PALEOENVIRONMENTAL ANALYSIS OF HALIFAX HARBOUR:

SEDIMENTOLOGY, PALEOCLIMATOLOGY, and HOLOCENE SEA LEVEL

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Abstract

Three cores (numbered 2, 9, 10) collected from Halifax Harbour using new submersible vibracoring equipment permits a reinterpretation of an acoustically distinct seismostratigraphic unit. This unit, never previously sampled, occurs in the base of Core 2. The benthic foraminiferal assemblages in the cores enable a determination of the paleoecology and paleoenvironment for the post-glacial history of Halifax Harbour. Foraminiferal species abundance and diversity permit an interpretation of the effects of organic and nutrient loading in the upper 30-70 cm, caused by an increased sediment flux and effluent discharge from anthropogenic sources on the marine benthic community. The presence of foraminifera within the distinct seismic unit requires a reinterpretation of the distinct seismic unit previously interpreted as lacustrine. The foraminiferal assemblage, in combination with the lithology, indicates an estuarine depositional environment. Peat and foraminiferal samples yielded three carbon-14 dates: (i) The peat sample from Core 9 (261-262 cm) is not *in situ*, but provides a date of 1,065 +/- 80 ybp. Erroneous peat dates may provide insight into previously unexplainable sea-level points. (ii) The peat sample from Core 10 (459-463 cm) is *in situ* and yielded a date of 7,770 +/- 260 ybp. (iii) The date yielded from a foraminifera sample (474-489 cm, 8,480 +/- 60 ybp) corresponds to a time when glaciers were no longer present in Nova Scotia. Therefore, the age suggests that a paleoenvironmental interpretation of estuarine deposition is realistic. Carbon-14 dating permits the construction of an extended Holocene relative sea-level curve by plotting carbon-14 dates against corresponding sample depths (sample depth in core plus water depth). The new sea-level curve in this study indicates that the inner continental shelf experienced initial emergence, followed by a prolonged period of submergence from 7500 ybp to the present. The theoretical model of glacio-isostatic rebound, resulting in the migration of the peripheral forebulge following deglaciation, can explain the various sea-level curves observed in Atlantic Canada, but may not be able to explain short term fluctuations in relative sea level.

Key Words: foraminifera, Halifax Harbour, seismostratigraphy, estuarine, Holocene, sea level, peripheral forebulge, eustatic

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Acknowledgements

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Halifax Inlet is a body of water including inner and outer Halifax Harbour, Northwest Arm, Eastern Passage, The Narrows, Bedford Basin, and Bedford Bay (Fig. 1.1; Fader *et al.* 1991). Using detailed seismic surveys, sidescan sonar, and sediment samples, Fader and Miller (1992), Miller *et al.* (1990), and Miller and Fader (1988) studied the sediment distribution in Halifax Inlet to assist the proposed Halifax Harbour Cleanup. Seismic reflection studies around Georges Island (Fig. 1.1) recognized a continuous, coherent, high-amplitude seismic facies in the harbour subsurface overlain by Holocene mud (Fig. 1.2; Fader *et al.* 1991). Prior to the present investigation, sampling of this seismostratigraphic unit was unsuccessful because of debris on the seabed and operational problems (G. Fader pers comm). However, new vibracoring techniques provided access to these sediments and the fauna contained within them. This distinct seismic unit occurs over a large area of the harbour (Fig. 1.3). Fader (1991) and Fader *et al.* (1991) suggest that the unit represents lacustrine sedimentation. Benthic foraminiferal assemblages, together with carbon-14 dating (providing chronological control), improve our understanding of the paleoecology and paleoenvironment of this distinct seismic facies.

Foraminifera are unicellular organisms belonging to the Subphylum Sarcodina, class Rhizopoda (Loeblich and Tappan 1964). Foraminifera differ from other Sarcodina by the possession of mineralized tests (Haq 1978). Foraminifera can possess one of three types of test: (1) chitinous, (2) agglutinated/arenaceous, or (3) calcareous. Foraminifera are divided into planktonic and benthic groups. Planktonic species (free-floating) occur mainly in the photic zone of the open ocean. In contrast, benthic species (bottom-dwelling) have restricted movement and occur in all benthic marine environments. As a

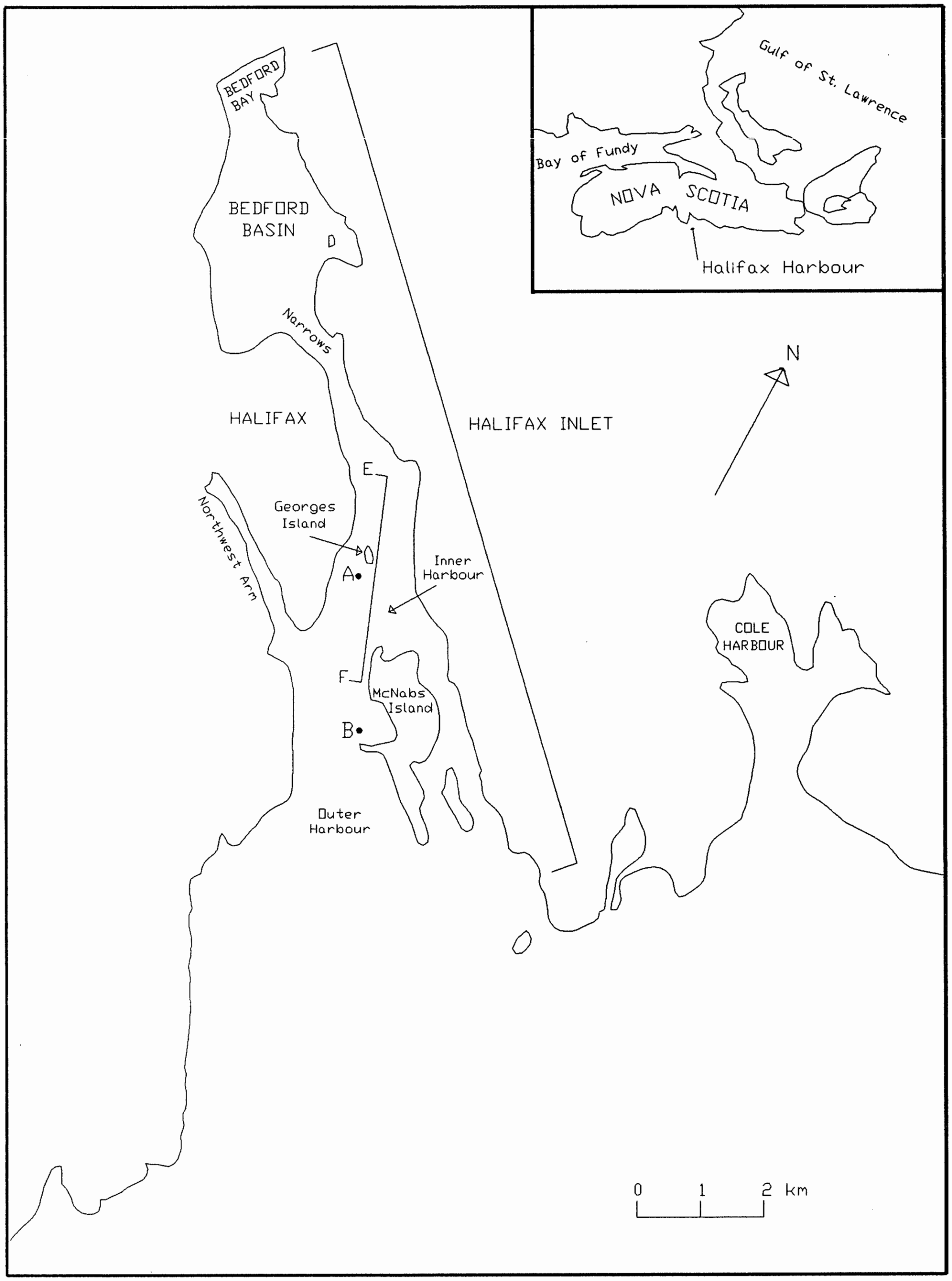

Figure 1.1 Location map of Halifax Inlet, N.S. Legend: A= position of Cores 2 and 10, B= position of Core 9; line E-F is the location of the acoustic seismic line seen in Figure 1.2 (after Gregory 1971).

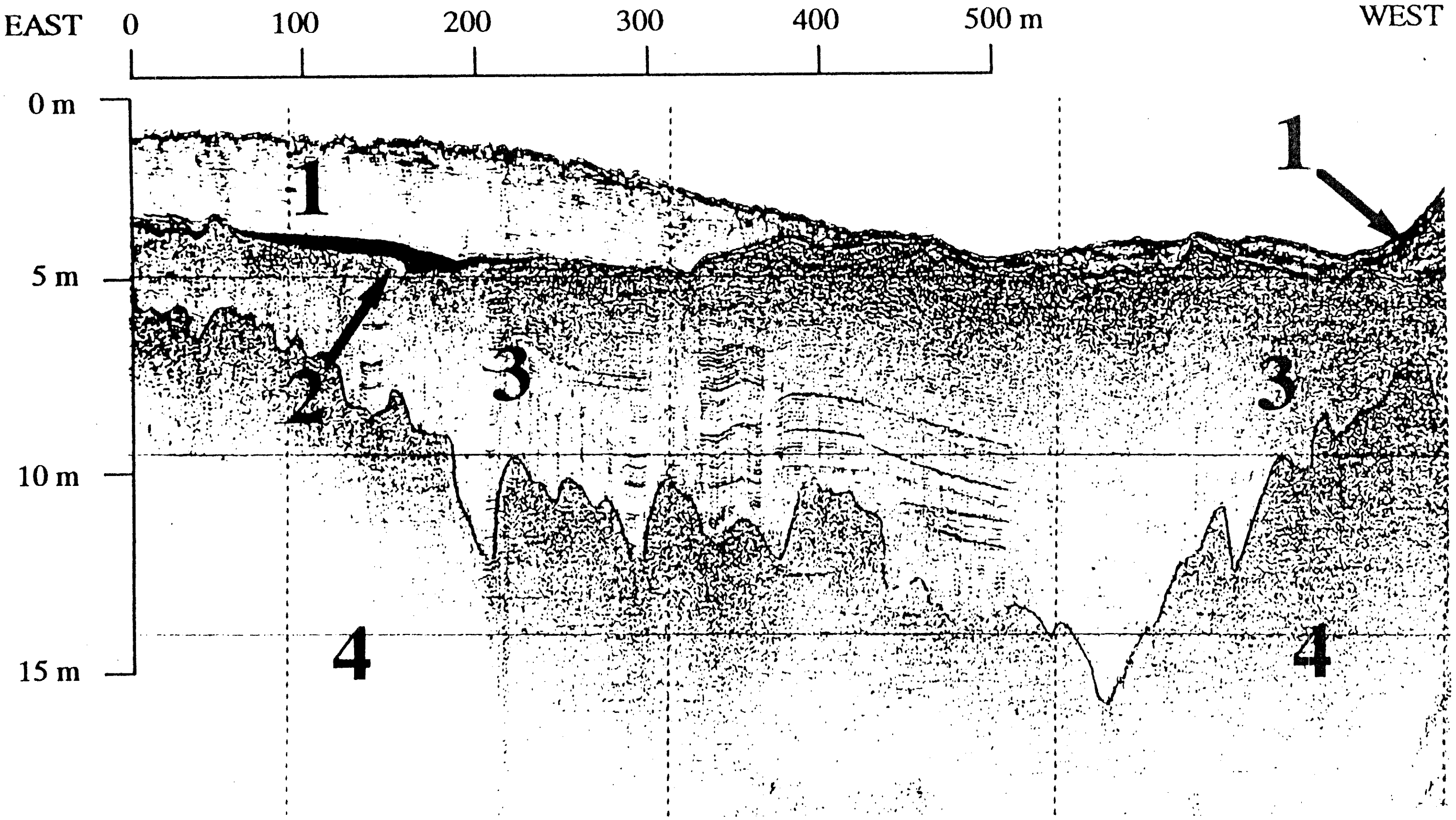

Figure 1.2 Seismic profile in Halifax Harbour, southeast of Georges Island, shown as line E-F on Figure 1.1. Legend: 1= Holocene mud, 2= transgressive lag, 3= lacustrine sediment, 4= acoustic basement (Meguma Group overlain by a uniform blanket of till) (from Miller *et al.* 1990).

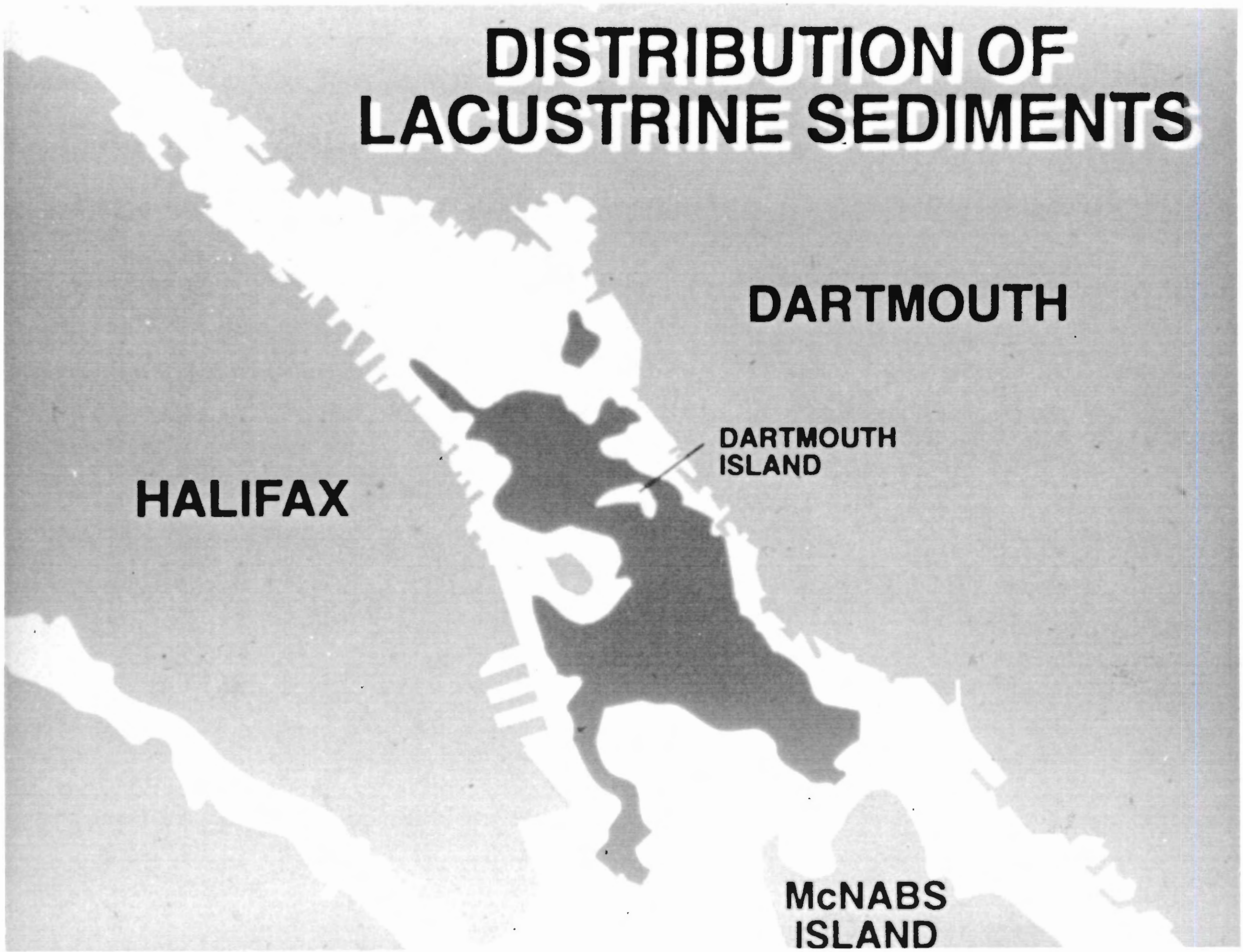

Figure 1.3 Distribution of a distinct seismic unit within Halifax Harbour; interpreted by Fader (1991) and Fader *et al.* (1991) as representing lacustrine deposition (from Fader *et al.* 1991)

result of their limited movement, most benthic foraminifera occur *in situ* and are valuable aids for determining both age relations and depositional environments (Haq 1978). Factors that determine foraminiferal habitats include temperature, salinity, pH, and feeding rates, which are all variable at different water depths (Murray 1991). Thus, foraminifera are important indicators of paleoenvironment. For example, a fauna dominated by *Elphidium excavatum* forma *clavatum*, a species common in this study, and *Cassidulina reniforme* indicates glacial marine conditions (Scott *et al.* 1984).

New information provided from foraminiferal analysis, sedimentology, and carbon-14 (C^{14}) dates permits a reinterpretation of the widespread, seismically distinct sediments within Halifax Harbour. Such a reinterpretation, based on micropaleontology, has broad implications for the glacial and post-glacial history and the paleoenvironment of this region.

1.2 Purpose

The purpose of this thesis is to reconstruct the paleoenvironment of the inner Halifax Harbour using foraminiferal populations from vibracores (Fig. 1.1), to determine the origins and depositional environment of the acoustically distinct sediment unit (Fig. 1.2), to add new data to the regional sea-level curve, and to determine the significance of changing sea level on the paleoecology of Halifax Harbour.

1.3 Scope

The scope of this investigation is to address the paleoenvironmental history of Halifax Harbour using foraminiferal distributions, sedimentology of soft-sediment cores, seismostratigraphy, and C^{14} dating. The subject of pollution (contaminants in sediments), which is discussed in detail by Buckley and Winters (1992), is only marginal to this study. Modern foraminiferal zonations (Scott *et al.* 1980), seismic data (Fader *et al.* 1991), and regional models of glacial history (King and Fader 1986, Stea *et al.* in press) provide the basis for interpretation.

1.4 Physical Setting

The inner Halifax Harbour is part of a 25 km long, north-west oriented inlet on the east coast of Nova Scotia (Fig. 1.1). Halifax Harbour is an estuary in which the largest single source of fresh water is the Sackville River and sometimes waste water discharge in summer months. The Sackville River has an average annual inflow of $5m^3s^{-1}$ and a maximum spring runoff of $9m^3s^{-1}$ (Petrie and Yeats 1990). The harbour has a typical estuarine circulation, featuring a seaward flow of low-salinity surface water and a landward flow of higher-salinity bottom water. Minor mixing occurs at the interface between the two layers (Petrie and Yeats 1990). Buckley and Winters (1992) attribute local variations in the general circulation pattern to wind and tidal influence.

Circulation patterns may affect sediment distribution within the harbour. The surficial sediments of the inner harbour consist mainly of Holocene mud. This mud is patchy and thin, and appears as infilling on a rough and irregular till surface (Fig. 1.2; Fader *et al.* 1991). The patchy distribution of Holocene mud may result from the effects of stronger currents produced by narrower water pathways east and west of Georges Island. North of Georges Island, a 7 m thick deposit of Holocene mud trends north, towards Dartmouth Cove. This deposit appears to have formed in the lee of the island under flood-dominated flow (Fader *et al.* 1991). East-northeast of Georges Island are a number of small, isolated, linear, ridge-like deposits of gravel partially blanketed by

Holocene mud. Fader *et al.* (1991) interpreted these deposits to represent drumlin-like features, which may be similar in origin to Georges Island but on a smaller scale. However, these gravel ridge-like deposits could also represent gravel barriers found in an estuary.

In the subsurface surrounding Georges Island, seismic reflection data (line E-F on Fig. 1.1) indicate the presence of a thick sediment sequence (Fig. 1.2). Fader *et al.* (1991) interpreted this sequence as lacustrine sediments overlain conformably by a thin layer of sand and perhaps gravel, and the overlying Holocene mud. The lacustrine sediment accumulated in the central part of the harbour surrounding Georges Island before post-glacial marine transgression (Fader *et al.* 1991). New micropaleontological and stratigraphic information permits a reinterpretation of the "lacustrine" deposits, which are defined by their conformity with basement and high intensity, continuous reflections.

The level of contamination (metallic and organic compounds) in bottom sediments of Halifax Harbour is among the highest recorded in marine harbours and estuaries in economically-developed countries (Buckley and Winters 1992). Because the cores cover the pre-settlement transition, the benthic foraminiferal assemblage has the potential to display a detectable response to urban pollution.

1.5 Previous Work

Because of the preliminary nature of this investigation (analysis of sediments never previously sampled), few local data bases are available to compare with the results of this study. Under these circumstances, studies from adjacent areas are useful. Such studies include: the extensive investigations on the continental shelf off eastern Nova Scotia by King and Fader (1986), which provided the basis for sedimentological interpretation in this thesis; the numerous seismic studies of Halifax Harbour by Fader (1991) and Fader *et al.* (1991); and the most recent study of Halifax Harbour by Buckley and Winters (1992), which focused on the contamination of Halifax Inlet by examining surface samples. Another study, by DeIure (1983), investigated short cores in the outer Halifax Harbour. Her study, however, mainly involved storm deposits in the outer harbour and contains little information pertinent to the present investigation.

Complementing the above geological research is an extensive body of micropaleontological work. Of this work, those most relevant to this study include Scott *et al.* (1984), which provided an interpretation of benthic foraminiferal faunas from glacial-interglacial transitions, as well as Scott *et al.* (1980), Scott and Medioli (1980a, b), and Honig and Scott (1987), which provided the basis for foraminiferal identifications and defined estuarine-marsh faunas across eastern Canada. Williamson (1983) and Williamson *et al.* (1984) provided information on the foraminiferal distribution on the Scotian margin, with many of the same species occurring in this study; Miller *et al.* (1982a) examined three cores from the Bedford Basin, with stratigraphies similar to those found in this study; and finally, Gregory (1971) examined several hundred surface samples from the entire length of Halifax Inlet. Gregory (1971) is the most comprehensive study of foraminifera in Halifax Harbour to date.

Application of marsh foraminiferal zonations, as defined by Scott and Medioli (1978, 1980a), in the stratigraphic record can locate former sea-level points. Holocene relative sea-level studies can be divided into two categories: those that detail the last 4,000-5,000 ybp, and those that deal with the time prior to 5,000 ybp. The data exhibiting the highest resolution deal with the last 4,000 ybp. Many continuous records occur in marsh areas from 4,000 ybp to the present. Prior to 4,000 ybp, only isolated points exist offshore and cannot provide a basis for determining a high resolution sea-level signal. This high resolution sea-level signal is, in part, the result of the methods used to determine relative sea-level points. Marsh foraminiferal zonations have a resolution of +/- 10 cm, which eliminates errors associated with miscellaneous shells, undifferentiated peats (which can be either marine or freshwater deposits), and other less precise methods (Scott *et al.* 1986).

Scott *et al.* (1987) used marsh foraminiferal zonations to define relative sea-level points. Honig (1987) used estuarine sedimentation coupled with microfossil assemblages to show a transgressive sequence during the Holocene. Boyd and Honig (1992) also used stratigraphic characteristics and relationships, in combination with microfossil assemblages and modern estuarine processes, to show transgressive conditions in local areas. Scott *et al.* (1986) compiled data from several sites in the Maritimes and compared the foraminiferal data to the theoretical models of Quinlan and Beaumont (1981, 1982). Brown (1993) provided the first high resolution relative sea-level curve for the Eastern Shore of Nova Scotia using a series of sea-level points from 4,000 ybp to the present.

Sea-level changes attributed to water volume changes are eustatic effects, whereas isostatic adjustments cause sea-level changes through land movement (either rebound or subsidence). Relative sea-level (RSL) change refers to the movement of water in relation to land. RSL does not specify the mechanism for the sea-level change, eustatic or isostatic, just that there has been a net rise or fall of sea level relative to land. Because of Nova Scotia's location on a passive margin, most movements of sea level probably result from post-glacial isostatic adjustments and not tectonism (Scott *et al.* 1986).

Contradictory evidence on RSL is abundant in the literature. Scott and Medioli (1982) present a maximum low stand of RSL of only 30 m below present sea level along the Nova Scotia shoreline. However, King and Fader (1986) and Fader (1989) suggest a low stand at about -120 m on the mid-outer part of the continental shelf, with sea level subsequently transgressing the area. As well, Forbes *et al.* (1991) present a sea-level point of -40 m for the inner part of the Nova Scotia continental shelf. Stea *et al.* (in press) present the most current RSL curve constructed with a dated mussel valve fragment at -65 m. Their new sea-level curve conflicts with previously calculated RSL curves based on geophysical models, primarily in the amplitude and rates of RSL change.

1.6 Organization

The second chapter of this study addresses methodology. A separate discussion of methods is necessary not only because techniques are important in micropaleontology, but also because it details a new system of vibracoring. The third chapter presents the results of core stratigraphy, foraminiferal analysis, isotope analysis, and sea-level point determinations. Because Core 10 and Core 2 are from closely spaced locations, the description of Core 10 is prior to Core 9 in Chapter 2. Chapter 4 addresses some of the pertinent questions posed at the onset of this investigation. The final chapter concludes and summarizes the main points of this investigation.

CHAPTER 2 METHODS

2.1 Introduction

Three soft-sediment cores were obtained from the inner harbour of Halifax Inlet using a Rossfelder® Vibracorer. Because the Rossfelder® Vibracorer, a submersible unit, is an instrument recently acquired by Dalhousie University, a brief discussion of the operating procedure is necessary. Also described in this chapter is the laboratory work: core splitting, core sampling, sample preparation, and foraminiferal examination. The final section of this chapter deals with the analytical methods conducted outside Dalhousie University. Analysis of foraminiferal assemblages, seismic profiles, and carbon-14 dates provide information concerning the paleoenvironment of Halifax Harbour.

2.2 Vibracoring

Vibracoring is an efficient and versatile method for obtaining long, well-preserved cores in semi-consolidated, water-saturated sediments from wetlands, lakes, harbours and even the deep ocean. Unlike the vibracoring methods described in Brown (1993) and Honig (1987), the submersible Rossfelder® Vibracorer is powered by electricity generated by the vessel. The vibracorer generates approximately 11,000 pounds of vertical force to penetrate muds, sands, and most stiff clays. As well, the buoyant frame assists the vibracorer to be operational in water depths up to 500 m.

