Microfossil Evidence for Recent and Past Changes to Hudson Bay Oceanography

by

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ABSTRACT

In 2005, box cores were collected throughout the Hudson Bay and Strait. A detailed micropaleontological data set has been generated from these cores for this study and is combined with geochemical and geochronological data to observe temporal and spatial oceanographic changes throughout the bay and strait. All of the cores show an increase in tintinnid species and agglutinated foraminifera, and coincident decreases in calcareous foraminifera in younger core sections. In general, these microfossil trends are correlated with higher organic matter content of the younger core sections. This results from a more extensive freshwater plume that causes lowered pH in the superficial sediments and conditions less favourable for the preservation of calcareous tests. Furthermore, with a ^{14}C age constraint in one of the cores, the mid-Holocene depositional and paleoceanographic history is represented, and provides evidence of marine invasion by 7100 cal yrs BP.

LIST OF ABBREVIATIONS USED

ACIA	Arctic Climate Impact Assessment
BC	Box Core
C	Carbon
Cal yrs	Calendar Years
CASES	Canadian Arctic Shelf Exchange Study
CCGS	Canadian Coast Guard Ship
CDOM	Chromophoric Dissolved Organic Matter
Cs	Cesium
CTD	Conductivity, Temperature, and Depth
NODC	National Ocean Data Center
NOSAMS	National Ocean Science Accelerator Mass Spectrometry Facility
OC	Organic Carbon
Pb	Lead
Pers comm	Personal Communication
Ra	Radium
RA	Relative Abundance
Rn	Radon
SE	Standard Error
SEM	Scanning Electron Microscope
SPM	Suspended Particulate Matter
SST	Sea Surface Temperature
TN	Total Nitrogen
δ13C	Stable Carbon Isotopic Composition
Δ R	Marine Reservoir Age

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CHAPTER 1 INTRODUCTION

The Hudson Bay is a large inland sea that crosses both polar and boreal ecosystems. The bay freezes over yearly making scientific investigations and measurements largely unattainable for several months of the year (ACIA, 2005); however sedimentation processes continue, and bottom sediments accumulate. These deposits, which include microfossil tests, ice-rafted debris, and previously suspended particulate matter, provide a record of the environmental conditions under which they were deposited. In this study, sedimentological and chronological data are used to temporally and spatially reconstruct the recent oceanographic and sea ice conditions within the Hudson Bay region.

With the recent warming temperature trends (ACIA, 2005), the reduction of Arctic sea-ice extent has become a concern among scientists and local inhabitants who use the sea-ice in their everyday lives. It is important to observe changes in these environments over time using sensitive bio-indicators. Benthonic foraminifera are one of the most important tools used in monitoring bottom water environmental conditions due to their sensitivity and special ecological tolerances (Boltovskoy et al., 1991). Recent studies in the Arctic (Amundsen Gulf & Beaufort Sea) have used foraminiferal assemblages to characterize paleo-environments and sea-ice cover changes over the last 1000 years (Gibb, 2009; Scott et al., 2008a, b; Schell et al., 2008). However, ongoing scientific research is required to document these changing environments. Recent expeditions (*CCGS Amundsen* & *Hudson*) have begun exploring the sub-Arctic region, which is considered particularly vulnerable to the effects of a climate warming.

This thesis characterizes the down-core distribution of foraminifera in a set of box cores (BC) collected throughout the northern sub-Arctic Hudson Bay and western Hudson Strait. Four box cores from a west-east transect across the Hudson Bay (BC-10, BC-12, BC-13, & BC-14) are contrasted with two cores (BC-3 & BC-15) from the westernmost Hudson Strait. Based on ^{210}Pb, ^{137}Cs, and ^{14}C dating, the cores have both recent (110 yrs BP) and older Holocene (~ 7000 cal yrs BP) sediments. The down-core distribution of foraminifera examined in this thesis is used to help determine the temporal and spatial response to recent changes within the environment over those time intervals.

The main questions addressed by this study are as follows:

1) What are the differences in microfauna from the Hudson Bay to the more oceanic Hudson Strait?
2) Has the recent warming boosted productivity or created taxonomic shifts in the microfauna present in the Hudson Bay region?
3) Do the microfaunal assemblages show any indication of the influence of different water masses (Atlantic and Arctic Ocean) affecting the region?
4) Is there any post-deglacial evidence to show the timing of marine invasion within the region?
5) How do the microfossil trends from the cores in this study fit in with other regional studies (i.e. Leslie, 1963, 1965)?

CHAPTER 2 BACKGROUND

2.1 STUDY AREA

The Hudson Bay is a large (1370 km long, 1050 km wide) but shallow (~ 150 m deep) shelf sea located on the southern margin of the Canadian Arctic. Figure 2.1 is a map of the study area shown with bathymetry, sea-surface circulation, and box core locations. The basin is bound to the north-northwest by Nunavut, in the west by Manitoba, in the south by Ontario, and in the east by Quebec. It is connected in the East to the Atlantic Ocean via the Hudson Strait, and in the North to the Arctic Ocean by Foxe Basin via Roes Welcome Sound and Foxe Channel.

The bay is a unique environment influenced by high volumes of freshwater that discharge from surrounding rivers, Arctic ice floes from the north, and the tidally controlled inflow of Atlantic Ocean water from the east. Freshwater plumes extending from riverine sources are deflected to the right, creating a counterclockwise cyclonic gyre within the bay (Fig. 2.1). Arctic ice floes enter the bay from Roes Welcome Sound and Foxe Basin, and Atlantic water enters the deeper bay via the Hudson Strait. Water originating from Hudson Bay (Riverine freshwater) and Foxe Basin (Arctic ice-floe) join the southeasterly flow in Hudson Strait. The Baffin Current enters the Hudson Strait south of Baffin Island and becomes the northwesterly drift along the Baffin Island side of the strait. This creates a dynamic estuarine environment with both Arctic and Atlantic waters entering at depth, and freshwater plumes entering and exiting within the surface layer.

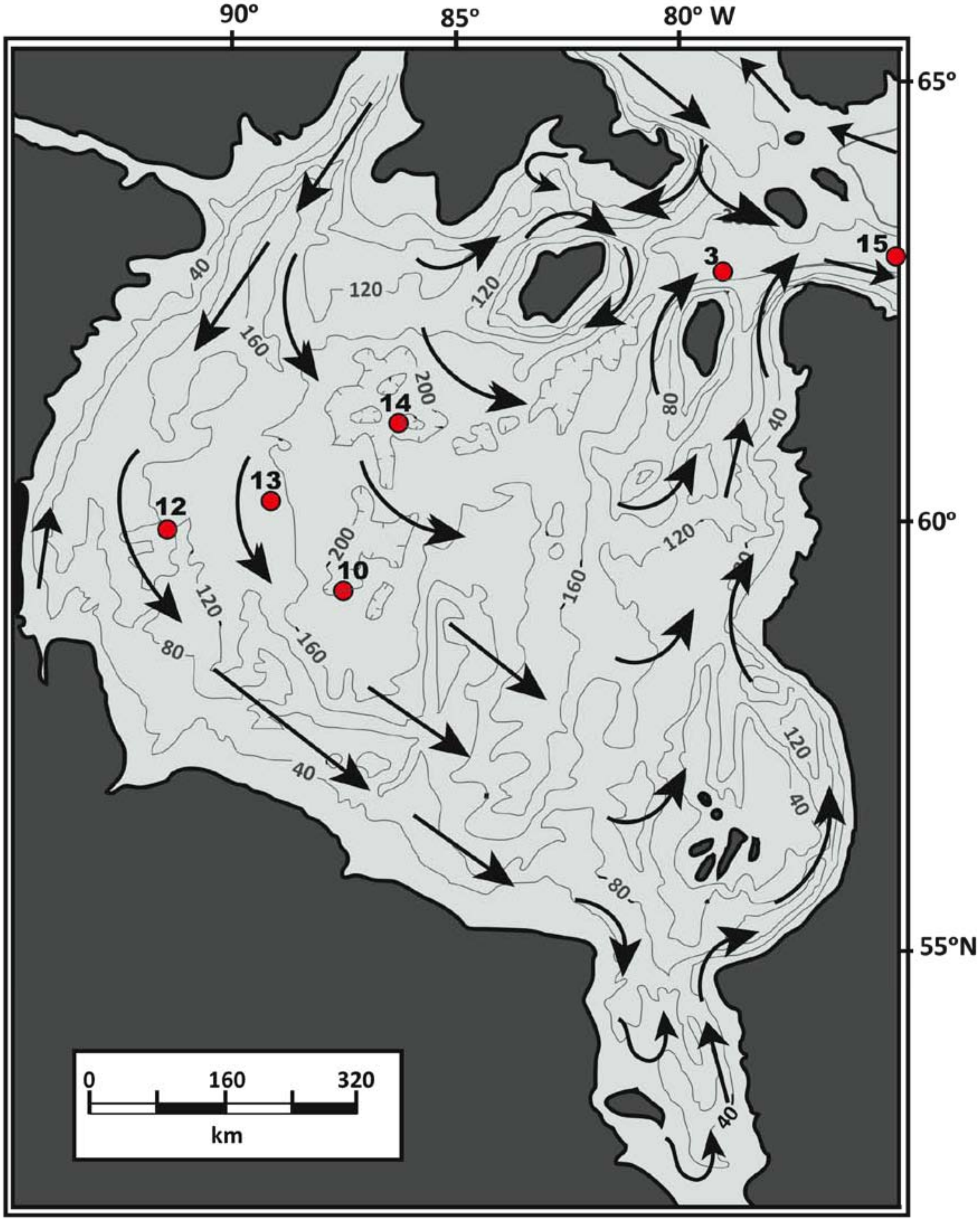

Figure 2.1 – The study area, Hudson Bay, Canada. Box cores are shown with circulation (Prinsenberg, 1986) within the bay and the sea floor bathymetry (Pelletier, 1986).

Large volumes of freshwater discharge (annual mean ~ 12.5 X 10^3 m^3/s) into the bay contributing 85 cm of freshwater to the surface layer (Prinsenberg, 1977); sea-ice nearly doubles this, contributing another 140-160 cm of freshwater during the ice-free seasons (Prinsenberg, 1984).

The bay is an oceanic environment that lies on the frontier of polar and boreal ecosystems. The bay covers a vast area crossing three ecological zones from north to south– the sub-Arctic environment, the taiga shield, and the boreal shield. To the southwest lies the Hudson Bay lowlands where estuaries and marshes border the coast of the bay and are slowly re-emerging by isostatic rebound following the last deglaciation (Hillaire-Marcel & Fairbridge, 1978). Due to its vast expanse, the bay's dynamics have a widespread influence on Canadian climate.

The bay freezes over yearly, and thus is only navigable for several months of the year, making scientific investigation difficult. The geochemical and micropaleontological analyses of box cores collected in the ice-free season of 2005 are used in this study to temporally and spatially constrain the changes that have occurred in the Hudson Bay and Strait environment over the last 50, 150, and 7100 years.

Hydroelectric developments have been underway in the Hudson Bay region since the mid-1970's. The major hydroelectric systems are on the Nelson-Churchill (western Hudson Bay), the Great Whale-Little Whale (southeastern Hudson Bay), La Grande-Eastmain (eastern James Bay), and the Nottaway-Broadback-Rupert Rivers (southeastern

James Bay). These developments would have the largest effect on the bay mainly during the winter months when river runoff is naturally low (Prinsenberg, 1980). Prinsenberg (1984) suggests that Hudson Bay would react more slowly to manmade changes (such as dams, diversions, and reservoirs) than the more southern James Bay partly because discharge rates in James Bay are twice as large compared to Hudson Bay, and because during the melt-season, ice floes move south and melt (Granskog et al., 2007), providing more freshwater contribution to the more southerly regions. Dery et al. (2005) noted higher annual freshwater yields from the eastern coast and attributed the lower volume of freshwater discharge on the western coast of Hudson Bay to low precipitation and high evaporation rates in the Canadian prairies and elevated retention rates in river reservoirs located west of Hudson Bay.

Prinsenberg (1984) speculated that changes from hydroelectric developments would eventually affect local atmospheric conditions. These changes are not well documented because impact studies do not tend to include the downstream effects (Prinsenberg, 1980). Effects on conditions in offshore waters of Hudson Bay and even on the North Atlantic are not well known (Stewart & Lockhart, 2005). Saucier and Dione (1998) suggest that bay-wide effects of hydroelectric development are small compared to natural variability observed in the sea ice cover. River runoff is largely constrained to the near shore environments, and the yearly sea-ice melt is more evenly distributed throughout the bay (Granskog et al., 2007). The regulated distribution of the freshwater plume by the hydroelectric development, and the increasing ice-free (open water) days may provide a longer period where microfauna are able to thrive and proliferate in abundance. A study of Devon Island sediments (Gajewski et al., 1997) showed that warming since the mid-1900's caused a shifts in diatom algal floras, and the introduction of diatoms to lakes, which were previously too light limited due to ice-cover. Temperatures within this region began to warm after the Little Ice Age (1550 - 1900, Jones et al., 2001; 1600 - 1850, Kaufman et al., 2009). Some studies show that this warming is concentrated in the last 50 years (Kaufman et al., 2009) and others show a warming over the last 150 years (Overpeck et al., 1997; Smol et al., 2005; Mann & Bradley, 1999).

Scientific interest in this sub-Arctic region has resulted from regional climate change, the decrease in the overall extent and thickness of the sea ice (Gough & Wolfe, 2001), and the impending impacts that these changes may have on nearby communities (ACIA, 2005). This region is plausibly acting as a warning signal and a forecast for other polar environments.

2.2 OCEANOGRAPHIC CONDITIONS

Hudson Bay is the world's largest inland sea. The bay is a large estuarine basin with fresher, less dense water at the surface and more saline, denser water at depth (Pett & Roff, 1982). On average, the bay's salinity is much lower than that of the world's oceans, and this can be attributed to many factors including high terrestrial runoff, yearly sea-ice melt, high precipitation/low evaporation rates and limited access to the Atlantic Ocean.

Drinkwater et al. (1991) documented salinity and temperature using a Guildline Digital CTD device throughout the Hudson Bay and Strait region in the late summer of 1982. At the surface, salinity was ~ 30‰ within the bay, with higher values (~ 32‰) in the Hudson Strait; however at a depth of 50 m salinity increased to ~ 32‰ in the bay and ~ 33‰ in the strait.

Prinsenberg (1984) showed that the bay is the least saline on the southwestern coast (~ 25 - 27‰) where the Nelson and Churchill Rivers discharge and more saline near the middle of the bay. More recent data (National Oceanographic Data Center [NODC], 2010) compliment Prinsenberg's early study and reveal high volumes of low salinity surface water are present in southern Hudson Bay and in James Bay where Great Whale River and several other large rivers discharge (Fig. 2.2). Low salinity surface water is also present along the western coast of the bay where the Churchill River discharges.

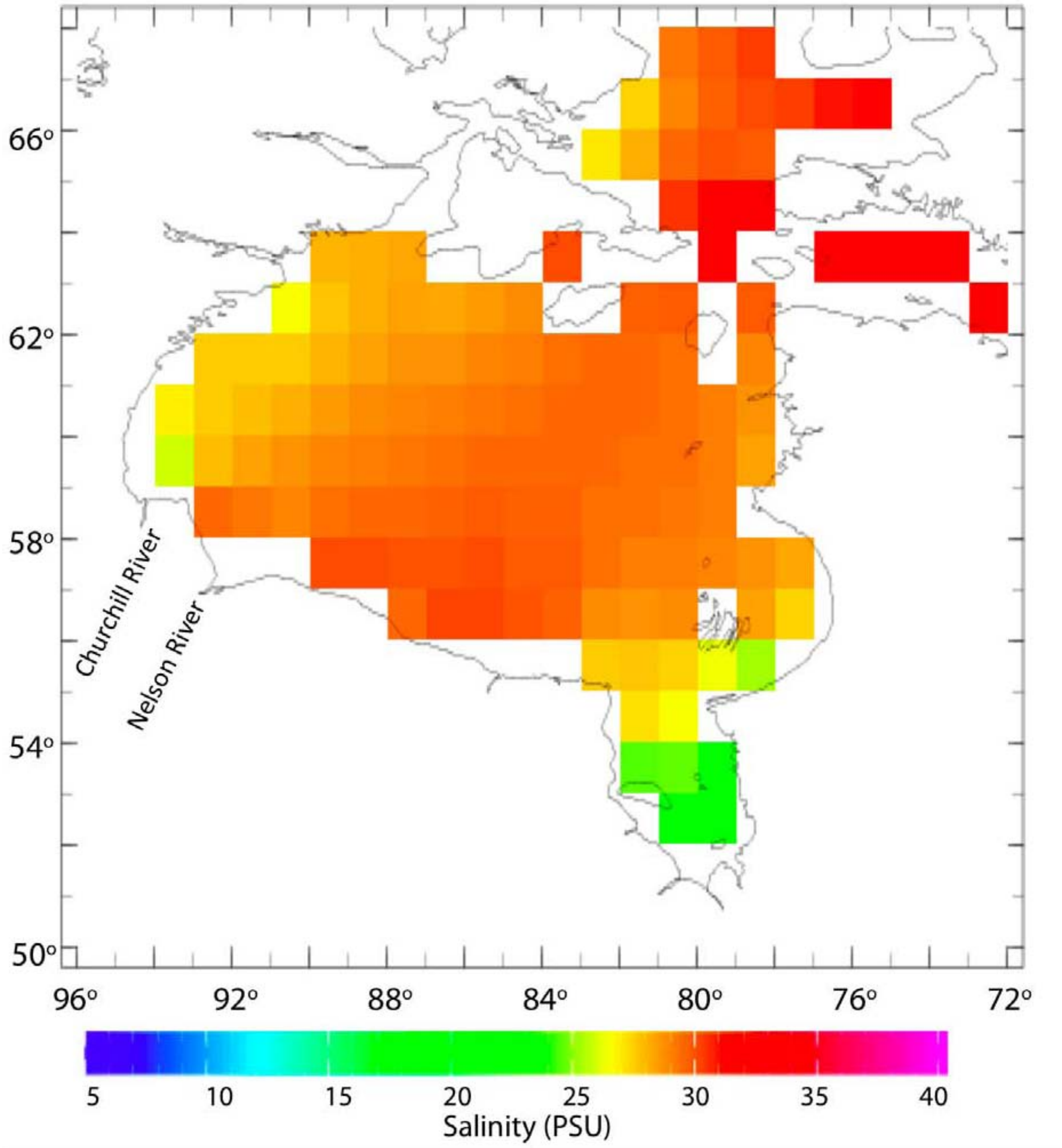

Figure 2.2 – Surface salinity throughout the Hudson Bay and Strait (NODC, 2010)

Temperatures measured at the surface were about 6°C in the central bay area and decreased to 2°C in the strait; at a depth of 50 m, temperatures were about -0.5°C and -1.5°C respectively (Drinkwater et al., 1991). Sea surface temperatures are available through NASA's Giovanni database, and monthly averages are shown in Figure 2.3 for 2005. A detailed examination of the last 8 years (1997 - 2005) of data collected by the Giovanni database reveals that the Hudson Bay has slightly warmed over that time period (not shown).

High volumes of freshwater that discharge into the bay greatly influence the temperature and salinity of the surface waters. Coriolis force deflects riverine freshwater plumes to the right and creates a counter-clockwise cyclonic gyre, which controls the bay's surface circulation (Fig. 2.1). Dunbar (1982) suggests that due to high volumes of freshwater discharge, the water column in Hudson Bay is relatively stable and vertical movement is discouraged. During the ice-covered months (November - July), wind turbulence does not affect the surface plume, however, some mixing occurs as a result of tidal influence (Freeman et al., 1982).

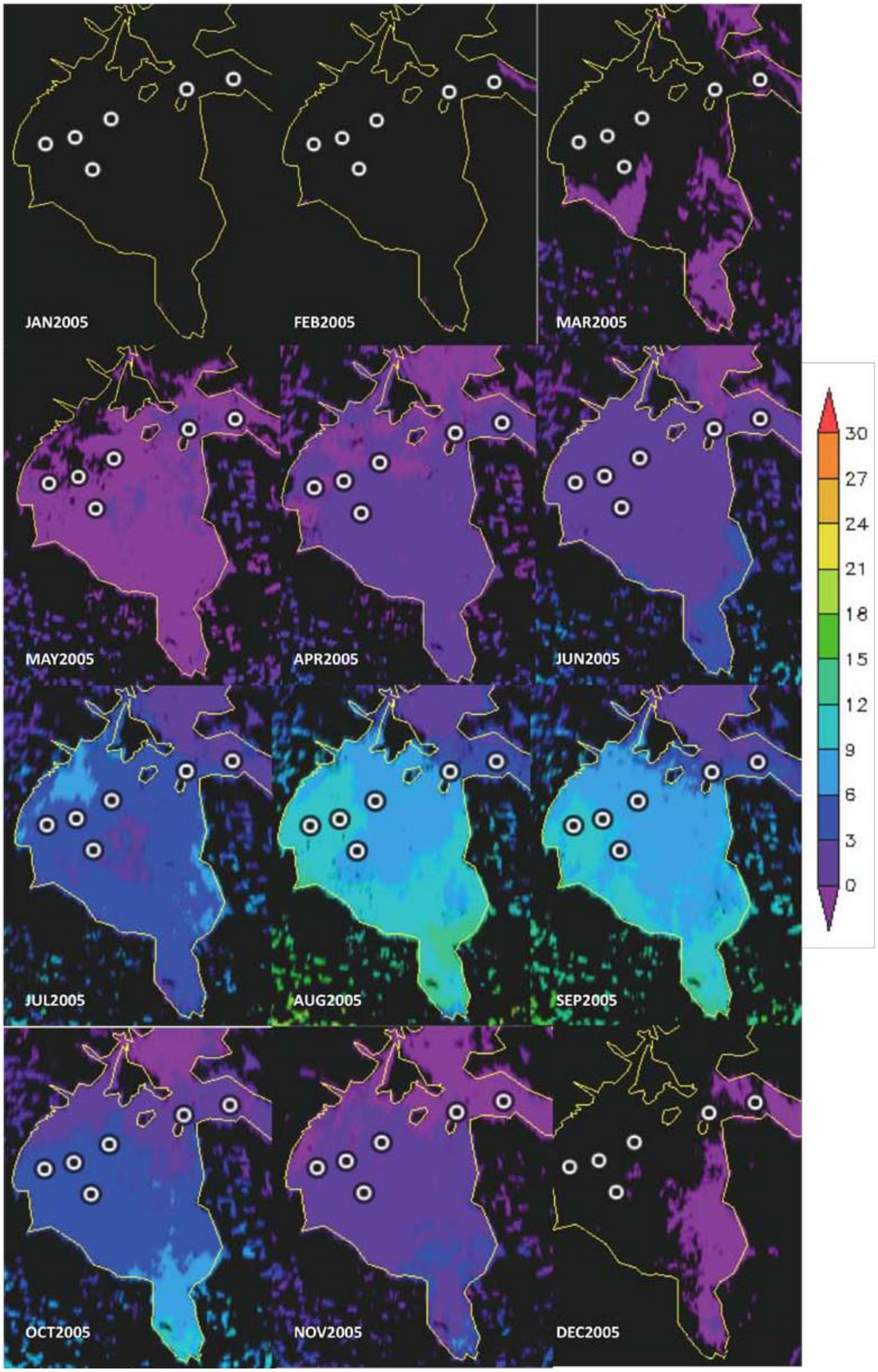

Figure 2.3 – Monthly Sea Surface Temperatures (SST) for the Hudson Bay region for 2005 modified from NASA's Giovanni Database (2010). Black areas within the bay are areas that are sea-ice covered. The circle symbols represent the box cores from this study.

Chromophoric dissolved organic matter (CDOM) data, which represent mostly terrigenous dissolved organic carbon, have been used in recent studies to determine the influence of riverine organics and freshwater plume extent in the Arctic (Scully & Miller, 2000) and in the Hudson Bay (Granskog et al., 2007). Scully and Miller (2000) found that increased input of CDOM from sea ice was a factor that needed to be considered in some Arctic environments. With salinity measurements and optical property (a_{355}) data for CDOM, Granskog et al. (2007) were able to determine that terrestrial input from rivers governs CDOM variability in the Hudson Bay region, and that the central basin has similar CDOM absorption levels as the central Arctic Ocean and Beaufort Sea. CDOM satellite data collected daily from 1997 to 2005 (Giovanni, NASA) show that the entire bay is freshening, with most drastic changes occurring in the more southerly regions (not shown).

It is more difficult to study the deeper waters of Hudson Bay because they are ice-covered for a large part of the year. Barber (1967) described the deep waters within the bay as being a product of cold surface Arctic Ocean water from the north (Roes Welcome Sound) and east (Extension of Baffin Current), and warmer more saline Atlantic Ocean waters also from the east (Hudson Strait). The bay has an estuarine circulation pattern with oceanic bottom water in-flow from the Arctic and Atlantic Oceans and less saline surface water out-flow to James Bay and the Atlantic Ocean.

2.3 WISCONSINAN ICE SHEET & DEGLACIATION

The Wisconsinan Ice Sheet, the last major advance of the Laurentide Ice Sheet, covered most of North America, and formed multiple ice domes over the Hudson Bay region (Dyke & Prest, 1987). The ice-dammed Lake Agassiz-Ojibway, which formed at the southern margin of the Laurentide Ice Sheet, drained northward about 8470 cal yrs BP and penetrated below the ice sheet in the Hudson Bay Region (Lajeunesse & St-Onge, 2008). Deglaciation occurred rapidly over 400 years (Josenhans & Zevenhuizen, 1990), and marine waters inundated the Hudson Bay region. As the ice sheet melted, marine water would have flowed in through the Hudson Strait and flooded the lowlands in the formation of the Tyrell Sea (Shilts, 1986). During the Wisconsinan, the Hudson Strait was thought to have been an active conduit of ice (from $^{16/18}O$ isotopic signatures, Andrews et al., 1983), and due to blockages of ice in the strait, it has been postulated that there may have been periods when Hudson Bay may have contained mostly fresh or low salinity water (Vilks et al., 1989).

The Wisconsinan Glaciation ended about 15000 yrs BP, however, the Hudson Bay region was not ice-free until 8000 yrs BP (Dyke & Prest, 1987). The Hudson Bay uplifted ~ 315 meters due to glacio-isostatic rebound over the last 8000 years (Vincent et al., 1987), and the region continues to uplift at a rebound rate of about 60 cm/100 yrs (Josenhans & Zuivenhuizen, 1990). With differential rates of eustatic sea-level rise and isostatic uplift, the influence of the Atlantic and Arctic Ocean on the Hudson Bay was most likely quite variable through time.

To maintain context with other regional studies, this discussion will use radiocarbon (^{14}C) years before present (^{14}C yrs BP) rather than calendar years. Uncalibrated radiocarbon years do not incorporate reservoir effects, and are usually reported in ^{14}C years BP, where 0 yrs BP is defined as the year 1950 (Karlén et al., 1966). Prior to 8000 ^{14}C yrs BP, rates of increase in glacio-isostatic rebound were obscured by mean sea level (MSL) rise (18000 - 10000 ^{14}C yrs BP) allowing the entry of ocean waters through the Hudson Strait, and the creation of the Tyrrell Sea (by 8000 ^{14}C yrs BP) in the Hudson Bay region (Hillaire-Marcel & Fairbridge, 1978). From 8000 to 6000 ^{14}C yrs BP, the rate of isostatic uplift accelerated (+100 m in 2000 yrs), and a eustatic rise of sea level of about 20 m is apparent (Hillaire-Marcel & Fairbridge, 1978). By 7800 ^{14}C yrs BP, marine water had penetrated under the ice as far south as James Bay lowlands, and the transition from freshwater, pro-glacial lake conditions to marine conditions was very rapid in this area (on the order of 400 years, Josenhans & Zevenhuizen, 1990; Shilts, 1986).

Glacial advances and retreats were responsible for shaping much of the Hudson Bay coast and sea floor (Shilts, 1986). Glaciogenic features on the Hudson Bay sea floor are still well preserved due to limited post-glacial sedimentation and ice scour in the deeper regions of the bay. These features include exposed glaciogenic sediments, arc-shaped scours (up to 1 km long & 3 m deep), sandwaves, and channels (Josenhans et al., 1988; Lajeunesse & St-Onge, 2008).

2.4 RECENT SEA ICE

The formation of sea ice during the winter begins on the western side of the bay, spreading eastward in November (Gough et al., 2004); the summer thaw begins in March with ice-free conditions by July (Fig. 2.3). During the summer months, a typical marine environment exists, but during the freeze-up months the bay is insulated by ice and snow and cold air masses extend down into southern Canada (Prinsenberg, 1984).

The Arctic's decreasing sea ice extent (Gough & Wolfe, 2001) and duration (Smith, 1998) is predicted to continue; melt days per summer calculated from 1979 to 1996 increased by 5 days per decade (Smith, 1998). Due to the ice albedo effect, this reduction in sea ice will affect the planetary balance, cause more radiation absorption, and ultimately contribute to a warmer climate. Using computer simulations, Gough and Wolfe (2001) have predicted the disappearance of sea ice in the Hudson Bay by as early as 2050.

