The Relationship of Coastal Drumlins to Barrier Beach Formation Along the Eastern Shore of Nova Scotia

Submitted in Partial Fulfillment of the
requirements for the Degree of Bachelor
of Science, Honours
Dalhousie University
Halifax, Nova Scotia
March 1984

Submitted by Gary Sonnichsen

DALHOUSIE UNIVERSITY
Department of Geology
Halifax, N.S. Canada B3H 3J5 Telephone (902) 424-2358 Telex: 019-21863

DALHOUSIE UNIVERSITY, DEPARTMENT OF GEOLOGY

B.Sc. HONOURS THESIS

Author: Gary Sonnichsen

Title: The Relationship of Coastal Drumlins to Barrier Beach Formation Along the Eastern Shore of Nova Scotia.

Signature of author

Date: March 1984

Distribution License

DalSpace requires agreement to this non-exclusive distribution license before your item can appear on DalSpace.

NON-EXCLUSIVE DISTRIBUTION LICENSE

You (the author(s) or copyright owner) grant to Dalhousie University the non-exclusive right to reproduce and distribute your submission worldwide in any medium.

You agree that Dalhousie University may, without changing the content, reformat the submission for the purpose of preservation.

You also agree that Dalhousie University may keep more than one copy of this submission for purposes of security, back-up and preservation.

You agree that the submission is your original work, and that you have the right to grant the rights contained in this license. You also agree that your submission does not, to the best of your knowledge, infringe upon anyone's copyright.

If the submission contains material for which you do not hold copyright, you agree that you have obtained the unrestricted permission of the copyright owner to grant Dalhousie University the rights required by this license, and that such third-party owned material is clearly identified and acknowledged within the text or content of the submission.

If the submission is based upon work that has been sponsored or supported by an agency or organization other than Dalhousie University, you assert that you have fulfilled any right of review or other obligations required by such contract or agreement.

Dalhousie University will clearly identify your name(s) as the author(s) or owner(s) of the submission, and will not make any alteration to the content of the files that you have submitted.

If you have questions regarding this license please contact the repository manager at dalspace@dal.ca.

Grant the distribution license by signing and dating below.

______________________________ ______________________________

Name of signatory Date

ABSTRACT

The Eastern Shore of Nova Scotia is experiencing post-glacial rise in relative sea level, resulting in a transgressive coastal environment. Drowned estuaries are fronted by eroding drumlin headlands which provide a sediment source for barrier beach formation. The rate of this coastal transgression is largely dependent on the drumlin sediment supply, as determined from drumlin volumes, cliff erosion rates and the grainsize distribution of the drumlin tills.

Studies of Hartlen Point and Terminal Beach drumlins, and Lawrencetown Beach, were undertaken to determine whether present beaches are derived from existing drumlins, or are the cumulative result of previous drumlin erosion cycles. Drumlin volumes and cliff erosion rates were calculated from aerial photograph analysis and field measurements. The stratigraphy and correlation of the drumlin tills were determined from grainsize, colour variations, cliff mapping and existing literature. The sediment volume of Lawrencetown Beach was measured from aerial photographs, beach plain vibracores and high resolution acoustic profiles of the shoreface sediments.

A sediment budget calculated for Terminal Beach drumlins and the adjacent Lawrencetown Beach, shows that the drumlins of the Eastern Shore do not appear to provide sufficient beach sediment volumes to form existing barrier beaches. The additional volume is concluded to be provided by onshore transport of previously eroded drumlin sediment.

ACKNOWLEDGEMENTS

Special thanks to Dr. R. Boyd, for his supervision, support and patience throughout this project. Also to Ralph Stea of N.S.D.M.E. for helpful discussion and information. Thanks also to Diana Friesen and Rob Robertson for their assistance and company in the field, and to Norma Keeping for kindly typing this manuscript.

TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

1.1 Introduction

The Eastern Shore is located on the Atlantic coast of Nova Scotia and consists of an intricate region of drowned estuaries, beaches and drumlins. Its morphology is the product of extensive and repeated glacial events. Surficial deposits present today are predominantly the result of the last major ice advance during late Wisconsinan times.

The Eastern Shore study area extends along the coast for thirty kilometers, between Halifax Harbor to the west and Jeddore Cape, to the east (see Figure 1). It is characterized by a field of seventy drumlins, trending 150°-170° (Bowen and Boyd, 1983) or approximately NNW-SSE, formed from a major ice advance in the same direction. Within and surrounding the drumlin field is a blanketing till sheet which averages 3 meters thick (Stea and Fowler, 1979) derived from erosion of underlying bedrock, pre-existing tills and transported glacial sediments.

The two study areas (Figure 2) which comprise the bulk of this project were selected as representative of the typical coastal constituents along the Eastern Shore. They are the two major sources of drumlin material along the coast and have adjacent barrier beaches associated with them. Also the information base provided by earlier

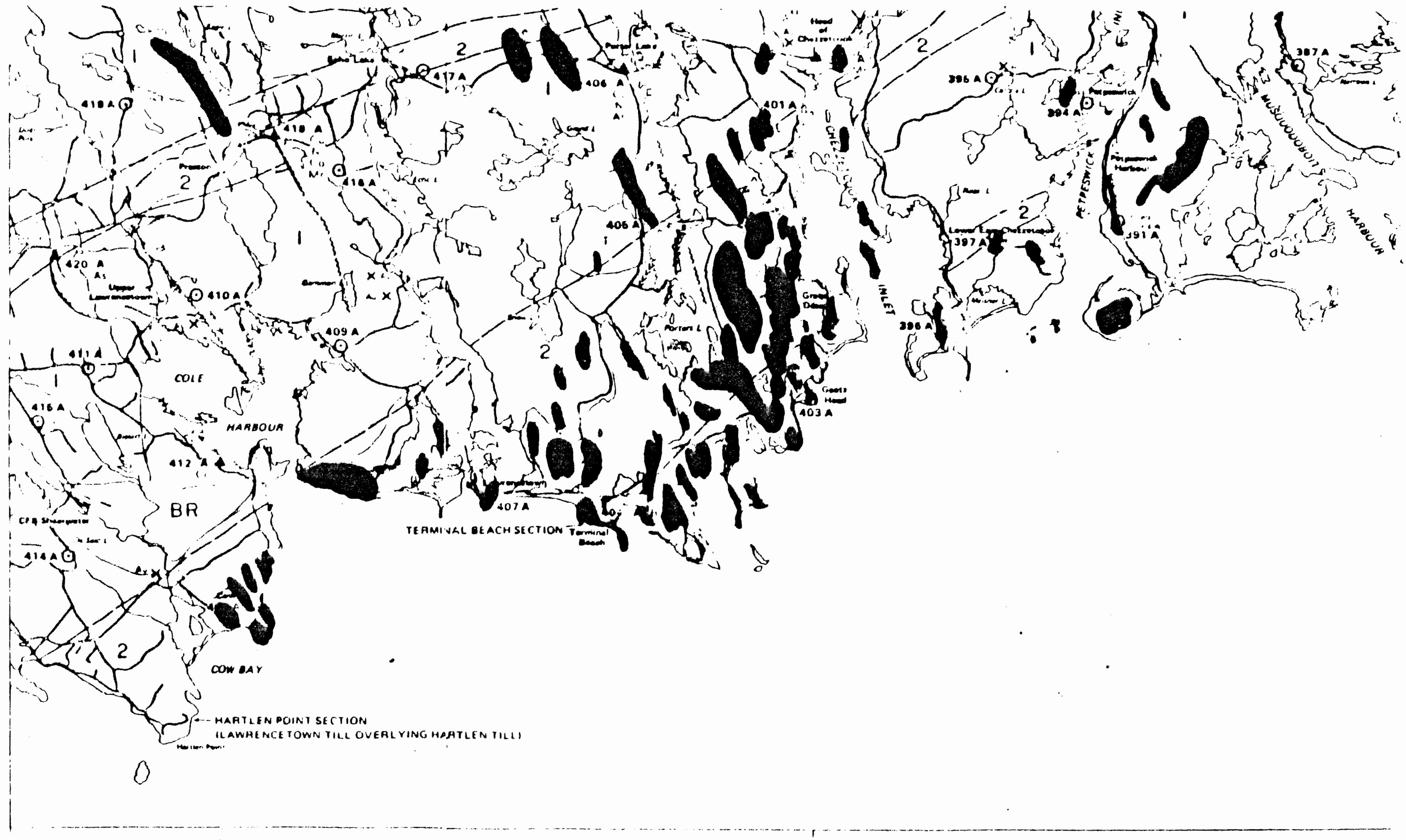

Figure 1 Eastern Shore Region showing coastline and drumlins (from Stea and Fowler's 1979, sheet 3)

investigators, and accessibility for sampling proved helpful to a project of limited scope such as this.

Hartlen Point

The Hartlen Point area is seen on Figures 1 and 2 as a drumlinoid till headland situated at the mouth of Halifax Harbor, southeast of Dartmouth. The cliff exposures sampled are at the southernmost end of the drumlin, past the Hartlen Golf Course. Figure 2 reveals the specific sample sites. Erosion of Hartlen Point sediments provides a potential source for the Cow Bay - Silver Sands Beach directly to the east.

Terminal Beach

This second study site is located 40 kilometers northeast of Halifax on Route 7. The area sampled consists of three coalescing drumlins which form a 2 kilometer expanse of eroding sea cliffs, with a maximum height of 26 meters. Figure 2 depicts the Terminal Beach area with the specific sample locations plotted.

Lawrencetown Beach, one kilometer to the west, receives the sediment eroded from Terminal Beach cliffs. Evidence for this is seen in dominant wave approach direction, coastal orientation, sediment texture and barrier geomorphology; all of which point to the drumlin cliffs as the sediment source (Bowen and Boyd, 1983).

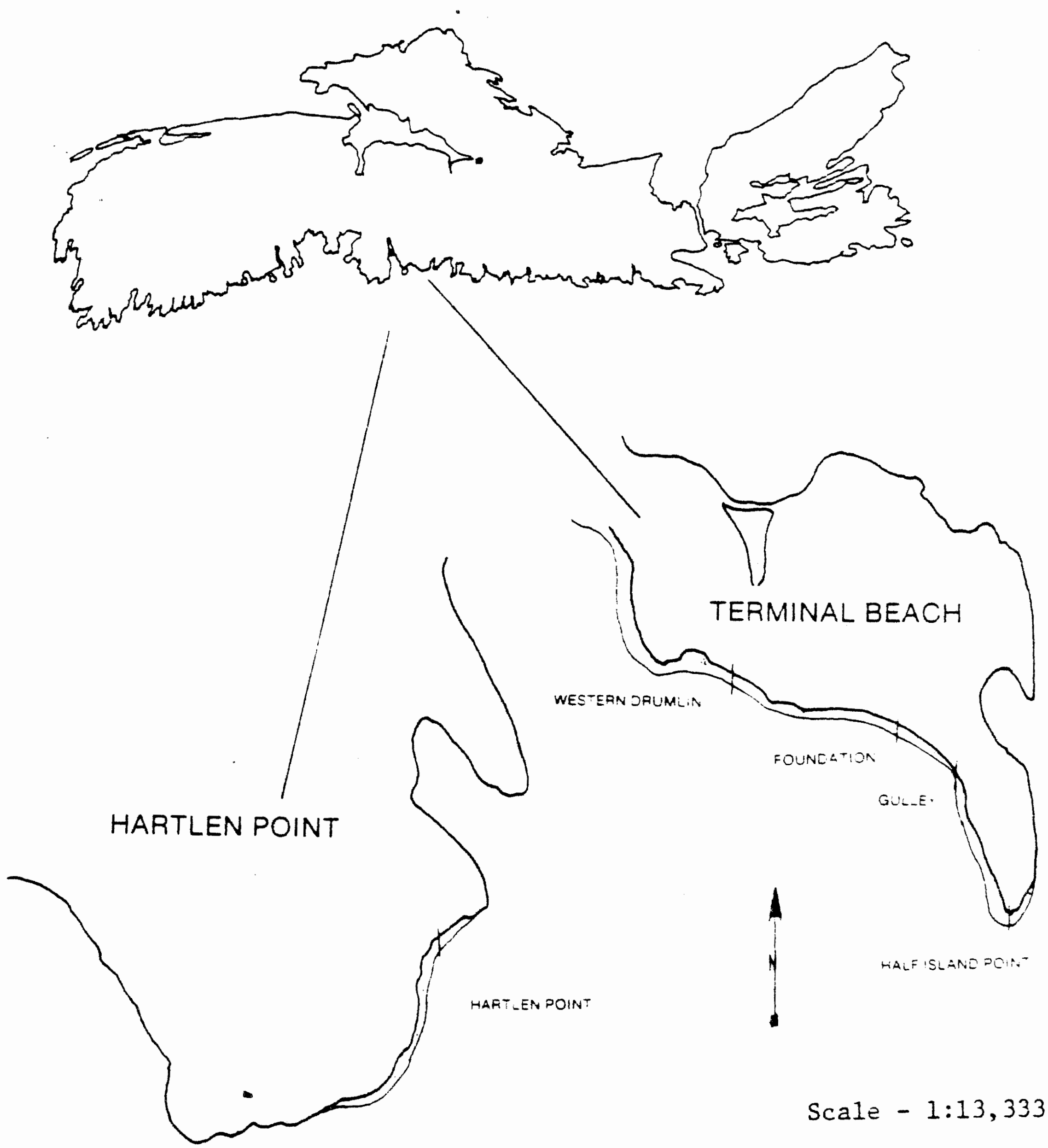

Figure 2 Hartlen Point and Terminal Beach. Sample Sites on Eastern Shore of Nova Scotia

