COMPARISON OF LATE HOLOCENE OCEANOGRAPHIC AND SEDIMENTOLOGIC RECORDS FROM THE AMUNDSEN GULF, NORTHWEST TERRITORIES

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Submitted in Partial Fulfilment of the Requirements
for the Degree of Bachelor of Science, Honours
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April 28 2006

ABSTRACT

Analysis of sediments was performed on two box cores collected as part of the Canadian Arctic Shelf Exchange Study (CASES). The two stations examined (stations 403B (59 m) and 415B (56 m)) are located in the Amundsen Gulf. The study was undertaken in order to develop a record of changes in the sedimentologic and oceanographic history of the area. Arctic benthic foraminiferal assemblages of the Late Holocene (403B) and Pleistocene (415B) have contrasting sedimentation rates. Core 403B is from an area of high sedimentation from on the Beaufort Shelf, where the Mackenzie River outputs sediments. Core 415B is from an area of low sedimentation on the steep slope of Banks Island, and lacks sediment input from a large river system. Core 415B is from a location that has drumlin-like features and ice-scouring, which are revealed with multibeam sonar. By comparing and contrasting 403B and 415B, a broader interpretation of the natural history of the Amundsen Gulf is revealed. Foraminifera >63 µ from 403B revealed that this is a shelf environment abundant in *Cassidulina reniforme*, *Islandiella teretis*, *Spiroplectammina biformis*, and *Elphidium spp*., with an interval barren in foraminifera, except for a rare assemblage of *Reophax spp*. The most abundant foraminifera >45-63 µ from 403B were *Bolivina arctica, Textularia earlandi*, *Reophax scotti* and *Eggerella advena*. There were more foraminifera >63 µ than >45-63 µ.Foraminifera >63 µ from 415B revealed that this was once a Pleistocene shoreline abundant in *Bolivina arctica*, as well as *Spiroplectammina biformis* and *Reophax arctica*. The environment gradually became a shelf environment abundant in *Spiroplectammina biformis*, *Textularia earlandi*, and *Trochammina globigerinforims*. The most abundant foraminifera >45-63 µ from 415B were *Bolivina arctica, Textularia earlandi,* and *Spiroplectammina biformis*. There were significantly more foraminifera >63 µ than >45-63 µ. More individuals were found in 415B than in 403B, and the species diversity was slightly higher in 415B than in 403B. Core 403B represents approximately the last 350 years of a shelf environment with an interval barren in foraminifera. This barren zone could be due to carbonate dissolution. When trying to find similar past environments such as this one, only deep-water environments seem to match. Core 415B is a progressively deeper environment, which starts as a Pleistocene shoreline and becomes deeper with the abundance of deep-water species and shelf species. Both cores seem to show that they have been influenced by either Arctic Surface Water or Arctic Intermediate Water in their natural history. This study will contribute to the assessment of factors that presently influence sea ice cover, a key element of the Arctic ecosystem.

Key Words: foraminifera, Amundsen Gulf, Late Holocene, Pleistocene, Arctic, Canadian Arctic Shelf Exchange Study.

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ACKNOWLEDGEMENTS

The following work would not have been possible without the help of my supervisor Dr. David B. Scott,to whom I express my thanks. Dr. Scott provided me the valuable opportunity to participate in the Canadian Arctic Shelf Exchange Study (CASES) over the past year. He also assisted in providing some background literature, preliminary data and photography from CASES, assistance in foraminiferal identification and direction in interpretations of the results that I produced. Data collection and support was possible through CASES and affiliated groups, CCGS *Amundsen*, Ocean Mapping Group at the University of New Brunswick, Natural Sciences and Engineering Research Council of Canada, Natural Resources of Canada (Bedford Institute of Oceanography), Canada Foundation for Innovation (CFI) and ArcticNet. I would like to thank Dr. Patrick Ryall for giving the Honours Thesis class deadlines, encouraging the class to present in various conferences over the past year, and assistance in correcting rough drafts. I owe credit to Chloe Younger at the Centre for Environmental and Marine Geology at Dalhousie University for the x-rays of the boxcores, the use of the laboratory, archiving notes, showing me various methods to process the samples and descriptions of the samples. Dr. Trecia Schell gave me tips on producing the foraminiferal percentage graphs and supplied me with recent literature on the Amundsen Gulf. I owe credit to Kate Jarrett at the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia, for splitting, photographing, and helping with the preliminary description of the boxcores. Frank Thomas at BIO produced the scanning electron microscope photographs. Hasley Vincent, a Ph.D. Candidate at Dalhousie University, helped me with the schematic vertical sections and allowed me to use his template for stratigraphic columns in Corel Draw. I would also like to thank everyone at the Department of Earth Sciences at Dalhousie for a great undergraduate experience and the graduating class of 2006. Finally I would like to my parents for their continual support over the past four years as well as my extended family in Halifax.

CHAPTER 1 INTRODUCTION

The ecological impacts of climate warming are a popular topic of study in today's scientific community. Previous reports by the Intergovernmental Panel on Climate Change (IPCC) predicted that doubling of carbon dioxide in the atmosphere would result in global average annual temperatures to increase by 1.5 to 4.5°C. Computer models today have predicted this increase to be as high as 11°C, however some scientists are not convinced with these models, but do believe that higher increases are possible (Adam, 2006). Climate change can be defined as the variation of the average state of climate over an extended period of time (Baede, 2001). The Canadian Arctic is demonstrating dramatic changes to its climate, which are evident in changes to the permafrost and sea ice cover. These changes can affect the well-being of species which depend on particular ecological processes and conditions that have been typical of this Arctic region. Changes in the Arctic climate can also affect Inuit communities of the region, whose traditional way of life is dependent on access to marine mammals and other species in turn dependent on what is now a threatened Arctic environment. The Inuvialuit of Banks Island find it increasingly dangerous to hunt on the sea ice (Ashford and Castleden, 2001). The extreme climatic conditions present many practical challenges to conduct research of the Arctic region. Consequently, the collection and analysis of historical changes in Arctic oceanography and sedimentation data is a valuable means of beginning to shape a more thorough scientific understanding of Arctic natural history.

1.1 Aim

Over the course of a year (September 2003- August 2004), the Canadian Arctic Shelf Exchange Study (CASES) operated from the Canadian Coast Guard Ship, CCGS *Amundsen* in Western Canadian Arctic (Fig. 1.1). The research activities of CASES involved the collection of a multitude of scientific data from the Beaufort Shelf ecosystem (Fig. 1.2). The focus was to determine the impacts of climate warming on the biological and physical processes of the Beaufort Shelf, and apply these conclusions on global scale (CASES, 2004).

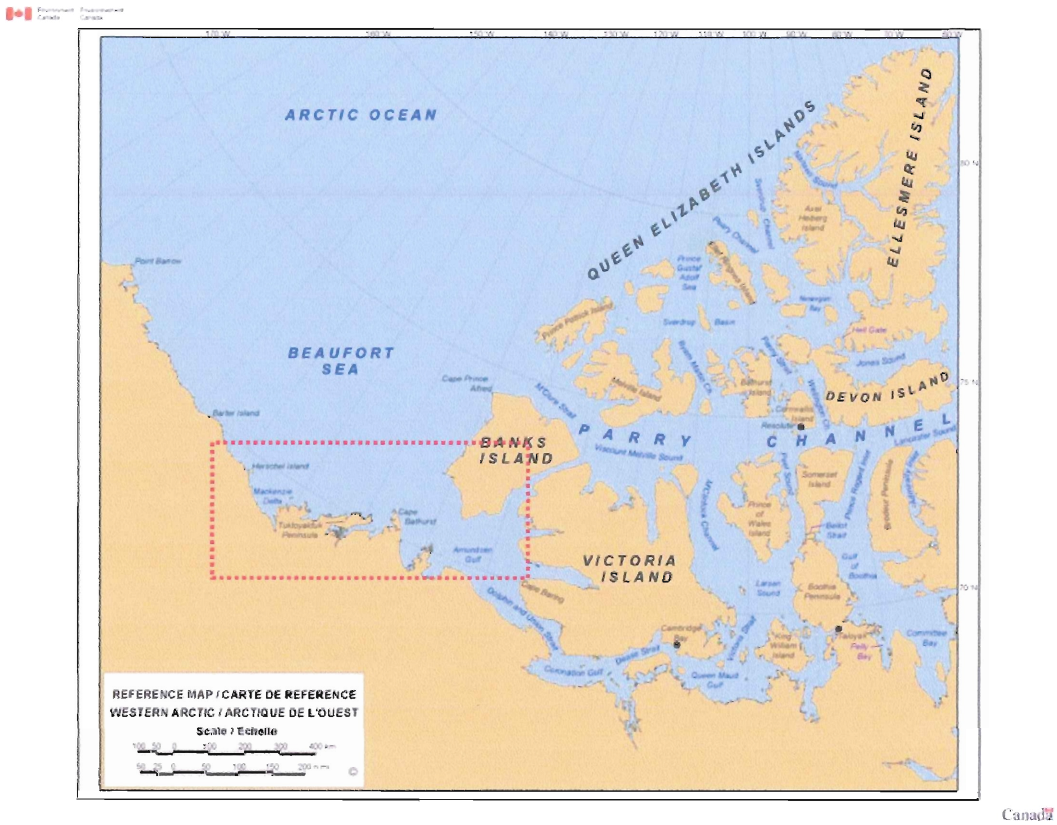


Figure 1.1: Location of Beaufort Sea and Amundsen Gulf in Western Canadian Arctic Ocean. A red dotted box indicates the CASES study area seen in Figure 1.2 (modified from Canadian Ice Services, Environment Canada).

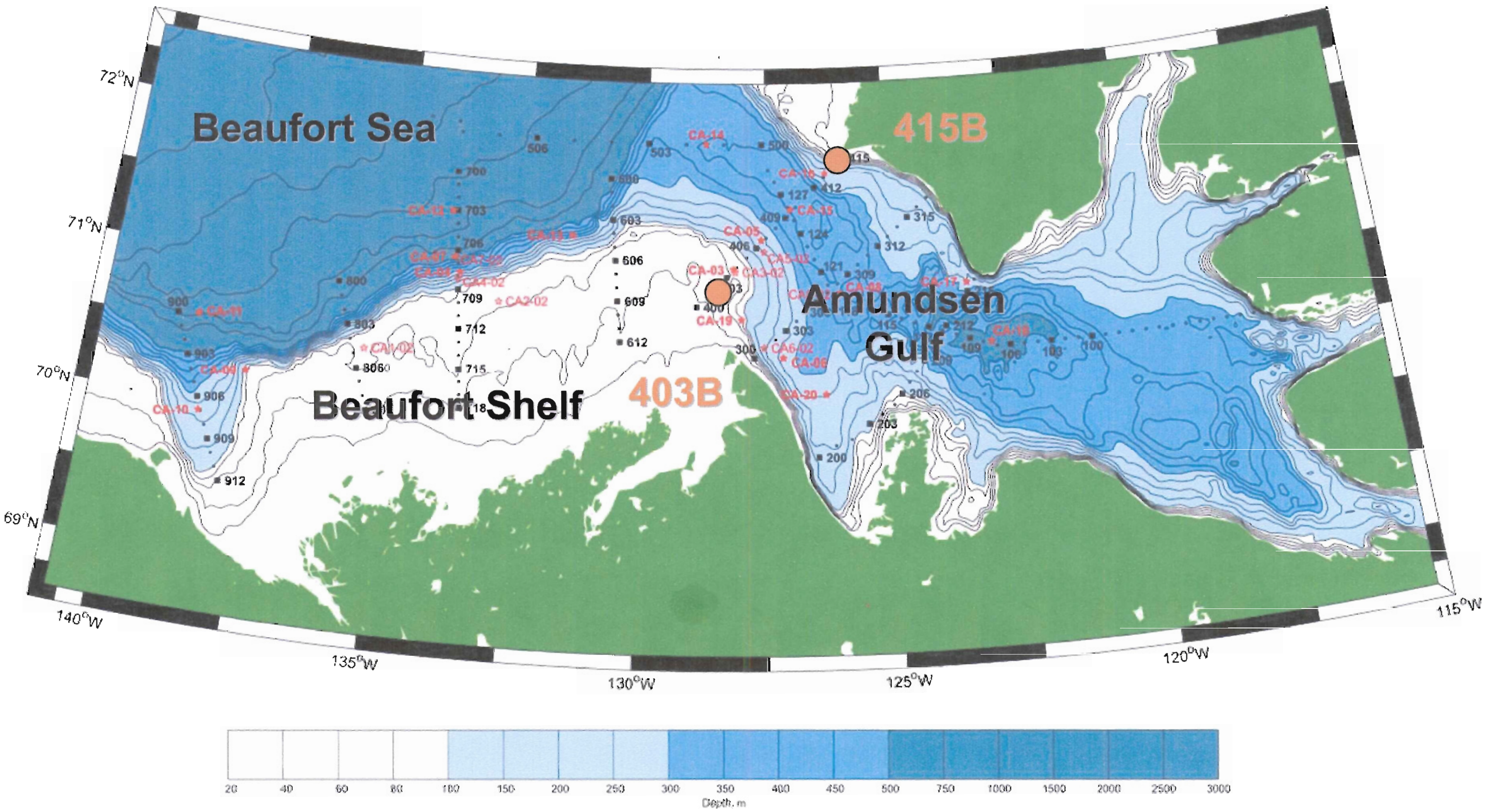


Figure 1.2: Location of boxcores 403B and 415B from the Amundsen Gulf, Northwest Territories (from CASES, 2004).

CASES (Leg 8, 9: June to September 2004) collected 51 boxcores and 10 piston cores from the Beaufort Shelf. The 51 boxcores were used to obtain pushcores and surface samples for foraminifera, dinoflagellettes, and larger shells. Ten piston cores, sections of gravity cores, 9 plankton tows (40-50 m deep), and 6 drift sediment traps (~50 ml) were also obtained. The two CASES boxcores (403B and 415B) discussed in this thesis were collected in July of 2004 from opposite sides of the Amundsen Gulf, located on the southeast side of the Beaufort Sea, offshore of the Northwest Territories, Canada (Fig. 1.2). The 29 cm long boxcore from station 403B was collected at water depth of 59m (latitude 71°06.777'N, longitude 128°18.302'W). The 22 cm long boxcore from station 415B was collected at water depth of 56 m (latitude 71°54.455'N, longitude 125°52.092'W). The comparison of these two boxcores is used to show differences in foraminiferal assemblages between an environment of high sedimentation (core 403B) and an area of low sedimentation with evidence of glaciation (core 415B). Areas of low sedimentation usually allow for the entire section of the Pleistocene (Scott and Vilks, 1991). This contrast will provide insight into glacial records and Arctic productivity.

1.2 Biogenic Sediments: Foraminifera

An effective way of obtaining data on Arctic paleoceanography is the use of biogenic sediments, such as foraminifera, to indicate boundaries for water masses and the specific Arctic environment (Thurman and Trujillo, 2002). Oceanographic factors such as salinity, temperature, oxygen concentration, turbidity and carbonate dissolution, are influential to the distribution of foraminifera.

