Coastal Sedimentation at Lawrencetown Beach

Eastern Shore, Nova Scotia

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Sediment, Foraminifera Work	6
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Abstract

The Lawrencetown beach ridge plain is located approximately 25 kilometres northeast of Halifax, along the Eastern Shore of Nova Scotia. It consists of two beach ridge complexes, one sub-parallel and the other sub-perpendicular to the present coastline. The formation of beach ridges began approximately 700 years B.P. Their presence is the result of marine reworking of sediments derived from drumlins during transgression. Their configuration is related to a drumlin, now a submerged boulder retreat shoal located between Lawrencetown Head and Half Island Point. The process of beach ridge formation is discussed and put into the context of an evolutionary model, which is concerned with the development of coastal sedimentation along the Eastern Shore of Nova Scotia.

Acknowledgements

I would like to express my gratitude to Dr. R. Boyd for suggesting my topic and advising me throughout the project.

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Evolutionary Model for the Eastern Shore, Nova Scotia

Introduction

Lawrencetown Beach is situated on the Eastern Shore of Nova Scotia, approximately 25 kilometres northeast of Halifax. The significance of landforms in this area, in particular beach ridges, are best understood by placing them into the context of an evolutionary model of coastal sedimentation. The evolutionary model for the Eastern Shore region (Boyd and Bowen, 1983) begins with stages 1 and 2, glaciation and subsequent ablation, accompanied by a change in relative sea level (RSL). This is followed by a continuous cycle of depositional and erosional events (stages 3 to 6). These occur in response to a constantly rising RSL encountering discrete sediment sources in the form of drumlins.

This thesis is intended to place Lawrencetown beach ridges into the context of the Eastern Shore evolutionary model. The formation, as well as the age and rate of formation were determined from observation and surveying of present landforms along the Eastern Shore coastal zone. The developmental stages of landforms were determined through the comparison of recent landforms and the study of literature, maps and air photographs, recorded since initial settlement in the mid-1700's. C^{14} analyses, sediment and microfossil research, completed the research.

Evolutionary Model for the Eastern Shore

Stage 1: Continental Glacier and Ice Shelf

The Nova Scotian coastline has been influenced by successive glaciations throughout the Pleistocene. The ice sheet of the most recent Wisconsinan glaciation is believed to have extended over the continental shelf. The boundary between grounded and floating ice was marked by a terminal moraine (King, 1980), located 30-40 km offshore lies in water depths of 150 m below sea level on the central Scotian Shelf. The ablation of the ice sheet which began 18,000 years B.P. (King, 1980) revealed a variety of erosional and depositional features.

The bedrock including the Cambro-Ordovician Meguma Group which occurs along the Eastern Shore region often outcrops or occurs close to the surface. It consists of Halifax Formation slates and Goldenville Formation quartzites which often possess a glacially striated or scoured surface.

Bedrock often forms a core for depositional features called drumlins. These are mounds of till consisting of unsorted clay to boulder size sediments. Drumlins are 0.5 to several kilometres long, up to 50 metres high and are oriented in a north to south or northwest to southeast direction. Drumlins often occur in swarms of 10's to 100's of individual streamline hills.

Lodgement and/or ablation tills are another important glacial deposit. These tills are usually less than a few metres thick, covering large areas of bedrock (Stea and Fowler, 1981).

Stage 2: Relative Sea Level Rise and Estuary Formation

The effects of glaciation and ablation upon RSL have been geophysically modeled by many including Quinlan and Beaumont (1981). Their models have been based upon the peripheral bulge concept of Newman and others (1971). This concept claims that sublithospheric material is squeezed outward from an isostatically subsiding ice sheet, creating a peripheral bulge. Upon glacial unloading this sublithospheric material and resultant bulge migrates back toward the former ice centre due to isostatic disequilibrium.

Geophysical models attempt to predict the change in RSL for a specific section of coastline. The net change will be the cumulative effect of eustatic changes from the release of glacial meltwater and isostatic changes caused by adjustments of the lithosphere in relation to the migration of the peripheral bulge. The result for a coastline is a complex and locally varying RSL history.

Quinlan and Beaumont (1981) predict a maximum RSL low of -30 metres between 6,000 and 8,000 years B.P. and a rising RSL since then. Micropaleontological evidence from a core off Lunenburg Bay, N.S. (Scott, 1982) indicates a maximum RSL low of -27 metres 7,000 years B.P. Studies of Chezzetcook Inlet, N.S. indicate a RSL of

-6.5 metres, 2,000 years B.P. (Scott, 1977). The rate of RSL rise is calculated to be 38 cm/100 years since 7,000 years B.P., with a more recent rate of 32 cm/100 years since 2,000 years B.P.

The rise in RSL following deglaciation resulted in the drowning of river valleys and the breaching of coastal lake boundaries to form estuaries. Resistant bedrock highs and drumlins account for the headlands which separate estuaries.

Stage 3: Barrier Genesis and Progradation

The coastal sedimentation cycle is controlled by a rising sea level which results in the erosion of headlands. Unconsolidated sediments of drumlins are easily reworked. Finer sediments are transported alongshore and landward. Coarser sediments too large to be transported far accumulate at the headlands and form a boulder retreat shoal. Finer sediments from the erosion of till sheets and bedrock are added to the cycle. Sediments for the initial cycle following deglaciation may have also been derived from glacio-fluvial outwash generated from the final stages of ice sheet ablation. Coastal sediments from sources such as raised beaches formed during the initial RSL regression may also have contributed. Sandy sediments moving shoreward accumulate in the quieter water at the estuary mouth. If sediments accumulate at a rate greater than the rise in RSL, barriers initially in the form of spits, will build vertically and prograde seaward. Under suitable conditions the spit may prograde in a longshore direction and form a beach ridge. Continued longshore progradation of beach ridges constricts the estuary producing tidal inlets. Sediments may accumulate as flood and ebb tidal delta complexes associated with tidal inlets. If the sediment supply is great enough and the estuary has an alternate outlet the beach ridges may prograde to form a continuous barrier across the estuary. Salt marshes often form along the perimeter of the estuary. Continued sedimentation results in a seaward progradation of beach ridges to form a beach ridge complex.

Stage 4: Barrier Retreat

Isolated drumlins and shoreface deposits are eventually eroded. Once the rate of sediment supply falls behind the rise of RSL the barrier will cease to prograde. The shoreline will begin to retreat landward. Sediments derived from beach erosion are blown into growing dune fields and are lost to the estuary behind the beach ridges. Reduction in barrier width results in washovers and further removal of sediments from the beach face. Eventually permanent breaching of the barrier occurs and tidal inlets are established.

Stage 5: Barrier Destruction

Marine and subaerial erosion processes combined with rising RSL result in the destruction of the barrier. As the effects of washover intensify more tidal inlets are formed. Finally the subaerial barrier is destroyed. Remnants form landward migrating spits, and intertidal shoals. Other sediments are transported up tidal channels into the estuary and accumulate in tidal flats and marsh deposits.

Stage 6: Barrier Restablishment

Sediments released during the destruction of the barrier remain in the nearshore zone. As the shoreline retreats a new drumlin may be encountered. Concentrated headland erosion of this new drumlin source results in increased sedimentation in the estuary. Spits and barriers again begin to form by the mechanisms described for stage 3 aided by the large volume of remnant sediments from the preceding barrier. Stages 3-6 continue as a cycle resulting in the reduction in size of the original estuary, and continual infilling of the estuary by tidal flat and marsh sediments.

