Morphological Changes in Chezzetcook Inlet: An Historical Study Using Air Photography Composites

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Abstract

This thesis provides an analysis of the sedimentological and morphological changes observed in Chezzetcook Inlet from 1766 to 1998 using air photograph composites and maps from 1766 and 1854.This study explores the environmental factors responsible for change, while providing semi-quantitative data on the scale of morphology and sedimentation change occurring in Chezzetcook Inlet.Chezzetcook Inlet is an estuary located in Eastern Shore, Nova Scotia, Canada at 44°34'N longitude and 63°50'W latitude and is approximately seven kilometers in length and four kilometers in width. Two major sedimentological and morphological changes appear to have taken place in Chezzetcook Inlet over the past 232 years: a dramatic episode between 1766 and 1854, and a well documented period between 1945 and 1997. Changes between 1766 and 1854 are associated with the growth of sand and gravel spits near the inlet entrance. Changes between 1945 and 1997 are associated with the extensions of spits and marsh colonization. The drastic growth of Red Island, lagoon closure and sediment infilling at Cape Entry, beach migration and lagoon formation at Story Head, and the extension of spits and marsh colonization at the Three Islands highlight the changes in this period. Construction in the area, storm activity and rising sea level probably account for the increased sedimentation and/or erosion that is causing morphological changes in Chezzetcook Inlet.

Key Words: morphology, sedimentation, Chezzetcook Inlet, air photograph composites

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Chapter 1: Introduction

1.1 Objective and Thesis Statement

The objective of this study is to report on the morphological changes that have occurred in Chezzetcook Inlet, Nova Scotia over the last ~230 years (1766-1998). Questions to be explored include: How has the morphology of Chezzetcook Inlet changed during this period? What factors contributed to these changes? How have these changes affected the sedimentation/erosion cycle? How much marsh increase/decrease has there been?

Chezzetcook Inlet is under environmental pressure from many sources (building of roads, forestry practices, relative sea-level rise and storm activity). Recommendations suggested from this project may help to ease the negative environmental changes occurring in the Inlet.

This study is a continuation and an update of the previous work in Chezzetcook Inlet done by Scott (1980). The present experiment is significant because of the updated and/or new air photographs obtained from the Province of Nova Scotia (Land Information Center) by the author, and the resulting new data and observations of the area obtained from these new air photographs. Future research or experiments on this topic can now use the new data and new digital maps of the area, created by the author and D.B Scott, to obtain detailed information about the study area.

Air Photographs

Year	No. of Photos	Scale	BW/Colour	Level of Tide
1945 (summer)	5	~1:20000	BW	Mid to High
1964 (summer)	6	~1:15000	BW	Mid to Low
1974 (summer)	22	1:10000	Colour	Mid to Low
1982 (summer)	9	1:10000	Colour	Low
1992 (summer)	12	1:10000	Colour	Low
1997 (summer)	2	1:50000	BW	Mid to Low

Charts

Year	Author	Level of Tide	BW/Colour
1766	Capt. James Cook	N/A	BW
1854	British Admiralty	Low	BW

Table 1.1 Breakdown of air photographs and charts on selected categories.

1.2 Scope

The scope of this experiment is limited to six sets of air photographs (1945\1962\1974\1982\1992\1997) and two maps (1766 and 1854) of the Chezzetcook Inlet area (Table 1.1). The reliability of extrapolating results from air photographs and maps is unknown because many of the air photographs are of differing scales. The maps are old and fragile and only photographs of the maps could be used for analysis, resulting in less accuracy than data taken directly from the original maps. These distinctions must be accounted for when interpreting results.

1.3 Chezzetcook Inlet

Chezzetcook Inlet is located in Eastern Shore, Nova Scotia, Canada at 44°34'N longitude and 63°50'W latitude (Figure1.1). The inlet itself is approximately seven kilometers in length and four kilometers in width (Figure 1.2) opening into the Atlantic Ocean. Scott (1980) has described the physiography of the inlet. This description can be used because the basic physiography has stayed the same since 1974: all the islands and channels are still present. The mouth of the inlet is characterized by large sand and gravel spits, having westerly and northerly extensions at Cape Entry and extending both north and east from Story Head. Red Island is primarily a sandbar. The largest features inside

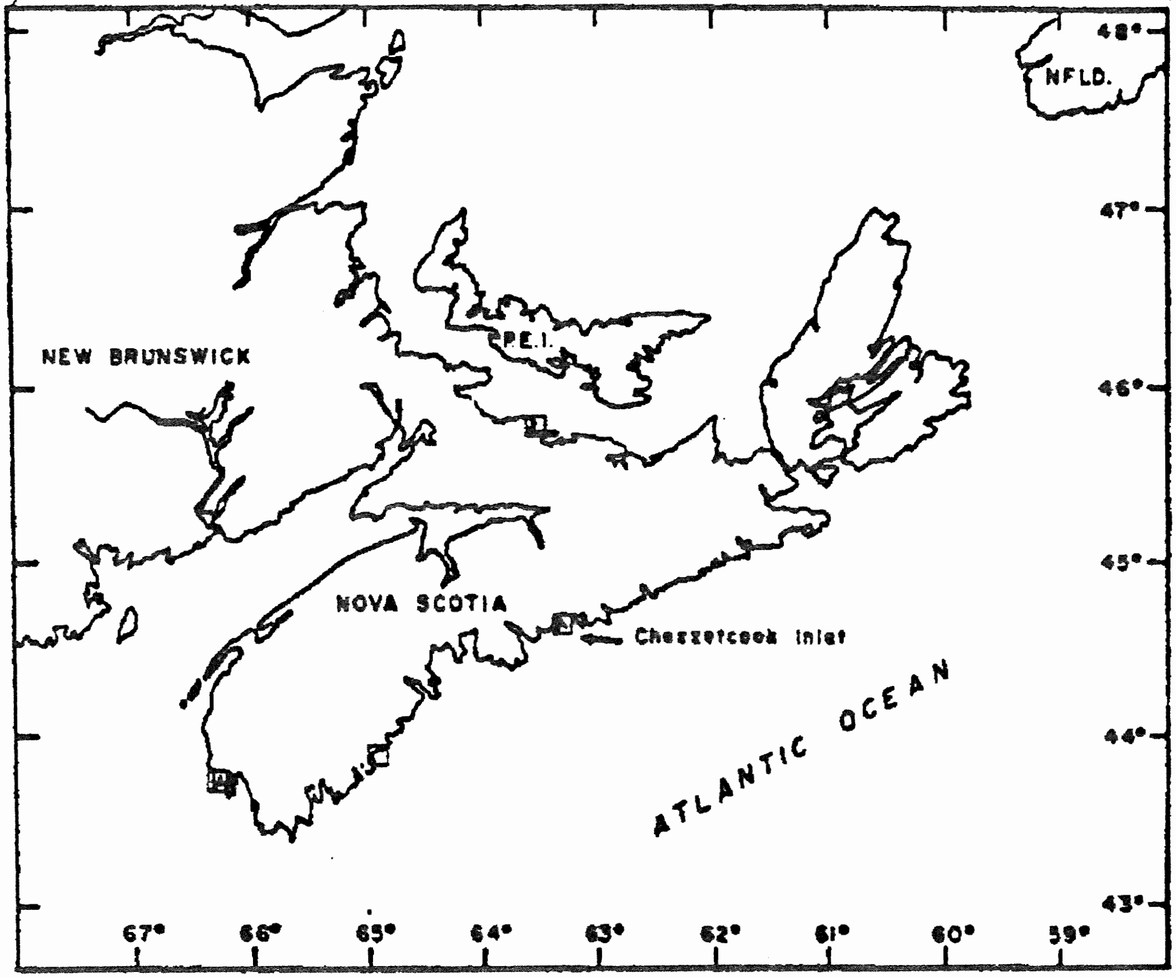

Figure 1.1 Location map showing the position of Chezzetcook Inlet on the Atlantic Coast of Nova Scotia (Scott,1980).

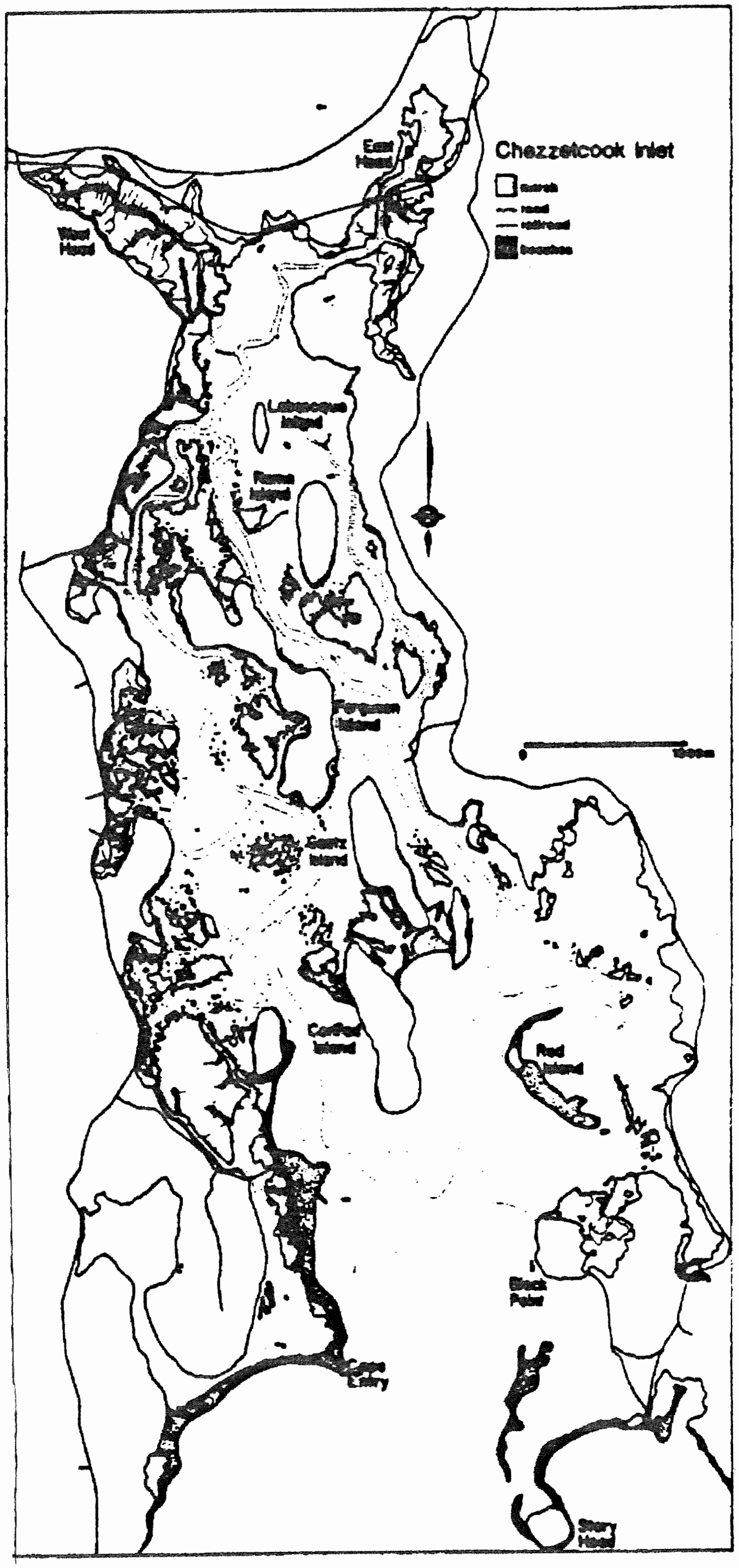

Figure 1.2 Physiography of Chezzetcook Inlet (1974) (Scott, 1980).

the inlet are the extensive intertidal mudflats and salt marshes. A network of channels that dissect the mudflats drains the intertidal areas. The channels begin at the head of the estuary as one large channel originating from the East Head, which bifurcates just west of Labreque Island. A small channel enters the main channel just above the bifurcation point and both continue down the estuary and empty into a large central area just south of Conrad Island. The upper part of the channel system at East Head appears to be the remnant of a river channel but the channels in the open part of the inlet appear to be formed by tidal currents.

The inlet can be subdivided into three general areas: the nearshore area south of Conrad Island where the channels disappear into a large turbulent, shallow zone that is subtidal; a large central region containing large mudflats and many drumlin islands; and an upper region which has comparatively narrow channels and a well developed marsh area, the East and West heads.

1.4 Geology of the Study Area

The oldest rocks that crop out along the Eastern Shore are the Cambro-Ordovician Meguma Group. These are generally considered to be metamorphosed turbidite deposits (Schenk et al.1980). They consist of a sand-dominant, resistant quartzite lithology, the Goldenville Formation, and a shale dominant more easily weathered lithology, the Halifax Formation. In Chezzetcook Inlet, there are areas where Halifax slates are observed (Scott, 1977b). The outcrops occur along the south shore of the West Head and along the eastern side of the inlet.

Areas of study along the Atlantic coast of Nova Scotia (Chezzetcook, Lawrencetown Beach) exhibit the characteristic geomorphology of formerly glaciated areas (Figure 1.3). The only other lithologies exposed along the Eastern Shore are unconsolidated Pleistocene glacial deposits which preserve the record of the latest glaciation (Wisconsinan) (Boyd et al, 1987). These deposits take the form of tills, some of which are characterized by drumlin accumulations. Chezzetcook Inlet has many drumlin islands (e.g. Conrad Island, Ferguson Island). Coincidentally, Chezzetcook Inlet has a well-developed marsh system. This could indicate a causal relationship between the drumlin and marsh formation with the islands providing protection from waves and strong currents as well as generating a large supply of sediments to newly forming marsh areas (Scott 1977b).

1.5 Organization of Thesis

This thesis is divided into six chapters. Chapter 1 introduces the objectives, scope and the geology of the study area. Background information on air photographs and sea-level change in the Holocene epoch is provided in Chapter 2. Chapter 3 discusses how the author constructed the air photograph composites and how data are collected from these composites. Chapter 4 provides the observational and measured data obtained in each time sequence composite. Chapter 5 is a discussion of the results and how they compare to other studies completed in the Chezzetcook Inlet area. Chapter 6 provides conclusions and makes recommendations both environmentally and in methodology for future research in the Chezzetcook Inlet area.

