and the intensity of wave attack. If the rise of sea level or amount of wave attack increases the barrier island can be destroyed offshore; on the other hand if the rise in sea level decreases and the slope increases the barrier island will be driven shorewards and become a land beach. The barrier island is thus one of the most dynamic coastal landforms; it is subject to continual change in configuration and topography because of its environmental situation. The barrier islands of Kouchibouguac Bay, the Canadian Maritimes, and the United States have formed in this way.

The two main processes determining the present position and form of barrier islands are wind and wave action. Since it is impractical at this level of study to measure these processes directly, indirect indicators must be used. The processes can act over a short period of time (seasonally) or over a long period to produce the changes which can be observed on the barriers. Since these processes cannot act to any large degree without affecting the sediments on the barriers, then the processes should be reflected in the sediment characteristics. It is the purpose of Chapter 4 to examine grain size in order to characterize environments on the barriers and to indicate the responsible processes. Chapter 5 is a study of the shape and sphericity of the sediments as they relate only to the processes acting on the barriers.

On a long term basis the study of sediment characteristics is insufficient in explaining the changes in this barrier system. Most of the change in configuration is the result of wave action, which depends upon the energy distribution of waves in the bay. The above lends itself well to simulation modelling. Chapter 6 is an attempt at characterizing the energy distribution and explaining the change in barrier island configuration over time using the theory of wave refraction and the construction of wave refraction diagrams.

Since most change on the barrier islands occurs around inlets, this thesis will attempt, in Chapter 7, to define the criteria of inlet stability using current measures from Richibucto Inlet and the empirical relationships for predicting stability established in the literature. Because of the number of variables involved in inlet stability this study will only be a cursory treatment of the subject, but any discussion of change in this barrier island system would be incomplete without knowledge of inlet behaviour.

This thesis is thus an attempt at studying a barrier island system with the intention of characterizing the nature of and processes responsible for its genesis. The primary objective throughout will be to describe a section of the Canadian coastline that has been virtually ignored in the literature. The secondary objective of this thesis is the study of a barrier island system upon which the results of other studies can be verified and the body of knowledge of the processes responsible for these systems can be enlightened.

CHAPTER 2

DESCRIPTIONS OF BARRIER ISLANDS

SETTING

a) General

The barrier islands of Kouchibouguac Bay are situated at the head of the Northumberland Strait in the extreme southwestern Gulf of St. Lawrence along the north shore of New Brunswick between 46° 41' to 46° 53' north and 64° 44' to 64° 56' west (Fig. 1:1). The barrier islands consist of 29 km of sand beaches and dunes running in an arc from south to north (Fig. 2:1 and 2:2). The ends of this system are semipermanently joined to the mainland, but the bulk of the chain consists of two islands separated from each other by Blacklands Gully and from the southern spit by Richibucto Inlet and from the northern spit by Little Gully. These three inlets are offshore from the three main rivers of the area--the Kouchibouguacis, Richibucto and Kouchibouguac respectively. The rivers themselves are entrenched and small but open into estuaries 15 to 30 km from the ocean, and into shallow lagoons behind the barrier islands (Fig. 2:3 and 2:4).

b) Geology

The dominant bedrock of the area is a buff,

Fig. 2:1 Barrier islands of Southern Kouchibouguac Bay.

Fig. 2:2 Barrier islands of Northern Kouchibouguac Bay.

Fig. 2:3 Richibucto River Estuary

Fig. 2:4 Kouchibouguac River Estuary

feldspathic, massive sandstone, with some green siltstone and pebble conglomerate, of the Richibucto Formation, Pictou Group, Pennsylvanian Age (Gussow 1953). In places along the Richibucto and Kouchibouguac rivers and at the base of cliffs near Richibucto Cape and Point Sapin, the underlying Scoudouc Formation is exposed. The bedrock though massive breaks down readily when weathered and is easily eroded from the cliffs near the headlands of the bay. This bedrock is covered by a layer, less than 1 m thick, of sandy till and outwash deposits which were laid down by the locally nourished and regionally influenced Appalachian ice complex of the Wisconsin glaciation (Prest and Grant, 1969).

c) Land Stability

After glaciation much of the coastal land area was submerged below sea level and marine clays were laid down. The land then rose above modern sea level with isostatic rebound and for the last several thousand years has been undergoing submergence. Grant (1970, p. 677) measured the present rate of submergence at 25 cm per century at Charlottetown, Prince Edward Island, and there is evidence to suggest that the rise in sea level has been substantial. Kranck (personal communication August 18, 1970) shows evidence of three wave built terraces in Kouchibouguac Bay going down to 25 m and dating up to 6,300 years before present.

Frankel and Crowl (1961, p. 352) found peat deposits in Cascumpeque Harbour, Prince Edward Island at depths of 6.8 m below sea level. There are also isolated occurrences of buried forests along the Northumberland Strait and Bay of Fundy shores of New Brunswick. The evidence suggests overwhelmingly that the Kouchibouguac Bay is one of present submergence.

d) The Offshore Area

Kranck (1967) carried out a detailed study of the offshore area of Kouchibouguac Bay and found that the bottom of the bay was made up of bedrock and gravel deposits on topographic highs and sand deposits in topographic lows. Most of the gravels are locally derived but foreign rock types are common and probably have been deposited by glaciation or ice rafting. The dominant sands in the bay are quartz, feldspar, and mica while the dominant heavy minerals are hematite magnetite, zircon, tourmaline, garnet, amphibole and pyroxenes. The bathym etry for the area conforms to the shape of the bay with three shoal or ridge areas protruding from the northernmost point of the barrier, Blacklands Gully and Richibucto Cape. Between the bay and Prince Edward Island there is a deep trough up to 39 m deep which extends northwards into the Gulf of St. Lawrence. A more detailed discussion of the bathym etry will appear in the chapter on wave refraction.

e) Wind Regime

Kouchibouguac Bay has a very limited fetch window to winds from the Gulf of St. Lawrence. The maximum fetch is 790 km to the northeast-east northeast towards Newfoundland and the Strait of Belle Isle. To Anticosti in the north northeast it is 320 km, but outside of these two directions the fetch is negligible. It is 64 km to the northern tip of Prince Edward Island, and from there southwards Prince Edward Island effectively shelters Kouchibouguac Bay. For all other directions, the barrier islands in Kouchibouguac Bay are sheltered by the New Brunswick mainland.

The predominant winds for this area based on accumulative hourly date from Summerside, Prince Edward Island for the period 1956 to 1970 (excluding 1958, June 1960, and May 1959) are from the south to northwest (57.31% of all winds, Fig. 1:1). The two important fetches have only 10.38% of all winds and only 28.52% of all winds come from fetches having any bearing on wave formation for this area. Of these latter winds, 28.33% will not be able to generate waves that can affect the islands because of winter ice conditions in January, February and March. Though the predominant winds do not affect the wave regime of these beaches, the dominant wind (the direction of maximum wind speeds) for each month comes 46.25% of the time from fetches affecting the beaches of the bay. Even though this area is not exposed to much of the wind affecting the wave regime the strongest winds do affect this regime. Though the fetch window for winds generating waves is limited, after wave refraction this window becomes slightly larger. A proper description of the wave regime lies outside this chapter and will be outlined when the wave refraction patterns for the bay are discussed.

f) Ice Conditions

Mention is made above of the effect of ice conditions in the bay. A study by Forward (1954) for a period 1940 to 1952 reveals that the beaches in this bay are usually ice-bound by December 15. From this time to about mid-March, pack ice builds up seaward into the Gulf of St. Lawrence and, depending upon spring temperatures and wind directions, most of the ice is gone from the bay between April 1 and April 25.

g) Tides

The tides in this study area have a minimal effect on barrier island topography. The bay is affected by two amphidromic centers,--one in the Northumberland Strait southeast of Cape Richibucto and one northwest of the Magdalen Islands, so that the tides are semi-diurnal (Farqhuarson, 1962). The tidal range of these tides is low and ranges to a maximum of .93 m with a mean range of .67 m (Canadian Tide and Currect Tables 1971 v. 2 p. 17).

DETAILED DESCRIPTION OF THE BARRIER ISLANDS

The following description is based upon interpretive mapping and profiling from the 1965 air photographs of the barrier islands. The offshore bars, major inlet channels, shoreline, backshore beaches, dune cliffs, dune ridges, overwash channels, and lagoon and ocean shoals were mapped from paired air photographs using a radial line plotter. These maps were joined in a mosaic to produce a generalized descriptive map of the barrier island system from its northernmost point to French Island in the south (Fig. 2:5). The basic description of the islands is derived from this map and added reconnaissance detail. In order to provide a more detailed study of the sediments and topography of the islands the four areas marked on Figure 1:1 as Beaches 1 to 4 were chosen to be representative of the islands as a whole. These areas were mapped in detail from the ocean shore to the top of dune crest and five profiles were taken across each mapped area. (See Appendix 1 for details of construction of these four maps.) For consistency the beach area between Beach 3 and 4 was also mapped in a similar manner. The profiles on these sections were surveyed by levelling and tape measuring of distances. Bench marks were established for later reference using 1.8 m iron fence posts and profiles were surveyed at right angles to shore with reference to a compass bearing. The profiles were spaced evenly apart but the actual profile line was chosen randomly. All profiles are representative of the mapped beaches and of the actual topography of the beach.

a) South Beach

South Beach is the southernmost spit and curves westward from Richibucto Cape for a distance of 6.7 km (Fig. 2:7). It consists of recurved dune ridges which suggest growth of the ridges from Richibucto Cape westwards up to the breakwall of Richibucto Inlet. The distal end of the spit appears to have been a separate island at one time with growth of recurved ridges seawards from a point 300 m from the end of the spit. For the most part the dunes are vegetated with marram grass but the older and lower dunes towards the lagoon support mosses and some wild rose shrubbery. The ridges are at present undergoing landward erosion with a cliff that ranges up to 2 m in

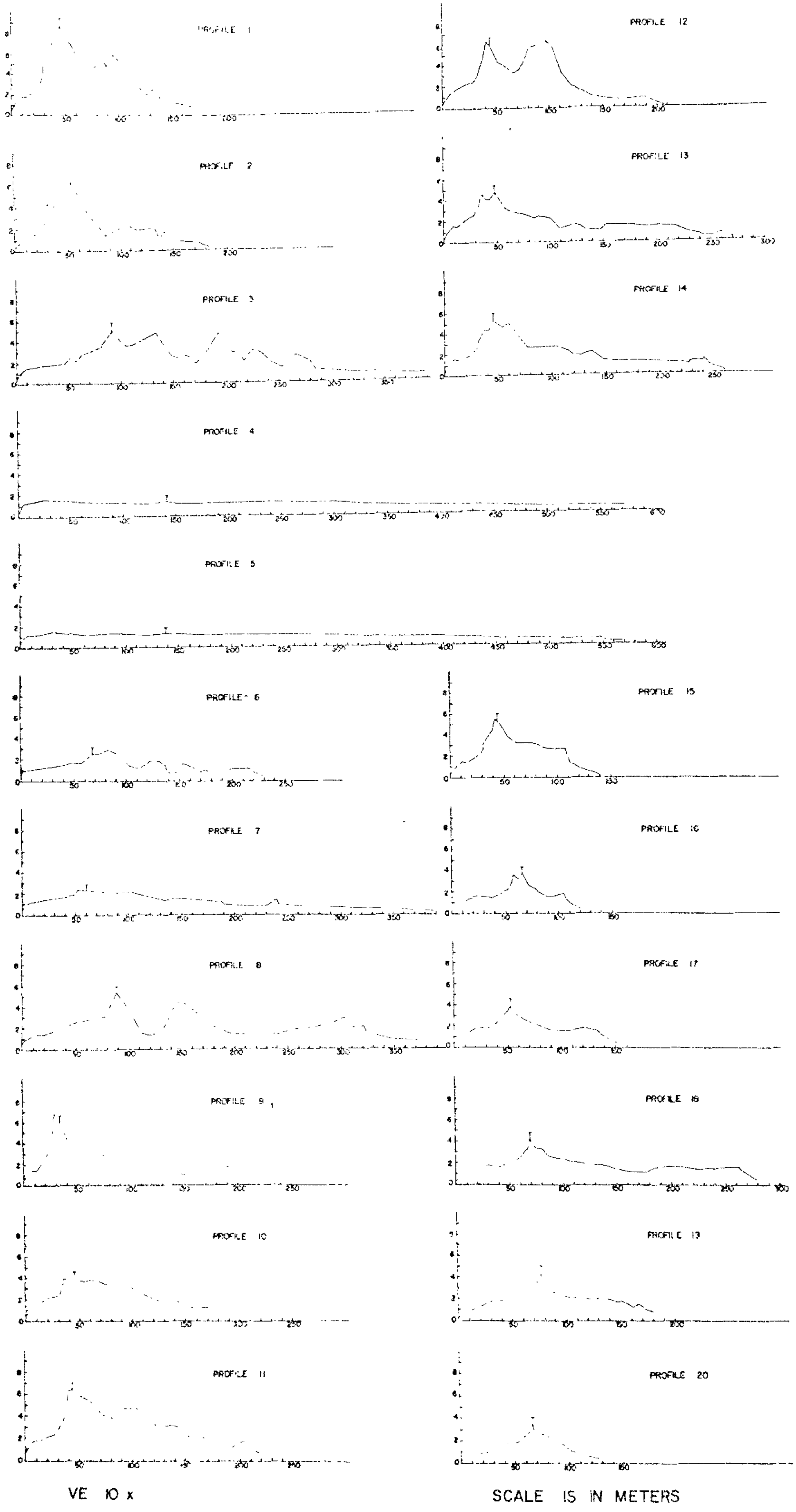


Fig. 2:6 Topographic profiles of selected sites.

Fig. 2:7   Areal view of South Beach

Fig. 2:8   Eroding dune cliff on South Beach

height (Profile 1, Fig. 2:6; Fig. 2:8). From this cliff the dune ridges reach a height of 8.5 m above low tide at the front of the barrier. Because the dune ridges overlap each other the rest of the dune complex appears as low hummocky dune topography (Profiles 1 to 3, Fig.2:6).

The major feature on South Beach is an infilled inlet (1.5 m above low tide level) which once cut across the main trend of the dune ridges. Whereas this barrier island is quite narrow (less than 200 m wide), the infilled inlet merges into tidal flats up to 600 m from the ocean. These tidal flats are very low in relief (Profile 4 and 5, Fig. 2:6) and consist of wind and wave generated mega-ripples. The foreshore area of the lagoon borders on the dune complex with little or no backshore, while the lagoon itself is very shallow (less than .6 m deep) and, except for an extension towards Richibucto Village, is never more than 600 m wide.

The ocean beach consists of large cusps which fit the rip cell pattern developed in the single offshore bar. From the ocean the beach rises to a berm 1 m above low tide and then extends 15 to 30 m to the erosion slip in front of the dune ridge (Fig. 2:9; Fig. 2:11). The backshore on this beach is usually above wave action and

Fig. 2:9 Ocean Beach on South Beach.

Fig. 2:10 Areal view of Richibucto Inlet.

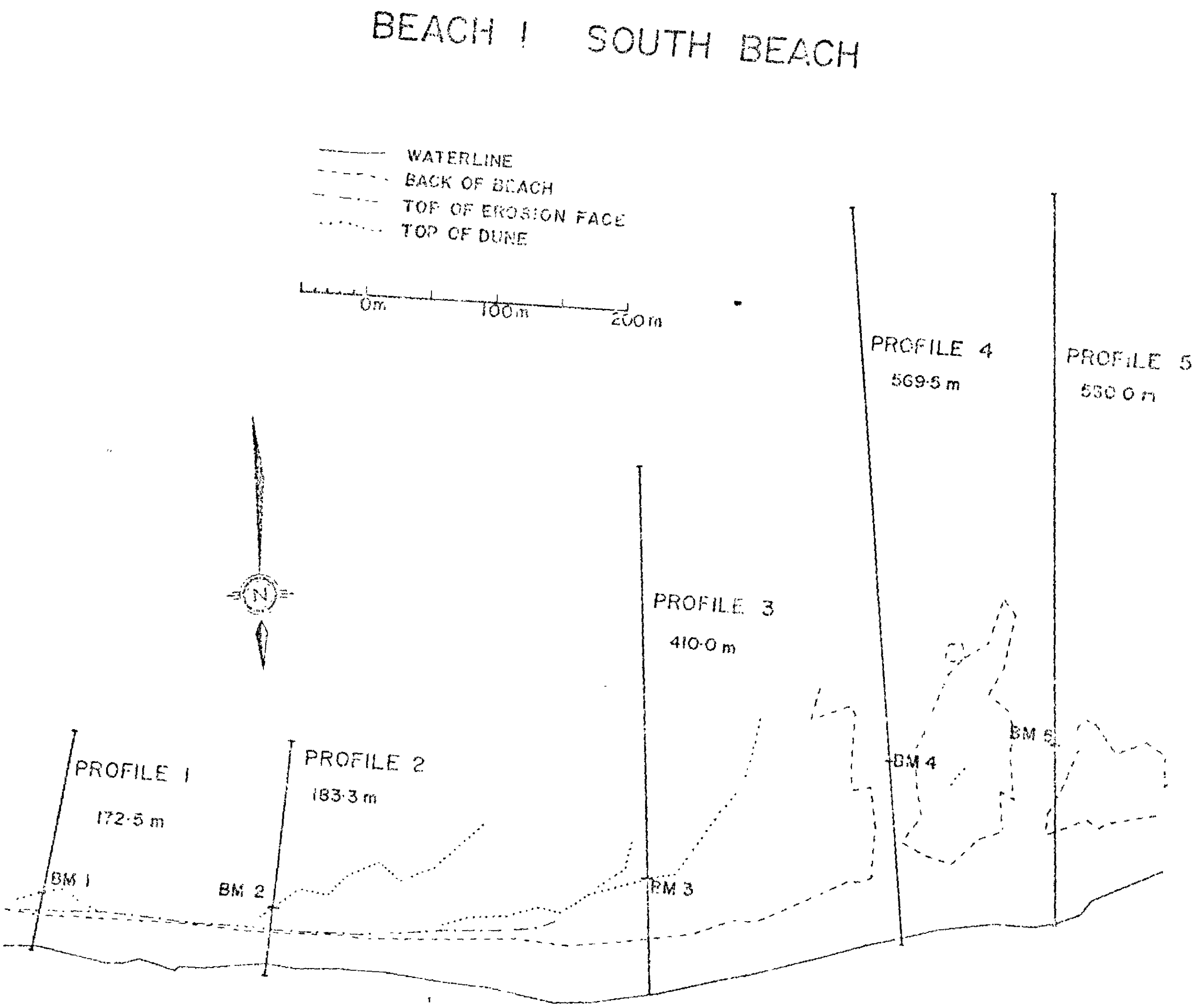


Fig. 2:11 Surveyed map of South Beach.

for the most part in summer is undergoing little wave action. The ocean beaches consist of medium sand (1.6-1.90) which is well sorted (.33-.360) while the dune and lagoon sands are also medium sized (1.70) but slightly less well sorted (.38-.410).

b) Richibucto Inlet

The dominant feature in the southern part of the islands is Richibucto Inlet (Fig. 2:10). This inlet is the continuation of Richibucto River and represents a major north meander in its channel. The inlet is a maximum of 760 m wide and 1,200 m long. The channel is banked on the lagoon sides by two wide shoals which are breached by two tidal distributary channels and banked on the northern ocean side by an extensive shoal 600 m wide which is the extension of the offshore bar system of North Beach (Fig. 2:5). This shoal parallels South Beach for 2.7 km at which point it is breached by the main channel. The shoal then continues as an offshore bar southeast parallel to South Beach. The maximum depth of the channel is 12 m in the lagoon but this depth descreases to 7.5 m in the actual inlet and to as low as 5 m offshore from South Beach. The inlet is controlled at its mouth by manmade breakwalls along the shore of North Beach, and by a single breakwall running at a right angle to South Beach. Of all the inlets in the bay this one is by far the largest and most stable.

c) North Beach

North Beach is the 7 km long barrier island lying between Richibucto Inlet and Blacklands Gully. It can be broken down into two parts,---an area affected by Blacklands Gully and an area not affected by this inlet. The latter is a series of prograding dune ridges that are very linear and not recurved. The best example of progradation occurs around Richibucto Inlet where a series of eight dune ridges have grown seawards in front of each other (Fig. 2:5). This area has the same sequence of vegetation as South Beach. Northwards the barrier island narrows to an average width of 120 m and the dune ridges overlie others towards the lagoon as evidenced by buried soil horizons in dissected areas. The dune ridge reaches a height of 9 m but the front is undergoing erosion and has been pocketed by blowouts and badly dissected in the past by storm waves (Fig. 2:12, Fig. 2:5). The lagoon behind this section, except for washover fans 1,100 m north of Richibucto Inlet, is free of tidal flats and shoals. It increases in width northwards and merges from depths of 1 to 2 m into salt marshes landward.

The dissected part of North Beach ends at an infilled inlet which is slowly undergoing dune development

Fig. 2:12 Dissected dune topography on North Beach.

Fig. 2:13 General View of defunct inlet on North Beach.

(Fig.2:13). This inlet was about 760 m wide but is now infilled 270 m across the island. It consists of a series of interlocking washover channels which drain into the lagoon and between these channels are small dunes which are protected on the ocean side by a partially continuous ridge 3 m above low tide level (Profiles 6 and 7, Fig. 2:6). The tidal flats on the lagoon side of this area consist of soft sands and are usually covered with each high tide. Behind this area in the lagoon are the remnants of the tidal channels and shoals which were associated with this inlet. The shoals consist of firm sand and extend halfway across the 3.7 km width of the lagoon at this point. At low tide they are less than .3 m below water while the channels which cut through them may be over 1.2 m deep.

The dune ridges north of this area are completely different from those in the southern part of the island. Though they are slightly recurved, they are still linear, but they run at almost right angles to the ocean shore and indicate growth of the island southwards (Fig. 2:5). Near the infilled inlet, the ridges recurve behind each other (Profile 8 and 9, Fig. 2:6). The ridges are undergoing erosion on the ocean side with cliffs, reaching 4 m in height, backing the ocean beach (Fig. 2:14; Profiles 9 and 10, Fig. 2:6). At the back of the dune area there is a

Fig. 2:14 Eroding dune cliffs on North Beach.

Fig. 2:15 Exposed marsh deposits at Blacklands Gully on the ocean side of North Beach.

low but prominent dune ridge which appears to be undergoing active accretion (Profiles 8 to 10, Fig 2:6) at right angles to the older ridges. The dune ridges are stable and covered in marram grass which grows into wild rose shrubbery, mosses, and sedges on the older and lower ridges. The ridges reach a height of 7 m above low tide in the south (Profile 9, Fig. 2:6) but decrease in height northwards. The island in this area reaches a maximum width of 350 m but decreases northwards towards Blacklands Gully. The northern part of the island appears to be retreating over marsh deposits which are now exposed on the ocean side of the beach (Fig. 2:15).

The offshore area of North Beach consists of a parallel series of two or three bars which merge into the shoals of Blacklands Gully to the north and Richibucto Inlet to the south. The inner bar is very continuous while the second major outer bar is severed and discontinuous in places. The ocean beach outlined on Figure 2:16 is roughly representative of North Beach. This beach is indented into the washover channels in the defunct inlet for a width of 60 m but for the most part the beach here is only 15 to 30 m wide. The beach either lacks a berm (Profiles 6, 7, and 10, Fig. 2:6) or else has a very small one which ranges up to 1 m above low tide (Profiles 8 and 9, Fig. 2:6). The beach sands are again medium sized (1.6-1.8ϕ)

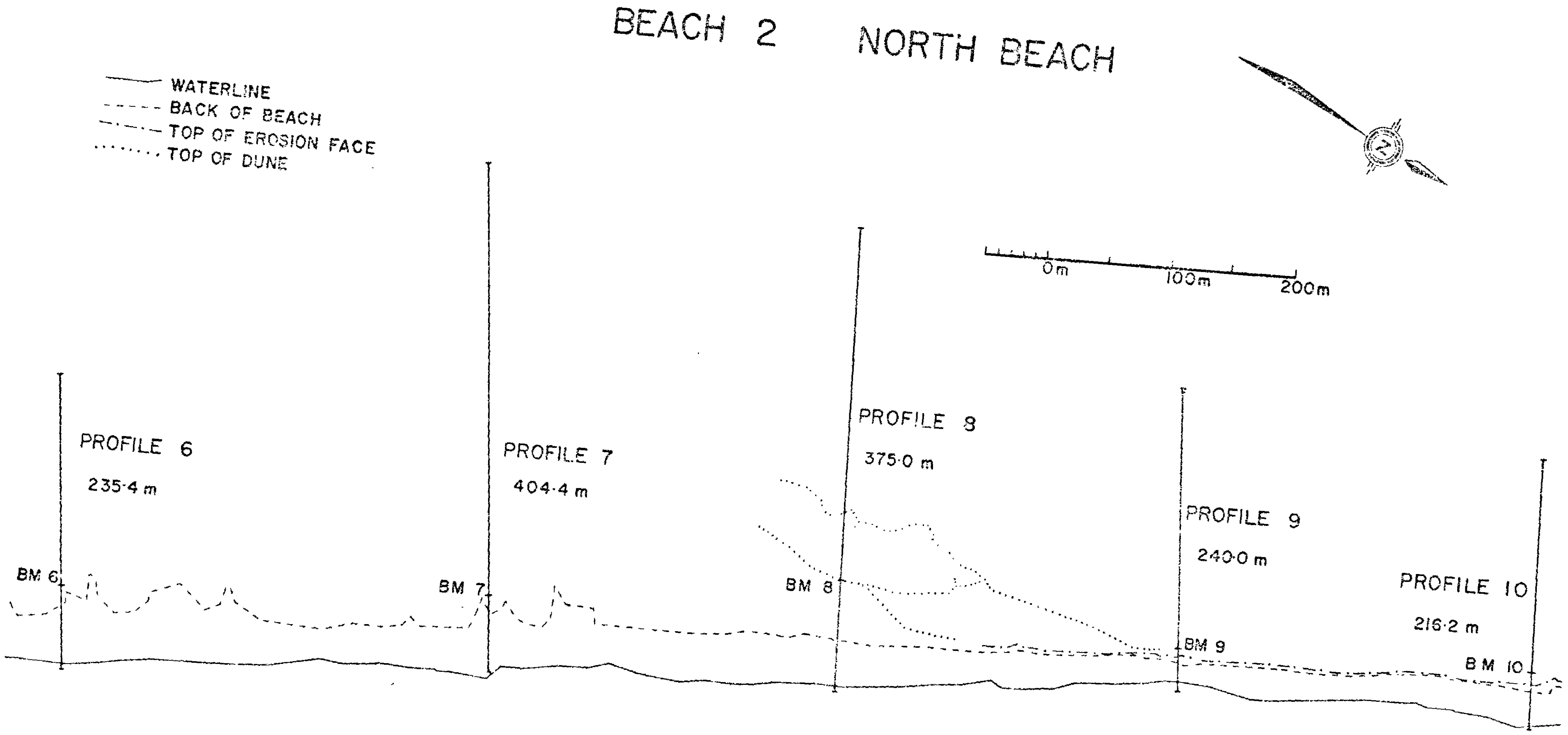


Fig. 2:7b Surveyed map of North Beach

and well sorted (.38-.470) while the dune and lagoon intertidal sands are slightly finer (1.7-1.80) but of the same sorting (.38-.460). North Beach has the same range of sediment sizes as South Beach but there are major topographic differences in the more dissected dune ridges and the more mature development of dune growth in the defunct inlet.

d) Blacklands Gully

Whereas Richibucto Inlet is an integral part of South Beach, Blacklands Gully ranks as a major physiographic unit. The present Blacklands Gully covers 2.6 km of coastline though it has ranged along 6.7 km of coastline as indicated by defunct inlets in the adjacent barrier islands. It is offset about 1.5 km south of the present Kouchibouguacis River, and consists of two main tidal channels,-- the northern one leading by a meandering channel into the Kouchibouguacis estuary and the other bifurcating around a relict tidal delta into Kouchibouguacis lagoon (Fig. 2:17 and 2:18; Fig. 2:5). This latter entrance joins up behind North Beach with the relict tidal channels from the defunct inlet previously described. There is also a dredged channel joining it to the Kouchibouguacis River. Between the two entrances is a series of low sand islands which according to air photograph evidence (to be described

Fig. 2:17 Southern part of Blacklands Gully from the air.

Fig. 2:18 Air view of the main channel of Blacklands Gully.

in a later chapter) was once part of North Beach. These islands form the core of an area of extensive shoals (Fig. 2:5) which become very complex on the ocean side of the inlets and are often awash at low tide. These shoals in the southern part of the Gully extend up to 760 m from the coastline and in the north they take on the appearance of a distributary tidal delta around the inlet. The whole complex has been very unstable over time. The inlets are navigable for fishing boats but the depths in the channels rarely exceed 1.8 m at low tide with most of the channels less than .9 m deep.

e) Beach 3

Lying between Little Gully and Blacklands Gully is a 6.4 km long barrier island which represents a homogeneous unit only slightly affected in the southernmost part by Blacklands Gully. This island runs almost due north and has a maximum width of 550 m, being widest in the south and decreasing northwards. The dune ridges of the island have evolved around two points,--the first of which is 670 m from Blacklands Gully and consists of a series of seven recurved ridges which overlap towards Blacklands Gully (Fig. 2:5). The northern ridges from this point recurve into what is now an infilled defunct inlet which still has washover channels similar to the relict inlet on North Beach. Crossing this inlet on the ocean side is a dune ridge about 5 m in height (Profiles 11-15, Fig. 2:6; Fig. 2:19). The second center of dune evolution is in the center of the barrier with old, discontinuous recurved ridges running outwards from this center. These ridges recurve into three very prominent cuspate forelands and appear to be the reason for the existence of these features. All of these dune ridges are pocketed with many old blowouts which are now vegetated. The vegetation on these ridges is similar to the northern part of North Beach. The recurved ridges are non-existent in the northern part of the island where only the main frontal dune and a very small dune at the back of the lagoon exist (Fig. 2:20; Profiles 13 to 15, Fig. 2:6). Almost the whole length of the frontal dunes has undergone erosion (Fig. 2:5 and 2:19) so that a cliff with a maximum height of 3 m now backs most of the ocean beach. Whereas the cliffs on South Beach had a large erosion slip slope, the erosion slip slope is virtually non-existent here (Profiles 11 and 12, Fig. 2:6).

The offshore area has a single bar which starts at Blacklands Gully and fades out over halfway up the island. A second ridge overlaps this ridge halfway up the island and continues towards Little Gully where it

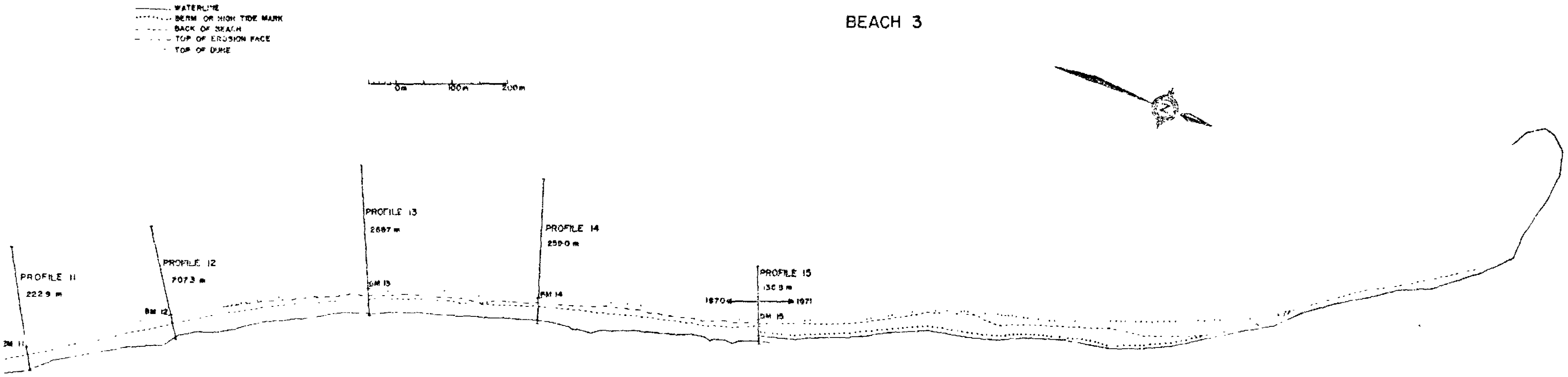


Fig. 2:19 Surveyed map of Beach 3

merges with shoals and two smaller offshore bars coming from the island (Fig. 2:5). The lagoon behind this island is dominated by shoals from Blacklands Gully and shoals which surround Kelly's Beach and continue into Little Gully. Kelly's Beach is the closest point to the mainland for any of the barrier islands (less than 120 m away) and the lagoon north and scuth from this point widens into the Kouchibouguac and Kouchibouguacis Rivers respectively. The shoals and lagoon depths are similar to those behind North Beach.

The ocean beach for this island ranges from 15 to 30 m in width and has a distinct berm 1.5 m above low tide for most of its length (Profile 11, 13, and 15, Fig. 2:6). At the extreme northern end the dune area becomes extinct and the island consists of beach which is overwashed during storms. The beach sands are medium-sized (1.2-1.5Ø) but only moderately to well-sorted (.35-.56Ø). The effect of wind eroding the surface layers of these beaches is evident in the field from the presence of coarse lag sands on the surface of the beach. The dune and intertidal lagoon sands are also medium-sized (1.4-1.6Ø) and are well-sorted (.39-.48Ø). This barrier island is very similar in topography to the northern part of North Beach but the variety of features is not as great as on North Beach. The general tendency of this island is for barrier topography

Fig. 2:20 Dune complex on Beach 3.

Fig. 2:21 Areal View of Little Gully.

to become less complex and more subdued northwards towards Little Gully.

f) Little Gully

The northern most major inlet in this barrier system is Little Gully. This inlet, 210 to 460 m wide and 490 m long, is offset .8 km north of the Kouchibouguac River (Fig. 2:21). The 1965 air photography shows a shallow entrance through the barrier island south from this inlet (Fig. 2:5), but 1971 mapping of the area shows no such breach (Fig. 2:19). The channel bifurcates inside the lagoon with one main channel leading to Kouchibouguac River and a second channel meandering and bifurcating towards Black River. A small distributary channel with a tidal delta exists just inside the lagoon on the north side of the inlet. The lagoon side of the inlet is extensively sand shoaled with depths less than .3 m at low tide while the whole lagoon behind consists of very shallow water over mud. The inlet itself averages 1.8 m in depth but the main channel does obtain depths of 3.7 m. The ocean side of the inlet consists of shallow sand shoals which merge with the offshore bars from the beaches surrounding the inlet. The main channel cuts through the center of this shoal area but a second distributary channel cuts through the shoal along the shore of the southern barrier island while a very small one parallels the northern spit. Of all the inlets in the barrier system this one represents closely the classic description of inlets outlined by Price (1963). The inlet, because of the shoaling, is not stable but by no means does it approach the unstable condition of Blacklands Gully.

g) The Northern Spit

The northern barrier is a semi-permanent spit which curves from Little Gully 4.3 km northwards and merges into a salt marsh on the mainland (Fig.2:5; Fig. 2:22). The island narrows from 300 m in the south to less than 90 m in the north and the low dune ridges decrease northwards from a height of just over 4.5 m to less than 2 m. These ridges recurve at the southern end but for the most part are subdued and linear with just a single ridge on the ocean side and low hummocky topography towards the lagoon (Profiles 15-20, Fig. 2:6). The dunes consist mainly of marram grass and at present are undergoing fresh sand accretion (Fig. 2:23). The evolution of these dunes is difficult to interpret but it appears that there has been only simple and slow development around a center 540 m north of Little Gully (Fig. 2:5) with the rest of the spit undergoing dune development and subsequent wave destruction through overwashing (Profiles 19 and 20, Fig. 2:6).

The offshore area near Little Gully consists of a

Fig. 2:22 Areal view of Little Gully and the Northern spit.

Fig. 2:23 Recent sand accretion on the dunes on Beach 4.

meandering bar which becomes linear and parallel to the shoreline northwards. The lagoon behind the spit is shallow (less than 1.2 m) and up to .7 km wide. It consists of shallow sand shoals which are awash at low tide behind the barrier and which show evidence of tidal channels along its whole length (Fig. 2:5). The ocean beach is very cuspate and has attached bars extending offshore towards Little Gully (Fig. 2:24). It averages from 50 to 80 m wide and consists of several berms ranging from 1.5 to 2.2 m above low tide (Profiles 19 and 20, Fig. 2:6; Fig. 2:24; Fig. 2:25). The ocean beach sands are medium sized (1.6-1.7Ø) and well-sorted (.37-.44Ø) while the dune and intertidal lagoon sands are the same size (1.5-1.7Ø) but less well-sorted (.41-.54Ø). The whole northern spit appears to be dominated in summer by wind erosion and deposition to a greater degree than the other beaches. Whereas the other islands have dominant dune and relict inlet areas, this barrier is dominated by the ocean beach and has little in the way of a dune complex. The reason for this difference is probably lack of sediment supply and as a result this part of the barrier system is not able to provide dune defenses against inundation by large storm waves.

PROFILING OF KOUCHIBOUGUAC BAY

In conjunction with the surveyed profiles which

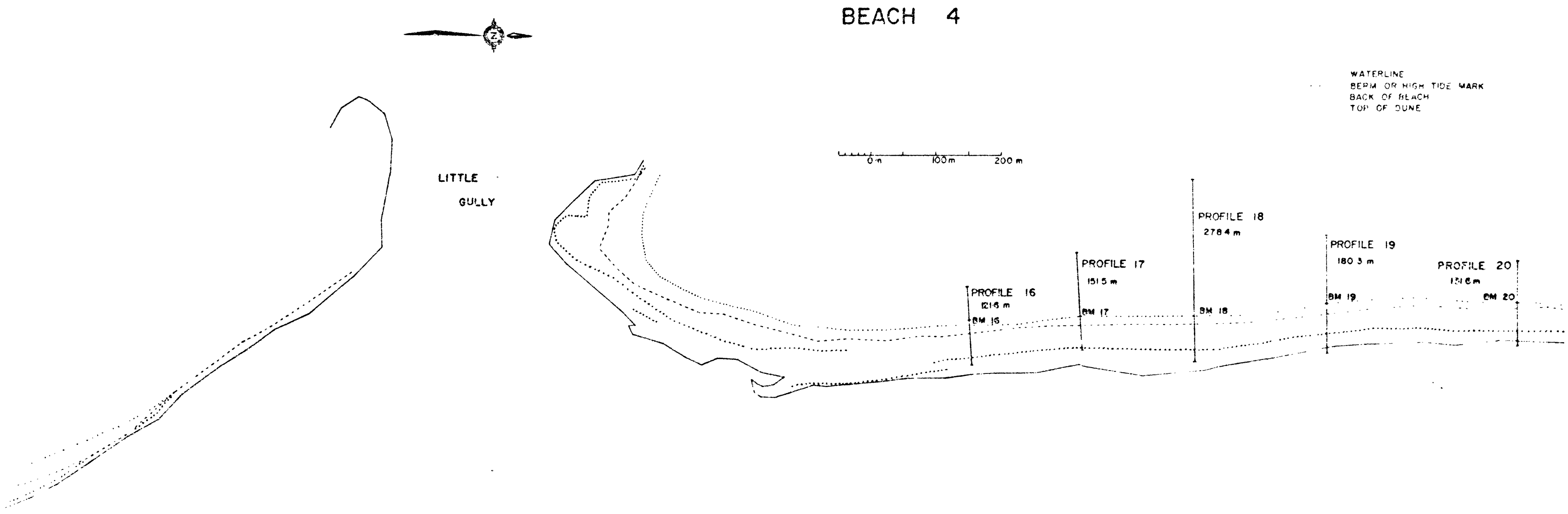


Fig. 2:24 Surveyed map of Beach 4

Fig. 2:25 Ocean Beach on the Northern spit.

Fig. 2:26 Echo sounding apparatus used in profiling.

were considered to be representative of each segment of the barrier system, echo sounding profiles of the bay were carried out offshore from these profiles. Though Kranck (1967, pg. 2253) shows variation in the offshore sediments of the bay, these offshore profiles can be considered characteristic of long stretches of the coastline. King (1965) was able to distinguish from echo tracings the texture of material by the shape of the bottom surface and the degree of sound penetration. Using his descriptions and correlating soundings made in Kouchibouguac Bay with visual observation of the sediments, it was also possible to distinguish sediment size along these profiles.

The sounding was done using a Kelvin Hughes echo sounder mounted on a small boat as illustrated in Figure 2:26. The profiles were carried out seaward from the land profiles and referenced to shore using a tacheometer bearing on the boat. Since the tacheometer position and beach profile positions were mapped accurately (Fig. 2:11, 2:16, 2:19, and 2:24), the tracing could then be corrected for scale by triangulation and interpolation. Since it was necessary to have calm water conditions for sounding and accurate positioning of the seaward profiles, offshore profiles for Profiles 2 and 3, South Beach had to be disregarded. The effect of the ebbing tidal current from Richibucto Inlet over the offshore bar on North Beach for those profiles tended to drift the boat east of the profile line so that triangulation under the above scheme was impossible. The profiles are drawn up and presented with a 1:50 vertical exaggeration in Figure 2:27.

The profiles of Richibucto Inlet (Profiles 1-5, Fig. 2:27) show that the inlet is asymmetrical and obtains a maximum depth of 5 m with sand to silt-sized material on the bottom. The inlet sides are quite steep and the planed shoal off North Beach contains a very large volume of sand. Even though this shoal protects South Beach from wave action at lower tides there is still a pronounced offshore bar at 2 to 2.5 m below water level on South Beach. The shoal also acts as a normal beach in the offshore area with development of a large offshore bar on the ocean side.

The profiles offshore from North Beach suggest that the barrier island is actually a shallow lens of sand overriding the bottom of the bay. There is a sharp break in slope at 1000 m distance from shore separating the sand lens from a very rough bouldery bottom (Profiles 9 and 10, Fig. 2:27 especially). Kranck (1967, p. 2253) shows bedrock offshore in this area but the traces here reveal either

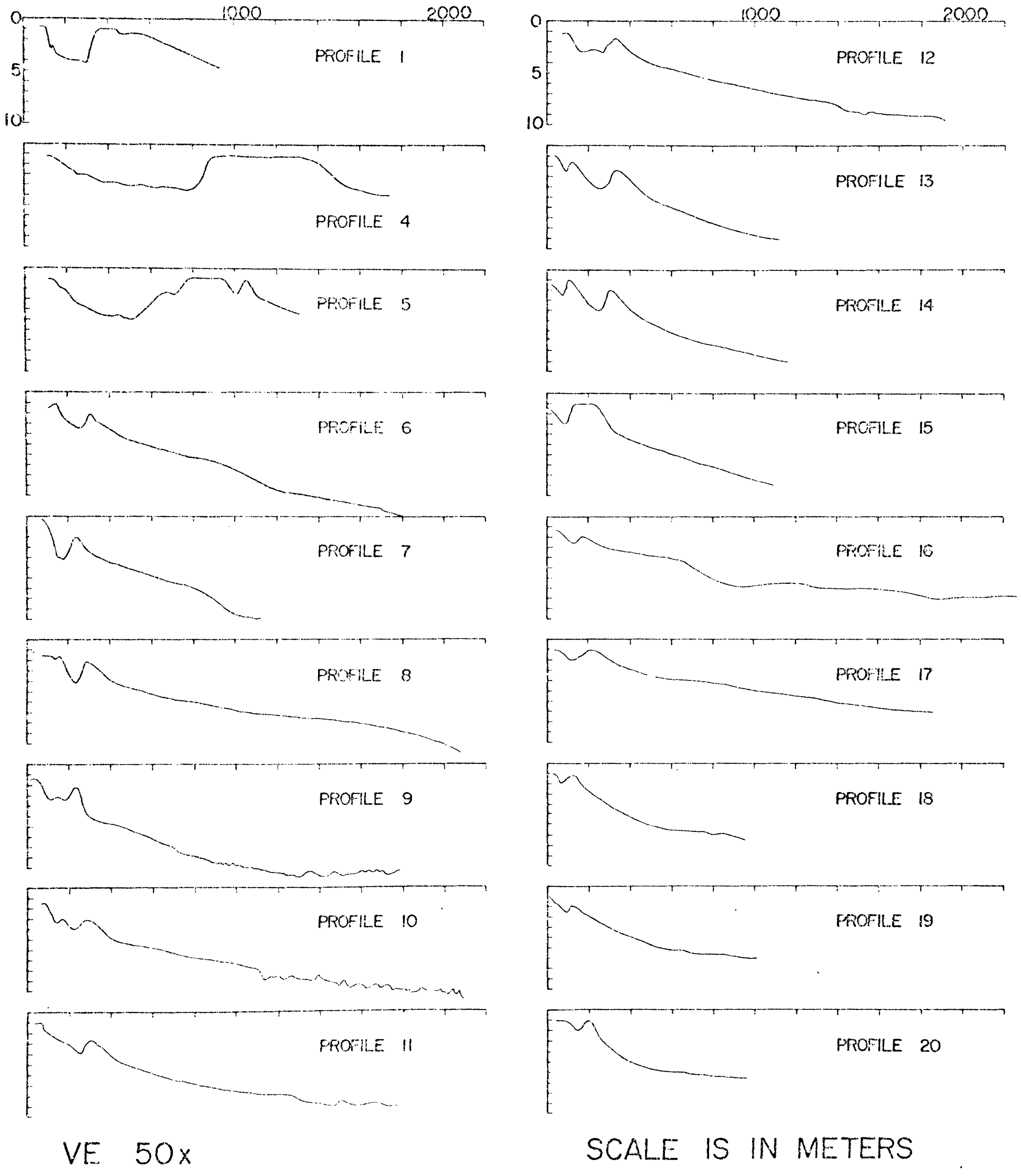


Fig. 2:27 Echo profiles of Kouchibouguac Bay.

very dissected bedrock or boulders. The offshore bars along this coastline are very well-developed with two distinct bars,--one at 1 m depth and another at 2 m. The trough between these bars is up to 4 m deep and at Profiles 9 and 10 a small bar has developed on the bottom. The sand size appears to be decreasing gradually offshore with the slope of the bottom decreasing from the second offshore bar. Much of the offshore area past this latter bar is also covered with small sand waves to a maximum depth of 11 m for the bay, 2 km from shore.

The offshore area opposite Beach 3 is a much steeper beach reaching depths of 9 m within 1.1 km of shore. It is also a much smoother area with some trace on the southernmost profile (Profile 11, Fig. 2:27) of gravels or sand covering the underlying bedrock or boulders. The profiles are dominated by two offshore bars at depths of 1-1.5 and 1.5-2.5 m. In the north the major bar merges into the shoal complex of Little Gully (Profile 15, Fig. 2:27). The offshore bars are very asymmetrical on Profiles 13 and 14 with a very gradual slope on the seaward side compared to the shoreward side. For the most part the offshore area consists of sand which becomes gradually finer offshore.

The offshore area of the northern barrier like the island is very subdued in relief. The bay is much shallower here with a slope usually tapering off at a depth of 7 to 8 m, 800 m from shore. There is only one major bar at a depth of 1 to 1.5 m and the trough between it and shore is only 1 m deep. The undulating surface where the slope tapers off indicates a thin veneer of sand covering a rougher surface underneath. Again the grain size of the material is decreasing rapidly from shore.

CONCLUSIONS

The barrier and offshore profiles together, and in light of barrier island evolution, suggest a veneer of sand 10 to 15 m in thickness overriding a very rough bedrock or boulder surface. The offshore profiles all show characteristic bar development and decrease in grain size and slope from shore. These profiles also reveal that there is a sufficient supply of sand within the range of wave action for movement of material up and down the beach under constructive and destructive wave action. The presence of sand waves on some of the offshore profiles and the presence of overlapping berms on the northern spit suggest that this process of sand movement was occurring at the time of profiling.

In comparison with other barrier systems in the southern Gulf of St. Lawrence the barrier islands of Kouchibouguac Bay offer a simplified scheme. The limited fetch window filters out all but north to east northeast waves and the duration of winds from these directions is limited. In comparison to Hog Island, which is part of the northern barrier island chain of Prince Edward Island, Kouchibouguac Bay has dune ridges which are less complex and dominating and as much as 10 m lower in relief. The relict inlets on the Kouchibouguac Bay islands are small and immature in development compared to the systems on Hog Island. The vegetative sequence here is also less developed and the lagoon systems behind the islands cannot compare to the size of Malpeque Bay, Prince Edward Island. The implication is that the barrier islands being studied here are simplified versions of others in the Gulf. One of the major difficulties of any study, complexity, has thus been reduced here so that it should be possible to apply the basic results of this study to the rest of the southern Gulf.

If the theory of barrier island growth is to hold then there should be some evidence of change in island position relative to shore over time. Some of the shifts in inlet position and shape and the process of sand movement on the beaches should also be evident over time. The descriptions of the barrier islands and inlets presented here all indicate changes. The next chapter will discuss factual evidence for these gross changes in barrier island configuration since 1800 and smaller seasonal changes for the period 1970 to 1971.

CHAPTER 3

EVIDENCE FOR CHANGE IN THE CONFIGURATION AND TOPOGRAPHY OF THE BARRIER ISLANDS

Since the descriptions of the barrier islands of Kouchibouguac indicate that the barriers are undergoing form changes, then it should be possible to pinpoint and measure these changes using map, air photographic and surveying evidence. It has been pointed out previously that the barriers in Kouchibouguac Bay are characteristic of the Southern Gulf of St. Lawrence and in fact they are part of the Eastern American Barrier island system. The literature on the United States part of this system shows conclusively that these systems are migrating shoreward and are unstable geomorphic forms. Hoyt and Henry (1967, p. 78) using corings found evidence of inlet migration southwards on Sapelo Island, Georgia of up to 1 km with truncated dune ridges on the northern part of the island. In a later article (1971) they conclude that the barrier islands south of Cape Hatteras are retreating landward as evidenced by the presence of lagoon deposits below the dune ridges which here were indicative of non-prograding coast. Dillon (1970) observed virtually the same results for the Charlestown Pond barrier of Rhode Island but concluded that washovers and lack of sediment supply to replenish this sand after storm attack was the main cause of landward retreat of this barrier. It shall be the purpose of this chapter to show that the barrier islands of Kouchibouguac Bay are not unique in the Eastern North American context.

FIELD EVIDENCE FOR CHANGE

The washover fans of South and North Beach, the recurved ridges of the dune complexes, the infilled tidal inlets, the truncated ridges of the northern part of North Beach, and the frontal dune cliff all compare with description of change on the United States systems; but the field evidence for change is even more conclusive than this descriptive evidence. The beaches at Richibucto Head have overridden the marsh deposits behind and these deposits were also exposed on North Beach at Blacklands Gully (Fig. 2:15) and this latter situation is repeated on Hog Island, Prince Edward Island, where a much wider island with higher dune ridges has overridden the lagoon deposits. There is also evidence that the marshes on the shoreward side of the lagoon are being eroded. In the spring of 1971 large peat masses were found on the tidal flats on the lagoon side of the northern barrier (Fig. 3:1). This peat appeared to have been eroded from a peat cliff up to 2 m in height along the mainland.

Fig. 3:1 Eroded marsh segments on the back of the Northern spit.

Not only was there evidence of retreat of the barrier but there was evidence for changes in the configuration of the island as outlined by dune ridges. On South Beach just north of Profile 3 there are the remains of an old wharf sitting halfway across the barrier island while the main dune ridge on North Beach contains many remnants of ship wrecks. Nails collected from one wreck in a blowout on the lagoon side of the frontal dune ridge were dated by Gerald Stevens (communication through Daryl Cook, May 16, 1971) as no later than 1840. The boat could have been built before this time with these nails but the beaching of the boat had to occur before the turn of the century since it is doubtful whether a boat built at this time could have lasted more than 60 years.