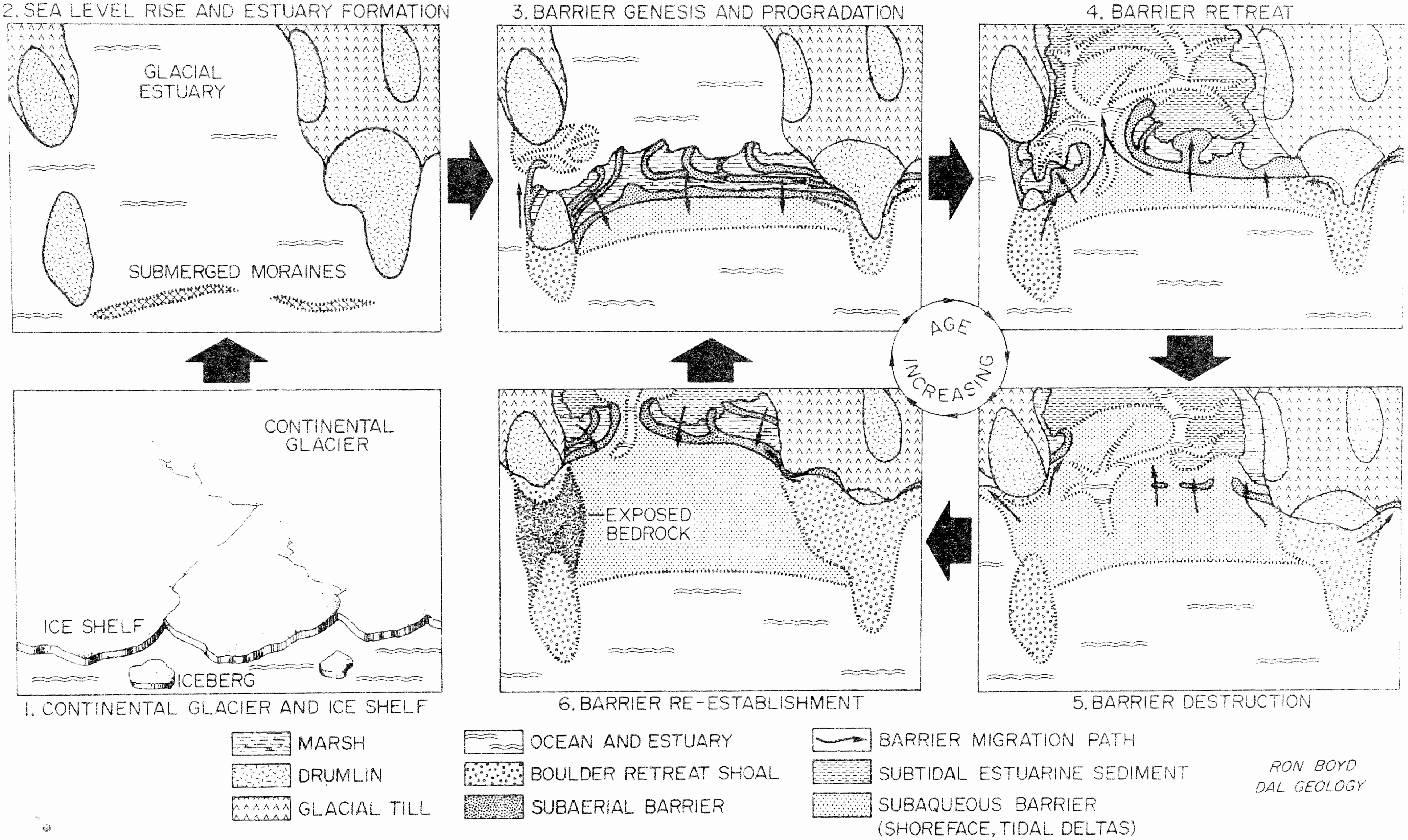


Figure 1. Evolutionary Model for the Eastern Shore, Nova Scotia

Chapter 2

Description of Beach Ridges and Study Area

Beach Ridge Defined

Morphologically a beach ridge complex consists of a series of ridges separated by depressions called swales. Ridges are elongate, and subparallel to one another. Developing along the coast they tend to follow the original coastline. Curray (1967) states that the average spacing between beach ridges along the coast of Nayarit, Mexico is approximately 50 metres, with swales being 1 to several metres below the ridge crest. Ridges range from a few metres to several hundred metres in width and can be followed in some cases up to 50 kilometres (Curray, 1967). Davies (1957) claims the width and spacing of ridges is dependent upon the rate of ridge growth. Rapid growth results in smaller, closer spaced ridges. Slow growth results in the greater addition of wind blown sand culminating in larger, wider spaced ridges.

Although morphology is important in the recognition of beach ridges their mode of formation and stratigraphy distinguish them from morphologically similar features such as cheniers.

A beach ridge complex forms by successive accretion to the coastline during a period of high sediment availability resulting in a depositional regression. Typical stratigraphy would exhibit a continuous sand deposit from the beach ridge, underlain by shoreface sand. Depending upon the depositional history this sequence could be underlain by bedrock, estuarine clay or mud, marsh sediments, or offshore sediments.

Morphologically similar features called cheniers form from alternating short term local transgressional and regressional events. They form as a result of an increased rate of sediment influx causing a depositional regression. When the sediment supply is reduced the mudflats deposited during the regression are winnowed by wave action. Coarse material is piled up in a ridge called a chenier. Stratigraphically they consist of sand and shell lenses on top of marsh and mudflat deposits (Gerdes, 1982). The type example exists in southwestern Louisiana where typical cheniers are 50 to 500 metres wide and extend for tens of kilometres (Hoyt, 1969).

Distinguishing between beach ridges and cheniers is necessary in order to interprete depositional environments, paleogeography and the geologic history of the coastal area under study.

Review of Literature

Beach ridges are often mentioned as being present on a coastline, their morphology is defined, dimensions are noted but very few geologists entertain the question of what mechanisms form them.

D.W. Johnson (1919) summarized the ideas of his time and wrote a comprehensive paper on the topic of beach ridges. He concluded that the most essential requirement for the formation of beach ridges was the reduction in the slope of the immediate offshore profile. He contended that the shallowing of the profile would place it out of equilibrium with the average wave conditions. The waves would adjust the profile by transporting sediment shoreward in an attempt to regain an equilibrium profile. Sand would accumulate in a sub-aerial position as a ridge within the beach profile. He related the construction of a new ridge with storm waves which brought in more sand due to increased suspension. However, he did not think that a particular ridge could be linked to a particular storm. He even hypothesized that "only the more prolonged activities of less violent wave action" were represented as ridges.

Davies (1957), studying beach ridges in Tasmania, Australia, concluded that "the beach berm is the incipient sand beach ridge". He agreed with Johnson's ideas of profile disequilibrium by stating that the shoreline progradation is initiated by a shoaling of the offshore profile. Davies claimed the profile change can result from increased sedimentation, a falling sea level or reduced tidal range.

Davies claimed beach ridges are formed by long wavelength waves with low wave heights. They adjust the profile by resteepening the beach and piling excess material shoreward in the form of a beach berm. Davies mentioned the destructive nature of storm waves. Their backwash carries sediment in suspension seaward, with only a negligible amount of sediment thrown landward out of the reach of the surf. Davies concluded that the incipient ridge is built by calm weather waves and is only established as a permanent ridge when enough wind blown sand and the formation of a new berm allow it to resist storms.

Hails (1969) agreed with the method of formation outlined by Davies and stated that it is completely applicable to the development of the Umina-Woy Woy Beach Ridge System at Broken Bay, New South Wales.

Curray (1967) studied a beach ridge plain in Nayarit, Mexico. He related the upward building and emergence of a longshore bar (low tide terrace) to the successive accretion of a new beach ridge. Conditions of abundant sediment supply and low wave action are required for the bar to emerge to sea level. Low wave action must be maintained, the bar enlarges, captures wave action and becomes a new ridge if it can be maintained throughout storms. The ridge slowly becomes higher and larger from wind blown sand.

Psuty (1967) studied beach ridges in Tabasco, Mexico. Beach ridges were grouped in strand plains adjacent to rivers because of the abundant sediments being discharged. He attributed the formation of successive beach ridges to storms which come on a seasonal basis. Sediments accumulate as a berm primarily during raised water conditions of the seasonal storms. Erosion characterized the lower portion of the beach but the upper portion gained height and breadth through intermittent addition from washover deposition. During the calm season the lower beach would widen seaward. Sufficient progradation of the lower beach would protect the ridge from storms and eventually form a new berm, stranding the newly developed ridge.

Authors seem to differ in the exact mechanisms and conditions responsible for the formation of beach ridges. Some differences may be attributed to the authors' interpretation. Since it is often made from post-depositional investigation it may not be totally correct. Shore processes are variable in local strength and influences. Beach ridges may actually form in somewhat different ways in different locations.

Some of the consistent ideas expressed by the authors include the need for abundant sediment. They attributed ridge formation to waves resteepening a shallowed shoreface profile by transporting sediments shoreward. Rivers are often noted as the sediment source and are a favoured location for beach ridge formation with longshore currents redistributing the sediment. There are usually a greater number and wider ridges near the river mouth with fewer thinner beach ridges downcurrent away from the sediment source.

Hails (1969) claimed sediments for beach ridges in Broken Bay, New South Wales were brought in from the offshore zone. Coastal erosion of bedrock is considered to be less significant than other sources of sediments because of low rates of sediment supply.

Many authors attributed the construction of beach ridges to calm weather. Some authors suggested that they were formed by storm waves, while others suggested that they resulted from a combination of storm and calm water waves.

Eolian sand capping was considered by most authors to be an important phase in the construction and preservation of beach ridges. Eolian sand enlarges a ridge vertically and horizontally allowing them to resist storm erosion.

There are only vague quantitative values given for the rate of beach ridge formation by the authors mentioned. Davies states that a successive ridge will form in a "series of years" while Psuty states that it takes an "undeterminable number of seasons".

Thom (1978) studied C^{14} dates from beach ridge complexes in Australia. By dividing the number of ridges observed into the difference calculated from the two endpoint C^{14} dates Thom calculated the rate of beach ridge formation. He noted that there were periods of rapid growth over some isolated time periods. As a result total averages usually suggest a misleading rate of formation. The highest rate of formation was 1 ridge every 13 years for a limited set of ridges. The total average rate of ridge formation for a complex was in the vicinity of 75 years per ridge.

Beach ridges have formed during times of overall eustatic standstill as well as transgression (Hoyt, 1969 and Hails, 1969). They have also formed during times of overall eustatic regression (Bird, 1973). Beach ridges form as a result of a balance between sediment supply, wave energy and RSL change.

Recent studies have modified ideas presented in the summary of D.W. Johnson (1919). They generally concern extensive beach ridge plains in geological settings quite different from Nova Scotia. However the features and processes described can be related to the comparatively small beach ridge plains associated with the glaciated landforms along the Eastern Shore of Nova Scotia.

Description of Study Area

Lawrencetown Lake is a brackish estuary which exists between two bedrock ridges. Two drumlins lie seaward of the lake and form headlands on both sides of the estuary. Half Island Point lies to the east, while Lawrencetown Head lies to the west (Figure 2). A barrier beach (Lawrencetown Beach) with an associated dune complex is located between the headlands and separates the estuary from the ocean. There is however an opening (Lawrencetown Inlet) west of Lawrencetown Head which allows tidal waters to infiltrate the estuary resulting in the deposition of a flood tidal delta. The perimeter of the estuary, especially the seaward portion is the site of a marshy environment. There exists two beach ridge complexes adjacent to the eastern section of the estuary directly behind the dune complex. One complex trends north-northwest to south-southeast. It is almost perpendicular to the present shoreline and consists of 7 ridges separated by swales. The larger complex consists of 18 ridges separated by swales. It is almost parallel to the present coastline with an overall west to east orientation, however 3 distinct trends can be noticed (Figure 2, 3). The initial, most northerly ridges are arcuate with a northeast to southwest trend. Ridges located in the middle of the complex are less arcuate and trend west to east. The most southern ridges are oriented in a northeast to southwest trend but are not as arcuate as the most northerly ridges.

The dimensions of ridges and swales are variable, however swales are generally twice as wide as ridges. The average width of ridges is 8 metres while swales average 18 metres. Ridges and swales possess different vegetation allowing for easy differentiation when viewed from the air. Ridges are often colonized by mosses, grasses, shrubs and spruce trees. Swales generally possess a wetter environment and are colonized by mosses, grasses, pitcher plants and cranberry bushes.