Being the largest inland body of water that freezes over yearly, the Hudson Bay influences the weather and vegetation patterns of central Canada (Prinsenberg, 1980). The impact of warming may be first recognized in the more marginal sub-Arctic regions, which are considered more sensitive (ACIA, 2005). The Hudson Bay is situated at the sub-Arctic margin, and receives large inputs of terrestrial sediments and freshwater; the environmental effects of a warming will be felt sooner and more strongly in this region.

2.5 FORAMINIFERAL STUDIES

Foraminifera are planktonic and benthonic single-celled protists that have a shell or test, which can be made of agglutinated, calcareous or organic material. Foraminifera are one of the most abundant meiofauna in the ocean, but more importantly their fossil tests are preserved in bottom sediments. Particular species can be placed within certain environmental ranges, and their record thus provides important information about the conditions under which they were deposited. Most foraminifera in the Hudson Bay and Strait are benthonic, spending the majority of their lives crawling slowly on or just below the sediment surface. The planktonic forms are more common in oceanic environments.

Some of the earliest researchers of the 19th century that studied Arctic foraminifera include Parker and Jones (1865), Norman (1877), Brady (1878), and many others, and they focused heavily on taxonomic classifications. Later in the 20th century, Joseph Cushman became one of the most influential scientists in foraminiferal research, with 554 scholarly publications (i.e. Cushman, 1922; 1944; 1947). Nörvang (1945), Höglund (1947), Phleger (1952) and Loeblich and Tappan (1953) also made contributions to Arctic foraminiferal research. Recent Arctic studies focus on the use of these microfossils as indicators of recent and paleo-environmental changes within the Arctic based on their distribution, abundance, and diversity (Leslie, 1963; Lagoe, 1979; Bilodeau et al., 1990; Scott & Vilks, 1991; Scott et al., 2008a; Wollenburg & Kuhnt, 2000; Wollenburg et al., 2001; Wollenburg et al., 2004).

Even though research on Arctic foraminifera has been carried out (see above), a limited number of studies have examined foraminifera within the Hudson Bay and Strait region. Cushman (1921) described foraminifera from three surface samples from the bay; however, sampling recovery was only from a water depth of 20 metres on the southeastern coast of the bay. Since vertical zonation has an effect on the type of species present in the sedimentary record (Scott et al., 2001), Cushman did not acquire an appropriate representation of the bay's foraminifera.

Scott and Martini (1982) found that the abundances of recent marsh foraminifera and tintinnids (freshwater ciliates) from the southwestern coast of the Hudson Bay were ten times less than in more temperate climates; they attributed the lack of productivity to the shorter summer seasons and harsher winter climates associated with a higher latitude. They also encountered Tyrrell Sea deposits (from the early deglaciation) only a few centimeters below the marsh modern marsh material. Bilodeau et al. (1990) examined foraminiferal assemblages from piston cores in the Hudson Bay/Strait and southern Hudson Bay area (near BC-3; Fig. 2.1) to establish the postglacial paleoceanography of the region, and found distinct paleoecological changes since deglaciation.

Several studies document the regional deglacial history. Vilks et al. (1989) characterized the post-glacial micropaleontology and sedimentology of the Hudson Strait region. Haberzettl et al. (2010) interpreted marine processes following the final outburst of Lake Agassiz-Ojibway in the Hudson Bay and Strait. The cores from these studies, which are in proximity to the cores from this study, will be discussed further in Chapter 5.

Sedimentation rates have been examined for the last 1000 years in southeastern Hudson Bay (Jenner & Piper, 2002), however, these are in proximity to deltaic sedimentation and are much higher than in the more northern-central regions in this study. Sedimentation rates are further discussed in Chapter 5.

Leslie (1963; 1965) was the first to fully document the distribution of foraminifera in modern sediments for the entire Hudson Bay. In one study (Leslie, 1963) he identified a total of 62 species from 8 stations. By comparing foraminiferal trends to bottom bathymetry and sediment texture, Leslie (1963) noted three distinct assemblages: (1) Near Shore, (2) Central Basin, and (3) Central High; each characterized by their own distinctive microfaunal assemblages. Since temperature and salinity are fairly constant throughout the bottom waters of Hudson Bay, Leslie (1965) concluded that there was little relationship with microfaunal trends; however his study did show that depth and substrate are major controls on the distribution of the bay's foraminifera.

These studies and others (Boltovskoy et al, 1991; Scott et al., 2001) show that the preserved tests of marine foraminifera and tintinnids are effective indicators of environmental conditions under which they lived. This thesis uses the down-core micropaleontological record of six cores to determine recent and millennial-scale changes to the Hudson Bay environment.

CHAPTER 3 METHODS

On Leg 2 of the ArcticNet 0502 marine expedition (2005), the crew aboard the *CCGS Amundsen* collected piston and box cores to better understand the sedimentation and sea floor dynamics within the Hudson Bay and Hudson Strait region. Bathymetry (EM300) and sub-bottom profiler (3.5 kHz transducer array) images assisted the crew in selecting suitable coring locations and in avoiding areas of low sedimentation and slumping. This thesis investigates the micropaleontological composition of 6 box cores (4 from the north central bay and 2 from the Hudson Strait). The micropaleontological analyses of these box cores provide abundance, biodiversity, and productivity of recent microfossils, establishing a baseline and a correlative tool for future micropaleontological investigations within the region. The paleontological data are combined with the geochronology and geochemical data measured on the same box cores (Kuzyk et al., 2009).

3.1 SEDIMENT SAMPLING AND STORAGE

Fifteen 20 x 30 cm box cores penetrating to a maximum of 50 cm below the sea floor were collected throughout the Hudson Bay and Strait in September and October of 2005. Six of these cores (Fig. 2.1) were chosen for micropaleontological analysis at Dalhousie University. The box core location (latitude & longitude), lengths and water depths are shown in Table 3.1.

Table 3.1 - Water depth, core length, and location of each box core

	Box Core	**Latitude**	**Longitude**	**Water Depth**	**Core Length**
Inner Hudson Bay	**10**	59°03’36.00”N	87°32’60.00”E	200 m	40 cm
	12	59°58’48.00”N	91°57’36.00”E	116 m	25 cm
	13	60°26’24.00”N	89°21’36.00”E	145 m	45 cm
	14	61°23’60.00”N	86°12’00.00”E	244 m	45 cm
Hudson Strait	**3**	62°45’36.00”N	79°00’00.00”E	395 m	40 cm
	15	63°02’60.00”N	74”18’36.00”E	430 m	45 cm

The box cores were sampled at 1 cm intervals between 0 - 10 cm core depth, 2 cm intervals between 10 - 20 cm core depth, and 5 cm intervals for the remainder of each core. Samples were placed in 500 ml glass jars and stored on the ship at -20°C until demobilization. The frozen samples were sent to the Freshwater Institute at the University of Manitoba and sub-sampled for geochemical and micropaleontological analyses.

3.2 MICROPALEONTOLOGICAL METHODS

In 2008, 110 frozen sediment sub-samples of known volume (5 - 12 cm^3) were sent to Dalhousie University's Core Laboratory for micropaleontological analysis. One of the benefits of having samples that were frozen immediately after sectioning was that the foraminifera that were alive during collection would have their protoplasms intact. Rose Bengal was added to the samples as they thawed, and aided in the differentiation between the living and the dead tests. This is essential to this study because then we know which species were living there as opposed to species that might have been transported after dying (e.g. by ice rafting or currents) or reworked from older sediments as was the case for many foraminifera found in the Hudson Bay lowlands (Scott & Martini, 1982).

All samples were volumetrically determined and washed through 45 µm and 63 µm sieves to remove the smaller particles (mud, clay, and organic matter) and to sort the varying sizes of foraminiferal tests; some were also washed through a larger 250 µm sieve for ease of observation. The sieved samples were stored in a liquid suspension of alcohol and water in sealable 120 ml plastic containers until enumeration. Many studies ignore the smaller sized (45 - 63 µm) foraminifera, however recent studies (Scott et al., 2008a, 2008b; Schell et al., 2008) have shown that this size fraction can make up 50% or more of the total abundance of foraminifera. In this study, both the > 45 µm and > 63 µm samples were counted separately for ease of identification due to varying size ranges between taxa and were later combined (App. 1A-F); this inherently aided in giving counting totals that were over 600 individuals per interval, reducing the overall margin of error.

Samples with a large abundance of foraminifera (n > 700) were split using Scott and Hermelin's (1993) 8-partition wet-splitter technique to avoid counting an excessive number of specimens. The samples were poured into a vertical column of turbulent water and settled into the eight compartments at the bottom of the chamber. Patterson and Fishbein (1989) suggest aiming for counting totals of 300 individual foraminifera to obtain relatively low margins of error; this is in agreement with Phleger (1960), who also thought this value was sufficient for quantitative examination. Prior to counting the foraminifera, total abundance was estimated. If the estimated abundance of foraminifera in a sieved sample was n ≈ 1200, for example, the sample was split into eight fractions (n = 150) using the wet splitter method, and two fractions were combined (n = 300) to obtain the desired abundance.

The samples were kept in liquid suspension and observed in a petri dish under a 20X-60X reflected light binocular microscope. Foraminifera (amoeboid protists) and tintinnids (ciliate protists) tests were identified and counted to obtain the number of specimens per 10 cm^3 of bulk sediment. The number of different species in a sample had no weight on the counts required to accurately measure the abundance of a particular species (Patterson & Fishbein 1989); however, detailed information on species diversity is important to better understand the ecological and oceanographic controls in a particular location within the bay. Once micropaleontological analyses were complete, the samples were stored in glass scintillation vials with a buffered formalin solution to prevent bacterial growth and dissolution of the calcareous tests.

Microfossils in each sample were identified to the species level where possible, using papers published from the Hudson Bay region (Leslie, 1963, 1965), historical SEM images and sketches (e.g. Loeblich & Tappan, 1953; Barker 1960), and the type slides from the collection in Dalhousie University's Core Laboratory.

3.3 SCANNING ELECTRON MICROSCOPE (SEM)

Select foraminifera were gold-coated and photographed using the SEM at the Sexton Campus Facility, Dalhousie University. The SEM is a cost effective, quick and efficient way of observing morphological features on foraminiferal tests. The SEM provides high-resolution (100 - 500 µm) images that will provide a visual archive of microfauna in the sediment of the Hudson Bay and Strait (Plates 1 & 2).

3.4 GEOCHRONOLOGY & GEOCHEMICAL ANALYSIS

3.4.1 RADIOCARBON ANALYSIS

One 4 mg sample, containing about 1000 *Cassidulina reniforme* and *Islandiella teretis* individuals was picked from an interval (16 - 18 cm depth) of one of the inner bay cores (BC-13), where calcareous foraminifera are most abundant. The sample was sonicated in a 3% hydrogen peroxide solution, rinsed with distilled water to clean the tests, and placed in a clean plastic vial. The sample was sent to the National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) in Massachusetts for ^{14}C analysis. The radiocarbon years are calibrated to give calendar years. Marine reservoir ΔR values calculated from mollusks in the Canadian Arctic vary according to region (Coulthard et al., 2010). Region 7 of Coulthard et al. (2010) encompasses the Hudson Bay area and has

ΔR value of 110 ± 65 years. This reservoir correction was used to correct the raw radiocarbon age (6700 ± 40 ^{14}C yrs BP) using the online calibration program CALIB (REV. 6.0.1; Stuiver et al., 2005) to obtain the calibrated age (7093 ± 179 cal yrs BP). The radiocarbon date obtained for this study is used along with ^{210}Pb and ^{137}Cs (Kuzyk et al., 2009) to determine the box core's chronology, which is shown in detail in Appendix 2.

3.4.2 ^{137}Cs AND ^{210}Pb ANALYSES

^{137}Cs is a fallout fission product from nuclear explosions that first appears in worldwide sediment records by 1954, with peaks in concentrations by 1963 (Peirson, 1971). ^{210}Pb is a naturally occurring radioisotope produced in the ^{238}U decay chain and has a half-life of 22.3 years, making it suitable for the investigation of sediments up to 120 years old (Ghaleb, 2009). There are two components that make up the ^{210}Pb inventory in sediments: supported and unsupported (or excess) ^{210}Pb. The supported component is produced within the sediments by radioactive decay of ^{222}Rn, and the unsupported component, which is derived from the ^{222}Rn that diffuses from the earth's surface, decays to ^{210}Pb and is deposited by rainfall or dry fallout.

Kuzyk and colleagues (2009) sub-sampled the box cores for geochronological analyses. Analyses of both ^{137}Cs and ^{210}Pb were completed at the Environmental Radiochemistry Laboratory in the Soil Science Department at the University of Manitoba. ^{137}Cs was analyzed by spectroscopic gamma ray analysis with concentration estimates in dpm/cm^3. ^{210}Pb was analyzed in an Ortec Dual Alpha Spectrometer, and the total activity was determined via the ^{210}Po daughter isotope at cm intervals in the core. Supported ^{210}Pb is estimated from ^{226}Ra measurements from 3 to 5 sections from each core as well as the ^{210}Pb in the deeper levels in each core. Excess or unsupported ^{210}Pb is determined by subtracting supported ^{210}Pb activity from total activity. The sedimentary layer, in which the unsupported ^{210}Pb activity becomes indistinguishable from the supported ^{210}Pb activity, is approximately 110 to 120 years. The excess ^{210}Pb is fit to a steady state, advective-diffusive model, which can estimate sedimentation rates within the ^{210}Pb domain (i.e. from the bottom of mixed layer to the depth where excess ^{210}Pb is undetectable). The ^{210}Pb data, ^{137}Cs data, and a more detailed description of the methods are published in Kuzyk et al. (2009).

3.4.3 GEOCHEMISTRY

Geochemical analysis included determination of sedimentary organic carbon (OC) and total nitrogen (TN) concentrations at the University of British Columbia. Total nitrogen and organic carbon were analyzed using a Carlo Erba NA-1500 Elemental Analyzer, and the carbon isotope composition (δ13C) of organic matter was measured by an in-line isotope ratio mass spectrometer. More detailed methodology and results of these analyses can be found in Kuzyk et al. (2009).

CHAPTER 4 RESULTS

Foraminifera and tintinnid assemblages help to determine the spatial and temporal changes that have occurred within the Hudson Bay and Strait region in recent times (last 110 yrs) and older Holocene (~ 7100 yrs BP) time intervals. In this chapter, assemblages of dominant and key species found at each station throughout the Hudson Bay and Strait are presented together with the geochemical data for each core. The species relative abundance data are given in Appendices 1A-F. Also included in the appendices are: 1) tintinnid total abundance, 2) total number of foraminifera, 3) total percent abundance of species in the 45 - 63 μm range, and 4) total percent abundance of calcareous foraminifera. An important aspect of understanding temporal variability in the analysis of foraminiferal assemblages is to place the records on a time-scale.

4.1 BOX CORE CHRONOLOGIES

The last 50 years of sediment deposition are delineated by looking at the material above the first appearance (1954) and spike (1964) of ^{137}Cs (Peirson, 1971), as long as these data support the ^{210}Pb data, which are used to date the last 110 years of sediment deposition. In this thesis, an age model for each core is constructed for the last 110 years (App. 3) based on the ^{137}Cs first appearance and peak, the base of the unsupported ^{210}Pb domain, and the sedimentation rates obtained from model results for the same cores (Kuzyk et al., 2009). This approach is helpful in deciding whether the ^{137}Cs data corroborate the ^{210}Pb data, and when they do not, the sedimentation rates are extrapolated upward from the bottom of the unsupported ^{210}Pb domain to determine the depth of the year 1954 (~ 50 yrs BP) in the core section. For the remainder of the sediment (> 110 yrs), sedimentation rates are uncertain.

The ^{14}C date acquired from BC-13 helps in constraining the age of some of the older sediment sections. The box core geochronology is shown in Figure 4.1 (A) and (B). The surface mixed layer is the layer where unsupported ^{210}Pb is mixing due to bioturbation and shows no decay with depth. Textural changes noted both by Kuzyk et al. (2009) and Younger (Pers. comm., 2008) are also shown. The stations are subdivided into two groups, the inner bay box cores (BC-10, BC-12, BC-13, & BC-14) and the strait box cores (BC-3 & BC-15).

Several of the cores have relatively low fluxes of the nuclides ^{210}Pb and ^{137}Cs. Hermanson (1990) found that fluxes of these nuclides were lower in the Arctic than in the mid-latitudes because the seasonal sea-ice cover prevents input of the unsupported ^{210}Pb, and for supported ^{210}Pb, permafrost prevents the exhalation of the gas ^{222}Rn. Nevertheless, Hermanson (1990) noted that these nuclides can still be useful for geochronological purposes in the Arctic.

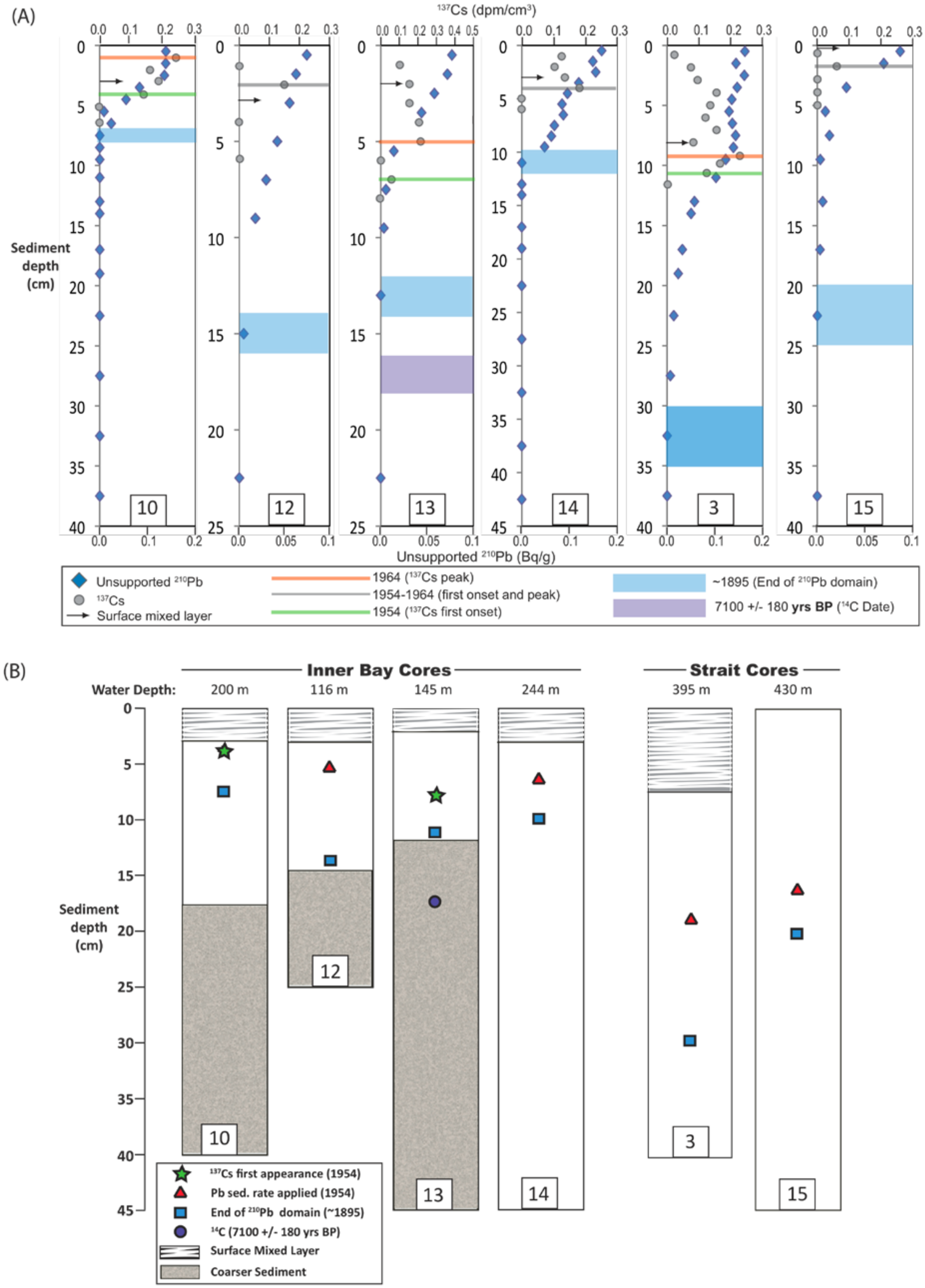
(A)
137Cs (dpm/cm3)
Sediment depth (cm)
10
12
13
14
3
15
Unsupported 210Pb (Bq/g)
Unsupported 210Pb
137Cs
Surface mixed layer
1964 (137Cs peak)
1954-1964 (first onset and peak)
1954 (137Cs first onset)
~1895 (End of 210Pb domain)
7100 +/- 180 yrs BP (14C Date)
(B)
Inner Bay Cores
Strait Cores
Water Depth:
200 m
116 m
145 m
244 m
395 m
430 m
Sediment depth (cm)
137Cs first appearance (1954)
Pb sed. rate applied (1954)
End of 210Pb domain (~1895)
14C (7100 +/- 180 yrs BP)
Surface Mixed Layer
Coarser Sediment

Figure 4.1

Figure 4.1 – (A) Box cores with geochronological results for ^{137}Cs , ^{210}Pb, and ^{14}C analyses. ^{137}Cs first onset (1954) and peak (1964), the base of the unsupported ^{210}Pb domain (1895), and ^{14}C date (7100 ± 180 calendar years [cal yrs] BP) are shown. The shaded areas around the ^{210}Pb and ^{14}C data show the sampling interval. Note that the depths (y-axis) at each core are variable. Arrows mark the bottom of the surface mixed layers. (B) A simplified geochronology for each core section. Surface mixed layers are shown with a line near the surface of the cores, and the deeper textural changes found in 3 of the cores (BC-10, BC-12, & BC-13) are shaded. The inferred 1954 date in BC-12, BC-14, BC-3, and BC-15 was determined by extrapolating the sedimentation rate (Kuzyk et al., 2009) upward from the base of the ^{210}Pb domain, as shown in Appendix 3.

4.2 INNER BAY CORES: RESULTS

The inner bay cores are located centrally in the northwestern region of the bay (Fig. 2.1). BC-12, BC-13, and BC-14 form a transect which becomes progressively deeper with increasing distance from the Nelson and Churchill Rivers, and BC-10 lies to the south of this transect. The following sub-sections will describe the lithology, chronology, microfossil assemblages, and geochemical results for each core section.

4.2.1 BC-10

Core Description **–** Located 415 km from the western coast, BC-10 was taken at a water depth of 200 m, measures 40 cm in length, and consists of a dark olive grey to brown sand. A darker and coarser sediment texture was noted in the deeper part of the core, from 17.5 – 40 cm (Kuzyk et al., 2009; C. Younger, pers. comm., 2009), and this is marked by changes in the microfaunal assemblage (Fig. 4.2).

Chronology: ^{137}Cs and ^{210}Pb − The first onset (1954) of ^{137}Cs occurs at 4 cm, and peaks (1964) at 1.5 cm (Figs. 4.1; 4.2). In this core, ^{226}Ra values (necessary to distinguish between supported and unsupported ^{210}Pb) are variable; this causes some uncertainty in the age model and could represent mixing (Dr. Kuzyk, Pers. comm., 2010). A sedimentation rate of 0.06 cm/yr (0.04 - 0.08 cm/yr) was obtained from the model result (Kuzyk et al., 2009). The ^{137}Cs first onset is complimentary to the ^{210}Pb data (App. 4, Table A4-1) and is used to represent 1954. The bottom of the unsupported ^{210}Pb domain (7 cm) was determined from raw data provided by Dr. Kuzyk.

Assemblage Description – A total of 51 species of foraminifera, 23 calcareous and 28 agglutinated species, are present throughout the core (App. 1A). Foraminifera ranged in size from 45 to 300 microns, however, more than 50% of the individuals are in the 45 to 63 μm size range (Fig. 4.2). The total number of foraminifera (per 10 cm^3) decreases up the core from over 8000 individuals at the base to less than 1500 at the surface.

At the base of the core, the relative abundance of calcareous foraminifera is nearly 100%. This value decreases above the textural change (17.5 cm) to a complete barren zone between 4 - 2 cm (~ 50 yrs ago), but shows recent increases to 25% at the surface (2 - 0 cm). Interestingly, some of the calcareous species, seem to last throughout the core while others disappear completely. *Cassidulina reniforme*, *Islandiella teretis*, and *Fursenkoina fusiformis* and a small percentage of planktics (~ 3%) only appear near the base (> 20 cm), however, *Buliminella hensoni* persists in the upper parts of the core (Fig. 4.2).

In recent sediments (6 - 0 cm), the dominant microfauna are the agglutinated (arenaceous) foraminifera (> 75%), including: *Textularia* spp. (*T. earlandi, T. torquata*), *Reophax arctica*, and *Saccammina difflugiformis* (see App. 1A). Another agglutinated planktic microfauna, *Tintinnopsis rioplatensis*, appears above the textural transition zone (17.5 cm) and proliferates in the last 110 years.

Geochemical data: Organic Carbon, Nitrogen and **δ^{13}C** – The percentage of organic carbon and total nitrogen increase from the base (0.56%; 0.036%, respectively) to the surface (1.1%; 0.15%). Notable increases in both occur above the textural transition zone (17.5 cm). The δ^{13}C value increases from the base (-22.8‰) to the surface (-20.4‰) of the core (not shown).

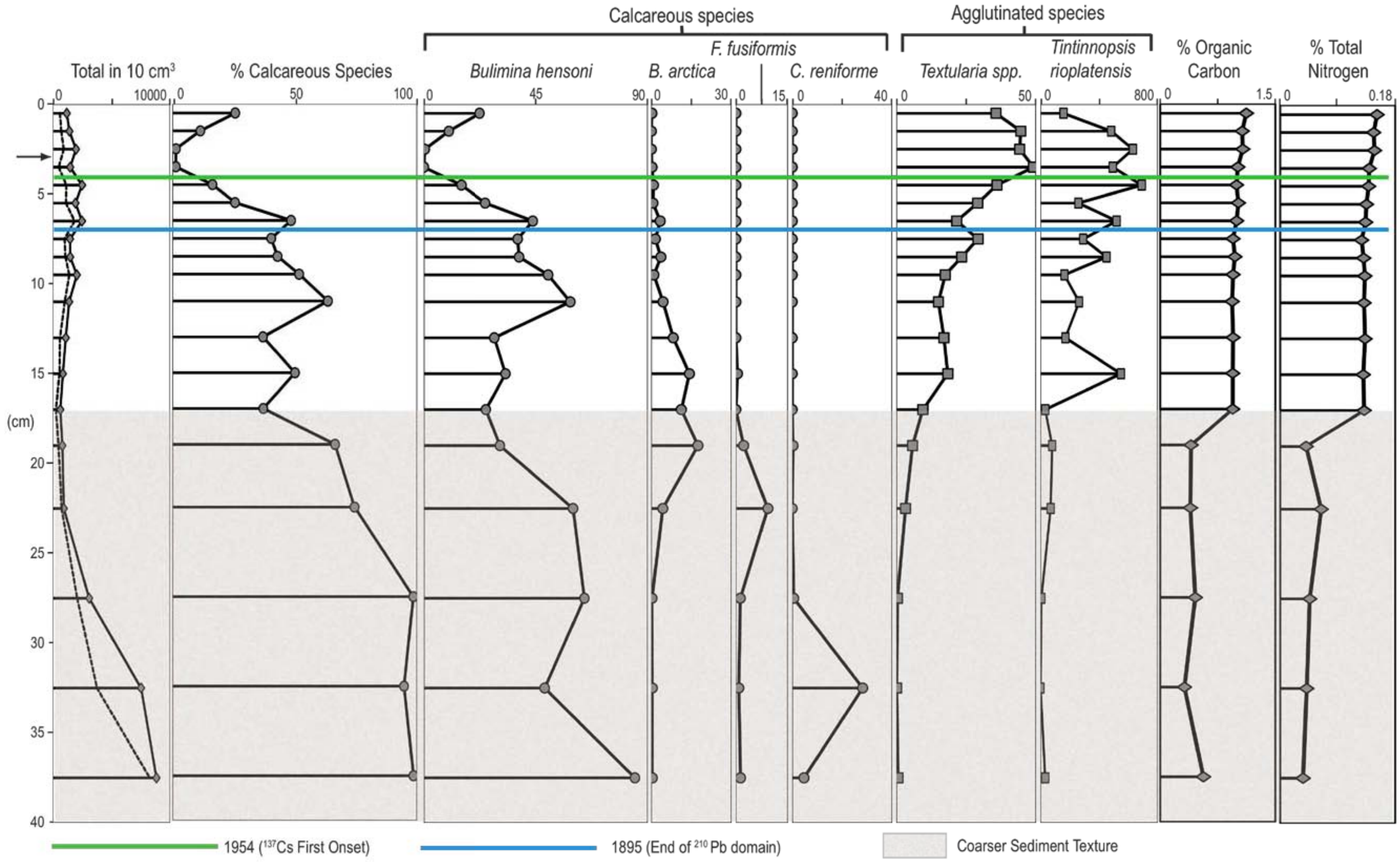

Figure 4.2 – BC-10 relative abundance of foraminifera and total number of individual foraminifera and tintinnids are shown down the core section with the dates (1954, 1895) acquired from ^{137}Cs and ^{210}Pb geochronology. The dashed line represents the foraminifera in the 45 to 63 micron size fraction, and the surface mixed layer is shown with an arrow. Geochemical data, % OC and % TN, are also shown (Kuzyk et al., 2009).

