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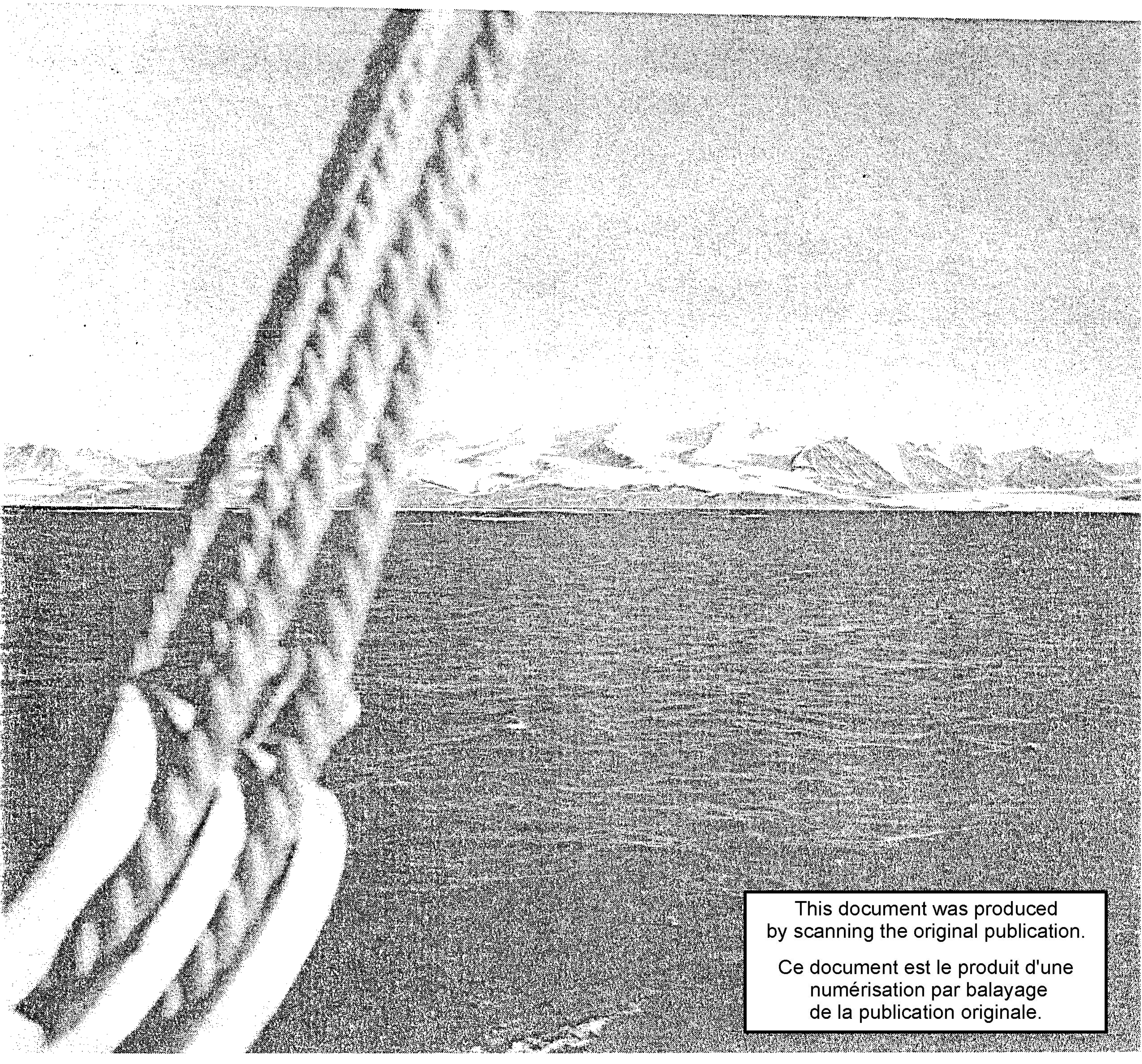
TRANSGRESSIVE SEDIMENTATION, EASTERN SHORE, NOVA SCOTIA



EASTERN SHORE FIELDTRIP

LEADERS: RON BOYD, TONY BOWEN AND CECILY HONIG

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EASTERN SHORE FIELD TRIP
FIELD STOP DESCRIPTIONS

by Ron Boyd and Duncan FitzGerald

STOP 1 HALF ISLAND POINT

Half Island Point provides a panoramic view of the Eastern Shore. The point forms part of the largest drumlin in the area and is being rapidly cut back by wave erosion. Drumlin cliff erosion forms the major source of sediments for the Eastern Shore beaches. Sand and gravel sizes are transported westward into the Lawrencetown coastal compartment. Boulder size material remains as a retreat shoal seen at the base of the cliff. Boulder retreat shoals mark the former sites of eroding drumlins. Cliff erosion rates along Half Island Point average around 1m/yr. and rates as high as 3m/yr. have been recorded.
Glacial stratigraphy at Stop 1 consists of four major units: a basal grey lodgement till overlain in turn by glaciofluvial sediments, Hartlen till and red Lawrencetown till. Glacial striae and till fabric indicate a northwesterly source. Pebble lithology consists primarily of locally derived clasts of quartzite and slate with around 10% far travelled clasts of granite, red sedimentary rocks (sandstone and mudstone) and basalt. Basalt and the sedimentary rocks are derived from at least as far as the Bay of Fundy. Sand content of this till cliff section averages 20-40%.

STOP 2 LAWRENCETOWN BEACH

Sediment derived from the Half Island Point source accumulates in the Lawrencetown barrier. At the beach stop a steep gravel beach can be seen, with progressive fining in the western (downdrift) direction and finally ending in a sand beach near Lawrencetown Head. The barrier consists of a beach ridge plain towards Lawrencetown Lake, a dune field and a gravel beach with low tide sand terrace. A boulder retreat shoal in the surf zone marks the site of a former drumlin which has controlled the orientation of the beach ridges. Seismic refraction surveys indicate an average of 5-10m of sediment thickness across the barrier and a maximum of 25m in the location of two former tidal inlets at either end of the present beach. Behind the beach a steepened drumlin slope marks the location of a sea cliff along a probable former coastline.

STOP 3 LAWRENCETOWN HEAD AND THE EBB TIDAL DELTA

The top of Lawrencetown Head provides an overview of Lawrencetown Inlet, the adjacent beach ridge complex (to the west) and the Lawrencetown Lake backbarrier system. The inlet is fronted by a shallow ebb-tidal delta and backed by several flood-tidal deltas. The position of the inlet throat is primarily a function of the meandering character of the tidal inlet channel and sand deposition along Stony Beach. The morphology of the ebb tidal delta is highly variable and is best developed during the summer period of low wave energy. At this time the components of the ebb tidal delta include a main ebb channel flanking channel margin linear bars and terminal lobe. Marginal flood channels and swash bars may also be present. As winter approaches and wave energy increases, sand from the ebb tidal delta is transported onshore. This process together with increased onshore and longshore sediment transport from the west cause a deflection of the main ebb channel to an easterly position along Lawrencetown Head. The main ebb channel has ebb-oriented large 2D ripples while the marginal flood channel has flood-oriented large 3D ripples.

STOP 4 FLOOD-TIDAL DELTA

The flood tidal deltas at Lawrencetown Inlet are located at positions where the channel increases its width. The first flood delta forms at the confluence of the Eel River and the Lawrencetown tidal channel. The western margin of the flood tidal delta has attached to the beach ridge complex. The remainder of the delta is well developed, containing a flood ramp with flood oriented large 2D ripples, an ebb shield (the high landward portion of the delta) and an ebb spit with ebb oriented bedforms. Further landward in the back barrier environment are found several more flood tidal deltas. Their presence indicates a continuing infilling of Lawrencetown Lake. Tidal current measurements taken at the nearby roadbridge demonstrate that the maximum flood tidal currents are 50-60 cm/s stronger than the ebb currents. This tidal asymmetry is caused by the shallow depth of the inlet channel resulting in a large degree of shoaling of the tidal wave.

AN EVOLUTIONARY MODEL FOR TRANSGRESSIVE SEDIMENTION ON THE EASTERN SHORE OF NOVA SCOTIA

R. Boyd[1], A.J. Bowen[2], R.K. Hall[1]

[1] Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia. B3H 3J5

2 Department of Oceanography, Dalhousie University, Halifax, Nova Scotia. B3H 3J5

1. INTRODUCTION AND OBJECTIVES

The Eastern Shore of Nova Scotia faces the Atlantic Ocean along an east-northeast trending coastline from Halifax to Chedabucto Bay (figure 1). The area examined in detail in this paper lies between Halifax Harbour and Jeddore Cape, 35km to the east. Throughout its length, this coastal zone is characterised by a system of linear, shore-normal estuary systems and intervening headlands. Estuary-mouth barrier systems infill the seaward margin of most estuaries. Many of the barrier systems contain tidal inlets and associated tidal delta deposits.

Strong contrasts exist between individual estuaries and barrier systems along the Eastern Shore. Some estuaries such as Porters Lake (figure 1) are predominantly fresh to brackish with strong salinity contrasts at the seaward end. Others such as Chezzetcook Inlet are predominantly marine systems throughout. Correspondingly, some barrier systems such as those in the entrance to Chezzetcook Inlet are actively building, while others are experiencing serious erosion (Martinique Beach) or have recently been destroyed (Rocky Run barrier). Our objective in this paper is to explain the genesis of the Eastern Shore coastal zone and to provide a model for its subsequent and ongoing evolution.

2. PHYSICAL PROCESSES

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2. PHYSICAL PROCESSES

The two major physical parameters controlling sediment dispersal on the Eastern Shore are waves and tides. Tides here are semi-diurnal and mesotidal, with a maximum spring range of 2.1m (Canadian Hydrographic Service, 1984). The highest tidal current velocities are generated within estuary inlet throats and estuarine tidal channels. Tidal currents provide the major mechanism for landward transport of sand - mud sized sediments through these estuaries.

Waves are responsible for reworking glacial sediments exposed along the coast and transporting sand - cobble sized material alongshore into the estuary mouth barriers. Waves arriving on the Eastern Shore primarily result from the pas sage of mid latitude cyclonic depressions which track west to east or southwest to southeast across continental North America. When the storm track passes across the continental shelf of the Canadian Maritimes, waves which propagate towards the Eastern Shore are generated in the NE and SE quadrants of the approaching depression. The resulting ocean fetch is relatively short, beween 100 and 500km. A less common but significant additional source is from the northeastward passage of hurricanes and tropical depressions originating near the Carribean Sea and Gulf of Mexico.

The wave climate received on the Eastern Shore is dominated by wind waves generated on the Scotian Shelf superimposed on a component of lower amplitude, longer period Atlantic swell. The modal wave (for which the product of wave power x frequency of occurrence is at a maximum) is for waves of 1.5-2m height and 9-10s wave period. Average annual wave power is 2.14 x 10^4 watts per metre. Wave power displays a marked seasonality, with minimum values received from May - September and maximum values, representing frequent winter storms, occurring from October to April. These Eastern Shore features are characteristic of a northern hemisphere, east coast wave environment (Davies, 1980).