Although numerous ridges are highlighted on air photographs by vegetation there is not always a large difference in elevation between ridges and swales when observed in the field. This results in difficult recognition of some ridges. As a result, detailed work on Lawrencetown beach ridges was concentrated on well defined ridges which could be easily differentiated by field observation.

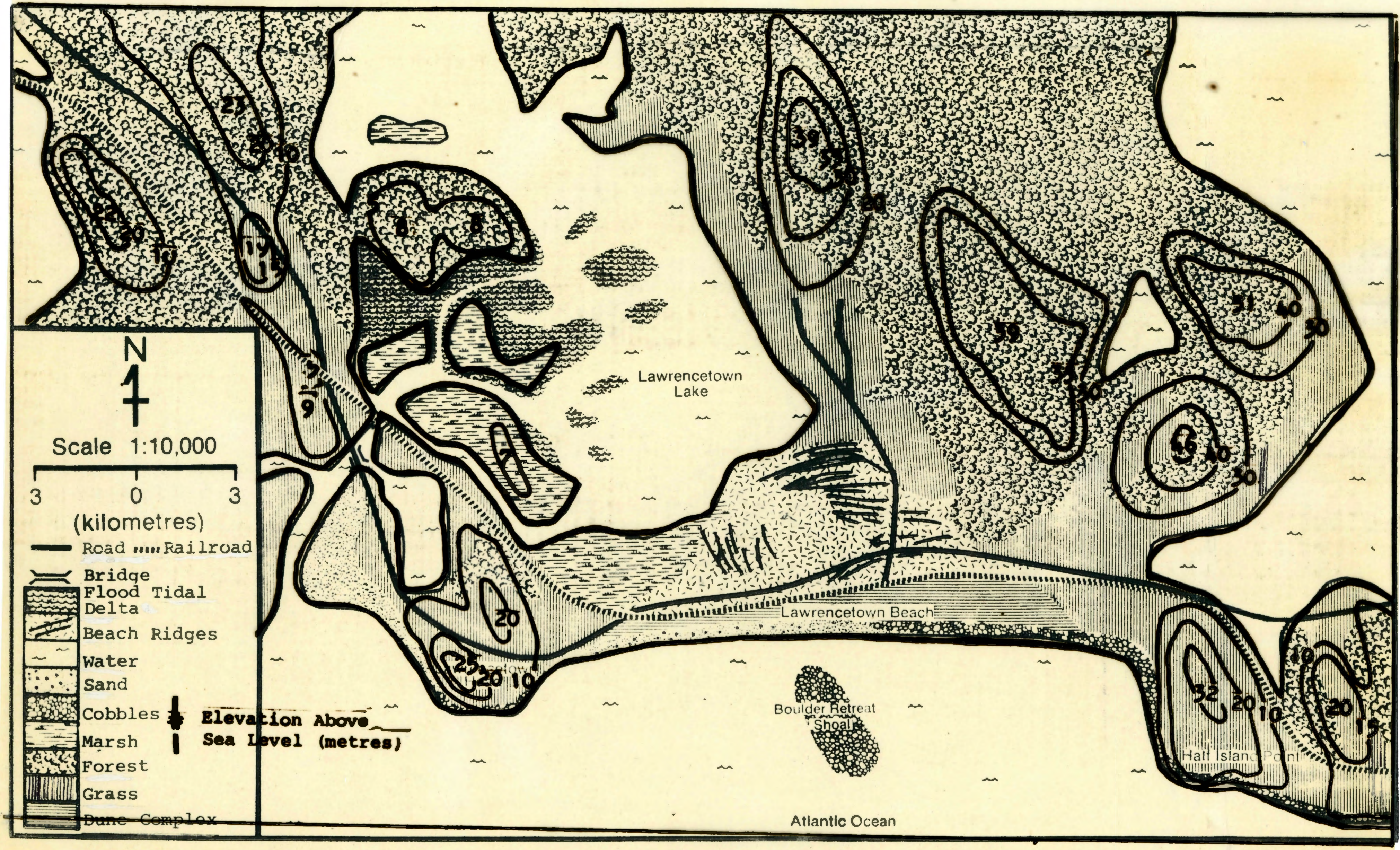
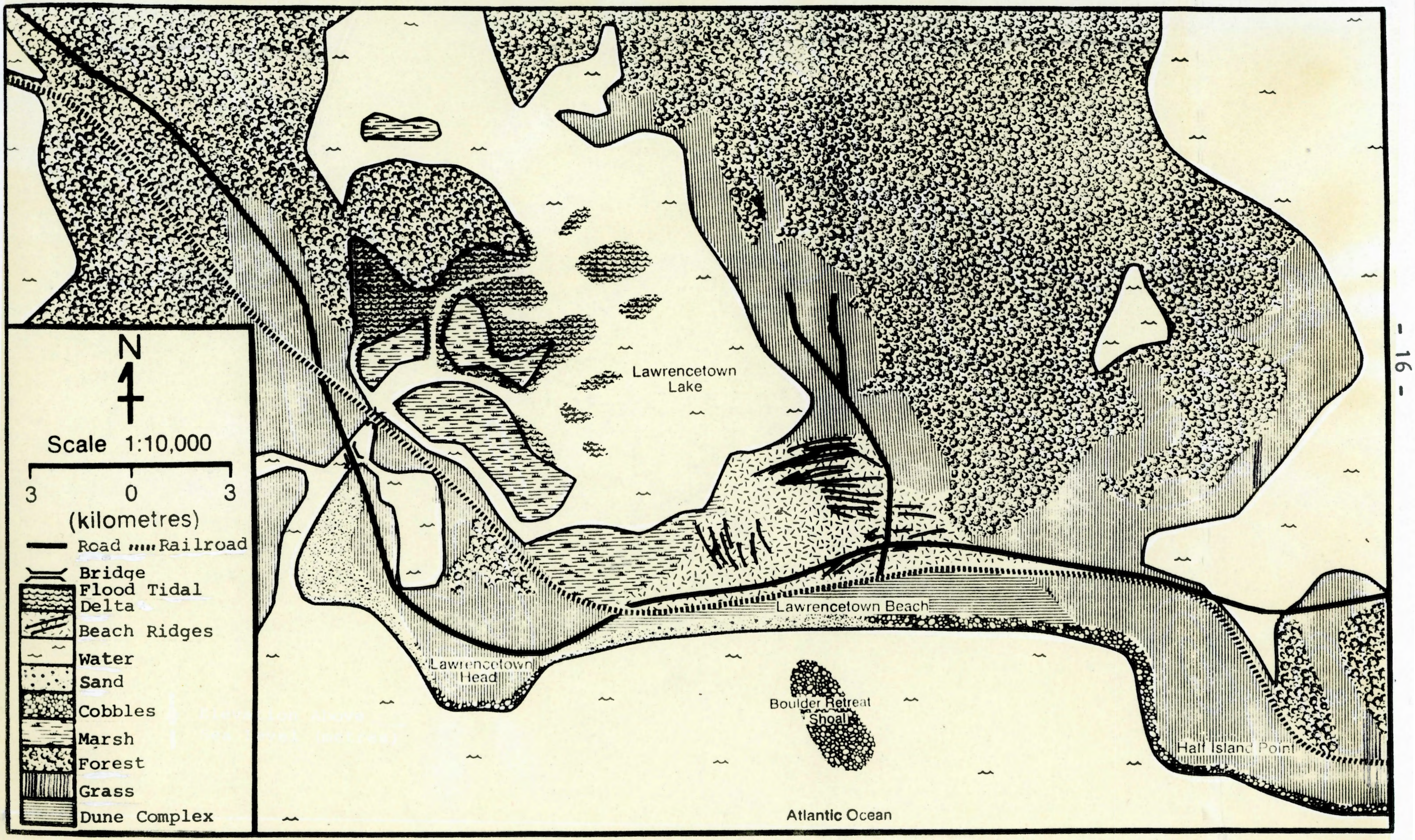