Other evidence suggesting only recent formation of the main dune ridges occurs on the north side of the main defunct inlet in North Beach. Here wood samples were collected between two dune ridges (Fig. 2:16) and sent for dating, but were refused because samples in similar environments were giving only recent meaningless dates. A Sable Island, Nova Scotia sample dated 210 ± 130 years while one in a dune in the barrier islands of Prince Edward Island dated 130 ± 130 years (communication through S. B. McCann with W. Blake Jr., January 11, 1971). There is air photographic evidence to suggest that the frontal ridge which trapped this debris (Profile 11, Fig. 2:6) was built up within the last 40 years.

The presence of buried soil horizons on North Beach also attests to the fact that the dune ridges of the barrier island are changing. In several places the soil horizon had a definite 1 to 2 cm organic layer and a visible leached horizon which could only have developed over a long period of time on a stable dune ridge and could only have been preserved when a dune ridge on the ocean side of the barrier grew over top the back ridge. Though this evidence shows rapid change in the position and growth of the dune ridges the change in the barrier island can be more dramatic. In 1970 the northern barrier was in fact a spit joined to the mainland in the north. However, in 1971, a tidal inlet cut across a low section of the barrier where the dune ridges merged into wave deposited sands. The inlet was about 30 m wide and had low recurved ridges on the lagoon side. The storms in the winter of 1970-1971 were, from local reports, nothing exceptional; yet a large and major change in the northern barrier had occurred. In what manner, direction and with what rates the barrier islands are changing can only be examined by looking at recorded evidence.

MAP EVIDENCE

The first accurate map of any of the barrier islands is the Des Barres chart of 1781 (Ganong 1897, p. 347). This map shows the area around Richibucto Inlet as a single recurved dune ridge from the north and from the east, surrounded by extensive shoals. This early charting became the basis of further bathymetric maps of Richibucto Inlet and Kouchibouguac Bay and their barrier islands. (For a listing of source maps used in this thesis see Appendix 2.) The earliest accurate map of the bay is the Thomas Wright Chart of 1807. This map shows the barrier islands substantially different from the present ones. These differences are shown on Figure 3:2 where an arrow pointing to the barrier island from the lagoon indicates the date of a map showing a breach at this point and an arrow pointing to the barrier islands from the ocean indicates infilling of a breach at this point. The 1807 map shows a breach at the north end and in the middle of the northern spit, at the site of Beach 3, in the area of the presently infilled inlet north of Blacklands Gully, and on the south side of the present Richibucto Inlet. The major accretional difference from the present barriers occurs at the extreme western end of South Beach which was joined to French Island. The present trend of relict dune ridges on South Beach supports this latter contention. In 1807 the barrier islands as a unit were very dissected.

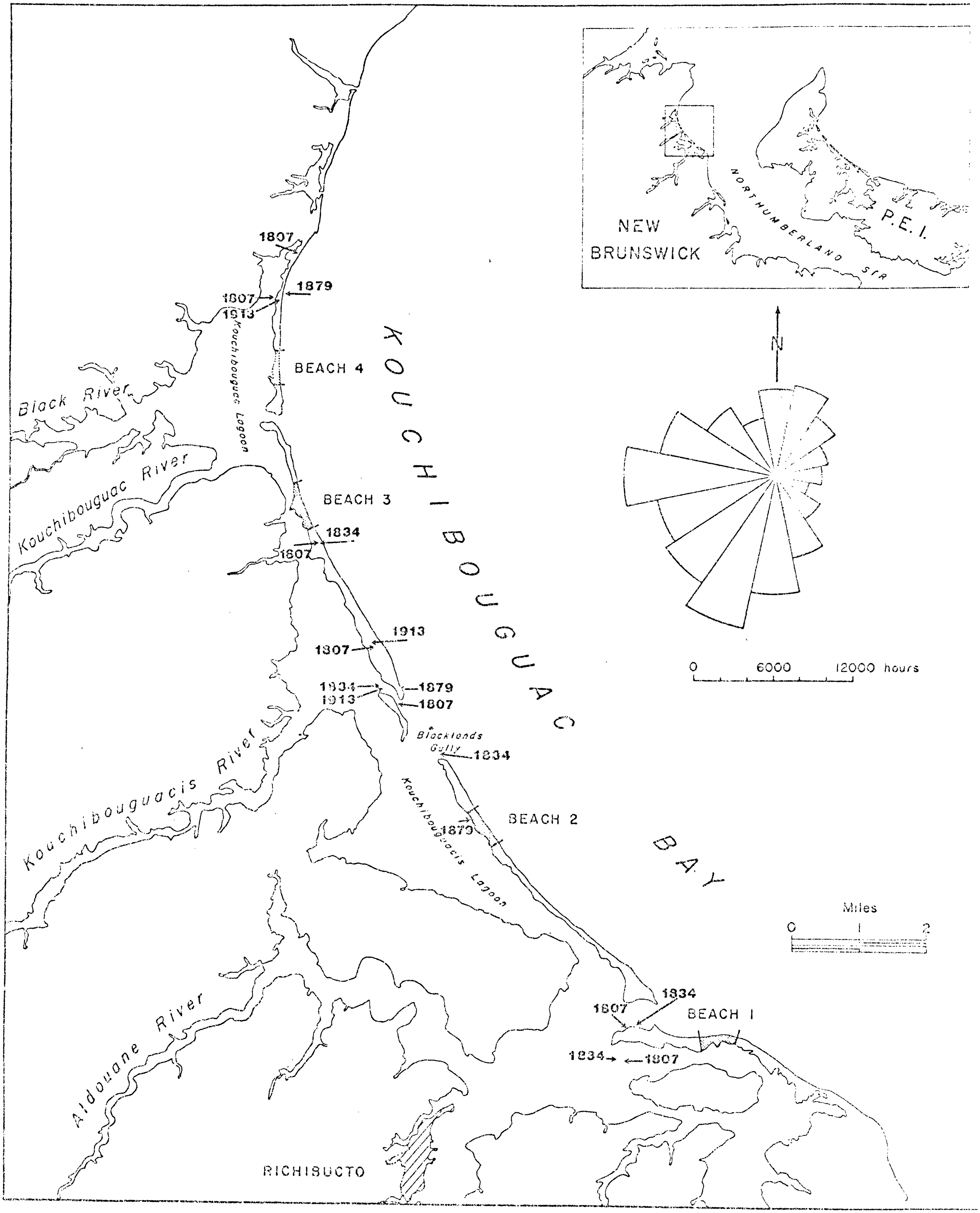


Fig. 3:2 Areas of major change since 1800.

The 1834 map by Herbert shows infilling of many of the breaches present in 1807. The South Beach breach is infilled and no longer are the barrier islands connected to French Island. North Beach has been infilled to form a continuous island up to the present main inlet of Blacklands Gully which has been opened since 1807. The inlet above Blacklands Gully is still open but the one at Beach 3 has been closed. The 1879 map in the Atlas of the Maritime Provinces shows infilling of the inlet in the middle of the northern spit, and of the present main inlet of Blacklands Gully. The defunct inlet which was surveyed as Beach 2 was opened by this date. The southern section of the bay is now relatively stable and by 1913 the inlet in the middle of the northern spit and the present main inlet of the Blacklands Gully had reopened. By this latter date the inlet just north of Blacklands had closed. The bathymetric maps of the bay after this date appear to be based on the 1913 map but by this time air photography had been flown for the bay. Assuming that this map evidence is relatively accurate, these barrier islands have undergone very substantial breaching and infilling over a one-hundred-year period with the Blacklands Gully and the northern spit areas being the most active and most unstable.

Following the Des Barres chart of 1781, the

British Admiralty and the Canadian Hydrographic Service carried out continuous bathymetric surveys of the area around Richibucto Inlet. These maps consist of accurate surveys of the shoreline and have the advantage of common reference points through time. The 1839 map of this area shows progradation of North Beach around Richibucto Inlet seaward while South Beach, as a slender spit, has been growing westward. (The bathymetric change of these maps will be discussed in the chapter on wave refraction.) By 1894 South Beach had widened and North Beach had undergone rapid progradation. When both of these maps are referenced to each other, South Beach appears to have retreated shorewards at several points. By 1930 North Beach had been stabilized by breakwalls at the inlet and South Beach had undergone a major breaching. The shoreward retreat of the barriers was still small but by 1969 North and South Beach had undergone landward retreat of about 150 to 200 feet. Except for the inlet which has undergone slow infilling since 1930, the shore configuration of South Beach has stabilized. The significant note about these small scaled maps is the retreat of the barriers shoreward and the growth of North Beach and breaching of South Beach. Based on these small scaled maps and the larger scaled ones, these barrier islands have undergone the type of change reported for other systems along the Atlantic Coast.

AIR PHOTOGRAPHIC EVIDENCE

Sequential air photography is a well-established procedure for delineating change in coasts (Zeigler and Ronne, 1957; Moffit, 1969; Langfelder, Stafford and Amein, 1970; and Stafford and Langfelder, 1971) and outside of surveys over time, it is the most accurate means of measuring and illustrating change. Often map evidence can be inaccurate and revisions often depend upon political decisions so that the time span between mapping can be prohibitive. Yet air photography itself is by no means an absolute. The greatest inaccuracy in air photography is the correction of relief and tilt distortions and the assumption of a continuum between coverages. With regard to the latter point, photographs along this section of coastline have been taken often enough that one can assume that the direction and frequency of change is a continuum.

If a study is based on shoreline change then often it is difficult with panchromatic film to delineate the exact shoreline in shallow waters; however, the high tide limit on a beach can be perceived easily (Stafford and Lanfelder 1971, p. 570). This limit was used as the basis for shoreline delineation in shallow water areas. Relief distortion was corrected using a radial line plotter,; however, the required principal points necessary for this correction were often situated over water and could not be precisely transferred to adjacent photographs. In these cases the points were transferred under stereoscopic viewing. Finally since sequential photography often involves different scales between years the common scaling of the changes becomes a problem. Since the three areas of photography mapped,--Richibucto Inlet, Blacklands Gully and Little Gully, were either near land or had distinct, permanent features, common reference points could be placed on each set of maps which could then be common-scaled using an enlarging-reducing machine. The maps presented as Figures 3:3 to 3:5 were constructed under these limitations for the years 1930, 1944-45, 1959, and 1965 where photography existed.

The variability of barrier and inlet position is well illustrated by these maps for a 35-year period. Though the 1930 photography was not available for Richibucto Inlet (Fig. 3:3), this area has undergone little change in the gross configuration of the islands. Since 1930 the breach on South Beach has undergone slow infilling with the expansion of a tidal delta into the lagoon. There has also been growth of tidal flats behind North Beach, but these flats have been eroded back by 1965. There was some progradation of shoreline on North Beach since 1944

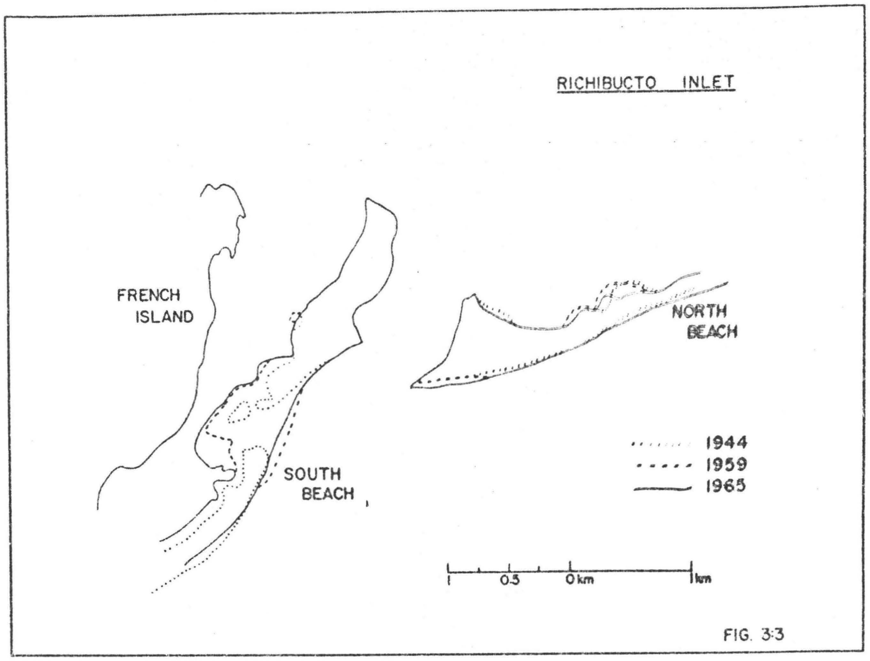


FIG. 3:3

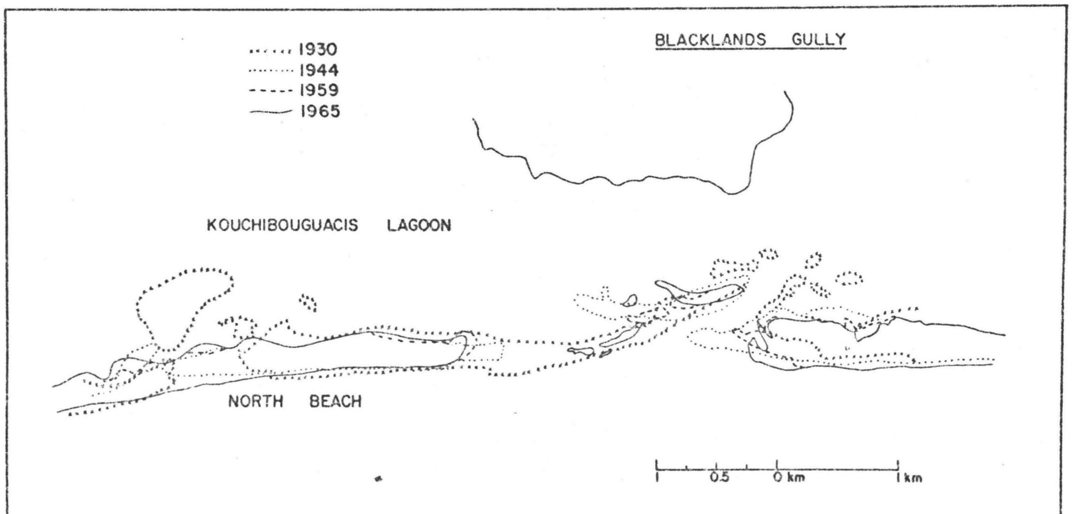


FIG. 3:4

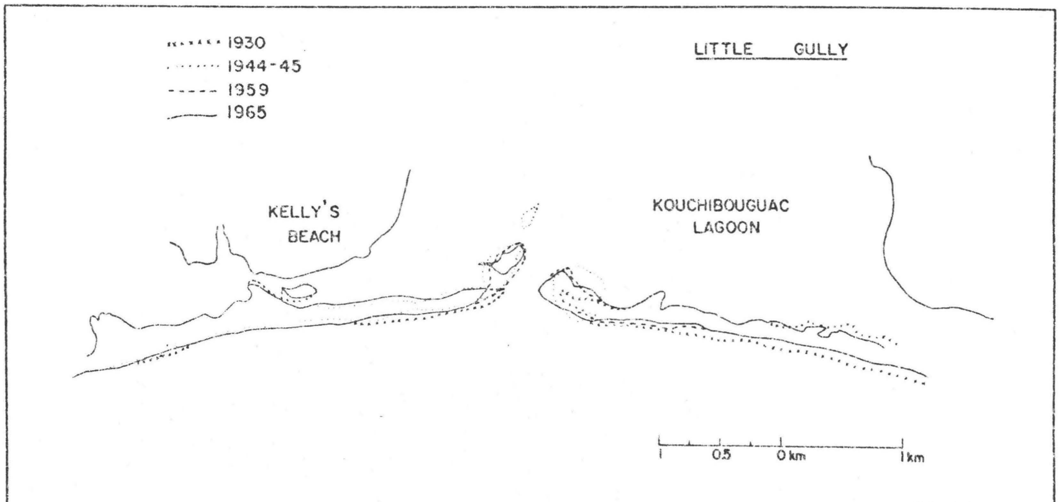


FIG 3:5

Fig. 3:3-3:5 Changes in the shoreline of select sites.

but this can be explained as beach recovery after storm activity at the time the 1944 photography was flown. What is more noteworthy on this map is the retreat of South Beach east of the breach--a retreat which could only be made possible by erosion of the dunes on the barrier.

Blacklands Gully is the most variable area since 1930 and it appears somewhat chaotic (Fig. 3:4). In 1930 there was a breach in North Beach with extensive shoaling and island formation on the lagoon side while northwards the island is continuous to Gull Island with again many small islands in the lagoon. By 1944-45, the breach in North Beach had narrowed considerably, the shoals had disappeared, and there was shoreward retreat on the island. A second inlet had opened leaving Gull Island in the middle of Blacklands Gully. The northern inlet had also narrowed as the barrier island to the north grew southwards and seawards and the islands in the inlet area of the lagoon disappeared. By 1965 the breach in North Beach had closed and the isolation and dissection of Gull Island from this barrier was becoming more complete. The barrier north of Blacklands had been eroded northwards but still continued to grow seawards. Whether the intense dissection and accretion around Blacklands Gully is unidirectional or cyclic is difficult to determine but the area is by no means stable in island configuration.

The Little Gully area has also undergone change but it tends to be more ordered and unidirectional (Fig. 3:5). The barriers for the most part here have been undergoing shoreward retreat with only minor changes in the lagoon area. The northern spit since 1930 has tended to prograde southwards with its maximum growth at the distal end in 1944-45. The greatest change has occurred to the south of Little Gully where the barrier island has recurved since 1930 into the lagoon with the exception of minor breaching, retreat and growth. It appears that this area had undergone the greatest change towards the inlet with only minor fluctuations occurring elsewhere. This air photography offers conclusive and exact evidence that this barrier system is undergoing permanent change. It is very pronounced around the three major inlets--Little Gully, Blacklands Gully and Richibucto Inlet and more dramatic where the barrier island has been breached and infilled. The seasonal nature of this change does not appear on sequential air photography and can best be examined by looking at the area of the barrier most likely undergoing change--the ocean beach.

PROFILES

To this end, surveying of the ocean beach up to the bench marks on the dune crest was carried out along the 20 profile lines for the periods August 7 to 15, 1970; May 9 to 11, 1971; and June 20 to 22, 1971. The weather conditions at the time of surveying were characteristic of the field season. In 1971, winds were prevalent before and during surveying and in 1971, southwest winds had dominated much of the six weeks between May 9 to June 20. The profiles for these times have been referenced to common bench marks and are presented in Figure 3:6.

The general tendency for the Beaches between 1970 and 1971 is erosion of the ocean beaches with exceptions. This change except for profiles at the ends of the bay, where it was reversed, was greatest on the ocean foreshore beach. The variability of erosion and accretion during the winter of 1970-1971 on the ocean foreshore area can best be explained by the cuspate nature of the beaches where a shift of a cusp in one direction or the other would create a pronounced change in the beach regarding erosion or accretion. For the most part the downcutting of the ocean beach can be explained by the tendency for destructive waves to comb down the beach and move sand offshore. These changes are the result of normal beach processes.

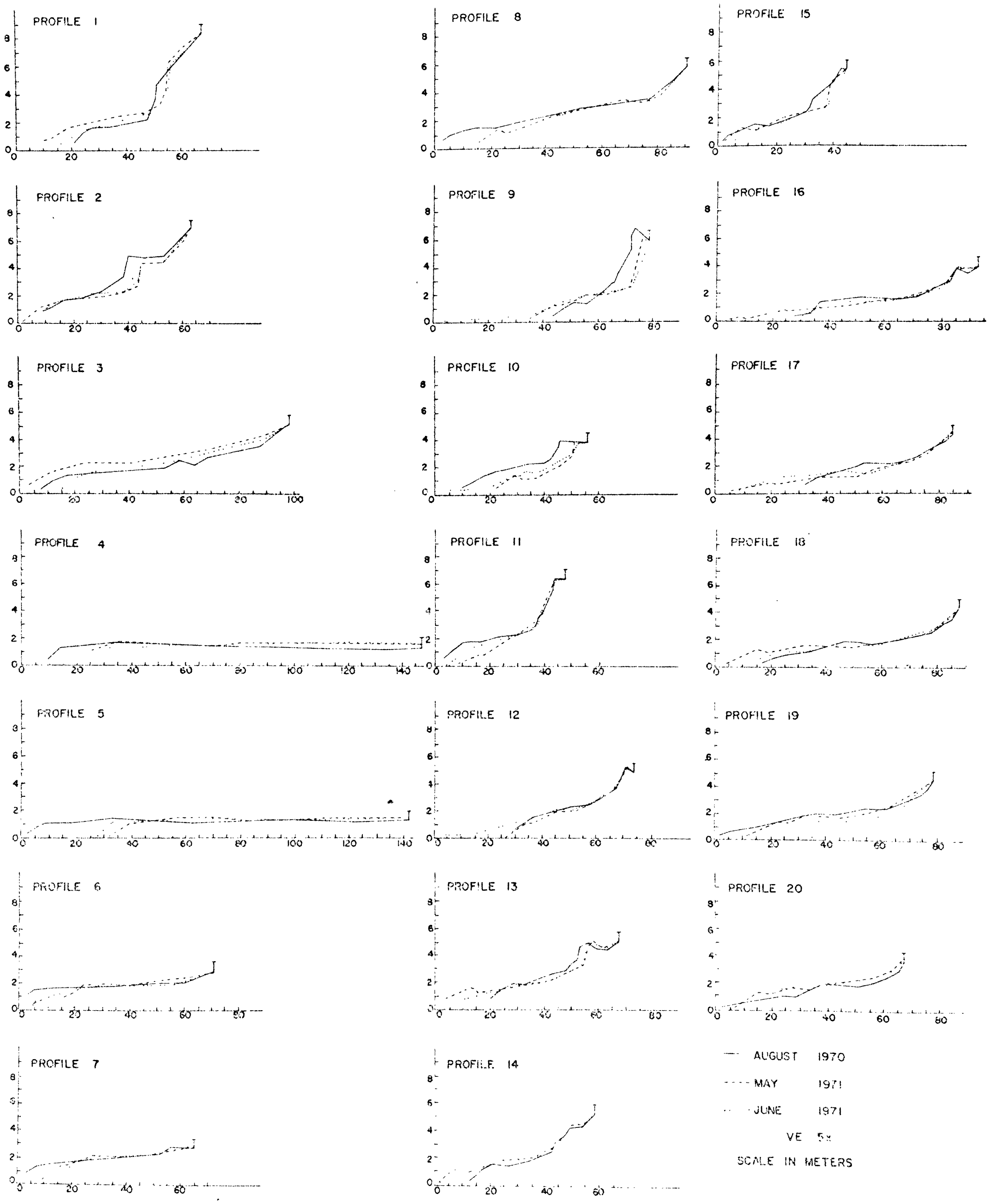


Fig. 3:6 Topographic profiles of the ocean beach over time.

The noticeable and, at this time, irreversible change during the winter is the erosion landwards of the dune cliff. This change (up to 4 m) was most noticeable on those profiles having a dune cliff in 1970 (Profiles 1-2, 9-10). Yet only those profiles in the south of the bay were affected whereas those on Beach 3 had undergone little if any erosion (Profiles 11 and 12). The difference between areas is likely due to patterns of wave refraction in the bay while the erosion probably results from storm waves running up a frozen beach and undercutting a frozen cliff face. However some of this erosion appears to be the result of wind process. Between May and June 1971 there was no storm activity or tides which affected the dune ridges, yet erosion had occurred on the ocean dune slope of Profile 3, 15, 18 to 20. The cause appears to be wind erosion which was also able to reduce the ocean backshore on Profiles 1, 3 to 6, 8, and 19 and erode the dune ridge on Profiles 1, 3, 11, 13, 15, and 18 to 20 in a six-week period. However wind had significantly accreted the ocean backshore on Profiles 2, 7, and 9 to 12 and the dune ridge on Profiles 2, 14, and 17. Though wave action during the winter is responsible for much of the erosion and accretion on the ocean beach it appears that wind deflation and accretion can act upon the beaches and account for changes to the same magnitude.

That part of the beach predominantly affected by wave action in the six-week period had also undergone change. The profiles in the southern part of the bay had undergone reduction which was in places of the same magnitude as the change between 1970-1971. The northern part of the bay except for Profiles 18 and 19 had undergone substantial accretion within the six-week period. Often during the six weeks, low waves (less than .3m in height, and 5-second period) were breaking on the beaches in the north part of the bay. These waves were virtually non-existent south of Blacklands Gully where Prince Edward Island and the New Brunswick coastline to the south sheltered the bay. One small storm with waves .6m in height and a 5- to 6-second period occurred within this period and affected the southern beaches below Blacklands Gully more than those in the north. It is possible that the destructive waves of this storm, coupled with the lack of constructive waves were responsible for erosion of the southern beaches in this six-week period and that the presence of constructive waves in the northern part of the bay with little destructive wave action was responsible for the buildup on those beaches.

CONCLUSIONS

Wind and wave processes appear to play an important role in changing the topography of these beaches. There are two types of changes occurring on these islands as a result of these two processes. First, there are the cyclic, seasonal, small scale changes which influence the beach and dune areas. The berms, cusps and accretions and erosions on the beaches and dunes are only temporary and the events which are responsible are often random and local, as evidenced by the surveyed profiles over time. Second, there are the large scale, often irreversible, though at times cyclic, changes. These changes show up over a short period under detailed measurement as was the case with erosion of the dune cliff, but often these changes are only noticed over a long period of time. The retreat of the barriers landward as evidenced from air photographs and maps and the progressive growth of the barriers around Little Gully are examples of this change. This change can be dramatic--an inlet is breached under a series of successive storms; an inlet is shoaled as constructive waves and littoral drift fill it in, but it is cyclic to some extent as evidenced by the breaching and infilling in the Blacklands Gully area. This second type of change thus accounts for much of the configuration of the barrier islands.

The observations on these barrier islands from descriptions, surveyed profiles, air photographs and map evidence indicates that these barriers are not unique in the context on Eastern North American barrier islands. Much of the field evidence for change is also found on Hog Island, Prince Edward Island as are the descriptive indicators evidenced from air photographs. The barriers in the Eastern Atlantic system have been shown to be retreating shoreward and undergoing continual changes in configuration; the barrier islands of Kouchibouguac are no exception.

The fact that these barriers have and do change over time has been established here; but the processes involved, without detailed field observations, are not as easily recognized. These processes on a seasonal scale are however reflected in characteristics of size, shape and sphericity of the sediments. On a longer scale the magnitude and direction of change are dependent upon the frequency, amount and direction of energy input to the beach and here simulation modelling of wave patterns in the bay should be indicative of the changes described above. It is the purpose of the remainder of this thesis to examine the sediment characteristics of the sands and to simulate wave patterns in the bay in order to reaffirm and enlarge upon the observations and conclusions presented so far.

CHAPTER 4

GRAIN SIZE ANALYSIS

INTRODUCTION

Grain size analysis of sediments is an important component of many beach studies. It is generally recognized that size frequency distributions of sands are genetically significant (Inman 1949, p. 68; Friedman 1967, p. 352) and hence reflect the processes of erosion and deposition in a beach environment. The studies of size frequency distributions concentrate on many varying aspects of the distributions. Doeglas (1946) and Spencer (1963) have investigated the environmental characteristics of the sediment by examining shape of the distribution, while Mason and Folk (1958) and Friedman (1962), in determining environments and process, examined comparisons of the grain size distribution statistics. Friedman (1961), Duane (1964), and Fox, Ladd, and Martin (1966), on the other hand, related the value and magnitude of various moment measures of these distributions on beach and dune areas to process and energy. These latter studies postulate a theoretical basis for the characteristics of moment measures in different environments. The use of grain size analysis is thus more than just a descriptive tool; it is also useful in the interpretation of process and environment in coastal areas.

The investigation of grain size analysis for sands on the beaches in Kouchibouguac Bay was carried out using samples collected from the twenty surveyed profiles of the islands. The description and interpretation of these samples was attempted using bivariate plots developed by Folk and Ward (1957), statistical testing of sample parameters, and profiling of the mean, standard deviation, skewness, 5th and 95th percentiles of the grain size distributions across the beaches.

The statistical tests were carried out to assess the similarity of samples across space and through time. This assessment was carried out for three reasons. The first reason was to determine whether or not the samples differed from each other for a specific location on the beach between profiles and beaches. Implied in this is the question of uniformity of sample characteristics for similar topographic locales. The second reason was to determine whether or not these samples differed across the barrier island along a profile line. Implied in this is the existence of distinct sediment environments across the barrier islands. The third reason was to determine whether or not samples from the same locations differed over time (in this case from August 1970 to 1971). These assessments were made using, firstly, z scores and F tests for sets of two samples, and then analysis of variance for groups of samples. By these means it was hoped that the processes working on the barrier islands could be defined.

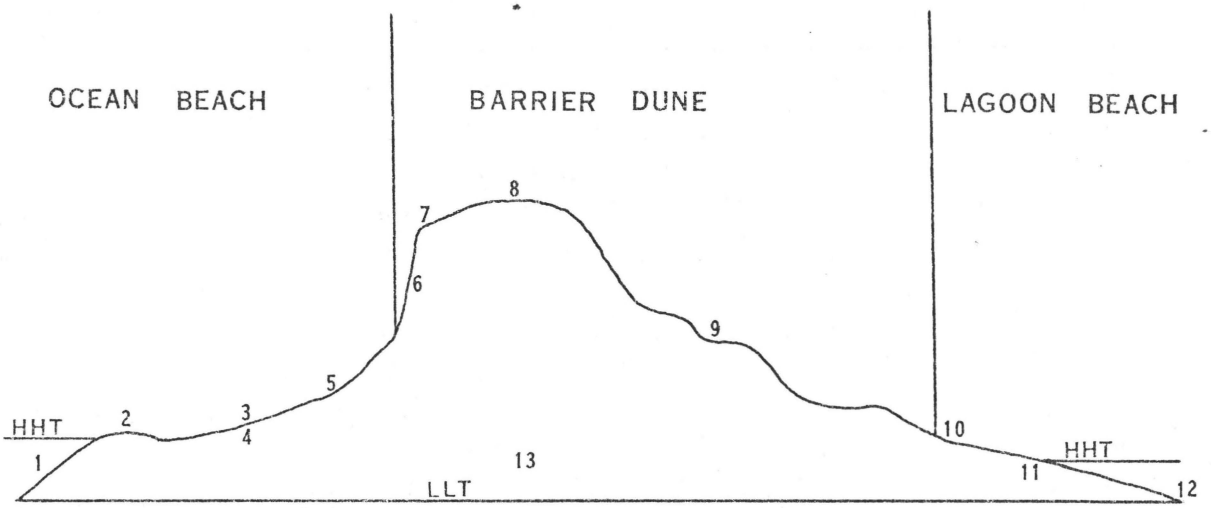
SAMPLING SCHEME

The main objective of sampling is to choose random samples which are representative of set populations. The basis for sampling of these populations is the sedimentation unit--that thickness of sediment which was deposited under relatively constant physical conditions (Otto 1938, p. 575). The fundamental sedimentation unit is the lamina; but for practical purposes composite samples of several laminae are used. The composite sample, unlike single lamina, maintains the requirement of randomness (Gees 1969, p. 43), but poses problems when grain size parameters are analysed statistically because it is not truly representative of a single population. Krumbein (1953, p. 865) states that beach samples should also be collected from an area of several inches at a consistent depth and from equivalent parts of the beach. These samples should also be taken far enough apart to bring out regional rather than local variations in sediment characteristics. Within these limitations, sampling was carried out along the twenty surveyed profiles in the ocean beach, barrier dune, and lagoon beach environments. These three environments are

TABLE 4:1 LOCATION AND DEPTH OF SAMPLES

CODE	DEPTH	POSITION ON PROFILES
1	5 cm	intertidal ocean
2	3 cm	high tide or berm ocean
3	surface	surface mid-beach ocean
4	2 cm	mid-beach ocean
5	surface	back of beach ocean
6	2 cm	erosion face of dune
7	surface	top of erosion face
8	surface	top of main dune
9	surface	mid-barrier dune
10	2 cm	mid-beach lagoon
11	3 cm	high tide lagoon
12	2 cm	intertidal lagoon
13	2 cm	middle of infilled inlet

FIG. 4:1 Idealized locations of sediment samples.



defined for sampling purposes as illustrated in Figure 4:1.

Each sample consisted of fifty grams of sand, taken from an area of approximately 10 square cm, parallel to beach laminae and within a one cm depth range. Table 4:1 gives the code of the sample, the depth at which the sample was taken, and its position on the barrier island. In 1970, samples were taken from all outlined areas except the mid-barrier dune area. In 1971, this latter area along with the ocean high tide or berm, the surface ocean mid-beach and the back of the ocean beach areas were resampled. Wind direction and speed as well as wave direction and magnitude were constant during the period of sampling along the twenty profiles. However, in 1970 a storm interrupted sampling of the first and last ten profiles and cut back the ocean beaches substantially. Thus the ocean intertidal and high tide or berm samples for the two sets of profiles are not representative of processes of the same magnitude. All other sample areas appeared to be little affected by this storm.

Since the major objective of sampling was to observe regional changes along the beaches and process differentiation of sands across the barrier island, local contamination of the beach environments by dune environment sediment and the production of lag deposits on the open exposed beaches through the action of winds was a problem. An attempt was made to negate these factors for the ocean and lagoon foreshore areas by removing the first two cm of sand from the surface of the sample area before sampling. This procedure has been justified by Anan (1969, p. 278) as giving more representative samples of the beach. This surface material, for the ocean mid-beach sample area, was compared statistically with the subsurface sample for justification of the sampling technique. These results are presented later with the analysis of the samples.

PRIMARY ANALYSIS

a) Mechanical Analysis

A fixed format was followed in sieving these samples in order to remove any bias in the mechanical analysis. The samples were split into 30-35 gram segments and were then oven-dried at 100° C. In the case of the lagoon beach samples, or any which contained organic matter, the materials were heated to 170° C. for 14 hours. Organic content was never greater than .5 per cent by weight. Because of the sampling procedure on the foreshore beaches, the influence of any salt crusts which may have formed on the surface of the beach was removed. However, in a few samples from the intertidal area, salt was a visible but minor component of the sample. All samples were sieved by half phi intervals from -2.5 phi to +4 phi for fifteen minutes and the sieved fractions were then weighed to the nearest one-hundredth of a gram. The amount of material below +4 phi was nil for most samples except the lagoon intertidal ones where it constituted less than 1 per cent by weight. The result of this procedure was the consistent fractionation of the samples, free of measureable contaminants, with as little bias as possible. The distributions with few exceptions were open-ended (non-truncated) and continuous--criteria which were required for the statistic analysis used in testing these samples.

b) Calculation of Grain Size Statistics

The grain size statistics of these distributions were calculated using a computer program developed by Schlee and Webster (1967). This program uses moment measures based on a continuous parabolic interpolation of the weight frequency of each half phi class. The program thus smoothes the distribution without additional data and gives a more accurate calculation of mean, standard deviation, skewness and kurtosis than would be achieved with the existing form of the data. The program also contains an exponential interpolation for the tails of the distribution; but, because this resulted in exaggeration of skewness and kurtosis values, this part of the program was dropped.

STATISTICAL ANALYSIS

a) Grain Size Parameters and Bivariate Plots

The grain size parameters are related to the type of transportation and deposition, the process of erosion, availability of material, and the energy level of the environment (Greenwood 1969, p. 1351). Of these parameters, skewness is probably the most environmentally sensitive indicator. Negative skewness is characteristic of beach sands, while positive skewness is characteristic of wind-blown material. The standard deviation is also to some extent environmentally constrained since beach and dune sands are generally better sorted than sands from other environments. The environmental sensitivity of kurtosis, however, is not as valid. Friedman (1961, p. 517) and Koldijk (1967, p. 65) have concluded that kurtosis is not environmentally sensitive. In fact, kurtosis is not even a consistent statistic. Mathematically, kurtosis is a measure of peakedness relative to the normal curve---the family of curves being an important criteria when specifying kurtosis (Baker 1968, p. 680). However, Kaplansky (1945, p. 259) gives examples of curves, which are comparable to normal distributions, but which have kurtosis values varying from 2.75 to 4.5 (3 being the fourth moment of a normal curve). McCammon (1962, p. 92) states that it is also possible to have asymmetrical distributions with a kurtosis value of 3. Besides its mathematical inconsistency, kurtosis is such a sensitive measure to random fluctuations in a distribution that it reacts to any sampling and measurement error in the distribution. These facts make it apparent that for studies of grain size analysis kurtosis should not be used and for this thesis, kurtosis will be ignored as an environmentally sensitive parameter.

Because each individual grain size parameter except kurtosis has environmental significance, then combinations of these parameters should bring out distinctive environments. The success of these bivariate plots as developed by Folk and Ward (1957) and Mason and Folk (1958) has been questionable. Much of the disagreement on their use lies in the method of calculating grain size parameters. Folk and Ward (1957) and Mason and Folk (1958) used graphic measures; however, Gees (1965, p. 213) points out that moment measures may not be as reliable when trying to determine the depositional environment of sands. (Moment measures were used in this study.) Friedman (1961, p. 515) has pointed out that the terminal environment is the crucial factor in the use of bivariate plots.

Just because a sand comes from a beach zone in sampling does not mean it was deposited by waves. Since the sands in each topographical environment may be intermixed by two or more different processes to such a degree that only a strict sampling method could separate the different origins of the sand (Jones, 1970 p. 1212), the bivariate plots are not always related to topographical environments. Biederman (1962, p. 183), Schlee, Uchupi, and Trumball (1964, p. 122), and Hails (1967, p. 1064) point out that the dominance and type of source material may also prevent the differentiation of environments in these plots so that they may not even distinguish process environments.

The use of bivariate plots in assessing the similarity of samples across space only produced a random pattern with no breakdown of sands into dune or beach environments. Duane (1964, p. 867) and Moiala and Weiser (1968) also found a random pattern for similar beach conditions. Whether this random pattern for Kouchibouguac Bay sediments was due to dominance of a single source, or intermixing of deposits resulting from one or more processes, or error in sampling cannot be ascertained without more data about the sediments. Other factors may also be more important in characterizing these sands. If there is a great deal of variability in the spatial influence of different processes then the bivariate plots are useless.

The fact that mean, standard deviation and skewness are environmentally sensitive cannot be denied; but the combination of such parameters following Folk and Ward's technique was not effective on sands taken from the barrier islands of Kouchibouguac Bay. The distinguishing of environments for these sands lies in more detailed statistical analysis.

b) Normality Criteria for Parametric Statistical Testing

Statistical testing depends on whether a sample is normally or non-normally distributed. In sedimentology, it is often assumed that size distributions are log normal (Friedman, 1962 p. 752), but the fact that skewness can be used as an environmental indicator of sediments contradicts the statement that size distributions are log normal, since a normal distribution has no skewness. The degree of normality, like skewness, of any grain size distribution is affected by the type and origin of material, the process involved and the sampling and operational error. In order to use parametric tests such as the z scores, the F test, and analysis of variance, the assumption upheld in the literature that grain size distributions approximate log normality was made for all samples.

c) z Scores and F Tests

The assessment of the similarity of sands through time and space according to the three lines of investigation proposed at the beginning of this chapter can be carried out by looking at groups of samples or at individual samples. The comparison of two individual samples involves testing two parameters of each sample,--the mean and the variance. If the variances of two samples are different, then the populations are different. However, if the variances are the same, then the means of the samples must be different in order for the populations to be different. The testing of variances involves the F test where

$$F = \frac{S_1^2}{S_2^2} \quad \text{or} \quad \frac{S_2^2}{S_1^2} \qquad \text{(whichever is larger)}$$

S_1^2 and S_2^2 are the variances of the samples (Freund 1967, p. 269). The testing of means involves the z score where

$$z = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \qquad \text{(Freund 1967, p. 255)}$$

$\bar{x}_1$ and $\bar{x}_2$ are the sample means,

S_1^2 and S_2^2 are their respective variances, and

n_1 and n_2 are the respective population numbers.

In order to use these tests n, the population size, must be defined. n is required in calculating the degrees of freedom when setting a significant limit for F and in calculating the z score directly. Jones (1969, p. 1473) states that n should be expressed in terms of units of the population and reflect the total size of the sample, while being independent of the mean and standard deviation. Schlee and Webster's computer program uses, as a basis for calculating grain size parameters, percentages. n becomes 100 and thus satisfies Jones's criteria. The drawback of using 100 for n is that it is arbitrary and constant regardless of the total weight (Jones 1969, p. 1474), but this value has one unique advantage in that it is standard for all grain size distributions. This becomes very convenient when comparing large numbers of samples.

Because of the number of comparisons made, and in order to simplify presentation of data, it is necessary to group the results of the F tests and z scores. If this grouping is used to compare environments along profiles for a single beach, then the degree of spatial homogeneity of the different processes affecting that beach must be known. This involves an examination of whether or not there are differences in samples between profiles and beaches for a specific location on the beach. Table 4:2 is a summary of the percentage of total possible similarities between samples for each specific location on the

TABLE 4:2 COMPARISON OF SAMPLES FROM THE SAME TOPOGRAPHIC LOCALE ON ONE BEACH WITH EACH OTHER AND WITH SAMPLES ON THE OTHER BEACHES IN TURN.

Values in matrix are percentage of total comparisons similar for each beach
Significance level at .01

OCEAN INTERTIDAL

BEACH	1	2	3	4	BEACH
	30	28	4	0	1
		10	0	8	2
			0	16	3
				10	4

OCEAN HIGH TIDE OR BERM 1970

BEACH	1	2	3	4	BEACH
	100	48	0	32	1
		30	4	24	2
			30	4	3
				20	4

OCEAN HIGH TIDE OR BERM 1971

BEACH	1	2	3	4	BEACH
	70	72	28	24	1
		40	32	24	2
			40	40	3
				30	4

OCEAN MID-BEACH SURFACE 1970

BEACH	1	2	3	4	BEACH
	60	20	0	28	1
		20	0	36	2
			20	0	3
				10	4

OCEAN MID-BEACH
SURFACE
1971

BEACH	1	2	3	4	BEACH
	70	28	16	42	1
		10	24	32	2
			20	12	3
				90	4

OCEAN MID-BEACH
AT DEPTH

BEACH	1	2	3	4	BEACH
	100	40	0	52	1
		30	28	56	2
			40	36	3
				40	4

OCEAN
BACK OF BEACH
1970

BEACH	1	2	3	4	BEACH
	100	33	20	20	1
		40	10	30	2
			40	12	3
				40	4

OCEAN
BACK OF BEACH
1971

BEACH	1	2	3	4	BEACH
	80	64	8	56	1
		50	16	64	2
			30	16	3
				40	4

TOP OF DUNE
CREST

BEACH	1	2	3	4	BEACH
	100	53	13	67	1
		40	12	60	2
			40	12	3
				60	4

	BEACH	1	2	3	4	BEACH
MIDDLE OF BARRIER		100	47	0	60	1
			40	16	60	2
				100	16	3
					50	4

	BEACH	1	2	3	4	BEACH
LAGOON HIGH TIDE		60	72	32	28	1
			50	32	32	2
				50	48	3
					50	4

	BEACH	1	2	3	4	BEACH
LAGOON INTERTIDAL		50	56	24	44	1
			50	32	40	2
				60	36	3
					80	4

same beach and between beaches. Since each beach for each location contains five samples, then a total of ten comparisons is possible for a comparison of samples on the same beach, and twenty-five for a comparison of samples between beaches.

Table 4:2 shows that for Beach 1, a very high proportion of the samples from the same topographic locations are similar. Beach 4 ranks second, while Beaches 2 and 3 have a low proportion (often less than 50 per cent). Almost all the samples in the intertidal areas on the ocean side of the barrier are in unique populations. There is very little similarity between sample locations on any beach here. The beaches on the lagoon side of the barrier are more uniform and similar in sample parameters than their respective ocean beaches. The dune environment and back of ocean beach are also more consistent than the ocean beach. When comparing 1970 and 1971 samples, the 1971 samples are more similar to each other at each topographic locale than their 1970 counterparts.

There thus appears to be some relationship between the uniformity of samples on a particular beach and the magnitude of energy input into the environment and the dominance of wind or wave process in an area. The ocean intertidal area is subject to constant wave action which varies in intensity through time and space because of varying wave conditions and wave refraction. Though the energy input into this area is not consistent over space, over time it can be high. The berm or high tide mark and the backshore area for 1970 samples do not have as much energy input since waves only reach these areas at highest tide; but these areas are modified to some extent by wind. The difference between the uniformity of beach locales in 1970 and 1971 results from the length of time over which wind is acting on wave deposited material. The samples in 1971 were taken in late spring, while the 1970 samples were taken in August. Wind action in 1970 was able to produce lag deposits and was able to deposit wind blown sands; yet, the effect of wind on the beaches was not necessarily uniform. Thus more samples in 1970 were dissimilar for one locale on the ocean beach than for 1971. The samples on the ocean backshore areas for 1970 were probably being affected by local wind variations due to the orientation of the beach to dominant wind direction and topographic effect on winds. The samples for 1971 were not affected as much because the length of time for wind action was smaller. Despite the effect of wind, these sands however were still characteristic of wave deposition.

The uniformity of the dune areas is most likely due to the fact that only wind processes are dominant here. To a large degree, wind speed and direction were consistent at any one time in the dune areas on these beaches. The process is thus a consistent one over space. The uniformity of the lagoon beach samples is due to the low energy environment. Because the magnitude of wave processes is low in these areas, the variation in energy distribution will not affect the sediment parameters as much as on the ocean beaches.

It is also noteworthy that many samples from the same locale on a beach were more similar to other beaches than they were to each other. Beach 2 had sample parameters which were consistently comparable to Beach 1 samples, more so than to each other. Beach 4 also was more comparable to Beach 1 than to itself for samples on the ocean beach (1970) and in the dune area. Beach 4 and Beach 2 also had good agreement between samples from the same areas. The exception that stands out here, is Beach 3. Consistently the individual sample parameters from Beach 3 showed little or no similarity to their counterparts on other Beaches. This condition held despite the processes involved in determining the sediment parameters and it held over time with 1970 and 1971 samples.

It thus appears that when comparing sample parameters on individual basis, using the F test and z score, that there is some process controlled uniformity on a beach for each separate topographic locale. There also appears to be some control in either process or sediment source between Beaches 1, 2, and 4; and it also appears that Beach 3 is unique for all environments on the island and over time, it appears that sediment source rather than process is more important.

With some idea of the uniformity of sands on each beach it is possible to use the F tests and z scores to investigate whether or not the samples differ along the profiles. Here each topographic locale was compared to another in turn for each beach, and the number of similarities noted. Since each beach contains five samples in each topographic locale, then the total possible number of similarities is five. Table 4:3 is a summary of the data using this method. Since the samples to be compared should be contemporaneous, only data for 1970 was used.

The most obvious result shown in Table 4:3 is that over half of the samples for Beach 1 are similar to each other along the profile, while the other three beaches have relatively the same proportion of samples equal to each other. (Beach 1 is only dissimilar in the areas where wind-blown sediment has been deposited.) For all beaches, there is very poor agreement between the ocean intertidal area and the rest of the profile. The agreement between adjacent environments along the profile is also poor especially on the ocean beach for Beaches 3 and 4. This is especially evident on Beaches 2 and 3, when comparing the surface sediment of the ocean mid-beach to the sediment at depth (row 3 versus row 4). The sampling technique, whereby samples were taken below the surface of the beaches, seems justified in this latter result. Apparently

TABLE 4:3 COMPARISON OF SAMPLES ALONG A PROFILE, SUMMED FOR EACH OF FOUR BEACHES

Values in the matrix are the number of similar comparisons referenced to a maximum of 5.
Significance level at .01

BEACH 1

ROW NO.

2	3	4	5	8	11	12	ROW NO.
3	1	1	2	0	2	3	1
	2	3	3	5	5	2	2
		4	3.3	3.3	3	3	3
			5	5	2	3	4
				1.7	3.3	1.7	5
					3.3	1.7	8
						1	11

TOTAL 74.6/140

BEACH 2

ROW NO.

2	3	4	5	8	11	12	ROW NO.
0	1	1	1	1	0	1	1
	2	3	2	1	1	2	2
		2	1	1	2	0	3
			2	0	1	3	4
				2	2	2	5
					3	0	8
						1	11

TOTAL 38/140

BEACH 3

ROW NO.							ROW NO.
2	3	4	5	8	11	12	
0	0	1	1	0	0	0	1
	1	2	1	3	1	0	2
		1	1	1	0	2	3
			1	2	1	0	4
				3	3	1	5
					3	4	8
						3	11

TOTAL 36/140

BEACH 4

ROW NO.							ROW NO.
2	3	4	5	8	11	12	
0	0	1	0	1	1	1	1
	1	1	3	3	2	1	2
		4	2	3	2	1	3
			1	2	3	0	4
				2	1	2	5
					1	1	8
						2	11

TOTAL 42/140

on these beaches, the surface material is very much different from that 1 cm below. On both these beaches the majority of the surface samples are negatively skewed (-.085 to -1.365Ø), while the underlying material is only slightly skewed (.063 to -.131Ø). It appears that wind winnowing of sediments is prevalent on Beaches 2 and 3, but not on Beaches 1 and 4 where the sample parameters of the surface material and of material at depth are similar. On these latter two beaches, the best agreement between samples is with the backshore beach and dune area. Another significant result is that the ocean beach sample parameters, with the exception of Beach 1, are not similar in characteristics to the lagoon beach parameters. On Beach 1, there is good agreement between these two areas and this agreement probably results from the fact that large storms can throw material back into the lagoon area through an infilled inlet area on this beach. The lagoon material here is just derived from the ocean foreshore and offshore areas.

From these results, there appears to be similarity between the ocean beach and dune areas with respect to sediment mean and standard deviation on Beaches 1 and 4, but not 2 and 3. For all beaches, except Beach 1, samples in adjacent areas along the profiles are not from similar populations. Beach 1 appears to have a mixture of sediment between the lagoon beach and ocean beach, as well as between the dune area and ocean beach. Whether these results are prevalent through time can partially be answered by examining whether or not samples from the same location differ over time.

This investigation involves comparing the samples on the most active part of the barrier islands, the ocean foreshore, from 1970 to 1971. The F test and z score again were used for testing. The data for corresponding samples on similar topographic locales for each beach for the two years were grouped using the same method as was used in Tables 4:2 and 4:3. The percentage of comparisons of 1971 samples in agreement with 1970 samples for each row on each beach is also given. This data is presented in Table 4:4 which shows relatively little if any change between 1970 and 1971 for Beach 1. Not only were the corresponding samples in agreement, but when samples from 1971 were compared with any sample from the same environment for 1970, they showed hardly any significant difference. What is perhaps more significant is the fact that the back of the beach on Beach 1 had been eroded back during the winter of 1970 for a distance of one to two meters. It appears here that the dune crest behind

TABLE 4:4 COMPARISON OF SAMPLES FOR 1970 TO THOSE FOR 1971 FOR THE OCEAN FORESHORE AREAS ON EACH BEACH

Significance level .01

	BEACH	NO. OF CORRESPONDING SAMPLES AGREEING (MAX:5)	PERCENTAGE OF ALL POSSIBLE COMPARISONS AGREEING BETWEEN TWO YEARS
	1	5	96
	2	2	36
<u>ROW 2</u>	3	0	16
	4	1	32
		******	
	1	4	52
	2	0	20
<u>ROW 3</u>	3	1	24
	4	2	62
		******	
	1	5	76
	2	2	40
<u>ROW 5</u>	3	3	40
	4	0	24

the ocean beach may be supplying the material for the beach since the material sampled from the face of the dune cliff is statistically the same as the back of beach and mid-beach material for 1970 and 1971. The greatest agreement between the two years for Beaches 2 and 3 is also the back of beach sample. The cliff material on these beaches only compares favourably with 1970 samples and not with 1971 ones. Statistically it seems that Beaches 2, 3, and 4 have undergone some change in sample parameters during the winter of 1970, but Beach 1, though undergoing the most change in topographic form on the beaches, has the least change in mean and standard deviations of the samples.

d) Analysis of Variance

The z scores and F tests compared two samples at a time with the results being grouped, but analysis of variance tests whether or not the variation between the means of a group of samples is significantly greater than the variation within the groups for a fixed significance level (Freund 1967, p. 304). Thus if analysis of variance gives no significant difference between samples, all that can be said about the samples is that there is as much variation within the groups being tested as variation between the means of these groups. The samples are not similar! Analysis of variance besides requiring normality demands equal variances in the groups being compared (Freund 1967, p. 303). In regard to the latter criteria, Griffiths (1967, pp. 383-385) points out that equality of variances can be assumed unless the F values are very large. Since no F values of the magnitude Griffiths mentioned occurred for these samples it was assumed that the data had equal variances.