3. RELATIVE SEA LEVEL

Holocene relative sea level (RSL) in Atlantic Canada has been dominated by the ablation of continental ice masses. Large volumes of water are withdrawn from ocean basins as ice thickness increases on land, causing a fall in RSL. Areas under thick continental ice accumulation experience an isostatic sinking due to extra crustal loading. Areas such as the Eastern Shore, which lie close to the ice margin, experience less RSL fall than the ocean basin as a whole. However, coastal zones lying close to the ice margin experience the passage of a glacial forebulge (Quinlan and Beaumont, 1981). Following ice recession, the glacial forebulge migrates inward through the marginal ice zone. This migration initially causes a fall in RSL as the forebulge approaches, followed by a RSL rise after passage of the forebulge crest.

The late Wisconsinan ice advance reached its maximum in Nova Scotia between 32 and 12kybp (thousand years before present). Late Wisconsinan crustal loading was insufficient during deglaciation to produce any higher RSL than that experienced at present. During forebulge migration, RSL on the Eastern Shore fell to a minimum of at least -27m around 7-12kybp (Scott and Medioli,. 1982). King (1967a,b;1970) favors a much more extensive SL lowstand based on the existence of submarine terraces at a uniform depth of 115-120m. RSL has risen from depths of -27m, 7kybp to its present level (see Fig. 2) at an average rate of 35cm/100years (Scott and Medioli, 1982). Tide gauge records from Halifax Harbour (Grant, 1970) indicate that RSL is continuing to rise at current rates of about 40cm/100 years.

4. COASTAL GEOLOGY

The oldest rocks which crop out along the Eastern Shore are the Ordovician Meguma Group. These are generally considered to be metamorphosed turbidite deposits (Schenk et al. 1980). They consist of a sand-dominant, resistant quartzite lithology - the Goldenville Formation, and a shale dominant more easily weathered lithology - the Halifax Formation. These bedrock lithologies are the only two found at present along the Eastern Shore and are often exposed as the headlands defining individual coastal systems and separating estuaries. The Meguma Group structure is dominated by large NE-SW trending folds and cross-cutting faults which trend NW to SE. Locally, relief of 40-60 m has been cut into the Meguma Group by glacial action during Pleistocene times. This relief takes the form of linear scours and valley systems, again trending NW-SE, paralleling the main ice transport direction and occasionally coinciding, as at Porters Lake, with the cross-cutting bedrock faults.

The only other lithologies exposed along the Eastern Shore are unconsolidated Pleistocene glacial deposits which almost exclusively preserve only the record of the latest (Wisconsinan) glaciation (Fig. 3). These deposits take the form of either basal lodgement or ablation tills, some of which are characterised by drumlin accumulations. Lodgement or ablation tills are usually locally derived and average less than 3m in thickness. They are referred to as slate till or quartzite till depending on the underlying Meguma bedrock lithology (Stea and Fowler, 1979). Drumlin tills contain a mixture of locally-derived and far travelled lithologies and are typically a mixture of several till types. These types include slate till, quartzite till and Lawrencetown till, with Lawrencetown till containing the majority of far travelled clasts and providing drumlin cliffs with their characteristic red-brown colour.

The occurrence of barrier systems and associated abundant sediments in the coastal zone of Atlantic Nova Scotia is closely linked to the distribution of till and, in particular, drumlin fields. Piper et al. (in press) and Wang and Piper (1982) detail examples of coastal sediment accumulation when drumlin fields intersect the coastline around Lunenburg on Nova Scotia's South Shore and along the southeast coast of Cape Breton. In contrast, geomorphology is characterised by bare rocky cliffs where glacial sediments are sparse, such as along the coastal granite outcrop southwest of Halifax. Within the Eastern Shore drumlin field bounded by Halifax Harbour, Jeddore Cape and extending north to the #7 Highway, 79 individual drumlins occur, ranging in size from 200m x 100m to 3.4 km x 1 km. Approximately

25% of the total ocean coastline is currently composed of drumlins. The heights of these drumlins range between 5m and 20m and they contain a sand/cobble component of up to 40-60% by volume. Drumlin and associated thinner till sheets therefore represent the single most important sediment source on the Eastern Shore.

5. EVOLUTIONARY COASTAL MODEL

Our method of interpreting the development of the Eastern Shore coastal zone is to construct a model identifying discrete stages of coastal genesis and subsequent evolution. This model provides a method for summarising development of the 13 estuarine-barrier compartments in this region, each of which exhibits a wide variety of physical characteristics and most of which are in different stages of evolution. In the model, a representative coastal compartment is constructed. It contains a composite set of physical features which are characteristic of several Eastern Shore compartments at that stage of evolution. Specifically (Figure 4), Stages 1 and 2 identify coastal genesis in early Holocene times and are not repeated. Stages 3 through 6 currently occur in a repetitive, cyclic form for each estuary compartment. The time scales and detailed geomorphology of this evolutionary process depend on the transgression history as new estuaries and sediment sources are progressively encountered.

5A. STAGE 1 - CONTINENTAL GLACIER AND ICE SHELF

A complex glacial history was experienced throughout the Nova Scotia mainland and continental shelf during Pleistocene times. The majority of glacial stratigraphy post-dates the last interglaciation (around 125 kybp). The glacial sequence appears to be best described as derived from a three till - three phase glaciation (Stea 1982, 1983) composed of Early, Middle and Late Wisconsinan events. The Early Wisconsinan glaciers originated from major Laurentide ice masses and traversed Nova Scotia as far as the present shelf edge (Grant and King 1984, Prest 1984). Early Wisconsinan glaciers deposited a thick till sequence both on land (e.g.

the East Milford Till of Stea, 1982) and offshore, where it is referred to as Scotian Shelf Drift (King, 1970). The ice grounding line is marked by the subglacial Scotian Shelf end moraine complex formed 28-30 kybp (King 1969). This moraine complex marks the zone of liftoff between landward grounded ice and a seaward floating ice shelf which existed from throughout middle to late Wisconsinan times (Figure 4.1). Comparable conditions are observed today primarily in Arctic or Antarctic environments such as the Ross Ice Shelf. Later Wisconsinan ice advances were responsible for Eastern Shore deposition of local slate till, quartzite till and the overlying Lawrencetown Till (Stea 1980, Stea and Fowler 1979). The last Wisconsinan glaciation seems to have been derived only from local glacial source regions such as the South Mountain region in the Atlantic Uplands (Grant and King 1984). The ice thickness estimates of Quinlan and Beaumont (1982) suggest a 250 m thick icecap covered the Eastern Shore until around 16 kybp with deglaciation complete by around 12 kybp. Late Wisconsinan ice flow direction on the Eastern Shore maintained a consistent NW to SE orientation with glacial striae trends ranging from 121° to 174° E of N. Drumlinoid till accumulations and the linear bedrock scours now occupied by lakes and estuaries on the Eastern Shore also conform to a NW-SE orientation, suggesting formation and/or major modification by Late Wisconsinan ice.

5B. STAGE 2 - RSL RISE AND ESTUARY FORMATION

This second model stage represents a transition phase between the glacial cover of Stage 1 and the active coastal erosion and sediment reworking of Stage 3. Initially in Stage 2, RSL fell to at least -27 m. If ice was still present at this time, sedimentation on the Eastern Shore would have been characterised by morainal and glaciomarine deposition on what is now the Inner Scotian Shelf. If this sea level fall was preceded by ice recession then fluvial channeling and outwash-style sedimentation would have resulted. With eventual removal of the ice, the Eastern

Shore would have been exposed as a glacially sculpted landscape consisting of linear scours and ridges formed in the Meguma bedrock or the remaining drumlinoid till deposits. The final ice ablation phase infilled glacial scours with a linear network of lakes aligned in the SE direction of ice flow (see Figure 3). These lakes remain a common feature of the Eastern Shore landscape with typical densities of 50 lakes per 100 km^2. Although not all are accurately charted, glacial scouring has often resulted in relatively deep valley systems. Porters Lake, for example, is over 25m deep while Bedford Basin is over 72m deep. Large lakes may range up to 10 km long and 1-2 km wide.

RSL rise along the Eastern Shore commenced around 7-12 kybp. At this time transgression of the inner Scotian Shelf commenced, turning the most seaward lakes into marine to brackish estuary systems influenced by tidal processes (Figure 4.2).

STAGE 3 - BARRIER AND ESTUARINE SEDIMENT ACCUMULATION

The combination of rising RSL and moderate to high wave power resulted in extensive reworking of glacial deposits intersected by the transgressing shoreline. Stage 3 describes a period in which drumlins and other till accumulations act as primary sediment source regions for sediment ranging in size from clay to boulders (Figure 5). Sediments follow a variety of dispersal paths, depending on their grainsize. Wave erosion of drumlin sediment sources generates a sediment component of cobble to boulder size material which waves are incompetent to transport away from the seaward face of the drumlin. As transgression continues, this coarse lag gravel deposit mantles the seafloor above former drumlin sites. The drumlin mud component is transported away from the sediment source areas in suspension to accumulate as Le Have Clay in mid shelf basins (King, 1970; King and Fader, 1985) or to be transported by tidal currents into lower-energy depositional sites within estuaries.

Very fine sand to cobble sizes experience wave-generated longshore transport to accumulate in estuary mouth barrier systems downdrift. The dimensions of the resulting littoral drift cell are determined by the dimensions of each individual estuary compartment. No evidence exists for sediment bypassing between compartments. Strong contrasts in sediment texture and composition exist between adjacent compartments (Boyd and Bowen, 1983).

There is also contrast in the direction of dominant littoral transport within each compartment. Transport direction is controlled by the orientation of each local headland-beach coastal segment to the most frequent south to southwest wave approach direction. A second control is exerted by the location of the major drumlin sediment source. The Cole Harbour and Martinique compartments face south or southeast and their major sediment sources lie to the west. The resulting sediment transport is west to east, as evidenced by decreasing sediment size downdrift and the long term eastward progradation of gravel spits (Boyd and Bowen, 1983). Lawrencetown beach faces south and its major sediment source, Half Island Point, lies to the east (Figure 6). Sediment transport in the Lawrencetown compartment is from east to west.

