COASTAL EVOLUTION AT GRAND PRE

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Abstract

This study builds on the work of Manning (2010) by introducing new data that further develops the coastal evolution of Grand Pré. Grand Pré is a Canadian National Historic Site that is in the process of becoming a UNESCO heritage site because of its rich Acadian history. The Grand Pré area, located in the south-west region of the Minas Basin, consisted of tidal marshlands before the Acadian settlers arrived in the late 1600s. Acadian settlers converted salt marsh and mudflats to farmland using dykes. This study focuses on the western region of Grand Pré and seeks to identify transgressive and regressive cycles from sediments collected using vibracoring techniques. Sediments are analysed for Foraminifer content using a microscope. The high to middle marsh is identified by the presence of *Trochammina inflata, Trochammina macrescens,* and *Tiphotrocha comprimata* while mudflat regions are identified by the presence of *Haynesina orbiculare* and *Elphidium williamsoni*. The new data highlights an important transgressive event experienced in the region. It also indicates that Acadian influence decreases in the western region.

Key words: Grand Pré, Minas Basin, Acadian, vibracore, Foraminifer, marsh, mudflat, *Trochammina inflata, Trochammina macrescens, Tiphotrocha comprimata, Haynesina orbiculare, Elphidium williamsoni*

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CHAPTER 1: INTRODUCTION

1.1 Study area

1.1.1 Grand Pré

Grand Pré is a rural community that lies in the south-west region of the Minas Basin in the Bay of Fundy in Nova Scotia (Figs. 1.1 & 1.2). The Gaspereau and Avon Rivers discharge along the eastern shore of Grand Pré. The Gaspereau River is to the south while the mouth of the Avon River is located east of Grand Pré. The Cornwallis River, which is west of Grand Pré, discharges on its western shores. Grand Pré is approximately 4 km wide and 3.5 km in length. Long Island is located to the north and it is about 50 percent built up (infrastructure present) while the rest is mostly wooded. The Grand Pré National Historic site is located in the south of the region. The majority of the central regions of Grand Pré are cultivated farmland, which is where this study was conducted.

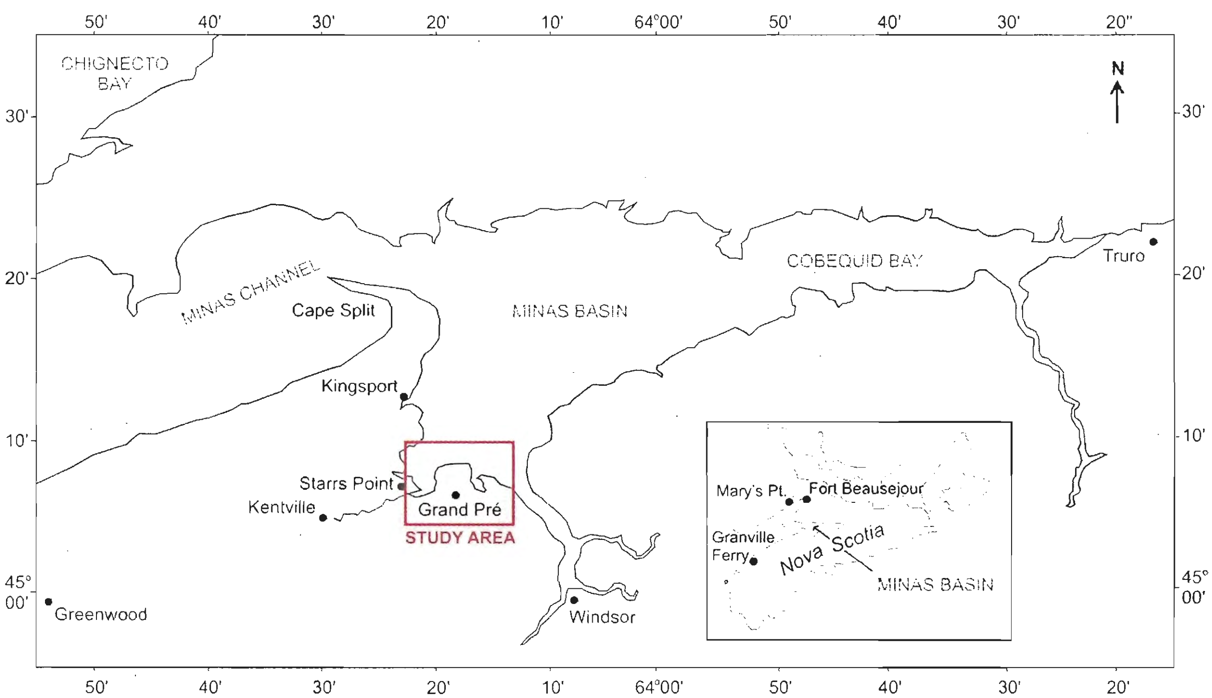


Figure 1.1: Regional map of the Minas Basin illustrating the location of the Grand Pré study area (after Manning (2010) and Amos and Mosher (1985).

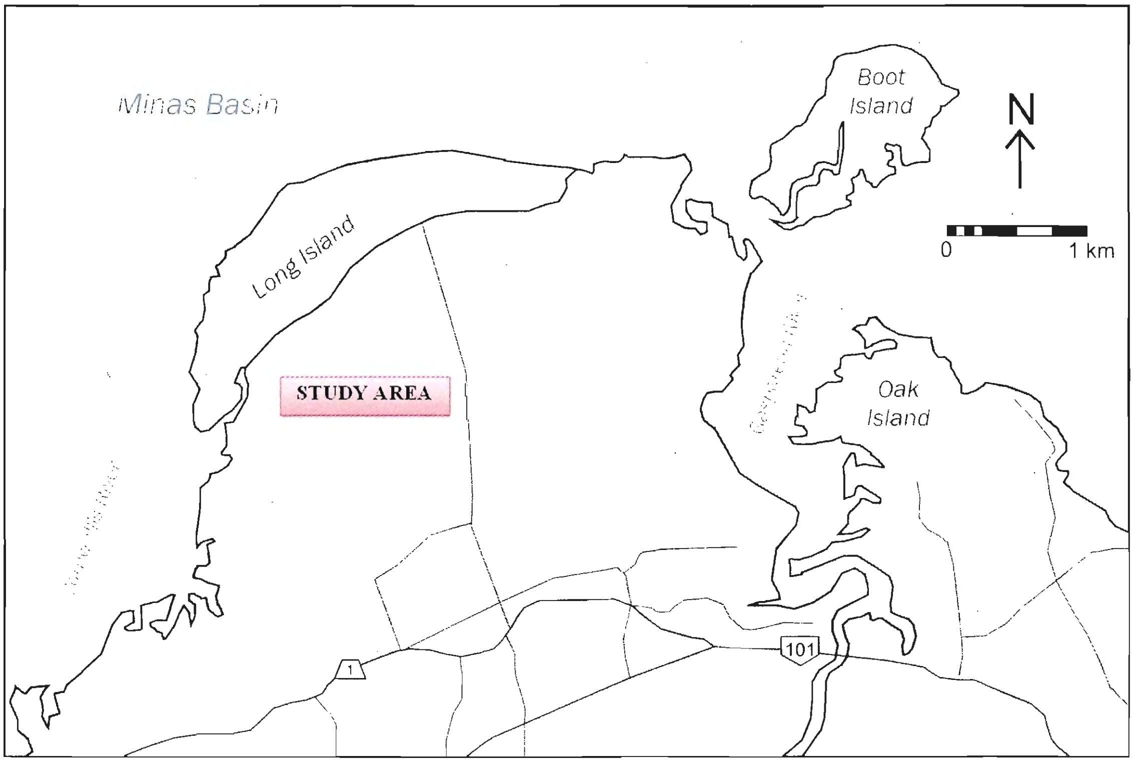


Figure 1.2: Map of Grand Pré showing the location of the study area (after Manning, 2010)

1.1.2 Bay of Fundy

The Bay of Fundy is located between New Brunswick and Nova Scotia and off the state of Maine on the Atlantic coast (Fig.1.3). It is underlain by the Fundy Basin which is an early Mesozoic rift basin (a half-graben). Desplanque and Mossman (2004) explain that Paleozoic (or older) faults on the northwestern margin of the Fundy Basin were reactivated in the Early Mesozoic (at the onset of the opening of today's Atlantic Ocean). This resulted in continental sedimentation and sedimentary infilling of the Basin through to the Mid Triassic. By the Triassic-Jurassic transition, large volumes of basaltic magma were deposited on Triassic sediments followed by further clastic sedimentation until the Mid Jurassic. This sedimentary-igneous sequence was then folded, uplifted, and tilted. Cretaceous sediments appear to have then been deposited mainly in available pockets of lowlands.

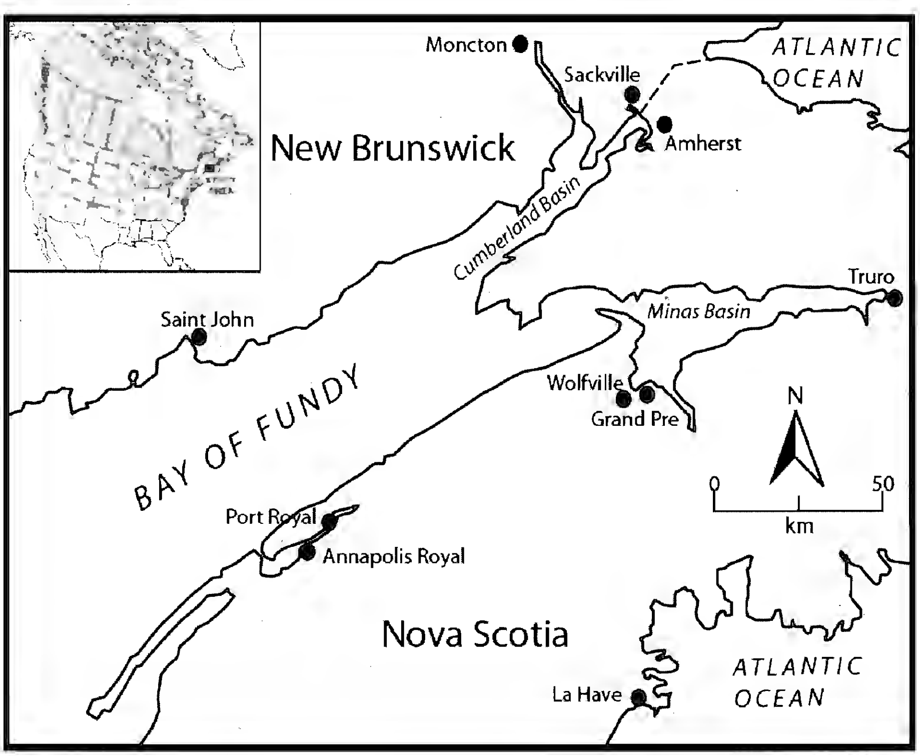


Figure 1.3: Location of the Bay of Fundy (after Graf and Chmura 2010)

By the Early Wisconsin the Laurentide ice sheet covered most of Canada, extending as far as the Great Lakes to the south. Swift and Lyell (1967) suggest that repeated Quaternary glaciations downcut into the Bay of Fundy creating a relatively flat striated floor with troughs filled glacial drift, submarine moraines, and boulder fields. During the late Quaternary, the Fundy coast experienced emergence due to land depression from the weight of ice. Emergence, described by Welsted (1976), is the upward movement of land, relative to sea level, resulting from uplift in land, a drop in sea level, or a combination of the two as the ice load melts and the mantle below can flow back to its original position (Quinlan and Beaumont, 1981). Therefore it is usually called "relative" sea–level rise. By the Mid-Wisconsin, as the last ice sheets receded, the depth of the Bay of Fundy decreased as the land surface rebounded faster than the sea level could rise. The Fundy Basin can be divided into three Triassic sub-basins which are half grabens, each with a strike-slip component; they are the Fundy, Minas, and Chignecto sub-basins.

Bay of Fundy Tides

The Bay of Fundy-Gulf of Main tidal system has its smallest tidal amplitude at the edge of the continental shelf from which the tidal amplitude becomes gradually amplified through the system to the upper Bay of Fundy, where the largest tides are found (Scott & Greenberg, 1983). The amplification factor ranges from 1m (one), on the edge of the continental shelf, to over 16m in the macrotidal areas in the Minas Basin (Fig. 1.4). Tidal amplitudes have increased at a non-uniform rate over time. According to Scott and Greenberg (1983), tidal amplitude increased most rapidly between 7000 to 4000 years ago and increased least rapidly from 4000 years ago to present. The major factor affecting the tides of the Bay of Fundy (and their amplitudes) is the water depth over Georges Bank (and not relative sea- level changes within the bay). Today, the

Bay of Fundy contains the world's largest tides, with amplitudes as high as 16 metres and a period of 12.42 hours.