1.2 Literature Review

The Eastern Shore Holocene transgression is a direct result of the presence and ultimate retreat of late Wisconsinan ice cover.

The amount of ice cover, coupled with factors such as temperature and ocean basin size determine the rate of relative sea level rise.

King (1969) proposed a grounded ice sheet extending 30-40 kilometers offshore, as evidenced, from terminal moraine systems which parallel the coast. Estimates of thickness, as well as extent, were computed from a geophysical modelling of glacial unloading effects by Peletier and Andrews (1976) (as quoted in Quinlan and Beaumont, 1981). Grant (1977), (as quoted in Quinlan and Beaumont 1981) employed depositional and erosional features to derive a more limited ice cover. Quinlan and Beaumont (1981) utilized the above geophysical model with higher resolution. This, as well as field observations led them to propose an ice cover intermediate between Peletier and Andrew's, and Grant's. This gives an ice sheet approximately 500 meters thick and extending offshore to the outer Scotian Shelf.

Establishment of minimum late Wisconsinan sea level is essential to a determination of sea level rise along the Eastern Shore and resultant coastal retreat. A submarine terrace situated 110-115 meters below present sea level is considered by King (1980) to represent a late Wisconsinan low stand of sea level. In contrast, Scott and Medioli (1982) employed micropaleontological analyses of a saltmarsh core from Lunenburg Bay, to derive a minimum relative sea level of 27 meters below present. Quinlan and Beaumont (1981) utilized the concept of a migrating glacial forebulge to suggest a minimum sea level intermediate between King's and Scott and Medioli's.

The presence of glacial sediments and landforms along the Eastern Shore has caused the formation of a characteristic coastal morphology experiencing sea level transgression. Nova Scotia tills were first studied in detail by Grant (1963) who employed pebble lithologies to distinguish between tills of different provenance. He also found drumlins to often be composed of separate tills with specific features. Nielsen (1976) refined the till descriptions and extents using grain size, mineralogy, color, texture and lithology. Recent local additions to mapping and correlation were made through geochemical differentiation of coastal drumlin tills (Podolak & Schiltz, 1978, Stea and Fowler, 1979).

The prominent position of drumlin erosion in beach genesis has been observed by Bowen and Boyd (1983), Bowen et al. (1975) Wang and Piper (1982). Bowen and Boyd (1983) incorporated much of the above to generate an evolutionary model of the Eastern Shore of Nova Scotia. The model suggests a cyclic coastal response to the marine Holocene transgression, centering on barrier beach genesis and subsequent destruction.

The two specific study sites of this project possess a solid information base provided by previous researchers. The Hartlen Point stratigraphy and tills have been described by Grant (1963), Nielsen (1976), Podolak and Schiltz (1978) and Stea and Fowler (1979). The erosional nature of the sea cliffs was examined by Easton (1981) and

Bowen and Boyd (1983). Terminal Beach was studied stratigraphically by Stea and Fowler (1979), and erosionally by Easton (1981) and Bowen and Boyd (1983).

1.3 Purpose

Proposals

This thesis is an attempt to quantify the relationship between Eastern Shore drumlin erosion and adjacent barrier beach formation. A measure of the supply of sediment being provided by present-day drumlins will determine whether existing beaches are the result of a single episode of drumlin supply or are the cumulative results of previous drumlins erosion cycles.

Using Hartlen Point and Terminal Beach as specific sites the objectives of this study were to:

1) Sample, and analyse the sediment texture of drumlin sea cliffs in the study area.
2) Investigate the presence of stratigraphic units using literature, grain size, color, carbonate content and compactness of the tills.
3) Determine drumlin volumes and dimensions.
4) Incorporate sediment production rates and beach volumes into a practical sediment budget for the Lawrencetown Beach drumlin-barrier beach system.

Application

The utility and practical application of the above proposals will relate chiefly to coastal management concerns. A knowledge of production rates of beach sediment will allow prediction of:

1) The temporal stability of a beach system.
2) The effect of artificial sediment removal.
3) The ability of a barrier beach to recover from natural and human damage to the beach and dune systems.
4) The relationship of present barrier beaches to drumlin erosion cycles.

The till units sampled at Hartlen Point and Terminal Beach are considered representative for the Eastern Shore. Thus a quantitative assessment of the grainsize distribution of the individual tills could be applied to other drumlins in which the till units are found.

CHAPTER 2

2.1 Glacial History of Nova Scotia

Nova Scotia has experienced glaciation throughout the Quaternary. The last major glacial event occurred between 32,000 and 12,000 B.P. (Stea, 1979) in the Late Wisconsinan. From approximately 18,000 years ago to 11,000 (Before Present - B.P.) the ice cover retreated to behind the present coastline (Bowen et al., 1975) thereby uncovering the erosional and depositional features left behind by the ice.

2.2 Glaciation of Eastern Nova Scotia

Glacial events have sculpted the present topography in two ways:

1) The extensive erosion of bedrock and existing sediments. The effects of the erosion can be seen in the smoothed and flattened highlands incised glacial valleys throughout the province.
2) The subsequent deposition of the glacially-derived sediments. The resulting glacial drift was deposited in topographic lows, moraines and as a thin sediment sheet.

Drift, the general term for glacially deposited sediment is usually divided into two major types: unsorted and unstratified till and the sorted, stratified outwash deposits (Davis, 1983). Deposition from ice or meltwater determines which of the two types will form. In this study, the general classification scheme of Boulton (1972) with the modifications made by Nielsen (1976) will be employed. Depending on the supraglacial-englacial source of the till, three types are distinguished:

1) Flow till - released supraglacially and has undergone deformation due to flow.

2) Melt-out till - released supraglacially or subglacially from stagnant ice.

3) Lodgement till - deposited beneath actively moving ice and has undergone shear deformation.

The main forms of deposition along the Eastern Shore are of two types: The first is a ubiquitous till sheet formed from lodgement and/or ablation tills. This is draped over most of Nova Scotia in varying thicknesses; on the Eastern Shore it ranges from 0-4 meters thick (Stea and Fowler, 1979). Drumlins are the second type of glacial deposit along the Eastern Shore.

Drumlins

Drumlins are low streamlined hills with an inverted spoon shape, derived from subglacial ice bed processes. They generally have a blunt upflow (stoss) side and a long tapered lee face. By presenting the steeper face to the ice the drumlin inpedes formation of flow vortices in the rear which would result in ice flow resistance (Chorley 1959, p. 339). Drumlins range from 1 to 60 meters in height and can be kilometers long (Menzies, 1979).

Drumlins are constrained to a very narrow distribution pattern. They are found clustered in fields close to the outer margins of past ice sheets and behind end moraines. Because of the absence of correlation with either bedrock lithology or topographic conditions, drumlin genesis is considered dependent on characteristics of the ice flow.

With respect to composition of drumlines, there is a complete gradation independent of outward form and within a single field from rock to drift (Flint, 1957 as quoted in Smalley and Unwin, 1968, p. 68). They may have a single or multiple till origin, and often mantle a bedrock core.

Theories of drumlin origin have been grouped mainly into either erosional or depositional models. New data and studies however, have shown this to be too simplistic, as components of both are usually present in a drumlin. The modified erosional theory of Gravenor (1953) appears to provide the simplest, most cohesive explanation of drumlin origin. Its basic tenet is a reworking of proglacial till formed in front of a temporarily halted advancing glacier.

Tills of the Eastern Shore

Nielsen (1976), based on his own work, and that of previous investigators (see section 1.2), concluded that except for localized pockets of older till at Milford and north of Yarmouth, all the tills deposited before the "classical" Wisconsinan were eroded by the ice that deposited the present till sheet.

A loose oligomictic sandy till sheet is the most extensive unit on the Eastern Shore, (Grant, 1963). Grant noticed the composition of the till mirrored that of the underlying bedrock and changed rapidly as it passed over lithologically different bedrocks. In the area of the Eastern Shore dealt with in this study, the underlying bedrock is predominantly the Goldenville Formation of the Cambro-Ordovician Meguma Group (Stea and Fowler, 1979). This is a quartzite flysch and forms the Quartzite Till which is the most widespread till unit in the area (Stea and Fowler, 1979). Close inland in scattered areas the Slate Till is found overlying the slate bedrock of the Halifax Formation of the Meguma Group. Both of these units contain approximately 90% of local clasts (Stea and Fowler, 1979). Granite tills overly the isolated patches of granite outcrop to the West and East.

Although tills are usually derived locally from underlying bedrock, one till which characterizes the Eastern Shore is composed of far-travelled clasts from the Cobequid Highlands and Minas Basin. This Lawrencetown Till, found as the major drumlin till in the area, is a red, moderately compact clayey till with a facies gradation to a brown compact sand-silt till (Stea and Fowler, 1979). These facies represent minimum and maximum incorporation of local clasts in the matrix.

A third major till type exposed on the Eastern Shore is a grey compact homogenous till with a silty matrix. Informally named Hartlen Till, it was considered to be (1) a basal lodgement till deposited in the earliest phase of the late Wisconsinan, (Nielsen, 1976) or (2) an early Wisconsinan event, (Stea and Fowler, 1979). At other locations on the Eastern Shore a similar grey lodgement till underlies the Hartlen

Till. It has not been correlated with the Hartlen Till as it may represent an earlier glacial event (Stea and Fowler, 1979).

2.3 Till Stratigraphy and Correlation

Figure 3 shows drumlin till stratigraphy and correlation at specific localities along the Eastern Shore, including Hartlen Point and Terminal Beach.

Hartlen Point cliffs are composed of two tills. The lower till unit is a grey, highly compacted silty till (Nielsen, 1976) with approximately 90% quartzite clasts and 5% foreign (Stea and Fowler, 1979). It has been informally called Hartlen Till by Stea and Fowler (1979). The upper till is a reddish, less compacted till with a clay matrix and 15% foreign pebbles (Stea and Fowler, 1979).

Terminal Beach consists of a basal grey till overlain by glaciofluvial sediments, an upper unit of grey, compact till and is mantled by reddish clay till.