The extent of sand and gravel accumulation in estuary mouth barriers depends on the balance between the rate of sediment supply to the rate of RSL rise. If the sediment supply balance is positive, barrier systems may build vertically and also prograde seaward (Figure 4.3). The first form of barrier accumulation is in spits adjacent to drumlin sediment sources. Further accumulation results in longshore progradation of spits into beach ridges. Beach ridges are locally capable of building seaward as beach ridge plains if supply is sufficient, as evidenced by Lawrencetown Inlet Beach and Lawrencetown Beach (Figure 7). Beach ridge orientation at Lawrencetown Beach shows clear progradation from eastern sources at Half Island Point together with additional control from an older eroded drumlin in the center of the beach. Erosion rates along the 10-20 m high, 2.5 km-long Half Island Point drumlin presently average 1 m/year. Sand to cobble sizes make up an average 45% of total drumlin volume which consequently results in an annual sediment supply of $17600m^3$ from Half Island Point to the Lawrencetown barrier (Sonnichsen, 1984). Sediment accumulating at Lawrencetown first prograded 16 eastern ridges, all aligned with the present beach. Further sediment supply continued westward progradation from the eroded mid-beach drumlin in the form of 8 recurved spits trending perpendicular to the present beach. At their time of formation, the spits probably paralleled a tidal inlet at the western end of the beach. The final phase of barrier building prograded the last beach ridge further westward to link up with the Lawrencetown Head drumlin at the western end of the compartment thus closing the tidal inlet. Hoskin (1983) using ridge morphology and C^{14} dating indicated that the initiation of ridge sedimentation at Lawrencetown began around 800ybp and was complete by 350ybp. A similar history of compartment infilling by beach ridge progradation accounts for the development of Lawrencetown Inlet beach 1 km to the west, except for the final phase of inlet closure which has not yet occurred.

If an estuary has a sufficiently large tidal prism with no alternative outlet, a tidal inlet may be maintained throughout Stage 3 barrier genesis and progradation. Under these conditions a significant proportion of sediment potentially available for barrier building will be transported through tidal inlets and accumulate in flood and ebb tide deltas. This apears to be the case at the prograding Rainbow Haven barrier, where the large tidal prism of Cole Harbour has maintained an active tidal inlet.

5D. STAGE 4 - BARRIER RETREAT

During Stage 4, the critical balance changes between sediment supply and RSL, resulting in the ending of barrier progradation and the onset of barrier retreat. The most obvious reason for this change lies in the reduction of sediment supply from depleted drumlin sources. Typical drumlins along the Eastern Shore are 1 km long by 0.5 km wide. For cliff retreat rates of 1 m/year, the lifespan of a drumlin and its dependent barrier is less than 1000 years. The coastal retreat of the drumlin will also eventually limit beach progradation as these two adjacent shoreline segments become more aligned. Reduced sediment supply can also result from secondary causes such as diversion into tidal inlets or eolian bypassing. Barrier systems respond to negative changes in the sediment supply/RSL balance by entering a stage of coastal retreat (Figure 4.4). This stage is first characterised by barrier erosion as the shoreline successively occupies a more landward position. In some cases sediment eroded from the beach may initiate active dune growth early in Stage 4, while the retreating foredune is marked by a scarp such as at the western end of Martinique Beach (Figure 8). Further development into Stage 4 is characterised by barrier breaching in the form of overwash and tidal inlet processes. High water levels resulting from storm surge and wave action (e.g. Boyd and Penland, 1981) enable transport of water and sediment through locations of lowest barrier elevation. Washovers are common in Stage 4 barriers at the eastern end of Martinique Beach (active 1974-79, Figure 9) and many gravel barriers between Three Fathom Harbour and Petpeswick Inlet. Overwash channels in Stage 4 may progress to become permanent tidal inlets in response to rising RSL and resulting increase in estuarine tidal prism.

Sediment dispersal trends in Stage 4 are characterised by net landward transfer of barrier sand. The loss of this sand accelerates the retreat process by removing the material needed for post-storm beach rebuilding. Barrier breaching in Stage 4 followed by overwash and permanent tidal inlet formation occurred at Conrads Beach in fall 1962. Since 1962, sand from Conrads Beach has been continuously transferred to the new flood tide delta which now infills West Marsh and covers an area of over 0.5km^2 (Figure 10). Silver Sands beach across the entrance to Cow Bay illustrates a coastal system whose evolution from Stage 3 to 4 has been artificially accelerated by aggegate mining. McIntosh (1916) described the beach system as consisting of a series of gravel ridges and two mid beach drumlins which backed an extensive sand beach. Relative stability continued until 1954. However, between 1956 and 1971 some two million tons of sand and gravel were removed from the beach. As early as 1960, the western end of the beach had collapsed, the beaches tied to the shoals east of Hartlen Point had disappeared and the inlet to Cow Bay had widened noticeably. The main beach became much thinner and by 1964 averaged only half the width of 1954 (Huntley, 1976). The remainder of the sand not trucked away during the mining operation was removed by tidal processes to accumulate in the Cow Bay flood tide delta. The result of mining combined with natural evolution produced 50-80m of beach retreat between 1954-71 and reduced Silver Sands to a thin boulder barricade.

5E. STAGE 5 - BARRIER DESTRUCTION

In the presence of a rapidly rising RSL a coastal barrier system must maintain an active sediment supply or ultimately be destroyed. By Stage 5, Eastern Shore barriers receive minimal sediment from their depleted drumlin sources. At a rate of RSL rise around 35cm/100years, a typical barrier along the Eastern Shore with no active sediment supply would be submerged in less than 700 years. In reality, the effects of marine and subaerial erosion processes acting in combination with rising RSL may accomplish the barrier destruction in a much shorter time. Each of the processes operating during Stage 4 serves to remove sediment from the critical area of the beach face to dune systems, washovers or estuarine and flood tide delta locations where it is no longer available for beach rebuilding during post-storm recovery phases. The result of continuing sediment depletion and RSL rise is an increase in washover intensity, the formation of more tidal inlets and finally the destruction of the barrier. During this phase, the sand and gravel that once formed the barrier is actively reworked into spits and intertidal to subtidal shoals (Figure 4.5). Some beach material from the destroyed barrier systems, together with other finer grained material, accumulates in tidal flat, distal flood tidal delta and marsh environments within the infilling estuary. This material is not all lost permanently to the barrier system. As the shoreline eventually reaches further up the estuaries previously deposited back barrier material may once again contribute to barrier sediment supply as it is exhumed at the shoreface.

Flying Point at the eastern end of Martinique Beach and Wedge Island off Three Fathom Harbour are examples of depleted drumlin sources (Figure 11C). They are characterised by well developed boulder shoals extending seaward from the present shoreline. A further and final phase of drumlin depletion takes the form of armoured offshore islands such as Shut-In Island near Three Fathom Harbour or Egg Islet near Conrads Beach. These former drumlin headlands have lost all unconsolidated sediment above the low water line, except for a surficial covering of large boulders. Many former drumlins may be identified on the inner shelf as isolated topographic highs such as those seaward of Petpeswick Inlet (figure 1). They have also been identified as former drumlin sites in Mahone Bay by Piper et al. (in press). Bedrock may be exposed at the seafloor or along the coast where original sedimentary deposits were thin or where bedrock highs crop out.

A well defined example of a Stage 5 coastal system can be seen at the Rocky Run barrier between Graham Head and Half Island Point. The transition from a Stage 4 to Stage 5 coastal system can be identified by a sequence of aerial photographs taken between 1954 and 1982 (Figure 11A-C). Another example of a Stage 5 system occurs between Rudey's Head and Sellars Head. This system is characterised by the absence of an extensive landward estuary and the sediments from the destroyed barrier have completely infilled a small back barrier bay, occurring now as intertidal shoals.

5F. STAGE 6 - BARRIER RE-ESTABLISHMENT

The final evolutionary model stage describes a period when the destroyed barrier remnants of Stage 5 migrate up the estuary to re-establish new barrier systems in a more landward location (Figure 4.6). The migration is driven by ongoing RSL rise and requires one or both of: a) a new sediment source, and b) a new set of headland anchor points. When these conditions are met barrier generation begins anew, following the pattern described for Stage 3. However Stage 6 barrier generation differs from the original phase of barrier formation in that it has two sediment sources in addition to new till and drumlin headlands adjacent to the Stage 6 barrier site. These two additional sources are: 1) the old Stage 5 barrier remnants, and 2) the back barrier sands of the estuary and flood tide delta. Both these sources of sediment are made available through shoreface retreat (Fischer, 1961; Swift, 1975) as earlier barrier and back barrier sediments are re-exposed on the retreating shoreface.

The procedure for new barrier formation in Stage 6 is as follows. The intertidal shoals of Stage 5 migrate landward until they encounter new headland anchor points. Usually these anchor points are either drumlins or outcropping bedrock and their location within the estuary provides a lower energy site for barrier accumulation than would have been possible on the open coast. Initially spits prograde from the headland anchors until stabilisation takes place. The large reservoir of sand remaining in the nearshore zone is gradually incorporated into the new barrier as the shoreface retreats. Concurrently new sediment may also be arriving from adjacent drumlin sites. This sediment influx again leads to beach ridge development and beach ridge plain progradation. The reformation of barrier systems in Stage 6 illustrates the ongoing cyclic nature of the model. The history of sea level transgression on the Eastern Shore is one of barrier development, barrier destruction accompanied by estuarine infilling followed by barrier re-establishment as the system continually evolves landward through cyclic translation.

Two sites along the Eastern Shore are currently in the process of establishing new barrier systems. Steering Beach, a series of intertidal shoals which existed at the entrance to Musquodoboit Harbour around 1945 had migrated 550 m landward to establish a new linear barrier by 1974,a rate of around 20m per year. Sediment was almost exclusively derived from the pre-existing shoal complex which stabilised on one new bedrock anchor point at Indian Island and another on the main Musquodoboit Harbour tidal channel levee. Red Island, Gaetz Island and Conrod Island are three sites of new barrier formation within Chezzetcook Inlet (Scott, 1980). Red Island grew from a small bedrock nucleus just over 100 m long in 1854 (Figure 12A) to an 1100 m long barrier with recurved spits by 1974 (Figure 12B). Erosion of Conrod Island drumlin further to the west has provided sediment to join Conrod Island to Gaetz Island with a 300 m long barrier with incipient beach ridge plain formation (Figure 13).

6. DISCUSSION

Coastal evolution on the Eastern Shore of Nova Scotia represents a stepwise form of Swift's (1975) concept of shoreface retreat. On the Eastern Shore retreat is not a continuous process but occurs in alternate periods of barrier growth and decay within the overall framework of shoreface retreat. The underlying cause of coastal transgression here is ongoing RSL rise, apparently still responding to glacial forebulge passage after the Wisconsinan deglaciation. An additional component of RSL in Nova Scotia may be the eustatic rise indicated by Hicks (1978) and others along the eastern coast of the United States. Commonly reported values of RSL rise on the east coast of North America are around 12 cm/100 years (Emery, 1980; Gornitz et al., 1982). The additional 28 cm/100 years which occurs along the Eastern Shore not only indicates the effects of glacial unloading but represents the margin by which RSL rise on the Eastern Shore exceeds that on the comparable passive margin coast further south.

