ASPECTS OF THE COASTAL GEOMORPHOLOGY OF LES ÎLES DE LA MADELEINE USING REMOTE SENSING TECHNIQUES

ASPECTS OF THE COASTAL GEOMORPHOLOGY OF LES ÎLES DE LA MADELEINE USING REMOTE SENSING TECHNIQUES

by

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ABSTRACT

Remote sensing imagery has proven useful in studying the coastal geomorphology of les Iles de la Madeleine. Standard panchromatic photography provided the basis for mapping of the island and aided in the interpretation of the evolution of this tombolo system. This study presents a systematic evaluation of five types of remotely sensed data: (1) colour infrared photography, (2) conventional colour photography, (3) panchromatic photography (red and green bands), (4) black and white infrared photography and (5) thermal line scan imagery as applied to the southern portion of les Iles de la Madeleine. The results of this study have shown that beach investigations are enhanced through the use of multisensor imagery, and that colour infrared provides the best single source for data aquisition.

ACKNOWLEDGEMENTS

There are many people who deserve my sincerest thanks for the assistance which they have given me at the various stages of this research. I wish to thank my supervisors Dr. S. B. McCann and Dr. P. J. Howarth who suggested the study area and for their advice and continual encouragement during the preparation of this thesis.

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CHAPTER 1

INTRODUCTION

1:1 INTRODUCTORY REMARKS

Aerial photography has been used in the study of coastal geomorphology for a number of years (Coleman, 1948; Marks and Ronne, 1955; Sonu, 1964). With increased use of remote sensing methods and sophistication of both mapping systems and methods of analysis, aerial photography has expanded its potential in coastal studies. A number of recent papers (Dolan and Vincent, 1973; Pestrong, 1969) have attempted to explore the possibilities and delineate the field, thus raising some unanswered questions.

This thesis outlines a study of the uses of aerial photography in an area which exhibits an interesting number of depositional coastal forms which have not previously been studied in any great detail. The study area les Îles de la Madeleine, is an assemblage of seven rock islands joined by tombolos. Located in the Southern Gulf of St. Lawrence, (Fig. 1:1) the islands present an interesting range of depositional features characteristic of sand beaches. Examples of the supratidal features of dune ridges and beach, intertidal marshes and tidal flats, and subtidal features of offshore bars and shoals can be clearly seen.

An interpretative study of standard black and white photography has been made to produce a morphological description of the supratidal,

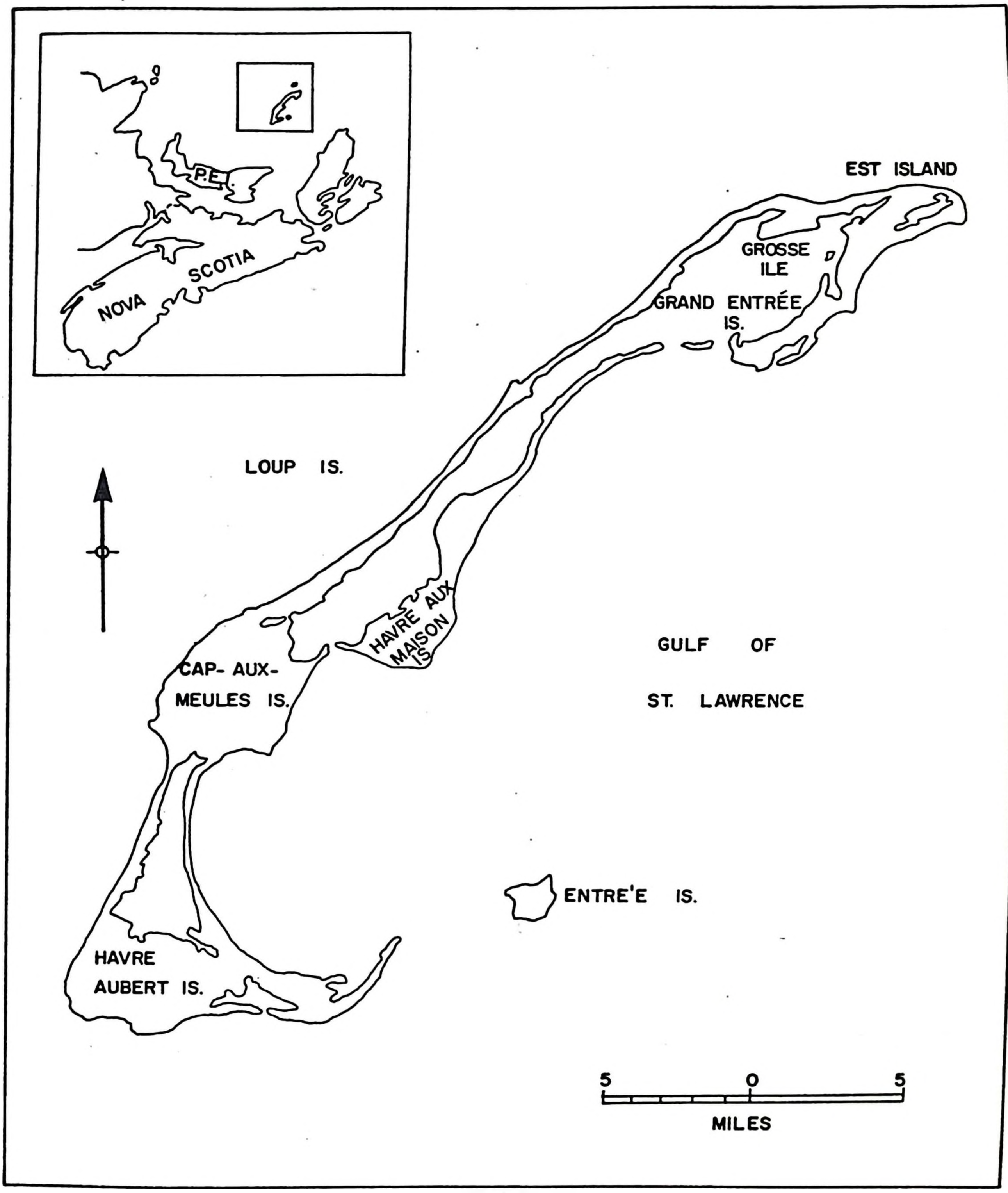


Fig. 1:1 Location of les Îles de la Madeleine in the Southern Gulf of St. Lawrence

intertidal and subtidal features, as well as to obtain inferences about processes acting on the island. Other photography including colour infrared, colour, black and white infrared and thermal line scan imagery has been utilized in order to establish the potential of each sensor for aquiring data in the coastal environment. Thus, this thesis contributes to both coastal geomorphology in a further understanding of the coastal processes of les Îles de la Madeleine, as well as providing some useful data about film capabilities in the coastal environment. Relevant field work and the preliminary study of the standard black and white photographs was considered a necessary prerequisite to the evaluation of the more sophisticated film types.

In addition to the information derived from the aerial photographs, it was also possible to evaluate historical maps dating back to 1765 in order to interprete the evolution of this remarkable tombolo system.

1:2 SCOPE OF THE STUDY

A variety of depositional and erosional environments are present in les Îles de la Madeleine. Hence, significantly different dune systems are present. Chapter Two details the variety of systems dividing them into convenient units for description, as well as providing some general description that characterizes the area. Chapter Three provides a more detailed analysis of the morphology of the dune systems and beach area so that some statement could be made about the processes acting upon the coastal reaches of les Îles de la Madeleine. Remote sensing has proven to be a useful technique in the area of coastal geomorphology, but its usefulness is dependent upon proper selection of film types and the area to be studied, so as to obtain the maximum amount of relevant data. Chapter Four outlines the nature of this remote sensing program and evaluation procedure. As anticipated, some film types are more useful for identifying particular features than others, while in other cases, the combined use of several images provides the maximum data required. Chapter Five details the results of the analysis of the film types and makes recommendations for selection of films in future coastal studies. Some conclusions and recommendations are made in Chapter Six about the general future of remote sensing in coastal geomorphology.

1:3 LITERATURE REVIEW

As in many branches of earth science, the increased use and increasing sophistication of remote sensing systems has provided an important element in the study of coastal geomorphology. Coastal environments are particularly suited to study with aerial photographs because of the long distances associated with the linear extent of the form and the relatively rapid rate of change of the shoreline. Photographic analysis of beaches and coastal areas can provide almost any type of information covering physical conditions. Research into shore processes and materials continues to provide sign posts whereby more and more detailed information can be gleaned from photographic analysis without the necessity of detailed field observations, personal reconnaissance, or consultation of masses of corroborative ground information (Coleman, 1948).

In the study of coastal processes the basic requirements call for coverage of the coastal mechanism as simultaneous recordings of waves, currents and topography. To date, there are no conventional methods or instruments which have been able to fulfil the basic requirements of simultaneous coverage over a sufficient areal extent. Hence, aerial photographic coverage of the beach zone becomes the obvious answer to the problem of simultaneous coverage.

In general, the two main values of aerial photographs for any type of geomorphic interpretation are that some types of features show up more clearly on the photos than on the ground and that many features can be recognized that are not shown on topographic maps. Also, when a large area is viewed through the use of aerial photographs, patterns not apparent from the ground may show up clearly on the photos. This is particularly true of submerged features such as patterns of submarine bars and troughs.

Panchromatic Photography and Sequential Studies

The quantitative rendition of water depth, waves, currents and sediment drift by aerial photography is of particular significance (Tewinkel, 1963; Marks and Ronne, 1955). Aerial photography provides an essentially instaneous, synoptic view of the circulatory pattern of a very large area (Keller, 1963). Water, transporting sediment in the form of littoral or up currents appears clearly on aerial photographs as lighter toned channels in the water. Thus, the path of currents can be followed and relative positions of erosion and deposition can be interpreted from this pattern. Measurement of submarine features is important in investigating offshore sediment movement and the changing nearshore environment. Standard panchromatic photographs are adequate for the measurement of these areas of submerged topography (Lundahl, 1948; Sonu, 1964).

The transient nature of the beach provides difficulty when attempting to monitor beach change with respect to erosion and deposition. The existing aerial photograph provides a permanent record of the location of the beach so that it may be compared at future dates to note the long term changes or trends in coastal erosion (Stafford, and Langfelder, 1971). In this respect the aerial photograph is better than any map or chart since it records an infinite amount of ground detail. Sequential photography has been described as an excellent tool for the recording of long term changes,since the photos provide an exact basis for measuring net changes in dimensions or shapes between successive photographic dates (El-Ashry and Wanless, 1967). Unfortunately, difficulties are encountered in the quantitative interpretation of changes in the shoreline resulting from the lack of continuous day to day coverage. All that can be inferred is that a change has taken place sometime between the two dates. The change may have been steady and long term or of short duration due to violent storm activity.

Infrared, Colour and Colour Infrared Photography

Recent developments in black and white infrared, colour and colour infrared photography have proved extremely valuable to coastal studies. Colour film has the property of excellent water penetration; thus its value to coastal investigation is readily understood. Used in conjunction with standard panchromatic film, it has aided with identification of water bodies and significant navigational features in the area of coastal mapping (Theurer, 1959). Colour film also allows the determination of relative depths of water important for hydrographic charts (Geary, 1968; Schneider, 1968). Colour infrared film emphasizes patterns related to the physical and chemical properties of the water and the suspended matter it may contain, especially at the surface (Hunter and Glenbird, 1970). This is caused by increased absorption by water of light at longer wavelengths. Both colour infrared and black and white infrared have proved extremely useful in the mapping of the shoreline due to the excellent land/water contrast (Jones, 1957). Colour and colour infrared films have also proven instrumental in studying tidal marshlands (Seher and Tueller, 1973; Anderson and Wobber, 1973; Hubbard and Grimes, 1972; Pestrong, 1969). Colour photos render the scene as viewed by the human eye, thus easing the interpretation problem of indentification of species of marsh vegetation; while the colour infrared film displays the most distinctive soil-vegetation-water contacts. This enables a detailed analysis of the marsh vegetation, its distribution and vigor to be carried out.

Thermal Infrared Imagery

Thermal infrared imagery is similar to conventional photographs only as a pictorial representation of an imaged thermal scene, thus providing information not readily available through other remote sensing techniques. The principle of thermal detection is based upon the fact that all bodies emit radiation. Consequently remotely observed radiation intensity is partially dependent on the objects temperature, em issivity and the transmittance of the atmosphere.

Hence, detection of specific objects on the imagery is related to the temporal and spectral characteristics exhibited by the objects radiation. This type of imagery has provided an effective means of determining general trends in vegetation cover, water detection, and sediment movement (Tuyahov and Holz, 1973; Orr and Quick, 1971). Interpretation of these trends provides information concerning offshore currents and existing wind systems. Through colour enhancement of thermal imagery taken at low water it has been possible to discriminate the tidal flooding pattern of the marsh (Reimold, Gallagher and Thompson, 1973). Thermal infrared imagery provides the most useful information when used in conjunction with a standard panchromatic photograph. While the tonal variations on the imagery caused by differences in the emissivity and temperature of the terrain material are distinct, difficulty arises in the interpretation of these tones in the coastal environment.

High Altitude Photography

Since the release of high altitude photographs for civilian use in 1969 (Eyre, 1971), their potential in coastal work has gradually been realized. The high altitude photograph provides a regional overview enabling one to recognize by characteristic signatures unusual features which occur at widely separated localities. With this type of photograph averaged conditions and rates of change can be established and provide some kind of regional relationship, providing an integration of processes and sand response occuring along the coast. The high altitude photograph has proved extremely useful in investigating aerial and temporal distribution of crescentic coastal features (Dolan and Vincent, 1973). Of primary significance is the fact that high altitude photographs provide a "big picture" perspective while maintaining good resolution characteristics (Keene and Pearcy, 1973).

E.R.T.S. Imagery

Monitoring wetlands on a regular basis for protection from man made and natural reductions in wetlands productivity, and monitoring the tidal and offshore marine currents for placement of erosion control structures i.e. groins, bulkheads, are viewed as potential uses for the Earth Resources Technology Satellite (E.R.T.S.-1) imagery (Wobber and Anderson, 1973). The potential for detailed analysis of the coastal environment is limited by the scale of the imagery. Thus its usefulness will lie mostly in recognition of broad changes in beach trends.

Southern Gulf of St. Lawrence

Recent remote sensing studies have been completed in the Southern Gulf of the St. Lawrence by Bryant (1972). He used sequential photos to monitor beach change and inlet migration over a 35 year period in the barrier islands of Kouchibougiac Bay, New Brunswick. A second project by McCann, Bryant and Armon (1972), to study late winter ice conditions along parts of the coastlines of New Brunswick, Prince Edward Island and the Magdalen Islands utilized high altitude photography covering both the visible and the infrared section of the spectrum. Mapping of selected areas and an assessment of the information on ice characteristics during the spring breakup season obtained from the different types of photography was completed.

The potential uses of information gained from a systematic interpretation of sensor imagery are vast and valuable to man in many disciplines. From an evaluation of the literature it may be concluded that beach investigations are enhanced by the use of remote multisensor imagery, for they provide as much or more information with less effort than is required to obtain certain pieces of data in the field.

To date, most of the coastal remote sensing investigations comment only on what can actually be seen on the photographs ignoring a most important aspect of this technique. Future studies should be directed to directly integrating the photographic data with the interpretation of the area in question.

1:4 THE COASTAL SETTING OF LES ÎLES DE LA MADELEINE

Location

The archipelago of les Îles de la Madeleine, (Fig. 1:2), consisting of seven rock islands, lies in the southern Gulf of St. Lawrence between the longitudes 61°08' and 62°13' W and latitudes 47°12' and 47°51' N (Canadian Hydrographic Charts 4451). The island system is hook shaped and extends approximately 40 mi. in a N45 E direction.

From the southeast to the northeast the principle islands are Havre Aubert (Amherst) Island, Cap-aux-Meules Island, Havre-aux-Maisons (Alright) Island, Loup Island, Grosse-Île, Est Island, and Grand-Entrée (Coffin) Island. These seven islands actually form a

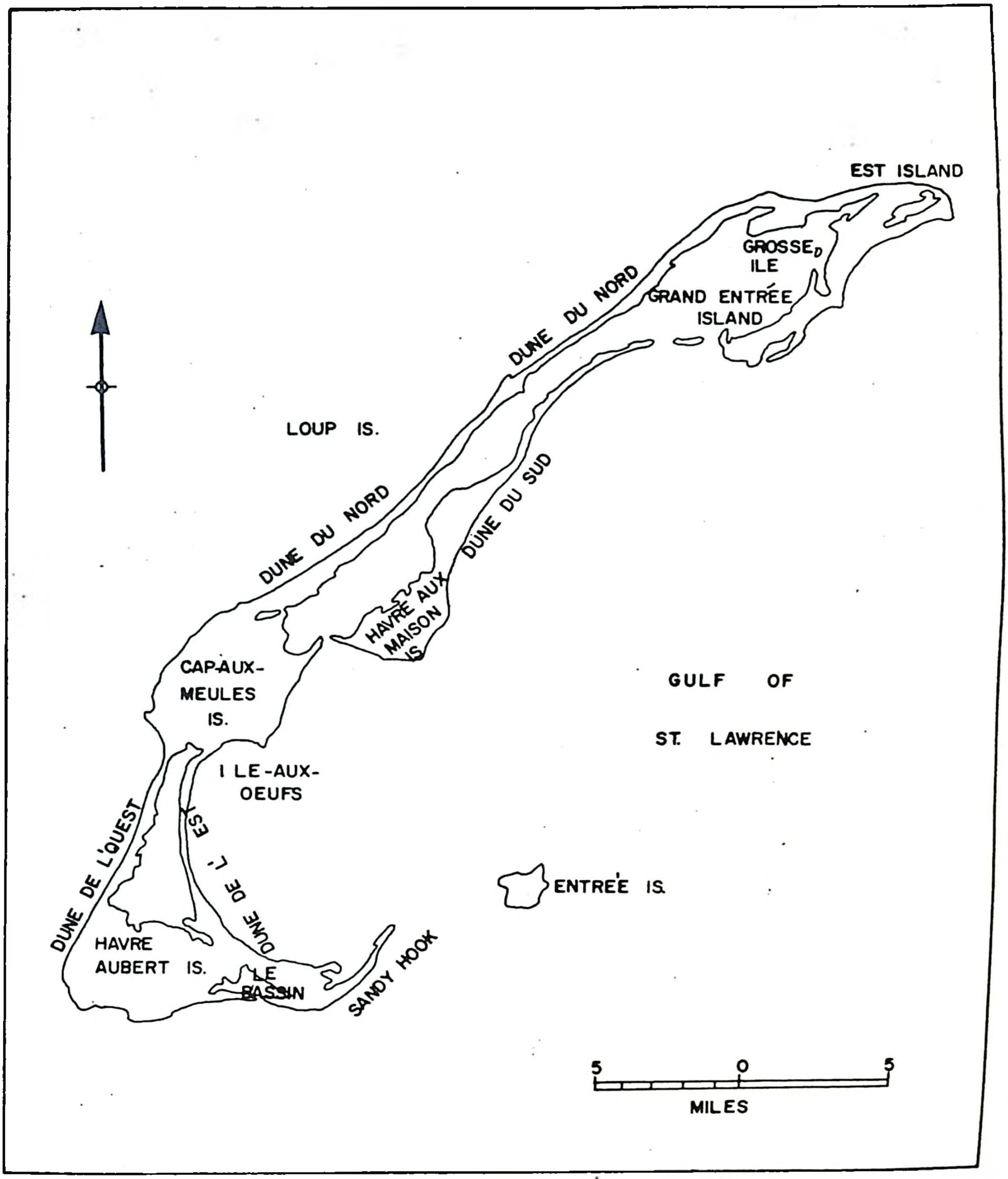


Fig. 1:2 Names of Individual Islands that Compose les Îles de la Madeleine

single unit, being joined by sand dunes or tombolos. There are several isolated islands, including Corps Mort Island, Entrée Island, Brion Island, and Rocher aux Oiseaux. There are also numerous cliffed rock islands representing the remnants of marine erosion (Sanschagrin, 1964) either bordering the main islands or in the lagoons separating them.

Geology

The geological history of les Îles de la Madeleine has been fully documented by Richardson (1881), Alcock (1941) and Sanschagrin (1964). These writers all agree that les Îles de la Madeleine belong to the Appalachian system and form part of the Gulf of St. Lawrence Lowlands which extends as far as New Brunswick and P.E.I. The consolidated rocks of the islands consist of an older series of sedimentary and volcanic rocks, a younger formation of grey sandstone, and a still later formation consisting largely of red sandstone. The sandstone laps around the hills of older rocks and covers about three quarters of the island.

The oldest rock, the Havre-aux-Maison formation belongs to the Windsor Group and can be subdivided into two members. First, there is the Cap-Asile member, consisting of inter-stratified volcanic and sedimentary rocks. The rocks include basaltic lava flows,some andesite and rhyolitic types, as well as tuffs and agglomerates. These latter rocks are interbedded with conglomerates, sandstone,siltstone, partly fossiliferous limestones and calcareous shales and non-fossiliferous red and greyish green agrillites. In places, this assemblage contains fairly regular beds of gypsum. The second member, the Bassin-aux-

Hûitres member, consists entirely of sedimentary rocks of Upper Windsor Age. They consist of fossiliferous limestone, calcareous shale, red and grey agrillites and gypsum. Lying discordantly on the Windsor is a series of non-fossiliferous red and greyish green sandstone. Sanschagrin, (1964) places the sandstone age as Permo-Carboniferous. Lithologically, the red sandstone of les Îles de la Madeleine are very much the same as those of P.E.I..