Foraminifera are single-celled protozoans that have a range in size from macroscopic to microscopic. They ingest other organisms, since they do not photosynthesize. Foraminifera are in close relation to radiolarians and coccolithophores, however, radiolarians are siliceous, and coccolithophores photosynthesize (Thurman and Trujillo, 2002). Lagoe (1977) stated that most Arctic foraminifera are of the suborder Rotaliina (95%) and others fall under the suborder Miliolina (5%), and very few under Textulariina. Foraminifera can be classified as being calcareous or agglutinated. Lagoe (1977) also stated that agglutinated species only account for 0.1 percent of the total fauna (Cooper, 1964; Anderson, 1963; Todd and Low, 1966; Leslie, 1963; Phleger, 1952; Vilks, 1969).

Calcareous foraminifera have calcite tests with chambers, and are a significant source of calcium carbonate biogenic ooze. Calcareous foraminifera are typically abundant in shallow areas (Lagoe, 1977), beneath warm surface water (Thurman and Trujillo, 2002), where the environment has high salinity and is non-turbulent. Such an environment can be found in the Arctic, after sea ice has melted (Schell et al., 2005). Calcareous species that are highly ornamented are thought to be correlated to high availability in calcium carbonate in cold, Arctic waters (Lagoe, 1977).

It is thought that the bottom water in the Arctic originates from the North Atlantic. Therefore the carbonate compensation depth for the North Atlantic should be similar to the Arctic Ocean, which is between 4,500 and 5,000 m (Li et al., 1969). The carbonate compensation depth is the depth at which carbonate dissolution begins. The stations in this project were not subject to the carbonate compensation depth, since they are at 60 m depth have areas abundant in calcareous species (Lagoe, 1977).

Agglutinated foraminifera form from detrital sand or silt grains glued together by organic material or hematitic cement. Agglutinated foraminifera are typically in abundance where there is high biological productivity and more organic matter. They are often in areas where the seawater has low oxygen due to high biological demand and lower pH causing low carbonate preservation (Schell et al., 2005). Agglutinated foraminifera are abundant in deep Arctic waters, and often dominant on the Arctic and subarctic shelf and shallow sea (eg. *Eggerella*, *Textularia*, *Adercotryma* , *Trochammina* and *Reophax*) (Lagoe, 1977). Scott and Vilks (1991) found for the first time a diverse assemblage of agglutinated species at depths of 800 to 1,000 m in deep-sea Arctic material near the Fram Strait.

1.3 Background

1.3.1 Late Quaternary Paleoceanography

The Quaternary period is in the Cenozoic Era and spans the Pleistocene Epoch (1.8 Ma – 10,000 years ago) and the Holocene Epoch (10,000 years ago to present). The Late Quaternary period is characterized by the last glaciation between 80,000 and 10,000 years ago. Ice sheets oscillated in size many times during the Quaternary, but were at their largest around 21,000 years ago, which is known as the Last Glacial Maximum (LGM). Global sea level at this time was 120-135 m lower than it is today. The Late Quaternary ice sheets affected the chemistry and circulation of the oceans, the atmosphere, albedo of the surface and sea level (Siegert, 2001). The Younger Dryas climate reversal was a sudden switch in the ocean conveyor about 12,000 to 11,000 years ago. It caused the sea surface temperature (SST) in the North Atlantic to become colder and therefore land masses in the region became colder, reversing deglaciation (Imbrie et al., 1992; Hughes et al., 1998).

1.3.2 Water Masses and Circulation

It is important to know the oceanographic conditions of the areas that are under study. As stated earlier, foraminiferal assemblages can characterize different oceanographic conditions.

Oceanic convection in the world oceans is driven partly by climatic conditions in the polar regions, allowing seawater to form into sea ice and produce brines. The formation of sea ice causes the upper layer of the ocean under it to increase in density and salinity. This water sinks to form a water mass known as deep-water, which is particularly important in the Arctic Ocean because it is where ice formation generates the Arctic Bottom Water (ABW) in the Greenland and Norwegian Seas (Fig. 1.3). Heat transport is enhanced or restricted due to the turning on or off of heat pumps across a glacial-interglacial cycle (Siegert, 2001).

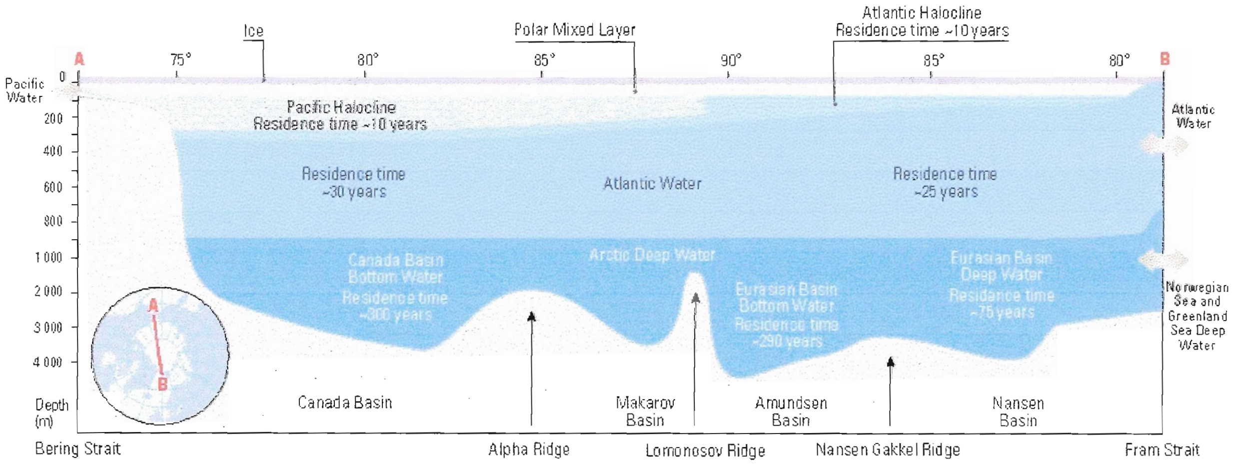


Figure 1.3: Schematic diagram representing a three-layer structure of the Arctic Ocean, with the Arctic Surface Layer above the Atlantic Intermediate Water and Arctic Deep Water. The residence time of water molecules of the various water masses are shown (AMAP, 1998).

1.3.3 Shelf Dynamics

There are five major rivers that flow into the Arctic Ocean. These rivers are the Yenisey River, Lena River, Ob River, in Russia and the Mackenzie River, and Yukon River in Canada. These are shown in Figure 1.4. The Mackenzie River has about 281 km^3 of discharge annually (Grabhorn, 2004).

The Canada Basin (Fig. 1.4) has two different environments when considering seafloor physiography, sedimentary processes and oceanography. Canada Basin environments are located in the west, where relatively warm freshwater runoff from two major rivers empties onto the shallow Beaufort Shelf. In the summer, there is open water or intermittent polar pack ice. The second environment is the deep shelf off Queen Elizabeth Island where there is very little runoff and few sediments from the shelf and channels that run between the islands. The shelf and channels act as a conduit for the south-easterly flow of offshore Arctic water toward Baffin Bay. Throughout the melting season, most channels are covered with multilayer pack ice and the extent of open water can be limited to shore leads and occasional polynya (Vilks, 1989).

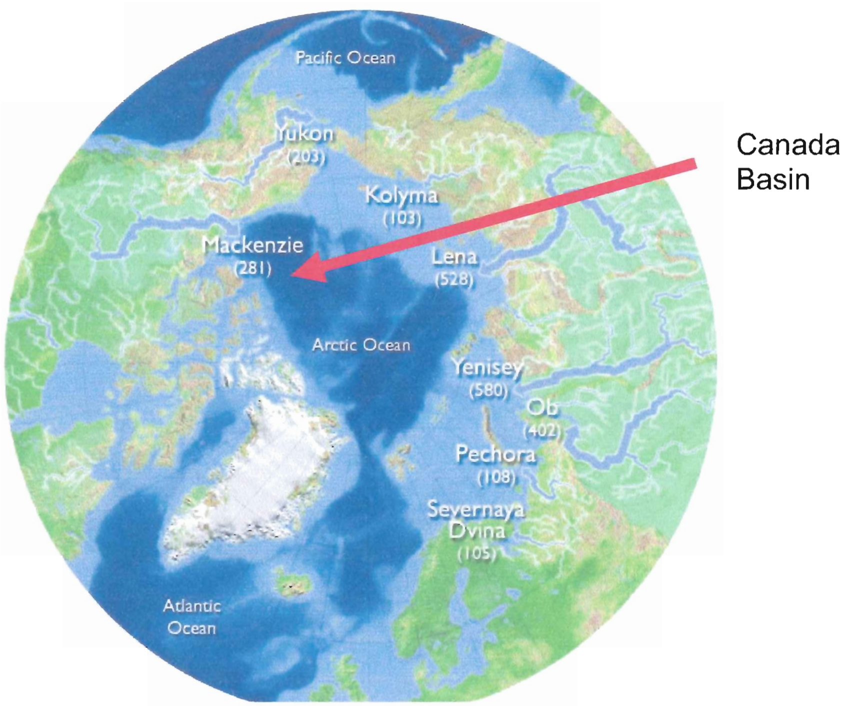


Figure 1.4: Location of the major river systems in the Arctic. Numbers refer to the discharge in cubic kilometers per year (modified from Grabhorn, 2004).

The seafloor morphologies at stations 403B and 415B contrast each other. The Beaufort Shelf is relatively shallow and slopes gently towards the 100 m isobath where a sharp slope break characterizes the shelf edge. In contrast, offshore Banks Island is steeper and the shelf is shorter (Fig. 1.2).

The seafloor at station 403B (Fig. 1.5a) has sediment with brittle stars, starfish, and shell fragments, while the seafloor at station 415B shows a significant amount of cobbles and pebbles, and various sea urchins along with sediment and shell fragments (Fig. 1.5b). The cobbles and pebbles are rounded and may represent a past shoreline.

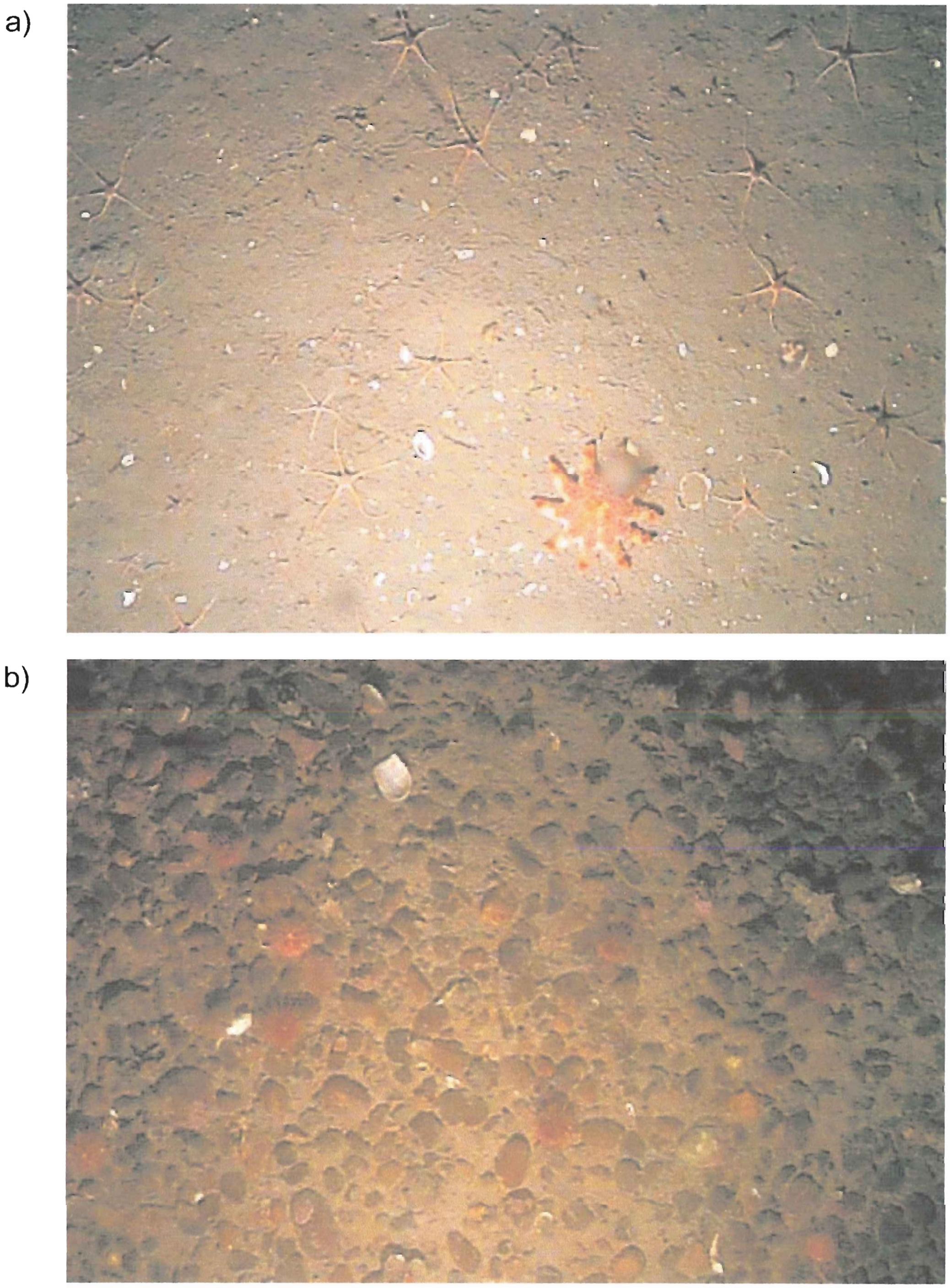


Figure 1.5: Photographs of the Amundsen Gulf floor a) station 403B b) station 415B (CASES, 2004).

1.3.3.1 Sedimentation Rate

Harper and Penland (1982) reported that the Yukon and the Mackenzie rivers deliver silt and sand onto the Beaufort Shelf, which is redistributed by longshore currents. Without interference by winds, the Mackenzie River sediment plume normally migrates along the coast towards the east, near station 403B.

Sedimentation rates for station 403 were estimated by using rates from known neighbouring stations. Station 406 is located on the gentle slope between the eastern side of the Beaufort Shelf and the Amundsen Gulf (latitude 71°18.66'N, longitude 127°41.91'W). Pb^{210} dating found sedimentation rates at 406 were found to be 0.08 cm per year (from Amundsen and Cochran, SUNY, 2006). If sedimentation rates at 403 were similar to 406, core 403B would represent approximately the last 363 years. If sedimentation rates were similar to another neighbouring station, 206 (latitude 70°19.28'N, longitude 124°50.69'W), which has a rate of 0.16 cm per year, then core 403B would represent approximately the last 181 years. The sedimentation rate for station 406 is used later as part of the interpretation in Chapter 4.

Studies by Ku and Broecker (1967), Hunkins and Kutschale (1967) and Clarke (1970) found sedimentation rates in the Arctic Ocean to be between 0.015 and 0.003 cm per 100 years. Sedimentations rates were found to be 0.49 cm per

100 years in the Canadian Arctic Archipelago area, which was thought to be a short runoff season (data was also very scarse at this time) (Vilks, 1969). Sedimentation rates for station 415 were not produced and there are no adequate neighbouring stations to approximate a rate. Scott et al. (1989) reported 1 cm per 10^4 years in the central Arctic Ocean. As stated earlier, sometimes areas of low sedimentation allow for the recovery of the entire Pleistocene section (Scott and Vilks, 1991). Core 415B has evidence for it being part of the Pleistocene, and this will be discussed later on in this report.