The assessment of the similarity of sands through time and space can be made using analysis of variance along the same lines of investigation as were used for z scores and F tests. The difference between the latter and analysis of variance, is that analysis of variance, rather than considering comparisons between two samples, compares groups of samples. A one-way analysis of variance was used to test whether the mean grain size of samples from one topographic locale on a specific beach was different from those from the same locale on other beaches. It was also used to compare the mean grain size of one specific topographic locale for all profiles together. A two-way analysis of variance was used to test whether the mean grain size of samples from different topographic locales on the same beach was different along the profiles and across the beach. It was also used to test whether samples from one topographic locale on each beach for 1970 were different from the samples from the same locale for 1971, and whether they were also different along the beach. The data was tested at significance levels of .05 and .01. Table 4:5 shows the F values of results between beaches for the same topographic locale for 1970 and 1971 samples. Table 4:6 shows the same thing as Table 4:5 only all beaches were analyzed at once for each topographic locale. Table 4:7 shows the F values of results for different topographic locations on each beach, while Table 4:8 gives the F values of the results between 1971 and 1970 samples. In the tables, F_1 defines the F value for comparisons between topographic locations and between 1970 and 1971. F_2 defines the F value for comparisons between profiles.

With reference to the question of whether there is a difference between each beach for a specific topographic locale, several results are evident. The first general result is that there is little homogeneity between beaches as far as mean grain size is concerned using analysis of variance. The ocean beach (1970) shows very little agreement between beaches; but there is no consistent similarity either with adjacent beaches or remote ones. The lack of differences between beaches for the

TABLE 4:5 COMPARISON FOR EACH TOPOGRAPHIC LOCALE OF SAMPLES FROM ONE BEACH TO EACH OTHER BEACH IN TURN USING ANALYSIS OF VARIANCE

Significance level of .05 marked *
Significance level of .01 marked **
--not tested because of lack of data

	BEACH	1	2	3	4
ROW 1	1		.64	3.53	1.19
	2			.13	.00
	3				.13
	4				

	BEACH	1	2	3	4
ROW 2 1970	1		1.89	20.86**	.00
	2			6.73*	.80
	3				10.07*
	4				

	BEACH	1	2	3	4
ROW 2 1971	1		.37	1.18	2.56
	2			1.74	5.10
	3				.01
	4				

	BEACH	1	2	3	4
ROW 3 1970	1		8.33*	95.84**	8.21*
	2			27.58**	.14
	3				40.19**
	4				

	BEACH	1	2	3	4
ROW 3 1971	1		.43	5.97	3.44
	2			2.07	.00
	3				3.90
	4				

	BEACH	1	2	3	4
ROW 4	1		5.71*	43.46**	6.67*
	2			5.63*	.01
	3				5.15
	4				

	BEACH	1	2	3	4
ROW 5 1970	1		--	--	--
	2			8.13*	.32
	3				1.99
	4				

	BEACH	1	2	3	4
ROW 5 1971	1		.21	10.88*	.81
	2			32.44**	.00
	3				9.03*
	4				

	BEACH	1	2	3	4
ROW 8	1		--	--	--
	2			14.62**	.00
	3				19.00**
	4				

	BEACH	1	2	3	4
ROW 11	1		.14	9.79*	12.78**
	2			5.86*	8.30*
	3				.39
	4				

	BEACH	1	2	3	4
ROW 12	1		.24	10.73*	4.12
	2			9.18*	3.93
	3				2.60
	4				

TABLE 4:6 COMPARISON OF EACH TOPOGRAPHICAL LOCATION FOR ALL BEACHES FOR 1970

Significance level of .05 marked *
Significance level of .01 marked **

ROW	F
1	.54
2	6.59**
3	27.17**
4	7.57**
5	2.61
8	11.12**
11	6.11**
12	5.23**

TABLE 4:8 COMPARISON OF OCEAN FORESHORE AREAS FOR 1970 TO 1971 FOR EACH BEACH

Significance level of .05 marked *
Significance level of .01 marked **

ROWS		BEACH			
		1	2	3	4
2	F_1	.01	1.77	16.37*	.75
	F_2	2.53	.30	3.49	.30
3	F_1	3.27	.00	6.16	.14
	F_2	.36	1.79	2.27	.18
5	F_1	6.19	8.13	.35	4.46
	F_2	14.66*	5.10	1.42	3.08

TABLE 4:7 COMPARISON OF TOPOGRAPHICAL LOCATIONS ACROSS AND ALONG EACH BEACH

Significance level of .05 marked *
Significance level of .01 marked **
-- not tested because of lack of data

F_1 is comparison across beach on profile lines

F_2 is comparison along the beach, between profiles

ROWS		BEACH			
		1	2	3	4
1,2,4	F_1	9.29*	.59	.47	1.52
1970	F_2	1.51	.92	.54	.82
3,4	F_1	.75	.03	7.91*	1.10
1970	F_2	.37	2.96	1.93	5.17
2,3,4	F_1	3.65	2.80	2.09	5.39*
1971	F_2	.43	2.91	3.68	.86
2,4,11,12	F_1	1.51	1.35	4.20*	1.66
1970	F_2	.76	.06	.71	1.00
8,9,5	F_1	--	.30	.43	.45
	F_2	--	.41	.22	1.87
5,8	F_1	--	.13	.32	.69
	F_2	--	.25	.11	.90
8,11	F_1	--	5.55	4.05	21.83**
	F_2	--	10.16*	4.67	1.63
9,3	F_1	--	1.85	.53	2.59
1970	F_2	--	1.21	.80	2.47
11,12	F_1	.44	1.29	.09	10.99*
	F_2	1.04	.79	3.04	2.49

intertidal area probably stems from the fact that the variation of mean grain size within one beach is as great as that between beaches. Whether the same holds true for the ocean beach samples of 1971 cannot be proven; but the fact remains that there is not as much difference between the ocean beaches for 1971 as there is for 1970. Apparently there is some process occurring which differentiates the ocean beaches in the summer of 1970 but does not in the spring of 1971. Similar results, but results not as definite, were obtained when individual samples were compared and the results grouped. The opinion then is that the effect of wind is felt on the beaches to varying degrees; but in the spring wind has not been acting on the beaches long enough to create lag and wind-blown deposits. Analysis of variance tends to bring out the effect of wind and the length of wind process on the ocean backshore better than the comparison of individual samples.

Another evident fact shown in Table 4:5 is that Beach 3 is not in agreement with other beaches. For a few topographic locations such as the high tide mark on the ocean and lagoon beaches, back of ocean beach and top of dune crest Beach 3 is the only beach with significant differences from other beaches. This observation is in agreement with the comparison of individual sample parameters shown in Table 4:2. This beach is unique in grain size characteristics.

When all the samples for 1970 from one specific location were taken together, there was virtually no similarity between beaches. Table 4:6 shows that only the ocean intertidal area and the back of the ocean beach were not different. Analysis of variance of mean grain size has shown that there is a significant variation between beaches for Kouchibouguac Bay. This difference seems to hold for most topographic locations across the beach profiles.

The analysis of variance on samples across the beach profiles for each beach was not as revealing as the individual comparisons of the F test and z score. Table 4:7 shows that there were very few, if any, differences between samples along profiles. The testing was not done on all possible combinations of locales, but was done on groupings of samples from locations which may have undergone similar processes. Since the usefulness of analysis of variance actually lies with significant differences between samples, these results cannot be explained with confidence. If the similarities shown in Table 4:7 are justified, then mean grain size does not differ significantly along or across profiles. The work using grouping of individual samples has already shown that there are differences along profiles and that homogeneity through one topographic location on each beach is not that good for some beaches. It thus seems that the lack of significant differences with analysis of variance is due to the variation between samples in a group being as great as that between groups.

The results appear the same for comparison of 1970 means to 1971 means. The same reasons as before seem to be in force since the differences shown in Table 4:8 represent only isolated occurrences. Analysis of variance has given results comparable to the individual comparison of samples only for the testing of the same topographic locale between beaches. The fact that it tends to summarize data and is thus wasteful of it makes it unsuitable in fully explaining any process of change occurring on the beaches of Kouchibouguac Bay. Analysis of variance is a powerful test, but it has failings in its theoretical basis when explaining results.

e) Profiles of Mean, Standard Deviation, Skewness, and 5th and 95th Percentiles

So far only those trends which have a statistically significant base have been examined and commented upon.

Size distributions, besides being characterized by grain size parameters, are also characterized by the shape of the tails of the distributions. Doeglas (1946) studied grain size distributions by examining the shape of their tails on probability paper and found them to be environmentally sensitive. This method however is subjective and is a generalization of environment that does not really distinguish the behaviour of sediments in that environment.

The tails can also be characterized quantitatively using the 5th and 95th percentiles. Thus instead of qualitatively describing the shape of the tails of a grain size distribution, the degree of fineness or coarseness of the tail can be defined statistically as a phi value. The measure is consistent between distributions and the relative coarseness or fineness of the tail can be compared to other distributions to give an indication of the behaviour of the sediment within one process dominated environment or between environments.

Fox, Ladd, and Martin (1966) constructed grain size statistic profiles across a beach zone in Lake Michigan. They believed that these profiles characterized the topographic and energy profile of the beach. It is also possible for such profiles to reflect the processes which are occurring and to indicate differences between areas. Fox, Ladd, and Martin's profiles were extended for mean, standard deviation, and skewness, as well as for the 5th and 95th percentile across the barrier island for each profile and along the beaches for each topographic locale. The profiles themselves may not show statistically significant results, but they do show broader trends which elucidate on some of the results shown in the statistical analysis of the sediments. These profiles also make use of parameters which can describe the grain size distribution more fully than the three main statistical parameters of a grain size distribution.

The means, standard deviations and skewness values were averaged together to form one representative profile for each beach. This averaging gives regional characteristics of these parameters across the barrier island without emphasizing local factors. The profiles across the barrier for each beach are shown in Figure 4:2. The horizontal scale in this figure is not proportional to actual distances on any one beach. These profiles show a decrease in mean grain size across the ocean foreshore with a corresponding decrease in standard deviation. This same trend is carried into the dune area, though the standard deviations are not as low as on the ocean foreshore.

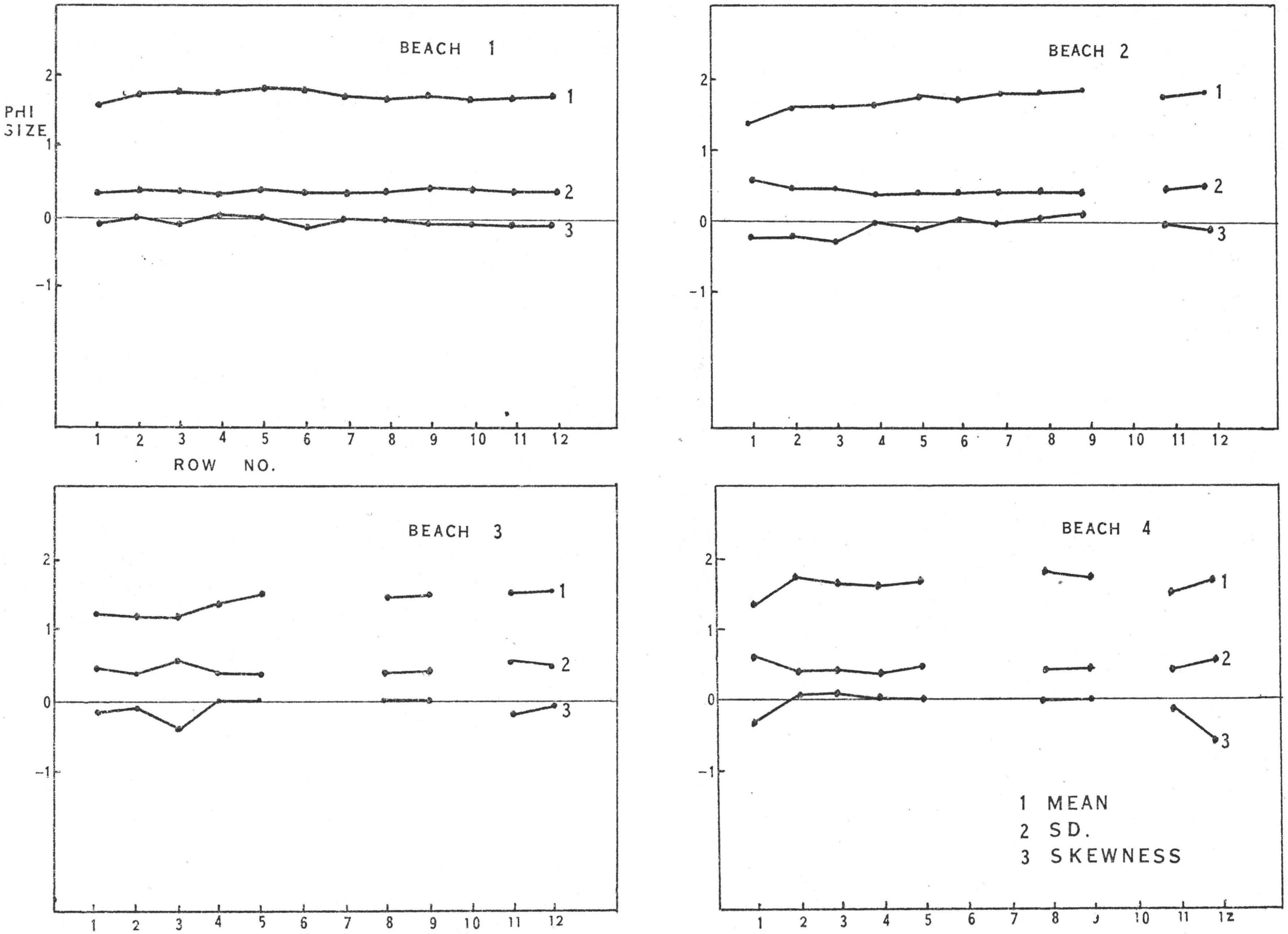


Fig. 4:2 Profiles of mean, standard deviation, and skewness for each sampled beach

For Beach 1 and 4, the lagoon foreshore is comparable in mean grain size to the ocean foreshore and greater than the dune environment. This may be due to the fact that during storms sediment is carried into the lagoon area through an infilled inlet on Beach 1 and directly over the low dune ridge on Beach 4. Beaches 2 and 3 show a consistent decrease in mean grain size across the barrier island, while the standard deviation tends to increase for the lagoon foreshore area. The profiles across the lagoon foreshore are the reverse of the ocean foreshore, as mean grain size decreases into the intertidal area while standard deviation increases. The profiles for mean grain size parallel the topography of the ocean foreshore area to a moderate degree, but this relationship breaks down in the dune and lagoon areas. Though Fox, Ladd, and Martin's work was restricted to the beach offshore and nearshore areas on a tideless sea, their observation that mean grain size profiles parallel the topographic profile cannot be applied to the dune and lagoon areas of these beaches and can only be partially applied to the ocean foreshore areas.

Skewness has been shown to be environmentally sensitive with negatively skewed phi values characteristic of high energy environments where waves have winnowed out fines or where wind has created lag deposits. When energy input to an environment decreases such as in a dune environment where wind is depositing material or in quiescent waters such as the lagoon environments, skewness will be increasing positively. The presence of lag deposits on the surface of the ocean beaches of Beaches 2 and 3 is obvious as indicated by the higher negative skewness values. Beach 1 and Beach 4 however are almost the reverse with Beach 1 having near positively skewed values on the beach and negatively skewed values in the dune area. This may be due to the fact that winds at the time of sampling (August 1970) were blowing sand out of the dune area and depositing it on the beach. Thus the surface samples of the dune were becoming more negatively skewed as finer sands were removed, while the beach was becoming less negatively skewed as this sand was deposited. This explanation also accounts for the skewness values on the same locales on Beach 4. The presence of large negative skewness values on the lagoon side of Beach 4 can be accounted for by the low topography of this section of the beach, where it is feasible during large storms for material to be carried right over the barrier. Most of the material carried over in this manner would be coarser sediment.

If skewness is environmentally sensitive for the reasons stated, then the values of the 5th and the 95th percentiles should reflect the skewness values and back up these conclusions. Figure 4:3 shows the profiles of the 5th and 95th percentiles using the same plotting arrangement as with the other parameters. The variation of the percentiles across the profiles follows a definite pattern for the beaches. The two percentiles on Beach 1 are very uniform across the barrier island and any change between locales is equal for each percentile with a shift towards a coarse tail being followed by an equal shift in the same direction for the fine tail. This uniformity and parallelism breaks down progressively going north towards Beach 4. The 95th percentile is also much more uniform across the beaches than the 5th percentile. Generally, the ocean beach has a coarser 5th percentile with respect to the 95th percentile than the lagoon beach, which has coarser sediment than the dune areas. The behaviour of the coarse tail of the sediment distributions across the beach in relationship to the 95th percentile appears to be indicative of energy input into these beaches.

In order to ascertain whether or not the 95th and 5th percentile reflected the skewness values of the distributions, a linear regression was applied to the percentiles and skewness values for each beach. The correlation coefficient gives the strength of the linear rela-

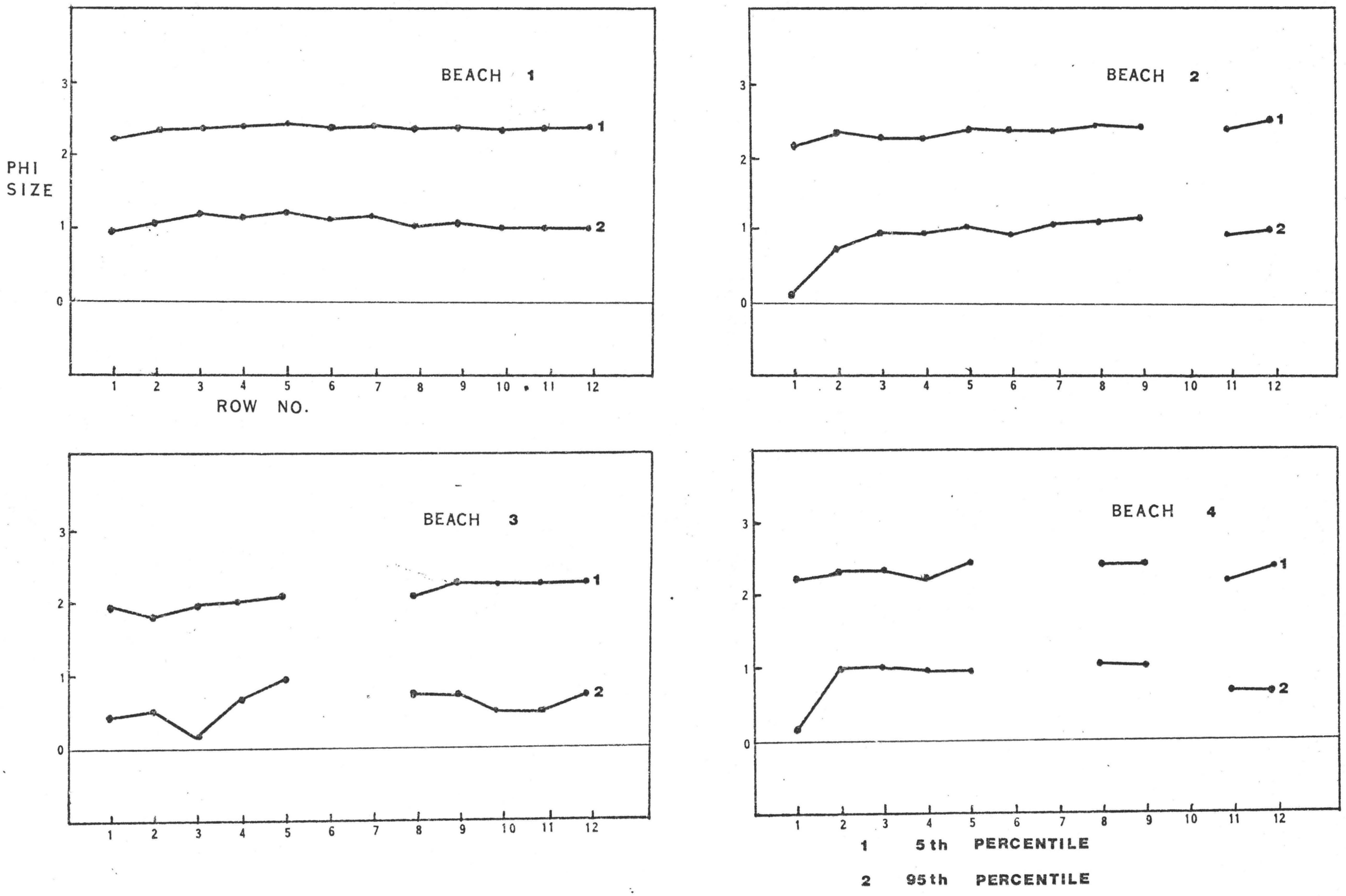


Fig. 4:3 Profiles of the 5th and 95th percentiles for each sampled beach

tionship between the two variables (Freund 1967, p. 355). This value was used as an indicator of the relationship between percentiles and skewness. The results are shown in Table 4:9. This table shows that the 5th percentile or the coarse end of the distribution is a better indicator of skewness values than the 95th percentile. When these correlation coefficients were tested for significance at the 5 per cent level following Snedecor and Cochran (1967, pp. 183-185, p. 557), only the 5th percentile compared significantly with skewness values for Beach 1 and 3. It thus appears for these beaches that the greater the degree of coarseness in the distribution, the more negative the skewness values. The coarse tail of the distribution has more of an effect on skewness than the fine tail. These profiles seem to indicate that the processes which are winnowing sand are more dominant than those which are

TABLE 4:9 CORRELATION COEFFICIENTS OF LINEAR REGRESSION BETWEEN SKEWNESS AND THE 5TH AND 95TH PERCENTILES OF GRAIN SIZE DISTRIBUTIONS

BEACH	5TH PERCENTILE	95TH PERCENTILE
1	.90	.24
2	.58	.41
3	.94	.28
4	.73	.13

depositing finer material. Since wave action has had little recent effect on the samples for 1970, it appears that wind deflation is an important process on these beaches and that the inherent characteristics of wave action, on the ocean backshore especially, ranks second in importance.

Profiles were also made of these same parameters for each topographic locale from profile 1 to 20. The mean, standard deviation, and skewness profiles are outlined in Figure 4:4, while the 5th and 95th percentile profiles are shown in Figure 4:5. Figure 4:4 shows variation in standard deviations and skewnesses of the distributions between these profiles for the ocean foreshore samples in 1970, but less so for 1971 samples. All other sample locations with the exception of the lagoon intertidal area show little variation between skewness or standard deviation values in Kouchibouguac Bay. Ignoring the deviations of one or two profiles, there is a general tendency for mean grain size to increase towards Beach 3 and then decrease slightly again for Beach 4 with all locations on the barrier except 1971 ocean high tide or berm, and surface of ocean mid-beach sample areas. This trend was evident in the statistical testing of the sediments when mean grain size on Beach 3 was tested as an unique popula-

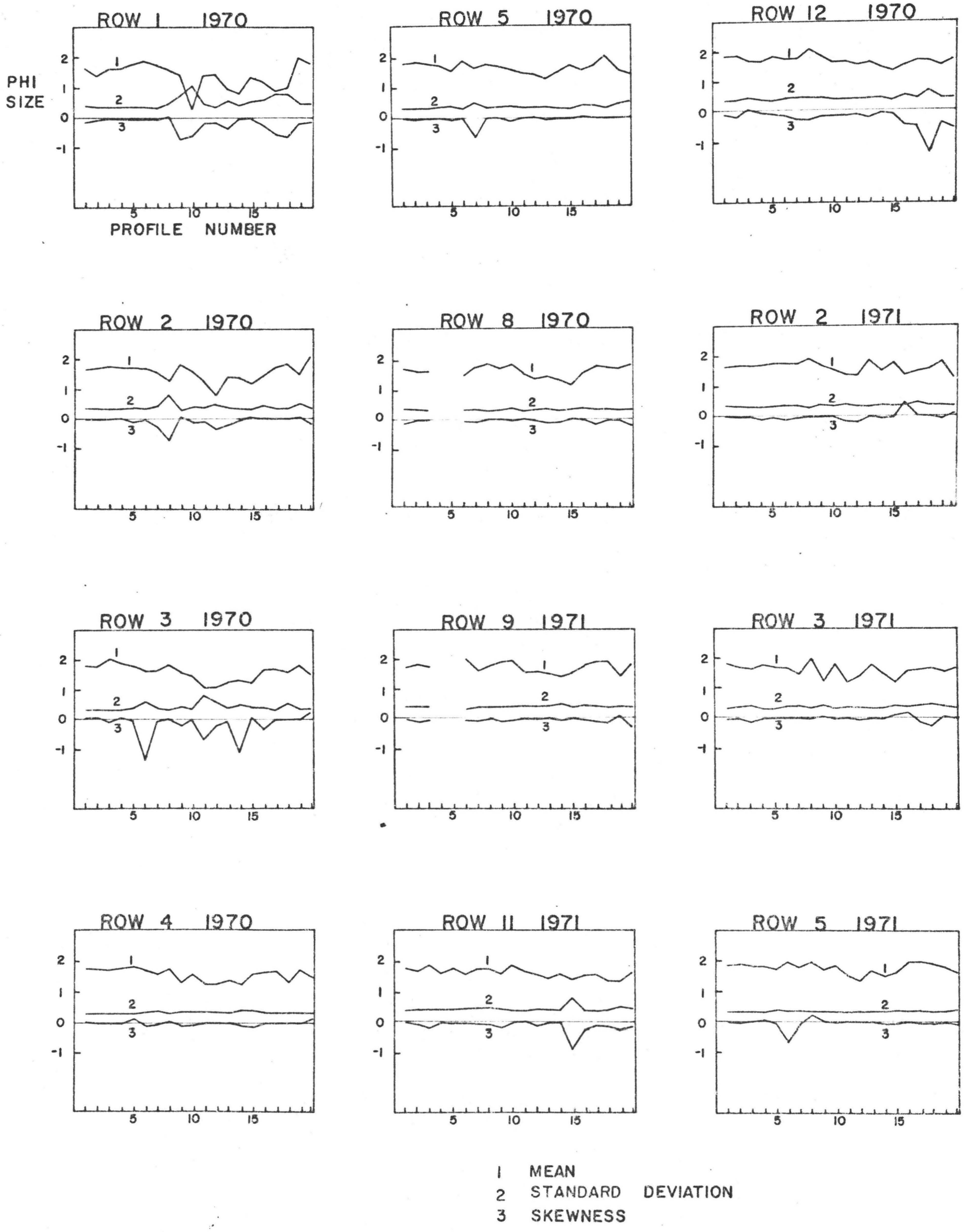


Fig. 4:4 Profiles of mean, standard deviation and skewness from Profile 1 to 20 for each environment.

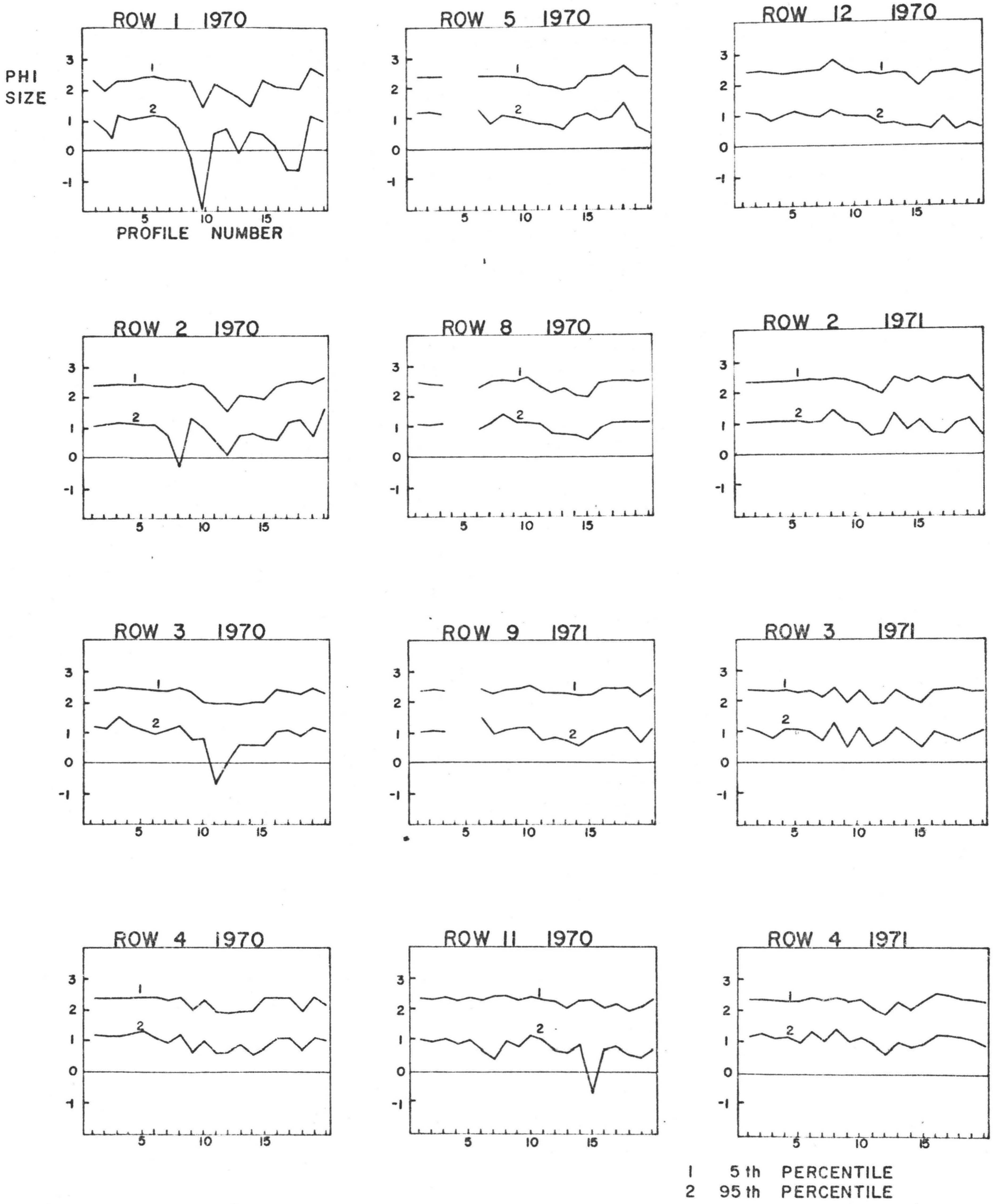


Fig. 4:5 Profiles of the 5th and 95th percentiles from Profile 1 to 20 for each environment.

tion compared to the other beaches. Figure 4:5 does not show any consistent increase in the position of the 5th and 95th percentile along the coast to parallel that of mean grain size; but the percentiles for Beach 3 (except for the intertidal samples) clearly show a shift to greater phi size when compared to the other beaches. There is definitely coarser sediment on Beach 3 for most locations.

These changes in the mean grain size and percentiles for the first three beaches are not related to any trend in the mean grain size of sand sediment in Kouchibouguac Bay as evidenced by Kranck (1967, p. 2258) in her studies of offshore sediments. Nor do they appear to be related to the presence of bedrock or gravel deposits in the Bay (Kranck 1967, p. 2253). It was mentioned previously that Beach 3 may differ from the other beaches in regard to sediment source. Since there is little difference in offshore sediment between the beaches, it seems reasonable that the major source of sand supply is not sediment from Kouchibouguac Bay. (The sediment of Kouchibouguac Bay being taken as that sediment offshore from the offshore bars.) The proximity of Beach 3 to the mainland suggests that the sand for this beach comes from the mainland through erosion of the underlying bedrock and the sandy till cover of the mainland, as the barrier island is driven shorewards.

Visual evidence in the surf zone on Beach 4 indicates that bedrock is close to the surface in this area although no evidence for the position of bedrock exists for Beaches 1 and 2. The hypothesis put forward is that the beaches in this Bay acquire their sediment through landward erosion of the underlying bedrock and mainland sediments. Longshore drift may shift sediment along the beaches but the consistent, and statistically significant difference of these sands on Beach 3 and the agreement of standard deviations and skewnesses of the grain size distributions with the other beaches, suggest a dominance of source material rather than process as the reason for coarser grain size on this beach.

CONCLUSIONS

This study of grain size analysis has been limited but the results are revealing in terms of the methods used and the distinction of environments. The mean, standard deviation and skewness of a grain size distribution are for the most part environmentally sensitive, but kurtosis has been shown to be a doubtful statistic in this regard. Folk and Ward (1957) introduced bivariate plots wherein these statistical parameters were compared to each other to outline different sedimentary environments. The use of these plots has been shown to be dependent on the means of calculation of the statistics, the time of deposition or erosion of the sediment and the dominance of source material. These plots did not produce any pattern whereby sediments of Kouchibouguac Bay could be classified and it appears that the above reasons explain why.

Statistical tests were used to assess the similarity of sands across the beaches, along the islands and over time. These tests were broken down into two groups. The first involved z scores and F tests whereby the means and standard deviations of two samples were compared. The second test involved the use of analysis of variance on groups of samples. The latter test proved ineffective because it generalized data and was incapable of explaining similarities in the results. The z scores and F tests revealed that there was a general homogeneity in samples for any one topographic locale that was dependent on the energy input and the dominance of a single process. Even though this homogeneity existed for each beach, often the samples of one beach were more similar to other beaches for the same topographic locale. The exception to this was Beach 3 which invariably had sands different from the other beaches for all samples across the island; yet the environments on this beach were as distinguishable from each other as those on the other beaches. The anomaly of sands on Beach 3 seems to be a result of sediment source since Beach 3 is the closest of any beach to the mainland. If the sediments on the beaches are derived from landward erosion of tills and underlying bedrock then Beach 3 will be dominated to a greater degree by the source of sediments since it lies closest to its sediment source. Beach 1 which had few differences between sands from different topographic locales appeared to be undergoing a complete mixing of sediment over the island.

Over time there is a variation in sediments in the ocean foreshore area. Wind erosion of the beach for Beaches 2 and 3 and wind deposition on Beaches 1 and 4 are evident from the results for 1970; however, these effects do not appear for samples taken in the spring of 1971. There is no doubt that wind is an active agent on these dunes and is able to transfer sand from the dune area to the beach and back, but this process is only active in summer when the islands are not frozen or snow-covered. The storms in winter appear to be able to destroy any effects that wind might have had on the ocean beach during the summer.

Profiles of the mean, standard deviation, skewness, and the 5th and 95th percentiles were constructed along and across the barrier islands to see if there was any trend in these parameters over space. Mean and standard deviations tend to decrease from the ocean to the lagoon with some variations between the Beaches in the lagoon area. The skewness profiles across the barriers reflect the lag deposits and wind-deposited sands on the ocean foreshore. These skewness values in many instances are negative in the dune area and in low areas because of winnowing and deposition of coarse sediments through overwashing by storm waves respectively. The profiles of the 5th and 95th percentile reflect the skewness results but a linear regression of these percentiles to skewness values reveals that the coarse tail of the distribution is more characteristic of skewness than the fine tail. The greater the degree of coarseness, the more negative the skewness values. These same profiles along the barrier islands do not show any great variation, but Beach 3 again stands out with lower mean grain size values than the other beaches although its standard deviations and skewness values are comparable to the other beaches.

The grain size analysis of sediments in Kouchibouguac Bay has shown that not all the methods used in the literature are effective here in analysis. The z scores and F tests along with the profiles of grain size parameters have revealed differences which are related to the processes occurring here, and the time when and over which these processes act. Grain size analysis, however, involves only one aspect of a sediment. Griffiths (1967, p. 43) states that a statement of size without shape, on theoretical grounds, is meaningless when attempting to evaluate results. Though this opinion is extreme, it is possible to study the shape of sediments on these islands. If the property of sediment size can be used to distinguish process and environment, then surely the shape of the particle should be able to reinforce the results of grain size analysis.

CHAPTER 5

SHAPE AND SPHERICITY

INTRODUCTION

Most of the emphasis in identification of sedimentary environments so far in this thesis has been in classifying parameters of the grain size distribution, but such definition has been shown in the preceding chapter to be relative not absolute. That is, the environments are not identified by fixed values of the grain size parameters, but are identified by the comparison of one environment to another with allowance made for the variability of processes within an area. Additionally, no identification of environment or the processes involved should rest totally on one measure. The addition of shape and sphericity measures to sediment analysis allows for a more complete picture of what processes actually are occurring on these barrier islands. These latter concepts have been used for beach areas by Pettijohn and Lundahl (1943), Mattox (1955), Blatt (1959), and Shepard and Young (1961) to varying degrees of success and it is now recognized that the sphericity and shape of a particle reflect the processes of erosion, transportation and deposition.

It is important to note that sphericity and shape are not synonymous. Wadell (1932, p. 445) defined sphericity originally as the approximation of the surface area of a sphere having the same volume as the particle to the surface area of the particle. Since spheres have the least surface area for the greatest volume, they have the greatest settling velocity, and sphericity thus becomes an indication of the settling velocity of a particle relative to an equivalent sphere. The sphericity measure is an hydraulic measure. Shape however defines the geometric form of a particle and it is possible for two geometrically different particles to have the same sphericity but not for two particles with different sphericities to have the same shape.

The aim of this chapter is to define firstly various sphericity and shape measures used in the literature. An appendix to the chapter (Appendix 3) is devoted to an evaluation of the effectiveness of such measures in distinguishing processes and environments and with this as a base, selected samples of sand grains from the beaches and dunes were examined to try and differentiate environments of wind and wave process. This chapter is thus an appraisal of the effectiveness of shape and sphericity measures in beach studies and is not meant to stand alone. The results presented are not the only means of distinguishing environments but together with the beach descriptions and the definition of processes using grain size analysis, this study is an attempt at completing the knowledge of the processes responsible for some of the seasonal change of the barrier islands of Kouchibouguac Bay.

MEASURES OF SPHERICITY AND SHAPE

a) Sphericity

The concept of sphericity was first introduced by Wadell (1932, p. 445), but because the surface area of particles is difficult to measure, modifications of the concept have been made. Krumbein (1942, p. 623) popularized a measure whereby the volume of the particle was compared to that of a circumscribed sphere. (For a list of formulae presented in this chapter see Appendix 4.) He assumed that the particle itself could be approximated to a triaxial ellipsoid; however, when settling rates of these particles were measured they did not agree with those calculated using Krumbein's formula (Krumbein 1942, p. 628). Sneed and Folk (1958, p. 118) criticized Krumbein's formula on the basis of it being hydraulically unsound and instead introduced a measure which involves the maximum projection area of the particle since particles settle in water with their maximum projection area at right angles to the direction of flow. Graf (1965, p. 550) has experimentally shown this latter point to be true for elliptically shaped objects and Sneed and Folk (1958, p. 122) found good agreement between measured settling velocities of particles and ones calculated using their formula. Aschenbrenner (1956), introducing yet another measure, returned to Wadell's original definition of sphericity but used a tetrakaidekahedron as his reference form. He argued that the unsmooth tetrakaidekahedron was a better approximation to the form of sand grains than an ellipsoid.

Though a tetrakaidekahedron may approximate the form of sand grains better, the triaxial ellipsoid still stands as the better reference form for larger smooth sediment particles. However an error in the latter approximation occurs with skewed ellipsoids. The volumes of a triaxial ellipsoid and a skewed ellipsoid are the same, but surface area increases as the ellipsoid becomes skewed (Flemming, 1965, p. 382). Since Wadell's original definition of sphericity involved surface area, an ellipsoidal approximation of skewed particles would than give a surface area for the particles less than the actual one. Because most workers have used triaxial ellipsoids as the reference form for particles, the present author returned to Wadell's original definiton of sphericity and used another measure based on the surface area of triaxial ellipsoids. Thus four measures defined in the literature can be used to calculate the sphericity of particles. Two of the measures, Aschenbrenner's and the triaxial ellipsoidal approximation, are based on Wadell's original definition of sphericity; one, Sneed and Folk's is based on hydraulic equivalence; and the other, Krumbein's, is an operational formula which has none of these advantages.

b) Shape

One of the first methods for classifying particles according to form was developed by Zingg (1935, p. 55). He plotted the ratio of the intermediate axis over the longest axis to that of the smallest one to the intermediate and came up with a classification of particles based on four shapes--spherical, disc-shaped, rod-like, and bladed. (For illustration of classifications mentioned here, see Appendix 5.) The emphasis of this diagram was on the degree of similarity of a particle to a sphere and the approximation of the particle to either a prolate or an oblate spheroid. The former emphasis was related to the concept that particles through abrasion tend ultimately towards spheres. This concept has been shown by Rayleigh (1943, p. 330) and Carroll (1951, p. 211) to be invalid in nature. The second emphasis is more important, as it reflects the original shape of particles or the environmental processes acting upon particles. Williams (1965, p. 996) developed a formula which expressed mathematically the degree of oblateness or prolateness as a single statistic, whereby positive values indicate an oblate spheroid (the longest and intermediate axes tend to be equal) and a negative value indicates a prolate spheroid (the intermediate and short axes tend to be equal). Sneed and Folk (1958, p. 119) set up a different classification which has the same emphasis as the Zingg diagram, but breaks down the shape of the particles into ten categories. Their diagram compares the ratio of the short to long axis with the ratio of the long minus the intermediate axis to the long minus the short axis.

With these three shape measures,--Zingg's and Sneed and Folk's subjective classifications and Williams' which is a defined mathematical relationship,--the form of particles on these beaches can be used to distinguish differences in the sands of the islands.

Three dimensional measurements were taken on samples made of sixty quartz sand grains, size 0.5-1.0 phi, from the sieved fraction of the ocean mid-beach at depth, back of ocean beach, back of lagoon beach and top of dune crest sites for selected profiles (Table 5:1). Quartz grains were used in order to keep the analysis consistent with work in the literature (Russell and Taylor 1937, p. 252; Hulbe 1955, p. 302; and Sahu and Patro 1970, p. 55). Because of the difficulty in separating quartz and feldspar grains without dying the quartz, some feldspar is probably included in the sample, but Pettijohn and Lundahl (1943, p. 75) did not judge the inclusion of feldspar as that influential in interpreting sphericity and shape results. The selection was restricted to a limited size range because of the fact that sphericity varies with grain size (Russell and Taylor 1937, p. 250; and Pettijohn and Lundahl 1943, p. 73).

The axes of the sand grains were taken as mutually perpendicular lengths according to a scheme outlined by Krumbein (1941, pp. 65-66) and were measured according to a procedure outlined by Hulbe (1955). A mould measuring 6 by 6 mm was filled half full with clear casting resin and then filled with water. The grains were dropped individually through this water so that the maximum projection area of the grain was perpendicular with the sides of the mould. The water was drained, the mould filled

TABLE 5:1 LOCATION OF SAND SAMPLES FOR SHAPE AND SPHERICITY ANALYSIS

First number is the profile number.
Second number is the code for location on the beach.
For an explanation of code see Chapter 4, p.

SAND

1-4	1-12	1-5	1-8
2-4	2-12	3-5	
3-4	3-12		
4-4	4-12		
	5-12		
6-4	6-12	6-5	9-8
7-4	7-12	8-5	
8-4	8-12	10-5	
9-4	9-12		
10-4	10-12		
11-4	11-12	11-5	11-8
12-4	12-12	13-5	
13-4	13-12	15-5	
14-4	14-12		
15-4	15-12		
16-4	16-12	16-5	16-8
17-4	17-12	20-5	
18-4	18-12		
19-4	19-12		
20-4	20-12		

with resin, and after hardening of the resin, the cast was removed. Each sample was then projected at 20 to 30 times magnification onto a screen and the longest (a) and intermediate (b) axes were measured. The shortest (c) axis was measured by rotating the cast 90 degrees. The final sample size was set at fifty since about 8 per cent of the sand grains were not aligned properly. These triaxial measures were then fed as input into computer programs for sphericity and shape calculations.

ANALYSIS

a) Testing

The sphericity calculations for each sample were grouped at .05 intervals for the Sneed and Folk, and Krumbein measures and at .025 intervals for the other measures. The shape data was grouped according to each individual classification on the Zingg, and Sneed and Folk diagrams and for each .1 class interval for Williams' statistic. A summary of these results is presented in Table 5:2. The two best sphericity calculations--Sneed and Folk's and Aschenbrenner's-- and Williams' shape parameter were tested for all combinations of samples of sand grains using the Kolmogorov-Smirnov two-sample test (Siegel 1956, pp. 127-131) at the .05 level of significance. These measures were chosen on the basis of conclusions presented in Appendix 3. The other shape measures were tested in the same manner using the Chi-Square two-sample test (Siegel 1956, pp. 104-111). Because of the number of comparisons made, for purposes of presentation, the results have been grouped using the same method as was used in testing the means and standard deviations of

TABLE 5:2 SUMMARY OF SHAPE AND SPHERICITY MEASUREMENTS FOR SAND

First number is the beach.
Second number is the code for location on the beach.
Where no number is given, the geographic location on the beach is noted.

MEAN AND STANDARD DEVIATION OF SPHERICITY MEASURES

MEASURE	1-4		2-4		3-4		4-4		1-12		2-12	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
FOLK	.748	.097	.782	.094	.773	.085	.770	.081	.758	.085	.744	.097
KRUMBEIN	.760	.073	.810	.075	.762	.080	.765	.077	.753	.079	.749	.074
ASCHEN.	.901	.036	.914	.031	.909	.030	.910	.029	.903	.033	.898	.039
ELLIPSOID	.948	.035	.960	.027	.955	.029	.956	.028	.951	.032	.945	.037

	3-12		4-12		1-5		2-5		3-5		4-5	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
FOLK	.733	.091	.754	.091	.729	.095	.719	.075	.760	.077	.765	.086
KRUMBEIN	.742	.072	.761	.079	.744	.079	.733	.073	.738	.086	.742	.087
ASCHEN.	.895	.037	.903	.034	.894	.046	.892	.031	.903	.031	.904	.033
ELLIPSOID	.942	.036	.950	.034	.941	.044	.939	.030	.949	.030	.950	.032

	1-8		2-8		3-8		4-8	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
FOLK	.752	.086	.754	.090	.784	.074	.770	.078
KRUMBEIN	.735	.067	.756	.070	.765	.076	.736	.080
ASCHEN.	.900	.034	.904	.035	.914	.024	.905	.027
ELLIPSOID	.947	.032	.950	.033	.960	.023	.951	.026

PERCENTAGE OF OBLATE AND PROLATE SAND GRAINS

BEACH	OBLATE	PROLATE
1-4	58.8	41.2
2-4	67.8	32.2
3-4	45.3	54.7
4-4	49.6	50.4
1-12	44.4	55.6
2-12	54.0	46.0
3-12	52.2	47.8
4-12	51.8	48.2
1-5	56.9	43.1
2-5	60.9	39.1
3-5	35.8	64.2
4-5	32.0	68.0

BEACH	OBLATE	PROLATE
1-8	36.0	64.0
2-8	47.1	52.9
3-8	30.0	70.0
4-8	34.0	66.0

WILLIAMS' SHAPE MEASURE - PERCENT IN EACH CATEGORY

MEASURE	1-4	2-4	3-4	4-4	1-12	2-12	3-12	4-12
-1.0 - -0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.9 - -0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.8 - -0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.7 - -0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
-0.6 - -0.5	0.0	0.0	1.6	0.4	0.4	0.8	0.0	2.0
-0.5 - -0.4	1.0	0.8	4.1	2.4	2.4	0.8	2.0	0.8
-0.4 - -0.3	6.5	5.4	6.5	7.2	7.1	4.0	6.3	5.5
-0.3 - -0.2	11.1	14.1	15.1	13.6	13.5	14.1	9.8	9.4
-0.2 - -0.1	10.1	12.9	14.7	13.2	15.5	11.7	12.2	13.3
-0.1 - 0.0	12.6	14.1	12.7	13.6	16.7	12.5	17.3	17.3
0.0 - 0.1	14.1	14.6	11.4	16.4	10.7	13.8	14.1	13.3
0.1 - 0.2	16.6	14.6	17.6	17.6	14.3	16.9	10.0	12.9
0.2 - 0.3	15.1	13.8	9.4	9.2	11.9	12.5	11.4	12.5
0.3 - 0.4	7.0	5.8	4.9	2.4	4.8	7.7	8.2	7.8
0.4 - 0.5	5.0	3.3	1.2	3.6	2.8	3.2	6.7	3.5
0.5 - 0.6	1.0	0.4	0.8	0.4	0.0	0.8	1.2	1.6
0.6 - 0.7	0.0	0.0	0.0	0.0	0.0	1.2	0.4	0.0
0.7 - 0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8 - 0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.9 - 1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	1-5	2-5	3-5	4-5	1-8	2-8	3-8	4-8
-1.0 - -0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.9 - -0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.8 - -0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.7 - -0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.6 - -0.5	0.0	1.3	0.6	1.0	2.0	0.0	0.0	0.0
-0.5 - -0.4	0.0	0.7	4.6	5.0	2.0	0.0	0.0	8.0
-0.4 - -0.3	4.9	6.0	9.9	7.0	14.0	5.0	12.0	16.0
-0.3 - -0.2	5.9	6.0	17.2	10.0	14.0	15.7	20.0	22.0
-0.2 - -0.1	18.6	11.9	17.2	24.0	14.0	13.7	16.0	16.0
-0.1 - 0.0	13.7	13.2	14.6	21.0	18.0	17.6	22.0	4.0
0.0 - 0.1	8.8	16.6	14.6	12.0	10.0	5.9	10.0	18.0
0.1 - 0.2	23.5	17.2	10.6	10.0	8.0	17.6	8.0	2.0
0.2 - 0.3	8.8	15.2	6.6	5.0	6.0	11.7	6.0	8.0
0.3 - 0.4	9.8	7.9	2.0	5.0	10.0	7.8	4.0	4.0
0.4 - 0.5	5.8	2.6	2.0	0.0	0.0	3.9	2.0	2.0
0.5 - 0.6	0.0	1.3	0.0	0.0	2.0	0.0	0.0	0.0
0.6 - 0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.7 - 0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8 - 0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.9 - 1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ZINGG SHAPE DIAGRAM - VALUES IN PERCENTAGES

MEASURE	1-4	2-4	3-4	4-4	1-12	2-12	3-12	4-12
sphere	53.8	64.6	60.8	62.4	55.2	46.8	47.1	58.0
disc	29.6	20.8	18.0	16.8	22.2	31.5	30.2	23.9
rod	15.1	12.9	20.0	18.8	20.6	18.5	17.6	14.6
blade	1.5	1.7	1.2	2.0	2.0	3.2	5.1	3.5

	1-5	2-5	3-5	4-5	1-8	2-8	3-8	4-8
sphere	48.0	41.7	49.0	54.0	52.0	54.9	62.0	48.0
disc	32.4	33.1	10.6	13.0	22.0	25.5	10.0	14.0
rod	16.7	21.2	36.4	29.0	26.0	17.6	28.0	38.0
blade	2.9	4.0	4.0	4.0	0.0	2.0	0.0	0.0

SNEED AND FOLK'S SHAPE DIAGRAM - VALUES IN PERCENTAGES

MEASURE	1-4	2-4	3-4	4-4	1-12	2-12	3-12	4-12
compact	14.6	23.8	20.0	18.8	14.3	12.9	9.4	15.3
compact platy	10.6	14.2	9.4	7.6	10.7	7.3	10.6	9.8
compact bladed	27.6	22.5	23.7	27.6	24.6	27.0	27.1	29.4
compact elongated	19.1	21.7	23.7	22.0	24.2	20.2	18.0	20.8
platy	5.0	3.3	1.6	3.2	2.0	4.4	8.2	5.5
bladed	18.6	12.5	13.1	10.8	15.9	20.6	18.4	12.9
elongated	4.0	2.1	8.6	8.0	7.5	6.9	7.5	5.9
very platy	.5	0.0	0.0	0.0	0.0	.4	0.0	.4
very bladed	0.0	0.0	0.0	0.0	.8	.4	.8	0.0
very elongated	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	1-5	2-5	3-5	4-5	1-8	2-8	3-8	4-8
compact	9.8	6.6	12.6	14.0	6.0	13.7	20.0	14.0
compact platy	12.7	11.9	4.6	7.0	8.0	11.7	8.0	6.0
compact bladed	22.5	31.1	26.5	28.0	28.0	21.6	22.0	14.0
compact elongated	20.6	9.3	27.8	25.0	28.0	21.6	32.0	36.0
platy	8.8	5.3	1.3	0.0	4.0	3.9	2.0	2.0
bladed	20.6	25.2	9.9	10.0	12.0	23.5	6.0	10.0
elongated	2.9	10.6	16.6	15.0	14.0	3.9	10.0	18.0
very platy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
very bladed	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
very elongated	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

grain size. The comparisons were grouped according to each beach using nine sets of comparisons as follows:

1) ocean mid-beach to ocean mid-beach
2) high tide lagoon to ocean mid-beach
3) back of ocean beach to ocean mid-beach
4) dune crest to ocean mid-beach
5) high tide lagoon to high tide lagoon
6) back of ocean beach to high tide lagoon
7) dune crest to high tide lagoon
8) back of ocean beach to back of ocean beach
9) dune crest to back of ocean beach.

b) Coarse Sand Analysis

The sand grain analysis showed a tendency for sphericity to decrease in the following order; ocean mid-beach, high tide lagoon, and back of ocean beach (Table 5:2). There was little if any trend along the beaches. Since the back of the beach samples tend to have the lowest sphericity and since these samples have been shown to be for the most part wind-deposited, Mattox's view (1955, p. 114) that in aeolian shape sorting the low sphericity grains move further, would appear to be substantiated. (See Appendix 3 for a discussion of aeolian shape sorting.)