A brief description of the Rossfelder® Vibracorer follows. With a plastic liner (8 cm inside diameter) inserted inside the core barrel (10 cm outside diameter), the power head is attached, and a core catcher is riveted to the base of the core tube (Fig. 2.1). This assembly is hoisted, and the core tube is guided and clamped into place in the weight chest. Next, the unit is lowered until the power head is at the air-water interface, where

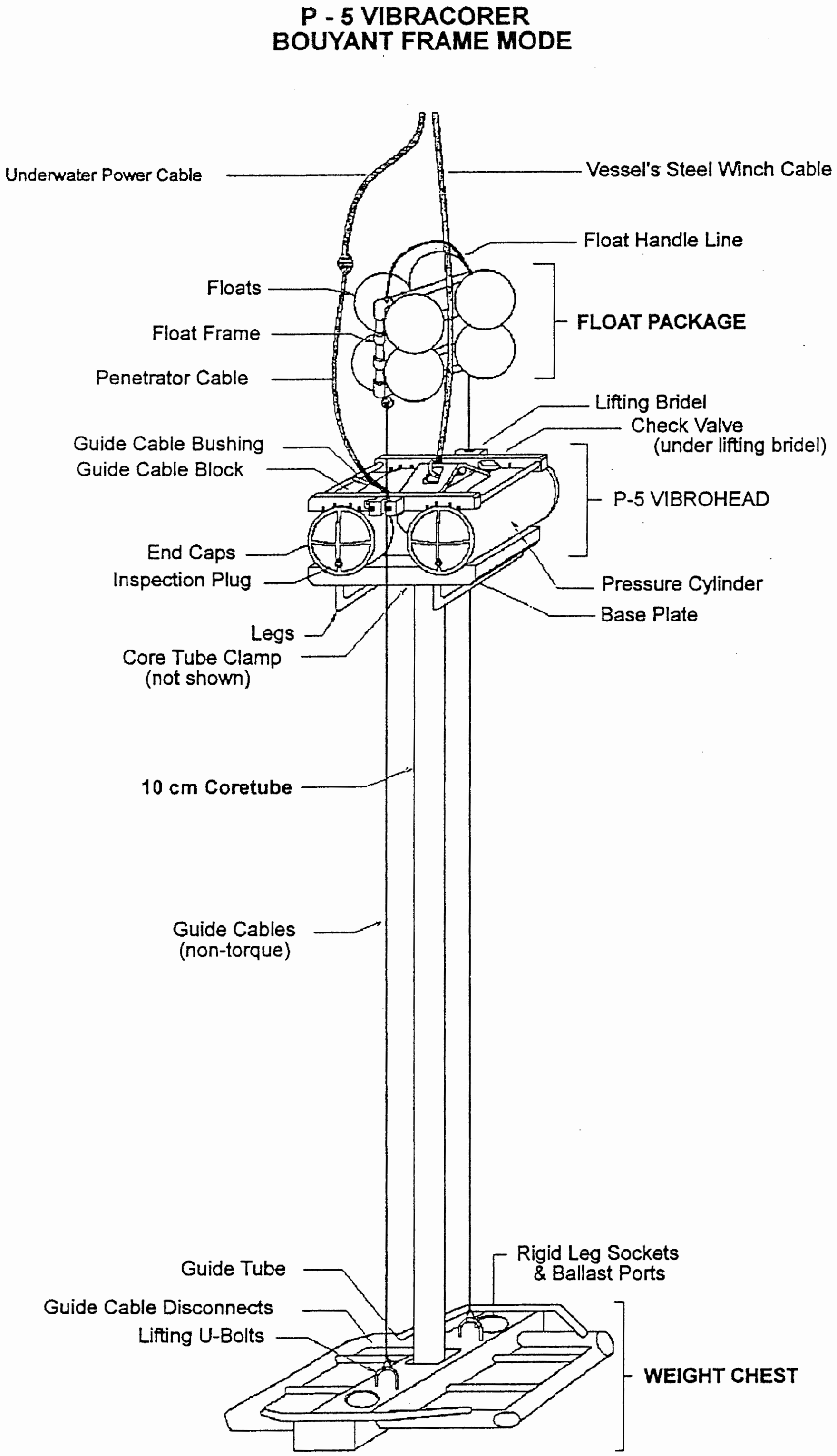

Figure 2.1 The Rossfelder® Vibracorer. Note the buoyant frame which assists the corer to remain upright while submerged.

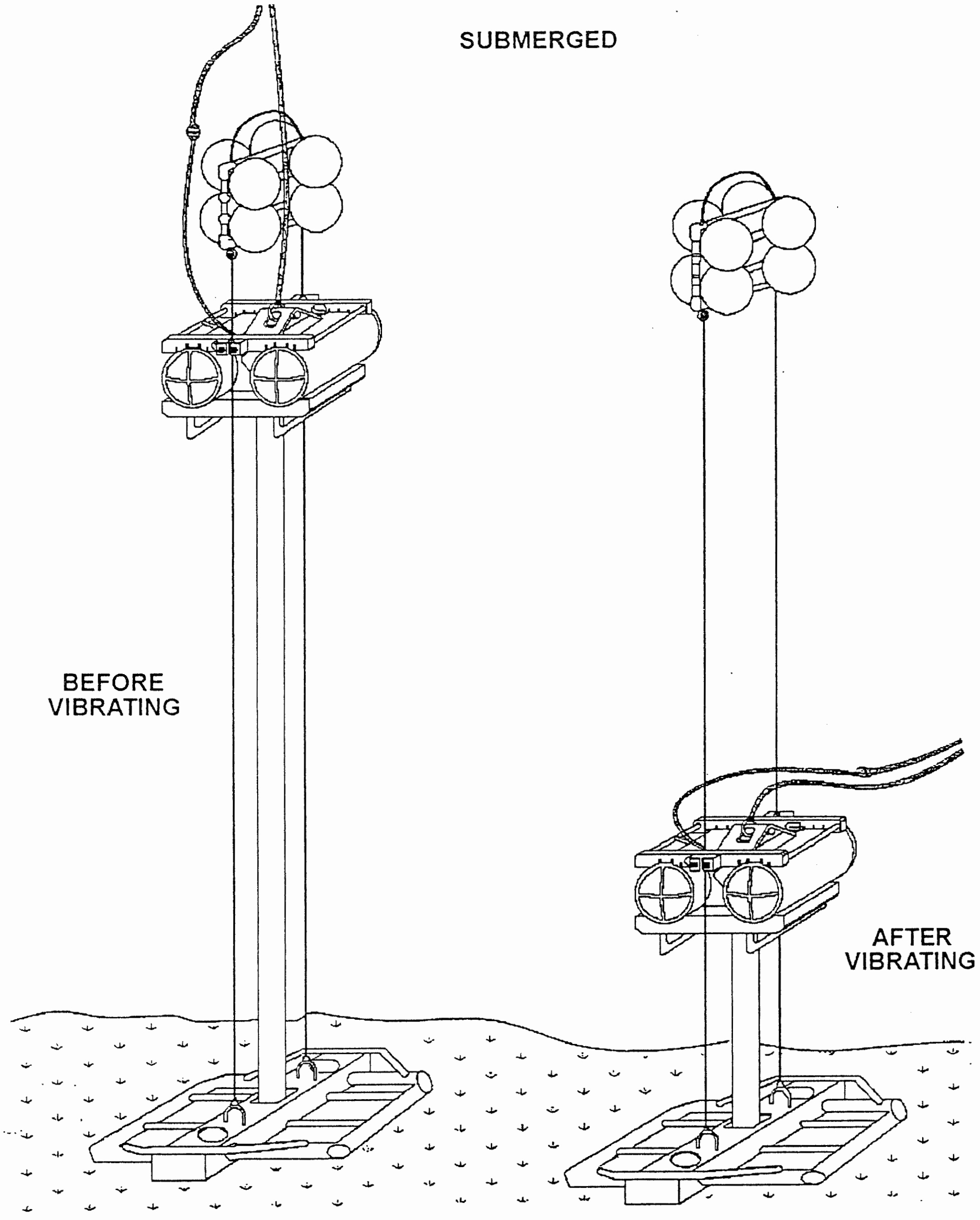

Figure 2.1 continued.

the float package is attached to the top eyes of the guide wires (Fig. 2.1). These guide wires are non-torquing cables that prevent twisting or tangling of the core barrel and the guide wires. The float package assists the vibracorer to remain vertical while on the seafloor before the vibracorer becomes seated in the sediment. The entire unit is lowered from the ship by cable until it rests on the bottom, at which point coring is started by switching on the electrical power.

During coring, the vessel must maintain its position by using fore and aft engines; if position is not maintained the core tube can be damaged or lost as a result of a non-vertical pull-out. During retrieval, as the vibracorer reaches the air-water interface the deploying procedures are reversed. The extent of mud on the outside of the core barrel indicates the penetration depth.

Upon retrieval the core tube is cleaned so that penetration depth can be observed for the next deployment. The core catcher rivets are broken off and drilled out, and the plastic core liner is removed. The core length is noted, to be compared with the apparent penetration depth, from the mud line, to determine compaction caused by coring. The core is then cut into 1.5 m storage lengths. Core tops and bottoms, cruise and site numbers, as well as dates are marked on the core tubes. The core sections are capped, and sealed with electrical tape. Core sections, which are 8 cm in diameter, are stored in a cold room at temperatures between 2-4°C at the Atlantic Geoscience Centre, Bedford Institute of Oceanography, Dartmouth, Nova Scotia.

2.3 Sampling

Sampling involved initial splitting of the cores with a specially built core-splitting device at the Bedford Institute of Oceanography. Because the sediment remains within a plastic liner when split, the splitting device was necessary to minimize contamination of the core by plastic pieces. Once split, one half of the core was designated as an archive, and the other as a working half. The cores were then described and photographed (Appendix A and B respectively). Sampling involved the removal of a standard volume of 10 cc of sediment at each interval. Samples were taken above, at, and below all color and lithological boundaries and at 50 cm intervals where the core was homogeneous. Material removed from the core was replaced with styrofoam plugs to prevent the core from caving during storage.

Samples for foraminiferal analysis were washed through a 63 micron sieve. The 63 micron sieve allows the clay-silt fraction to be washed away while retaining fine organic matter, sand grains, and tests of the microfossils in the sediments. Material not passing through the sieve was collected and placed in labelled vials. If a sample contained excess organic material, the organic material was removed by decantation and placed in a second vial. The decanted organic material was examined as a separate fraction of the total. All samples were stored in denatured ethanol (to prevent bacterial growth) until analyzed. After examination was completed, formaldehyde was added to further arrest bacterial growth.

2.4 Foraminiferal Examination

Individual samples were immersed in water and placed in a circular petri dish. Samples containing abundant foraminifera were split using a wet splitter (Scott and Hermelin 1993) so that equal fractions could be examined. Fractions were examined until a statistically significant number of specimens (at least 300) was reached. Samples that were entirely sand, or contained a large sand fraction, were slowly oven dried. Dried samples were then floated using a standard heavy liquid (carbon tetrachloride, CCl_4, specific gravity = 1.58) technique (Scott *et al.* 1980). All foraminiferal identifications were done using a Zeiss binocular microscope having 20x, 40x, and 80x magnification.

2.5 Carbon Isotopes

Carbon is an important element in nature and is one of the basic elements found in all life forms. Carbon has three isotopes, two of which, carbon-12 and -13, are stable, whereas carbon-14 is radioactive. The short half-life of carbon-14, 5730 years, makes it a useful isotope to date Pleistocene events. The carbon-14 dating technique is based on the ratio of carbon-14 (C^{14}) to carbon-12 (C^{12}).

Carbon-14 is constantly formed in the upper atmosphere (Levin 1991) by the bombardment of cosmic rays which are high-energy particles (mostly protons) (Fig. 2.2). These high-energy particles strike the atoms of upper-atmospheric gasses, splitting their nuclei into protons and neutrons (Fig. 2.2; Monroe and Wicander 1994). Carbon-14 forms when a neutron strikes an atom of nitrogen-14. As a result of this collision, the nitrogen atom emits a proton, captures a neutron, and becomes C^{14} (Fig. 2.2). Carbon-14 combines quickly with oxygen to form CO_2, which is distributed by wind and water currents around the globe (Levin 1991). CO_2 is utilized by photosynthetic plants to build tissue; these plants containing C^{14} are then consumed by animals (Fig. 2.2), and the isotope becomes part of their tissue as well (Levin 1991).

The newly formed C^{14} is rapidly assimilated into the carbon cycle, and along with carbon-12 and -13, is absorbed at a nearly constant ratio by all living organisms. When an organism dies, however, C^{14} ceases to be replenished, and the ratio of C^{14} to C^{12} decreases as C^{14} decays back to nitrogen by a single beta decay, in accordance to the C^{14} rate of

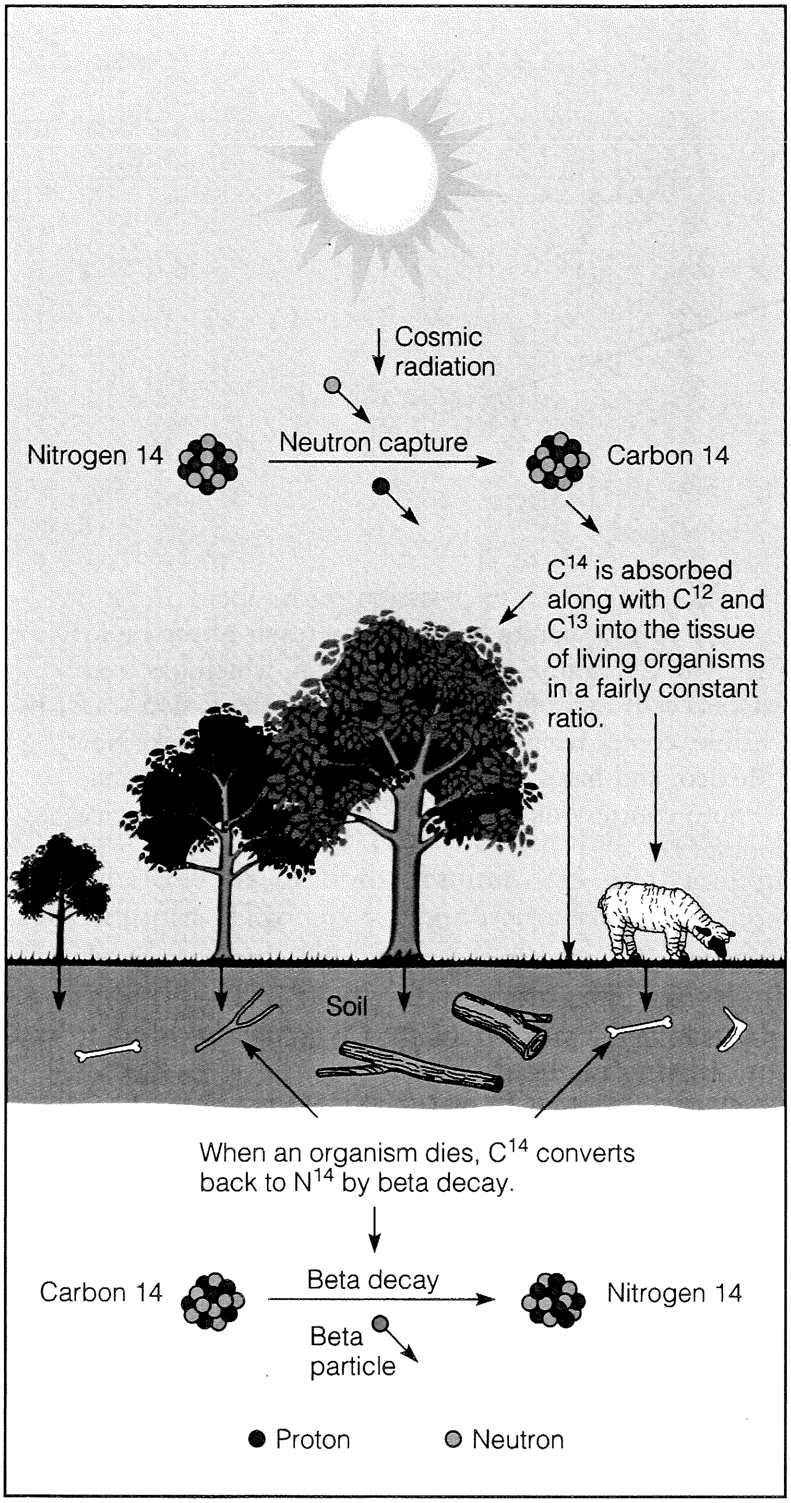

Figure 2.2 The carbon cycle showing the formation, dispersal, and decay of carbon-14 (from Monroe and Wicander 1994).

decay (half-life) (Fig. 2.2; Monroe and Wicander 1994). An age is estimated from the ratio of C^{14} to C^{12} (Levin 1991).

Currently, the ratio of C^{14} to C^{12} is constant in both the atmosphere and living organisms (Monroe and Wicander 1994). However, evidence from tree ring dating suggests that the production of C^{14}, and thus the ratio of C^{14} to C^{12}, has varied somewhat over the past several thousand years. As a result, C^{14} ages are corrected to reflect such variations in the past (Monroe and Wicander 1994).

Two samples were carefully selected from peat horizons at 260-261 cm in Core 9 and 459-463 cm in Core 10. Additionally, a 15 cm section was removed from the working half of Core 2 to obtain sufficient hand-picked calcareous foraminifera for an accelerator mass spectrometer (AMS) date. The AMS sample was removed from the interval 474-489 cm and sent to Beta Analytical. The two peat samples were sent to Kreuger Enterprises for analysis.

Kreuger Enterprises describe the pre-treatment of the peat samples as follows: "The entire sample was dispersed in a large volume of water and the clays and organic matter were eluted away from any sand and silt by sedimentation and decantation. The clay/organic fraction was then treated with hot dilute HCl to remove the carbonates. It was then filtered, washed, dried, and roasted in oxygen to recover carbon dioxide from the organic matter for the analysis". The CO_2 gas produced was captured in a 2 litre counter, and counted over a two-day span to obtain an accurate $C^{12/14}$ ratio which was translated into a date by using the Libby half life (5730 yr.) for C^{14}. The procedure for the accelerator date was different because $CaCO_3$ was used as the C^{14} source, rather than organic plant material. The pre-treatment for AMS dates is described by Beta Analytical as follows: "The sample was attacked with dilute acid to release carbon dioxide (CO_2). The

CO_2 collected was purified and reacted with hydrogen on a cobalt catalyst to produce graphite". The CO_2 gas was then analyzed using a mass spectrometer to obtain the $C^{12/14}$ ratio.

Also provided with the age results were the del (δ) ^{13}C value for each sample (Eqn. 2.1).

$$\left(\frac{{}^{13}C/{}^{12}C\ \text{sample} - {}^{13}C/{}^{12}C\ \text{standard}_{PDB}}{{}^{13}C/{}^{12}C\ \text{standard}_{PDB}}\right) \text{ x } 1{,}000 \tag{2.1}$$

However, unlike carbon-14, biological and inorganic processes, rather than age, determine $\delta^{13}C$ values. Plants, during respiration, preferentially consume C^{12} from the atmosphere producing a lower than standard $C^{13/12}$ ratio.

The scale for $\delta^{13}C$ values ranges from zero for seawater to -30 $^{o}/_{oo}$ (parts per thousand) in humic acids. Typical values for an environment where terrestrial plants are dominant ranges from $\delta^{13}C_{PDB}$ = -25 to -30 $^{o}/_{oo}$. However, because fresh water contains humic acid, a freshwater input is capable of lowering the $\delta^{13}C$ values. Typical values for high marsh and low marsh are $\delta^{13}C_{PDB}$ -26.6 $^{o}/_{oo}$ and -20 $^{o}/_{oo}$ respectively. Therefore, the $\delta^{13}C$ value provides an indication as to whether the sample is marine or lacustrine in nature, helps to determine the amount of marine "reservoir" effect, and is useful for calibrating C^{14} dates.

CHAPTER 3 RESULTS

3.1 Introduction

The cores examined in this study were collected from the inner Halifax Harbour (Fig. 1.1) during August of 1993. Using new vibracoring techniques and equipment, deployed from the *M.V. Tignish Sea*, ten cores were retrieved; however, this study uses only Cores 2, 9, and 10. Results of the lithological analyses, the foraminiferal analyses, the foraminiferal population assessment problems, the seismic reflection profile near Cores 2 and 10 (Fig. 1.1) together with the carbon-14 dates and $\delta^{13}C$ values, are the subject of this chapter. The final section of this chapter contains two new sea-level points derived from carbon-14 dates and foraminiferal assemblages.

3.2 Core 2

3.2.1 Lithology

Core 2 was retrieved in 20.5 m of water northwest of Georges Island at 44°38’24"W, 63°33’03"N and is 512 cm in length (Figs. 1.1, 3.1). The top 30 cm of Core 2 comprises Unit 1 and consists of an unconsolidated, black (5Y 3/1, Munsell Soil Color Chart, see photographs in Appendix B) organic mud with a sharp basal contact (Fig. 3.1). Unit 2 extends from 30-414 cm (Fig. 3.1), and consists of a massive, olive brown (5Y 5/3) sandy mud. Throughout Unit 2, visible shell fragments, gas cracks and H_2S gas mottling, are present (Appendix B). Within Unit 2 is a large slate cobble located at 199-204 cm. The lower portion of Unit 2 (333-414 cm) is a transitional zone, which has a gradational upper boundary and sharp lower boundary. This transitional zone contains less shell material and, as with the rest of Unit 2, is olive brown in color (Appendix B).

Lithologic Unit 3 in Core 2 extends from 414 cm to 446 cm (Fig. 3.1). Unit 3

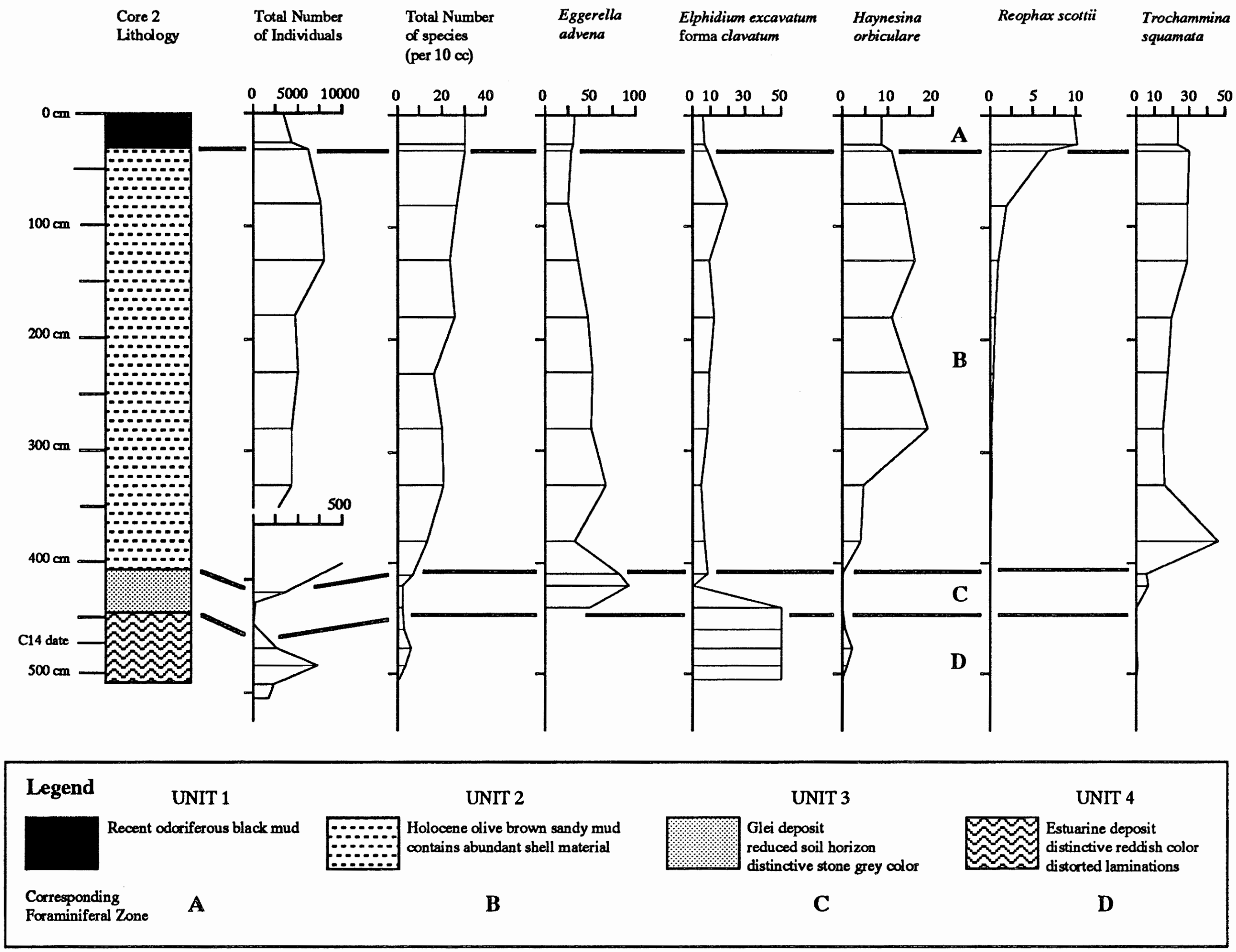

Figure 3.1 Core 2 schematic vertical section, species density, species diversity, and foraminiferal percentages and zonations plotted against core depth. Note the scale change on the species density plot which expands the scale of the lower portion of the plot.

has a distinctive stone grey color (5Y 6/1), contains no shell fragments, and has a higher pebble content than Unit 2 (Appendix B). The basal boundary of Unit 3 is irregular, but remains sharp with the underlying sediment. Contorted laminae characterize the basal unit (Unit 4, 446-512 cm, Fig. 3.1). Distortion of the laminae over the entire diameter of the core, and not just at the sediment edges (adjacent to the core barrel), suggests that the laminae are *in situ* features of the sedimentary unit and were present prior to coring.

3.2.2 Foraminiferal Assemblages

The foraminiferal assemblages identified within each core aid in defining foraminiferal zones. Substantial increases or decreases in the percentages of individual foraminifera, total abundances, and/or species diversity define a foraminiferal zone. A zone boundary marks the beginning or end of a significant trend, whether it be the domination of one species or the absence of another.

The foraminiferal assemblages in samples from Core 2 contain a diversity that ranges from 1 to 30 species (Fig. 3.1; Table 3.1). The total numbers of foraminifera range from 4 to 8008 per 10 cc of sediment, with a decrease in total abundance and species diversity with increasing depth (Fig. 3.1; Table 3.1).

Conforming to the upper two lithological units are foraminiferal Zones A and B. Zone A extends from 0-30 cm whereas Zone B extends from 30-414 cm. These two foraminiferal zones consist mainly of four main species: *Eggerella advena*, *Elphidium excavatum* forma *clavatum*, *Haynesina orbiculare*, and *Trochammina squamata*. *E.advena* is the dominant species with *E. excavatum f. clavatum* and *H. orbiculare* comprising the secondary species (Fig. 3.1). Larger abundances of *Buccella frigida* and *Reophax scottii* in the upper portion of the core distinguishes Zone A from Zone B (Fig. 3.1; Table 3.1).