In the Canada Basin area, Lagoe (1977) found that variations in substrate (weight percent coarse sediment) did not have an influence on foraminiferal distribution. However, Fagerlin (1971) found a correlation with the dominance of *Eponides tener* in coarse sediment and the dominance of *Stetsonia horvathi* in finer sediment.

1.3.4 Sea Ice Cover

In the winter, sea ice along the continental margin of the Beaufort Sea consists of offshore polar pack ice, shore fast ice, and first year ice between the two zones, which is about 1-2 m thick (Barber and Hanesiak, 2004). These characteristics suggest some very practical challenges to sedimentation data from an environment such as this one.

Barber and Hanesiak (2004) examined sea ice concentration changes over the period of 1979 to 2000. The purpose of this study was to assess the spatial and temporal responses of sea ice to changes in atmosphere and oceanic forcing in the region of the Western Canadian Arctic.

CASES divides the region of the Western Canadian Arctic into three regimes (Fig 1.6): 1) offshore pack ice, which is mobile annually, and multiyear in regions beyond the extent of the maximum landfast ice, 2) landfast sea ice, which forms annually within the coastal margins over the continental shelves, and 3) the Cape Bathurst Polynya complex, which consists of a series of leads and a latent heat polynya within the Amundsen Gulf. The flaw lead polynya system is usually located on the shelf break between the Amundsen Gulf and the Beaufort Sea. Figure 1.7 shows leads and cracks in the central pack of the southern Beaufort Sea with dark areas indicating open water and light areas indicating sea ice (Barber and Hanesiak, 2004).

Summer ice in the Beaufort Sea varies from season to season. Normally in April, a polynya of open water is formed at the entrance of Amundsen Gulf and it expands towards the west. The breakup begins in mid-July along the coast of the Beaufort Sea. In August, the open water in a normal year may extend 180-300 km off the Canadian coast (Fig. 1.8). The average time of freeze-ups in the Beaufort Sea is the second week of October (Fig. 1.9) (Barber and Hanesiak, 2004).

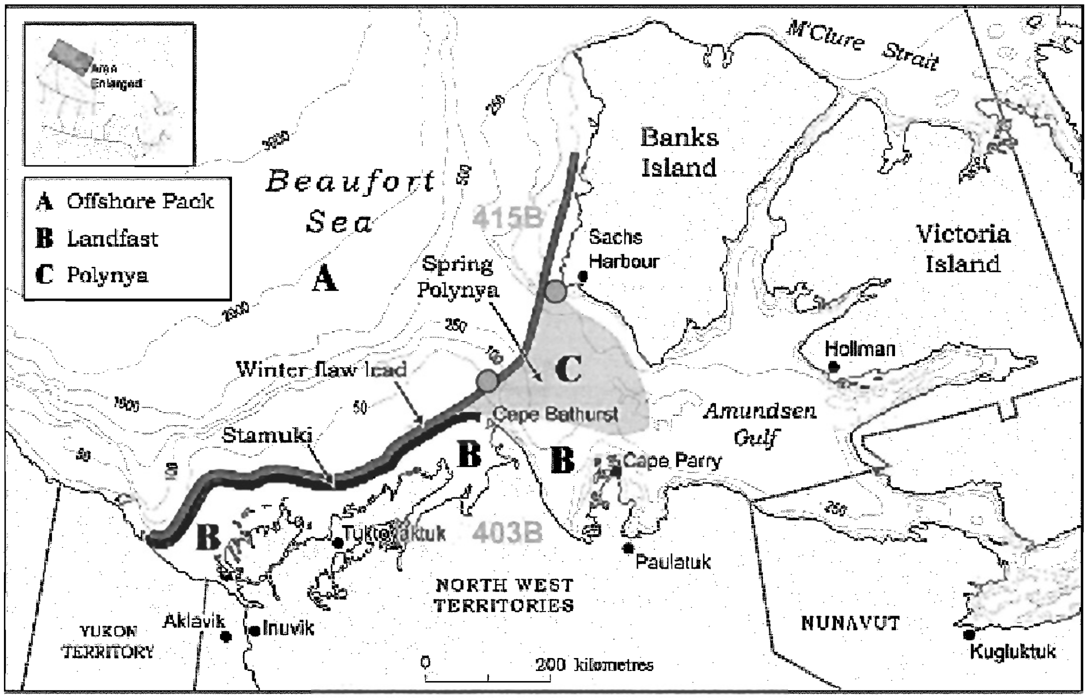


Figure 1.6: The three sea ice regimes A) offshore pack ice B) landfast ice and C) polynya location and shape in the CASES study region of the Western Canadian Arctic, in relation to 403B and 415B (modified from Barber and Hanesiak, 2004).

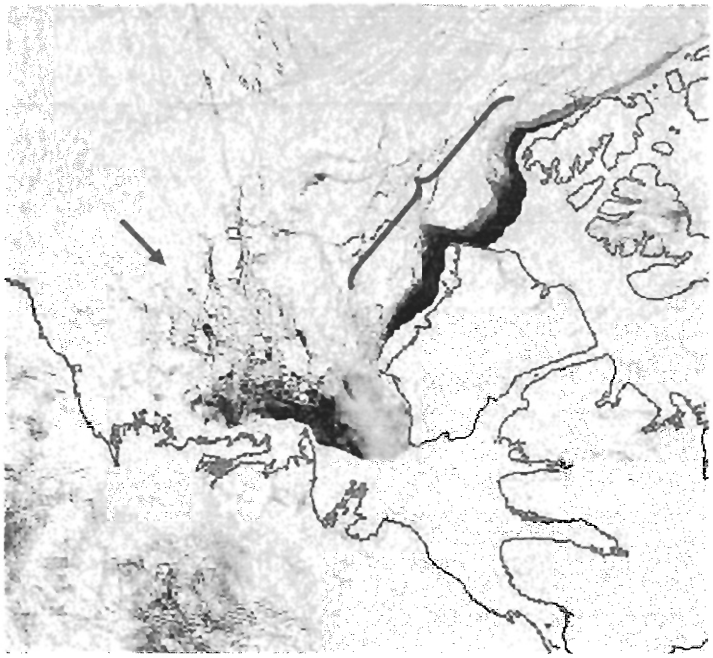


Figure 1.7: Leads and cracks in the central pack ice in a NOAA AVHRR image of the southern Beaufort Sea including the CASES site area. Dark areas indicate open water and light areas indicate sea ice. (modified from Barber and Hanesiak, 2004).

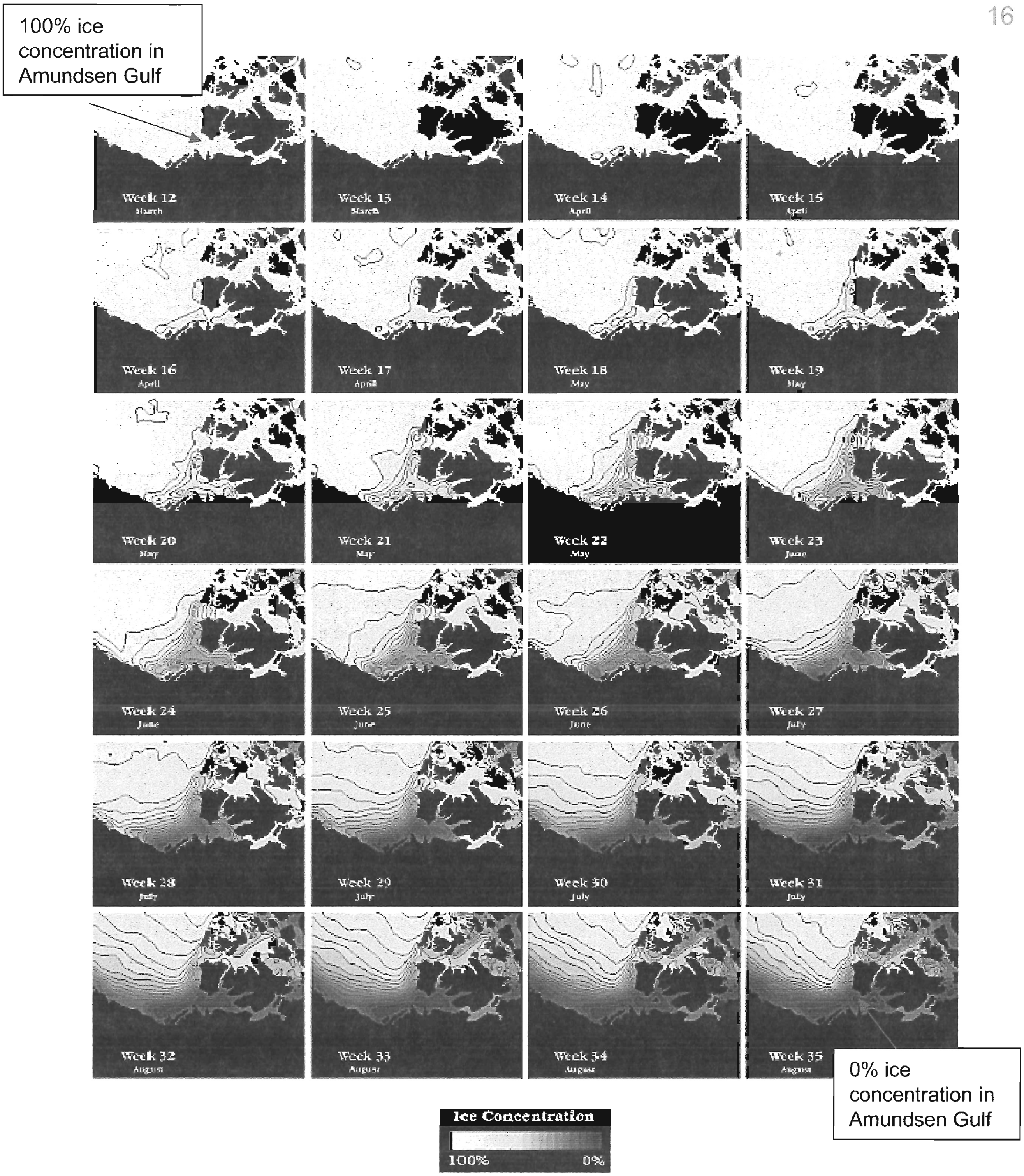
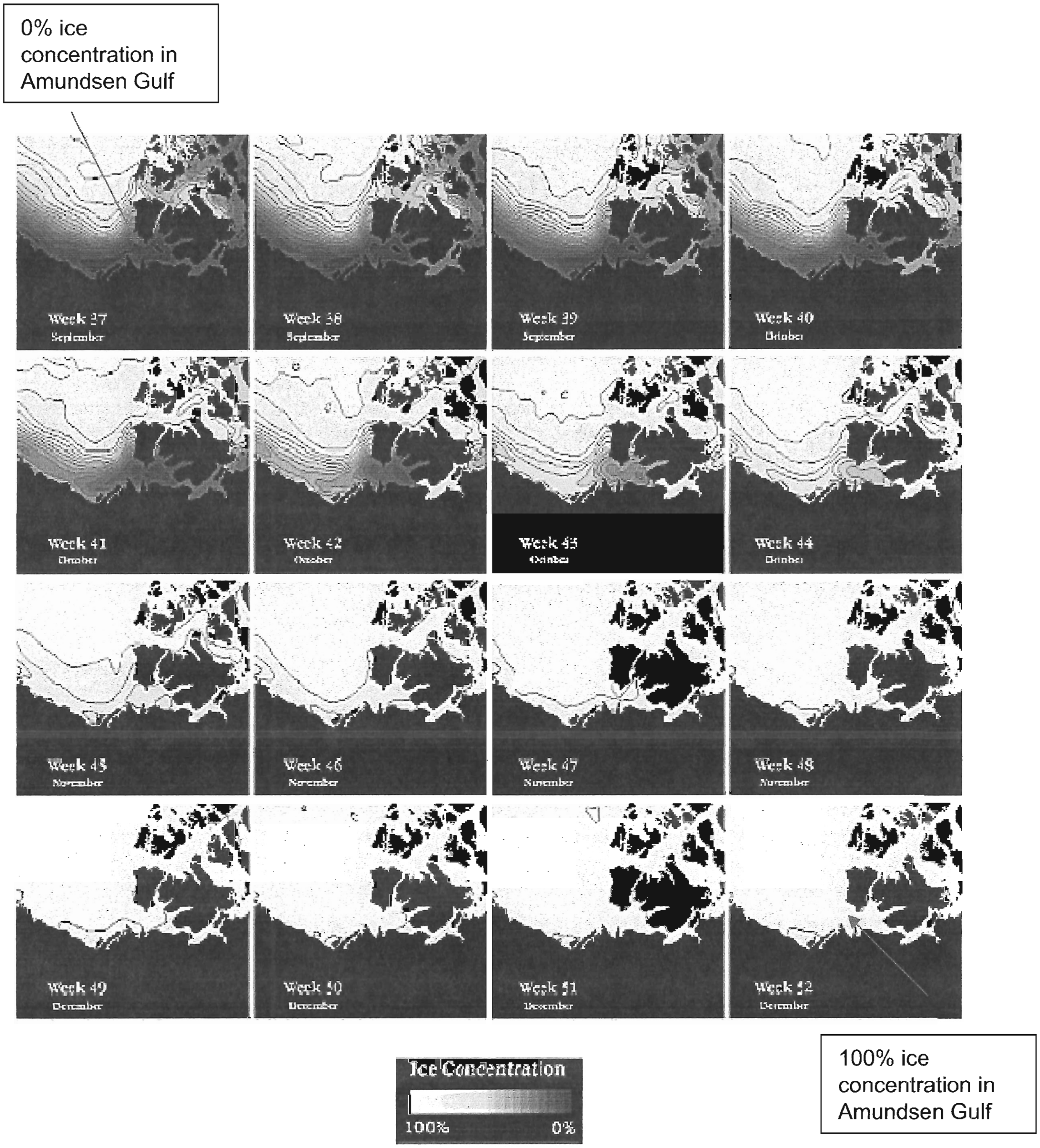


Figure 1.8: The average sea ice concentrations (%) in the site area during breakup (decay) from 1979 to 2000, weeks 12 to 35 (Barber and Hanesiak, 2004).



0% ice concentration in Amundsen Gulf

100% ice concentration in Amundsen Gulf

Figure 1.9: The average sea ice concentrations (%) in the site area during freeze-up (formation) from 1979 to 2000, weeks 37 to 52 (Barber and Hanesiak, 2004).

1.3.5 CTD, Transmissometry and Fluorescence Measurements

Measurements on conductivity, temperature and depth (CTD) of the water column at various stations were taken on the CCSG *Amundsen* (Miller, 2004). Figure 1.10A shows measurements from 403B and Figure 1.10B is CTD measurements from 415B. These measurements indicate the temperature, salinity, and particle distribution with depth.

1.3.5.1 Temperature

Temperatures were collected in the summer months. The water column at station 403B had temperatures that decline dramatically with depth, with 2°C in the upper layer of the water and becoming as low as -1°C with depth. This explains why there are an abundance of deep water foraminifera species in the surface sediments.

The water column at 415B has temperatures that decline at a constant rate with depth. Temperatures at the surface are around 5.5°C, and decline to -1.5°C at a lower depth when compared with 403B.