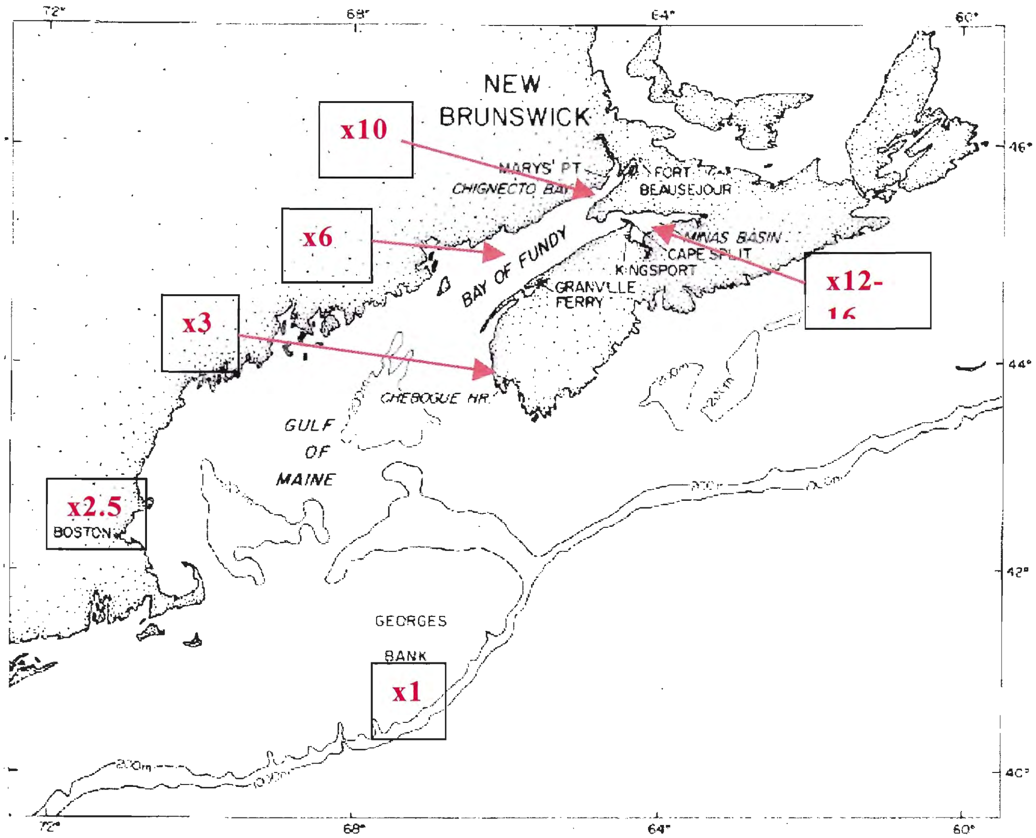


Figure 1.4: Tidal amplification for the Bay of Fundy – Gulf of Maine system. Map shows the amplification factor which ranges from 1 to 16 for regions within the tidal system (modified after Scott and Greenberg, 1983).

Minas Basin

The Minas Basin contains approximately 1050 metres of Triassic successions, the thinnest of all three sub-basins (Fig. 1.5). The Wolfville Formation is 800 metres thick and the overlying Blomidon Formation is 250 metres thick. The North Mountain Batholith is a composite basalt bed that caps the Blomidon Formation. It is located near the Triassic-Jurassic boundary (Leleu and Hartley, 2010). The Wolfville Formation lies unconformably on the Carboniferous metasediments of the Meguma Terrane (Leleu and Hartley, 2010).

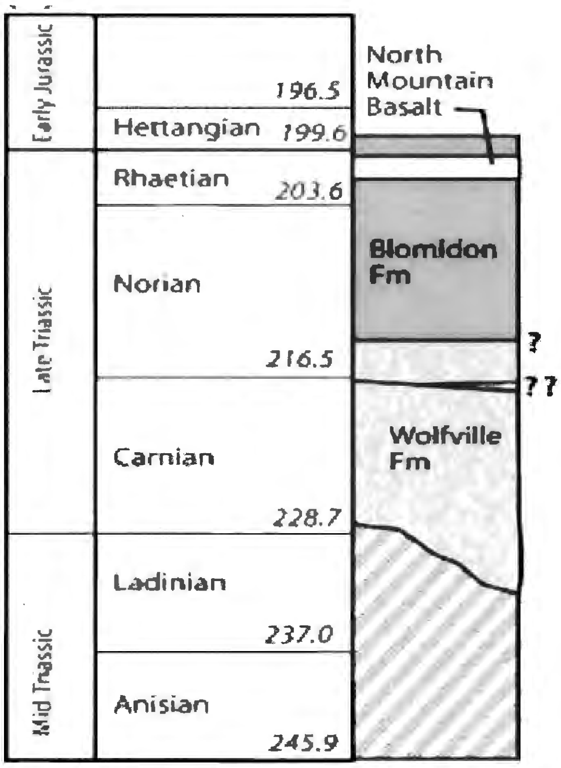


Figure 1.5: Stratigraphic History of the Minas Basin (after Leleu and Hartley, 2010)

Grand Pré - Geology

Most of Grand Pré is underlain by the Triassic Wolfville Formation of the Fundy Group (Fig. 1.6) (Keppie, 2000). This Formation consists of fine to coarse-grained fluvial sandstones, aeolian dune deposits and alluvial fan sediments (Leleu and Hartley, 2010). The sandstones are fluvial or aeolian, the conglomerates are fluvial and there are also minor deltaic-lacustrine deposits in this Formation (Keppie, 2000). According to Leleu and Hartley (2010), the Wolfville Formation was deposited under semi-arid to sub-humid conditions. The lower part of the formation lies in the south of the Minas Basin while the upper part lies in the south western region of the basin.

Near the south of Grand Pré one can find outcrops of the earlier Carboniferous Cheverie Formation, part of the Horton Group. This Pre-Triassic Formation consists of arkoses, sandstones, siltstones, and conglomerates, all with a fluvial origin (Keppie, 2000)

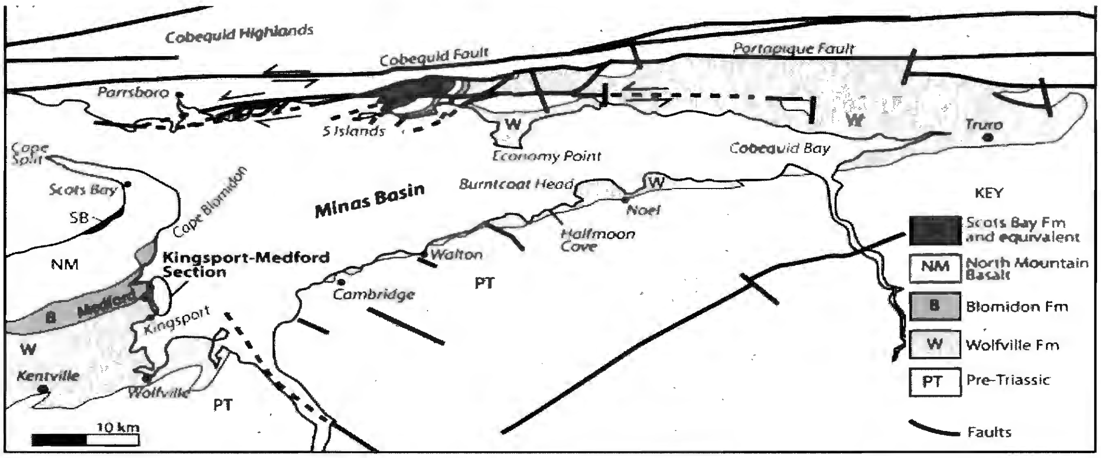


Figure 1.6: Geological Map of Minas Basin (after Keppie, 2000)

1.2 History

Grand Pré is home to the Grand Pré National Historic Site, which commemorates Acadian settlement of the Minas Basin. Grand Pré was first settled around 1680 by Pierre Melanson de la Verdue. The first settlers built dykes which held back the tides along the basin. With the tides held back, rich pastures and fertile farmland were created. By the mid 18^{th} century, Grand Pré had grown to become the largest Acadian community around the Bay of Fundy and the Nova Scotia coastline. In 1713, the area came under British rule but the Acadians remained. By 1744, England and France were at war and by 1755 the Acadians were expelled from Nova Scotia to British colonies in the south from Massachusetts to Georgia. By the end of 1755, over 6000 Acadians were deported from all over Nova Scotia and their villages were burnt to the ground. The deportation continued until 1763 when England and France were no longer at war (Société Promotion Grand-Pré, 2010).

Bleakney (2004) suggests that there were approximately 12 periods of dyke construction at Grand Pré (Fig. 1.7). Each period of dyke construction enclosed a new area of farmland that was made into productive farmland before a new area was developed. The dykes built by the Acadians were made from wet grassy sods that were cut using a specialized type of shovel. At the base of the dykes, they constructed aboiteau or sluice gates to control drainage and facilitate the one-way flow of excess fresh water out of the dyked lands. Dyking progressed from the south-central region (roughly where the National Historic site sits today). Dyking then proceeded roughly north, then east, then west, then east again.

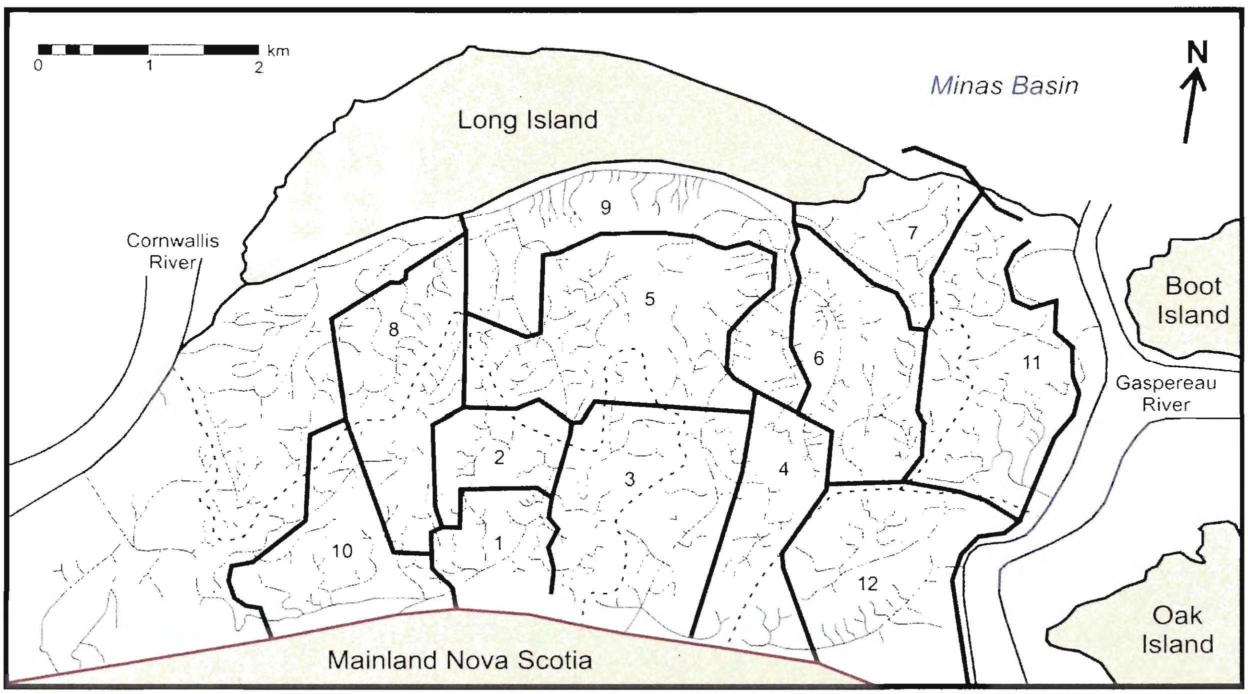


Figure 1.7: Map of Grand Pré showing the location of dykes and farming plots. The plots are ranked numerically from 1-earliest to 12-latest (modified by Manning, 2010, after Bleakney, 2004).

1.3 Transgression and Regression

The position and shape of the coastline at Grand Pré has varied over time. With relative sea level rising, evidence of both pro-gradational and retro-gradational events have been recorded in the sediments (Greenberg and Scott, 1983, Manning, 2010). A transgression is the relative rise of sea level onto the land (Fig, 1.8) (Prothero and Schwab, 2004). A transgression can lead to the development of a retro-gradational system where the shoreline moves landward. Other factors contributing to retro-gradation include decreased sediment supply, increased accommodation space, and subsidence of land (example, tectonic subsidence).

Pro-gradation is the extension of the shoreline, or the building out of the land, into a water body such as a lake or sea, due to excess sediment supply (Fig. 1.8) (Prothero and Schwab, 2004). Pro-gradation can result from a regression or the relative fall of sea level off the land. Other factors contributing to a pro-gradational system include increased sediment supply, decreased accommodation space, and uplift of the land (example, tectonic uplift). Overall, the shoreline moves seaward. The development of a saltmarsh provides evidence of pro-gradation as sediments accumulate and become stabilized by marsh grasses.

When the shoreline appears to be relatively stable, this can be described as aggradation. Neither pro-gradation of retro-gradation of the shoreline is occurring at this time (Prothero and Schwab, 2004). During aggradation, sediment supply is keeping pace with rising sea level.