4.2.2 BC-12

Core Description – BC-12 was taken 160 km from the western coast of the bay at a water depth of 116 m and measures 25 cm long. Sediment texture is a medium-grained sand with coarser sand below 15 cm (Kuzyk et al., 2009).

Chronology: ^{137}Cs and ^{210}Pb – ^{137}Cs is only present within the surface mixed layer and does not corroborate the ^{210}Pb results (App. 3; Table A3-2). Therefore, the sedimentation rates are extrapolated upward from the base of the ^{210}Pb domain (14 cm) to obtain the 1954 date (5 cm). Sedimentation rates from the model result (0.15 cm/yr) are considerably higher than at BC-10 (0.06 cm/yr).

Assemblage Description – A total of 59 species, 29 calcareous and 30 agglutinated, are present in BC-12. Similar to BC-10, a high percentage of foraminifera were identified in the 45 - 63 micron size range (> 40%). There are over 3500 individual foraminifera (per 10 cm^3) at the base (Fig. 4.3), and this decreases (average ~ 1500) in the middle of the core (15 - 3 cm), and increases again at the surface (~ 3200). Coincidentally, the total number of foraminifera follows trend with the relative abundance of calcareous foraminifera, which is highest at the base of the core. *Cassidulina reniforme*, *B. hensoni* and *I. teretis* have a combined relative abundance of 70% at the base of the core, but decrease and disappear before the transition zone (15 cm). Similar to the other inner bay cores, the relative abundance of calcareous foraminifera decrease up the core section from the textural transition zone (15 - 2 cm), with a small spike in calcareous species (*F. fusiformis* - 3%, *C. reniforme* - 3%, *E. clavatum* - 4%, *Lagena* sp. - 5%) at the surface (2 - 0 cm). In this core section, when calcareous species are not present, inner linings have been found reaching up to 25% of the relative abundance (Fig. 4.3).

The agglutinated species, *T. torquata*, *R. arctica*, and S. *biformis,* are constant throughout the core with lower relative abundances near the base and surface of the core. The tintinnids, as in BC-10, appear after the transition zone (15 cm), about 110 years ago (Fig. 4.3), and proliferate in the last 50 years (5 - 0 cm).

Geochemical data **–** Similar to BC-10, an increase in both the percentage of organic carbon and total nitrogen is noted from the base (0.639% OC; 0.054% TN) to the top (1.31% OC; 0.153% TN) of the core section (Fig. 4.3), with a notable increase at the transition zone. The δ13C values (not shown, see Kuzyk et al., 2009) also increase from the base (-23.9‰) to the surface (-21.7‰) of the cores.

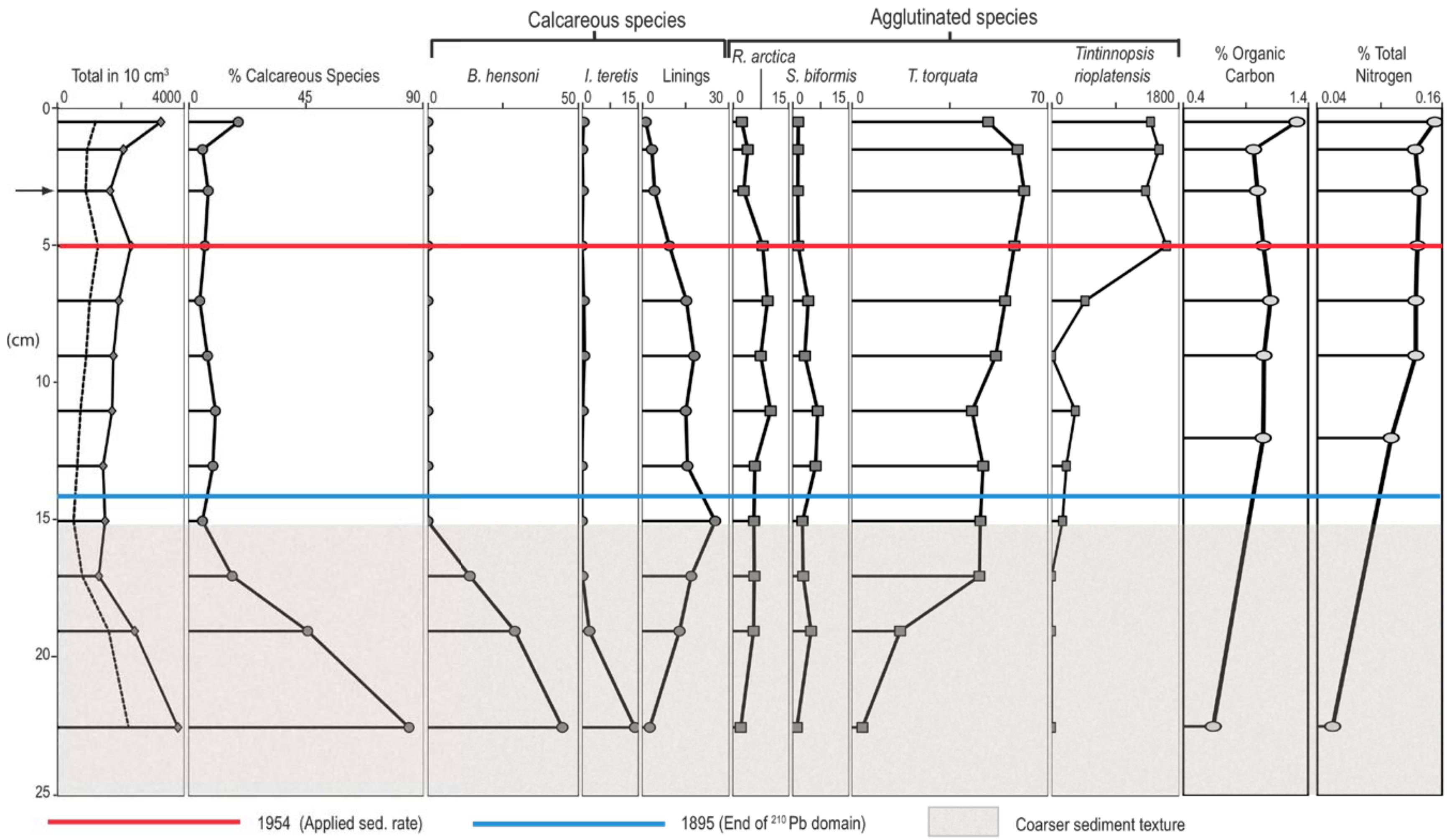

Figure 4.3 – BC-12 relative abundance of foraminifera and total number of individual foraminifera and tintinnids are shown down the core section with the dates (1954, 1895) acquired from ^{137}Cs and ^{210}Pb geochronology. The dashed line represents foraminifera within the 45-63 micron size range, and the arrow represents the surface mixed layer. Geochemical data, %OC, %TN, are also shown (Kuzyk et al., 2009).

4.2.3 BC-13

Core Description – BC-13 was taken 300 km from the western coast at a water depth of 145 m and measures 45 cm long. The sediment is a medium-grained sand that transitions to a coarser-grained sediment near the base of the core (Kuzyk et al., 2009).

Chronology: ^{137}Cs, ^{210}Pb and ^{14}C − Analysis of the age model (App. 3, Table A3-3) shows that the ^{137}Cs first onset (7.5 cm) corroborates the ^{210}Pb data, and thus is used to represent 1954. Radiocarbon analysis (^{14}C) of calcareous foraminifera from the 16 to 18 cm interval provide a date of 7100 ± 180 cal yrs BP.

Assemblage Description – BC-13 has a total of 52 foraminifera species, 30 calcareous and 22 agglutinated (App. 1C). The total number of foraminifera (per 10 cm^3) at the base of the core (45 - 17 cm) is over 20000 individuals; this total decreases to ~ 5000 individuals (Fig. 4.4) near the surface. Calcareous species make up nearly 100% of the microfauna near the base of the core (45 - 17 cm). Their abundance decreases steadily to about 15% (16 - 5 cm), and then increases to about 40% in the last 50 years (5 - 0 cm).

Geochemical data – Geochemical analyses were only completed in the top 25 cm of the 45 cm section. An increase in the percent of organic carbon and total nitrogen occurs near the sediment textural transition (0.64% OC; 0.055% TN) to the top (1.3% OC; 0.15% TN) of the core; δ13C values also increase from 25 cm (-23.2‰) to the top (-21.5‰) of the core (not shown, see Kuzyk et al., 2009).

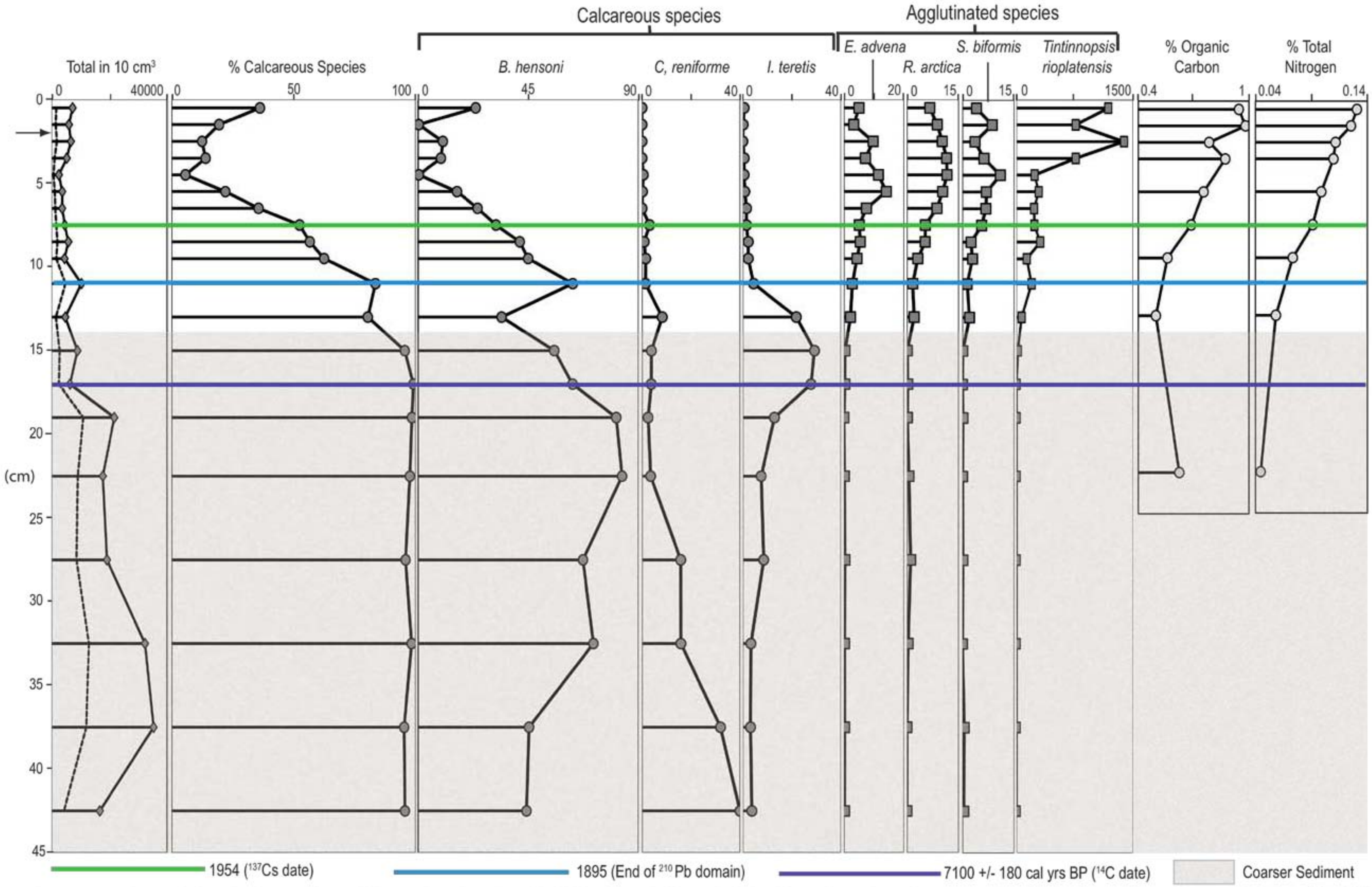

Figure 4.4 – BC-13 relative abundance of foraminifera and total number of individual foraminifera and tintinnids are shown down the core section with the dates (1954, 1895) acquired from ^{137}Cs, ^{210}Pb, and ^{14}C geochronology. The dashed line represents foraminifera within the 45-63 micron size range, and the arrow represents the surface mixed layer. Geochemical data, %OC, %TN, are also shown (Kuzyk et al., 2009).

4.2.4 BC-14

Core Description – BC-14 was taken 415 km from the western coast at a water depth of 244 m and measured 45 cm long. The sediment throughout this core has a very fine-grained sand texture compared to the other inner bay cores (C. Younger, pers. comm., 2008). BC-14 is from a deeper area than the other cores and contrasts with the other inner bay cores, particularly due to: 1) the lack of a transition zone, 2) the presence of tintinnids throughout the entire core section rather than just the last 110 years, and 3) the presence of planktic foraminifera at relatively low abundances throughout the core.

Chronology: ^{137}Cs and ^{210}Pb – The first onset of ^{137}Cs occurs at 4 cm, and does not corroborate the ^{210}Pb data, so the sedimentation rate from the age model (App. 3) is used to determine 1954 (6 cm). The unsupported ^{210}Pb were indistinguishable at 10 cm, however, similar to BC-10, the ^{226}Ra measurements for supported ^{210}Pb were variable throughout the core, and this creates further uncertainty in the date.

Assemblage Description – The total number of foraminifera in BC-14 averages around 1000 individuals, which is significantly less than the other cores. Although BC-14 lacks a transition zone common to the other inner bay cores, a similar trend in the abundance of calcareous foraminifera is present. The relative abundance of calcareous foraminifera is highest (> 75%) in the base and mid sections of the core (45 - 16 cm), is barren at ~ 5 cm, and increases (> 50%) in the surface sediments (5 – 0 cm; last 50 yrs).

The dominant calcareous species are *B. hensoni* and *C. reniforme*; however *C. reniforme* is only present in the bottom half of the core at relatively low abundances. The tintinnids, which maintain an average of about 200 individuals throughout the core section, show no significant change. This contrasts with the tintinnid records from the other inner bay cores which all show an appearance of the species in the last 110 years and their proliferation in the last 50 years (Fig. 4.5).

Geochemical Data - The percentage of organic carbon and total nitrogen show a slight increase from the base to the surface of the core. The $\delta^{13}C$ ratio also slightly increases from the base (-21.6‰) to the top (-20.8‰) of the core (not shown; Kuzyk et al., 2009).

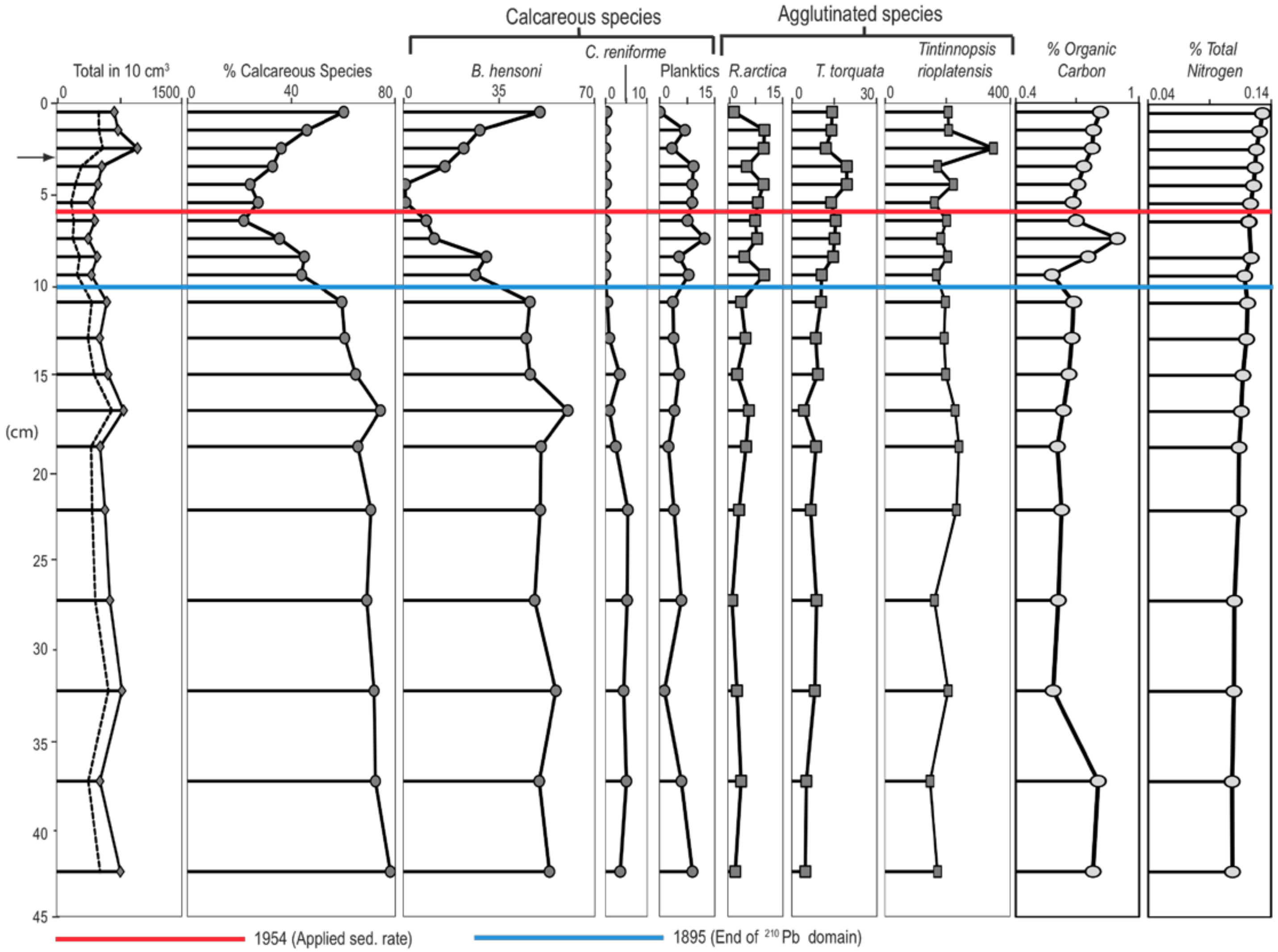

Figure 4.5 – BC-14 relative abundance of foraminifera and total number of individual foraminifera and tintinnids are shown down the core section with the dates (1954, 1895) acquired from ^{137}Cs and ^{210}Pb geochronology. The dashed line represents foraminifera within the 45-63 micron size range, and the arrow represents the surface mixed layer. Geochemical data, %OC, %TN, are also shown (Kuzyk et al., 2009).

4.2.5 SUMMARY OF RESULTS: INNER BAY CORES

The inner bay cores (BC-10, BC-12, BC-13, & BC-14) are located at varying depths (200 m, 116 m, 145 m, & 244 m; respectively) in the northwest central region of Hudson Bay. An interesting trend common to three of the inner bay cores (BC-10, BC-12, & BC-13) is the textural transition zone. The transition zone denotes a switch from coarser (lower part of core) to finer sediment (upper part of core). In the coarser sediment, calcareous species dominate the core section making up over 80% of the microfauna; however above the transition zone, the relative abundance of calcareous foraminifera decreases and agglutinated foraminifera increasingly appear in the finer sediment. A notable increase in the percentage of organic carbon and total nitrogen is also present above the textural change in each core. The freshwater ciliate, *Tintinnopsis rioplatensis*, only appears in the recent sediment (last 110 years) above the transition zone (Figs. 4.2 - 4.5).

Sedimentation rates in the inner bay region, as determined by Kuzyk et al. (2009), are similar in BC-13, BC-14, and BC-10; however, sedimentation rates in BC-12 are almost 3 times greater. This may be associated with its closer proximity to riverine sources (Churchill & Nelson River) on the western coast of the bay.

Radiocarbon analysis of one BC-13 sample indicates an age of 7100 ± 180 cal yrs BP for the 16 to 18 cm interval; interestingly, this early Holocene date lies just below recent sediment (13 cm, ~ 150 yrs) and within the coarser sediment. The presence of similar transition zones, geochemistry, microfaunal assemblages (foraminifera & tintinnids), and sedimentation rates in 3 of the inner bay cores (BC-10, BC-12, & BC-13) are all strong indications that these sediments are of comparable age, although additional radiocarbon dates would be required to show this definitively. More radiocarbon dates could not be acquired because of an insufficient number of calcareous tests in the other core sections.

4.3 STRAIT BOX CORES: RESULTS

4.3.1 BC-3 (HUDSON BAY ENTRANCE)

Core Description **–** BC-3 was taken at a water depth of 395 m and measures 40 cm long. The sediment consists of medium grained sand and some beige organic material (C. Younger, pers. comm., 2009). This core is located north of Mansel Island near the boundary between the entrance to Hudson Bay and Strait.

Chronology: $\boldsymbol{^{137}}$***Cs and*** $\boldsymbol{^{210}}$***Pb*** **–** The first onset of ^{137}Cs occurs at 11 cm and is not complimentary to the ^{210}Pb data (App. 3). The sedimentation rate of 0.18 cm/yr from the model result (Kuzyk et al., 2009) was extrapolated upward from the base of the ^{210}Pb domain (30 cm) to obtain the 1954 date (19 cm).

Assemblage Description **–** There was a total of 60 species in BC-3, and 37 of these species were calcareous (see App. 1E). The total number of individual foraminifera averaged around 6000 individuals throughout the core (Fig. 4.6). *Cassidulina reniforme*, *B. hensoni*, and *F. fusiformis* are the dominant calcareous species of the assemblage. *Elpidium clavatum* and *I. teretis* are also present throughout. The relative abundance of calcareous species follows the trend of the inner bay cores, but shows a much gentler decrease from 90% at the base to 45% at the top of the core (Fig. 4.6). Tintinnids increase in abundance near the surface of the core, similar to some of the inner bay cores.

***Geochemical Data* –** The percentage of organic carbon and total nitrogen fluctuate throughout the core, and increase slightly from the base (1.1% OC; 0.15% TN) to the top (1.1% OC; 0.17% TN). There is no significant change in the ratio of $\delta^{13}C$; however, the down-core trend fluctuates from the base (-21.4‰) to the top (-21.5‰) of the core (not shown, see Kuzyk, 2009).

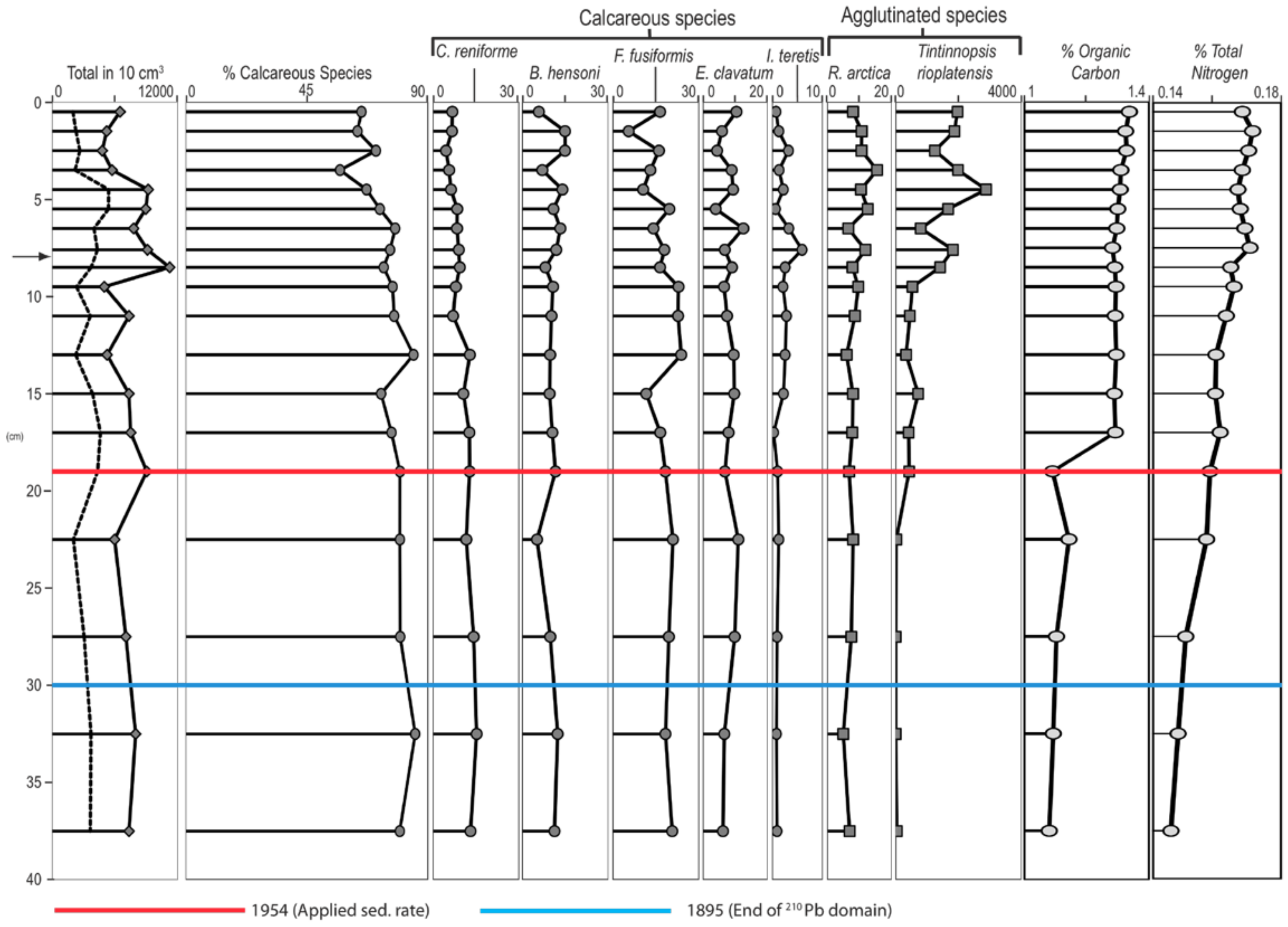

Figure 4.6 – BC-3 relative abundance of foraminifera and total number of individual foraminifera and tintinnids are shown down the core section with the dates (1954, 1895) acquired from ^{137}Cs and ^{210}Pb geochronology. The dashed line represents the 45-63 micron size fraction, and the arrow represents the surface mixed layer. Geochemical data, %OC and %TN, are also shown (Kuzyk et al., 2009).

4.3.2 BC-15

Core Description – BC-15 was taken at a water depth of 430 m and measures 45 cm long. The sediment texture is fine-grained sand with some black sediment, which becomes entrained in the agglutinated tests at 12 to 16 cm. BC-15 is located south of Baffin Island in the Hudson Strait, and 300 km east of BC-3 (Fig. 2.1).

Chronology: ^{137}Cs and ^{210}Pb – The first onset of ^{137}Cs occurs at 2 cm, and does not corroborate the ^{210}Pb data. The sedimentation rate (0.07 cm/yr) is extrapolated up from the base of the ^{210}Pb domain (30 cm) to obtain the 1954 date (16 cm). Low total ^{210}Pb values throughout the core may reflect mixing (Dr. Kuzyk, pers. comm., 2010).

Assemblage Description – BC-15 shows no significant changes throughout the core assemblage in terms of relative abundances (Fig. 4.7). Most of the small peaks (which potentially represent a change) are within the limits of error. Calcareous foraminifera are dominant, with *C. reniforme*, *B. hensoni*, *F. fusiformis*, and *E. clavatum* being the most important species.

Geochemical Data – The percent of organic carbon (~ 0.86%) and total nitrogen (~ 0.10%) in BC-15 show very little change. The δ^{13}C ratio fluctuated slightly from the base (-21.4‰) to the top (-21.0‰) of the core section (not shown, Kuzyk et al., 2009).