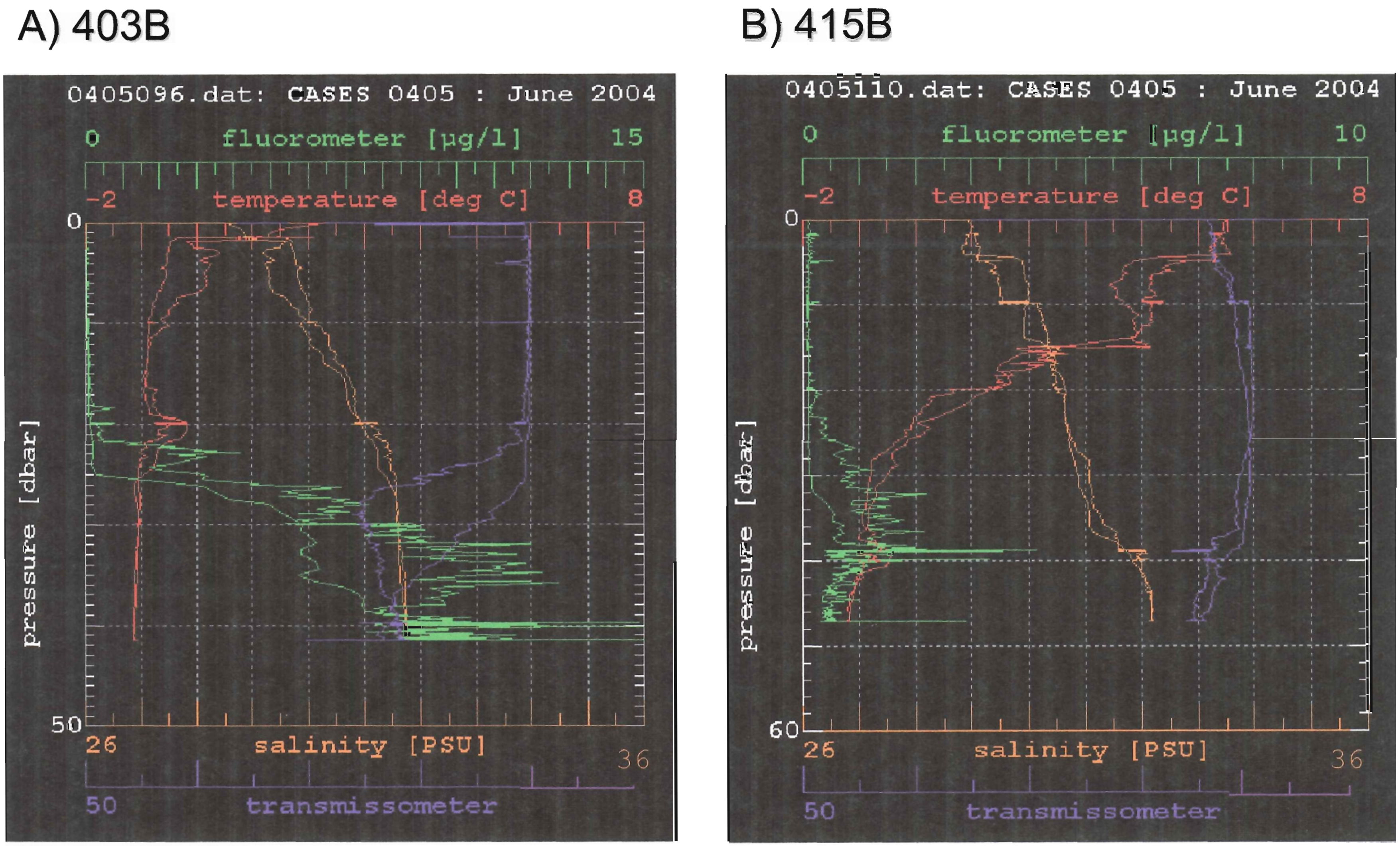


Figure 1.10: Conductivity-temperature and depth (CTD) measurements for A) 403B and B) 415B. Temperature (red), salinity (orange), transmissometer (purple), fluorometer (green) (Miller, 2004).

1.3.5.2 Salinity

Both stations 403B and 415B show that salinity increases with depth. Station 403B has salinity ranging from 28.5-31.5 PSU, and station 415B has salinity ranging from 29-32 PSU.

1.3.5.3 Conductivity: Transmissometry and Fluorescence

Transmissometric data reveals that the upper water column at 403B has slightly more suspended particles than 415B, but declines dramatically between 20-30 dbar. The water column at 415B has slightly fewer particles after 35 dbar.

Fluorescence at 403B starts to increase with depth at 20 dbar, and is at a maximum of 12-15 µg/l below 40 dbar. Fluorescence at 415B is much lower than 403B and increases with depth at 25 dbar, reaching a maximum of 4 µg/l at 40 dbar.

1.3.6 Primary Production

Annual primary production in the ice-covered Arctic water is very low relative to other areas of the world, due to the low average radiation from the sun, and because of snow and ice cover obstructing radiation to the euphotic zone (English, 1961). The phytoplankton production undergoes extensive seasonal variations in response to the fluctuations of available energy. Usually between April and October there is algal growth and melting sea ice that releases algae which initiates the spring bloom of phytoplankton (Subba Rao and Platt, 1984). Foraminifera are influenced by the primary production rates, since they feed on algae and organic debris (Boltovskoy and Wright, 1976).

1.3.7 Previous Work on Arctic Foraminifera

Parker and Jones (1865) studied foraminifera from the North Atlantic and Arctic Oceans, which included the Davis Strait and Baffin Bay. There have been significant explorations in the Canadian Arctic in the last 60 years.

Cushman (1948) explored foraminiferal assemblages in the region from the Bering Sea to Greenland, which included Hudson Bay. Loeblich and Tappan (1953) studied the taxonomy of the Arctic and subarctic species and remarked on the ecology of Point Barrow. Carsola (1952) discovered that *Nonionellina labradorica* is rare east of Colville River and in the Chukchi Sea, *N. labradorica* is related to the warmer water hugging the Point Barrow area (Fig 1.1). In Vilks et al. (1979), *N. labradorica* was rare on the Canadian Basin shelf and traces were in the deepest water of Helca and Gripper Bay. Phleger (1952) explored the foraminiferal distribution in northern Baffin Bay and Parry Channel system in the Canadian Arctic as well as the Greenland Arctic. Anderson (1963) explored recent distribution patterns of foraminifera in the Bering Sea. Marlowe and Vilks

(1963) and Vilks (1964, 1969, 1976) explored the area of the inter-islands seas of Queen Elizabeth Island.

Surface sediments collected from the Queen Elizabeth Islands interisland seas had agglutinated foraminifera in waters shallower than 200 m, except in East Bay and offshore Mackenzie King Island, which extended to 284 m, located behind a sill that impedes free entrance of the deeper waters from the Arctic Ocean, which originates from the Atlantic and is warmer and more saline (Marlowe and Vilks, 1963; and Vilks 1964, 1969, 1976).

Iqbal (1973) explored the M'Clure Strait and found assemblages to be influenced by the proximity of the Arctic Ocean. Foraminifera occur in numbers ten times higher on the continental shelf than in M'Clure Strait proper.

The sandier and slightly shallower sediments of the Arctic Ocean continental shelf are dominated by calcareous faunas, because of shallower and seasonally warmer water that permits calcium carbonate stability. The dominant agglutinated are *Trochammina nana* and *Saccammnina sphaerica.* The dominant calcareous species include *Islandiella teretis* (*Cassidulina laevigata*), *I. norcossi*, and *Cibicides lobatulus* (Vilks, 1989).

Lagoe (1977) examined more that thirty samples from depths deeper than 3,709 m. None of these samples contained more than 300 individuals and about half of the samples were barren in foraminifera in the Beaufort Sea. The few agglutinated foraminifera examined were from depths from 3,709 to 3,812 m, which was dominant in calcareous species. In this study, he found Textulariina in the deeper stations, which conquered with the dominance of agglutinated species in deep-water (about 1000 m) found in certain east Greenland fjords by Thorson (1934) and Sparck (1933). Lagoe (1977) found in general that 75% of the Arctic fauna fall under four species of the Rotaliina: *Stetsonia horvathi* (32%), *Epistominella arctica* (19%), *Eponides tener* (14%) and *Eponides tumidulus* var. *hovathi* (9%). These abundant species were not heavily ornamented, and it was concluded that this was due to the lack of sufficient amounts of calcium carbonate. An important ecological conclusion from Lagoe (1977) was that even though there is a variation in species with depth, most species have been found across a wide range of depths, indicating that depth is not of primary importance.

Holocene benthic foraminifera discussed by Vilks, Wagner, and Pelletier (1979) were rich in 49 piston cores of the Beaufort Shelf facing the Mackenzie River delta. The inner shelf was dominated by *Elphidium spp.*, *Buccella frigida* and *Eggerella advena*, despite redistribution due to ice scouring. *Elphidium exc.* f. *clavatum* delineates the area on the shelf that is most commonly covered by the sediment and freshwater plume of the Mackenzie River runoff. The outer shelf zone was found to be dominated by *Islandiella teretis* and consisted of *Islandiella helenae* and *Cassidulina laevigata*.

Shallow environments with warmer water invasions from the Arctic Intermediate Water (AIW) are delineated by *Cassidulina reniforme* (Ishman and Foley, 1996). Vilks (1989) found low-diversity in calcareous species of the Amundsen Gulf, where the bottom water was within the Atlantic layer, which is warm and saline. *Cassidulina laevigata* was the dominant calcareous species found by Vilks (1989) in this area. There was increase in diversity towards the Prince of Wales Strait and Viscount Melville Sound, which was dominated by *Cassidulina laevigata,* and *Elphidium exc.* f. *clavatum*. This area is shallower and within the Arctic Surface Water (ASW), which is cold and more saline. The shallow water agglutinated species *Spiroplectammina biformis* (Vilks, 1989; Madsen and Knudsen, 1994) marks the ASW (Ishman and Foley, 1996), and represents a glaciomarine habitat, along with *Textularia earlandi* (Korsun and Hald, 2000).

When comparing the western basins with the less saline and colder bottom water of Jones Sound, Vilks (1989) suggested that species diversity was higher with higher productivity in an area that has mixing Baffin Bay and Arctic Ocean waters. This area is dominant in the agglutinated species *Aecotryma glomerata*, which is not very common in the western Arctic Archipelago basins.

High ratios of benthonic to planktonic foraminifera were found by Scott et al. (1989) in most Quaternary sediments in the central Arctic. Contrary to Markussen et al. (1985), who found 80-99% planktonic foraminifera and up to 2%

benthonic foraminifera, Scott et al. (1989), demonstrated a 1:1 ration between planktonic and benthonic foraminifera that characterize sediments of the Arctic deep-water. This is true because smaller size fractions were described in Scott et al. (1989), where only >0.150 mm foraminiferal assemblages were described in Markussen et al. (1985).

Stable-isotope measurements were performed on the planktonic species *Neogloboquadrina pachyderma* and on the benthonic species *Oridorsais umbonatus*, in Scott et al. (1989). As stated earlier, the first report of a high-resolution in benthonic foraminifera of the central Arctic Ocean was made in this report, which was dominated 60-70% by *Stetsonia horvathi* and 4-20% by *Valvulinera arctica* , *Eponides tumidulus*, *Oridorsalia umbonatus* and *Buliminella hensoni*. There were traces of *Robertinoides charlottensis*, *Bolivina arctica*, *Triloculina trihedral*, *Planulina wuellerstorfi* and *Quinqeloculina spp* .

Samples from the western Arctic in Lagoe (1977) at depths of 1,000 m to 3,800 m had significant amounts of *Bolivina arctica* (> 5%) only at station 6, which has been suggested by Scott et al. (1989) that this could be an erosional surface, since *Bolivina arctic* is rare in other areas of the present day Arctic Ocean. In Scott and Vilks (1989) it was stated that *Bolivina arctica* could help identify the Pleistocene/Holocene boundary, since the mid-Pleistocene is abundant in *Bolivina arctica*.

Polyak et al. (2004) stated that elongated foraminifera, such as *Spiroplectammina biformis*, *Bolivina arctica*, and *Reophax arctica*, are thought to indicate high productive of infaunal environments.

Foraminifera provide a unique opportunity to investigate the effect of low temperatures and long winter seasons with very low primary production. Paleoceanographers are interested in these foraminifera to reconstruct the extent and chronology of high latitude Quaternary glaciations on the continental shelves (Vilks, 1989). With the results of previous work, interpretations of the sedimentologic and oceanographic records for the Amundsen Gulf can be produced.

Changes in the sedimentation of the Arctic ecosystem need to be explored because these may provide a means of monitoring and assessing changes in Arctic ecosystem. The Arctic is highly vulnerable to changes in climate. This study will add to the assessment of the effects that presently influence sea ice cover and that are important in the understanding of the coastal shelf regions of the Arctic and their productivity.

CHAPTER 2 METHODS

2.1 Site Description

2.1.1 Objectives of CASES 2003-2004 Project 2.8

The objectives of the CASES 2003-2004 Project 2.8 were to obtain decadal-millennial scale records of quantitative variations in Mackenzie River discharge, to reconstruct sea ice history, summer sea surface temperature (SST) and salinity, and to assess primary productivity and carbon storage during the past 10,000 years.

2.1.2 Technology Used to Locate and Analyze Areas of Interest

The first task for Project 2.8 was to select suitable sites for coring by choosing a site with high sediment accumulation, and avoiding areas of slumping, low sedimentation, and ice keel disturbances (< 50 m water depth). The main tools used were multibeam sonar and a sub-bottom profiler (3.5 kHz). Multibeam sonar allows for 3D images of the sea floor. Figure 2.1 shows the drumlin-like feature on the sea floor near 415B. Sub-bottom profiling allows for a cross-section of the sediment layers and sedimentary structures. Fig 2.2 shows that the sea floor in the area of these two stations is relatively flat, except for the glacial features seen at the surface. Other techniques include backscattering images (habitat mapping), physical properties of sediment (multisensor core logger), tomodensitometry (CAT-Scan) and paleomagnetism. An example of a bathymetic image is shown in Figure 2.3, which is taken from at 415B and shows evidence for ice scouring. Proxies used for paleoclimatic reconstructions were dinoflagellate cysts, pollen, spores, diatoms and foraminifera. CASES 2003-2004 collected 44 cores and 7 piston cores. In total, 51 cores and 10 piston cores were collected. Figure 2.4 shows scientists aboard the H.M.S. *Amundsen* extracting a core from the boxcore.

Other interesting findings on the cruise included mud volcanoes from sites 805A and 805C, ice scours, drumlin-like features (Fig 2.1), and slope failure.