The red mantling tills at both localities are correlated with Lawrencetown Till on the basis of color and a high foreign clast component (Stea and Fowler, 1979). The upper grey till at Terminal Beach is correlated with the lower Hartlen Till by color and compactness. Stea and Fowler refrain from correlating the lower grey till at Terminal Beach despite similarities, because it may represent a separate glacial event than does the deposition of the Hartlen Till.

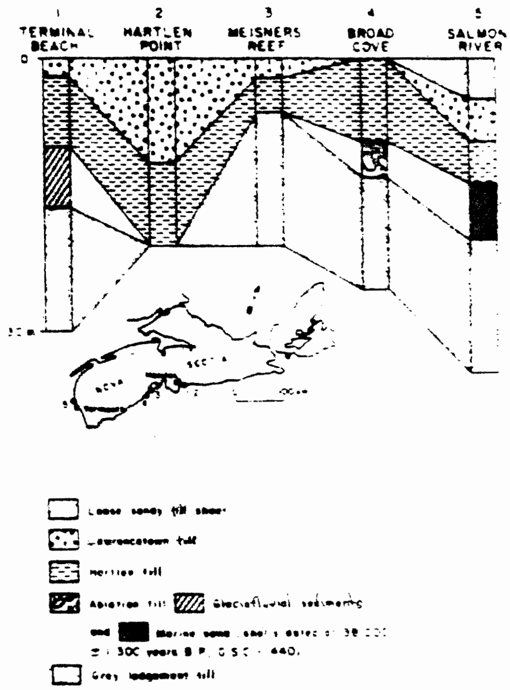

Figure 3. A correlation of major sections exposed along the Atlantic coast of Nova Scotia; the Terminal Beach and Hartlen Point sections are taken from Stea and Fowler, 1979; the Salmon River section is taken from Neilsen, 1976.

2.4 Pleistocene Sea Level History of Nova Scotia

The Eastern Shore relative sea level has varied eustatically and isostatically as a result of changes in regional and world glacial ice cover. The maximum extent of the last glacial advance occurred approximately 20,000 years B.P. with ablation starting 18,000 years B.P. (Bowen, et al., 1975).

King (1980) using submerged Scotian Shelf terraces considered the minimum sea level of this period to be 110-120 meters below present. Quinlan and Beaumont (1981) predict coastal sea level change due to a migrating peripheral forebulge which formed from ice burden on the lithosphere. This model predicts a slight emergence as the crest of the bulge passed the Eastern Shore followed by steady submergence. They have found a possible confirmation of their model in a core collected by Scott and Medioli (1981) from Lunenburg Bay. The core shows a salt marsh peat with marine sediments above and below, which implies emergence and subsequent submergence of the coast. The peat gives a minimum sea level of -27 meters below present with a ^{14}C date of 7,070 $\pm$ .300 years B.P. This is more in line with the minimum sea level predicted by Quinlan and Beaumont than the sea level inferred by King. His is 40 meters higher than that predicted by Quinlan and Beaumont. With the absence of any dates from the submarine terraces it seems best to accept Quinlan and Beaumont's model which finds agreement with the data provided by Scott and Medioli.

Approximately 18,000 years B.P. the ice began to retreat (Bowen et al., 1975). Sea level rose correspondingly as a result of both the eustatic and isostatic responses to the diminishing ice cover. Along the Eastern Shore, Scott (1981) has determined sea level rise from dates provided by cores from Lunenburg Bay, Halifax Harbour and Chezzetcook Inlet. From these data sea level rose from -27 meters at 7,000 years B.P. to its present position at a rate of 38 cm per 100 years for the first 5,000 years and 32 cm per 100 years for the last 2,000 years, (Bowen and Boyd, 1983).

2.5 Holocene Transgression

Sea level rise along the Eastern Shore has forced a landward retreat of the coastline, through erosion and submergence. As the sea moved steadily landward, the drumlins at the mouth of drowned estuaries and lakes began to erode. The erosion of the headland drumlins occurs by:

1) Undercutting of cliff exposures through wave action, thereby making them unstable
2) Slumping of unstable cliff section by groundwater fluidization. Since the sea level began to rise, the Eastern Shore has transgressed 5.8 kilometers as evidenced by the present position of -27 m isobath.

2.6 The Evolutionary Model of the Eastern Shore

The Holocene transgression has generated a complex cyclic response in the development of the coastal morphology. Bowen and Boyd (1983) present on evolutionary model for "summarizing the response of a large

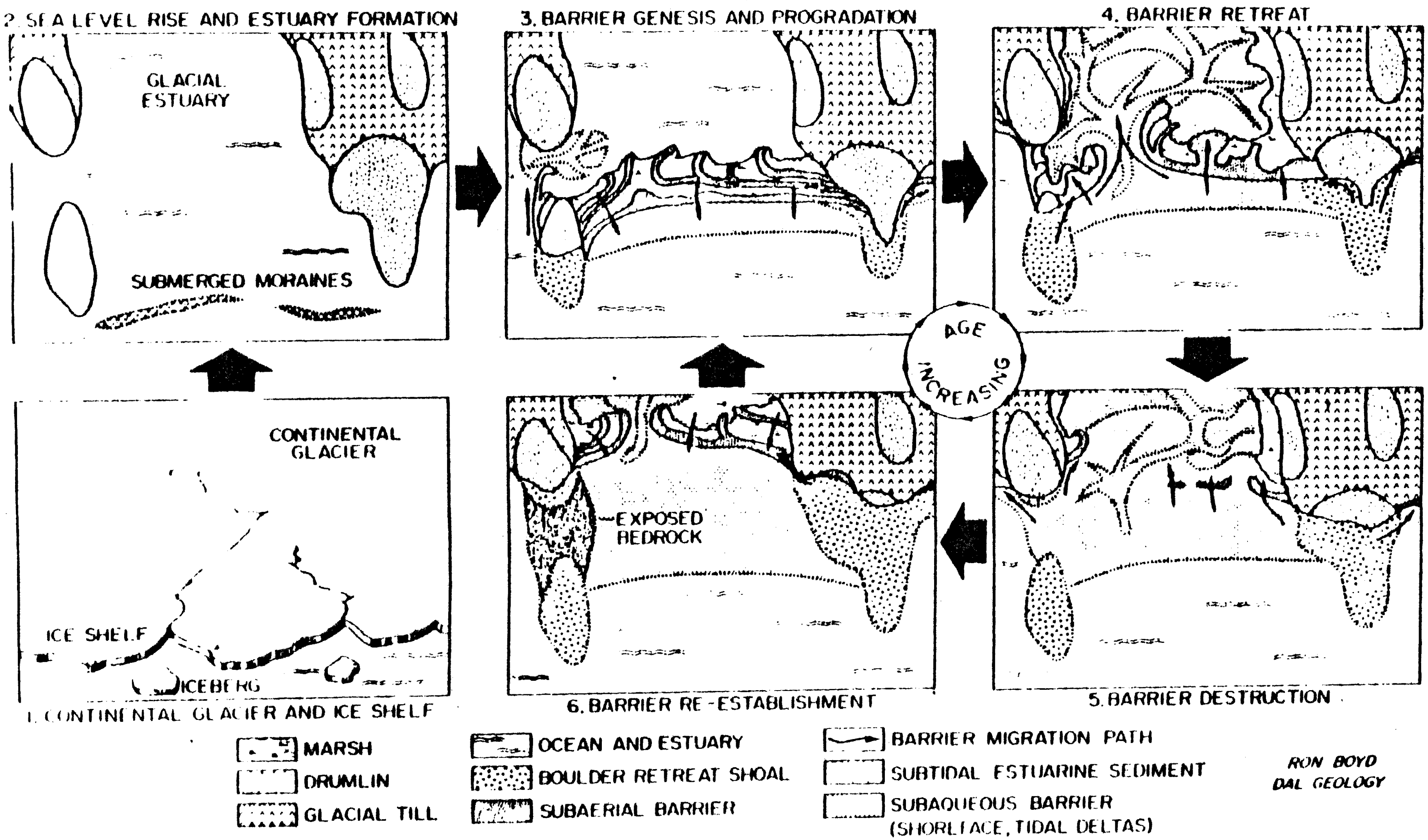

Figure 4: A conceptual model for genesis and evolution of beaches along the Eastern Shore, Nova Scotia.

coastal region to both the temporal variability generated by the dynamic shoreline behavior and the spatial variability present in the distribution of geomorphic features" (pg. 19). There are six evolutionary stages to this model (Fig. 4).

Stage 1 - Continental Glacier and Ice Shelf

The model starts with the last major ice advance and its subsequent ablation. In its wake the ice left an eroded landscape draped with the resulting sediments (as described in section 2.2).

Stage 2 - Relative Sea Level Rise and Estuary Formation

As relative sea level rose scoured bedrock depressions and river valleys along the coast were progressively submerged by the rising sea. Along the Eastern Shore, the lakes and drowned estuaries intersected drumlin fields which were capable of forming bounding headlands with a large supply of glacial sediments.

Stage 3 - Barrier Genesis and Progradation

As the sea rose through the Holocene Epoch, the sediments of the estuary headland drumlins and ground moraine are continually eroded and reworked by ocean waves. Under the influence of longshore currents, the wave derived sediments are transported along shore to form estuary mouth spits adjacent to the headland drumlins. The extent of the forming spit is dependent on both the rate of sea level rise and the amount of sediment production. Varying amounts of sand and gravel are produced by eroding drumlins. The grain sizes too large to be transported form a boulder retreat in front of the eroding drumlin.

If the useable sediment volume is sufficient, the barrier spits will prograde across the estuary mouth, and keep pace with the rising sea level by building vertically. The resulting barrier beach may also accrete horizontally to form a beach ridge plain if there is a positive sediment supply, relative to the rising sea.

Stage 4 - Barrier Retreat

The headland drumlins represent a finite supply of beach sediment. When the sediment production dwindles to the point where it cannot keep up with rising sea level, the beach stops prograding and eventually retreats into the estuary.

The retreat is a gradual process and is initiated by the loss of sand from the dunes and beach, through washovers and tidal inlets. The tidal inlets maintain a breach in the barrier and act as a sediment trap or sink in the back beach area allowing the formation of a flood tide delta. The sediment transported into the back beach area is permanently lost to the present beach but remains behind it.

Stage 5 - Barrier Destruction

This is a continuation of barrier degradation initiated in Stage 4. With continuing washover phenomena, more tidal inlets form, thereby speeding the transport of sediment into the back lagoon. The sands and gravels which previously formed the barrier are reworked and form spits and intertidal shoals in the back estuary or deposit in the backshore marshes.

Stage 6 - Barrier Re-establishment

This is a repetition of the Stage 3 barrier establishment but with an important difference. The sediments from the previous barrier beach are available for the establishment of a new barrier farther back in the estuary. The site for this new barrier may also be determined by the presence of new drumlin sediment sources which can act as anchors for the new prograding barrier beach system. Because of the additional sediment source, the establishment will be accomplished in a potentially faster time.

As long as the estuary and drumlin supply continue, it seems reasonable that the barrier beach may experience repetitive evolutionary cycles, in the face of a rising sea level. The drumlins, hold a key position in this model because they determine the temporal stability of the barrier beach and thus control the rate of landward coastal retreat.

2.7 Application to the Specific Study Systems

The Eastern Shore is comprised of component coastal systems which represent the spectrum of stages in Bowen and Boyd's (1983) evolutionary model. Depending on topography, sediment supply and shore processes, certain beaches may be actively accreting while others have or are about to collapse completely. In the context of the coastal systems to which they are related, Hartlen Point and Terminal Beach represent different stages of evolution.

Terminal Beach - Lawrencetown Beach System

Lawrencetown Beach has passed from Stage 3 to Stage 4 (Barrier Retreat) in the past several years. This is evidenced by the coarse beach material encroaching from the East and overtaking previous dune systems. Judging from the east-west trend in decreasing grainsize as well as coastal orientation and beach ridge geometry, Terminal Beach headland drumlins represent the main source of beach sediment. At the present, sediment is being lost from the system to Lawrencetown Lake by aeolian processes and by recent sand mining.