Depth (cm)	0-1	26-27	32-33	80-81	130-131	180-181	230-231	280-281	330-331	380-381	410-411	420-421	440-441	460-461	476-477	492-493	504-505
Total number of specimens	3369	4339	6185	7634	8008	4607	5000	4288	4247	550	176	16	4	138	365	117	89
Total number of species	30	30	30	27	24	26	16	20	21	13	7	2	2	3	6	4	1
Ammodiscus catinus	0.8	0.7	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0
Ammotium cassis	1.1	1.4	0.7	0.2	0.2	0	0	0.7	0.4	0	0	0	0	0	0	0	0
Bolivina pseudoplicata	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0
Buccella frigida	5.4	2.8	3	2.1	0.7	0.7	1.3	0.9	2.1	1.8	0	0	0	0	0.3	0	0
Buliminella elegantissma	0.3	0.2	0	0	0	0.2	0.1	0	0.1	0	0	0	0	0	0	0	0
Cassidulina reniforme	0.5	1.2	0.9	2	0.9	1.2	0.3	0.4	0.4	0	0	0	0	0	3.3	0	0
Cibicides lobatulus	0.2	0.1	0.04	0.3	0.1	0.2	0.2	0	0.3	0.4	0	0	0	0	0	0	0
Cribrostomoides crassimargo	0.8	0.6	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C. jeffresyi	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dentalina spp.	0.4	0	0.1	0.2	0.2	0	0	0	0	0.4	0	0	0	0	0	0	0
Eggerella advena	32.6	30.7	29.5	24.4	36.5	47.3	53	51.5	68.2	33.1	83	93.8	50	0	0	0	0
Elphidium bartletti	0.2	0	0.1	1.5	1	1.1	1.3	0.2	0.8	0.4	0	0	0	0	0.3	0	0
E. excavatum f. *clavatum*	5.3	6.7	8.3	19	9.4	11.9	9.3	8.6	4.9	6.7	8.5	0	50	98.6	94	89.7	100
E. excavatum f. *excavatum*	0	0	0.1	0.3	0.3	0.2	0	0	0	0	0	0	0	0.7	0	8.5	0
E. frigidum	0	0	0.04	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0
Epistominella takayanagi	0	0	0	0.2	0.4	0.2	0	0.2	0.1	0	0	0	0	0	0	0	0
Fissurina spp.	0.4	0.3	0.3	0.3	0.4	0.1	0	0.2	0	0	0	0	0	0	0	0	0
Fursenkoina fusiformis	0.3	1.1	0.9	0.8	0.7	0.8	0.5	0.5	0.3	0	0	0	0	0	0	0	0
Glabratella wrightii	0	0.7	0.04	0.1	0.2	0.1	0	0	0.2	0	0	0	0	0	0	0	0
Glomaspira gordialis	0.1	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haynesina orbiculare	8.6	8.7	10.9	13.9	16.2	10.9	15.1	19.1	4.8	3.8	0	0	0	0.7	1.9	0.9	0
Islandiella teretis	0.4	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lagena spp.	0.2	0.2	0	0	0	0.1	0.2	0.2	0	0.2	0	0	0	0	0	0	0
Miliammina fusca	0	0	0.04	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0
Nonionelina labradorica	0	0.1	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0
Oolina spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0
Pateoris hauerinoides	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0
Pyrgo williamsoni	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0
Quinqueloculina seminulum	0.1	0.3	0.2	0.2	0.4	1.3	0	0.9	0.4	0.2	0	0	0	0	0	0	0
Recurvoides turbinatus	1	0.2	0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reophax arctica	1.4	2.3	1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0
R. fusiformis	0.5	0.6	0.8	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
R. nodulus	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R. scorpiurus	0.1	0	0.04	0.2	0.2	0.9	0.2	0.2	0	0	0.6	0	0	0	0	0	0
R. scottii	9.8	10.2	6.7	1.9	0.9	0.4	0.2	0.05	0.1	0	0	0	0	0	0	0	0
Rosalina columbiensis	0	0	0	0	0.1	0	0	0.2	0	0	0	0	0	0	0	0	0
Saccammina atlantica	1.3	1	3.2	0.2	0.3	0.1	0.3	0.4	0.4	0	0	0	0	0	0	0	0
Spiroplectamina biformis	3.1	4.4	1.1	0.9	0.9	0.9	0.4	0.1	0.3	0.2	0.6	0	0	0	0	0	0
Textularia earlandi	0.6	0.3	0.1	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
T. torquatta	0	0.6	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
Trifarina fluens	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0
Triloculina arctica	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0
Trochammina inflata	0	0	0	0	0	0	0	0	0.2	0	0.6	0	0	0	0	0	0
T. lobata	0.3	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T. macrescens	0.6	0.6	1	1.6	1.2	0.6	0.5	0.4	0.4	6.2	0.6	0	0	0	0	0	0
T. squamata	23.5	23.6	29.5	28.9	28.5	19.9	17.2	15	15.8	46.2	5.1	6.3	0	0	0	0.9	0
Ostracod	9	8	18	186	8	13	5	64	64	11	23	0	0	3	3	10	2
Planktonics	9	0	3	6	8	0	0	8	0	1	0	0	0	3	0	5	0

Table 3.1 Core 2 population density, total species, foraminiferal percentage abundance, ostracod, and planktonic foraminifera distributions versus depth.

R. scottii shows a marked decrease in abundance down core. All other species form a negligible proportion of the total population. Table 3.1 shows low abundance species which were not plotted in Figure 3.1.

Foraminiferal Zone C coincides with lithologic Unit 3 (414-446 cm). Low species diversity and total numbers, 2 species and 16 individuals per 10 cc respectively, characterize Zone C (Table 3.1). The dominant species is *E. advena* (Fig. 3.1).

A dominant fauna of *E.excavatum f. clavatum* characterizes the final foraminiferal zone, Zone D (446-512 cm), and correlates with lithologic Unit 4 (Fig. 3.1). In addition to *E.excavatum f. clavatum*, a maximum of 6 species per sample is also present. Within the basal foraminiferal zone, the maximum number of specimens and species diversity occur simultaneously, whereas other intervals in this unit contain both fewer species and lower diversity (Fig. 3.1).

3.3 Core 10

3.3.1 Lithology

Core 10 was retrieved in 20.5 m of water northwest of Georges Island at 44°38’29"W, 63°33’19"N and is 512 cm in length (Figs. 1.1, 3.2). Because Core 10 is close to Core 2, their lithologies and foraminiferal assemblages should be similar. However, examination of Core 10 shows a marked difference between the basal units of the two cores (Figs. 3.1, 3.2, 3.3). The upper lithologic unit of Core 10 consists of a highly bioturbated, unconsolidated, black (5Y 3/1, Munsell Soil Color Chart) organic mud. Unit 1 extends from 0-35 cm, has a strong H_2S odor, and has a gradational lower boundary (Appendix B).

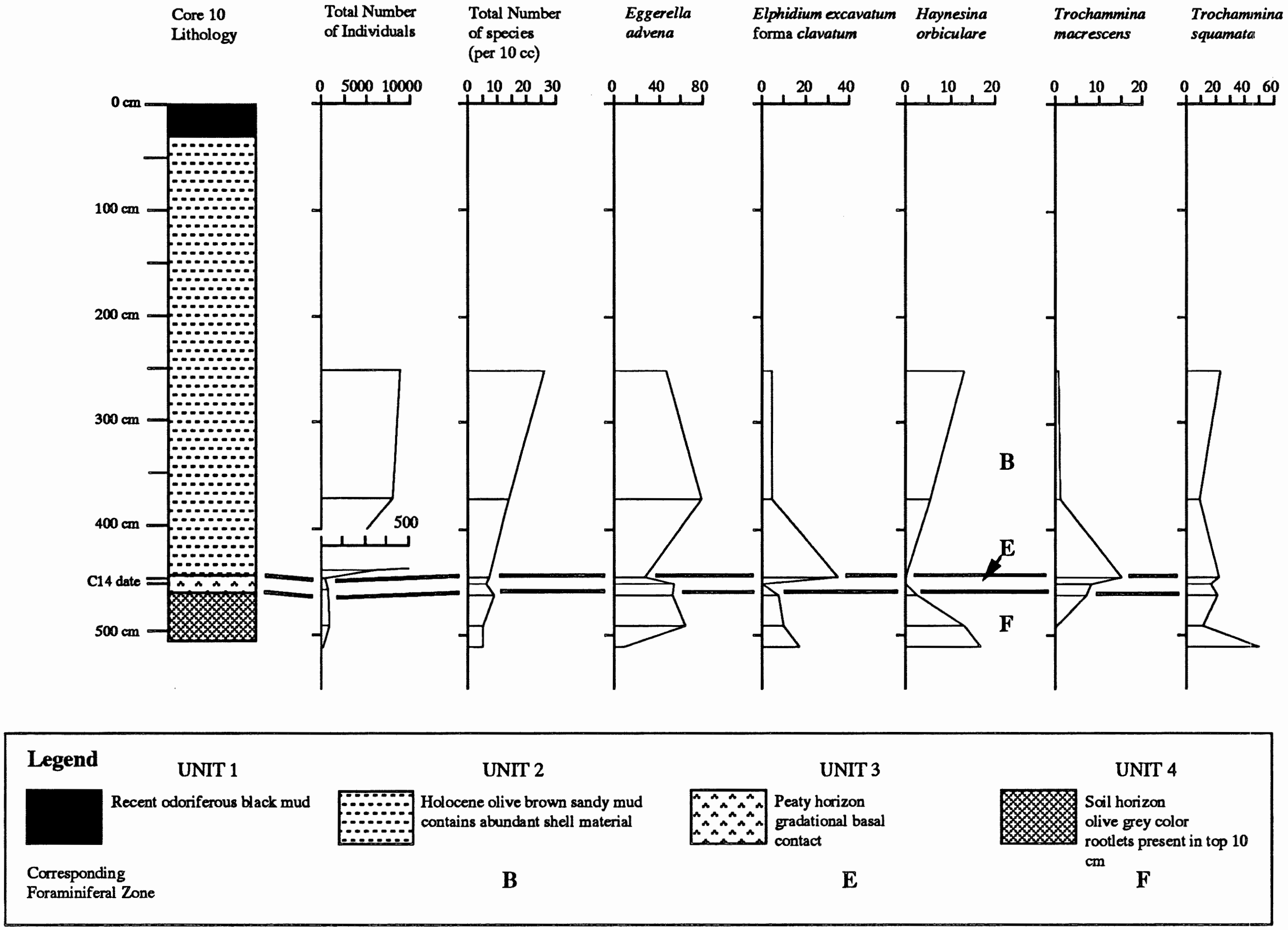

Figure 3.2 Core 10 schematic vertical section, species density, species diversity, and foraminiferal percentages and zonations plotted against core depth. Note the scale change on the species density plot which expands the scale of the lower portion of the plot.

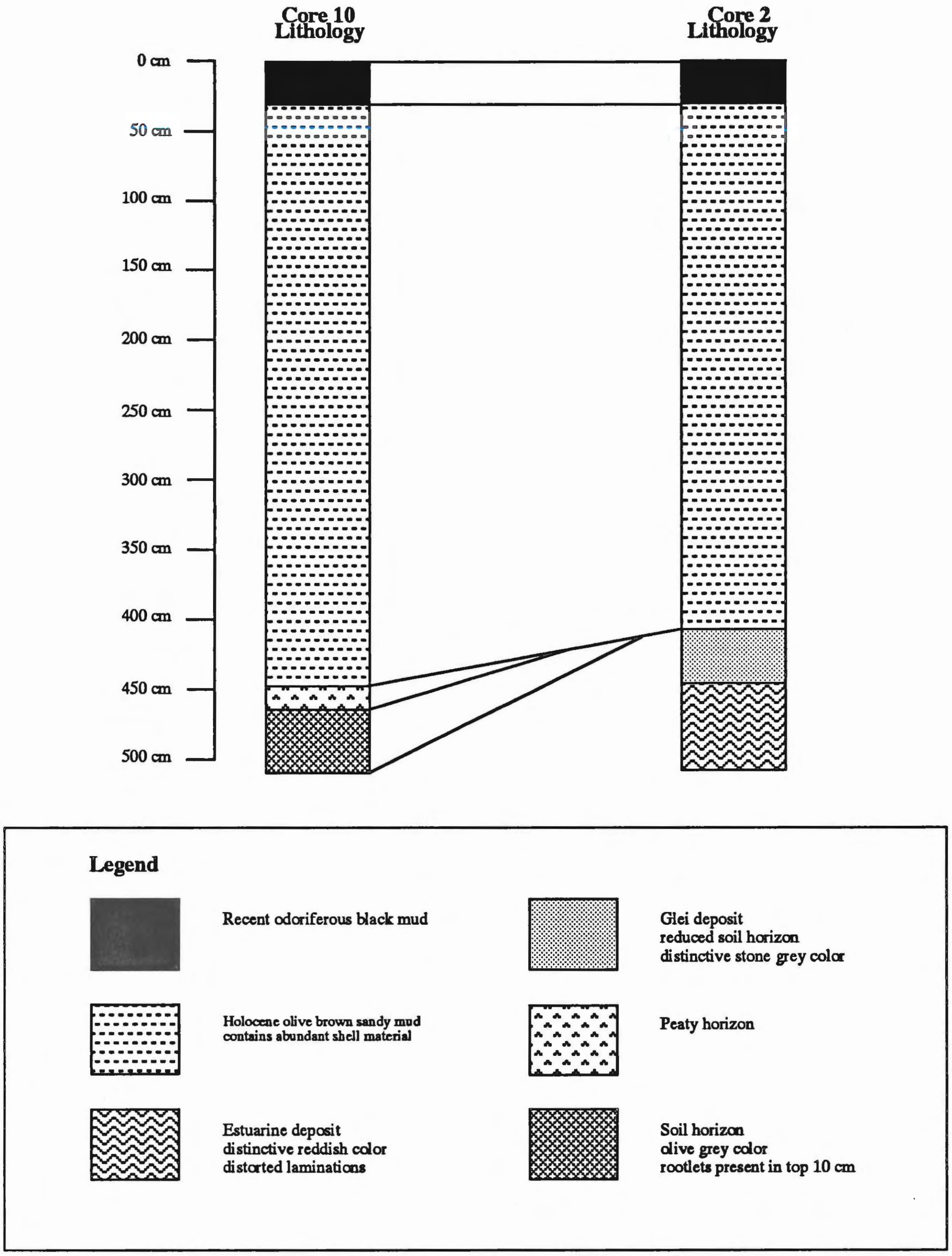

Figure 3.3 Lithological cross sections of Cores 2 and 10. Note the contrasting basal lithologies in comparison to their proximity as seen on Figures 1.1 and 3.5.

Unit 2 is an olive brown (5Y 5/3) sandy mud containing gas mottles and shell fragments. The majority of the second unit is homogeneous, extending from 35-449 cm (Fig. 3.2). However, localized zones of distinct cross laminae (280-310 cm, 352-360 cm), and three shelly layers (304, 307 and 317 cm), contrast the remaining homogeneity of Unit 2. From 420 cm to the base of Unit 2 at 449 cm, the shell content decreases. Unit 2 ends with a sharp basal contact with the underlying Unit 3 (Appendix B).

Unit 3 is a fibrous peat layer approximately 15 cm thick (449-464 cm, Fig. 3.2). Contained within the peat layer is a small sand lens. The peat layer also has a gradational lower boundary with the underlying Unit 4 (Appendix B). Below the peat unit is the basal unit, Unit 4, which consists of a homogeneous grey (5Y 5/1) sandy mud and extends to 512 cm (Fig. 3.3). The upper 10 cm is finely laminated and contains rootlet traces. Rootlet evidence, coinciding with the upper gradational boundary, suggests that the basal unit represents a soil horizon, and that Unit 3 represents an *in situ* peat layer.

3.3.2 Foraminiferal Assemblages

The proximity of Cores 2 and 10 suggested that the foraminiferal assemblages would be similar in the upper Holocene olive grey mud (Unit 2). Therefore, lithological Units 1 and the upper portion of Unit 2 were not sampled for foraminifera in Core 10. Within Core 10 the species diversity ranges between 5 and 26 species, whereas the species abundances range from 12 to 8976 individuals. The dominant foraminiferal assemblage which characterizes Zone B (250-449 cm) of Core 10 contains *E. advena*, *E.excavatum f. clavatum*, *H. orbiculare*, and *T. squamata* (Fig. 3.2; Table 3.2). *Trochammina macrescens* shows an increase towards the base of Zone B and is the dominant species in Zone E, but remains low in numbers (Fig. 3.2).

Depth (cm)	250-251	370-371	444-445	450-451	460-461	490-491	509-510
Total number of specimens	8976	7912	316	24	42	53	12
Total number of species	26	14	7	6	9	5	5
Ammodiscus catinus	0.1	0	0	0	0	0	0
Ammotium cassis	0.2	0.4	0	4.2	2.4	0	0
Buccella frigida	0.6	0.7	0	0	0	0	0
Cassidulina reniforme	0.2	0	0	4.2	0	1.9	0
Cibicides lobatulus	0.2	0	0	0	0	0	0
Dentalina spp.	0.2	0	0	0	0	0	0
Eggerella advena	47.3	79.7	26.9	54.2	52.4	64.2	8.3
Elphidium bartletti	0.1	0	0	0	0	0	0
E. excavatum f. *clavatum*	4.2	4.4	34.5	0	7.1	9.4	16.7
E. excavatum f. *lidoensis*	0.1	0	0	0	0	0	0
E. incertum	0.1	0	0	0	0	0	0
Fissurina spp.	0.4	0	0	0	0	0	0
Fursenkoina fusiformis	0.1	0.2	0	0	0	0	0
Haynesina orbiculare	13.3	5.4	0	0	2.4	13.2	16.7
Miliammina fusca	0.1	0	0	0	0	0	0
Quinqueloculina seminlum	0.3	0	0	0	0	0	0
Reophax arctica	0.3	0	0	0	0	0	0
R. scorpiurus	0.4	0.1	0	0	0	0	0
R. scottii	2.8	0.5	0	0	0	0	0
Saccammina atlantica	0.4	0	0	0	0	0	8.3
Spiroplectamina biformis	1.3	1	0.3	0	0	0	0
Textularia earlandi	0.3	0.2	0.6	0	2.4	0	0
T. torquata	0.3	0	0	0	2.4	0	0
Trochammina inflata	0	0	0.6	12.5	2.4	0	0
T.lobata	0.1	0	0	0	0	0	0
T. macrescens	0.9	1	15.2	8.3	7.1	0	0
T. squamata	23.7	9.2	21.8	16.7	21.4	11.3	50
Ostracod	24	8	22	0	0	0	0
Planktonic	0	0	0	1	0	0	0

Table 3.2 Core 10 population density, total species, foraminiferal percentage abundance, ostracod, and planktonic foraminifera distributions versus depth.

Foraminiferal Zones E (449-464 cm) and F (464-512 cm) show no distinctive patterns in relation to individual foraminiferal assemblages. Low species abundances and low species diversity characterize Zone F (Fig. 3.2). The tests of foraminifera in the decanted fractions of samples from Zone E and F were highly degraded. The decanted fractions of samples from Zone F also contained thecamoebians.

3.4 Core 9

3.4.1 Lithology

Core 9 was retrieved in 27 m of water west of McNabs Island at the entrance to inner Halifax Harbour (44°26'53"W, 63°32'36"N) and is 6 m in length (Figs. 1.1, 3.4). As in the previous two cores, a homogeneous, bioturbated, black (5Y 3/1, Munsell Soil Color Chart) odoriferous mud, extending from the top of the core to 90 cm, characterizes Unit 1 of Core 9 (Fig. 3.4; Appendix B). The interval from 60-90 cm is a transition zone in which the sediment becomes more consolidated. The lower contact of Unit 1 is gradational with Unit 2 below. Unit 2 (90-258 cm, Fig. 3.4) grades from an dark olive green/black (5Y 5/1) to the more typical olive brown (5Y 5/3) sandy mud in the lower portions. Compared with Cores 2 and 10, shell fragments are not as abundant. As well, minor color banding present at 170 cm becomes more prominent around 210 cm. Color variations throughout Unit 2 may be the result of layers rich in FeS_2. Unit 2 rests abruptly on the underlying peat layer, Unit 3. The peat layer, which contains visible wood fragments, has sharp upper and lower contacts and no visible rootlets extending below the lower contact (Appendix B).

The final lithologic unit in Core 9 (Unit 4) extends from the base of the peat lens (276 cm) to the base of the core at 600 cm (Fig. 3.4). The upper portion of Unit 4 (276-534 cm) consists of an olive grey/brown (5Y 3/1) fine-grained muddy sand. The upper

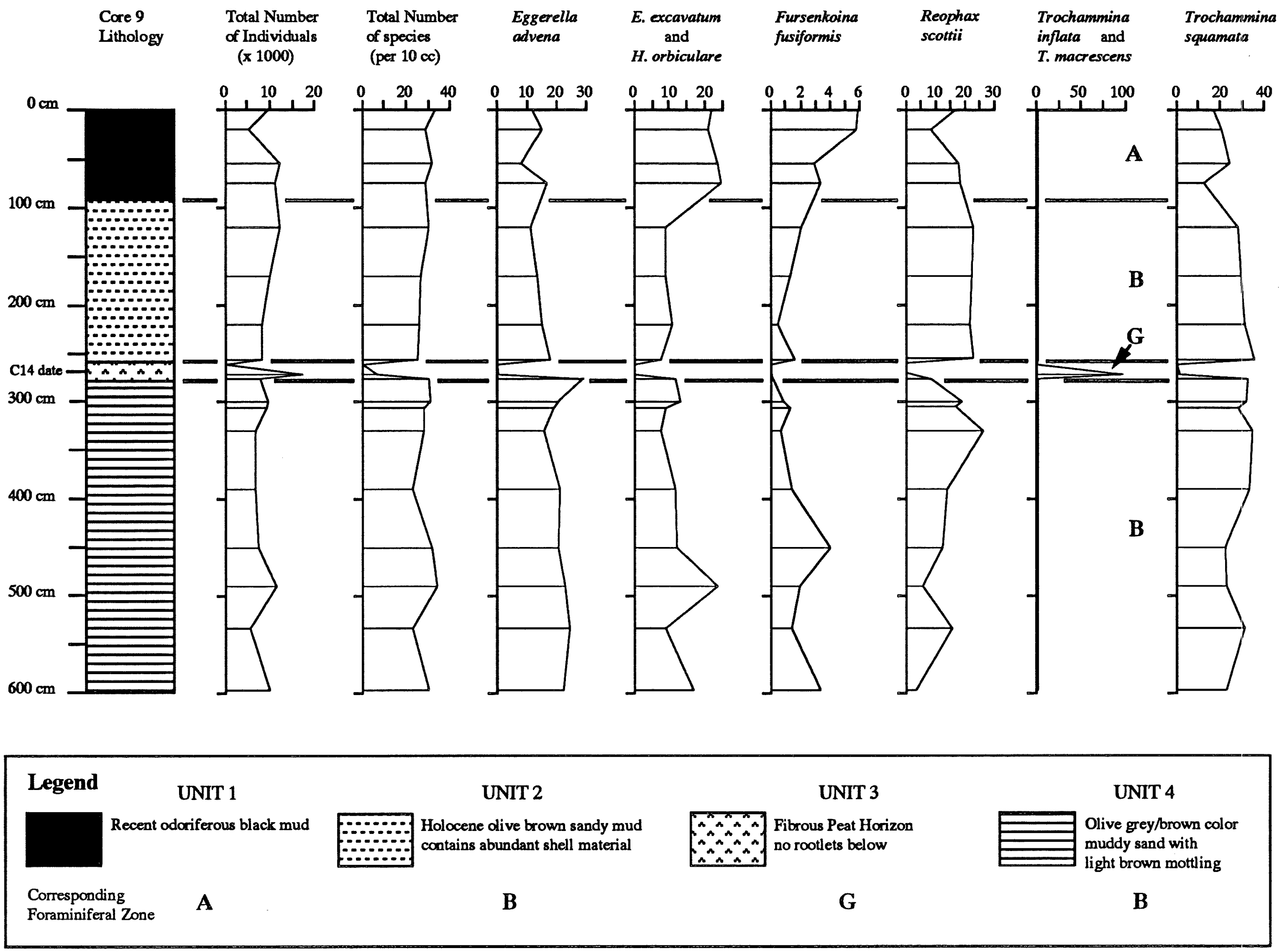

Figure 3.4 Core 9 schematic vertical section, species density, species diversity, and foraminiferal percentages and zonations plotted against core depth.

portion is highly bioturbated with light brown mottling. Visible organic layers are located at 301-302 cm, 322-323 cm, and 532-535 cm. At approximately 534 cm, a gradational change to a lighter olive grey (5Y 5/1) color occurs which characterizes the lower portion of Unit 4 (Appendix B). The lower portion appears to be not only more consolidated, but also less bioturbated. Increased sand content in the lower portion may account for the increased cohesiveness. As with the upper portion, peaty lenses occur at 551 cm and 580 cm (Appendix B).

3.4.2 Foraminiferal Assemblages

With depth in Core 9, the total number of specimens remains relatively constant whereas the species diversity increases slightly (Fig. 3.4; Table 3.3). The total number of species ranges from 23 to 34, with the exception of the displaced peat lens which contains 0 to 7 species. The total number of specimens per 10 cc ranges from 0 to 17,361 (Table 3.3).

Large abundances of *Eggerella advena*, *Elphidium excavatum* forma *clavatum*, *Haynesina orbiculare*, and *Trochammina squamata* characterize foraminiferal Zones A (0-90 cm), B (90-258 cm and 276-600), and G (258-276 cm) in Core 9 (Fig. 3.4). Other species prominent in Zone A, but which decrease in abundance with depth, are *Fursenkoina fusiformis*, *Buccella frigida* and *Cassidulina reniforme* (Fig. 3.4; Table 3.3).

Within Zones A and B the abundance of calcareous species decreases with increasing depth down core (Table 3.3). The combination plot of *E. excavatum f. clavatum* and *H. orbiculare* illustrates this decrease in calcareous species. Other species common throughout Zones A and B, but are not abundant in every sample, include: *Reophax scottii*, *Quinqueloculina seminulum*, and *Spiroplectammina biformis* (Table 3.3).