Figure 2. Environments and Topography of the Lawrencetown Area



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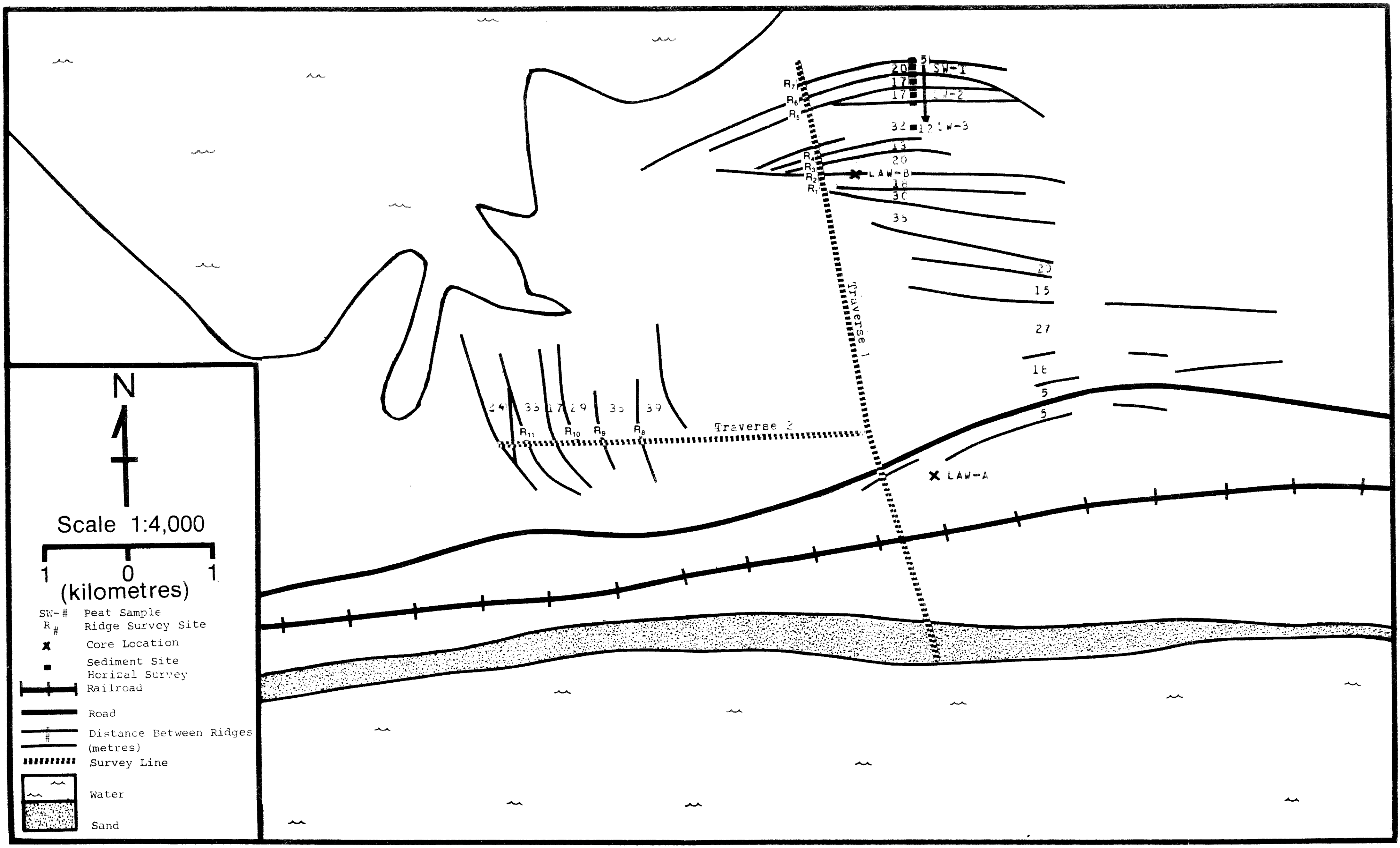


Figure 3. Lawrencetown Beach Ridge Complexes

Chapter 3

Procedures, Data and Discussion

Various procedures were followed to collect data. They can be categorized as either chronological or sedimentological research. Chronological research was aimed at determining the age and rate of formation of the Lawrencetown beach ridges. Sedimentological research was intended to enhance the understanding of beach ridge formation.

Chronological Research

Literature

Initially, historical literature was consulted. The Lawrencetown area was first settled in 1754. Unfortunately, any records kept were mainly concerned with the settlers' activities, they failed to go into much detail concerning geomorphology. It could be inferred however that the single connection between the lake and the ocean which is present today was the only one present in 1754.

Maps

A series of maps and navigational charts dating back to 1776 were analyzed with the intention of inferring stages of beach ridge formation. This was attempted by looking for changes along the coastline and lake perimeter. The area mapped in 1776 looked very similar to present day maps. As a result different stages could not be inferred.

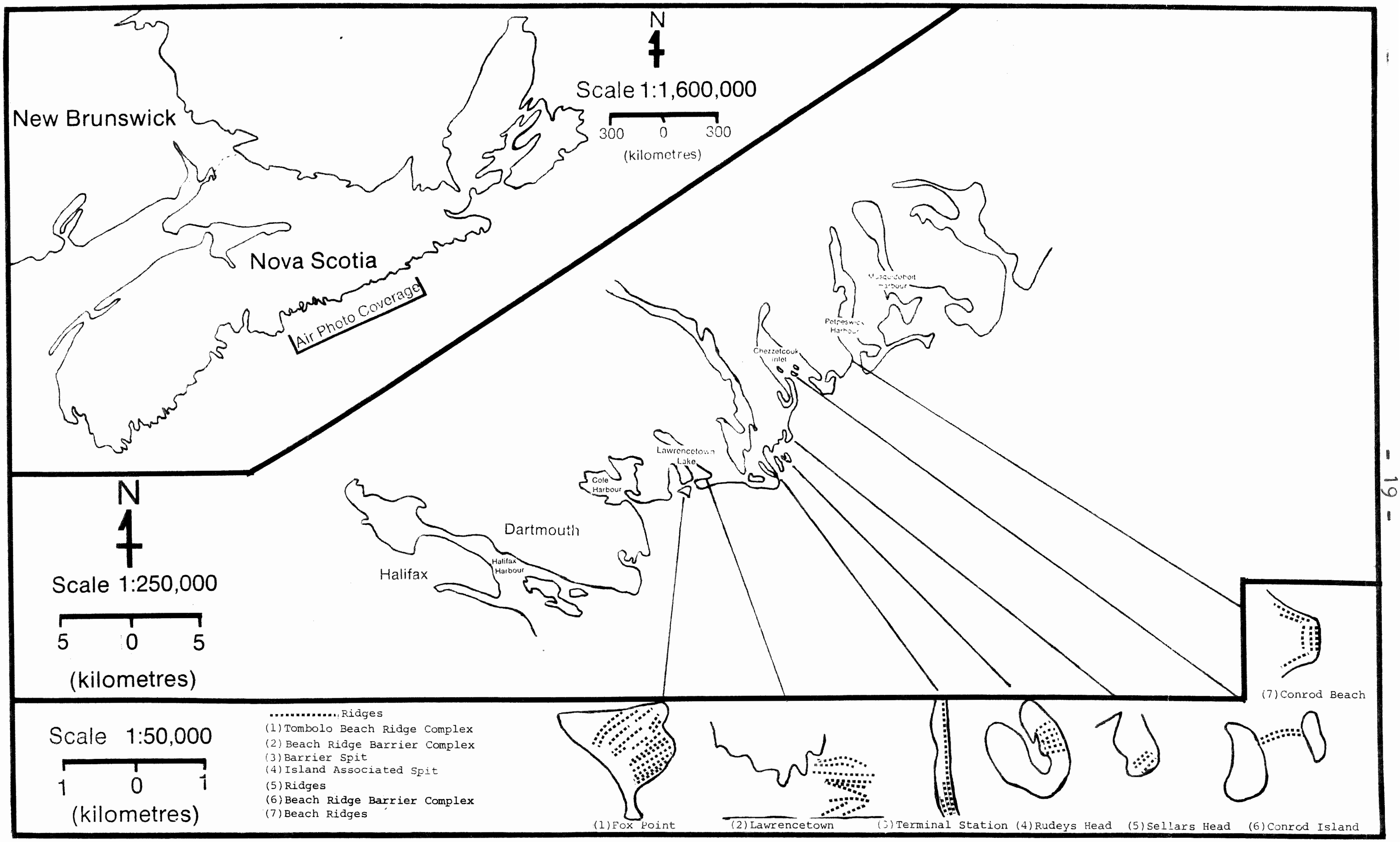


Figure 4. Ridged Features Along the Eastern Shore, Nova Scotia

Air Photos

Air photos covering the coast of Halifax County east of Halifax were analyzed. Figure 4 displays the location of ridged features along the coast. A detailed map of the environments and topography of the Lawrencetown Lake area (Figure 2) was made in order to aid in descriptions. Air photos taken in 1974 were compared with 1945 photos. The Lawrencetown Lake area was analyzed in an attempt to detect subtle changes not recorded on maps. The area appeared very similar, the beach ridges were identical, dune, tidal flood delta and marsh environments were all present and basically similar. Erosion of the headlands and the beach were detected. In 1945, Lawrencetown Beach was completely covered by sand while in 1974 the eastern portion was covered by cobbles. Half Island Point retreated approximately 50 metres, Lawrencetown Head 20 metres and Lawrencetown Beach 10 metres, between 1945 and 1974. The rate of retreat is calculated to be 1.72 m/yr, 0.69 m/yr and 0.34 m/yr respectively. The absence of sand on the eastern portion of Lawrencetown Beach may be attributed to the mining of sand in the 1950's and 1960's, since plenty of material has been eroding from the beach's major source, Half Island Point.

Carbon 14

Three swales between the most landward ridges (Figure 2) were sampled for accumulated peat. An auger was used to drill to the peat/sand interface. The interface represents the top of the swale, while the peat represents organics which accumulated in the swale since its formation. Peat from directly above the interface was sent to Krueger Enterprises Inc. in Massachusetts for C^{14} dating. They described their treatment of the sample as "The entire sample was dispersed in a large volume of water and the clays and organic matter were eluted away from any sand and silt by sedimentation and decantation. The clay/organic fraction was then treated with hot dilute HCL to remove any carbonates. It was then filtered, washed, dried and roasted in oxygen to recover carbon dioxide from the organic matter for the analysis". The dates received were based upon the Libby half life (5570 years) for C^{14}, and were calculated with reference to 1950 A.D. The error stated was ±1 standard deviation as stated by the analytical data. Their modern standard was 95% of the activity of N.B.S. Oxalic Acid.

The three dates were expected to give a minimum age for the beach ridge complex, as well as a rate of ridge formation. It must be realized that the C^{14} dates represent the time at which the peat accumulated and not necessarily swale formation. For example, if there were no plants growing in the swale or if the organics decomposed and failed to accumulate for some period the dates would not correspond to the swales formation. A sample of peat, especially peat which accumulated slowly, would contain organics from a range of ages. Thus, its C^{14} analysis would suggest a more recent averaged age.

The C^{14} ages received were SW-1: 125+/-115, SW-2: -65+/-145, and SW-3 425+/-140 C^{14} years B.P. From these dates it could be seen that the rate of ridge formation could not accurately be calculated.

Theoretically, based upon presumed seaward progradation, SW-1 is older than SW-2 which is older than SW-3. The unexpectedly young first two dates were attributed to the problems previously mentioned. Those swales were small and shallow. Map research did conclude that the total ridge complex was at least 207 years old. The date of SW-3 appears to be more realistic. It was a deeper, wider swale, presently covered by a floating cranberry bog. I believe the wetter environment allowed for a more efficient accumulation of organic material resulting in the more realistic C^{14} date.