Most of the islands are almost completely bordered by rock cliffs. Since over three quarters of the islands are underlain by red sandstone, that formation produces most of the cliffs. These red cliffs are usually less than 100 ft. high, and since the rock is non-resistant, it is readily attacked by waves (Alcock, 1941). On Amherst Island, Alright and north of Cap-aux-Meules on Grindstone, the central core of volcanic and gypsum rocks is exposed in coastal cliffs.

Glacial Evidence

The question, whether or not les Îles de la Madeleine were glaciated, is one about which there has been considerable disagreement. The earliest studies by Richardson (1881) and Chalmers (1895) resulted in the conclusion that the islands had never been subjected to continental glaciation and that erratic boulders and pebbles which were present had been dropped by floating ice. Clarke (1910) concurred with the view of Chalmers, that the islands were never subjected to glacial erosion. In 1915, Goldthwait found evidence of boulder clay containing solid boulders and pebbles of foreign origin on Havre Aubert Island. He concluded that the deposit was glacial till and was not formed by floating ice. Coleman (1919) found glacial deposits that were more weathered and ancient and thus believed that they were formed during an earlier and much more extensive glaciation than that of the Wisconsin Ice Sheet. Alcock (1941) confirmed the decision of the glaciation of les Îles de la Madeleine with evidence of a marginal ridge on Grand-Entrée Island and erratics high up on Grosse-Île.

Johnson (1925) believed that the shallows surrounding the island represented a faint elevation left by subaerial denudation on the floor of the St. Lawrence Lowland, while the islands are the highest knolls crowning this elevation left unsubmerged when the lower land was drowned. Since the time of the partial submergence, the islands have been reduced in size by a limited amount of wave erosion. The subaerial contours of the surrounding shallows have been more or less modified by marine deposition and abrasion.

Falaise (1954) believed it was possible to discern several shallow preglacial valleys that extended 10-15 mi. from the present shoreline, as determined from bathymetric maps. If these valleys exist, it would provide evidence of a considerable subsidence of the islands during the Pleistocene. An estimation of the amount of post-glacial uplift was made at 5 ft., as evidenced by the presence of an old beach deposit ending with a small scarp that is approximately parallel to the present shoreline near Cap-Vert Bay on Cap-aux-Meules Island. Loring and Hota (1966) have concluded that a well developed submarine terrace between approximately 28 and 34 fathoms around les Îles de la Madeleine, marks a former sea level, resulting from a standstill in the post-glacial transgression. The present archipelago of les Îles de la

Madeleine is believed to be a small remnant of a former larger elevated area.

CHAPTER 2

THE COASTAL DEPOSITIONAL FEATURES OF LES ÎLES DE LA MADELEINE (GENERAL)

2:1 INTRODUCTION

The recent sand or depositional sections of the coast of les Îles de la Madeleine may, for convenience of description, be divided into the five units indicated in Figure 2:1. Units one, two and three include the dune systems from the west coast to the east coast, which enclose the lagoons of the island. The remaining units, four and five, consist of two free growing spits, the former extending from the northeast extremity of the island, and the latter from the southeast. In viewing the island as enclosed lagoon units, it thus facilitates the examination of a total cross-section of the island morphology.

The form of the barriers on the west of les Îles de la Madeleine are remarkably different from the east coast. The windward beaches of this tombolo complex are unstable active dune systems which are in marked contrast to the lower, prograding barriers of the leeward, east-facing shore. An analysis of data of wind directions and speeds by McCann and Bryant (1972) at Summerside, P.E.I., assumed as a typical area of the Southern Gulf of St. Lawrence, revealed two important wind regimes. The prevailing winds were between south and northwest, while the strongest or storm winds were from the north and

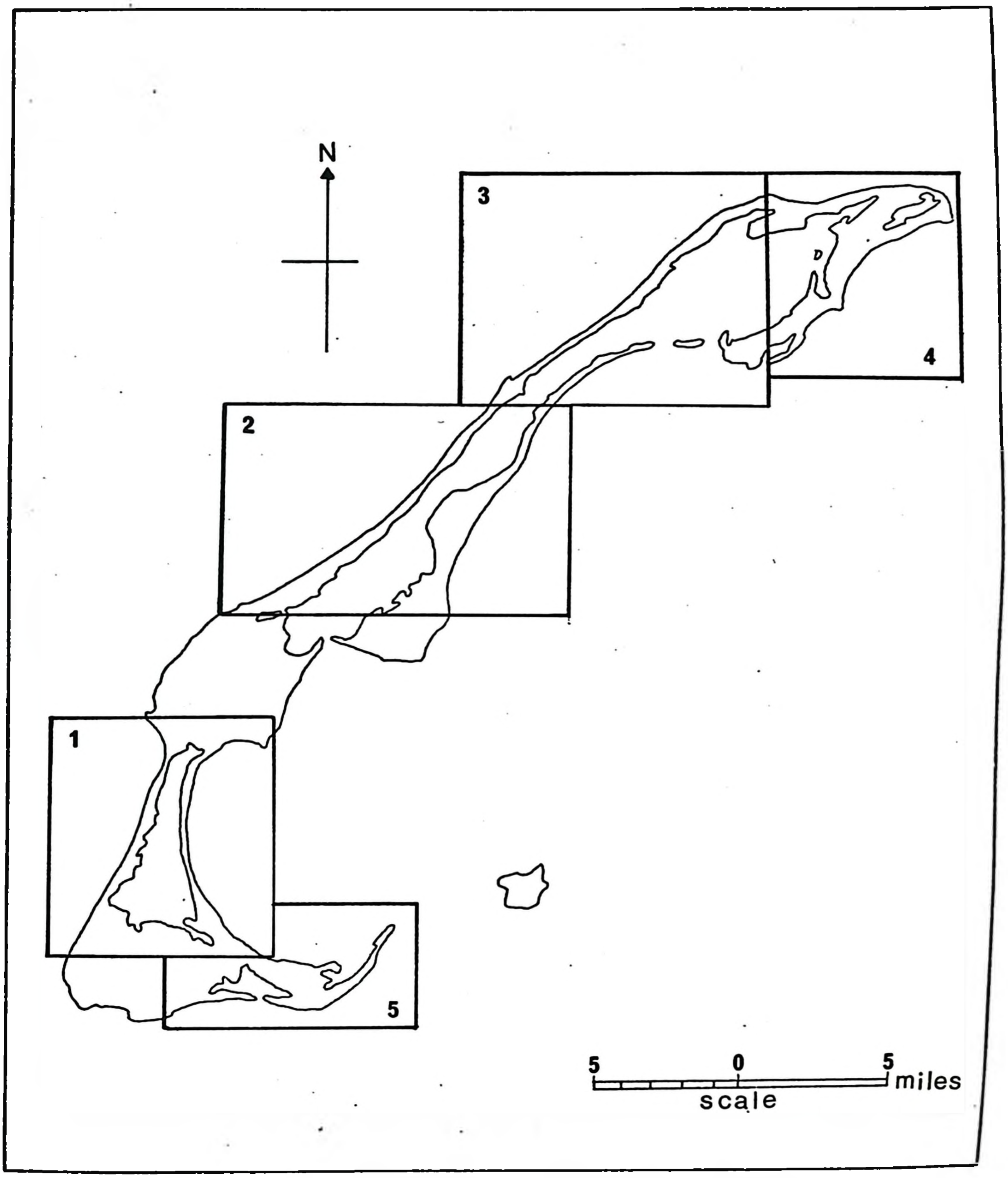


Fig. 2:1 The Location of the Five Units of Study

east southeast. This analysis thus supplies some evidence for the extremely eroded and broken nature of the west coast dunes as opposed to the more tranquil setting of the east coast. Evidence for this statement is presented in Chapter Three.

Before a discussion of the five units may proceed it is essential to understand the general nature of the various components present in each unit and their organization in space. As there is a recurring pattern of these components throughout the units a generalized cross-section across Unit 1 provides an illustration of this typical form (Fig. 2:2). Nine separate zones have been identified and within each of these zones features of both micro-scale and macro-scale may be discussed. The zones are as follows; the nearshore, the active open sea beach, the active dune ridges, the old dune ridges, the lagoon beach and finally the lagoon.

The nearshore zone will naturally include a discussion of the offshore bars with respect to their shape and continuity. The nature of the accreting and erosional cycle in the open sea beach zone is understood in terms of beach width and development of berm and foredunes. The active dune ridge zone differs significantly from the old dune ridge zone in that the active dunes are continually undergoing a cycle of erosion and accretion. The erosion cycle manifests itself in blowouts, which subsequently supply the material necessary to complete the accretive cycle. The presence or absence of a dune sea cliff or scrap faced dune front provides further evidence about the state of activity of the active dune unit. In marked contrast, the old dune ridge zone has been stabilized, for a considerable length of time, by a

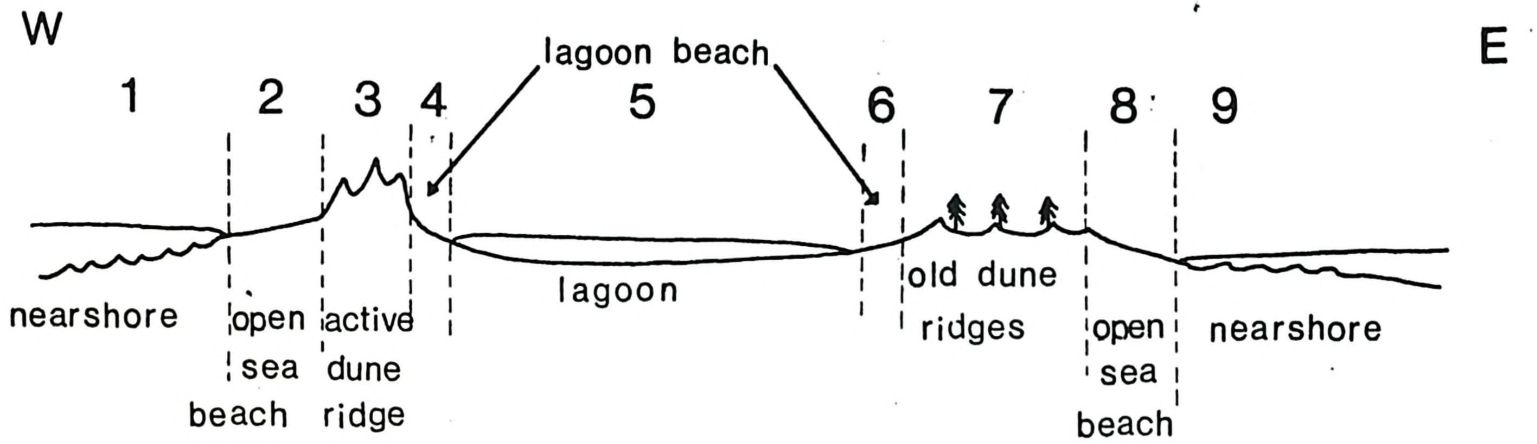


Fig. 2:2 Generalized cross-section across Unit 1.

variety of vegetation. Typically, the old dune ridges are lower in elevation and more regular in form and continuity. In viewing the lagoon it is important to note the depth of the lagoon waters and the extent and type of lagoon vegetation which provides supplementary information about lagoon activity. Finally, it is necessary to consider the state of activity and condition of the tidal inlets for a complete discussion of the total unit.

2:2 THE DUNE UNITS

Unit One

Unit 1 includes the two tombolos stretching in a northerly direction from Havre Aubert Island to Cap-aux-Meules Island. On the east coast, the tombolo is characterized by a series of regular dune ridges which generally are low in elevation while the vegetation covering this system is extensive and exhibits a well-developed dune vegetation sequence. The open sea beach appears to be actively accreting, with dune mounds developing in the backshore. Nearshore conditions are relatively simple, with a single continuous offshore bar extending along the length of the coast. In contrast, the discontinuous, narrow dune ridge system of the west coast is characterized by blowouts and large washovers. Stabilization of this system by vegetation has been inhibited by the continual blowing out of the sand dunes. Extending along the entire length of the dune ridge system is a dune sea cliff. The present condition of the open sea beach is one of erosive activity, as evidenced by the location of salt marsh vegetation on the sea side of the beach. Recently, a new tidal inlet has developed at the southern end of Dune de l'Ouest, although it is not of any great magnitude.

Unit Two

Dune du Nord stretching from Cap-aux-Meules Island to Loup Island is included in Unit 2 and a portion of Dune du Sud stretching from Havre-aux-Maison. The southern section of Dune du Sud, adjacent to Havre-aux- Maison Island is similar in character to the east coast of Unit 1 where a series of low, regularly spaced dune ridges extends approximately 1.5 mi. from east to west. A complex sequence of vegetation ranging from mature trees to simple dune grasses covers the dune ridge zone from open sea to the lagoon side. The development of a foredune along the open sea beach would tend to indicate that this beach is accreting. In the nearshore zone there are two continuous offshore bars extending the lengths of the coast. The west coast dune ridge zone is in marked contrast to the east. The form of this dune system indicates the existence of a destructive wind and wave regime as the entire length of the coast appears to be in a continual state of accretion and erosion induced by the development of huge blowouts. There is no apparent alignment of dune ridges due to this continual state of activity, but some of the largest dunes on the island, reaching heights of 20-30 ft., are located here. The steep scarp-faced dune ridge that lies along the open sea beach provides clues about the nature of erosive activity. Nearshore features consist of three continuous offshore bars.

Unit Three

Unit 3 consists of the tombolo extending north from Loup Island to Grosse-Île on the west coast and the remainder of Dune du Sud on the east coast. From Loup Island to the middle of Dune du Nord a more stable dune system exists with some development of interdune marsh. The extreme northern section is less stable, with large blowouts characterizing the surface. This section of the coast is influenced by the extreme storm waves from the north, which have produced a steep scarp-faced dune ridge. In the nearshore, one discontinuous bar parallels the coast while the two outer bars are continuous. The east coast provides a contrasting situation- one of instability, as the dune system has a history of washover activity and migration of inlets. Presently two tidal inlets isolate a small piece of the barrier from Grande Entrée on the east side and Dune du Sud on the west side. These tidal inlets are relatively large and have well developed ebb and flood deltas. Relic washovers are easily located due to their stabilization by marsh vegetation.

Unit Four

Units 4 and 5 are separate units simply because they represent a different set of morphological characteristics. Sandy Hook, Unit 4, extends approximately 4 mi. in a northeast direction from Amherst Island. Included within this unit, are the old dune ridges which surround le Bassin. The existing seaward dune ridge does not parallel the old ridge system, thus providing evidence for the existence of substantially different littoral conditions in the past. The distal end of Sandy Hook is undergoing considerable erosive activity, as evidenced by the severely dissected nature of the dune ridge, the steep cliff-face of which provides further evidence of existing storm activity. The nearshore conditions of this unit are unique on the island. A series of 4 offshore bars and a large area of shoals lies to the west of the spit. A large sediment plume extending about 2 mi. is visible off the tip of Sandy Hook.

Unit Five

Unit 5 encompasses the spit development of Est Island. The form of the old dune ridges implies a growing of the spit from two directions one from the northwest and a second from the south south-west. Many of the old dune ridges are dissected by marsh and areas of standing water. This unit is reasonably stable with a well developed vegetation sequence inhabiting the area. The southeast facing beach is considerably wider than the north beach with dune mounds accreting at its southern end. The end of the spit curves in a southerly direction with a smaller sediment plume visible off its tip.

From this general description of the five basic units it is apparent that a variety of conditions exist on les Îles de la Madeleine which manifest themselves in different forms. A more detailed description and morphologic analysis will be the basis of the subsequent chapter.

2:3 FIELD CHECKING PROCEDURE

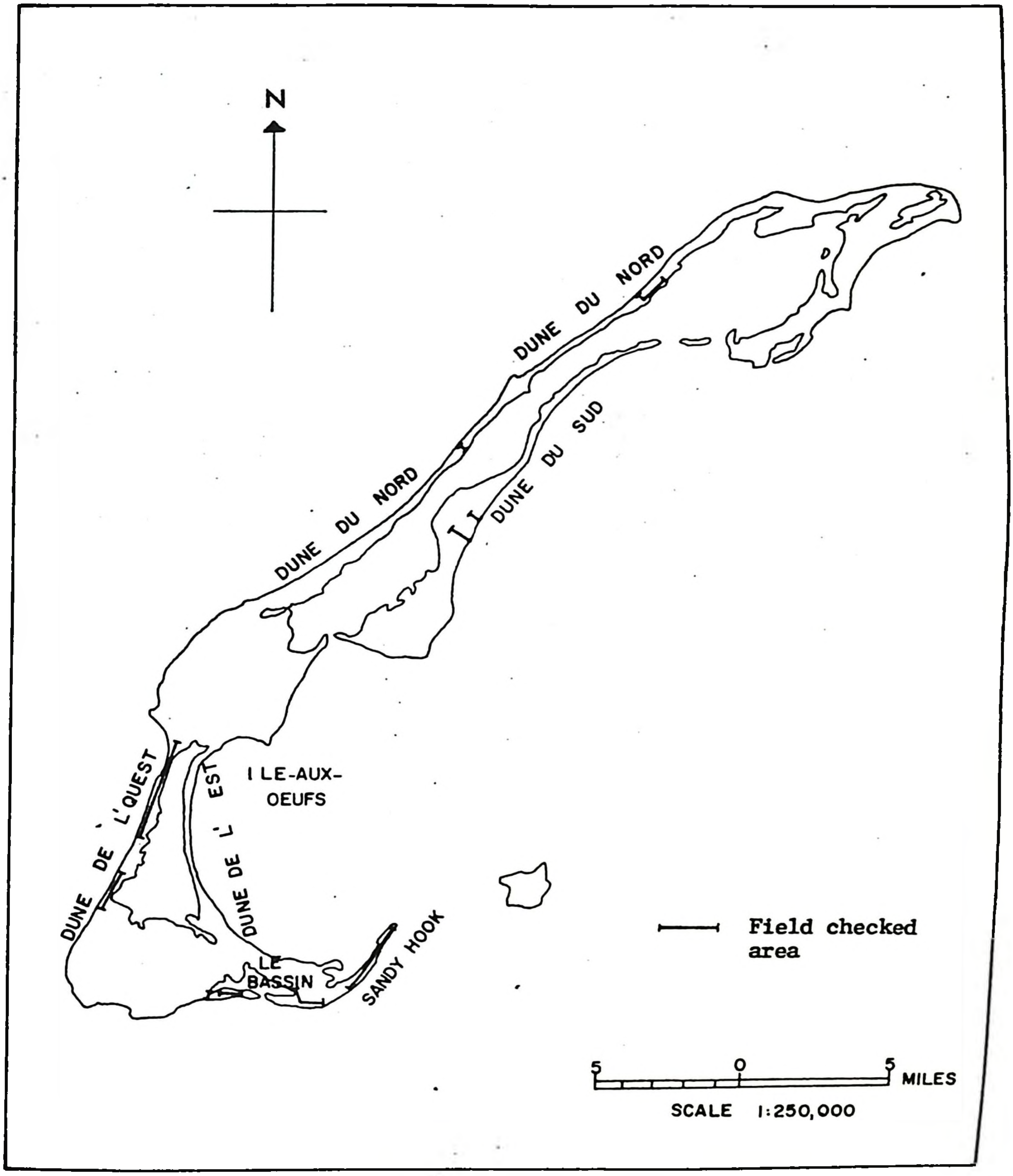


Fig. 2:3 Areas of Field Checking

Field checking for the 1969 and 1970, 1:12,000 scale panchromatic photography of les Îles de la Madeleine was conducted during the week of June 5 to June 11, 1973 (Fig. 2:3) following a week of familiarization with a previously investigated barrier island area in P.E.I. (John Armon, personal communication). Extensive walks over the beach and dune ridge areas yielded data to aid in the interpretation of the photography. Several sites considered representative of the ridge systems of the island were thoroughly investigated as to vegetal cover and dune ridge morphology. In many cases, it was not possible to transverse the intended area because of a deep growth of marsh and swamp. The field checking as such, made the author familiar with conditions existing on the island thus allowing a more accurate interpretation of the photography.

CHAPTER 3

THE COASTAL DEPOSITIONAL FEATURES OF LES ÎLES DE LA MADELEINE (AREAL DESCRIPTION)

3:1 INTRODUCTION

The following description is based upon interpretive mapping from the 1:12,000 scale 1969 and 1970 standard panchromatic photography of les Îles de la Madeleine. The photographs were obtained from the National Air Photo Library, catalogue numbers A21306 10-73 and A21672 1-161 respectively. Included in the Appendix is a diagram of the flight lines of the photos used. The major inlet channels, shoreline, backshore beaches, dune cliffs, dune ridges and washover channels were carefully mapped from stereoscopic pairs of photographs. Photography at this scale permits relatively easy interpretation of these features by one relatively familiar with the coastal environment, although such features as the berm line of the beach are not visible. The nature of the black and white photography permits only a limited interpretation of the vegetation inhabiting the area and consequently only broad regions of vegetative cover are noted. The completed map is at a 1:50,000 scale and is included in the backpocket of this thesis. A map of the offshore bars and lagoon and ocean shoals was completed in a similar manner, and it is also included in the backpocket. The basic description of this island in this chapter is derived from the map results and added reconnaissance detail. The five units, as previously outlined in Chapter 2 (Fig. 2:1) will form the basis for discussion.