Depth (cm)	0-1b	0-1a	20-21b	20-21a	54-55b	54-55a	74-75b	74-75a	120-121b	120-121a	170-171b	170-171a	220-221b	220-221a	256-257b	256-257a	261-262b	261-262a	271-272b	271-272a
Total number of specimens	4952	9552	3768	5008	6208	12336	5544	11280	3920	12212	3048	10110	4128	8008	3880	8184	0	0	4560	17361
Total number of species	25	33	24	29	29	32	26	29	22	30	22	27	23	26	22	25	0	0	4	7
Adercotryma glomerata	0	0	0	0	0	0	0	0	0.2	0.1	0	0	0	0	0	0	0	0	0	0
Ammodiscus catinus	0	0.6	0.6	1.2	1.3	0.8	0.4	0.5	0	0.1	0	0	0.4	0.6	0	0.1	0	0	0	0
Ammotium cassis	1.3	0.7	1.3	1	0.3	0.1	4.5	2.2	1.7	0.6	0.3	1.1	0	0	0	0	0	0	0	0
Bolivina pseodoplicata	0.2	0.3	0.2	0.2	0.1	0.5	0.3	0.4	0.6	0.9	0	0	0	0	0	0	0	0	0	0
Buccella frigida	5.5	2.9	5.9	4.9	4.3	24	4	2.3	8.4	3.2	5.2	2.8	4.7	2.4	4.7	2.2	0	0	0	0
Buliminella elejantissma	0	0.5	0	0.2	0.3	0.5	0	0.3	0	0.3	0	0.2	0	0	0.2	0.2	0	0	0	0
Cassidulina reniforme	4	2.9	3.2	2.5	4.8	3.3	4.3	2.1	4.1	2.4	0.3	0.2	0.4	0.2	2.9	1.4	0	0	0	0
Cibicides lobatulus	1	1	1.3	1.2	0.1	0.5	1	1.2	2.2	1.1	0.5	0.3	0.2	0.1	1.2	0.6	0	0	0	0
Cribrostomoides crassimargo	2.9	1.5	2.1	1.6	4.8	2.4	2.9	1.4	1.2	0.4	5	2.5	0.4	0.2	0	0	0	0	0.2	0.1
C. jeffresyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0
Cyclogyra involvens	0	0	0	0	0.9	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dentalina spp.	0	0	0	0.1	0.9	0.5	0	0	0.4	0.2	0	0.1	0.2	0.1	0.2	0.1	0	0	0	0
Eggerella advena	18.1	11.8	19.5	15.2	9.5	7.8	23.4	17	22.2	11.2	31.2	13.4	27.1	15.5	30.7	17.9	0	0	0	0.4
Elphidium barletti	2.4	1.3	1.7	1.3	0	0.5	2.7	1.3	5.9	1.9	3.7	1.6	5	2.6	4.3	2.1	0	0	0	0
E. excavatum f. clavatum	21.3	11.9	13.8	10.8	21.6	11	19.8	11.4	6.1	2.9	5.5	2.7	9.3	4.8	7.4	3.5	0	0	0	0
E. excavatum f. excavatum	0	0	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. excavatum f. gunteri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. frigidum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. incertum	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. margratasium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. subarticum	1.6	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. williamsoni	0	0	0	0	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0
Epistominella takayanagi	0	0.2	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0
Fissurina spp.	0	0.4	1.7	1.4	0.9	1	0.1	0.5	1.6	1.2	0.3	0.1	0	0	1	0.5	0	0	0	0
Fursenkoina fusiformis	3.9	5.9	6.2	5.8	4	2.9	1.4	3.4	2.7	2.1	2.1	1.3	0.8	0.4	3.3	1.6	0	0	0	0
Glabratella wrighti	0	1.8	0	0.9	0	3	0	2.6	0	3.1	0	0	0	0	0	0.1	0	0	0	0
Glomospira gordialis	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haynesina orbiculare	14.4	9.9	13.4	10.2	21.9	12.5	20.2	13.2	1.4	6.2	8.7	6.1	11.4	5.9	7.8	3.8	0	0	0	0
Islandiella teretis	0	0	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lagena spp.	0	0	0.2	0.2	0	0	0	0	0	0	0	0	0.2	0.1	0.4	0.2	0	0	0	0
Miliammina fusca	0	0.1	0	0	0	0	0	0.3	0	0	0	0	0	0.2	0	0	0	0	0.5	0.9
Milliolid spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nonionellina labradorica	0.3	0.2	0	0	0.1	0.1	0.1	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0
Pateoris hauerinoides	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrgo williamsoni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quinqueloculina seminulum	1.6	1.6	1.5	1.3	1.2	0.7	1.7	1.4	5.5	2	0.5	0.3	0.8	0.4	2.3	1.1	0	0	0	0
Recurvoides turbinatus	0.8	0.4	0.4	0.3	0.1	0.1	0.9	0.4	0.2	0.1	0.5	0.2	0	0	0.4	0.2	0	0	0	0
Reophax arctica	2.1	1.8	3	2.5	1.8	1.5	1.9	1.2	1	1.3	1.8	2.3	5.2	3.3	4.9	2.7	0	0	0	0
R. nodulos	0.5	0.3	0.2	0.2	0.4	0.2	0.1	0.1	0	0	0.3	0.1	0	0	0	0	0	0	0	0
R. scorpiurus	0	0	0	0	0	0	0.3	0.2	0	0	1.8	0.9	0.6	0.3	0	0	0	0	0	0
R. scottii	2.9	16.6	0	8.4	6.6	17.7	2.2	18.5	3.5	22.7	5.5	22.4	5.6	22	5.4	23	0	0	0	0.2
Rosalina columbiensis	4.4	2.6	4.9	3.8	2.3	1.2	0.9	1.1	6.9	3.7	0	2	0.6	0.3	0.8	0.4	0	0	0	0
Saccammina atlantica	0.5	0.3	0	0	0.1	0.1	0.6	0.3	2	0.7	0.3	0.1	0.2	0.1	0.6	0.3	0	0	0	0
Spiroplectamina biformis	5.8	3.5	4.9	3.9	5	3	4.2	3.2	4.9	2.4	14.2	7.2	16.5	8.7	3.9	2.1	0	0	0	0
Textularia earlandi	0.3	0.4	0.2	0.2	0.4	0.2	0	0	0	0.3	0	0.2	0.2	0.1	0.2	0.1	0	0	0	0
T. torquatta	0	0	0	0	0.3	0.3	0	0	0	0.2	0	0.2	0.2	0.2	0.4	0.3	0	0	0	0
Triloculina arctica	0	0	0	0	0.3	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trochammina inflata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99.1	42.8
T. lobata	0	0	0	0	0	0	0	0	0	0	0.3	0.1	0.2	0.1	0	0	0	0	0	0
T. macrescens	0	0.1	0	0.2	0	0.5	0.1	0.4	0	0.1	0.5	0.4	0	0.6	0	0.4	0	0	0	54.6
T. squamata	3.9	17.4	13.4	20.6	4.9	24.4	1.7	12.9	4.5	28.4	11.5	29.6	9.7	30.8	16.7	35.3	0	0	0.5	1.2
Gastropod	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusc	0	0	0	0	0	0	0	0	40	40	0	0	0	0	0	0	0	0	0	0
Ostracod	56	200	32	80	1	177	80	208	288	824	48	137	8	8	104	104	0	0	0	0
Plankonic	32	56	80	84	0	32	0	32	0	16	0	0	0	0	8	8	0	0	0	0

Table 3.3 Core 9 population density, total species, foraminiferal percentage abundance, gastropod, mollusc, ostracod, and planktonic foraminifera distributions versus depth. Two sets of data are presented in this table; the letter with the depth corresponds to the data before (b) and after (a) the decants were added to the sinks to obtain the total population.

Depth (cm)	277-278b	277-278a	300-301b	300-301a	306-307b	306-307a	330-331b	330-331a	390-391b	390-391a	450-451b	450-451a	490-491b	490-491a	533-534b	533-534a	597-598b	597-598a
Total number of specimens	3104	7744	4072	9528	5232	9360	2880	6720	3432	6832	3368	7360	7512	11384	5600	5600	6032	10024
Total number of species	21	30	28	31	24	28	24	28	22	23	24	32	28	34	23	23	30	30
Adercotryma glomerata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammodiscus catinus	0	0.2	0.2	0.1	0.5	0.4	0.3	0.2	0.2	0.2	0	0.1	0	0.1	0.1	0.1	0	0
Ammotium cassis	0.5	0.2	1.6	0.7	0.2	0.1	0.6	0.2	0	0	1.9	0.9	0	0	0	0	0	0
Bolivina pseodoplicata	0	0	0.2	0.3	0	0.3	0	0	0	0	0.5	1.2	0	0.2	0.3	0.3	0.3	0.3
Buccella frigida	3.1	1.2	1	0.6	0.9	0.8	1.1	0.5	1.9	1.1	0.7	0.7	1.1	0.9	2.4	2.4	1.7	1.2
Buliminella elejantissma	0	0	0	0.5	0	0.2	0.3	0.1	0	0.1	1	0.9	0.1	0.1	0.4	0.4	0.1	0.3
Cassidulina reniforme	2.3	0.9	2.2	0.9	4.1	2.4	4.7	2	4	2	2.4	1.4	3.5	2.4	4.1	4.1	5.7	3.8
Cibicides lobatulus	1.3	0.5	1.2	0.5	1.8	1.4	1.4	0.6	1.2	0.8	1.7	1.6	2.3	1.8	2	2	5.2	3.6
Cribrostomoides crassimargo	0.8	0.3	2	0.8	0.3	0.2	1.4	0.6	0	0	0.2	0.1	0.4	0.3	0	0	0	0
C. jeffresyi	0	0	0.2	0.3	0	0	0.6	0.2	0	0	0.5	0.2	0	0	0	0	0.1	0.1
Cyclogyra involvens	0	0	0	0	0.2	0.1	0	0	0	0	0	0.3	0	0	0	0	0	0
Dentalina spp.	0.3	0.1	0	0	0	0	0.3	0.1	0	0	0	0	0.3	0.3	0.1	0.1	0.5	0.3
Eggerella advena	36.6	29.1	34.2	20.8	29.7	19	29.2	16	34	21.5	32.3	21.1	28.5	23.3	24.6	24.6	25.9	22.3
Elphidium barletti	5.4	2.2	2.2	0.9	1.2	0.7	1.7	0.7	4	2	7.4	3.4	3.9	2.6	2.9	2.9	2.7	1.6
E. excavatum f. *clavatum*	12.1	4.9	20.2	8.6	8.6	4.8	10.3	4.4	9.8	8	15	8.7	21.2	14.2	4	4	16.3	11.2
E. excavatum f. *excavatum*	0	0	2.4	1	2	1.1	3.6	1.5	0	0	0	0.2	1.7	1.1	0	0	1.3	0.8
E. excavatum f. *gunteri*	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0
E. frigidum	0	0	0	0	0	0	0	0	1.9	0.9	0	0	0	0	0	0	0	0
E. incertum	0	0.1	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0
E. margratasium	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0
E. subarticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. williamsoni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epistominella takayanagi	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0.1	0.2
Fissurina spp.	0.8	0.3	0.6	0.4	1.2	0.9	0.8	0.5	1.2	0.7	0	0.9	0.6	0.6	0.4	0.4	0.4	0.8
Fursenkoina fusiformis	0	0.1	1	0.8	1.1	1.3	1.1	0.6	2.3	1.4	4.5	4.1	2.6	1.9	1.4	1.4	2.8	3.4
Glabratella wrighti	0	0.1	0	0.7	0.2	1.6	0	0.2	2.8	2.7	2.1	3.6	0	2.6	2.9	2.9	4.2	5
Glomospira gordialis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haynesina orbiculare	17	7	9.6	4.5	6.3	3.9	6.7	3	6.5	3.7	4	3.6	13.4	9.6	4.7	4.7	7.2	5.8
Islandiella teretis	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lagena spp.	0	0	0	0	0	0	0.3	0.1	0	0	0	0	0.1	0.1	0	0	0	0
Miliammina fusca	0.3	0.1	0.4	0.2	0	0	0	0	0.2	0.1	0.7	0.3	0.2	0.1	0	0	0.4	0.3
Milliolid spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0.4
Nonionellina labradorica	0.5	0.2	0.2	0.1	0	0	0	0	0	0	0	0	0.3	0.2	0	0	0.3	0.2
Pateoris hauerinoides	0	0	0.2	0.1	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
Pyrgo williamsoni	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.3	0.2
Quinqueloculina seminulum	5.7	2.3	0.2	0.3	12.8	9.7	0.6	0.2	3	1.5	3.6	2.7	2.8	1.8	0	0	8.4	5.2
Recurvoides turbinatus	0.8	0.3	0.6	0.3	0.3	0.2	0.3	0.1	0.5	0.2	0.5	0.2	0.4	0.3	0	0	0.1	0.1
Reophax arctica	2.6	2.1	2	2	1.8	1.3	3.9	1.8	0.9	0.5	0.7	0.7	0.4	0.4	1.1	1.1	0.5	0.3
R. nodulos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R. scorpiurus	0.8	0.3	0.2	0.1	0	0	0	0	0.7	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
R. scottii	0	8.7	3.3	19.1	6.1	16.8	11.1	26.3	1.4	14.2	1	12.3	1	5.8	15.7	15.7	0.5	3.5
Rosalina columbiensis	1.3	0.5	1.4	0.6	4.4	3.2	3.6	1.5	4.9	2.5	5	3.3	4.2	3.1	0.4	0.4	4.9	3.6
Saccammina atlantica	2.3	0.9	0.2	0.1	0.3	0.2	0	0	0	0	1	0.4	0.3	0.2	0.1	0.1	0.3	0.2
Spiroplectamina biformis	3.6	3.5	4.9	2.4	1.5	0.9	4.7	2.3	1.4	1.3	5.9	3.8	2	1.7	0.9	0.9	2.5	2.2
Textularia earlandi	0	0	0	0	0	0	0	0.1	0	0	0	0.1	0	0.1	0.1	0.1	0	0
T. torquatta	0	0	0.2	0.3	0	0.1	0	0.2	0	0	0	0	0	0	0	0	0	0
Triloculina arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trochammina inflata	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0	0
T. lobata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T. macrescens	0	0.8	0	0.8	0	0.6	0	0.8	0.2	0.7	0	0.5	0	0.6	0	0	0.1	0.5
T. squamata	0	32.5	7.7	31.5	14.4	27.9	11.7	34.9	11.7	33.5	5.7	22.4	7.5	23.2	30.9	30.9	6.4	22.7
Gastropod	0	0	0	0	8	8	0	0	8	8	0	0	24	24	0	0	0	0
Mollusc	0	0	0	0	0	0	0	0	8	8	24	24	0	0	0	0	40	40
Ostracod	56	56	88	88	264	656	72	112	80	144	304	444	200	296	104	104	296	512
Plankonic	0	0	0	0	0	32	0	0	16	16	24	56	24	24	0	0	24	32

Table 3.3 continued

The displaced peat lens at 258-276 cm (Zone G) contains an assemblage distinct from the rest of Core 9. The sample at 261-262 cm is barren of foraminifera, however, the sample at 271-272 cm contains an assemblage dominated by *Trochammina inflata* and *T. macrescens* (Zone G, Fig. 3.4).

3.5 Problems in Assessing Foraminiferal Populations

During the examination of individual samples, the sinks (heavy fraction) were examined separately from the decants (light fraction containing abundant organic material). In all cases the number of individual specimens was noted, before and after the decanted fraction was added to the sink fraction, to obtain the total foraminiferal percentages (representative data presented in Table 3.3). This procedure allows the percentage of individual specimens to be calculated before and after addition of the decant fraction. These percentage determinations are important in light of previous work where the decant fraction of each sample may not have been examined (e.g., Honig and Scott 1987).

Scott and Medioli (1983) and Medioli and Scott (1988) believed that decant fractions only added to the total number of specimens and did not affect the individual foraminiferal percentages. However, McCarthy (1984) and Collins *et al.* (1990) examined whole samples in addressing total thecamoebian populations. Upon examining the foraminiferal data for Core 9 (Table 3.3), a trend of not only an increase in total numbers but also a significant change in the dominant species is apparent. This change in dominant species affects the foraminiferal assemblage, which in turn could change the paleoenvironmental interpretation. For example, in Zones A and B of Core 9, before decant fractions were added, *E. advena* and *E. excavatum* forma *clavatum* were the dominant species. After addition of decant fractions, the dominant species change to include *R. scottii* and *T. squamata* (Table 3.3).

3.6 Seismostratigraphy

Seismic reflection data collected in the summer of 1990 (line E-F on Fig. 1.1; Fader and Miller 1992) was used for geological interpretation, and for locating potential core sites. The seismic profile shows five units. The units distinguished from seismic profiles are correlated to the lithologic units previously described. As a result of scale and resolution problems in seismic stratigraphy, thinner units are observed in the core but not on the seismic profile.

The upper unit on the seismic profile is the Holocene mud deposit (Fig. 3.5). This seismic unit correlates with lithologic Unit 2 in Cores 2, 10, and 9 (Figs. 3.1, 3.2, 3.4). The Holocene mud appears as an acoustically transparent unit with a few continuous, coherent, weak intensity reflectors (Fig. 1.2; Fader *et al.* 1991). Within the Holocene mud, Fader *et al.* (1991) distinguished large pockets of gas-charged (methane) sediments, which they interpreted as having been generated by the presence of organic material in the sediment.

The second unit observed on the seismic data is a layer which thins laterally (Fig. 3.5). This unit accounts for the contrasting basal lithologies between Core 2 and 10 and correlates with lithologic Units 3 and 4 of Core 10 (Figs. 3.2, 3.3). Seismic Unit 2 only occurs in local depressions in the underlying unit, which may suggest why Fader (1991) interpreted it as a transgressive lag.

The principal unit of interest on the profile is seismic Unit 3. High amplitude, continuous reflections, which are highly conformable to bedrock irregularities, characterize

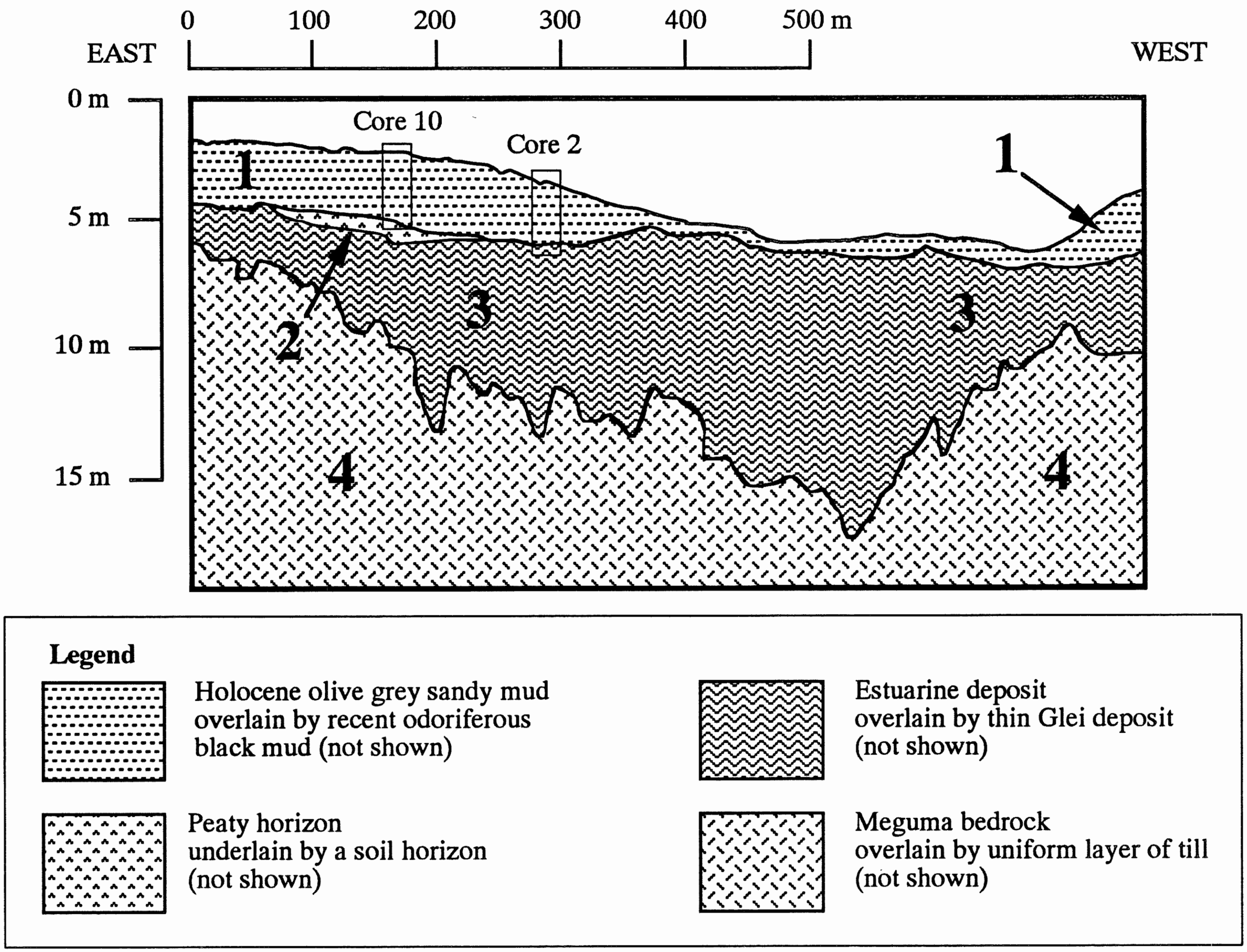

Figure 3.5 An interpretation of seismic profile E-F seen in Figure 1.2.

Unit 3 (Fig. 1.2). Fader *et al.* (1991) interpreted the upper surface of this unit to represent a transgressive erosional surface. This sediment package, which had never previously been sampled, occurs in the basal section of Core 2 (Unit 4) and was not sampled in the other cores (Fig. 3.1).

The basal unit observed on the seismic profile is bedrock (Fig. 3.5). The bedrock surface is likely overlain by a uniform layer of till not distinguishable on the seismic profile (G. Fader pers comm). Because the cores did not penetrate this unit, ground-truthing of this portion of the seismic profile was not possible.

3.7 Carbon-14 Dates and $\delta^{13}C$ Values

Carbon-14 dates determined for three samples, one from each core, provide chronological control and aid in constructing sea-level curves. Two samples were obtained from peat layers in Cores 9 and 10 at depths of 261-262 cm and 459-463 cm, respectively (Table 3.4). The third date comes from a 15 cm section of Core 2 (474-489 cm), in which more than 3,000 foraminifera were hand-picked to obtain a sample sufficient for an Accelerator Mass Spectrometer (AMS) analysis (Table 3.4).

The organic material from Core 9 yielded an age of 1,065 +/- 80 ybp. The organic material from Core 10 yielded an older age of 7,770 +/- 260 ybp (Table 3.4). The AMS foraminiferal date from Core 2 yielded the oldest date of 8,480 +/- 60 ybp (Table 3.4).

The $\delta^{13}C$ values that accompanied the age dates of the two peat samples from Core 9 and 10 are $\delta^{13}C_{PDB}$ = -26.1 $^{o}/_{oo}$ and -26.6$^{o}/_{oo}$ respectively (Table 3.4). The $\delta^{13}C$ value that accompanied the AMS foraminiferal date was $\delta^{13}C_{PDB}$ = -9.3 $^{o}/_{oo}$ (Table 3.4).

Sample	Core 2	Core 10	Core 9
Sample Number	AMS-10727	GX-19448	GX-19447
Description	foraminifera	peat	peat
Depth (cm)	474-489	459-463	261-262
C^{14} Dates (ybp)	8,480 +/- 60	7,770 +/- 260	1,065 +/- 80
$\delta^{13}C_{PDB}$ ($^{o}/_{oo}$)	-9.3	-26.6	-26.1

Table 3.4 Carbon-14 sample numbers, descriptions, depths, C^{14} dates and $\delta^{13}C$ values. Sidereal corrections were not done on these dates because the oldest date is too old to be corrected. If the other dates were corrected, they would not be comparable with the older date.

As stated in Section 2.5, the scale for $\delta^{13}C$ values ranges from zero for seawater to -30 $^{o}/_{oo}$ in humic acids. The $\delta^{13}C$ values for the two peat samples are both approximately $\delta^{13}C_{PDB}$ = -26.6 $^{o}/_{oo}$, suggesting that the values obtained are within the high marsh zonation, reflecting strong terrestrial input into the highest salt marsh zone.

The less negative $\delta^{13}C$ value from foraminiferal tests in Core 2 initially suggested that carbonate recrystallization may have occurred by acid in humic-acid-rich groundwater that may have contaminated the sample. However, this process should have also destroyed the foraminiferal tests. The negative $\delta^{13}C$ is a typical value for an estuarine type environment with a salt-water input; typical $\delta^{13}C$ values even for glacial meltwater do not exceed $\delta^{13}C_{PDB}$ = -5$^{o}/_{oo}$ (Scott *et al.* 1989a).

3.8 Sea-Level Points

Sea-level points obtained from an *in situ* peat in Core 10 and an AMS foraminiferal date from Core 2 (Table 3.5) aid in constructing a new sea-level curve (Fig.

3.6). The new relative sea level (RSL) points help to extend and resolve the sea-level curve between 9,000 ybp and 4,000 ybp. The sea-level curve presented in this study is based on $\delta^{13}C_{PDB}$ corrected ages (which correct marine samples for the total marine carbon content) and not sidereal corrected dates (which correct all dates, marine and lacustrine, by an equivalent standard). The dates are not corrected to sidereal years because the AMS date obtained from Core 2 was too old for the calibration program of Stuiver and Reimer (1986). Therefore, rather than having one date uncorrected for sidereal years, all dates were plotted as $\delta^{13}C_{PDB}$ corrected only.

An age determination on organic material from an *in situ* peat layer in Core 10 yielded a date of 7,770 +/- 260 ybp. Because the peat in Core 10 is a higher high water (HHW) indicator, and Core 10 was collected at 04:13 hrs (Atlantic Daylight Saving Time), during mean tidal level (Atlantic Coast Tide Tables 1993), 1 m is added to the water depth to compensate for the difference in sea level. This 1 m compensation changes the depth of the peat layer from -25.1 m (Table 3.4) to -26.1 m. Therefore, using a depth of -26.1 m, the data provides a sea-level point (Table 3.5) at 26 m below present sea level for the age determination (7,770 +/- 260 ybp).

The second sea-level point obtained in this study is in Core 2. An AMS date on foraminifera yielded a date of 8,480 +/- 60 ybp, at a depth of -25.3 m (Table 3.5). This sea-level point is not as precise as other points, because it represents a deposit that had to form below sea level, but could range from 1 m to 10 m below sea level; estuarine faunas are not as sensitive to water depth as marsh foraminifera (Scott and Medioli 1980a). However, this sea-level determination does provide a point at which sea level must have been at least as high as -25 m, probably several meters higher.

Using other published sea-level points from Chezzetcook Inlet (Brown 1993), Bedford Basin (Miller *et al.* 1982a), Lunenburg Bay (Scott and Medioli 1982), and the inner continental shelf (Forbes *et al.* 1988) (Table 4.1), in addition to the sea-level points from this study, aid in constructing a new sea-level curve (Fig. 3.6).

Age (ybp)	Lab number	Depth (m)	Description	Source
0		0		Current Sea Level
1,735	GX-18458	-3.5	Salt marsh	Brown 1993
2,710	GX-18454	-6.46	Salt marsh	Brown 1993
3,525	GX-5708	-8.2	Salt marsh	Brown 1993
3,820	GX-18459	-10.2	Salt marsh	Brown 1993
3,830	GX-18455	-11.5	Salt marsh	Brown 1993
5,830	GX-6806	-20	Organic	Miller *et al.* 1982a
7,070	GX-6490	-28	Salt marsh	Scott & Medioli 1982
7,500	GX-13972	-34	Salt marsh	Forbes *et al.* 1988
7,770	GX-19448	-26.1	Salt marsh	This Study
8,480	AMS-10727	-25.3	Foram	This Study

Table 3.5 Age, lab number, depth, description, and source of points used to construct the new sea-level curve.

3.9 Summary

Examination of three vibracores from Halifax Harbour shows that lithologic units correlate with foraminiferal zonations. Foraminiferal density and diversity are valuable aids in determining the depositional environments. Seismic profiles are useful not only for stratigraphic control but are also useful for determining core location. Carbon-14 dates provide chronologic control in an attempt to determine the timing of sea-level changes events and may provide additional information to construct Holocene sea-level curves.