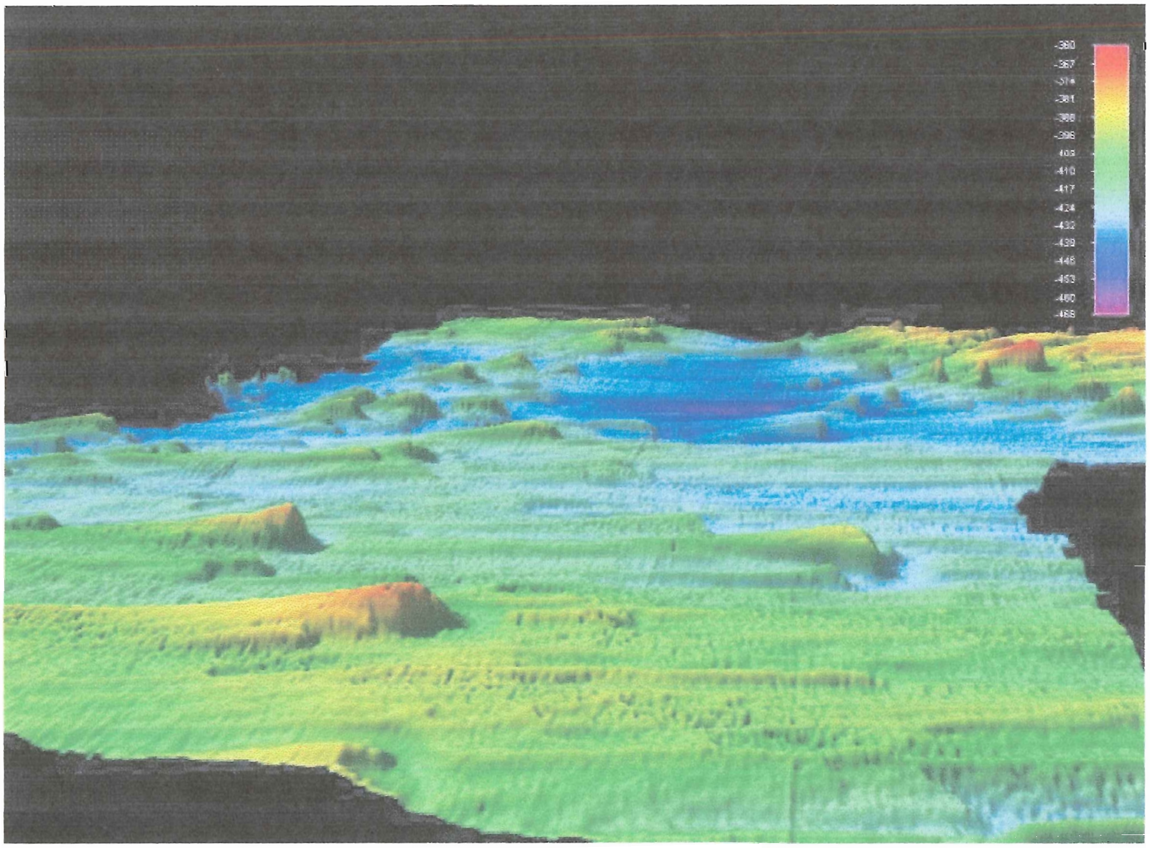


Figure 2.1: Multibeam sonar illustrating drumlin-like features near 415B in the Amundsen Gulf. Depth in meters (image generated by J. Bartlett, CHS, 2004).

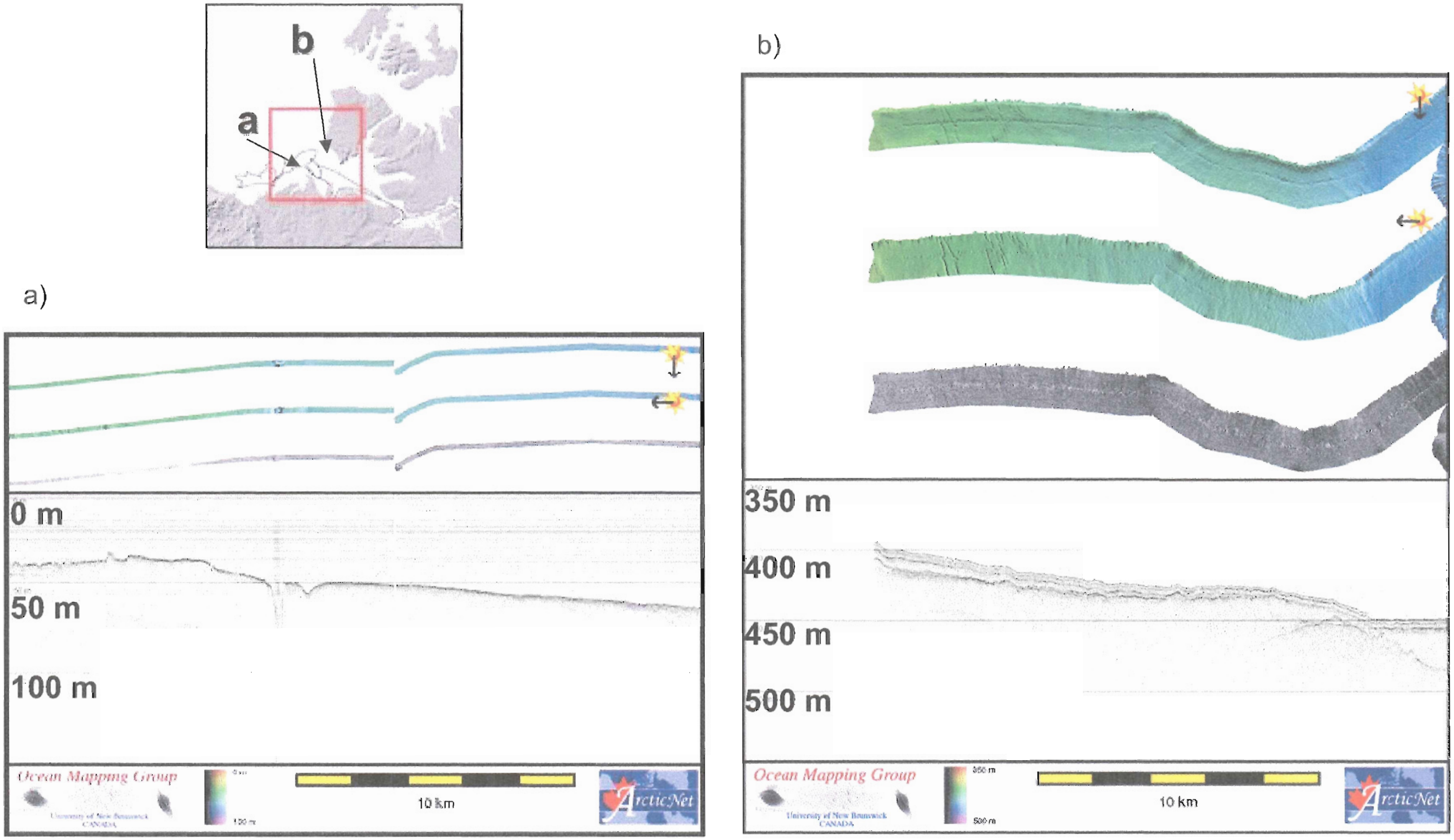


Figure 2.2: Sub-bottom profile of the area near station 403B (a) and 415B (b) in the Amundsen Gulf. Both stations have relatively even surface, but there are some irregularities, however this was adequate for coring. In both bathymetry images at the top, show that there is ice scouring in the marine sediments (from CASES, 2004).

Figure 2.4: The surface organisms are accounted for in each boxcore (left). Scientists extracting a core from a boxcore aboard the H.M.S. *Amundsen* in 2004 (right) (CASES, 2004).

2.2 Core Analysis

Cores 403B and 415B were selected because of their contrasting depositional environments. These cores are stored at the Bedford Institute of Oceanography (BIO) in Halifax, Nova Scotia, after the CCGS *Amundsen* cruise was completed. The cores were split, described and photographed at BIO and the second half of each core was kept in their archives. Core description included information on the depth, consistency, Munsell colour measurements (spectrophotometry), sedimentologic analyses (grain size), lithology and sedimentary structure (Figure 2.4.1).

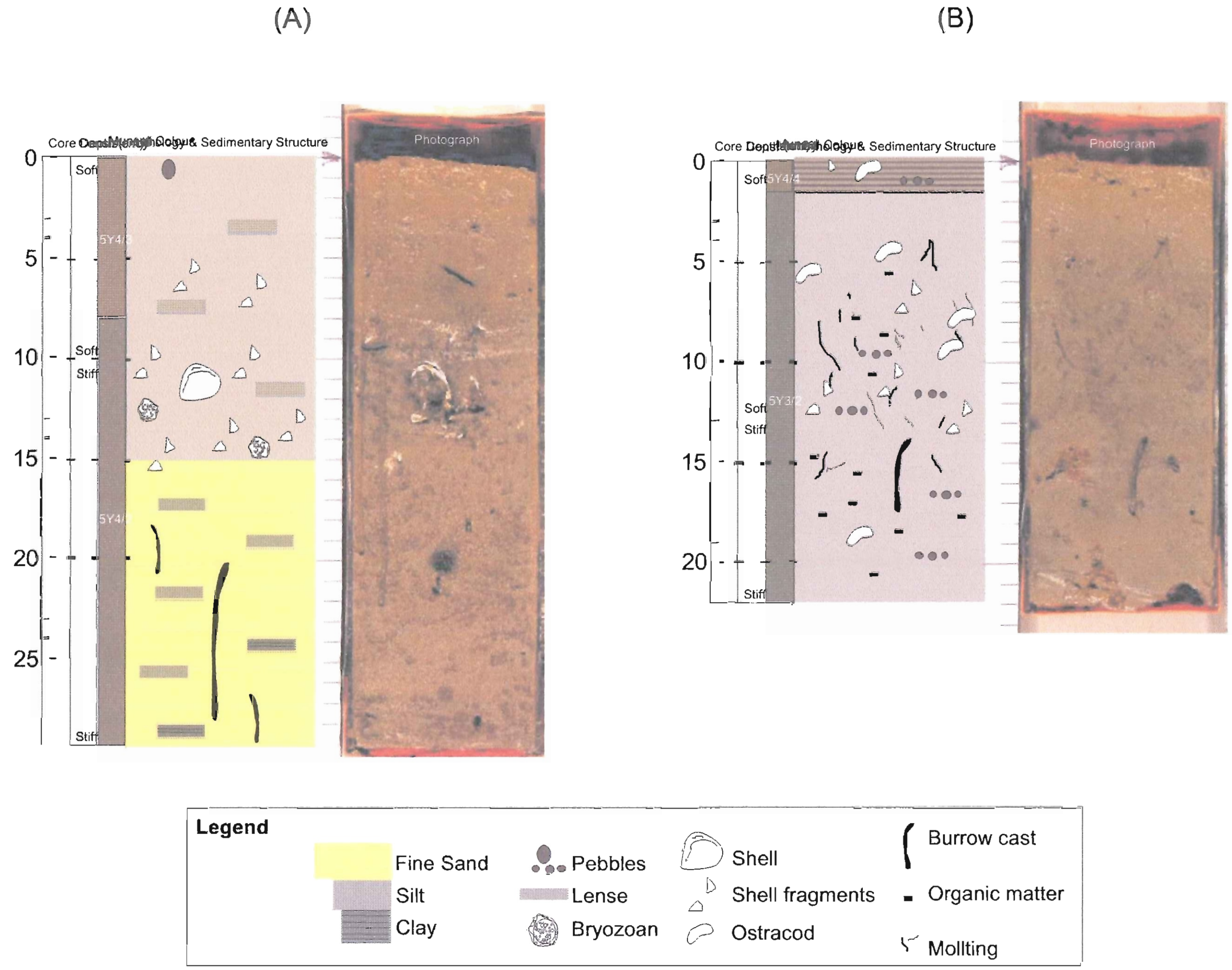


Figure 2.4.1: Schematic diagrams of lithology of boxcores 403B and 415B from the Amundsen Gulf, with accompanying photograph.

The cores were brought to the Core Laboratory at Dalhousie University where they were x-rayed and a strip was taken for ^{14}C and ^{210}Pb dating[1]. The cores where then sampled by taking one 10 cc sample at every 1 cm of the core and placing them in a small container with water and alcohol. The lids need to be tightly sealed so as not to let bacteria cause clumping of the sediment. Another 10 cc was collected for Dr. André Rochon at the Université du Québec à Rimouski for dinoflagellate cyst analysis. Each foraminiferal sample was washed through sieves to subdivide the > 63 µ and the > 45-63 µ size fractions (Fig 2.5A). The two sizes were placed in individual containers (Fig 2.5B). Using a microscope, each sample was described. The description included the abundance of calcareous and agglutinated foraminifera (common, rare), size of sediment grains (coarse, fine), presence of foraminifera fragments, shell fragments, burrow casts burrows, spicules, ostracods, and any other trends.

Figure 2.5A: A sample being washed with water and sieved at > 63 µ and > 45-63 µ.

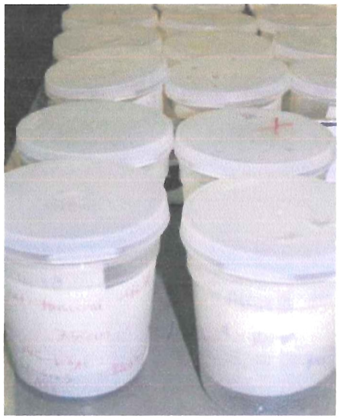


Figure 2.5B: A sample in small individual plastic containers.

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[1] Dating was not processed at the time of this thesis, but should be completed in the future as the CASES projects progesses.

2.3 Data Analysis

Foraminifera were identified using various Arctic foraminiferal plates, sketches, and scanning electron microscope photographs, as well as various taxonomic literature, (e.g. Barker, 1960) taxonomic notes on foraminifera dredged by H.M.S. *Challenger* accompanied by a reproduction of H.B. Brady's plates). Foraminifera were extracted from the sample using a fine brush and glued to a cardboard plate made specially for foraminifera cataloguing (Fig 2.6). The genera and species names of the specimens were recorded and correspond to a number marked on the plate as well as the interval it was taken from. If two examples of a specimen were found, one would be aligned showing a dorsal side and the other showing a ventral side, where it was possible to do so.

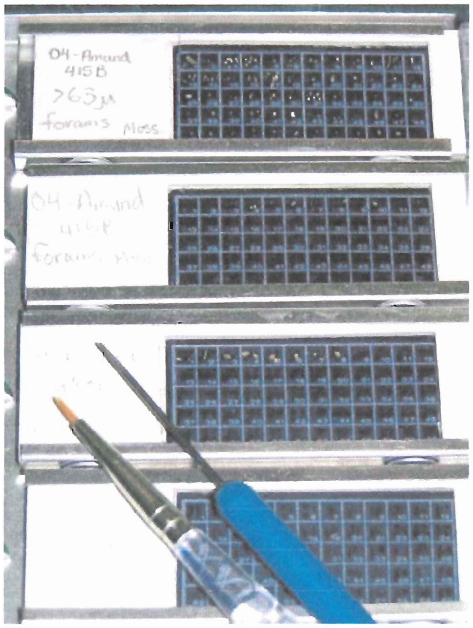

Figure 2.6: Cardboard plates with foraminifera glued to them. Fine brush and utensil are also shown.

CHAPTER 3 RESULTS

3.1 Lithological Descriptions

3.1.1 Lithological Description of 403B

The core from station 403B was 29 cm in length, from a water depth of 59 m, (latitude 71°06.777'N, longitude 128°18.302'W). A photograph and x-ray of 403B is seen in Figure 3.1.

The first 10 cm of 403B are a soft silty clay with minor sand. The top 1 cm had a 1 cm diameter pebble. The colour of the core is olive in the first 8 cm, and then changes to olive grey for the remainder of the core. White shell fragments are found between 5 and 15.5 cm, and a whole shell was at 11 cm (however it was split with the core). The silt becomes stiff and compact after 10 cm. There are lenses of fine sand in the silty clay at 11 cm. Between 15 and 29 cm the core changes to sand with some mud lenses, and at 24 and 26 cm there is clay. Between 18 and 28 cm there are large burrow casts.