Where relevant, historical detail concerning the development of the island dune systems has been obtained from historic maps. The old charts of the island produced in 1765, 1838 and 1956 permit inferences to be made about inlet position and growth of the dune ridges. Details of the maps used in this thesis are given in the Appendix. Some difficulties were encountered in comparing the old charts with one another due to the variations in scale and differing surveying techniques. Thus it was necessary to reduce the maps to a comparable scale so that the evolution of the islands tombolos, through time, could be evaluated. The results of this work are useful because they indicate, within narrow margins of error, the areas of change.

3:2 THE DUNE UNITS

Unit One

On the east coast of Unit 1 a series of nine regularly spaced old dune ridges (Fig. 3:1) extend from a southwest direction arching to the northeast. These ridges appear to be continuous, but dense vegetation cover makes this difficult to ascertain from the aerial photographs. In areas field checked (Eig. 3:2) the trees were growing on top of the ridges, while freshwater marsh vegetation filled the troughs. Black spruce (<u>Picea mariana</u>) and white spruce (<u>Picea glauca</u>) predominate as the tree cover, often reaching heights of 8-10 ft.. Such an extensive tree cover would imply that the dune ridges have maintained there present position for a considerable length of time.

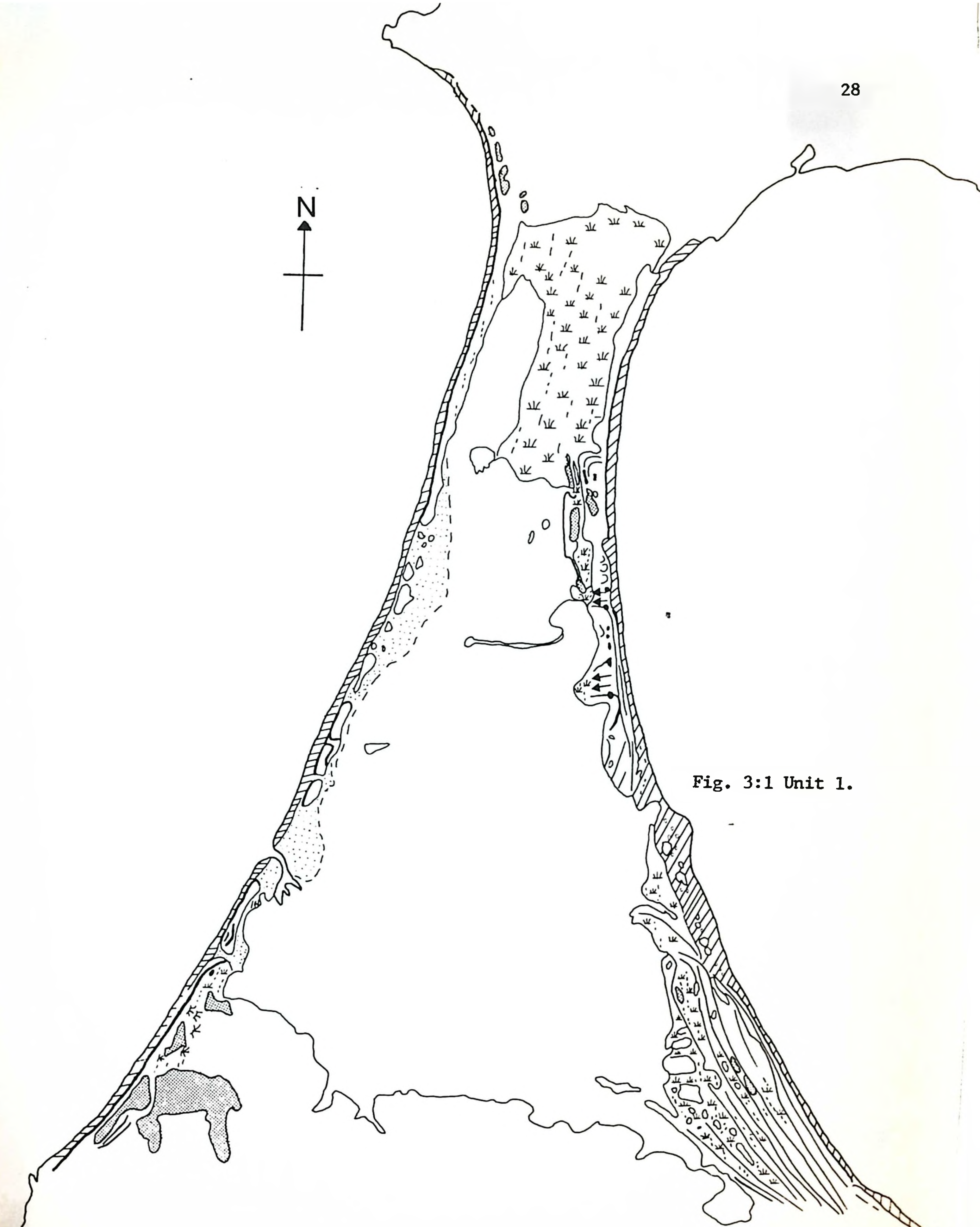
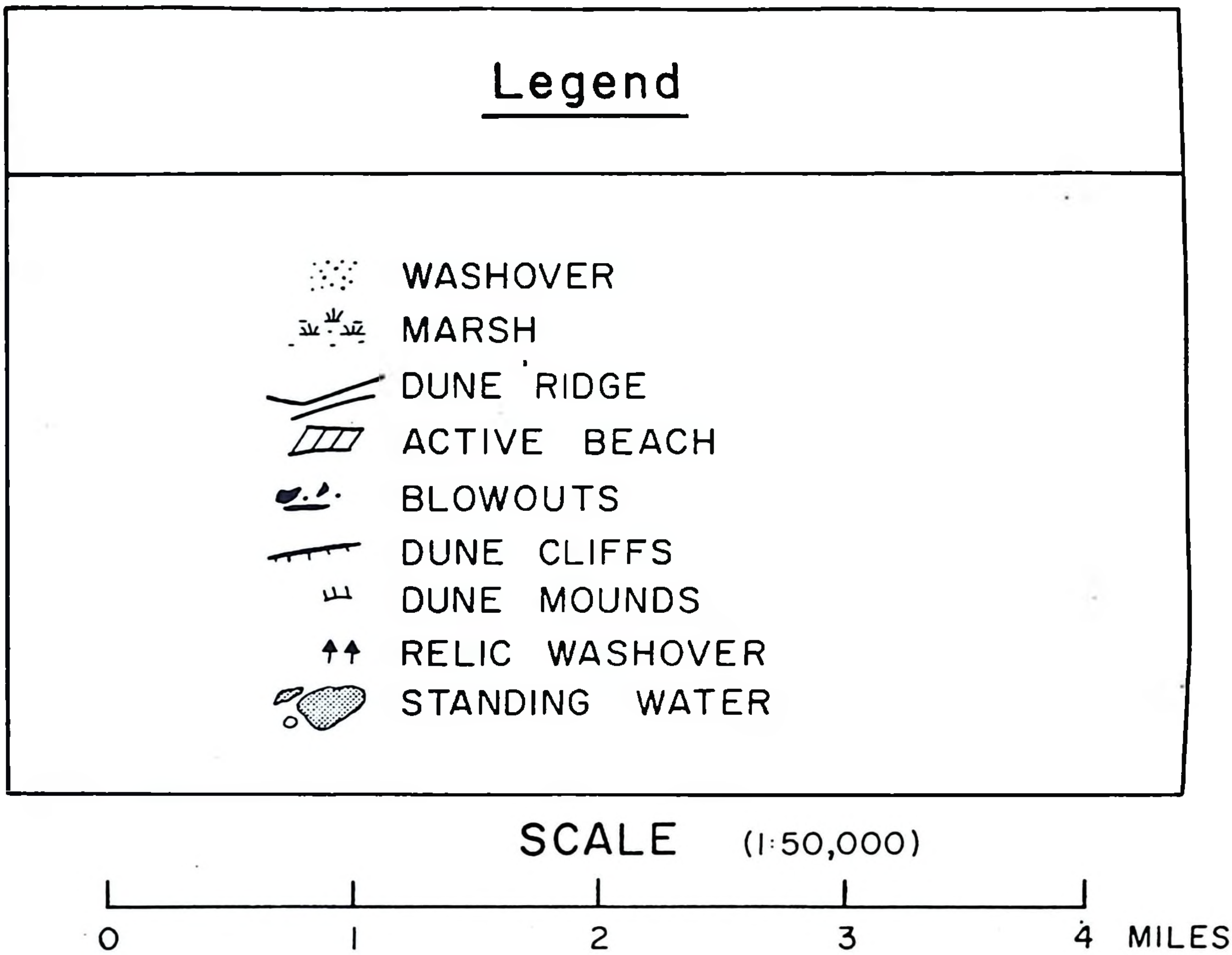


Fig. 3:1 Unit 1.



Legend for figures 3:1, 3:8, 3:16, 3:19 and 3:21.

Fig. 3:1(i).

Some blowouts pock the north end of these ridges, where the vegetal cover is not as extensive and lichen mats and marram grass (Ammophilia breviligulata) grow in profusion and stabilize the dune ridges.

Along the beach front, the ridge rises approximately 4 ft. in height, while the old dune ridges vary from 2-6 ft.. The trend of the modern beach indicates that the present dune ridge is developing under a similar set of wind and wave conditions to that which built the earlier ridges. The face of the seaward dune ridge is not cliffed, thus allowing some inferences to be made about its present state of activity. A prograding beach is usually of this nature.

Since the construction of a road extending from Cap-aux-Meules Island to Havre Aubert Island, the inlet which breached Dune de l'Est has closed (Fig. 3:3). Presently, the relic tidal delta, which was associated with this inlet, is still distinct. The delta covers an area greater than 1 mi. and has four major channels extending in a westerly direction for at least half the width of the present lagoon. The size of this tidal delta may indicate that the lagoon was once much larger in size. The ocean beach has filled the inlet entrance and dune mounds are accreting there.

Île aux Oeufs reflects a different set of littoral conditions. This system of ridges is significantly different from Dune de l'Est, since there is not the series of ridges or regularity in their development. At the north end of this section, where the sand beach joins the sandstone island, Cap-aux-Meules, a second inlet has closed, likely as a result of the construction of the road (Fig. 3:1). As in the previous case, the beach has filled in the entrance to the inlet, and the only

Fig. 3:2

Trees Growing on Top of Ridges of Dune de l'Est
with Freshwater Marsh in the Troughs

Fig. 3:3

Colour Infrared Photograph of Relic Tidal Delta of Dune de l'Est

evidence of an old inlet is the tidal delta which penetrates the salt marsh.

Predominant features of this area are two relic washovers (Fig. 3:1) which today are vegetated with marram grass (Ammophila breviligulata) and marsh vegetation on the lagoon side. The most southerly of the washovers (A on Fig. 3:4) has a series of three well developed dune ridges on the seaward side, indicating it is the older of the two: the northern washover (B on Fig. 3:4) corresponds to an old inlet located on Hollands map of 1765. In both instances, the ridge system has been truncated at the edge of the washover and at the site of the old inlet the ocean beach again has filled in and dune mounds are accreting on the backshore of the beach. The southern end of Île aux Ouefs provides the most information pertaining to the evolution of the ridges. Ridges trending in a northeast direction have been truncated by a series of three regular, fairly continuous ridges which run parallel to the seaward beach. None of the dune ridges reach tremendous heights, their maximum being approximately 5 to 6 ft..

A discontinuous dune ridge system extends along the west coast of Unit 1, forming the second tombolo which encloses Havre-aux-Basques (Fig. 3:1). In contrast to the east coast, the ridge system is less complex with a single ridge predominating, stretching south approximately 2.5 mi. from Cap-aux-Meules Island. This ridge has a high, steep face, attaining heights from 6-8 ft. and is stabilized principally by marram grass (Ammopholia breviligulata). The seaward beach is covered with pebbles, unlike any other beach at the southern end of the island, and is strewn with much other debris (Fig. 3:5). At the

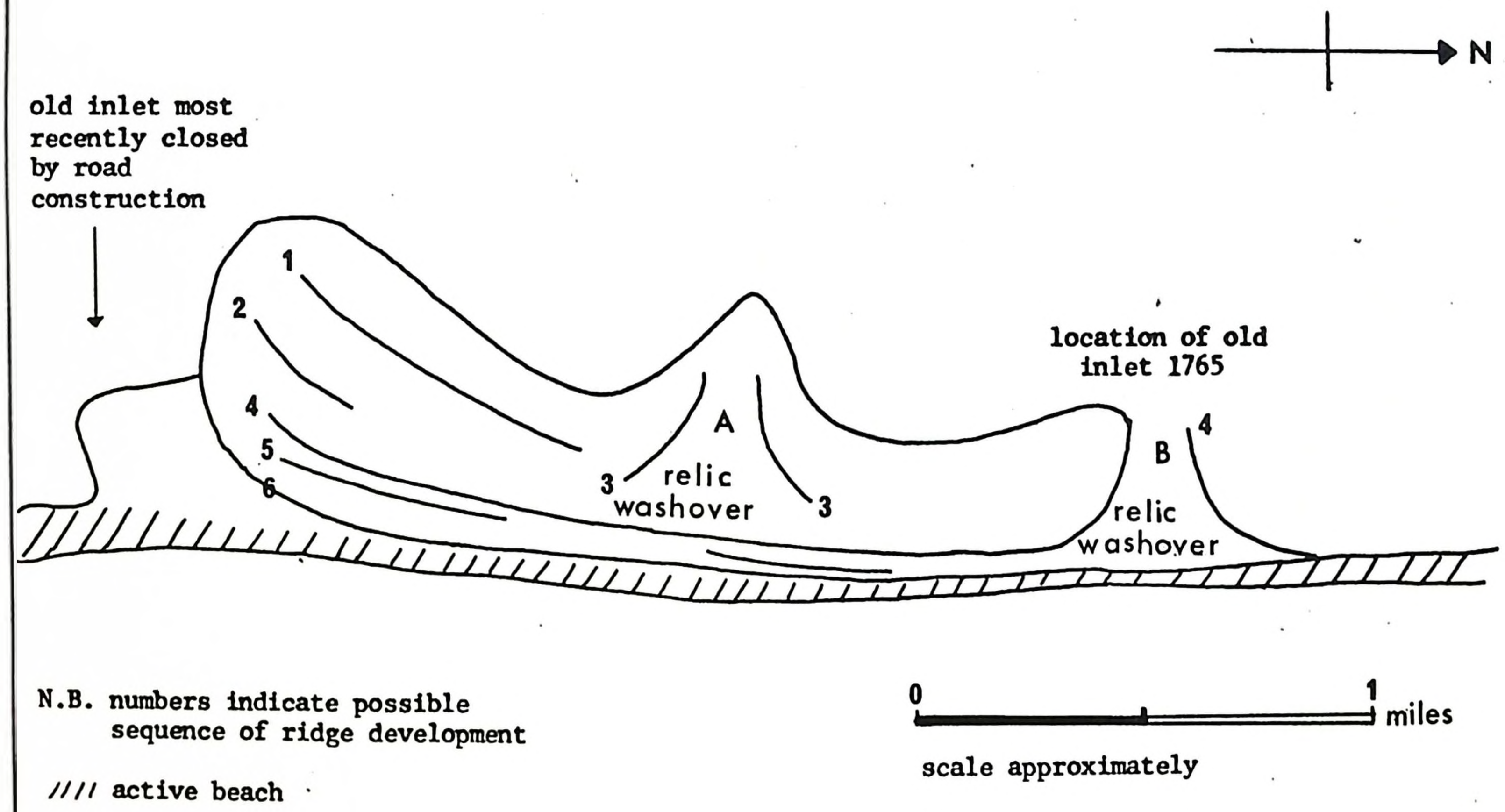


Fig. 3:4 Sketch diagram of proposed sequence of events in ridge development.

Fig. 3:5

Seaward Beach of Dune de l'Ouest Covered with Pebbles

Fig. 3:6

Extensive Marsh Development in the Lagoon Behind Ile aux Oeufs

southern extremity of this 2.5 mi. ridge the dunes are blown out and the remainder of Dune de l'Ouest appears as a dissected ridge where washovers break the continuity. Some of the ridge appears as wash-arounds, where the sea has not totally washed away the ridge, but has washed around the ridge leaving a remnant of the formally continuous ridge. These mounds are blown out along the sea face and are steeply scarped. During the reconnaissance study of this section, salt marsh evidence was found on the seaward side of the ridge indicating a retrograding dune face.

At the southern end, beyond Havre Aubert Island, a tidal inlet has developed, likely in response to the closing of the two inlets on the east coast. The inlet has developed on the border of a large washover, which is approximately 0.75 mi. wide, but the inlet itself is not large and does not have a clearly defined ebb and flood delta.

The lagoon, Havre-aux-Basques, enclosed by Unit 1 appears very shallow with sand deposits accumulating over a large area of the lagoon suggesting a gradual infilling. There has been extensive marsh development in the lagoon behind Île aux Oeufs, extending the full width of the lagoon at the north (Fig. 3:6) and stretching south approximately 2.5 mi.. It may be reasonable to assume that the lagoon will continue to develop marsh, with the closing of the two inlets on the east.

The evidence for historic change in this tombolo system is presented in Figure 3:7, where, within the limitations of the maps available, it is possible to delimit the changes in inlet position on the east and west coast of Unit 1. The west coast has been the most active in terms of numbers of inlets which have opened and closed over

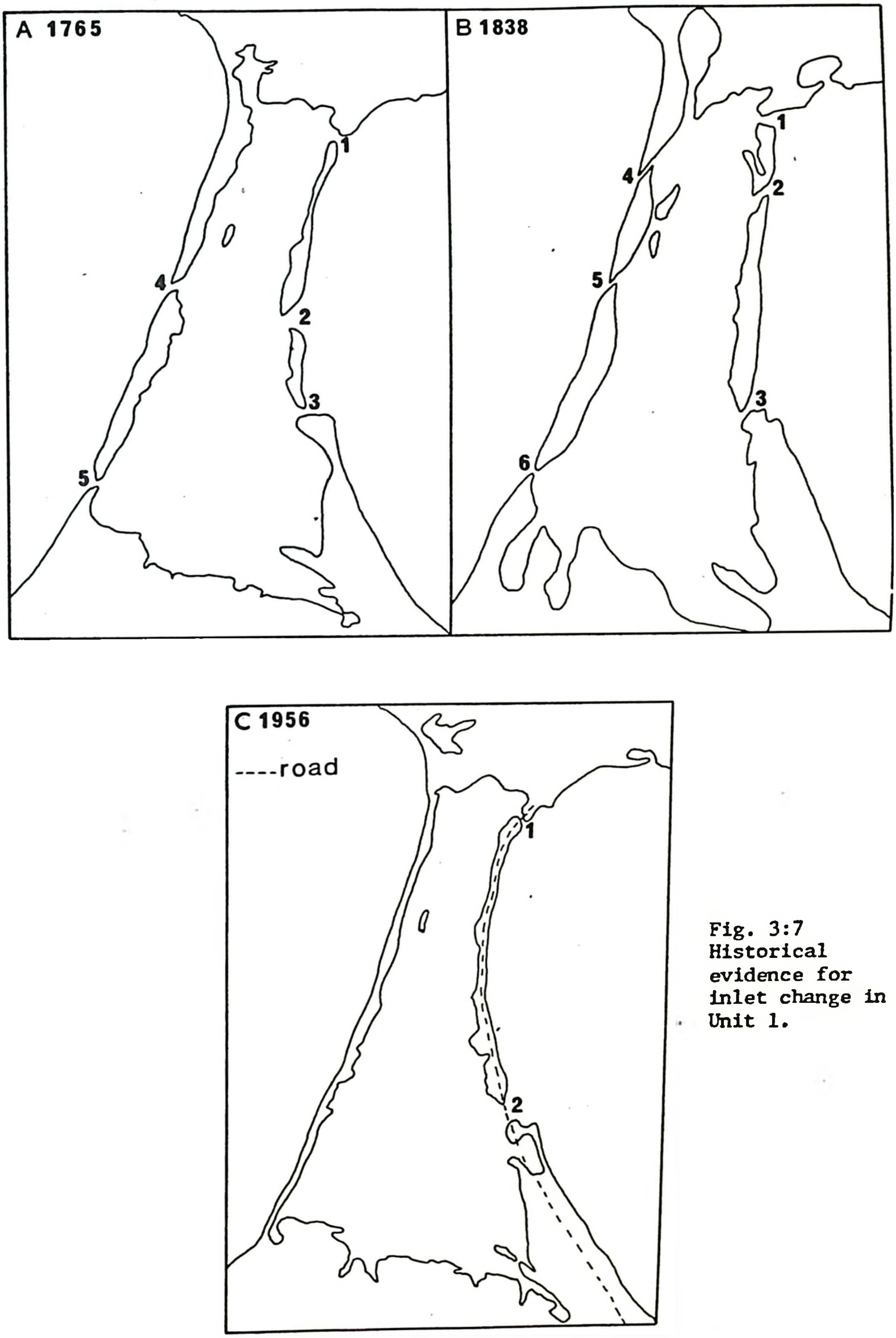


Fig. 3:7
Historical
evidence for
inlet change in
Unit 1.

the 190 year period. None of the inlets which existed in 1765 and 1838 (4 and 5 on Fig. 3:7A and 4,5 and 6 on Fig. 3:7B) are maintained today, although there is evidence of breached and slightly recurved dune ridges at the location of these relic inlets. The 1956 map evidence (Fig. 3:7C) shows a continuous coastline, which was subsequently breached prior to 1971. The east coast inlets (1 and 3 on Fig. 3:7 A and B) have been maintained for the full 190 year period, but the construction of a road, has since intiated their infilling and hence produced a continuous coastline. The location of inlet 2 on Figure 3:7 A and B has shifted during this time period, but there is good relic evidence for the location of this inlet (Fig. 3:4).