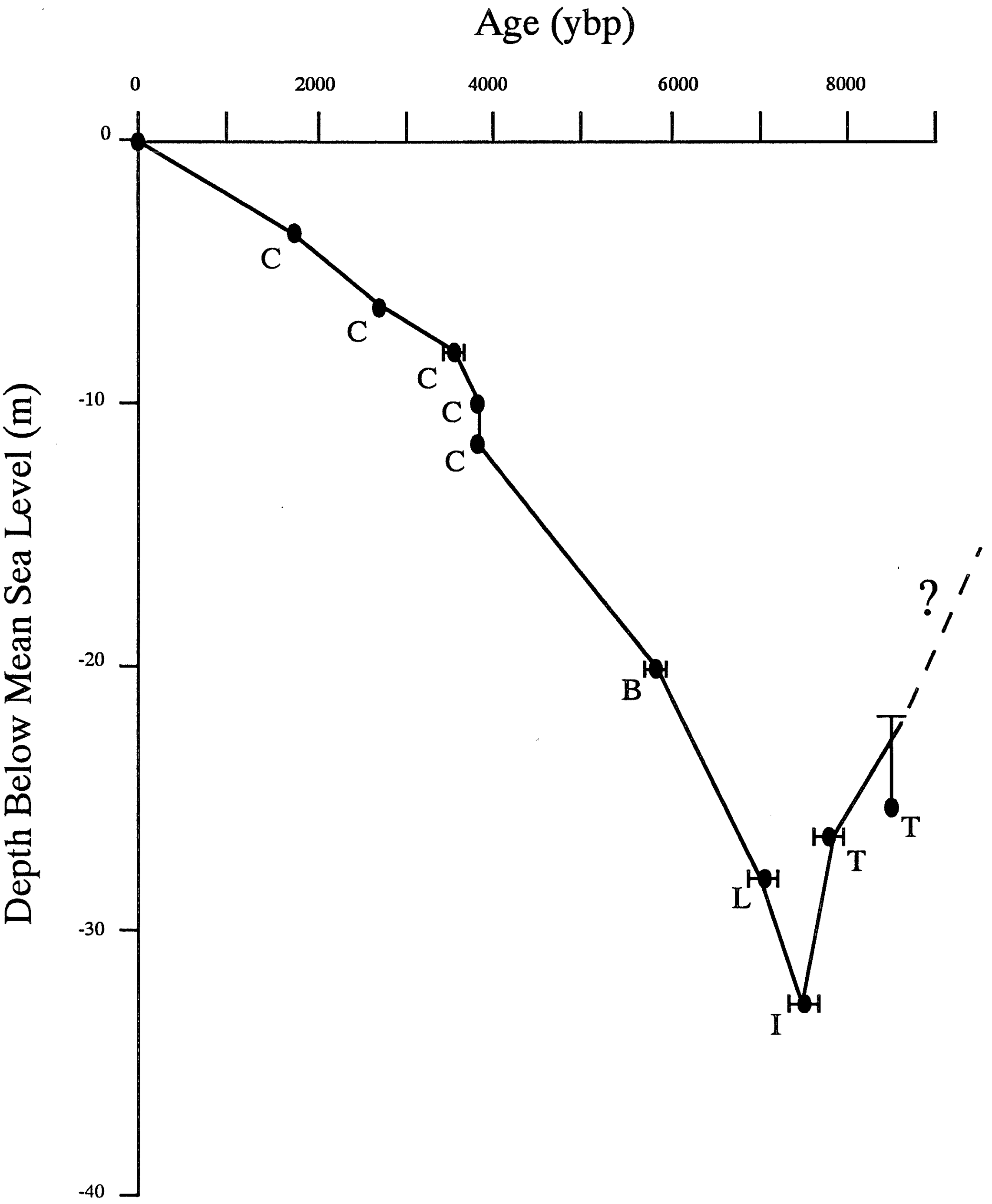

Figure 3.6 Holocene RSL curve for Halifax Harbour. The curve is a compilation of sea-level points from Halifax Harbour (this study, T), and other published points from Bedford Bay (B), Chezzetcook (C), Lunenburg Bay (L), and the inner continental shelf (I) (Table 3.5).

CHAPTER 4 DISCUSSION

4.1 Introduction

Presented in this chapter are the interpretations of foraminiferal zones defined on the basis of the foraminiferal assemblage, species abundance, and species diversity. Because foraminiferal assemblages are sensitive to organic content, they also aid in determining the degree of organic loading in a benthic environment. Foraminiferal assemblages, combined with core stratigraphies, C^{14} dates, and $\delta^{13}C$ values, are valuable for evaluating paleoenvironmental conditions. Carbon-14 dates of foraminifera and peat layers, as well as marsh foraminiferal zonations, provide the most accurate means of determining sea-level points at a given time. A discussion of the implications of the new sea-level curve on the sea-level history of Halifax Harbour follows the discussion of the theoretical model used to model sea-level change on a former ice margin. The final section provides a summary of the chapter.

4.2 Interpretations of Foraminiferal Zones

4.2.1 Zone A

Foraminiferal Zone A occurs in the upper 30 cm of Core 2 and the upper 90 cm of Core 9. Because the upper 250 cm of Core 10 was not processed for foraminifera, Zone A is not recorded in Core 10. However, Zone A probably occurs, because lithologic Unit 1 is identical in Cores 2 and 10. With increasing depth Zone A shows a slight increase in species abundance, but no significant change in species diversity (Figs. 3.1, 3.4) Although most of the major species present in Zone A increase in abundance in Zone B (Figs. 3.1, 3.4), *Reophax scottii*, *Fursenkoina fusiformis*, and *Elphidium excavatum* f.

clavatum/ *Haynesina orbiculare* decrease in percentage occurrence down core (Figs. 3.1, 3.4).

The decrease in the population abundances may be artificial, resulting from higher sediment input which would "dilute" the number of foraminiferal tests per sample. Also, the more seaward location of Core 9 may account for the slight increase in diversity in Zone A from Core 9 over Zone A from Core 2.

Halifax Harbour is generally an open estuary. However, the presence of *R. scottii*, a deep estuarine (a quiet, high organic matter, low oxygen environment) species and the increase in *F. fusiformis*, which is also tolerant of low oxygen conditions (Scott *et al.* 1980, 1984; Miller *et al.* 1982a), suggests that deep estuarine conditions now exist in the benthos of the inner Halifax Harbour, that possibly did not exist prior to anthropogenic impacts.

4.2.2 Zone B

Foraminiferal Zone B occurs in all cores and is characterized by uniform abundances of major species (Figs. 3.1, 3.2, 3.4), including high abundances of *Eggerella advena*, *Elphidium excavatum*, and *Trochammina squamata* in Cores 2, 10, and 9 with *R. scottii* only present in high abundances in Core 9 (Figs. 3.1, 3.2, 3.4). This zone represents a typical Holocene open estuary fauna.

4.2.3 Zone C

Foraminiferal Zone C occurs within lithological Unit 3 of Core 2. Unit 3 is interpreted as a glei deposit (R. Stea pers comm). A glei is a waterlogged soil or soil-horizon in which reduction may take place (Whitten and Brooks 1972). Deposits of similar nature commonly occur as sea level drops and eroded material deposits over existing deposits. In Nova Scotia, glei deposits often occur below bogs and marsh deposits (R. Stea pers comm). Therefore, the foraminiferal assemblage dominated by *E. advena* may represent either a highly stressed environment (extreme variations), or more likely, a non-marine deposit containing a reworked assemblage (D. Scott pers comm). The possibility of a reworked fauna appears to be realistic, in view of the transgressive unconformity interpreted to overlie the upper surface of Unit 3 (Fader *et al.* 1991).

4.2.4 Zone D

Foraminiferal Zone D is the most critical zone because it corresponds to the seismically distinct Unit 3 in Figure 3.5 (Unit 4 in Core 2; Fig. 3.1). An assemblage dominated by *Elphidium excavatum* with minor abundances of *H. orbiculare* characterizes Zone D (Fig. 3.1). The lack of a *E. excavatum* - *Cassidulina reniforme* assemblage determines that the zone does not represent a glaciomarine fauna. The assemblage present in Zone D is similar to that found by Bartlett (1966) and Scott *et al.* (1977, 1980) in the modern Mirimachi estuary, suggesting that Zone D represents an estuarine depositional environment.

4.2.5 Zone E

This foraminiferal zone corresponds to lithologic Unit 3 of Core 10 (Fig. 3.2). Low total abundances and low species diversity characterize Zone E (Fig. 3.2). *Eggerella advena*, *Trochammina squamata* and *T. macrescens* are the dominant species (Fig. 3.2). The presence of *T. macrescens*, even in low numbers, suggests that the peat layer represents a high marsh depositional environment. The low abundances may result from subsequent subaerial exposure and oxidation of foraminifera as sea level fell below this point (Scott and Medioli 1986). Further evidence to support the idea of subaerial exposure is the presence of degraded foraminifera in the decanted fractions. Degraded foraminifera represent poor preservation.

4.2.6 Zone F

The presence of rootlets extending from lithological Unit 3 in Core 10 into the underlying Unit 4 suggests that the peat layer is *in situ*, and that Unit 4 represents a soil horizon. No distinct trends are present in the foraminiferal assemblage data; however, the presence of thecamoebians in the decanted fractions of samples from Zone F suggests that the during the time of deposition this unit may have been close to the marine/freshwater margin (D. Scott pers comm).

The reduction in total numbers and diversity in both Zones E and F may be the result of the corresponding lithologies, a peat layer and an underlying soil horizon. The harsh environment, as a result of the fresh water input, may account for the low total abundances.

4.2.7 Zone G

Foraminiferal Zone G coincides with a fibrous peat horizon at 258-276 cm in Core 9 (Fig. 3.4). The upper portion of Zone G is barren, whereas the lower portion has an assemblage dominated by *Trochammina inflata* and *T. macrescens* (Fig. 3.4). An assemblage dominated by *T. inflata* and *T. macrescens* indicates a high marsh depositional environment (Scott and Medioli 1980b).

Although from similar lithologies, Zone G from Core 9 and Zone E from Core 10 have different foraminiferal assemblages. The lack of rootlets extending below the lower contact of Unit 3 in Core 9 suggests that the peat horizon is not *in situ*. The age of this salt marsh deposit (1,065 +/- 80 ybp), which represents a higher water deposit (based on benthic foraminifera), suggests that it was redeposited at this site in at least 23 m of water (sea level was only 3 m lower at 1,000 ybp, Fig. 3.6). This deposit (Unit 3, Zone G in Core 9) was probably not subjected to subaerial exposure because foraminiferal tests were not degraded, as they were in Zone E in Core 10. Also, because the peat layer is not *in situ*, its provenance is uncertain, whereas the peat horizon in Core 10 lies directly above its soil (Fig. 3.1).

4.3 Pollution

Using surface samples, Buckley and Winters (1992) provide the most recent work on heavy metal contamination of Halifax Harbour. The purpose of this section is not to quantify pollution, but to determine the effects of organic loading on the marine benthic community within the inner Halifax Harbour. Major changes in the marine biota during the recent period of urban development may be the result of increased sediment flux and effluent discharge.

If an increase in organic sediment flux and effluent discharge were to have negative effects on the benthic community, changes in the total species abundance and the species diversity should occur. The typical pollution response for all organisms is for a decrease in the total diversity, but an increase in the total population as a result of an increase in opportunistic species. However, in both Cores 2 and 9, where continuous samples were taken to the top of the core, neither the species diversity nor the species abundance plots show significant change (Figs. 3.1, 3.4). The lack of a general response to pollution may suggest that the increase in sediment flux and effluent discharge causes an

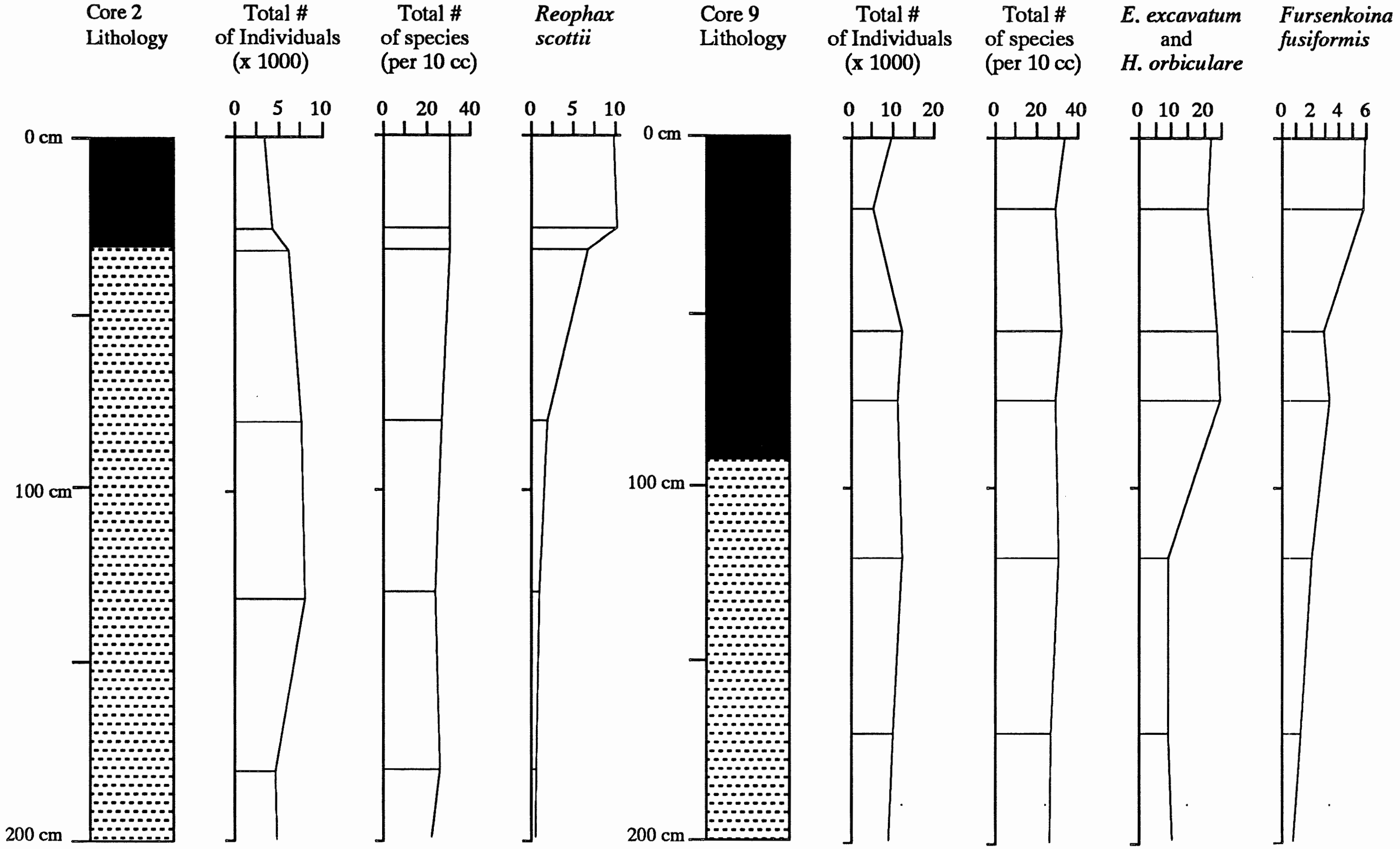

Figure 4.1 The upper sections of Cores 2 and 9. Schematic vertical section, species density, species diversity, and key indicator species percentages plotted against core depth.

increase in nutrient supply. This greater nutrient supply increases the food availability, and hence increases the capacity of the environment to support more organisms.

Although insufficient samples were examined to quantify the degree of pollution within the inner harbour, the use of key indicator species allows for a determination of the degree of pollution (organic loading) in Recent sediments in relation to the Holocene mud below. Because high numbers of *R. scottii* indicate a deep estuarine environment (Scott *et al.* 1980a, 1984; and Miller *et al.* 1982a), the decrease in abundance of *Reophax scottii* with increasing depth down Core 2 (dominant in Zone A, but not Zone B; Figs. 3.1, 4.1) suggests decreasing organic content below the surface of the core. Coinciding with the decrease in *R. scottii* is the decrease in abundance of *Fursenkoina fusiformis* in Core 9 (more dominant in Zone A than B; Figs. 3.4, 4.1). Like *R. scottii*, *F. fusiformis* typically occurs in deep estuarine conditions (Alve and Nagy 1986). The presence of *F. fusiformis* suggests that organic loading forms an oxygen-depleted environment which is more suitable for the growth of this species. These decreases in species abundance with depth may represent a change in the benthic environment, probably associated with an increase of organic input in Recent deposits. However, variables such as preservation potential and sedimentation rate may also affect the species abundance percentages.

Another foraminiferal trend in Core 9 is the decline in the calcareous fauna with depth as illustrated by the *Elphidium excavatum* f. *clavatum*/ *Haynesina orbiculare* plot (Fig. 4.1). Because most factors associated with pollution (i.e., increase organic input, decrease oxygen concentration, and even lower salinity) would act against calcareous species (D. Scott pers comm), the increase of calcareous species under probably unfavourable conditions is of interest. The only effect of pollution that might favour calcareous species is a slight increase in bottom temperature caused by an increase in effluent discharge; an increase in temperature favours calcium carbonate ($CaCO_3$) production. Enhanced calcium carbonate production occurs naturally in nearby salt marshes where $CaCO_3$ species occur in summer months, but are absent during winter months (Scott and Medioli 1980c).

As with any coring procedure, a clear indication that the sediment-water interface was sampled is uncertain. Also, a determination of the effect of increased organic input and effluent discharge on the basis of samples from the tops of two cores provides insufficient evidence to make definite conclusions. Detailed studies of organic content and foraminiferal assemblages in surface samples needs to be conducted to obtain conclusive evidence.

4.4 Paleoenvironmental Implications

Sediments previously interpreted as lacustrine, on the basis of seismic reflection profiles, seismic properties, and the previously accepted sea-level history (which placed the inner Halifax Harbour above sea level at the time) were never previously sampled. The sampling of this distinct unit allows for detailed foraminiferal and lithologic examination to determine the paleoenvironmental depositional setting. These sediments occur as Unit 4 in the base of Core 2.

The presence of foraminifera within Unit 4 of Core 2 contradicts a lacustrine depositional environment. The presence of foraminifera alone indicates a marine depositional environment. The dominant species within foraminiferal Zone D is *Elphidium excavatum* f. *clavatum*, with a minor percentages of *Haynesina orbiculare*.

The faunal assemblage above is similar to that identified by Bartlett (1966), Honig and Scott (1987), and Scott and Medioli (1980b) representing late stages of estuarine deposition. Foraminiferal assemblages, characterized by *Elphidium excavatum* f. *clavatum* and *Islandiella teretis* representing earlier stages of estuarine development (Scott and Medioli 1980b), are assumed to lie at depths greater than those cored in this study. *Elphidium excavatum* f. *clavatum* is apparently tolerant of a wide range of depths and salinities (Fillon and Hunt 1974, as cited by Honig and Scott 1987). Distinguishing the assemblages in this study from "warm ice margin" faunas is the absence of *Cassidulina reniforme* (Vilks 1981, Scott *et al.* 1984). An assemblage dominated by *Elphidium excavatum* f. *clavatum* without *C. reniforme* is characteristic of local estuarine fauna (Bartlett 1966, Scott *et al.* 1977, 1980b). Further evidence to support an estuarine depositional environment is the $\delta^{13}C$ value. The $\delta^{13}C$ value obtained from foraminifera in the estuarine unit of Core 2 ($\delta^{13}C_{PDB}$ = -9.3 $^{o}/_{oo}$) is typical of other estuarine values.

The occurrence of a grey clay layer (lithologic Unit 3) above Unit 4 is interpreted to represent a glei deposit (R. Stea pers comm; Figs. 3.1, 3.3). The presence of a reduced soil horizon overlying the estuarine deposit suggests that sea level must have fallen through this point. The foraminiferal assemblage demonstrates additional evidence for sea-level fall through this level. *Elphidium excavatum* f. *clavatum* is especially prevalent in estuarine (lowered salinity) environments (Scott *et al.* 1977, 1980). The upward increase of *Haynesina orbiculare* confirms a change to shallower, reduced salinity conditions, as sea level dropped. Corliss *et al.* (1982) defined an assemblage dominated by *H. orbiculare* and *Elphidium excavatum* f. *clavatum*, as characterizing decreasing salinity. Fillon and Hunt (1974, as cited by Honig and Scott 1987) identified *H. orbiculare* as a species characteristic of shallower depths and lower salinities than normal marine limits. The above trends of decreasing salinity and shallowing depths supports the idea of a falling sea level, discussed further in Section 4.5 (Fig. 3.6).

4.5 Peripheral Forebulge Concept

In parts of the world that were formerly glaciated, relative sea level is a function of the absolute volume of water available to the oceans as the ice melted, as well as the isostatic adjustments of the Earth's crust to post-glacial unloading (Honig and Scott 1987). Because Nova Scotia lies on a passive margin, most changes in sea level are the result of past glacial adjustments and not tectonism (Scott *et al.* 1986). Examination of foraminiferal assemblages from peat horizons, and sedimentology in cores collected from Halifax Harbour, permits the construction of a Holocene RSL curve that is not possible using data from offshore.

Clarke *et al.* (1978, as cited by Stea *et al.* in press) demonstrated the link between sea-level histories and ice sheet reconstructions. Based on these earlier principles, Quinlan and Beaumont (1981, 1982) modelled sea-level response using different ice models (a "maximum" and "minimum" ice load) for the Maritime Provinces of Canada. Their model detailed RSL change on the basis of the "peripheral bulge", first quantified by Peltier and Andrews (1976) as the Earth's response following deglaciation along former ice margins (Fig. 4.2). The peripheral forebulge is the result of extrusion of sublithospheric material to ice-free marginal areas as the Earth's crust subsides under ice load (Honig and Scott 1987, Scott and Medioli 1982). As the ice sheets ablate, initial elastic rebound, followed by isostatic disequilibrium, allows the excess sublithospheric material to flow back toward the former ice centre (Scott and Medioli 1982) (Fig. 4.2). However, because of the high

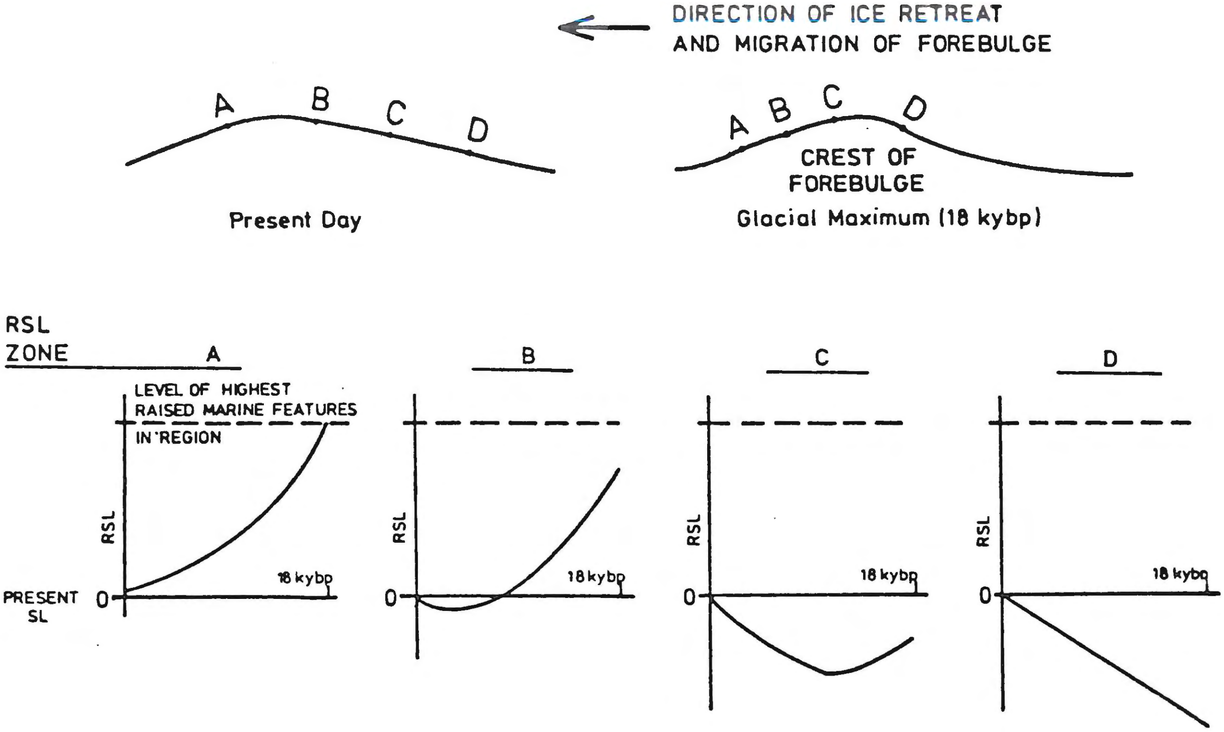

Figure 4.2 Forebulge migration following deglaciation and various sea level responses associated with location relative to the forebulge. Point D experiences only submergence; point C experiences emergence followed by submergence; point B experiences prolonged emergence followed by submergence; and point A experiences only emergence (from Scott *et al.* 1986).

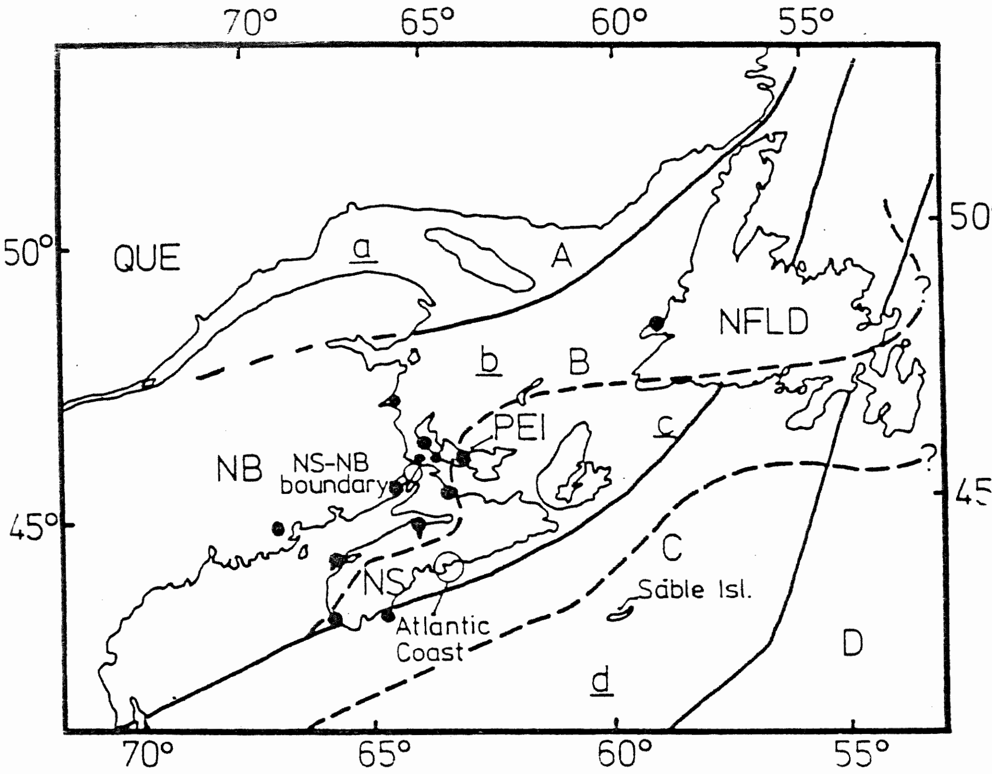

Figure 4.3 Observed versus theoretical RSL responses in Maritime Canada following deglaciation. Observed zones are represented by dashed lines and small letters, whereas, theoretical zones (the "maximum" model of Quinlan and Beaumont 1981) are represented by capital letters and solid lines. Letters indicate type of response as outlined in Figure 4.2 (from Scott *et al.* 1986).

viscosity of the mantle, the horizontal movement lags behind the initial elastic rebound (uplift) (Honig and Scott 1987). Therefore, the expression of the peripheral forebulge on the Earth's surface, at a point between the ice center and the forebulge crest, is a decrease in the rate of relative sea-level fall after the early rapid lowering associated with crustal elastic rebound (Honig and Scott 1987). In Atlantic Canada, the horizontal movement of the peripheral forebulge has produced sequential submergence-emergence curves, where shapes of the curves depend on the distance from the maximum ice load (Honig and Scott 1987).