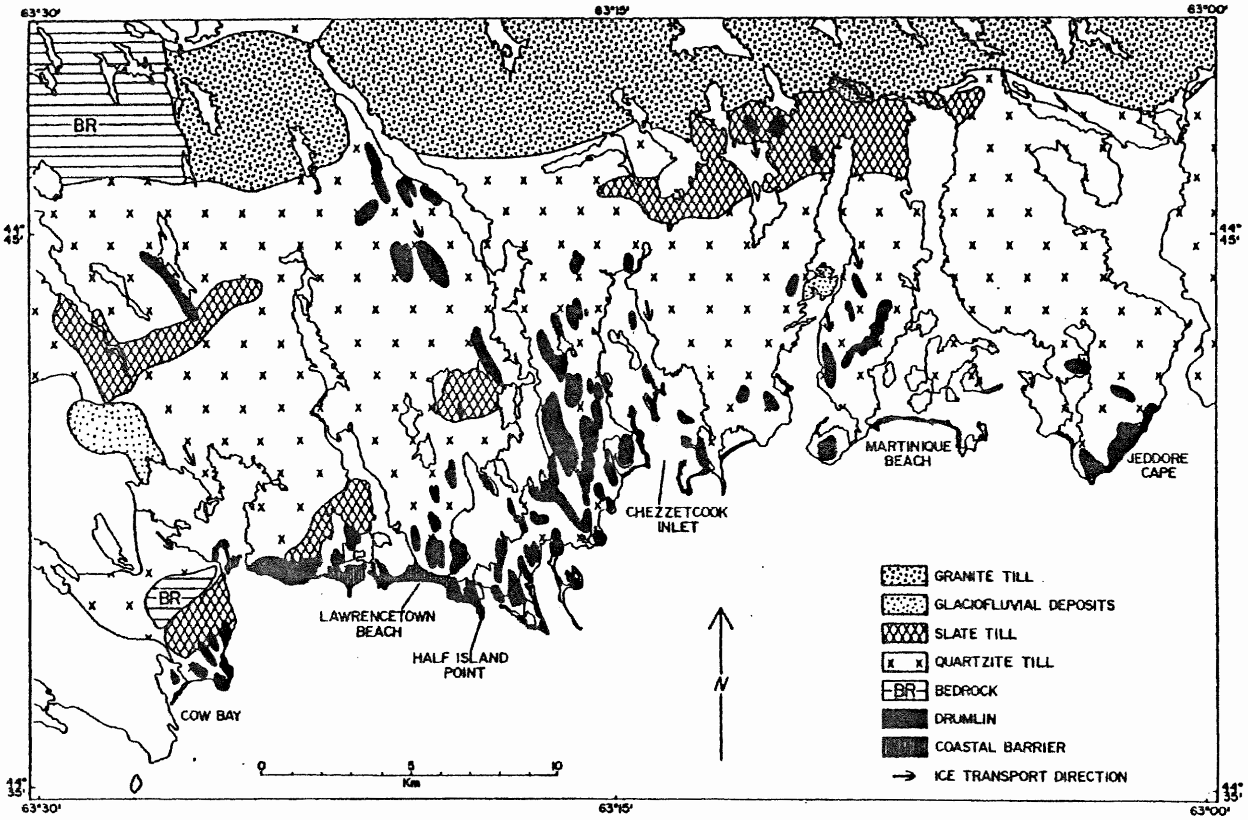

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Figure 1.3 Coastal geology of Eastern Shore, Nova Scotia (Boyd et al.1987).

Chapter 2:Background Information

2.1 Background Information

Airphoto interpretation to document coastal zone erosion, deposition and to infer sea-level change in the Holocene epoch are key subjects in this study and background information is presented below.

2.2 Airphoto Interpretation

Photo interpretation may be defined as the identification of objects on airphotos and the determination of their meaning and their significance. The art of airphoto interpretation was a little-known skill before 1939 and the advent of World War II. Within the following five or six years, however, countless military decisions were based on intelligence reports derived from aerial reconnaissance. After the war, many air-intelligence specialists converted their profound knowledge of photographic interpretation into diverse civilian applications. Today, photo-interpretation techniques are used to monitor coastal changes, assess crop diseases, locate new highway routes, and assess real estate (Avery and Berlin, 1985).

Aerial photography has been applied with varying degrees of success to each of the elements of the terrestrial environment for the extraction of quantitative information. The use of aerial photographs in geology and geomorphology forms a distinctive field which is sometimes separately called *photogeology and photogeomorphology* (Lo, 1976). The application of aerial photography is particularly suited to recording changes of geomorphological features over time. This involves the use of sequential or time-lapse photography that provides the basis for comparison through observations and quantitative measurements. As some of the changes or movements may be small, a high degree of accuracy must be achieved in both the observation and measured data components. Coastal zones are ideal candidates for air-photo study because of their ability to exhibit rapid change over a short period of time.

While air photo study appears to have many advantages, it also has its disadvantages. Image displacement, image distortion and parallax are some of the disadvantages of photograph interpretation.

Image distortions in air photographs are prominent and are a result of human error. Some of the causes are: improper flight path, improper shutter speed, light filters, improper film, and tilting of the camera lens (Avery and Berlin, 1985). Some or all of these problems are visible in each photograph taken and for the most part only account for small variations.

The "nadir" or isocenter of the air photograph represents the point of true location, the point which the camera taking the picture was directly above. All other parts of an air photograph are tilted away from the isocenter and as a result are not in their true location as in reality (Figure 2.1). Image displacement is always assumed in air photographs and can be corrected using mathematical calculation if the true locations are required.

Parallax is the apparent displacement of the position of a body, with respect to a reference point or system, caused by a shift in the point of observation (Lo, 1976).

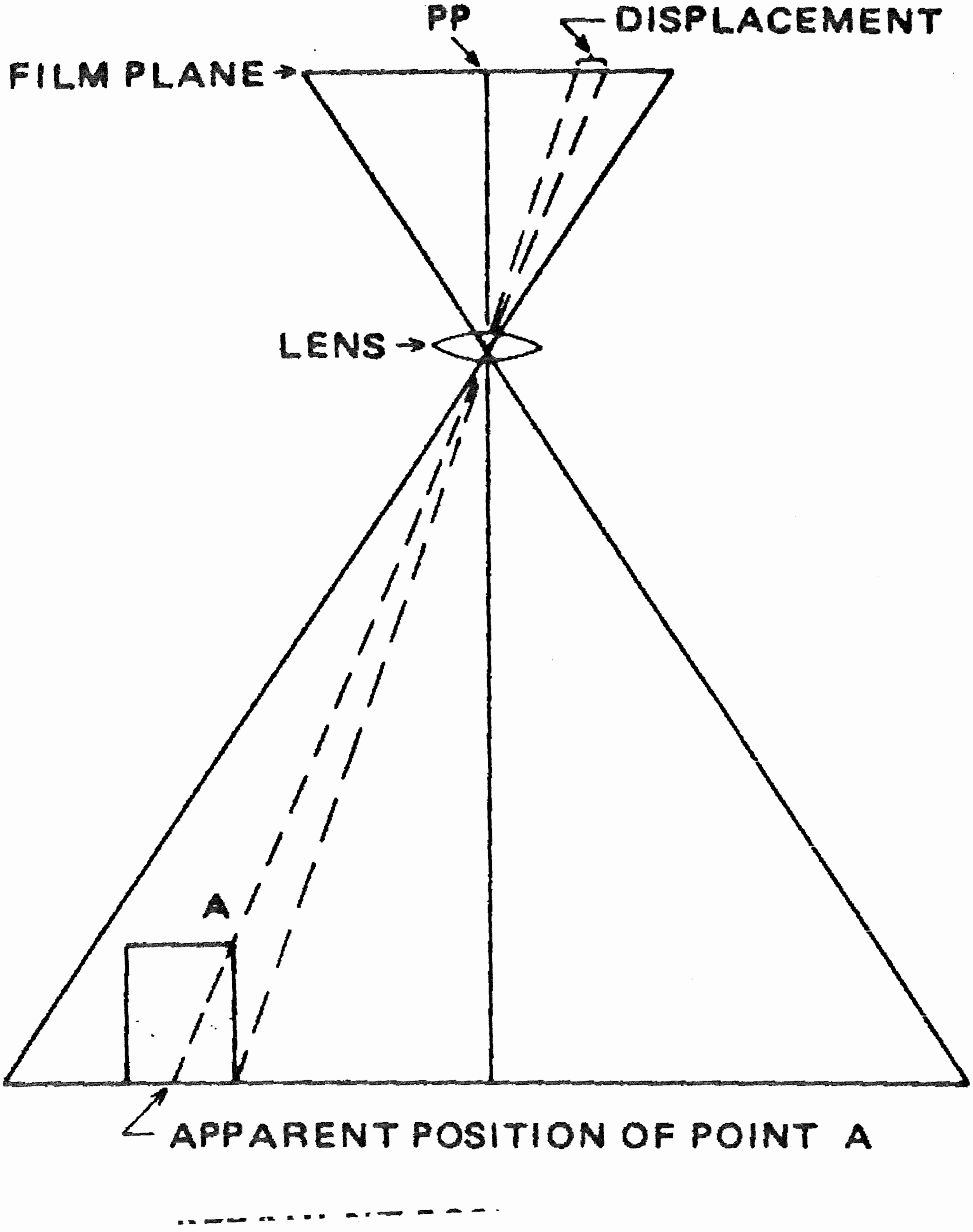


Figure 2.1 An example of relief displacement in a typical air photograph (Lo,1976).

Parallax only occurs during the overlapping of two or more air photographs and is best observed in Figure 2.2. In studies such as the authors' where large numbers of air photographs are overlapped to create composite images of an entire area the problem of parallax is quite apparent.

In working with air photographs it is important to assume errors such as image distortion, displacement and parallax when making observations and analysis. These errors can be corrected for or could be insignificant depending on the level of detail required.

2.3 Coastal Zone Geology

Coastal zone geology, a field almost unrecognized decades ago, is coming to the forefront of environmental geology. The reasons for its increasing prominence are manifold, but the expected acceleration in sea-level rise, due to the greenhouse effect (Pilkey et al.1989), and the resulting increase in shoreline erosion will get increasing attention because of its impact on human lives.

It is difficult to isolate and quantify all the specific causes of coastal erosion because of the great number of interacting variables (Figure 2.3). Despite this limitation researchers need to analyze both the major and minor influences at a given site to properly evaluate the potential factors and their interrelationships. The basis for prediction comes from such evaluation (Pilkey et al., 1989). Some of the factors that affect coastal land loss are waves, currents, storms, sediment budget, slope failure, climate, coastline composition, morphology, vegetation, and human activities.

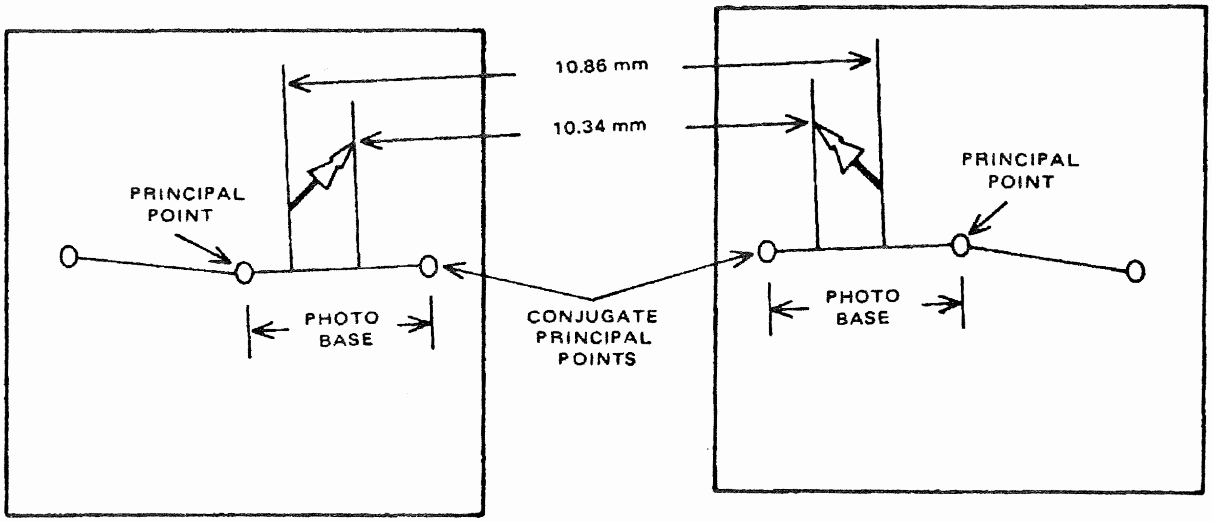


Figure 2.2 Direct measurement of differential parallax for a heavily displaced tree image (Avery and Berlin,1985). If these two air photographs were overlayed, the tree would be displaced by 0.53mm.

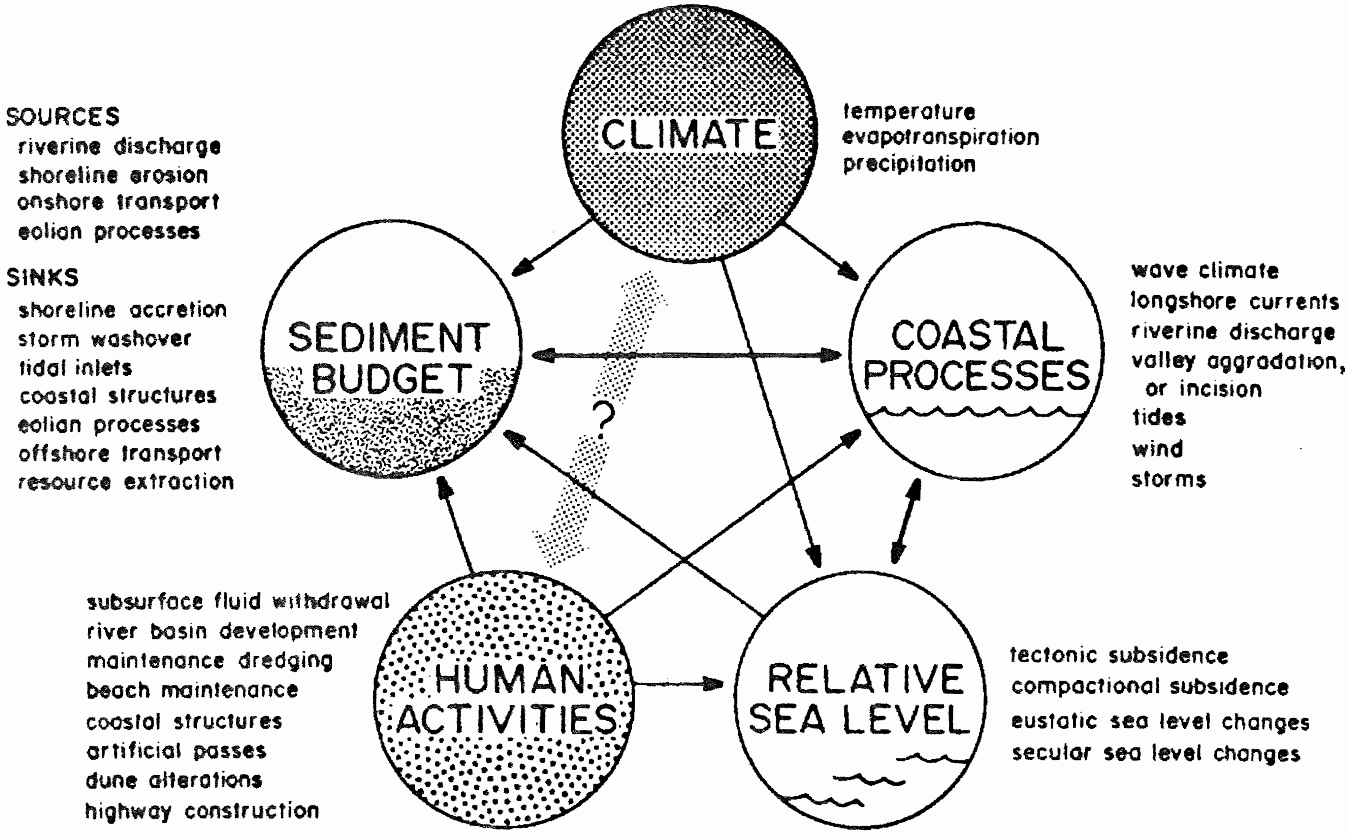


Figure 2.3 Interaction of agents affecting land loss. Arrows point towards dependant variables (Pilkey et al.1989).