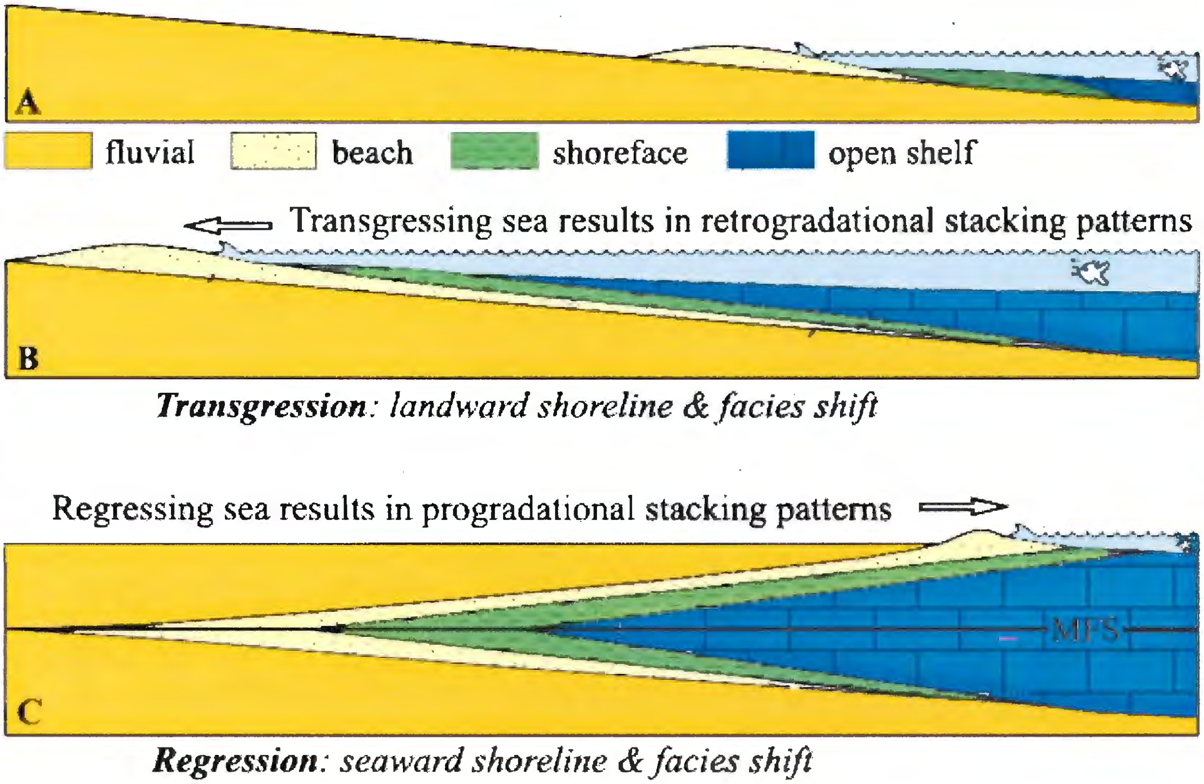


Figure 1.8: Transgression and regression (after Canteneau, 2002)

1.3 Salt Marsh Environment

A salt marsh is a coastal habitat formed on the border of marine and terrestrial environments, displaying characteristics of both environments. Marshes experience large variations in temperature, salinity, and pH (Phleger and Bradshaw, 1966, Scott et al. 2001). The movement and deposition of sediments are key processes that help to shape and develop the marsh. When the region becomes completely inundated by seawater, mudflats form and marsh vegetation becomes drowned. Grand Pré can be described as an estuarine salt marsh (Fig. 1.9) which is highly influenced by both tidal movement and fluvial activity but mostly by the dykes that were put in place in 1680 by the Acadians.

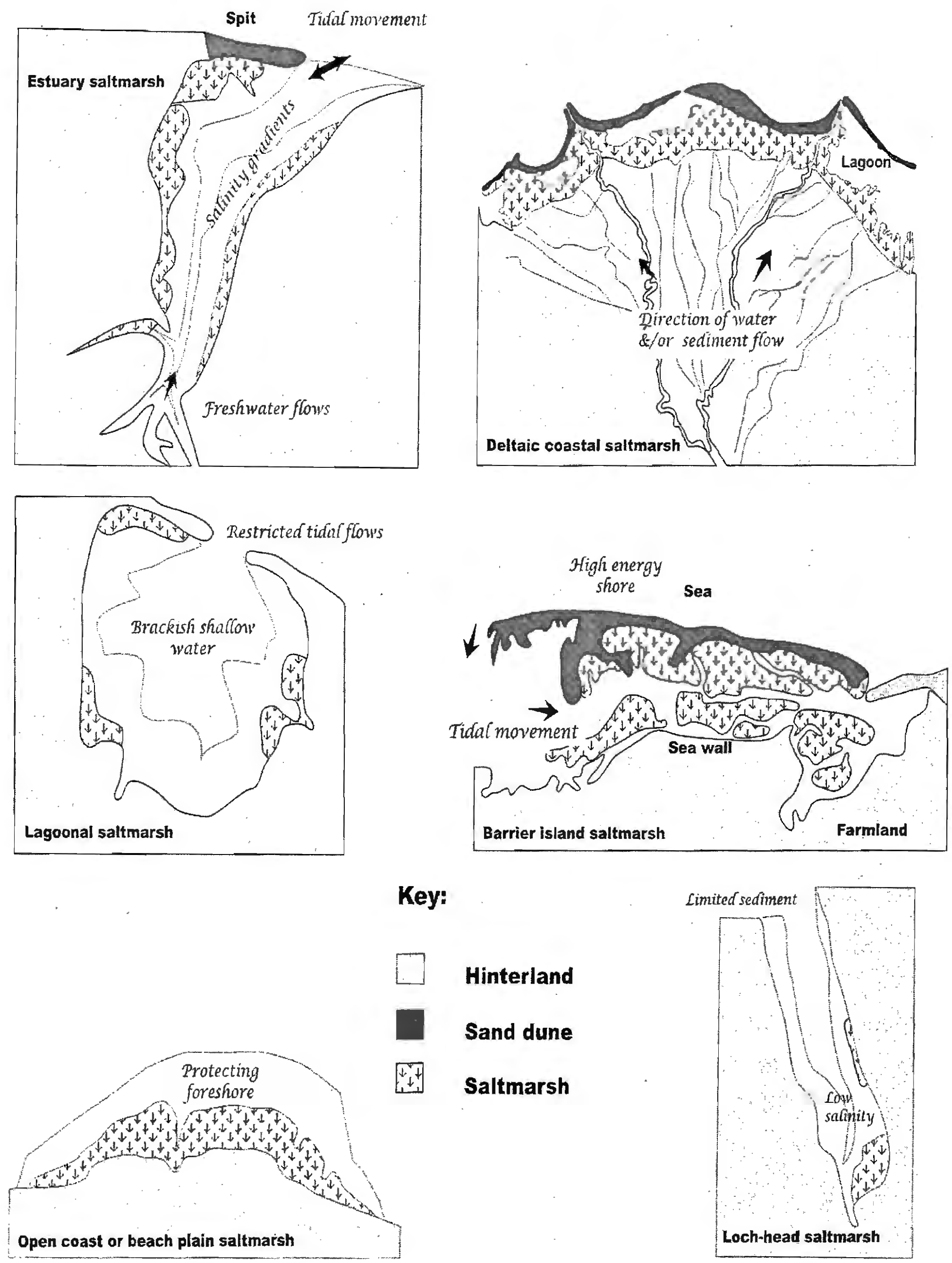


Figure 1.9: Some examples of salt marsh types (after Doddy, 2008).

1.4 Microfossils

Foraminifera belong to the Phylum Sarcodaria, Superclass Rhizopoda and Class Granuloreticulosa. They are unicellular organisms that contain protoplasmic extensions called pseudopodia. Most foraminifera are micro- or meio-fauna sizes, usually less than 1mm in size. Some foraminifera have a mineralized (calcareous) test or shell while others have may have a test composed of organic material and agglutinated sediments (Fig. 1.10) (Haq and Boersma 1998, Scott et al. 2001). Tests have unique characteristics that make it easy to distinguish one species from another. These characteristics include test composition, coiling pattern, chamber arrangement, suture pattern, and umbilicial position (Fig. 1.11).

When they die, foraminifera that produce non-calcareous tests are best preserved as fossils within marsh sediments because of the low pH in the anoxic marsh sediments. They naturally occur in large numbers and because they are so small, they can be easily collected in large numbers, making them a statistically significant population (Haq and Boersma 1998, Scott et al. 2001).

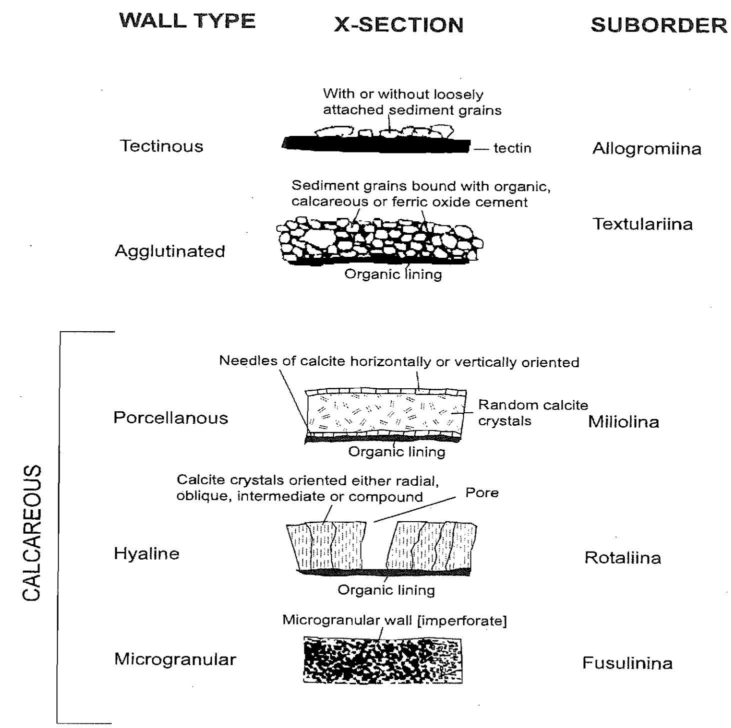


Figure 1.10: Different wall types for foraminifera (Scott et al, 2001)

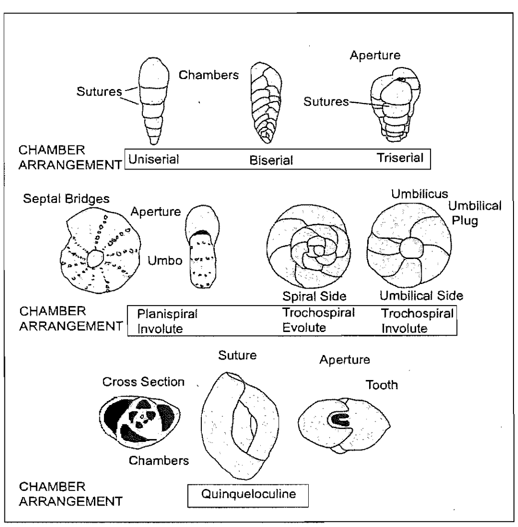


Figure 1.11: Characteristics shapes offoraminiferal tests (after Scott et al. 2001)

Foraminifera occupy every marine habitat, from highest water level to the deepest part of the oceans (Scott et al, 2001). Planktonic foraminifera are pelagic forms that are most abundant in the upper 200m of open oceans; benthic foraminifera live on the seafloor and are abundant in all parts of the world's marine environments (from salt marshes to the deepest parts of the oceans). Agglutinated foraminifera can live in environments of lowered salinities or colder water where calcareous foraminifera are unable to adequately precipitate carbonate. In areas of increased salinity and higher temperatures, agglutinated species are replaced by carbonate secreting foraminifera. If, however, the pH is lowered by low oxygen or high organic carbon (or both), such as in polluted environments and salt marshes, carbonate secreting foraminifera become less abundant or completely absent (Scott et al, 2001).

As shown in Figure 1.12, agglutinated foraminifera are typically found in brackish lagoons, estuaries, or salt marshes. These foraminifera are expected to be present in sediments that represent salt marshes of Grand Pré. Calcareous foraminifera are typically found in more saline environments including normal and hypersaline lagoons, carbonate platforms and shelf seas. Calcareous foraminifera will be expected in areas that represent mudflat zones at Grand Pré. Scott and Medioli (1978, 1980) established that marsh foraminifera, particularly upper marsh species, are similar worldwide and exist in vertical zones that are useful as sea-level indicators. These high marsh species tend to be mostly agglutinated.

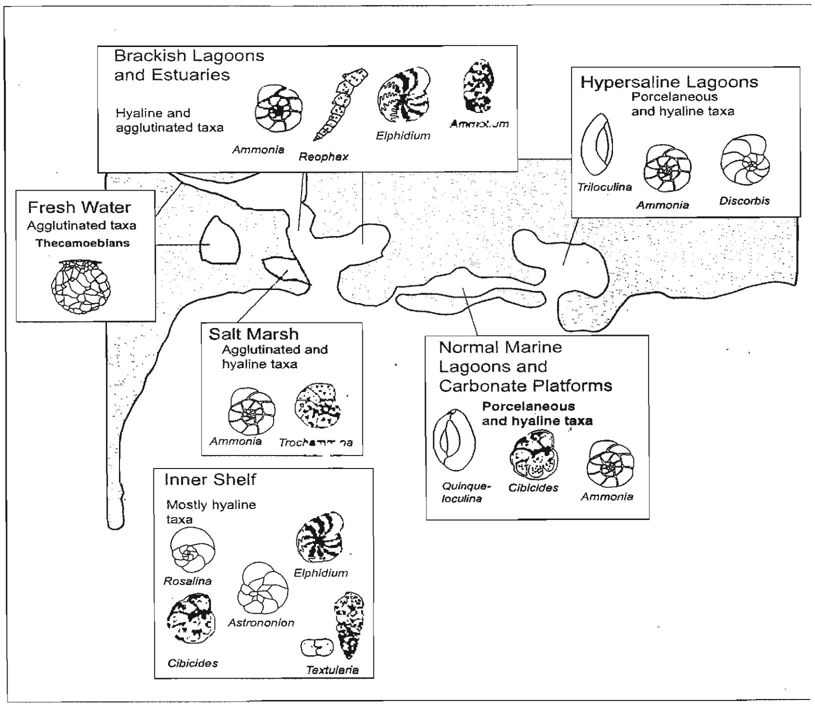


Figure 1.12: Typical foraminiferal distribution within a generalized marginal marine-nearshore environment (after Scott et al, 2001).