The reason for a stepwise rather than continuous form of shoreface retreat is related to the distribution of discrete local sediment supplies and the location of suitable headland anchor points. As the transgressing shoreline encounters either of these factors, a period of barrier building commences. Progradation of barriers results from sediment derived from eroding till, drumlin headlands or pre-existing barriers. When a period of sediment supply nears an end, RSL rise again becomes the dominant factor and shoreface retreat is resumed. In the Eastern Shore case, sediment appears to be well conserved within estuary compartments during transgression, probably as a result of the large sediment volumes transported behind the barrier prior to its destruction. Shallow seismic reflection profiling and side scan sonar surveys (unpublished data) show little evidence of extensive sand bodies at the sites of former barriers on the inner shelf, implying that the majority of the coastal sediment package keeps pace with the transgressing shoreline.

An important question concerning sediment supply involves the relative contribution of adjacent drumlin sources compared to the contribution supplied to the estuary by destruction of more seaward barrier systems generated in earlier evolutionary cycles. Sonnichsen (1984) considered this problem for Half Island Point, the largest drumlin source on the Eastern Shore. After calculating the drumlin sediment budget based on drumlin volume and erosion rate, he concluded that Half Island Point was capable of supplying 1.76×10^4 m^3 of barrier sediment per year. However, the total volume of the barrier and shoreface to a depth of 17m (the shoreface base as measured on offshore seismic profiles) was $4.55 \times 10^7 m^3$, therefore requiring 2560 years of continuous supply. This amount of time is much longer than original barrier formation according to Hoskin's (1983) dates (see Stage 3). In addition, the total sediment volume of Half Island Point is 1.3×10^7 m^3, thereby only providing 25% of the total sediment needed to form the Lawrencetown barrier. It seems that for large barriers like Lawrencetown, a single drumlin source even as large as Half Island Point is insufficient to create the barrier system in one evolutionary cycle. This again highlights the importance of sediment volume conservation during transgression on the Eastern Shore. One important implication of this conservation mechanism is for management policies regarding beach mining. The sediment volume in any barrier system may be large but the rate of renewal is on the order of several thousand years. Eastern Shore barriers are closed systems whose present sediment volume is the net product of many evolutionary cycles. Artificial sediment removal may be considered a permanent loss whose consequence is likely to be transformation of sand beaches to boulder barricades.

The presece of tidal inlets complicates the problem of determining the correct evolutionary stage for a coastal system. Estuaries are open to the ocean during Stage 5 barrier destruction. During the rebuilding phase, the continued existance of tidal inlets then becomes a question of balancing tidal processes against sediment supply and wave energy. If an estuary has a sufficiently large tidal prism (such as Cole Harbour), it appears capable of maintaining a tidal inlet throughout Stage 3. Systems which can maintain a permanent inlet during Stage 3 are also characterised by well developed ebb-tide deltas. When the tidal prism is reduced to the size of Cow Bay or smaller (Miseners Lake or Oyster Pond) and sufficient sediment supply is available for longshore spit progradation by waves, then the estuary inlet will close during Stage 3, and the lagoon may become fresh. The resulting salinity contrasts are likely to significantly change lagoonal ecology.

7. CONCLUSIONS

* The Eastern Shore of Nova Scotia is a mesotidal coastline which experiences a moderate to high energy wave climate. Relative sea level both at present and since 7 kybp has been rising at a rate of 35-40 cm/100 years.

* The geology and geomorphology of the Eastern Shore have been strongly influenced by glacial processes during Pleistocene times. Large continental ice sheets moving towards the southeast sculpted linear bedrock scours and deposited

till in sheets and drumlins.

* Subsequent coastal evolution has been summarised in a model of cyclic barrier genesis, decay and subsequent landward translation to new sites of barrier re-establishment. This evolutionary model is a form of stepwise shoreface retreat.

* Periods of barrier growth begin when the transgressing shoreline encounters new local sediment supplies or headland anchor points. Barrier destruction results from a diminishing of the sediment supply while RSL continues to rise. Barrier sediment is largely conserved during each evolutionary cycle by landward translation through tidal inlets, washovers and eolian dune fields.

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FIGURE CAPTIONS

Figure 1. The Eastern Shore of Nova Scotia between Halifax Harbour and Jeddore Head is an irregular coastline of headlands, intervening estuaries and coastal barrier systems. Holocene transgression of this coastline has resulted in a complex inner shelf topography.

Figure 2. Holocene sea level relative to the Eastern Shore. A transgression since 7000 BP has resulted in rates of RSL rise around 35 cm per

century (after Scott and Medioli, 1982).

Figure 3. Unconsolidated sediments on the Eastern Shore of Nova Scotia are primarily Wisconsinan tills. These tills consist of thin, locally derived lodgement and ablation tills such as Slate Till and Quartzite Till together with thicker, transported drumlin tills. Barrier systems form where drumlins intersect the coastline. Drumlins, estuaries and glacial striae all exhibit SE alignment indicating ice transport direction. (after Stea and Fowler 1979)

Figure 4. Coastal sedimentation along the Eastern Shore can be summarized in a six stage evolutionary model. Sediments are initially supplied from Pleistocene glacial sources (Stage 1). Following deglaciation relative sea level rise produces coastal transgression, transforming glacial valleys into estuaries (Stage 2). Subsequent evolution during Stage 3 consists of marine reworking of glacial deposits into prograding barrier systems. As sediment supply diminishes, barriers retreat (Stage 4), losing sand to washover dune and tiidal inlet sinks until finally they are destroyed (Stage 5). In Stage 6 barriers encounter new sediment sources or headland anchor points and re-establish further landward.

Figure 5. Cliff erosion along the Half Island Point drumlin. The wide range of grainsizes available can be seen in the exposed cliff face. The drumlin is being truncated at sea level (foreground) where it is overlain by a boulder retreat shoal in the process of formation.

Figure 6. The Lawrencetown coastal compartment is an example of barrier progradation. Here, sediment derived from the Half Island Point drumlin to the right (east) is transported westward into a beach ridge plain, infilling the Lawrencetown Lake estuary mouth (upper left).

Figure 7. Lawrencetown Inlet Beach (centre right) and Conrads Beach (centre left) are prograded beach ridge plains formed partly from sediment derived from the Egg Is.-Fox Is. depleted drumlin source lying immediately offshore.

Figure 8. Foredune scarp at the eastern end of Martinique Beach. This feature is characteristic of retreating barriers in Stage 4.

Figure 9. The Martinique Beach compartment is an early Stage 4 coastal system. Note the thin barrier and multiple washover fans at the near (east-ern) end of the beach.

Figure 10A. This breach in Conrads Beach occurred in 1962 and by 1982 had transported a considerable volume of barrier sand into a flood tide delta system in West Marsh (cf Figure 10B). Conrads Beach is an example of an advanced Stage 4 coastal system.

Figure 10B. A tidal channel at Lawrencetown Inlet beach (lower left) has been active throughout historical times and succeeded in infilling most of Lawrencetown Lake with a large flood tide delta complex.

Figure 11. Rocky Run barrier represents a historical example of Stage 5 barrier destruction. In Fig. 11A (1945) a wide barrier extends from Half Island Point (left) to Graham Head (right) and includes two depleted mid beach drumlins. By 1954 (Fig. 11B) the beach is considerably thinner, the drumlins almost disappeared and a breach has formed near Half Island Point. By 1974 (11C) the barrier has been destroyed and exists only in the form of intertidal and subtidal sand shoals. In the lower right hand corner are Wedge Island (far right), an example of a depleted drumlin source, and Shut In Island, an exhausted drumlin source, existing today as an offshore bedrock shoal. The eventual result of diminished sediment supply from drumlin sources in Stage 4 is barrier destruction in Stage 5, as illustrated by the Rocky Run barrier.

Figure 12. The evolution of Chezzetcook Inlet from 1945 (12A) to 1974 (12B) (from Scott, 1980) is an example of Stage 6 barrier re-establishment. Over a 29 year period the inlet has infilled to the high tide level, allowing the development of extensive marsh and tidal flat environments. Sediment from old barrier systems near Cape Entry and Stony Head have accreted new Stage 6 barriers at Conrad Island and Red Island.

Figure 13. Stage 6 barrier re-establishment inside the entrance to Chezzetcook Inlet. A beach ridge plain has commenced formation at Conrads Island centre left while Red Island (centre right) has grown by over 1000 m between 1854 and 1974. Note the extensive development of remnant Stage 5 intertidal sand shoals, moving landward to generate further

accretion at the new barriers.

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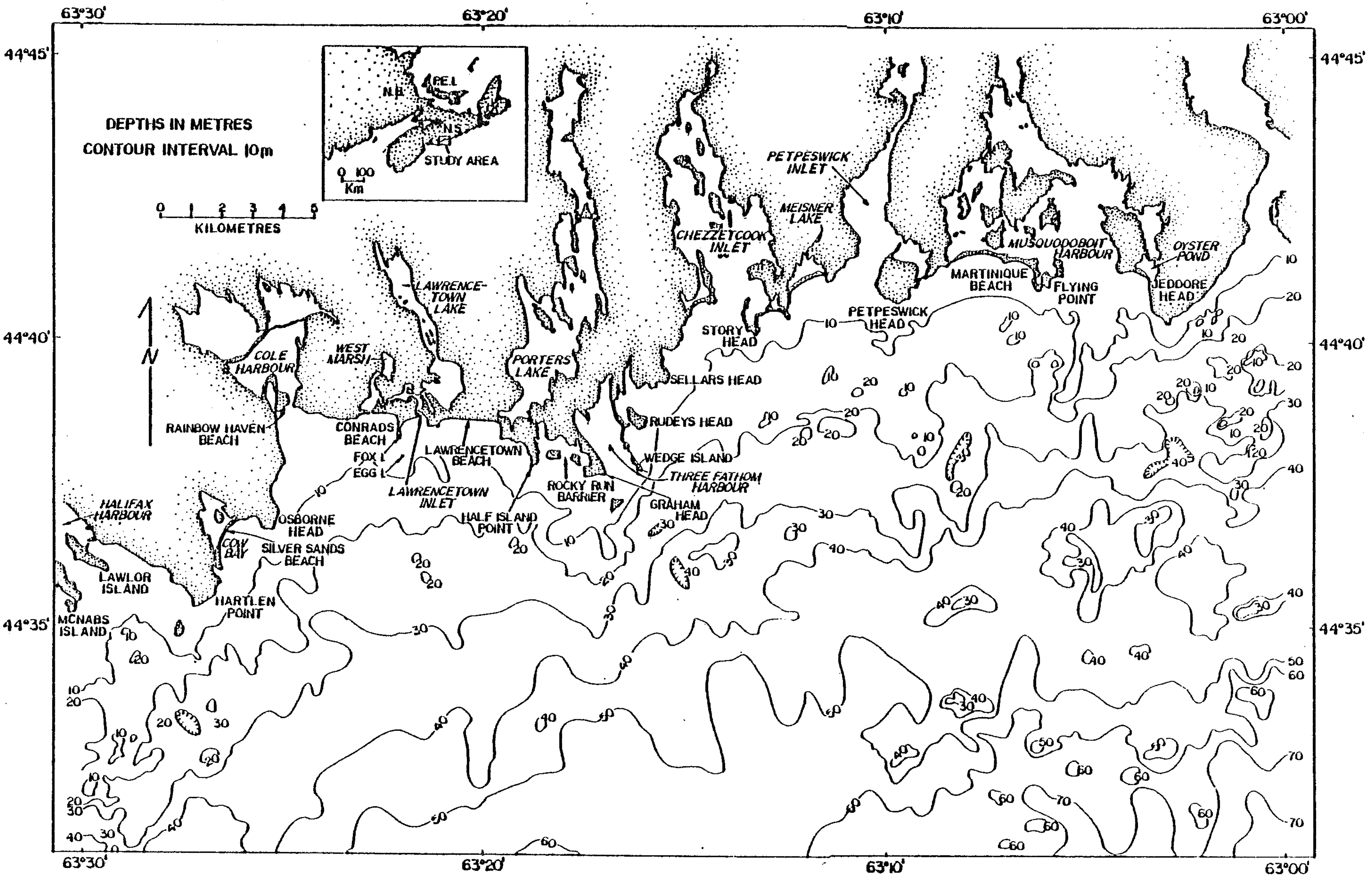