Coastal land losses indirectly caused by humans are difficult to quantify because human activities promote alterations and imbalances in the sediment budget, coastal processes and relative sea level (Pilkey, et al., 1989). Field data from around the world indicate that the activity causing the most land loss is coastal construction (Pilkey and Thieler, 1992). Coastal construction includes a broad range of projects, such as coastal development, beach maintenance, seawalls, highway construction, and forestry.

Geologists concerned with coastal zone management and implications of shoreline processes evaluate situations based on a broad range of economic, political, and environmental shoreline management alternatives. Conflicting social priorities often make these decisions very difficult. Shoreline properties and construction are big business and the environmental implications associated with them are often overlooked to ensure a large profit or to appease political pressures.

Coastal zone management is a key issue when discussing Chezzetcook Inlet. Human activities such as deforestation, highway construction, as well as natural phenomena (storms), have caused the rate of sediment input to vary, resulting in different morphological features seen in the Inlet.

2.4 Sea-level change in the Holocene

The movement of continental ice masses has dominated Holocene relative sea level (RSL) in Atlantic Canada. Large volumes of water are withdrawn from ocean basins as ice thickness increases on land, causing a fall in RSL. Areas such as the eastern coast of Nova Scotia, which lie close to the ice margin, experience less RSL fall than the basin as a whole (Boyd et al,1987). However, coastal zones lying close to the ice margin experience a glacial "peripheral bulge", introduced by Jamieson (1882, in Scott 1977b) as "...a tendency to bulge up in the region which lay immediately beyond this area of depression, just as we sometimes see in advance of a railway embankment, which not only depresses the soil beneath it, but also causes the ground to swell up further off."

The late Wisconsinan ice advance reached its maximum in Nova Scotia between 32000 and 16000 years ago. Late Wisconsinan crustal loading was insufficient during glaciation to produce any higher RSL than that experienced at present (Boyd et al.1987). During peripheral bulge migration, RSL on the eastern coast of Nova Scotia fell to a minimum of at least –65m around 11000 years ago (Stea et al. 1994). RSL has risen from depths of –30m at 7000 and had risen since that time at varying rates to the present (Scott and Medioli, 1982; Scott et al. 1995).

Chapter 3: Methods

3.1 Background

3.1.1 *Significance of the Experiment*

The present experiment is significant because of the updated and/or new air photographs obtained from the Province of Nova Scotia (Land Information Center) by the author and the resulting new data and observations of the area obtained from the new air photographs. Digital composite images of the area were constructed using computer programs (Adobe PhotoShop® and Adobe Illustrator®). This enables the researcher to eliminate some air photograph distortion and to view all the air photographs from one time period in one image, improving observations in both the immediate and sequential time period evaluations.

3.1.2 *Previous Work or Experiments*

There has been a substantial amount of work in coastal geology and geomorphology in Nova Scotia. Some studies have focused on beaches across Nova Scotia and their sediment supply changes (Taylor et al. 1985), while others have focused on individual beaches and cliffs for their study area (Piper et al. 1986).

There have been over 10 in-depth studies completed in and around the Chezzetcook Inlet area. Scott (1977a,b), Carter et al (1990) and Jennings et al (1993) will be mentioned in subsequent chapters because they deal with topics in Chezzetcook Inlet relevant to this project. Chezzetcook Inlet is unusual in that its size (7km long and 1km wide) enables it to have both coastal and terrestrial features. Sandbars, gravel bars, beaches, islands and marshes must be evaluated and a serial examination of air photographs provides an ideal database. Previous studies such Piper et al. (1986) have taken place on a much smaller scale where no need for air coverage was needed.

As mentioned in the previous chapter, the use of air photographs as a tool for data extraction and interpolation has been known since World War II. During that time, only one or two air photographs were used over a small area in short time sequence intervals. Subsequent studies such as Conway and Barrie (1994) have used air photo composites cut and pasted together to represent an area larger than one air photograph. El-Asham and Wanless (1964) used time sequence air photography to document changes in coastal zone erosion patterns and geomorphology. The author's study of Chezzetcook Inlet is unusual for two reasons. 1) The large area covered by the composites: the 7km long and 1km wide inlet requires ~22 air photographs to cover the area properly at 1:10000 scale. 2) The period covered by the study- seven documented intervals and 232 years- provides an unique time sequence study. Conventional time sequence air photographic studies run over a decade and some to a 20 -30 year interval.

3.2 Samples

3.2.1 *Location*

All of the air photographs of the Chezzetcook Inlet area of Nova Scotia were obtained from the Land Information Center of the Province of Nova Scotia in Halifax. The air photographs were taken at different time intervals and as a result are at different scales, quantity and quality (Table 1.1). Tide height during the photographs can affect results, especially when calculating changes in marsh development. With the exception of 1964 and 1945, all of the composites and charts were taken at low tide (Table 1.1). Tidal height is not crucial because even at high tide in the 1945 and 1964 composites, the marsh outline can be seen under the water.

Charts used in this study are representative of Chezzetcook Inlet. All maps were obtained from the Map Archives at Dalhousie University. Captain James Cook made the 1766 chart of the area during one of his many exploring voyages. The Royal British Navy during their survey of the Nova Scotia coastline made the 1854 Admiralty chart. The 1854 chart is more detailed than the 1766 chart, partly because Capt. Cook could not fit his ship entirely into the inlet, while the Navy could. Reasons for the change between the two time periods will be discussed in subsequent chapters.

3.2.2 *Preparation*

Air photographs were prepared into composites using computer programs (Adobe PhotoShop® and Adobe Illustrator®). First, the air photographs were scanned (as TIFF or JPEG files) into the Adobe PhotoShop ®. In this program images were "cropped". "Cropping" shaves the edges off the image; this feature is advantageous in this study because the edges of the air photographs contain the most distortion. The new slightly smaller images are then "pasted" into Adobe Illustrator ®, where they are connected with other images from the same time period into a composite image in a jigsaw puzzle-like manner. The composites then can be customized to the users' requirements by changing the scale, color, contrast, and text. As a result of their complexity, the composite images are very large files and often top 50MB in memory. Composites currently can only be stored on ZIP™ disks or on a JAZ™ disk.

The distortion present in the composites is considered unimportant in the scope of this study. Data obtained are at best semi-quantitative and is used to give the reader an approximate sense of change. If this study were to use morphological data for precise calculations the air photograph distortions would need to be corrected using stereo photos or a Topcon system.

3.2.3 *Identification*

Identification of islands, beaches, marshes and sandbars in the Chezzetcook area was initially done by Scott (1980). The author's study is intended to complement that work and add observations and data with new air photographs and technology. The major analysis addresses the changes that have taken place between the time intervals, chiefly in marsh, sand, and gravel environments.

3.3 Procedure

The design of this study follows the design completed by Scott (1980). Observations of progressive air photograph time sequences lead to conclusions on the causes of changes in the marsh, sand and gravel environments. Recommendations for future coastal zone management are given based on the conclusions of the study.

An addition to this experimental design in the author's study is data on geomorphologic changes. Data can be extracted from the air photographs based on a method used by El-Asham and Wanless (1964). This is a fixed-point method. Each composite has a determined fixed point (landmark, island, etc.), this can be used to find the scales of each composite relative to each other. Changes in sandbars, marshes and island shape can be then measured directly from the map. Erosion or accretion rates can be calculated on a constant interval at any point on the composite.

Chapter 4: Results

4.1 Introduction

The results of this project are obtained from the two maps and six air photograph composites of the Chezzetcook Inlet area (Figures 4.1 a-h and Appendix A) ranging in age from 1766 to 1997. Morphological data is compiled using two methods: 1) observational data and 2) measured data. Noting the visual changes noticeable in the Inlet between the photograph sets yields observational data. Measured data are obtained by calculating the amount of change in marsh, sand spit and beach area between the periods of documentation. These two data types complement each other and will provide a semi-quantitative assessment of the morphological changes that have occurred in the Inlet in the past 232 years.

4.2 Observational data

Comparison of 1766 and 1854 charts

The accuracy of the 1766 chart (Figure 4.1a) is low compared to the chart produced in 1854 (Figures 4.1 b and c). This may be the result of Cook's inability to navigate past the entrance of the inlet with a large sailing ship, because the major features (near the entrance) appear to be mapped accurately (Scott, 1980). The 1766 map shows a deep channel between the end of Cape Entry spit and the small drumlin just west of Conrad Island. By 1854 this deep channel was shallow and closed (Scott, 1980). The entrance to the inlet was also substantially shallower. A large mudflat is shown on the east side of Chezzetcook in 1766 and by 1854 mudflats covered most of the inlet. The

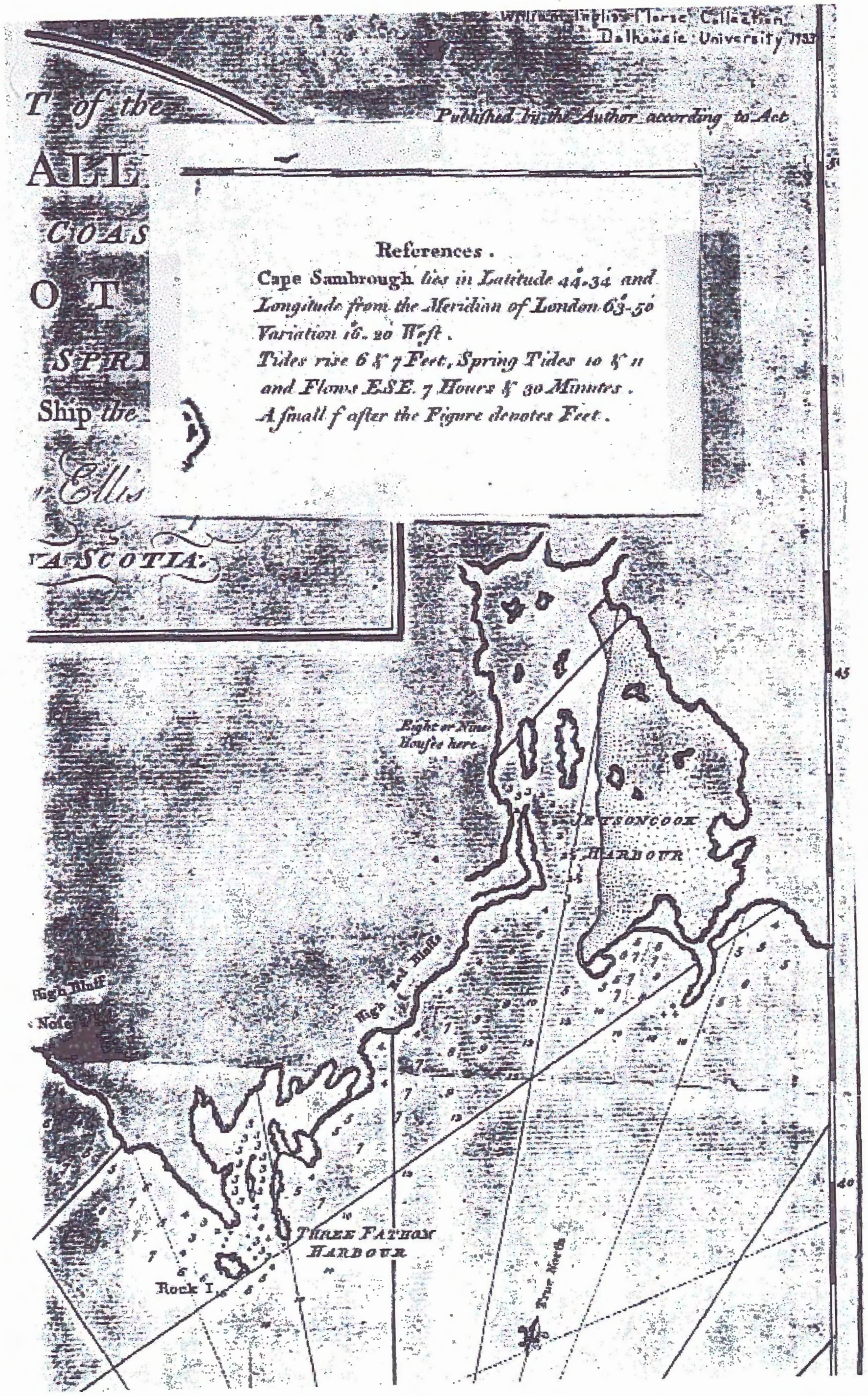


Figure 4.1 (a) Capt. James Cook's chart of Chezzetcook Inlet area in 1766.

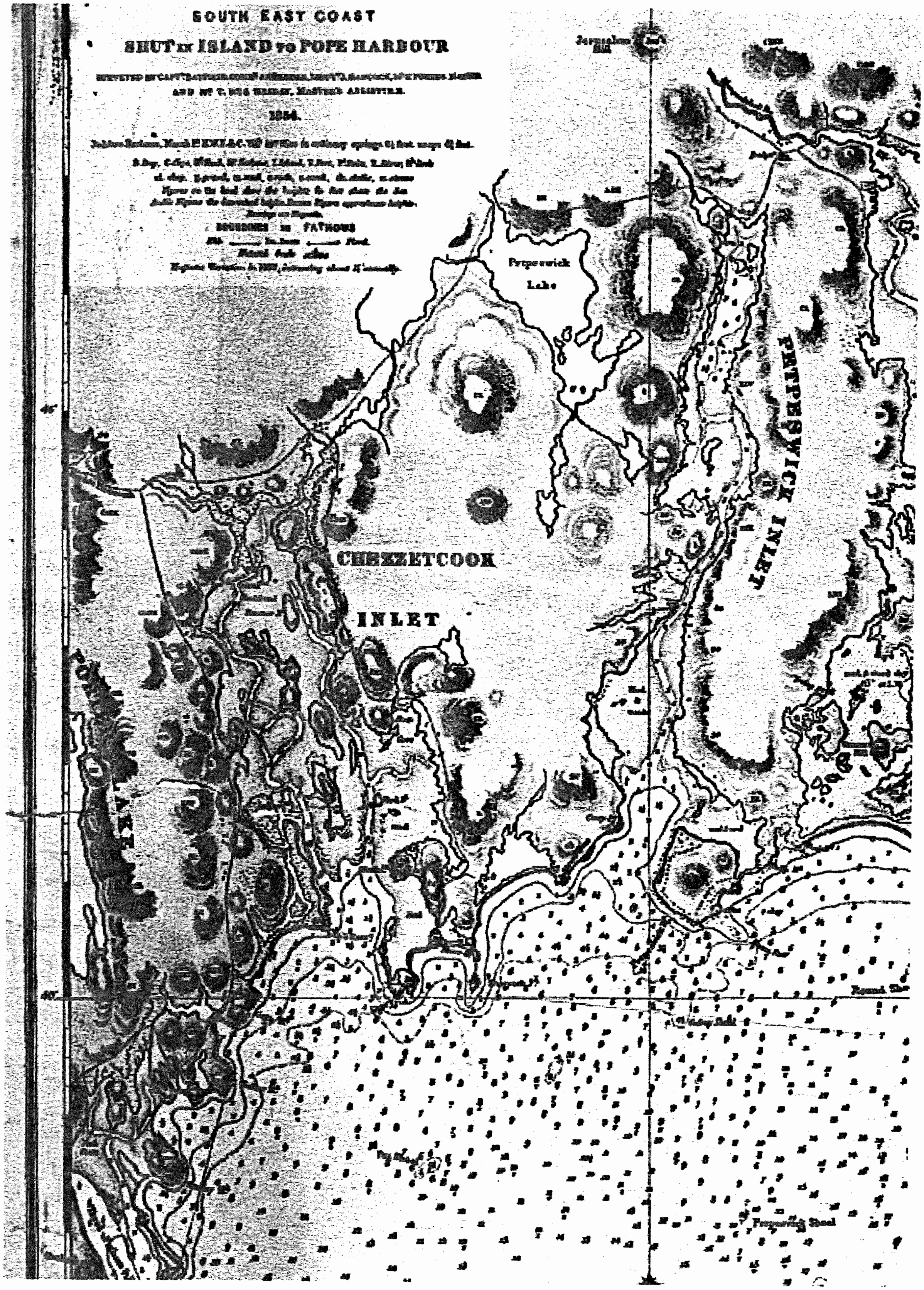


Figure 4.1(b) British Admiralty Chart of Chezzetcook Inlet area in 1854.