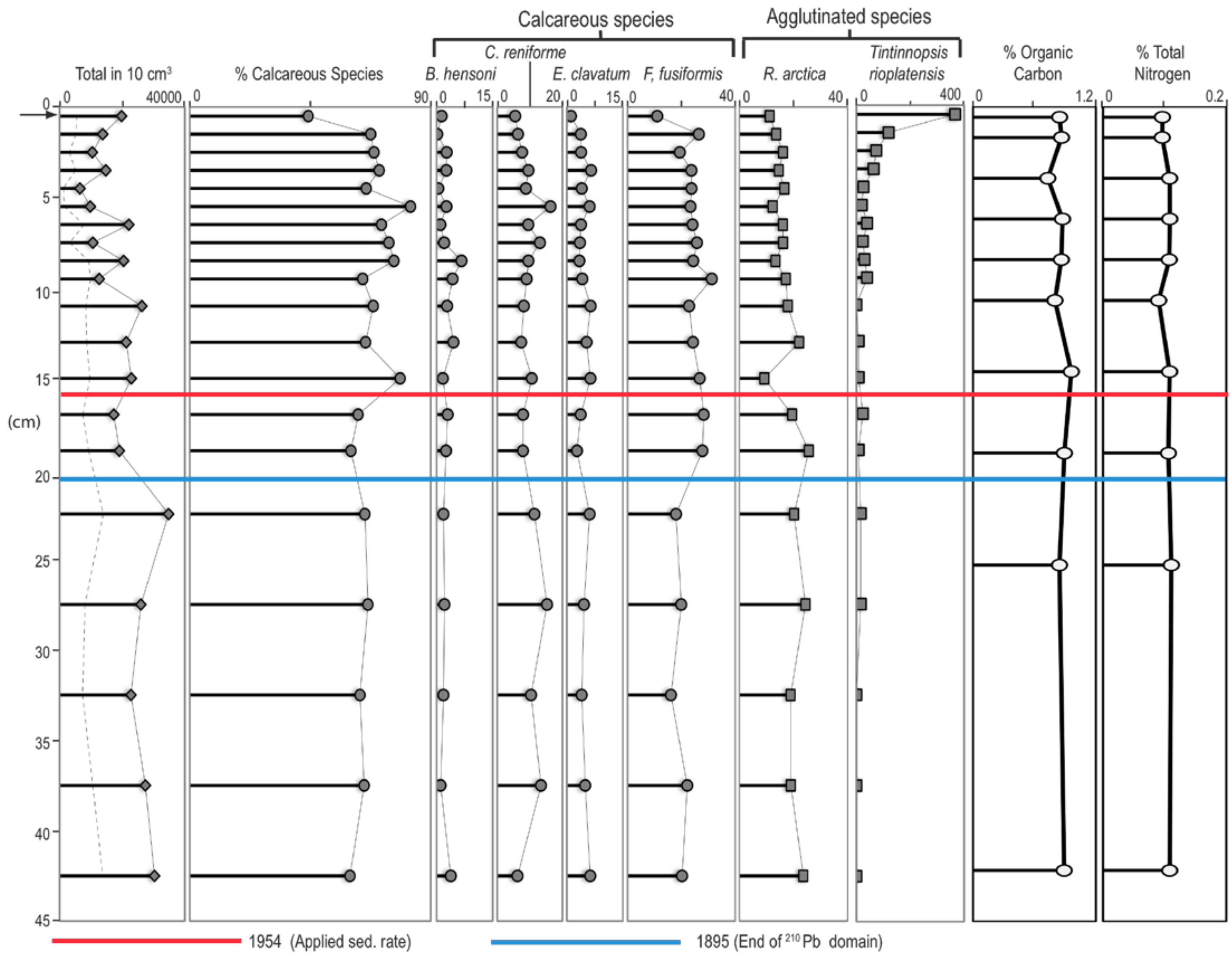

Figure 4.7 – BC-15 relative abundance of foraminifera and total number of individual foraminifera and tintinnids are shown down the core section with the dates (1954, 1895) acquired from ^{137}Cs and ^{210}Pb geochronology. The dashed line represents foraminifera within the 45-63 micron size range, and the arrow represents the surface mixed layer. Geochemical data, %OC, %TN, are also shown (Kuzyk et al., 2009).

4.3.3 SUMMARY OF RESULTS: STRAIT BOX CORES

Tintinnids appear in both of the strait box cores in the last 110 years, and proliferate near the surface of the box cores (~ last 50 years). BC-3 has ten-fold more tintinnids than BC-15, but BC-15 has about 4 times more foraminifera than BC-3. The relative abundance of calcareous foraminifera is high (> 70%) throughout the sediment in both box cores with decreases in the last 50 years, which contrast the results from the inner bay. It appears that BC-15 is either very mixed or has shown no change through time as all of the peaks in abundance are within the limits of error.

The sedimentation rate at BC-3 (0.18 cm/yr) is over double that at BC-15 (0.07 cm/yr). In both cores, the ^{137}Cs data were insufficient and did not corroborate the ^{210}Pb results, so the sedimentation rates were used in both box cores to determine the 1954 date, as shown in the age model in Appendix 3.

4.4 OTHER FORAMINIFERAL RESULTS

Apart from foraminiferal assemblages, numerous other micropaleontological data were collected in this thesis that are useful in evaluating changes within the core sections. These include: live versus total ratios, total number of individuals, and total number of species. These data are discussed below.

4.4.1 LIVE VERSUS TOTAL RATIOS

Box cores that are maintained in a frozen state are useful in determining which species were alive at the time of collection and which species were potentially transported to a particular area after death. Rose Bengal added to the viable (5 of 6) box cores aided in the differentiation between the living and dead species up to 5 cm down core for several of the box cores. Table 4.1 is a list of foraminifera species found alive at all locations within the Hudson Bay and Strait. They have been divided into two groups, agglutinated- and calcareous tests. The third test type, which is organic-walled, was represented by only one live species, *Allogromia* sp. Because of the ease of compaction of the organic test below the sediment surface, this species was often more easily identified at the surface sediment layer.

Table 4.1 - Foraminifera living throughout the Hudson Bay and Strait (2005). Species have been divided into agglutinated and calcareous tests**.**

Agglutinated Tests	Calcareous Tests
Adercotryma glomerata	*Bolivina* spp.
Ammotium cassis	*Buccella frigida*
Eggerella advena	*Cassidulina reniforme*
Hemisphaerina bradyi	*Elphidium clavatum*
Quinqueloculina agglutinans	*Elphidium excavatum*
Reophax arctica	*Eoponides pulchella*
Reophax guttifer	*Fursenkoina fusiformis*
Reophax scottii	*Islandiella teretis*
Saccammina difflugiformis	*Lagena* spp.
Spiroplectammina biformis	*Nonionella labradorica*
Trochammina nana	

The number of live specimens is over 50% of the total foraminifera at the surface of all of the cores. Figure 4.8 shows the percentage of live foraminifera at the surface down to 5 centimeters for cores BC-12, BC-13, BC-3, and BC-15. Samples of cores BC-10 and BC-14 thawed and weren't useful for this type of analyses.

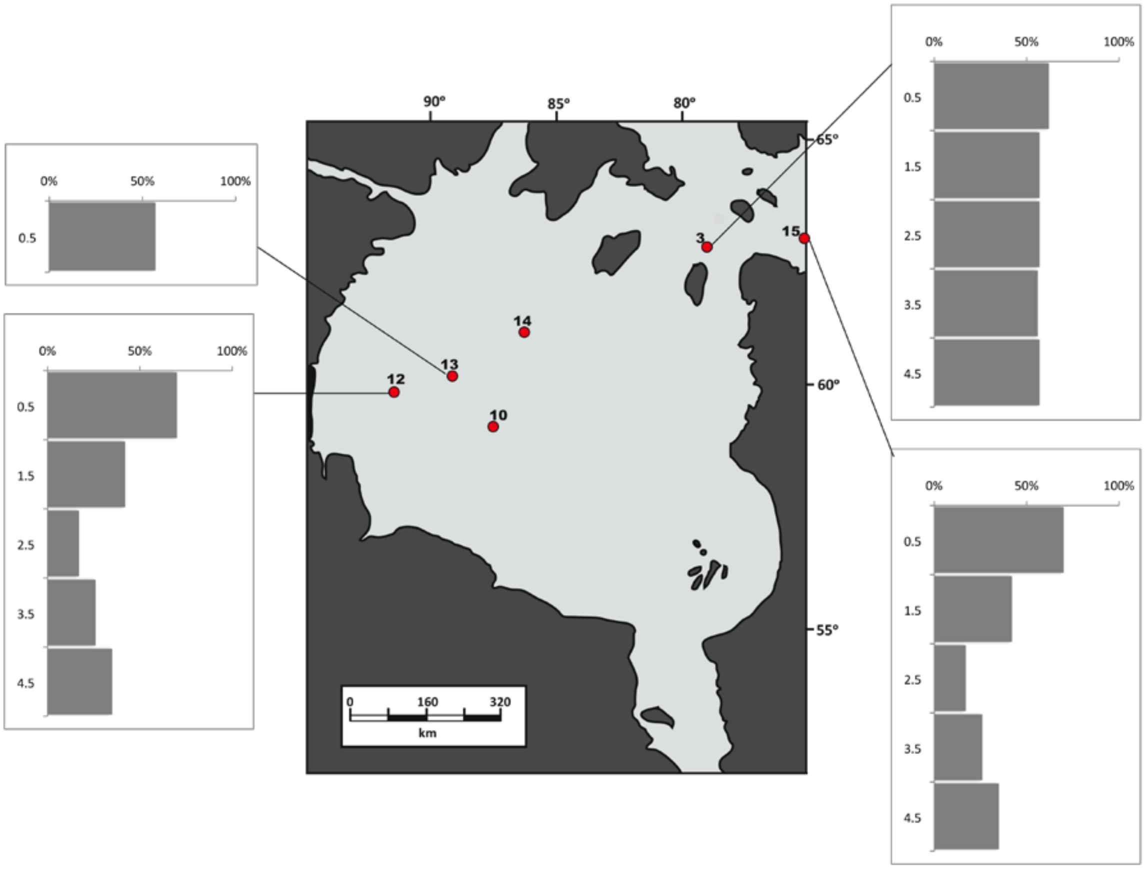

Figure 4.8 - Percentage of live foraminifera and tintinnids down to 5 centimeters for several of the cores.

All of the analyzed box cores show decreases in the percentage of live microfauna from the surface to 5 cm, except for BC-3. BC-3 shows little change and this is likely because it is within the surface mixed layer (8 - 0 cm).

4.4.2 TOTAL NUMBER OF INDIVIDUALS

The total number of individual foraminifera in each core depends on productivity, sedimentation rate, and in the case of calcareous foraminifera, the degree of carbonate preservation. The total number of individuals at each sampled interval in the core sections can be found in appendices 1A-F.

BC-13 had the highest number of foraminifera with over 5000 individuals at the surface, and over 35000 individuals at the base of the core. BC-14 had the least number of microfauna of all the box cores, with values around 500 to 1000 individuals. The highest numbers of foraminifera were observed at the base of the cores (oldest sediment).

4.4.3 TOTAL NUMBER OF SPECIES

A total of 55 genera and 95 species were identified from the Hudson Bay box cores in this study. This is comparable to Leslie's (1965) results based on 75 surface samples collected throughout the bay, where he identified 51 genera and 93 species. Of the 95 species identified in this study, 29 species previously undocumented were observed in this study; this could be a result of the larger size fractions used in previous studies. The foraminiferal assemblages from the strait box cores show higher diversity (20 - 38 species) than in the inner bay cores (16 - 31 species).

4.5 RESULTS SUMMARY

Agglutinated, calcareous and organic-walled foraminiferal tests were identified in the 6 Hudson Bay and Strait box cores. Results on the total number of foraminifera, the relative abundance of calcareous and agglutinated foraminifera, the total number of species and the live/total ratios are summarized below.

4.5.1 CALCAREOUS FORAMINIFERA

The relative abundance of calcareous foraminifera is highest at the base of all of the inner bay cores (64 - 98%). In the Hudson Strait, the relative abundance is fairly constant (> 65%) throughout the cores, with a slight increase in the younger sediment in BC-3. Four calcareous species, *B. hensoni*, *F. fusiformis*, *C. reniforme*, and *I. teretis* are present in varying abundances throughout most of the cores (5 - 0 cm). These species were found live in all cores analyzed for live/dead ratios (Table 4.1).

Buliminella hensoni is present in all cores, however the relative abundance of this species in the strait cores is much lower than in the inner bay cores, where it is the dominant calcareous species. *Fursenkoina fusiformis*, on the other hand, is more abundant in the strait box cores with an average relative abundance of 15% for BC-3 and 23% for BC-15. *Cassidulina reniforme* is generally only present at high relative abundances at the base of the inner bay cores, and throughout the strait cores decreasing from the base to the surface. *Islandiella teretis* is present in relatively low abundances (~ 3%) throughout the strait, but are much more variable in the inner bay cores. In BC-10 and BC-12, *I. teretis* is only present at the base of the cores (~ 15 - 25%), in BC-13, the species is only present in the middle of the core (~ 30%), and in BC-14 there are very low overall relative abundance of this species (~ 1%).

4.5.2 AGGLUTINATED FORAMINIFERA

A wide variety of species make up the agglutinated assemblage, however, only the dominant agglutinated species, *Textularia torquata*, *Reophax* spp., and *Trochammina* spp., will be discussed herein. These species are present at all stations and were alive at all depths analyzed for dead/live ratios (BC-3, BC-12, BC-13, & BC-15).

Textularia torquata is present throughout the strait at generally low relative abundances (< 6%), however in the younger sediment of the inner bay cores, the relative abundance is much higher. In BC-10 and BC-13, the relative abundance of this species varies around

25% in the upper parts of the core. Higher values were observed in BC-12 (~ 50%), and lower values in BC-14 (~ 15%). *Reophax* spp. (*arctica, guttifer, scorpiurus & scottii)* are present throughout all of the core sections, and most abundant within the Hudson Strait region. *Trochammina* spp. (*T. globigeriniformis, T. lobata, T. nana & T. squamata*) are present throughout all of the cores at relatively low abundances (< 5.5%), except for BC-14, which has slightly higher abundances (< 16%).

4.5.3 INNER BAY VERSUS STRAIT BOX CORES

There are several key differences between the Hudson Strait cores and the inner bay cores: 1) regional setting, 2) water masses, and 3) sampling depths. The inner bay cores are located within the northwestern part of the bay, and more likely to be affected by man-made changes to regional fluvial systems compared to the Hudson Strait cores, which may be more affected by the water masses entering from the Atlantic Ocean. It is also worth noting that the strait box cores were taken at greater water depths than the inner bay cores.

The following is a brief summary of several key differences between the sediment and microfaunal assemblages of the Hudson Bay and Strait. One of the key differences is the lithology. Three of the 4 inner bay cores (BC-10, BC-12, & BC-13) have coarser sediment at the base of the sediment section, which correlates well with % TN , % OC, and to the microfaunal assemblage, particularly the relative abundance of calcareous foraminifera (Figs. 4.2 - 4.4). The Hudson Strait cores are different in that the microfaunal assemblage is more diverse and the relative abundance of calcareous foraminifera shows little change throughout the entire core.

Two calcareous species*, B. arctica* and *N. barleeanum,* are common in the inner bay cores but are not observed (< 0.3%) in the strait cores. The relative abundances of the calcareous species, *Elphidium* spp. (*E. excavatum* & E. *excavatum* forma *clavatum*) and *B. frigida* are highest in the strait cores, with lower overall relative abundances in the inner bay cores. This is interesting because these species are typical of a deeper Arctic Ocean assemblage (Lagoe, 1979), and uncommon in North Atlantic assemblages (Hermelin & Scott, 1985).

Although BC-3 and BC-15 have been grouped together as the strait cores, they do show some differences in terms of geochemistry and microfaunal assemblage; these will be discussed further in Chapter 5.

CHAPTER 5 DISCUSSION

The following chapter will discuss the temporal and spatial variability in the microfaunal assemblages in context with the geochronology (50, 110 & 7100 yrs BP) and regional setting (Hudson Bay to Hudson Strait). Furthermore, the assemblages will be compared to previous micropaleontological research within the region (i.e. Leslie, 1963; 1965).

5.1 TAXONOMIC SHIFTS

Foraminiferal assemblage variability is controlled by a number of factors including dissolved oxygen, salinity, temperature, sea-ice cover, suspended particulate matter (SPM) and other geochemical factors, while freshwater plume extent and SPM variability are the main controlling factors of the tintinnid abundances (Scott & Martini, 1982; Scott et al., 2001) within the Hudson Bay and Strait.

Tintinnopsis rioplatensis, a freshwater ciliate, appears in the last 110 years to the Hudson Bay region and has proliferated in recent times (last 50 yrs). Figure 5.1 shows the distribution and abundance of this tintinnid throughout the region. Data from all of the cores (except BC-10 & BC-14) show that the appearance of *T. rioplatensis* occurred after 1895 (prior to 1954), and an increase in abundance is evident in more recent times (~ 1954 - 2005). BC-10 has an earlier onset of the species, possibly associated with the box core’s proximity to rivers discharging along the western coast.

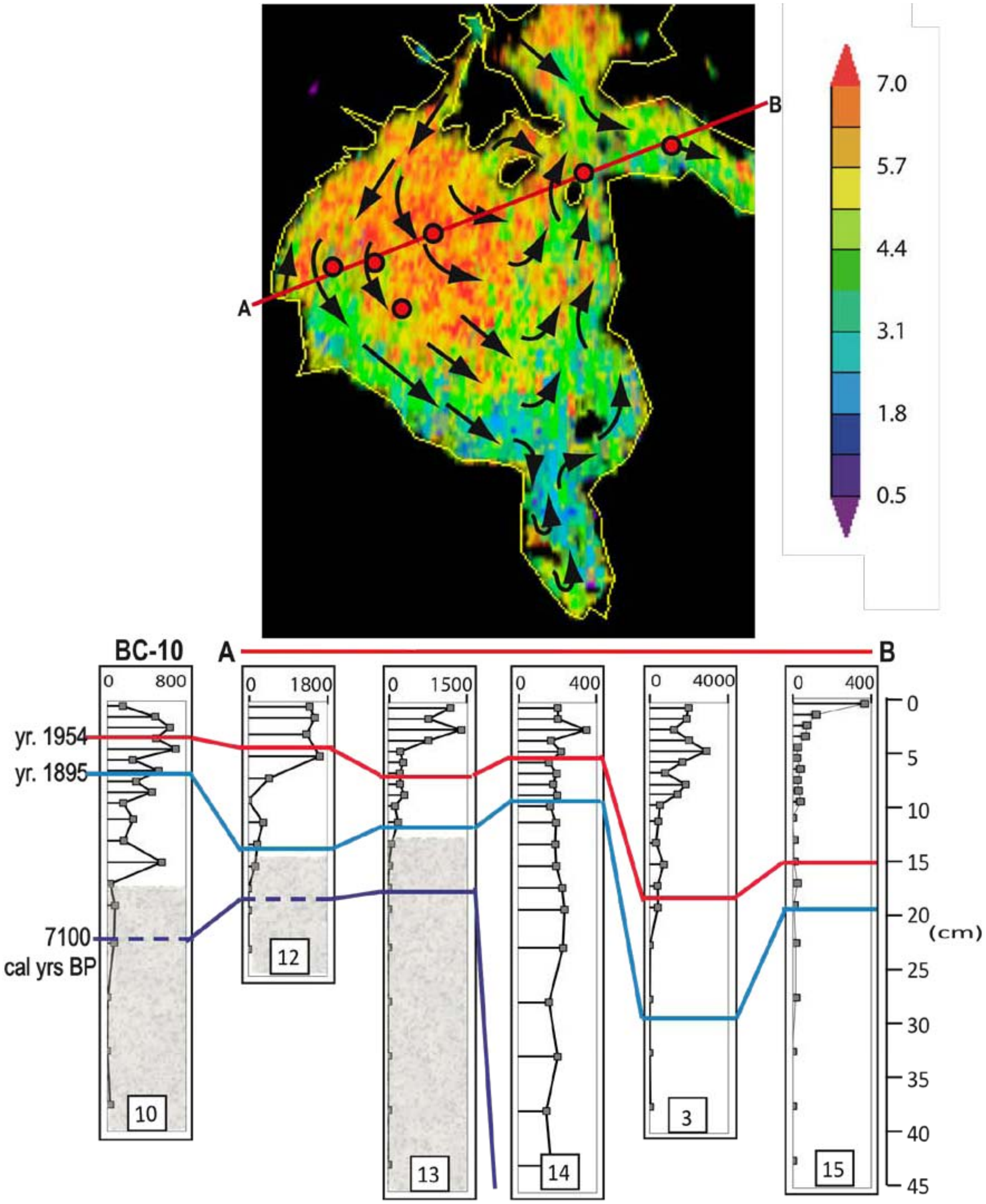

Figure 5.1 – Coloured dissolved organic matter (CDOM) displayed on a Google Earth map of Hudson Bay for August of 2005 (NASA Giovanni, 2010) with arrows showing surface circulation. In this case, CDOM is shown as an index (Morel & Gentilli, 2009), rather than as geochemical values. Warm colours represent higher values on the colour index and are associated with low terrestrial CDOM. The transect (A-B) crosses 5 of the 6 box cores of this study. Tintinnid totals are shown with the ^{210}Pb date (1895) and the 1954 date. The ^{14}C date from BC-13 is shown, and is correlated to BC-10 and BC-12, which have similar textural changes (shown above) and microfaunal assemblages.

BC-14 has tintinnids at relatively low abundance throughout the core section, indicating that sufficient freshwater and SPM have been present for some time (> 110 yrs) to sustain this small community of tintinnids.

Given the ecological preference of tintinnids observed previously (Souto, 1973; Scott et al., 2001), this finding strongly suggests that the freshwater plume has increased in extent, and SPM has become more available over the last 110 years compared to before. Hydroelectric developments reverse the seasonal cycle of the freshwater plumes by reducing the spring freshet and increasing discharge in the winter months, and thus potentially providing a more sustainable yearlong environment for tintinnids. However the reduced plume in the summer months would inevitably affect the tintinnids negatively. In a recent study (Dery et al., 2005), it was noted that the spring peak freshwater discharge associated with snow and ice melt advanced by 8 days, providing 8 more days for tintinnids to sustain a community at the surface. In this study, the tintinnids in the recent sediments throughout the Hudson Bay region indicate a greater volume of SPM and freshwater plume extent, which can be associated with both hydroelectric developments and climate warming in the region over the last 110 years.

This conclusion is supported by both $\delta^{13}C$ and the percent of organic carbon. The stable isotopic composition of carbon ($\delta^{13}C$) can be used to distinguish marine versus terrestrial sources of carbon. All of the $\delta^{13}C$ data show a slight increase in recent sediments, an indication of increasing inputs of terrestrial carbon to the region (Kuzyk et al., 2009). This trend is most pronounced in three of the inner bay cores (BC-10, BC-12, & BC-13).

Percentages of organic carbon and total nitrogen follow trend with one another in all of the cores and increase from the base to the surface, a likely result of an increase of riverine and sea-ice inputs. These findings are best explained in light of the overall climate warming trends, which results in the freshening of the Hudson Bay region from increased ice-free days and Arctic melt-water runoff. With more ice-free days, the volume and extent of the freshwater plume will increase (from riverine & sea-ice sources), and this will ultimately affect the salinity of the entire bay. Taxonomic shifts within the microfaunal assemblage are likely to result from a lowered regional salinity, and higher microfaunal production rates are likely to result from more ice-free days. This is evident in the inner bay cores where tintinnids and some arenaceous foraminifera appeared and proliferated in the last 110 years.

The Little Ice Age (1600 - 1850) had the coldest sustained temperatures of the last 8000 years, and recent decades (1950 - 2000) have been the warmest decades of the last 2000 years (Kaufman et al., 2009). The warming in the Arctic is enhanced relative to the global average (Kaufman et al., 2009), particularly in the sub-Arctic regions (ACIA, 2005), and inevitably with a warming, there will be more ice-free days and higher volumes of melt-water influencing this system. A decrease in ice cover is linked to high primary productivity and species shifts (Douglas & Smol, 1999), and this will likely continue to change the microfaunal community in the Hudson Bay environment. In the high Arctic, the increase in open water promotes more productivity in the surface water and when the organic matter enters the sediment it decays, causing dissolution of the calcareous forms (e,g. Wollenberg et al., 2001).

Calcareous foraminifera are effective bio-indicators of environmental change. The inner bay cores show a distinct transition from a dominantly calcareous assemblage (> 80%) in older sediments (> 6900 cal yrs BP) to a dominantly arenaceous assemblage in recent sediments (~ 1895 - 1954). This change is not evident in the Hudson Strait region, however BC-3 does show an overall decrease in calcareous foraminifera. Jennings et al. (2001) characterized foraminiferal assemblages in the Hudson Strait, and they show that increased faunal abundance and a lower percentage of calcareous foraminifera characterize cold intervals in the 17th and 19th centuries. These trends were interpreted to reflect greater mixing and cooling of bottom water during these times.

In this study, dominantly calcareous assemblages in the older sediments of the Hudson Bay region are interpreted to reflect a strong Atlantic Ocean influence, shown by the presence of a higher diversity, more Atlantic-type species and, higher numbers of foraminifera. The dominantly arenaceous assemblages that appear in the younger sediment are thought to be related to a stronger Arctic water influence. The slight increase in calcareous microfauna in recent sediments (2005 - 1954) of the inner bay cores is likely associated with recent regional climate change more so than influence from different water masses, as both Arctic- and Atlantic-type species are present. Figure 5.2 shows the relative abundance of calcareous foraminifera along a transect in the Hudson Bay and Strait region.

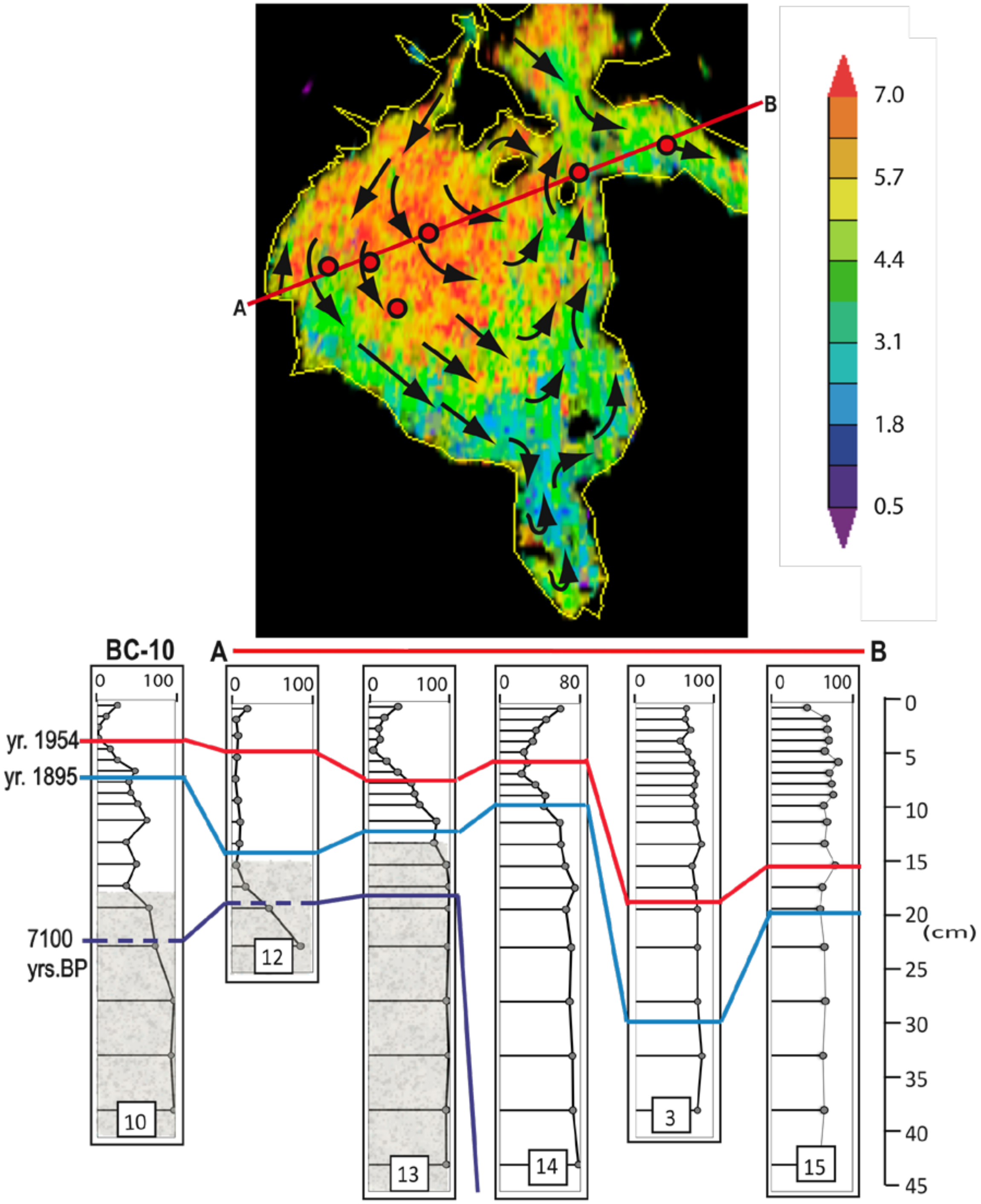

Figure 5.2 CDOM are displayed on a Google Earth map of Hudson Bay for August of 2005 (NASA Giovanni, 2010). Warm colours represent higher values on the colour index and are associated with low terrestrial CDOM, and thus less of a riverine influence. The transect (A-B) crosses 5 of the 6 box cores of this study. Relative abundances (%) of calcareous foraminifera are shown with the ^{210}Pb date (1895) and the 1954 date. The ^{14}C date from BC-13 is shown, and is correlated to BC-10 and BC-12, which have similar textural changes (shown above) and microfaunal assemblages.

The type of calcareous species present in the cores also shows a distinction between the bay and strait. The inner bay cores are dominated by the species *B. hensoni* (> 40%), a deep Arctic species, and in the Hudson Strait cores, this species makes up less than 15% of the relative abundance (Figs. 4.2 - 4.7). The Hudson Bay appears to be more affected by Arctic waters, having more Arctic-type species; whereas the Hudson Strait, is more diverse and productive, and has less Arctic-type species.