Hartlen Point - Silver Sands Beach

Silver Sands Beach has recently begun a transition from Stage 4 to Stage 5 - Barrier Destruction. Previously a wide sandy barrier beach, today it is a thin gravel beach with numerous tidal inlets. The back beach lagoonal area is heavily infilled by a flood tide delta with intertidal shoals and spits. The entire system has retreated approximately 500 meters into the estuary from its original position adjacent to Hartlen Point, which appears to be the major sediment source.

CHAPTER 3

METHODS

3.1 Drumlin Sampling

During the period October to December, 1983, forty-three drumlin samples were collected from Hartlen Point and Terminal The samples ranged from 0.5 to 1.5 kg, and were dug or scraped from the sea cliff surface at each sample site. Repeated visits to Hartlen Point and Terminal Beach were necessary because of the increased removal of masking slump material with the fall storm waves. This allowed representative sampling of mid and basal portions of the drumlins at each locality.

The objective of the field sampling was to determine the grainsize distribution and variability both vertically through the till units and horizontally along the drumlin face. Vertical cross-sections were sampled at each exposure and included individual samples of isolated sand lenses and zones of glaciofluvial material. Because of the inaccessibility of the cliff in certain exposures due to slope and slump material, samples were sometimes obtained off to the side of the vertical transect. The sampling within the transect was basically random although structured to include the inferred stratigraphy of the cliff.

The above samples were only representative of the pebble and finer till fractions. To accurately assess the boulder and cobble percentage, which forms a significant portion of the drumlin, would require a large and unwieldy sample. The method employed in this project, was an estimation of the percentage of gravel incapable of being moved by the nearshore processes, (designated as clasts greater than approx. 50 mm) based on surface exposures. A 1 meter^2 grid was pegged to the cliff at accessible spots and either photographed or a point count was carried out. The point counts were done at 10 cm intersect on the grid and the coarse fraction computed from the 121 points. At other areas the character of the till was such that a sample was representative of all size fractions.

At Hartlen Point, only a small area of the cliff displayed the two till units described by earlier workers (Grant, 1963; Nielsen, 1976; Stea & Fowler, 1979). The few samples of the lower till taken were collected from within this expanse while the overlying unit was sampled randomly across the entire cliff expanse.

3.2 Laboratory Analysis of Till Samples

Samples were split and quartered using the method outlined by Piper (1977). Between 10 and 40 grams was the typical sample size analyzed. Samples were disaggregated by manually stirring in water and subsequently wet sieved through a 63μ (4ϕ) sieve. The resulting silt and clay was then added to a 1 liter graduated cylinder and brought up to volume. Ten ml of 1% Calgon was sufficient to diflocculate the clay fraction in the samples analyzed. The 4ϕ and 8ϕ fractions (silt and clay) were pipetted using Stoke's Law and procedures outlined in Piper (1977).

The remaining > 4Ø material was dried and weighed.

The computed transportable grainsizes of the samples were then integrated with the boulder and cobble fraction, estimated from point counts in the respective sample localities.

3.3 Stratigraphic Mapping of Drumlin Tills

As a secondary but necessary objective, an attempt was made to determine the presence and extent of separate, mappable till units within each drumlin. This was done to explain and quantify any variations in the grainsize of the vertical transect samples. Knowing the percentage of the drumlin taken up by each till unit and their grainsize distribution allows a quick determination of the sediment volumes in the drumlin assuming the till is continuous throughout.

Field observations showed that the stratigraphic units, outlined by Grant (1963), Podolak & Shiltz (1928), Stea & Fowler (1979), varied in the drumlin in terms of lateral extent and thickness. Different areas also were characterized by glaciofluvial material and homogenous lenses of well-sorted sand and gravel. It is important to know if these are randomly scattered throughout the till units or constrained to a particular unit.

Different methods were used to establish the till stratigraphy at Hartlen Point and Half Terminal Beach. The till stratigraphy determined by Podolak and Shiltz (1978) and Stea and Fowler (1979) was the standard reference and framework for this project. Geochemical analyses of trace metals in the clay fraction was the main tool used by both Podolak and Shiltz (1978) and Stea and Fowler (1979) for distinguishing and correlating the tills described by previous workers Grant, (1963); Nielsen, (1976).

This study utilized comparative colors, sediment textures and degree of compaction to distinguish the tills in the field. To test the hypothesis that the units could be distinguished by the presence of calcium carbonate, the samples were treated with dilute HCl. A reaction, or bubbling, is indicative of calcium carbonate material.

Percentages of beach sediment, silt, and clay were compared from within different units to asess variations between tills.

3.4 Sediment Budget

To devise a comprehensive sediment budget for a coastal sedimentary environment, requires an asessment of the related sediment sources and sinks. By determining rates of sediment production and removal, one can predict the temporal stability of the coastal environment.

The barrier beach systems of the Eastern Shore can be separated into individual units with specific sediment sources and sinks. The existence of bedrock ridges extending seaward from Jeddore and Hartlen Point, restrict longshore transport of material in or out of the area. Also the barrier beaches are isolated from adjacent beaches because the headlands on either side induce a closed transport within the estuary.

Evidence for this is seen in the unique sediment textures and compositions within the isolated beach systems (Bowen and Boyd, 1983).

Rivers provide minimal or insignificant beach type sediments to the Eastern Shore (Bowen & Boyd, 1983). Any coarse material would be deposited by the rivers within the inland glacial lakes which the rivers flow through. Also the Meguma Group bedrock is very resistant and not easily eroded, especially with the overall low relief throughout the Eastern Shore. Thus, rivers can be discounted as a significant sediment source to the Eastern Shore.

Sediment sources can be restricted to two areas (1) erosion of drumlin and till headlands (2) onshore transport of offshore shelf sands and gravels.

With regards to the latter, the obvious source of offshore sands and gravels would be pre-existing barrier sediments encompassed by the rising sea level (as detailed in section 2.7). The material would be transported onshore with the rising sea, and with each new drumlin source eroded an additional sediment volume would be added to the retreating sand. Thus our present beaches may be a product of repeated barrier beach cycles, thereby representing numerous drumlin sand sources. As the shelf is presently draped with only a thin veneer of sand (Boyd and Hall, unpublished data), it appears that this is a real potential source of sediment.

A quantitative assessment of the contribution of presently eroding drumlins contribution to the beach will determine if the beaches are primarily the result of the presently eroding drumlins or the cumulative effect of several drumlin erosion cycles combined with onshore transport.

The annual volume of drumlin sediment contributed is computed from the length of the actively eroding cliff, the rate of erosion along the cliff, and the height of the eroding sea-cliffs. Drumlin heights were measured from 1978 orthometric maps and field measurements. Drumlin areas and cliff lengths were determined using a zero-correcting planimeter and 1982 aerial photographs.

Previous researchers have measured rates of cliff erosion from stake measurements and from the retreat measured off aerial photographs and orthometric maps. At Terminal Beach and Hartlen Point rates have been measured using both methods. At Half Island Point, stake measurements have shown retreats ranging from 0.15 m/year over 4 years in oblique cliff sections, to 3 m/year at its most seaward exposure (Bowen and Boyd, 1983; Boyd, unpublished data, 1984). Easton (1982) determined erosion from orthometric maps of 1945 and 1978 coastlines and found 1.44 m/year retreat at Half Island Point. At Hartlen Point, Piper et al. (1984, in preparation for G.S.C. paper) computed at 1.3 m/year retreat over 7 years. Bowen and Boyd (1983) found rates ranging from 0.5 to 2.76 m/year over 3 years. Again using retreat over 29 years from aerial photos, Easton (1982) computed an erosion rate of 0.49 m/year at Hartlen Point. Rates found at these localities are comparable to drumlin erosion rates elsewhere in Nova Scotia (Wang and Piper, 1982, Piper et al., 1984 in preparation). An overall rate of erosion at the study localities was determined using the above measurements and aerial photograph measurements undertaken in this project.

The amount of usable beach sediment was determined from the gross sediment volume eroded yearly, and by measurements of till grain size distribution. The dimensions of the beach and shoreface, which are the sites of sediment deposition, was computed from aerial photographs, vibracore measurements of beach thickness, and shore-perpendicular acoustic profiles of the shoreface.

CHAPTER 4

RESULTS

4.1 Introduction

This chapter provides a summary of the information compiled from fieldwork, lab analyses, photo interpretation and previous studies reported in the literature. A compilation of relevant data in tables and diagrams allows an interpretation of some trends, patterns and characteristics of Eastern Shore coastal sediments.

4.2 Grainsize

Forty-three samples were analyzed for grainsize distribution: 37 taken from Terminal Beach and 7 from Hartlen Point. Thirty-four of the samples were collected from vertical transects along the seacliffs (Table 1) and 9 represent isolated exposures of glaciofluvial deposits (Table 2).

Table I shows the till grainsizes, as determined from sieving, pipette analysis, and point count. Beach sediment percentages refer to that fraction of the sample which falls in the range of grainsizes found on the adjacent barrier beaches. Thus, it represents the till fraction capable of forming the barrier beach. For Lawrencetown Beach and Silver Sands Beach this sediment range is approximately from -5ϕ to 4ϕ. The course fraction includes the till clasts greater than -5ϕ. The silt represents the size range from -4ϕ to -8ϕ and the clay incorporates the finer than -8ϕ fraction. Table 1 groups the samples as top, middle or

Table 1: <u>Summary of the data on grainsize distribution of Terminal Beach drumlin till samples</u>

	Half Island Point			Gulley			Foundation			West Drumlin		X̄	G.D.
Top	N-19-2	N-12-7	N-18-2	N-12-3	0-10-3	N-12-12	0-10-4	N-12-1	N-17-7	N-17-3	N-17-5		
Coarse	-	3	2	3	3	-	-	-	-	-	-	1	
Beach	50.0	59.8	52.4	48.2	42.6	50.4	46.2	35.2	53.7	47.3	62.3	51.2	5.8
Silt	31.0	23.7	27.0	29.5	39.6	29.8	34.9	49.6	29.1	26.6	29.8	31.9	7.2
Clay	19.0	13.5	18.7	19.2	14.7	19.8	18.8	15.2	17.2	26.1	4.5	17.0	5.3

	HIP	Gulley	Foundation	West Drumlin			Random		X̄	S.D.
Middle	N-12-9	N-12-4	N-12-2	N-20-3	N-20-4	N-17-4	N-19-8	N-19-7		
Coarse	-	5	-	4	15	10	3	3	5	
Beach	50.0	44.1	36.3	48.3	39.4	45.9	54.4	56.8	46.9	6.9
Silt	26.1	26.7	33.9	32.0	28.4	34.0	22.1	21.5	28.1	4.9
Clay	24.0	24.2	29.8	15.7	17.2	10.1	20.5	19.9	20.2	6.00

Table 1: Summary of the data on grainsize distribution of Terminal Beach drumlin till samples

	Half Island Point			Gulley	Foundation	West Drumlin			$\bar{X}$	S.D.
Basal	N-12-11	N-17-1	N-12-10	N-12-5	N-18-1	N-20-1	N-20-2	N-17-5		
Coarse	3	-	-	8	8	15	10	5	6.1	-
Beach	36.1	35.2	41.2	37.7	38.8	41.4	35.5	37.6	38.0	2.4
Silt	32.2	49.6	28.7	26.4	27.1	27.3	30.5	29.4	31.4	7.6
Clay	28.7	15.2	30.1	27.7	26.1	16.3	23.9	28.0	24.3	5.1

Table II: Summary of the data concerning grainsize distribution of Hartlen Point drumlin till samples

Hartlen Point

	Top				$\bar{X}$	S.D.
Sample	0-7-3	0-7-7	0-7-8	0-7-9		
Coarse	8	3	-	3	3.5	3.3
Beach	54.2	52.4	48.5	53.8	52.2	2.61
Silt	29.3	25.9	42.1	33.7	32.7	7.0
Clay	8.5	18.8	9.5	9.5	11.56	4.8

	Basal				
Sample	0-22-10	0-28-13	0-28-14	$\bar{X}$	S.D.
Coarse		4.3	4.0	4.2	2.3
Beach		42.2	38.9	40.6	2.3
Silt		36.4	41.6	39.0	3.7
Clay		17.3	15.4	16.4	1.3

basal depending on the relative cliff position of the sample location. This allows comparison within transects, between transects and between the sample drumlins. Due to the low elevation and limited expanse of the till units at Hartlen Point, linear vertical transects were abandoned in favor of random vertical sampling of the entire cliff.