Figure 4.1 (c) British Admiralty Chart of Chezzetcook Inlet in 1854.

large marsh shown behind the Cape Entry spit in 1854 may not have been present in 1766, meaning it could have been solid land (Scott, 1980). It is difficult to determine if the change in the size of the mudflat is real since the detail on the 1766 map is not reliable landward of Conrad Island (Scott, 1980).

Comparison of 1854 chart and 1945

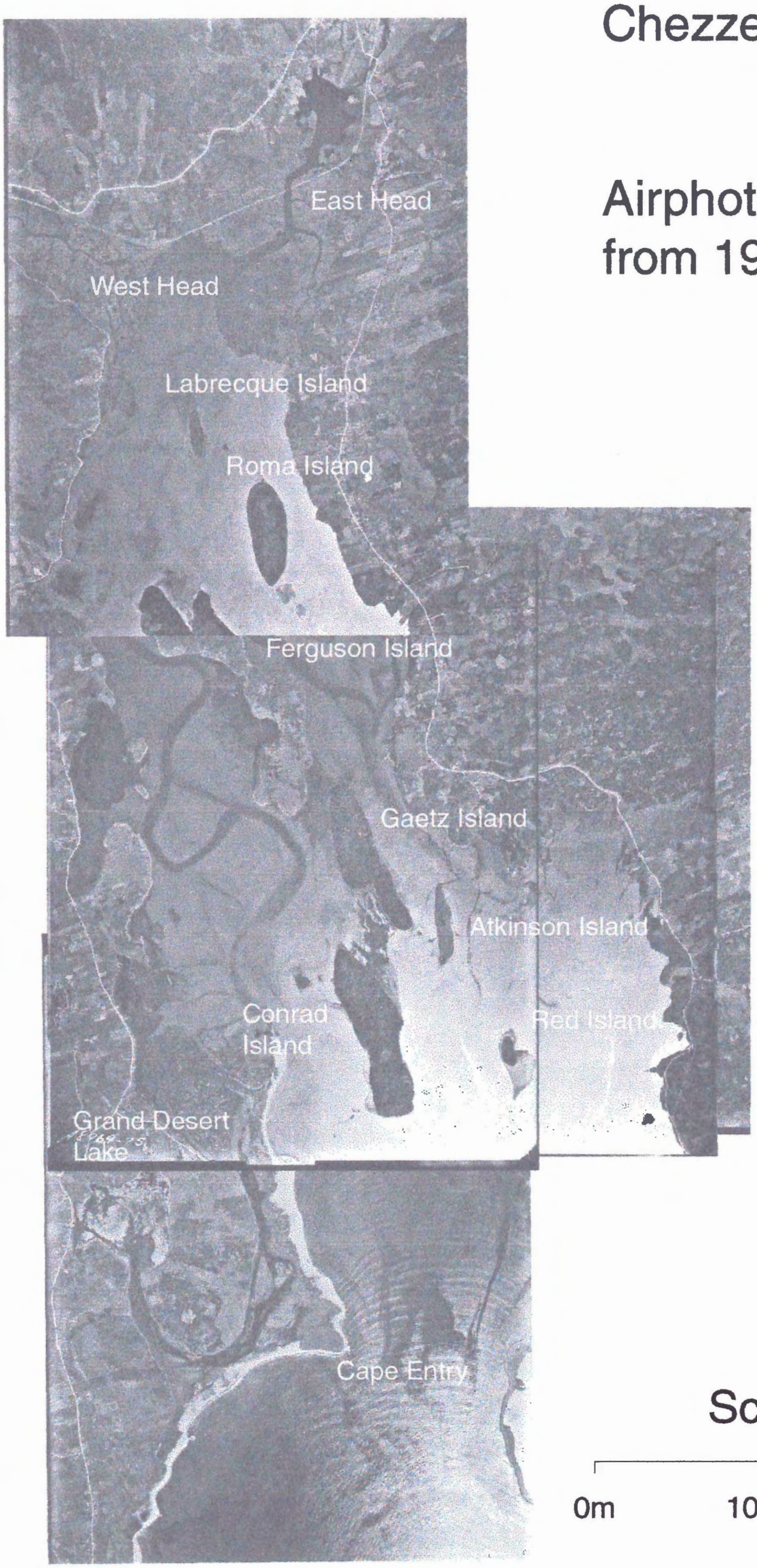
There are few major changes in the configuration of the inlet between 1854 and 1945. The 1945 composite (Figure 4.1 d) shows no noticeable expansion of the marsh areas. A new spit formed between Conrad and Gaetz Islands after 1854. The opening in the northern extension of Cape Entry spit is closed by 1945 and the houses on the small drumlin just west of Conrad Island suggest that this closure may have been artificial. The channel system has changed little since 1854; one new channel is observed in the 1945 composite in the area between Ferguson and Roma Islands. The pond to the east of Cape Entry is shown as swamp in 1854, but in 1945 it is shown as open water. The extent of marshes behind the Cape Entry spit (westerly extension) in 1854 appear greatly reduced by 1945. All islands remained the same size and shape between 1854 and 1945.

Comparison of 1945 and 1964

Changes between the 1945 and 1964 (Figure 4.1 e) composites are more pronounced than those between 1854 and 1945. Large movements of sand and gravel occurred near the entrance to the inlet. The spit on the west side of Conrad Island lengthened considerably between 1945 and 1964. This extension further constricted the main channel, which feeds the western part of the inlet. Atkinson Island (newly named in

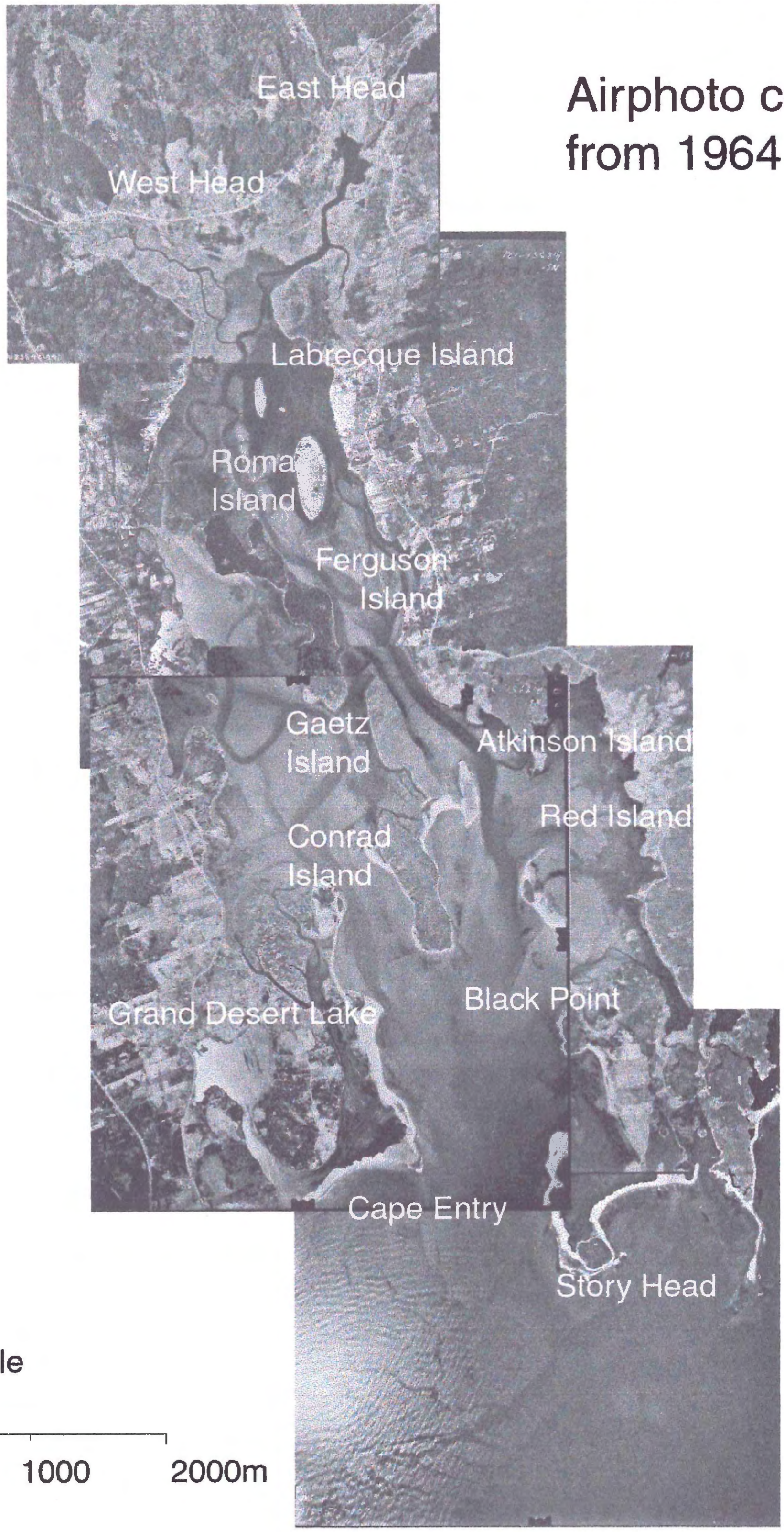
Chezzetcook Inlet

Airphoto Composite from 1945



Chezzetcook Inlet

Airphoto composite
from 1964



Scale

0m 1000 2000m

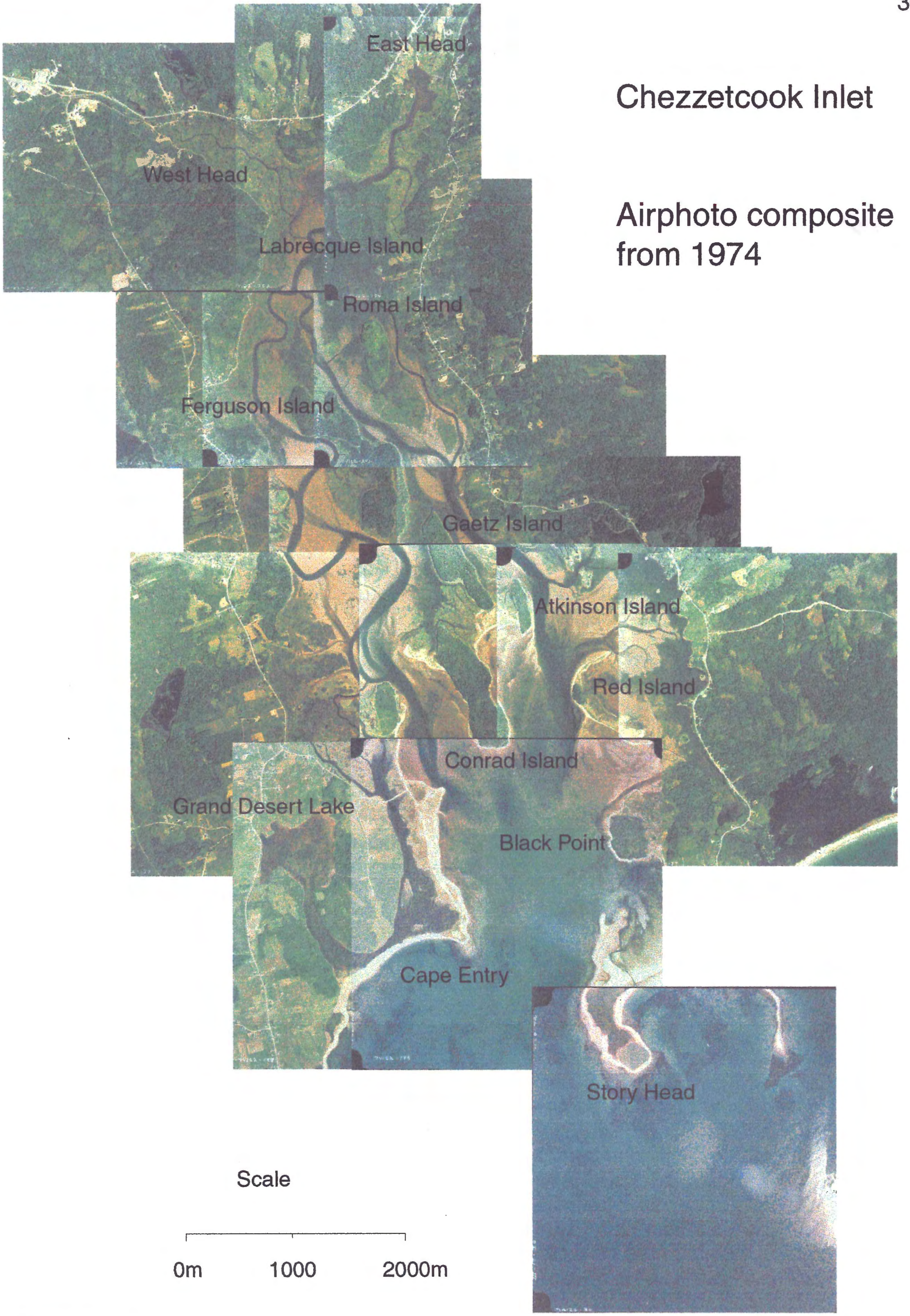
Figure 4.1 (e)

this study) southeast of Gaetz Island became connected by a sandbar to the main spit between Conrad and Gaetz islands. The most pronounced change in the 1945-1964 time period was in the vicinity of Red Island. It was a small, rounded island up until 1945; by 1964 it had an elongated, half moon shape. The spits at both Story Head (Figure 5.1) and Cape Entry moved landward significantly between 1945 and 1964. This had little effect at Story Head, but the Cape Entry spit has overridden existing marsh and isolated a small pond that had been open to tidal influence in 1945. Due to the tidal difference between the 1945 and 1964 composites (Table 1.1) marsh development is difficult to assess. Two major marsh colonizations are observed in spite of this difficulty. New marsh has also formed in West Head since 1945. Marsh plants colonized the large open mudflat north of Roma Island also in this time period.

Comparison of 1964 and 1974

The changes between the 1964 and 1974 composites are very minor compared to the major changes that occurred in the 1945-1964 time period. Many of the minor changes observed in the 1974 composite (Figure 4.1 f) are continuations of the major trends found in the 1964 composite. Red Island continued to transform in the 1974 composite, it extended into a conventional half-moon shape. Sand spits at Story Head and Cape Entry continued to move landward. The first infilling of sediment occurs at Grand Desert Lake. New spits formed off Atkinson Island. All other islands appear to have similar shape and size between 1964 and 1974.

There was no new marsh development in the northern portion of the inlet (West Head, East Head and Roma Island), while there was minor marsh development between Conrad and Gaetz islands.