Tables 5:3 and 5:4 give the number and percentage of differences out of the total possible differences for Sneed and Folk's and Aschenbrenner's measure of sphericity respectively. The number of differences is not large and

TABLE 5:3 TESTING OF SNEED AND FOLK'S SPHERICITY FOR COARSE SAND MATERIAL

Samples are grouped according to beach.
The numerator is the number of differences.
The denominator is the total possible number of differences.
Each section of the table represents a comparison of one environment to another for each beach.
A blank in the table represents no differences.
The percentage of total possible differences is given at the end of the table.

Mid-Beach

		1	2	3	4
Mid-Beach	1		3/20	2/20	4/20
	2		2/20	4/25	3/25
	3				
	4				

8.7%

Lagoon

		1	2	3	4
Mid-Beach	1				
	2	3/25	9/25	13/25	3/25
	3	1/25	4/25	7/25	2/25
	4		4/25	3/25	2/25

13.4%

Back of Beach

		1	2	3	4
Mid-Beach	1	1/8	6/12		1/12
	2	7/10	13/15	2/15	4/15
	3	2/10	9/15	1/15	1/15
	4	3/10	11/15		2/15

33.2%

Dune

		1	2	3	4
Mid-Beach	1			1/4	
	2		1/5		
	3				
	4				

2.6%

Lagoon

		1	2	3	4
Lagoon	1		2/25	1/25	
	2			1/25	
	3				1/25
	4				

2.2%

Back of Beach

		1	2	3	4
Lagoon	1	1/10	7/15		1/15
	2		4/15	2/15	1/15
	3		1/15	1/15	2/15
	4		7/15		

13.8%

Dune

		1	2	3	4
Lagoon	1				
	2	1/5		1/5	
	3			2/5	
	4				

5.0%

Back of Beach

		1	2	3	4
Back of Beach	1		1/6		1/6
	2			4/9	3/9
	3				
	4				1/6

18.9%

Dune

		1	2	3	4
Back of Beach	1			1/2	
	2		1/3	3/3	2/3
	3				
	4				

17.5%

TABLE 5:4 TESTING OF ASCHENBRENNER'S SPHERICITY FOR COARSE SAND MATERIAL

Samples are grouped according to beach.
The numerator is the number of differences.
The denominator is the total possible number of differences.
Each section of the table represents a comparison of one environment to another for each beach.
A blank in the table represents no differences.
The percentage of total possible differences is given at the end of the table.

Mid-Beach

		1	2	3	4
Mid-Beach	1		5/20		
	2		2/20	8/25	3/25
	3				
	4				

8.7%

Lagoon

		1	2	3	4
Mid-Beach	1				
	2	4/25	8/25	14/25	5/25
	3		3/25	2/25	
	4		4/25	1/25	

10.8%

Back of Beach

		1	2	3	4
Mid-Beach	1		4/12		
	2	5/10	13/15	8/15	2/15
	3	1/10	8/15		1/15
	4	2/10	10/15		1/15

28.9%

Dune

		1	2	3	4
Mid-Beach	1				
	2	1/5	1/5	1/5	1/5
	3				
	4				

5.3%

Lagoon

		1	2	3	4
Lagoon	1		2/25	1/25	
	2		2/25		4/25
	3				
	4				

3.9%

Back of Beach

		1	2	3	4
Lagoon	1		7/15		
	2		5/15	2/15	1/15
	3		4/15		
	4		3/15		

11.2%

Dune

		1	2	3	4
Lagoon	1				
	2	1/5	1/5	1/5	1/5
	3			1/5	
	4				

6.3%

Back of Beach

		1	2	3	4
Back of Beach	1				
	2		2/6		
	3		1/9	4/9	3/9
	4				

18.9%

Dune

		1	2	3	4
Back of Beach	1				
	2	1/3	1/3	1/3	1/3
	3				
	4				

12.5%

there are no anomalies peculiar to one beach as was the case in grain size analysis; however, the tables do show that the back of ocean beach samples are different when compared to other locations across the beach and have the greatest number of differences when compared to each other. The dune crest samples are very similar to the lagoon and mid-ocean beach samples so that outside of the back of ocean beach location there is little variation in sphericity on these beaches. Since these sands were sampled after winds had been moving sand seaward from the dune area and since the back of the ocean beach sands were wind-deposited, it would appear that some statistically significant aeolian sorting of sand on the basis of sphericity had occurred. The higher sphericity sands have remained in the dune area while the lagoon and mid-ocean beach (at depth) sands haye not been affected by wind sorting and deposition to as great a degree as those in the dune area and back of ocean beach respectively.

As regards the sensitivity of the measures in testing sphericity for these sands, Sneed and Folk's measure revealed more differences between samples than did Aschenbrenner's. Since Aschenbrenner's measure has been shown to be more sensitive to changes in the dimensions of oblate particles (Appendix 3), then most of these sands should be prolate. A summary of oblate and prolate percentages for each sample (Table 5:2) shows that the particles are not strongly oblate. The above conclusion about Aschenbrenner's measure is thus validated with these samples.

Table 5:2 also shows that there is a tendency for sand particles to be prolate on the dune crest for all beaches as well as on the ocean beaches of Beach 3 and 4. When the Chi-Square test of prolate and oblate differences was applied to the samples, most of the significant differences between samples resulted from comparisons with these areas (Table 5:5). The back of the ocean beach samples also significantly differed in the degree of prolateness and oblateness from the mid-ocean beach, high tide lagoon and the dune crest samples, while the dune crest samples were different from the mid-ocean beach and lagoon samples. These latter two samples however when compared showed little difference between each other and between other samples from the same environment.

The summary of prolate and oblate particles tested in Table 5:5 was based on Williams' measure; however, when this measure was broken into intervals and tested using the Kolmogorov-Smirnov test the results were not as clearly

TABLE 5:5 TESTING OF OBLATENESS AND PROLATENESS FOR COARSE SAND MATERIAL

Samples are grouped according to beach.
The numerator is the number of differences.
The denominator is the total possible number of differences.
Each section of the table represents a comparison of one environment to another for each beach.
A blank in the table represents no differences.
The percentage of total possible differences is given at the end of the table.

Mid-Beach

		1	2	3	4
Mid-Beach	1		2/20	5/20	3/20
	2			2/25	1/25
	3			3/20	3/25
	4				

9.2%

Lagoon

		1	2	3	4
Mid-Beach	1	9/20	2/20	2/20	1/20
	2	2/25			
	3	4/25	7/25	5/25	3/25
	4	4/25	2/25	1/25	

11.1%

Back of Beach

		1	2	3	4
Mid-Beach	1			7/12	6/12
	2			8/12	6/12
	3	3/10	6/15	4/12	3/12
	4	1/10	2/15	5/15	4/15

26.9%

Dune

		1	2	3	4
Mid-Beach	1	3/4		3/4	3/4
	2	1/5		5/5	2/5
	3	1/5		2/5	2/5
	4	2/5		2/5	2/5

42.1%

		Lagoon			
		1	2	3	4
Lagoon	1	1/25	5/25	4/25	6/25
	2		2/25	2/25	2/25
	3				
	4				

9.6%

		Back of Beach			
		1	2	3	4
Lagoon	1	3/10	7/15	4/15	4/15
	2	1/10		7/15	6/15
	3		1/15	6/15	4/15
	4	1/10	1/15	6/15	4/15

28.1%

		Dune			
		1	2	3	4
Lagoon	1			2/5	1/5
	2	3/5	1/5	3/5	3/5
	3	2/5		3/5	1/5
	4	2/5		2/5	2/5

31.3%

		Back of Beach			
		1	2	3	4
Back of Beach	1			3/6	2/6
	2			7/9	6/9
	3			1/6	
	4				

35.8%

		Dune			
		1	2	3	4
Back of Beach	1	1/2		2/2	1/2
	2	3/3		3/3	3/3
	3		1/3		
	4				

35.0%

TABLE 5:6 TESTING OF WILLIAMS' SHAPE STATISTIC FOR COARSE SAND MATERIAL

Samples are grouped according to beach.
The numerator is the number of differences.
The denominator is the total possible number of differences.
Each section of the table represents a comparison of one environment to another for each beach.
A blank in the table represents no differences.
The percentage of total possible differences is given at the end of the table.

Mid-Beach

		1	2	3	4
Mid-Beach	1			4/20	
	2			1/25	
	3			1/20	2/25
	4				

3.9%

Lagoon

		1	2	3	4
Mid-Beach	1	1/20			
	2				
	3		4/25	3/25	2/25
	4		3/25	1/25	

3.7%

Back of Beach

		1	2	3	4
Mid-Beach	1			7/12	6/8
	2			4/15	
	3	3/10	4/15	3/15	2/10
	4			3/15	2/10

17.9%

Dune

		1	2	3	4
Mid-Beach	1	1/4		3/4	3/4
	2				4/5
	3			1/5	2/5
	4				3/5

22.4%

Lagoon

		1	2	3	4
Lagoon	1		2/25	1/25	
	2				
	3				
	4				

1.3%

Back of Beach

		1	2	3	4
Lagoon	1	1/8	3/15	2/15	
	2			5/15	3/10
	3			4/15	3/10
	4			7/15	6/10

17.3%

Dune

		1	2	3	4
Lagoon	1				2/5
	2	1/5		3/5	2/5
	3			3/5	2/5
	4			1/5	1/5

18.8%

Back of Beach

		1	2	3	4
Back of Beach	1			4/6	2/4
	2			6/9	6/6
	3				
	4				

40.0%

Dune

		1	2	3	4
Back of Beach	1	1/2	1/2	1/2	2/2
	2			3/3	3/3
	3		1/3		1/3
	4				1/2

35.0%

defined (Table 5:6). Thus the summary of Williams' shape measure appeared to be better at revealing differences than did the raw data itself.

The majority of the sands approximated spheres according to Zingg's classification (Table 5:2), but the mid-ocean beach and lagoon beach sands were slightly more spherical and disc-shaped than the back of ocean beach and dune crest sands which were more rod-like. Table 5:7 shows similar results for the testing of the Zingg diagram to the Chi-Square test on the prolateness and oblateness but with fewer significant differences when comparing dune samples to the other areas. The testing however did show more differences when the samples from the mid-ocean beach were compared to each other and with other environments.

The sands also showed a large variation for the Sneed and Folk shape classification, but generally samples did not contain very platy, very bladed, or very elongated particles. The majority of particles were some form of either bladed or elongated with a few particles being platy. The tests between samples for Sneed and Folk's classification (Table 5:8) show similar results to the test of the Zingg diagram, with the dune samples having fewer

TABLE 5:7 TESTING OF ZINGG DIAGRAM FOR COARSE SAND MATERIAL

Samples are grouped according to beach.
The numerator is the number of differences.
The denominator is the total possible number of differences.
Each section of the table represents a comparison of one environment to another for each beach.
A blank in the table represents no differences.
The percentage of total possible differences is given at the end of the table.

Mid-Beach

		1	2	3	4
Mid-Beach	1		6/20	6/20	5/20
	2		3/20	3/25	4/25
	3				
	4				1/20

14.0%

Lagoon

		1	2	3	4
Mid-Beach	1	3/20	3/20	2/20	2/20
	2	3/25	9/25	12/25	5/25
	3	1/25	6/25	10/25	5/25
	4		6/25	9/25	5/25

21.3%

Back of Beach

		1	2	3	4
Mid-Beach	1	1/8	3/12	8/12	4/12
	2	3/10	6/15	9/15	3/15
	3	3/10	7/15	8/15	
	4	3/10	6/15	5/15	2/15

37.4%

Dune

		1	2	3	4
Mid-Beach	1	1/4		2/4	3/4
	2	1/5		2/5	5/5
	3			2/5	1/5
	4			1/5	1/5

25.0%

Lagoon

		1	2	3	4
Lagoon	1		3/25		1/25
	2				2/25
	3				3/25
	4				1/25

4.3%

Back of Beach

		1	2	3	4
Lagoon	1	1/10	1/15	8/15	
	2			9/15	3/15
	3			9/15	4/15
	4		6/15	10/15	4/15

28.1%

Dune

		1	2	3	4
Lagoon	1			1/5	1/5
	2			4/5	3/5
	3	1/5		5/5	4/5
	4			2/5	3/5

27.5%

Back of Beach

		1	2	3	4
Back of Beach	1			4/6	1/6
	2			7/9	2/9
	3			1/6	
	4				

28.3%

Dune

		1	2	3	4
Back of Beach	1			1/2	1/2
	2			2/3	1/3
	3	1/3	2/3		
	4				

20.0%

TABLE 5:8 TESTING OF SNEED AND FOLK'S DIAGRAM FOR COARSE SAND MATERIAL

Samples are grouped according to beach.
The numerator is the number of differences.
The denominator is the total possible number of differences.
Each section of the table represents a comparison of one environment to another for each beach.
A blank in the table represents no differences.
The percentage of total possible differences is given at the end of the table.

Mid-Beach

		1	2	3	4
Mid-Beach	1		6/20	3/20	3/20
	2		4/20	7/25	10/25
	3				3/25
	4				2/20

18.4%

Lagoon

		1	2	3	4
Mid-Beach	1	1/20			
	2	7/25	13/25	12/25	9/25
	3		6/25	5/25	2/25
	4		7/25	4/25	2/25

17.9%

Back of Beach

		1	2	3	4
Mid-Beach	1	1/8	2/12	7/12	2/12
	2	4/10	11/15	13/15	7/15
	3	3/10	8/15	5/15	1/15
	4	3/15	9/15	6/15	2/15

44.2%

Dune

		1	2	3	4
Mid-Beach	1	1/4		1/4	2/4
	2	4/5	1/5	1/5	5/5
	3	1/5			
	4	1/5			2/5

25.0%

Lagoon

		1	2	3	4
Lagoon	1		1/25		
	2		2/25	1/25	
	3				
	4				

1.7%

Back of Beach

		1	2	3	4
Lagoon	1	2/10	5/15	3/15	
	2	1/10	5/15	7/15	1/15
	3	1/10	1/15	6/15	2/15
	4	1/10	5/15	5/15	1/15

23.5%

Dune

		1	2	3	4
Lagoon	1			1/5	
	2			4/5	2/5
	3			4/5	3/5
	4				1/5

18.8%

Back of Beach

		1	2	3	4
Back of Beach	1		1/6	4/6	2/6
	2			6/9	3/9
	3			2/6	
	4				

34.0%

Dune

		1	2	3	4
Back of Beach	1				1/2
	2	1/2			3/3
	3		2/3		1/3
	4				

20.0%

differences than the test on prolate and oblate particles. These differences of samples for the Zingg and Sneed and Folk diagrams are not restricted to any one Beach and often the differences can be accounted for by one or two samples.

CONCLUSIONS

The ellipsoidal approximation of sphericity is a theoretically sound measure but because of its complexity it is not always a practical one. The Sneed and Folk and the Aschenbrenner measure theoretically proved sufficient as a measure of sphericity, whereas the Krumbein measure, though able to distinguish differences between samples as well as the other measures, was discarded as theoretically unsound. On the basis of practicality and soundness, the Sneed and Folk, and Aschenbrenner measures were used for testing the similarity of sphericity between samples from the beach and dune areas of the barriers. The analysis based on these measures though not as revealing as grain size analysis shows a trend for sphericity of sediments to follow a similar pattern as that defined in the literature. The recent wind-blown sands which accumulate in the lee of the dune ridge on the ocean side of the barrier islands had a significantly lower sphericity than the rest of the sands from the ocean and lagoon beaches and dune crest. Whereas grain size analysis can reveal differences between samples affected by the intensity of a process, sphericity analysis is only capable of distinguishing between sands which have undergone low intensity wind transport and those that have not.

The tests for shape are not that complete in that the largest percentage of possible differences occurring between samples was only 44.2%. The test of Williams' measure based on whether or not the particles are prolate or oblate appears to be the best indicator of shape differences in these sands in that it is the simplest classification of shape. The Zingg, and Sneed and Folk classifications are both subjective whereas Williams' measure is based on a mathematical relationship which defines particles as either prolate or oblate spheroids. The effect of process on these shapes may be difficult to explain without experiment, but the results obtained here imply that some shape sorting of particles is occurring. As shown with the results of the testing of prolate and oblate particles, the dune environment which is affected most by wind, is different from the other samples. The back of the ocean beach area, which at the time of sampling, mainly consisted of sands blown from the dune area is also different from the beach samples. The ocean beach and lagoon samples however are similar. These latter areas have more oblate-shaped grains which are significantly different from the more prolate-shaped sands from the dune and back of ocean beach areas.

It is reasonable to conclude on the basis of shape and sphericity measures that the lagoon and ocean beaches are composed of mainly wave-deposited sands which in the case of the ocean beach are being contaminated by wind-blown sands from the dune area as the result of predominately southwest to west winds in the summer. A more detailed areal and temporal examination of shape and sphericity could define these conclusions more clearly, but in conjunction with the observations and results of grain size analysis, these conclusions are valid in the interpretation of the processes responsible for the seasonal changes on the barrier islands of Kouchibouguac Bay.

CHAPTER 6

WAVE REFRACTION

INTRODUCTION

It has been established in Chapter 3 that much of the magnitude and direction of change in the configuration of the barrier islands is dependent upon the frequency, amount and direction of energy input to the beaches. This energy distribution is controlled spatially by wave refraction and exerts control over the beach profile and plan form. Wave refraction thus determines the severity of wave attack and also determines the amount and direction of longshore drift.

The basic theory of wave refraction rests in the fact that the phase velocity of a wave is dependent upon water depth when the ratio, water depth to wave length, is less than one to two. If the water depth under a wave front varies, then the wave front must refract to reflect the bottom topography. (For mathematical derivation of ideas discussed here, see Appendix 6). The energy per unit section of wave is dependent upon the height and length of the wave. The former changes as a function of the degree of wave refraction as calculated by the refraction coefficient, and as a function of water depth as calculated by the shoaling coefficient. Thus by knowing wave period, height, angle of approach to shore and the bottom topography, and assuming that energy does not move laterally along a wave crest, the energy per unit area of wave crest bounded by orthogonals (lines of equal distance at right angles to the wave front) in deep water can be calculated either relatively or absolutely along a coastline as the wave is refracted into shallow water.

Such calculations of wave refraction patterns have played a major role in the primary studies of most coastal areas. In a classic study, Shepard and Inman (1950) related wave refraction patterns to measured longshore current speeds and directions for waves of varying periods and directions along the Californian coast. Vallbrecht (1966) went further and related erosion of the coastline to the relative efficiency of longshore currents produced by concentrations of wave energy resulting from wave refraction. Cherry (1966) found that wave refraction diagrams were an alternative method to determining sand transport on a beach. He was able to find a relationship between wave refraction and median grain size and heavy mineral distributions in Drakes Bay. Richards and Bird (1970), for the Barbados, found that wave refraction exerted a basic control over the beach plan and form and were able to correlate wave energy to volumetric changes on a beach, while Reddy (1968), working on Belledune Point in Chaleur Bay, was able to correlate probable wave refraction patterns to observed beach change, based on aerial photographs. It was considered, therefore, that simulation modelling of wave refraction patterns would provide a valuable method for examining and explaining the beach processes, as they are related to change, for the barrier islands of Kouchibouguac Bay.

This chapter presents the results of computer simulation of the wave refraction patterns in Kouchibouguac Bay. By using assumptions based on the theory of wave refraction and by making simplifications of the real world situation,it is possible to build up the pattern of the energy distribution in the bay. Because such modelling requires specific wave directions, heights and periods affecting the southwestern Gulf of St. Lawrence and because measured wave data is non-existent, some development of realistic wave data has to be attempted for the area. Once the input for such modelling has been defined then idealized wave fronts can be brought into the southwestern Gulf and Kouchibouguac Bay using bathymetric data for these areas. The pattern of wave refraction for these waves gives a general picture of the energy distribution in the bay.

Since detailed bathymetric charting exists for the Richibucto Inlet area for the periods 1894 to 1969, wave refraction patterns were examined for this area on a large scale over this time period. Because the changes in beach configuration have been documented accurately for this area, it is hoped that these patterns over time can be used as an explanation for changes in the barrier islands.

The energy distributions presented in this chapter are based on divergence and convergence of wave orthogonals and are by no means absolute. This chapter is only concerned with defining the relative distribution of energy in the bay and accounting for some of the beach changes over time.

PROCEDURES FOR CONSTRUCTING WAVE REFRACTION DIAGRAMS

a) Graphic Means

The basic theory for wave refraction diagrams was presented after the Second World War by Sverdrup and Munk (1946a, b), Arthur (1946), and Munk and Traylor (1947). These papers were supplemented by Johnson, O'Brien and Isaacs (1948) and Arthur, Munk, and Isaacs (1952) who developed graphical means of constructing wave refraction diagrams using wave fronts. These graphical methods assume that the phase velocity of the wave crest is only dependent on wave length and water depth, that wave energy is confined between orthogonals, and that wave period is constant (Wiegel, 1964 p. 157). Johnson, O'Brien and Isaacs (1948) in constructing wave diagrams used orthogonals instead of wave fronts and assumed further, linearity between bottom contours and linearity of wave length and velocity over these contours. These graphical methods all have the fault of human error in their construction and tend to over- or underestimate refraction depending upon the wave's angle of approach to the bottom contours and its steepness (Wiegel, 1964 p. 172).

b) Computer Methods

Computer calculations of wave refraction diagrams using the orthogonal approach were introduced by Griswold (1963). The first attempts at computer calculation used grids of wave speed rather than depths as a basis for construction of wave rays. Wilson (1966, pp. 9-10) was the first to use a depth grid in which a plane approximation of the bottom topography based on a least squares fit of the four nearest points on the depth grid was used to calculate the depth of water over which a wave moved. Dobson (1967, p. 10) points out that this method does not allow for the calculation of wave heights and in fact the approximation of a plane surface is not precise in reality. Dobson (1967, pp. 22-27) introduced a program which used a second degree polynomial fit based on a least squares of twelve depths at grid intersections surrounding the area of interest. This latter method allows for both the calculation of refraction coefficients and wave heights. These computer methods thus allow for more accurate, more numerous and faster calculations.

Both the Wilson (1966) and the Dobson (1967) programs were tested and compared using similar depth grids and input by the present author. The Wilson program has a tendency to overrefract in areas where bottom topography is quite variable and shallow,and even over smooth bottom topography refraction is greater than with the Dobson program. Hardy (1968, p. 77) however judged the Wilson program to be better at approximating the real world wave refraction patterns in this respect. But on the basis of this testing, the Dobson program was the sole program used in the construction of wave refraction diagrams in the study area.

c) Input for the Dobson Computer Program

The Dobson program uses as basic input depth values taken from hydrographic maps in the form of a grid of square cells. These grids are formed by interpolating depth values at the grid intersections from the bathymetric charts. These values are then set in a matrix form for use in the computer program. As long as the assumption of parallel contours holds for this grid it can be expanded to cover any size area--the only limitation on the latter being error resulting from the type of map projection used for the chart (Hardy 1968b, p. 7083).

Along with this depth grid the x and y coordinates of points along the wave crest to be studied, together with the angle of approach of these points from the x axis of the grid are used as input. The wave height and period, along with the increment in grid units with which the wave is to be moved through the grid are also added. The program then calculates as output for each wave ray the x and y coordinates of points along the orthogonal, the angle of approach at these points, the interpolated depth, the maximum difference of this depth from the grid points used in interpolation, and the standard deviation of the least squares surface. The wave length, speed and height are calculated along with the refraction and shoaling coefficients. The calculation for each ray is terminated at the shoreline or when certain conditions needed in the programming are violated. An example of output is given in Appendix 7.

SIMULATION MODELLING OF WAVE REFRACTION IN KOUCHIBOUGUAC BAY

a) Data for Wave Period and Height

i) Theoretical Derivation

Representative wave period and height data for the study area can either be gathered by measurement or be developed from theory knowing the wind characteristics in an area. Except for a few observations in the field, observed data was virtually non-existent for the southern Gulf of St. Lawrence. The theoretical approach was thus attempted.

There are three theoretical approaches for forecasting wave characteristics from meteorlogical data--Sverdrup, Munk (1946a, b, 1947) and Bretschneider (1952), Pierson, Neuman, and James (1955), and Darbyshire (1955, 1956) and Darbyshire and Draper (1963). The Sverdrup, Munk and Bretschneider method is based upon empirical relationships. It uses the concepts of fetch and duration limited wave generation in which height and period of significant waves (the point at which the highest one third of the heights and periods of the wave spectrum occur) will increase with increasing fetch and duration of wind. When certain limits are reached, the height and period of waves generated by a fixed wind speed cannot increase. From empirical observations, Sverdrup and

Munk (1946a, 1947) and Bretschneider (1952) defined a series of graphs that allowed for the prediction of significant wave heights and periods based on wind speed, duration and fetch.

The Pierson, Neuman and James method is based upon theoretical considerations of the wave spectrum in which significant wave heights and periods are functions of the total enery accumulated in the wind generated wave spectrum. The authors present graphs defining this accumulated wave energy generated by wind speeds of varying durations and fetches and then relate the wave characteristics to this energy (Pierson, Neuman, and James, 1958).

The work of Darbyshire (1955, 1956) was based on precise measurements of wind and wave characteristics. His results are along the same lines of the others, but he shows that waves generated in deep water have different characteristics from those in shallow water under the same conditions (Darbyshire, 1955, p. 560). Darbyshire and Draper (1963, pp. 483-484) show further that wave characteristics are more or less independent of fetch greater than two hundred nautical miles, as opposed to the other methods which are dependent on fetch up to eighteen hundred miles or more (U.S. C.E.R.C. Tech. Rpt. No. 4, 1966 pp. 20 and 48).

Wiegel (1964, p. 239) states that no one method is better than the other, since they all are based on different sets of empirical data. Isaacs and Saville (1949, p. 509) found that the Sverdrup, Munk method predicted the correct wave heights, but underestimated wave periods while King (1966, p. 87) in summarizing the available literature, shows that all three techniques are applicable in varying instances and conditions and that no one technique appears better than the other two.

ii) Practicality of Theoretical Approach

The wave characteristics using these approaches are based on wind and duration data obtained from weather charts. The interpolation of wind and duration data from such charts can be faulty and involved. In order to simplify these variables, a model of wind speeds over the southern Gulf was proposed for the different fetches into Kouchibouguac Bay. The choice of stations recording hourly wind speed, duration and direction needed for such a model was limited to Miscou Island, New Brunswick, Summerside, Prince Edward Island, and Moncton Airport, New Brunswick. The feasibility of such modelling of wind data was investigated by comparing measured wind speed and direction using a Rimco-Sumner MK 11 recorder for Kouchibouguac Bay to these three stations for the period

August 3rd and 28th, 1970. The data was grouped for eight compass points and for each five miles per hour of wind speed and compared using the Chi-Square test (Gregory, 1964 pp. 159-162) at different probabilities (Siegel 1956, p. 249).

TABLE 6:1 COMPARISON OF KOUCHIBOUGUAC BAY WIND DIRECTIONS AND SPEED TO THOSE FROM MISCOU ISLAND, N.B., SUMMERSIDE, PRINCE EDWARD ISLAND, AND MONCTON, N.B. AUGUST 3-28, 1970

Values are probability of stations being similar

	MISCOU ISLAND	MONCTON	SUMMERSIDE
WIND DIRECTION	.1	.01	.8
WIND SPEED			
NNE	.2	.1	.05
ENE	.001	.1	.1
ESE	.5	.2	.2
SSE	.05	.001	.001
SSW	.05	.001	.001
WSW	.05	.001	.001
WNW	.001	.1	.001
NNW	.2	.5	.01

The results presented in Table 6:1 show that the Summerside station provided close agreement with measured wind direction in Kouchibouguac Bay; yet, none of the stations agreed in terms of wind speed. This lack of agreement was not due to machine error in recording wind speeds, but appeared to reflect individual behaviour of winds around each station. Because of the lack of agreement in wind speed which is a crucial variable in any modelling of wave characteristics, this model approach based on theory was deemed unfeasible.

iii) Published Data

Quon, Keyte, and Pearson (1963) carried out a comprehensive study of wave characteristics for the Gulf of St. Lawrence in the area bounded by Anticosti Island, Magdalen Islands, Cape Breton, and Southwest Newfoundland. Using the Pierson, Neuman and James method of forecasting wave characteristics, and weather charts at six hour intervals, they compiled characteristic hourly wave lengths and heights for the months of March to December for the period of 1956 to 1960 inclusive. A summary of this data (Quon, Keyte, and Pearson, 1963 pp. 25-34) showing the number of hours in this period in which waves of a certain period and height occurred is presented in Table 6:2. The frequency of occurrence of waves decreases rapidly as the length and height of the wave increases.

The application of these wave characteristics

TABLE 6:2 SUMMARY OF WAVE DATA FOR THE GULF OF ST. LAWRENCE IN HOURS.

	WAVE LENGTH										
WAVE HEIGHT	50	100	150	200	250	300	350	400	450	500	TOTAL
2	19279										19279
4	6545	1320	2412	197	157	74	46	12	30	7	8529
6	518	4177	154	97	66	39	25	2	19	4	5101
8	48	924	606	36	27	16	39	1	7		1704
10	4	542	524	17	18	23	18	4	5	6	1161
12	4	60	457	81	11	2	4	3		7	629
14		12	261	51	6	13	8		4	5	360
16		4	111	111	4						230
18		3	29	95	18						145
20			3	40	30						73
22			3	22	13						38
24			4	13	2						19
26					1						1
28						1					
TOTAL	26398	7042	2393	760	353	167	140	22	65	29	

directly to Kouchibouguac Bay is conditional. These characteristics are based on the largest fetches in the Gulf of St. Lawrence and to some extent the Atlantic Ocean. Thus some of the wave lengths may be too large for Kouchibouguac Bay which has smaller fetches then those used in the Quon et. al. (1963) study. In order to make this data more realistic for Kouchibouguac Bay, wave lengths above five hundred feet were ignored as being outside of the range of generation for the largest fetch into Kouchibouguac Bay. Secondly, because the Quon et. al. (1963) data was based on more fetch directions than are present in Kouchibouguac Bay, which has a limited north to east-northeast fetch window to the Gulf, there may be bias towards certain wave lengths and heights which cannot be generated in Kouchibouguac Bay. This limitation within the limits of this study is difficult to assess. The Quon et. al. (1963) data also represent a five year period, one which could have been characterized by frequent storms or quiescence uncharacteristic of the period of time for which the barrier islands have undergone recorded change. The Quon et. al. (1963) study also covers the period from March to December,--a period in which the shoreline of Kouchibouguac Bay can be ice-protected (Forward, 1954). Some of these conditions cannot be assessed properly for Kouchibouguac Bay, but the Quon et. al. (1963) paper is the most realistic approach for obtaining wave data for the Kouchibouguac Bay area.

b) Simplifying and Theoretical Assumptions of the Model

In order to simplify the study of wave refraction patterns in Kouchibouguac Bay, a series of limitations, generalizations and assumptions must be defined. The assumptions inherent in the theory underlying the construction of wave refraction diagrams are that all waves when positioned towards shore are in a steady state with no decay, diffraction or reflection of any wave moving towards the shore. It is also assumed that there is no loss of energy due to bottom friction and percolation into the sea bed on gentle slopes and in not too shallow water (Putman and Johnson, 1949 p. 67), and that there is no lateral spread of energy across wave crests over time (Battjes, 1968 p. 449).

In order to simplify the study, only the five wave directions, north, north-northeast, northeast, east-northeast, and east have been used to delineate important waves entering Kouchibouguac Bay. On the basis of the Quon et. al. study (1963) waves over 9.88 seconds (five hundred-foot wave length)have been excluded from consideration. Furthermore it is doubtful if any wave period above 6.25

seconds (two hundred feet) can be generated within the fetches of the bay or that any wave period below 6.25 seconds will refract outside of the bay. For the present, it is also assumed that the Magdalen Islands will not be a barrier to the formation of any wave which may ultimately enter Kouchibouguac Bay.

Because of the variation in time and height of tides in Kouchibouguac Bay and the southwestern Gulf of St. Lawrence (Farqhuarson, 1962 p. 38), it is further assumed that there is no tidal effect in Kouchibouguac Bay or the Gulf of St. Lawrence but that this is important in the detailed large-scale study of Richibucto Inlet. The effect of storm surge in the Bay and Gulf is ignored in this study. Since the study around Richibucto Inlet is concerned mainly with maximum effects of wave refraction, a tide of .8 m was added to all bathymetric charts of this area. This value is .2 m below the highest predicted tide for Richibucto Inlet (Canadian Tide and Current Tables v. 2, 1970 and 1971 pp. 17, 34-35), but it is an average value of high tide for monthly tidal cycles. It is also assumed that a storm surge is present for waves over 4.42 seconds (one hundred feet) in the Richibucto area since below this value the winds generating waves produce only a minimal storm surge.

c) Storm Surge Calculations

Storm surge is the rise of sea level due to the combination of reduced barometric pressure and wind-piling of water during the passage of storms along the coast (Wiegel, 1964 p. 108). The importance of storm surge is brought out when it occurs with high tides. Then, it can affect substantially a coastline which is normally inert to coastal process. The effect and magnitude of such surges has been well-documented by Wiegel (1964, pp. 304-305) for the United States and by King (1959, pp. 283-288) for Europe. The presence of a wave-cut cliff in the dunes on profiles 1, 2, 9 and 11 at 2.5 to 3 m above lowest low tide and the presence of debris lines standing more than 1 m in elevation above mean tide at the back of the lagoons suggest that there has been a storm surge up to 1 m or more in this area. Since no large storms occurred during the field seasons, no visible storm surge was measured; however, an attempt can be made in calculating the theoretical storm surge possible in this area for winds of varying speeds from the same directions as those considered for waves.

The formula for the calculation of storm surge was taken from Davis (1962), with modifications of equations from the U.S. Army Coastal Engineering Research

Center Technical Report No. 4 (1966, pp. 137-142). The pressure surge is based on the following formula:

$$Ps = 1.14(pn-po)(1-e^{\frac{-R}{r}})$$

where

Ps is the pressure surge,
pn is the pressure at the pheriphery of the storm,
po is the pressure at the storm center,
R is the radius from the storm center to maximum winds in miles,
r is the distance in miles from the storm center to the area of interest.

This pressure surge was calculated using data extrapolated from Daily Weather Maps (1970-1971). The atmospheric pressure surge used in this study was based upon a storm for December 18, 1970--a storm which had sustained wind speeds of thirty miles per hour. This pressure surge amounted to .16m.

The wind-piling of water was calculated using the following formula:

$$S = D((\sqrt{\frac{.00233V^2AFcosA}{D^2} + 1)} - 1)$$

where

S is wind setup for one interval of distance
D is depth of that interval
V is wind speed in miles per hour
Z is a constant
F is the interval of distance
A is the angle of wind to the distance F

A series of nine lines centered at Richibucto Inlet were drawn out to the three hundred-foot depth from the north to northeast. Depths for these lines were taken from Canadian Hydrographic Charts, Numbers 4023 and 4002. Arbitrary wind speeds of 45 and 60 miles per hour were used to represent maximum winds which would occur in this area for wave periods less than 6.25 and greater than 6.25 seconds respectively. Storm surge was calculated for winds from the same five directions used for wave approach to the area by breaking the nine lines into small intervals and calculating wind setup for each interval and summing it for each line. The maximum value calculated from these lines is the desired storm surge. Table 6:3 is a summary of the storm surge for Richibucto Inlet.

TABLE 6:3 STORM SURGE VALUES AT RICHIBUCTO BAR

WIND DIRECTION	WIND VELOCITY	TOTAL SURGE
N	45 m.p.h.	.92 m
NNE	45 m.p.h.	.98 m
NE	45 m.p.h.	.88 m
ENE	45 m.p.h.	.78 m
E	45 m.p.h.	.80 m
N	60 m.p.h.	.95 m
NNE	60 m.p.h.	1.44 m
NE	60 m.p.h.	1.41 m
ENE	60 m.p.h.	1.23 m
E	60 m.p.h.	1.24 m

These surge values were added to the grid of depths for all maps of Richibucto Inlet. A comparison of wave refraction patterns for varying wave periods from the northeast is shown in Figures 6:95, 6:98, 6:101, 6:96, 6:99, 6:102, and 6:97, 6:100, 6:103 for conditions of surge plus high tide, high tide only, and no tide or surge, respectively. These diagrams show little difference in wave refraction patterns between high tide, and high tide and surge conditions; but, the wave refraction patterns in low tide conditions are more pronounced compared to the other conditions. The addition of surge and high tide levels allows for a more realistic simulation of wave refraction behaviour on these beaches for storm situations.

d) Method of Investigation

Wave refraction patterns in the study area were developed using small-scale bathymetric maps of the Gulf and bay and large-scale maps of the Richibucto Inlet area. The small-scale maps were used to describe the general wave refraction patterns for the bay while the large-scale maps were used to study changing patterns in the Richibucto Inlet area for the period 1894 to 1964). Using the data in Table 6:2, rays were generated in deep water in the Gulf of St. Lawrence from the five directions stated using four wave periods--6.25, 7.65, 8.84, and 9.88 seconds. Once the rays entered Kouchibouguac Bay, they were then passed through a second, larger map of the bay and generated for one additional wave period, 4.42 seconds. Because of the scale difference between the two map areas, extra rays were positioned onto the Kouchibouguac Bay map assuming linearity of wave position, period, height and angle of approach between adjacent orthogonals. These rays once they entered the most recent smaller Richibucto Inlet map were positioned for each period and direction using fixed coordinates and generated towards shore. Table 6:4 is a summary of maps used in this study for wave refraction diagrams.

TABLE 6:4 MAPS USED FOR WAVE REFRACTION DIAGRAMS

MAP	AREA	SOURCE OF BATHYMETRY
Gulf of St. Lawrence	20,033 sq. mi.	Canadian Hydrographic Chart No. 4002 1969 ed.
Kouchibouguac Bay	723 sq. mi.	Kranck (1967, p. 2248)
Richibucto Bar 1964	4.3 sq. mi.	Canadian Hydrographic Field Sheet No. 4030
1955	2.1 sq. mi.	Canadian Hydrographic Field Sheet No. 2556
1930	3.4 sq. mi.	Canadian Hydrographic Field Sheet No. 4438 1930 ed.
1894	3.4 sq. mi.	British Admiralty Chart No. 2199 1894 ed.

The historical approach involved the positioning of the wave rays that were used on the Richibucto 1964 map, in the same relative position on maps of this area for 1894, 1930, and 1955. It was assumed that the bottom topography beyond the 24-foot depth was similar for each map. An attempt was made to start all rays entering these map areas at a depth of 24 feet or more. The main objective of this historical approach was to observe changes in the wave refraction pattern in a small area for which changes in bathymetry and shoreline form were documented.

e) Presentation of Bathymetry

In order to discuss and explain these wave refraction patterns, contour maps of the bathymetry were constructed using the same bathymetric input as for the wave refraction program. A computer program, CONAMAP, was used in the construction of these maps. Since the depths on the hydrographic maps were in fathoms, meters and feet, the program allowed each map to be referenced to a common unit of depth--feet, the basic measure for most Canadian Hydrographic Charts. Contours were constructed from the bathymetric data using a second degree polynomial, least squares approximation to the grid surface. Since this was the same basic procedure used in the Dobson (1967) wave refraction program for calculating depths, the contour maps, though not exact representations of the original source, represent the surface used in constructing wave orthogonals. These maps are shown in Figures 6:1 to 6:6. The location of each larger-scale map is shown on the

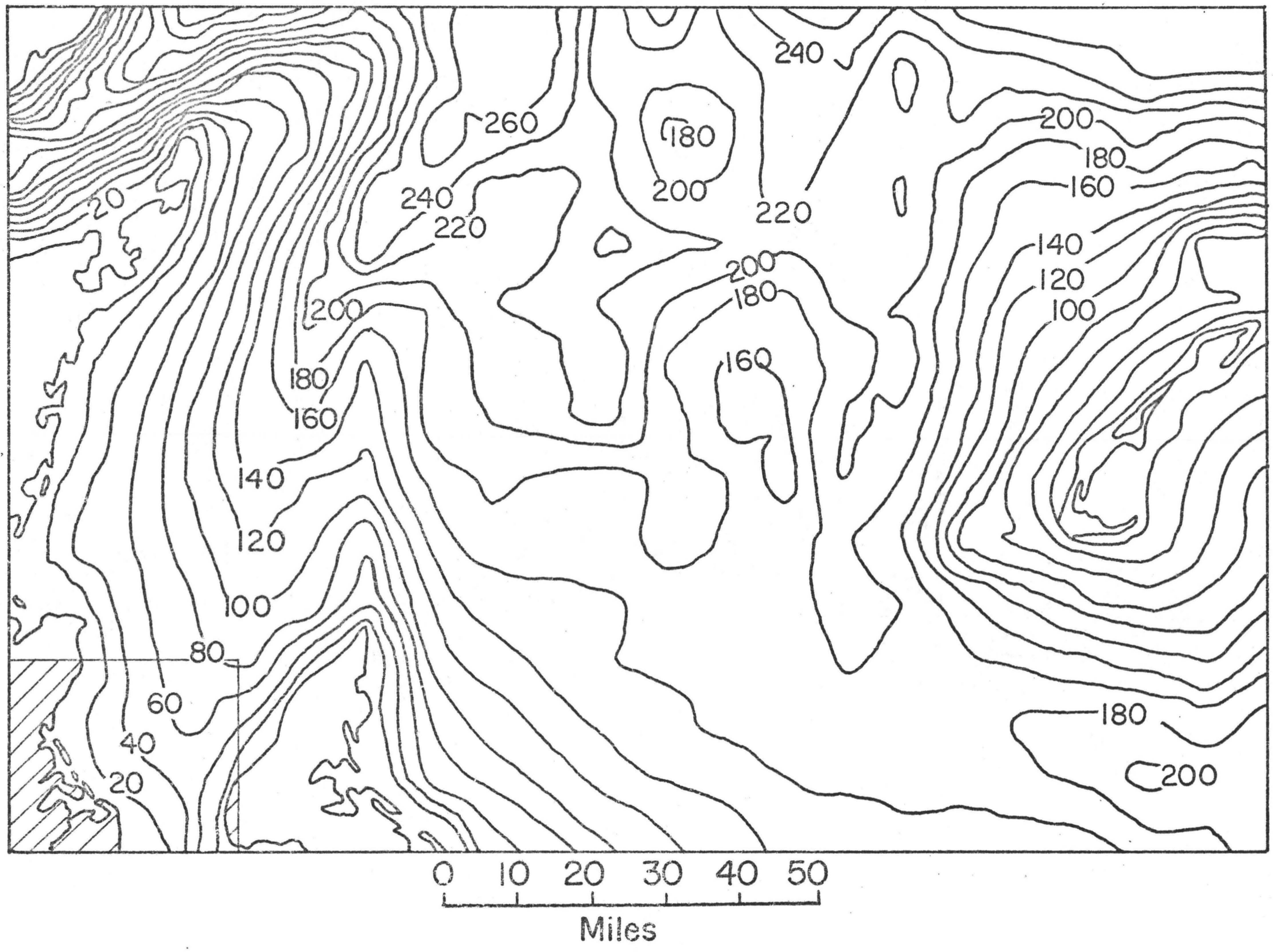


Fig 6:1 Bathymetry of the Southern Gulf of St. Lawrence

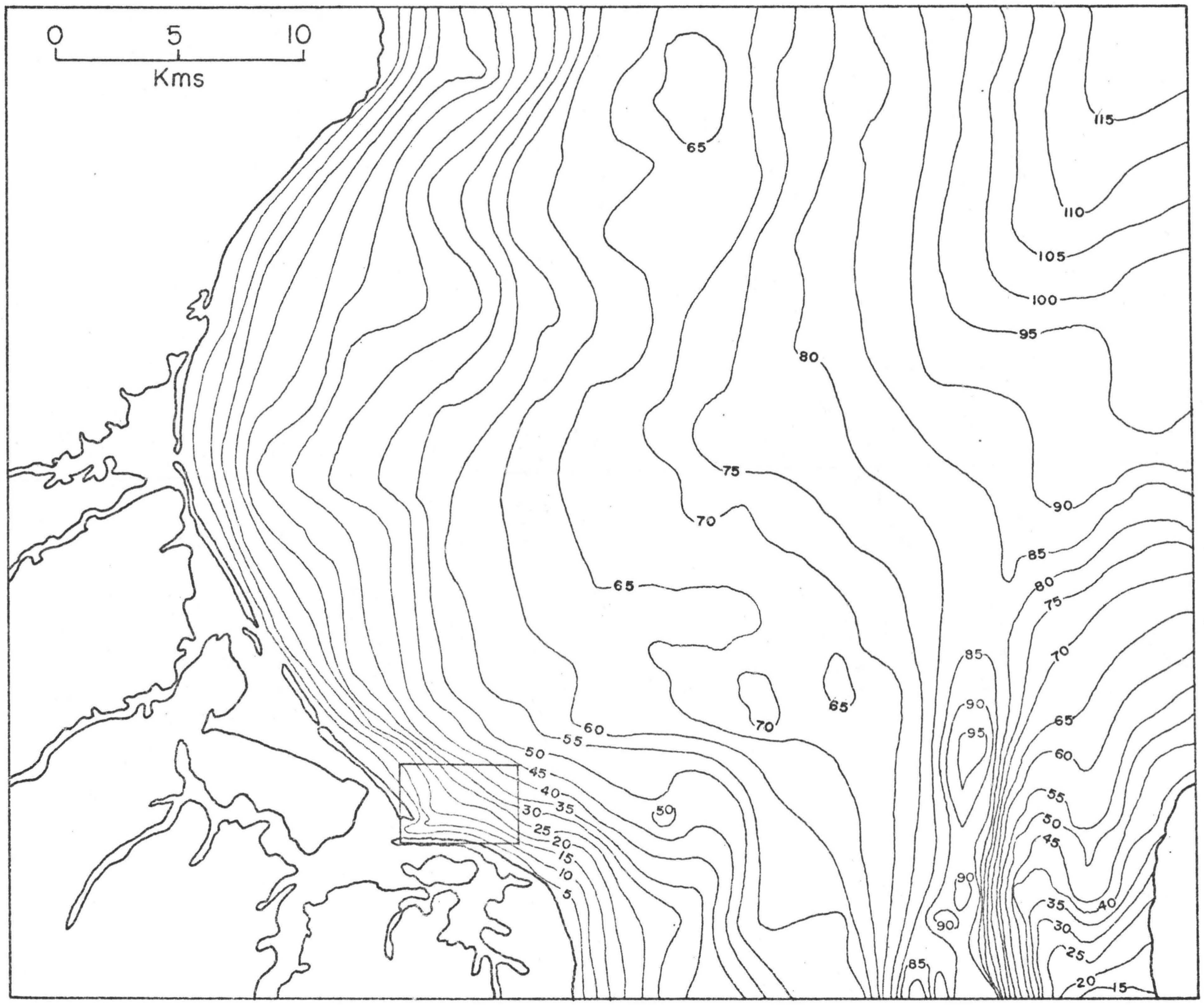


Fig. 6:2 Bathymetry of Kouchibouguac Bay

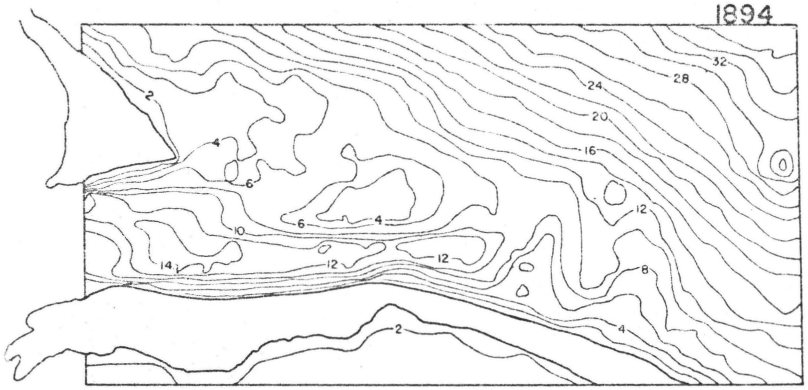


FIG. 6:3

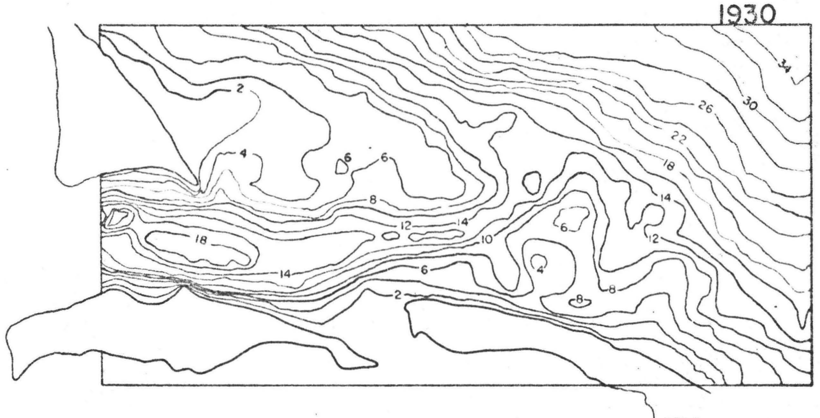


FIG. 6:4

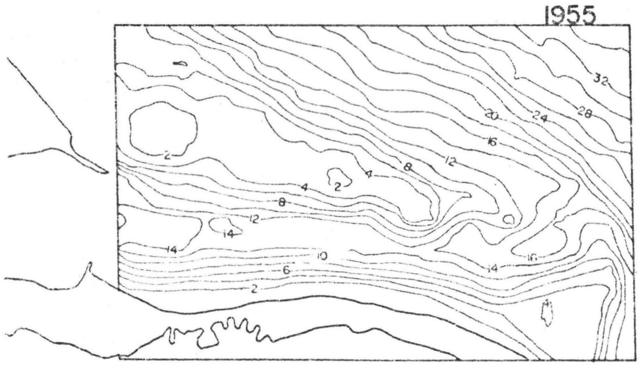


FIG. 6:5

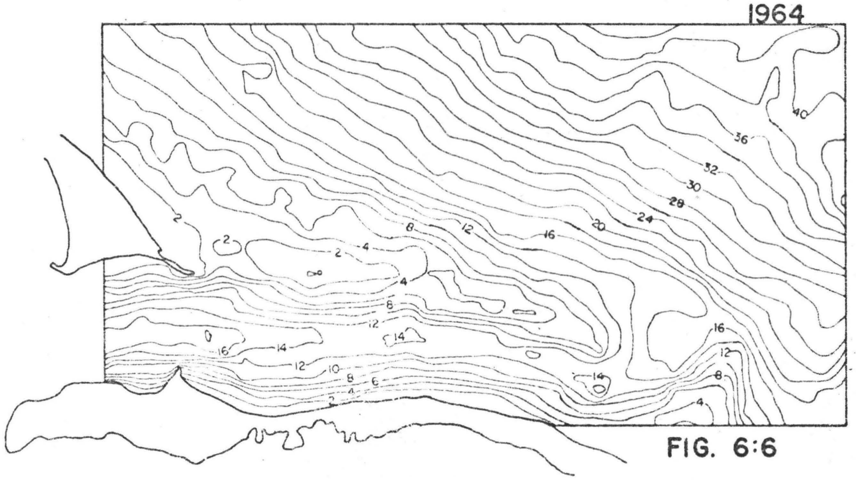


FIG. 6:6

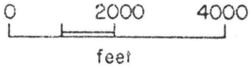


Fig. 6:3-6:6 Bathmetry of Richibucto Bar 1894-1964

previous smaller-scale map.