1.5 Previous Work

Marsh foraminiferal zonations are a useful and acceptable method to determine mean sea-level changes (e.g. Scott and Greenberg, 1983, Smith et al., 1984). This method is applicable to most tidal regimes including the extreme tidal ranges (16 metres) experienced in the Bay of Fundy. By identifying key indicator species, such as *Trochammina inflata,* for high marsh regions, important information about relative sea level changes was deduced. In the case of the Bay of Fundy a continuous sea-level rise occurred over the past 3525-4400 years of marsh deposition.

Comparable high marsh foraminiferal assemblages were also identified in Brazil by Barbosa et al (2005). Foraminifera include *Trochammina inflata* and *Haplophragmoides wilberti* (and occasionally *Polysaccammina ipohalina*). The Barbosa et al. (2005) study, which was conducted in Brazil, confirmed the value and reliability of foraminfer zonations in the study of mean sea-level changes because their results agreed with those found in temperate regions such Oregon, Maritime Canada, and New England.

Manning (2010) attributed the patterns of sedimentation at Grand Pré to the extreme tidal amplitude in the Bay of Fundy. He estimated that Grand Pré has experienced a 15 percent tidal amplitude increase over the last 3000 years. Bleakney (2004) suggested that the greatest acceleration in tidal amplification occurred approximately 3000-4000 years ago. This was based on the carbon-14 dates obtained for submerged trees (4400 years old) and a bed of oysters (3800 years old). The trees and oysters would have been buried during heavy sedimentation due to rising sea level worldwide and land subsidence in Nova Scotia. This contrasts with the information provided by Scott and Greenberg (1983) who suggested that the greatest rate of increase in tidal amplification occurred between 7000 and 4000 years ago resulting in the total range being strongly macrotidal by 4000 years ago. Scott and Greenberg's (1983) study is based on numerical tidal modeling and sea-level changes at Georges Bank.

Based on the investigation of seven cores, Manning (2010) found that before 2700 YBP, Grand Pré was entirely high marsh (salt marsh). At that time, the coastline was regressing and tidal change was at a standstill or possibly rising. Higher-high water markers identified in cores included *Trochammina inflata* and *Tiphotrocha comprimata*. At 2700 YBP, a local rise in sea level introduced mud, which lead to the creation of an intertidal mudflat that transgressed from the east to west of Grand Pré. The two main lower-low water indicators identified included the foraminiferal species, *Elphidium williansoni,* and gastropods. Following this transgression event, the high marsh rebuilt from the outer edge of the coastline to the centre of Grand Pré, creating a tidal creek system. The next major event was the arrival of the Acadians who dyked the land to control the drainage and create farmland.

CHAPTER 2: METHODS

2.1Vibracoring

Vibracoring is a procedure for extracting sediment cores from a wide variety of depositional environments, from pebble-sized gravel to peat (Fisher, 2004). The vibracore is a portable and light weight device with a low construction cost, simple assembly, and a relatively high rate of penetration in unconsolidated sediments (Smith, 1984). Vibracoring is based on the principle that saturated fine-grained sediments such as sand, silt, or clay, which are loosely packed, which become mobilized by extreme vibrations transmitted through the aluminum core barrel allowing the core to pass through the sediments (Smith, 1984). Coring into moist but unsaturated sediment is slow and difficult (Smith, 1984) while coring into unsaturated soils is nearly impossible (Fisher, 2004).

The vibracore consists of vibrating head attached to an aluminum pipe which is driven in by the strong vibrations generated by the vibracore head (Fig. 2.1). The vibrating head is powered by a gasoline engine. After the aluminum pipe is lifted into the desired position, the device is turned on and prodded into the ground with downward pushing, twisting, and rotating movements to assist penetration. Coring was carried on Friday October 22nd and Friday, November 19th, 2010. Coring was conducted by Dave Scott, Tom Duffet, Rob Fergusson, Catherine Cottreau-Robins and Bertha Louis. A total of 4 cores was collected. The cores were taken to the lab for splitting and observation.

Figure 2.1: Aluminum pipe with vibrating head being vibrated into the ground at Grand Pré

The four cores roughly line up along a transect which runs in an east-north-east to west-south-west direction. The longest core was 389 cm while the shortest core was 165 cm (Table 2.1).

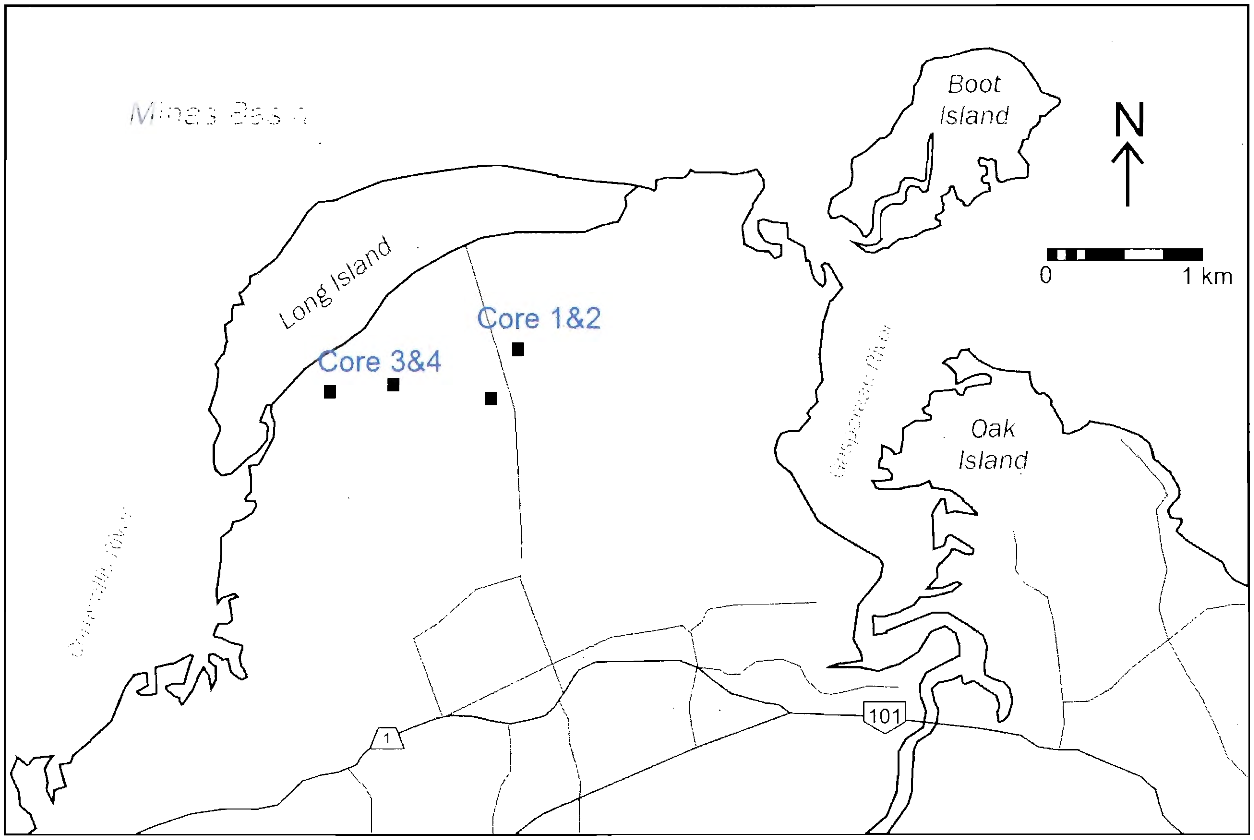


Figure 2.2: Core sampling locations at Grand Pré (after Manning 2010)

Core	**Length (cm)**	**Date collected**
Core 1	165	22nd October, 2010
Core 2	350	19th November, 2010
Core 3	389	19th November, 2010
Core 4	205	19th November, 2010

Table 2.1: Summary of cores collected from Grand Pré

2.2 Core Logging

Each core was split in half, lengthwise. One half was saved for archival purposes while the other half was used for sampling. All cores were sealed in airtight wrapping, labeled, and stored in a cold room. Each core was then logged (Table 2.2); this involved the observation, evaluation, identification, and recording of the various facies present in each. This key process provides useful information necessary to interpret the depositional environment (corelogging, 2010).

Core	**Facies**	**Environment**	**Facies Description**
Core #	Overall colour / Visible processes (oxidation, reduction, etc) / Other	High marsh / middle marsh / low marsh / mud flat	Size of facies, grain size, patterns, status of organics, contact description, etc

Table 2.2: Guide for description of core facies

2.3 Sampling and Processing

Samples were collected at 20 cm intervals down the core. The samples were washed and sieved through a 63micrometre sieve and preserved in alcohol. They were then observed under a microscope at magnifications of 20-50X.

Washing and sieving

Sieving aids in separating foraminifera from moist or wet (unconsolidated) sediment. To concentrate microfossils in the 63 micrometre fraction, which is the size range of most foraminifera, coarser sieves (500, 850, or 1000 micrometre) are stacked above the 63 micrometre sieve to collect the larger debris (Scott et al, 2001). Core samples were washed using stacked sieves to remove large debris, retain sand and foraminifera, and eliminate silt and clay-sized particles.

Preservation

After washing, core samples were preserved in a solution of alcohol and then sealed (when not in use) to reduce evaporation.

Sampling

A variety of tools were used to collect, sort, count, and store foraminifera; they include picks, brushes, counting trays, storage slides, wet splitter, and dry splitter (Fig.2.3) (Scott et al, 2001). Counting trays were particularly useful in this process because they are subdivided into multiple sections for easy counting.

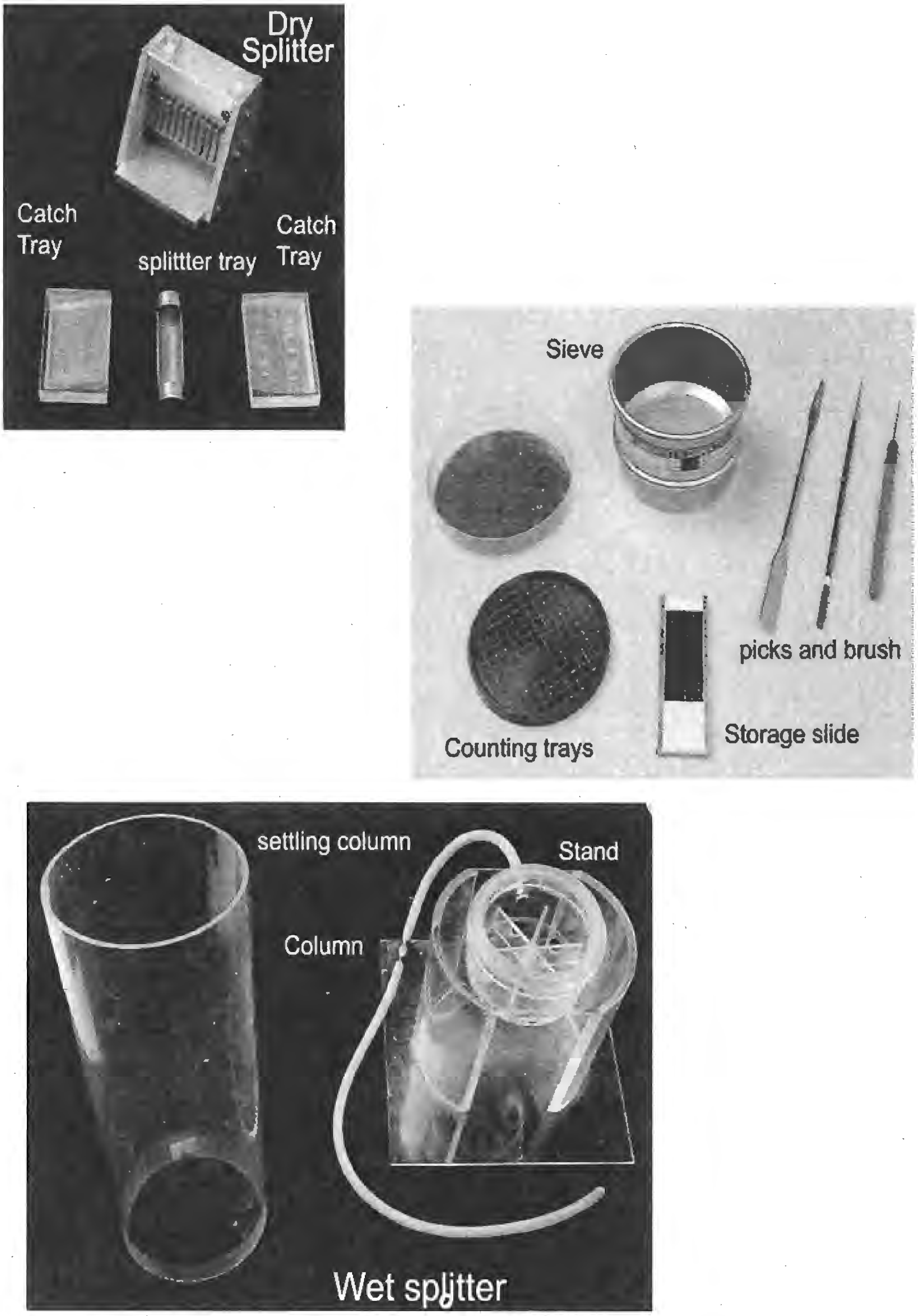


Figure 2.3: Apparatus used for sample splitting (after Scott et al, 2001).