Chezzetcook Inlet

Airphoto composite
from 1974

Figure 4.1 (f)

Comparison of 1974 and 1982

The changes between the 1974 and 1982 composites are even less significant than the minor changes that occurred in the 1964-1974 time period. The beach reached the headland at Cape Entry, causing the closing of the lagoon. The spit on the west side of Conrad Island appears to have extended slightly. Red Island had reached its conventional half-moon shape in the 1974 composite. In the 1982 composite, (Figure 4.1 g) a small thin spit has extended from the northern end of the island. All other islands appear to have the same shape and size between 1974 and 1982. There was no observable marsh development in the 1974-1982 time period.

Comparison of 1982-1992

The changes observed between the 1982 and 1992 composites are again relatively minor compared to the major changes observed in the 1766-1854 and 1945-1974 periods. The small spit off the north end of Red Island continued to extend during this period. The northern most sandspit at Cape Entry has slightly extended in the 1992 composite (Figure 4.1 h). All other islands appear to have similar shape and size between 1982 and 1992. There was no observable marsh development in this period.

Comparison of 1992-1997

The changes observed between the 1992 and 1997 composites are very slight. Fisherman's and Story Head beaches (Figure 5.1) meet to form a new lagoon at Story

Chezzetcook Inlet

Airphoto Composite from 1982

Figure 4.1 (g)

Chezzetcook Inlet

Airphoto Composite from 1992

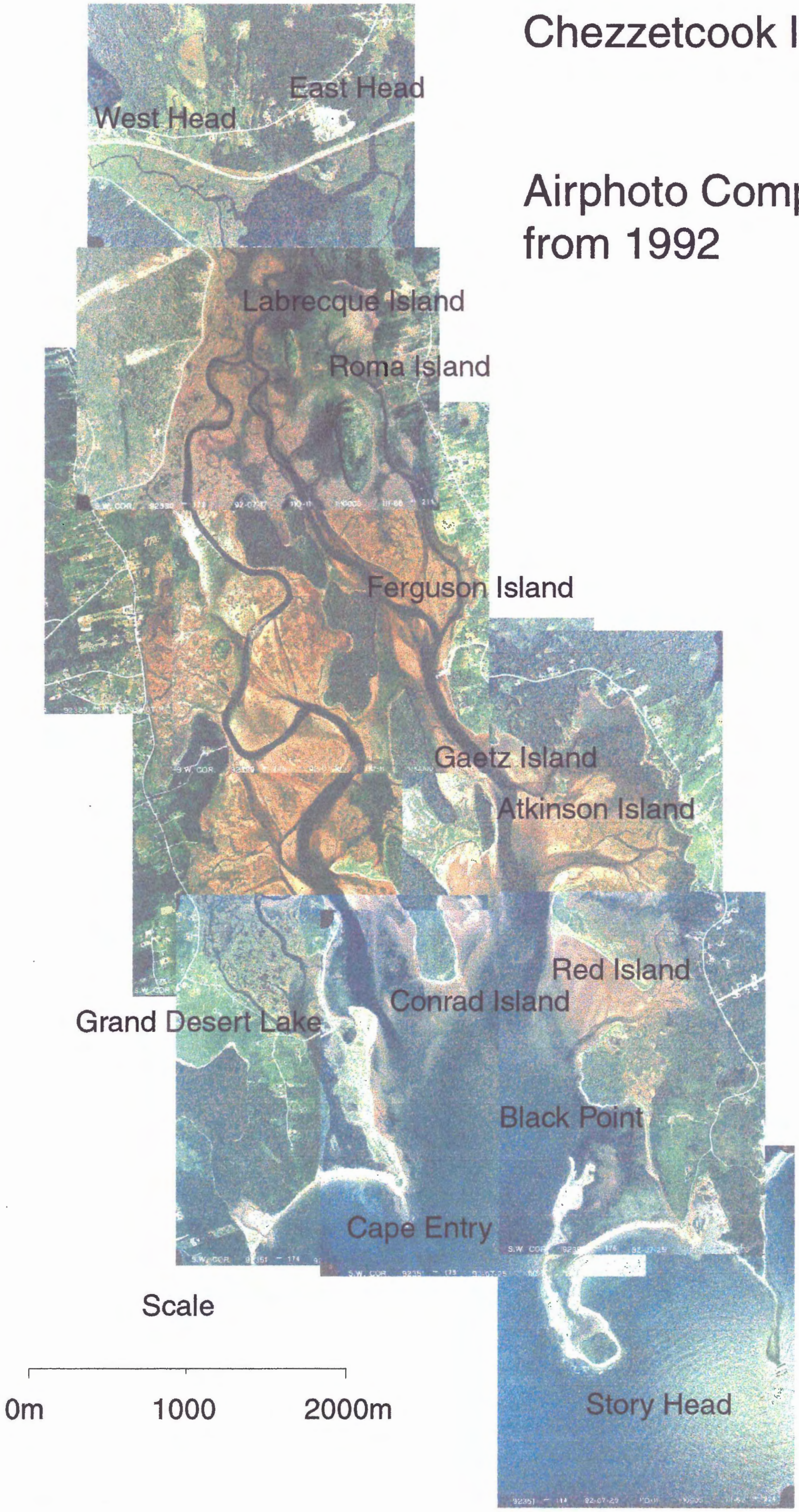
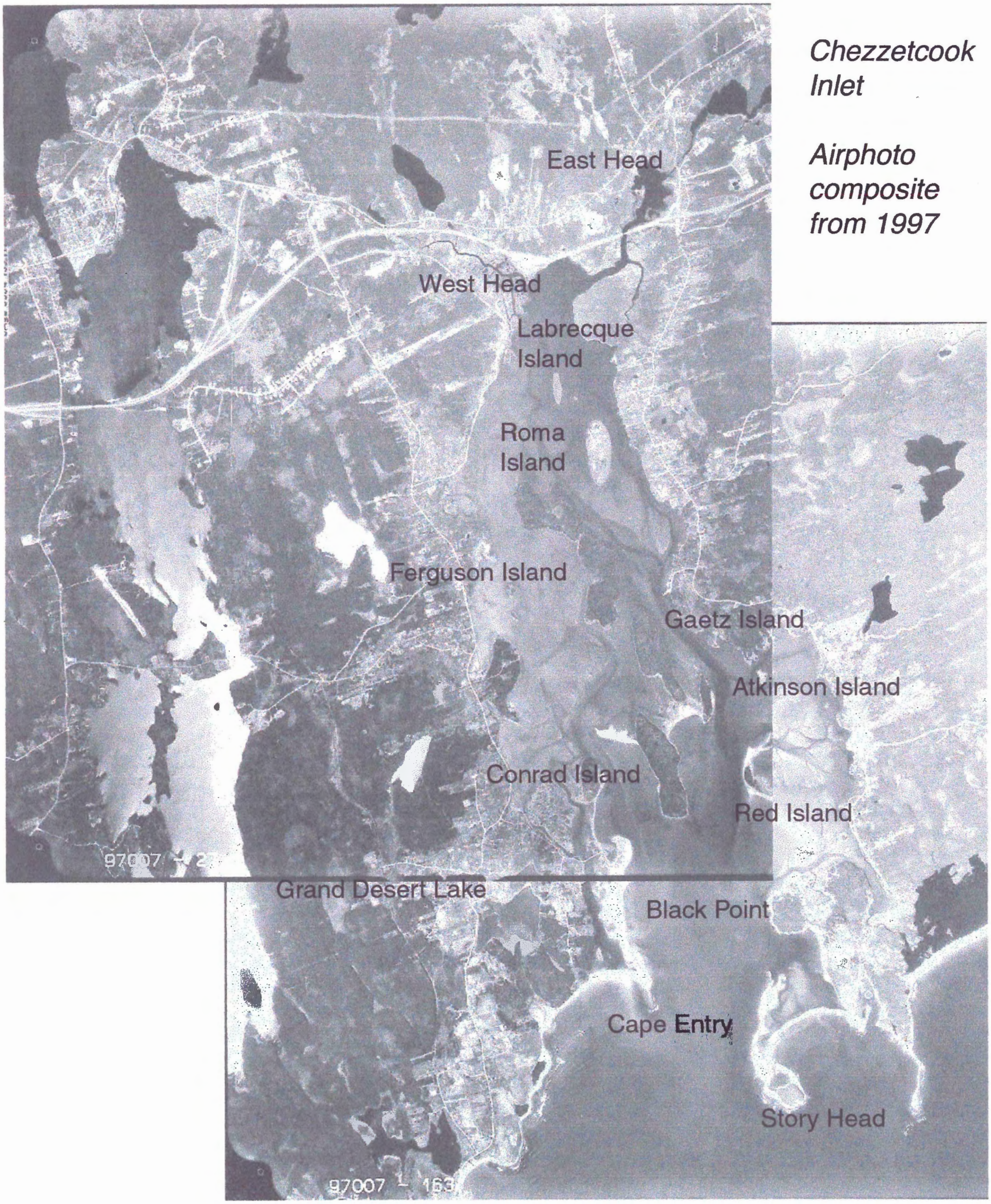


Figure 4.1 (h)



Chezzetcook Inlet

Airphoto composite from 1997

Figure 4.1 (i)

Figure 4.2 Area of marsh colonization since 1997 (brown area in water east of road). Photo taken by D.B Scott (October 1998).

Head (to be discussed in 4.2:Measured Data). It must be noted that this is the shortest time interval between any of the composites. The 1997 composite (Figure 4.1 I) may be used in future work to compare to a future time period. All islands appear to have similar shape and size, and no marsh development is observed between 1992-1997 period.

Comparison of 1997-1998

During recent fieldwork in the Chezzetcook Inlet area (Oct 98) a rapid colonization of marsh was observed east of Red Island. Marsh has colonized several small channels and occupied all the area from Red Island to the highway to the east (Figure 4.2). This marsh development is not seen in the 1997 composite and shows how marsh can overtake a large area in a short time, similar to the rapid colonization that occurred in the 1945-1964 period.

4.2 Measured Data

4.2.1 *Introduction*

Measured data in this thesis provide semi-quantitative estimates of change. The incorporated errors in the air photographs and the measuring errors in the isolated location composites (Figures 4.3 a-d) are significant. The purpose of the data is to focus on critical areas of change that are occurring in the Inlet during each time period and the approximate quantities in sediment transport, accumulation, or erosion that have occurred. The charts from 1766 and 1854 are not used in this analysis. Converting values from charts to air photographs on vastly different scales would only add further uncertainty to the data set.

Measured data are taken from four locations from the Inlet. These are the locations of the most significant and most interesting morphological changes. Red Island, Story Head, Cape Entry, and the Three Islands (a.k.a. Conrad,Gaetz and Atkinson Islands) have been selected and time sequence composites have been made with each area as the only feature in the image (ex. Figure 4.3 a). This allows the reader to focus on the area of study and closely examine the changes on a larger scale with improved resolution. The scale for each time sequence composite is again determined using the fixed point method.

4.2.2 *Red Island*

1945-1964

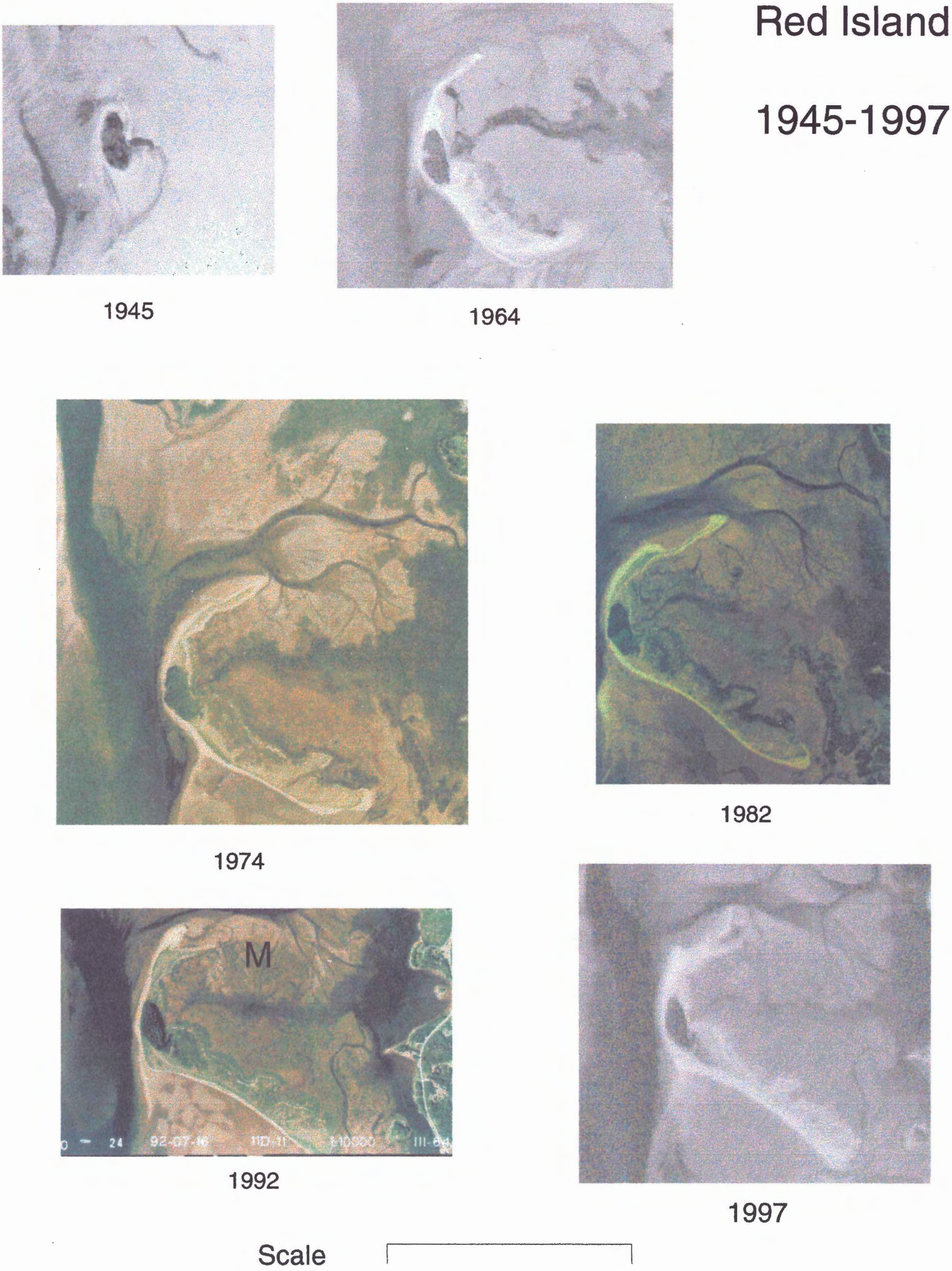
A drastic change in shape and size characterizes the changes at Red Island (Figure 4.3a) during this time period. Red Island went from a "short and fat" configuration in 1945 to a "long and skinny"crescent shape in 1964. The area of the island (including sand spits) increased from 230m long in 1945 to 910m long in 1964.

1964-1974

During this 10-year period Red Island continues to grow into a more pronounced crescent shape. This shape causes difficulties when measuring. Length is measured in small increments, possibly promoting measurement error propagation. Its length has increased to 1200m and its width (averaged value) has increased to 230m by 1974. Slight amounts of non-measurable marsh development are observed in close vicinity of the island.

Red Island

1945-1997



1945

1964

1974

1982

1992

1997

Figure 4.3 (a) M=marsh development

1974-1982

A 90m-spit extension off the northern section of Red Island is the only observable change during this time period. This spit extension constricts the channel to the immediate north causing a decrease in water velocity and resulting colonization of marsh in this area in the next time period.