DEPTHS IN METRES
CONTOUR INTERVAL 10m
KILOMETRES
0 1 2 3 4 5
N
N.B.
P.E.I.
N.S.
STUDY AREA
0 100
Km
63°30'
63°20'
63°10'
63°00'
44°45'
44°40'
44°35'
HALIFAX HARBOUR
LAWLOR ISLAND
MCNABS ISLAND
HARTLEN POINT
COW BAY
SILVER SANDS BEACH
OSBORNE HEAD
RAINBOW HAVEN BEACH
COLE HARBOUR
WEST MARSH
CONRADS BEACH
FOX I.
EGG I.
LAWRENCETOWN INLET
LAWRENCETOWN BEACH
LAWRENCE-TOWN LAKE
HALF ISLAND POINT
PORTERS LAKE
ROCKY RUN BARRIER
GRAHAM HEAD
THREE FATHOM HARBOUR
WEDGE ISLAND
RUDEYS HEAD
SELLARS HEAD
STORY HEAD
CHEZZETCOOK INLET
MEISNER LAKE
PETPESWICK INLET
PETPESWICK HEAD
MARTINIQUE BEACH
MUSQUODOBOIT HARBOUR
FLYING POINT
OYSTER POND
JEDDORE HEAD

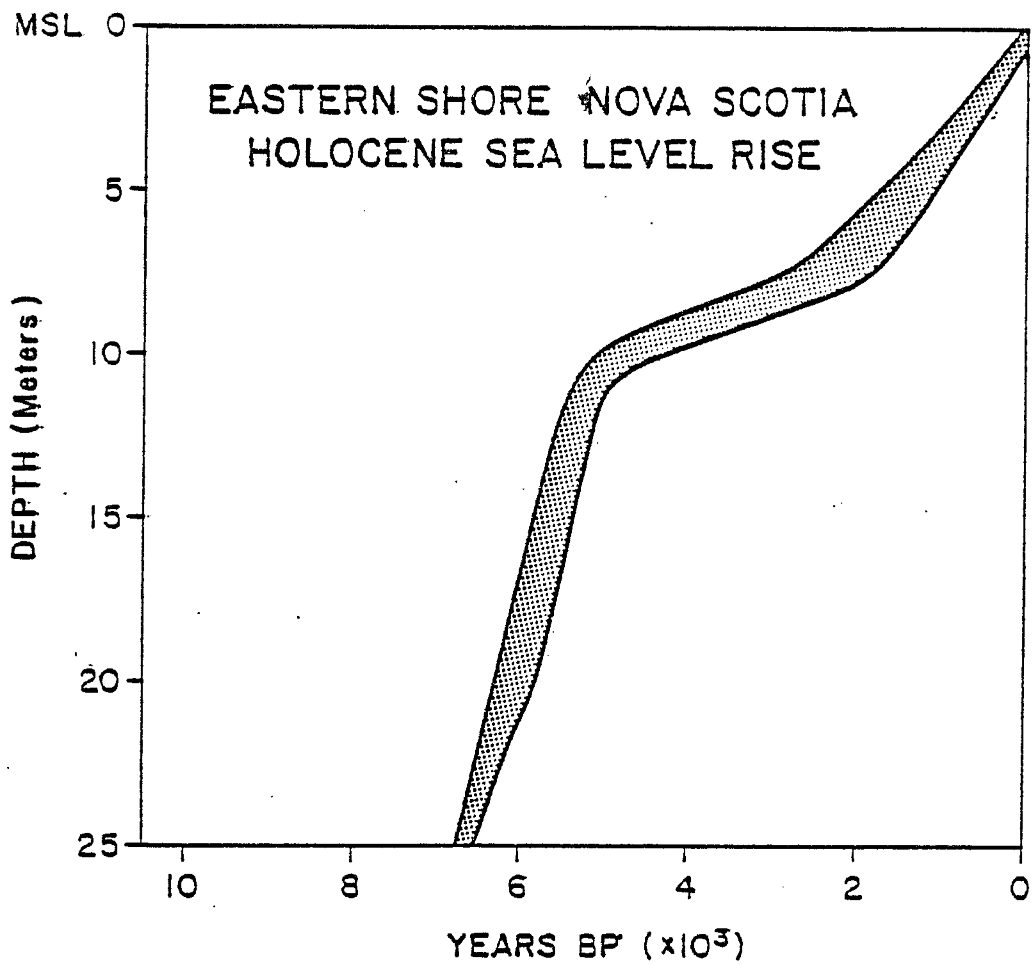
EASTERN SHORE NOVA SCOTIA
HOLOCENE SEA LEVEL RISE
MSL 0
5
10
15
20
25
DEPTH (Meters)
10
8
6
4
2
0
YEARS BP (x10^3)

Figure 2

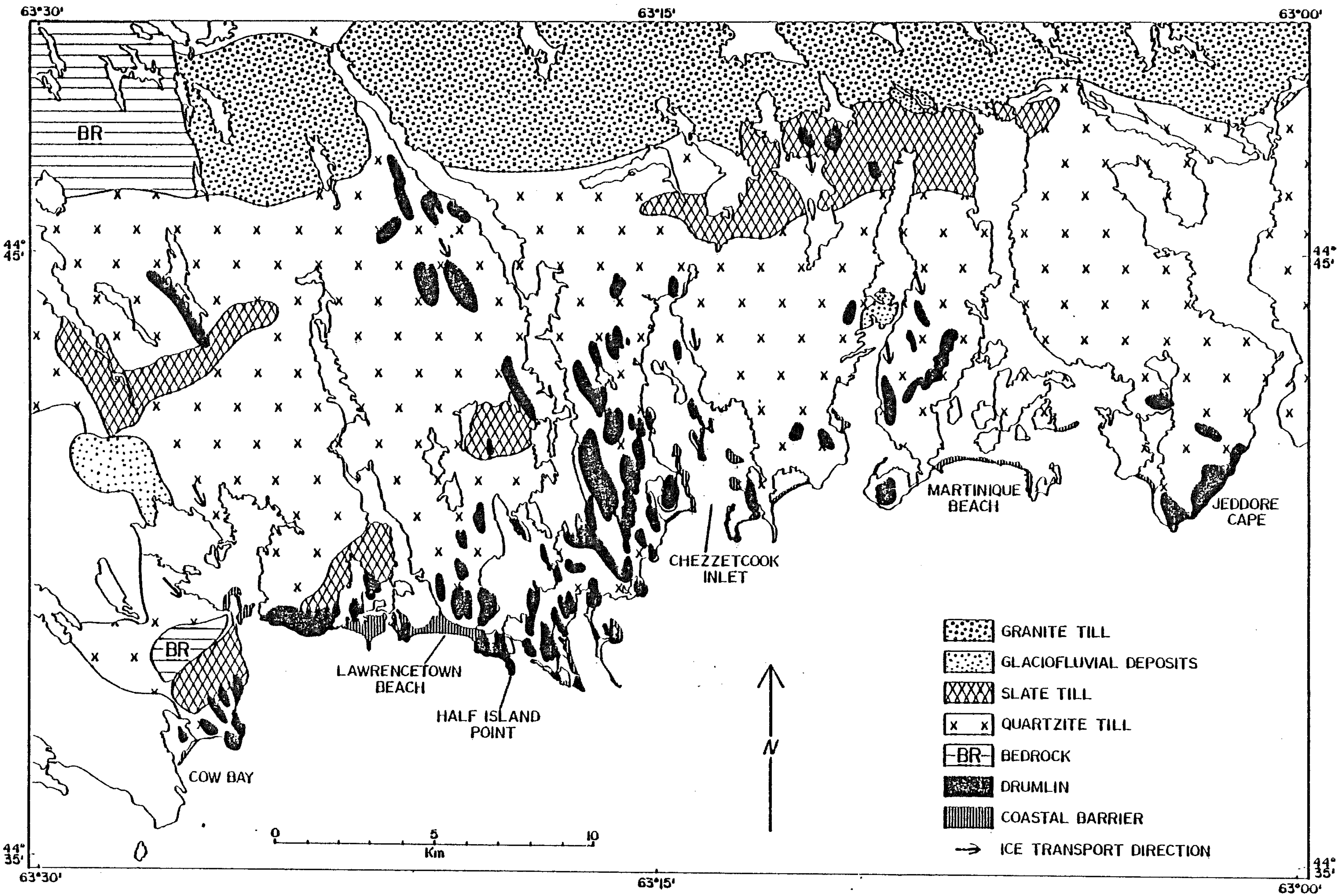
63°30'
63°15'
63°00'
44° 45'
44° 35'
BR
COW BAY
LAWRENCETOWN BEACH
HALF ISLAND POINT
CHEZZETCOOK INLET
MARTINIQUE BEACH
JEDDORE CAPE
N
0
5
10
Km
GRANITE TILL
GLACIOFLUVIAL DEPOSITS
SLATE TILL
QUARTZITE TILL
BEDROCK
DRUMLIN
COASTAL BARRIER
ICE TRANSPORT DIRECTION