Unit Two

The east coast of Unit 2 presents the most complex series of dune ridges on les Îles de la Madeleine in terms of numbers of dune ridges and the extent and variety of vegetation covering the unit (Fig. 3:8). The ridges of this section are regularly spaced and are continuous for almost their entire length of approximately 5 mi.. The first seven ridges of the series, moving inland from the ocean beach, vary in height, a maximum of approximately 10 ft. being attained. These ridges are separated by several continuous dune ridges which are considerably lower in elevation as illustrated in Figure 3:9. A large foredune is accreting along this shore (Fig. 3:10) at the southern extremity of Dune du Sud, which would imply that this east coast is prograding. Large blowouts pocket the ridges closest to the sea and where the water table reaches the bottom of the blowout a dark creeper

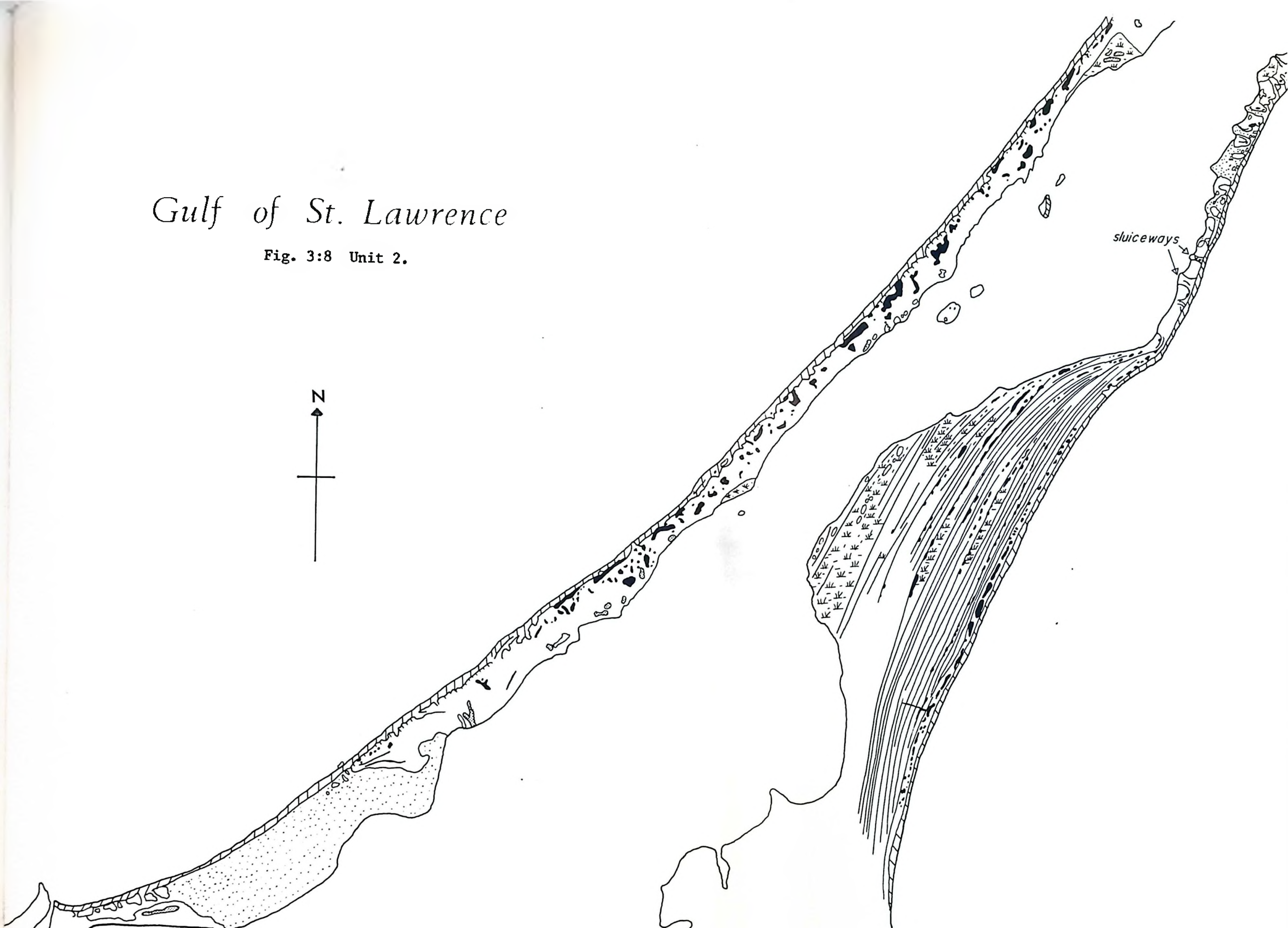


Fig. 3:8 Unit 2.

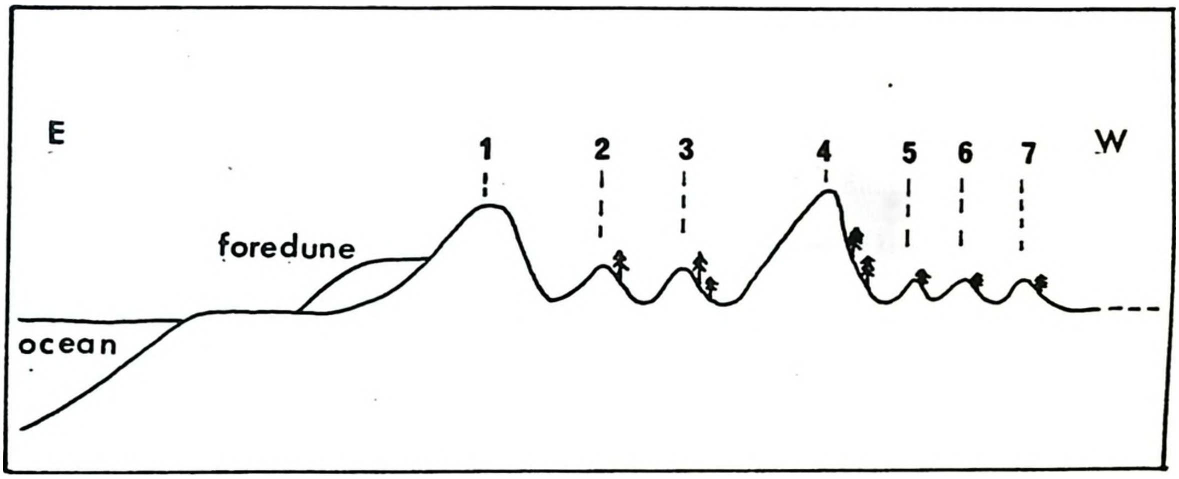


Fig. 3:9 Generalized cross-section of old dune ridges in Unit 2.

type vine grows there (Fig. 3:11). Figure 3:12 illustrates how the trees in this area, principally black spruce (Picea mariana), white spruce (Picea glauca) and some pine, grow on the protected back slopes of the dune ridges and tend not to grow tall but rather spread out like a bush.

Further inland the ridges become significantly lower in elevation and are widely spaced with such regularity implying that a steady wind and wave regime has existed. The regularity of growth and width of ridge spacing is unlike any other area on the island. A large proportion of the ridges are blown out, but the size of the blow outs is not as great as those along the ocean beach ridge. Fresh water marsh occupies the troughs between these ridges and the dense cover of pine and spruce trees is replaced by lower growing shrubbery and some evergreen bushes.

North of the series of regular ridges, Dune du Sud becomes a long arcuate bar which appears to have had a slightly more unstable history. The most notable feature of this area is the number of washovers and sluiceways that break the dune ridge of the ocean beach. The largest washover, approximately 0.25 mi. wide, has a large lobate fan extending into the lagoon. A 1956 air photograph of this area indicates that this washover is located at the site of a small tidal inlet, maintained by only one channel. Storm activity likely keeps the sluiceways and washovers active, while also maintaining a scarp faced dune ridge. The vegetation of this area is limited to marram grass (Ammophila breviligulata) and other low grasses and plants to stabilize the dune ridge.

Fig. 3:10

Foredune Accreting Along Southern Extremity of Dune du Sud

Fig. 3:11

Large Blowouts of Dune du Sud with Dark Patch Indicating Creeping Vine

Fig. 3:12

Black Spruce, White Spruce and Some Pine Grown on the Protected Back Slopes of Dune Ridges

Fig. 3:14

Severely Dissected Topography of West Coast of Unit 2

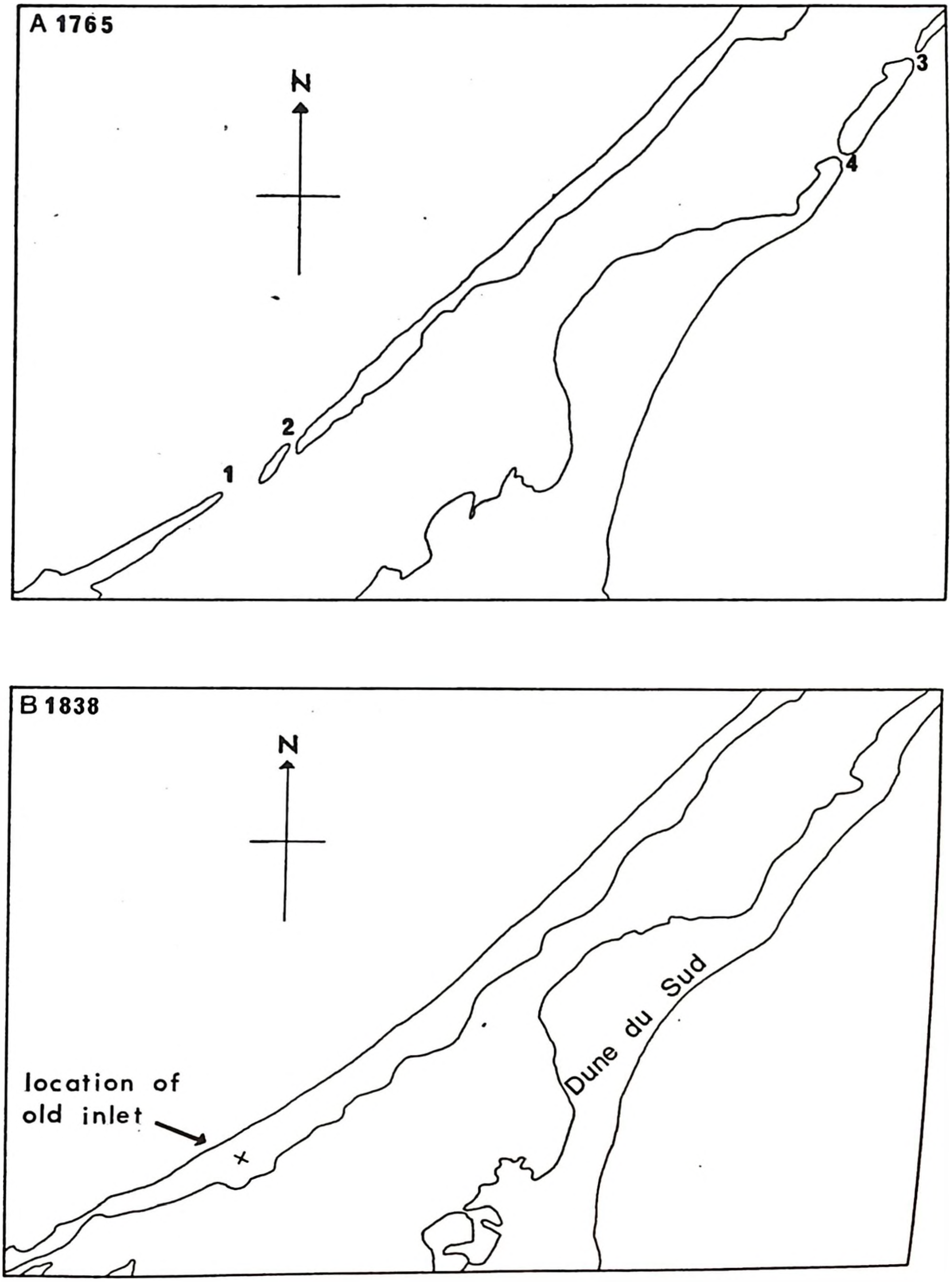


Fig. 3:15 Historical evidence of inlet change in Unit 2.

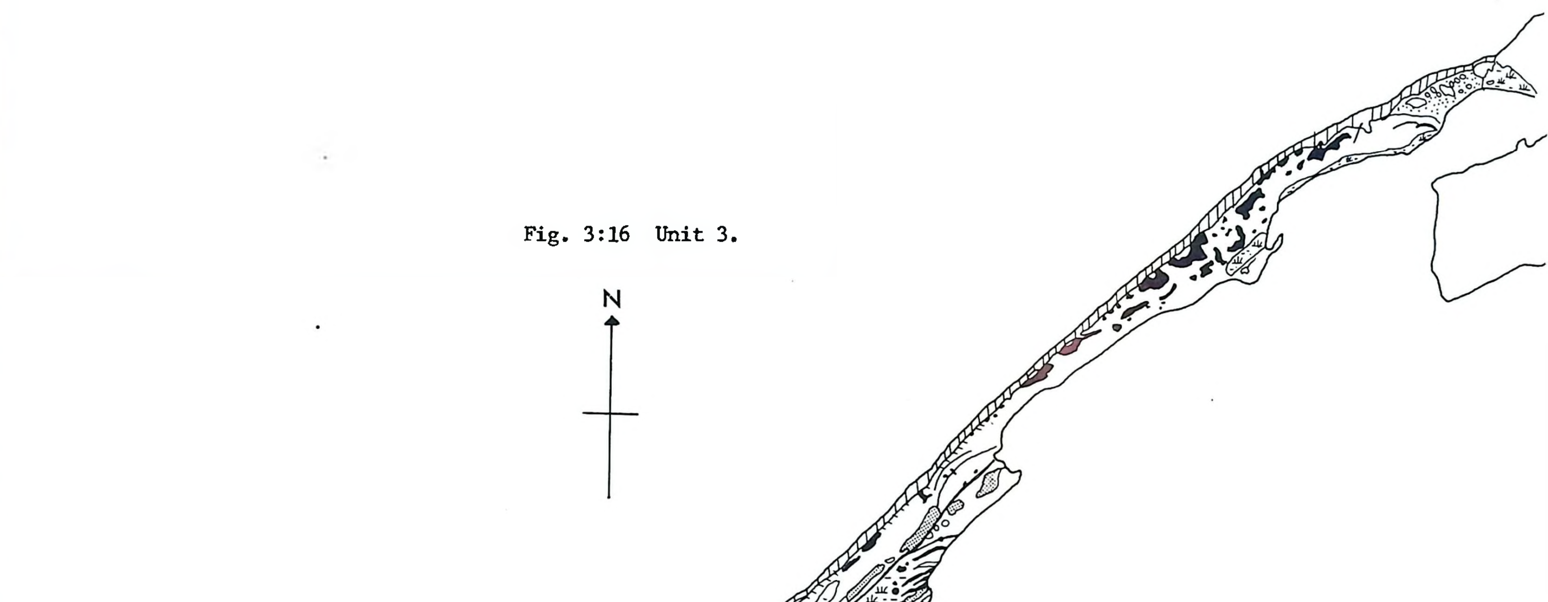
The lagoon zone of this unit is characterized by series of lobate fans, extending out from the active sluiceways and washover. The offshore zone is distinguished by two continuous bars running parallel to the shore line.

The west coast of Unit 2 may be described as an active dune ridge system, where the stability of the system is in a continual state of flux (Fig. 3:8). South of Loup Island, the dunes are severely blown out and partially stabilized by marram grass (Ammophilia breviligulata). The blowouts appear to be affected by winds from the southwest, since they are aligned in a northeast direction this side being the steep face. Figure 3:14 indicates the severely dissected topography of this area with the blowouts reaching depths of 20-30 ft.. There are no significant ridge trends, except for the cliff faced dune ridge running parallel to the ocean beach. The most significant feature of this system is a large washover, at the junction of Cap-aux-Meules Island and Dune du Nord, which is about 1.75 mi. wide. The maintenance of such a large washover would imply that a large sediment supply is available in this area.

The 1765 map evidence (Fig. 3:15 A) indicates that both the east and west coast of Unit 2 have had a history of tidal inlet breaching and infilling. By 1838, (Fig. 3:15 B) all four inlets had infilled but they have maintained this configuration to the present day, with the exception of a breach on the east coat shown on 1956 air photographs.

Unit Three

Fig. 3:16 Unit 3.



The east coast of Unit 3 is an unstable arcuate bar stretching from the southwest to the northeast for a distance of approximately 4 mi. (Fig. 3:16). This section is characterized by many sluiceways breaking the scarp face dune ridge facing the ocean beach and by extensive marsh development on the lagoon side. The largest washover (A on Fig. 3:16) is flanked on the north side by 3 short, recurved dune ridges. The distal end of this tombolo is subject to washover activity during stormy periods due to the narrowness of the dunes. A breach at the northern end of this extension has produced an island, approximately 1 mi. in length, which is very low in elevation and appears to undergo extensive washover activity, for there is little evidence of dune stabilization by vegetation. The tidal inlet separating this island from Grande Entrée is maintained by dredging operations. The offshore features of this coast consist of two continuous parallel bars extending the entire length of this unit.

The west coast of Unit 3, north of Loup Island reflects a more intensely active dune ridge system, which is severely dissected and pocked by huge blowouts. In some cases the blowouts reach the present water table and hence small ponds surrounded by marsh vegetation have developed. At the widest section of this unit, approximately 0.75 mi., there are four dune ridges with strong trends in a southwest to northeast direction. These ridges are stabilized by profuse growth of vegetation, ranging from lichen mats, low shrubs to pine and spruce trees reaching heights of 3-4 ft., while between the ridges (Fig. 3:17) there is heavy growth of marsh vegetation similar to that found in Unit 1. The seaward dune ridge is steeply scarped and blown out,

Fig. 3:17

West Coast of Unit 3. Dune Ridges are Stabilized by Profuse Growth of Vegetation and Heavy Growth of Marsh Inbetween

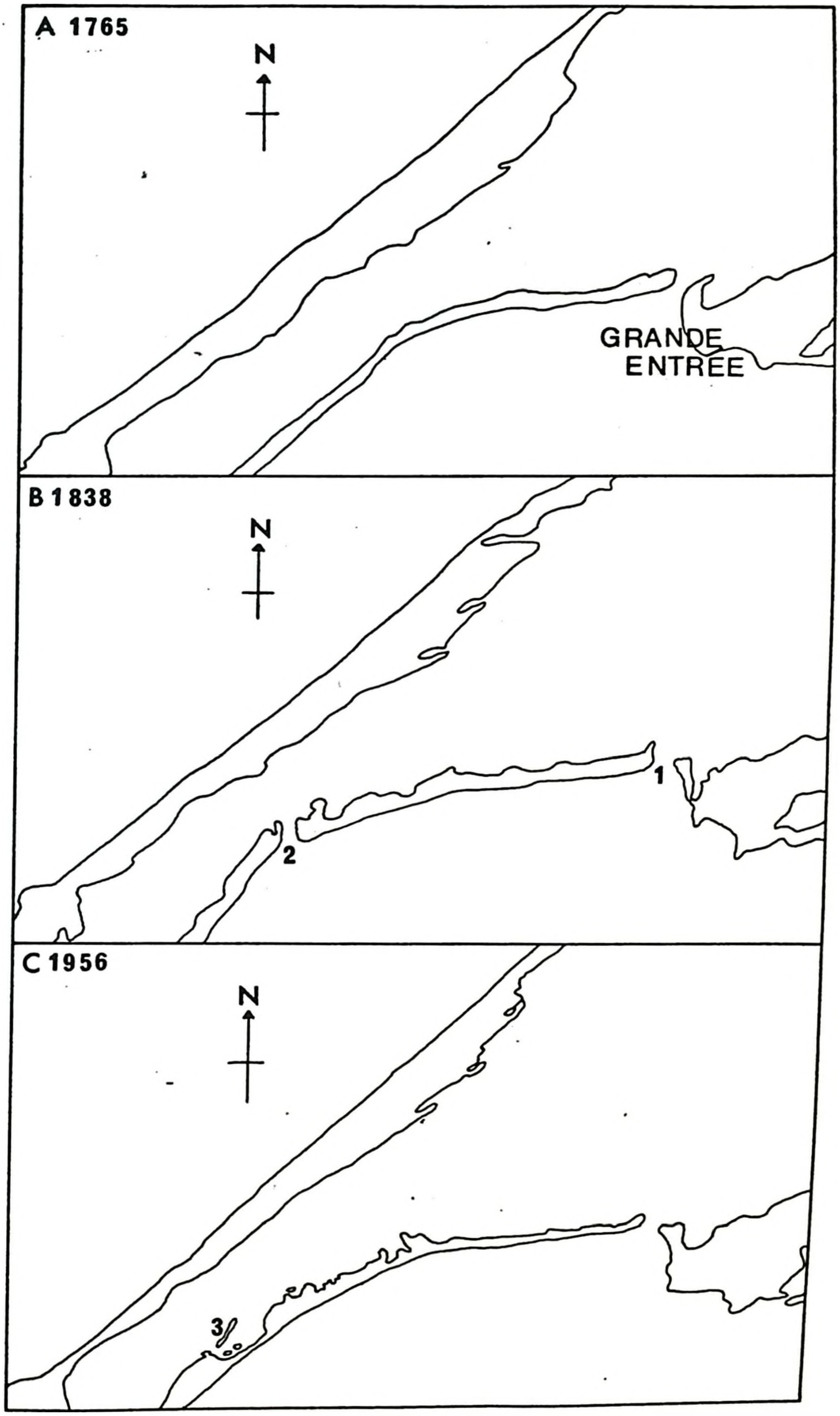


Fig. 3:18 Historical evidence for inlet change in Unit 3

reflecting the prevailing wind conditions affecting the west coast of les Îles de la Madeleine. A washover of approximately 0.75 mi. separates Grosse-Île from Dune du Nord and has several dune mounds accreting on it. A narrow lagoon beach extending for approximately 4.5 mi. is cuspate in nature; and the lagoon sand shoals appear in a criss-cross pattern varying in width from a few hundred feet to almost 0.5 mi..