1) There is vertical variability through the cliff sections.
   The mean sand component increases significantly from bottom to top while the clay decreases correspondingly. The silt appears to be less significantly variable.

2) There is horizontal variablity between the cliff cross-sections.
   As evidenced by the standard deviations, samples within the same cliff position (i.e. top, middle, basal) may vary about the mean grainsize percentage (by approximately 10% in the beach sediments more so in the other fractions). This reflects a random small-scale variability in an otherwise homogenous till.

3) There is some regional variability in the vertical cross-section and samples of Terminal Beach and Hartlen Point.
   The top till at Terminal Beach is comparable to the top unit at Hartlen Point but the basal till is significantly different at both locations, with respect to grainsize.

To visually represent the variations in and between the transects, the beach material, silt, and clay fractions have been plotted for the vertical sample sites (Fig. 5 (a-e)). At Hartlen Point samples from across the cliff are combined to show one transect with beach sediment values plotted (Fig. 5e).

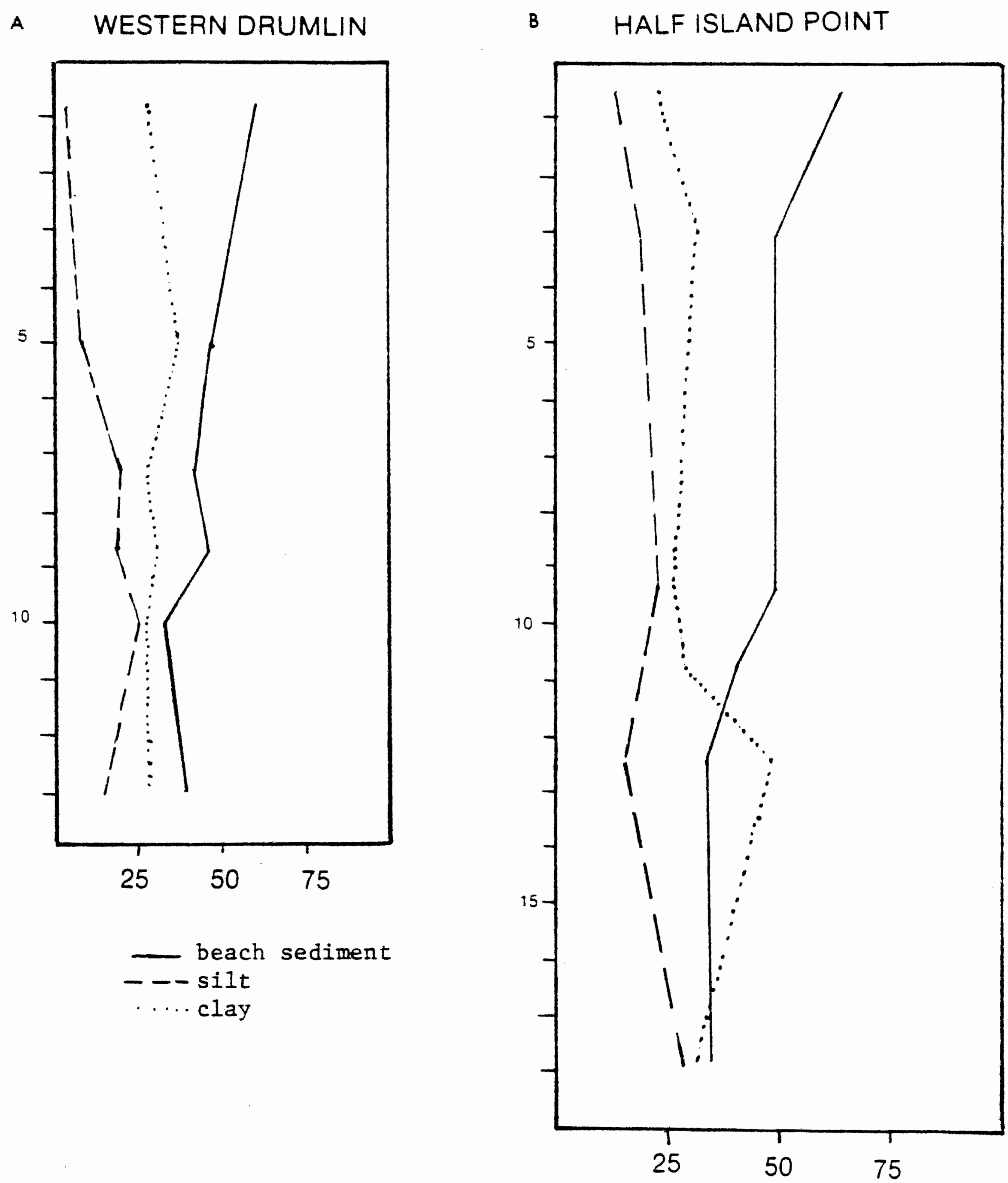

Figure 5 Vertical grainsize variation in drumlin cliff transects

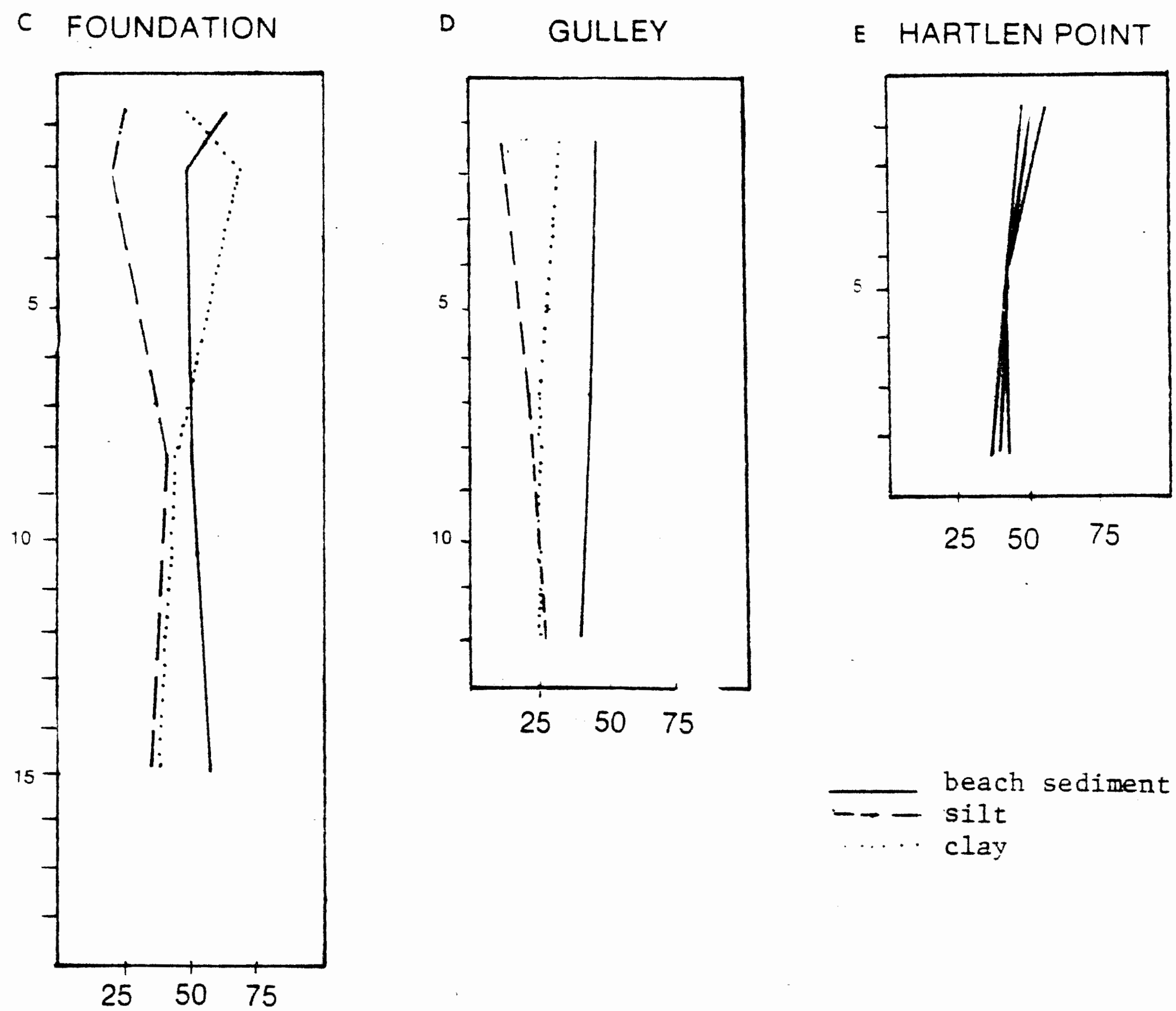

Figure 5 Vertical grainsize variation in drumlin cliff transects

Figure 5 shows that the vertical variations which are recognized at Terminal Beach in cross-sections A and B are absent in cross-sections C and D. The Western Drumlin (defined informally as the western expanse of eroding seacliffs) and Half Island Point both show similarities in vertical variability through the cliff. The Gulley and Foundation transects display a more linear pattern. Sampling was most complete and representative at the Western Drumlin and Half Island Point; both were devoid of slump, as evidenced by Photos 4.1 and 4.2. This difference between cross-sections may be the result of

1) more thorough sampling at Transects A and B

2) inclusion of non-representative slump in transects C and D.

4.3 Stratigraphy of Till Units

Using parameters such as colour, slope changes, compactness and grainsize discrete till units were distinguished at both Hartlen Point and Terminal Beach. The above techniques were used to supplement the till stratigraphy developed by Stea and Fowler (1979), Podolak and Shiltz (1978), Grant (1963) and Nielsen (1976).

At Terminal Beach three tills can be distinguished. The lowermost is a reddish gray highly consolidated cobbly till with boulders inbricated 150°-170°. The lower till has the least amount of sand (38%) and a higher percentage of boulders, individually and in boulder pavements (see photo 4.3).

The middle till unit has higher average percentages of sand (47%) and also localized, brownish sandy lenses which are waterbearing (see

Photo 4.1 Western drumlin displaying separate till units (at right) and vertical transect A. Note large rotational slump at left. (photo courtesy of R. Stea)

Photo 4.2 Half Island Point - vertical transect B. Note the slope variations of tills at left.

Photo 4.3 Basal till unit exposed at Foundation (vertical transect C). Note 1 meter ^{2} point count grid.