Figure 3

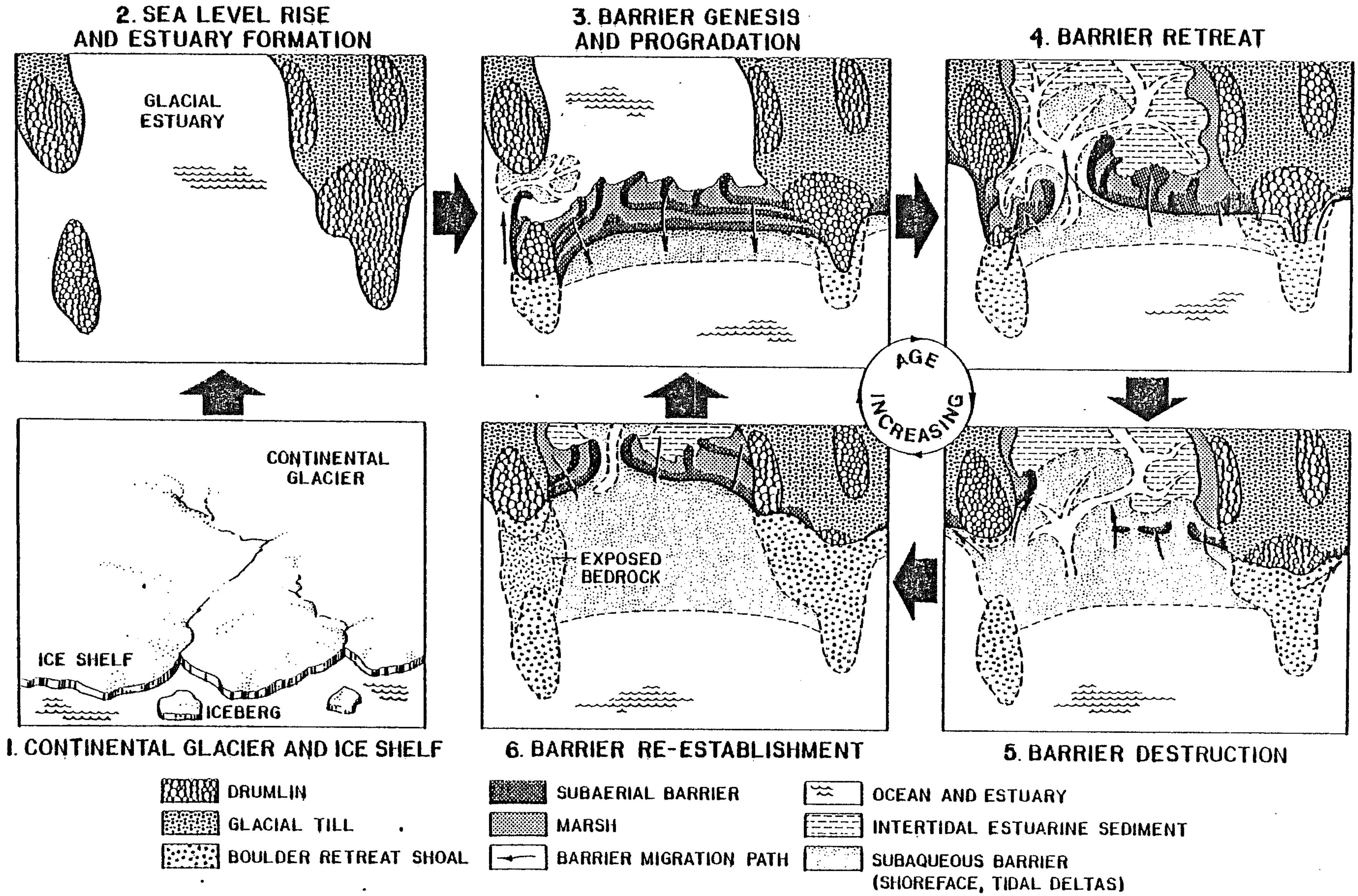
2. SEA LEVEL RISE AND ESTUARY FORMATION
GLACIAL ESTUARY
3. BARRIER GENESIS AND PROGRADATION
4. BARRIER RETREAT
AGE INCREASING
CONTINENTAL GLACIER
ICE SHELF
ICEBERG
EXPOSED BEDROCK
I. CONTINENTAL GLACIER AND ICE SHELF
6. BARRIER RE-ESTABLISHMENT
5. BARRIER DESTRUCTION
DRUMLIN
GLACIAL TILL
BOULDER RETREAT SHOAL
SUBAERIAL BARRIER
MARSH
BARRIER MIGRATION PATH
OCEAN AND ESTUARY
INTERTIDAL ESTUARINE SEDIMENT
SUBAQUEOUS BARRIER (SHOREFACE, TIDAL DELTAS)