2.4 Microfossil Identification

Core samples were then investigated under a simple stereomicroscope at magnitude 20-50x to identify and count foraminifera. The washed core sample was spread on the counting tray remaining completely immersed in fluid. Samples were sifted through using picks and / or brushes. Examples of each key foram species were collected and stored in a storage slide where it would later be glued for documentation purposes.

CHAPTER 3: RESULTS

3.1 Core Logging

Each core was logged to provide details of the facies present and their position in the core (Figure 3.1, Table 3.1). The top facies of each core consisted of reddish-brown oxidized mud. This mud was generally rich in organics with a small degree of black or yellow mottling. The depth of the reddish-brown layer ranged from 75 cm to 130 cm. The second major facies was a grey, reduced mud that gradually changed into a brownish-grey mud. The grey mud layer generally had a high degree of mottling. It ranged in thickness from 35 cm to 210 cm. The third facies consisted of brown mud and was only present in Cores 1 and 2, the two longest cores. This was a very thick layer which contained visible carbonate shell fragments (in Core 2).

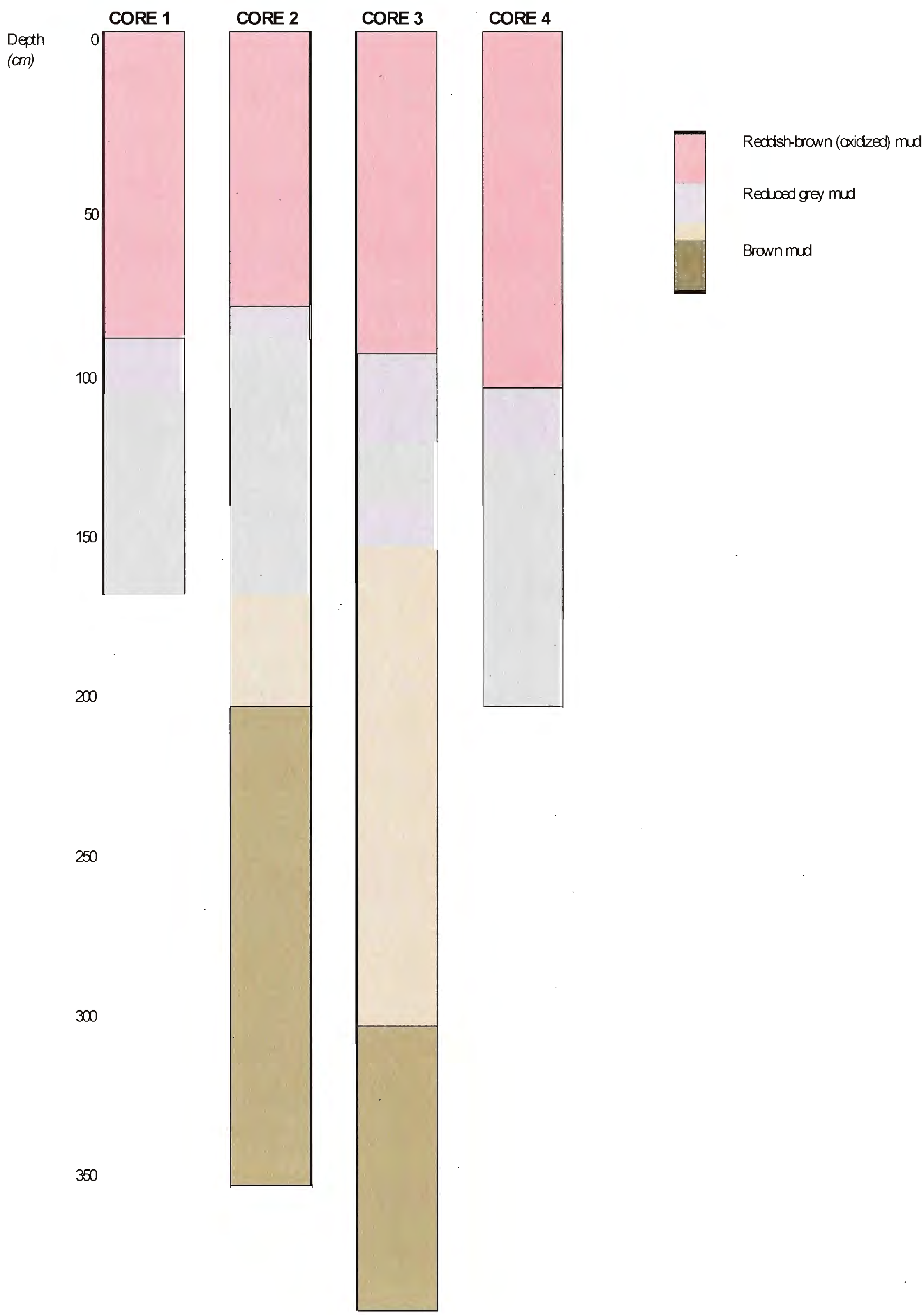


Figure 3.1: Distribution of core facies

Facies	**Core 1**	**Core 2**	**Core 3**	**Core 4**
Oxidized mud	90 cm, fine-grained, uniform red-brown colour, gradually transition to grey and grain-size, organics present, , dark grey and yellow mottling	75 cm, fine-grained, uniform colour and grain-size, organics present	90 cm, limited amount black and yellow-brown mottling, lots of organics	100 cm, organics present, mud interlayered with silty sand, some yellow mottling
Reduced mud	75 cm, grey, fine-grained, small red oxidized sections, organics present	90 cm, grey with yellow and dark grey mottling, organics present	60 cm, grey becoming dark grey with depth, black and yellow mottling	105 cm, yellow mottling, pocket of coarse grained sand
	-	35 cm, turns to brownish-grey	150 cm, turns to brownish-grey	

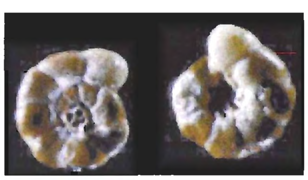
Brown mud	-	150 cm, brown mud inter-layered with silty sand, some red oxidized sections, organics present, black mottling, shell layers	90cm, brown grey, black and yellow mottling, reddish-brown towards end of section	-

Table 3.1 Description of core facies

3.2 Foraminifera identification

Cores were sampled at 20 cm intervals, with the first sample taken in the zone beneath the anthropogenic layer (this was grey reduced mud for each core). After samples were prepared, they were investigated under the microscope in order to identify the number of species of foraminifera presence and to count the number of specimens of each species present. To identify and distinguish between foraminifera, the test of each foraminiferid was identified and described (Table 3.2). The location of the foraminiferid within the core is also documented in Table 3.2 (below).

FORAM	ENVIRONMENT	DESCRIPTION

 *Trochammina inflata*	Grey reduced mud	Round to oval outline; upper side (view of whorls) and lower side (view of umbilicus) look different; agglutinated; brownish colour; test made up of fine-grained materials; surface appears smooth with dull shine; trochospiral; evolute coil; rounded and inflated chambers; chambers increase in size from proloculus to aperture; deep, open umbilicus; straight sutures at approximately 90 degrees to test edge; approx. 5-6 chambers in last whorl
 *Trochammina macresens f. polystoma*	Grey reduced mud	Oval to elongated outline; agglutinated; brownish; upper side and lower side look similar; flat test; planispiral to trochospiral; slightly involute coil; straight sutures at acute angle to test edge, 5-8 chambers in last whorl; more compressed than *T. inflata;*
 *Trochammina macresens f. macresens*	Grey reduced mud	Round outline; agglutinated; brownish; upper side and lower side look similar; flat; planispiral to trochospiral; evolute coil; straight sutures at approx 90 degrees to test edge, 5-8 chambers in last whorl; also more

 s f.	Grey reduced mud	Round outline; agglutinated; brownish; upper side and lower side look similar; flat; planispiral to trochospiral; evolute coil; straight sutures at approx 90 degrees to test edge, 5-8 chambers in last whorl; also more compressed than *T. inflata;*
Ti  ata	Grey reduced mud	Rounded outline; agglutinated; brownish colour; trochospiral; flat; involute; upper side and lower side look different; curved sutures at acute angle to test edge; Umbilicus not pronounced; 5-8 chambers in last whorl;
	Grey reduced mud	Approx. bean shaped outline; agglutinated; brownish colour; coiled in a quinqueloculine pattern
	Brown mud	Rounded outline; lenticular profile; calcareous shell; white colour; planispiral; involute (to partially evolute); curved suture; sutures at acute angle to umbilicus

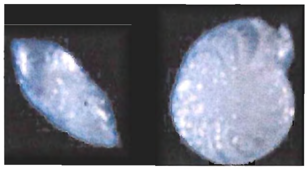
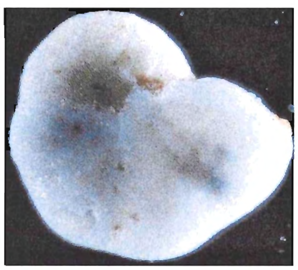
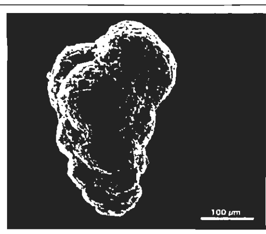
 *Elphidium williamsoni*	Brown mud	Rounded outline; lenticular profile; calcareous shell; white colour; planispiral; involute (to partially evolute); curved suture; sutures at acute angle to umbilicus area; upper and lower side look the same; umbilicus appears to be present on both sides; pores along sutures; 7-20 chambers in final whorl;
 *Haynesina orbiculare*	Brown mud	Rounded outline; calcareous shell; white colour; planispiral; slightly involute; curved suture; sutures at acute angle to umbilicus area; upper and lower side look similar; tubercules developed on umbilicus and parts of sutures located near umbilicus; 7-20 chambers in final whorl;
 *Eggerella advena*	Grey reduced mud and Brown mud zones	Rod-like shape; roughly triangular cross-section; agglutinated; brownish colour; later chambers triserial

Table 3.2 Main foraminifera identified in Grand Pré cores

3.3 Foraminifera count

The total number of foraminifera species and the total number of specimens within each species is available for each core inTables 3.3 to 3.6. Refer to Appendix A for relative species abundance charts for each core.

A total of 6 species was identified in Core 1 (Table 3.3). All species contained agglutinated tests. Foraminifera were most abundant at 160 cm depth. The species with the highest specimen count was *Eggerella advena*, which according to Table 3.2, can be found in both the reduced mud and the brown mud facies. The next most abundant species was the *Trochammina macrescens f. polystoma*, which is associated with reduced mud facies.

Core 1:165 cm

Depth (cm)	118	140	160
Total number of species	5	6	6
Total number of specimens	**19**	**18**	**42**
	% Abundance		
Ammobaculites exigus	0.0	11.1	2.4
Eggerella advena	52.6	72.2	31.0
Milliamina fusca	5.3	5.6	0.0
Tiphotrocha comprimata	10.5	11.1	16.7
Trochammina inflata	10.5	5.6	19.0
Trochammina macrescens f. macresens	0.0	5.6	4.8
Trochammina macrescens f. polystoma	21.1	0.0	28.6

Table 3.3: Foraminifera count for Core 1

A total of 10 species was identified in Core 2 (Table 3.4). Both agglutinated and calcareous foraminifera were present. Agglutinated species existed until a depth of around 175 cm; calcareous species were identified at depths below this. The highest foraminifera count occurred at 335 cm where 964 specimens were identified. The most abundant species in this core was *Haynesina orbiculare*.

Core 2: 350 cm

Depth (cm)	**155**	**175**	**195**	**215**	**235**	**255**	**275**	**295**	**315**	**335**
Total number of species	**5**	**5**	**3**	**6**	**8**	**10**	**10**	**10**	**9**	**6**
Total number of specimens	**25**	**36**	**765**	**499**	**621**	**540**	**461**	**599**	**910**	**964**
	% Abundance									
Bolivina pseudoplicata	0	0	0	0.2	1.3	2.6	1.3	3.0	1.6	0
Eggerella advena	12.0	30.6	0.0	3.2	3.4	2.0	4.1	3.5	2.3	2.1
Elphidium advena	0	0	0	0	0.6	1.9	0.7	0.8	0	0
Fursenkoina fusiformis				0	0	0.2	0.7	0.3	0.1	0
Haynesina orbiculare	0	0	99.3	90.0	90.2	83.5	82.2	79.1	87.4	92.9
Quinqueloculina seminulum	0	0	0	0	0.6	3.7	0.2	3.7	1.9	0.1
Tiphotrocha comprimata	40.0	19.4	0.4	3.8	2.3	3.9	5.4	4.7	2.7	1.3
Trochammina inflata	24.0	22.2	0	0.2	0.6	0.6	1.5	0.7	0.8	1.9
Trochammina macrescens f. macresens	12.0	5.6	0	0	0	0.2	0.7	0.5	0.2	0
Trochammina macrescens f. polystoma	12.0	22.2	0.3	2.6	1.0	1.5	3.3	3.7	3.0	1.7

Table 3.4: Foraminifera count for Core 2

A total of 6 species of foraminifera was identified in Core 3 (Table 3.5). Five species were agglutinated (the remaining species was calcareous). Agglutinated foraminifera were present until 280 cm, after which the core was dominated by *H. orbiculare* In fact, *H. orbiculare* was the most abundant foraminifera identified in this core. The region within the core with the highest foraminifera count occurred at 380 cm.