WAVE REFRACTION PATTERNS IN THE GULF OF ST. LAWRENCE

Wave refraction diagrams for the Gulf of St. Lawrence were drawn up for the five directions, N, NNE, NE, ENE, and E for periods of 6.25, 7.65, 8.84, and 9.88 seconds. The validity of the diagrams for waves originating from the north and east for periods 8.84 seconds and greater is questionable since the fetch in these directions is not large enough to generate these wave periods because of Miscou Island and the Magdalen Islands.

The wave refraction diagrams (Figures 6:7-6:25) show that wave orthogonals tend to diverge as the waves enter Kouchibouguac Bay. This divergence reflects the presence of a trough (Figure 6:1) which parallels the New Brunswick coastline and continues into the Northumberland Strait. This trough affects waves from north to northeast directions but for waves entering from the east or east-northeast, orthogonal divergence is caused by refraction of waves around an extensive ridge which is the submarine extension of the northern tip of Prince Edward Island. This divergence of orthogonals increases with wave period, but above 7.65 seconds wave refraction concentrates orthogonals along isolated sections of Kouchibouguac Bay (Figues 6:18-6:25). This concentration of wave energy is very

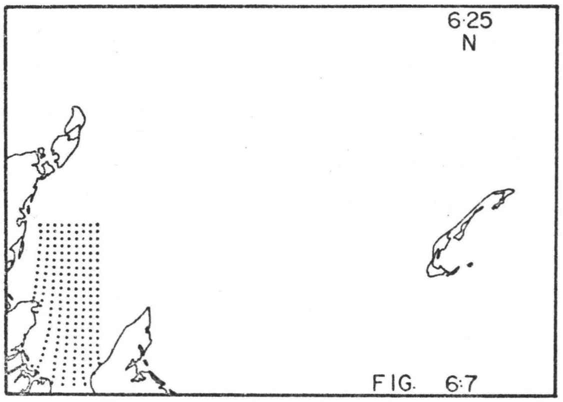


FIG. 6·7

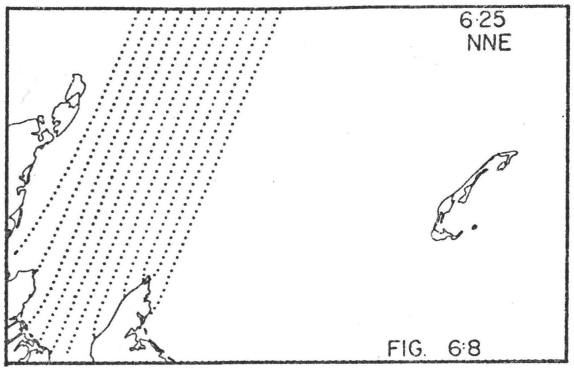


FIG. 6·8

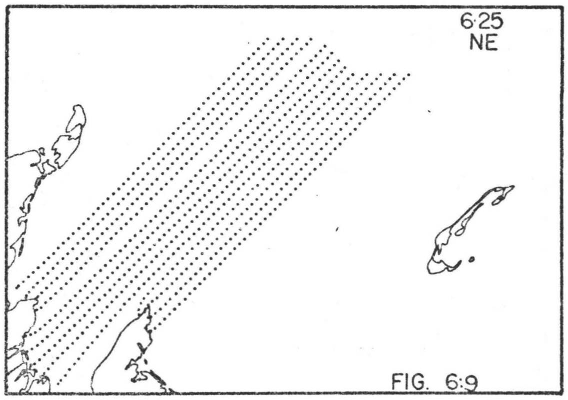


FIG. 6·9

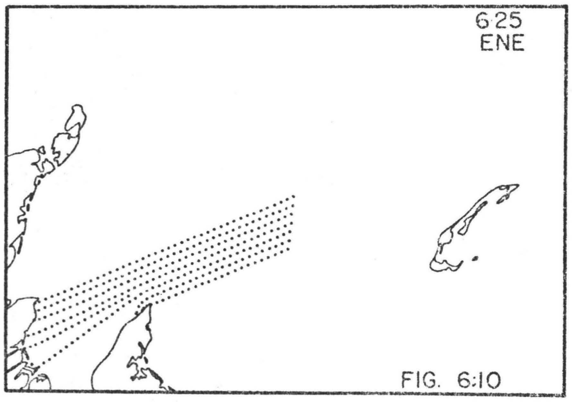


FIG. 6·10

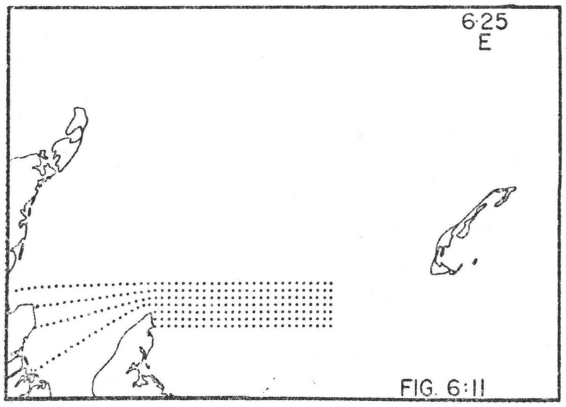


FIG. 6·11

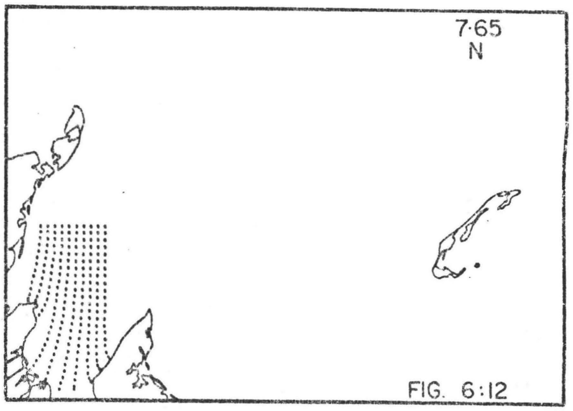


FIG. 6·12

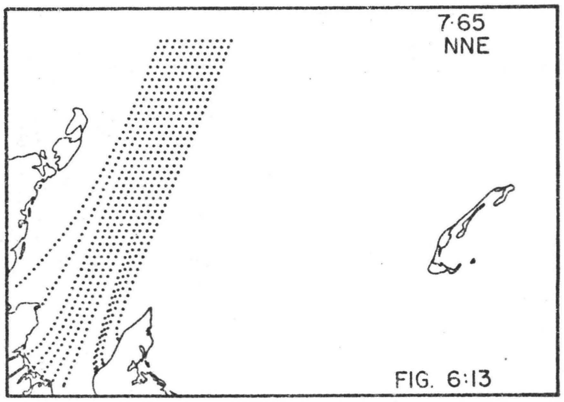


FIG. 6:13

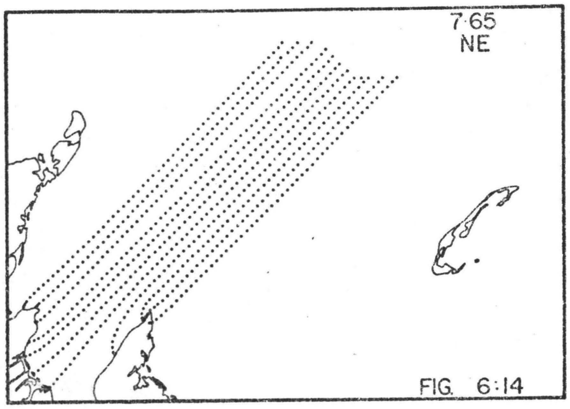


FIG. 6:14

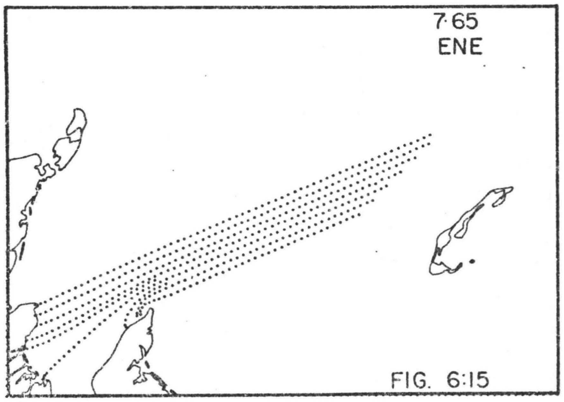


FIG. 6:15

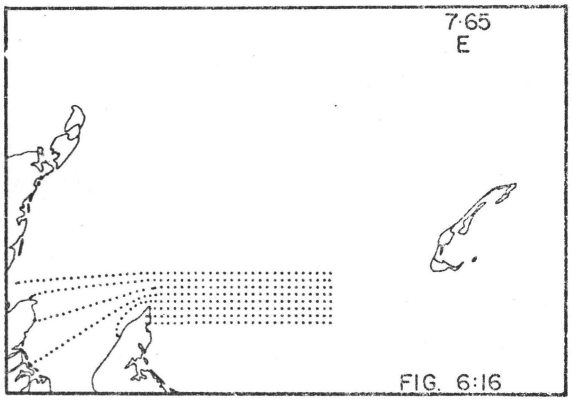


FIG. 6:16

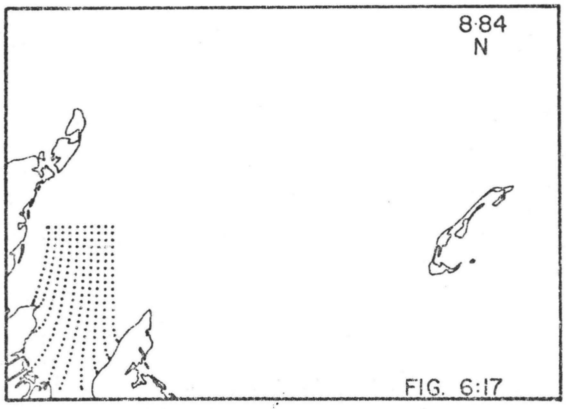


FIG. 6:17

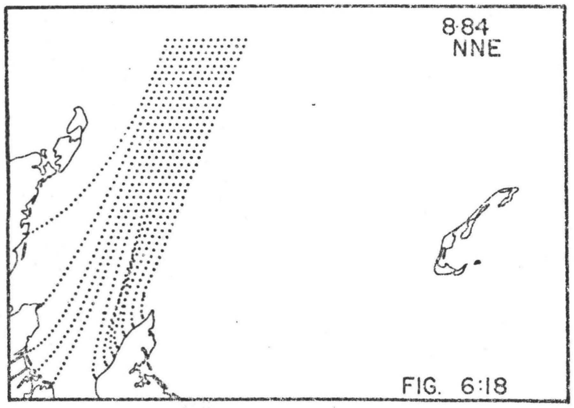


FIG. 6:18

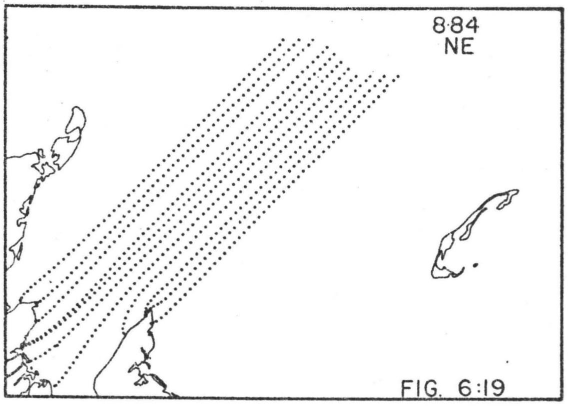


FIG. 6:19

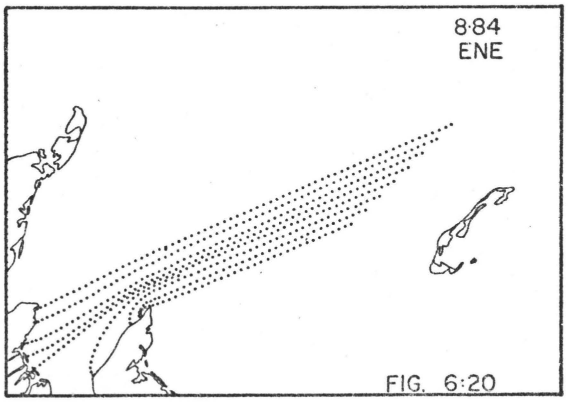
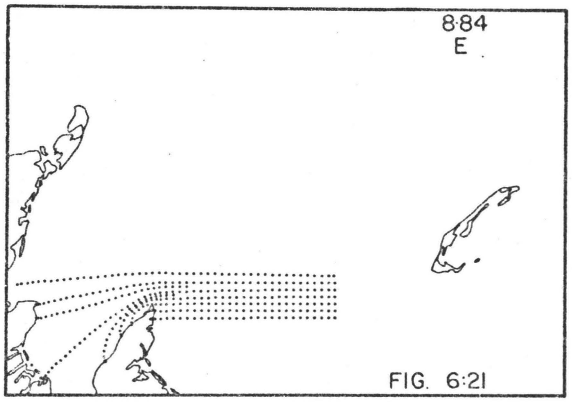


FIG. 6:20



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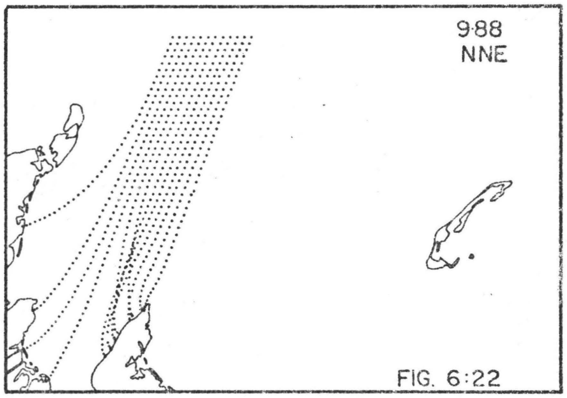

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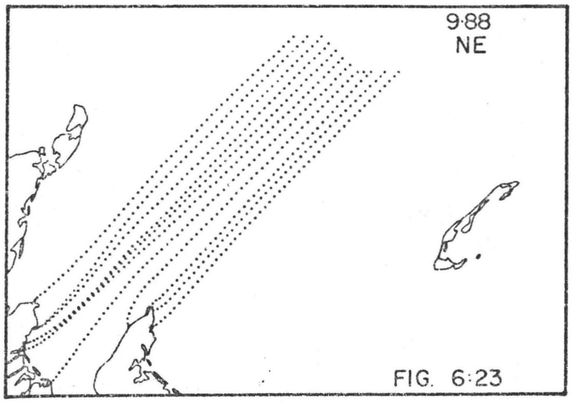


FIG. 6:23

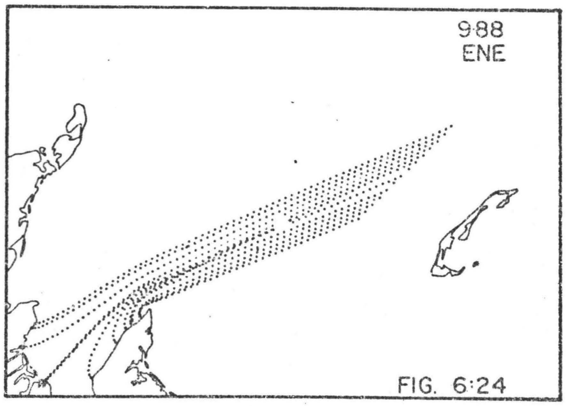


FIG. 6:24

pronounced along the northwest shore of Prince Edward Island in the bay and it appears that Prince Edward Island along with the northward extending submarine ridge, offers protection to the barrier islands of Kouchibouguac Bay from waves of large periods and from waves from the east and east-northeast.

The wave refraction pattern in Kouchibouguac Bay and along the New Brunswick coastline shows most of the wave action concentrated on the shore from Point Sapin to Kouchibouguac River. The southern part of the bay is relatively sheltered from larger storm waves. For wave periods below 7.65 seconds, the distribution of wave energy is relatively even along the barrier islands. Thus as waves enter Kouchibouguac Bay from the Gulf, there is a spreading of wave fronts as wave direction becomes more easterly and as wave period increases. This wave effect is a direct result of wave refraction by a parallel trough and ridge system extending from Kouchibouguac Bay northeast into the Gulf of St. Lawrence. The waves that have the greatest influence on the barrier islands in Kouchibouguac Bay are those of smaller wave periods and, for larger wave periods, those from the north-northeast and northeast.

WAVE REFRACTION PATTERNS IN KOUCHIBOUGUAC BAY

The wave orthogonals representing waves coming from the Gulf into Kouchibouguac Bay were extended into the larger and more detailed bathymetric map of Kouchibouguac Bay (Figure 6:2). Where wave orthogonals were spread too far apart as they entered this larger map, extra rays were positioned in the bay using linear interpolation of the wave characteristics derived from computer output. In addition wave refraction diagrams for waves of 4.42 seconds were also constructed. These diagrams are presented in Figures 6:26 to 6:47.

Wave refraction in the bay for a wave period of 4.42 seconds from all directions is not significant (Figures 6:26-6:31). There is some divergence of orthogonals in the northern part of the bay, but any concentration of wave energy occurs close to shore and is not large. Most of the northern half of the bay is sheltered by Point Sapin from waves from the north for all wave periods (Figures 6:30, 6:35, and 6:40). There is also divergence of orthogonals in the southern part of the bay for waves from the east and east-northeast because of the protection offered by Prince Edward Island (Figures 6:33, 6:34, 6:38, 6:39, 6:43, 6:44, and 6:47). Most of the wave refraction is influenced by two ridges protruding into the bay north-

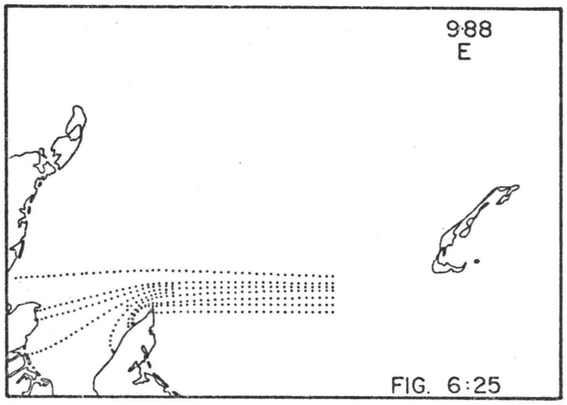


FIG. 6:25

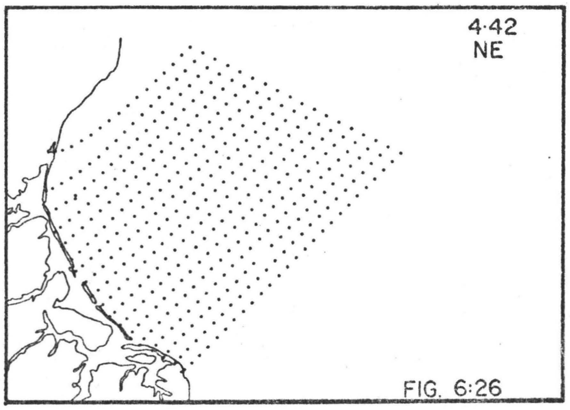


FIG. 6:26

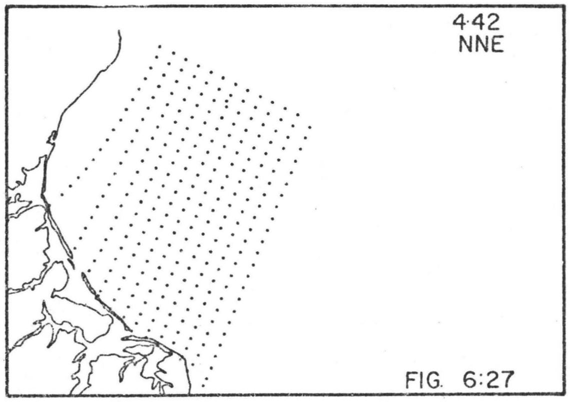


FIG. 6:27

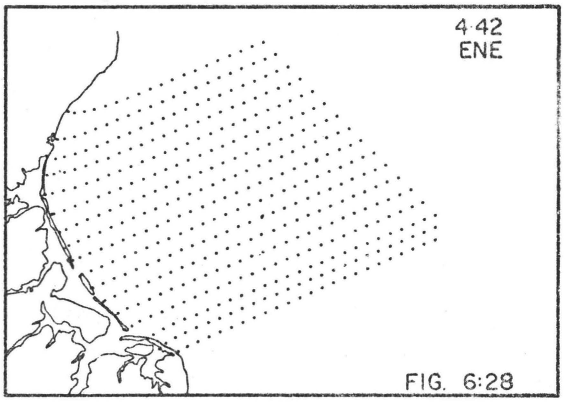


FIG. 6:28

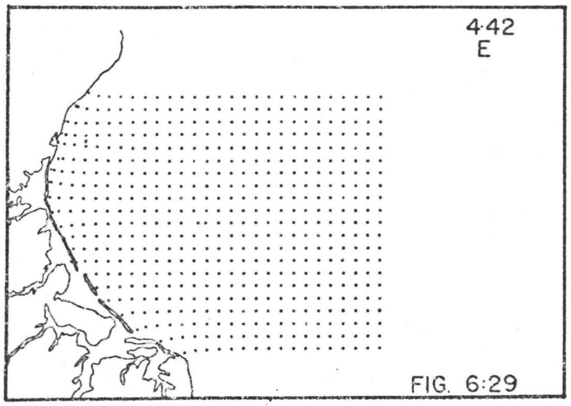


FIG. 6:29

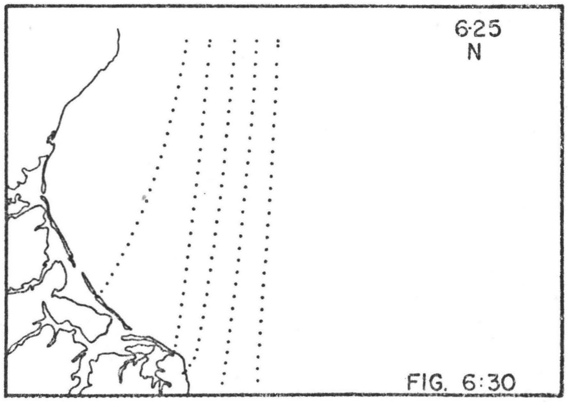


FIG. 6:30

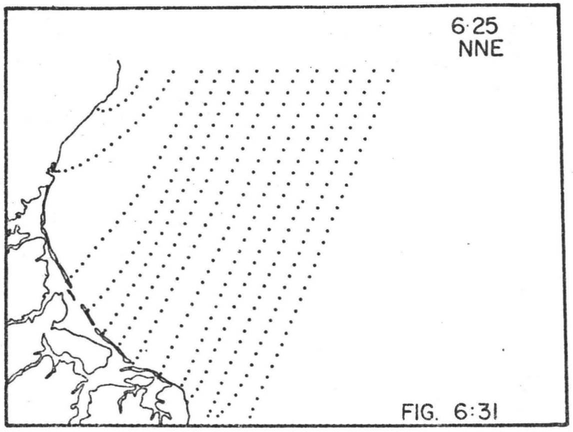


FIG. 6:31

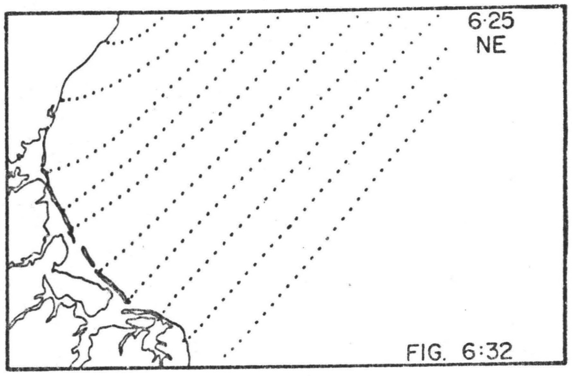


FIG. 6:32

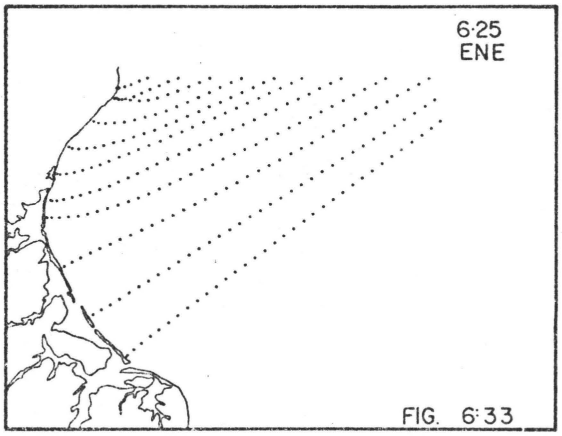


FIG. 6:33

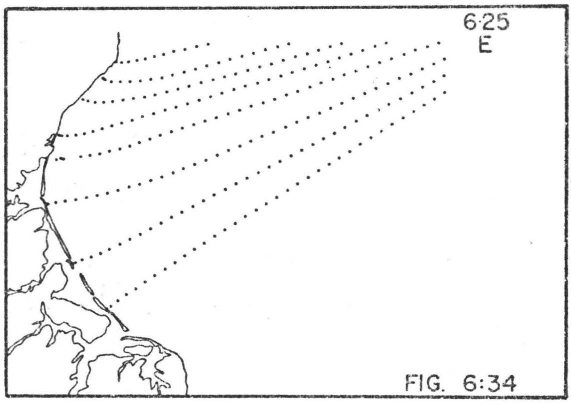
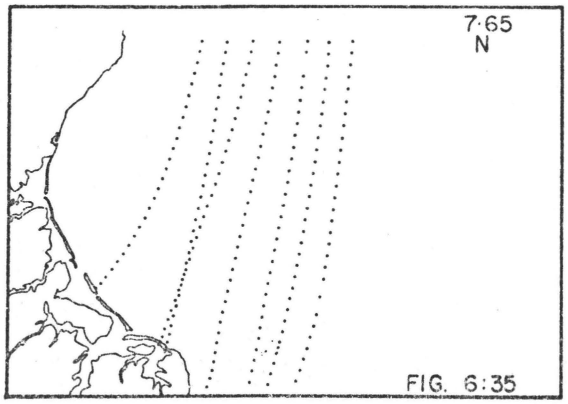


FIG. 6:34



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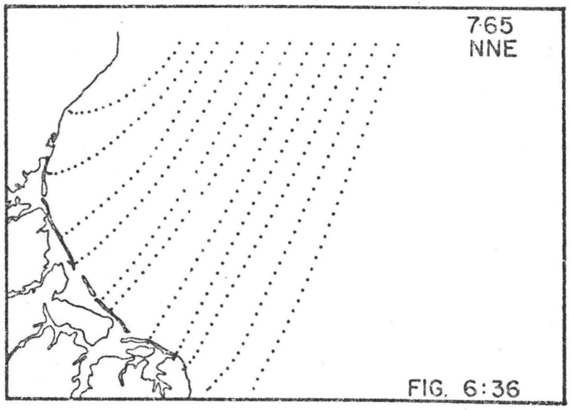


FIG. 6:36

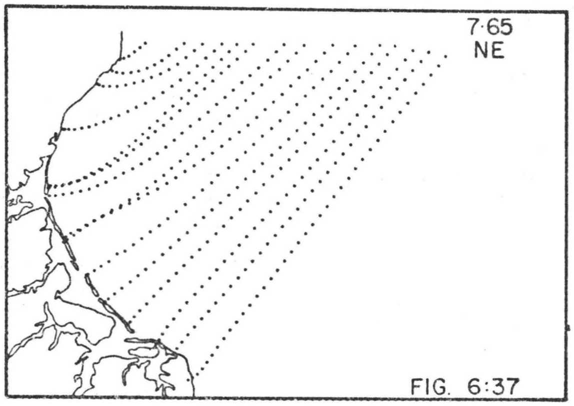


FIG. 6:37

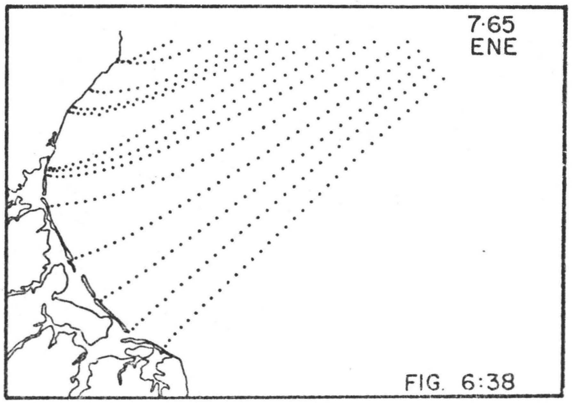


FIG. 6:38

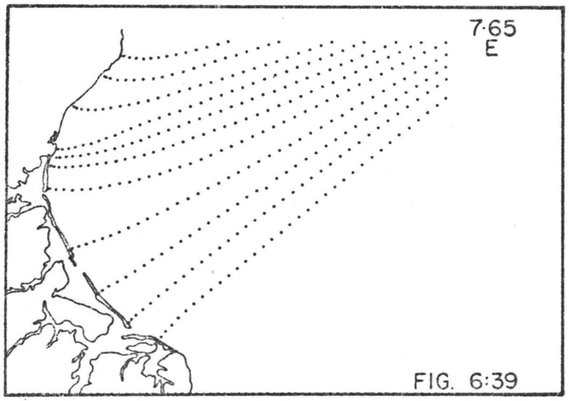


FIG. 6:39

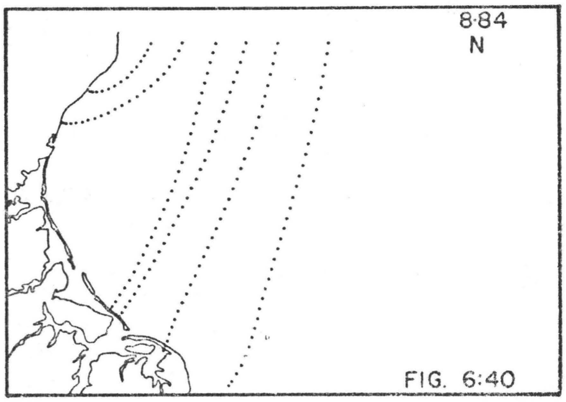


FIG. 6:40

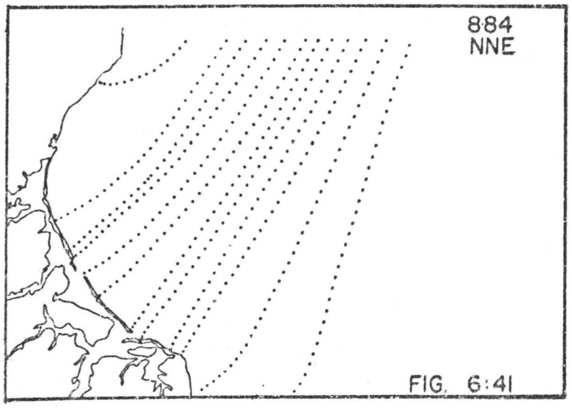


FIG. 6:41

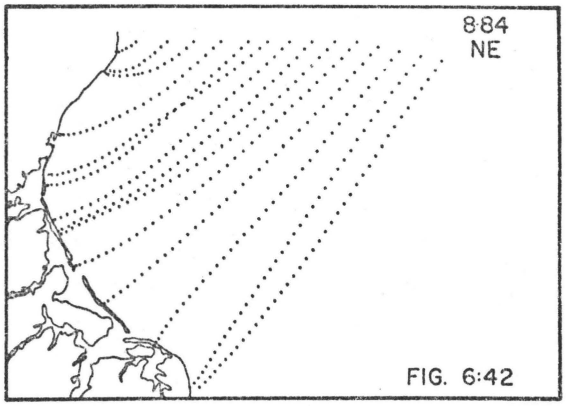


FIG. 6:42

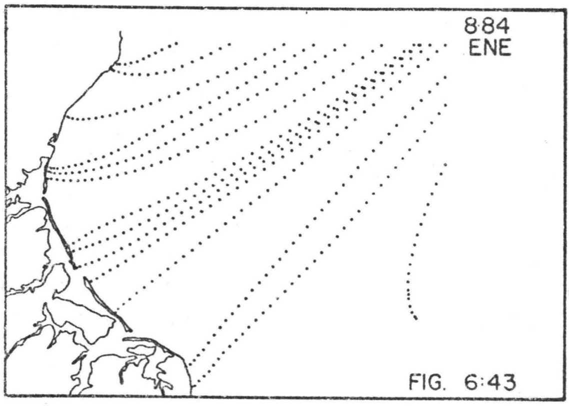


FIG. 6:43

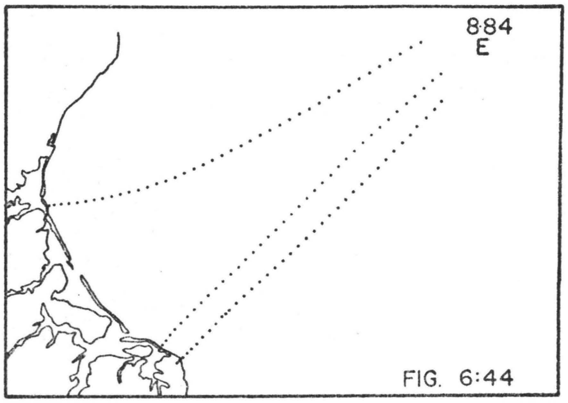


FIG. 6:44

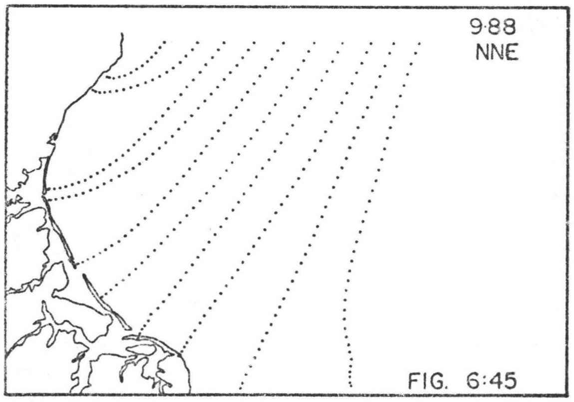


FIG. 6:45

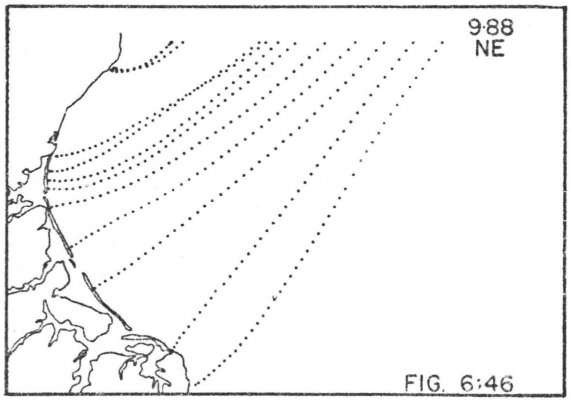


FIG. 6:46

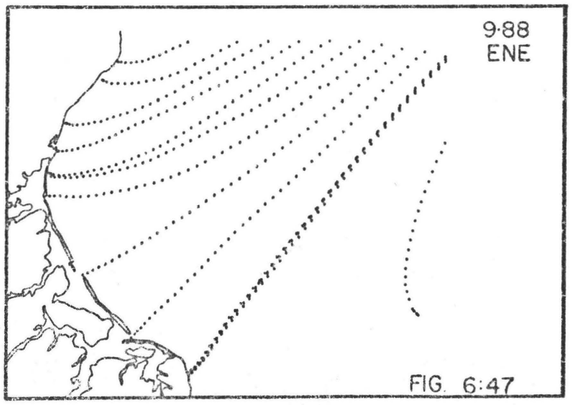


FIG. 6:47

east from Cape Richibucto and east from the most northern barrier island (Figure 6:2). The effect of this latter ridge is seen for waves coming from the northeast, east-northeast and east directions. For wave periods greater than 6.25 seconds, wave orthogonals are concentrated north of Kouchibouguac River (Figures 6:33, 6:34, 6:37-6:39, 6:42, 6:43, 6:46, and 6:47). This is in the area of Beach 4 which consists of a very narrow barrier island of low relief, subject to frequent overwashing. The wave regime of this section of Beach appears to be completely different from the rest of the barrier islands, and the limit of this wave pattern appears to be the Kouchibouguac River.

Wave orthogonals tend to spread out on North and South Beach because of the presence of a trough between the two main ridges in the bay. However, waves from the north-northeast do have a tendency to concentrate wave energy in these areas for wave periods of 6.25, 7.65, and 8.84 seconds (Figures 6:31, 6:36, and 6:41). It is noteworthy too, that waves of 8.84 seconds from the east-northeast concentrate wave energy in the Blacklands Gully area (Figure 6:43). For all other wave periods and directions there is usually divergence in Blacklands Gully area. This concentration of wave energy is a result of wave refraction around Prince Edward Island, as is the concentrareceive considerable wave action. The storms during the winter of 1970 and 1971 had predominantly north-northeast to northeast winds, and the resulting waves, if they followed the same patterns as evidenced in the wave refraction diagrams, would affect the southern beaches more than the northern ones. Since the profiles surveyed on Beaches 3 and 4 showed little or no change between 1970 and 1971, while Beaches 1 and 2 underwent considerable change, it seems likely that this postulated difference in wave regime for the bay exists in reality.

RETROPECTIVE ANALYSIS OF WAVE REFRACTION IN THE RICHIBUCTO INLET AREA 1894-1969

It has been pointed out previously in Chapter 3 that detailed maps of the barrier islands around Richibucto Inlet show that the islands are changing substantially in shape and are retreating shorewards. (A list of hydrographic charts used in this discussion is found in Appendix 2). The hydrographic information on these maps between 1839 and 1964 can also be compared by accurately referencing each to a known latitude and longtitude and reducing to a common scale. Since single fathom contours were present on most maps, this contour interval was used as a basis for comparison.

An overlay of maps, dating 1839, 1894, 1930 and 1969 is presented in Figures 6:48 to 6:50. A comparison of these contours indicates the major changes in bathymetry which have occurred in the Richibucto Area. Kranck (1967, pp. 2246-2248) carried out a similar study and concluded that the offshore shoal of North Beach was growing southeast as the result of longshore drift. This change is most evident in the comparison of the six- and twelve-foot contours in Figures 6:48 to 6:50. What these figures also reveal is that there is a shoreward retreat of the barrier islands and bathymetry above twelve feet. Beyond the twenty-four-foot depth contour the bottom topography has remained fairly constant since 1839 with most of the difference in depths possibly due to surveying error or inaccuracies in reducing measured values to lowest low tide.

A detailed examination of the maps for short periods of time also shows that these changes in bathymetry can be rapid. Between 1941 and 1944 a large area east of Profile 1 showed extensive shoaling from depths as great as twelve feet to four feet, while the navigation channel in the same area narrowed considerably. Between 1952 and 1955 the channel between North and South Beach underwent shoaling, while the offshore shoal on North Beach grew 80 m to the east and 90 m to the south. The shoaling and narrowing of the channel has continued up to the present.

FIG. 6:48

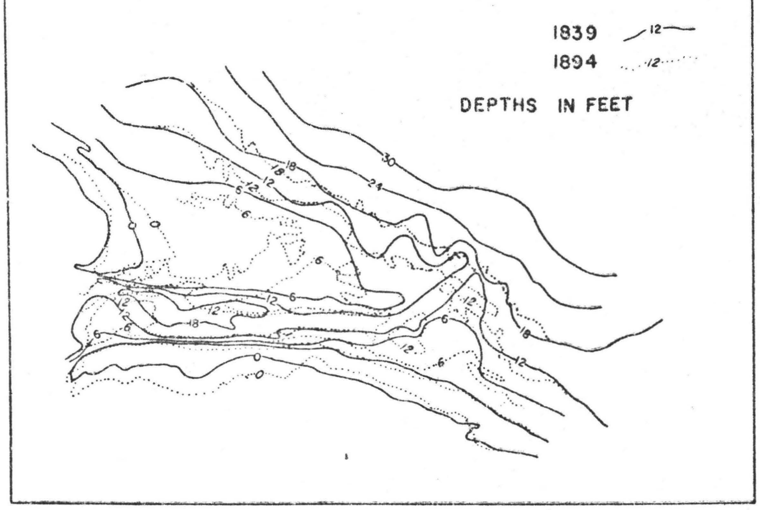


FIG. 6:49

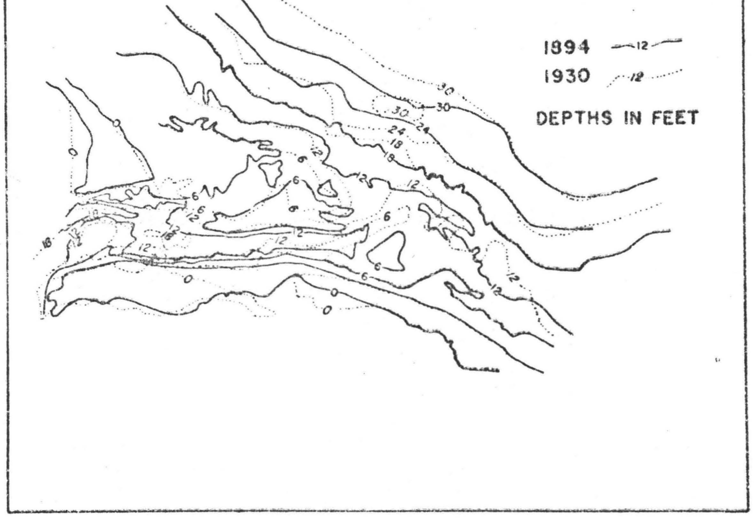
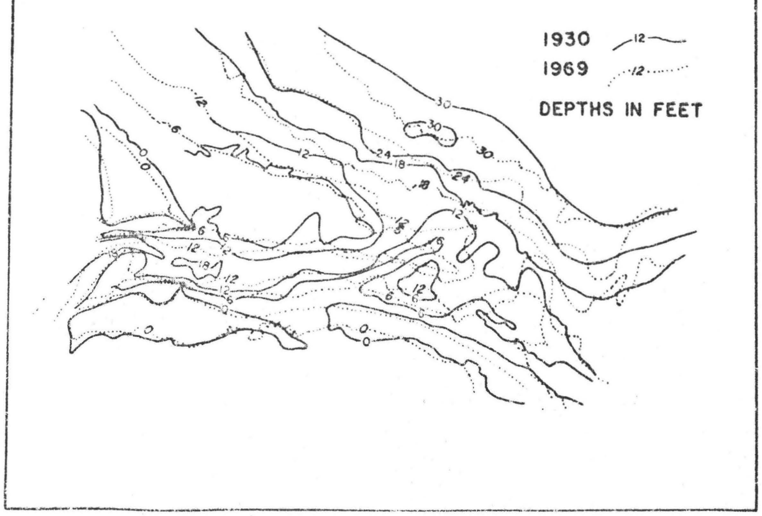


FIG. 6:50



Though the following study is based on a comparison of wave refraction patterns for the years 1894, 1930, 1955, and 1964, and though changes in the bottom configuration show a general trend over this time span, it must be noted that significant changes and fluctuations can occur within a short time period. It definitely appears that the growth of the offshore shoal on North Beach and the shifting of the navigation channel to the southeast is more than a result of longshore drift but is a direct result of breakwall construction on North Beach. If this is the case then a historical presentation of wave refraction patterns over this changing bottom bathymetry from 1894 to 1964 may be able to account for the breaching and shoreward retreat of South Beach. Presently the change in bottom topography may also account for the infilling of this breached area and the present erosion of the dunes to the east on South Beach.

The input of wave characteristics for these wave refraction diagrams was extrapolated from the results of wave refraction in Kouchibouguac Bay. This data was then used as input for the 1964 bathymetry and the position of each ray was noted as it entered other mapped bathymetric areas of previous years. Since all the wave refraction diagrams were referenced to a common scale, the above procedure ensured that all rays passing through the 1894, 1930, 1955, and 1964 bathymetry had the same original positions. The waves introduced into these maps were generated in the Gulf of St. Lawrence from the north-northeast, northeast, and east-northeast for wave periods of 6.25 to 9.88 seconds. It is important to note that the direction of wave approach referred to is the original direction in the Gulf of St. Lawrence and not the direction of approach into the Richibucto area. In some cases, waves that had dissimilar approaches in the Gulf are entering the Richibucto map area from very similar directions. A brief description of the wave refraction patterns will be given first and then a comparison of these patterns over time will be made for each of these four years.

a) Wave Refraction Patterns 1894

The wave refraction diagrams for this year are presented in Figures 6:51 to 6:62. For wave periods of 6.25 and 7.65 seconds the wave energy in this area is concentrated into numerous positions along the beach. The concentration of orthogonals can be picked out well for waves from the north-northeast (Figures 6:51 and 6:52), but for the other directions (Figures 6:55-6:56 and 6:59-6:60) this trend is not as obvious, since the spacing of orthogonals was reduced in order to accommodate a decreased angle of wave approach to the shore. As wave period in-

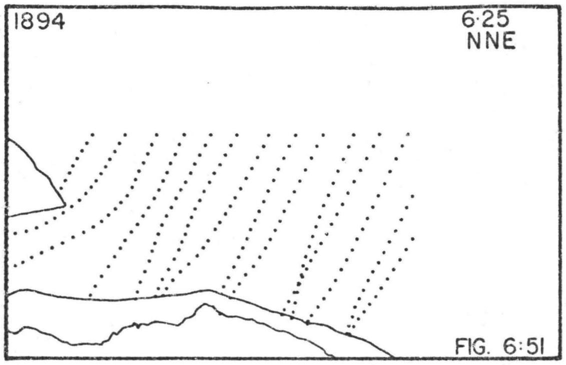


FIG. 6:51

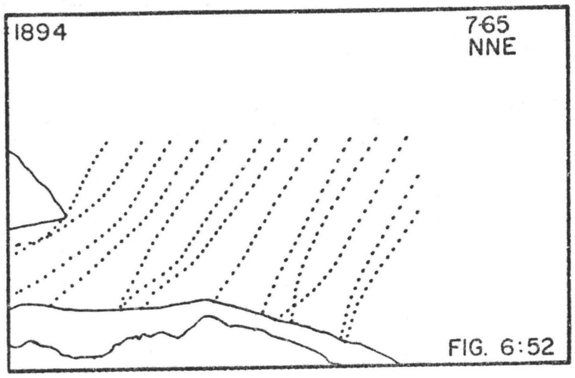


FIG. 6:52

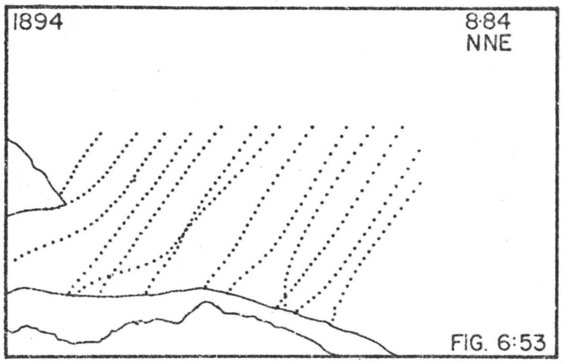


FIG. 6:53

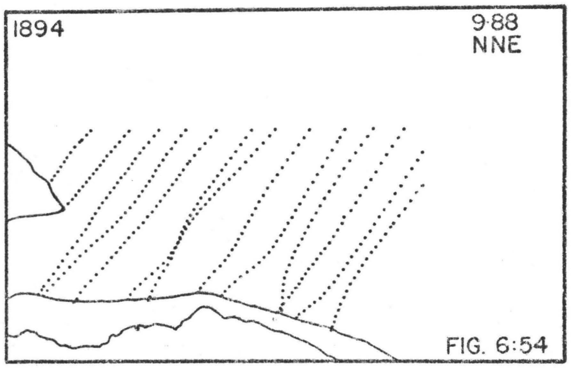


FIG. 6:54

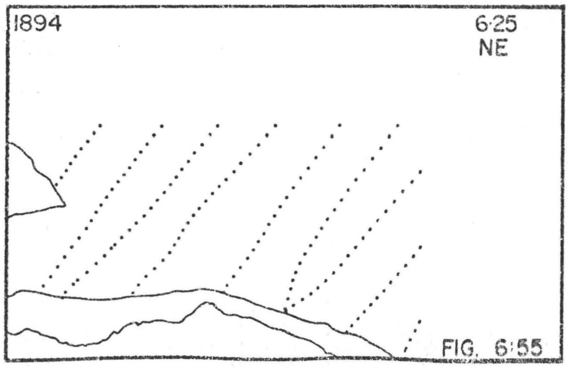


FIG. 6:55

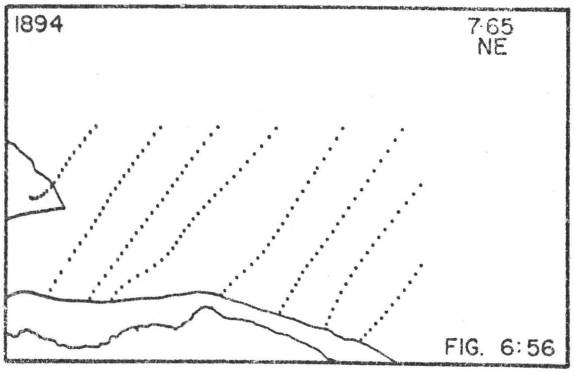


FIG. 6:56

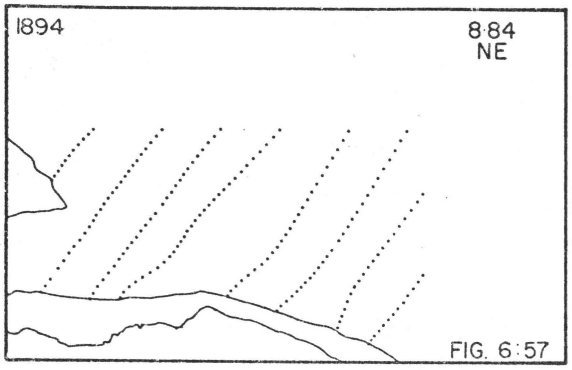


FIG. 6:57

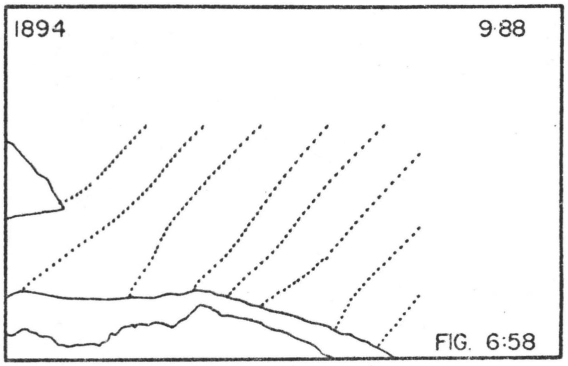


FIG. 6:58

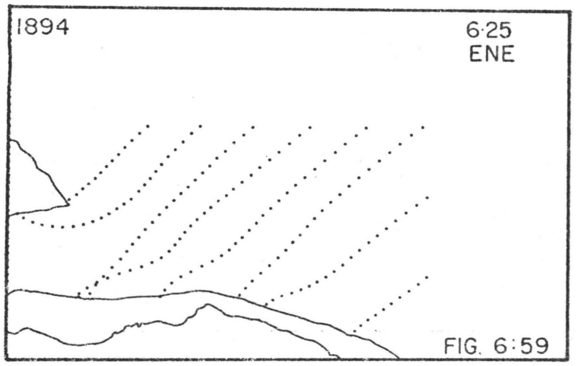


FIG. 6:59

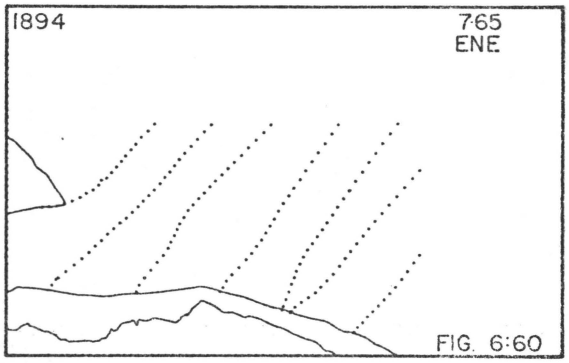


FIG. 6:60

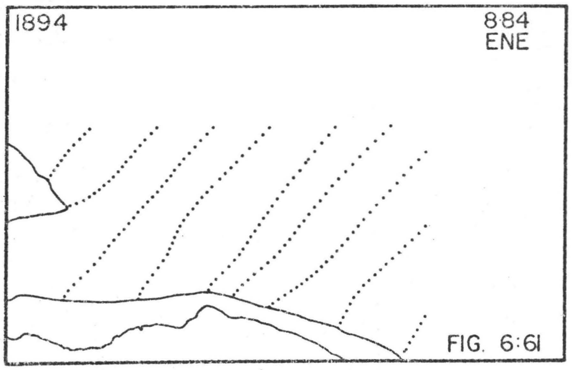


FIG. 6:61

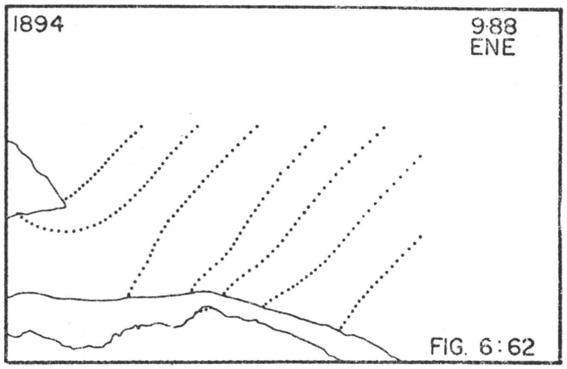


FIG. 6:62

creases wave orthogonals tend to concentrate in a few locations along the shoreline. The diagrams for 8.84 second period waves (Figures 6:53, 6:57 and 6:61) show a tendency for orthogonals to concentrate on both sides of the area which is now an infilling inlet. This tendency for concentration of wave orthogonals decreases as waves approach from a more easterly direction. As wave period increases to 9.88 seconds though the orthogonals are now concentrated in the center of South Beach (Figures 6:54, 6:58, and 6:62).