5.2 REGIONAL PRODUCTIVITY AND SEDIMENTATION RATES

The total number of foraminifera (per 10 cm^3) across the transect vary from 400 to over 35000 individuals (Fig. 5.3), and these totals are linked to recent and paleo-productivity. Productivity is highest in the older sediments of the inner bay cores (4000 - 35000 individuals) and throughout the Hudson Strait sediments (> 5000 individuals). In three of the inner bay cores (BC-10, BC-12, & BC-13), the total number of foraminifera are highest at the base of the cores below the textural change. At the textural change a gap in time is noted from ~7000 to ~200 years ago (including the Little Ice Age & Neoglacial Cold period), however this is not noted in the other inner bay core (BC-14). This missing sediment is assumed to be a result of non-deposition, but is more than likely a result of redistribution of the sediments. Unresolved intervals of sediments are also missing in several studies in the Hudson Strait (Andrews et al., 1995; St. Onge & Lajeunesse, 2008) and have been attributed to ice scour or redistribution of the sediments. This missing sediment is not observed in the Hudson Strait cores from this study, and this is possibly because the sedimentation rates in the Strait are higher and the transition was located in a deeper section than the box core was able to recover. Higher sedimentation rates in the Hudson Strait region, particularly near BC-3, are attributed to more sediment and fine organic particles from Foxe Basin ice (Anderson & Roff, 1980).

In contrast to the other inner bay cores, BC-14 appears to be all recent sediment. Henderson (1990) found that when sediments accumulate in very deep pockets (as in BC-14), they aren't as affected by redistribution by currents. BC-14, the deepest of the inner bay cores, had the lowest abundance of foraminifera and the lowest species diversity, but had similar sedimentation rates (in last 110 yrs) to the other inner bay cores. This is an indication that BC-14 is located in a much less productive area than the other inner bay cores; depth zonation (preferential habitat depths) may also be a factor.

In the Amundsen Gulf, Scott et al. (2008a) found fairly low total number of individual foraminifera (500 - 1000 individuals), and a high representation of Arctic species (*B. arctica* & *B. hensoni*) in the 45-63 µm size range. These species were found in the same size interval in the Hudson Bay and Strait; however, they are more common in the older sediment of the inner bay cores.

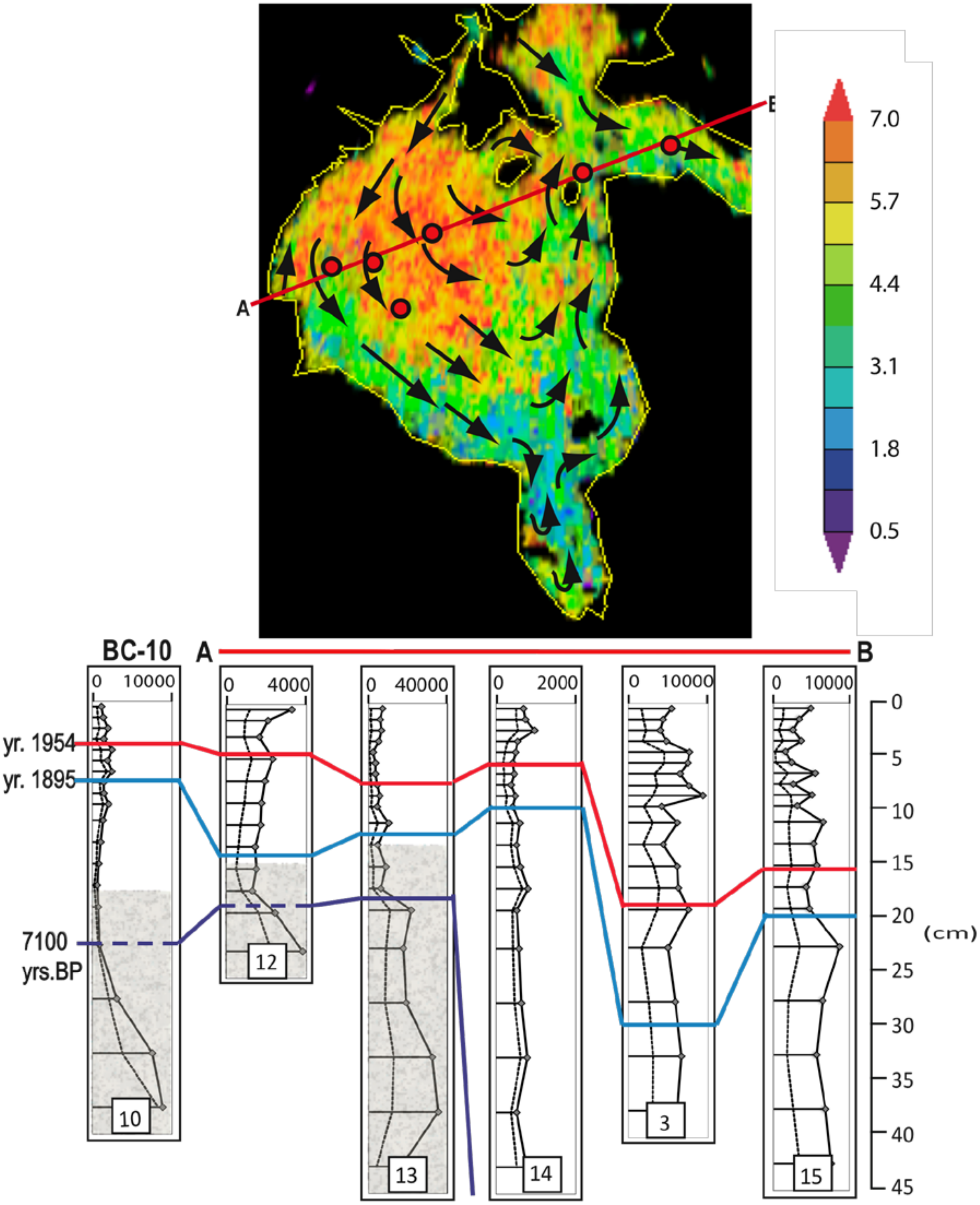

Figure 5.3 – CDOM are displayed on a Google Earth map of Hudson Bay for August of 2005 (obtained from NASA's Giovanni website). Warm colours represent higher values on the colour index and are associated with low terrestrial CDOM, and thus less of a freshwater riverine influence. The transect (A-B) crosses 5 of the 6 box cores of this study. The total number of foraminifera are shown with the ^{210}Pb date (1895) and the 1954 date. The ^{14}C date from BC-13 is shown, and is correlated to BC-10 and BC-12, which have similar textural changes (shown above) and microfaunal assemblages.

Low overall foraminiferal abundances in the younger core sections (last 110 years) in the Hudson Bay are present when the greatest influence from Arctic waters is suspected. Scott and Martini (1982) noted that foraminiferal productivity in the marshes within these regions is much lower than other regions of similar latitudes, and is a likely result of southward movement of sea-ice floes and cooler atmospheric temperatures extending south from the Arctic Ocean. These authors also noted that beneath the marsh sediments there was a rich fauna of Tyrrell Sea foraminifera and erosion of this sediment in other areas may be contributing to the calcareous fauna in the older parts of the cores examined here. This southward forcing of Arctic conditions likely reduces the productivity of the microfauna, and increases the number of arenaceous wall-types (*C. crassimargo, C. jeffreysi, E. advena, R. guttifer, T. earlandi, T. torquata, T. nana*) and Arctic-type (*I. teretis, B. frigida*) species.

Sedimentation rates for the ^{210}Pb domain in the Hudson Bay and Strait (~ 0.052 - 0.18 cm/yr, see Table 5.1) are given below. Similar sedimentation rates (~ 0.6 cm/yr) have been found in the recent sediment in the southeastern regions of the bay (Jenner & Piper, 2002).

Table 5.1 – Kuzyk and colleagues (2009) estimated sedimentation rates in the Hudson Bay by plotting excess ^{210}Pb data from each core into a steady-state advective-diffusive model, which accounts for both sedimentation and mixing. This table shows the sedimentation rates with minimum and maximum values for each box core location.

	Box Core	**Sedimentation Rate (cm/yr)**	**Min (cm/yr)**	**Max (cm/yr)**
Inner Bay Cores	10	0.06	0.04	0.08
	12	0.15	0.13	0.19
	13	0.073	0.06	0.09
	14	0.052	0.04	0.06
Strait Cores	3	0.18	0.14	0.28
	15	0.07	0.02	0.08

These findings suggest that higher productivity, lower sedimentation rates (as inferred by Leslie, 1965), and more influence from Atlantic waters in the older sections of the inner bay cores (BC-10, BC-12, & BC-13) produced the predominantly calcareous assemblage, with Atlantic-type (*B. pseudopunctata, N. barleeanum, Q. seminulum*) species and high total numbers of foraminifera. The lower sedimentation rates in the older sediment of these cores could explain why mid-Holocene sediments lie just below recent (~ 110 yrs) sediments. The Hudson Strait cores have higher productivity, diversity, and percentages of calcareous species throughout the entire core section. This infers a constant supply of Atlantic waters in the Hudson Strait in recent times, which can be easily explained by the close geographic proximity to the Atlantic Ocean.

Figure 5.4 shows the total number of foraminifera averaged over chronologically constrained time intervals throughout the bay and strait. Little change in the number of foraminifera in the Hudson Strait cores and in BC-14 could be an indication of constant sedimentation rates and/or production and little change in these environments. These maps (Fig. 5.4) clearly show the temporal changes to the inner bay sites, where the number of foraminifera is high in post-glacial sediments and lower in more recent sediments. It is possible that the high number of foraminifera in these regions is partly associated with lower sedimentation rates (more time for foraminiferal tests to accumulate), however, the total values observed in the base of BC-13 were very high and are more than likely associated with higher productivity from a greater influence of Atlantic waters.

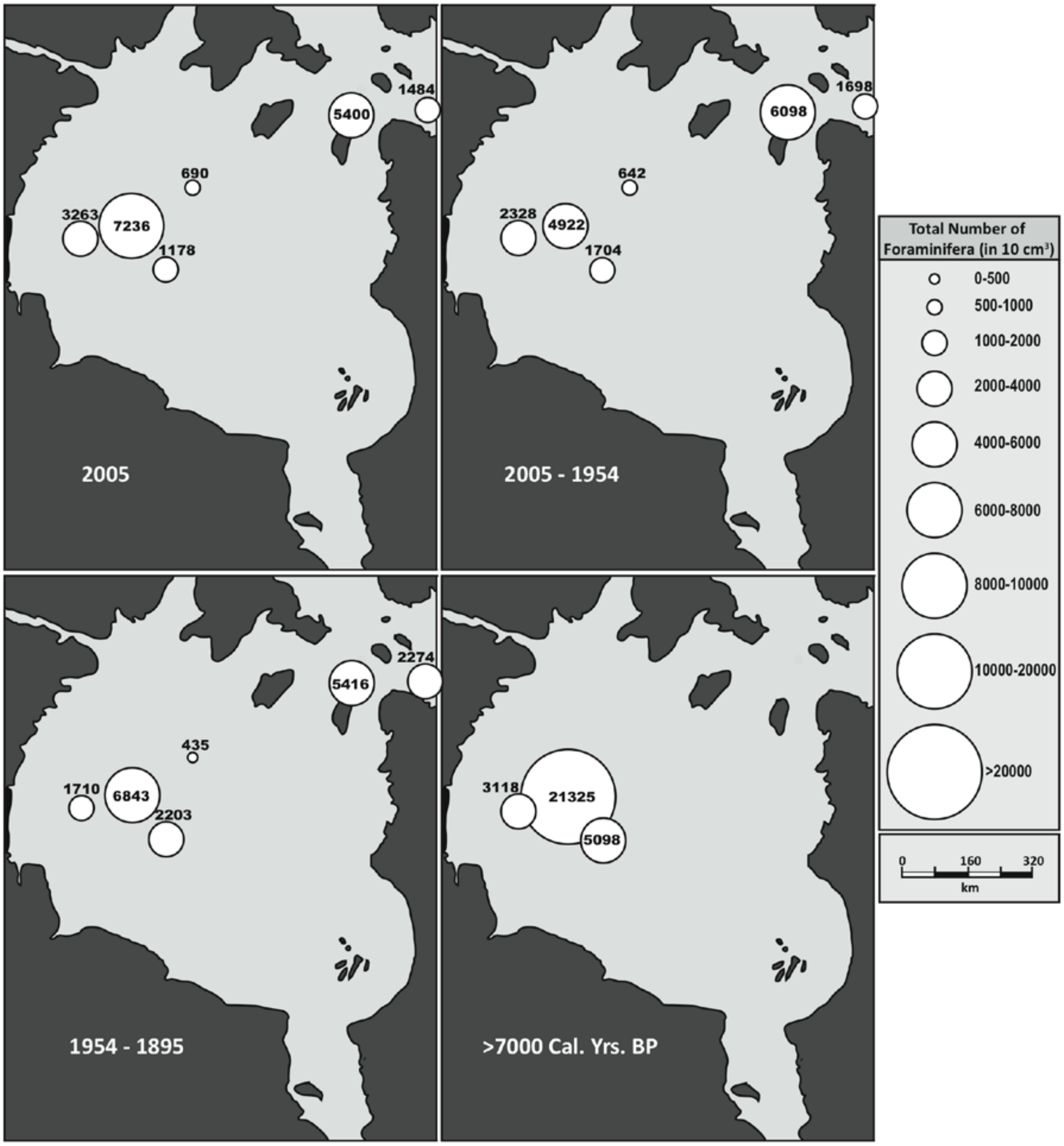

Figure 5.4 – The total number of foraminifera are shown averaged over chronologically constrained time intervals. The larger the circle is, the higher the abundance.

5.3 MARINE INVASION BY 7100 YRS BP

BC-13, located in the north central region of the bay, was dated with ^{14}C (6700 ± 40 ^{14}C yrs BP; 7100 ± 180 cal yrs BP at 18 - 20 cm core depth), and provides microfossil evidence that marine conditions were present. The 25 cm of marine deposition below this dated interval indicate that marine incursion had occurred earlier than 6700 ± 40 ^{14}C yrs BP (7100 ± 180 cal yrs BP). This is consistent with previous findings that show that marine strandlines appeared from southern James Bay region to northern Hudson Bay (Shilts, 1986) over a 2000-year period (~ 7900 - 5900 ^{14}C yrs BP),

Through investigating the microfaunal assemblage in two cores near the entrance to Hudson Bay from the strait (near BC-3), Bilodeau et al. (1990) found records of post-glacial events indicating harsh Arctic conditions within the north eastern region of the bay until after 6000 cal yrs BP, even though interglacial conditions had reached the southern Hudson Bay as it was invaded by the sea (8000 - 6500 cal yrs BP). Data from BC-13 suggest that interglacial marine conditions had reached the northwestern central region of the bay by 7100 ± 180 cal yrs BP, and although Arctic conditions persisted, the Atlantic Ocean had a significant influence on the makeup of the foraminiferal assemblage. After marine invasion, results from numerous analyses (geochemical & micropaleontological) presented here suggest a distinctive transformation from a completely calcareous to an arenaceous assemblage, possibly reflecting the different water masses and more organic matter flux influencing the region.

Foraminiferal assemblages from several coring sites along the eastern coast of Baffin Island (Williams et al., 1995) show a displacement of the calcareous zone by the arenaceous zone around 6000 to 5000 yrs BP, which is also observed at the same time on the Newfoundland/Labrador and the Nova Scotian coasts (Scott et al., 1984). This change in foraminiferal test wall types has been associated with the displacement of Atlantic water by the Baffin Land Current (Osterman & Nelson, 1989), which is highly corrosive (to $CaCO_3$). However the conditions in Hudson Bay are probably not influenced significantly by this offshore current but more with the local increase in the number of ice-free days.

With high emergence rates from isostatic rebound in the Hudson Bay region, it is possible that the influence of the Atlantic Ocean was reduced and more Arctic conditions ensued, explaining the transition from the more Atlantic-type (warmer, more productive) calcareous assemblage to the more Arctic-type (colder, harsher) arenaceous assemblage observed here. Sedimentation rates appear to have been extremely low during this transition with possible periods of non-deposition and/or erosion. Sedimentation rates in the younger sediments (last 110 years; Table 5.1) appear to be higher, as shown by the ^{210}Pb and ^{137}Cs geochronology from this study and previous estimates by Leslie (1965).

5.4 COMPARISON TO PREVIOUS REGIONAL STUDIES

Arenaceous foraminifera are important features of the recent sediments of all of the box cores in this study. *Textularia torquata* is an important species in the Hudson Bay region. It makes up a large percentage of the arenaceous microfauna of the recent sediments (last 110 years) in all of the box cores, except for BC-15, where it is present throughout the entire core section. Leslie (1963) and Phleger (1952) found that higher relative abundances of *T. torquata* are typically associated with deeper water (> 100 m). *Egerella advena* and *S. biformis* have been associated with shallower water, and are found in relatively low abundances throughout the Hudson Bay and Strait (Appendices 1A-F), with higher numbers appearing in the more recent sediment (last 110 years).

Leslie's (1965) cores had very low numbers of arenaceous foraminifera (< 5%) and high numbers of calcareous foraminifera (> 95%), except for one core along the eastern coast (50% arenaceous). The calcareous zones mentioned in Leslie's (1965) study are only present at the base (oldest sediment) of the cores in this study.

Buliminella hensoni, a common calcareous species in all of the cores in this study (Figs. 4.2 - 4.7), dominates the assemblage in the oldest sediment of the inner bay cores and is present at relatively low abundances throughout the strait cores and in the recent sediments of the inner bay. Leslie (1963; 1965) did not identify this species, however, this could be the species referred to as *Bulimina elegantissima* in his studies, which he found throughout the central bay and Hudson Strait entrance at relatively low abundances. This species is most abundant in the 45 to 63 μm size range, and Leslie might have observed greater numbers had he included the smaller size fractions (< 63 μm). *Cassidulina* spp. is only present in high numbers in the oldest (mid to late Holocene) sediment of the inner bay cores in this study, however the strait cores sustain a constant number of this species throughout the entire section. This genera is one of the most prolific species that Leslie (1965) found in the Hudson Bay region. This, together with the high number of calcareous foraminifera, indicate that Leslie's surface samples (1963; 1965) consisted mostly of older post-glacial sediment (1000's of yrs old), rather than more recent sediment (last 110 years), which could explain the 7100 cal yrs BP date in one of the cores

The percentage of organic carbon increases up each core section in this study with highest values (> 0.90%) at the surface (Figs. 4.1 - 4.7). Lower values (> 0.60%) are found in the oldest post-glacial sediment of the 3 inner bay cores (BC-10, BC-12 & BC-13). Leslie's (1965) surface samples throughout the Hudson Bay show a range from 0.14 to 0.74% organic carbon, with highest values in the western-central bay region (near BC-12 & BC-13) and northeastern strait region (near BC-3). It appears that Leslie's geochemical data correlates best to the older sediment of the cores in this study. Organic carbon values are operationally defined, and it is currently unknown if the methods in Leslie's (1965) study are complimentary to the methods used in this study, thus geochemical comparisons are not discussed further.

It would be generally presumed that Leslie's surface samples would correlate to the 1954 horizon (or slightly younger) in the cores in this study. However, based on many factors, including: 1) several of the foraminiferal species identified in Leslie's study were not found in this study, 2) some of the foraminiferal species (i.e. calcareous) found in his study were only found in the deeper sections of the cores here, and 3) tintinnids were not identified in Leslie's study; it is concluded that Leslie's (1963; 1965) "surface" samples from the central regions of the Hudson Bay actually correlate to the deeper sections (> 14 cm, below textural transition zone) of the inner bay cores. Sediment sampling technology has drastically improved over the last several decades and it is plausible that the grab coring technique employed by Leslie (1965) did not recover the actual sediment surface.

5.5 DISCUSSION SUMMARY

The Hudson Bay cores represent a unique west-east transect from central Hudson Bay to Western Hudson Strait. The microfaunal assemblage diversity, species present, relative abundance, and population density show distinct differences and trends across the transect.

On a general note, it appears that the microfaunal assemblages in the recent sediments of the Hudson Bay are linked to the length of the ice-free season, which is modulated by regional climate systems, more so than recent development in the region. A study of box cores closer to the mouths of rivers undergoing hydroelectric development would provide better insight on the impact of hydroelectric developments to the microfaunal assemblage. It is likely that hydroelectric development is slightly impacting the Hudson Bay ecosystem, as it currently provides a more permanent freshwater extension under the sea ice for planktonic species. This more permanent freshwater plume combined with more ice-free days is conducive to more productive surface waters, and thus more nutrients reaching the bottom sediments. The increase in Arctic water influence is also a factor considered in recent sediments, which appears to have created a taxonomic shift, transforming the assemblage from calcareous to arenaceous. This trend is not observed in the Hudson Strait sediments, however, the appearance and proliferation of tintinnids associated with more freshwater and SPM is found (Fig. 5.1).

Post-glacial sediments (7100 ± 180 cal yrs BP) in the Hudson Bay show a diverse predominantly calcareous microfossil assemblage and a very high number of foraminifera. This higher productivity and diversity, combined with the presence of Atlantic-water microfauna, are all strong indications that the Atlantic Ocean had more of an influence at this time. The dated interval also provides evidence that post-glacial marine invasion had occurred prior to 7100 ± 180 cal yrs BP. If further analysis of these cores is considered, radiocarbon dates should be obtained from the foraminifera in the deeper sections and at the sediment textural transition in the BC-13. This would aid in further constraining the timing of marine incursion and the time of non-deposition or erosion.

CHAPTER 6 CONCLUSIONS

1. The Late Holocene - modern Hudson Bay microfauna represent an assemblage typical of an oceanic system with estuarine circulation. Modern assemblages vary by geographical location within the bay. The deepest regions within the Hudson Bay and Strait are the least productive, with the lowest numbers of total foraminifera. Species more common to the Atlantic Ocean are more prominent in the Hudson Strait Region while Arctic-type species (e.g. *B. hensoni*) are more common within the Hudson Bay.

2. In the last 110 years, *Tintinnopsis rioplatensis*, a freshwater ciliate, appeared in the northwestern central region of Hudson Bay and proliferated in the last 50 years. A combination of factors is attributed to this increase, including regional climate warming, longer ice-free seasons, and more permanent freshwater plumes.

3. Sedimentation rates in the Hudson Bay region are variable with no apparent spatial (geographic) trend. Sedimentation rates in the region have increased in recent times (last 110 years), shown by a decrease in the overall number of foraminiferal tests with minimal change in diversity, and by the presence of a relatively thick cap of recent sediment overlying much older (mid-Holocene) sediment in several of the core sections. Leslie (1965) also reported much lower sedimentation rates corresponding to the deeper sediment in the cores of this study.

4. Evidence of post-glacial marine invasion within the Hudson Bay region by 7100 cal yrs BP (or earlier) is shown by the presence of post-glacial sediment (^{14}C - dated) with a calcareous foraminiferal assemblage associated with more Atlantic water influence. This assemblage has been correlated to sediments collected by Leslie (1965). The recent more arenaceous foraminiferal assemblages (~ last 150 yrs) are associated with an increased Arctic water influence. The high relative abundance of arenaceous fauna (up to 80%) in recent times in the Hudson Bay region was not reported in Leslie's study, as he only found values up to 5%. This observation, together with other lines of evidence, could suggest that his samples are made up of older sediments.

SYSTEMATIC TAXONOMY

The following is the systematic taxonomy for all foraminifera found in 6 box cores throughout the Hudson Bay and Strait region. Foraminifera are listed alphabetically by genus and species is provided where possible, otherwise only the genus is referenced. Bibliographic references were checked using the Ellis and Messina catalogue. References to foraminiferal SEM images are also listed here.

***Adercotryma glomeratum* (Brady)**
Lituola glomerata Brady, 1878, p. 433, pl. 20, figs. 1a-c.
Adercotryma glomerata (Brady). Loeblich and Tappan, 1953, p. 26, pl. 8, figs. 1-4; Barker, 1960, pl. 34, figs. 15-18; Williamson et al., 1984, p. 224, pl. 1, fig. 1.

***Allogromia* Rhumbler**
Allogromia Rhumbler, 1904.

***Ammotium cassis* (Parker)**
Plate 2, no. 9
Lituola cassis Parker, in Dawson, 1870, p. 177, 180, fig. 3.
Haplophragmium cassis (Parker). Brady, 1884, p. 304, pl. 33.
Ammobaculites cassis (Parker). Cushman, 1920, p. 63, pl. 12, fig. 5.
Ammotium cassis (Parker). Loeblich and Tappan, 1953, p. 33, pl. 2, figs. 12-16; Scott et al., 1977, p. 1578, pl. 2, figs. 1, 2; Miller et al., 1982a, p. 2362, pl. 1, fig. 8.

***Angulogerina angulosa* (Williamson)**
Uvigerina angulosa Williamson, 1858, p. 67, pl. 5, fig. 140.

***Astacolus hyalocrulus* Loeblich and Tappan**
Astacolus hyalocrulus Loeblich and Tappan, 1953, pl. 9, figs. 1-4.

***Astrononion gallowayi* Loeblich and Tappan**
Astrononion gallowayi Loeblich and Tappan, 1953, p. 90, pl. 17, figs. 4-7; Schafer and Cole, 1978, p. 27, pl. 9, fig. 3; Scott et al., 1980, p. 226, pl. 4, fig. 5.

***Bathysiphon argenteus* Heron-Allen & Earland**
Bathysiphon argenteus Heron-Allen & Earland, 1913.

***Bolivina arctica* Herman**
Bolivina arctica Herman, 1973, p. 140, pl. 1, figs. 1-7; Scott and Vilks, 1991, p. 241, pl. 5, figs. 1-10.

***Bolivina pacifica* Cushman and McCulloch**
Bolivina acerasa Cushman var. *pacifica* Cushman and McCulloch, 1942, Allan Hancock Expeditions, v. 6, n. 4, p. 185, pl. 21, figs. 2, 3.

***Bolivina pseudopunctata* (Höglund)**
Bolivina pseudopunctata Höglund, 1947, p. 273, pl. 24, figs 5a, b; pl. 32, figs 23, 24; text-figs 280, 281, 287.

***Buccella frigida* (Cushman)**
Pulvinulina frigida Cushman, 1922, p. 46, pl. 7, fig. 6.
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.
Eponides frigidus (Cushman). Cushman, 1941, p. 37, pl. 9, fig. 16.
Buccella frigida (Cushman). Anderson, 1952, p. 144, figs. 4a-c, 5, 6a-c; Schafer and Cole, 1978, p. 27, pl. 8, figs. 1, 2; Scott et al., 1980, p. 226, pl. 4, figs. 10, 11; Miller et al., 1982a, p. 2364, pl. 2, figs. 9, 10.

***Bulimina exilis* Brady**
Bulimina elegans d'Orbigny var. *exilis* Brady, 1884.
Bulimina exilis Whitelegge and Etheridge, 1907.

***Buliminella hensoni* Lagoe**
Buliminella elegantissima (d'Orbigny) var. *hensoni* Lagoe, 1977, p. 125-126, figs. 6c, f, pl. 3, figs. 20-22.
Buliminella hensoni Lagoe. Scott and Vilks, 1991, p. 28, pl. 2, fig. 7., Scott et al., 2008a, pl. 5, fig. 6c, f, pl. 3, figs. 20-23.

***Cassidulina laevigata* d'Orbigny**
Cassidulina laevigata d'Orbigny, 1826, p. 282, no. 1, pl. 15, figs. 4, 5; Scott, 1987, p. 327, pl. 2, fig. 10.

***Cassidulina reniforme* Nörvang**
Cassidulina crassa var. *reniforme* Nörvang, 1945, p. 41, text-figs. 6c-h.
Cassidulina reniforme (Nörvang). Scott, 1987, p. 327, pl. 2, figs. 11, 12.

***Cibicides lobatulus* (Walker and Jacob)**
Plate 1, nos. 5, 6, 7
Nautilus lobatulus Walker and Jacob, in Kanmacher, 1798 p. 642, pl. 14, fig. 36.
Truncatulina lobatula (Walker and Jacob). d'Orbigny, 1839a, p. 134, pl. 2, figs. 22-24; Brady, 1884, p. 660, pl. 92, fig. 10, pl. 93, fig. 1; Cushman, 1918, p. 16, pl. 1, fig. 10, p. 60, pl. 17, figs. 1-3.
Cibicides lobatulus (Walker and Jacob). Cushman, 1927b, p. 170, pl. 27, figs. 12, 13; Cushman, 1935, p. 52, pl. 52, figs. 4-6; Parker, 1952a, p. 446, pl. 5, fig. 11; Schafer and Cole, 1978, p. 27, pl. 9, figs. 1, 2; Scott et al., 1980, p. 226, pl. 4, figs. 8, 9; Williamson et al., 1984, p. 224, pl. 1, fig. 14.

***Cribrostomoides crassimargo* (Norman)**
Haplophragmium crassimargo Norman, 1892, p. 17, pl. 35, fig. 4.
Alveophragmium crassimargo (Norman). Loeblich and Tappan, 1953, p. 29, pl. 3, figs. 1-3.

***Cribrostomoides jeffreysi* (Williamson)**
Nonionina jeffreysii Williamson, 1858, p. 34, pl. 3, figs. 72, 73.
Alveophragmium jeffreysi (Williamson). Loeblich and Tappan, 1953, p. 31, pl. 3, figs. 4-7.