Micropaleontology Research

Micropaleontological research was carried out simultaneously with C^{14} research. This research was intended to reveal an assemblage of foraminifera deposited from a hypothetical salt marsh environment which would have been present in a newly formed swale. If present this assemblage of foraminifera could be related to a specific height in the marsh by referring to foraminifera zonation (Scott, 1978). A survey of the swales height with regard to present RSL would be related to the height inferred from the foraminifera assemblage. A net change in RSL would be calculated. The calculated change would be related to documented RSL changes (Scott, 1977) and a time of ridge formation would be calculated. Analysis of successive swales would allow a rate of ridge formation to be detected.

An auger and spade were employed to sample peat and sand from the interface zone of three swales (Figure 2). The sediment was wet sieved through a 1.0 Ø sieve onto a 4.0 Ø sieve. The sediments collected by the 4.0 Ø sieve were analyzed for foraminifera. If there was too much organic material obscuring the analysis it was decanted off, collected and analyzed separately for foraminifera.

The analyses did not detect any foraminifera in the peat or sand. The absence of foraminifera suggests that either they were not preserved or the swales never had an established salt water environment. A particular swale would have been isolated from the salt water following the establishment of a seaward beach ridge. This beach ridge would have acted as a barrier restricting salt water from the swale. Following this, sand would have been blown into the swale and it would have been colonized by vegetation. Prior to becomming a restricted swale, an area would have been subjected to turbulent shoreface environmental conditions, which would have been detrimental to foraminifera existence and preservation. Due to the fact that no foraminifera were found in the swale samples, the rate of ridge formation could not be determined by the process of foraminifera assemblage analysis.

Ridge Survey

It was inferred that the ridges observed at Lawrencetown are nearly the same height now as they were initially following their formation. Cobbles and boulders which were deposited by wave action are only a few centimetres to 10's of centimetres below the surface. The initial heights have been slightly elevated by the addition of wind blown sand and the growth of vegetation.

The Lawrencetown beach ridge complexes were surveyed in order to determine their relationship to mean sea level (MSL). A transit and scale were used to relate the ridge heights to high tide at Lawrencetown

Beach, as local benchmarks could not be located. These heights were related to MSL. The MSL value and tide heights used were from the nearest reference port, Halifax Harbour. The values of the survey were recorded in Table 1 and Figure 5.

A general survey of presently forming and recently formed beach ridges was conducted at two environmentally extreme locations. Conrod Beach, located within the protected waters of Petpeswick Inlet, and Fox Island, which is subjected to the full force of the Atlantic Ocean. (Lawrencetown Beach was probably an intermediate of these two areas as far as wave impact at the time of formation is concerned.) Ridge heights were related to present high tide levels and converted to present MSL values. Beach ridge crests were 3 metres above MSL at Fox Island and 1.5 metres above MSL at Conrod Beach. Beach ridge crests at Lawrencetown would have been between these two extremes immediately following formation.

Ridge heights surveyed at Lawrencetown were all within a limited range with no apparent trend. They ranged from 42 cm to 82 cm above present MSL on traverse 1 and from 70 cm to 124 cm above present MSL on traverse 2 (Figure 2). Some of the variation was attributed to differences in vegetation and eolian sand capping. Changes in ridge height were also attributed to changes in MSL over time. Theoretically, ridges formed by lower water levels will be less elevated than ridges formed by higher water levels, all things being equal. A MSL rise of 32 cm/100 yrs (Scott, 1977) was related to the range of ridge heights. From the limited range of heights it was inferred that the ridges measured on each traverse formed in a relatively short period of time, no greater than 100 to 200 years B.P. The mean value of ridge heights from both traverses was calculated to remove local variability. These values were subtracted from present heights of recently formed ridges and divided by the rate of MSL rise to give possible ages to the beach ridges (Table 2). The possible age of the beach ridges in traverse 1 is a maximum of 730 years and a minimum of 260 years. The possible age of the ridges on traverse 2 is a maximum of 640 years and a minimum of 170 years.

The minimum values can be considered unlikely because map evidence shows the entire beach ridge plain was present 207 years B.P. An intermediate value would probably be more representative of the actual wave conditions which existed when the beach ridges were formed. If the mean value of the two extremes is considered the beach ridges would be about 500 years old (Table 2). The maximum age of about 700 years places a limit on the age of the beach ridges. In conclusion, the Lawrencetown beach ridges probably started to form 500 years B.P., with a maximum age of about 700 years. The average rate of beach ridge formation can be calculated to be 28 to 40 years per ridge.

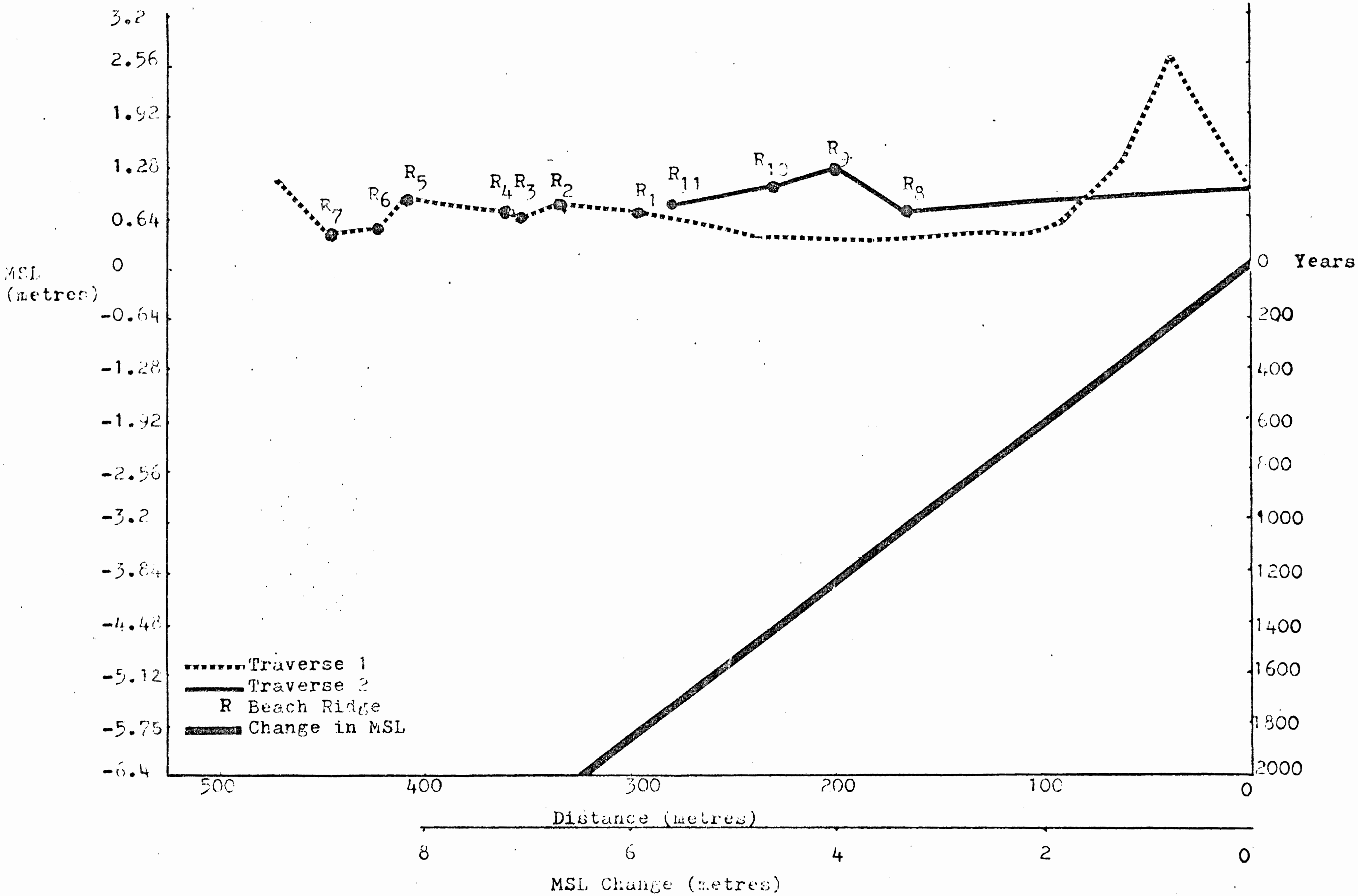


Figure 5. Graph of Traverse 1 and 2

Table 1. Ridge Heights

Traverse 1

Ridge	Distance Between Ridges (m)	Height Relative to MSL (cm)
1		69.5
2	40	81.4
3	20	62.5
4	13	71.3
5	50	89.0
6	17	50.3
7	20	42.1

Traverse 2

Ridge	Distance Between Ridges (m)	Height Relative to MSL (cm)
8		70.4
9	36	124.1
10	29	102.1
11	50	82.0

Average ridge height above present MSL

Traverse 1	66 cm
Traverse 2	95 cm

Recently formed ridge heights above MSL

Minimum	150 cm
Hypothetical	225 cm
Maximum	300 cm

Rate of MSL rise	32 cm/100 yrs

Table 2. Calculated Ridge Ages

Traverse 1	
Minimum	(150 - 66 cm) ÷ .32 cm/yr = 263 yrs
Hypothetical	(225 - 66 cm) ÷ .32 cm/yr = 497 yrs
Maximum	(300 - 66 cm) ÷ .32 cm/yr = 731 yrs
Traverse 2	
Minimum	(150 - 95 cm) ÷ .32 cm/yr = 171 yrs
Hypothetical	(225 - 95 cm) ÷ .32 cm/yr = 406 yrs
Maximum	(300 - 95 cm) ÷ .32 cm/yr = 640 yrs

Sedimentological Research

Grain size analysis was conducted along a vertical and horizontal profile. The vertical profile consisted of the analysis of 13 samples taken along the length of the Lawrencetown B core. The core was drilled through a beach ridge (Figure 2) and consisted of 6.64 metres of massive sand. The core description is accompanied by Scott's microfossil analysis (Figure 6). The statistical parameters were calculated from data of the previously sieved samples. The samples were separated into 0.5 Ø intervals ranging from <-1.0 Ø to >4.0 Ø.