Historical maps (Fig. 3:18) indicate that the east coast of this unit has undergone a significant number of inlet changes up until the present day. In 1765 one tidal inlet breached Dune du Sud, while by 1838 a second inlet (2 on Fig. 3:18 B) had formed and retrogression of the tombolo to the west had occurred. By 1956, the second inlet had closed and the remains (3 on Fig. 3:18 C) of the distal end of the 1838 tombolo appears in the lagoon. The 1970 map , (Fig. 3:16) indicates that once again this section of the coast had been breached in a new site by a tidal inlet, thus giving more evidence for the instability of the east coast.

Unit Four

The north spit (Fig. 3:19) of les Îles de la Madeleine presents a complex arrangement of coastal features, significantly different from any other area on the island. Development of this spit has been influenced by littoral conditions originating from the northwest and the southeast, hence producing two different trends in the dune zone. A large lake, Est Pond, numerous smaller lakes and extensive marsh development separates the southeast coast from the northwest coast. The northwest zone is characterized principally by dune ridges trending in

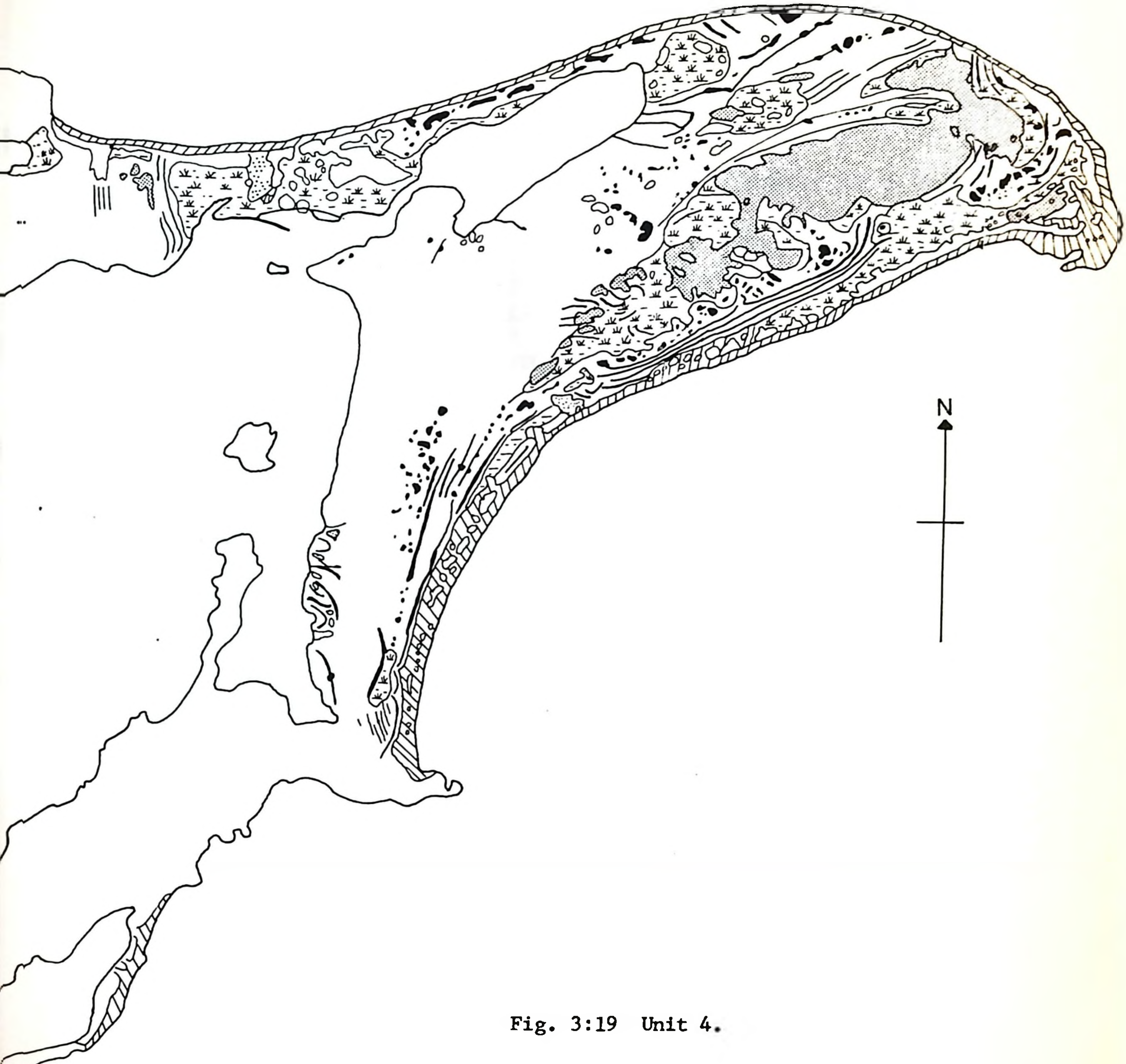


Fig. 3:19 Unit 4.

a north-south direction and a second series with their predominate orientation to the northeast. This is inconsistant with the present seaward dune ridge which is accreting along an east-west axis. These ridges are densely vegetated with a variety of evergreen trees and bushes, of considerable height, while the lowland areas support extensive marsh growth. Extending along the north reaches of Clarke Bay the seaward dune ridge is wide and pocked with large blowouts, which are aligned in a northeast direction. This suggests that the predominant winds from the southwest are affecting their development. To the south of Clarke Bay there is poor evidence of clearly defined ridges, but the area is extensively pocked with blowouts which have been partially stabilized by vegetation.

At the tip of the north spit, approaching Pointe de l'Est, the seaward beach is cuspate corresponding to the wavy offshore bar. The distal end of the spit is a hooked beach, recurving to the south, suggesting this is the direction of longshore transport. This is further substantiated by the presence of a large sediment plume.

The southeast seaward beach, stretching south to Old Harry Point, is considerably wider than the northeast beach and dune mounds are accreting on it. The dune ridge on the backshore of the beach is severely dissected by sluiceways, produced during storm activity, which has led to the development of marsh and wetlands. West of this marsh development lies a series of four parallel ridges, 2 mi. in length, and typically vegetated with marram grass (Ammophilia breviligulata). South of these ridges are a series of shorter dune ridges severely dissected by relatively small blowouts.

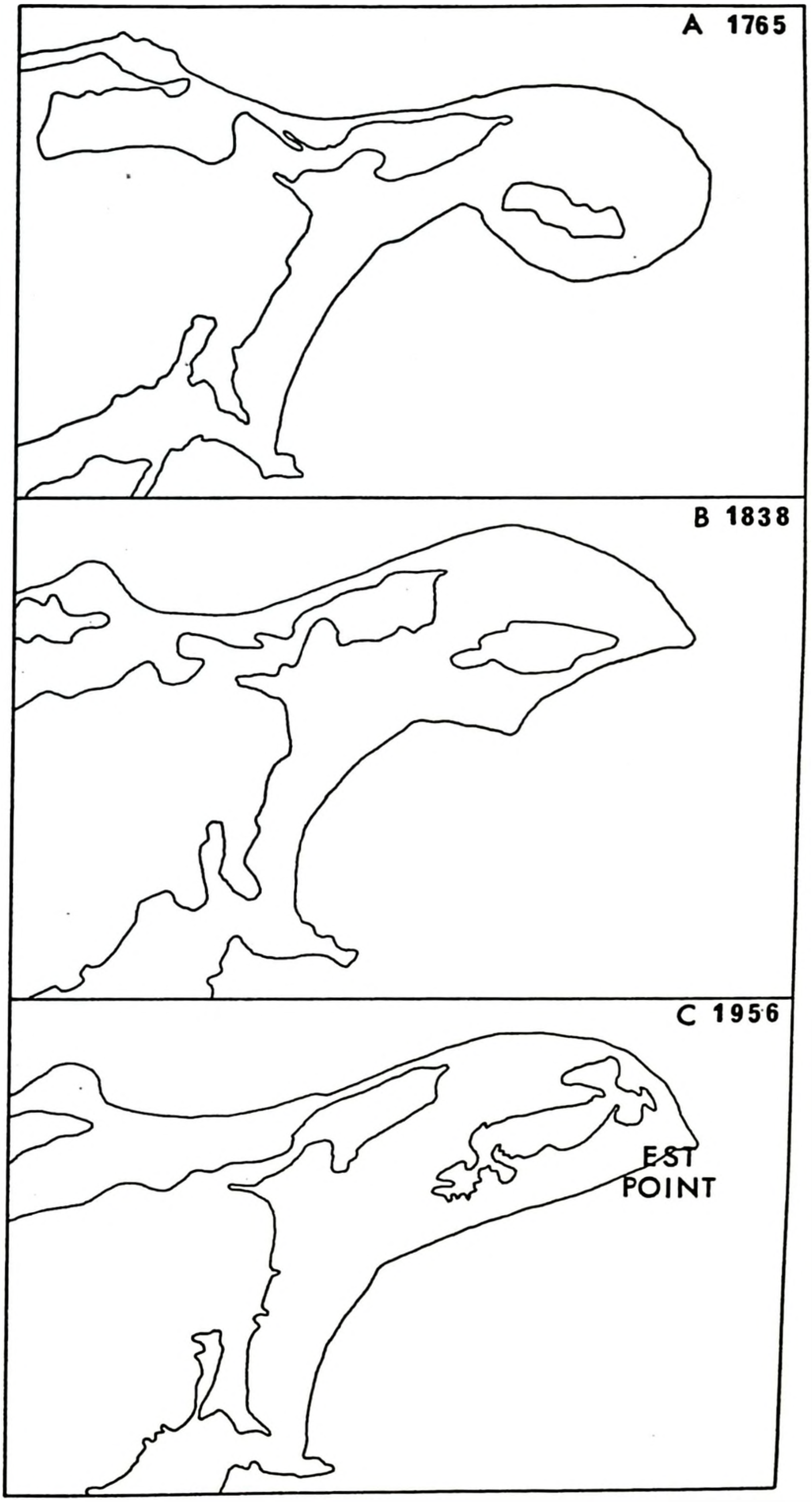


Fig. 3:20 Historical evidence for spit development in Unit 4.

The evolution of this unit is a complex one to understand from the orientation of the dune ridges. Historical maps (Fig. 3:20) indicate that the growth of this spit has been from the southwest prograding to its present position. The growth of the four parallel ridges along this coast appears to have occurred since the 1838 map was produced.

Unit Five

Unit 5 encompasses the southern most dune ridge zone of les Îles de la Madeleine. For convenience of discussion of this unit, it is perhaps best to consider it as two separate sections. Section A (Fig. 3:21) is an area of relatively old dune topography located on the east and west shores of the tidal inlet to le Bassin, while section B consists of a long narrow spit, Sandy Hook, which projects in a northeast direction for approximately 4 mi..

The nature of the two recurved dune ridges in section A which are stabilized by marram grass, cranberry, various xerophitic plants and some spruce trees on the west shore of le Bassin suggest growth of the ridges around the rock face of Havre Aubert Island. The low seaward dune ridge (Fig. 3:22) does not recurve, but is scarp faced for its entire length of approximately 2 mi., while the ocean beach is characterized by large cusps which correspond to a cuspate offshore bar. Behind the seaward ridge is an area of extensive marsh and unoriented dune mounds, while the intertidal marsh penetrates deeply behind the ridge and is inundated at HHT. The inlet to le Bassin is well established and hence a significant feature. The tidal delta

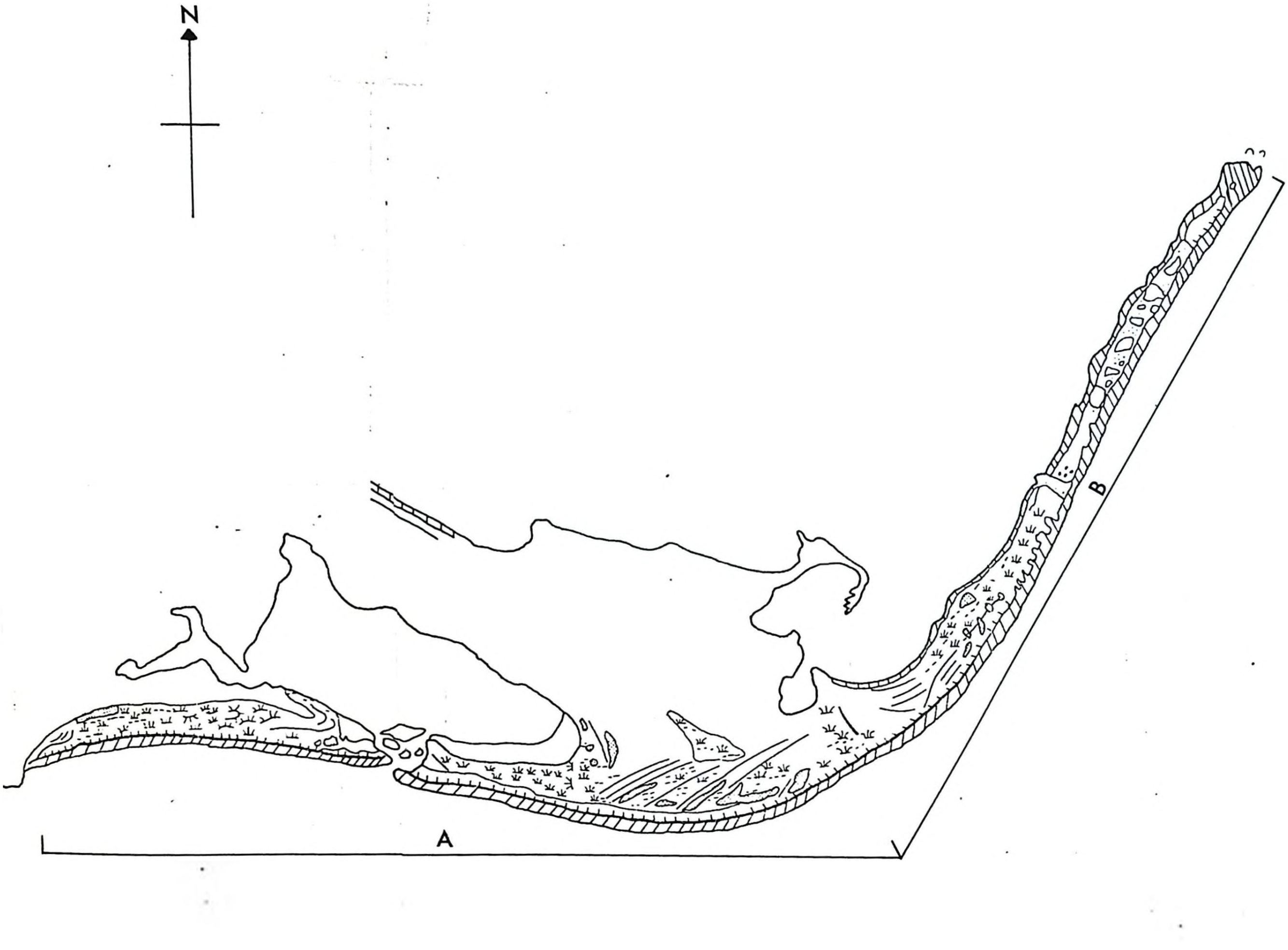


Fig. 3:21 Unit 5.

Fig. 3:22

Scarp Faced Low Dune Ridge

Fig. 3:23

Scarp Faced Dune Ridge of Sandy Hook

is well developed with sand flats being exposed at LLT. On the east side of le Bassin, extending as far as Baie du Bassin, there is a wide expanse of intertidal marsh which is inundated at HHT.

Between Baie du Bassin and Petit Bassin, lies a unit of six parallel dune ridges trending in a northeast direction. These old ridges, ranging in height from 3-5 ft., are semi-continuous, the troughs inbetween being filled with fresh water. At the eastern end of this unit the ridges are no longer continuous and appear as mounds in the marsh. The seaward dune ridge has a flat wide crest, reaching heights of about 6 ft.. The foredune along this wide cuspate beach is wide and flat with a cliffed face and the large cusps correspond to the same wavy pattern of the offshore bar. The difference between the orientation of this seaward dune ridge and the older ridges suggests that there has been a shift in the wind and wave regime.

At the proximal end of section B are remnants of old dunes. These form a series of four short dune ridges which have been truncated at both ends. The ridges are stabilized by a cover of marram grass and presently marsh fills the depressions between the dune remnants and some ponds of standing water are found. The seaward dune ridge is continuous from the east side of le Bassin to about one quarter of the length of the spit and attains heights of approximately 10 ft.. At this point the ridge becomes dissected by many washovers and the face of dune ridge is cliffed by wind and wave action (Fig. 3:23). On the bayside of the washover micro-spits are accreting in a south westerly direction suggesting that this is the direction of longshore transport. The distal end of the spit is characterized by extensive sand flats and

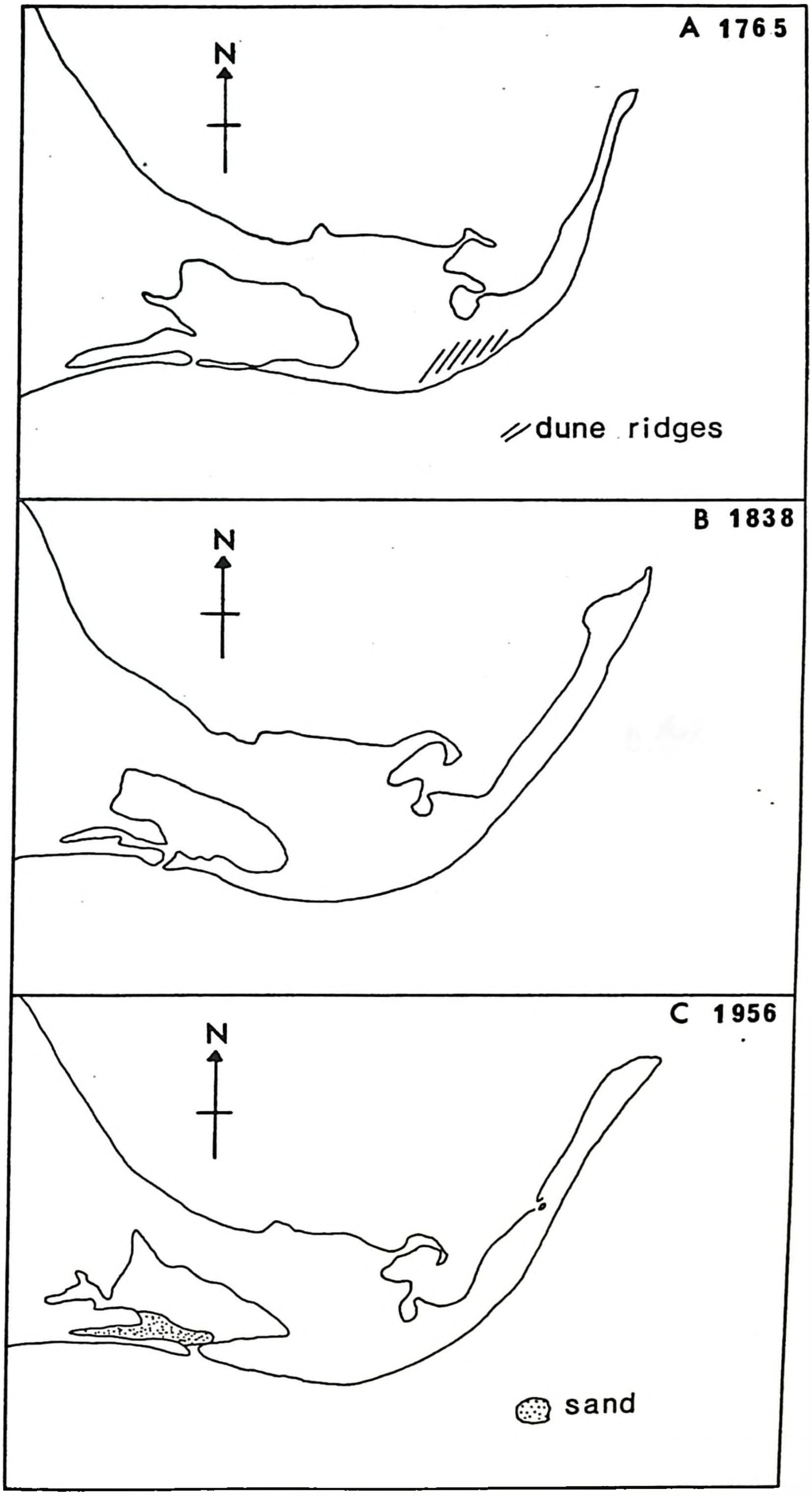


Fig. 3:24 Historical evidence for inlet migration and spit development in Unit 5.