***Cyclogyra involvens* (Reuss)**
Operculina involvens Reuss 1851, p. 370, pl. 46, fig. 20.
Cornuspira involvens (Reuss). Reuss, 1863, p. 39, pl. 1, fig. 2; Loeblich and Tappan, 1953, p. 49, p. 7, figs. 4, 5.
Cyclogyra involvens (Reuss). Scott, 1987, p. 327.

***Dendrophyra arborescens* (Norman)**
Psammatodendron arborescens Norman, 1881, p. 404.
Dendrophyra arborescens (Norman) Brady, 1884, p. 262, pl. 28, figs. 12, 13 [as *Hyperammina arborescens*].
Dendrophyra arborescens (Norman) Thomas et al., 1990, p. 229, pl. 1, fig. 4

***Dentalina baggi* Galloway and Wissler**
Dentalina baggi Galloway and Wissler, 1927, p. 49, pl. 8, figs. 14, 15; Loeblich and Tappan, 1953, p. 54, pl. 9, figs. 10-15.

***Dentalina frobisherensis* Loeblich and Tappan**
Dentalina frobisherensis Loeblich and Tappan, 1953, p. 55, pl. 10, figs. 1-9.

***Dentalina pauperata* d'Orbigny**
Dentalina pauperata d'Orbigny, 1846, p. 46, pl. 1, figs. 57, 58; Loeblich and Tappan, 1953, p. 57, pl. 9, figs. 7-9.

***Eggerella advena* (Cushman)**
Verneuilina advena Cushman, 1922, p. 141.
Eggerella advena (Cushman). Cushman, 1937, p. 51, pl. 5, figs. 12-15; Cushman 1948, p. 32, pl. 3, fig. 12; Phleger and Walton, 1950, p. 277, pl. 1, figs. 16-18; Scott et al., 1977, p. 1579, pl. 2, fig. 7; Scott and Medioli, 1980, p. 40, pl. 2, fig. 7; Scott et al., 1991, p. 385, pl. 2, figs. 1, 2.

***Elphidium excavatum* (Terquem) forma *clavatum* Cushman**
Elphidium incertum (Williamson) var. *clavatum* Cushman 1930, p 20, pl.7, figs. 10a, b.
Elphidium incertum (Williamson) and variants. Parker, 1952b, p. 448, pl. 3, fig. 16.
Elphidium excavatum (Terquem) forma *clavata* Cushman. 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, 14, pl. 6, figs. 1-5.

Elphidium 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-Anderson, 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 incertum **(Williamson)**
Polystomella umbilicatula (Walker) var. *incerta* Williamson, 1858, p. 44, pl. 3, fig. 82a.
Elphidium incertum (Williamson). Phleger, 1952, p. 83, pl. 14, fig. 7.

Elphidium subarcticum **Cushman**
Elphidium subarcticum Cushman, 1944, p. 27, pl. 3, figs. 34, 35.

Eoeponides pulchella **(Parker)**
Pninaella? pulchella Parker, 1952a, p. 420, pl. 6, figs. 18-20.
Eoeponides pulchella (Parker). Scott, 1987, p. 327.

Epistominella takayanagii **Iwasa**
Epistominella takayanagii Iwasa, 1955, p. 16, 17, text-fig. 4a-c.

Fissurina cucurbitasema **Loeblich and Tappan**
Fissurina cucurbitasema Loeblich and Tappan, 1953, p. 76, pl. 14, figs. 10, 11.

Fissurina marginata **(Montagu)**
Vemiculum marginatum Montagu, 1803, p. 524.
Fissurina marginata (Montagu). Loeblich and Tappan, 1953, p. 77, pl. 14, figs. 7-9; Parker, 1964, p. 625, pl. 98, fig. 11.

Fissurina serrata **Schlumberger**
Plate 1, no. 9
Lagena serrata Schlumberger, 1894, p. 258, pl. 3, fig. 7.

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, test-figures 219-233.
Virgulina fusiformis (Williamson). Parker, 1952a, p. 417, pl. 6, figs. 3-6, Parker, 1952b, p. 461, pl. 4, fig. 6
Fursenkoina fusiformis (Williamson). Gregory, 1970, p. 232; Scott et al., 1980, p. 228, pl. 3, figs. 9, 10.

Glandulina laevigata
Nososaria (Glandulina) laevigata d'Orbigny, 1826, p. 252, pl. 10, figs. 1-3.

***Glomobulimina auriculata* (Bailey)**
Bulimina auriculata Bailey, 1851, p. 12, figs. 25-27.
Globobulimina auriculata (Bailey). Schnitker, 1971, p. 202, pl. 5, fig. 6; Williamson et al., 1984, pl. 1, fig. 12.

***Glomospira gordialis* (Jones and Parker)**
Trochammina squamata Jones and Parker var. *gordialis* Jones and Parker, 1860, p. 304.
Glomospira gordialis (Jones and Parker). Cushman and Mcculloch, 1939, p. 70, pl.5, figs. 5, 6.; Todd and Brönnimann 1957, p. 22, pl. 1, fig. 22; Barker, 1960, p. 79, pl. 38, figs. 7-9.

***Haplophragmoides canariensis* (d'Orbigny)**
Nonionina canariensis d'Orbigny, 1839a, p. 128, pl. 2, figs. 33, 34.

***Haynesia orbiculare* (Brady)**
Plate 1, no. 1
Nonionina orbiculare Brady, 1881, p. 415, pl. 21, fig. 5.
Elphidium orbiculare (Brady). Hessland, 1943, p. 262; Gregory, 1970, p. 228, pl. 14, figs. 5, 6. *Protoelphidium orbiculare* (Brady). Todd and Low, 1961, p. 20, pl. 2, fig. 11; Scott et al., 1977, p. 1579, pl. 5, figs. 5, 6; Schafer and Cole, 1978, p. 28, pl. 10, fig. 5; Scott and Medioli, 1980, p. 43, pl. 5, fig. 7.
Haynesia orbiculare (Brady). Scott et al., 1980, p. 226.

***Hemisphaerammina bradyi* Loeblich and Tappan**
Plate 2, no. 11
Hemisphaerammina bradyi Loeblich and Tappan in Loeblich et al., 1957, p. 224, pl. 72, fig. 2.; Scott et al., 1977, p. 1579, pl. 3, figs. 7, 8; Schafer and Cole, 1978, p. 28, pl. 1, fig. 5; Scott and Medioli, 1980, p. 40, pl. 1, figs. 4, 5.

***Hyperammina elongata* Brady**
Hyperammina elongata Brady, 1878, p. 433, pl. 20, fig. 2a, b; Loeblich and Tappan, 1953, p. 19, pl. 1, fig. 6.

***Islandiella teretis* (Tappan)**
Cassidulina laevigata d'Orbigny. Brady, 1884, p. 428. pl. 54, figs. 1-3.
Islandiella teretis (Tappan). Scott, 1987, p. 328, pl. 2, fig. 13.

Lagena gracilima
Amphorina gracillima Seguenza, 1862, p. 51, pl. 1, fig. 37.
Lagena gracillima (Seguenza). Cushman, 1923, p. 23, pl. 4, fig. 5.

***Lagena laevis* (Montagu)**
Vermiculum laeve Montagu, 1803, Testacea Britannica, p. 524.
Lagena laevis (Montagu). Parker, 1964, p. 626, pl. 97, fig. 30.

Lagena meridionalis
Lagena gracilis Williamsoni subsp. *Meridionalis* Wiesner, 1931, p. 117, pl. 18, fig. 211.
Lagena meridionalis Wiesner. Loeblich and Tappan, 1953, p. 62, pl. 12, fig. 1.

***Lagena mollis* (Cushman)**
Lagena graccillima subsp. *mollis* Cushman, 1944, p. 21, pl. 3, fig. 3.
Lagena mollis Cushman. Loeblich and Tappan, 1953, p. 63, pl. 11, fig. 26.

***Nonion barleeanum* (Williamson)**
Plate 1, nos. 2, 3
Nonionina barleeanum Williamson, 1858, p. 32, pl. 4, figs. 68, 69.
Nonion barleeanum (Williamson). Scott, 1987, p. 328.

***Nonionella atlantica* Cushman**
Nonionella atlantica Cushman, 1947, p. 90, pl. 20, figs. 4, 5.

***Nonionella auricula* Heron-Allen and Earland**
Nonionella auricula Heron-Allen and Earland, 1930, p. 192, pl. 5, figs. 68-70.

***Nonionellina labradorica* (Dawson)**
Nonionina labadorica Dawson, 1860, p. 191, fig. 4.
Nonion labradoricum (Dawson). Loeblich and Tappan, 1953, p. 86, pl. 17, figs. 1-2.
Nonionellina labradorica (Dawson). Voloshinova, 1958, p. 142. Williamson et al., 1984, p. 224, pl. 1, fig. 11.

***Oolina borealis* Loeblich and Tappan**
Oolina borealis Loeblich and Tappan, 1954, p. 384.

***Oolina caudigera* Wiesner**
Lagena (Entosolenia) globosa (Montagu) var. *caudigera* Wiesner, 1931, p. 119, pl. 18, fig. 214.

***Oolina hexagona* (Williamson)**
Entosolenia squamosa (Montagu) var. *hexagona* Williamson, 1848, p. 20, pl. 2, fig. 23.
Oolina hexagona (Williamson). Loeblich and Tappan, 1953, p. 69, pl. 14, figs. 1-2

***Parafissurina fusiliformis* Loeblich and Tappan**
Parafissurina fusiliformis Loeblich and Tappan, 1953, p. 59, pl. 14, figs. 18, 19.

***Pattelina corrugata* Williamson**
Patellina corrugata Williamson, 1858, p. 46, pl. 3, figs. 86-89; Schnitker, 1971, p. 206, pl. 6, fig. 12.

***Pleurosomella brevis* Schwager**
Pleurosomella brevis Schwager, 1886

***Psammosphaera fusca* Schulze**
Psammosphaera fusca Schulze, 1875, p. 111, pl. 2, fig. 8.

***Pullenia bulloides* (d'Orbigny)**
Nonionina bulloides d'Orbigny, 1826, p. 293, no. 2.
Pullenia bulloides (d'Orbigny). Cushman and Todd, 1943, p. 13, pl. 2, figs. 15-18; Phleger et al., 1953, p. 47, pl. 10, fig. 19; Barker, 1960, p. 174, pl. 84, figs. 12, 13; Cole, 1981, p. 111, pl. 14, fig. 5.

***Pullenia subcarinata* (d'Orbigny)**
Nonionina subcarinata d'Orbigny, 1839b, p. 28, pl. 5, figs. 23, 24.
Pullenia subcarinata (d'Orbigny). Heron-Allen and Earland, 1932, p. 403.

***Pyrgo subsphaerica* (d'Orbigny)**
Plate 1, no. 11
Biloculina subsphaerica d'Orbigny, 1839a, p. 162, pl. 8, figs. 25-27.
Pyrgo subsphaerica (d'Orbigny). Parker, 1952a, p. 405, pl. 3, fig. 17.

***Quinqueloculina agglutinans* (Cushman)**
Quinqueloculina agglutinata Cushman, 1917, p. 43, pl. 9, fig. 2.
Quinqueloculina agglutinans d'Orbigny,1839a, p. 1-224.

***Quinqueloculina seminulum* (Linné)**
Serpula seminulum Linné, 1758, p. 786.
Quinqueloculina seminulum (Linné). d'Orbigny, 1826, p. 301; Scott et al. 1980, p. 231, p. 3, figs. 3-5; Scott et al., 1991, p. 386, pl. 2, fig. 16.

***Quinqueloculina stalkeri* Loeblich and Tappan**
Quinqueloculina stalkeri Loeblich and Tappan, 1953, p. 40, pl. 5, figs. 5-9.

***Recurvoides turbinatus* (Brady)**
Haplophragmium turbinatum Brady, 1881, p. 50: 1884, p. 312, figs. 9a-c.
Recurvoides turbinatus (Brady). Parker, 1952b, p. 402, pl. 2, figs. 23-24.

***Reophax arctica* Brady**
Plate 2, no. 1
Reophax arctica Brady, 1881, p. 405, pl. 21, fig. 2; Scott et al., 1980, p. 321, pl. 2, fig. 1; Miller et al, 1982a, p. 2362, pl. 1, fig. 6.

***Reophax dentaliniformis* Brady**
Reophax dentaliniformis Brady, 1884, p. 293, pl. 30, figs 21, 22; Barker, 1960, p. 62, pl. 30, figs. 20, 21; Cole, 1981, p. 23, pl. 16, fig. 23.

Reophax fusiformis **(Williamson)**
Proteonina fusiformis Williamson, 1858, p. 1, pl. 1, fig. 1; Höglund, 1947, p. 52, pl. 4, fig. 21.
Reophax fusiformis (Williamson). Brady, 1884, p. 290, pl. 30, figs. 7-11.
Reophax curtus Cushman, 1920, p. 8, pl. 2, figs. 2-3.; Loeblich and Tappan, 1953, p. 22, pl. 2, figs. 1-4.
Reophax subfusiformis Earland, 1933, P. 74, pl. 2, figs. 16-19; Höglund 1947, p. 82, pl. 9, figs. 1-2, 4 (not 3); pl. 26, figs. 1-36, pl. 27, figs. 1-19, text-figs. 43-50.
Reophax regularis Höglund, 1947, p. 86, pl. 9, figs. 11-12; pl. 26, figs. 37-43; pl. 27, figs. 24-27.

Reophax guttifer **(Brady)**
Lituola (Reophax) guttifera Brady, 1881, p. 49.
Reophax guttifera (Brady). Brady, 1884, p. 295, pl. 31, figs. 10-15.

Reophax scorpiurus **Montford**
Plate 2, nos. 2, 3, 4
Reophax scorpiurus Montford, 1808, p. 330; Cushman, 1920, pl. 1, figs. 5-7.

Reophax scottii **Chaster**
Plate 2, no. 10
Reophax scottii Chaster, 1892, p. 57, pl. 1, fig. 1; Miller et al., 1982a, p. 2362. pl. 1, fig.7.

Rhabdammina **Sars**
Rhabdammina Sars, 1869.

Robertinoides charlottensis **(Cushman)**
Cassidulina charlottensis Cushman, 1925, p. 41, pl. 6, figs. 6, 7.
Robertinoides charlottensis (Cushman). Loeblich and Tappan, 1953, p. 108, pl. 20, figs. 6, 7.

Rosalina **d'Orbigny**
Rosalina d'Orbigny, 1826.

Saccammina atlantica **(Cushman)**
Proteonina atlantica Cushman, 1944, p. 5, pl. 1, fig. 4.

Saccammina difflugiformis **(Brady)**
Plate 2, nos. 5, 6
Reophax difflugiformis Brady, 1879, p. 51, pl. 4, figs. 3a, b.
Saccammina difflugiformis (Brady). Thomas et al., 1990, p. 234, pl. 2, figs. 10-12.

***Spiroplectammina biformis* (Parker and Jones)**
Plate 2, no. 8
Textularia agglutinans d'Orbigny var. *biformis* Parker and Jones, 1865, p. 370, pl. 15, figs. 23, 24.
Spiroplectammina biformis (Parker and Jones). Cushman, 1927a, p. 23, pl. 5, fig. 1; Loeblich and Tappan, 1953, p. 34, pl. 4, figs. 1-6; Schafer and Cole, 1978, p. 19, pl. 3, fig. 2; Scott et al., 1980, p. 231, pl. 2, fig. 2.

***Stetsonia arctica* (Green)**
Epistominella arctica Green, 1960, p. 71, pl. 1, figs. 4a, b.
Stetsonia horvathi Green, 1960, p. 72, pl. 1, figs. 6a, b.
Epistominella sp. Lagoe, 1977, p. 126, pl. 4, figs. 19-21.
Stetsonia arctica (Green). Scott and Vilks, 1991, p. 35, pl. 3, figs. 5-15, pl. 4, figs. 19-21.

***Textularia earlandi* Parker**
Textularia earlandi Parker, 1952b, p. 458 (footnote), pl. 2, fig. 4.

***Textularia torquata* Parker**
Plate 2, no. 7
Textularia torquata Parker, 1952b, p. 403, pl. 3, figs. 9-11.

***Trifarina fluens* (Todd)**
Plate 1, nos. 14, 15, 16, 17
Anglogerina fluens Todd, in Cushman and Todd, 1947, p. 67, pl. 16, figs. 6-7.
Trifarina fluens (Todd). Scott et al., 1980, p. 231, pl. 4, figs. 12, 13; Scott, 1987, p. 329.
Trifarina angulosa (Williamson), Williamson et al., 1984, pl. 1, fig. 15.

***Trochammina globigeriniformis* (Parker and Jones)**
Lituloa nautiloidea Lamarck var. *globigeriniformis* Parker and Jones, 1865, p. 407, pl. 17, fig. 96.
Trochammina globigeriniformis (Parker and Jones). Cushman, 1910, p. 124, text figs. 193-195.

***Trochammina lobata* Cushman**
Trochammina lobata Cushman, 1944, p. 18, pl. 2, fig. 10; Gregory, 1970, p. 180, pl. 4, figs. 5, 6.

***Trochammina inflata* (Montagu)**
Nautilus inflatus Montagu, 1808, p. 81, pl. 18, fig. 3.
Rotalina inflata Williamson, 1858, p. 50, pl. 4, figs. 93, 94.
Trochammina inflata (Montagu). Parker and Jones, 1859, p. 347; Phleger, 1954, p. 646, pl. 3, figs. 22, 23; Scott et al., 1977, p. 1579, pl. 4, figs. 6, 7; Scott and Medioli, 1980, p. 44, pl. 3, figs. 12-14, pl. 4, figs. 1-3; Scott et al., 1990, p. 733, pl. 1, figs. 3a, b; Scott et al., 1991, p. 388, pl. 3, figs. 7, 8; Scott et al., 1995, p. 294, figs. 6.10-6.17.

***Trochammina nana* (Brady)**
Haplophragmium nanum Brady, 1881, p. 50; Brady, 1884, p. 311, pl. 35, figs. 6-8.
Trochammina nana (Brady). Loeblich and Tappan, 1953, p. 50 pl. 8, fig. 5a-c.

***Trochammina squamata* Parker and Jones**
Trochammina squamata Parker and Jones, 1860, p. 304; Parker, 1952a, p. 460, pl. 3, fig. 4. Parker, 1952b, p. 408, pl. 4, figs. 11-16. Scott and Medioli, 1980, p. 45, pl. 4, figs. 6,7.

***Valvulineria arctica* Green**
Valvulineria arctica Green, 1960, p. 71, pl. 1, fig. 3a-c.

***Tintinnopsis rioplatensis* Souto**
Tintinnopsis rioplatensis Souto, 1973, p. 251, figs. 5-8.
Difflugia elegans Penard, 1890; Scott and Martini, 1982, table 1, 2.
Difflugia bacillariarum Perty, 1849; Medioli and Scott, 1983, p. 20, pl. 5, figs. 16-19, pl. 6, figs. 1

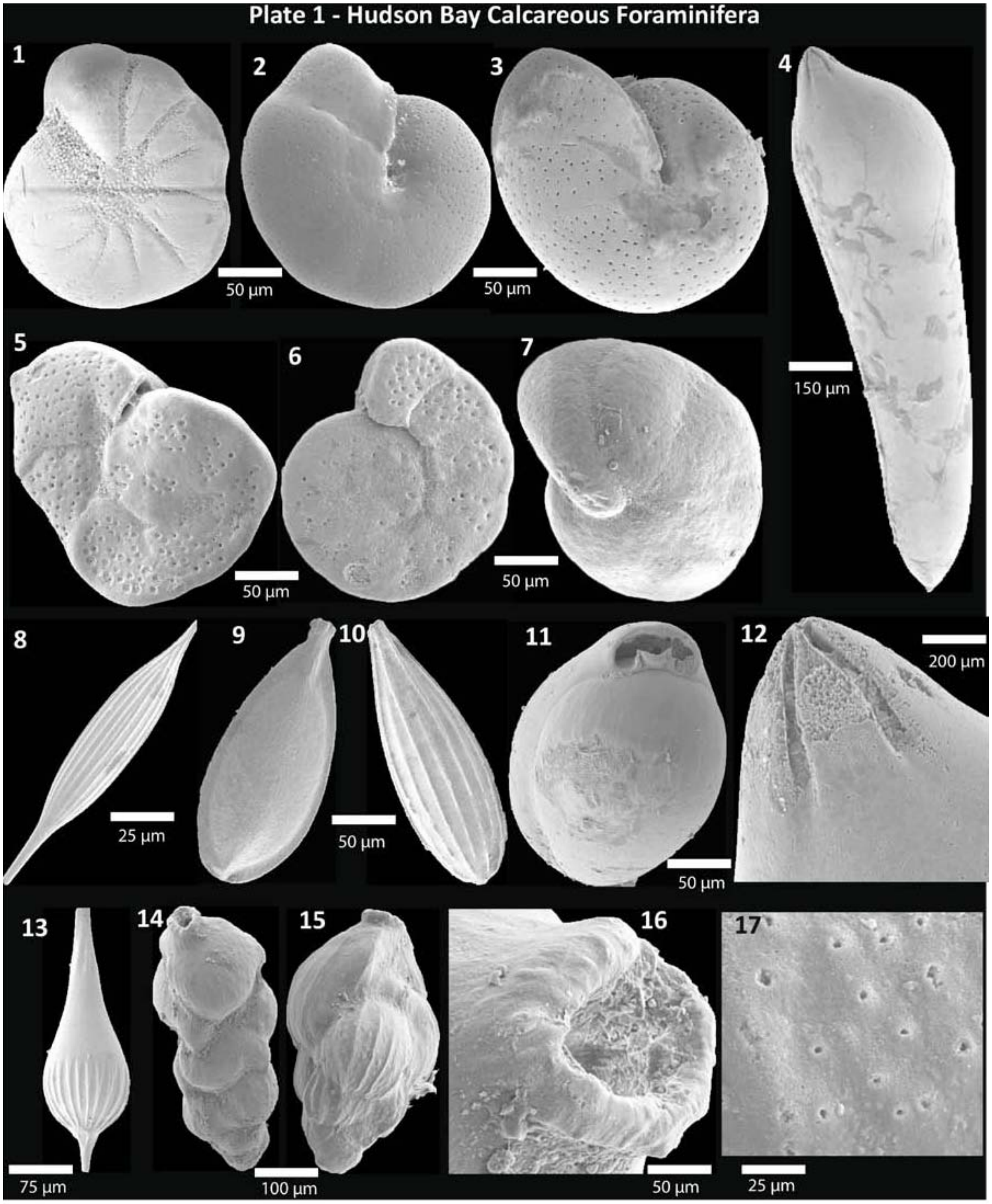

Plate 1 – 1) *Haynesia orbiculaire*, 2) N*onion barleeanum* [ventral], (3) [dorsal], 4) *Dentalina* sp., 5) Deformed *Cibicides lobatulus* [ventral], 6) *Cibicides lobatulus* [ventral], 7) [dorsal], 8) *Lagena* sp., 9) *Fissurina serrata*, 10) Lagena sp., 11) *Pyrgo subsphaerica*, 12) *Dentalina* sp. [apertural], 13) *Lagena* sp., 14) *Trifarina fluens* [ventral], 15) *Trifarina fluens* [dorsal], 16) *Trifarina fluens* [aperture] 17) *Trifarina fluens* [test wall].

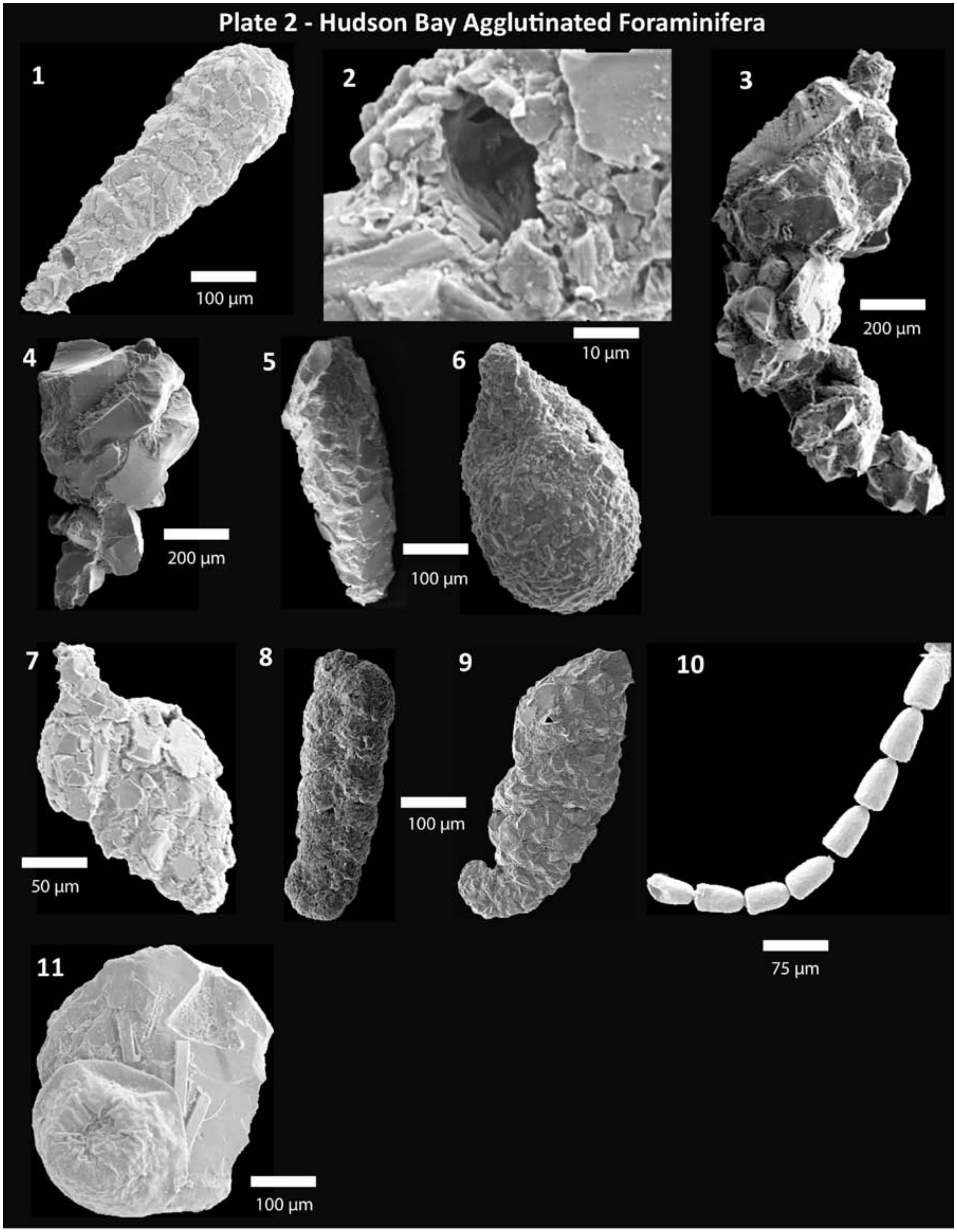

Plate 2 – 1) *Reophax arctica*, 2) *Reophax arctica* (apertural), 3) *Reophax scorpiurus*, 4) *Reophax scorpiurus*, 5) *Saccammina difflugiformis*, 6) *Saccammina difflugiformis*, 7) *Textularia torquata*, 8) *Spiroplectammina biformis*, 9) *Ammotium cassis*, 10) *Reophax scottii*, 11) *Hemisphaerammina bradyi*

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APPENDIX 1

Microfossil assemblages for each box core have been assembled and are shown in the following Appendices 1 A-F. Depths down core are listed with the relative abundance of foraminifera throughout the section. Foraminifera are identified to the genus and species level where possible, otherwise, they are identified to the genus level and marked sp. (1 unknown species) or spp. (2 or more species). At the bottom of the table, the total number *Tintinnopsis rioplatensis*, a freshwater ciliate, is shown. Other useful data shown here are the total number of foraminifera, the percentage of foraminifera in the 45 to 63 micron size range, and the percentage of calcareous foraminifera.