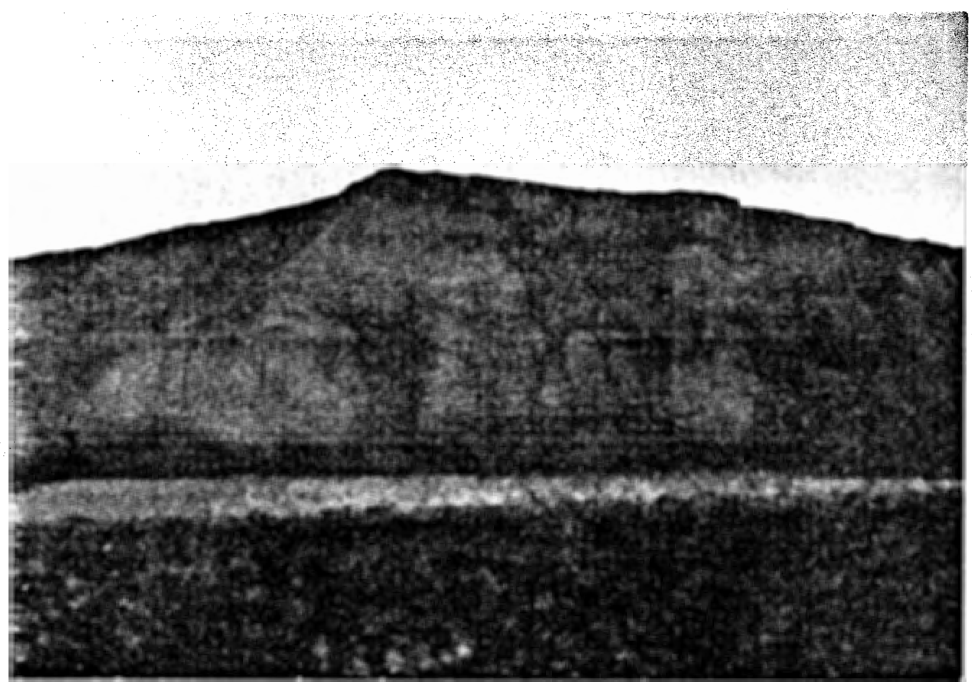

Photo 4.4 Half Island Point showing dark water-bearing lenses of sorted sediments. Notice the boulder lag in the forefront. Also the small slump in the upper left of the photo.

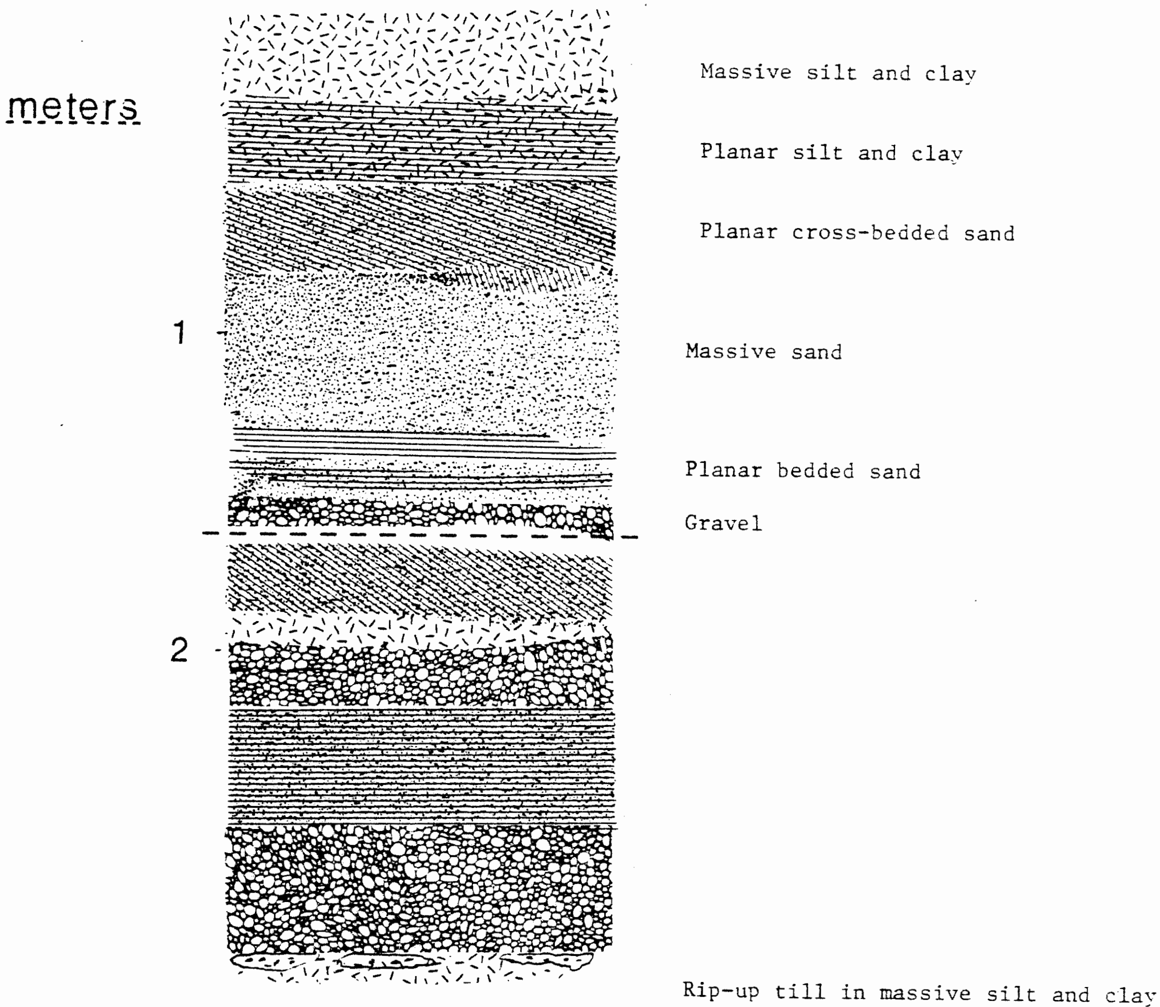

Figure 6 Scaled cross-section of glaciofluvial sediments exposed in Western drumlin sediments were loosely consolidated, oxidized and well sorted. The upper section was exposed 4 meters to the left of the lower section which is seen in Photo 4.5

Photo 4.5 Glaciofluvial sediments exposed in Western Drumlin, Terminal Beach. Note the cross stratification in upper sand bed. (Photo courtesy of R. Stea)

Table III: **Summary of data on grainsize distribution of glaciovluvial and sand lens samples from Terminal Beach**

	Sample	Sand	Silt	Clay
Glaciofluvial				
	D82	97.34	1.58	1.08
	D83	30.50	54.72	14.88
	D84	98.33	1.57	0.10
	D85	42.13	50.43	7.43
	D86	97.65	1.60	0.75
	N-20-5	78.80	20.16	0.64
Sand Lenses				
	N-12-6	88.63	5.82	5.55
	N-17-2	88.82	7.54	8.84
	N-12-8	96.75	1.99	1.26

photo 4.4). They are interpreted to be water-derived because of the high degree of sorting. An extensive glaciofluvial deposit was also found in the middle till in Western Drumlin (Figure 6; Photo 4.5). These sediments are considered to be glaciofluvial because of the high degree of sorting and stratification. The sediments are loosely consolidated, often show unidirectional cross-bedding and appear to be continuous into the cliff.

The sand lenses sampled (Table III) are constrained mainly to this middle unit, although random isolated samples were found throughout the cliffs.

The upper till unit mantles the drumlin at Terminal Beach. Cobbles within the reddish-brown till have no preferred orientation and are largely granite (R. Stea pers. communication). Of the three, the upper till contains the largest percentage (51%) of beach sediment.

At Hartlen Point the till stratigraphy is more straightforward with two distinct till types, photo 4.6 displays these till units. The lowermost is Hartlen Till (informally named by Stea and Fowler, 1979), a grey, highly consolidated cobbly till with 40% sand and 40% silt. The upper till is a more loosely compacted reddish till which comprises the bulk of the Hartlen Point cliffs. Sand lens occurrence is much more infrequent at Hartlen Point.

Boulders and cobbles make up 4% of the cliff exposures but were most abundant in the basal till portions. Boulder pavements (photo 4.3) were present at both Hartlen Point and Terminal Beach. These were considered by Nielsen (1976) to be a shearing phenomenon. They are linear features,

Photo 4.6 Two till units exposed at Hartlen Point. The pictures shows the sharp contact and colour variations between the tills.

Photo 4.7 Drumlin cliff at Hartlen Point showing portion of a 50 meter expanse of Hartlen Till - grey basal areas.

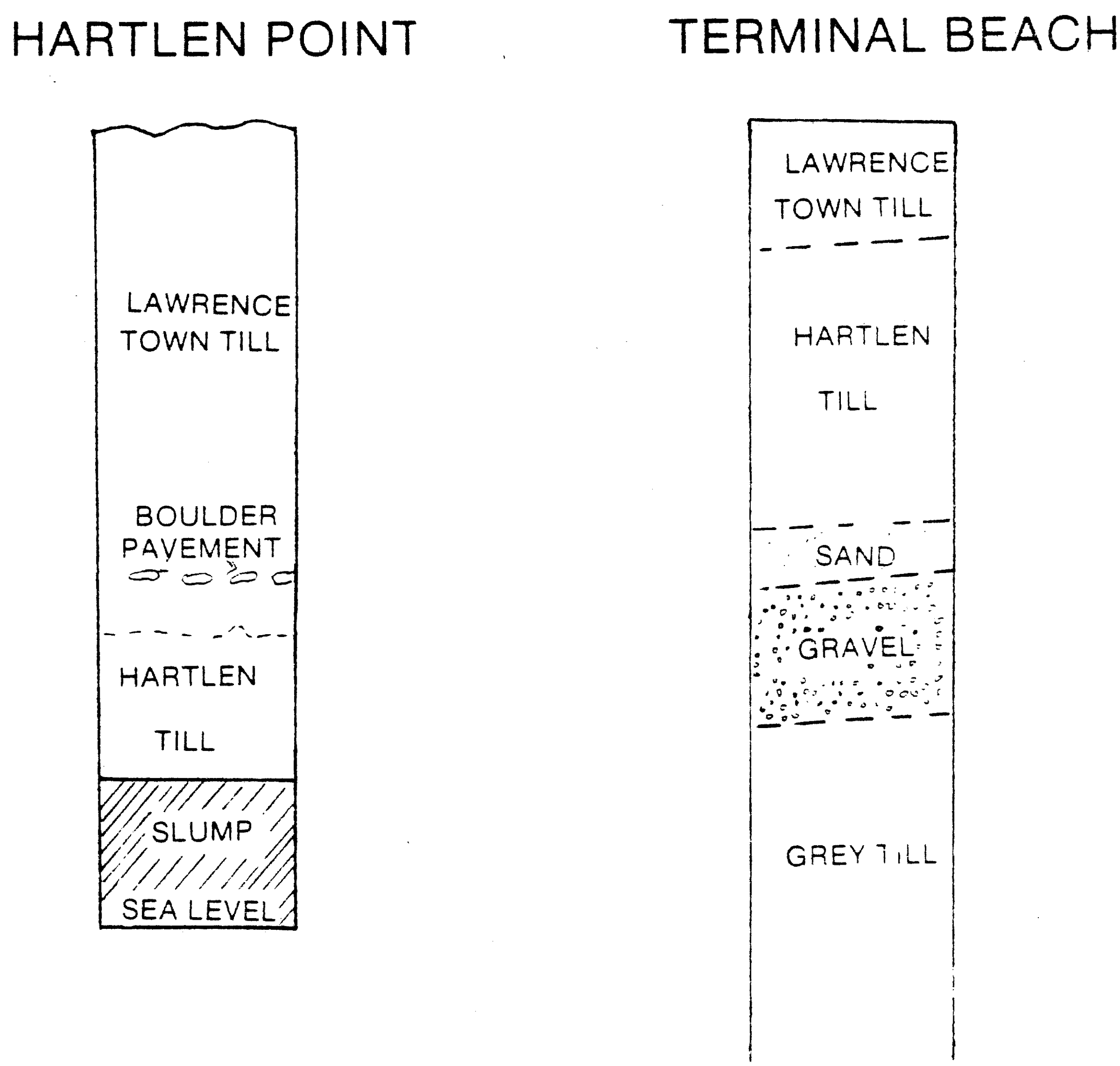

Figure 7 Till Stratigraphy and Correlation at Hartlen Point and Terminal Beach (Stea and Fowler, 1978).

one boulder thick and laterally continuous for tens to hundreds of meters along the cliff. They comprise approximately 1% of the cliff surface at Terminal Beach and much less at Hartlen Point.