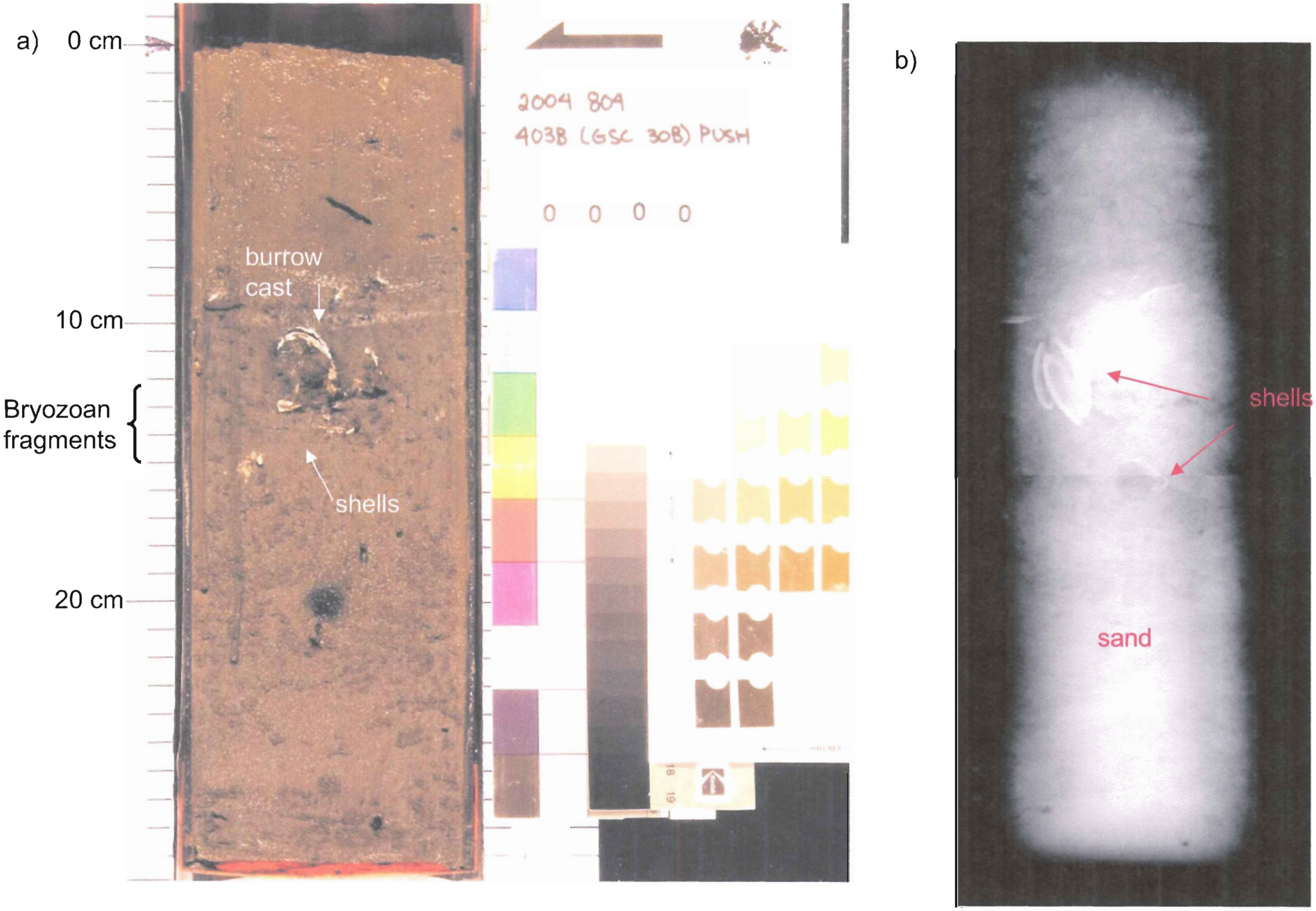

Figure 3.1: a) Photograph of boxcore 403B shows bryozoan and shell fragments as well as whole shells and mottling from burrow casts (thin dark brown areas) and b) x-ray of boxcore 403B also shows the shells.

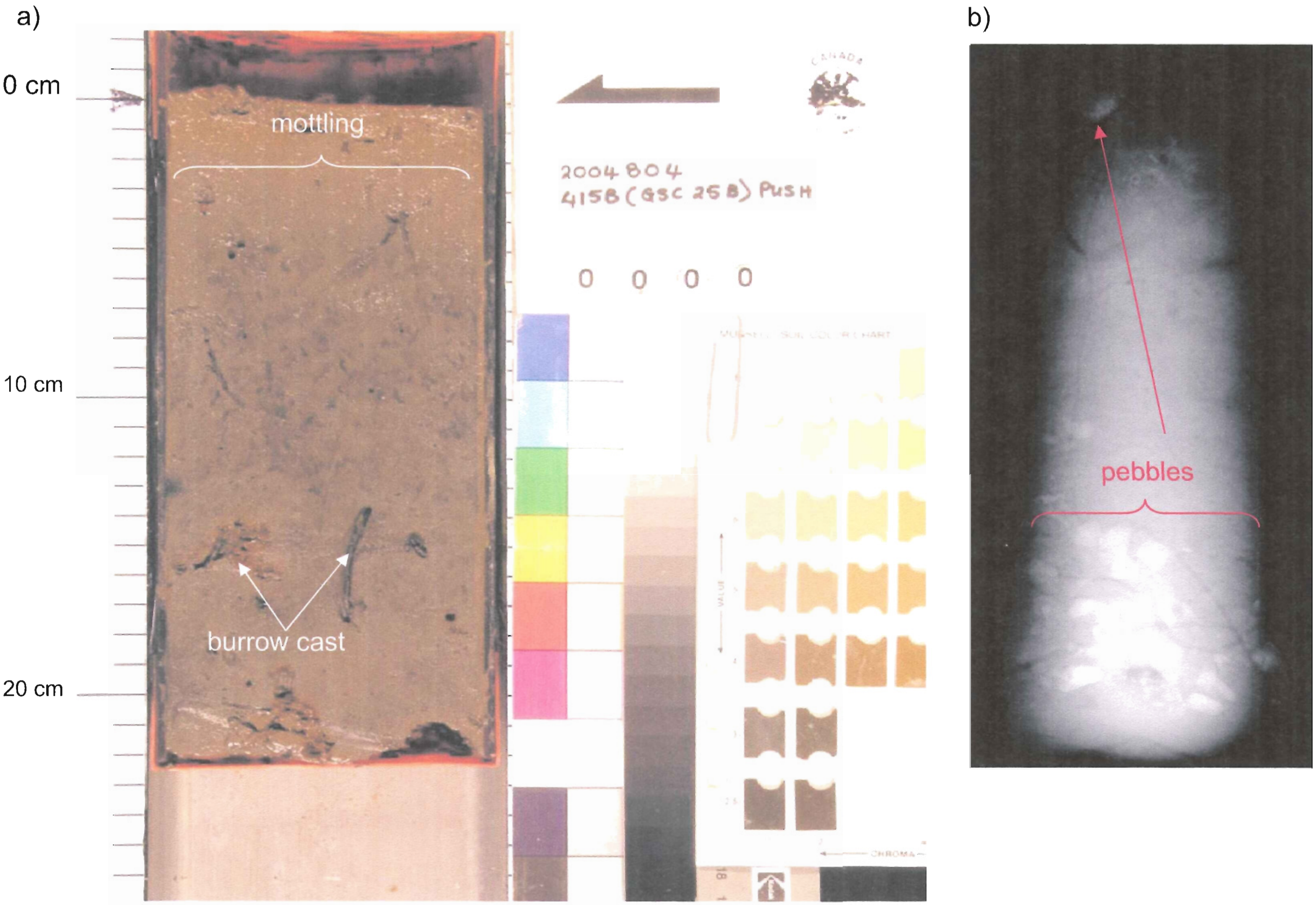

Figure 3.2: a) Photograph of boxcore 415B shows mottling from burrow casts (thin dark brown areas) and b) x-ray of boxcore 415B shows pebbles, one at the surface and many in the last few centimeters of the boxcore.

3.1.2 Lithological Description of 415B

The 22 cm deep core from station 415B was collected at water depth of 56 m, (latitude 71°54.455'N, longitude 125°52.092'W). A photograph and x-ray of 415B is seen in Figure 3.2.

The first 1.5 cm of 415B is olive coloured soft clay with pebbles at the surface. The rest of the core is stiff slit with some soft mud that grades into a dark olive grey colour. Black mottling patterns start at 4.5 cm and continue down the core. Large features, such as shells and burrow casts appear between 13.5 and 17.5 cm. There is orange colouration near one of the burrow casts. The core ends at 22 cm. There are intervals which have silt and pebble sized coal sediments (6-11 cm, 15-19 cm, and 21 cm). The presence of pebbles indicates that this could have been a shoreline.

3.2 Biostratigraphical Descriptions

3.2.1 Biostratigraphical Description of 403B

Surface foraminiferal samples from 403B and 415B were examined by CASES in 2004. Appendix C shows that in 10 cc of sediment, 1020 individual foraminifera of 33 species where found > 63 μ, and 900 individual foraminifera of 10 species where found > 45-63 μ. The number of individuals is high in the surface sediments and significantly decreases down core. The abundant species in the surface samples from > 63 µ were *Elphidium exc. f. clavatum* (12.6%), *Islandiella teretis* (10%), and *Textularia earlandi* (16.2%), while at > 45-63 µ, there was abundance in *Buliminella hensoni* (29.3%), *Eoeponides pulchella* (14.7%) and *Textularia earlandi* (29.3%).

Species diversity in core 403B ranges from 1 to 20 species per 10 cc, and the total number of individual foraminifera range from 6 to 426 per 10 cc of sediment (Appendix B). There were also shell fragments between 9 and 15.5 cm, and an intact mollusc shell at 10 cm. Bryozoan fragments are found between 12 and 15 cm (Figure 3.1, Figure 3.3).

The calcareous species *Islandiella teretis* (28.8%) increases between 0 and 5 cm as the agglutinated species *Spiroplectammina biformis* becomes less abundant in the upper 7 cm of the core, going from 25.4% to 6.5% abundance (Fig. 3.4). Between 10 and 18 cm, the calcareous species *Islandiella teretis* (50%), *Cassidulina reniforme* (32.5%), and *Elphidium spp.* (10.0%) are the most abundant, however, after 18 cm they decrease dramatically to zero (Figure 3.4).

The species diversity and total number of individuals is extremely low between 19 and 23 cm. The agglutinated species *Reophax spp.* is rare in this interval, but is the bulk of the fauna (100%).

Islandiella teretis becomes more abundant at 23 cm (33.3%) and increases until the end of the core at 29 cm (54.4%).

Species diversity at > 45-63 µ from 403B ranged from 2 to 17 per 10 cc and the total number of individuals ranged from 8 to 191 per 10 cc (Appendix D). *Bolivina arctica* was the only consistently abundant species throughout the core (7.7-75.0%). This size fraction also demonstrated the lower species diversity and population at around 20 cm. There is an interval at 7 to 9 cm, where *Fursenkoina fusiformis* is appears and is abundant (33.8-39.5%).

3.2.2 Biostratigraphical Description of 415B

Surface foraminiferal samples from 415B show that there were 324 individual foraminifera from 34 species at > 63 µ, and 102 individual foraminifera from 9 species at > 45-63 µ (Appendix C). The species in abundance in these surface samples > 63 µ were *Islandiella teretis* (38.0%), while at > 45-63 µ there was abundance in *Buliminella hensoni* (17.6%), *Spiroplectammina biformis* (23.5%) and *Textularia earlandi* (23.5%).

In core 415B, the species diversity per 10 cc of sediment ranges from 12 to 34 species, and the total number of individual foraminifera range from 170 to 1008 per 10 cc of sediment (Appendix E). There were also spicule-like fragments in the upper 8 cm, ostracods between 6 and 10 cm, and shell fragments and burrow casts found throughout the core.

The agglutinated species *Spiroplectammina biformis* is generally the most abundant throughout the core (9.2-31.9%). The agglutinated species *Hyperammina* was only present between 0 to 4 cm, were it declined dramatically from 13.8% to 0. This is also where the core changes from stiff silt to soft clay and mottling disappears (Figure 3.6).

The only abundant calcareous species between 4 and 7 cm was *Islandiella teretis* (14.8 - 24.2%). Low percentages were only for *Spiroplectammina biformis* (13.5%), *Textularia earlandi* (0.4%) and *Trochammina globigeriniformis* (6.6%) as seen in Figure 3.6.

Bolivina arctica (4.3%) and *Cassidulina reniforme* are minor calcareous species in core 415B. *Cassidulina reniforme* has a maximum at 7 cm (4.7%) and 15 cm (6.5%), which are the same intervals that have *Islandiella teretis* starting to decrease in abundance (Appendix E).

There are abundant agglutinated species between 12 and 13.5 cm; *Textularia earlandi* (17.8%) and *Trochammina globigeriniformis* (16.0%), with their maximum abundance percentages in this interval.

Towards the bottom of the core, between 13 and 22 cm, lower values for species diversity and number of individual foraminifera were found (Appendix E), which is also where there are pebbles, organic clasts, burrow casts, mottling and shell fragments (Appendix C). Agglutinated species (71.4 - 90.3%) are more abundant in the foraminiferal assemblage between 13 and 22 cm, which was comprised of *Spiroplectammina biformis (*45.1% at 20 cm), *Bolivina arctica* (20.8% at 19 cm), *Reophax arctica (*11.5% at 19 cm), and *Trochammina globigeriniformis* (9.4% at 18 cm). The maximum abundance percentage for *Reophax arctica* is restricted to the lower part of the core, between 14 and 20 cm. The calcareous species *Islandiella teretis* and *Cassidulina reniforme* were not present between 18 and 22 cm.

Species diversity at > 45-63 µ from 415B ranged from 2 to 10 per 10 cc and the total number of individuals ranged from 6 to 266 per 10 cc (Appendix F). There is a lower population of foraminifera > 45-63 µ between 2 and 5 cm, which is generally the same interval that shows a high population of foraminifera > 63 µ. There seems to be a shift in the ratio of the two size fractions between 7 and 10 cm, where foraminifera > 45-63 µ and > 63 µ are closer to being equal in population size, compared to other regions of the core. As in the > 63 µ size fraction, the > 45-63 µ size fraction demonstrates relatively constant species diversity, with a slight decline towards the end of the core. *Bolivina arctica* (10.7-89.4%), *Textularia earlandi* (4.2-35.3%), and *Spiroplectammina biformis* (4.5-46.2 %).