As demonstrated above, and as predicted by the model of Quinlan and Beaumont (1981), changes in RSL vary in accordance with the position of the peripheral forebulge. Points inside the most extreme part of the bulge emerge as the bulge crest approaches, and subside as the crest passes (Scott and Medioli 1982) (Fig. 4.2; Zone A of Quinlan and Beaumont 1981). The closer a site is to the inside position of the forebulge (see point c, Fig. 4.2) the less emergence and more submergence the point undergoes, and the earlier the time of transition from emergence to submergence (Scott and Medioli 1982). Points outside the peripheral forebulge crest, such as Sable Island, (Zone D of Quinlan and Beaumont 1981) only experience submergence, as the crest of the forebulge migrates landward (Fig. 4.2; Scott *et al.* 1987, 1989b).

4.6 Sea-Level Implications

The lack of post-Wisconsinan-age raised marine features, formed by crustal rebound after the last glacial maximum, along the Atlantic coast of Nova Scotia provides reasonable support that the present RSL is at a post-glacial highstand along this coast

(Stea *et al.* in press); however, it does not necessarily imply that RSL rose monotonically to the present level (Miller *et al.* 1982a).

A reinterpretation of a seismically distinct unit (Unit 3, Figs. 1.2, 3.5) dramatically changes the sea-level history of Halifax Harbour. The previous interpretation of this unit as lacustrine, demands that sea level was much lower at the time of deposition. A reinterpretation of the paleoenvironment to estuarine suggests that sea level was higher, inside the harbour, when these sediments were deposited. The thickness of the estuarine deposits in Halifax Harbour suggests that sea level must have been stable for a prolonged period to deposit a unit as thick as seismic Unit 3 ($\approx$25 m) with no apparent unconformities in the seismic record. The presence of a soil horizon above the estuarine deposit suggests that sea level must have fallen through this level to produce conditions, including subaerial exposure and weathering, suitable for soil production. The occurrence of a transgressive unconformity suggests that sea level then rose from its lower position. This sequence of events dramatically changes the sea-level history, compared with the simple version of continued sea-level rise from some lower point on the inner continental shelf presented by Fader (1989).

The combination of C^{14} dates from peat and foraminifera samples, and the position of the sample in the core, combine to establish a new sea-level curve (Fig. 3.6). In general, the new sea-level curve suggests that Halifax Harbour experienced initial emergence from some time prior to 9,000 ybp to 7,500 ybp, followed by submergence from 7,500 ybp to the present.

This new sea-level curve corresponds to Zone c (Fig. 4.3) of the observed zonations of Scott *et al.* (1987) and the theoretical zonations of Quinlan and Beaumont (1981). As the ice ablated and retreated, the peripheral forebulge migrated landward towards the ice center, causing emergence of the inner continental shelf. After the crest of the forebulge passed, the area submerged again to depths greater than the previous emergence, eliminating all former raised marine features on the Atlantic coast of Nova Scotia. The migrating forebulge model can account for fluctuations in the sea-level curve on the order of that presented by Stea et al. (in press). However, no present model can account for the dramatic emergence (between 7,700 ybp and 7,500 ybp) presented in the sea-level curve from this study (Fig. 3.6).

Stea *et al.* (in press) suggest a low stand of sea level at -65 m at 11,650 ybp. The low stand presented in this thesis may not be a true low stand, but may represent a fluctuation in an extremely complicated sea-level curve with more than one fluctuation. The use of sea-level points from other areas of the coast (point I on Fig. 3.6 from the inner continental shelf; Forbes *et al.* 1988) may account for the sharp fall in sea level. Therefore, regional variations may be a further source of complication which suggest sharp contrasts in the sea-level response over short distances. Other areas in the Maritimes display sharp contrasts in sea-level histories over short distances, so the sharp contrast would not be anomalous. In New Brunswick, the presence of raised marine features at +10 m in Moncton and at +75 m in St. John provides proof of different sea-level effects over small distances (approximately 150-200 km). Further evidence for differential sea-level change comes from Prince Edward Island which has raised marine features at +12 m on the western end of the island and no emergence features on the eastern end, a distance of approximately 200-250 km (Scott *et al.* 1981, 1987b). From the above discussion, regional sea-level curves do not define global sea-level changes, and may not even be applicable at the regional scale on former ice margins.

4.7 Summary

Although Buckley and Winters (1992) showed high metal contamination in surface samples from Halifax Harbour, the benthic foraminiferal community does not show the characteristic pollution response of decreasing diversity and increasing abundances of a few opportunistic species. The increase in sediment flux and effluent discharge may have increased nutrient availability and food supply in the benthic community, thereby increasing species abundance and species diversity. The increase in effluent discharge may have not only produced a nutrient-rich environment, but also increased the bottom temperature that allows different faunas to flourish. Using the increased abundances of *Reophax scottii* and *Fursenkoina fusiformis* as indicators, enabled the determination that the Recent sediment may be organically enriched compared with Holocene sediment.

Reinterpretation of acoustically distinct sediments aids in determining the paleoenvironmental setting of Halifax Harbour. Sediments previously interpreted as lacustrine now appear to represent an estuarine depositional environment. This interpretation also has broad implications for re-evaluating sea-level history of Halifax Harbour.

Isostatic response following deglaciation explains major sea-level fluctuations on the inner continental shelf of Nova Scotia, but may not accurately describe small fluctuations in an extremely complicated sea-level history. Migration and collapse of the peripheral forebulge across the continental shelf resulted in early regression (Scott and Medioli 1982), followed by differing rates of transgression. Halifax Harbour and the inner continental shelf experienced emergence from pre-9,000 ybp to 7,500 ybp followed by submergence from 7,500 ybp to the present.

CHAPTER 5 CONCLUSIONS

5.1 Conclusions

Benthic foraminiferal assemblages, and their distribution in soft-sediment cores taken from Halifax Harbour, allow the determination of the paleoecology and paleoenvironment for the post-glacial history of the harbour. As paleoenvironmental indicators, foraminiferal assemblages permit a reinterpretation of an acoustically distinct sediment unit within the Harbour, and also help to determine former sea levels.

Foraminiferal species diversities and abundances in Halifax Harbour do not illustrate the typical pollution response of benthic organisms to increased organic loading as a result of an increase in sediment flux and an increase in effluent discharge. An increase in species diversity in foraminiferal Zone A of Cores 2 and 9 may indicate that the increase in nutrient supply increased the carrying capacity of the benthic community. The presence of *Reophax scottii* and *Fursenkoina fusiformis* suggests that deep estuarine, low oxygen, benthic environments now exist in the benthic environment of Halifax Harbour, as opposed to the open estuarine environment that was present prior to anthropogenic effects. The input of effluent discharge, stimulating warmer bottom water conditions, may account for the increase in abundance of calcareous fauna upwards in the core.

The presence of foraminifera, alone, indicates that the interpretation of a distinct sediment unit in Halifax Harbour as a lacustrine deposit is incorrect. The foraminiferal assemblage, in combination with sedimentary sequence, indicates that the unit in question is an estuarine deposit. This new information, combined with lithology, sea-level points, and C^{14} dates for chronological control, aids in constructing a new sea-level curve.

The presence of estuarine deposits overlain by a glei deposit in the harbour suggests that sea level stood higher, at a time earlier than previously believed, dropped to a lower level (not a low stand), and has subsequently risen. The construction of a sea-level curve using C^{14} dates for chronological control aids in placing time constraints on these events. The sea-level curve indicates that Halifax Harbour experienced initial emergence, followed by a prolonged period of submergence from 7,500 ybp to the present. Glacio-isostatic rebound, resulting in the migration of the peripheral forebulge, following Wisconsinan deglaciation explains some of the features of sea-level curves in Maritime Canada, but may not be able to account for smaller fluctuations in a complicated sea-level history.

SYSTEMATIC TAXONOMY

Adercotryma glomerata (Brady)
Lituola glomerata BRADY 1878, v. 1, p. 433, pl. 20, figs. 1a-c.
Adercotryma glomerata (Brady).- LOEBLICH and TAPPAN 1953, v. 121, p. 26, pl. 8, figs. 1-4.- VILKS 1969, p. 44, pl. 1, fig. 15.- GREGORY 1971, p. 173, pl. 11, figs. 9-11.- COLE 1981, p. 29, pl. 4, figs. 5-6.

Ammodiscus catinus Höglund
Ammodiscus catinus HÖGLUND 1947, p. 122, pl. 8, figs. 1, 7.- GREGORY 1971, p. 166, pl. 1, fig. 7.

Ammotium cassis (Parker)
Lituola cassis PARKER in Dawson 1870, p. 177, fig. 3.
Ammobaculites cassis (Parker).- CUSHMAN 1920, p. 63, pl. 12, fig. 5.
Ammotium cassis (Parker).- LOEBLICH and TAPPAN 1953, p. 33, pl. 2, figs. 12-18.- GREGORY 1971, p. 176, pl. 3, fig. 5.

Ammotium salsum (Cushman and Brönnimann)
Ammobaculites salsus CUSHMAN and BRÖNNIMANN 1948, p. 16, pl. 3, figs. 7-9.
Ammoscalaria fluvialis PARKER 1952a, p. 444, pl. 1, figs. 24, 25.
Ammotium salsum (Cushman and Brönnimann).- PARKER and ATHEARN 1959, p. 340, pl. 50, figs. 6, 13.- SCOTT *et al.* 1977, p. 1578, pl. 2, figs. 4, 5.- ZANINETTI *et al.* 1977, p. 177, pl. 2, figs. 4, 5.- SCOTT 1977, p. 165, pl. 2, figs. 11-13.

Bolivina pseudoplicata Heron-Allen and Earland
Bolivina pseudoplicata HERON-ALLEN and EARLAND 1930, p. 181, pl. 3, figs. 36-40.- PARKER 1952a, p. 444, pl. 4, fig. 11.- GREGORY 1971, p. 212, pl. 10, figs. 7-9. - COLE and FERGUSON 1975, p. 32, pl. 6, fig. 6.- SCOTT 1977, p. 167, pl. 8, fig. 3.

Buccella frigida (Cushman)
Pulvinulina frigida CUSHMAN 1921, p. 144.
Eponides frigida (Cushman) var. *calida* CUSHMAN and COLE 1930, p. 98, pl. 13, figs. 13a-c.- PHLEGER and WALTON 1950, p. 277, pl. 2, fig. 21.- PARKER 1952a, p. 449, pl. 5, figs. 3a, b.
Eponides frigidus (Cushman).- CUSHMAN 1942, p. 37, pl. 9, figs. 16, 17.- PARKER 1952a, p. 449, pl. 5, figs. 2a, b.
Buccella frigida (Cushman).- ANDERSEN 1952, p. 144, figs. 4a-c, 5, 6a-c.- GREGORY 1971, p. 220, pl. 12, figs. 1-3.- COLE and FERGUSON 1975, p. 33, pl. 8, figs. 8, 9.

Buliminella elegantissima (d'Orbigny)
Bulimina elegantissima d'ORBIGNY 1839, p. 51, pl. 7, figs. 13, 14.
Buliminella elegantissima (d'Orbigny).-CUSHMAN 1919, p. 606.- PARKER 1952b, p. 416, pl. 5, figs. 27, 28.- GREGORY 1971, p. 211, pl. 10, figs. 5, 6.- COLE and FERGUSON 1975, p. 33, pl. 6, figs. 8, 9.- SCOTT 1977, p. 168, pl. 7, figs. 1, 2.

Cassidulina reniforme (Nørvang)
Cassidulina crassa var. *reniforme* NØRVANG 1945, p. 41, text-figs. 6c-h.
Cassidulina crassa (d'Orbigny).- SCOTT *et al.* 1980, p. 226, pl. 4, figs. 1-2.
Cassidulina reniforme (Nørvang).- SEJRUP and GUILBAULT 1980, p. 79-85, text-figs. 1-3.

Cibicides lobatulus (Walker and Jacob)
Nautilus lobatulus WALKER and JACOB 1798, p. 642, pl. 14, fig. 36.
Cibicides lobatulus (Walker and Jacob).- PARKER 1952a, p. 449, pl. 6, fig. 26.- FEYLING-HANSSEN 1964, p. 339, pl. 19, figs. 1-3.- VILKS 1969, p. 50, pl. 3, fig. 17.- COLE 1981, p. 104, pl. 12, fig. 4.

Cribrostomoides crassimargo (Norman)
Haplophragmium crassimargo NORMAN 1892, p. 17.
Labrospira crassimargo (Norman).- HÖGLUND 1947, p. 11, fig. 1, text-figs. 121-125.
Cribrostomoides crassimargo (Norman).- LESLIE 1965, p. 158, pl. 2, figs. 2a, b.- WILLIAMSON 1983, p. 209, pl. 1, figs. 6-7.

Cribrostomoides jeffreysi (Williamson)
Nonionina jeffreysi WILLIAMSON 1858, p. 34, pl. 3, figs. 72, 73.
Cribrostomoides jeffreysi (Williamson).- BARBIERI and MEDIOLI 1969, p. 855, fig. 4.- VILKS 1969, p. 45, pl. 1, figs. 17a, b.- COLE 1981, p. 30, pl. 6, fig. 6.

Cyclogyra involvens (Reuss)
Operculina involvens REUSS 1850, v. 2, p. 370, pl. 46, fig. 30.
Cyclogyra involvens (Reuss).- LOEBLICH and TAPPAN 1961, p. 49, pl. 7, figs. 4, 5.

***Dentalina* spp.** (Remark: This genus was not identified to the species level)

Eggerella advena (Cushman)
Verneuilina advena CUSHMAN 1921, p. 141.
Eggerella advena (Cushman).- CUSHMAN 1937, p. 51, pl. 5, figs. 12-15.- SCOTT and MEDIOLI 1980a, p. 38, pl. 2, fig. 7.

Elphidium bartletti Cushman
Elphidium bartletti CUSHMAN 1933, p. 4, pl. 1, fig. 9.
Cribrononion bartletti (Cushman).- SCOTT *et al.* 1980, p. 226, pl. 2, fig. 7.

Elphidium excavatum (Terquem) group
Polystomella excavatum TERQUEM 1876, p. 429, pl. 2, figs. 2a-d.
Elphidium excavatum (Terquem).- CUSHMAN 1944, p. 26, pl. 2, fig. 40.

Elphidium excavatum Terquem) **forma *clavatum*** Cushman
Elphidium incertum (Williamson) var. *clavatum* CUSHMAN 1930, p. 20, pl. 7. fig. 10.
Elphidium incertum (Williamosn) and variants PARKER 1952a, p. 448, pl. 3, fig. 16.
Elphidium excavatum (Terquem) forma *clavatum* MILLER *et al.* 1982b, p. 124, pl. 1, figs. 5-8; pl.2, figs. 3-8; pl. 3, figs.3-8; pl. 4, figs. 1-6; pl. 5, figs. 4-8; pl. 6, figs. 1-5.

Elphidium excavatum (Terquem) **forma *excavatum*** Terquem
Polystomella excavata TERQUEM 1876, p. 429, pl. 2, fig. 2.
Elphidium excavatum (Terquem).- CUSHMAN 1930, p. 21, pl. 8, figs. 1-7.- CUSHMAN 1944, p. 26, pl. 2, fig. 40.- BENDA and PURI 1962, p. 325, pl. 1, fig. 16.- HANSEN and LYKKE-ANDERSEN 1976, p. 10, pl. 6, figs. 1-6.
Elphidium excavatum (Terquem) forma *excavata* (Terquem).- MILLER *et al.* 1982b, p. 128, pl. 1, figs. 9-12; pl. 2, figs. 1, 2; pl. 3, figs. 1, 2; pl. 4, figs. 13-16; pl. 5, figs. 15, 16; pl. 6, figs. 6-8, 14.

Elphidium excavatum (Terquem) **forma *gunteri*** COLE
Elphidium gunteri Cole 1931, p. 34, pl. 4, figs. 9, 10.- PARKER *et al.* 1953, p. 8, pl. 3, figs. 18, 19.- PARKER 1954, p. 508, pl. 6, fig. 16; PHLEGER 1954, p. 639, pl. 2, figs. 3, 4.- BANDY 1956, p. 194, pl. 30, fig. 19.- LEHMANN 1957, p. 348, pl. 3, figs. 1-4.- LANKFORD 1959, p. 2098, pl. 2, fig. 7.- BENDA and PURI 1962, p. 335, pl. 1, fig. 11.- SCOTT *et al.* 1991, p. 385, pl. 2, fig. 15.

Elphidium excavatum (Terquem) **forma *lidoensis*** Cushman
Elphidium lidoense CUSHMAN 1936, p. 86, pl. 15. fig. 6.
Elphidium excavatum (Terquem) forma *lidoensis* MILLER *et al.* 1982b, p. 134, pl. 1, figs. 17-20; pl. 4, figs. 7-12; pl. 5, fig. 9; pl. 6, figs. 15, 16.

Elphidium frigidum (Cushman)
Elphidium frigidum CUSHMAN 1933, p. 5, pl. 1, fig. 3.- GREGORY 1971, p. 227, pl. 14, fig. 3.- COLE and FERGUSON 1975, p. 34, pl. 7, figs. 6, 7.- SCHAFER and COLE 1978, p. 27, pl. 10, figs. 2a, b.
Cribroelphidium frigidum (Cushman).- SCOTT 1977, p. 170, pl. 6, fig. 6.

Elphidium incertum (Williamson)
Elphidium umbilicatula (Walker) var. *incerta* WILLIAMSON 1858, p. 44, pl. 3, fig. 82a.

Elphidium margartaceum (Cushman)
Elphidium advenum (Cushman) var. *margartaceum* CUSHMAN 1930, p. 25, pl. 10, figs. 3a, b.

Elphidium williamsoni (Williamson)
Polystomella umbilicatula.- WILLIAMSON 1858, p. 42-44, figs. 81-82.
Elphidium excavatum (Terquem).- CUSHMAN 1930, p. 21, pl. 8, figs. 4-7.
Cribrononion cf. *alvarezianum* (d'Orbigny).- LUTZE 1965, p. 101, pl. 15, fig. 46.
Elphidium umbilicatulum (Williamson).- LÉVY *et al.* 1969, p. 96, pl. 1, fig. 6a; pl. 2, figs. 1, 2.
Elphidium williamsoni (Williamson).- Haynes 1981, p. 430.

Epistominella takayangii Iwasa
Epistominella takayangii IWASA 1955, p. 16-17, text-figs. 4a-c.- LESLIE 1965, p. 160, pl. 9, figs. 10a-c.- SCHAFER and COLE 1978, p. 27, pl. 8, figs. 3a-b.

***Fissurina* spp.** (Remark: This genus was not identified to the species level)

Fursenkoina fusiformis (Williamson)
Bulimina pupoides (d'Orbigny) var. *fusiformis* WILLIAMSON 1858, p. 64, pl. 5, figs. 129, 130.
"*Bulimina*" *fusiformis* (Williamson).- HÖGLUND 1947, p. 232, pl. 20, fig. 3; text-figs. 219-233.
Virgulina fusiformis (Williamson).- PARKER 1952b, p. 461, pl. 4, fig. 6; p. 417, pl. 6, figs. 3-6.
Fursenkoina fusiformis (Williamson).- GREGORY 1971, p. 232.- SCOTT 1977, p. 172, pl. 7, figs. 9, 10.

Glabratella wrightii (Brady)
Discorbina wrightii BRADY 1881, p. 413, pl. 21, fig. 6.
Eponides wrightii (Brady).- PARKER 1952a, p. 450, pl. 5, figs. 4a, b.
Glabratella wrightii (Brady).- LESLIE 1965, p. 161, pl. 10, fig. 7.- COLE and FERGUSON 1975, p. 35, pl. 8, figs. 10, 11.- SCOTT 1977, p. 172, pl. 7, figs. 11-13.- SCHAFER and COLE 1978, p. 28, pl. 8, fig. 5.

Glomospira gordialis (Jones and Parker)
Trochammina squamata var. *gordialis* JONES and PARKER 1860, p. 304.
Glomospira gordialis (Jones and Parker).- CUSHMAN and McCULLOCH 1939, p. 70, pl. 5, figs. 5, 6.

Haynesina orbiculare (Brady)
Nonionina orbicularis BRADY 1881, p. 414, pl. 21, fig. 5.
Haynesina orbiculare (Brady).- BANNER and CULVER 1978, p. 188.

***Lagena* spp.** (Remark: This genus was not identified to the species level)

Miliammina fusca (Brady)
Quinquelouilina fusca BRADY 1870, p. 47, pl. 11, figs. 2, 3.
Miliammina fusca (Brady).- PHLEGER and WALTON 1950, p. 280, pl. 1, figs. 19a, b.- SCOTT and MEDIOLI 1980a, p. 55, pl. 3, fig. 4.

***Miliolina* spp.** (Remark: This genus was not identified to the species level)

Nonionellina labradorica (Dawson)
Nonionina labradorica DAWSON 1860, p. 191, fig. 4.
Nonion labradorica (Dawson).- CUSHMAN 1927b, p. 148, pl. 2, figs. 7-8.
Nonionellina labradorica (Dawson).- SCHAFER and COLE 1978, p. 28, pl. 9, fig. 4.- COLE 1981, p. 110, pl. 13, fig. 20.

***Oolina* spp.** (Remark: This genus was not identified to the species level)

Paterois hauerinoides (Rhumbler)
Quinqueloculina subrotunda (Montagu) forma *hauerinoides* RHUMBLER 1936, p. 206, 217, 226; text-figs. 167, 208-212.
Quinqueloculina subrotunda (Montagu).- PARKER 1952b, p. 456, pl. 2, figs. 9a, b, 10a, b. - PARKER 1952b, p. 406, pl. 4, figs. 4a, b.
Paterois hauerinoides (Rhumbler).- LOEBLICH and TAPPAN 1953, p. 42, pl. 42; pl. 6, figs. 8-12; text-figs. 1a, b.- GREGORY 1971, p. 188, pl. 6, figs. 3, 4.- COLE and FERGUSON 1975, p. 39, pl. 11, figs. 4, 5.- SCOTT 1977, p. 174, pl. 7, figs. 6-8.- SCHAFER and COLE 1978, p. 28, pl. 11, fig. 5.

Pyrgo williamsoni (Silvestri)
Biloculina williamsoni SILVESTRI 1923, v. 76, p. 73.
Pyrgo williamsoni (Silvestri).- LOEBLICH and TAPPAN 1953, p. 48, pl. 6, figs. 1-4.

Quinqueloculina seminulum (Linné)
Serpula seminulum LINNÉ 1758, p. 786.
Quinqueloculina seminulum (Linné).- d'ORBIGNY 1826, p. 303.- GREGORY 1971, p. 187, pl. 6, fig. 1.- COLE and FERGUSON 1975, p. 40, pl. 10, fig. 7.- SCOTT 1977, p. 175, pl. 7, figs. 3-5.- SCHAFER and COLE 1978, p. 29, pl. 12, fig. 4.
Miliolina seminulum (Linné).- WILLIAMSON 1858, p. 85, pl. 7, figs. 183-185.
Quinqueloculina seminula (Linné).- CUSHMAN 1929, p. 59, pl. 9, figs. 16-18.- PARKER 1952a, p. 456, pl. 2, figs. 7a, b.- PARKER 1952b, p. 406, pl. 3, figs. 21a, b, 22a, b; pl. 4, figs. 1, 2.

Recurvoides turbinatus (Brady)
Haplophragmium turbinatus BRADY 1881, p. 50.
Recurvoides turbinatus (Brady).- PARKER 1952b, p. 402, pl. 2, figs. 23, 24.- VILKS 1969, p. 45, pl. 1, fig. 19.- GREGORY 1971, p. 176, pl. 3, figs. 3, 4.- COLE 1981, p. 32, pl. 6, figs. 7, 8.

Reophax arctica (Brady)
Bigenerina artica BRADY 1881, p. 405, pl. 21, figs. 2a, b.- CUSHMAN 1944, p. 31, pl. 3, fig. 9.
Reophax artica (Brady).- PARKER 1952b, p. 395, pl. 1, figs. 6, 7.- GREGORY 1971, p. 168, pl. 2, fig. 3.- COLE and FERGUSON 1975, p. 40, pl. 1, fig. 9.- SCOTT 1977, p. 175, pl. 3, fig. 5.- SCHAFER and COLE 1978, p. 29, pl. 2, fig. 5.

Reophax fusiformis (Williamson)
Proteonina fusiformis WILLIAMSON 1858, p. 1, pl. 1, fig. 1.
Reophax fusiformis (Williamson).- BRADY 1870, p. 290, pl. 30, figs. 7-11.- PARKER 1952a, p. 395, pl. 1, figs. 11-19.

Reophax nodulosa Brady
Reophax nodulosa BRADY 1879, v. 19, p. 52, pl. 4, figs. 7, 8.- COLE 1981, p. 25, pl. 4, figs. 7, 8.

Reophax scorpiurus (de Montfort)
Reophax scorpiurus dE MONTFORT 1808, p. 330.- LOEBLICH and TAPPAN 1953, p. 24, pl. 2, figs. 7-10.- LESLIE 1965, p. 169, pl. 1, figs. 6, 7.

Reophax scottii Chaster
Reophax scottii CHASTER 1892, p. 57, pl. 1, fig. 1.- WILLIAMSON 1983, p. 207, pl. 1, fig. 11.

Rosalina columbiensis (Cushman)
Discorbis columbiensis CUSHMAN 1925, p. 43, pl. 6, fig. 13.
Rosalina columbiensis (Cushman).- LANKFORD and PHLEGER 1973, p. 127-128, pl. 5, figs. 10-12.

Saccammina atlantica (Cushman)
Proteoina atlantica CUSHMAN 1944, p. 5, pl. 1, fig. 4.- PHLEGER 1952, p. 85, pl. 13, figs. 1, 2.
Saccammina atlantica (Cushman).- VILKS 1969, p. 43, pl. 1, fig. 13.- BARBIERI and MEDIOLI 1969, p. 853, pl. 1, fig. 4.- COLE 1981, p. 13, pl. 1, fig. 14.

Spiroplectammina biformis (Parker and Jones)
Textularia agglutinans (d'Orbigny) var. *biformis* PARKER and JONES 1865, p. 370, pl. 15, figs. 23, 24.
Spiroplecta biformis (Parker and Jones).- BRADY 1878, p. 376, pl. 45, figs. 25-27.
Spiroplectammina biformis (Parker and Jones).- CUSHMAN 1927a, p. 23, pl. 5, fig. 1.- PARKER 1952b, p. 402, pl. 3, figs. 1, 2.- GREGORY 1971, p. 177, pl. 3, fig. 6.- COLE and FERGUSON 1975, p. 42, pl. 3, fig. 3.- SCOTT 1977, p. 176, pl. 3, fig. 4.- SCHAFER and COLE 1978, p. 19, pl. 3, fig. 2.