All of these patterns are a result of four shoal areas which follow a linear path in the 1894 bathymetry. These shoals follow a line from east of North Beach, southeast to where South Beach leaves the map area (Figure 6:3). The first two shoals are part of the offshore bar along North Beach. They are separated by the channel from two cuspate shoals which are joined to South Beach. The pattern of wave refraction for wave periods of 6.25 and 7.65 seconds is directly related to the presence of all four shoals but because wave refraction is less with smaller wave periods, these shoals cause wave energy to be concentrated on many sections of beach. As wave period increases the waves are refracted to a greater degree and tend to reflect dominant features of the bathymetry.

Because the direction of wave approach into this area is very similar for different originating wave directions, there is not that great a difference in wave refraction patterns between waves of different original directions. The main point with this bathymetry is the concentration of wave energy into fewer locations along the beach with increasing wave periods. Even with wave refraction patterns as they are, over a variety of wave directions and wave periods no one section of the 1894 coastline is undergoing exaggerated erosion.

b) Wave Refraction Patterns 1930

In 1930 the wave refraction patterns show a definite concentration of wave energy into three areas of South Beach for all wave periods and wave directions. The bottom bathymetry (Figure 6:4) is basically the same as 1894, but the shoals offshore from North Beach have decreased in size and become more continuous, while the cuspate shoals offshore from South Beach have increased in size and now extend further from shore. The effect of this latter shoal area is seen on all diagrams (Figures 6:63-6:75) as a concentration of orthogonals on South Beach in the area of Profiles 1 and 2. The offshore shoal on North Beach causes a concentration of orthogonals around the breakwall on South Beach for north-northeast waves of 6.25 second

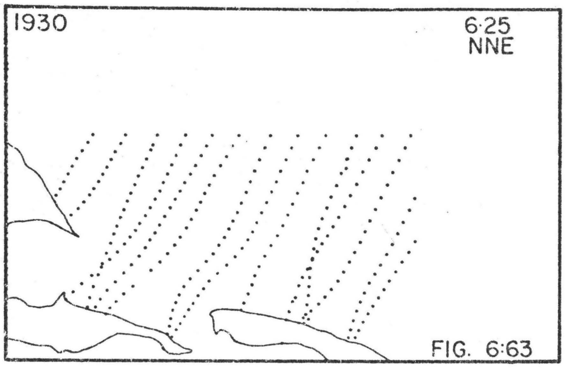


FIG. 6:63

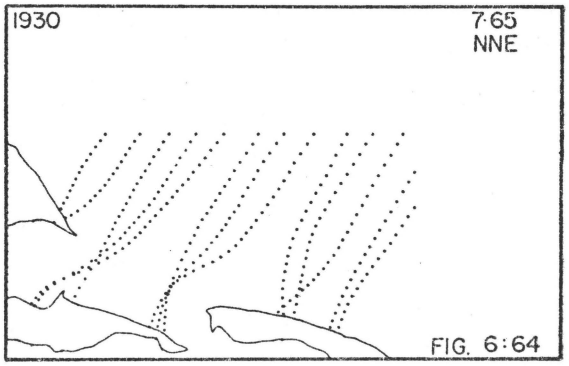


FIG. 6:64

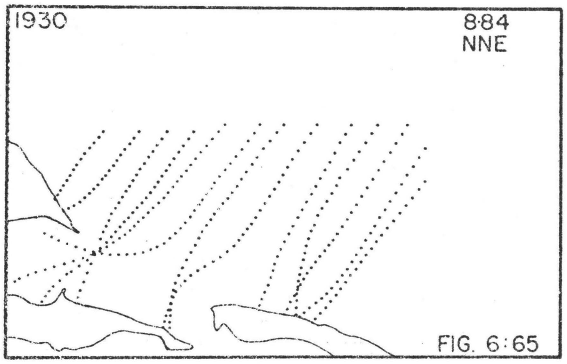


FIG. 6:65

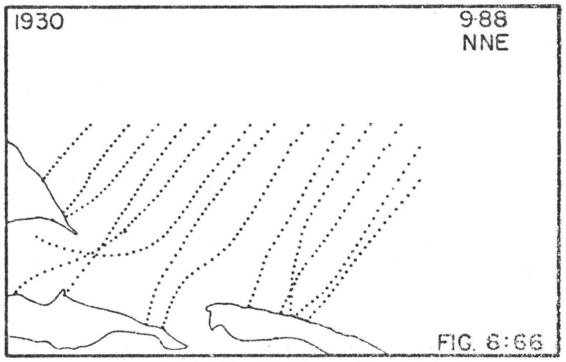


FIG. 6:66

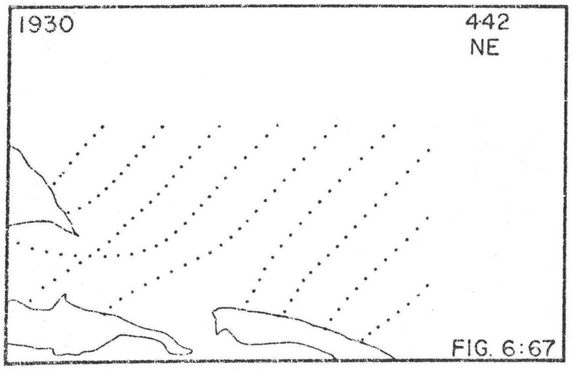


FIG. 6:67

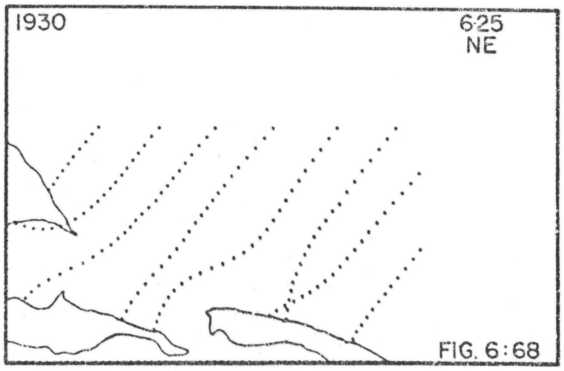


FIG. 6:68

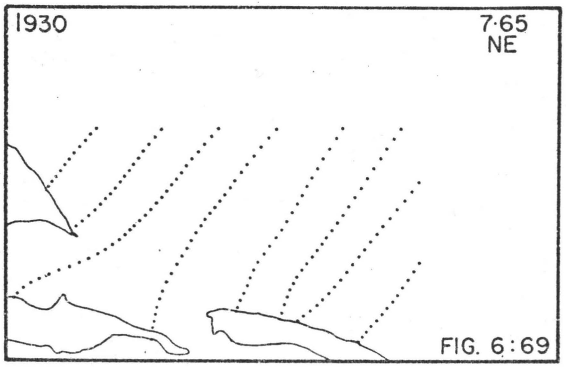


FIG. 6:69

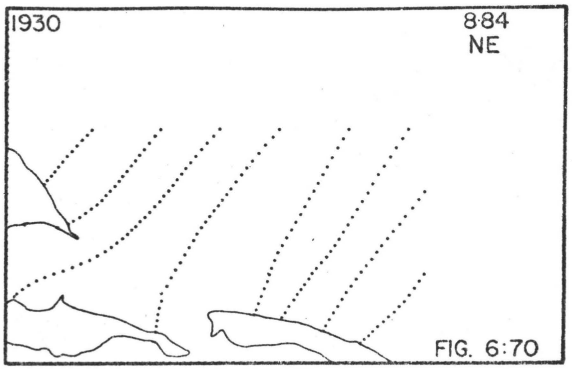


FIG. 6:70

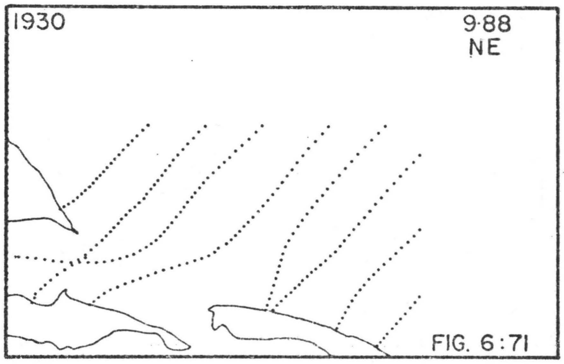


FIG. 6:71

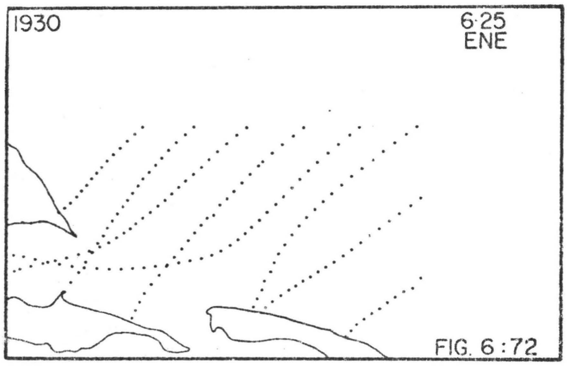


FIG. 6:72

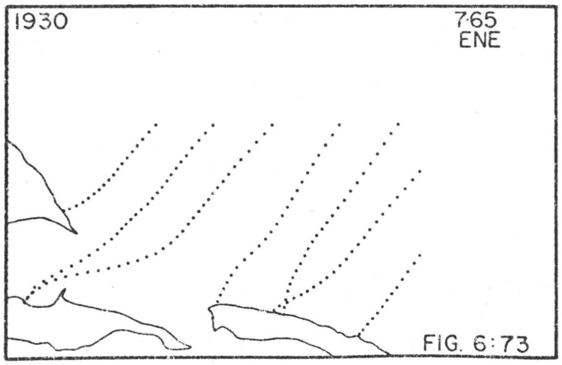


FIG. 6:73

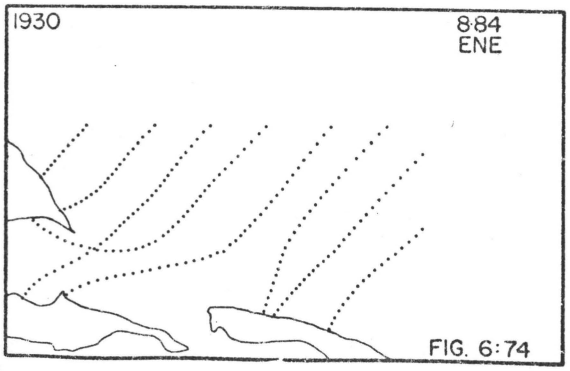


FIG. 6:74

periods (Figure 6:63). This concentration of wave orthogonals shifts into Richibucto Inlet as wave period increases (Figures 6:64-6:66) and as waves approach from a more easterly direction (Figures 6:71, 6:72, and 6:74). There is also a tendency for wave refraction around the east end of this shoal causing a concentration of wave energy in the breached area of South Beach for waves of all periods from the north-northeast (Figures 6:63-6:66).

Thus, whereas the bottom bathymetry of 1894 caused wave energy to concentrate in many areas along the shore, the 1930 bathymetry (Figure 6:4), because it is less irregular and because it consists of more uniform shoal areas, causes waves to refract into three main areas on South Beach--the area around the breakwall, the beach just east of the breach and the breach itself. Whereas no area of South Beach in 1894 was undergoing dominant erosion, it appears that for 1930 these three areas receive the bulk of wave energy for all wave periods and wave directions. Thus, if these diagrams are realistic, the shoreline east of the breach should be retreating in storms while the breach in South Beach should have been kept opened. The map evidence after 1930 suggests that this is in fact what has happened.

c) Wave Refraction Patterns 1955

By 1955 the shoals offshore from South Beach had disappeared and the shoal offshore from North Beach had become very regular in shape and depth and had extended southeast (Figure 6:5). The major features are now the channel mouth and the east end of the offshore shoal on North Beach. The wave refraction patterns for 1955 (Figures 6:76-6:87) are a response to these forms. Because the offshore topography is smoothed most of the wave energy is distributed evenly over South Beach. The only consistent area of orthogonal concentration is the east side of the now infilling inlet and the area of Profiles 1 to 3. This pattern holds for all wave periods and directions with the exception of some wave energy concentration in the infilled inlet which is most noticeable for north-northeast waves (Figures 6:77 and 6:79). Thus the extension of the offshore bar on North Beach to the southeast, as the result of the breakwalls within Richibucto Inlet, has caused wave energy to be concentrated further along South Beach east of the infilling inlet. This inlet area is not receiving as much wave attack and thus, instead of being able to maintain itself, it is being infilled.

d) Wave Refraction Patterns 1964

By 1964, the offshore bar of North Beach has continued to grow to the southeast, but the shoal has built

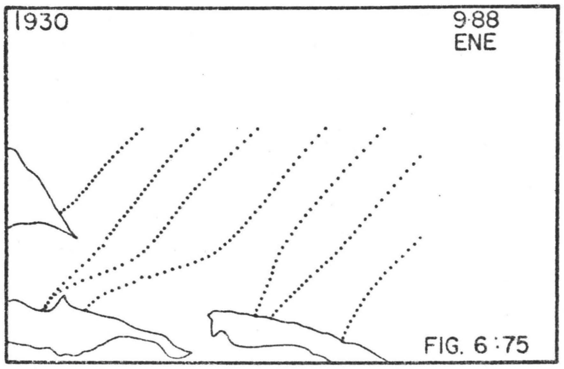


FIG. 6:75

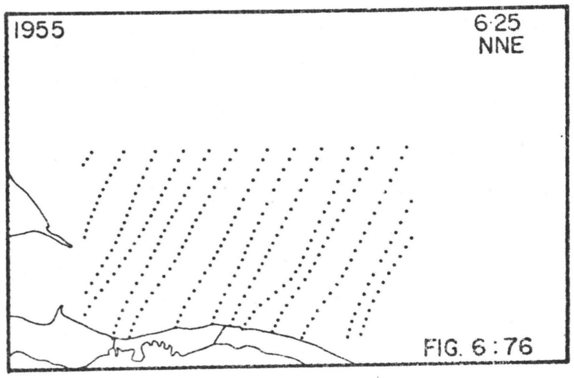


FIG. 6:76

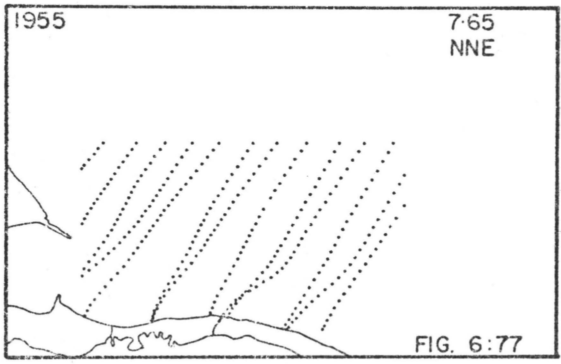


FIG. 6:77

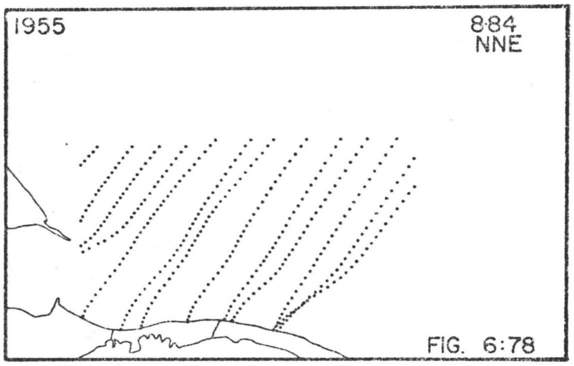


FIG. 6:78

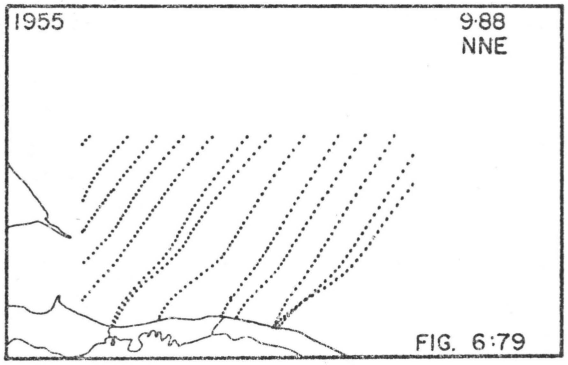


FIG. 6:79

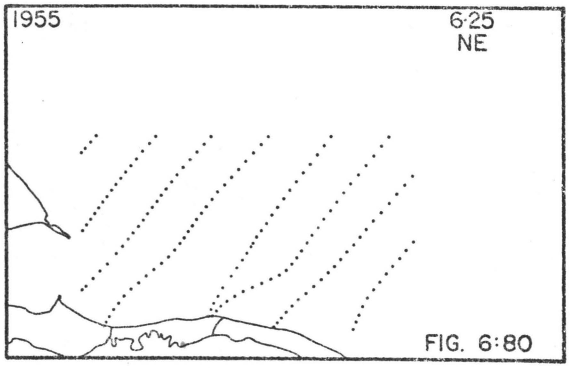


FIG. 6:80

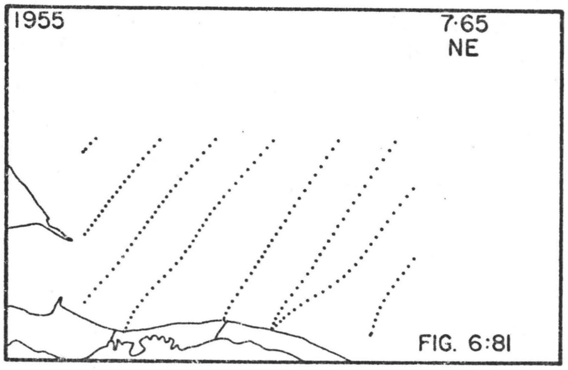


FIG. 6:81

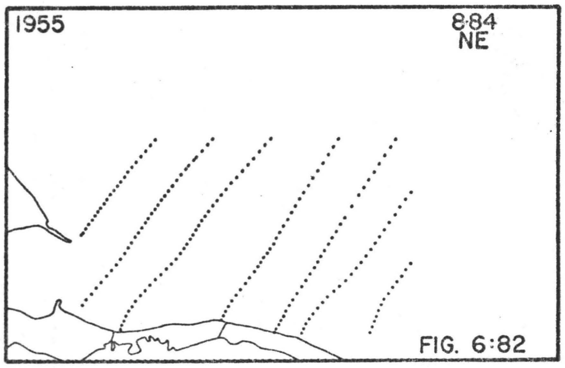


FIG. 6:82

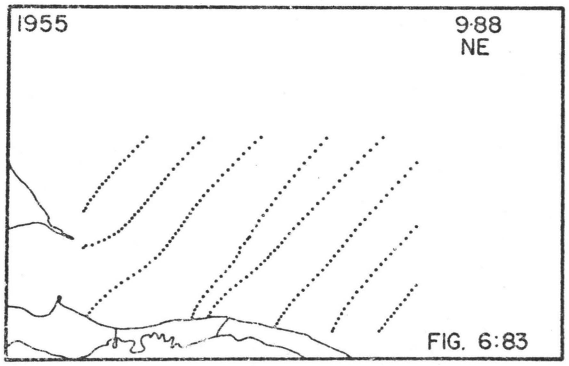


FIG. 6:83

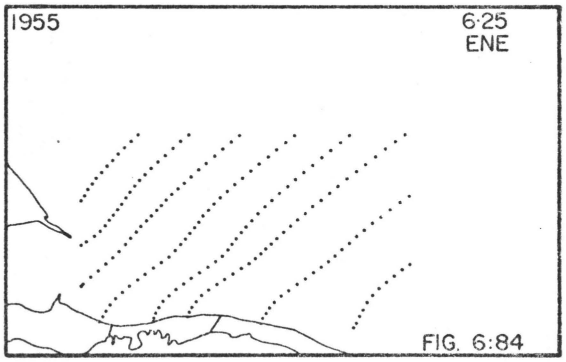


FIG. 6:84

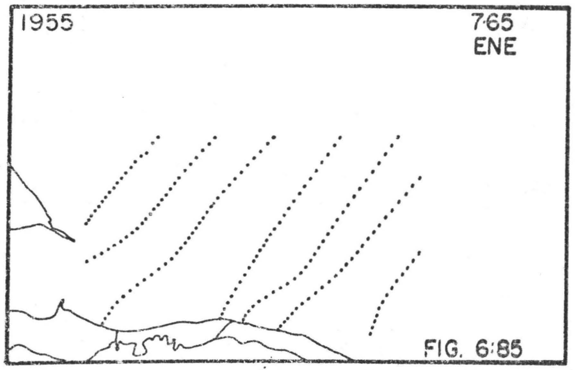


FIG. 6:85

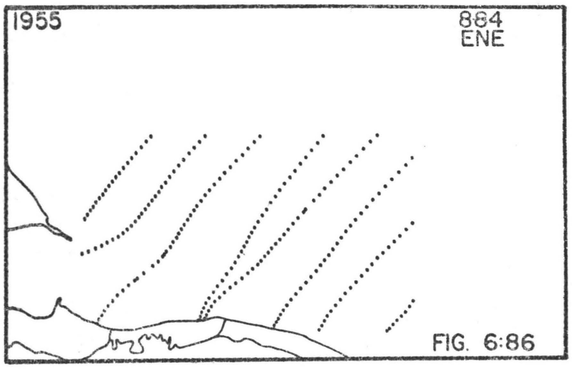


FIG. 6:86

upwards. The channel offshore from South Beach now swings sharply northeastwards past this shoal and a predominant cuspate shoal has begun to build up just east of Beach 1 (Figure 6:6). The wave refraction pattern for 1964 is very similar to that for 1955, but waves are now responding to increased shoaling of the North Beach bar. Thus, there is a concentration of wave energy on South Beach on the west side of the now infilled inlet for most wave periods and directions (Figures 6:88-6:95, 6:98, 6:101, and 6:104-6:108). Waves are also being refracted through the mouth of Richibucto channel onto South Beach in the area of Profiles 1 to 3. For the smaller wave periods of 6.25 seconds wave energy is distributed relatively evenly along South Beach (Figures 6:88, 6:91, 6:95, and 6:105) but for wave periods greater than 6.25 seconds for waves from all directions the infilled inlet of South Beach is protected as waves are refracted to each side (see Figures 6:89, 6:93-6:94, 6:101, and 6:108 for the best examples). Thus at present, South Beach should be undergoing erosion around the sides of the infilled inlet which is now increasing in height and becoming a stabilized landform. If the present trends of bathymetric change continue, then the area east of the infilled inlet on South Beach should continue to undergo erosion.

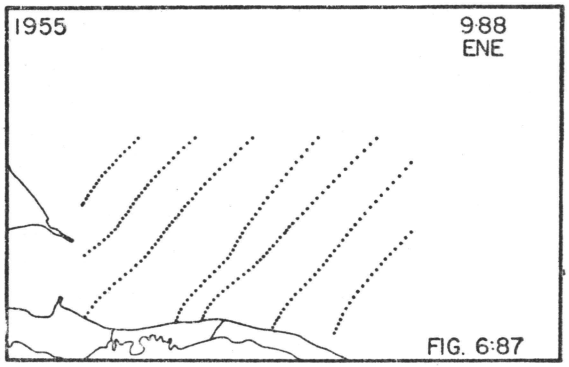


FIG. 6·87

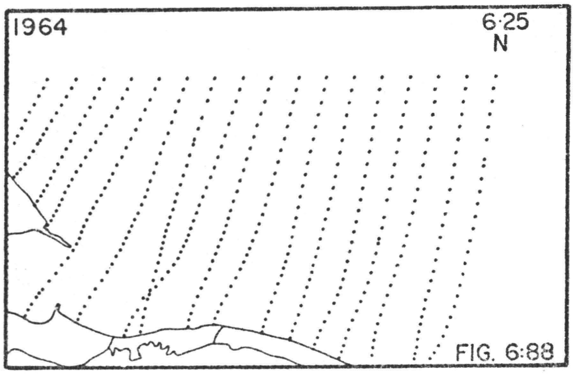


FIG. 6·88

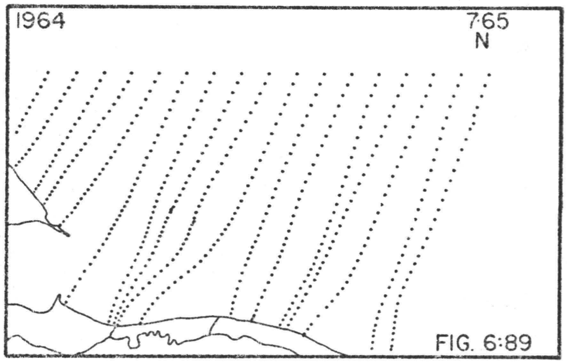


FIG. 6·89

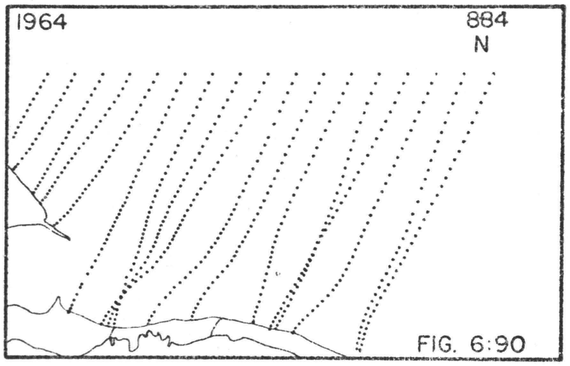


FIG. 6·90

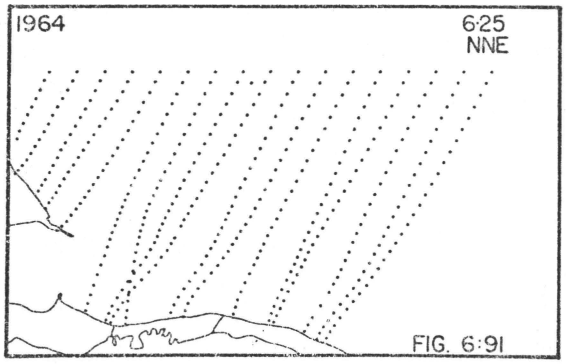


FIG. 6·91

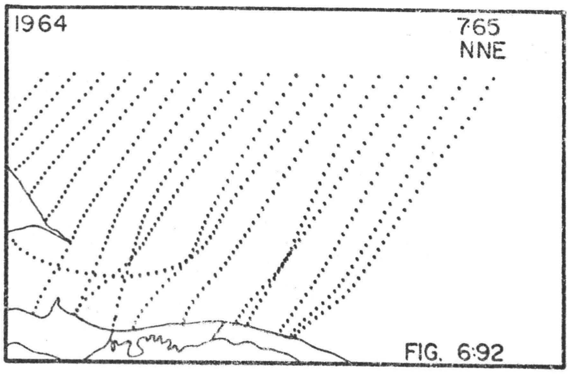


FIG. 6·92

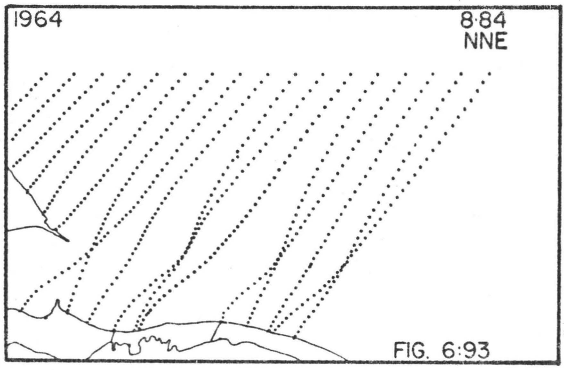


FIG. 6:93

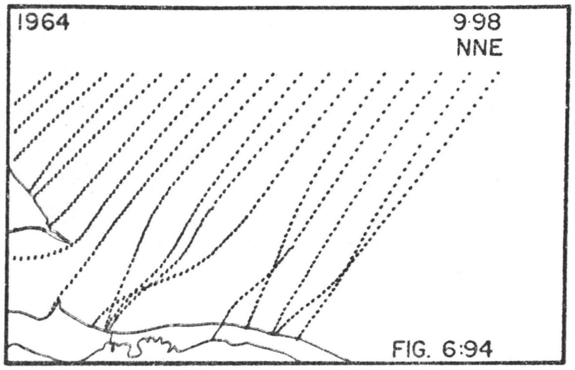


FIG. 6:94

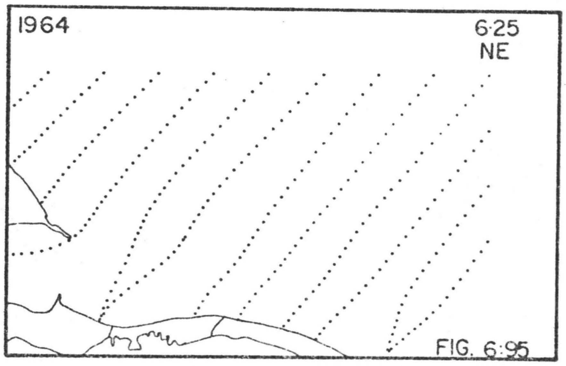


FIG. 6:95

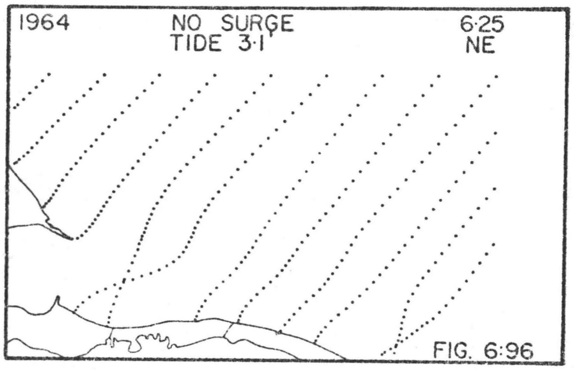


FIG. 6:96

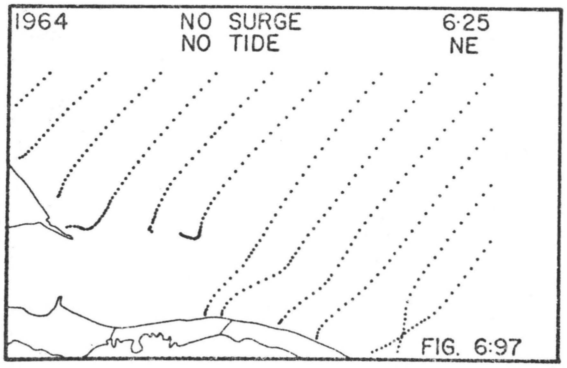


FIG. 6:97

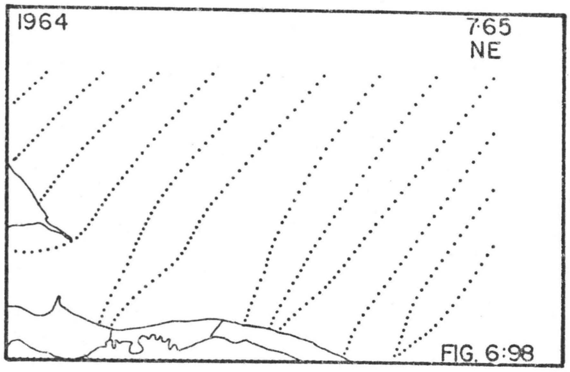


FIG. 6:98

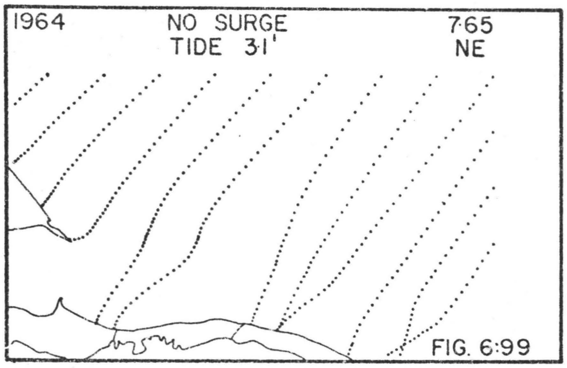


FIG. 6:99

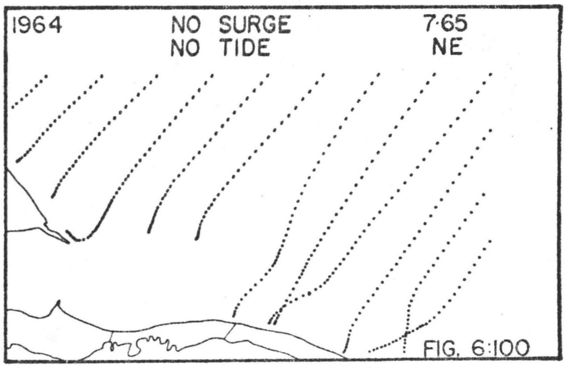


FIG. 6:100

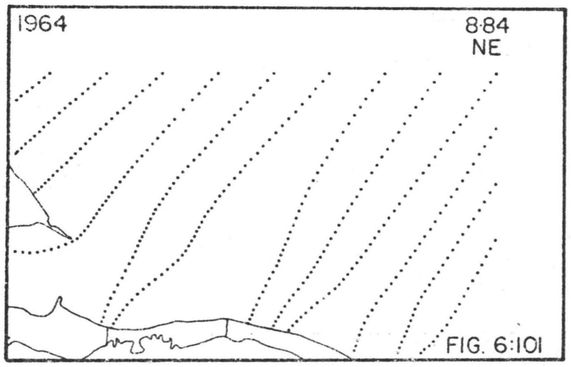


FIG. 6:101

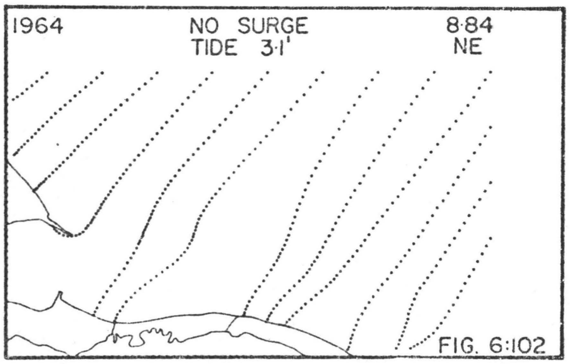


FIG. 6:102

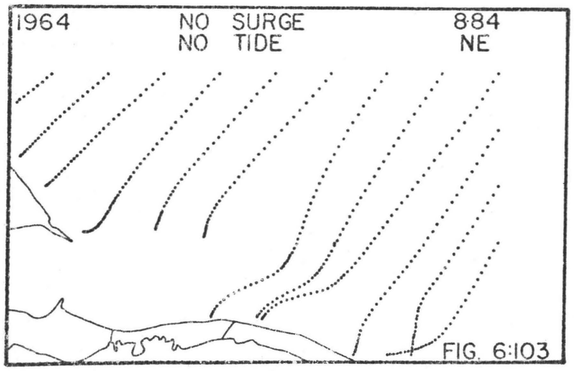


FIG. 6:103

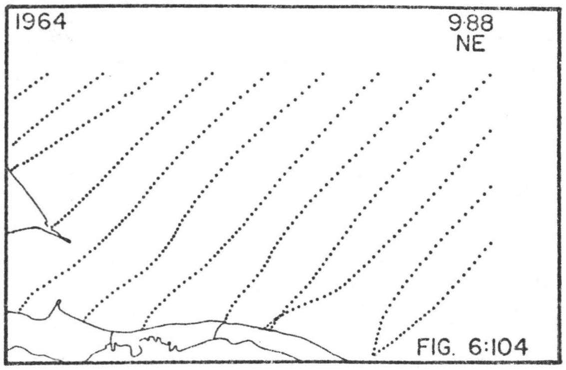


FIG. 6:104

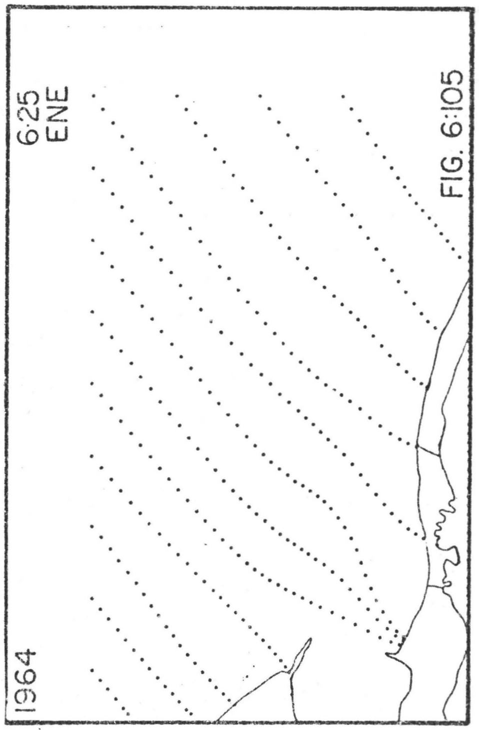


FIG. 6:105

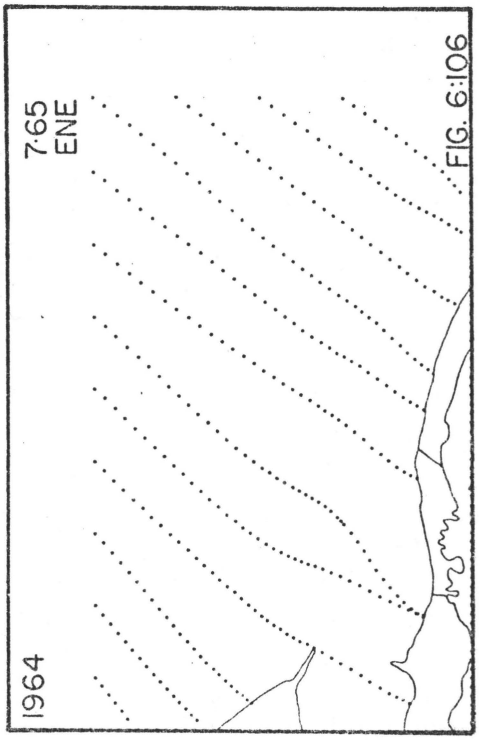


FIG. 6:106

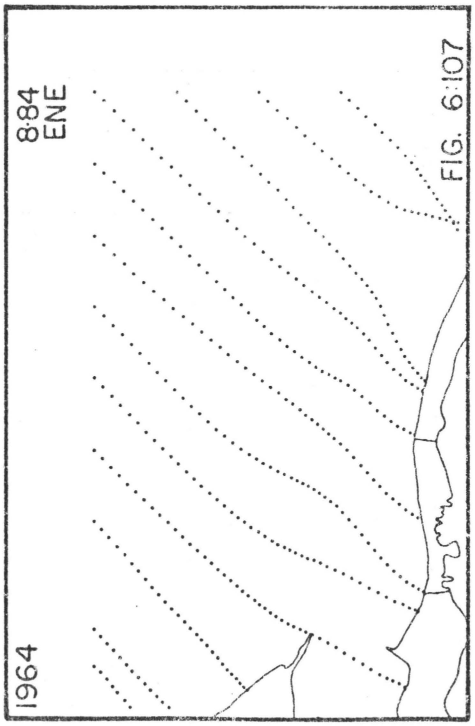


FIG. 6:107

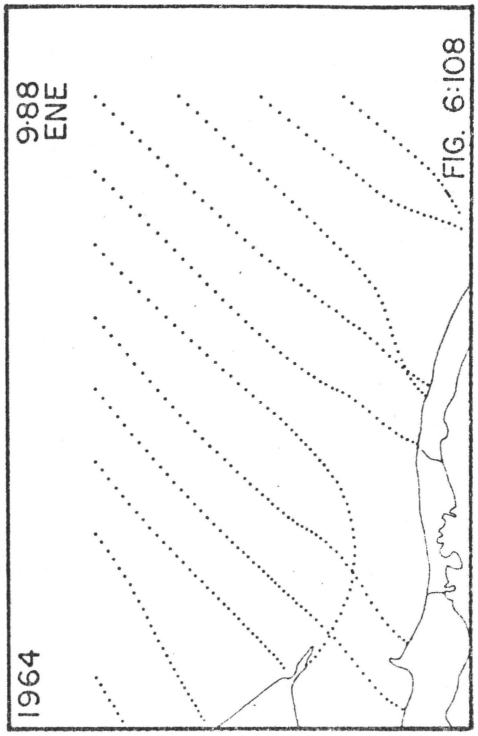


FIG. 6:108

PROBABILITY OF WAVE OCCURRENCE

Since only wave periods of 6.25 seconds or more were investigated some probability of occurrence should be stated. Quon et. al. (1963, p. 54) in their study of wave characteristics produced a graph outlining the probability of occurrence of different wave periods. This graph is summarized in Table 6:5 and shows that the waves, which have been studied here only account for 5% of all waves. Thus it may be possible for smaller waves to induce a large proportion of coastal change, but the fact that wave refraction decreases with decreasing wave period and the fact that these lower wave periods account for most seasonal change on the beaches, suggests that any large scale change in beach configuration is produced by large

TABLE 6:5 PROBABILITY OF OCCURRENCE OF WAVE PERIODS FOR ALL DIRECTIONS, MIDDLE OF THE GULF OF ST. LAWRENCE

Frequencies are based on a ten month effective wave season

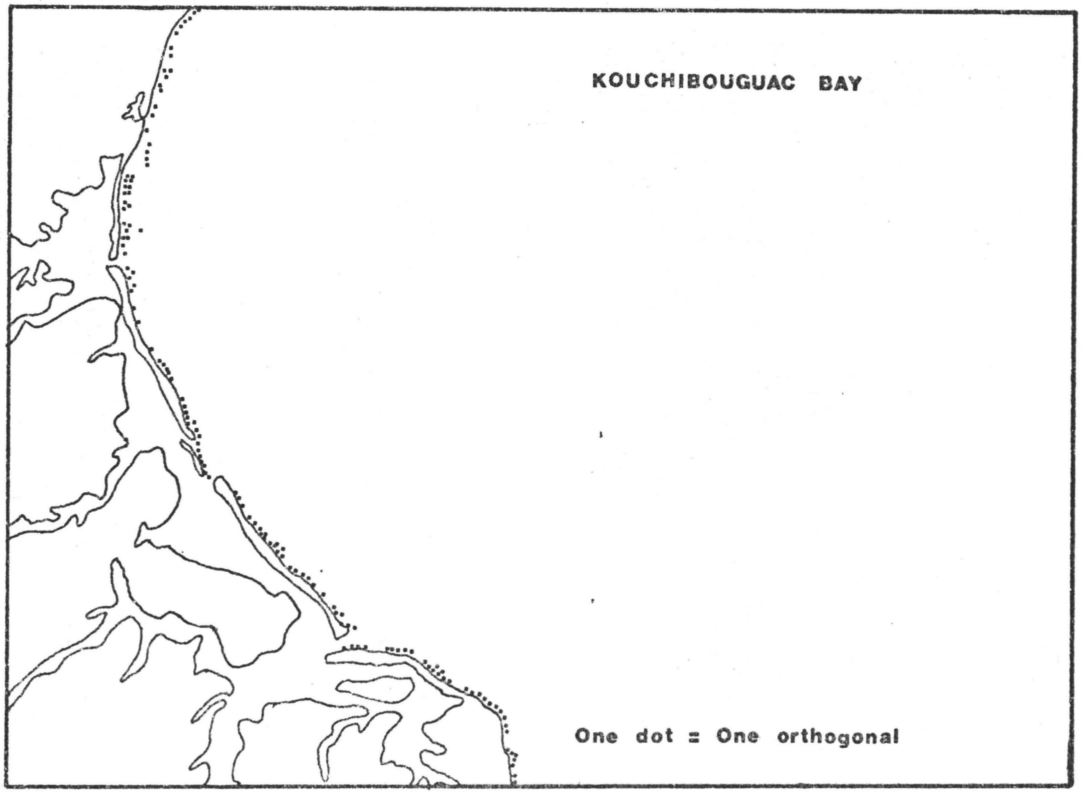
WAVE PERIOD	PROBABILITY	FREQUENCY
3.13 secs.	.3	108 days/yr.
4.42 secs.	.11	39.6 days/yr.
5.41 secs.	.043	15.5 days/yr.
6.25 secs.	.02	7.2 days/yr.
6.99 secs.	.011	4.0 days/yr.
7.65 secs.	.007	2.5 days/yr.
8.27 secs.	.004	1.4 days/yr.
8.84 secs.	.0035	1.3 days/yr.
9.38 secs.	.0025	1.0 days/yr.
9.88 secs.	.0014	.5 days/yr.

period waves 6.25 seconds and greater.

These probabilities of wave occurrence can also enlighten upon the reason for the breaching of South Beach between 1894 and 1930. It was noted that for the 1894 bathymetry large storm waves were concentrated in the center of South Beach, and it is possible that several storms with waves greater than 8.84-second periods could have breached this area. However, when one considers the fact that such waves occur less than two days per year (Table 6:5) and that these waves would have to be associated with high tide conditions and with wind surge in order to erode the dune ridge protecting this beach, this explanation appears less likely. A better explanation can be found in the changing bathymetry between 1894 and 1930. The diagrams for 1930 show a concentration of refracted wave orthogonals into this breached area for north-northeast waves for all wave periods. Since this is the dominant storm wind direction affecting this area and since the concentration of wave energy is unaffected by wave period, the probability of wave occurrence affecting this breached area is increased. The breaching of South Beach is thus not related to any one wave period but is caused by the refraction of all wave periods as a result of a change in offshore bathymetry. This change in bathymetry from map evidence seems to be related to the construction of breakwalls on North Beach. Thus the breach in South Beach appears from this evidence to be indirectly related to the development of North Beach rather than to the influence of any single storm.

CONCLUSIONS

The accurate modelling of any wave refraction patterns requires realistic wave characteristics and complete bathymetric coverage of the area of interest. On a general scale and for the Richibucto Inlet area the bathymetric data has been sufficient but the wave characteristics used in the modelling for Kouchibouguac Bay have had to be obtained indirectly. What this chapter has attempted is the definition of the patterns of energy distribution in the bay and their application to changes in the configuration of the barrier islands. When all the orthogonals used in this study are overlaid at the shoreline some idea of the relative intensity of energy input to the islands can be obtained for wave periods from 6.25 to 9.88 seconds for important fetches affecting the area. When this overlay (Figure 6:109) is classified according to light, moderate or heavy concentrations of wave energy, and compared to Figures 3.1-3.4, there is a marked agreement between areas of heavy and moderate energy concentrations



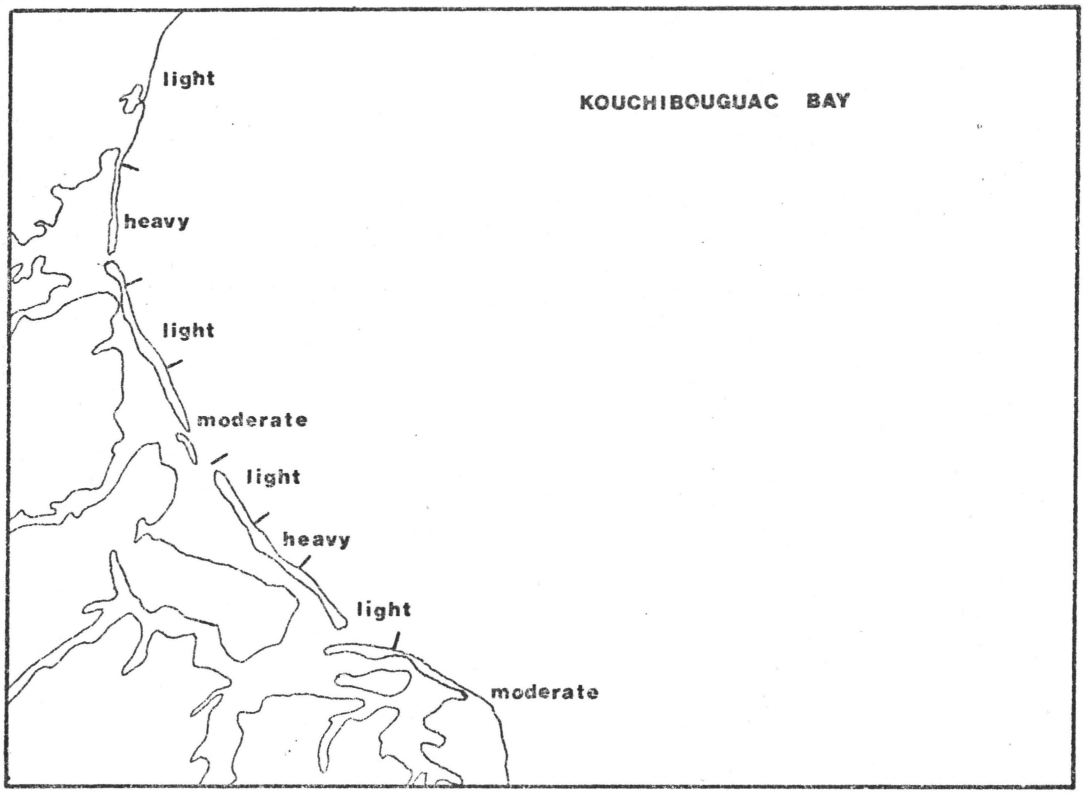


Fig. 6:109 Concentration at shore of all wave orthogonals used in the study.

and those which have undergone definable change in island configuration over the last 150 years. The differences between these figures can be explained by the fact that not all the wave periods and wave directions have equal probabilities of occurrence but the wave refraction patterns seem to be able to explain the changes around Blacklands Gully and the subdued nature of the northern spit.