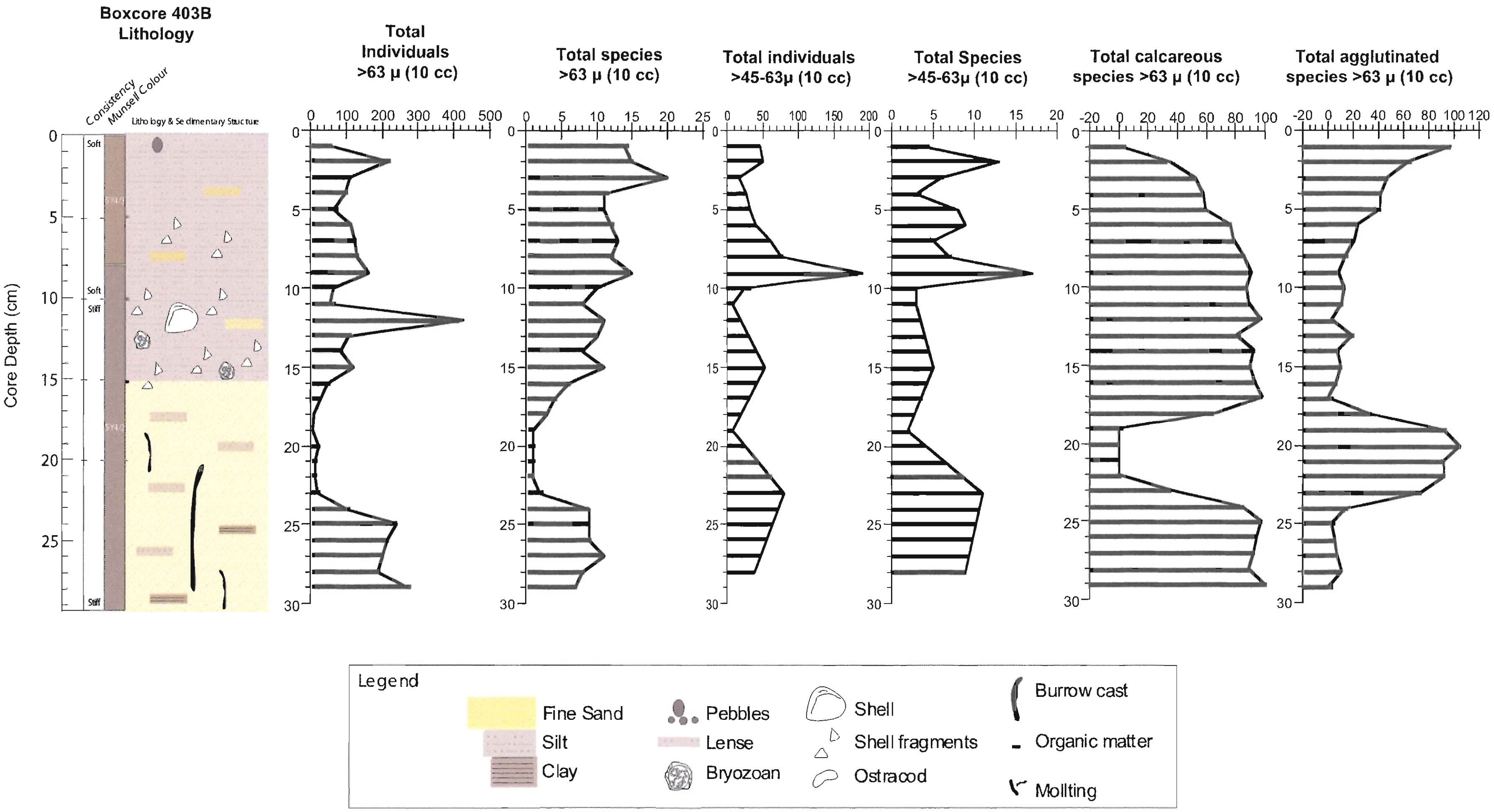

Figure 3.3: Boxcore 403B schematic vertical section with foraminiferal percentages in 10 cc plotted against core depth. Total individuals and species per 10 cc in the > 63 µ size fraction are compared with total individuals and species per 10 cc in the > 45-63 µ size fraction, and total calcareous and agglutinated species per 10 cc in the > 63 µ size fraction.

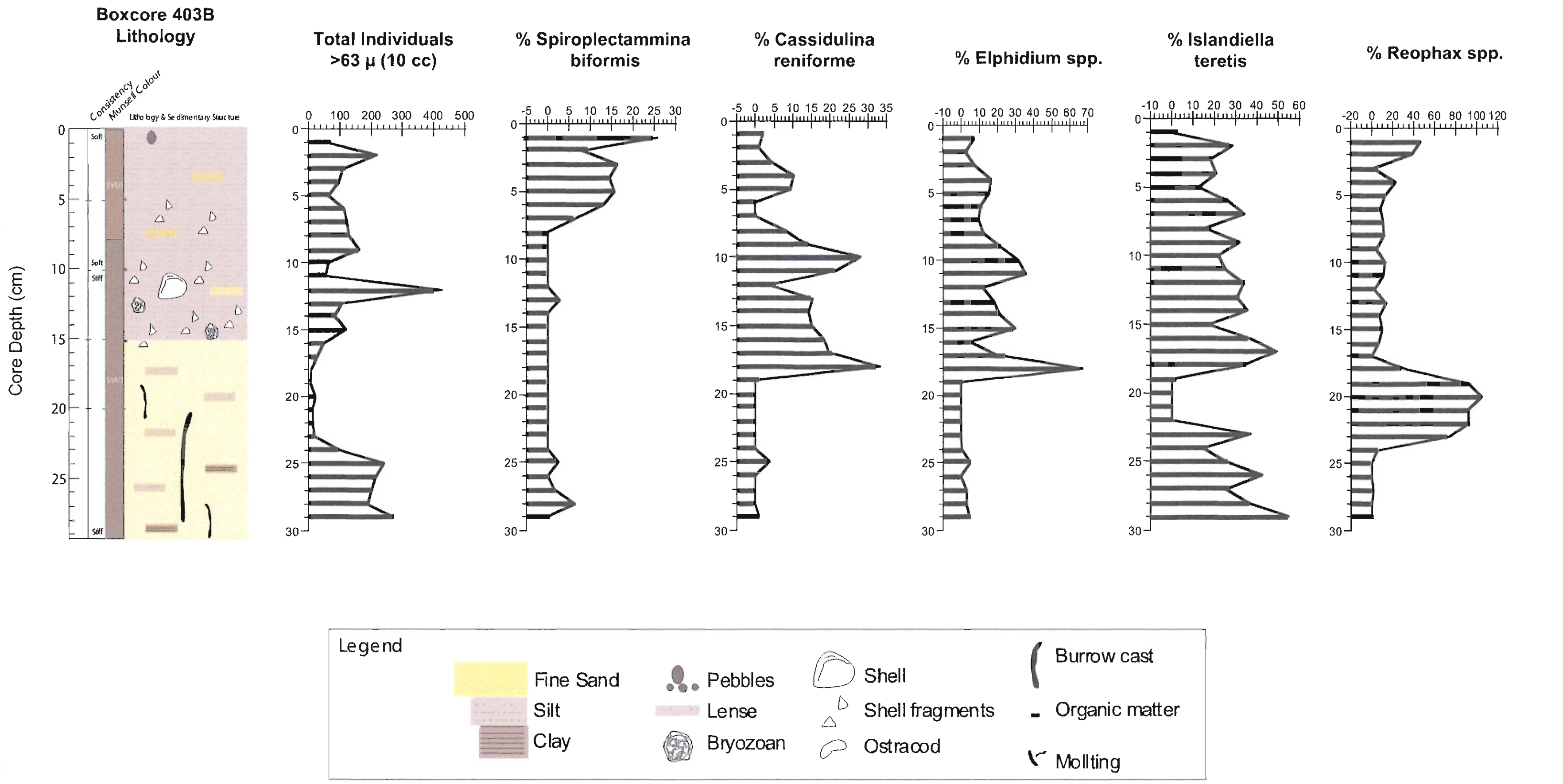

Figure 3.4: Boxcore 403B schematic vertical section with foraminiferal percentages in 10 cc plotted against core depth for >63 µ size fraction. Calcareous foraminifera *Spiroplectammina biformis*, *Cassidulina reniforme*, *Elphidium spp.*, *Islandiella teretis* and the agglutinated *Reophax spp.* are compared with total individuals in 10 cc.

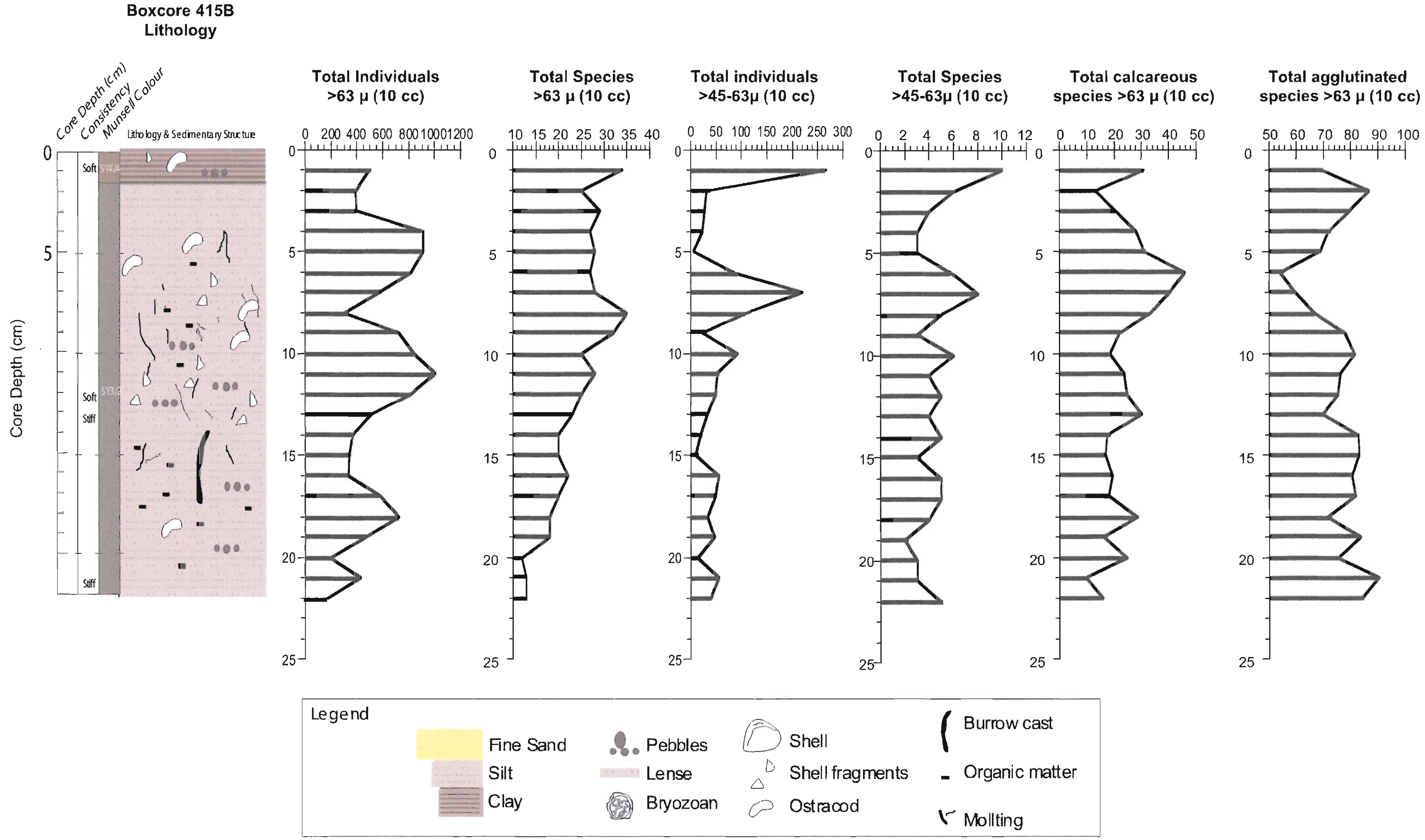

Figure 3.5: Boxcore 415B schematic vertical section with foraminiferal percentages in 10 cc plotted against core depth. Total individuals and species per 10 cc in the > 63 µ size fraction are compared with total individuals and species per 10 cc in the > 45-63 µ size fraction, and total calcareous and agglutinated species per 10 cc in the > 63 µ size fraction.

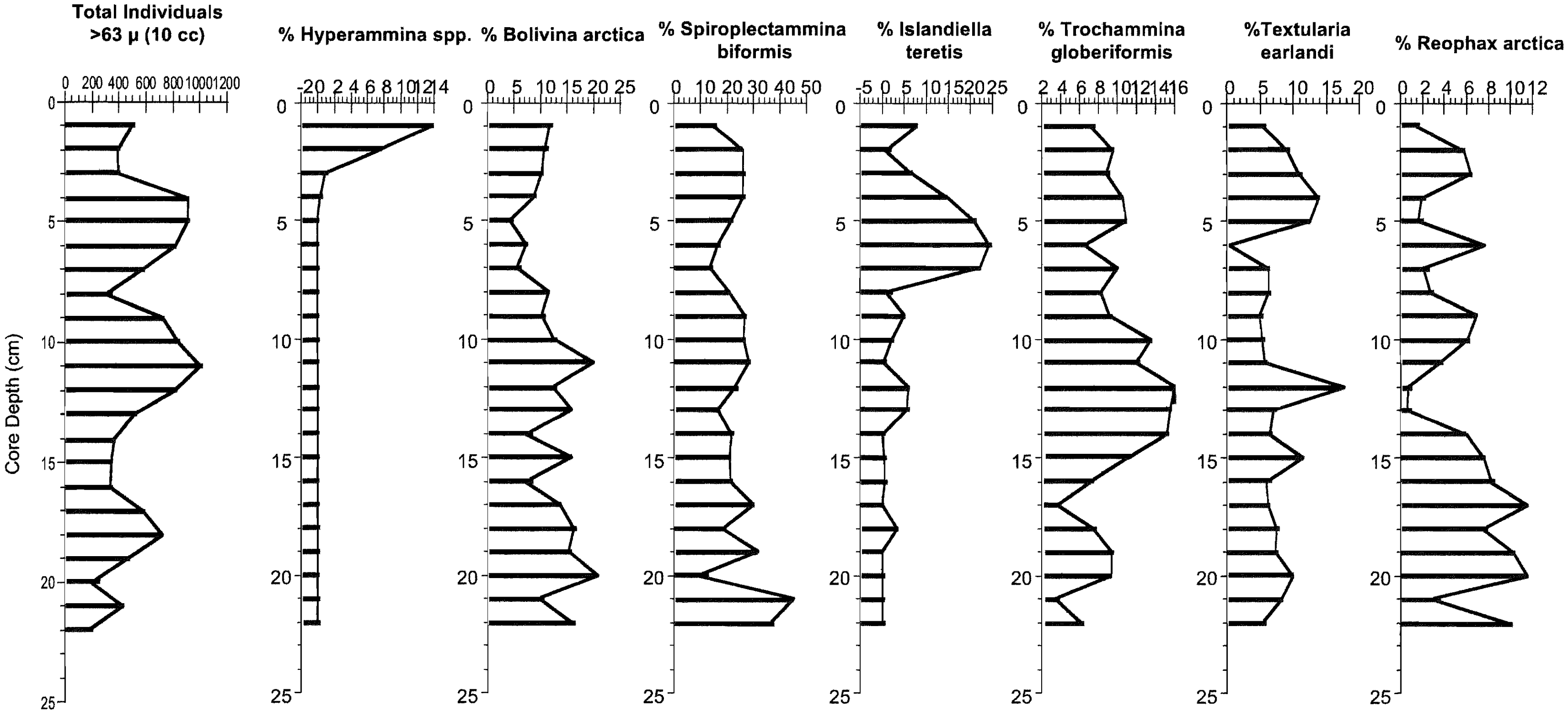

Figure 3.6: Boxcore 415B schematic vertical section with foraminiferal percentages in 10 cc plotted against core depth for > 63 μ size fraction. Agglutinated foraminifera *Hyperammina spp., Spiroplectammina biformis, Trochammina globigeriformis*, *Texturlaria earlandi* and *Reophax arctica*, and the calcareous foraminifera *Islandiella teretis* and *Islandiella teretis* are compared with total individuals in 10 cc.