Figure 4

FIGURE 5

FIGURE 6

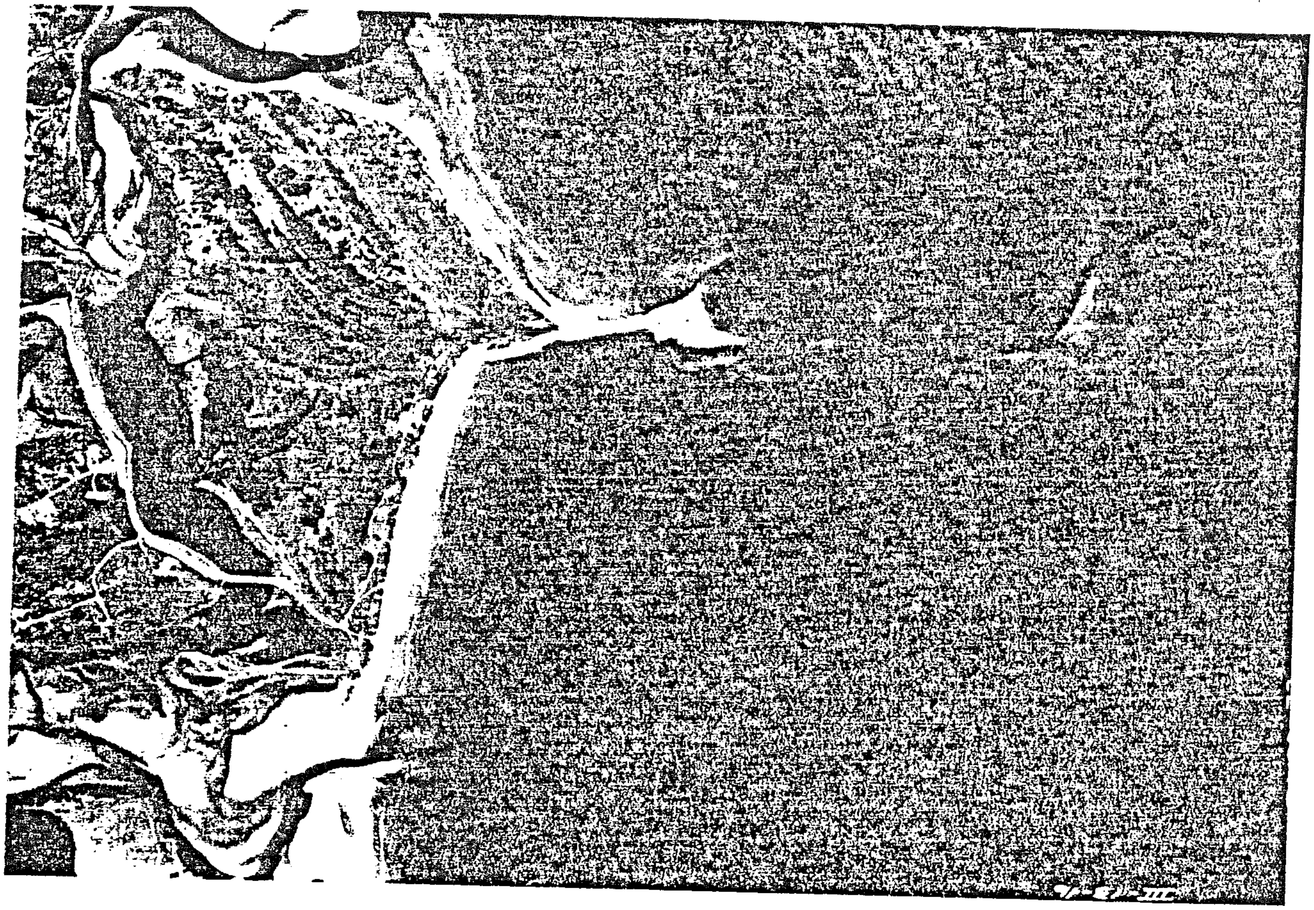

FIGURE 7

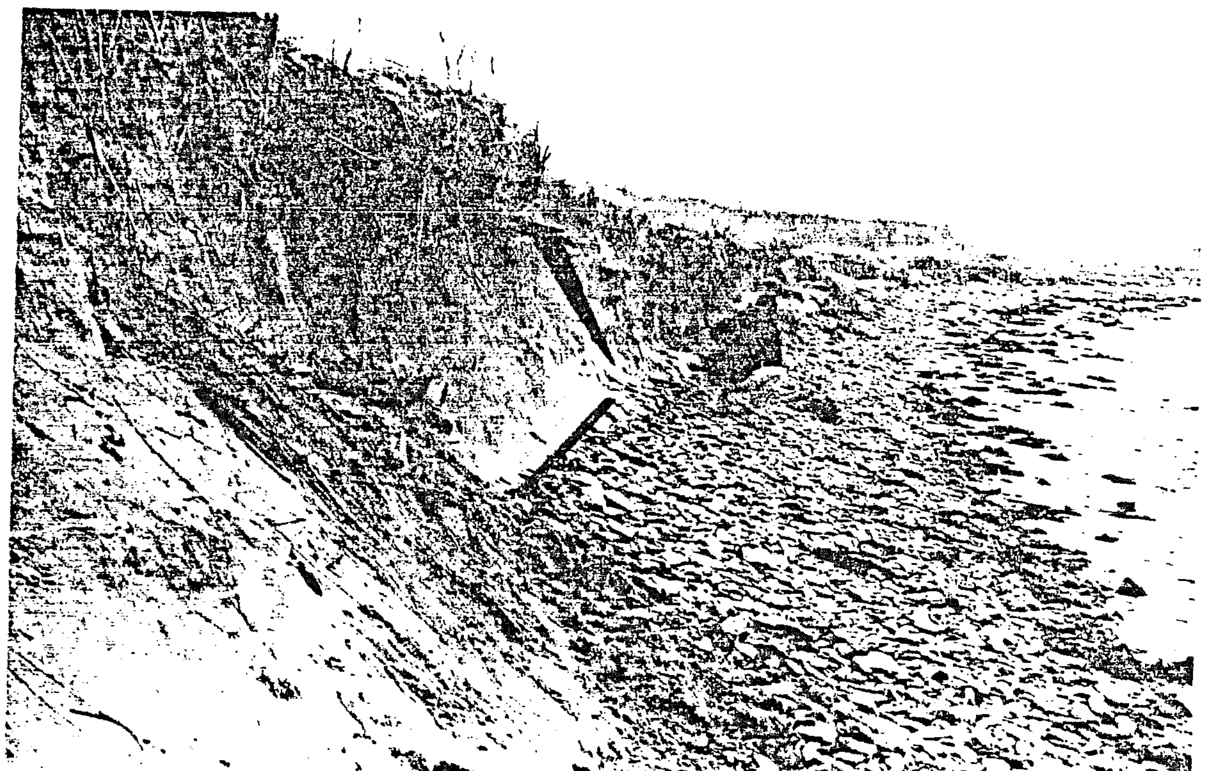

FIGURE 8

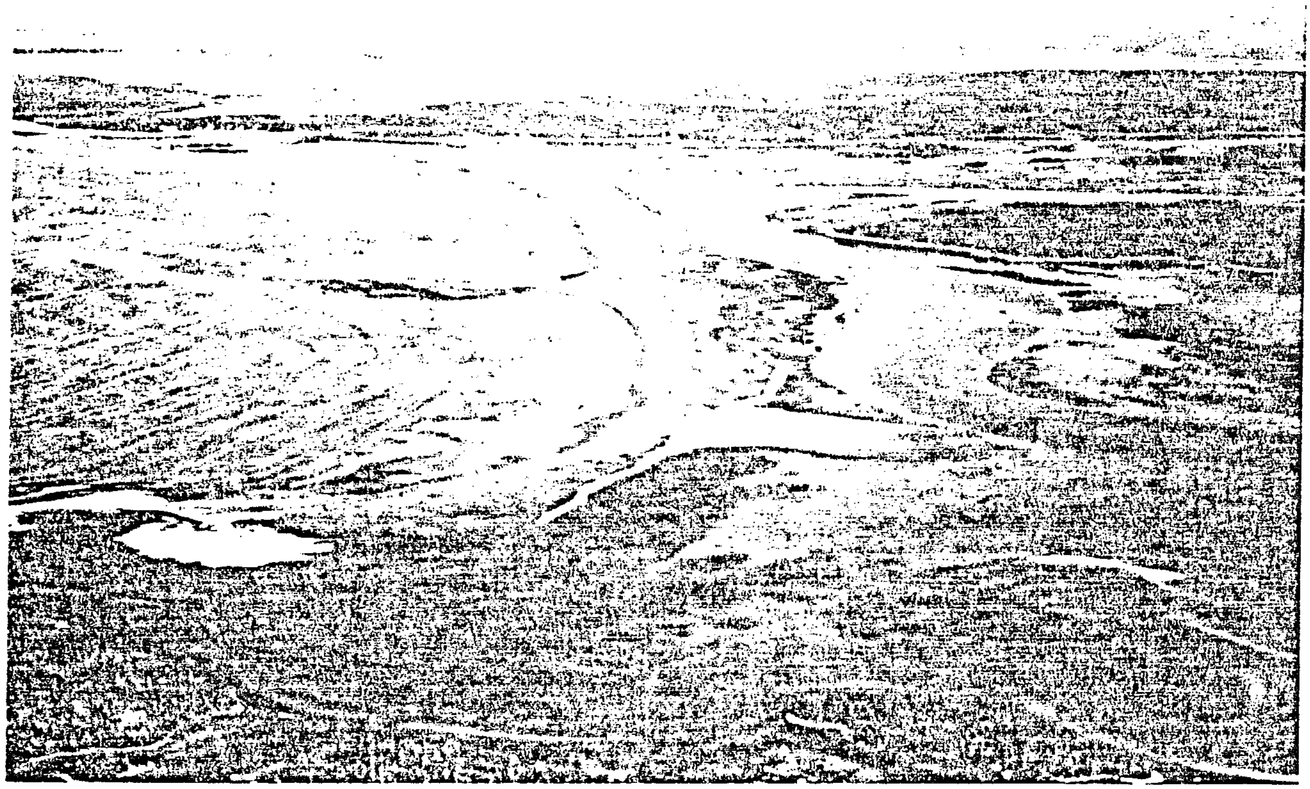

FIGURE 9

FIGURE 10A

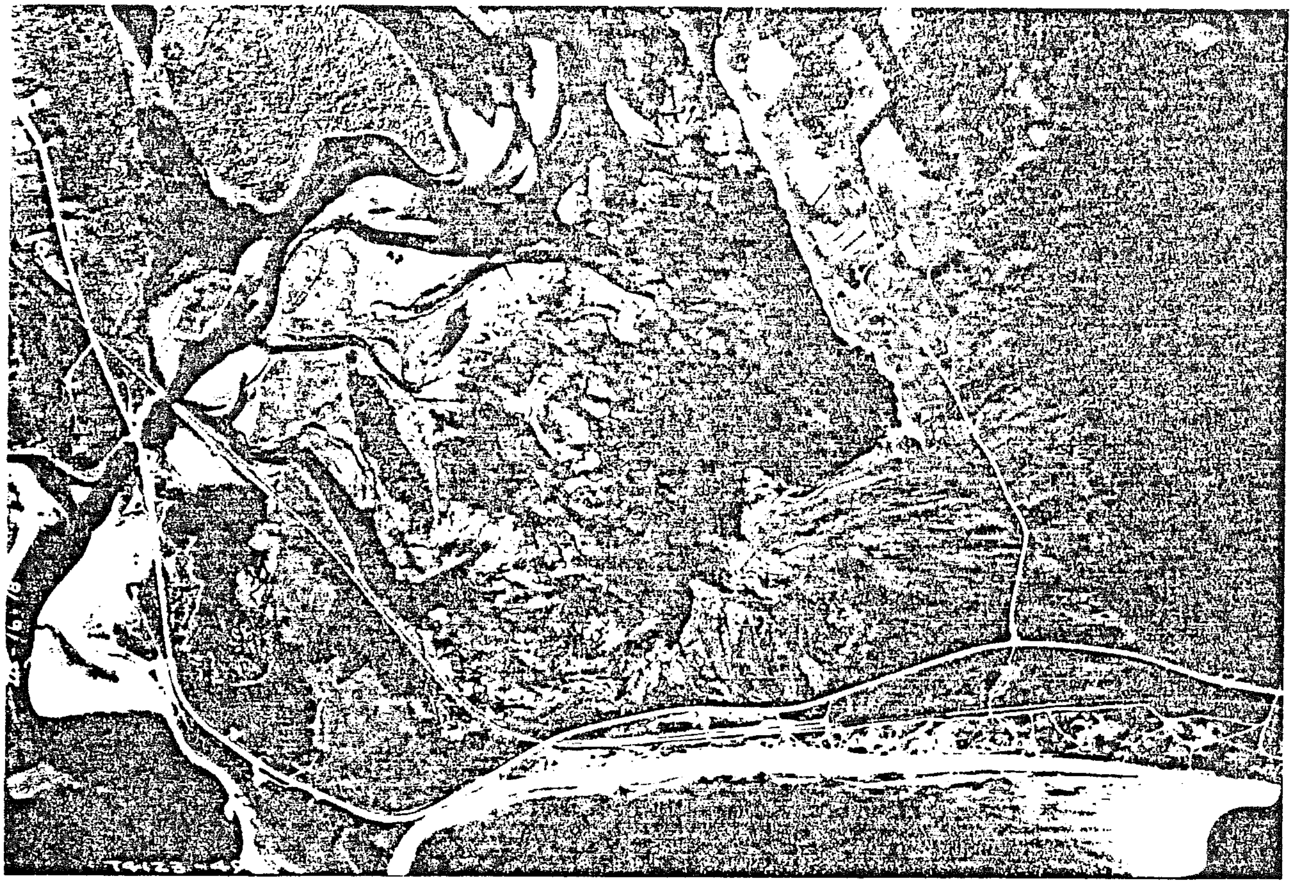

FIGURE 10B.