The horizontal profile consisted of the analysis of surficial sediment from 4 ridge and 4 swale locations (Figure 2). Sediment from the swales were collected by the use of an auger which was drilled to the peat/sand interface. Sediment from the ridges was collected by digging below the surface vegetation with a spade. The sediments were boiled in 30% hydrogen peroxide to remove the organics. The sediments were then oven dried and dry sieved into 0.5 Ø intervals ranging from <-1.0 Ø to >4.0 Ø.

Statistical parameters calculated include mean, standard deviation, skewness and kurtosis. The process used for these calculations is called the method of moments (Folk, 1974). The equations used are as follows:

Mean Ø $= \frac{\Sigma DW}{\Sigma W}$ Standard Deviation Ø $= \frac{\Sigma[W(M-D)^2}{\Sigma W}$

Skewness $= \frac{\Sigma f(D-M)^3}{100\sigma^3}$ Kurtosis $= \frac{\Sigma f(D-M)^4}{100\sigma^4}$

D = midpoint of class interval.

W = weight.

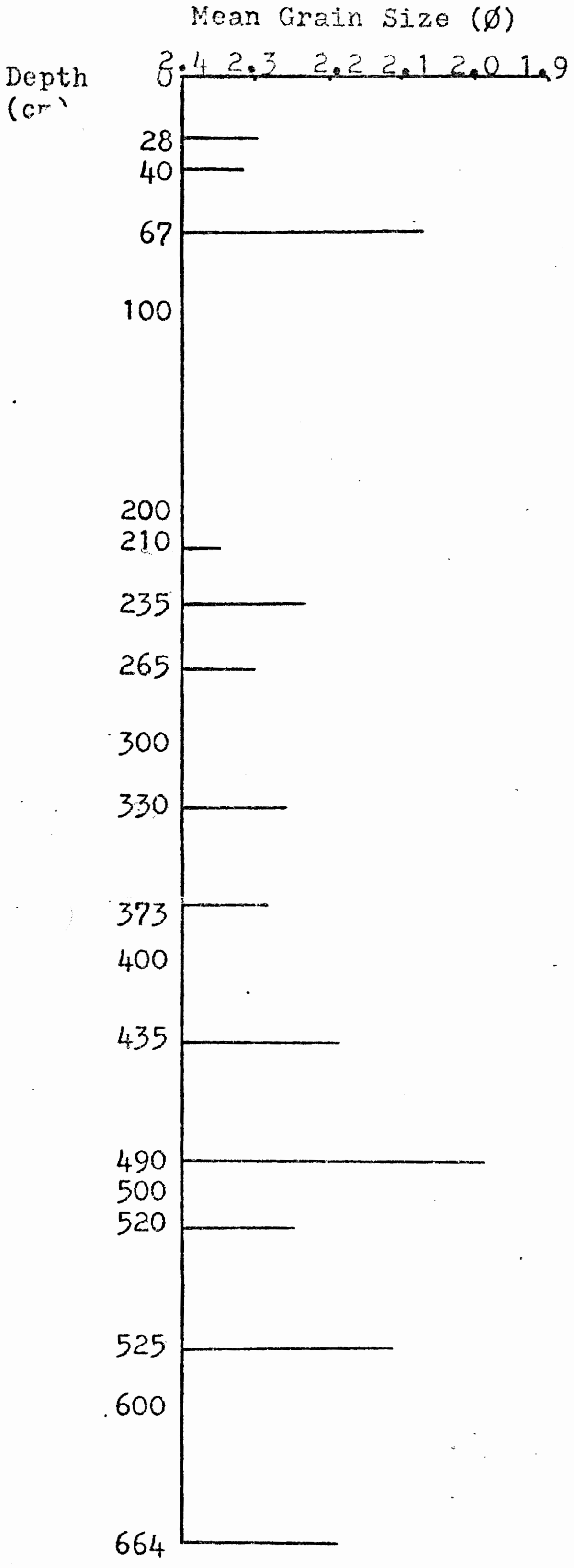
M = mean of sample.

f = frequency.

σ = standard deviation of sample.

Conclusions

Data from grain size analysis was condensed and placed into Table 3. Typical grain size distribution for the two profiles are presented in Figures 7 and 8. Analysis of the data suggested that relatively consistent conditions had prevailed throughout the depositional history of each profile. Samples from the vertical profile were fine grained, well to medium sorted, with grain size distribution displaying a sharp peak about the mean. Scott's micropaleontological analysis revealed only 1 foraminifera. The lack of foraminifera can be explained by considering the conditions under which the sediments accumulated. Shoreface sediments were moved shoreward by waves, resulting in an accumulation of sand in the form of a submerged ridge (longshore bar). Eventually storm wave construction and deposition resulted in the emergence of the ridge to a subaerial position. The ridge continued to grow in width and height as sediments were deposited by wave surge and wind transportation. The beach ridge was built upon sands deposited on the shoreface under turbulent conditions. These depositional environments did not have conditions which were conducive to the existence or preservation of foraminifera. As a result, the core was almost void of foraminifera.



(0-70 cm) Light to dark yellowish brown
well sorted, subrounded to angular, medium sand
Massive with mottling rootlets and pebbles
throughout
(28 cm) One foraminifera Cassidulina reniforme
(70-200) Void

(200-294 cm)	Moderate dark brown
(300-384 cm)	Moderate dark brown
(400-500 cm)	Moderate dark brown
	<u>Same sediment description but no foraminifera present</u>
(500-600 cm)	Dark yellow brown
(600-664 cm)	Dark yellow brown

Figure 6. Lawrencetown B Core Description (82-518 LB)

Table 3. Grain Size Analysis Vertical Profile

Sample Site (cm)	Mean Ø	Standard Deviation	Skewness	Kurtosis
28	2.306	.391	+0.876	8.322
40	2.333	.283	-1.512	63.866
67	2.081	.877	-2.478	10.805
210	2.347	.446	+0.093	8.696
235	2.235	.487	-0.822	11.481
265	2.276	.509	-1.156	10.533
330	2.265	.395	-0.681	15.412
373	2.297	.514	-1.031	8.882
435	2.184	.452	-0.820	8.773
490	1.979	.848	-2.479	10.699
520	2.236	.467	-0.104	8.209
575	2.116	.678	-1.501	7.843
664	2.167	.595	-0.961	6.848

Table 4. Grain Size Analysis Horizontal Profile

Sample Site	Mean Ø	Standard Deviation	Skewness	Kurtosis
5	1.680	.709	+0.754	5.046
6	1.524	.828	+1.382	6.438
7	1.423	.984	+0.712	4.462
8	1.812	.792	+1.107	5.142
9	1.819	.688	-0.263	6.494
10	1.972	.593	-0.203	5.011
11	1.268	.819	+0.547	5.051
12	2.458	.677	+0.188	4.136