The simulation modelling of wave refraction diagrams also indicates that Kouchibouguac Bay is under two wave regimes. The northern section of the Bay is affected by waves originating to east-northeast and east, while the southern part of the bay is under the influence of waves from the north-northeast and northeast. These regimes are defined by wave refraction around the northern tip of Prince Edward Island and around banks in Kouchibouguac Bay for waves from these specific directions.

The degree and location of erosion by storms on South Beach is not controlled as much by the direction or period of these storm waves as by the shape and location of the offshore bar on North Beach and the behaviour of the offshore channel at its mouth. The effect of building breakwalls in this inlet was the differential erosion of South Beach. As the offshore bar on North Beach has responded to this breakwall, erosion has been concentrated into particular areas on South Beach. The map evidence since 1839 shows relatively little retreat of South Beach up until 1930, but since then most of the erosion of South Beach has occurred and the wave refraction diagrams show that erosion will be a continuing process on this beach. This study has shown that wave refraction diagrams when modelled sufficiently can explain the long term changes in barrier island configuration.

CHAPTER 7

INLETS

INTRODUCTION

The changes in the form of the barrier islands in Kouchibouguac Bay over time can be explained by wave refraction patterns; however, the most dramatic change in configuration of the islands has occurred around various tidal inlets and breaches of the barrier islands. This change in inlet position and shape, outside of small migratory shifts due to longshore drift accumulations on one side of the inlet, depends ultimately upon certain stability conditions of which wave refraction is just one factor. The ability of the inlet to maintain an equilibrium situation between the amount of littoral drift entering the mouth of the inlet and the amount of material discharged through an inlet in a tidal cycle defines this stability (Bruun 1967b, p. 350).

Defining exactly the stability of these inlets would have involved both measurement of tidal discharge and longshore drift. The type of measurement required was beyond the scope of this thesis; but some attempt at describing the behaviour of the tidal currents in the inlets over time was judged necessary. This chapter describes the measurement of tidal currents, mainly in Richibucto Inlet, over phases of a tidal cycle, with some work carried out on Little Gully and the channel offshore from South Beach. Within the context of the literature these measurements can be used to define generally some of the behaviour and stability of the inlets in Kouchibouguac Bay.

The smaller inlets which have appeared and disappeared over time in Kouchibouguac Bay can be attributed to storm action and the inability of the inlet's hydraulics to flush the normal littoral drift from the channel. However, over the period for which historical evidence exists, three inlets in the Bay have remained stable in relative position though not in configuration. These inlets are Richibucto Inlet, Blacklands Gully, and Little Gully at the mouths of the Richibucto, Kouchibouguacis and Kouchibouguac Rivers respectively. Kranck (1967, p. 2261) believed that the barrier bars were superimposed upon these three rivers at an early stage of development and it is feasible that these three inlets are not only linked to the existing estuaries, but that they are continuums from the time the barrier islands originally formed.

Though the three inlets have similar origins, they are by no means similar in appearance or behaviour. Richibucto Inlet, since 1894, has been controlled at both ends by breakwalls and has undergone little shifting since 1930. Little Gully however is uncontrolled but has the same simple entrance. It has the characteristic shape of most uncontrolled inlets (O'Brien 1967, p. 403; and Price 1963, p. 284) with two crescent offshore bars at its mouth and a tidal delta in the lagoon. Little Gully appears to be a stable inlet in position but the shoals around the inlet indicate an inability for tidal currents to clear completely the channel. Blacklands Gully is a very massive and unstable inlet consisting of more than one channel which bifurcates at the ocean and lagoon entrances. Blacklands Gully represents an area of heavy sedimentation and shifting of unstable inlet entrances.

MEASUREMENT OF TIDAL CURRENTS

a) Drogues

The method of measurement of tidal currents was based on a technique used for current measurement at the mouth of the Niagara River, Ontario by the Canada Center for Inland Waters. A Drogue device (see Appendix 8 for diagram), consisting of two plastic sheathed aluminum frames measuring .9 and .6 m and joined to each other at a 60 degree angle, was suspended from a styrofoam float in the inlet at maximum depths of 1.8, 3.7, and 5.5 m. The drogues were positioned and tracked in turn at the upstream end of the inlet every two hours in spring tide conditions. The tracking involved positioning of the drogue in the inlet from two known positions by using a tacheometer and a directional level at regularly timed intervals. This data was then converted to velocities in meters per second and plotted on maps of the inlet areas.

b) Measurement of Inlet Topography

Because the drogues became grounded or dragged the bottom at certain depths in Richibucto Inlet, it was essential to know the bottom configuration of this inlet. This was accomplished using a Kelvin Hughes Recording Echo Sounder in the same manner as for the profiling offshore from the surveyed beach profiles. Profiles of Richibucto Inlet were taken at 30 meter intervals perpendicular to two surveyed lines running along the south shore of North Beach. These soundings were then corrected to low tide and select depths were taken and accurately positioned in the inlet. These spot depths were then contoured by hand to produce the bathymetry shown in Figure 7:1. No attempt was made to sound Little Gully because of its shallowness, and drogues were positioned only at 1.8 m depths where visual observation from a boat

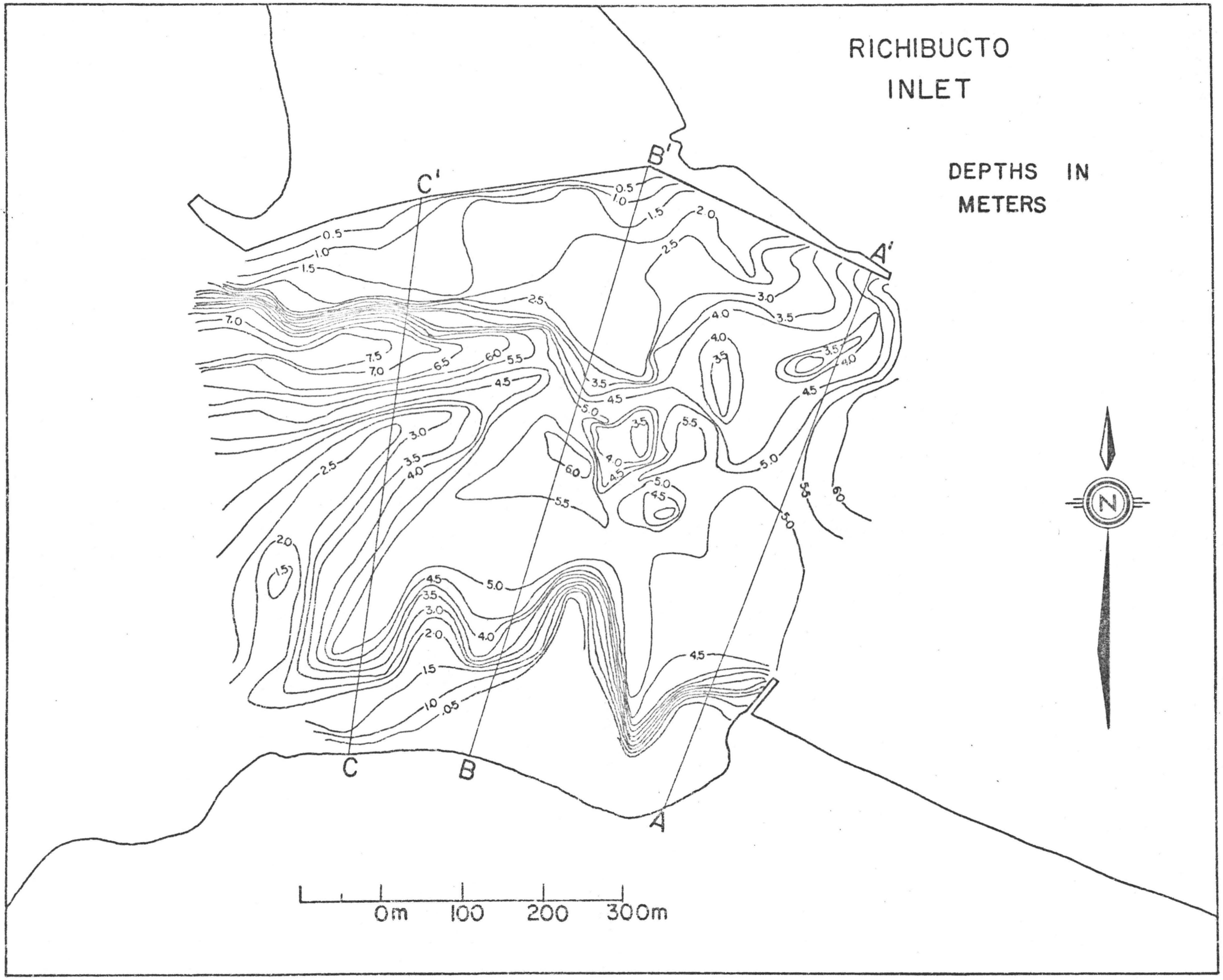


Fig. 7:1 Bathymetry of Richibucto Inlet 1971

could determine if they were grounding in the channel. Drogue work was limited to a depth of 3.7 m in the channel offshore from South Beach.

INTERPRETATION OF THE DATA

a) Mapped Results

Figures 7:2 to 7:9 show the mapped tracks and directions of the drogues for May 28th, June 12th, and June 14th 1971 in Richibucto Inlet. The minimum acceptable contour at which the drogue will not drag the bottom is presented for corresponding high and low tide conditions. In most runs, the drogue at the 1.8 m depth did not ground but the drogue at the 3.7 depth often dragged along the bottom for part of the run. The drogue at 5.5 m was invariably dragging the bottom of the inlet. All the drogues were intentionally positioned in the inlet so that they did not touch the bottom; yet the tracks of these drogues, in most cases, follow straight paths in the inlet regardless of the bottom topography which is made up of a large meandering channel in the center of the inlet. Most of the drogues according to the contour map should be able to navigate the channel without grounding or dragging the bottom; but if the theoretical basis of the drogue actually moving as part of the body of water in the current is correct, then it must be deduced that the currents at depth in the inlet are not following the

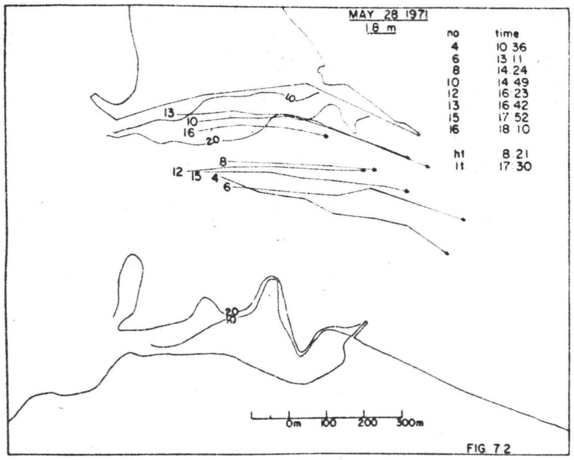


FIG 7.2

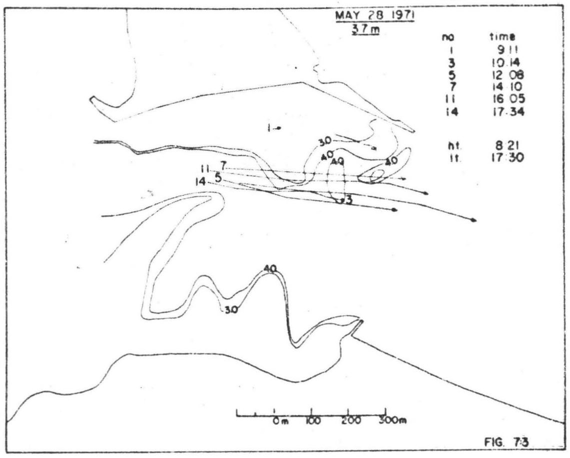


FIG. 7.3

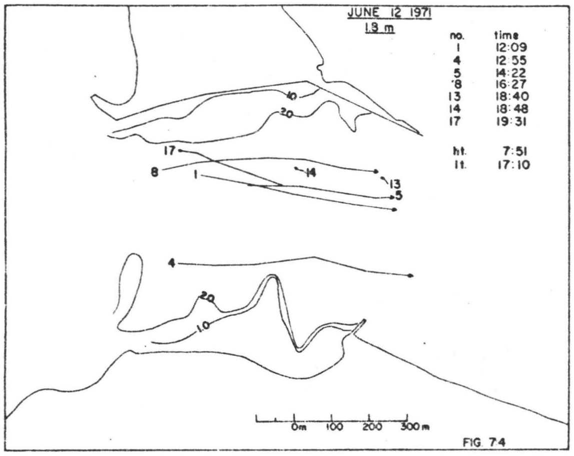


FIG 7.4

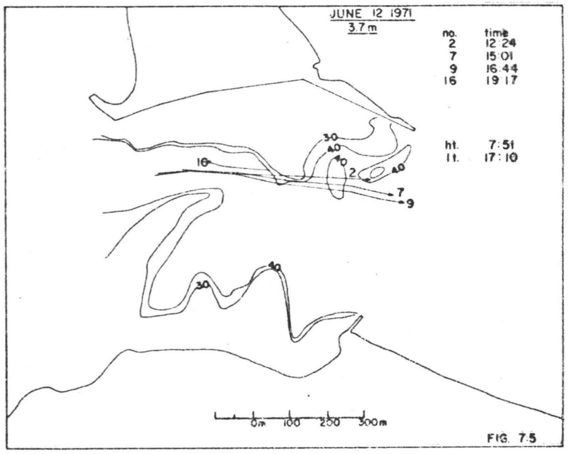


FIG. 7.5

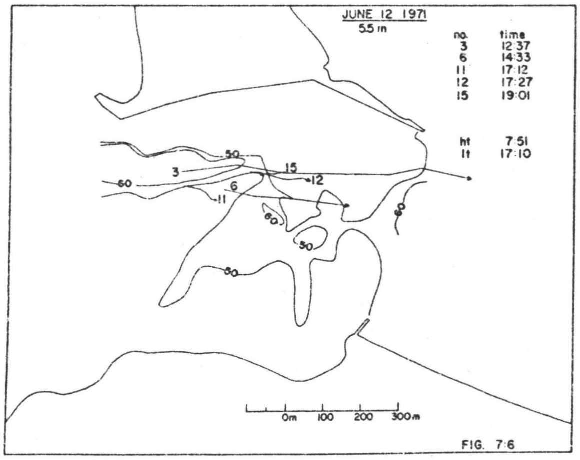


FIG. 7.6

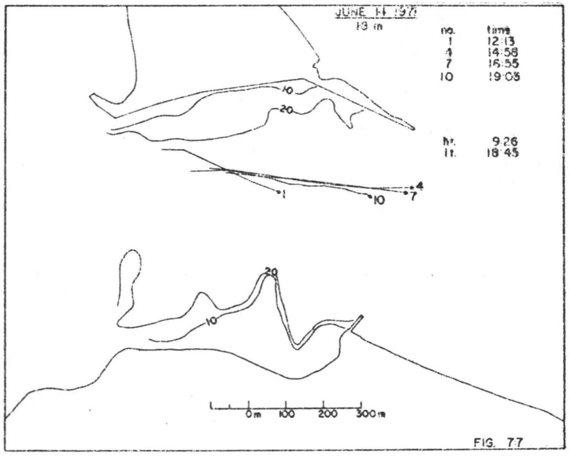


FIG. 7.7

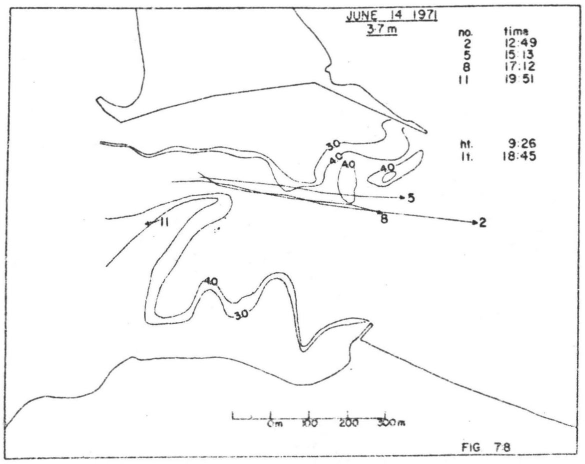


FIG 7.8

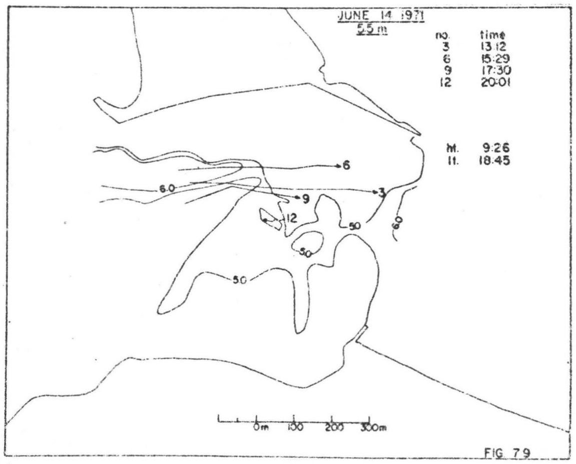


FIG 7.9

Fig. 7:2-7:9 Drogue tracks in Richibucto Inlet channel but impinging upon the sides of the meander. If this is the case, then the deep shoals which appear in the channel at the mouth of this inlet should be undergoing erosion.

b) Velocity Measures over Time

The computed velocities for each drogue run were averaged and these averages were plotted against the time of day. Though the 5.5 m drogue depths are not accurate they are presented for comparison. Graphs for Richibucto Inlet are shown in Figures 7:10 to 7:12 with the time of predicted low and high tide (Canadian Tide and Current Tables v. 2 Gulf of St. Lawrence 1971). These figures show that the maximum velocities obtained depend upon the tidal range with a slight lag of about 1 hour in a change of tidal current direction after the predicted tidal change. The results offshore from South Beach, though not as complete, tend to substantiate these observations. The average maximum velocities of these runs, recorded at spring tide, approximate very well those recorded by Bruun (1967b, p. 359) for a series of controlled and uncontrolled inlets in the United States. The results also show a decrease in velocity with depth and in the case of Figure7:10, a decrease with proximity towards shore or decreased depth of water. In many studies of tidal currents it is assumed

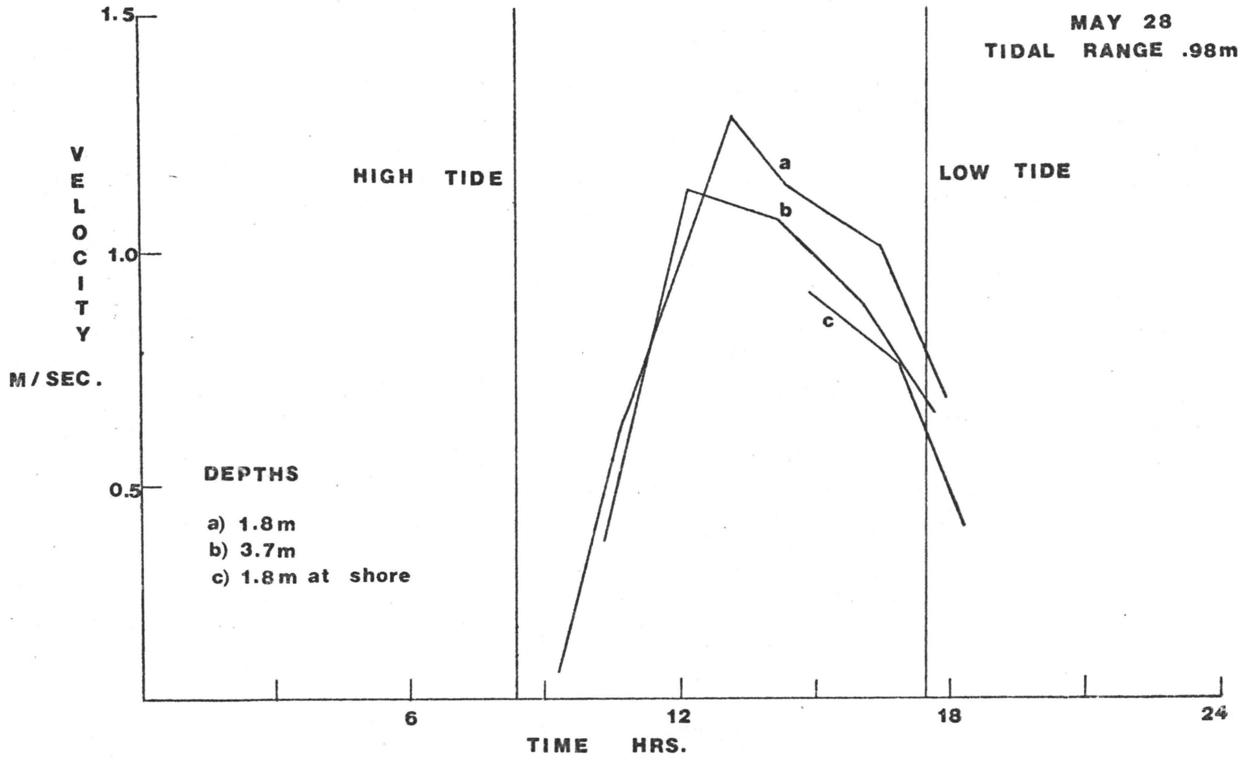


Fig. 7:10 Velocity measures at depth May 28, 1971

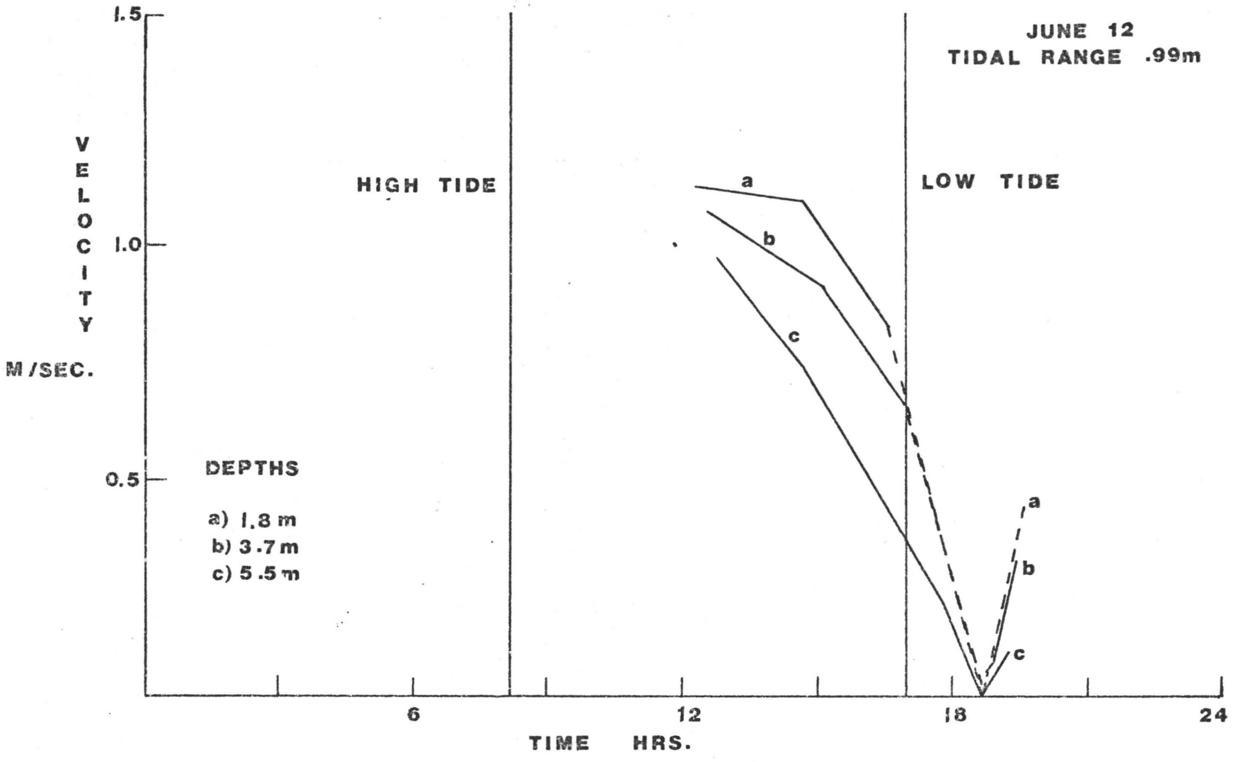


Fig. 7:11 Velocity measures at depth June 12, 1971.

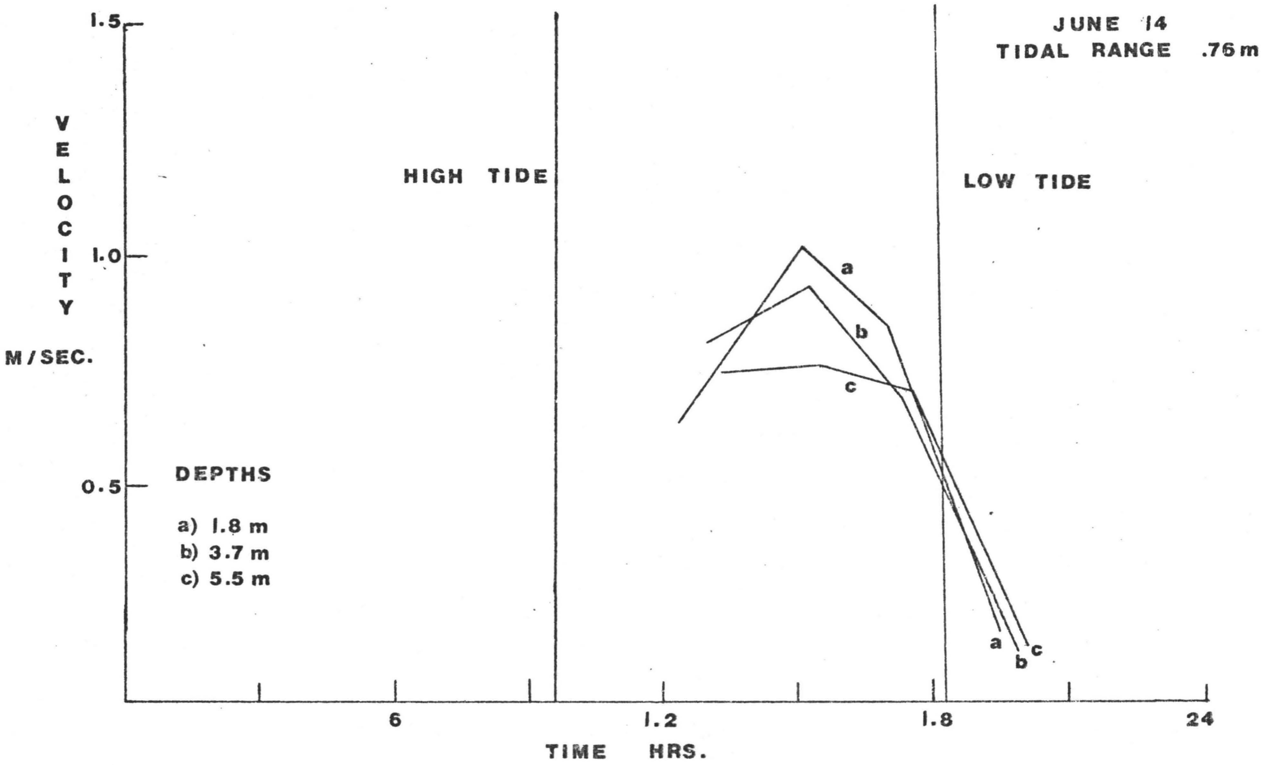


Fig. 7:12 Velocity measures at depth June 14, 1971.

that tidal current velocities over time are sinusoidal (Brown 1928, p. 532; Bruun and Gerritsen 1958, p. 18; and O'Brien 1967, p. 400) and these figures would tend to substantiate that assumption, though the change in velocity is much greater with a change in tide than it is between tides. Thus it is possible to state from these graphs that the velocity of the tidal current is sinusoidal over time, lags behind the change in tide, and decreases with depth in the water and with depth of the inlet.

c) Discharge and Tidal Prism

Three profiles of Richibucto Inlet marked on Figure 7:1 were constructed in order to observe discharge behaviour along the inlet and attempt some calculation of the tidal prism. The profiles (Figures 7:13-7:15) were constructed for low tide conditions and the cross sectional area was calculated for the inlet above 1.8 m and below. These values were also corrected to high tide conditions. The velocities measured at each profile across the inlet were classified either as high tide or low tide velocities and then velocities for the upper 1.8 m of water depth were used to calculate discharge of the cross section in the upper area of the cross section, while velocities for 3.7 m of water depth were used for the rest of the cross sectional area. The discharges were then

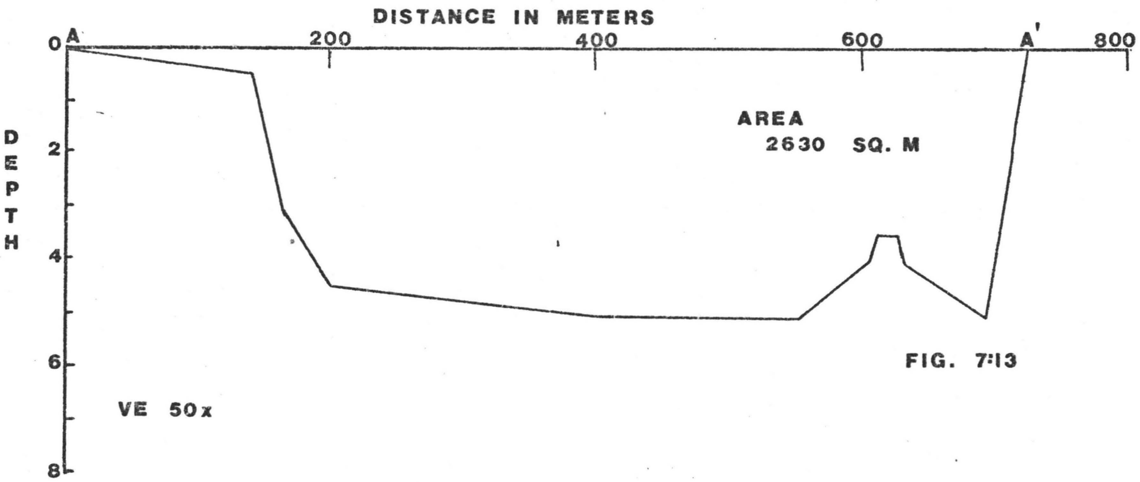


FIG. 7:13

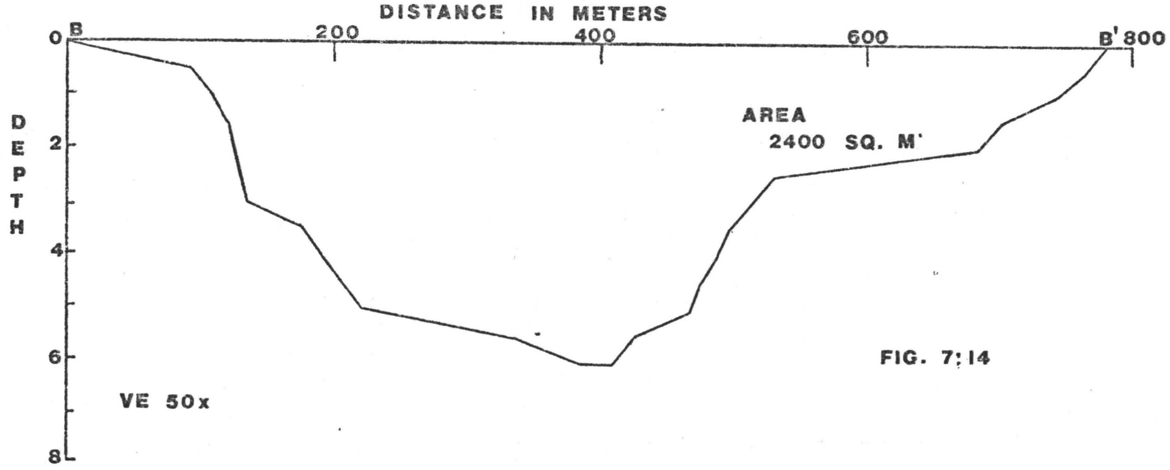


FIG. 7:14

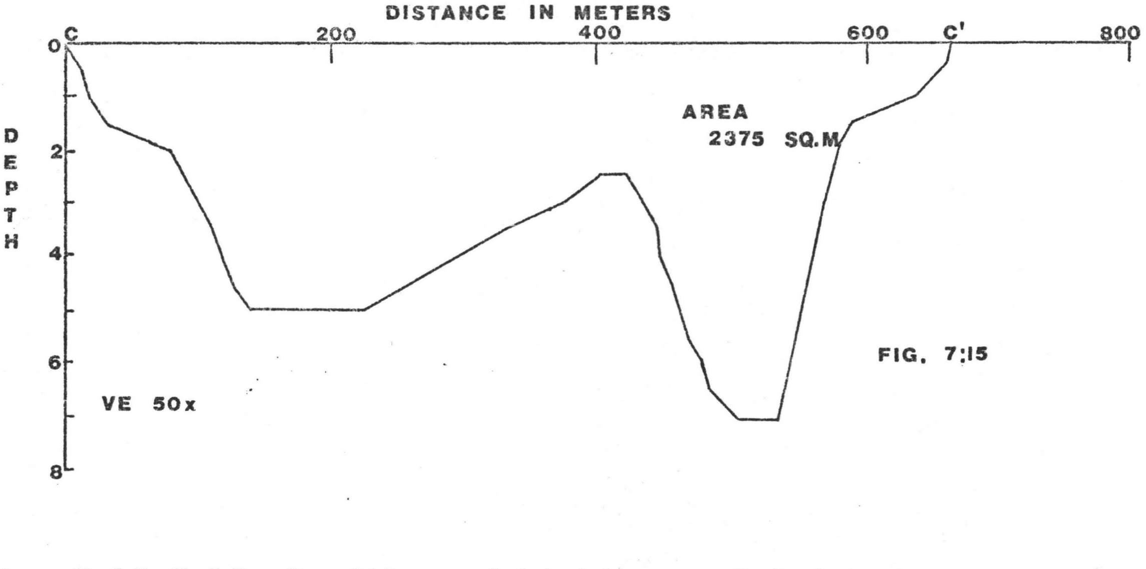


FIG. 7:15

Fig. 7:13-7:15 Profiles of Richibucto Inlet summed with the result being a calculation of discharges at three cross sections of the inlet for various times in the tidal cycle. These results are shown in Table 7:1.

The cross sectional area is not constant along the inlet, but increases towards the mouth. If the discharge through cross section CC_1 is to remain the same at the other cross sections then the velocities of the current at these points must adjust accordingly. Table 7:1 shows a maximum discharge at the mouth of the inlet with the upper end of the inlet having lower discharges. The discharges tend to be equal at low tide, but when current velocities in the inlet are at a maximum the discharges, as calculated, vary considerably along the inlet. Since logically the discharge cannot vary along the inlet then either the method of calculating discharge is faulty or else the velocities measured in the inlet are not representative of the whole cross section. The discharges presented here and especially those calculated for cross section AA_1 are too high when set in the context of other inlets (Bruun 1967a, p. 120). The technique of calculation likely has some error, but a better explanation would appear to be variation in current velocity across the inlet as shown in Figure 7:10 where velocity decreased with decreased depths of the inlet.

TABLE 7:1 CALCULATED DISCHARGE VALUES FOR PARTS OF A TIDAL CYCLE FOR THREE DAYS IN RICHIBUCTO INLET AT THREE PROFILES

Values are in cubic meters per second.

May 28, 1971
High Tide 8:21
Low Tide 17:30

TIME	AA_1	BB_1	CC_1
10:30	1.5×10^3	1.2×10^3	
12:30	4.9×10^3	3.0×10^3	
14:30	3.5×10^3	3.2×10^3	
16:15	2.1×10^3	2.5×10^3	
17:45	1.7×10^3	1.6×10^3	

. . . .

June 12, 1971
High Tide 7:51
Low Tide 17:10

TIME	AA_1	BB_1	CC_1
12:15	3.6×10^3	3.2×10^3	2.8×10^3
14:50	3.1×10^3	3.1×10^3	2.6×10^3
16:35	1.9×10^3	1.8×10^3	1.8×10^3
19:30		$.8 \times 10^3$	$.9 \times 10^3$

. . . .

June 14, 1971
High Tide 9:26
Low Tide 18:45

TIME	AA_1	BB_1	CC_1
12:40	2.5×10^3	2.2×10^3	1.6×10^3
15:10	3.0×10^3	2.9×10^3	2.6×10^3
17:10	2.4×10^3	2.2×10^3	2.0×10^3
19:25	$.3 \times 10^3$	$.6 \times 10^3$	$.7 \times 10^3$

It is also possible to calculate the tidal prism (the volume of water flowing through an inlet in a tidal cycle) by using these cross sections and an empirical relationship defined as follows:

$$A = 4.69 \times 10^{-4}\ P^{0.85} \quad \text{(O'Brien 1967, p. 399)}$$

Where

A is the minimum flow cross sectional area in $ft.^{-2}$

p is the volume of tidal prism on a spring or diurnal tide in $ft.^{3}$

A value of $3.6 \times 10^{7}\ m^{3}$ was obtained at profile CC_1 for mean tide. This value compares with measured values in many smaller inlets along the United States Gulf and Atlantic coasts (Bruun 1967a, p. 120). It appears reasonable to state that Richibucto Inlet is behaving hydraulically like many other inlets in coastal America when a comparison of velocities and tidal characteristics is made.

INLET STABILITY

If the concept of the inlet as a sediment trap for littoral drift holds then the stability of that inlet must be maintained by flushing out this material with each tidal ebb. Bruun and Gerritsen (1958, p. 6) state four main reasons why this is not necessarily so. Firstly, if the length of the inlet increases or, secondly, if the inlet subdivides or increases its cross sectional area, then the tidal current is reduced as a result of increased friction and the ability to maintain inlet stability is impaired.

Thirdly, if there is any decrease in the area of the lagoon, the amount of water capable of generating sufficient currents in an inlet also decreases. Fourthly, storms can also overwhelm the inlet with sediment from increased littoral drift. At the same time storms may also clear shoals from the inlet mouth by changing the patterns of wave refraction and may enhance the flushing ability of a tidal inlet by increasing the cross sectional area through scouring by storm-pounded waters in the lagoon. Most of the variables involved here can be quantitatively described and various indices have been developed to characterize inlet stability.

The most extensive work on these indices has been carried out by Bruun and Gerritsen (1958, 1961) with some modification by Battjes (1967). Most of their indices however involve a knowledge of longshore drift amounts,-- a variable which is difficult to measure accurately in the field. Bruun (1967b, p. 358) has defined an empirical relationship between the Chezy coefficient and the cross sectional area of an inlet which can be used to describe the stability of most inlets. The relationship is as follows:

$$C = 30 + 5\log A$$

where C is the Chezy coefficient in $m^{\frac{1}{2}}sec^{-1}$
A is the cross sectional area in m^2.

For Chezy coefficients above 45 $m^{\frac{1}{2}}sec^{-1}$, inlets are relatively stable. Chezy coefficients were calculated for the three profiles of Richibucto Inlet outlined on Figure 7:1 for low tide conditions. The values are as follows:

CC_1 Chezy coefficient 46.9 $m^{\frac{1}{2}}sec^{-1}$
BB_1 Chezy coefficient 46.9 $m^{\frac{1}{2}}sec^{-1}$
AA_1 Chezy coefficient 47.0 $m^{\frac{1}{2}}sec^{-1}$

On the basis of this calculation Richibucto Inlet appears to have the required Chezy coefficient to maintain stability. Since map evidence over the past 80 years shows a tendency for Richibucto Inlet to become more stable with time and in light of the above results, it can be stated that Richibucto Inlet is stable. For this inlet to become unstable, between 200,000 and 300,000 cubic meters per year of littoral drift would have to be entering the mouth of the inlet (Bruun 1967a, p. 124). It is doubtful that this section of coastline is receiving this amount of material and what longshore drift is coming along this section of coast tends to be transported parallel to South Beach along the extensive offshore shoal on North Beach.

Compared to Blacklands Gully and Little Gully, Richibucto Inlet has a substantially larger cross sectional area. The Chezy coefficient decreases rapidly for cross sectional areas below that of Richibucto Inlet and it would appear that frictional forces at the inlet sides in the other inlets would be increased. The tidal prism for Blacklands Gully and Little Gully is also smaller than for Richibucto Inlet, simply because the area of lagoon feeding the inlets with water at ebb tide is sharply reduced. For these reasons and because of the presence of shoals around these inlets, it is very doubtful if they can be called stable inlets in the sense that they are able to flush out all the littoral drift travelling north or south along the coast. The extensive shoals and flats just landward of Blacklands Gully and Little Gully suggest that these two inlets are sediment traps for most of the littoral drift along these sections of barrier islands.

CONCLUSIONS

The inlets in Kouchibouguac Bay appear to be of two types,--those which are storm-induced by breaching of the barrier islands and those which have formed as part of the evolution of the barrier islands. The former are very short-term and quickly infill under normal wave action. These infilled inlets, though short-term, are vulnerable to future storm activity. There is evidence for at least five of these inlets along the barrier islands with the most recent being the breaching of the northernmost barrier island near its land connection in the winter of 1970 to 1971. The second type of inlet has maintained the same relative position over time with, in the case of Blacklands Gully, many short-term fluctuations. Together these inlets offer the most striking change to the form of the present barrier islands.

The amount of change of these inlets depends on the relationship of the amount of littoral drift passing by an inlet and the ability of this inlet to keep the material in movement along the coast. Because of the difficulty in measuring tidal currents in shoaling inlets, the stability of these inlets was studied in the more simplified Richibucto Inlet. This latter inlet appears to be similar to many other inlets along the United States coastline with a sinusoidal change in velocity over the tidal cycle, a lag in velocity increase with the change of tide and calculated maximum velocities of around 1.0 meters per second. From calculated Chezy coefficients of 46.9 $m^{\frac{1}{2}}sec^{-1}$ compared to critical ones of 45.0 $m^{\frac{1}{2}}sec^{-1}$, this inlet also appears to be stable.

In comparison to the other major inlets here, Richibucto Inlet is unique. The dimensions and characteristic shoals of Blacklands Gully and Little Gully imply instability. Though the field measurement of inlet behaviour is cursory, the air photography and map evidence backs up the conclusions presented here. If the barrier form in Kouchibouguac Bay is to change around the major inlets, it will be most dramatic around Blacklands Gully and then Little Gully. Richibucto Inlet appears to be controlled by its present breakwalls and, outside of changes caused by the offshore shoal extending southeast from North Beach, should remain stable.

CHAPTER 8

CONCLUSION

This thesis has described a section of the Canadian barrier island coastline in New Brunswick which has not been thoroughly investigated before. From this description it has been shown that the barrier islands of Kouchibouguac Bay are undergoing similar processes to other better known barrier systems in Eastern North America. The shoreward retreat of the barriers and the rapid change in island configuration, as shown by map and air photographic evidence in this study, attest to this fact. The similarities to other systems with regard to processes, as shown by sediment size and shape analysis, is also further indication that Kouchibouguac Bay is just one segment of a much larger barrier island system. Though the descriptions of the Kouchibouguac Bay barrier islands and the evidence for change constitute an important part of the thesis they are not the total essence of it. An attempt has also been made largely by indirect methods to investigate the processes at work. It is the purpose of this chapter to summarize the findings about the processes acting on and responsible for this system.

It may be noted that this study has been time-limited in two ways. First, the field seasons covered only summer months, and at that, not even the whole summer season. The major storm season in the early spring and fall, the time of ice freeze-up and break-up and the processes acting upon these islands in winter have never been observed. In this regard the implications of simulation modelling of wave refraction which have been presented have never been compared to real world conditions. No storm such as would produce the wave conditions which were used in the modelling has ever been observed by the author. Secondly, the field seasons represent only a small segment of time in the evolution of these barriers. The barrier island system could have been passive or very active compared to conditions over the past century or more. The sediment analysis and inlet studies could thus be unrepresentative of the "normal" conditions which prevailed on these islands. Yet the results and conclusions based on field research do support historic evidence explaining the evolution of this system.

Sediment size and shape analysis have provided a basis for delineating and explaining the processes at work on these islands. It has been shown that in summer wave action does not dominate the system but that wind action through erosion and deposition of sand controls the sediment characteristics of the three main environments on the island--the lagoon beach, the ocean beach and the dune complex. During the summer, outside of the occasional minor storm, sands are blown from the dune area and contaminate, through deposition, the wave-deposited sands on the beaches. The sands on the beaches are often eroded and deposited either in the dune complex or offshore in the lagoon or ocean.

The size characteristics of the sands also delineate the type of process, intensity of process and to some extent the source of sediments, but the full usefulness of size analysis has been hampered in this study by the intermixing of sediments from different environments. The chaotic variations in size characteristics across the beaches and along the islands attest to this fact. However the beaches, as sampled in a limited scheme, do show two significant variations. Firstly, South Beach is very uniform in size characteristics irrespective of the environment from which the sands were sampled. Either the sands have been sorted to a sameness in longshore transport or they have been intermixed by wind and wave processes to such a degree that they are indistinguishable. Secondly, where the barrier island approaches closest to shore at Beach 3, the sands are significantly coarser than on the other islands. Since these barriers are eroding the underlying bedrock and tills as they retreat shorewards, Beach 3 is closer to the source of sediment supply while the other islands are composed of sands which have undergone some selective sorting. All of the sediment characteristics described for these islands can be explained by either the type and intensity of the process or by the source of sediment supply.

Though wind has been shown to prevail in the summer and though it is responsible for dune growth and blowout erosion, the major changes in island configuration, --the breaching, infilling, and dune erosion are related to the distribution of wave energy in the bay. Simulation modelling of these patterns for various wave periods and directions shows that the barrier islands are affected by two wave regimes. Waves originating from the east-northeast to east have little influence upon the barrier islands south of the Kouchibouguac River but concentrate north of it. On the other hand waves from the north-northeast to northeast concentrate in the southern part of the bay and diverge greatly in the north. Thus different areas in the bay can be undergoing significant wave attack while other areas are protected from the same waves. This was the case with storms during the winter of 1970-

1971 when the barriers in the southern part of the bay underwent erosion of the dune front while the northern section of the bay remained relatively unscathed. For all wave directions and periods, the simulation of wave refraction diagrams explains the change in beach configuration for the last 150 years and the subdued nature of the northern island. Those areas which have undergone the most change are those areas which receive the greatest concentrations of wave energy.

In studying the relevance of wave refraction simulation as a tool for explanation of island change, the Richibucto area was reviewed for the period 1894 to 1964. The diagrams show that the breaching and infilling of the inlet on South Beach and the erosion of dunes here can be explained by wave refraction patterns. Significantly the changes in the bottom offshore configuration which are responsible for these patterns are related to the construction of breakwalls in Richibucto Inlet. This construction has caused the lineation and growth of offshore shoals which now form one continuous bar paralleling South Beach. The construction has stabilized the inlet but altered the offshore topography and wave refraction patterns for a now eroding South Beach.

The construction of the breakwalls was carried out to stabilize Richibucto Inlet. Studies of flow characteristics through this inlet show that these attempts have been successful. Most of the change in the island configuration occurs around the inlet areas. Using Richibucto Inlet as a base it becomes apparent that Blacklands Gully is a very unstable inlet while the third inlet, Little Gully, shows mapped evidence of stability with unstable shoals at its ocean and lagoon mouth. This inlet stability is related to the ability of the inlet to flush out trapped longshore drifted sediments and to wave refraction patterns which show either a spreading or a concentration of wave energy in these areas.

Based on the evidence and observations gathered by this author these conclusions are reasonable; but any such study is never complete for it should also propose questions and problems for further research. A more detailed sampling scheme over a small area of the islands and over a short time period would possibly improve the delineation of sediment environments and the responsible processes. Credibility of the wave refraction diagrams could be improved through a simple comparison of computed patterns with ones shown on air photographs, while the discussion on the distribution of wave energy in the bay could be quantified by adding wave height data to the simulation model. Finally the deductions about changes on South Beach as a result of wave refraction over a changing bathymetry need testing in other areas. Despite these criticisms this thesis should shed light on processes acting upon barrier island systems and the nature of other such systems in the Southern Gulf of St. Lawrence.

APPENDIX 1

The mapping of Beaches 1 to 4 was carried out using a self-reducing tacheometer and meter survey poles. Two base lines on the middle of the ocean beach and on the top of the dune crest were used for mapping. The tacheometer was positioned at stations offset 150 to 200 m from each other on these base lines and each station was zeroed to one other station and tied in with a measured distance and angle to four other ones, one of which was the next position for the tacheometer. The tacheometer was set up alternately on the ocean beach and the dune crest and the whole grid of stations was referenced periodically by angles to known positions present on topographic and bathym etric maps (navigation lights, church spires, wharfs, and houses). In this manner a cross referenced grid of mapping stations could be referenced to true north. By positioning the bench marks of the surveyed profiles in this grid and by knowing the compass bearing of the profile lines, the barrier and offshore profiles could then be accurately positioned on these maps.

From these stations, beach detail was mapped at spaced points by angles and distances along the ocean shore, the backshore of the ocean beach, the top of the talus slope (where feasible), the top of the erosion face of the dune cliff and the top of the dune ridge for 1970 on Beaches 1 to 3 and for 1971 on the island from Beach 3 to Profile 20. In the latter area, the top of berm also was mapped. The stations were then positioned at a scale of 50 meters to the inch on a map and points on the Beach detail outlined above were accurately positioned from each station in turn and joined up. The result after reduction was a detailed map showing the outline of the barrier island from the ocean shore to the top of the dune crest. The maps allowed for the accurate positioning of barrier and offshore profiles and the positioning of drogues in the channel offshore from South Beach and in Little Gully. They also allowed for detailed descriptions of select sections of the barrier islands undergoing the influence of wave and wind processes.

APPENDIX 2 LIST OF MAPS USED IN THESIS

A) HISTORICAL

1. Des Barres J.F.W. 1781. The Harbours of Richibucto and Buctush on the West Shore of the Gulf of St. Lawrence.
2. Thomas Wright 1807. Extensive Soundings for the St. Lawrence River, Chaleur Bay, Northumberland Strait and Bay of Fundy.
3. Map of New Brunswick compiled at the Colonial Dept. by L. Herbert, 1834.
4. Atlas of the Maritime Provinces (New Brunswick section) Northumberland and Kent Counties.
5. Canadian Hydrographic Chart, BA2034, 1913 ed.

B) HYDROGRAPHIC CHARTS

SOURCE	NO.	EDITION
British Admiralty Chart	2199	1839
	2199	1894
Canadian Hydrographic Chart	4438	1930
	4438	1941
	4438	1944
	4438	1952
	4438	1956
	4438	1960
	4438	1964
	4438	1969

C) MAPS USED IN WAVE REFRACTION

AREA	SOURCE	NO.	EDITION
Gulf of St. Lawrence	Canadian Hydrographic Chart	4002	1969
Kouchibouguac Bay	Kranck (1967, p. 2248)		
Richibucto Bar 1964	Canadian Hydrographic Field Sheet	4030	

1955	Canadian Hydrographic Field Sheet	No. 2556	
1930	Canadian Hydrographic Field Sheet	No. 4438	1930 ed.
1894	British Admiralty Chart	No. 2199	1894 ed.