1982-1992

During this 10-year period Red Island continues to alter its crescent shape. The northern spit extension observed in the 1974-1982 period has decreased its length while maintaining the same volume; it has altered into an "L" shape. Marsh (green, due to blooming in summer season) has colonized an area of about 62000m^2 adjacent to the northern spit extension (labeled M in Figure 4.3a). This can be directly linked with the constriction of the channel in the 1974-1982 time period.

1992-1997

There is no marsh development in this short 5-year interval. A new small spit of 50m in length has formed off the northern spit extension.

4.2.3 *The Three Islands*

1945-1964

The most significant changes occur in the Gaetz and Conrad Islands region during the 1945-1964 time period (Figure 4.3b). The spit on the west side of Conrad Island greatly increased its area from 4100m^2 in 1945 to 20000m^2 in 1964. A new spit extended from Atkinson Island to both Conrad and Gaetz Islands. The Atkinson/Conrad extension is 200m in length and the Atkinson/Gaetz extension is 140m in length. A spit at the southern end of Conrad Island has decreased from 70m in 1945 to 20m in 1974.

Marsh movement and colonization is difficult to determine using black and white air photographs. Any marsh data taken from black and white air photographs (ie.1945-1964 comparison) should be considered less accurate than marsh data taken from two color air photographs (i.e. 1974-1982 comparison). There is significant marsh development between Conrad and Gaetz Islands during this time period. The marsh on the western edge of Gaetz Island has increased its area from 4100m^2 in 1945 to 29000m^2 in 1964. Small amounts of unmeasurable marsh development also occur on the east side of Gaetz Island.

1964-1974

The spit on the western side of Conrad Island increases its length from 270m in 1964 to 360m in 1974. The width of the Atkinson Island spit (east side) widens from 90m in 1964 to 140m during this time period. There is no noticeable marsh development in this 10-year interval.

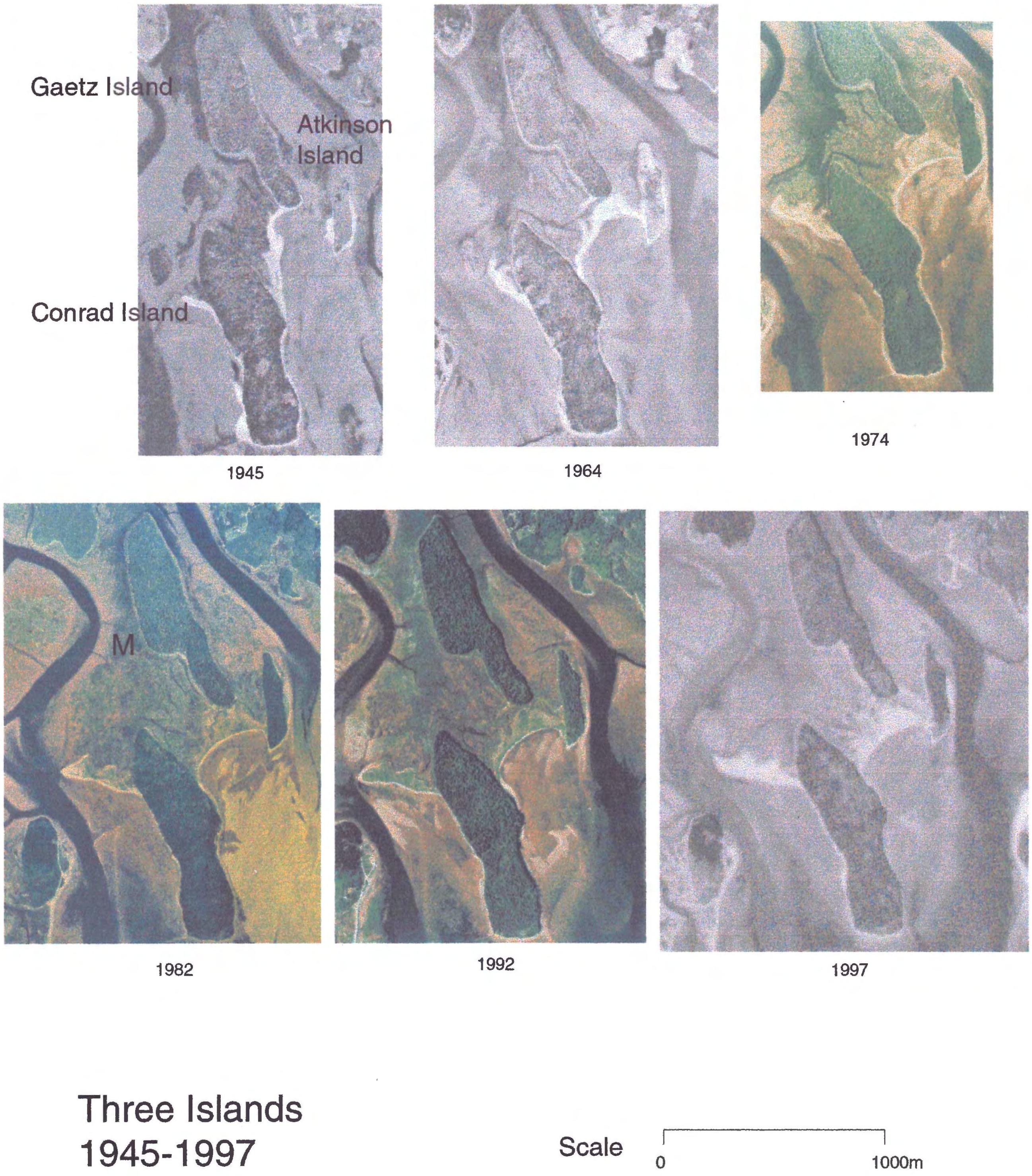


Figure 4.3 (b) M= Marsh Development

1974-1982

During this time period all spits appear the same size and shape. In the 1974 air photograph (mid tide) there appears to have been significant marsh colonization (labeled as M in Figure 4.3b) northeast of Conrad Island by the time of the 1982 air photograph (low tide). The dark green area north of the marsh in 1974 is eel grass (subtidal), while the lighter green material in 1982 is salt marsh (intertidal) (Mackinnon and Scott, 1983).

1982-1992

There are no measurable changes in spit size or shape and marsh development in this 10-year interval.

1992-1997

The 1997 image has been constructed from a 1:50000 air photograph and as a result the contrast and resolution of this image are poor. Changes in spit size or configuration can be seen, but marsh development is almost impossible to see with any certainty.

The spit west of Conrad Island extended 50m during this time interval.

4.2.4 *Story Head*

The author could find no airphoto coverage of Story Head in 1945. The analysis of the morphological changes at Story Head will begin with the 1964-1974 time period. (Figure 4.3c)

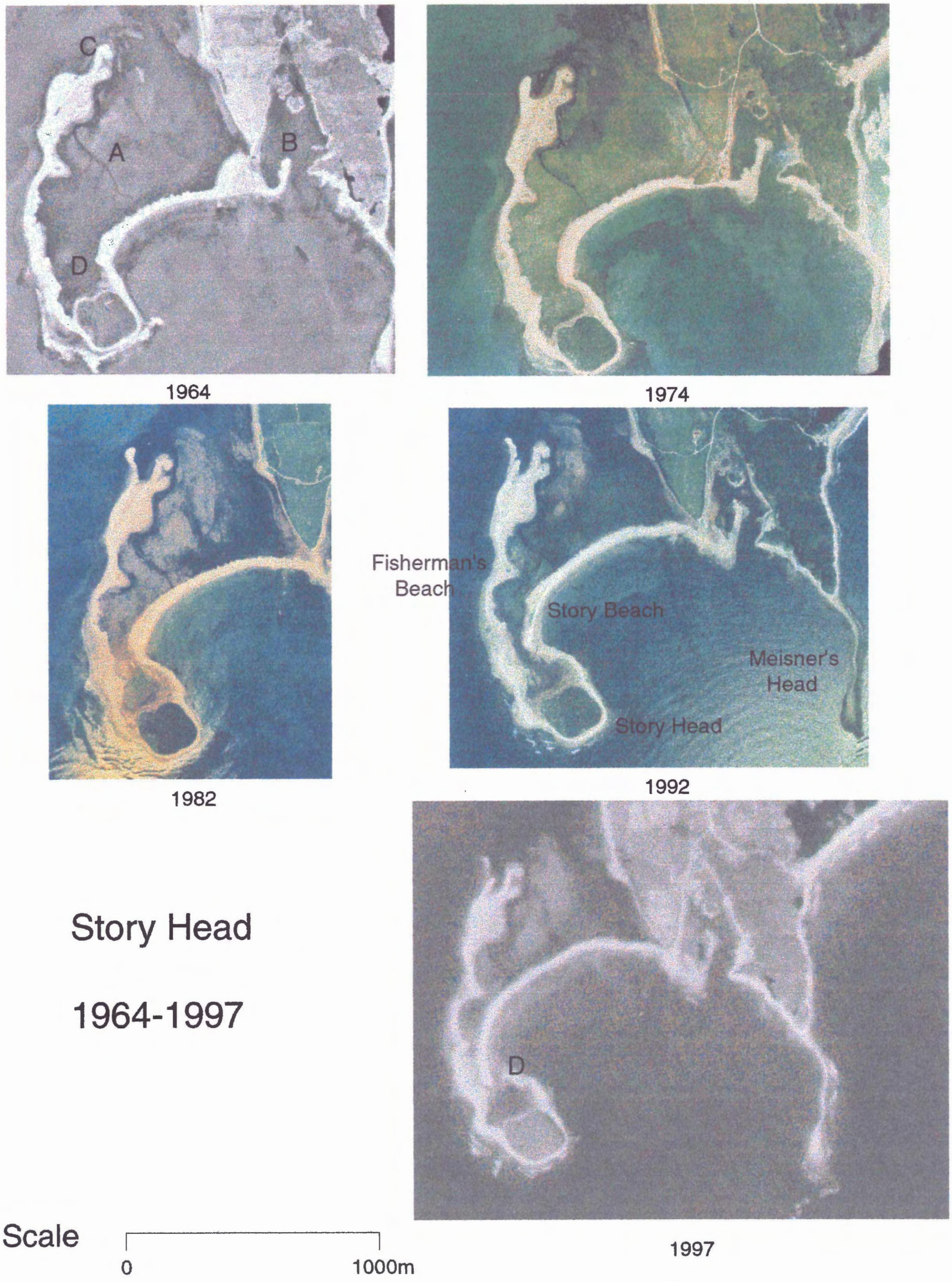


Figure 4.3 (c) A= narrowing of beaches, B=extension of spit, C=extension of finger spit, D= closing of Story head lagoon.

1964-1974

The width of Story Head (distance between Fisherman's and Story Head beaches adjacent to the headland, labeled A in Figure 4.3c) decreased by 130m during the 10-year interval (labeled A in Figure 4.3c). The Story Head beach is moving landward in a transgressive cycle, while the Fisherman's beach is remaining stationary, causing this narrowing. The spit to the west of Meisner's Head has extended from 160m in 1964 to 270m in 1974 (labeled B in Figure 4.3c). In the northern section of the Fisherman's beach a finger spit had formed by 1974 (labeled C in Figure 4.3c). This does not appear to have been the result of sediment accumulation, but rather sediment migration, as a "bulge" of sediment in 1964 (in the same area) has transformed its shape into the finger spit shape seen in 1974.

1974-1982

The Story Head beach continues to move landward causing the width to decrease a further 70m, leaving the width between the beaches at 300m. The finger spit, which formed in 1974, has continued to change shape, while the volume of sediment in the area has stayed about the same. A significant narrowing has occured directly north of Story Head itself. The landward movement of the eastern beach has caused a "bottle neck effect" directly north of Story Head, the two beaches have almost joined in this area producing a narrow 50m wide swath. (labeled D in Figure 4.3c).

1982-1992

The landward movement of the beach continued in this 10-year interval. The width between the beaches decreased a further 50m, leaving the total width at 250m. The width of the channel directly north of Story Head is now only 35m.

1992-1997

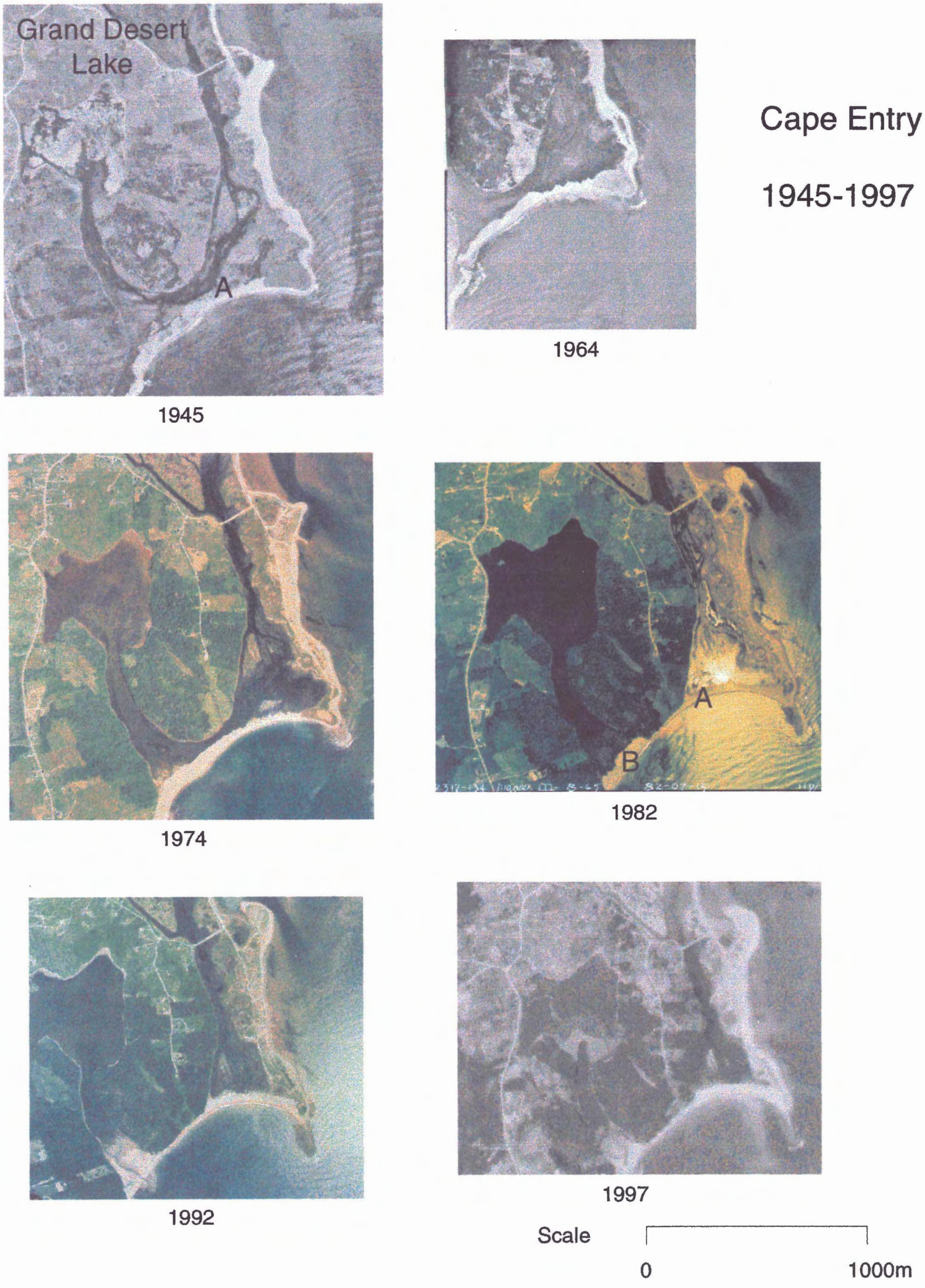
This short 5-year interval is characterized by drastic changes at Story Head. The two beaches have joined directly above Story Head, isolating the northern channel and causing a lagoon-like structure directly above Story Head. The Story Head beach moved over 30m landward in this 5-year time interval. The connection of the beaches and the changes to the channel system could lead to drastic morphological changes to the Story Head area in the immediate future. In addition to the major changes observed, a finger spit north of the Fisherman's beach has broken off from the main spit and has become isolated.