Textularia earlandi Parker
Textularia earlandi PARKER 1952a, p. 458 (footnote).- SCOTT and MEDIOLI 1980a, p. 227, pl. 2, fig. 1.

Textularia torquata Parker
Textularia torquata PARKER 1952b, p. 403, pl. 3, figs. 9-11.- VILKS 1968, p. 18, pl. 1, figs. 10, 11.- GREGORY 1971, p. 179, pl. 4, figs. 1, 2.

Trifarina fluens (Todd)
Angulogerina fluens TODD in Cushman and Todd 1947, p. 67, pl. 16, figs. 6, 7.
Trifarina angulosa (Williamson).- GREGORY 1971, p. 217, pl. 11, fig. 5.
Trifarina fluens (Todd).- FEYLING-HANSSEN in Feyling-Hanssen *et al.* 1971, p. 242, pl. 7, figs. 12-15; pl. 18, fig. 10.- COLE and FERGUSON 1975, p. 42, pl. 6, fig. 10.- SCOTT 1977, p. 177, pl. 8, figs. 12, 13.- SCHAFER and COLE 1978, p. 29, pl. 7, fig. 3.

Triloculina arctica (Cushman)
Quinqueloculina arctica CUSHMAN 1933, p. 2, pl. 1, figs. 3a-3c.- SCOTT 1987, p. 336, pl. 1, fig. 22.

Trochammina inflata (Montagu)
Nautilus inflata MONTAGU 1808, p. 81, pl. 18, fig. 3.
Trochammina inflata (Montagu).- PARKER and JONES 1859, p. 347.- BOLTOVSKOY and VIDARTE 1977, p. 39, pl. 4, figs. 11, 14.- ZANINETTI *et al.* 1977, pl. 1, figs. 1, 2.- SCOTT and MEDIOLI 1980a, p. 39, pl. 3, figs. 12-14.
Siphotrochammina elegans ZANINETTI *et al.* 1977, pl. 2, figs. 8, 10 , 11.

Trochammina lobata Cushman
Trochammina lobata CUSHMAN 1944, p. 18, pl. 2, fig. 10.- PARKER 1952b, p. 408, pl. 4, figs. 8a, b.- SCHNITKER 1971, p. 212, pl. 1, fig. 18.- COLE and FERGUSON 1975, p. 14, pl. 4, figs. 5, 6.

Trochammina macrescens Brady
Trochammina inflata (Montagu) var. *macrescens* BRADY 1870, p. 290, pl. 11, figs. 5a-c.
Jadammina polystoma BARTENSTEIN and BRAND 1938, p. 381, figs. 1a-c, 2a-1.
Trochammina macrescens (Brady).- PHLEGER and WALTON 1950, p. 281, pl. 2, figs. 6, 7.-BOLTOVSKOY and VIDARTE 1977, p. 39, pl. 4, figs. 12, 13.- SCOTT and MEDIOLI 1980a, p. 39, pl. 3, figs. 1-8.

Trochammina squamata Parker and Jones
Trochammina squamata PARKER and JONES 1865, p. 407, pl. 15, figs. 30, 31a-c.- SCOTT and MEDIOLI 1980a, p. 41, pl. 4, figs. 6, 7.

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APPENDIX A

CORE LOGS

1

CENTRE FOR MARINE GEOLOGY, DALHOUSIE UNIVERSITY

CRUISE STATION LOG

Ship: Tigнish Sea
Sea State: [illegible]
nd:
ismics: 3.5 KHZ.

Gear: P5 [illegible]
([illegible] = 85mm inside).
Sample Owners: [illegible] Scott, [illegible] Stea
G. Fader, C. Schafer

Cruise: [illegible]
Station: # 2
Check for
Sec: ✓
Lat: 44° 38.24
Long: 63° 33.03
SatNav/Loran C:
Other: GPS Trymark
Water Depth: 20.5 metres
Local Area: Hfx [illegible]
[illegible] #1(≈)
Date: Aug 23/95 ~~GMT~~:

Attempts	1st	2nd	3rd	4th	5th	6th
Type Sampling						
Start Time	3.07(85) ←	1507				
Bottom Time	3.12	1513				
Depth						
Wire Angle						
Success	Limited					
Penetration	appeared to	be 18 ft				

Grab Surface Rating:
Colour:
escription: Using 40 ft of core barrel

Gravity Length:
Trigger Wt. Length:
Piston Length: ≈ 598 cm
Rock Core Length:
Damage:
Description: 41 ft too much for [illegible] mud

Sample Storage List (in order, noting surface type or core type, containers incl[...] [...]ore catcher and core cutter)

Core 3 NB Top of core sloshed + washed out on deck
0-150 pc (NB mud lying [illegible] in core barrel, ≈ ½ m)
150-300 pc
300-450 pc
450-598 pc
Bottom 32 cm fell out on deck (598 + 63 cm) wrapped in plastic w/orientation + in plastic bag.
Core catcher in plastic bag
Core cutter " " " (reddish mud, very stiff).

NB Core liner had jammed in barrel, tapped out!

Remarks Over →

Catalogued by: C. [illegible]

ATLANTIC GEOSCIENCE CENTRE Core.

CRUISE NUMBER. 93 Scenda

SAMPLE NUMBER. Core 2

TOTAL LENGTH. CM.

SAMPLE TYPE PS Vibracore.

CALENDAR DATE. Sept 2/93

~~PROJECT~~ NUMBER. 0-100

GEOGRAPHIC LOCATION. Georges Island

SYMBOL LEGEND III

DESCRIBED BY. D Scott

PAGE 1 OF 6

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
0						Black organic mud		
10						16cm banded black organic mud		
20								
30						olive (5Y 5/3) massive Sandy mud gas cracks. shell bearing.		
40								
50								
60						67 Section 1		
70						" "		
80								
90								
100								

NOTES.

ATLANTIC GEOSCIENCE CENTRE Core 2

CRUISE NUMBER. 93 Secunda	SAMPLE NUMBER. Core 2	TOTAL LENGTH. CM.
SAMPLE TYPE PS Vibracore	CALENDAR DATE. Sept 2 /93	PROJECT NUMBER. 100-200 IV
GEOGRAPHIC LOCATION. Georges Island	SYMBOL LEGEND	
DESCRIBED BY. D Scott	PAGE 2 OF 6	

☐ ____ ☐ ____ ☐ ____

☐ ____ ☐ ____ ☐ ____

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
0								
10						Olive (5y 5/3)		
20						massive sandy mud		
30						shelly		
40						gas cracks.		
50								
60								
70								
80								
90								
2100						199-204 large cobble slate ice ball		

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 2

CRUISE NUMBER. 93 Leander
SAMPLE NUMBER. Core 2
TOTAL LENGTH. CM.
SAMPLE TYPE PS Vibracore
CALENDAR DATE. Sept 2/93
PROJECT NUMBER. 200-300
GEOGRAPHIC LOCATION. Georges Island
DESCRIBED BY. D Scott
PAGE 3 OF 6

SYMBOL LEGEND

☐ ____ ☐ ____ ☐ ____
☐ ____ ☐ ____ ☐ ____

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
200						olive massive (5Y5/3) sandy mud.		
10						End Section 2 (216cm)		
20						olive massive 5Y 5-3 sandy, mud (Black FeS2 mottling)		
30						" shells abundant "		
40						gas cracks.		
50								
60								
70								
80								
90								
300								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 2

CRUISE NUMBER. 93 Scandal

SAMPLE NUMBER. Core 2

TOTAL LENGTH. CM.

SAMPLE TYPE P5 Vibracore

CALENDAR DATE. Sept 2/93

~~PROJECT~~ NUMBER. 300-400

GEOGRAPHIC LOCATION. Georges Island

SYMBOL LEGEND VI

DESCRIBED BY. D Scott

PAGE 4 OF 6

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
0						5Y 5/3 olive massive silty mud		
10								
20						FeS_2 mottling		
30						333 → contact gradational increasing stony pebbles		
40						becoming clayey? ↓		
50								
60						366 Section 3		
70						olive grey ↓		
80								
90								
400								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 2

CRUISE NUMBER. 93 Scanda

SAMPLE NUMBER. CORE 2

TOTAL LENGTH. 513 CM.

SAMPLE TYPE DS Vibracore

CALENDAR DATE. Sept 2/93

~~PROJECT~~ NUMBER. 400-500

GEOGRAPHIC LOCATION. Georges Island

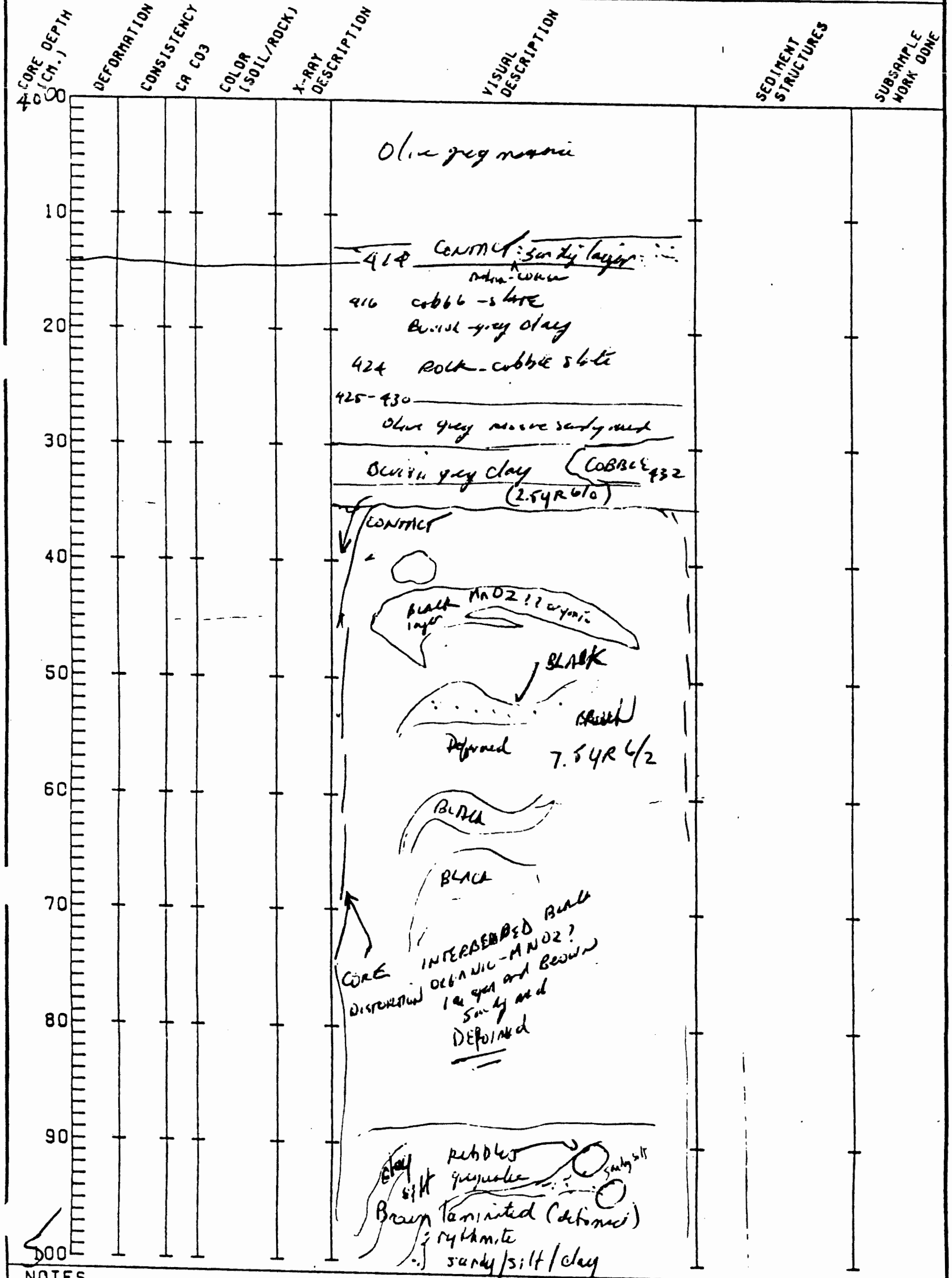
SYMBOL LEGEND VII

☐ ____	☐ ____	☐ ____
☐ ____	☐ ____	☐ ____

DESCRIBED BY. D Scott/STEA

PAGE 5 OF 6

CORE DESCRIPTION



Olive grey massive

414 CONTACT: sandy layer medium-coarse

416 cobble - slate

Bluish grey clay

424 Rock - cobble slate

425-430

Olive grey massive sandy mud

Bluish grey clay (2.5YR 6/0) COBBLE 432

CONTACT

Black layer MnO2 ?? organic

Deformed 7.5YR 6/2

CORE DISTORTION

INTERBEDDED BLACK ORGANIC-MNO2? layer and BROWN sandy mud

DEFORMED

pebbles greywacke

Brown laminated (deformed) rythmite sandy/silt/clay

NOTES.

ATLANTIC GEOSCIENCE CENTRE Core 2

CRUISE NUMBER. 93 Scandal

SAMPLE NUMBER. Core 2

TOTAL LENGTH. 512 CM.

SAMPLE TYPE PS V, Bracewell

CALENDAR DATE. Sept 2/93

~~PROJECT~~ NUMBER. 500-513

GEOGRAPHIC LOCATION. Georges Island

SYMBOL LEGEND VIII

DESCRIBED BY. D Scott

PAGE 6 OF 6

☐ ____	☐ ____	☐ ____
☐ ____	☐ ____	☐ ____

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
0						Brown sandysilt/silt/clay rythmite 7.5YR 6/2. End of Section 4		
10								
20								
30								
40								
50								
60								
70								
80								
90								
100								

NOTES.

CENTRE FOR MARINE GEOLOGY, DALHOUSIE UNIVERSITY

CRUISE STATION LOG

Ship: Tignish Sea

Sea State: Calm.

d: — very light.

Seismics: — None —

Gear: P5 vibracore.

Sample Owners: D. Scott, R. Stea, G. Fader, C. Schafer.

Cruise: 93-Scandia

Station: 10

Check for Sec: ☑

Lat: 44°38.29

Long: 63° 33:19

SatNav/Loran C:

Other: GPS :

Water Depth:

Local Area: Hfx Hbr., off Georges Island.

Date:

GMT:

Attempts	1st	2nd	3rd	4th	5th	6th
Type Sampling						
Start Time						
Bottom Time						
Depth						
Wire Angle						
Success						
Penetration	≈20 ft.					

Grab Surface Rating:

Colour:

escription: Organic mud, to clayey grey sand/silt.

Gravity Length:

Trigger Wt. Length:

Piston Length: approx 497 cm.

Rock Core Length:

Damage:

Description:

Sample Storage List (in order, noting surface type or core type, containers incl'di- ore catcher and core cutter)

	0-150			
	150-289			
	289-449			
	449-599			
	core	catcher in plastic bag		
	core	cutter " " "		

emarks Over →

Catalogued by:

ATLANTIC GEOSCIENCE CENTRE

Core 10

CRUISE NUMBER. 93 Secunda

SAMPLE NUMBER. Core 10

TOTAL LENGTH. 512 CM.

SAMPLE TYPE PS Vibracore

CALENDAR DATE. Sep 12/93

~~PROJECT~~ NUMBER. 0-100

GEOGRAPHIC LOCATION. Georges Island

SYMBOL LEGEND X

☐ ____ ☐ ____ ☐ ____

☐ ____ ☐ ____ ☐ ____

DESCRIBED BY. Scott/Stea

PAGE 1 OF 1

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
0								
10						"GOO ZONE" DISTURBED BLACK MUCK STRONG H2S odour		
20								
30						BLACK FeS2 ??		
40						olive grey 5Y 5/3 Sandy mud black FeS2 mottling		
50								
60								
70								
80								
90								
100								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 10

CRUISE NUMBER. 93 Sandar	SAMPLE NUMBER. Core 10		TOTAL LENGTH. 512 CM.
SAMPLE TYPE D5 Vibracore	CALENDAR DATE. Sept 2/93	~~PROJECT~~ NUMBER. 100 - 200	
GEOGRAPHIC LOCATION. Georges Island			
DESCRIBED BY. Scott / SEA	PAGE 2 OF 6		

XI

SYMBOL LEGEND

☐ ____ ☐ ____ ☐ ____

☐ ____ ☐ ____ ☐ ____

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
0						olive grey 5Y 5/3 sandy mud Black FeS_2 mottling		
10								
20						Section 2 125		
30						olive-grey 5Y 5/3 mottling diminishes sandy mud Shell bearing ↓		
40								
50								
60								
70								
80								
90								
100								

2

NOTES.

ATLANTIC GEOSCIENCE CENTRE Core 10

CRUISE NUMBER. 93 Secunda	SAMPLE NUMBER. Core-10	TOTAL LENGTH. 512 CM.
SAMPLE TYPE PS Vibracore	CALENDAR DATE. Sept 2/93	~~PROJECT~~ NUMBER. 200-300
GEOGRAPHIC LOCATION. Georges Island	SYMBOL LEGEND XII	
DESCRIBED BY. Scott/STRA	PAGE 3 OF 4	

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☐ ______ ☐ ______ ☐ ______

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
200						O-G sandy mud 5Y5/3		
210						SECTION 2		
20								
30						olive-gray sandy mud 5Y5/3		
40						~~-3T7 shell layer~~		
50								
60						↓		
70								
80								
90								
300								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 11

CRUISE NUMBER. 93 Scanda	SAMPLE NUMBER. Core 10	TOTAL LENGTH. 572 CM.
SAMPLE TYPE P5 Vibracore	CALENDAR DATE. Sept 2/93	~~PROJECT~~ NUMBER. 400-500 XIII
GEOGRAPHIC LOCATION. Georges Island		SYMBOL LEGEND
DESCRIBED BY. Scott/STEA	PAGE 4 OF 6	☐ ___ ☐ ___ ☐ ___
		☐ ___ ☐ ___ ☐ ___

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
300						304 Shell layer ○ ○		
						307 shell layer		
10								
20						olive grey sandy mud		
30								
40						○ Stone		
						347 shell layer		
50								
						cobble Meguma. ▭		
60						362 Section 3		
						Olive-grey sandy mud. 5Y 5/3.		
70								
80								
90								
400								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core

CRUISE NUMBER. 93 Scanda	SAMPLE NUMBER. BRE10	TOTAL LENGTH. 512 CM
SAMPLE TYPE P5 Vibracore	CALENDAR DATE. Sept 2/93	~~PROJECT~~ NUMBER. 300-400 XIV
GEOGRAPHIC LOCATION. Georges Island		
DESCRIBED BY. Scott/STEA	PAGE 4 OF 6	

SYMBOL LEGEND

☐ ____ ☐ ____ ☐ ____

☐ ____ ☐ ____ ☐ ____

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DON
400						shelly "		
10						Olive grey sandy mud 5Y5/3		
20						becoming less shelly ↓		
30								
40								
50						stone sharp contact fibrous peat (seeds sandy layers		
60						peat		
70						grey — faintly laminated fine Sand		
80								
90								
500								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 10

CRUISE NUMBER. 93 Secunda	SAMPLE NUMBER. Core 10		TOTAL LENGTH. 512 CM.
SAMPLE TYPE P5 Vibracore	CALENDAR DATE. Sept 2/93		~~PROJECT~~ NUMBER. XV 500-512.
GEOGRAPHIC LOCATION. Georges Island		SYMBOL LEGEND	
DESCRIBED BY. Scott/Sea	PAGE 6 OF 6	☐ ____ ☐ ____ ☐ ____	
		☐ ____ ☐ ____ ☐ ____	

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
0						SAND		
10						End of core 512 CM		
20								
30								
40								
50								
60								
70								
80								
90								
100								

NOTES.

CENTRE FOR MARINE GEOLOGY, DALHOUSIE UNIVERSITY

CRUISE STATION LOG

Ship: Tignish Sea.

Sea State: calm

d: very light

Seismics: — None —

Gear: P5 vibracore
30 ft barrel

Sample Owners:

Cruise: 93 Secunda

Station: 9

Check for Sec: ✓

Lat: 44° ~~xx~~ 26:53

Long: 63° 32:36

SatNav/Loran C:

Other: GPS. :

Water Depth: 27 metres

Local Area: Hfx Hbr, near east end of McNabs Is., Hbr entrance

Date: aug 25/93 GMT:

Attempts	1st	2nd	3rd	4th	5th	6th
Type Sampling						
Start Time						
Bottom Time	03:13 (ES)					
Depth						
Wire Angle						
Success						
Penetration	appears full					

Grab Surface Rating:

Colour:

escription:

Gravity Length:

Trigger Wt. Length:

Piston Length:

Rock Core Length:

Damage:

Description:

Sample Storage List (in order, noting surface type or core type, containers inc ore catcher and core cutter)

Core 9	0–150 cm	Top sloppy.		
	150–300			
	300–349			
	349–354	Small plastic bag,	orientated	
	504–354			
	304–643			
	core	catcher in plastic bag		
	core	cutter "	" "	

Remarks Over →

Catalogued by:

ATLANTIC GEOSCIENCE CENTRE

Core 1

CRUISE NUMBER. 93 Seandia	SAMPLE NUMBER. Core 9	TOTAL LENGTH. 600 CM.
SAMPLE TYPE P.S Vibracore	CALENDAR DATE. Sept 2/93	~~PROJECT NUMBER~~ XVII 0-100
GEOGRAPHIC LOCATION. McNabs Island	SYMBOL LEGEND	
DESCRIBED BY. Scott/SKA	PAGE 1 OF 6	

☐ ____ ☐ ____ ☐ ____

☐ ____ ☐ ____ ☐ ____

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
0								
10						Soupy		
20						"GOO" ZONE		
30						Black odoriferous mud		
40								
50						distorted		
60						becoming coherent		
70								
80						↓		
90						dark olive gray 5y 5/1		
100								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core

CRUISE NUMBER. 93 Scanda	SAMPLE NUMBER. Core 9	TOTAL LENGTH. 100 CM.
SAMPLE TYPE PS Vibracore	CALENDAR DATE. Sept 2/93	~~PROJECT~~ NUMBER. 100-200 XVIII
GEOGRAPHIC LOCATION. McNabs Island	SYMBOL LEGEND	
DESCRIBED BY. Scott/Spea	PAGE 2 OF 2	

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
11 0						5y 5/1 olive-black sandy mud		
10						Section 2 1/5		
						void		
20						dark olive grey 5y/5/3 sandy mud shells, [illegible]		
30								
40								
50						shells throughout		
60						Light olive grey 5y5/2		
70						becoming banded FeS2? black layers		
80								
90						large shell 		
200								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 9

CRUISE NUMBER.	93 Scanda	SAMPLE NUMBER.	Core 9	TOTAL LENGTH.	600 CM.
SAMPLE TYPE	PS Vibracore	CALENDAR DATE.	Sept 2/03	~~PROJECT~~ NUMBER. XIX	200-300
GEOGRAPHIC LOCATION.	McNab's Island				
DESCRIBED BY.	Scott/Stea	PAGE 3 OF 6			

SYMBOL LEGEND

☐ ____ ☐ ____ ☐ ____

☐ ____ ☐ ____ ☐ ____

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
20.0								
10						banded Light olive-grey sandy mud 5Y 3/1 — 5Y 3/2		
20						dark fine Sz layering		
30								
40								
50								
60						sharp contact. eroded ∧ ∧ ∧ ∧ Salt marsh ~~Sphagnum~~ ? peat ∧ (?) wood Section 2 268 ∧		
70						Fragments ∧ ∧ ∧ ∧ ∧ Peat ∧ ∧ ∧ ∧		
80						olive grey 5Y 3/1 fine muddy (shelly) Sand		
90						(BIOTURBATED)		
300						organic layer 301-302		

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 9

CRUISE NUMBER. 93 Leamla

SAMPLE NUMBER. CORE 9

TOTAL LENGTH. 600 CM.

SAMPLE TYPE PS Vibrocore

CALENDAR DATE. Sept 2/93

~~PROJECT~~ NUMBER. 300-400

GEOGRAPHIC LOCATION. McNabs Island

SYMBOL ~~LEGEND~~

DESCRIBED BY. Scott/~~STEA~~

PAGE 4 OF 6

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
300						olive-grey muddy fine sand bioturbated.		
10						section 3/4		
20						olive-grey sandy mud. NB peat lens [illegible] LENS (5Y 3/1)		
30						BIOTURBATED COBBLE		
40						↓		
50								
60								
70								
80								
90								
400								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 9

CRUISE NUMBER. 93 Seando

SAMPLE NUMBER. Core 9

TOTAL LENGTH. 600 CM.

SAMPLE TYPE D5 Vibracore

CALENDAR DATE. Sept 2/93

~~PROJECT~~ NUMBER. 400 -500 XXI

GEOGRAPHIC LOCATION. McNabs Island

SYMBOL LEGEND

DESCRIBED BY. Scott/STEA

PAGE 5 OF 6

☐ ____ ☐ ____ ☐ ____

☐ ____ ☐ ____ ☐ ____

CORE DESCRIPTION

CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DON
4 0						dark olive grey sandy, mud bioturbated 5Y(3/1 - 3/2		
10								
20						↓		
30								
40								
50								
60						Section 46.3		
70						" "		
80								
90								
5 100								

NOTES.