APPENDIX 1A: BC-10 Microfossil Assemblage

Depth (cm):	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	11	13	15	17	19	22.5	27.5	32.5	37.5
Allogromia sp.	0.9		0.6	0.3															
Adercotryma glomerata	1.6	2.1	3.0	3.4	4.2	2.5	1.1	0.8	0.5	1.2	1.2	4.2	2.4	2.6	4.0	2.0	0.5	0.1	
Astronion gallowayi																		0.1	
Bathysiphon argenteus		0.2	0.4	0.1	0.3	0.4	0.6							0.2					
Bolivina arctica	0.2			0.3	0.8	0.6	3.3	1.5	3.6	1.0	4.4	8.2	14.3	11.2	17.5	4.3	0.3	0.4	0.4
Bolivina sp.																	0.2	0.2	0.3
Buccella frigida																		0.3	
Buliminella hensoni	22.5	10.0	0.4		15.1	24.7	43.9	37.8	38.4	50.0	58.9	28.4	32.9	25.0	30.7	60.0	64.6	48.6	84.8
Cassidulina reniforme															0.3		0.6	28.2	4.7
Cibicides lobalatus																		1.3	
Cribrostomoides crassimargo	0.7	0.2	0.4	0.5	0.6	1.2	0.3	0.1	0.6	0.5	0.3	0.7		0.2	0.8	0.1	0.3	0.1	
Cribrostomoides jeffreysi	0.2	0.2	0.4		0.3				0.1	0.3					0.3	0.4	0.1	0.3	0.1
Cyclogyra involvens	1.6	1.1	0.8	0.8	0.5	0.2	0.6	0.5	0.3	0.2			1.1					0.1	
Dendrophyra arborescens				0.3	0.2	0.3			0.1										
Dentalina frobisherensis																	0.2		
Eggerella advena	0.7	2.4	3.0	1.4	1.4	1.8	0.2	2.2	0.7	0.9	0.7	0.2	1.1	1.6	1.0	0.3			
Elphidium exc forma clavatum																		1.5	
Elphidium exc forma excavatum			0.2				0.3	0.3			0.1		0.2		2.8		0.3	0.4	0.5
Elphidium subarcticum																	0.2	0.2	
Fissurina sp.				0.3														0.1	
Fursenkoina fusiformis													0.5		2.3	9.2	1.3	0.9	1.4
Glomospira gordialis	0.9	1.1	1.2	1.5	1.1	0.6	1.6	0.8	0.8	1.0	0.1	0.2		0.6					
Haplophragmoides canariensis														0.4					
Hemisphaerammina bradyi												0.2	0.2	0.6	0.5				
Hyperammina spp.	0.9	0.6	0.6		0.3		0.1												
Islandiella teretis													0.2		10.4		25.9	8.7	5.8
Lagena sp.	0.3						0.3		0.5						0.3		0.3	0.1	
Nonion barleeanum	0.9							0.1	0.2	0.4	0.1	0.4	1.1	0.9	1.5	0.2	4.5	1.7	0.4
Oolina borealis																		0.1	
Oolina hexagona																		0.1	
Psamosphaera fusca	0.7		0.2		0.3				0.2	0.4	0.7	1.1	0.3	0.2	0.2			0.3	
Quinqueloculina agglutinans	1.8	1.3	3.2	3.7	4.3	4.9	1.6	2.7	2.9	3.1	1.6	4.6	0.6	7.5	2.8	3.0			
Recurvoides turbinatus	0.2									0.1									
Reophax arctica	6.1	8.3	8.9	4.7	5.0	5.2	5.8	6.3	5.1	3.5	1.4	1.5	2.5	1.8	1.9	0.9			
Reophax dentaliformis		0.2	0.2																
Reophax fusiformis																0.6			
Reophax guttifer			0.6	0.3	0.2	0.2		0.3		0.3				0.3					
Reophax scorpiurus	4.3	3.2	4.6	2.2	3.9	2.5	0.4	0.5	0.7	2.3	1.5	2.0	1.0	1.1	0.5	0.1		0.6	
Reophax scottii				0.3	0.3	0.2	0.3				0.3								
Rhabdammina sp.	0.3																		
Saccammina difflugiformis	7.4	12.3	16.9	21.0	17.1	20.5	14.0	12.0	19.8	12.6	12.6	21.1	13.4	21.8	10.7	7.5		2.0	0.6
Spiroplectammina biformis	1.2	1.9	1.4	2.7	2.7	2.3	1.7	3.3	0.7	3.7	0.5	1.5		0.2					
Textularia earlandi	9.8	16.1	13.1	14.0	9.8	6.7	6.2	8.9	5.5	6.6	4.5	5.3	6.4	0.8	1.9	0.4	0.2	0.1	0.2
Textularia torquata	25.8	28.4	31.0	35.1	26.2	22.4	15.4	20.3	17.9	10.9	10.6	11.7	12.0	8.7	3.9	2.8	0.2		0.4
Trifarina fluens	0.2							0.1							0.7	0.6	0.2	0.2	
Trochammina globigeriniformis	6.3	4.5	4.2	2.0	2.1	1.0	0.6	0.5	0.4			5.7	6.7	10.1	1.8	3.3	0.2	0.2	
Trochammina inflata												0.2							
Trochammina nana	4.5	4.9	3.0	5.2	2.9	1.6	1.4	0.7	1.0	0.7	0.4	2.9	3.4	4.0	3.3	4.1		0.3	
Trochammina pseudoinflata	0.2	0.6	1.4		0.3									0.2					
Stetsonia actica		0.2								0.2							0.3	0.3	
Planktics																		2.7	0.2
Tintinnopsis rioplatensis (10 cm^3)	157	483	632	494	692	259	520	292	452	163	264	170	550	32	80	69	5	0	32
Total Foraminifera (10 cm^3)	1178	1407	1972	1470	2492	1924	2481	1456	1473	2045	1382	1092	842	623	798	925	3089	7530	8846
% 45-63 microns	50.5	49.7	46.7	33.1	45.9	57.4	74.5	67.6	72.5	68.1	72.5	54.2	65.3	41.9	59.1	78,9	67.2	50.0	93.5
% Calcareous Foraminifera	25.7	11.4	1.4	1.4	16.4	25.6	48.5	40.4	43.0	51.8	63.5	37.0	50.1	37.1	66.5	74.4	98.5	94.7	98.6

APPENDIX 1B: BC-12 Microfossil Assemblage

Depth (cm)	**0.5**	**1.5**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**22.5**
Allogromia sp.	3.4	5.4	2.9	1.9	0.2	0.5			0.2			
Adercotryma glomerata	0.5	0.3	1.4	0.4	0.1	0.4	0.7	0.5	0.9	0.4	1.3	1.1
Ammotium cassis									0.1	0.1		
Astacolus hyalacrulus												0.1
Astronion gallowayi												
Bolivina arctica		0.2							0.7	0.4	7.5	5.5
Buccella frigida	0.5	2.4	0.1	0.3	0.4	1.4	2.3	3.7	1.5	0.2	0.9	1.4
Buliminella hensoni										14.2	28.9	44.6
Cassidulina reniforme	3.2		0.2	0.3		0.3	0.5	0.9			0.4	11.3
Cibicides lobalatus												0.5
Cribrostomoides crassimargo										0.1		
Cyclogyra involvens	1.1	0.4	0.4	0.2	0.2		0.6		0.2			
Dendrophyra arborescens	0.2											
Dentalina pauperata										0.2		
Dentalina sp.												
Eggerella advena	0.1	0.2		0.9	2.1	1.4	1.7	1.3	0.7	1.9	4.3	1.6
Elphidium exc forma clavatum	3.9	1.7	0.5			2.1	4.5	2.8	1.6	0.7	1.4	0.5
Elphidium exc forma excavatum			0.3			0.1	0.1	0.1				0.5
Elphidium subarcticum						0.1		1.1	0.2			
Eoponides pulchella	1.7			0.2	0.2	0.5	0.3		0.3		2.5	1.8
Fissurina serrata				0.2								0.2
Fursenkoina fusiformis	2.7				0.2	0.2	0.2				1.1	2.7
Haplophragmoides canariensis												
Haynesia orbiculaire							0.5	0.3	0.3			0.1
Hemisphaerammina bradyi	9.1	9.0	10.1	6.9	2.9	2.9	5.4	4.5	5.0	0.8	0.9	0.4
Hyperammina spp.	0.1											
Islandiella teretis	0.5	0.1	0.2		0.5	0.6	0.2			0.2	2.0	14.0
Lagena sp. 1	5.0	0.4	5.5	4.8	2.7	0.3	0.3	0.3	0.2		0.4	0.1
Lagena sp. 2						1.4	0.7					
Nonion barleeanum												0.6
Nonionella labradorica										0.1	0.5	0.1
Oolina sp.												0.1
Parafissurina sp.	0.1			0.1		0.2						
Psammosphaera fusca		0.1	0.1				0.1				0.1	
Pyrgo sp.	0.1		0.1									
Quinqueloculina seminulum	0.3	0.1	0.2	0.2	0.1	0.3	0.2	0.2	0.3	0.9		
Recurvoides turbinatus	2.4	0.8	0.7	1.0	0.4	1.4	1.4	0.6	0.9	0.4	0.2	0.2
Reophax arctica	2.5	4.0	3.0	8.0	9.3	7.4	10.1	5.9	5.7	5.8	5.6	2.2
Reophax dentaliniformis												
Reophax fusiformis							0.1					
Reophax guttifer				0.6	1.8	1.4	0.3	0.3	0.5	4.0	2.1	0.4
Reophax scorpiurus	0.2	0.2	0.1				0.1					
Reophax scottii	0.4	0.4	0.2	0.5		0.7		0.2	0.7		1.0	
Rhizammina sp.		0.3	0.1	0.1	0.1							
Saccammina difflugiformis	9.2	7.4	3.4	2.5	2.1	2.3	3.1	4.9	3.2	2.7	1.2	0.6
Spiroplectammina biformis	1.6	1.5	1.5	1.6	4.2	3.3	6.7	6.1	2.7	2.8	4.9	1.2
Stetsonia actica										0.4		
Textularia earlandi		0.2	1.2					0.2			0.1	0.1
Textularia torquata	48.7	59.2	61.5	58.0	54.7	51.4	42.9	46.9	45.9	45.6	17.4	3.9
Trifarina fluens			0.2		0.2							
Trochammina globigeriniformis												
Trochammina nana	0.7	1.2	0.5	0.5	1.2	1.1	0.2	0.3	0.5		1.0	
Trochammina pseudoinflata								0.1			0.4	0.6
Planktics												0.2
Linings	1.3	3.5	4.4	9.5	15.3	18.0	15.1	15.6	25.1	16.9	12.9	2.7
Tintinnopsis rioplatensis (10 cm^3)	1396	1516	1328	1624	472	1	336	208	155	0	0	0
Total Foraminifera (10 cm^3)	3263	2076	1654	2317	1931	1759	1716	1434	1496	1299	2432	3803
% 45-63 microns	36.5	44.9	53.4	54.9	52.2	51.2	41.7	42.9	33.4	59.7	66.2	58.9
% Calcareous Foraminifera	19.1	5.4	7.6	6.3	4.4	7.3	10.4	9.4	5.4	16.8	45.6	84.4

APPENDIX 1C: BC-13 Microfossil Assemblage

Depth (cm):	**0.5**	**1.5**	**2.5**	**3.5**	**4.5**	**5.5**	**6.5**	**7.5**	**8.5**	**9.5**	**11**	**13**	**15**	**17**	**19**	**22.5**	**27.5**	**32.5**	**37.5**	**42.5**
Adercotryma glomerata	8.2	15.9	11.8	14.1	14.8	11.5	9.4	8.6	7.0	6.3	3.0	3.1	1.3			0.2	0.1	0.3	1.3	1.2
Allogromia sp.	1.3	2.4	2.8	2.3	6.3	0.8	0.8	0.5	1.4	0.8	0.1	0.2	0.1							
Bolivina arctica	0.1	0.1		0.7	2.0	1.8	7.0	12.2	7.4	9.6	11.1	10.5	2.6	0.2	0.5	1.0	2.1	2.7	3.3	2.5
Bolivina pseudopunctata	0.1	12.8	0.3	0.7				0.1	0.2	0.4		0.3	0.4	0.2			0.3	0.1	0.5	
Buccella frigida	0.7	1.3	0.3	0.7	1.0	1.6	0.9	1.4	1.2	0.7	0.3	1.2	1.1	1.9	0.3	0.4			0.1	
Buliminella hensoni	23.6	0.3	10.1	9.3	0.3	15.9	24.4	31.9	41.6	45.0	63.2	34.2	55.7	63.1	80.9	83.3	67.3	71.6	45.4	44.3
Cassidulina reniforme					0.5	0.2		3.1	0.9	1.5	1.4	8.3	3.9	3.8	2.5	3.5	15.8	15.9	32.0	39.9
Cibicides lobatulus															0.1	0.1	0.3	1.1	3.1	0.6
Cribrostomoides crassimargo	0.5								0.2			0.1								
Cribrostomides jeffreysi			0.1		0.3		0.1	0.1												
Cyclogyra involvens		0.3	1.1	0.7		0.4		0.4	0.5	0.2	0.1	0.1				0.2			0.2	
Dentalina baggi					0.3						0.1									
Eggerella advena	5.0	3.3	9.7	7.2	11.5	14.1	7.5	5.1	5.4	4.4	2.8	2.2	0.4	0.3		0.2	0.4	0.2	0.2	0.2
Elphidium exc forma clavatum	0.3	0.5				0.2	0.1			0.3	0.6	1.2	0.8	0.4	0.4	0.5	0.8	2.4	5.8	2.9
Elphidium exc forma excavatum									0.3		0.6									
Elphidium incertum															0.1					
Eoponides pulchella	0.5		0.5	0.2		0.4	0.4	0.2	0.3	0.9					0.2			0.1		
Epistominella takayanagii		0.4			0.5			0.4	0.2	0.2		0.2							0.2	
Fissurina serrata															0.0	0.1			0.2	0.2
Fissurina cucurbitisima																		0.1		
Fursenkoina fusiformis	9.9	3.3		0.4	0.3	0.2	0.6	0.3	0.3	0.1	0.1	0.2	0.2	0.1	0.2	0.4	0.4	0.2	0.2	0.6
Glomospira gordialis	0.5	0.3																		
Haynesia orbiculaire						0.2	0.2		0.2								0.1			
Hemisphaerammina bradyi	1.8	4.8	2.4	1.8	5.1	2.6	2.3	1.7	1.8	1.5	1.1	2.9	1.1		0.7	0.7	0.6			
Hyperammina sp.	1.7	2.4	0.3	1.3																
Islandiella teretis	0.5	0.1		0.5	0.5	0.8	1.5	1.4	2.2	2.2	4.4	21.8	29.2	27.7	12.9	7.4	8.5	3.3	3.1	3.6
Lagena mollis				0.5								0.1								
Lagena sp.									0.1	0.4										
Nonion barleeanum								0.3	0.1	0.1		0.8	0.3	0.4	0.1	0.2	0.3	0.6	0.6	0.8
Nonionellina labradorica			0.1						0.1											
Oolina borealis												0.1								
Oolina sp.																			0.1	
Parafissurina spp.											0.1									
Pattelina corrugata		0.1							0.1						0.1	0.1				
Psammosphaera fusca	0.1		0.4	0.2		0.4						0.1								
Pyrgo subsphaerica							0.1						0.3	0.5						
Quinqueloculina agglutinans		1.3	0.1	1.1			0.1	0.1		0.1										
Quinqueloculina seminulum																			0.5	0.2
Reophax arctica	6.6	8.8	10.2	11.4	11.6	10.3	8.7	5.3	5.3	3.1	1.6	2.1	0.1	0.2	0.1	0.6	1.1	0.3		
Reophax fusiformis	0.4																			
Reophax guttifer	0.5	1.0		0.7	1.9	3.4	2.0	1.4	1.5	0.9	0.2	0.3	0.1		0.2					
Reophax scorpiurus	0.9		0.6	1.1		0.4	0.5	0.1	0.1	0.1		0.1					0.1			
Reophax scotti		0.4	1.5			0.4		0.1		0.1										
Saccammina difflugiformis	13.7	4.8	5.0	8.2	6.7	2.0	2.9	1.5	3.2	0.5	1.1	0.9	0.2		0.1	0.3	0.4	0.2		
Spiroplectammina biformis	4.1	8.6	3.7	6.3	11.0	6.9	6.8	5.6	2.5	2.9	1.4	2.1	0.1		0.2		0.1		0.5	0.4
Textularia earlandi	0.7	1.6	1.6	0.2		0.8	0.3	1.1		0.4		1.4								
Textularia torquata	15.5	22.0	32.9	26.8	22.1	20.2	17.3	13.3	13.0	12.4	3.8	2.8	0.6	0.1	0.2	0.4	1.0	0.2	0.5	0.2
Trifarina fluens	0.4	0.3	0.1	0.2	0.3	0.2	0.5	0.6	1.1	1.0	1.6	1.2	1.3	0.6	0.2	0.2	0.1		0.1	
Trochammina globigeriformis									0.1			0.1	0.1						0.1	0.2
Trochammina nana	1.6	2.7	4.4	3.2	2.9	3.6	4.5	2.3	1.2	3.0	1.5	1.2	0.1	0.2	0.2		0.4	0.2	2.2	2.1
Trochammina squamata														0.1						
Planktics						0.2									0.1	0.3		0.1	0.1	
Linings	0.5	0.3		0.2	0.2	0.6	1.4	0.7	0.8	1.0			0.4							0.2
Tintinnopsis rioplatensis (10 cm^3)	1180	760	1384	760	232	284	224	228	304	130	192	64	16	0	0	0	0	0	0	0
Total Foraminifera (10 cm^3)	7236	5987	6677	5232	2464	3643	3610	4530	5784	4450	10295	4714	8928	6343	21717	17707	19150	32352	35333	16672
% 45-63 microns	43.4	32.9	44.7	38.1	35.9	48.3	57.1	58.2	67.9	71.4	76.8	61.4	60.9	65.3	83.7	85.1	74.6	79.8	56.4	51.1
% Calcareous Foraminifera	36.2	19.5	12.5	14.0	5.7	22.0	35.6	52.4	56.6	62.5	83.5	80.4	95.5	99.1	98.4	97.6	95.8	98.3	95.2	95.6

APPENDIX 1D: BC-14 Microfossil Assemblage

Depth (cm):	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	11	13	15	17	19	22.5	27.5	32.5	37.5	42.5
Allogromia sp.	1.0	1.5	0.3						0.4							0.3	0.3	0.1	0.2	
Adercotryma glomerata	0.3	0.4	0.5	1.1	2.0	1.9	1.3	1.1	2.9	0.2	1.0	0.4	1.1	0.2	0.6	0.9	1.1	1.0	0.8	0.3
Bathysiphon argenteus					0.4	0.2	1.1	1.1	0.4	1.0	0.5	0.6	0.2		1.5	0.3			0.4	0.5
Bolivina arctica	0.9	1.4	4.2	4.2	3.8	1.2	0.2	0.3		0.5	1.5	0.6	1.3	1.4	3.6	3.3	2.8	4.3	4.0	4.3
Bolivina pseudopunctata	1.2	0.8	0.4	0.7	0.4				0.2	0.5	0.8	1.7	1.3	1.2	1.9	1.6	1.1	1.3	1.3	1.0
Buccella frigida	1.9	0.1	0.1		0.2			0.3						0.1			0.2	0.3	0.2	
Buliminella hensoni	49.9	28.0	22.1	15.3	0.8	1.0	8.5	11.4	30.4	26.4	46.3	44.9	46.3	60.0	50.3	50.0	48.0	55.7	49.6	53.3
Cassidulina reniforme	0.3				0.2						0.5	1.0	3.4	1.0	2.5	5.3	5.2	4.3	5.0	3.5
Cibicides lobalatus																0.2				
Cribrostomoides crassimargo			0.4	0.2		1.4	1.1				1.0				0.4		0.2	0.1		
Cribrostomoides jeffreysi	0.1		0.6																	
Cyclogyra involvens	1.0	1.6	1.2	1.5	2.0	5.0	2.2	2.9	3.3	0.2	2.2	1.9	0.7	0.9	1.0	0.3		0.9	0.8	0.1
Dentalina frobisherensis																			0.2	
Dentalina sp.			0.1	0.2																
Eggerella advena	1.9	1.5	3.1	2.6	1.8	1.7	0.9	2.1	1.8		2.2	1.9	2.0	2.2	2.5	0.9	0.5	0.8	1.3	0.8
Elphidium exc forma clavatum	0.7	1.6			0.2				1.0	0.7			0.7	0.6		0.7	0.6	0.9		0.1
Elphidium exc forma excavatum		0.1														0.2				
Eoponides pulchella	0.3	0.4	0.2		0.4		0.2	0.3		0.5	0.5	1.0	0.5	0.5		0.3	0.3			
Fursenkoina fusiformis				0.2	0.4		0.7		0.4	2.9	0.7	1.9	3.4	2.1	1.1	3.1	3.0	0.9	2.9	3.4
Glomospira gordialis		0.3	0.1	1.1	0.2			0.5												
Hemisphaerammina bradyi	2.3	4.1	5.8	4.6	5.6	10.5	11.3	8.7	3.1	9.4	3.3	4.8	2.1	3.2	5.2	4.5	4.2	2.7	4.2	2.4
Hyperammina sp.	0.3	1.8	2.4	1.7	0.8		0.2				0.2									
Islandiella teretis	0.4	0.4			0.4	0.2				0.5	0.5	1.0	0.3	0.7	0.4	1.0	1.3	1.3	1.3	2.1
Lagena sp.	0.3	0.1	0.3	0.2													0.3			
Nonion barleeanum	0.3	0.4	2.5	0.4				0.5		0.2		1.4		0.7	0.2	0.3	0.3	0.3	0.6	0.4
Oolina caudigera														0.1	0.2					
Psammosphaera fusca																0.5	0.2	0.3		0.1
Pullenia bulloides		0.1	0.1		0.2			0.3												
Quinqueloculina seminulum	0.1	0.5	0.7	0.9	1.4	1.4	0.4	2.1	1.8	0.7	1.0	0.6	0.2		0.2			0.1	0.2	0.5
Recurvoides turbinatus			0.3	0.4		0.2	0.2		0.2	0.5										
Reophax arctica	1.7	9.9	9.7	5.2	9.7	8.1	7.4	7.9	4.5	9.8	3.7	4.8	2.6	5.7	5.0	3.1	1.3	2.6	3.7	2.1
Reophax fusiformis									0.2		0.3	0.2								
Reophax guttifer	0.9	1.1	1.7	0.6	1.0	0.7	0.9	0.5	0.2	0.5	0.8	0.6	0.2	0.2	1.3	2.1	0.9	0.8	0.8	0.3
Reophax scorpiurus	2.6	0.7	2.0	2.2	4.6	5.7	2.8	3.7	2.9	4.6	2.3	1.7	1.3	0.6	0.6	0.5	0.6	0.6	0.2	0.1
Reophax scottii	0.3				0.2	0.2	1.1	1.1	0.4	0.5	0.2	0.2	0.5				0.9	0.1	0.4	
Saccammina difflugiformis	8.7	6.8	8.2	5.5	15.7	9.8	11.8	10.6	12.3	7.7	6.8	7.7	6.3	1.9	5.7	4.5	6.1	3.8	3.3	2.8
Spiroplectammina biformis	1.6	1.9	4.3	5.9	5.2	5.0	5.7	3.2	3.9	4.1	3.3	3.1	4.9	3.2	1.1	1.0	2.4	1.3	1.3	2.0
Textularia earlandi	0.4	1.1	0.1	0.2	1.4	2.9	5.7	3.2	1.6	1.0	1.8	1.0	2.3	2.4	1.1	0.3	0.6	3.6	3.1	1.6
Textularia torquata	14.2	14.0	12.0	19.3	19.4	13.9	15.5	15.1	14.6	10.6	10.3	8.5	9.3	4.4	8.6	6.7	8.8	8.2	5.2	4.8
Trochammina lobata	1.4	2.0	5.8	7.6	3.4	4.8	4.1	3.4	2.3	3.8	0.8	0.8	0.3	0.2		0.3	1.1	0.1	1.5	1.6
Trochammina nana	2.0	6.8	6.0	9.2	4.0	5.5	7.2	2.1	3.3	2.6	1.7	2.7	2.0	0.9	0.6	2.4	1.7	2.2	1.3	2.6
Planktics	0.1	6.9	3.4	9.2	8.9	8.9	7.6	12.2	5.3	7.9	3.7	3.9	5.4	4.1	2.5	4.0	6.0	1.4	6.0	8.9
Juvenile calcareous	2.8	3.3	0.6		4.8	9.6	2.0	5.3	2.5	2.9	1.8	0.8	1.3	0.6	1.7	0.2		0.1	0.2	0.1
Linings		0.3	0.6		0.2			0.3			0.3	0.4	0.3	0.5	0.2	1.0	0.2			0.1
Tintinnopsis rioplatensis (10 cm^3)	202	203	346	168	218	158	197	178	200	164	193	189	194	224	236	228	158	202	144	168
Total Foraminifera (10 cm^3)	690	736	967	543	496	418	459	378	487	417	601	517	615	803	523	580	638	783	520	763
% 45-63 microns	73.3	69.0	57.3	54.9	45.8	42.6	45.3	52.1	57.1	59.5	70.0	72.5	73.2	82.4	79.2	73.4	72.7	79.2	73.1	68.4
% Calcareous Foraminifera	60.1	45.9	36.1	32.8	24.2	27.3	21.8	35.4	45.0	43.9	59.4	60.5	64.7	74.2	65.6	70.5	69.0	71.8	72.3	78.0

APPENDIX 1E: BC-3 Microfossil Assemblage

Depth (cm):	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	11	13	15	17	19	22.5	27.5	32.5	37.5
Adercotryma glomeratum	3.0	0.6	2.4	2.7	1.6	0.4			0.6	0.6	1.3	0.7	0.1	0.8	0.2	0.2	0.5	0.5	0.2
Allogromia sp.									2.9	0.2	0.8	0.5	0.8	1.3	1.1	0.6	1.1	1.0	0.9
Ammotium cassis	0.1	0.2	0.2										0.1				0.1		
Angulogerina angulosa										0.6									
Astacolus hyalocrulus										0.2	0.1								
Astronion gallowayi			0.8	0.3							0.1								
Bolivina arctica	0.1	0.2	0.4						0.6	0.2	0.1			0.8	0.4	0.2	0.1	0.4	
Bolivina pacifica											1.7								
Bolivina pseudopunctata	4.6	7.2	4.4	3.2	3.0	5.2	4.6	2.4	3.5	3.7	2.1	2.9	4.2	3.2	1.9	3.9	1.2	3.7	2.1
Buccella frigida	5.6	2.0	1.8	2.7	1.8	3.3	1.6	2.3	4.9	3.3	4.2	2.2	3.4	2.2	2.6	5.6	1.9	2.2	2.4
Buliminella hensoni	9.8	24.9	24.9	11.7	23.4	18.2	22.2	19.8	13.5	17.9	17.1	16.3	16.0	17.5	19.4	8.7	16.4	20.6	18.8
Cassidulina reniforme	11.3	11.1	7.6	9.4	10.5	14.1	14.0	15.0	15.6	13.3	11.7	21.4	17.7	21.1	21.3	19.3	23.6	25.3	21.8
Cibicides lobatulus			0.4		0.3					0.4	0.3	0.4		0.3	0.4	0.2	0.1	0.2	0.2
Cribrostomoides crassimargo				0.2															
Cribrostomides jeffreysi							0.1												
Cyclogyra involvens																		0.1	0.2
Eggerella advena	0.4	3.5	1.6	1.0	2.3	0.5	0.7	1.1	0.9	0.8	0.3		0.1	0.4				0.1	
Elphidium exc forma clavatum	10.4	5.9	4.4	8.9	9.3	4.0	12.5	6.8	9.0	6.6	7.5	9.5	9.7	7.9	6.8	11.0	9.8	6.6	6.2
Elphidium exc forma excavatum			0.8	0.7	0.5	0.3	0.3	0.4			0.3	0.2				0.3			0.2
Elphidium sp.		0.2																	
Eoponides pulchella		2.0	2.0	1.0	1.9	1.9	1.5	0.6	1.8	1.0	1.6	1.8	3.7	2.3	3.4	2.4	2.2	2.9	2.6
Fissurina sp.	1.0	0.2	0.4	0.2															
Fissurina cucurbitasema	1.2	0.2			0.5	1.9	0.6	1.1	0.3	0.6			0.5	1.2	0.4			0.2	
Fissurina marginata																0.3		0.1	
Fissurina serrata																0.2			
Fursenkoina fusiformis	16.4	5.5	16.1	13.1	10.6	19.7	14.1	17.9	16.4	22.9	22.7	23.8	11.7	16.5	18.3	20.9	19.5	18.3	20.7
Glandulina laevigata								0.4			0.6				0.4		0.1		
Glomospira gordialis	0.3	0.2		0.7	0.4		0.1		0.1	0.2	0.1							0.2	
Haplophragmoides canariensis				0.3															
Hemisphaerammina bradyi	3.6	1.1	0.6	0.7	1.4	0.5	0.4	0.8	0.8	1.2	0.3	1.3	0.5	0.4	0.9	1.3	2.9	1.7	1.1
Islandiella teretis	0.7	1.3	3.2	1.3	2.2	0.6	3.3	5.9	2.6	2.1	2.8	2.6	2.2	0.3	1.1	1.3	1.0	0.8	0.9
Lagena graccilima				0.2	0.3		0.4	0.2	0.1	0.2	0.1	0.2	0.1	0.5	0.2				
Lagena meridionalis											0.1								
Lagena mollis					0.3	0.1		0.4			0.1		1.3	0.8	0.2		0.3		0.4
Nonionella auricula				0.2		1.3		0.6	0.9	0.8	1.1	1.5	0.5	0.4	0.9	0.5	1.2	0.5	0.9
Nonionella labradorica	4.1	2.6	2.8	4.2	2.5	0.5	2.4	1.3	3.0	2.3	1.3	1.1	1.0	1.3	1.5	2.6	1.1	1.4	0.8
Parafissurina fusuliformis						0.1			0.3										
Pattelina corrugata		0.4		0.2			0.1			0.6	0.3	0.4	0.1	0.3	0.4	1.8	0.5	1.2	0.9
Pleurostomella brevis										0.6									
Pyrgo subsphaerica						0.5							0.1						
Quinqueloculina agglutinans	0.6	0.2	0.6	0.2	0.2							0.4	0.4	0.1		0.2		0.2	0.2
Quinqueloculina seminulum						0.3	0.1	0.6	0.6										
Quinqueloculina stalkeri									0.1		0.8					0.2			
Reophax arctica	8.0	10.7	10.6	15.4	10.5	12.6	6.5	11.8	7.9	9.6	8.6	6.0	8.0	7.8	6.8	8.1	7.5	5.0	7.0
Reophax guttifer		0.7	0.4	1.5	1.7		1.5		0.2	0.2	0.6		1.8				0.3		1.9
Reophax scotti	0.1	3.0						0.4											
Rhabdammina sp.	0.6					0.6				0.2						0.2			
Robertinoides charlottensis				0.2						0.2	0.3					0.2			
Rosalina sp.		0.2	0.4								0.1		0.1						0.2
Saccammina atlantica									1.0	0.8	0.3	0.4							
Saccammina difflugiformis	5.5	2.4	1.8	0.7	1.0	0.4	1.5	0.8	1.5	1.0	0.8			0.6	0.2	1.1	0.4	0.2	0.2
Spiroplectammina biformis	1.5	0.6	0.6	0.5	0.8	0.4	0.3	0.4	1.2	0.2	1.0	0.7	0.1	0.8	1.1	0.8	0.1	1.6	0.9
Textularia earlandi		0.2		0.2					0.2		0.1				0.2				
Textularia torquata	6.5	7.6	5.0	11.9	6.9	3.9	3.9	5.1	3.7	3.9	4.5	2.2	8.7	3.8	4.5	3.5	3.3	3.0	2.3
Trochammina globigeriniformis			0.6					0.2											
Trochammina nana	1.6	1.8	0.8	2.0	2.5	1.4	0.6	0.2	0.8	0.6	0.6	0.4	0.7	1.7		0.5	1.1	0.6	0.4
Trochammina squammata				0.3	0.1														
Planktics									0.3		0.1	0.4	0.1			0.2	0.5	0.5	0.2
Linings	2.8	3.5	2.6	4.4	3.4	7.0	6.4	3.2	4.7	3.3	3.2	2.7	6.0	5.9	5.5	4.5	3.0	0.7	5.5
Tintinnopsis rioplatensis (10 cm^3)	1968	1872	1248	1984	2880	1672	800	1824	1416	536	456	336	720	416	432	24	8	8	40
Total Foraminifera (10 cm^3)	5400	4336	3984	4768	7636	7440	6480	7578	9344	4148	6112	4368	6104	6248	7520	4968	5864	6636	6112
% 45-63 microns	30.7	43.7	55.4	38.3	58.9	60.2	51.3	47.6	33.2	46.7	49.8	42.9	52.7	61.5	48.1	34.1	43.4	46.5	49.6
% Calcareous Foraminifera	65.3	63.8	70.7	57.4	67.2	72.2	77.8	75.9	73.5	76.9	77.4	84.6	72.6	76.4	79.6	79.5	79.7	85.2	79.5