4.2.5 *Cape Entry*

Observing Cape Entry using this methodology, two major changes will be examined closely; the infilling of the base of Grand Desert Lake (labeled A in Figure 4.3d) and the closing of the lagoon to the southeast of Grand Desert Lake (labeled B in Figure 4.3d).

Cape Entry

1945-1997



1945

1964

1974

1982

1992

1997

Figure 4.3 (d) A= lagoon closure B= sediment infill

1945-1964

The lagoon starts to close during this time period. The distance between the headland and the beach has decreased from 180m in 1945 to 110m in 1964. The infilling of Grand Desert Lake has not yet begun. The infilling of the lake is dependent on the closing of the lagoon. Once the lagoon closes, the sediment transport rate of the beach sediment directly to the south of Grand Desert Lake in the lagoonal direction is zero, because there is now no mode of sediment transport (water). Any storm activity would then wash the accumulated sediment off the beach and in the direction of the channel that feeds Grand Desert Lake, where it accumulates.

1964-1974

The lagoon continues to close, the distance between the headland and the beach is 80m. As a result of the lowered channel velocity, the sedimentation rate in the lagoonal path has decreased. Some of the sediment is finding alternate routes and it is during this time period that the first evidence of sediment infill of Grand Desert Lake is observed.

1974-1982

In the 1982 air photograph the distance between the headland and the beach is 0m, and the lagoon has been closed (from the personal experience of D.B Scott and F.Medioli, the lagoon was open at least as late as 1976). The beach moved 80m landward in an 8-year interval. The portion of the beach which reached the headland is now noticeably thinner, a result of the immediate reduction in sediment accumulation. Infilling of Grand Desert Lake continues, the sediment now reaches 200m into the lake from the beach origin, compared to 130m in 1974.

1982-1992

With the lagoon now closed the only change that occurs at Cape Entry during this time period is the continued infilling of Grand Desert Lake. The sediment continues to accumulate in the channel connected to Grand Desert Lake. It reaches a distance of 250m from the beach in 1992.

1992-1997

The sediment does not have appear to have moved in the channel during this short time period, remaining at 250m from the beach in 1997.

Chapter 5: Discussion

5.1 Introduction

Discussion of the results is divided into four sections. The first section compares the author's results with the Scott (1980) study on which this project is based. The second section compares the author's results with the study of Carter et al. (1990) who studied the development of Story Head. The third section of the discussion compares the author's results with the model of sea-level change in the Holocene epoch. The last section will discuss the implications and conclusions of the author's results. The goal of this chapter is to provide a broad spectrum of comparison and results in which to make proper conclusions about the author's data and observations in the subsequent Conclusion chapter.

5.2 Comparison with Scott (1980) Study

Scott (1980) concluded that two major episodes of sedimentological and morphological changes had taken place in Chezzetcook Inlet: a drastic episode between 1766 and 1854 and a well-documented episode between 1945 and 1974. Based on the results of the composites the author agrees with the sedimentological and morphological changes observed by Scott, but disagrees with time periods between the changes and their environmental causes.

The well-documented period of marsh development and spit migration described by Scott (1980) is correct in its description but is in the incorrect time period. The composites composed by the author clearly show that the changes described by Scott occurred in the 1945-1964 time period, not the 1945-1974 period. This correction can be made because of the availability of air photos from 1964, not used in Scott's 1980 study.

Environmental pressure on Chezzetcook Inlet caused the morphological changes observed during the 1766-1854 period. Scott (1980) concluded that the changes were the result of increased sedimentation on a regional scale through the increase in the amount of terrestrial sediment supplied to the inlet as a result of the farming practices and logging introduced by the early European settlers 200 to 300 years ago. While this is probably an important factor (in marsh development of the West Head and East Head areas), this alone cannot account for the drastic changes occurring at Story Head and Cape Entry during this time period. Story Head and Cape Entry are chiefly composed of coarse-grained gravel till. The 1766-1854 period was characterized by major transformations in the configurations of these headlands. In 1766 the entrance to Chezzetcook Inlet was too narrow to allow Cook's ship to enter (Scott, 1980). In 1854 the entrance was much larger due to the migration of gravel spits and transformations to the headlands. Major channels in the inlet were also much shallower (the mouth of the inlet shows 2.5 fathoms in 1766 and 1 fathom in 1854). A significant source of sediment movement, such as a storm, is needed to move this large volume of gravel. Deforestation of the area could not be the sole cause of the migration. Historical records shows that seven major storms (Delure, 1983) hit the Halifax area during the 1766-1854 period. A succession of erosion and migration caused by storms could be an explanation for the significant movement of gravel.

5.3 Comparison with Carter et al (1990) Story Head Study

The Carter et al. (1990) study involved morphological changes to Story Head and its beaches in the 1945 to 1974 time period. This study also used air photographs, resulting in maps and images of Story Head (Figures 5.1 and 5.2) showing the changes occurring during the 1945 to 1974 time period.

Carter's study concludes that the retreat of Story Head has occurred in two phases. Firstly, after 1954, the Story Head barrier began to move rapidly onshore, an acceleration that coincided with a portion of the barrier underwater. Secondly, since 1985, the rate of translation has been approximately 3-6m/year while the Story Head beach continues to move landward towards Fisherman's beach.

Carter et al.(1990) indicated that the rate of movement of Story Head beach has been 3-6m/ year since 1985. Atkinson's 1982-1992 data on Story Head beach indicates the beach moving 50m during this period or ~5m/year. The 1992-1997 data from my study indicates the beach moving 30m during this period or ~6m/year. The present Story Head is the remnant of a much larger drumlin, the scar of which may be traced onshore north of Meisner's Head. The total sediment released from this drumlin would be in the order of 10^6 to $10^7 m^3$,of which 10^5 to 10^6 m^3 would be composed of coarse gravel and sand (Carter et al.1990). As the drumlin erodes, the coast develops both morphological and sedimentological feedback. Of importance is the segregation of the sediment supply

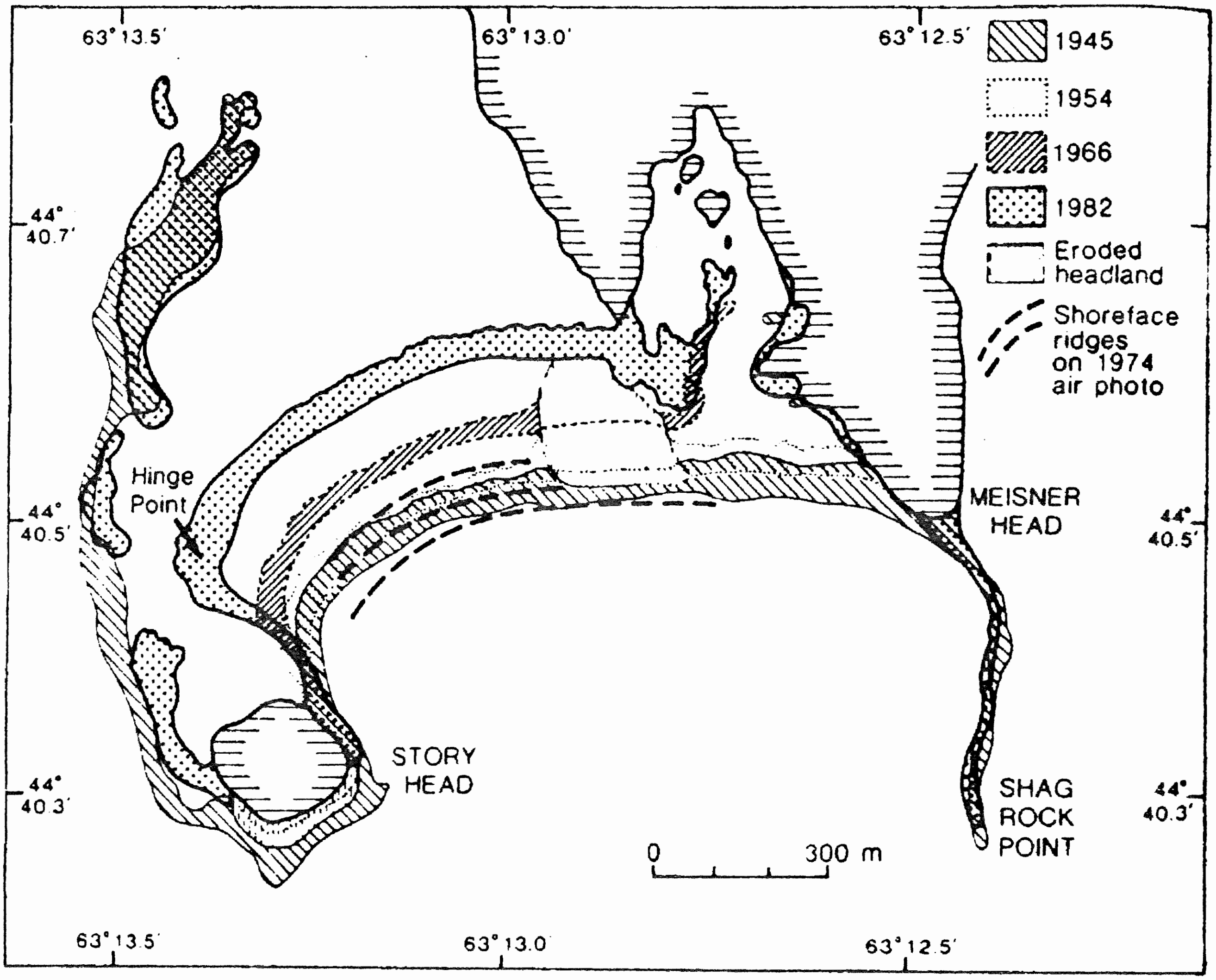


Figure 5.1 Coastal changes at Story Head and on flanking barriers between 1945 and 1982, taken from air photographs (Carter et al. 1990).

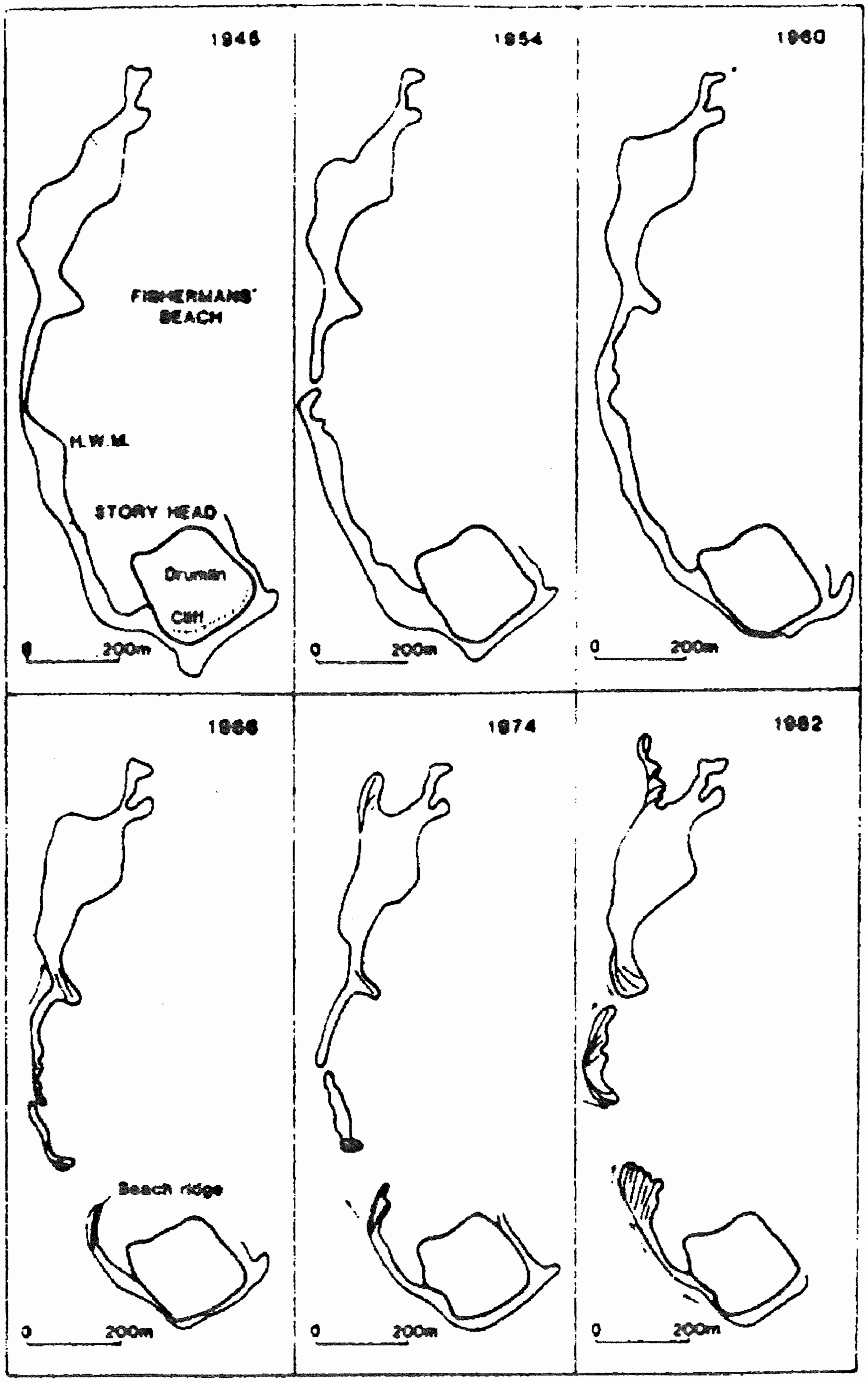


Figure 5.2 Changes in spit configuration on Fisherman's Beach between 1945 and 1982, from air photographs (Carter et al. 1990).

into sub-populations. Once established, these may influence shoreline development over a long period of time.

Sediment eroded from the drumlin has accumulated in the Story Head area, Chezzetcook Inlet area, and offshore. Carter et al. (1990) indicated that Fisherman's beach has accreted ~4000m^3 of gravel and coarse sediment since 1945. The author observed Meisner's Head and a spit to the west becoming progressively larger from the 1945 to 1997 period (Figure 4.3c). Although no quantitative data exist, sediment eroded from Story Head drumlin has accumulated in Chezzetcook Inlet. Accretion of this sediment is partly responsible for the morphological changes observed in the lower part of the Inlet over the past 50 years (possibly longer).