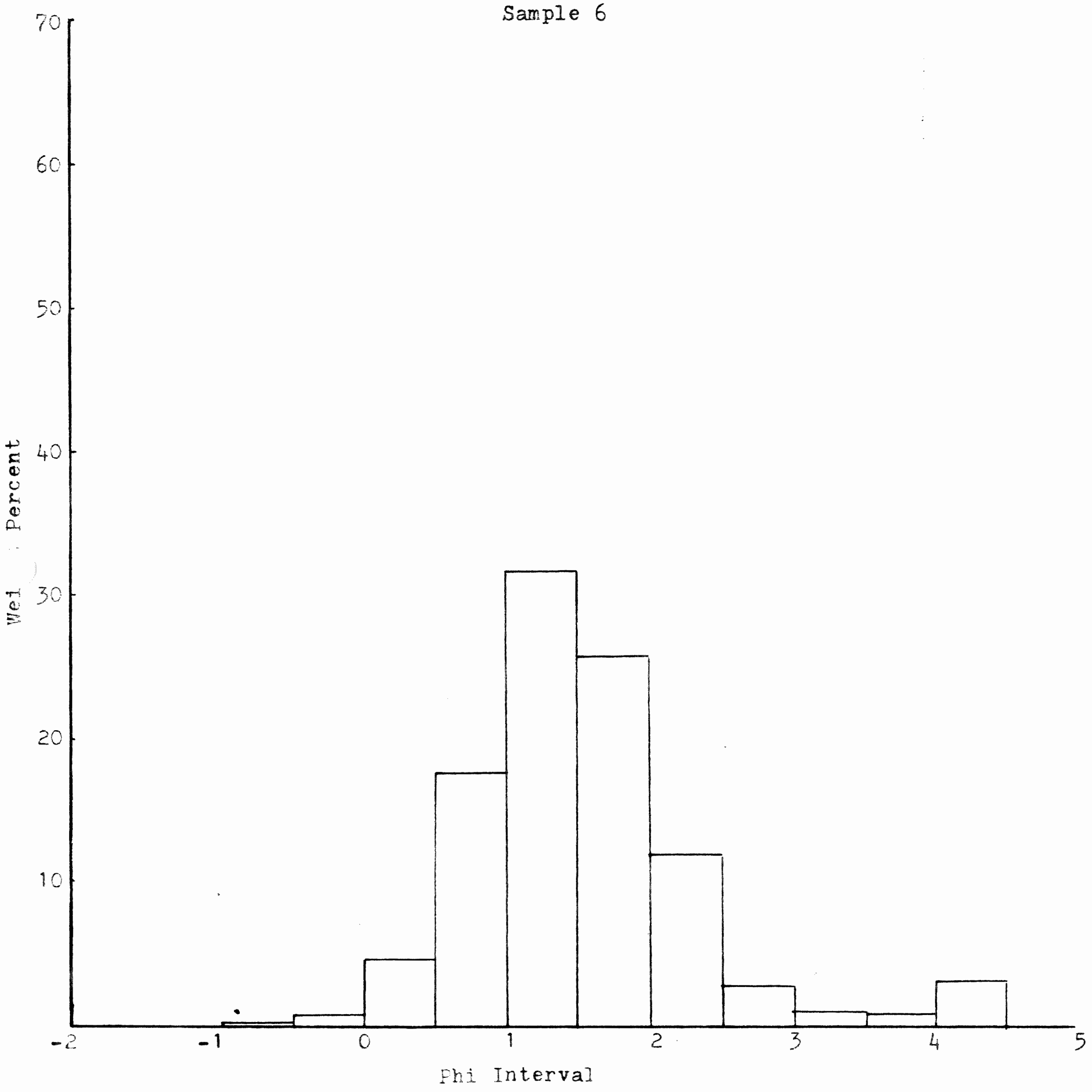


Figure 7. Typical Grain Size Distribution from the Horizontal Profile

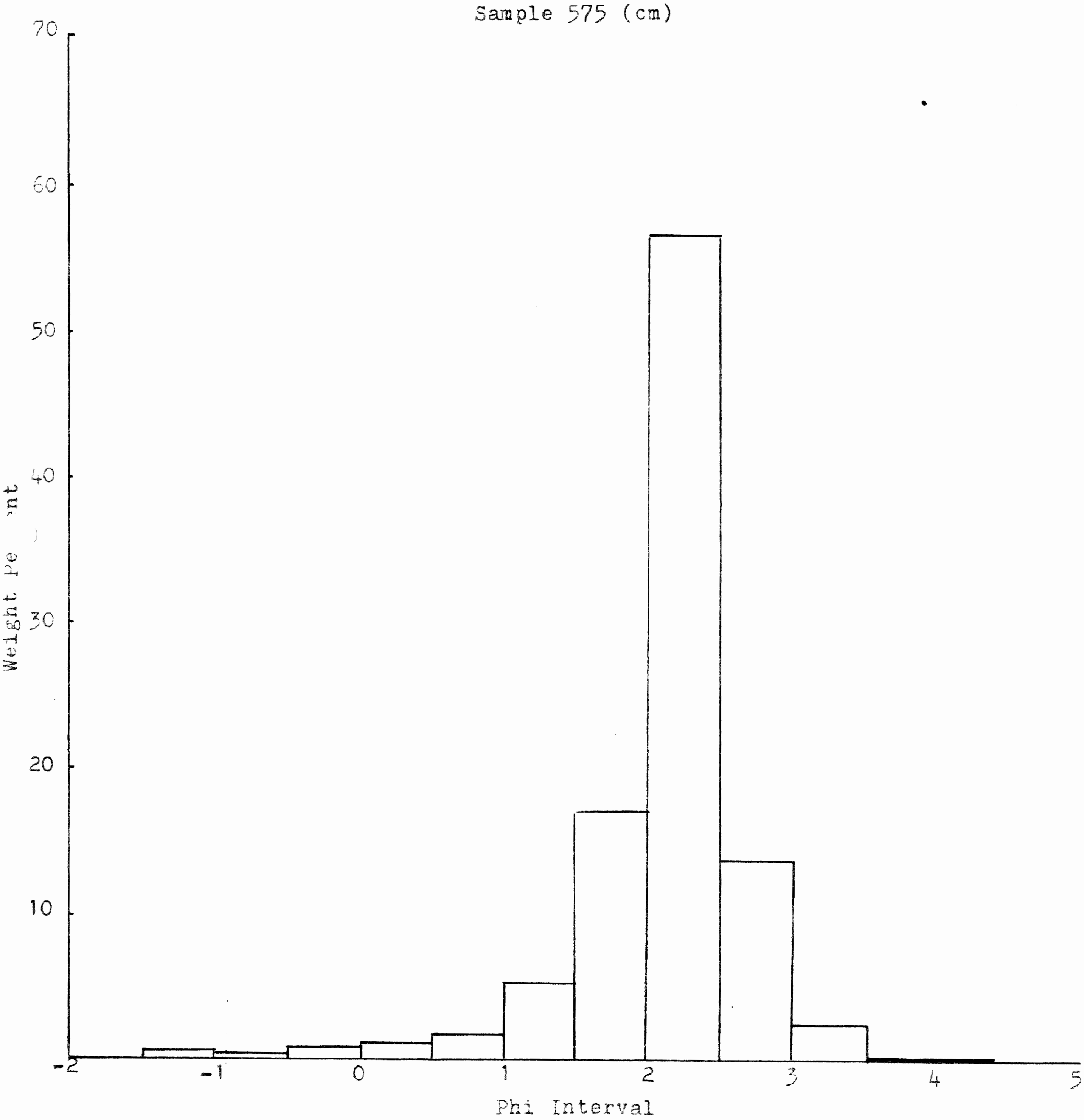


Figure 8. Typical Grain Size Distribution from the Vertical Profile

Samples from the horizontal profile were more variable than samples from the vertical profile. They were medium grained and moderately to well sorted. Their grain size distribution displayed more gently sloping distributions with less peakedness.

The differences between the two profiles can be explained by referring to the conditions of deposition. The vertical profile represents sediments which were deposited mainly in the shoreface zone. The horizontal profile represents sediments deposited in more turbulent waters of the upper shoreface and beachface zones. This explains why the horizontal profile samples are coarser grained. The other differences can also be related to differences in depositional environments. Most of the fines (>4 Ø) from samples of the horizontal profile are believed to be related to the abundance of organic material in the samples. Humic acid from the vegetation and the boiling procedure during preparation may have broken down some of the less resistant minerals into finer particles. Organic residue may have also contributed to the (>4 Ø) fraction.

Chapter 4

Evolutionary Model for the Lawrencetown Beach Ridge Plain

Introduction

An evolutionary model dealing with the formation of landforms and environments is proposed for the Lawrencetown beach ridge plain. The evolution was controlled by a continually rising RSL of 32 cm/100 years (Scott, 1977) which encountered discrete accumulations of easily erodable glacial till, in the form of drumlins. The glacial till was composed of sediments ranging from clay to boulder size particles. The drumlins relief enabled them to become headlands situated at the mouth of a drowned estuary.

The thesis area is illustrated (Figure 9) as a series of drumlins. When related to the present, Half Island Point is to the east, the boulder retreat shoal is the smaller drumlin to the west of Half Island Point, and Lawrencetown Head is the drumlin to the west of the smaller drumlin. These drumlins are situated in front of an estuary which is now Lawrencetown Lake. Boulder shoals situated further offshore are believed to represent eroded drumlins. The evolutionary model of the Lawrencetown beach ridge plain is illustrated in Figure 9.

Stage 1 (approx. 1000 years B.P.) Established Barrier Beach

This stage is hypothetically represented by a continuous barrier beach between Half Island Point and the middle drumlin, as well as recurved spits attached to the west side of the middle drumlin. These structures formed when the water of this area was protected by seaward drumlins. These seaward drumlins supplied sediments for the barriers construction and were almost totally eroded by this stage. Stage 1 of the Lawrencetown model can be related to the general evolutionary model of the Eastern Shore, as it is equivalent to the final product of stage 3 (Barrier Genesis and Progradation). An example of stage 1 can be seen today at Story Head, located 10 kilometres northeast of Lawrencetown Beach.

Stage 2 (approx. 700 years B.P.) Barrier Erosion and Spit Formation

The supply of sediments to the barrier beach was reduced as the seaward drumlins were reduced to boulder retreat shoals. The barrier beach began the retreat process (described in stage 4 of the Eastern Shore's general evolutionary model). The barrier beach was breached and tidal inlets formed, resulting in the formation of flood tidal deltas. Spits associated with the middle drumlin also began to retreat. Sediments were transported further inland, where they accumulated in the quiet water of the estuary mouth and began to form new spits. The drumlins which initially provided anchorage for the barriers became increasingly subjected to ocean processes and began to erode. A similar stage may be seen today at Cow Bay, located 7 kilometres northwest of Lawrencetown Beach.

Stage 3 (approx. 500 years B.P.) Beach Ridge Formation

The original barrier beach became completely eroded, and it s sediment transported landward where it accumulated as beach ridges in the quieter water of the estuary mouth. Marshy environments began to develop along the perimeter of the estuary behind the beach ridges. Drumlins continued to erode, larger sediments remained to form boulder retreat shoals while finer sediments were added to the prograding beach ridges and to recurved spits which were forming on the western side of the middle drumlin. A similar stage may be seen today in Chezzetcook Inlet, located 8 kilometres northeast of Lawrencetown Beach. The relevant area includes Roasts Hay Island, Conrod Island and Indian Island.