ATLANTIC GEOSCIENCE CENTRE

Core 9

CRUISE NUMBER. 93 Secondr	SAMPLE NUMBER. Core 9.	TOTAL LENGTH. 600 CM.
SAMPLE TYPE PS Vibracore	CALENDAR DATE. Sept 2/93	~~PROJECT~~ NUMBER. 500-600 XXII
GEOGRAPHIC LOCATION. McNabs Island		SYMBOL LEGEND
DESCRIBED BY. Scott Brest	PAGE 2 OF 6	☐ ___ ☐ ___ ☐ ___ ☐ ___ ☐ ___ ☐ ___

CORE DESCRIPTION

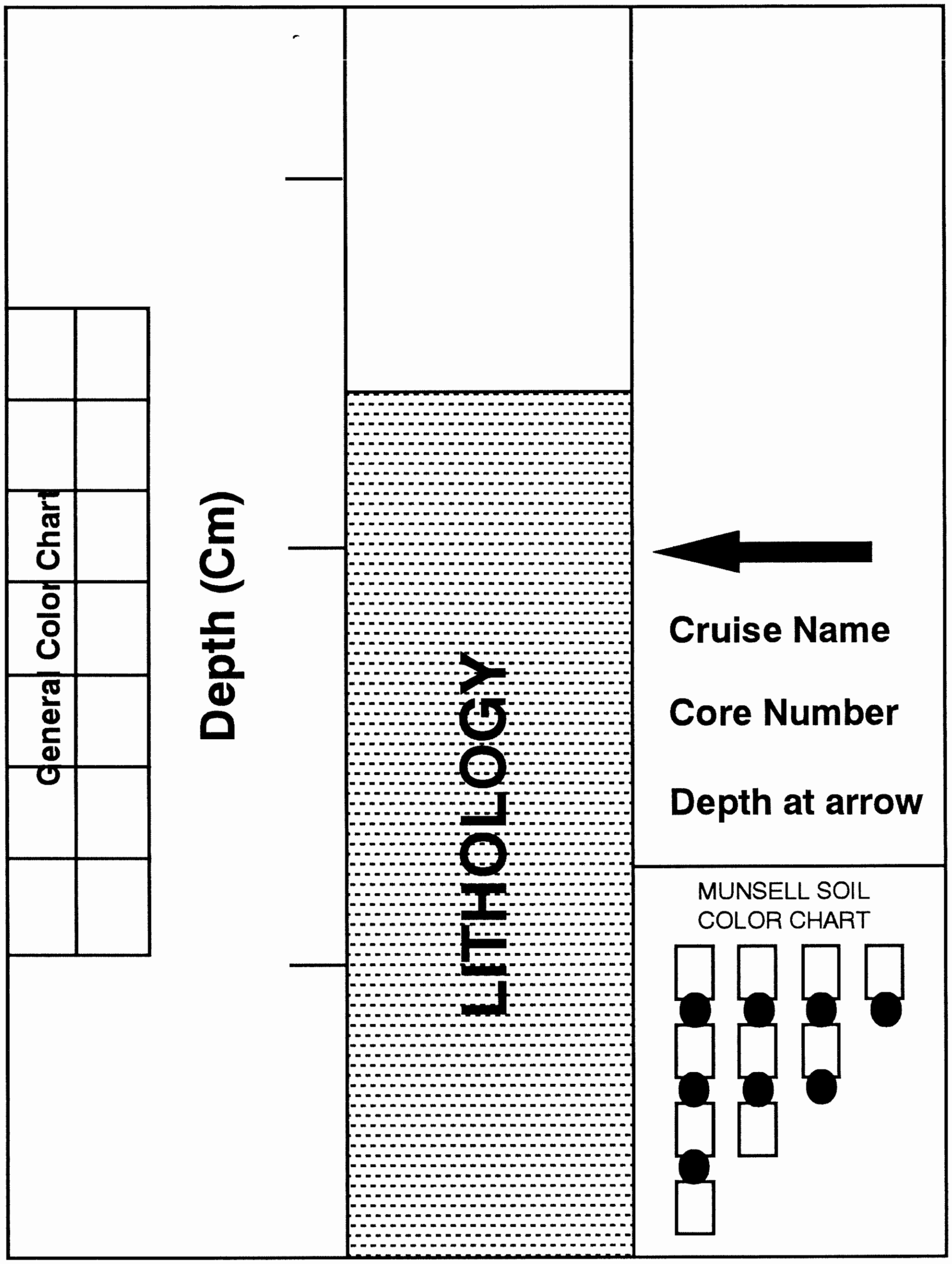
CORE DEPTH (CM.)	DEFORMATION	CONSISTENCY	CA CO3	COLOR (SOIL/ROCK)	X-RAY DESCRIPTION	VISUAL DESCRIPTION	SEDIMENT STRUCTURES	SUBSAMPLE WORK DONE
500								
						dark olive grey sandy		
10						mud		
						bioturbated		
						31		
20								
						532-535		
30						peat lens		
40								
						Light olive grey		
50						551- peat		
						sandy mud		
						bioturbated.		
60								
70								
80						peat		
90								
600						END		

NOTES.

APPENDIX B

CORE PHOTOGRAPHS

Core Photograph



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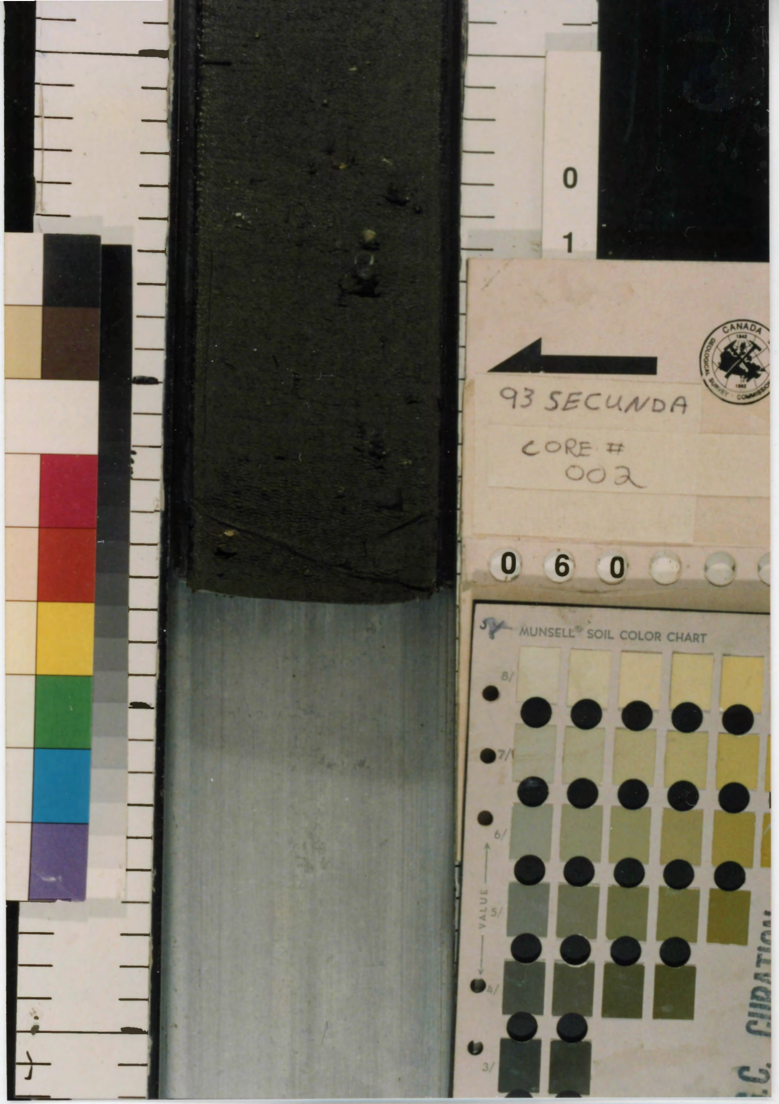
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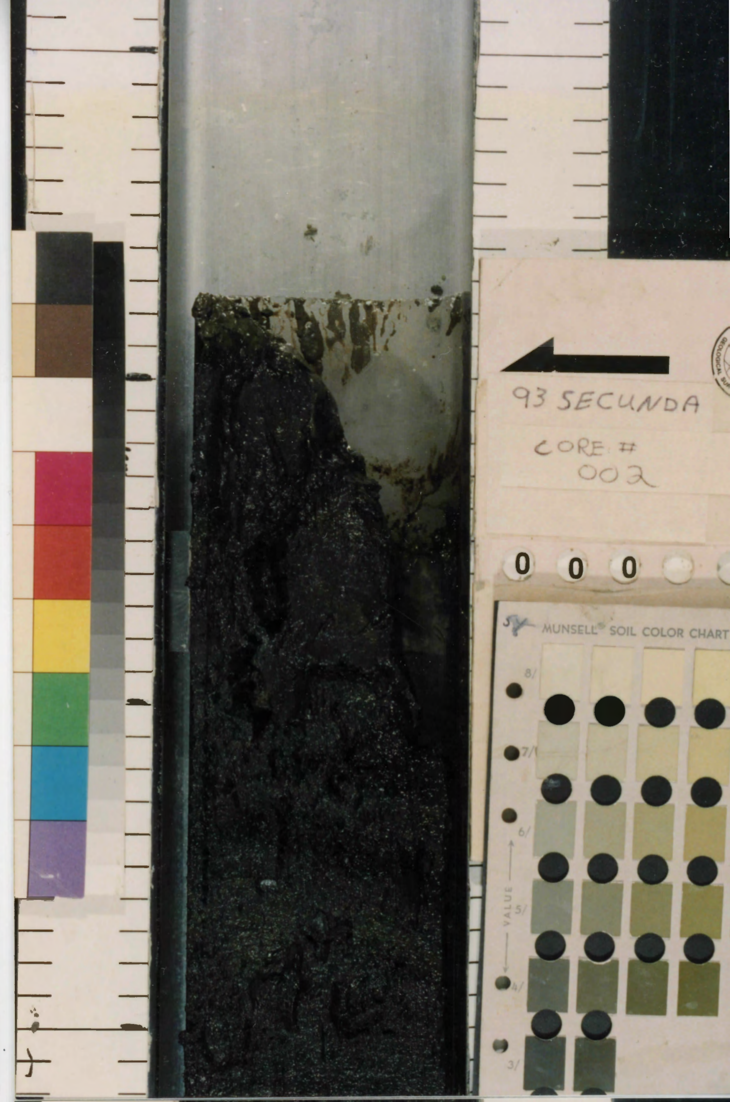
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0 9 0
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VALUE
Black
Brown
White
Magenta
Red
Yellow
Green
Cyan


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93 SECUNDA
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CURATION
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White
Magenta
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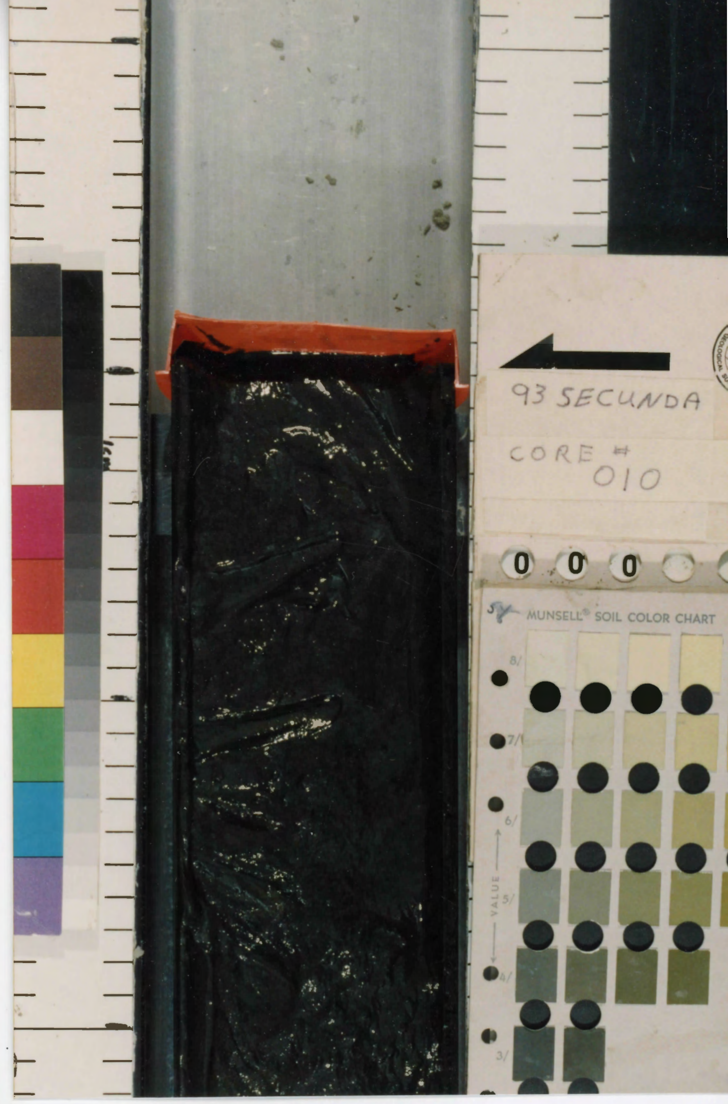
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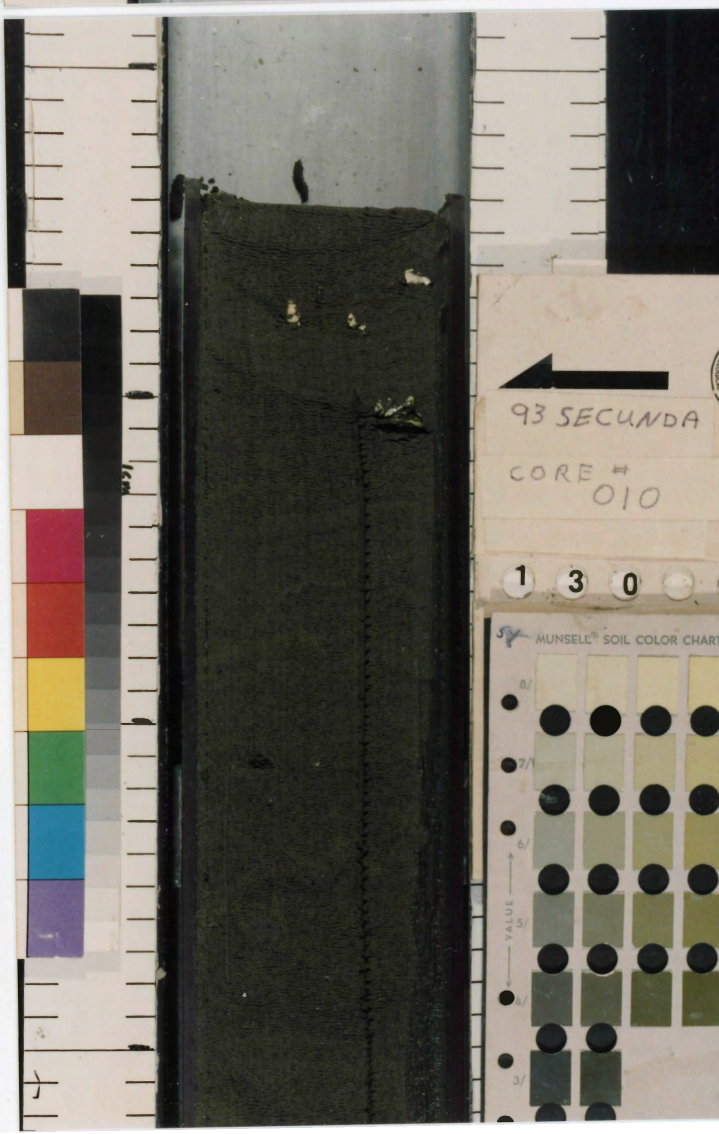
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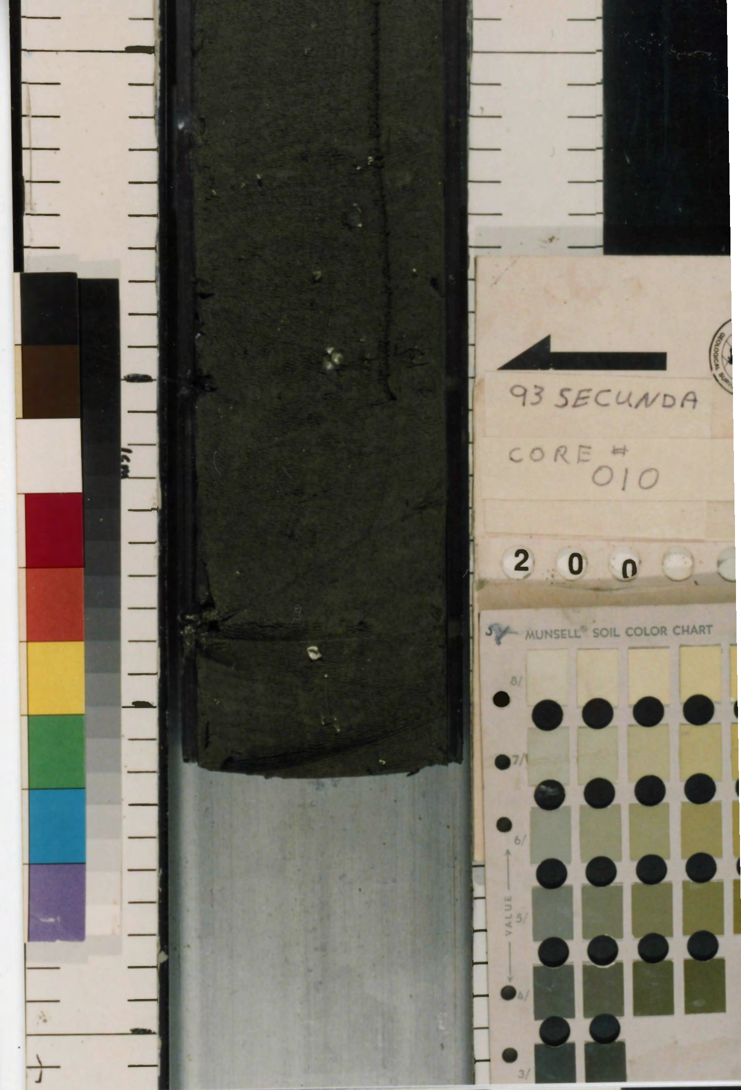
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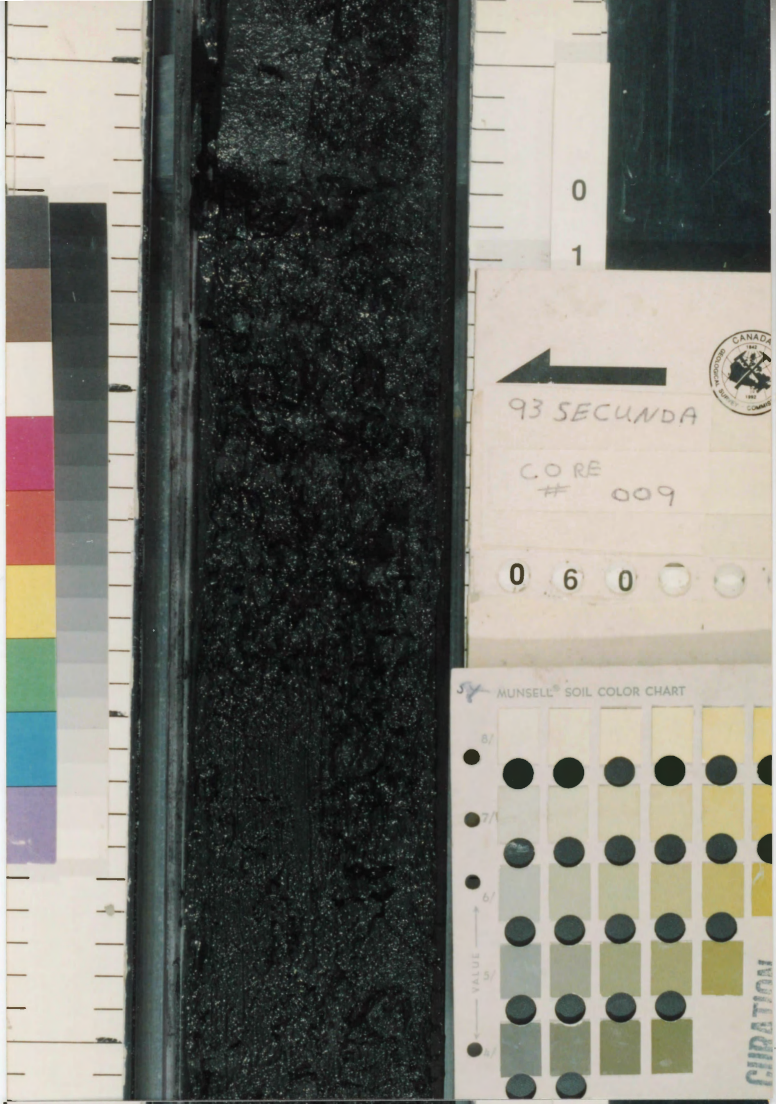
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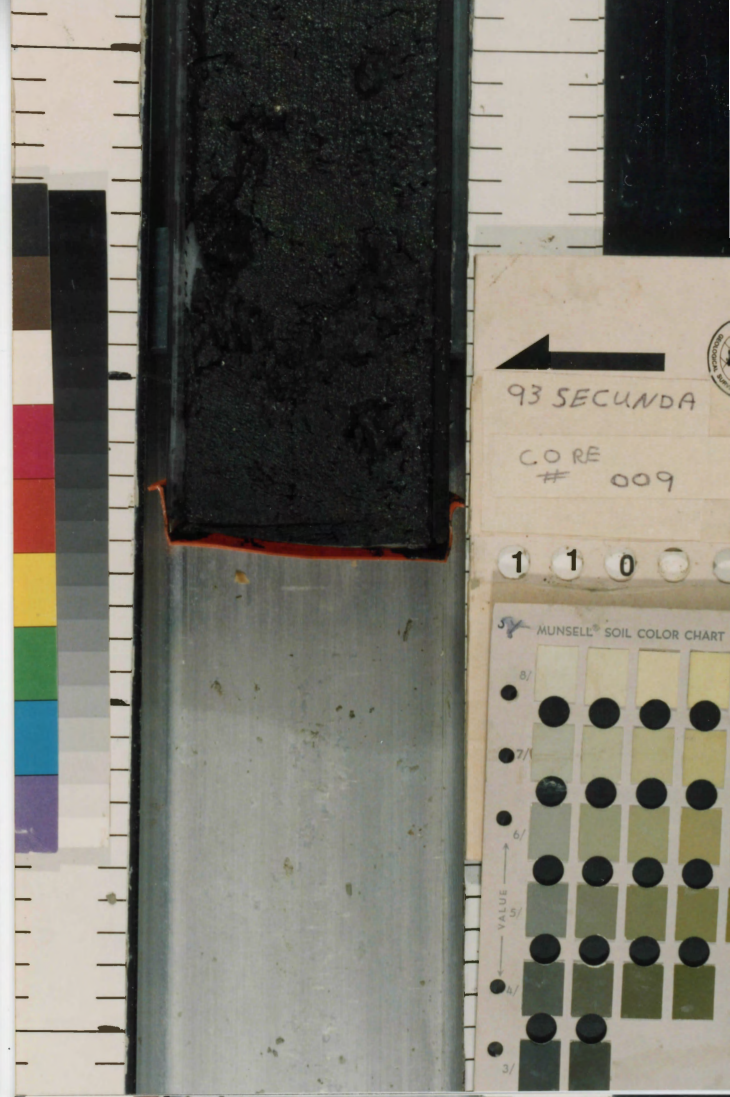
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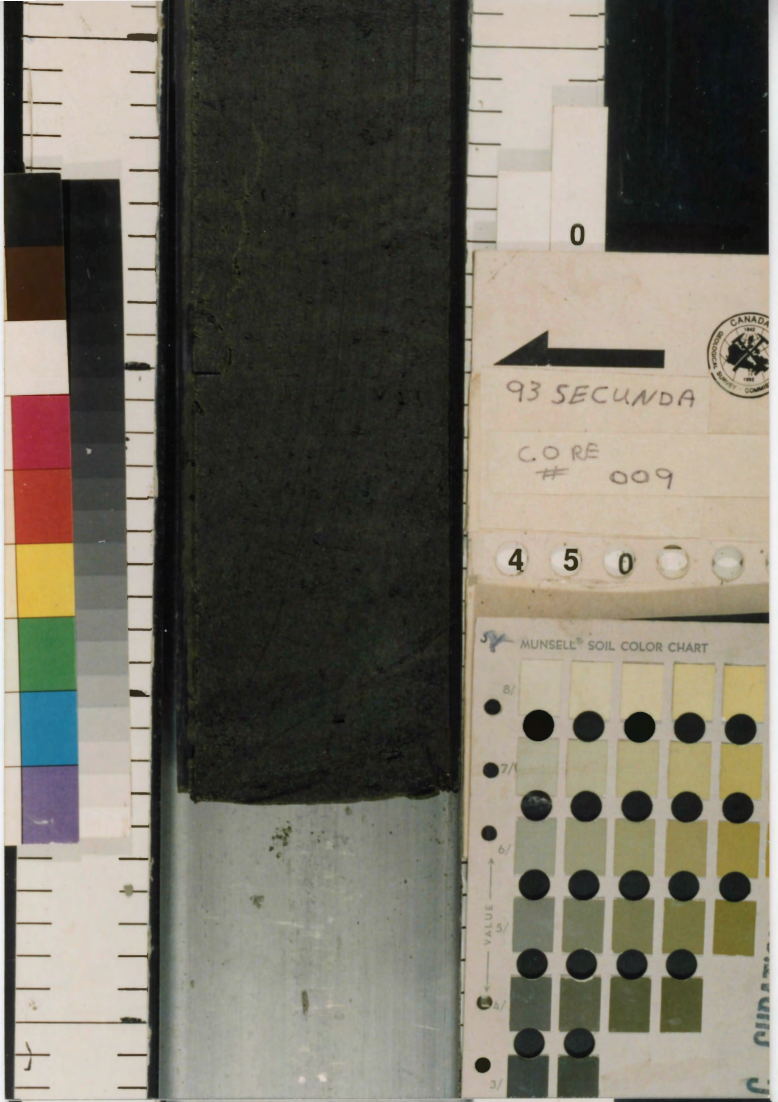
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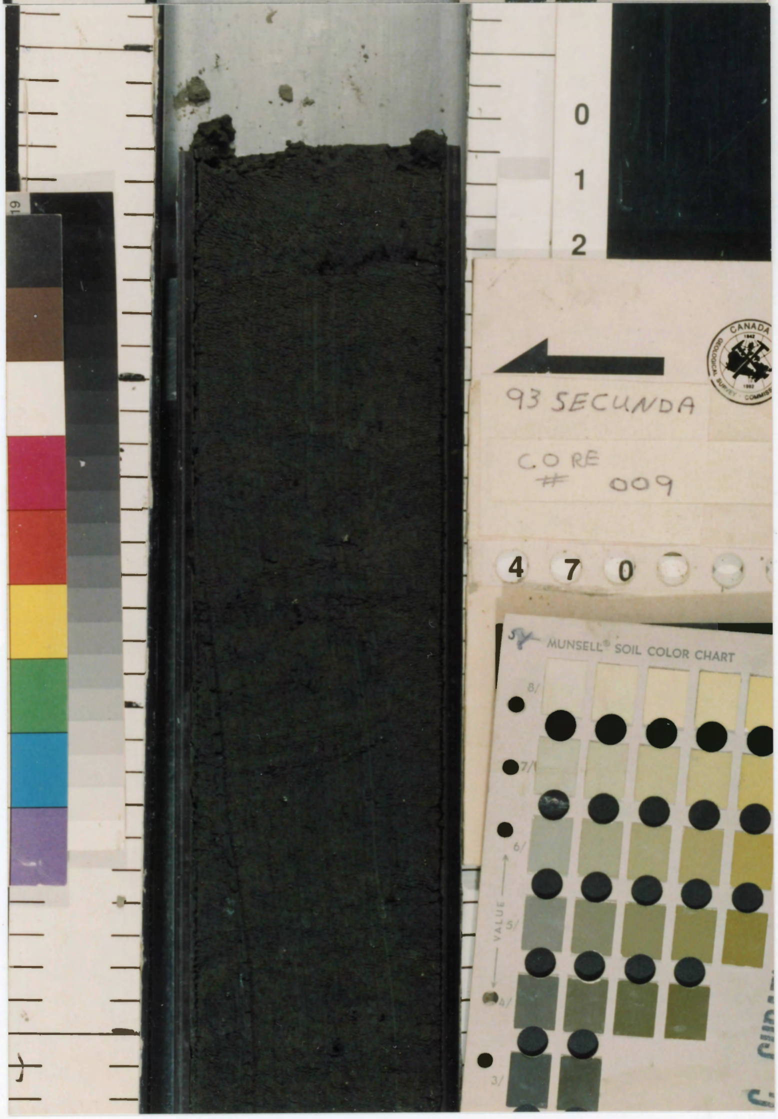
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CANADA
93 SECUNDA
CORE # 009
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MUNSELL® SOIL COLOR CHART
VALUE
G.C. CURATION

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CORE # 009
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93 SECUNDA
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G.C. CURATION

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CORE # 009
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