The intent of this comparison of the author's data and observations with that of the data and observations of Carter et al.(1990) is to complement and reinforce the usage of air photography as a tool in observing change in Chezzetcook Inlet. Carter et al. (1990) used air photography from periods unavailable to the author (1954, 1960, and 1966). These time periods combined with the 1982-1997 period covered by the author but not covered by Carter et al.(1990) provides a more detailed study of Story Head. The erosion rate of Story Head beach (3-6m/year-Carter and 6m/year-Atkinson) and the morphological changes at Story Head are in agreement in both studies.

5.4 Comparison with Holocene Sea-Level Change

As discussed in Chapter 2, relative sea level is rising on the eastern shore of Nova Scotia at a rate of 20cm/100 years (Scott et al.1995). A sea level curve for Chezzetcook

Inlet is shown in Figure 5.3 (Scott et al.1995). This curve shows a rapid rise of sea level between 4500 to 3500 years ago (~1m/100 years) and a slower sea level rise to 20cm/100 years for the past 3500 years. From stratigraphic work completed in Chezzetcook Inlet (Figure 5.4) indicates the marsh at West Head is approximately 80cm above mean sea level (Scott, 1980). The lower part of the deposit is 70cm below mean sea level (the deposit is 1.5m thick). Lowest marsh begins to colonize mudflats at or slightly below mean sea level. Therefore mean sea level must have been 40 –70cm lower at the time this deposit began to form. The last 200 years can have an assumed 20cm/100 year rate of sea level rise, therefore 200 years ago the relative sea level was 40cm lower than present (Scott, 1980). The 1766-1854 time period fits into the 200-year interval. Hence, the marsh area in the northern portion of Chezzetcook Inlet was probably not present or just forming in 1766. The morphology changed from a intertidal mudflat to an area of marsh colonization. The change in morphology in the last 200 years can be linked to the coming of the European settlers and their logging and farming practices that added sediment to the mudflats. Sediment migration from storm activity is unlikely to have reached the West Head and East Head areas. Sea level is rising in the area (20cm/100 year) and drowning should be expected, but sediment supply has been able to outpace sea level rise to substantially fill the upper part of the inlet. This is significant environmentally and geologically because the coming of European settlers had indirectly caused wide-reaching changes to a previously stable marine environment. The recognition that the changes were caused by human activities may aid the planning of future developments along the coastal zone (Scott, 1980).

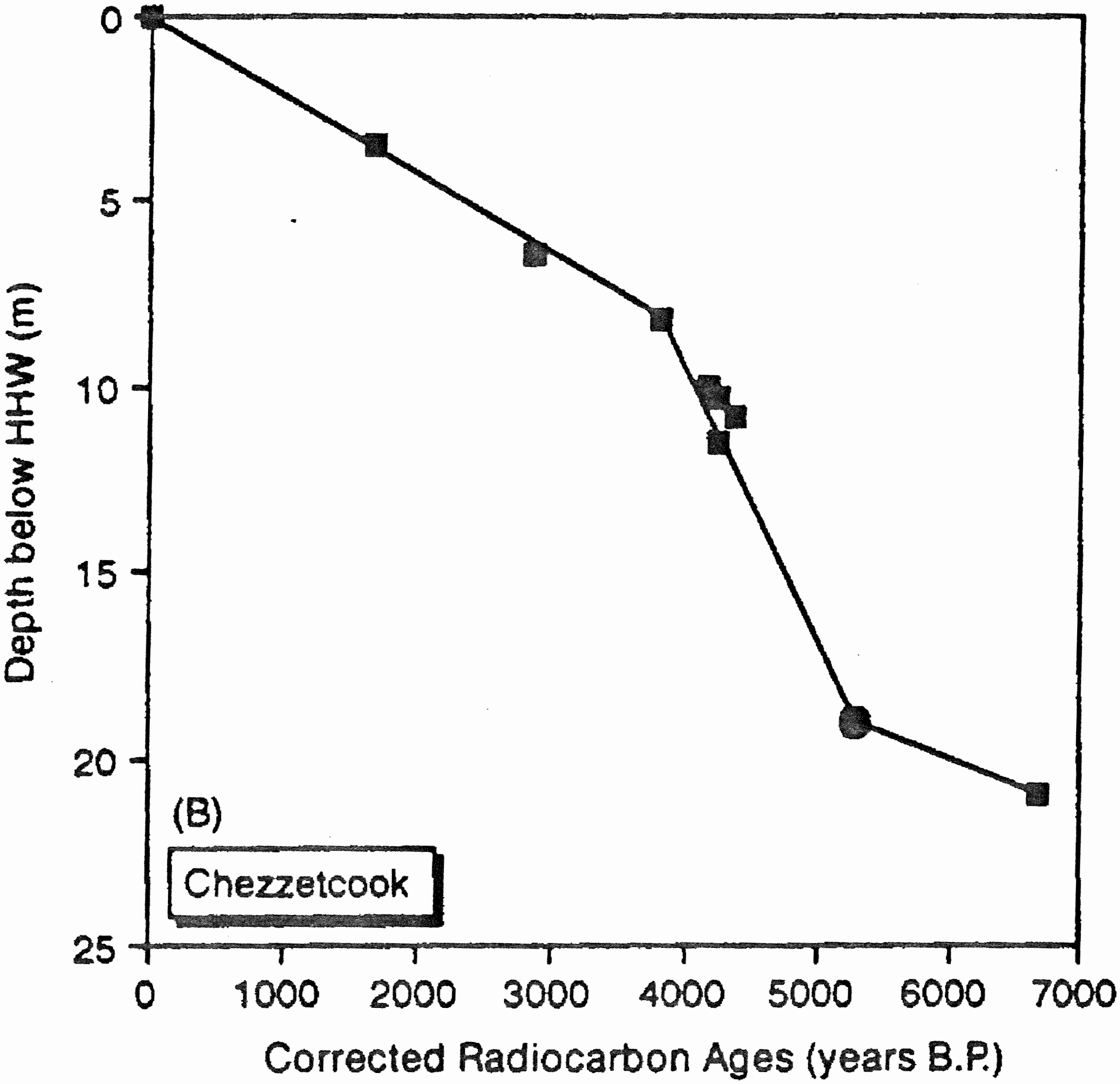


Figure 5.3 Sea level curve for Chezzetcook Inlet (Scott et al. 1995).

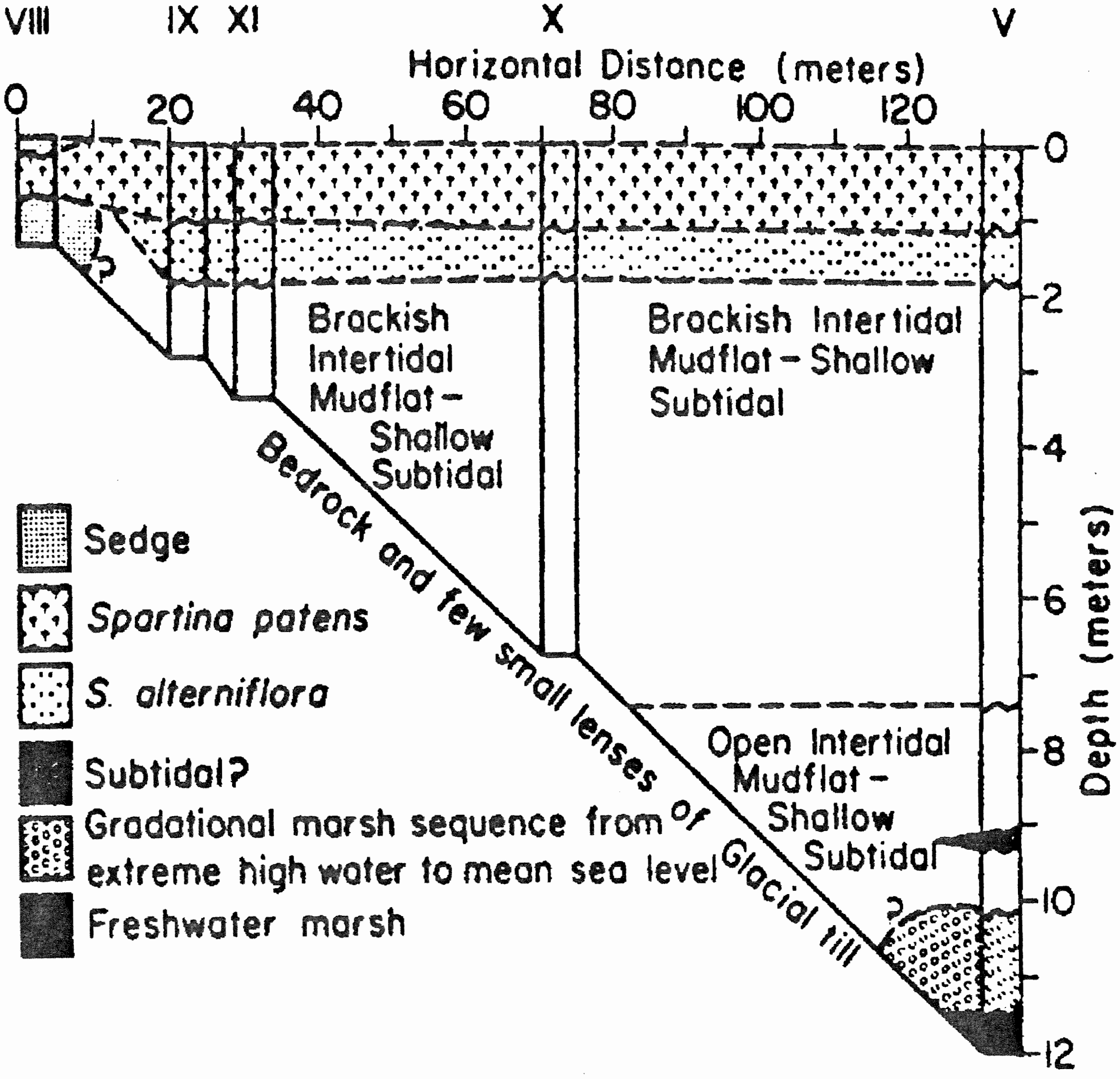


Figure 5.4 Drill hole stratigraphy from West Head based on foraminiferal content in the sediments (Scott 1980).

5.5 Implications of Authors' Results

Two major sedimentological and morphological changes appear to have taken place in Chezzetcook Inlet over the past 232 years: a dramatic episode between 1766 and 1854, and a well documented episode between 1945 and 1997. The first episode was apparently a more regional event with effects in at least two separate harbors (Three Fathom and Chezzetcook) (Scott, 1980). The second episode is confined to the Chezzetcook Inlet area.

Changes between 1766 and 1854 are associated with the growth of sand and gravel spits near the inlet entrance. The enlargement of the spits near major channels, such as the spit on western Conrad Island, may have caused changes in the current speeds and therefore the sedimentation rates, possibly promoting much of the new marsh that formed between 1945 and 1997. The regional marsh and spit growth between 1766 and 1854 is more difficult to account for. The apparent formation of marsh and shallowing of channels is inferred to have taken place as a result of an increase in sedimentation on a regional scale due to an increase in sediment supply. The most likely explanation is an increase in the amount of terrestrial sediment supplied to the inlet as a result of logging and farming practices introduced by early Europeans settlers 200 to 300 years ago (Scott, 1980) with small contributions of sediment coming from storm activity.

Changes between 1945 and 1997 are associated with the extensions of spits and marsh colonization. The drastic growth of Red Island, lagoon closure and sediment infilling at Cape Entry, beach migration and lagoon formation at Story Head, and the extension of spits and marsh colonization at the Three Islands highlight these changes. The causes of changes between 1945 and 1997 are manifold compared to the agents of change in the 1766-1854 period. The growth of Red Island and the spit extensions at the Three Islands and marsh colonization are manifestations of sediment migration and accretion. Construction in the area, storm activity and other human activities could have provided enough sediment input into Chezzetcook Inlet to account for these morphological changes. The lagoon closure and sediment infilling at Cape Entry and the beach migration at Story Head indicate transgressive characteristics and are attributed to the rising sea level. The rising sea level and a minor amount of storm activity have caused drastic drumlin erosion at both Story Head and Cape Entry during the 1945-1997 period. The seaward drumlin face at Cape Entry is eroding at a rate of ~9m/year (Gavin Manson, personal communication), while the drumlin face at Story Head is eroding 3-6m/year (Carter et al. 1990). At Cape Entry, the headland has eroded to the beach, causing a lagoon to close and is directly responsible for the transport of sediment into Grand Desert Lake. At Story Head, relative sea-level rise has caused the landward movement of Story Head Beach and the accretion of gravel on Fisherman's Beach, but has not eroded the drumlin as observed at CapeEntry.

Further highway construction across East and West Head in 1988 is probably responsible for sediment input and the resulting marsh colonization of the area east of Red Island (Figure 4.2). This is significant environmentally and geologically because there is strong evidence that the construction across a marsh region has indirectly caused wide-reaching changes to a previously stable marine environment. The recognition that the changes are caused by human activities may aid the planning of future developments along the coastal zone.

Chapter 6: Conclusion

6.1 Conclusions of Study

Two major sedimentological and morphological changes appear to have taken place in Chezzetcook Inlet over the past 232 years: a dramatic episode between 1766 and 1854, and a well documented period between 1945 and 1997.

Changes between 1766 and 1854 are associated with the growth of sand and gravel spits near the inlet entrance. The most likely explanation is an increase in the amount of terrestrial sediment supplied to the inlet as a result of logging and farming practices introduced by early Europeans settlers 200 to 300 years ago (Scott, 1980) with small contributions of sediment coming from storm activity.

Changes between 1945 and 1997 are associated with the extensions of spits and marsh colonization. The drastic growth of Red Island, lagoon closure and sediment infilling at Cape Entry, beach migration and lagoon formation at Story Head, and the extension of spits and marsh colonization at the Three Islands highlight these changes. Construction in the area, storm activity and rising sea level provide enough sediment input into Chezzetcook Inlet to account for these morphological changes.

Further highway construction across East and West Head in 1982 is responsible for sediment input and the resulting marsh colonization of the area east of Red Island (Figure 4.2). This is significant environmentally and geologically because the construction across a marsh region has indirectly caused wide-reaching changes to a previously stable marine environment. The recognition that the changes were caused by human activities may aid the planning of future developments along the coastal zone.

6.2 Recommendations for Future Work

To better represent the data in the future combining this project with a GIS system is vital. GIS is an information system applied to geographical and geological data. GIS systems use geographically referenced data as well as non-spatial data in the contexts of data capture, data management, manipulation of data, analysis, modeling and display.

In relation to the author's project, the first step in implementing a GIS system to the measured and observational data is to rasterize each individual air photograph composite. Rasterizing converts the composites into many small "cells" which have their own values of space in the image. The rasterized composites would then be orthorectified. Orthorectification can be done in some GIS programs; this corrects the composites' inherent distortion due to the air photographs, and adds correct elevations to the image (all areas are represented as flat in normal air photography). Attribute values can now be assigned to each of the cells in a composite. For example, a cell that is marsh would be assigned a 1 value, sand a 2 value, roads a 3 value, etc. This is a time consuming effort that is needed because the composites are now in a binary form. Each cell has a numeric value, and then layers and other composites could be manipulated to the users wants and needs. For example, to get a numerical area of marsh growth from two sequential time periods, requires overlaying the two binary images; where the marsh values have changed their binary number in the resulting new image there is new marsh growth. Areas, perimeters, hectares and other measurements are can be made using this method. Using a GIS in this capacity will result in quicker, diverse and more reliable data than the author's data in this study.

Appendix A

See attached laminated air photograph composites of Figures 4.1 (d-I)

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