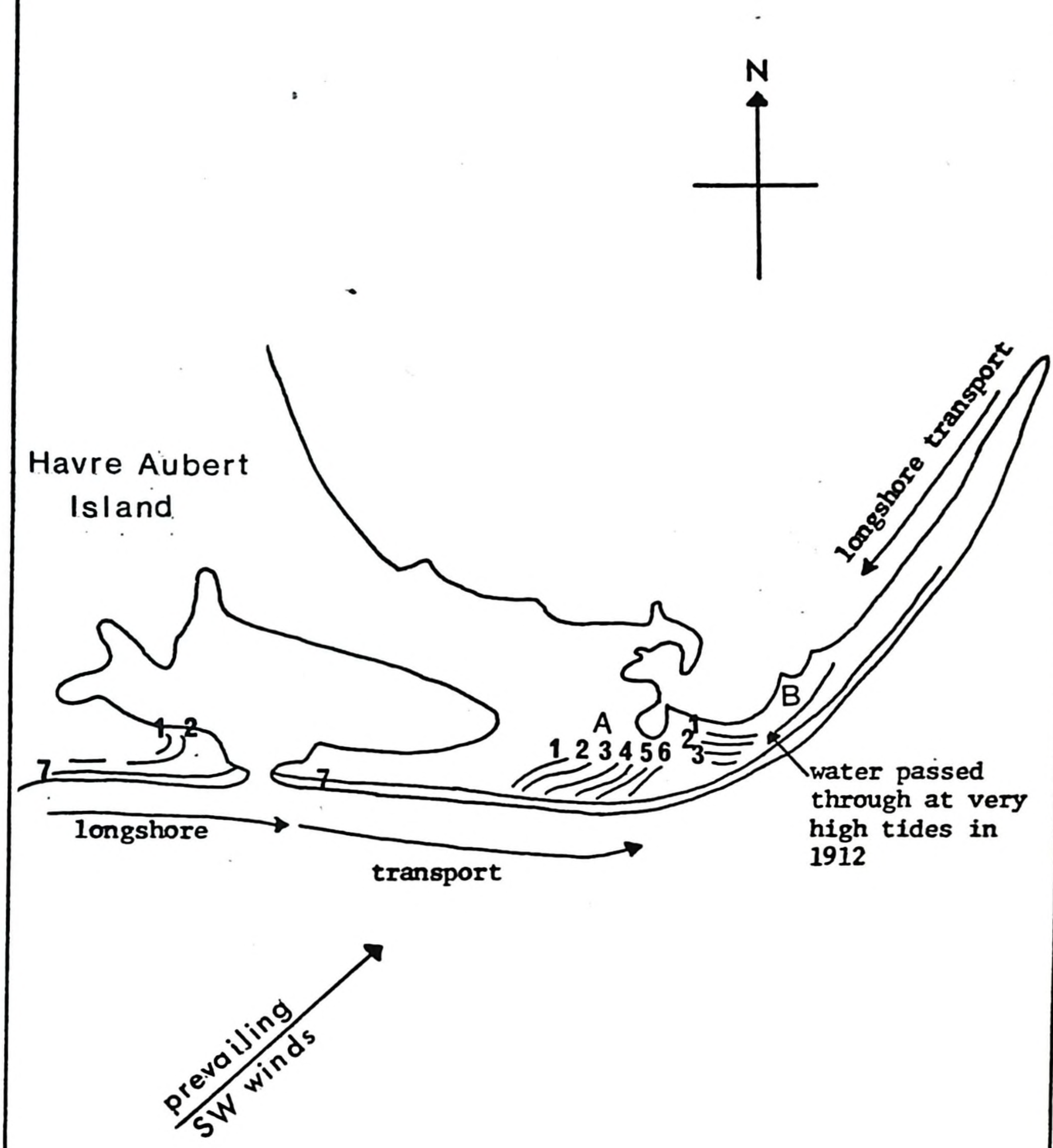


Fig. 3:25 Generalized sketch diagram to indicate proposed sequence of dune ridge development.

sand shoals which extend out into a sediment plume for approximately 2 mi.. The orientation of the growth of the spit suggests that it is influenced substantially by the prevailing winds from the southwest and littoral currents travelling in a northeast direction.

Figure 3:24 presents historic evidence for tidal inlet migration and the changing dimensions of Sandy Hook, with respect to length and width. It is obvious from maps that the inlet to le Bassin has slowly been migrating in a westerly direction and that there has been some infilling by marsh development behind the seaward dune ridge. The length and width dimensions of the spit have varied through time, a fact previously documented by Sanschagrin (1964). He found the recorded distance between the distal end of the spit and Entry Island varied from 17,980 ft. in 1765 to 16,620 in 1959.

A generalized diagram of Unit 5 (Fig. 3:25) indicates the possible sequence of development of the dune ridges and the direction of longshore transport. The oldest dune ridges (A on Fig. 3:25) were mapped as early as 1765 by Samuel Holland. A map produced in 1912 indicated that at very high tides water passed through the dune ridges, (B on Fig. 3:25), thus providing evidence for their present day truncated appearance. The migration westward of the tidal inlet provides evidence for the direction of longshore transport.

3:3 SUMMARY

The preceding discussion of the five units clearly indicates that the east and west coasts of les Îles de la Madeleine are significantly different in their form. The wind and wave conditions play a

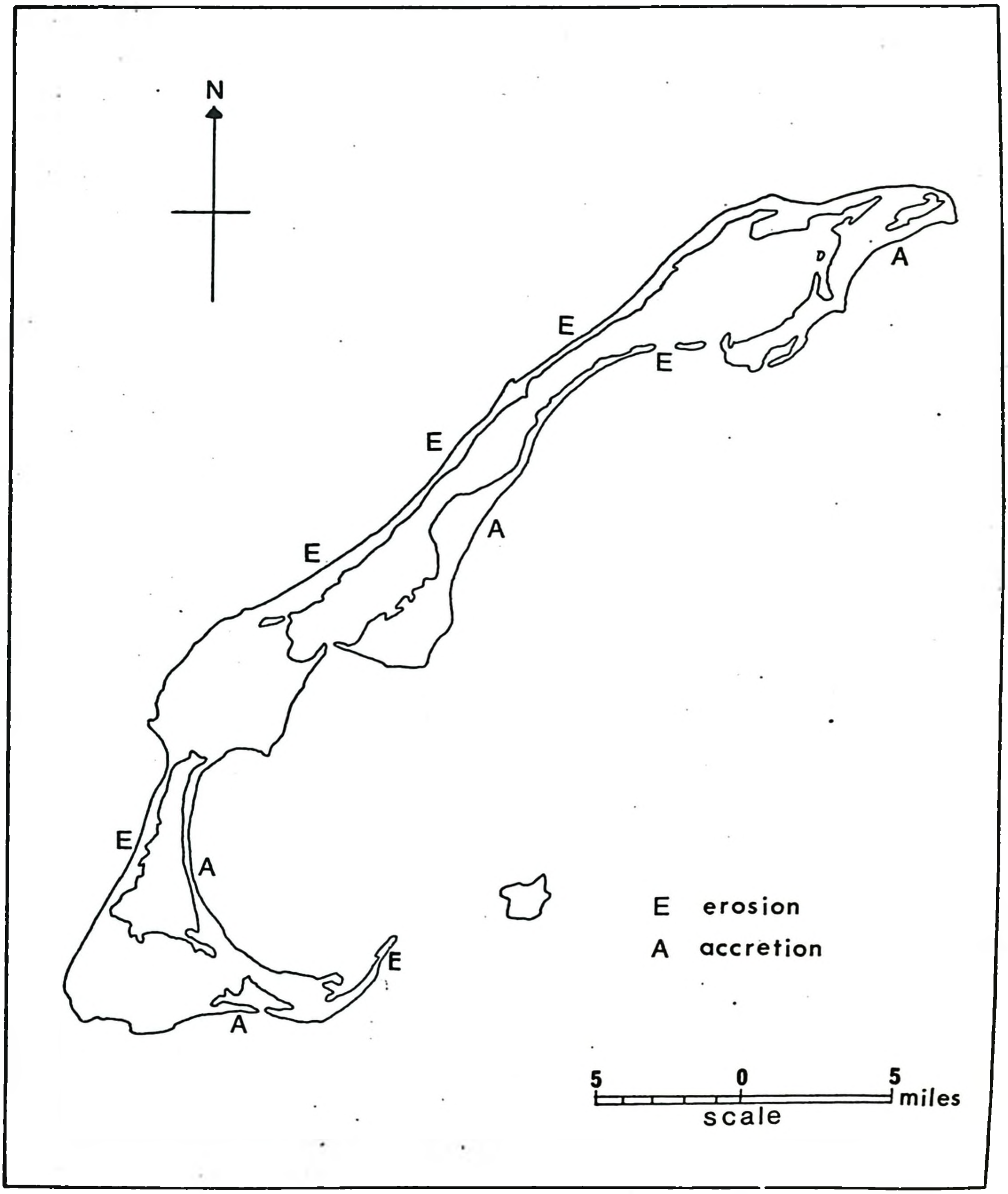


Fig. 3:26 Summary Map of Erosive and Accretive Activity

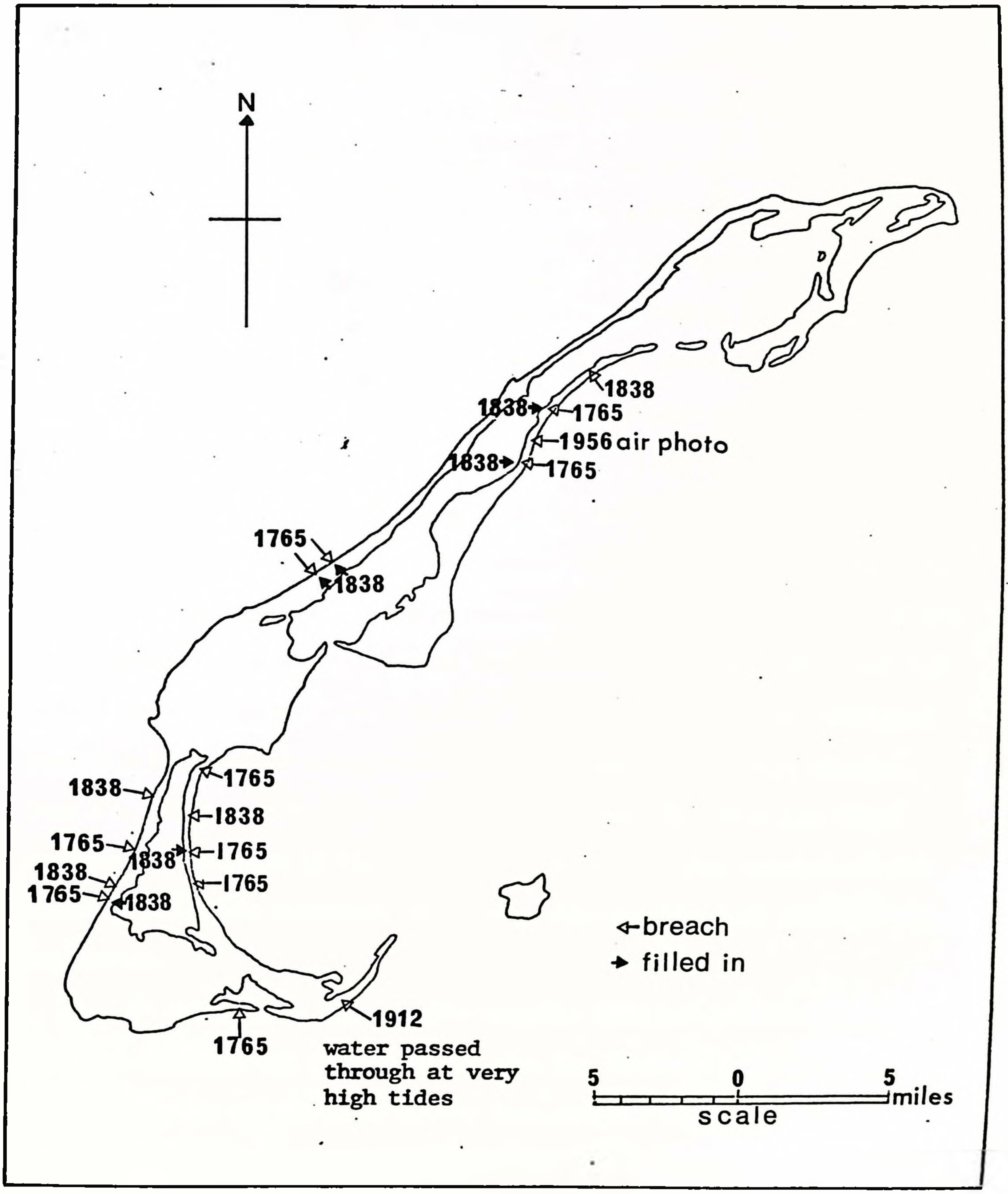


Fig. 3:27 Summary Map of Inlet Breaching and Infilling

significant role in changing the topography of these units. Figure 3:26 provides a map summary of the general areas of erosive and accretive activity on the island as determined from the air photos. It is apparent from this study that the west coast is a retrograding system that displays the characteristics of an active dune ridge system. The presence of a scarp faced dune ridge running the length of the coast and the preponderance of blowouts and ridge breaching attest to the erosive activity. In marked contrast, the east coast is presently an area of accretive activity. Evidence for this lies in the presence of two well developed old dune ridge zones which have been substantially stabilized by vegetation. The sediment plumes extending from the distal ends of the north and south spits provide evidence for the direction oflongshore transport and consequently their direction of growth.

In viewing the historical map evidence it is apparent that the island has endured an active history of inlet breaching and infilling. Figure 3:27 provides a map summary of the location of these changes. Over the 190 year period a number of inlets have breached the ridge systems as evidenced by their truncated nature. Other remains of this activity are relic washovers which have subsequently been stabilized by vegetation.

In conclusion, the air photographic data has provided substantial evidence for the statement that the windward beaches of this tombolo complex are unstable active dune systems which are in marked contrast to the lower, prograding barriers of the leeward, east-facing shore.

CHAPTER 4

THE USE OF REMOTE SENSING TECHNIQUES IN THE STUDY OF COASTAL DEPOSITIONAL FEATURES

(A) INTRODUCTION AND PROCEDURES

4:1 INTRODUCTION

Remote sensing techniques are gaining increasing importance in the study of coastal geomorphology. The purpose of this study is to evaluate the capabilities of multi-sensor imagery in the coastal environment in terms of its ability to detect specific coastal features. Recent technological improvements in remote sensors, sensor platforms and recording media have greatly enhanced the capability of collecting such information. But this increase in quality is only potential information until it is interpreted (Tuyahov and Holz, 1973). The usefulness of the data aquired from such imagery is determined by the ability of the coastal geomorphologist to take this information and interpret its significance in an analysis of the coastal situation.

This study presents the results of the interpretation of five types of remotely sensed data: (1) colour infrared photographs (the prime sensor), (2) conventional colour photographs, (3) black and white infrared photographs, (4) conventional panchromatic with red and green bands and (5) thermal infrared imagery. The signatures produced by selected features on the imagery were defined and evaluated. The evaluations were based upon the ease of interpretation of the features and resolution characteristics of each film. A frame by frame comparison of each of the film types was made to determine the usefulness of each film/filter combination for detecting or enhancing particular features when viewed through a Bausch and Lomb Zoom 240 R.

4:2 THE STUDY AREA

The area selected for this detailed remote sensing study was the southern portion of les Îles de la Madeleine (Fig. 4:1). The reasons for selecting this area were twofold. First, the author conducted a preliminary mapping study of the southern section of the island using standard panchromatic photographs in order to produce a rough base map for field checking purposes. In compiling this map the author gained some familiarity with the study area and the associated coastal features before entering the field. Secondly, the preliminary investigations revealed that a broad range of coastal features were present and would provide an excellent test of the sensitivity of the films in this coastal environment. Consequently, the preliminary familiarization programme and variety of features, within such a relatively small area, made this test site ideal.

4:3 THE PHOTOGRAPHY

The photographic coverage used for this study was flown by the Canada Centre for Remote Sensing over les Îles de la Madeleine on June 6, 1973. The flying height for the photography and the thermal line scan was 4,000 ft. and the nominal scales of photography provided were

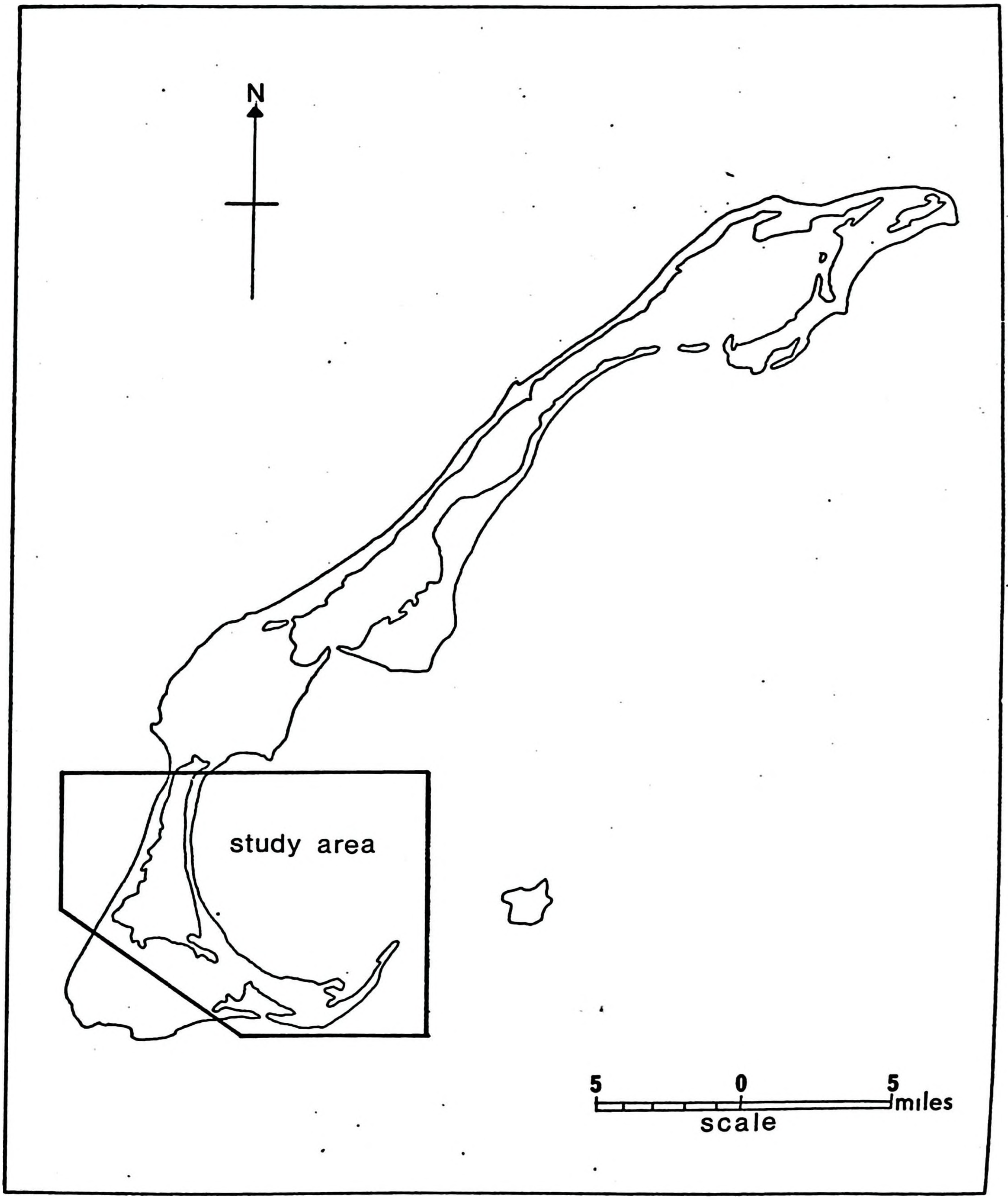


Fig. 4:1 Study Area in the Southern Portion of les Îles de la Madeleine

1:14,400 on 9" format film and 1:16,000 on 70 mm. format film in the various film/filter combinations detailed in Table 4:1. The thermal

TABLE 4:1

DETAILS OF PHOTOGRAPHY FLOWN FOR TASK 73-152

June 6, 1973. Altitude 4,000 feet.