Stage 4 (approx. 400 years B.P.) Beach Ridge Progradation

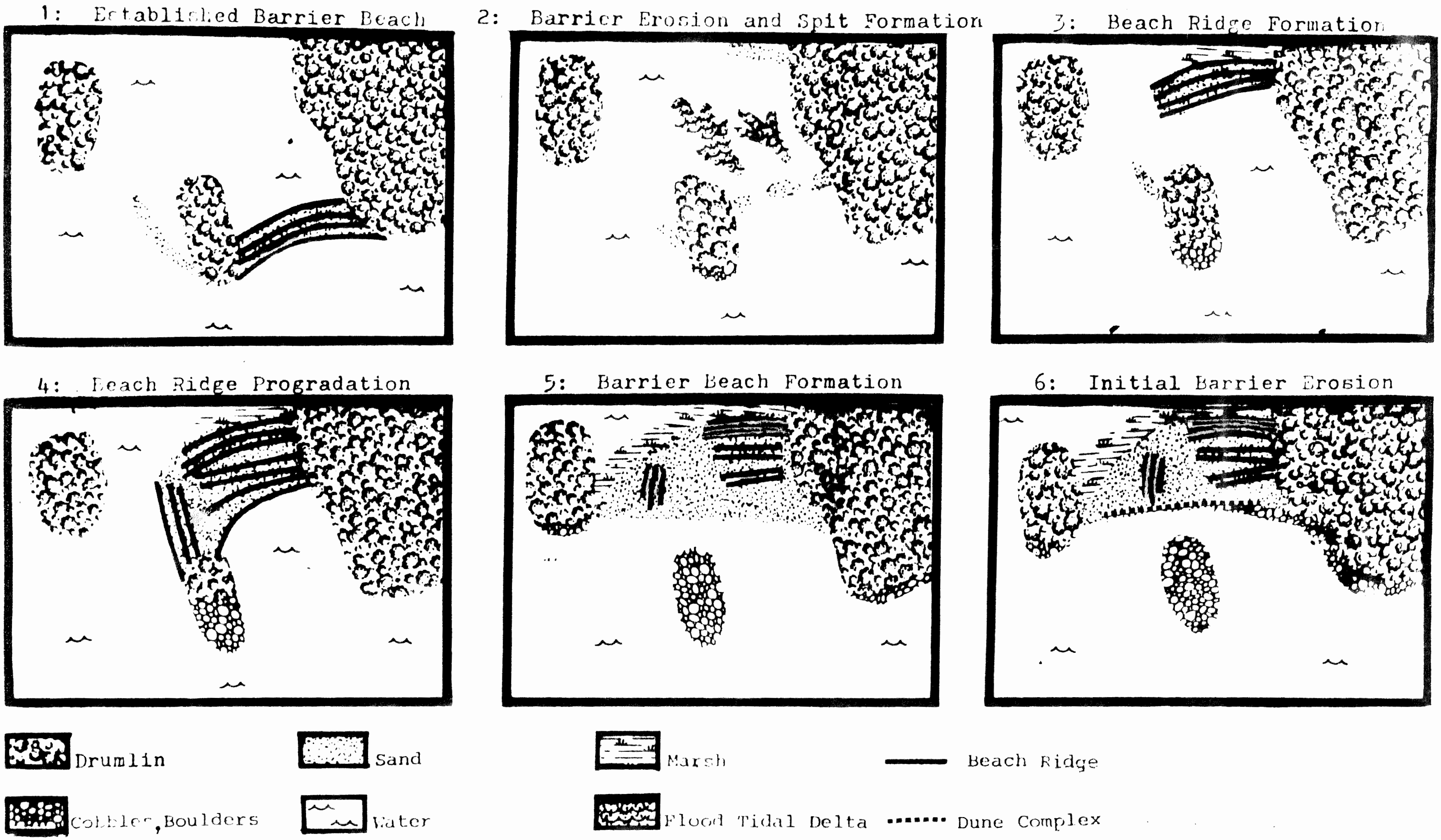
The middle drumlin continued to erode at a more rapid pace than the others. Beach ridges and spits continued to prograde, forming a continuous barrier between the middle drumlin and Half Island Point. Storms or nondepositional periods resulted in erosional truncations. The shoreface profile was adjusted during these periods, thus beach ridges which formed following these events were oriented differently. Three different trends developed during the progradation of the complex. Tidal exchange through the inlet between the middle drumlin and Lawrencetown Head became restricted as more sediments were deposited. Reference to the site mentioned in stage 3 is the best comparison to this stage.

Stage 5 (approx. 300 years B.P.) Barrier Beach Formation

The middle drumlin was eventually submerged, only a boulder retreat shoal remained. Continued sediment deposition infilled the tidal inlet between Lawrencetown Head and the middle drumlin, stopping its tidal exchange. A continuous barrier beach formed between Half Island Point and Lawrencetown Head. Only 1 inlet (Lawrencetown Inlet) remained, connecting the estuary and the ocean. Marshy environments continued to become established along the estuary perimeter. Stage 5 is very similar to the present conditions, it only lacks erosional features which were formed in stage 6.

Stage 6 (present day) Initial Barrier Erosion

Today, the remaining drumlin headlands continue to erode, dune fields are established behind Lawrencetown Beach and the eastern portion of the beach is covered by cobbles. The beach is in an erosional state which may be the result of insufficient sediment supply from Half Island Point. The mining of sand in the 1950's and 1960's may be linked to its present state. Today, Lawrencetown Beach can be placed at the beginning of stage 4 of the Eastern Shore evolutionary model.



1: Established Barrier Beach

2: Barrier Erosion and Spit Formation

3: Beach Ridge Formation

4: Beach Ridge Progradation

5: Barrier Beach Formation

6: Initial Barrier Erosion

Figure 9. Evolutionary Model for the Lawrencetown Beach Ridge Plain

Chapter 5

Conclusions

The literature review revealed that many of the ideas summarized by D.W. Johnson (1919) have been modified over the years by a variety of geologists. It was seen that beach ridges can form under any eustatic condition. Beach ridge formation is the result of a balance between sediment supply, wave energy and RSL change. Detailed studies of beach ridges are limited, and few precise rates of beach ridge formation are available. The most extensive studies have concerned large beach ridge plains in Mexico and Australia. These studies may be used as a guide to assist in the interpretation of the comparatively smaller beach ridge plains associated with the glacially modified landscape of the Eastern Shore of Nova Scotia.

Beach ridge formation on the Eastern Shore of Nova Scotia is part of a sedimentation cycle which is driven by a continually rising RSL which encounters and erodes discrete sediment sources in the form of drumlins. Beach ridges will form when the rate of sediment supply exceeds the rate of RSL rise. Sediments are supplied by proximal drumlins and sediment barriers which were supplied by previously eroded seaward drumlins.

The first evolutionary stage of Lawrencetown beach ridges corresponds to the end of stage 3 of the general Eastern Shore evolutionary model. The Lawrencetown model progressed through the Eastern Shore sedimentation cycle as seaward barriers eroded and beach ridges prograded. The orientation of the two beach ridge complexes at

Lawrencetown is strongly related to a drumlin, now a boulder retreat shoal which exists between Half Island Point and Lawrencetown Head. The three trends seen in the larger complex are the result of orientation changes of beach ridges formed following storms or periods of nondeposition.

C^{14} analyses and ridge survey suggested that Lawrencetown beach ridges began to form a maximum of 700 years B.P. A more probable date of 500 years B.P. was suggested after consideration of wave conditions. The first 7 beach ridges of the larger complex formed over a period of 100-200 years, at an average rate of 1 ridge per 14 to 28 years. The overall average rate of beach ridge formation is 1 ridge per 28 to 40 years.

The final stage of the Lawrencetown model represents the area as it is today. Lawrencetown Beach is undergoing initial barrier retreat which corresponds to the beginning of stage 4 of the Eastern Shore model. Lawrencetown Beach consists of only cobbles in the eastern portion, while the entire beach is backed by dunes. In 1945, the entire beach was covered by sand. The reduced coverage of sand may be related to sand mining operations in the middle of the century. Half Island Point is the source of most of the sediment supplied to Lawrencetown Beach. It is presently eroding as much as 3 metres per year in some locations (Boyd and Bowen, 1983). Between 1945 and 1974 it eroded at an average rate of 1.7 m/yr. With such an abundant sediment supply, a sandy beach should have been maintained. Since sand removal is no longer permitted, the beach may re-establish itself and prograde again at some future time.

Appendix

Maps Used

Year: 1776
Scale: ?
Compiled by: ?
Particulars: Atlantic Neptune Series No. 37

Year: 1853
Scale: 1:60,000
Compiled by: Admiralty Chart

Year: 1972
Scale: 1:10,000
Compiled by: Department of Lands and Forest
Particulars: Orthophoto mapping, contoured

Air Photography of Eastern Shore Beaches

Year: 1982
Scale: 1:10,000
Source: Department of Lands and Forests
Colour

Year: 1974
Scale: 1:10,000
Source: Macdonald Science Library
Colour

Year: 1945
Scale: Alt. 11,000', focal length 8.25"
Source: Department of Lands and Forests
Black and white

Ridge Survey

Traverse 1

H.	BS	FS	BS-H.	H.-FS	Ht Rel SL(ft)	Ht Rel SL(cm)	Ht Rel MSL	Comments
5.09		10.54		-5.45	0.0	0.0	100.0	
5.09		10.54			+5.45	+166.1 x	266.1	
		9.45		-4.36	+1.09	+33.2	133.2	
5.16	2.63		-2.53		-1.44	-43.9	56.1	
		5.65		-0.49	-1.93	-58.8	41.2	
		5.53		-0.37	-1.81	-55.2	44.8	TBM #1
4.99	4.58		-0.41		-2.22	-67.7 x	32.3	
		4.83		+0.16	-2.06	-62.7	37.3	
4.69	5.75		+1.06		-1.00	-30.5	69.5	ridge 1
		4.3		+0.39	-0.61	-18.6	81.4	" 2
4.67	4.05		-0.62		-1.23	-37.5	62.5	" 3
		4.38		+0.29	-0.94	-28.7	71.3	" 4
4.77	5.53		+0.58		-0.36	-11.0	89.0	" 5
		6.04		-1.27	-1.63	-49.7	50.3	" 6
4.42	4.15		-0.27		-1.9	-57.9	42.1	" 7
		3.24		+1.18	-0.72	-21.9	78.1	

Traverse 2

H.	BS	FS	BS-H.	H.-FS	Ht Rel SL(ft)	Ht Rel SL(cm)	Ht Rel MSL	Comments
4.40	4.02		-0.38		-2.19	-66.8	33.2	
		4.34		0.06	-2.13	-64.9	35.1	
4.32	4.10		-0.22		-2.35	-71.6	28.4	BM #2
		2.94		1.38	-0.97	-29.6	70.4	ridge 8
4.30		4.38		-0.08	-1.05	-32.0	68.0	
4.66	5.46		0.8		-0.25	-7.6	92.4	
		3.62		1.04	+0.79	+24.1	124.1	" 9
		5.38		-0.72	+0.07	+2.1	102.1	" 10
		5.32		-0.66	-0.59	-18.0	82.0	" 11
4.54	4.26		-0.28		-0.87	-26.5	73.5	

H. = Height of transit
BS = Back site
FS = Forward site

Ht Rel SL = Height relative to sea level
MSL = Mean sea level
TBM = Temporary benchmark

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