APPENDIX 1F: BC-15 Microfossil Assemblage

Depth (cm):	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	11	13	15	17	19	22.5	27.5	32.5	37.5	42.5
Adercotryma glomerata	2.5	0.9	0.3	0.3	0.2			0.3			0.2	0.2	0.3		0.2		0.2			
Allogromia sp.	5.0	1.6	1.5	3.5	1.3				0.4		0.2	1.1								
Astronion gallowayi	0.4	0.5	0.3	0.1			0.1				0.2						0.2			
Bathysiphon argenteus	0.9	0.1					0.3				0.2	0.2								0.1
Bolivina arctica		0.1					0.1				0.1			0.4				0.1	0.1	
Bolivina pseudopunctata	3.5	2.8	2.0	2.7	2.2	2.0	1.0	2.4	1.6	0.9	1.4	2.1	2.5	1.3	2.0	0.7	1.8	1.8	1.4	1.2
Bolivina sp.									0.6											
Buccella frigida	4.9	6.3	9.4	6.1	6.6	10.1	8.0	10.8	7.0	1.4	9.6	5.7	8.4	4.6	5.0	6.6	6.9	11.1	4.7	6.3
Buliminella hensoni	1.3	0.1	2.7	2.6	0.4	2.6	1.0	2.0	6.7	4.3	2.8	4.5	1.7	2.9	2.5	1.8	2.1	1.8	1.1	3.8
Cassidulina laevigata											0.5									
Cassidulina reniforme	5.5	6.4	7.6	9.6	8.8	16.4	9.6	13.1	9.6	9.0	8.2	7.4	10.6	7.9	7.9	11.4	15.3	10.4	13.4	6.2
Cibicides lobatulus	1.3	1.2	2.0	1.6	2.4	0.3	0.7	1.2	2.7	0.6	1.3			0.4	0.3	1.8	2.5	1.1	2.3	1.7
Cribrostomoides crassimargo																				
Cribrostomoides jeffreysi																				
Cyclogyra involvens	0.3				0.1	0.3	0.4		0.2			0.2						0.3	0.6	
Dentalina sp.						0.3			0.2											
Discorbis sp.									0.4							0.6			0.5	
Eggerella advena	0.9		1.6	0.9	2.3	1.3	0.6		0.6	0.2	0.7	1.5	0.8	1.7	0.5	0.6		0.6	0.2	1.0
Elphidium exc forma clavatum	1.1	3.7	3.8	6.5	4.0	6.1	3.8	3.5	3.3	4.1	6.3	5.3	6.3	3.7	2.7	6.1	4.6	3.9	4.9	6.2
Elphidium exc forma excavatum	1.3	2.3	0.8	1.4	0.4	1.0	0.7	0.6		0.2	1.2		0.3	0.4	0.2	0.2	0.7	0.6	0.2	
Elphidium sp.												0.2								
Epistominella takayanagii	0.5					0.3							0.4						0.2	
Eoponides pulchella	3.3	3.5	4.9	4.7	2.4	3.3	8.0	6.1	3.3	5.7	3.2	5.4	3.2	2.6	2.5	5.0	3.0	3.9	3.9	2.2
Fissurina cucurbitasema											0.5									
Fissurina marginata		0.4							0.2				0.6							
Fissurina serrata			0.2		0.2							0.2	0.6				0.2		0.5	
Fissurina sp.		0.6	0.2				0.6													
Fursenkoina fusiformis	11.1	26.5	19.5	23.8	23.8	23.4	24.2	25.8	24.4	31.3	22.9	24.4	26.8	28.3	27.9	18.0	20.0	16.2	22.2	20.3
Globobulimina auricula arctica		0.3		0.1																
Glomospira gordialis																				
Haplophragmoides canariensis								0.1												
Haynesia orbiculaire			0.2	0.3	0.2		0.4	0.1				0.2			0.2		0.2		0.2	
Hemisphaerammina bradyi	15.1	0.9	1.3	0.4	0.3	0.7	0.9	0.2	0.8			0.5		0.9	0.5			2.0	1.3	0.2
Hyperammina spp.									0.2											
Islandiella teretis	3.0	5.7	6.3	4.1	6.6	4.9	5.2	3.9	3.3	0.5	4.1	1.8	4.5	1.7	3.2	5.1	1.2	1.4	2.6	3.0
Lagena laevis									0.2											
Lagena mollis											0.1		0.8	1.1	0.7	0.2	0.2	1.3	0.8	0.4
Lagena sp. 1	0.1	0.3	0.1		0.4															
Lagena sp. 2	0.8	0.1	0.4	0.6		0.3	0.1				0.2	0.5	0.3	0.4	0.3	0.4		0.3		
Nonion barleeanum				0.2	0.4	0.3		0.6	0.6					0.2						0.6
Nonionella atlantica	1.0	2.5	1.9	1.5	0.7	1.5	0.7		0.4		1.2	3.3	5.7	2.2	1.3	2.4	1.5	3.8	2.9	1.7
Nonionellina labradorica	1.1	2.2	2.1	1.6	3.7	2.5	3.9		2.9	0.7			1.7	0.4	0.2	1.3	2.2	2.2	0.5	1.3
Oolina borealis													0.3							
Oolina hexagona																	0.2	0.6		
Oolina sp.	0.1			0.1													0.2			
Parafissurina sp.		0.1			0.4	1.0		0.3		0.1				0.2						
Psammosphaera fusca																				
Pullenia subcarinata	1.9			0.3																
Pyrgo subsphaerica					0.4															
Quinqueloculina seminulum	0.1			0.1	0.7									0.9		0.2			0.2	
Recurvoides turbinatus	0.3	0.2																		
Reophax arctica	11.2	13.6	16.1	14.6	16.6	12.3	16.1	16.1	13.3	17.2	17.9	22.1	9.2	19.5	25.7	20.2	24.4	19.0	19.0	23.7
Reophax guttifer		0.3	0.4	0.4	0.6	0.2	0.4	1.6	0.6	1.3	0.9	0.8	0.7	1.1	1.3	0.9	0.2	0.3	0.6	0.6
Reophax scorpiurus	0.3																			
Reophax scottii	1.1	1.7	1.0	1.2	0.8	0.5	0.9	1.0			0.6	1.4	0.3	0.7	0.5	1.3	1.0	0.4	0.4	1.3
Robertinoides charlottensis				0.3									0.3							
Saccammina difflugiformis	4.0	0.5	0.6	0.2	0.9	0.3			0.4		0.5	0.3				0.2		0.6		
Spiroplectammina biformis	2.2	2.6	2.5	2.2	2.2	1.6	3.2	1.5	1.4	4.2	1.2	2.9	1.1	2.4	1.5	2.8	4.7	2.8	4.9	2.9
Stetsonia arctica					0.2			0.1							0.3					
Textularia torquata	8.9	8.6	5.6	6.1	5.2	2.9	4.5	5.1	5.7	11.0	5.5	3.6	7.3	6.3	8.6	3.5	1.6	6.3	4.9	9.5
Trifarina fluens		0.5	0.3	0.2		0.3	0.1		0.2					0.2		0.2			0.5	
Trochammina nana	3.0	0.7	1.2	0.7	1.4	0.2	0.7	1.2	1.8	0.5	3.5	2.0	1.1	1.8	0.8	3.3	1.0	2.9	1.8	1.7
Trochammina pseudoinflata		0.1																		
Valvulineria arctica		1.2					1.3	1.7	1.8	1.4	1.6	0.2	2.1	0.4	0.8	1.3	0.7	1.0	0.5	0.7
Planktics	0.3	0.2	1.1		0.4	2.9	0.6	0.3		0.1	0.2	0.2				0.4	0.5			0.4
Lining	1.8	0.6	1.7	1.3	2.4	0.2	1.9	0.5	5.3	5.3	2.7	2.6	2.2	5.2	2.3	3.7	2.3	3.4	2.8	3.1
Tintinnopsis rioplatensis (10 cm^3)	367	120	74	64	26	20	40	24	30	40	0	8	8	24	8	16	16	0	0	0
Total Foraminifera (10 cm^3)	4947	3436	2609	3688	1620	2444	5528	2652	5113	3160	6568	5320	5728	4328	4768	8704	6488	5696	6848	7576
% 45-63 microns	1367	1290	778	1262	282	368	1944	798	2310	2460	2080	2160	2416	1832	2320	3488	2016	1824	2640	3440
% Calcareous Foraminifera	44.2	67.6	68.9	70.8	66.0	82.5	71.6	74.4	76.3	64.6	68.6	65.7	78.6	62.9	60.2	65.4	66.6	63.6	65.2	59.9

APPENDIX 2 – ^{14}C RESULTS

Foraminifera (*I. teretis* & *C. reniforme*) picked from the 18-20 cm interval of box core 13 was radiocarbon dated at NOSAMS. Below (Table A3-1) are the results for this analysis.

Table A3.1 – ^{14}C analysis results from NOSAMS

Receipt #	81138
Date Reported	8/24/14
Submitter Identification	Benthic Foraminifera
Type	Foraminifera
Process	(HY) Hydrolysis
Accession #	OS-81778
F Modern	0.4344
Fm Err	0.0021
Age	6700
Analytical Error	40

Table A3.2 –Radiocarbon Date Calibration

Radiocarbon age	6700 ± 40 ^{14}C yrs BP	provided by NOSAMS
Δ R value	110 ± 65 yrs	from Coulthard et al. (2010)
Calibrated Age	6914 – 7271 cal yrs BP	from CALIB. REV. 6.0.1
Mean Calibrated Age	7093 ± 179 cal yrs BP	calculated from calibrated age
Avg. Mean Calibrated Age	7100 ± 180 cal yrs BP	rounded mean calibrated age

APPENDIX 3: Geochronological Interpretation – Age Model

Age models were constructed for each of the cores based on the end of the excess ^{210}Pb domain (~1895), ^{137}Cs first onset (~ 1954), and the sedimentation rates (App. 2). When the ^{137}Cs data corroborate the ^{210}Pb data, (BC-10 and BC-13) the ^{137}Cs first entry depth is used as a time marker. However, when the ^{137}Cs data do not agree with the ^{210}Pb data, the sedimentation rates are extrapolated upward from the base of the ^{210}Pb domain (BC-3, BC-12, BC-14, & BC-15).

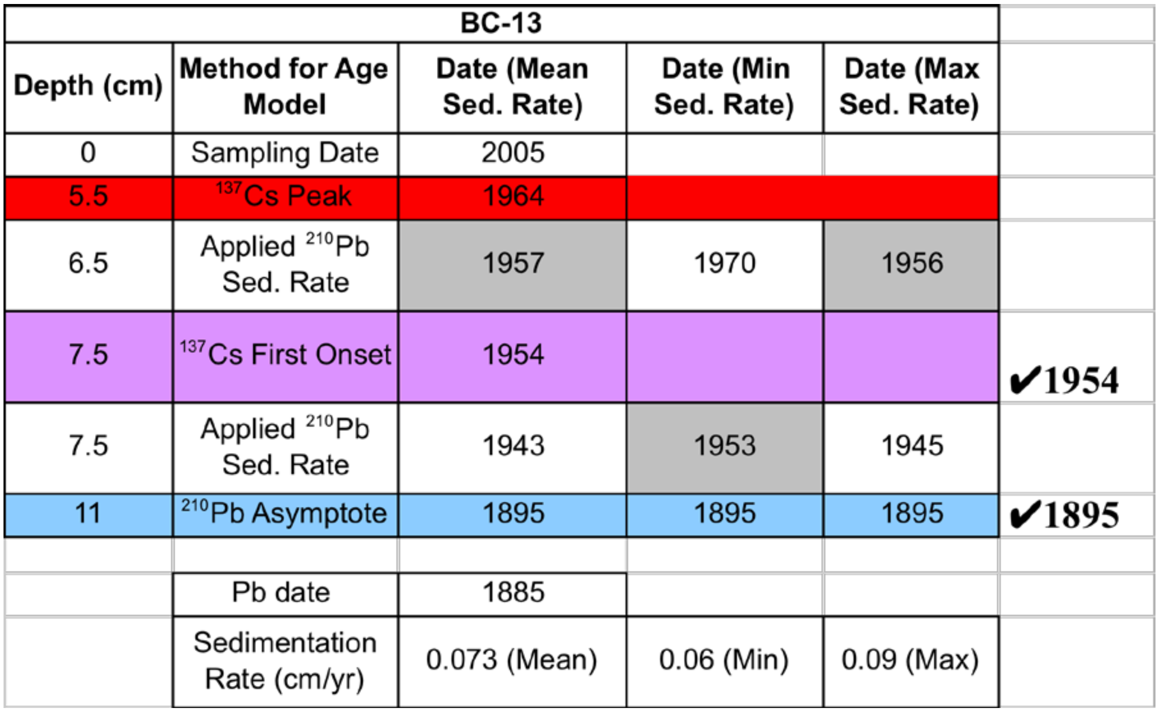
Table A3.1 – Age model and geochronology for BC-10. Since the ^{137}Cs data corroborate the ^{210}Pb data, they are used to represent 1954 (4 cm).

BC-10					
Depth (cm)	**Method for Age Model**	**Date (Mean Sed. Rate)**	**Date (Min Sed. Rate)**	**Date (Max Sed. Rate)**	
0	Sampling Date	2005			
1	^{137}Cs Peak	1964			
2	Applied ^{210}Pb Sed. Rate			1901-1986	
3	Applied ^{210}Pb Sed. Rate	1912-1997		1895-1980	
4	^{137}Cs First Onset	1954			**✓ 1954**
4.5	Applied ^{210}Pb Sed. Rate	1887-1972	1908-1993	1876-1961	
7	^{210}Pb Asymptote	1845-1930	1845-1930	1845-1930	**✓~1895**
	Pb date	1845-1930			
	Sedimentation Rate (cm/yr)	0.06 (Mean)	0.04 (Min)	0.08 (Max)	

Table A3.2 – Age model and geochronology for BC-12. The first onset of the ^{137}Cs in BC-12 is within the mixed layer and does not corroborate the ^{210}Pb data, so the sedimentation rate is used to determine the 1954 date (5 cm)

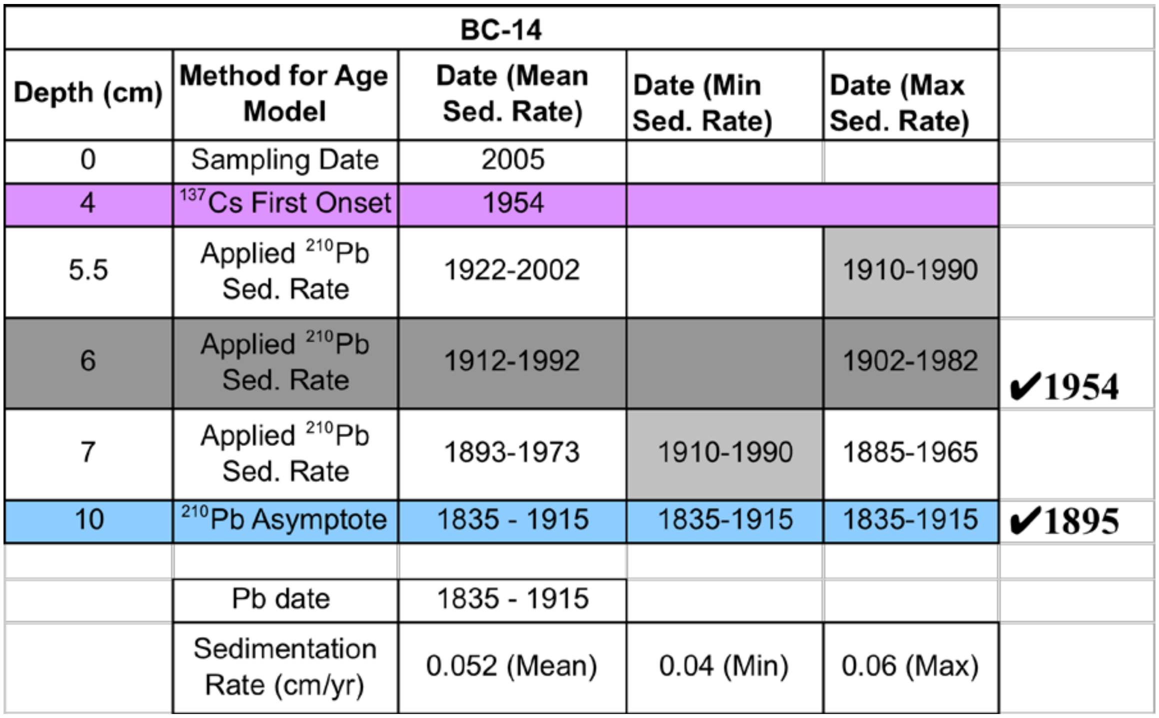
BC-12					
Depth (cm)	**Method for Age Model**	**Date (Mean Sed. Rate)**	**Date (Min Sed. Rate)**	**Date (Max Sed. Rate)**	
0	Sampling Date	2005			
2	^{137}Cs First Onset	1954			
3	Applied ^{210}Pb Sed. Rate	1968	1980	1953	
5	Applied ^{210}Pb Sed. Rate	1955	1964	1942	✔**1954**
6	Applied ^{210}Pb Sed. Rate	1948	1957	1937	
14	^{210}Pb Asymptote	1895	1895	1895	✔**1895**
	Pb date	1895			
	Sedimentation Rate (cm^2/yr)	0.15 (Mean)	0.13 (Min)	0.19 (Max)	

Table A3.3 – Age model and geochronology for BC-13. The first onset of ^{137}Cs is complimentary and within range of the ^{210}Pb data, and is used to represent 1954 (7.5 cm).



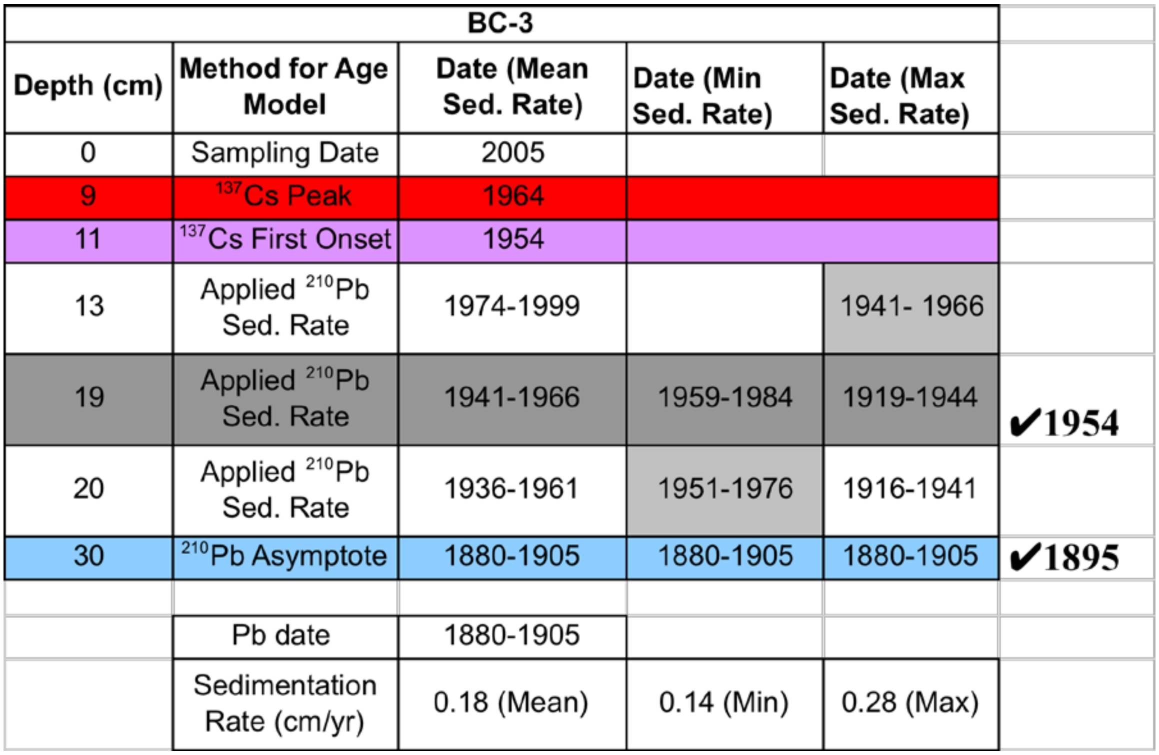
BC-13					
Depth (cm)	**Method for Age Model**	**Date (Mean Sed. Rate)**	**Date (Min Sed. Rate)**	**Date (Max Sed. Rate)**	
0	Sampling Date	2005			
5.5	^{137}Cs Peak	1964			
6.5	Applied ^{210}Pb Sed. Rate	1957	1970	1956	
7.5	^{137}Cs First Onset	1954			**✓1954**
7.5	Applied ^{210}Pb Sed. Rate	1943	1953	1945	
11	^{210}Pb Asymptote	1895	1895	1895	**✓1895**
	Pb date	1885			
	Sedimentation Rate (cm/yr)	0.073 (Mean)	0.06 (Min)	0.09 (Max)	

Table A3.4 – Age model and geochronology for BC-14.The sedimentation rate is used in BC-14 to determine the 1954 date (6 cm), as the ^{137}Cs does not corroborate the ^{210}Pb data.



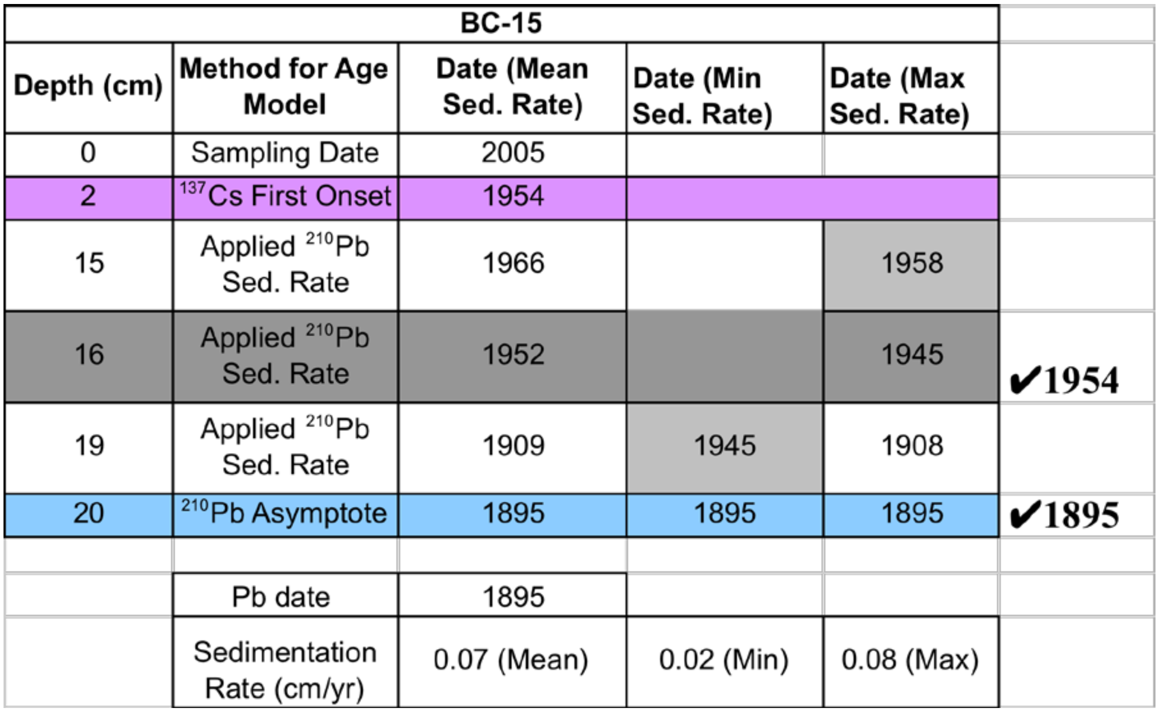
BC-14					
Depth (cm)	**Method for Age Model**	**Date (Mean Sed. Rate)**	**Date (Min Sed. Rate)**	**Date (Max Sed. Rate)**	
0	Sampling Date	2005			
4	^{137}Cs First Onset	1954			
5.5	Applied ^{210}Pb Sed. Rate	1922-2002		1910-1990	
6	Applied ^{210}Pb Sed. Rate	1912-1992		1902-1982	✔1954
7	Applied ^{210}Pb Sed. Rate	1893-1973	1910-1990	1885-1965	
10	^{210}Pb Asymptote	1835 - 1915	1835-1915	1835-1915	✔1895
	Pb date	1835 - 1915			
	Sedimentation Rate (cm/yr)	0.052 (Mean)	0.04 (Min)	0.06 (Max)	

Table A3.5 – Age model and geochronology for BC-3. The sedimentation rate is also used in BC-3 to determine the 1954 date (19 cm), as the first onset and peak in ^{137}Cs are not complimentary.



BC-3					
Depth (cm)	**Method for Age Model**	**Date (Mean Sed. Rate)**	**Date (Min Sed. Rate)**	**Date (Max Sed. Rate)**	
0	Sampling Date	2005			
9	^{137}Cs Peak	1964			
11	^{137}Cs First Onset	1954			
13	Applied ^{210}Pb Sed. Rate	1974-1999		1941- 1966	
19	Applied ^{210}Pb Sed. Rate	1941-1966	1959-1984	1919-1944	✓1954
20	Applied ^{210}Pb Sed. Rate	1936-1961	1951-1976	1916-1941	
30	^{210}Pb Asymptote	1880-1905	1880-1905	1880-1905	✓1895
	Pb date	1880-1905			
	Sedimentation Rate (cm/yr)	0.18 (Mean)	0.14 (Min)	0.28 (Max)	

Table A3.6 – Age model and geochronology for BC-15. The sedimentation rate is also used in BC-15 to determine the 1954 date (16 cm).



BC-15					
Depth (cm)	**Method for Age Model**	**Date (Mean Sed. Rate)**	**Date (Min Sed. Rate)**	**Date (Max Sed. Rate)**	
0	Sampling Date	2005			
2	^{137}Cs First Onset	1954			
15	Applied ^{210}Pb Sed. Rate	1966		1958	
16	Applied ^{210}Pb Sed. Rate	1952		1945	**✔1954**
19	Applied ^{210}Pb Sed. Rate	1909	1945	1908	
20	^{210}Pb Asymptote	1895	1895	1895	**✔1895**
	Pb date	1895			
	Sedimentation Rate (cm/yr)	0.07 (Mean)	0.02 (Min)	0.08 (Max)	