FIGURE 11A

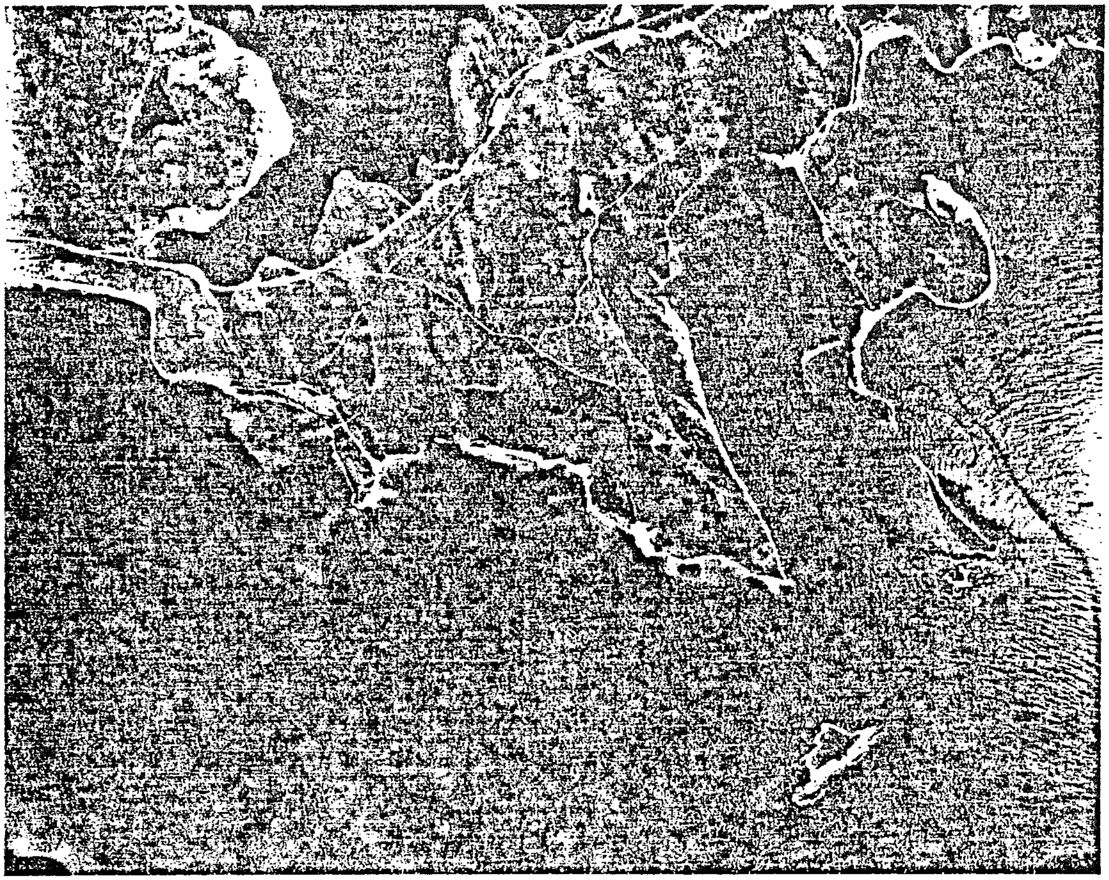

FIGURE 11B

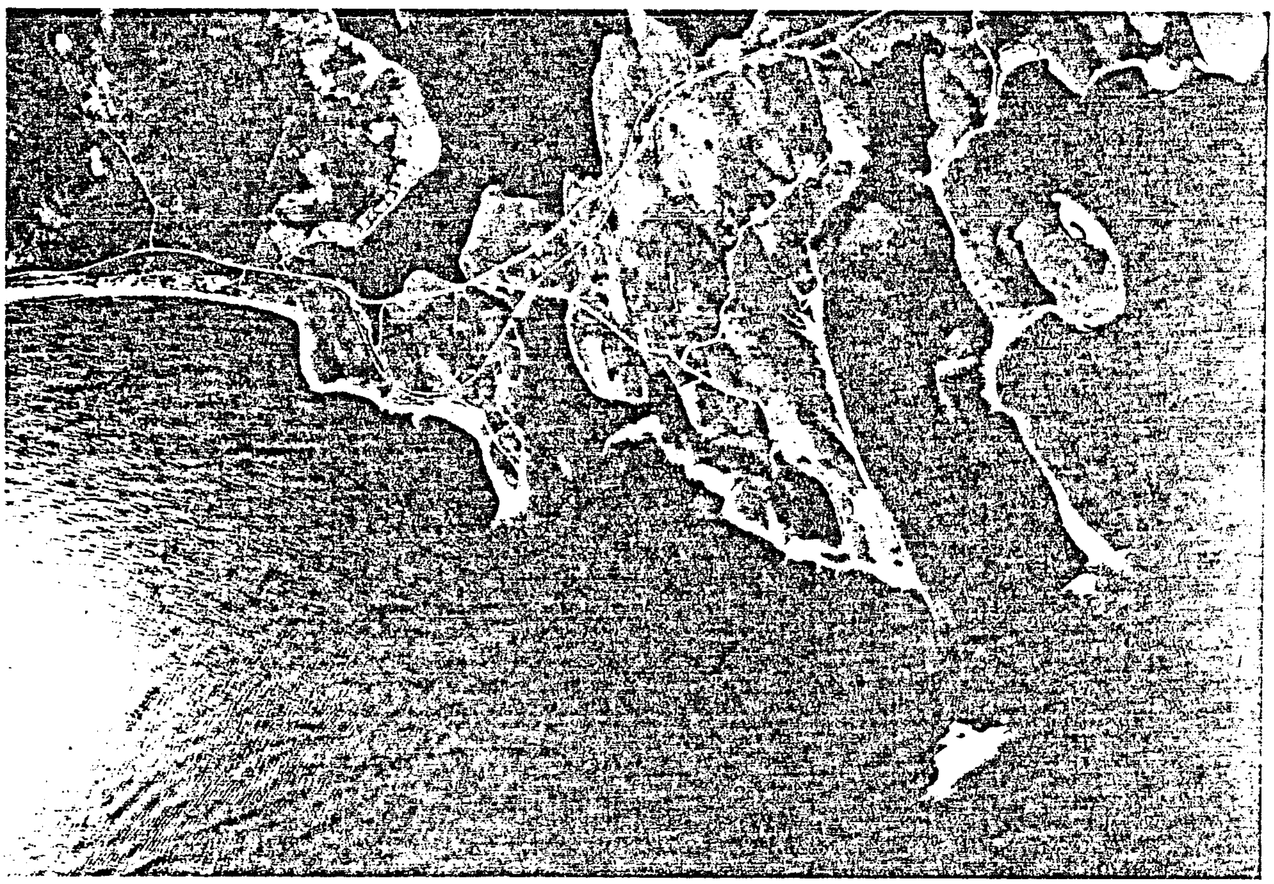

FIGURE 11C

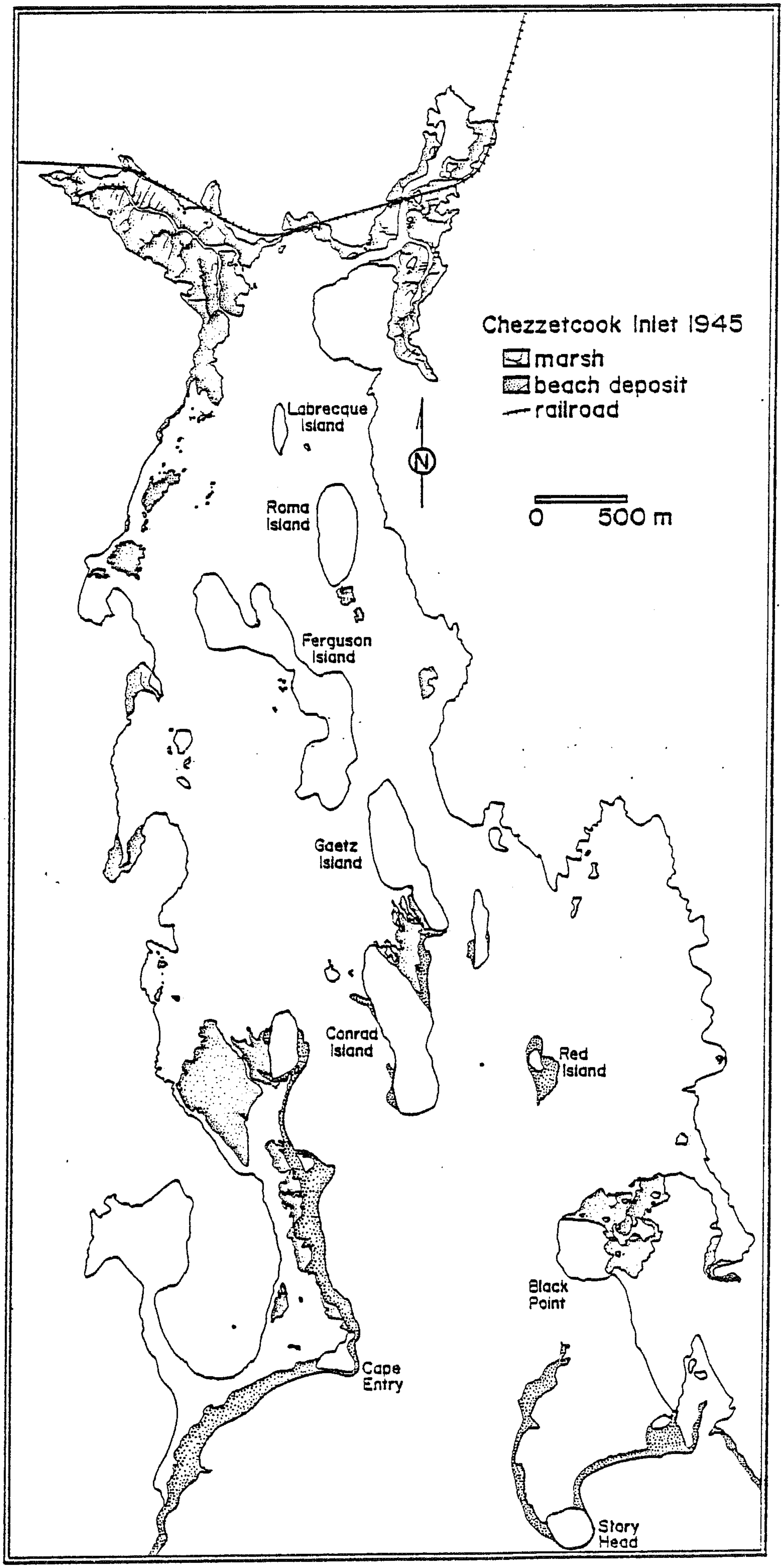
Chezzetcook Inlet 1945
marsh
beach deposit
railroad
N
0 500 m
Labrecque Island
Roma Island
Ferguson Island
Gaetz Island
Conrad Island
Red Island
Black Point
Cape Entry
Story Head

FIGURE 12A

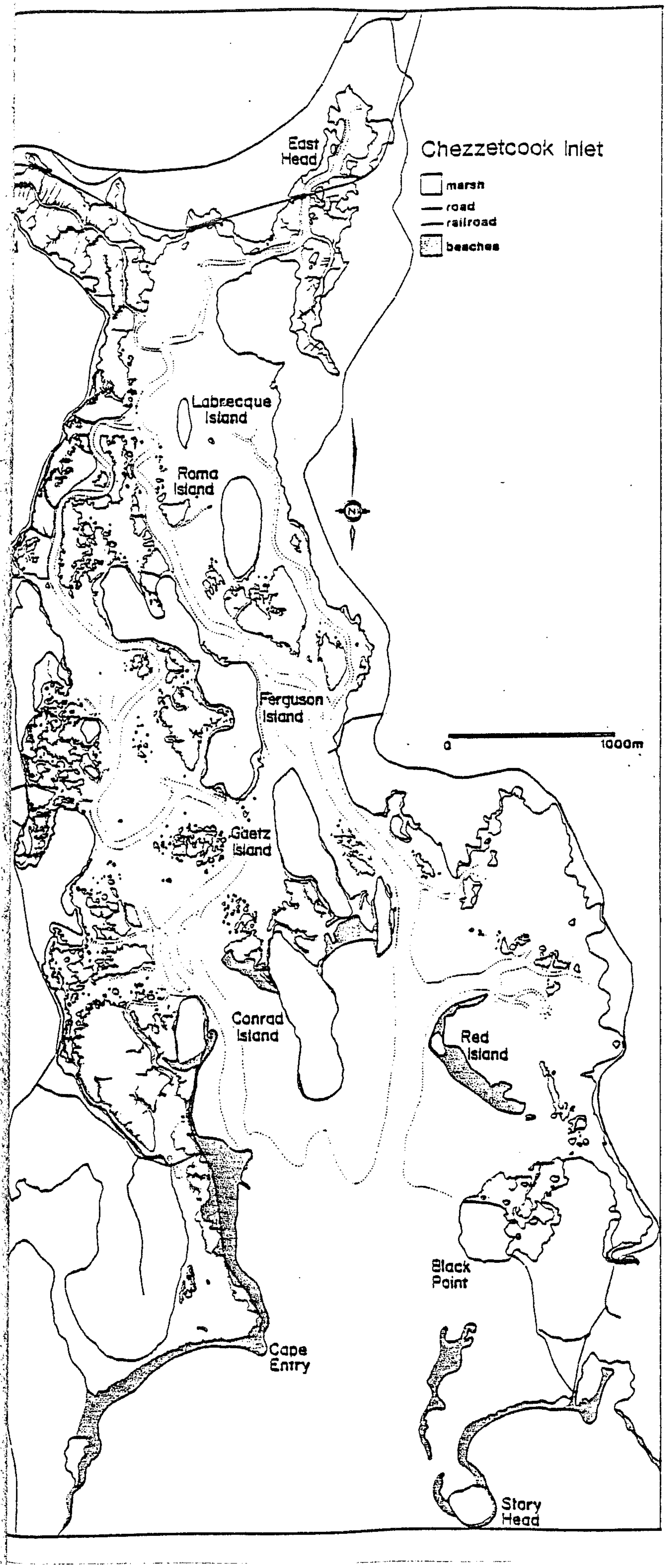
Chezzetcook Inlet
marsh
road
railroad
beaches
East Head
Labrecque Island
Roma Island
Ferguson Island
0
1000m
Gaetz Island
Conrad Island
Red Island
Black Point
Cape Entry
Story Head

FIGURE 12B

FIGURE 13.

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