Core 3: 390 cm

Depth (cm)	100	120	140	160	180	200	260	280	300	320	360	380
Total number of species	**5**	**5**	**3**	**5**	**5**	**5**	**4**	**4**	**6**	**6**	**5**	**6**
Total number of specimens	**7**	**24**	**13**	**85**	**91**	**16**	**35**	**23**	**126**	**77**	**436**	**979**
	% Abundance											
Eggerella advena	14.3	70.8	38.5	52.9	41.8	43.8	60.0	56.5	29.4	39.0	8.9	6.5
Haynesina orbiculare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.4	9.1	80.5	88.0
Tiphotrocha comprimata	14.3	8.3	30.8	12.9	30.8	18.8	20.0	21.7	26.2	29.9	6.0	3.8
Trochammina inflata	14.3	4.2	0.0	5.9	9.9	12.5	0.0	8.7	8.7	7.8	3.7	1.1
Trochammina macrescens f. macresens	14.3	4.2	0.0	1.2	1.1	6.3	8.6	0.0	0.8	1.3	0.0	0.1
Trochammina macrescens f. polystoma	42.9	12.5	30.8	27.1	16.5	18.8	11.4	13.0	9.5	13.0	0.9	0.4

Table 3.5: Foraminifera count for Core 3

Core 4 contained 5 species of foraminifera, which were all agglutinated (Table 3.6). The most abundant species was *E. advena* followed by *Tiphotrocha comprimata*. The highest foramifera count was identified at a depth of 200 cm.

Core 4: 205 cm

Depth	160	180	200
Total number of species	**4**	**4**	**5**
Total number of specimens	**44**	**83**	**85**
	% Abundance		
Eggerella advena	52.3	55.4	48.2
Tiphotrocha comprimata	31.8	21.7	10.6
Trochammina inflata	4.5	15.7	16.5
Trochammina macrescens f. macresens	0.0	0.0	5.9
Trochammina macrescens f. polystoma	11.4	7.2	18.8

Table 3.6: Foraminifera count for Core 4

3.4 Summary of Results

Figure 3.2, a revision of Figure 3.1, shows the typical succession of facies observed in Cores 1-4 from Grand Pré. Core logging and foraminifera identification have been used to define the position of the saltmarsh and mudflat zones.

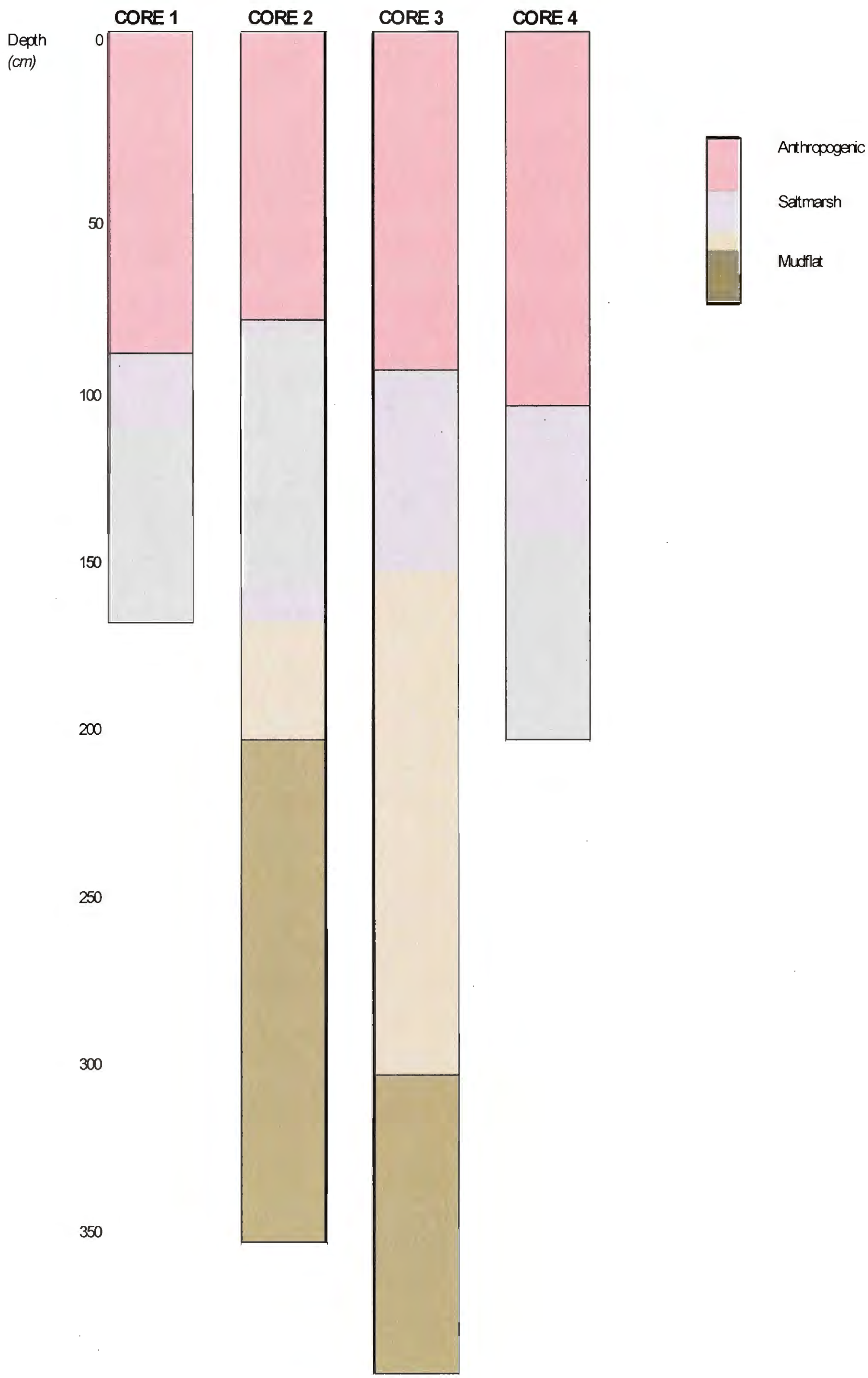


Figure 3.2: Succession of facies observed at Grand Pré.

Three main facies were observed: anthropogenic, marsh (high and low), and mudflat. Horizons were defined primarily by a sediment colour change and foraminiferal associations, and were separated by gradual boundaries. Anthropogenic facies were red-brown in colour (oxidized), contained high organic content, and were generally devoid of formas. The anthropogenic layer ranged in thickness from 75-130 cm.

Grey reduced mud represented the marsh regions. This layer also contained high organic content and contained various agglutinated foraminifera such as *Trochammina inflata*, *Tiphotrocha comprimata*, *Trochammina macrescens f. polystoma*, and *Trochammina macrescens f. macrescens. Eggerella advena* were generally present in all horizons where other foraminifera existed. The marsh zones were generally 35-105 cm thick. High to middle marsh can be distinguished from the low marsh areas by the regions with high abundance of *Trochammina inflata* and *Tiphotrocha comprimata.*

Brown mud represented the mudflat regions. Mudflat regions generally contained less organics. Key foraminifera found in this region include *Haynesina orbiculare* and *Elphidium advena. Haynesina orbiculare* were the most abundant foraminifera in this horizon. Mudflat regions ranged in a minimum thickness of about 150-175 cm since it is not assumed that the core reached the bottom of the mudflat zone.

CHAPTER 4: DISCUSSION

Data collected from Grand Pré cores suggest the presence of a progradational system, where there was a gradual growth / extension of the salt marsh by accompanied by a rise in the relative sea level. The data show foraminiferal distribution primarily for the north-northwestern region of Grand Pré. This supplements the work done by Manning (2010) to provide a more complete picture of the coastal evolution of the region. In Figure 5.1, the work done by Manning (2010) is represented by grey circles.

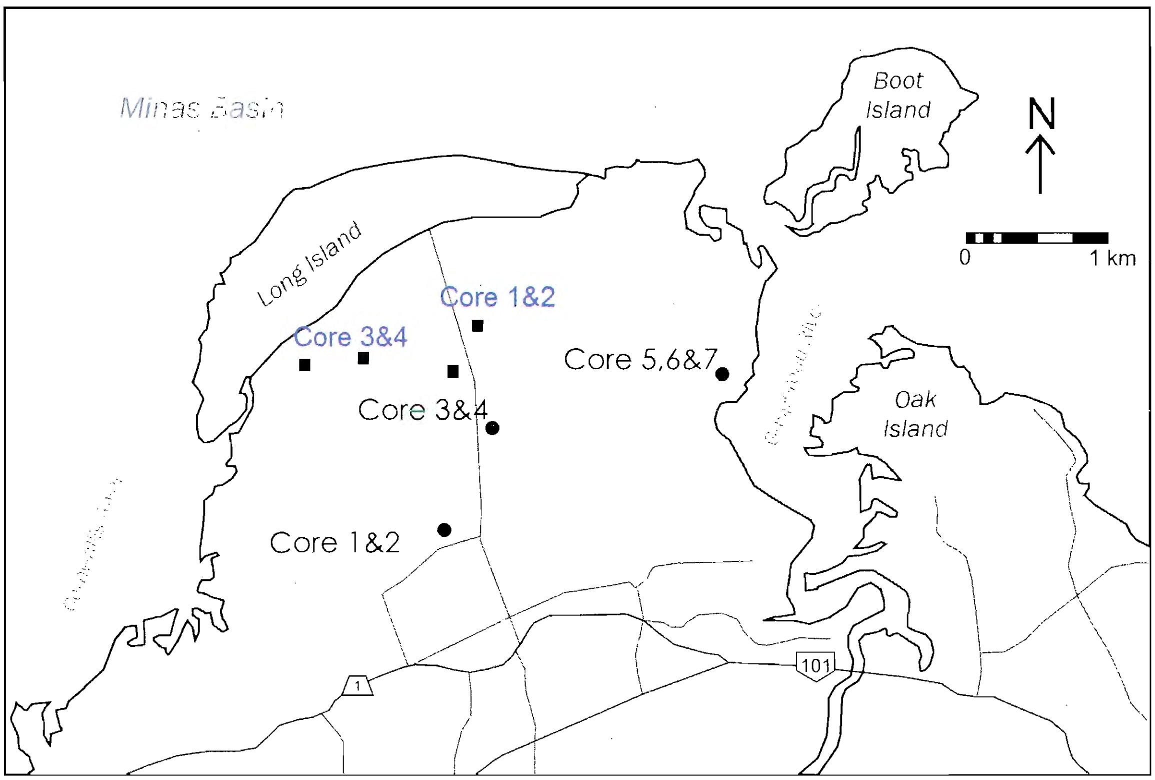


Figure 4.1: Comparison of sample points taken in this study (black squares) and by Manning (grey circles) (2010)

Two cores (Cores 2 and 3) collected sediments deep enough to provide evidence of the existence of mudflat facies. In these instances, mudflat facies were found at depths greater than 200 cm. It is possible that if Cores 1 and 4 were longer, mudflat facies could have also been identified.

Core 1 was halted at 165 cm because of equipment failure and Core 4 was halted at 205 cm because of difficulty in vibrating through thick, organic-rich sediments.

Mudflat facies, the bottom-most facies, were the first (or oldest) environment to be found in the cores collected at Grand Pré. The identification of shell fragment layers and the presence of whole specimens of pelecypods and gastropods suggest that a shallow marine environment, such as an intertidal mudflat, existed. *H. totteni* was a rare gastropod occurrence at 295 cm in Core 2. Ostracod tests were also very abundant within mudflat facies. The most abundant mudflat foraminiferid identified was *Haynesina orbiculare*. According to Scott and Medioli (2001), *H. orbiculare* prefers cold water and lower salinity. In addition, some specimens had whitened tests, indicating that higher pH conditions were present at some time. These two key points confirm that the shallow marine environment was situated near to the salt-marsh.

The mudflats would have formed when the sea inundated the land, drowning vegetation and depositing thin layers of fine-grained sediment. Overall, the mudflat layer was very thick (over 80 cm). Because of this thickness, they would not make very good sea-level indicators.

On top of the mudflat layer is the marsh layer. Marsh regions can generally be divided into two main groups: high marsh and low marsh. Over time, the mudflat experienced an increase in sediment deposition and accumulation. A major sediment source is from fluvial sources. Sediment accumulation could have also been the result of a small fall in local sea level. As sediments accumulated, the mudflat environment changed into a low marsh environment that was still flooded daily by the tides. In time, a few hardy plants grew and further stabilized the sediments. Within this zone, agglutinated foraminifera became more common and foraminifera with calcite tests disappeared. A low count of *T. macrascren f. polystoma* and the absence of *T. inflata* are generally good indicators of low marsh.