(i)

Format	Roll No.	Film	Filter	Band
70 mm. (fl. 3")	277	2402	25	red
	279	2405	12 & 58	green
	280	2424	89B	infrared
	281	2445	HF3	colour
9" (fl. 8.5cm)	686	2443	ZEISS D 540 NM	colour infrared

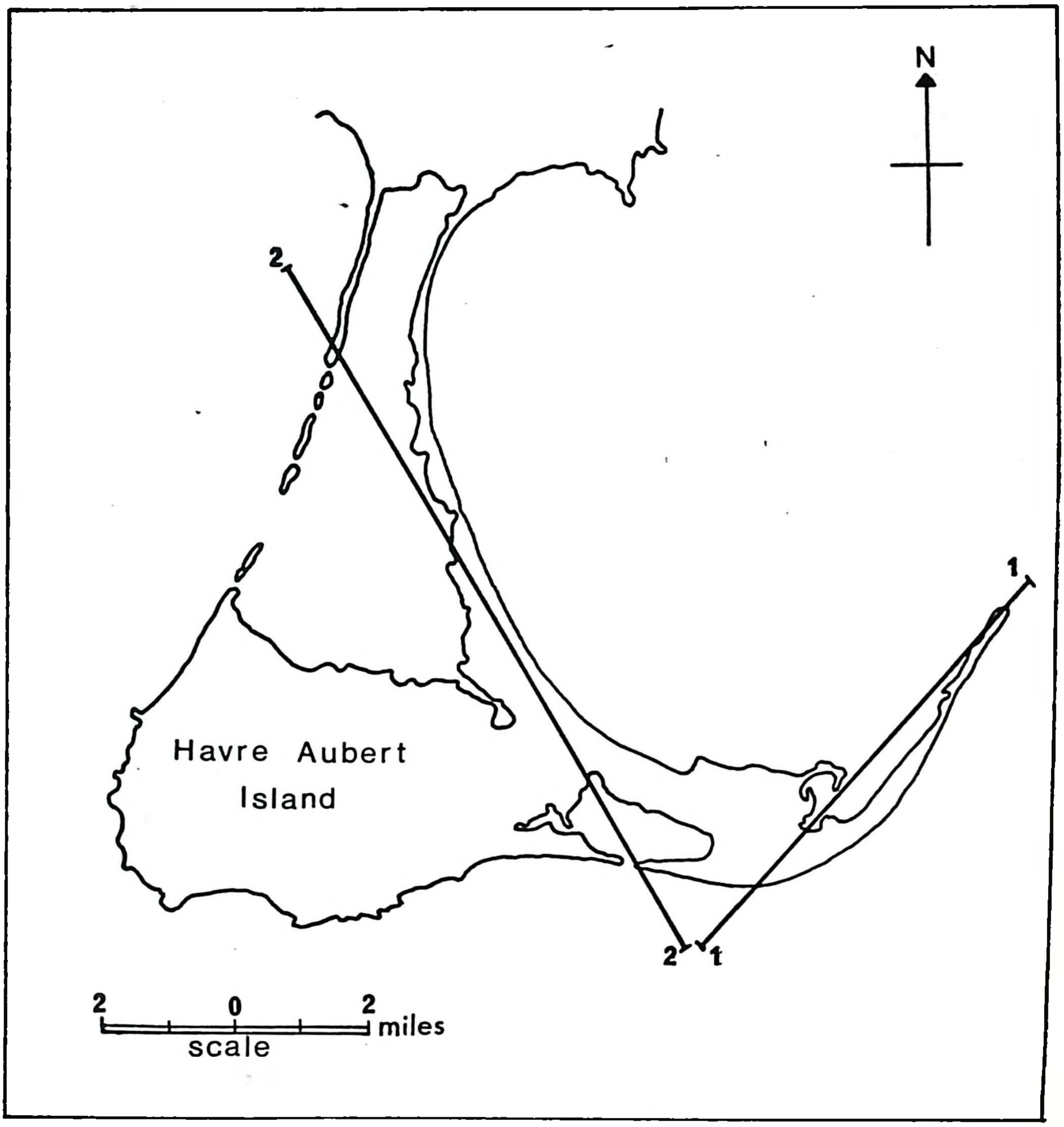
(ii)

Format	Sensor	Filter
Thermal Line Scan	Daedalus 3-5 PRT5 #387 8-14	Daylight

line scan was flown between the hours of 1851 and 1914 G. M. T.. The intial leg of the mission was flown from Havre Aubert along Sandy Hook (Fig. 4:2) and the second leg flew over le Bassin to Dune de l'Ouest.

Fig. 4:2

Flight Lines for Remote Sensing Study



The flight was successful in supplying photography that was only slightly underexposed and thus useful for this study.

4:4 BASIC ORIENTATION

Due to the unconventional nature of colour infrared photographs and thermal line scan imagery, a slightly different approach and thinking is required for imagery interpretation. Colour infrared film differs from ordinary colour film in that the three image layers are sensitized to green, red and infrared instead of blue, green and red. In the final colour transparency the blue lightwaves are attenuated by the use of a yellow filter. The original green images as blue. The red images as green and the infrared appears as bright red or magenta. The original colours are shifted to longer wavelengths and present a new rendition of the subject. Table 4:2 presents the film sensitivities of colour and colour infrared film. One advantage of the colour infrared film is that it produces a stronger colour contrast on the false colour film than the normal colour film (Remote Sensing National Academy of Science, 1970).

Thermal infrared imagery is similar to conventional photographs only as a pictorial representation of an imaged thermal scene. The imaged gray scale densities on black and white film represent relative levels of emitted infrared radiation rather than visible light. To understand and exploit the information presented on infrared imagery, a comprehensive knowledge must be acquired of the thermal behavior of the imaged objects and its responses to temporal and environmental changes.

The thermal infrared imagery was collected by a Daedalus infrared line scanner. This scanner is a single channel optical mechanical

TABLE 4:2

PRINCIPLES OF OPERATION OF NORMAL COLOUR FILM

AND AREOCHROME INFRARED: TYPE 2443

Spectral Region	U.V.	Blue	Green	Red	Infrared
Normal colour film sensitivities		blue	green	red	
Colour of dye layers		yellow	magenta	cyan	
Resulting colour in photo		blue	green	red	
AREOCHROME IR sensitive		blue	green	red	infrared
Sensitivities with yellow filter			green	red	infrared
Colour of dye layers			yellow	magenta	cyan
Resulting colour in photo			blue	green	red

(adapted from Fritz, 1967;pp.1129.)

line scan radiometer that records energy reflected or emitted from the earths surface onto a magnetic tape. A field printer was then used to produce a negative film from the magnetic tape. To perform these functions, the line scanner typically consists of four basic components: (1) scanner optics, (2) detector, (3) recording unit and (4) power supply. The scanner optics collect the emitted radiation and focus it upon the detector. The detector transfers the infrared energy into an electrical signal which is amplified and transmitted to the recording unit. The recording unit converts the electrical signal into visible light by means of a cathoderay tube. The light fluctuates in proportion to the original infrared signal and is then used to record an image of the original infrared scene on black and white film.

Because the thermal infrared image is a graphical display of shades of gray, it must be determined whether the interpreted imagery is negative or positive. The infrared imagery used during this study is a negative transparency, thus the warmer areas or those emitting relatively more infrared energy image darker in tone. The cooler areas which are emitting less energy, image lighter.

The black and white infrared film produces slightly different images than panchromatic film. The black and white tone rendition of the ground scene is altered from that obtained with panchromatic film and certain objects are made more distinct owing to the enhancement of contrast between these objects and the background (Specht, 1970). This greater contrast is due to the higher and lower reflectances of certain objects in the infrared range. The infrared film is sensitive to longer wavelengths of light, its sensitivity extending beyond the red band into the reflective portion of the infrared. Because the blue end of the spectrum is cut out the infrared film has haze cutting capabilities.

4:5 SELECTION OF RELEVANT COASTAL FEATURES

The study area provides a wide variety of coastal features to test the sensitivity of each film type. The selection of the features was intended to encompass the relevant land, water and lagoon features of this environment that enable the coastal geomorphologist to interpret the geomorphology of the area. The list of features selected are included in Chapter 5 and a description of some of these features is included in the glossary of terms in the Appendix. It is the purpose of the following chapter to present the results of the interpretation of these various films.

CHAPTER 5

THE USE OF REMOTE SENSING TECHNIQUES IN THE STUDY OF COASTAL DEPOSITIONAL FEATURES (B) RESULTS

5:1 INTRODUCTION

In this chapter the results of the feature delineation evaluation from the various film types is presented. Table 5:1 outlines the evaluation of the films on a four point scale of (E) excellent, (G) good, (P) poor and (U) unsatisfactory identification and interpretation of the features. The 70 mm panchromatic film, black and white infrared film, colour film and thermal line scan were all negative transparencies so that features are imaged in reverse tones than normally expected. The 9x9 colour infrared film was a positive transparency. For the purpose of the following discussion of this evaluation, some associated features have been grouped together under one heading.

5:2 IMAGERY INTERPRETATION RESULTS

Dune Ridges, Foredune, Dune Cliffs and Blowouts

On the colour infrared film the seaward dune ridge is easily separated from the active beach zone on the basis of the marram grass vegetation which gives the ridges a slight blue-grey colour and rough texture on the photograph. The older dune ridges are a darker blue-grey colour and smoother in texture and indicate some patches of lichen

TABLE 5:1

DELINEATION OF FEATURES ON PHOTOGRAPHY

Coastal Features	Colour Infrared	Colour	Panchro-matic (red)	Panchro-matic (green)	B & W Infrared	Thermal Imagery
Land Features						
Dune Ridges	E	E	G	G	G	E
Foredune	E	E	G	G	P	G
Dune Cliffs	E	E	G	G	G	G
Blowouts	E	G	G	G	G	U
Active Beach	E	E	P	E	G	E
Blown Sand	E	E	E	E	G	G
Cusps	E	E	E	E	G	E
Spits	E	E	E	E	E	E
Washover	E	E	G	G	G	G
Washover Delta	E	E	G	G	G	G
Vegetation	E	E	P	P	P	P
Water Features						
Tidal Inlet	E	E	E	E	E	E
Tidal Delta	E	E	E	G	U	E
Tidal Flat	E	E	E	G	U	P
Sand Flat	E	E	G	G	U	P

TABLE 5:1 (continued)

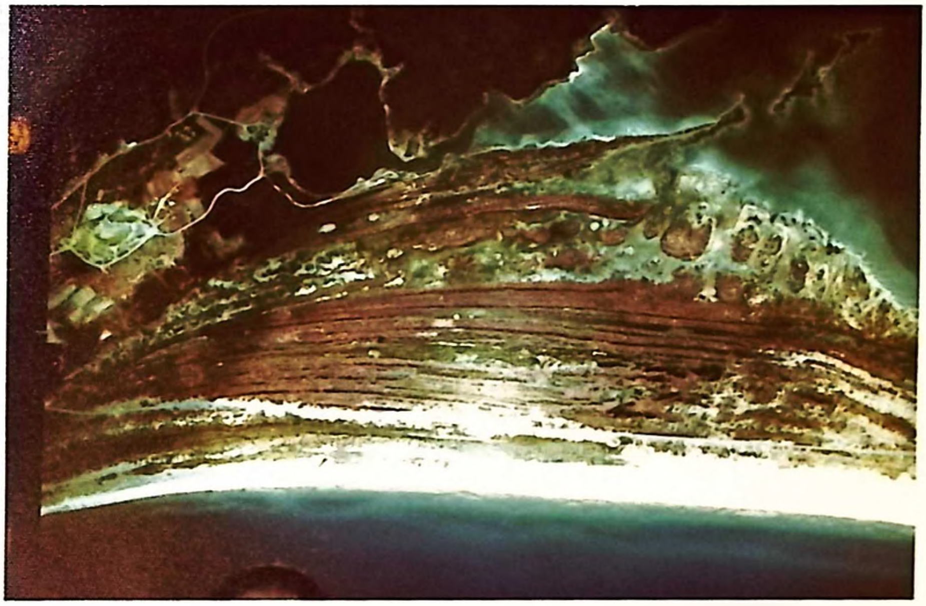
Coastal Features	Colour Infrared	Colour	Panchromatic (red)	Panchromatic (green)	B & W Infrared	Thermal Imagery
Offshore bars and associated up cells	E	E	E	E	U	U
Standing Water	E	E	G	G	E	G
Mega Ripples	E	E	G	G	U	U
Sand Waves	E	E	G	G	U	U
Ridge and Runnel	E	E	E	E	U	P
Shoreline/ Water	E	G	G	G	E	P
<u>Lagoon Features</u>						
Lagoon Marsh	E	E	G	P	P	G
Sand Flat	E	E	G	G	U	P
Intertidal Marsh	E	E	P	P	P	P

Quality of delineation: Excellent (E)
Good (G)
Poor (P)
Unsatisfactory (U)

vegetation (Fig. 5:1). The infrared reflectance of the evergreen trees, results in a distinctive red hue on the film and helps delineate the form of the older ridges. This form is not easily detected on other films. The foredune is contrasted from the seaward dune by lack of vegetation, difference in elevation and consequently different infra-red reflectance. The detection of the foredune of the beach is significant as this feature indicates whether the dune ridge is eroding or accreting. The uneven texture of the foredune is distinct from the active beach. The difference in moisture content also contributes to the ease of identification. The moisture content is important to the identification of that portion of the beach which is subject to continual inundation by wave surge. The sharp edge of the dune cliff appears distinct because of the slight shadow that is cast and also because of the abrupt limit in vegetation growth. The unvegetated blowouts are easily detected from their characteristic U-shape and appear as a white hole in the vegetated dune ridge. In some cases the vegetation has begun to stabilize the blowout and small grey patches appear at the bottom of such blowouts. Through an examination of the preferred alignment of these blowouts it is possible to determine the prevailing wind direction.

The red band of the panchromatic film provides a better picture of the old dune ridges than the green band. This is due to the poor colour saturation of the vegetation image and less contrast of the water filled trough on the green band. This makes the ridge topography less distinct. On the red band the marram covered dunes are dark in colour with a smooth texture in contrast to the more heavily vegetated

Fig. 5:1
Colour Infrared Photograph of
Old Dune Ridges on
Dune de l'Est



dunes which appear mottled in tone. The characteristic irregular shape of the foredune and lack of vegetation makes this feature easily identified on the red band. On the green band the dune cliff appears as a knife sharp edge against the active beach because of tonal change resulting from moisture variation.

The old dune ridges are clearly emphasized on the black and white infrared film by the vegetation cover and also because the water in the troughs is clearly detected. The seaward dune ridge is less distinct because the greater tonal contrast on the black and white infrared film produces either very light or very dark images. Due to the angle of the sun at the time the photography was taken, a shadow has been produced in the foredune area and consequently there has been no infrared reflectance. Blowouts appear very dark against the marram covered dunes because of the difference in infrared reflectance of bare sand and a vegetated surface.

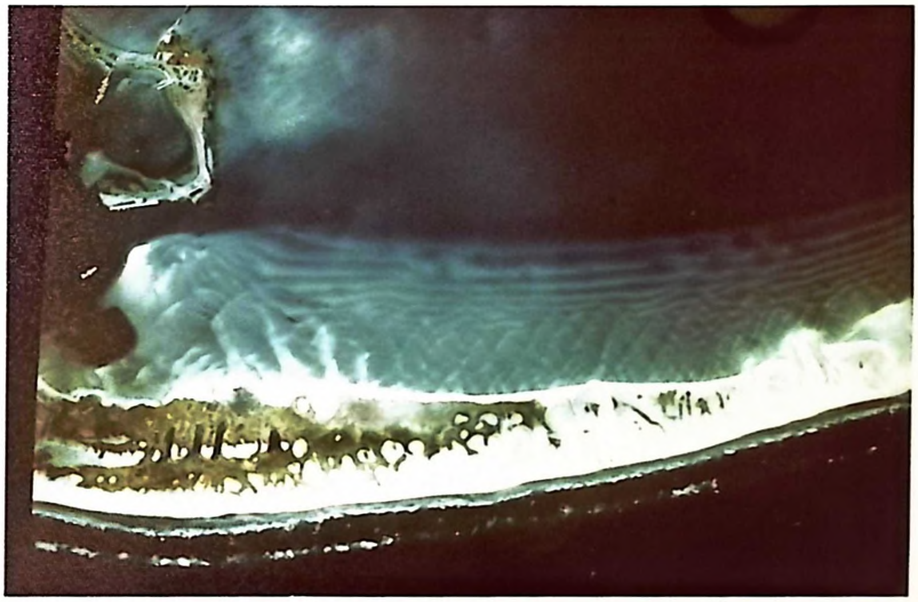
The dune ridge along Sandy Hook appears dark on the thermal imagery indicating that it is warmer and has higher emissivity than the surrounding features. This could be due to the fact that the south facing slope receives more intense radiation resulting in higher temperatures. The difference in moisture content between the active beach and the dune ridge is apparent, as the moisture laden active beach images cooler i.e. lighter in tone. The marsh areas inbetween the old dune ridges of Dune de l'Est also are rendered as cooler and consequently help to delineate the ridge form. The dune cliff appears as a thin dark line along the active beach. This is probably a response to the lack of vegetation. The foredune is difficult to distinguish from the dune cliff because there is not much difference in temperature or materials. The identification of the dune cliff allows delineation of the areas of erosion. Blowouts were undetectable on the thermal imagery in response to a poor temperature contrast between the dune ridge surface and blowout.

Active Beach, Blown Sand, Spits and Cusps

The active beach can be divided into two zones- the foreshore zone which appears light blue or white on the colour infrared film due to the dry, blown sand. Within this zone the berm line or extent of high tide is visible (A on Fig. 5:2). The second zone, the backshore appears darker blue because of increased moisture content related to the presence of the water table. The cuspate nature of the shoreline is clearly evident because of excellent shoreline/water delineation. Cuspate features formed by the high tide swash appear on the foreshore. The blown sand appears as light coloured barchans on the moist active beach. The orientation of these features also reveals the direction of the prevailing winds. Spit development along the lagoon beach of Sandy Hook is clearly evident. These spits are micro-features developing above the low water line and are a result of the longshore transport in a southwest direction (B on Fig. 5:2).

The colour photography also displays potential for use in moisture detection and delineation. The beach areas of different moisture content are delineated by a progressively darker shade of purple. However, as one might expect the contrast and delineation was not as well defined as on the colour infrared film.

Fig. 5:2
Colour Infrared Photograph Indicating Extent of Berm Line on Sandy Hook also Visible are the Developing Spits on the Lagoon Beach



Both bands of the panchromatic film were superior to the black and white infrared in the imaging of the active beach. This is because of the greater range of grey tones that distinguish the differences in moisture content that occur in different zones of the beach. The blown sand is clearly evident on all three types of photography due to the moisture differences between the two surfaces. There is evidence of sediment in the water surrounding the spit on the panchromatic film. Due to lack of water penetration the black and white infrared film does not display this information, although their form above the water is clearly evident.

Although lacking the resolution of the colour infrared photographs the thermal infrared line scan imagery also makes possible the detection and delineation of areas of contrasting moisture content. The portion of the active beach which is continually inundated by the surge images warm i.e. dark. The backshore of the beach images a light tone indicating the cooler nature of this sand. The blown sand appears as a light (cool) wavy line on the warmer backshore. The cool appearance is caused by dryness, high reflectivity and lack of compactness of the sand. The spits developing on the lagoon beach of Sandy Hook appear as dark (warm) linear lines. The warm image is produced due to differences in emissivity. The cuspate nature of the shoreline is apparent. The micro-cusp features on the foredune of Dune de l'Est are distinct because of the differences in moisture content and associated differences in emission.

Washover, Washover Delta or Fan and Vegetation

The relic washovers (Fig. 5:3) on Dune de l'Est are easily identified on the colour infrared photography on the basis of the characteristic truncated dune edges. In the area of the washover fan vegetation and marsh growth has stabilized the area and serves to delimit the extent of old washover activity. The new washover and active sluiceways on Sandy Hook (Fig. 5:2) are typified by light blue blown sand covering the moist beach. The accumulation of blown sand indicates that this area is only inundated during storm activity.