APPENDIX 3 THEORETICAL CONSIDERATIONS OF SHAPE AND SPHERICITY MEASURES

The interpretation of shape and sphericity depends upon the original shape of the particle and the behaviour of these measures as the three axes of the particle change. Thus the characteristics of these measures should be defined before any interpretation is presented. Since a wide range of measures has been presented in this thesis, some attempt should also be made at judging the most sensitive and realistic measure for the identification of environments.

a) Original Shape and Effect of Process

The underlying assumption in most studies of particle shape and sphericity is that the particle originally had a crude shape and sphericity that has been selectively modified by process. Thus the present shape and sphericity should reflect the process of the present environment. The effect of process on a particle through attrition or selective sorting has been open for debate. Tester (1931, p. 5) found that the original shape of pebbles had a control on the resulting shape and Jones (1953, p. 200) concluded that the presence of non-oblate or non-prolate pebbles in nature was due to the original shape of the material as it was frost-shattered or broken off from parent rock. Carroll (1957, p. 207) found that the shape of a particle was controlled by the lamination and jointing of the parent rock. Thus the final shape and sphericity of any pebble size material may not be due to the attrition of the particle by differing process, but more or less the ability of a process to selectively sort different shapes.

The effect of original shape on sand grains is a more difficult question to investigate. The source of sand grains for these beaches is the underlying sandstone bedrock and the tills and odd fluvio-glacial deposit in the area. It has been stated by Thiel (1940, p. 124) and experimentally proven by Keunen (1958, p. 53; 1959, p. 189) that quartz sand grains are very resistent to abrasion and that they can undergo several cycles of erosion and deposition with little change. Thus the original shape of these sands depends ultimately upon the source of the sandstone and glacial materials. It is assumed here that the sands of this area are similar in origin.

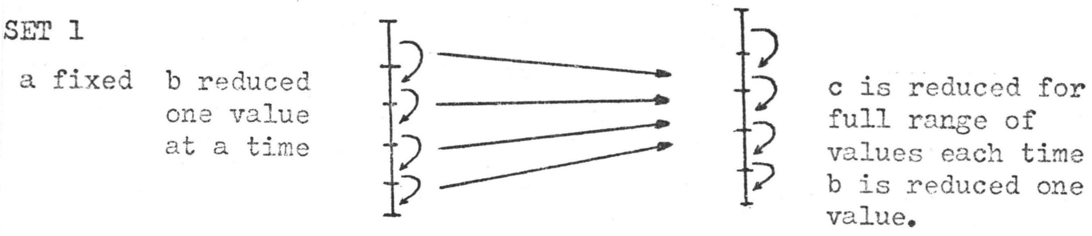
Blatt (1959, p. 202) states also that the type of quartz defines the shape of the quartz grains. Ingerson and Ramisch (1942, p. 595), also stating this opinion, noticed that most quartz grains originating from metamorphic rock were elongated parallel to the c axis. Smalley (1966, p. 628), in assuming that quartz grains form random patterns in granite, postulated that by chance 11.1% of all sand grains should be spherical, 22.2% bladed, and 66.7% disc- or rod-shaped on the basis of a Zingg diagram. Blatt (1959, p. 205) found that most sand grains were compact bladed according to Sneed and Folk's diagram. Observation of grains from the Kouchibouguac beaches do not follow these results consistently or closely (Table 5:2). The alternative answer is that, though original shape dominates these sands, selective sorting of these sands as they were laid down in a fluvial environment during the Pennsylvanian and recent sorting on the barrier island could account for this lack of agreement with the literature.

There is also the question of whether sphericity can be influenced by process. Mattox (1955, p. 113) found that low spherical sand grains move better in wind than ones of high sphericity; however, when dune areas and beach areas are compared, the sphericities of their sands may be similar because of mixing of the two environments. If wind is very strong then little selective sorting occurs and because the beach area can change so rapidly, then a comparison of beach and dune sands may be invalidated by time (Mattox 1955, pp. 113-114). In order to avoid contamination of beach sands by aeolian sands, the ocean beach was sampled at depth in hopes of obtaining sand deposited solely by wave action. In this way, comparison of sphericity and shape of the sands can reveal the effects of process on the barrier islands.

b) Behaviour of Measures as Axes Change

In order to examine the behaviour of sphericity and shape measures as the axes of a particle changes, two sets of hypothetical axes measures were used as input to the various formulae. In the first set, the long axis (a) was fixed throughout and each time the intermediate axis (b) was reduced a fraction, formulae were calculated as the short axis (c) reduced from b towards zero. In the second set with the long axis again fixed, the short axis (c) was varied from a to c. In this way all possible combinations of axes could be examined.

SET 1



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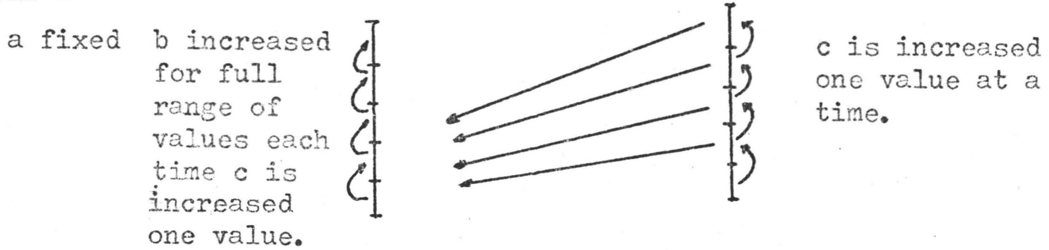


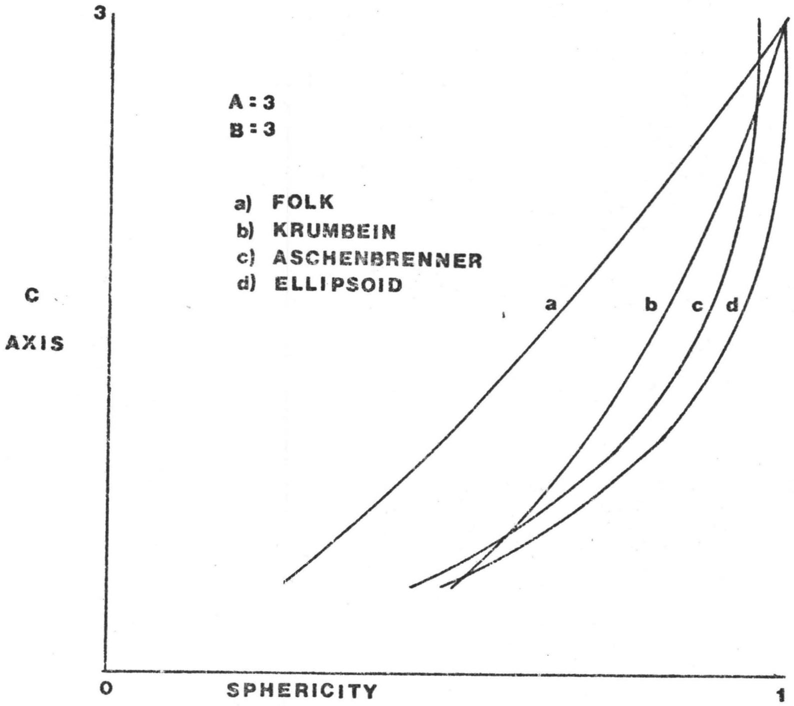


Fig. A1 Changes in Sphericity values with a change in the c axis. B equals 3.

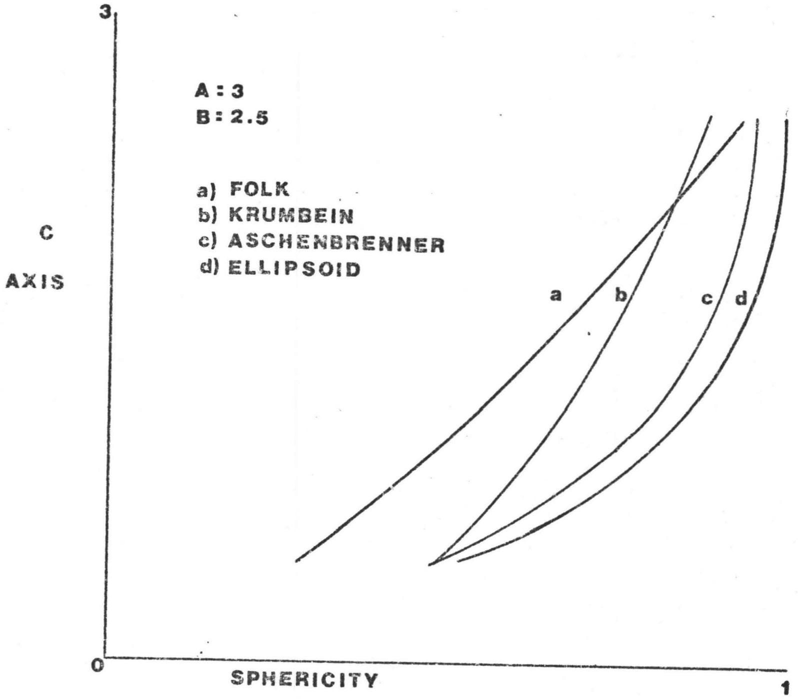


Fig. A2 Changes in Sphericity values with a change in the c axis. B equals 2.5.

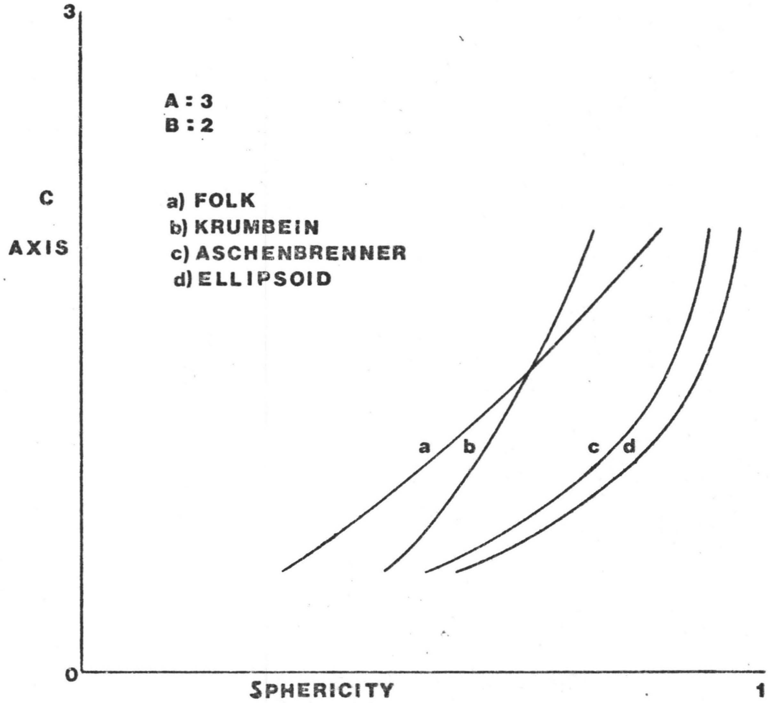


Fig. A3 Changes in Sphericity values with a change in the c axis. B equals 2.

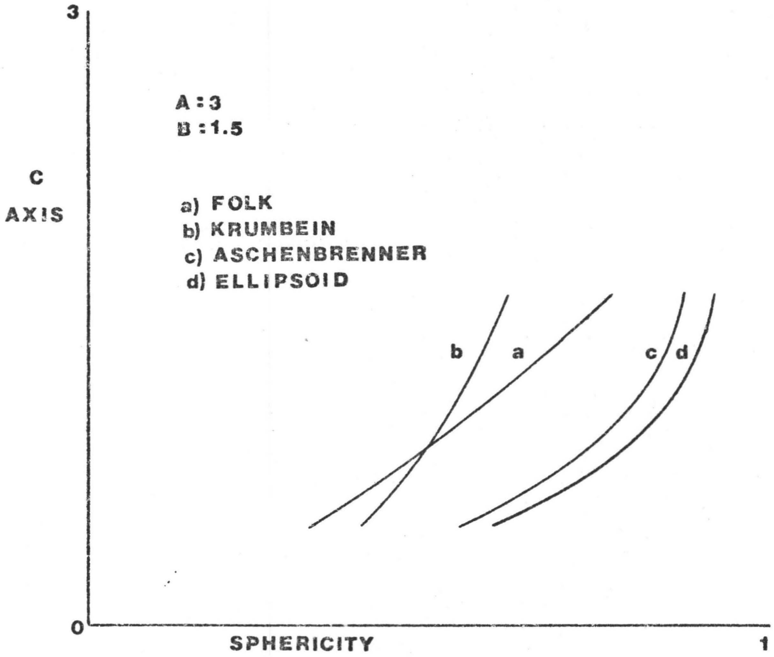


Fig. A4 Changes in Sphericity values with a change in the c axis. B equals 1.5.

Figues A1 to A4 illustrate parts of the first step. The x axis is the calculated sphericity value, while the y axis represents the change in the c axis of the particle. The particle becomes less spherical from Figures A1 to A4. These figures consistently show excellent similarity between Aschenbrenner's measure and that based on an approximation of an ellipsoid for all figures. As the particle becomes less spherical, Krumbein's measure tends to approximate Sneed and Folk's measure more than Aschenbrenner's. As for sensitivity of sphericity as the axes change, the Aschenbrenner measure and ellipsoid approximation only show large change as the particle becomes more oblate--that is as the difference between the c and b axis increases. Sneed and Folk's measure shows almost linear decrease in sphericity with a decrease in the c axis. This change increases slightly as the particle becomes prolate.

Figures A5 to A8 show the second set of axes where the b axis varies as the c axis changes in steps. The y axis is now the change in the b axis of the particle and the particle becomes more spherical from Figure A5 to A8. Again Aschenbrenner's and the ellipsoid approximation measure have similar curves, and both show very little change in sphericity for a change in axes.

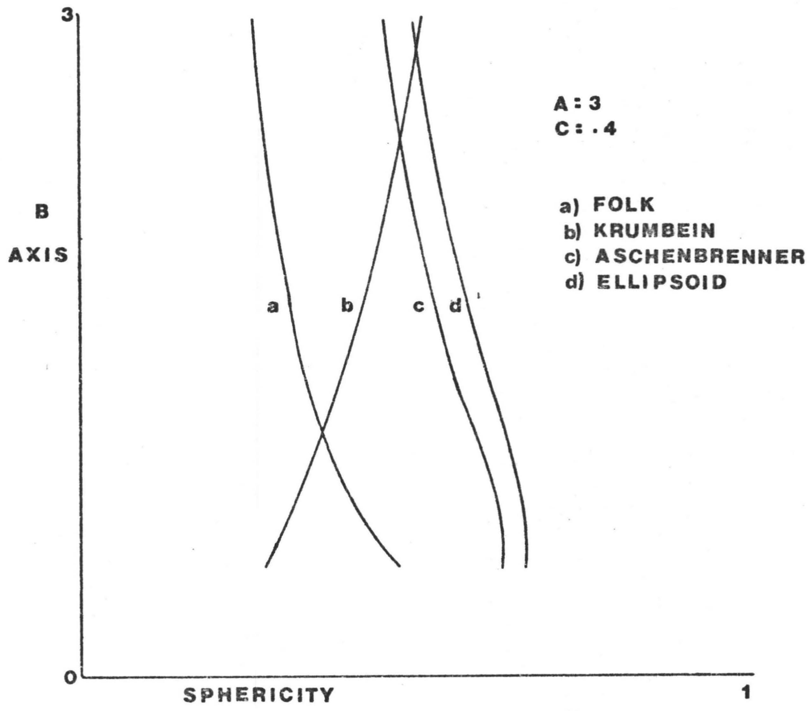


Fig. A5 Changes in Sphericity values with a change in the b axis. C equals .4.

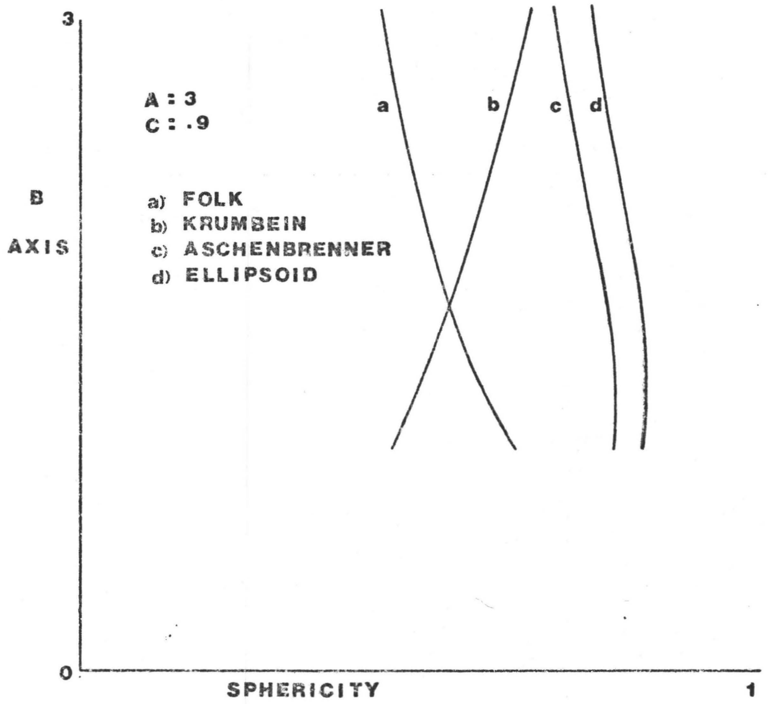


Fig. A6 Changes in Sphericity values with a change in the b axis. C equals .9.

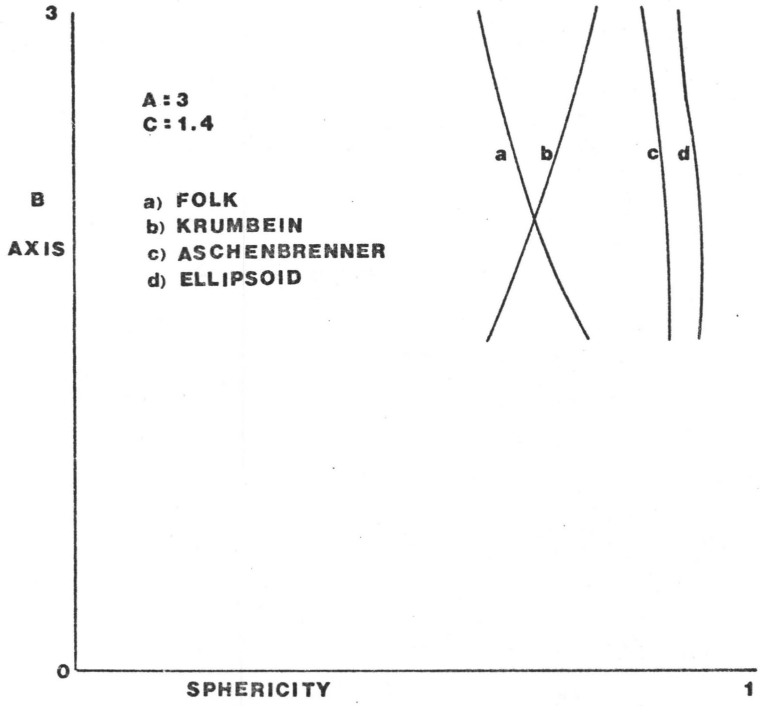


Fig. A7 Changes in Sphericity values with a change in the b axis. C equals 1.4.

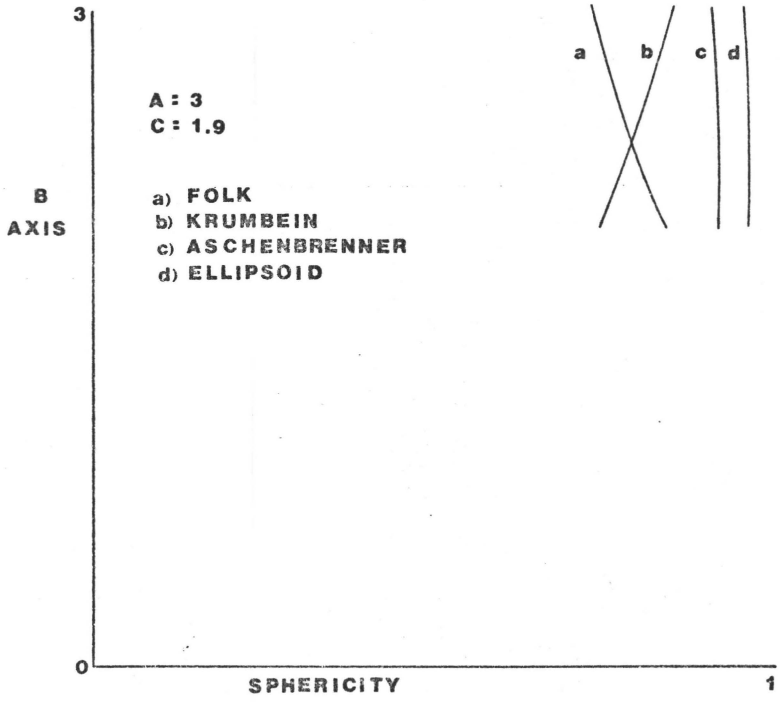


Fig. A8 Changes in Sphericity values with a change in the b axis. C equals 1.9.

The greatest change in sphericity occurs with Krumbein's measure, but the sphericity changes opposite to that of the other measures, because Krumbein's sphericity emphasizes maximum projection area which decreases more rapidly as the particle becomes more prolate than does the surface area of the particle which is in fact increasing in these examples as the particle becomes more prolate and more spherical. The differences between these measures decreases as the particles become more spherical. The best measure for oblate and prolate particles as to sensitivity of the measure with change in particle axes is Sneed and Folk's measure, while Aschenbrenner's measure along with the ellipsoid approximation is better for particles which are oblate. Krumbein's measure is equally effective for all shapes except it is theoretically incorrect.

These same two sets of hypothetical axes were used as input for Williams' shape measure. Figure A9 is a graph of this statistic for a changing value of c as b is decreased in steps while Figure A10 shows a changing value of b for a stepped increase of c. The y axis is the value of Williams' statistic with positive values representing oblateness and negative values, prolateness. The x axis is the change of the c or b axes and each line

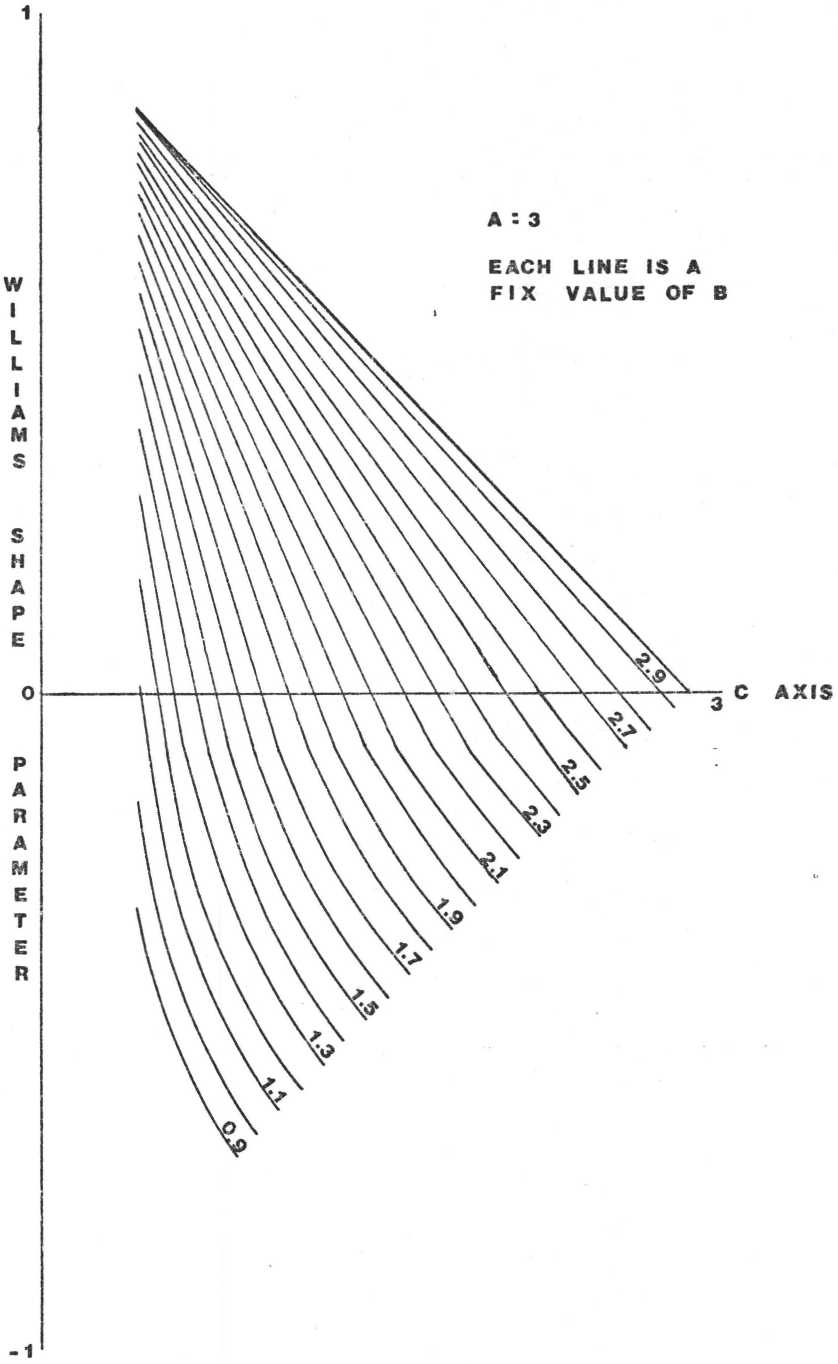


Fig. A9 Changes in Williams' Shape Parameter with a change in the C axis.

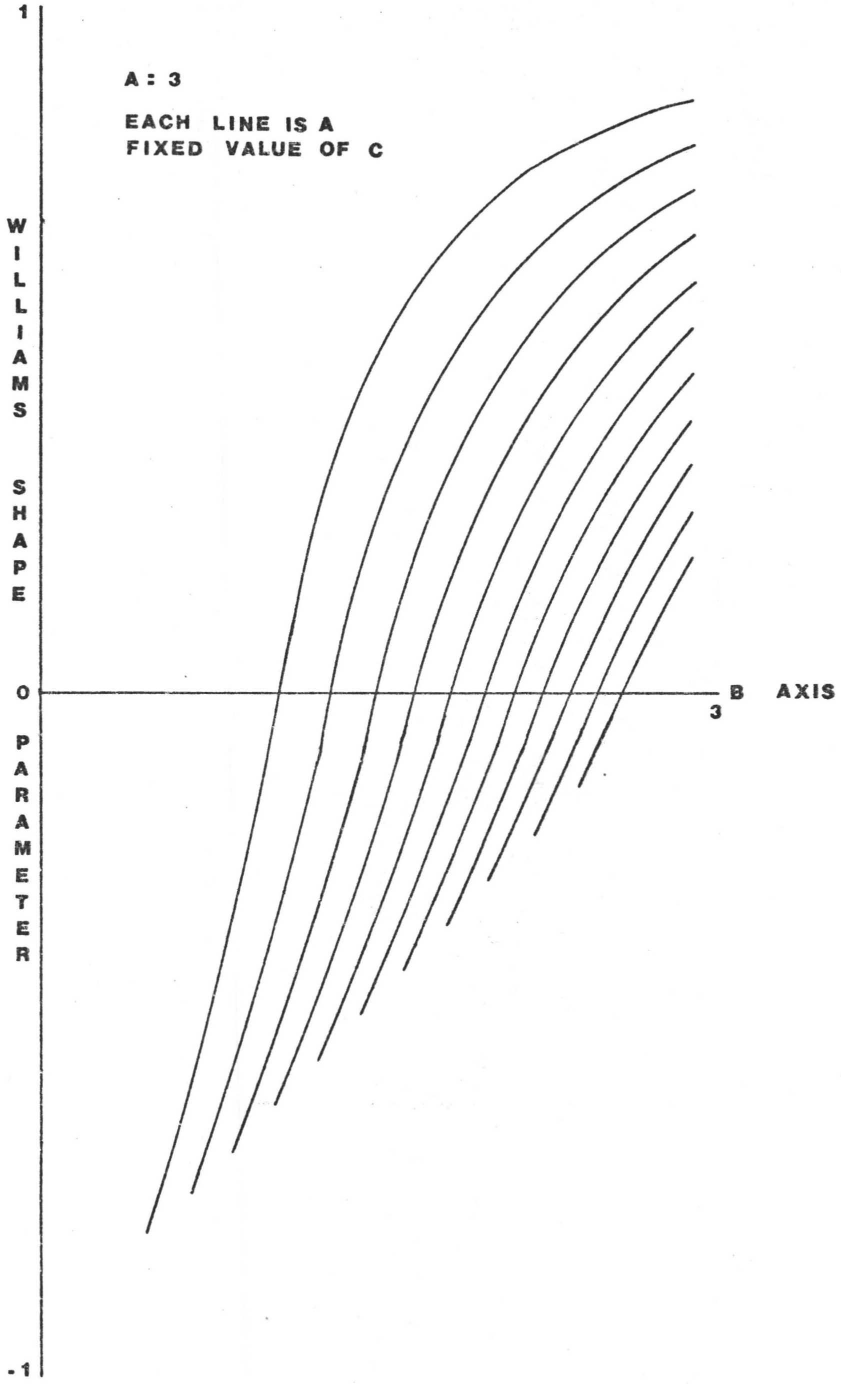


Fig. A10 Changes in Williams' Shape Parameter with a change in the B axis.

on the graph represents a fixed value of b or c respectively. The two figures, though not complete to zero, are representative of most shapes that do occur in reality. The figures show a dominance of oblate particles, that is if all ratios of the three axes of a particle had equal probabilities of occurrence, the majority of particles would tend towards oblate spheroids. The figures show that as the particle becomes prolate and less spherical, Williams' shape measure changes rapidly with small changes in the axes. Thus Williams' measure is sensitive to changes for the same types of particles as Sneed and Folk's sphericity measure, but less sensitive for those of Aschenbrenner's.

c) Comparison of Sphericity Measures

In order to test the degree of similarity of these sphericity measures, a linear regression was performed on a few random samples. The correlation coefficient was used as the indicator of similarity between measures and all coefficients proved significant at the 1% level of significance based on tests from Snedecor and Cochran (1967, pp. 184-185,557). The results are presented in Table A1. As can be seen the Aschenbrenner and ellipsoid approximation measures of sphericity are

TABLE A1 COMPARISON OF SPHERICITY MEASURES FOR SIMILARITY

A - Aschenbrenner's measure
E - Ellipsoid approximation
F - Sneed and Folk's measure
K - Krumbein's measure

SAMPLE	MEASURES TESTED	CORRELATION COEFFICIENT
Sand-3-12	F - K	.74
	K - A	.88
	F - A	.93
	A - E	1.00
Sand-20-5	F - K	.64
	K - A	.68
	F - A	.84
	A - E	1.00
Sand-17-12	F - K	.73
	K - A	.77
	F - A	.93
	A - E	1.00
Sand-1-8	F - K	.55
	K - A	.75
	F - A	.92
	A - E	.99

highly correlated, with Aschenbrenner's method being a very good approximation of the original formula put forward by Wadell (1932, p. 445). The Sneed and Folk, and the Aschenbrenner measures are also highly correlated, implying that Sneed and Folk's measure approximates the definition of sphericity, but it is less in magnitude than Aschenbrenner's measure. Krumbein's measure correlates better with Aschenbrenner's method than with Sneed and Folk's, but the difference may not be significant. Though Krumbein's measure correlates significantly with the others, it has the lowest correlation and fits Wadell's original definition the poorest of any measure. The best and most realistic measures for differentiating the sphericity of particles appear from these results to be Sneed and Folk's and Aschenbrenner's measures.

APPENDIX 4 SHAPE AND SPHERICITY FORMULAE

a equals the largest diameter of the particle.
b equals the largest diameter of the particle at right angles to a.
c equals the largest diameter of the particle at right angles to the a-b plane.
p equals c/b.
q equals b/a.

WADELL

$$\psi = \frac{Ss}{Sr} \qquad \text{(Wadell 1932, p. 445)}$$

where
ψ is sphericity
Ss is the surface area of a sphere, same volume as the particle
Sr is the surface area of the particle

KRUMBEIN

$$\psi = \sqrt[3]{\frac{bc}{a^2}} \qquad \text{(Krumbein 1942, p. 623)}$$

SNEED AND FOLK

$$\psi = \sqrt[3]{\frac{c^2}{ab}} \qquad \text{(Sneed and Folk 1958, p. 118)}$$

ASCHENBRENNER

$$= \frac{12.8\sqrt[3]{p^2q}}{1 + p(1 + q) + 6\sqrt{1 + p^2(1 + q^2)}}$$

(Aschenbrenner 1956, p. 19)

ELLIPSOID APPROXIMATION

$$= \frac{Ss}{Se} \qquad \text{(Aschenbrenner 1956, p. 29)}$$

where
$Ss = 4\pi(abc)^{2/3}$

$Se = 2\pi(c^2 + \frac{ab}{\sin\gamma}(\sin^2\gamma\ E(\gamma,K) + \cos^2\gamma\ F(\gamma,K)))$

where

$$\gamma = \cos^{-1}(c/a)$$

$$K = \frac{a}{b}\sqrt{\frac{b^2 - c^2}{a^2 - c^2}}$$

E and F are elliptic integrals of the first and second kind respectively.

ZINGG (Zingg 1935, p. 55)

$b/a \leq .667$ blade
$c/b \leq .667$

$b/a > .667$ disc
$c/b \leq .667$

$b/a \leq .667$ rod
$c/b > .667$

$b/a > .667$ sphere
$c/b > .667$

WILLIAMS' SHAPE INDEX (Williams 1965, p. 996)

$$W = \left(1 - \frac{ac}{b^2}\right) \quad \text{when } b^2 > ac$$

$$W = \left(\frac{b^2}{ac} - 1\right) \quad \text{when } b^2 \leq ac$$

$W < 0$ prolate spheroid
$W > 0$ oblate spheroid

SNEED AND FOLK SHAPE INDEX (Sneed and Folk 1958, p. 119)

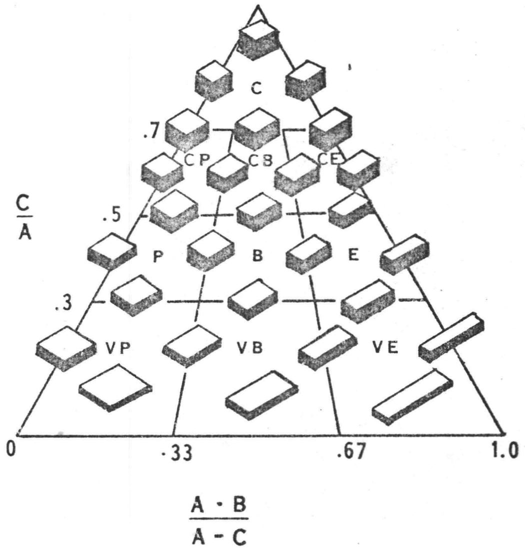
$$R1 = c/a$$

$$R2 = \frac{a - b}{a - c}$$

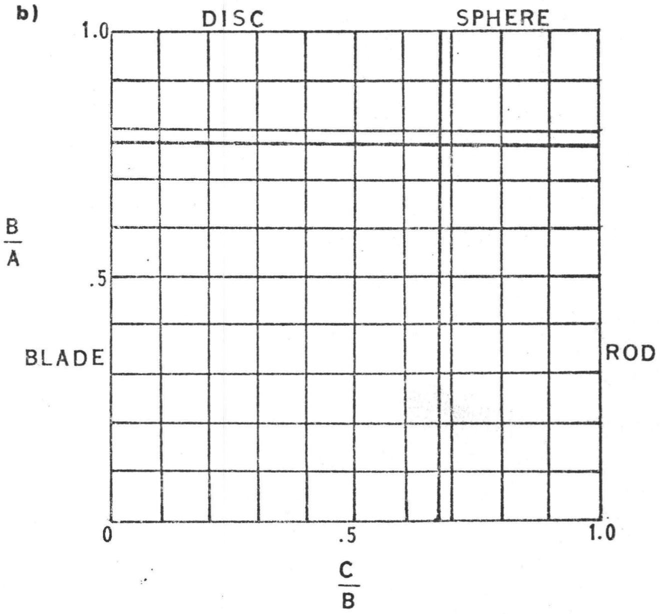
$R1 > .7$		compact
$.7 \geq R1 > .5$	$R2 \leq .333$	compact platy
$.7 \geq R1 > .5$	$.333 < R2 \leq .667$	compact bladed
$.7 \geq R1 > .5$	$R2 > .667$	compact elongated
$.5 \geq R1 > .3$	$R2 \leq .333$	platy
$.5 \geq R1 > .3$	$.333 < R2 \leq .667$	bladed
$.5 \geq R1 > .3$	$R2 > .667$	elongated
$R1 \leq .3$	$R2 \leq .333$	very platy
$R1 \leq .3$	$.333 < R2 \leq .667$	very bladed
$R1 \leq .3$	$R2 > .667$	very elongated

APPENDIX 7 DIAGRAMS OF a) SNEED AND FOLK'S SHAPE CLASSIFICATION
b) ZINGG'S SHAPE CLASSIFICATION

a)



b)



APPENDIX 6 DERIVATION OF EQUATIONS FOR WAVE REFRACTION

The Equations for wave velocity are

1 $$C^2 = \frac{gL}{2\pi}\tanh\left(\frac{2\ d}{L}\right) \qquad \text{where } d/L < \tfrac{1}{2}$$

2 $$C^2 = \frac{gL}{2\pi} \qquad \text{where } d/L > \tfrac{1}{2}$$

U.S. C.E.R.C. Tech. Rpt. No. 4 pp. 62-63

Where

C is wave velocity
g is acceleration due to gravity
L is wave length
d is water depth

In equation 1, wave velocity is dependent on depth; but in equation 2, it is not. Thus refraction is possible only for $d/L < \frac{1}{2}$.

3 Since $$\frac{\sin\alpha 1}{\sin\alpha 2} = \frac{C_1}{C_2} \quad \text{(Snell's Law)}$$

U.S. C.E.R.C. Tech. Rpt. No. 4 p. 65

Where

$\alpha 1$ is the angle of wave front to a contour at time 1
C_1 is the respective wave velocity
$\alpha 2$ is the angle of wave front to a contour at time 2
$C2$ is the respective wave velocity

Then from equation 1

$$\frac{\sin\alpha 1}{\sin\alpha 2} = \frac{\sqrt{\frac{gL_1}{2}\tanh\left(\frac{2\pi d_1}{L_1}\right)}}{\sqrt{\frac{gL2}{2}\tanh\left(\frac{2\pi d_2}{L_2}\right)}}$$

$$\frac{\sin^2\alpha 1}{\sin^2\alpha 2} = \frac{L_1\tanh\left(\frac{2\pi d_1}{L_1}\right)}{L_2\tanh\left(\frac{2\pi d_2}{L_2}\right)}$$

But $$\frac{L}{Lo} = \tanh\left(\frac{2\pi d}{L}\right)$$ Munk and Traylor 1947 p. 25

Where

Lo is the deep water wave length

Therefore $$\frac{\sin^2\alpha 1}{\sin^2\alpha 2} = \frac{L_1 \frac{L_1}{Lo}}{L_2 \frac{L_2}{Lo}}$$

$$\frac{\sin^2\alpha 1}{\sin^2\alpha 2} = \frac{{L_1}^2}{{L_2}^2}$$

4 $$L_2 = \frac{\sin\alpha 2}{\sin\alpha 1} L_1$$

Thus wave length is a function of the angle of wave approach to the contours

Since $\frac{H}{Ho} = KrKs$ Dobson 1967 p. 11

5 $H = HoKrKs$

Where

H is the wave height
Ho is the wave height in deep water
Kr is the refraction coefficient
Ks is the shoaling coefficient

6 $Kr = \sqrt{\frac{bo}{b}}$ Wiegel 1964 p. 157

Where

bo is the separation between orthogonals in deep water
b is the separation between orthogonals at the point of interest

7 $$Ks = \left(\frac{Co}{c(1-(4\pi d/L)/\sinh(4\pi d/L)}\right)^{\frac{1}{2}}$$

Dobson 1967 p. 11

Where

c is the wave celerity
Co is the deep water wave velocity

But

8 $$E = \rho g(\frac{LH^2}{8})$$ King 1959 p. 10

Where

E is the wave energy per foot of wave crest per wave length

ρ is the mass density of water

g is acceleration due to gravity

Thus as shown by equation 4 and 5, wave energy per foot of wave crest per unit wave length is a function of the angle of movement of the wave crest to contours, of wave refraction and of wave shoaling.

APPENDIX 7

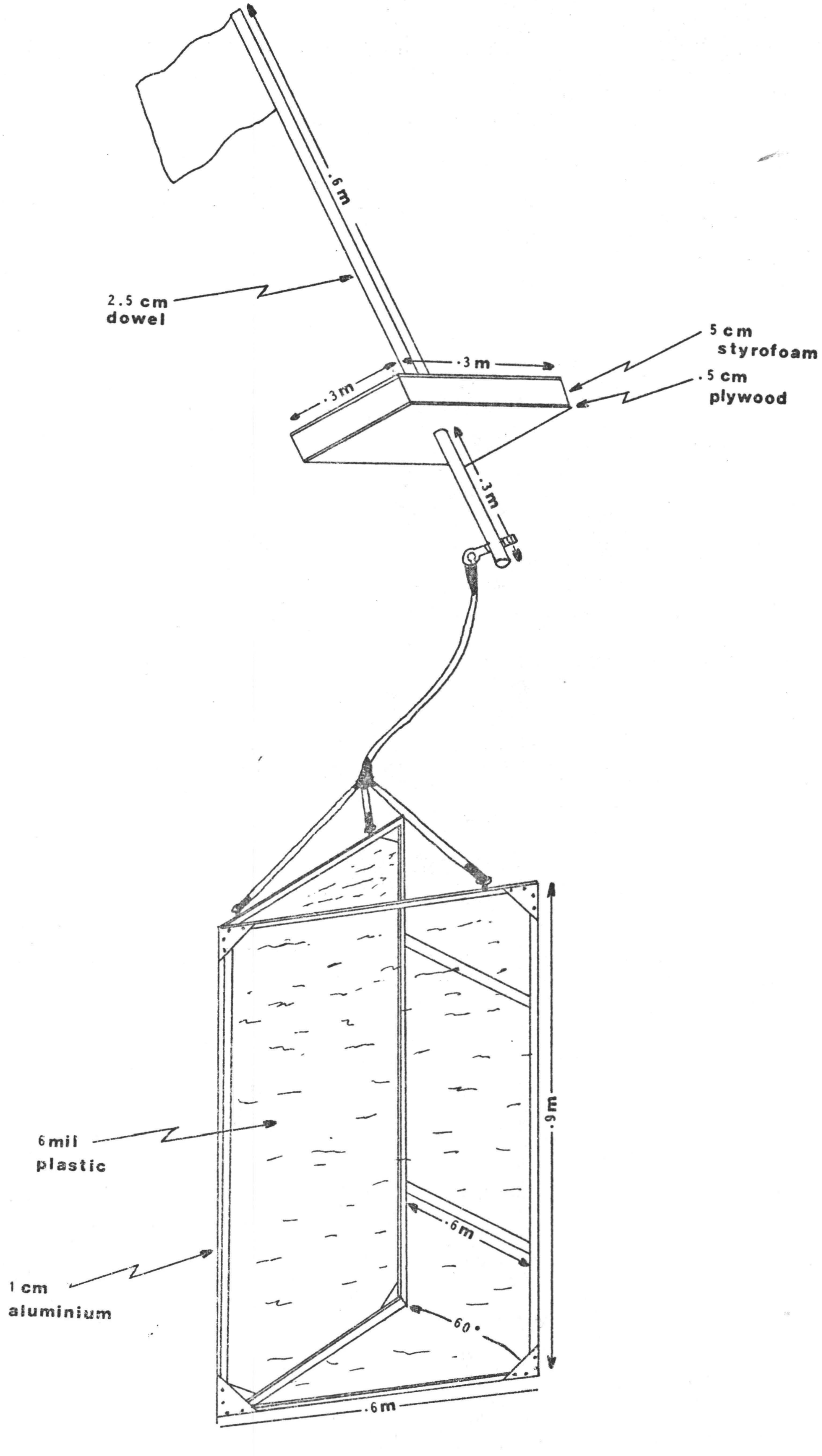
SAMPLE COMPUTER OUTPUT FOR WAVE REFRACTION

```
RICHIBUCTO BAR 1894
SET NO. 1, PERIOD = 6.25 SECS., RAY NO.  1, TIME STEP = +.716 SECS.

   POINT    X        Y       ANGLE      DEPTH    ERROR    FIT  LENGTH     SPEED     HEIGHT     KR        KS

     1    10.84    28.00    -124.70      .00      .00     .00   200.02    32.00      6.30    .0000     .0000
    10    10.51    27.53    -124.57    15.00    17.27     .26   126.47    20.24      6.05    .9980     .9624
    20    10.16    27.01    -124.09    14.74    17.57     .26   125.57    20.09      6.02    .9907     .9646
    30     9.82    26.50    -123.20    13.41    14.44     .20   120.68    19.31      6.03    .9793     .9875
    40     9.50    26.00    -121.69    12.46    16.74     .22   116.95    18.71      6.05    .9727     .9875
    50     9.20    25.51    -120.73    11.65    17.90     .22   113.60    18.18      6.08    .9676     .9977
    60     8.92    25.03    -120.04    10.20     5.35     .08   107.16    17.14      6.17    .9608    1.0194
    70     8.65    24.56    -119.06    10.02    10.16     .15   106.30    17.01      6.15    .9553    1.0225
    80     8.40    24.10    -118.22     9.75    10.45     .15   [illegible] [illegible] 6.15  .9504    1.0273
    90     8.15    23.63    -117.88     9.78    10.86     .14   105.18    16.83      6.12    .9457    1.0267
   100     7.90    23.16    -117.93    10.08    11.52     .17   106.61    17.06      6.06    .9411    1.0214
   110     7.65    22.69    -118.04    10.65    18.51     .24   109.21    17.47      5.97    .9358    1.0122
   120     7.39    22.21    -118.41    10.50    18.78     .24   108.54    17.37      5.92    .9268    1.0145
   130     7.13    21.73    -119.68    10.72    14.57     .18   109.54    17.53      5.82    .9134    1.0111
   140     6.86    21.27    -121.43     9.28     7.37     .07   102.71    16.43      5.84    .8939    1.0362
   150     6.60    20.86    -123.25     6.91    16.57     .17    89.83    14.37      6.03    .8744    1.0943
   160     6.35    20.49    -126.42     6.29    18.21     .17    85.97    13.76      6.07    .8638    1.1149
   170     6.08    20.16    -131.01     5.94    19.29     .17    83.70    13.39      6.13    .8623    1.1278
   180     5.80    19.87    -136.48     5.38    15.89     .12    79.91    12.79      6.29    .8678    1.1508
   190     5.49    19.61    -143.01     5.34    16.00     .12    79.65    12.74      6.39    .8801    1.1525
   200     5.16    19.39    -150.48     5.58    15.33     .12    81.26    13.00      6.48    .9007    1.1424
   210     4.78    19.21    -158.92     6.22    21.30     .15    85.51    13.68      6.55    .9310    1.1174
   220     4.37    19.09    -168.23     6.37    20.79     .15    86.47    13.84      6.80    .9708    1.1121
   230     3.94    19.04    -177.90     6.96    17.34     .12    90.08    14.41      7.03   1.0207    1.0930
   240     3.49    19.[illegible] -1[illegible]7.15  6.60  18.27  .1[illegible] [illegible]  14.07  7.50  1.0780  1.1042
   250     3.08    19.14    -196.84     5.69    21.19     .12    82.06    13.13      8.15   1.1375    1.1375
   260     2.72    19.29    -206.84     4.20    30.70     .12    71.02    11.36      9.10   1.1901    1.2131
   270     2.44    19.46    -215.81     2.88    44.81     .12    59.21     9.47     10.20   1.2268    1.3194
   280     2.23    19.63    -223.52     1.79    72.00     .12    46.98     7.52     11.58   1.2478    1.4728
   290     2.09    19.78    -229.98      .99   130.45     .12    35.05     5.61     13.43   1.2558    1.6980
   300     2.01    19.89    -234.78     -.14  -664.41     .11    24.82     3.97     15.93   1.2563    2.0124
RAY STOPPED,  REACHED SHORE.  X = 2.01,  Y = 19.89
```

APPENDIX 8 DIAGRAM OF A DROGUE



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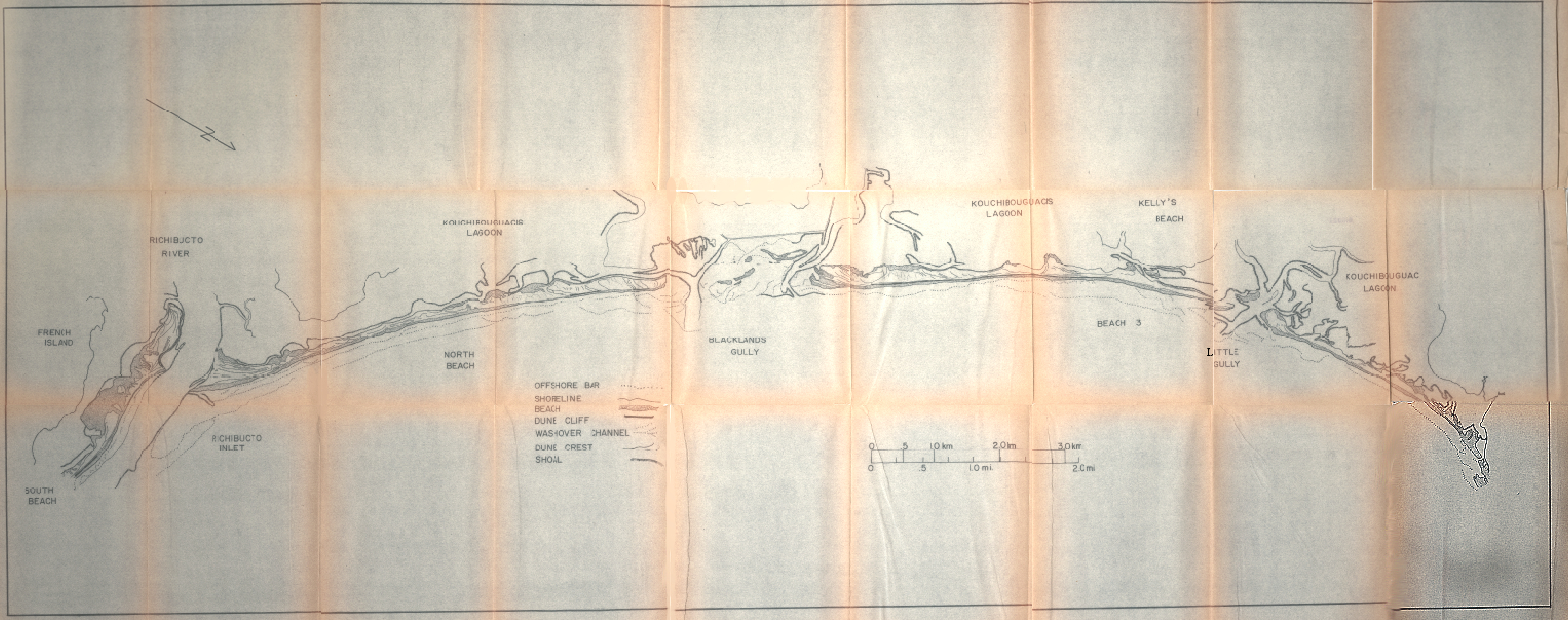
RICHIBUCTO
RIVER
FRENCH
ISLAND
SOUTH
BEACH
RICHIBUCTO
INLET
KOUCHIBOUGUACIS
LAGOON
NORTH
BEACH
BLACKLANDS
GULLY
KOUCHIBOUGUACIS
LAGOON
KELLY'S
BEACH
BEACH 3
LITTLE
GULLY
KOUCHIBOUGUAC
LAGOON
OFFSHORE BAR
SHORELINE
BEACH
DUNE CLIFF
WASHOVER CHANNEL
DUNE CREST
SHOAL
0
.5
1.0 km
2.0 km
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.5
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