On top of the low marsh environment was the high marsh environment characterized by the existence of larger numbers of agglutinated foraminifera. By this stage, the low marsh has accumulated sufficient sediments so that marsh grasses grow easily and further stabilize the soil. Marsh regions were areas of diverse flora and fauna and therefore have characteristically high amounts of organic materials in the cores. Agglutinated foraminifera are most common here; important high marsh indicators include: *T. inflata* and *T. macrascens f. polystoma*.

Cores 1 and 2 are located near Manning's (2010) Cores 3 and 4 (Fig 5.1). Both core sets showed that calcareous foraminifera, typical of the mudflat, were identified from approximately 200cm in depth. As we move further to the northwest, foraminifera counts seem to drop and the samples (Cores 3 and 4 of this study) contained a high sand content. Overall, this study region contained a high count of calcareous foraminifera.

While all of the cores of this study showed the sequence of mudflat facies as the bottom-most layer (in cores) being overlain by saltmarsh facies (Trend A) (Fig. 4.2), only about half of the cores investigated by Manning (2010) showed this trend. The remaining three of the seven cores in Manning's (2010) study showed a unique sequence of saltmarsh facies as the bottom-most, overlain by mudflat facies, which were then overlain by another layer of salt-marsh facies (Trend B). These trends are illustrated in Figure 5.2 which shows that Trend A is predominant in northern Grand Pré along a west-east transect, while Trend B is predominant in central Grand Pré along a southwest-northeast transect.

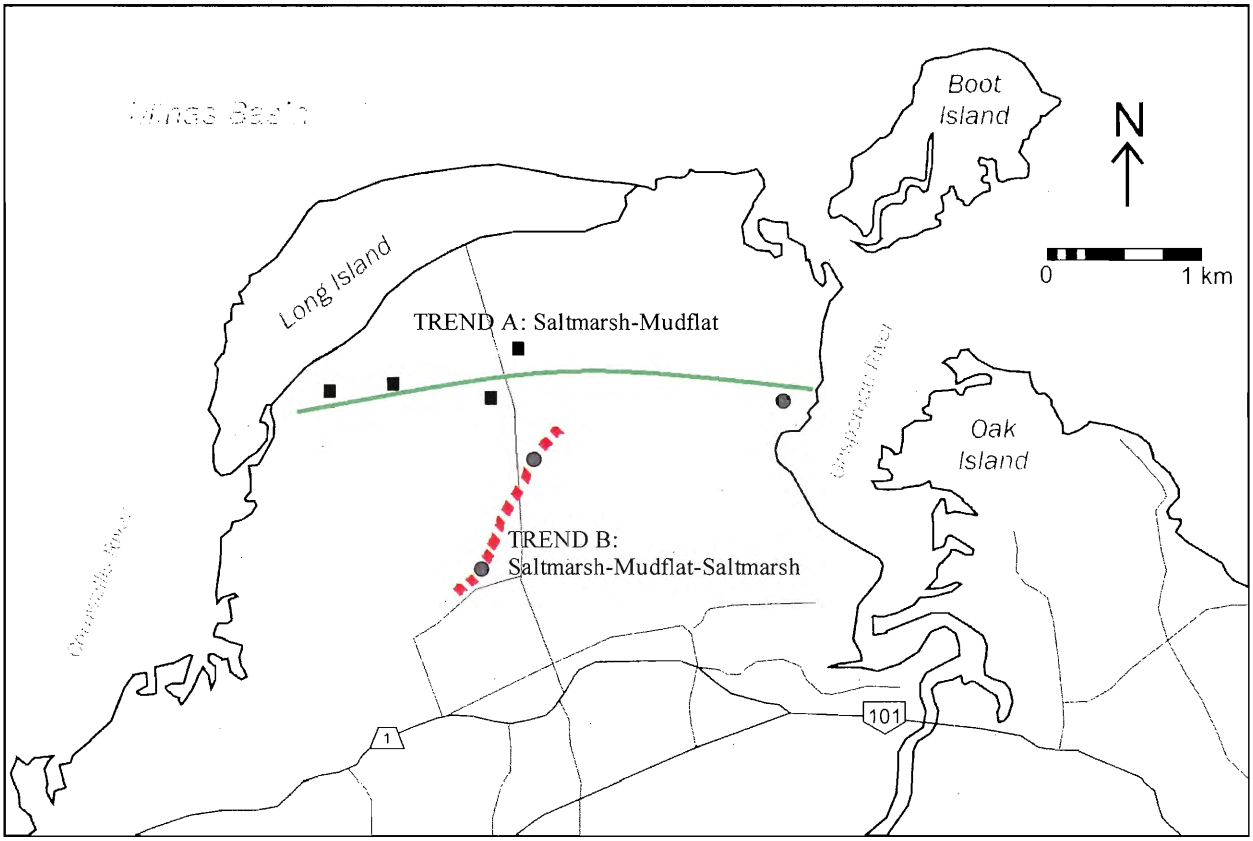


Figure 4.2: Comparing trends in facies sequences with Manning's (2010) study

These results (Trend B) suggest that the central region of Grand Pré experienced a different coastal evolution that the northern region. Based on Manning's (2010) findings, we know that the region was entirely high marsh before 2700 years ago. By 2700 YPB, a local sea level rise infiltrated the western coastline of Grand Pré, creating an intertidal mudflat. This influx of mud reached the central region and did not affect the eastern side of Grand Pré. Over time, the saltmarsh began to rebuild itself in the western region due to sediment accumulation and the stabilization of sediments by marsh grasses.

The results of this study are consistent with the pattern illustrated in Trend A (Fig. 4.2) where the mudflat slowly became replaced by low marsh then high marsh. By the time the Acadians arrived in the 1600's, they found saltmarshes at Grand Pré, with a lot of farming potential. They began to dyke the marshes to create farmland. Their farming practices utilized practices that aerated the soil giving it the oxidized appearance. It is most likely that the Acadians arrived when most of the region was at low to high marsh.

Analogue and Sea-level curve

An important analogue to the Grand Pré region is Kingsport which is approximately 4 km away (Fig. 4.3). Based on the sea level curves (Fig.4.4) discussed by Manning (2010) and Scott and Greenberg (1983), we can correlate our high marsh zones to get an approximation of what the sea -level curve for the area will be. High marsh makes a good indicator for sea-level change because it is usually a thin abrupt layer. Using a high marsh zone identified in Core 3 at around 160 cm and also using the Kingsport relative sea-level curve as an approximation for conditions at Grand Pré, we can determine that the high marsh was in place 1 000 years ago.

Figure 4.3: Location of Kinsport relative to Grand Pré.

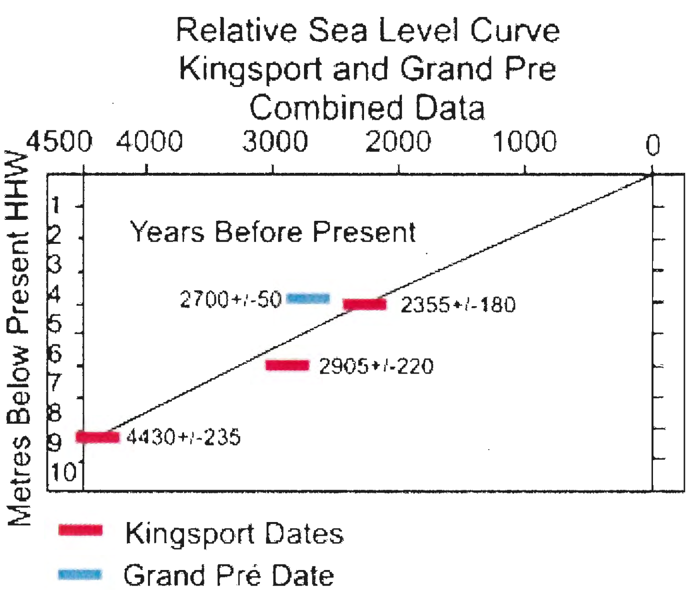


Figure 4.4: Combined relative sea level curve for Kingsport and Grand Pré (modified from Scott and Greenberg (1983) and Manning (2010).

Anthropogenic sediments

While Bleakney (2004) suggested that dyking (and associated farmland development) progressed from the south-central region (roughly where the National Historic site sits today) then to the north, east, west, then back east to find the latest plots (Fig. 1.7), the anthropogenic layers in the cores may suggest a different story. The thinnest anthropogenic sediment layers were found in the south central region suggesting that farming activity may have been limited here. Given that a new plot was only dyked off after the previously created plot was brought into farming production, one would assume that the earliest plot would have been the longest-farmed plot. Overall, the data in this study and Manning's (2010) work show that anthropogenic sediments are thinner in the western region of Grand Pré and thicker in the east. This suggests that the east would have been farmed more extensively than the west. This is a contrast to Bleakneys (2004) conclusions which suggest that last prepared plots (and therefore the plots exposed to farming for the least amount of time) were in the east.

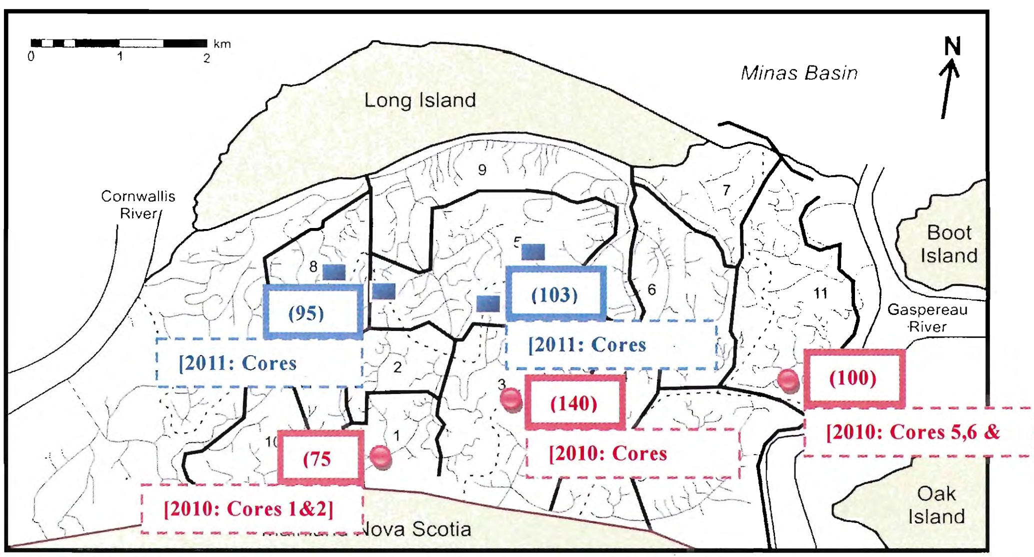


Figure 4.5: Summary of anthropogenic sediment depths for Grand Pré (modified by Manning, 2010, after Bleakney, 2004)

CONCLUSION

There are three main facies observed in Grand Pré cores; they were anthropogenic, marsh (high and low), and mudflat. Foraminifera were identified in saltmarsh and mudflat sediments. The most abundant saltmarsh species of foraminifera included *Trochammina inflata*, *Trochammina macrescens f. polystoma*, and *Tiphotrocha comprimata.* The most abundant species overall were the mudflat facies, *H. orbiculare.* This indicates that the northwestern region of the Grand Pré contained a very important mudflat zone. This is likely an entry / exit point for seawater entering and leaving the marsh zone as a result of the Bay of Fundy tides. It is also the site where the Acadians built a dyke that still exists today, confirming that this region was probably part of an important intertidal zone.

The overall picture for Grand Pré is a progradational system where a local transgression occurred. Given that mudflat facies were the bottom-most layers in cores suggested that the region was covered by seawater which deposited fine muds over it. Over time, increased sediment supply and decreased accommodation space resulted in the gradual growth / extension of the salt marsh despite relative sea level rise.