4.4 Till Thickness

The three till units exposed at Terminal Beach have variable thicknesses along the drumlin cliffs as assessed from grainsize, slope variations and photographs, in conjunction with the pre-existing stratigraphic sections (Fig. 7). The Hartlen Till was exposed for approximately 50 meters in the core of the Hartlen Point drumlin (see photo 4.7). Nielsen (1976, p. 39) noted a 75 meter exposure implying less obstructing slump deposits, were present. This will be taken as the maximum for calculations of Hartlen Till sediment texture.

The results of the till measurements are summarized in Table IV.

4.5 Calcium Carbonate Content

Dilute hydrochloric acid was administered to portions of samples collected from all areas of Hartlen Point and Terminal Beach. This was to test the hypothesis that till units could be differentiated on calcium carbonate content. This would reflect different provenances of the glacial tills. Table V displays the results of the HCl test. Hartlen Point shows a definite trend, with positive results restricted to basal till samples, and negative results to the mantling till. The line dividing the cliff samples from Hartlen Point in inbedded to show

Table IV: Drumlin till thicknesses as measured from cliff exposures at Terminal Beach and Hartlen Point

Terminal Beach

Till Unit	Half Island Point	Gulley	Foundation	Western	Drumlin	Average
Top	3 meters	2	5	3	2	3.1 m
Middle	8.5 meters	5	8	5	6	6.3 m
Basal	7.5 meters	6	6	6	5	6.6 m

Hartlen Point

Till Unit	1	2 (Nielsen (]976)	Average
Upper	6 meters	7.6	6.8 m
Lower	2 meters	1.6	1.8 m

- Measurements of drumlin till thicknesses as exposed in early eroding sea-cliffs

TABLE V : HCl Test for Calcium Carbonate in Till Samples

	Half Island Point	Gulley	Foundation	Western Drumlin	Hartlen Point
Top	N-12-7 –	0-10-3 +	0-10-4 –	N-17-6 –	0-7-7 –
	N-19-2 +		N-12-1 +	D-8-1 +	0-7-8 –
					0-7-9 –
					0-22-11 +
Middle	N-12-9 +	N-12-4 +	N-12-2 +	N-17-4 –	
				N-20-3 +	
				N-20-4 +	0-28-14 +
					0-22-10 +
					0-28-13 +
Basal	N-12-11 +	N-12-5 +	N-18-1 +	N-17-5 +	
	N-17-1 +			N-20-1 +	
	N-12-10 +				

the two till stratigraphy. At Terminal Beach again, one sees a reaction in basal samples and more ambiguous results in the upper tills.

The data support the division of the Hartlen Point into two tills. For Terminal Beach the presence of calcium carbonate does not seem to be an accurate method of till differentiation. Ground water dissolution may account for anomalous calcium carbonate reactions in the upper till unit.

4.6 Sediment Budget for Eastern Shore

Introduction

To determine if barrier beaches on the Eastern Shore are the product of presently eroding drumlins or repetitive drumlin erosion cycles (refer to the Evolutionary Model section 2.7), one has to compare the rate of beach sediment production to the rate of rising sea level. If the volume of sediment being produced by drumlin erosion is not sufficient to provide a net gain, then other sources of sediment must be considered. A probable source would be offshore sands and gravels from previously eroded drumlins (refer to section 3.4).

To determine the amount of beach sediment eroded annually from the Hartlen Point and Terminal Beach drumlins, the till dimensions, grainsize distribution, and erosion rates were incorporated. Corrections were then made for glaciofluvial material and for boulder pavements in the cliffs.

The erosion rates utilized in this project represent an averaged result derived from previous studies and aerial photograph measurements undertaken by the author (see section 3.4).

Aerial Photograph Retreat Measurements

The aerial photographs from 1974 were compared to the 1982 photographs to measure the erosion of the cliffs at Hartlen Point and Terminal Beach. The photographs were taken at different altitudes and with lenses of different focal lengths, thus necessitating a scale correction.

1974 altitude - 5600'

lens focal length - 152.46 mm

$$\text{scale} = \frac{152.46 \text{ mm}}{1{,}680{,}000 \text{ mm}} = 1{:}11{,}020$$

1982 altitude - 5400'

lens focal length -151.84 mm

$$\text{scale} = \frac{151.84 \text{ mm}}{1{,}620{,}000 \text{ mm}} = 1{:}10{,}670$$

As retreat was measured from the 1974 photos, the distance eroded is at the same scale as the 1974 photo. This value can then be converted to a true distance.

$$\frac{1}{11{,}020} = \frac{\text{eroded distance (m)}}{x}$$

$$x = \text{eroded distance (m)} \times 11{,}020 \text{ mm}$$

Table V displays the measured map distance of erosion and its conversion to actual erosion. The retreat rate is measured from the erosion divided by the time span; in this case 8 years.

As Easton (1982) makes no mention of corrections for scale differences, which are assumed to exist between 1945 and 1974 aerial

Table VI: Summary of Cliff Erosion Measurements

Location	Photo Retreat	Actual Retreat	Time Span	Erosion Rate
Terminal Beach 1	1 mm	11.02 m	8 yrs	1.38 m/yr
2	.6 mm	6.61 m	8 yrs	0.83 m/yr
3	.75 mm	8.27 m	8 yrs	1.03 m/yr
4	.25 m	2.76 m	8 yrs	0.34 m/y
5	.1 mm	1.10 m	8 yrs	0.14 m/y
6	.2 mm	2.20 m	8 yrs	0.28 m/y
7	2 mm	22.04 m	8 yrs	2.76 m/yr
Hartlen Point 1	.8 mm	8.82 m	8 yrs	1.1 m/y
2	.5 m	5.51 m	8 yrs	0.69 m/y

photos, this report will ignore these photo measurements.

From previous studies and data from the author's photo measurements the following erosion rates are considered representative for the drumlin cliffs in the study locations.

Terminal Beach Erosion Rates

1.38 m/yr

0.83 m/y   Average 1.34 m/yr

1.03 m/y

0.34 m/y

0.14 m/y

0.28 m/yr

2.76 m/yr

3.02 m/yr

3.43 m/yr

0.17 m/yr

Hartlen Point

1.1 m/yr

0.69 m/yr   Average 1.11 m/yr

1.3 m/yr

1.35 m/y (avg.)

Terminal Beach Sediment Production Rate

To determine beach sediment production rates, an equation must be devised which incorporates

1) the different till thickness and their respective beach sediment percentages

   ($Till_1$, $Till_2$, $Till_3$) represent average till thickness in meters

   (y_1, y_2, y_3) represent the till beach sediment percentages

2) length of drumlin cliffs eroding 1900 m

3) cliff erosion rate - 1.34 m/yr

4) glaciofluvial deposits beach sediment contribution

   This is derived from the dimensions of the glaciofluvial sections their average beach sediment percentage and the net amount eroded annually. This provides a gross volume. The net volume is computed by subtracting the beach sediment that would be produced from a comparable amount of till sediments. The unpredictable occurence and dimensions of sand lens material discouraged attempts to quantify the amount of the drumlin that they take up. At the vertical transects measured in this study the lens material ranged from 0-11 percent of the cliff surface. Field observations suggest an average percentage of less than 1% overall. As a maximum assessment 2% will be used in glaciofluvial calculations.

   $(0.02 \times 1900 \text{ m} = 16 \text{ m} \,.\, 1.34 \text{ m/y}) - (.79 - .45)$

   $= 277 \text{ m}^3\text{/yr}$

5) boulder pavements represent an amount of coarse material not

asessed by cliff point counts; they must be incorporated in the equation.

The boulder pavements were determined to encompass aprroximately 1% of the cliff surface = 0.01 x 1900 m . 16 m . 1.34 m/y = 407 m^3/yr

Total beach sediment eroded yearly:

($Till_1$ * y_1 * $Till_2$ * y_2 + $Till_3$ - y_3) * drumlin length x erosion rate + (glaciofluvial - boulder pavements)

= [(3.1 m * .512) + (6.2 m * .456) + (6.7 * 0.38)] .190m .1.34 m/yr + (277 m^3/yr - 407 m^3/yr)

= 17,721 m^3/y - 130 m^3/yr

= 17,591 m^3/yr

17,591 m^3 of beach sediment is eroded annually from Terminal Beach.

Hartlen Point Sediment Production Rate

Hartlen Point requires similiar calculations but glaciofluvial material and boulder pavements can be considered negligible (see section 4.3). Also, corrections must be made for the Hartlen Till which was not seen to be continuous throughout the cliff exposures. Only 75 meters of exposure has been observed and recorded in the literature.

Beach sediment eroded yearly

Till = Hartlen Till area = 75 m * 1.8 m

Till = Lawrencetown Till area = (1350 * 6.8 m) + (1280 * 1.8 m)

[(Till area * y) + (Till area * y)] * erosion rate

= [(135 m^2 * .406) + (11,484 m^2 x .522)] * 1.11 m/yr

= 6715 m^3/yr

6715 m^3 of beach sediment is eroded annually at Hartlen Point.

Lawrencetown Beach Volume

The site of deposition for the drumlin beach sediments is considered to be the adjacent barrier beach systems. The volume of sediment which makes up Lawrencetown Beach is totalled from the three components which comprise the barrier beach system:

1) the shoreface deposits found subaqueously in front of the barrier
2) the subaerial beach plain
3) dunes which mantle portions of the beach plain.

a) Shoreface

A shore-perpendicular, high-resolution seismic reflection profile of surficial sediments places the seaward edge of the shoreface at 2300 m offshore in 17 m of water depth. This is designated as the point where sorted beach sediments pass into bedrock and till deposits.

The volume of the shoreface was calculated from an assumed wedge geometry with a constantly rising slope from the base to the top of the shoreface (beginning of subaerial beach). The shoreface was extended laterally parallel to the 2 kilometer length of Lawrencetown Beach.

Shoreface volume = (1/2 base x height) x 2000 m

$$= \frac{(17\ m \times 2300\ m)}{2} \times 2000\ m$$

$= 3.9 \times 10^7\ m^3$ of shoreface sediments

This volume of shoreface sediments represents a maximum model. The wedge shaped, homogeneous shoreface represents an idealistic shoreface.

Table VII: Summary of drumlin dimensions and calculated sediment production rates from Terminal Beach and Hartlen Point

	Area	Cliff Ht.	Cliff Length	Volume	Erosion Rate	Total/yr	Beach Sed/yr
Terminal Beach							
	8.31×10^5 m^2	16 m	1900 m	1.33×10^7 m^3	1.34 m/yr	40736 m^3/y	17591 m^3/y
Hartlen Point							
	1.52×10^6 m^2	10.9 m	1350 m	1.66×10^7 m^3	1.11 m/yr	16334 m^3/y	6715 m^3/yr

Table VIII: Summary of Lawrencetown Beach component dimensions and total beach sediment volume

Lawrencetown Beach Sediment

	Length	Width	Area	Depth	Volume
Beach Plain	2 km	varies	6.16×10^5	10 m	6.16×10^6
Shoreface	2 km	2.3 km	$4.6 \times 10^6\ m^2$	17 m $\rightarrow$ 0 m	$3.91 \times 10^7\ m^3$
Dunes	-	-	$1.18 \times 10^5\ m^2$	2 m	$2.36 \times 10^5\ m^3$

Total Volume = $4.55 \times 10^7\ m^3$

It is used because of the lack of seismic data which would reveal the true shoreface dimensions and volume.

b) Beach Plain

The area of the subaerial beach plain was calculated from 1982 aerial photos using a zero-correcting planimeter. It was found to be 6.16×10^5 m^2.

The thickness of the beach deposits was taken as approximately 10 m. This was determined from beach seismic data from the Eastern Shore which points to a maximum of 10 meters of beach sediment. Vibracores taken from the Eastern Shore have only recovered from 6 to 8 meters of beach sediment but none of these penetrated to the underlying sediments. Thus there appear to be at least 10 meters of beach sediment. The volume of the beach plain sediments was calculated as sediments 6.16×10^6 cubic meters.

c) Dune

Aoelian dunes overly the 10 meters of beach sediment over an area of 1.18×10^5 m^2 as determined from planimeter measurements of the 1982 aerial photographs. These dunes are approximately 2 m thick as assessed from field observations. These dunes represent a volume of $2.36 * 10^5$ m .