The colour film also permitted excellent delimitation of the areas of washover activity. The characteristic delta on the lagoon side of the washover is clearly evident because of the excellent water penetration of colour film. The natural rendition of the vegetation stabilizing the relic washover would permit a detailed analysis.

The panchromatic bands permitted reasonable delimitation of the washovers based on their characteristic shape. But the washover delta is not as clearly defined as on the colour infrared film because of poor water depth penetration. On the black and white infrared, the limits of the unsubmerged washover delta are apparent due to the excellent shoreline/water delineation.

On the thermal infrared imagery the washover images light (cool) compared to the active beach. This washover is not subject to the continual inundation of wave surge, which would cause a warm image, but is only inundated during storm activity. The relic washovers of Dune de l'Est appear darker (warmer) and more mottled in tone because of the presence of stabilizing vegetation. The truncated ridges appear as very dark lines due to their warmer nature. The washover delta which

Fig. 5:3
Colour Infrared Photograph Indicating
the Relic Washovers of
Ile aux Oeufs

extends into Havre aux Basque has a slightly warmer image than the surrounding lagoon water. This would be due to the shallow depth of water covering the delta which consequently would cause a greater difference in temperature and emissivity.

The colour and colour infrared photography provides the most variety of information concerning vegetation patterns. The variety and differences in sequences of vegetation is accurately interpreted from the colour infrared film using the differences in the infrared reflectance characteristics (Fig. 5:1). At this time of year the plants are just beginning to recuperate from the winter so that there are patches of new growth apparent. The blue-grey marram covered dunes are distinct from the lower marsh areas which image from red to purple on the colour infrared. In the area of the old dune ridges of Dune de l' Est, fresh water marsh troughs are easily separated from the spruce covered dune ridges. A more thorough knowledge of the infrared reflectance characteristics of the various plants would permit a more detailed analysis of vegetation sequences.

The panchromatic bands permit the delimitation of broad zones of vegetation. For example it is possible to distinguish heavily treed areas from areas of low scrub growth. Likewise, broad belts of vegetation are resolvable on the black and white infrared film. In the area of the old dune ridges the tree covered dunes are easily differentiated from the swampy troughs on the basis of contrasts in infrared reflectance and moisture content.

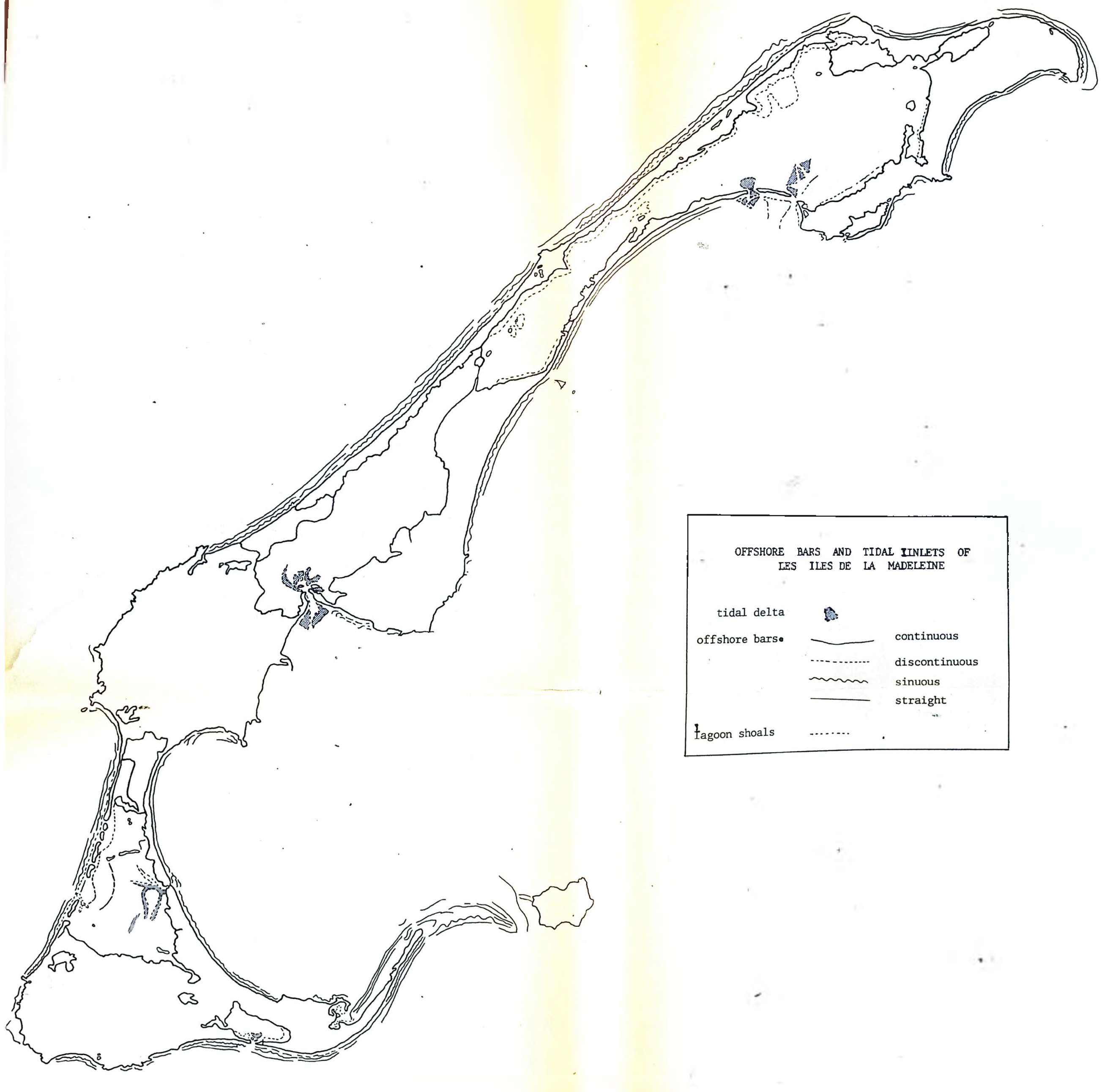
The thermal infrared imagery also provided a means of distinguishing the extent of vegetation. The heavily forested dune image is light (cool) in contrast to the dark (warm) swamp filled troughs.

Tidal Inlets, Tidal Delta, Tidal Flats and Sand Flats

The tidal inlet and tidal delta of le Bassin are distinct on the colour infrared photography (Fig. 5:4). The exposed sand of the tidal delta appears in gradations of blue. The submerged ebb and flood channels are also apparent. The extreme colour contrast between water and sand emphasizes the sand formation. The relic tidal delta in Havre-aux-Basques (Fig. 3:3) is still evident although it is difficult to distinguish between the ebb and flood channels. The exposed sand flats are a muddy brown colour as opposed to the blue lagoon beach. The colour of the sand flats may be attributed to the intertidal plants which grow there. The submerged sand flats are easily detected because of the sediment laden water associated with them.

The excellent water penetrability of colour film provides a reliable means of identifying the tidal inlet and tidal delta. In fact, more detail can be derived from the colour concerning the nature of the ebb and flood channels. It is also possible to determine if the tidal delta is submerged. The position and condition of the relic tidal delta in Havre-aux-Basque is also visible. The colour film permitted excellent delineation of the sand flats in le Bassin and the tidal flats, composed of marshy vegetation.

On the panchromatic photography the position of the tidal inlet to le Bassin is emphasized by the break in the dune system. Due to poor contrast limits on these films, the tidal delta and associated ebb and flood channels are not as clearly imaged as on the colour and colour


OFFSHORE BARS AND TIDAL INLETS OF
LES ILES DE LA MADELEINE
tidal delta
offshore bars
continuous
discontinuous
sinuous
straight
lagoon shoals

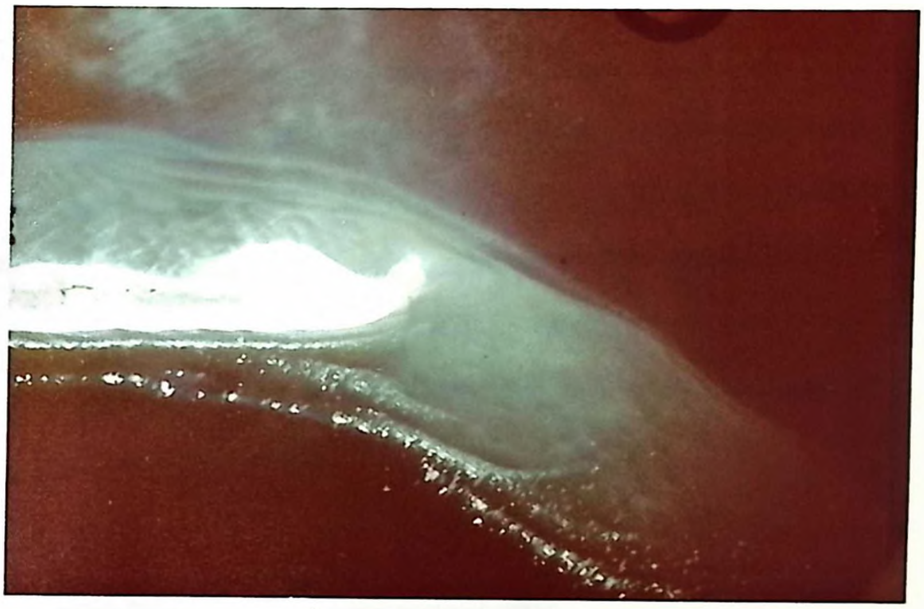
infrared photography. The sand flats in Havre-aux-Basque are visible, but some of the contrast is lost in the area of le Bassin and consequently the sand flats are not as evident. Poor water reflectivity does not permit the resolution of submerged features like sand flats and the tidal delta on the black and white infrared film.

The thermal infrared imagery is also useful in detecting the tidal inlet and tidal delta of le Bassin. The resolution of these features is not as precise as on the colour infrared film. This would be due to the lack of abrupt temperature boundaries, which would permit a more distinct image. The relic pattern in Havre-aux-Basque is evident in the shallower portion of water where there would be temperature differences related to the depth of water. The sand flats along the lagoon side of Sandy Hook image dark (warmer) than the surrounding water. Again this may be related to the difference of temperature related to the depth of water.

Offshore Bars and Associated Rip Cells, Standing Water, Mega Ripples and Sand Waves, Ridge and Runnel, and Shoreline/Water

The breaking waves on the offshore bars permit excellent delineation of this feature on the colour infrared and colour photography. The series of reticulate bars in the lagoon waters of Sandy Hook (Fig. 5:5) are distinct appearing white on the colour infrared photography. The offshore bars closest to the beach are more distinct because of greater bottom reflectivity in shallow water. Rip cell patterns are evident along the coast of Dune de l'Ouest. Due to the excellent shoreline/water contrast of the colour infrared photography the ridge and runnel pattern is revealed at low tide. The colour

Fig. 5:5
Sediment Plume Extending off the end of Sandy Hook. Note Reticulate Bars in Lagoon of Sandy Hook



contrast of this film also permits the detection of mega ripples and sand waves, located in Havre-aux-Basques. The standing water is easily located in the marsh areas and intertidal zone on the basis of low infrared reflectance. The occurance of standing water provides some indication of the water table in this area.

The form and extent of offshore bars is easily identified on both bands of the panchromatic photography although the red band shows this distinction more clearly. Identification of the offshore bars on the black and white infrared photography was totally unsatisfactory, except where the bar became exposed. Some of the ridge and runnel topography was evident on this photography but not enough to permit a reliable interpretation. Identification of the bodies of standing water is significantly better on the black and white infrared due to the low infrared reflectance of water. The outline of these ponds can be seen quite distinctly.

The offshore bars are undetectable on the thermal infrared imagery. This probably results from the increased depth of the water which minimizes the possibility of increased emissivity. Also, there is no record of mega ripples, sand waves or ridge and runnel topography for essentially the same reasons.

Ponds of standing water are difficult to separate from the marsh filled troughs when interpreting the thermal infrared imagery by itself. When the colour infrared photography was used in conjunction with the thermal infrared imagery a clearer delineation was possible. The shoreline/water line is not as distinct as on the colour infrared film because there is not an abrupt change in the temperature or emissivity gradient associated with these features.

Lagoon and Intertidal Marsh

The colour infrared and colour photographs provide the most information about lagoon and intertidal marsh. It is possible to detect those areas which are inundated at high tide consequently support a different type of vegetation. Channels running through the lagoon marsh are evident (Fig. 5:3). The panchromatic photography does not permit an extensive interpretation of these marsh areas because of the limited range of grey tones.

The thermal infrared imagery permits the delineation of broad areas of marsh, but it is difficult to discriminate between intertidal and lagoon marsh. This is primarily due to a gradual and uniform increase in moisture from intertidal marsh to the shallow waters of the lagoon.

4:3 SUMMARY

This study has been an attempt to show the information gathering and extraction capability of colour infrared, colour, panchromatic and black and white infrared photography, and thermal infrared imagery. All five sensors displayed significant and varied capabilities providing valuable information concerning the coastal environment. Colour infrared photographs provided the best means for water (moisture) and vegetation detection and delineation. It also presented the most potential for detailed vegetation analysis e.g. determination of plant communities and vigor. Conventional colour was most effective in water penetration and analysis of submerged features, and presented the most natural rendition of the scene. The thermal infrared imagery provided a means of determining general trends of vegetation cover and water detection. The panchromatic bands and black and white infrared photography provided an adequate rendition of this environment, but did not permit detailed analysis of any of these features. From this analysis it is apparent that the colour infrared film at the scale 1:14,000 supplemented with colour photography if possible provides the most detail about the coastal environment.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The potential uses of information gained from a systematic interpretation of remote sensing imagery are vast and valuable in many disciplines. The use of les Îles de la Madeleine as a study site provided an opportunity to evaluate the effectiveness of the sensors in an environment which is both dynamic and poorly understood. The results of the investigation provided useful data on the physiography of les Îles de la Madeleine.

This study shows that beach investigations can be enhanced through the use of remote multisensor imagery. Each sensor can make valuable contributions to the data collected. Multisensor imagery increases the interpreters work load but gives him valuable assistance in understanding imagery signatures and relating them to ground features. The results derived from a combination of imagery are more valuable than that from a single source operating in a narrow range or at a specific wavelength.

From the recent air photography and historical map evidence it is evident that les Îles de la Madeleine is an area which is in continual flux. Substantial evidence has been presented for an explanation of the development of the island dependent upon the different sets of wind and wave conditions. From the interpretation of the the standard panchromatic air photographs it is apparent that the windward beaches of this tombolo complex are unstable active dune system; while the lower, prograding barriers of the leeward east facing shore are in marked contrast. It has been possible to identify the areas of marked erosion and accretion so that these may be monitored and perhaps examined in the future.

Recommendations

It is apparent from this analysis, that for a complete study of the coastal processes acting in the beach environment increased ground truthing must be conducted in conjunction with the acquisition and study of remotely sensed data. Specific data pertaining to the wind and wave energy environments would then permit quantitative statements to be made about these processes. The colour infrared photography at the 1:14,000 scale has provided the best method for evaluation and delimitation of coastal features of varying scales. If this photography is used in conjunction with ground information an improved approach to the analysis of the coastal environment can be anticipated.

APPENDIX

List of Historical Maps

Used in This Thesis

1. Holland, Samuel. 1765. A Plan of the Magdalen, Brion, Bird, Entry and Dead Mans Islands in the Gulph of St. Lawrence.
2. British Admiralty Chart 1134. Published 1838.
3. Canadian Hydrographic Chart 4451. Published 1956.

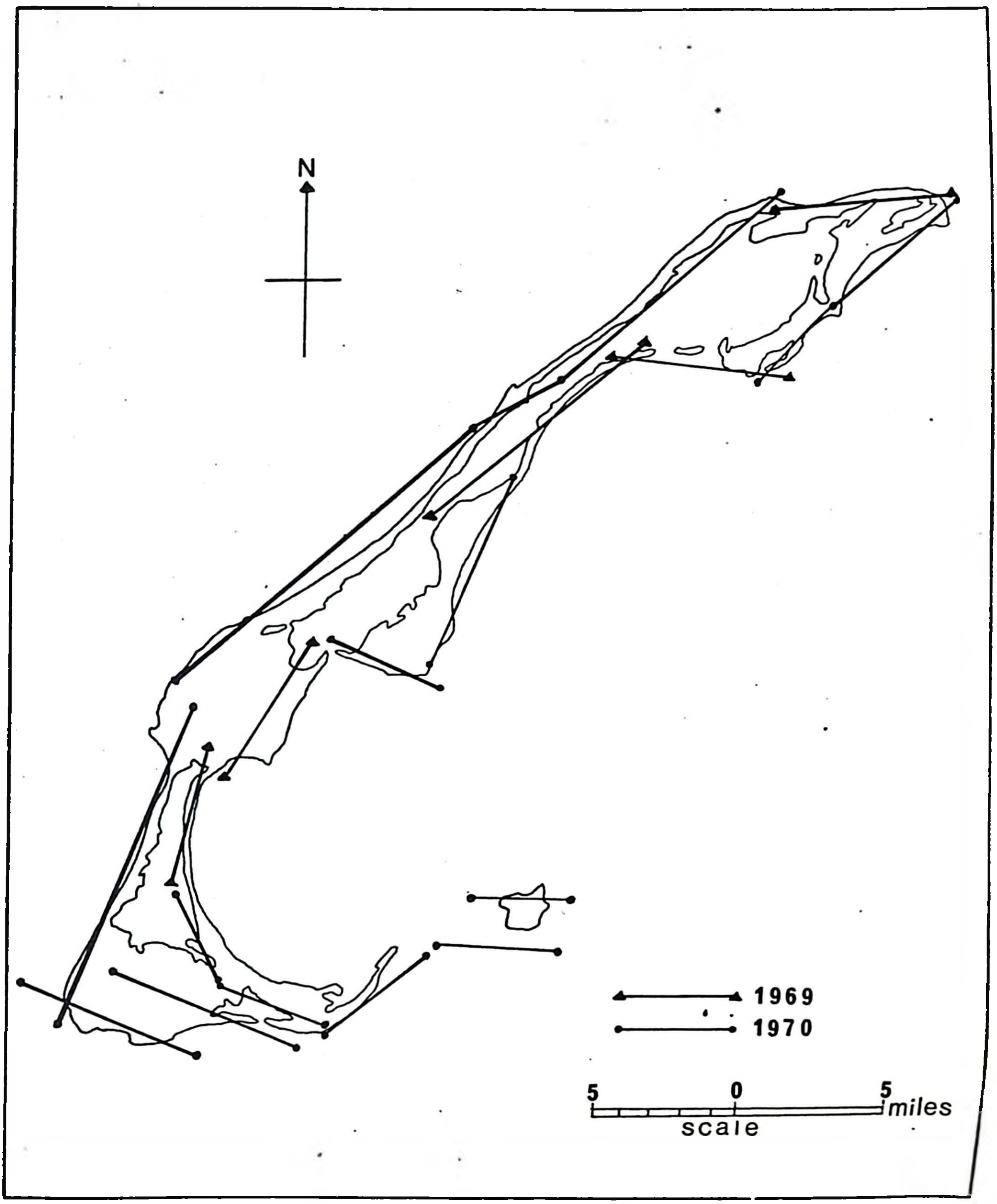


Diagram of Flight Lines for 1969 and 1970
Standard Panchromatic Photography

GLOSSARY

Blowout Dune:-a break in plant cover of coastal dunes allows landward transfer of the dune sand developing a depressed passage (blowout) across the dune ridge and generally building a higher U-shaped dune inland from the coastal dune ridge.

Dune Ridge:-a ridge of sand blown a short distance inland from the beach. Where the shore is being extended into the sea (prograded) there may be a series of sub parallel dune ridges.

Lagoon:-a shallow water bay extending parallel to the coast behind a barrier. The water may vary from fresh or brackish to the normal salinity of sea water, and even to dense brine. Many lagoons have been filled with delta, tidal delta washover or marsh sediments.

Mega Ripples:-wavelength between 2 and 20 feet.

Offshore Bar:-a slightly submerged sand ridge generally parallel to the shore a short distance from the beach. At some places there are series of parallel longshore bars at increasing distances from the beach.

Rip Current:-a current in which a narrow band of water moves away from shore, returning excess water carried shoreward by the ordinary wave motion. It may be recognized as a breach in a line of breaking waves.

Sand Waves:-wavelength greater than 20 feet.

Tidal Delta:-when flood tides enter a tidal inlet across a barrier they deposit part of their load in the lagoon just inside of the inlet, forming a delta supplied with sediment supplied from the ocean rather than from a river.

Tidal Flat:-a marshy or muddy land covered and uncovered by rise and fall of tides. Tidal flats are largest where land slopes are low and tidal range is high.

Tidal Inlet:-a breach in a coastal barrier generally opened by a major storm and maintained by a tidal flow.

Washover:-the transfer of beach sand across to the lagoon side of a barrier through sluiceways during a storm.

<u>Washover Delta or Fan</u>:-a triangular deposit on the lagoon side of a barrier transported from the beach through a gap in a barrier during a hurricane or other violent storms.

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