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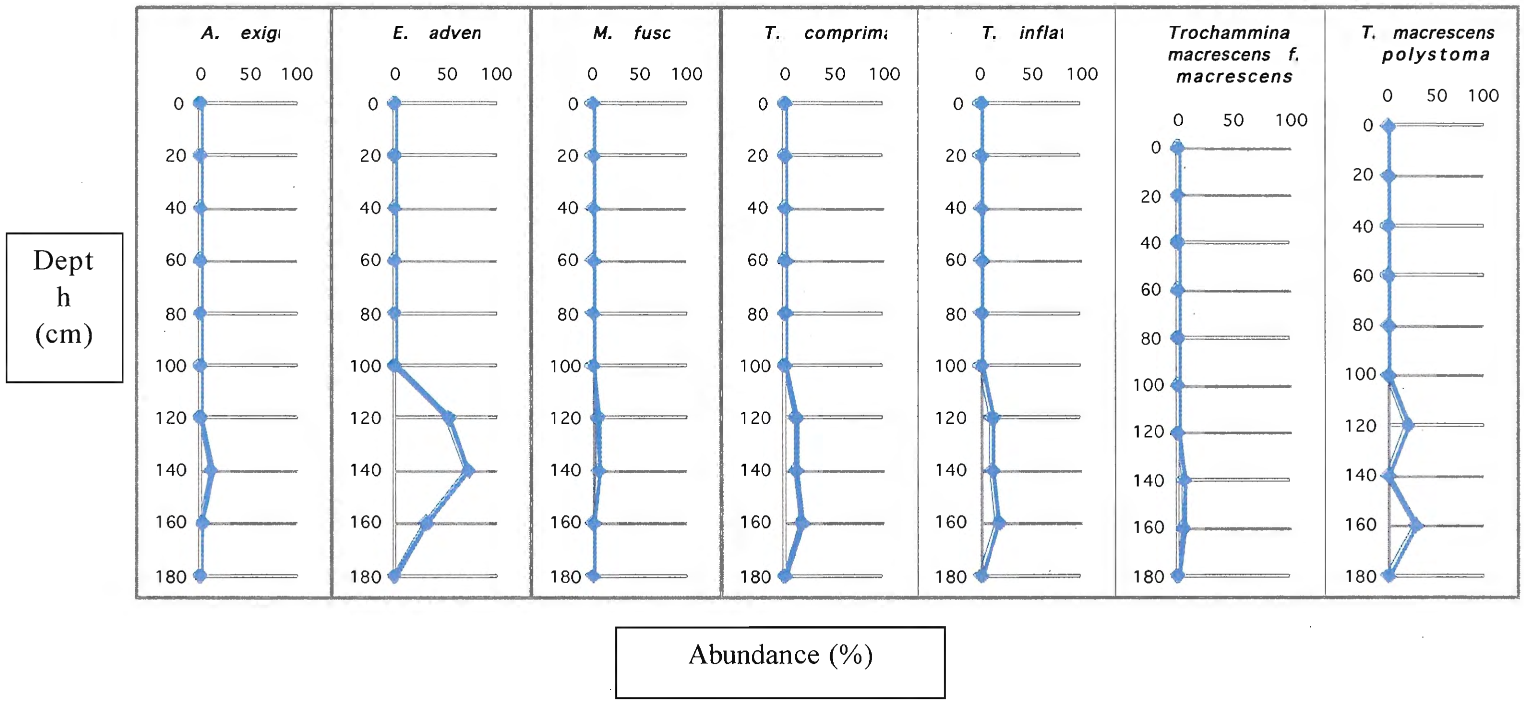
APPENDICES

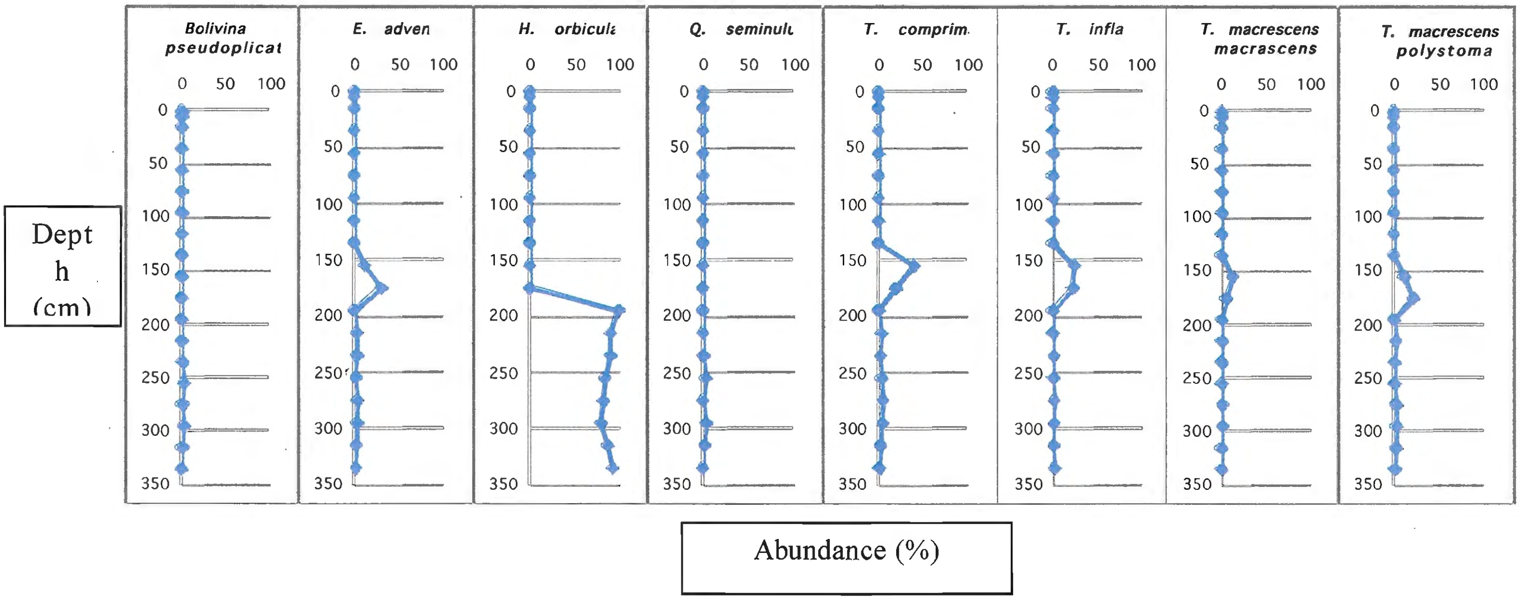
RELATIVE SPECIES ABUNDANCES FOR CORES 1-4

RELATIVE SPECIES ABUNDANCES FOR CORES 1-4

CORE 1

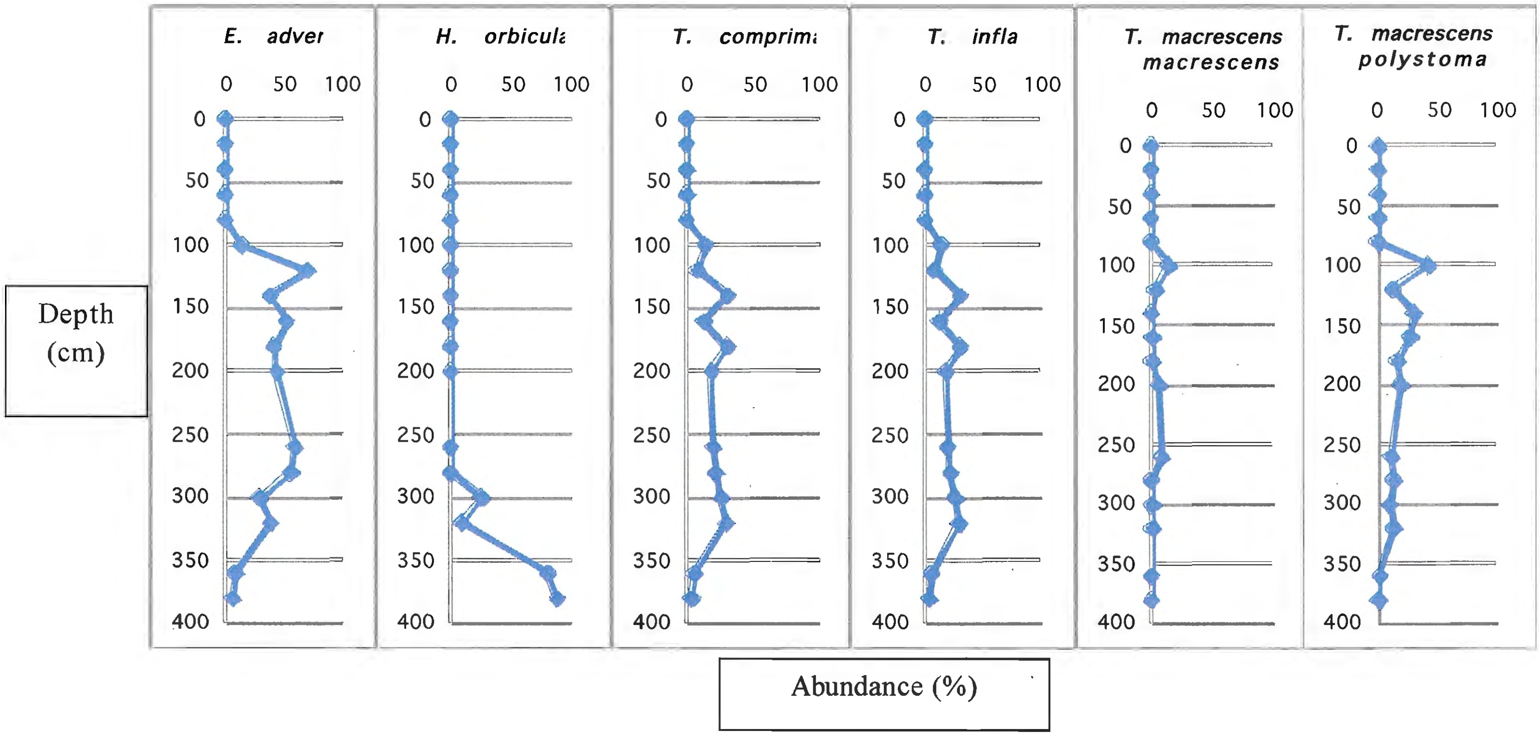


CORE 2

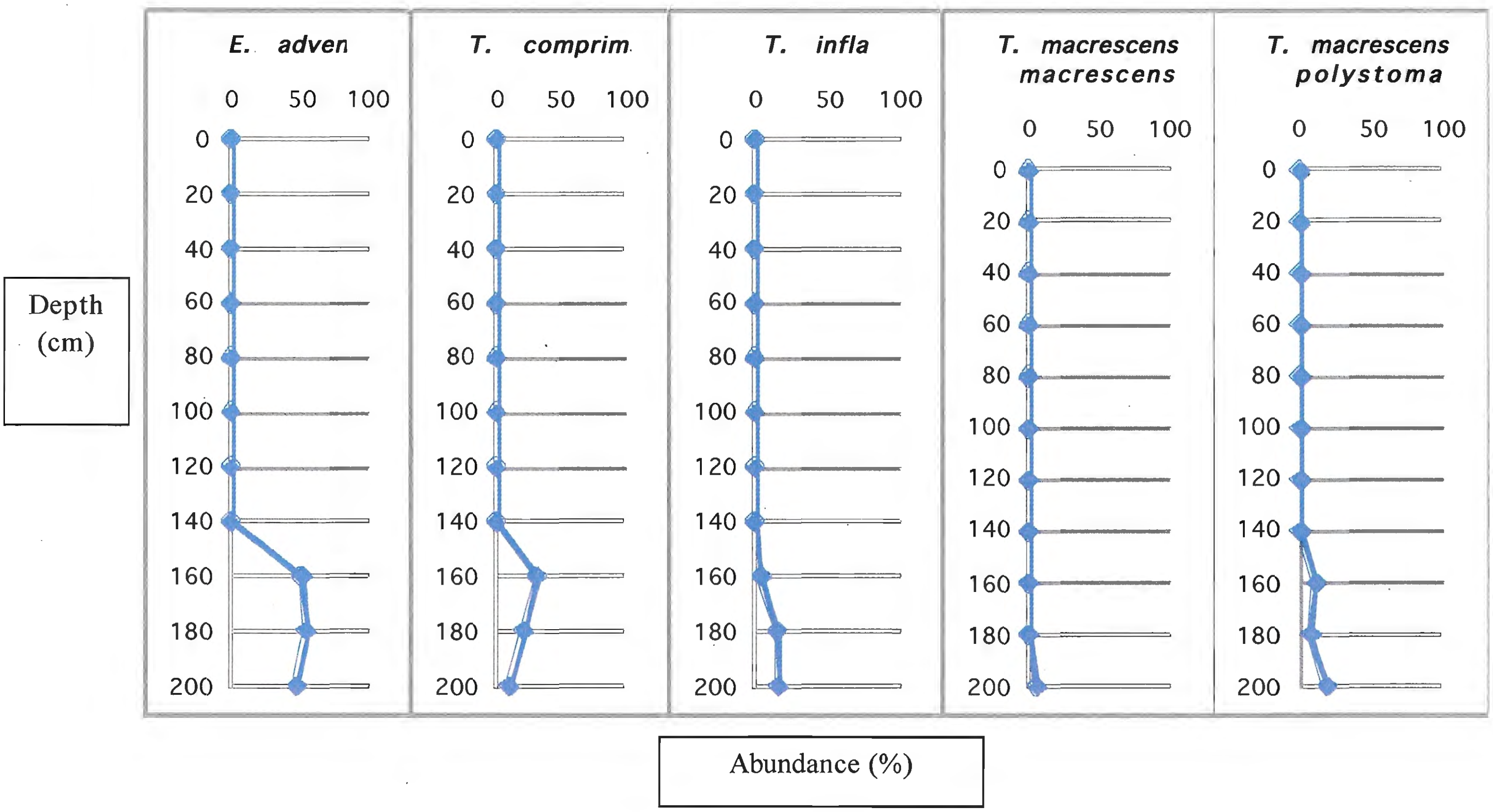


Bolivina pseudoplicat
E. adven
H. orbicul
Q. seminul
T. comprim
T. infla
T. macrescens macrascens
T. macrescens polystoma
0 50 100
0
50
100
150
200
250
300
350
Depth (cm)
Abundance (%)

CORE 3


E. adver
H. orbicula
T. comprima
T. infla
T. macrescens macrescens
T. macrescens polystoma
0
50
100
150
200
250
300
350
400
Depth (cm)
Abundance (%)

CORE 4:



E. adven
T. comprim
T. infla
T. macrescens macrescens
T. macrescens polystoma
0
50
100
0
20
40
60
80
100
120
140
160
180
200
Depth (cm)
Abundance (%)