Summary

Table VI summarizes the drumlin dimensions calculated volumes and sediment production rates for Terminal Beach.

Table VII gives similiar data for the Lawrencetown Beach components and the total beach volume.

The total volume of beach sediment at Lawrencetown Beach was calculated to be 4.55×10^7 meters^3. This represents the maximum possible volume for the barrier system. The beach sediment production rate of Terminal Beach drumlin cliffs is 17,591 m^3 per year. If this rate is assumed to have been continuous through time, then it would require 2560 years to form the present day barrier beach, assuming drumlins are the only sediment source.

CHAPTER 5

DISCUSSIONS AND CONCLUSIONS

5.1 Discussion

A sediment budget requires a careful assessment of the balance between sediment sources and sinks (see section 3.4). However in this project certain aspects of the sources, sinks and the depositional beach are known only superficially or, not at all, thus necessitating some assumptions on the part of the researcher.

The nature of the drumlin source itself can be problematic. Random variations in deposition, as a result of changing topography and glacial dynamics, discourage efforts to generalize a drumlin's composition. By limiting sampling to one or two drumlins and more specifically, one cross-section (the seacliffs), one has to assume homogeneity within the entire drumlin. However there could, in fact, be a bedrock core within the Terminal Beach drumlins, or a large interior change in sand and gravel content. In this project it was assumed that the cliff cross-section was representative for the study site. Support for this can be found in the adjacent Eastern Shore drumlins which show

1) a lack of a bedrock core
2) a comparable composition within the cliff tills to that found at the Hartlen Point and Terminal Beach (Nielsen, 1976, Stea, 1979).

Drumlins have an inherent variability in grainsize within the till units; again related to the ice dynamics and varying sediment load. By sampling randomly and often across the cliffs it was assumed that this heterogeneity would be accounted for by providing an averaged result.

Sand lenses add further complexity to the drumlin composition, since they are discontinuous random occurrences. Although mainly constrained to the middle till unit, the lenses occur throughout the drumlins at Terminal Beach and infrequently at Hartlen Point. At present, with a maximum 2% of the Terminal Beach cliffs composed of sand lens material, they do not add significantly to the beach sediment volume; they provided 280 m^3 out of a yearly volume of 17,600 m^3 of beach sediment. If the interior of the tills has a much larger sand lens content, this would affect the production rate.

The erosion rates utilized in this study were derived from synthesizing the results of several erosion studies (see section 3.4). These results vary from 0.17 m/yr to 3.43 m/y depending on both the time span from which they were calculated and specific cliff area measured. Thus it is necessary to average a large number of measurements, to ensure a representative rate.

A lack of comprehensive information concerning Lawrencetown Beach coastal stratigraphy again necessitated certain extrapolations from known data. The most serious lack is seen in information regarding the shoreface sediment accumulation. Using a high resolution seismic reflection profile (Boyd and Hall, unpublished data) the base of the shoreface was located 2300 meters offshore; this was identified as the area where postglacial coastal sediments passed into glacial till and bedrock. The water depth was 17 m at this distance offshore. In the absence of other shore-perpendicular profiles the shoreface was extended laterally for the length of Lawrencetown Beach. The volume of the subaqueous shoreface was then calculated from a shore-parallel wedge with a right triangle geometry. This assumes the 17 meter base of the shoreface can be linearly extended onshore, and laterally extended parallel to the beach. This is a maximum assessment of the shoreface volume. If accurate the shoreface represents 86% of the calculated barrier sediments at Lawrencetown Beach. However if the shoreface is, in fact, a blanket or veneer of sand overlying till, bedrock or lagoonal sediments, then this seriously alters the sediment volume. Further seismic and drill data are needed to assess the true shoreface sedimentary environments and actual sand volume.

Lawrencetown Beach was inferred to have started forming a maximum of 700 years B.P., on the basis of ^{14}C radiocarbon dates from beach ridges studied by Hoskins (1983). However this only deals with subaerial beach accumulation and ignores the possible pre-existing shoreface sediments. If present, these sediments would decrease the required sediment production rate from the drumlins, necessary to form the present beach deposits. If one considers the shoreface to predate present beach formation, a rate of beach sediment production of 9200 m^3/yr would be sufficient to form the existing barrier beach. If so, Terminal Beach erosion could account for Lawrencetown Beach.

Till stratigraphy described at the site locations is basically similar to that outlined by Stea and Fowler (1979), (Fig. 7). As this report represents the first attempt to assess grainsize variations in till units, the results were insufficient to correlate the units with till at other Eastern Shore locations. Color, compaction and stratigraphic sequence in the cliffs support Stea and Fowler's conclusion that Lawrencetown Till overlies Hartlen Till. At Terminal Beach, the Hartlen Till was found to contain significantly larger amounts of glaciofluvial sand lens material. However the majority of this glaciofluvial deposit was found within the vertical cross-section described by Stea and Fowler (1979). This sand lens material and larger proportions of beach-sized till matrix were the distinguishing features between the mid- and basal-till units. If these variations were a product of changing ice flow and ice properties rather than the result of a separate glacial event, then there appears to be little reason for separating the lower Grey Till from the Hartlen Till. At Hartlen Point the measured grainsize distribution concurred with the inferred double till stratigraphy of Grant (1963), Nielsen (1976), Podolak and Shiltz (1978) and Stea and Fowler (1979) (see Fig. 7). The Hartlen Till contained appreciably less sand lens material than the 2% estimated for Terminal Beach. This may be caused by differences in underlying sediments and topography or else variations in glacial ice properties.

5.2 Conclusions

This project was designed to provide an assessment of drumlin characteristics and their relation to Eastern Shore barrier beaches. From the evidence collected drumlin features such as stratigraphy, grainsize and the erosion of seacliffs have been clarified and/or quantified.

Drumlins at Hartlen Point and Terminal Beach are composed of separate till units. These are considered to be the result of deposition from separate glacial events. In Terminal Beach cliff exposures, three separate tills were identified:

1) a basal grey lodgement till
2) an intermediate grey Hartlen Till with associated glaciofluvial deposits
3) a mantling deposit of red Lawrencetown Till.

Hartlen Point displays a core of Hartlen Till with an extensive cover of Lawrencetown Till. The Hartlen Till at this exposure displays only rare occurences of glaciofluvial lens material.

The drumlin sediment composition differs between the individual tills, especially with respect to beach sediment percentages. At both Hartlen Point and Terminal Beach the beach sediment percentage increases up through the till units. The grainsize distribution of each till varies slightly throughout the unit. As well, the grainsize of the Hartlen Till, was found to contain more beach sediment at Terminal Beach than at Hartlen Point.

Larger cliff expanses and a more rapid rate of erosion cause a much larger beach sediment production rate at Terminal Beach than at Hartlen Point. Approximately 17,600 cubic meters of usable beach sediment is provided annually by Terminal Beach cliffs.

Based on geomorphology, as well as grainsize trends, the eroded sands and gravels from these drumlins are inferred to be contributing to adjacent barrier beach sediments. The Terminal Beach sediment budget, which is based on a maximum assessment of Lawrencetown Beach volumes, shows that drumlin erosion has provided insufficient sediment for beach and shoreface formation in a 700 year time frame. Thus sand and gravel was probably transported inshore with the Holocene transgression as pre-existing barrier sediments. Since Terminal Beach drumlins represent one of the largest potential beach sediment sources, it is concluded that other Eastern Shore barrier beaches are also dependent on offshore sediments for their formation.

With respect to the evolutionary model of the Eastern Shore, the lack of sufficient sediment production rates appears to support the cyclic nature of drumlin erosion and barrier formation. The barrier beach seems to be a gradually accumulating deposit which is dependent on more than one drumlin sediment source.

REFERENCES

BOWEN, A. J. and BOYD, R., 1983. The Eastern Shore Beaches: Final Report to N. S. Dept. of Lands and Forests, 71 pp.

BOWEN, A. J., EDMOND, D. P., PIPER, D. J. W., and WELSH, D. A., 1975. The maintenance of beaches, Technical Report, Institute of Environmental Studies, Dalhousie University, Halifax, 582 pp.

BOYD, R. and HALL, R. K., 1983. Unpublished data.

BOYD, R., 1984. Unpublished data.

CHORLEY, R. J., 1959. The shape of drumlins. J. Glaciol. 3 : 339-344.

DAVIS, R. A., 1983. Depositional Systems. Prentice-Hall Inc., New Jersey, 669 pp.

EASTON, J. A., 1982. Marine and coastal geology between Hartlen Point and Jeddore Cape, Nova Scotia, unpublished B.Sc. thesis, Dalhousie University, Halifax, N. S., 58 pp.

GRANT, D. R., 1963. Pebble lithology of the tills of southeast Nova Scotia, unpublished M.Sc. thesis, Dalhousie University, Halifax, N. S.

GRAVENOR, C. P., 1953. The origin of drumlins. Am. J. Sci., 251 : 674-681.

HOSKIN, S., 1983. Coastal sedimentation at Lawrencetown Beach, Eastern Shore, Nova Scotia; unpublished B.Sc. thesis, Dalhousie University, Halifax, N. S., 46 pp.

KING, L. H., 1980. Aspects of regional surficial geology related to site investigation requirements - Eastern Canadian shelf: in Ardus, D. A., (ed.) Offshore Site Investigation (London), p. 1-34.

MENZIES, J., 1979. A review of the literature on the formation and location of drumlins. Earth-Sci. Review, 14 : 315-359.

NIELSEN, E., 1976. The composition and origin of Wisconsinan tills in mainland Nova Scotia, unpublished Ph.D. thesis, Dalhousie University, Halifax, N. S.

PIPER, D. J. W., 1977. Manual of sedimentological techniques, Dalhousie University, Halifax, N. S., 103 pp.

PIPER, D. J. W., MUDIE, P. J., LETSON, J. R. J., BARNES, N. G., IULIUCCI, R. J., (in preparation). The marine geology of the Inner Scotian Shelf of the South Shore, Nova Scotia. G.S.C. Paper

PODOLAK, W. E. and SHILTZ, W. W., 1978. Some physical and chemical properties of till derived from the Meguma Group, southeast Nova Scotia; Geological Survey of Canada, Paper 78-1A, p. 459-464.

QUINLAN, G. and BEAUMONT, C., 1981. A comparison of observed and theoretical postglacial relative sea level in Atlantic Canada; Can. J. Earth Sci. Vol. 18, 1146-1163.

SCOTT, D. B., 1977. Distributions and population dynamics of marsh-estuarine foraminifera with applications to relocating Holocene sea level; Ph.D. thesis Dalhousie University, Halifax, N. S., 252 pp.

SCOTT, D. B. and MEDIOLI, F. S., 1982. Micropaleontological documentation for early Holocene fall of relative sea level on the Atlantic coast of Nova Scotia: Geology v. 10, p. 278-281.

SMALLEY, I. J. and UNWIN, D. J., 1968. The formation and shape of drumlins and their distributional and orientation in drumlin fields; J. Glaciol., 7 : 377-390.

STEA, R., 1979. A study of succession of tills exposed in a wave-cut drumlin, Meisner's Reef, Lunenburg County, Nova Scotia Dept. of Mines and Energy Report 80-1, p. 9-19.

STEA, R. and FOWLER, J., 1979. Minor and trace element variations in Wisconsinan tills, Eastern Shore region, Nova Scotia. Nova Scotia Dept. of Mines and Energy Paper 79-4.

WANG, Y. and PIPER, D. J. W., 1982. Dynamic geomorphology of the drumlin coast of Southeast Cape Breton Island. Maritime Sediments and Atlantic Geology, 18 : 1-27.