CHAPTER 4 DISCUSSION

4.1 Interpretation of 403B

4.1.1 Low Salinity, Shallow Water Environment

The surface sediments are restricted to the Arctic Surface Water (ASW), with the presence of *Elphidium exc. f. clavatum* delineating the inner shelf (Vilks et al. 1979), and a freshwater plume (Scott and Vilks, 1991), which explains the low salinity values in Figure 1.10A. *Islandiella teretis* indicates the outer shelf (Vilks, 1979), and *Textularia earlandi* indicates a glaciomarine environment (Korsun and Hald, 2000).

4.1.2 *Spiroplectammina biformis* Biofacies

Spiroplectammina biformis are in abundance in the first 7 cm of the core. They decline as the calcareous species become more abundant, and this marks the marks the ASW (Ishman and Foley, 1996). *Spiroplectammina biformis* represents a glaciomarine habitat (Korsun and Hald, 2000) and is in a shallow water environment (Vilks, 1989; Madsen and Knudsen, 1994).

4.1.3 Slightly Shallower Environment with Warmer Water Source

The dramatic increase in calcareous species between 7 and 19 cm represents a slightly shallower environment and the invasion of warmer Arctic Intermediate Water (AIW). *Cassidulina reniforme* indicates this warmer water source (Ishman and Foley, 1996), *Elphidium spp.* Indicates a warmer ice margin, and the continental shelf (Polynak et al. 2004), and *Islandiella teretis* delineates the outer shelf zone (Vilks, 1979). The shell and bryozoan fragments and the intact mollusc shell, also indicate that this was a shallow marine environment. *Bolivina arctica* is abundant in this interval as well, but the number of individuals is lower than at > 63 μ over all.

4.1.4 Change in Environment and Barren Zone

There is an unusual barren interval between 16 and 23 cm where there is low species diversity and population. The only foraminifera were large *Reophax spp.* in low numbers. The interval must represent a major change in environment, because the decline in species diversity and population is large, and the sediment size changes from being predominantly silt to fine sand. Since the interval represents a time frame of around 100 years, the change could not be very significant in terms of sea level change. There is no example of a similar environment today in this study area, except for some that are deep water environments (e.g. 850 with a water depth of 1071 m). The previous work of

Scott and Vilks (1991) has seen lower species diversity from 3,500 to 4,000 m in the Fram Basin. Seasonal mixing of low-salinity surface and Arctic Atlantic water is described in Scott and Vilks (1991) and Scott et al. (1989), as being the result of a barren zone in unit L, due to carbonate dissolution and only agglutinated foraminifera that do not exist at present. The area is similar to that found above 1,000 m in the Eurasian Basin (Scott et al., 1989).

4.1.5 *Islandiella teretis* Biofacies

The appearance of *Islandiella teretis* between 23 and 29 cm represents the outer shelf zone (Vilks, 1969), of a shallow marine environment with fine sand sediments and large burrow casts.

4.2 Interpretation of 415B

4.2.1 Higher Salinity, Shallow Water Environment

The surface sediments of this station represent the outer shelf zone with abundance in *Islandiella teretis* (Vilks, 1969), and the constant decrease in temperature (Fig. 1.10B) with depth in the water column could suggest mixing. Salinity is slightly higher than 403B, perhaps due to the lack of a large freshwater source. A deeper environment is represented in the upper portion of the core between 0 and 4 cm, with abundant deep water fauna, *Spiroplectammina* *biformis* and *Hyperammina spp.*. The presence of *Hyperammina spp.* could represent a turbidite environment. There is no significant mottling until the *Hyperammina spp.* decline.

4.2.2 *Islandiella teretis/Cassidulina reniforme* Biofacies

A switch to a glacial environment could be marked with the increase in *Islandiella teretis,* indicating the outer shelf between 4 and 7 cm (Vilks, 1969). The minor appearance of *Cassidulina reniforme* could indicate some warmer water from the AIW (Ishman and Foley, 1996), as *Islandiella teretis* starts to decline. There is an increase in the agglutinated species *Textularia earlandi* and *Trochammina globerinformis*, between 10 and 15 cm and a decrease in *Spiroplectammina biformis* and *Reophax arctica*. It seems that this environment is more productive for foraminifera > 63 µ, then for foraminifera > 45-63 µ.

4.2.3 Pleistocene Sediments

The lower 11 cm of the core could be Pleistocene with the abundance of *Bolivina arctica* (Scott et al., 1989; Scott and Vilks, 1991). The presence of *Spiroplectammina biformis*, *Bolivina arctica*, and *Reophax arctica* in high percentages may indicate high productivity, recalling that elongated foraminifera are thought to be indicators of relatively high productive infaunal environments (Polyak et al., 2004). *Spiroplectammina biformis* is found to be abundant in shallow waters in the Arctic (Vilks, 1989; Madsen and Knudsen, 1994), and marks the ASW (Ishman and Foley, 1996).

4.2.4 Shoreline Sediments and Lower Species Diversity and Population

Transgression is represented down core with the presence of pebbles representing a shoreline. The last 10 cm of the core have lower values for species diversity and number of individual foraminifera (Appendix E), which could be due to the increase in pebbles, organic clasts, burrow casts, mottling and shell fragments (Appendix B).

CHAPTER 5 CONCLUSION

Stations from opposing sides of the Amundsen Gulf have different sedimentological features and some differing and some similar foraminiferal assemblages. These reveal their oceanographic influences. Core 403B begins with an abundant in calcareous faunas and represents an outer shelf zone that turns into a barren environment, which could be due to carbonate dissolution. This type of barren environment, however, is only seen in much deeper water. A warmer ice margin and a warm water source from the AIW are represented after the barren zone, which is abundant in calcareous species. This environment becomes shallower and becomes influenced by ASW with a freshwater plume source. Core 415B starts with low species diversity most likely because of the high amounts of pebbles that most likely represents a Pleistocene shoreline that is under the influence of ASW. The environment becomes deeper with indications of an outer shelf followed by a deeper environment with some turbidity. The environment becomes an outer shelf again, indicated by abundant outer shelf calcareous species.

Other Late Holocene barren intervals found in the other shallow environment piston cores and boxcores should be compared with the one in 403B. Sedimentation rates from a neighbouring station (406) were used for 403B to obtain an approximate age for the core, which could to be about 350 years.

With more reports from the Canadian Arctic Shelf Exchange Study, a greater understanding of the impacts of climate warming on the biological and physical processes can be achieved. Conclusions on the Arctic's response to warming will benefit the livelihood of Arctic species and the Inuit communities.

SYSTEMATIC TAXONOMY

Adercotryma glomerata (Brady)

Lituola glomerata Brady, 1878, p. 433, pl. 20, figs. 1a-c.
Adercotryma glomerata (Brady). Barker, 1960, pl. 34, figs. 15-18; Williamson et al., 1984, p. 224, pl. 1, fig.1.

Ammobaculites exigus Cushman and Brönnimann

Ammobaculites exigus Cushman and Brönnimann, 1948.

Ammotium cassis (Parker)

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.

Astracolis spp.

Astrononion gallowayi Loeblich and Tappan. (Appendix A, Figs. 1)

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.

Bolivina arctica Herman

Bolivina arctica Herman, 1973, p. 140, pl. 1, figs. 1-7, text fig. 3.

Botellina spp.

Brizalina spathulata (Williamson)

Brizalina spathulata Williamson, 1971.- Murray: p. 111, pl. 45, figs 1-4.
Textularia variabilis Williamson, 1858, var. *spathulata* Williamson: p. 76, pl. 6, figs. 164, 165.

Brizalina subaenariensis (Cushman)

Bolivina subaenariensis Cushman, 1922a, p. 46, pl. 7, Fig. 6.
Brizalina subaenariensis (Cushman); Williamson et al., 1984, p. 224, pl. 1, Fig. 8; Scott, 1987, p. 327, pl. 1, Fig. 11.

Buccella frigida (Cushman)

Pulvinulina frigida Cushman,1922b, p. 144.
Eponides frigida (Cushman) var. *calida* Cushman and Cole, 1930, p. 98, pl. 13, Fig. 13a-c; Phleger and Walton, 1950, p. 277, pl. 2, Fig. 21.

Buliminella hensoni Lagoe
Buliminella elegantissima d'Orbigny, var. hensoni Lagoe, 1977.

Eponides frigidus (Cushman)

Eponides frigidus 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.

Cassidulina reniforme Nørvang. (Appendix A, Figs. 2)

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

Cibicides lobatulus (Walker and Jacob)

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, 1952, 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). (Appendix A, Figs. 3)

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

Cribrostomoides jeffreysi (Williamson)

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

Cyclogyra involvens (Reuss). (Appendix A, Figs. 4)

Operculina involvens REUSS 1851, v. 2, p. 370, pl. 46, fig. 30.

Dentalina spp.

Discorbis squamata Parker

Discorbis squamata Parker, 1952.

Eggerella advena (Cushman)

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

Genus ELPHIDIUM de Montfort, 1808

Elphidium bartletti Cushman. (Appendix A, Figs. 5)

Elphidium bartletti Cushman, 1933, p. 4, pl. 1, Fig. 9; Schafer and Cole, 1978, p. 27, pl. 10, Fig. 4.
Cribrononion bartletti (Cushman). Scott et al., 1980, p. 226, pl. 2, Fig. 7.

Elphidium crispum Linné

Elphidium crispum Linné, 1785, pl. 1, fig. 6.

Elphidium excavatum (Terquem). (Appendix A, Figs. 7)

Polystomella excavata Terquem, 1876, p. 429, pl. 2, Fig. 2.
Elphidium excavatum (Terquem) formae Miller et al, 1982b, (all).
  Elphidium excavatum forma *clavatum* MILLER ET AL., 1982.
  Elphidium excavatum forma *excavatum* MILLER ET AL., 1982.

Elphidium subarcticum Cushman. (Appendix A, Figs. 6)

Elphidium subarcticum Cushman 1944, p 27 pl 3 figs 34a,b,35.- Buzas 1966, p. 585-594 pl. 92 figs. 7-10.- Buzas 1985, p. 1087 figs. 8.1, 8.2.
E.albiumbilicatum (Weiss).- Knudsen 1971, p. 268 pl. 10 figs. 15-19, pl. 19 figs. 4-8.
E. magellanicum Heron-Allen & Earland 1932, p 440 pl. 16 figs. 26-28.
E. frigidum Cushman. Buzas et al. 1985, p. 1084, figs. 7.3, 7.6.
E. halandense Brotzen 1943

Elphidiella arctica Parker & Jones

Elphidiella arctica Parker & Jones, 1865.- Knudsen 1971, p. 284 pl. 14 fig. 1.

Epistominella takayangii Iwasa

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

Eoeponidella pulchella Parker

Eoeponidella pulchella Parker, 1952.

Fissurina spp.

Fursenkoina fusiformis (Williamson)

Bulimina pupoides d'Orbigny var. *fusiformis* Williamson, 1858, p. 64, pl. 5, figs. 129,130.
Fursenkoina fusiformis (Williamson). Gregory, 1970, p. 232; Scott et al., 1980, p. 228, pl. 3, figs. 9,10.

Glandulina spp.

Globigerina bulloides d'Orbigny
Globigerina bulloides d'Orbigny, 1826.

Glomospira chorodies

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

Hiarbiculare spp. Haynesina orbiculare

Haplophragmoides canariensis d'Orbigny
Haplophragmoides canariensis d'Orbigny, 1839.

Haynesina orbiculare (Brady). (Appendix A, Figs. 8)
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.
Protelphidium 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, 1980b, p. 43, pl. 5, Fig. 7.
Haynesina orbiculare (Brady). Scott et al., 1980, p. 226 (note).

Hemispaerammina bradyi Loeblich and Tappan
Hemisphaerammina bradyi Loeblich and Tappan *in* Loeblich and Collaborators, 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, 1980b, p. 40, pl. 1, figs. 4,5.

Hyperammina friabilis Brady
Hyperammina friablis Brady, 1884.

Hyperammina spp. Brady.
Hyperammina sp., Brady, 1878.

Islandiella teretis (Tappan). (Appendix A, Figs. 9)
Cassidulina teretis Tappan, 1951, p. 7, pl. 1, figs. 30a-c.
Islandiella teretis (Tappan). Scott, 1987, p. 328, pl. 2, Fig. 13.

Jaculella acuta Brady

Jaculella acuta Brady, 1879.

Genus LAGENA Walker and Jacob (in Kanmacher), 1798. (Appendix A, Figs.10)

Miliolina spp.

Nodosaria spp.

Nonion barleeanum (Williamson)

Nonionina barleeanum Williamson, 1858, p. 32, pl. 4, figs. 68, 69.
Nonion barleeanum (Williamson). Scott, 1987, p. 328.

Nonionellina labradorica (Dawson)

Nonionina labradorica Dawson, 1860, p. 191, Fig. 4.
Nonionellina labradorica (Dawson). Williamson et al., 1984, p. 224, pl. 1, Fig.11.

Genus OOLINA d'Orbigny. pl. 2. fig. 18a, 18b.

Oridorsalis umbonatus Reuss

Oridorsalis umbonatus Reuss, 1851.
Rotalia umbonata Reuss, 1851.

Planulina wuellerstorfi Schwager

Planulina wuellerstorfi Schwager, 1866.

Psammosphaera fusca Schulze

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

Pseudopolymorphina novangliae (Cushman)

Polymorphina lactea (Walker and Jones) var. *Novangliae* Cushman, 1923, p. 146, pl. 39, figs. 6-8.

Pyrgo williamsoni (Silvestri)

Biloculina williamsoni Silvestri, 1923, p. 73.
Pyrgo williamsoni (Silvestri). Loeblich and Tappan, 1953, p. 48, pl. 6, figs. 1-4.

Quinqueloculina agglutinans (d'Orbigny)

Quinqueloculina agglutinans d'Orbigny, 1839, p. 195, pl. 2, figs. 11-13.- Bock, 1971, p. 16, pl. 4, fig. 3-5.

Quinqueloculina lamarckiana d'Orbigny

Quinqueloculina lamarckiana d'Orbigny, 1839, p. 189, pl. 11, figs. 14, 15.- Cushman, 1921, p. 65, pl. 15, figs. 13, 14.- Cushman, 1922, p. 64.- Cushman, 1929, p. 26, pl. 2, fig. 6. Bock, 1971, p. 19, pl. 6, figs. 7-9.- Todd and Low, 1971, p. 8, pl. 2, fig. 10.

Quinqueloculina seminulum (Linné). (Appendix A, Figs. 11)

Serpula seminulum Linné, 1758, p. 786.

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

Recurvoides turbinatus (Brady). (Appendix A, Figs. 12)

Haplophragmium turbinatus BRADY 1881, p. 50.

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

GENUS *Reophax* de Montfort, 1808

Reophax arctica Brady

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, 1881.- Jones 1994, pl. 30, figs. 21-22.

Reophax fusiformis (Williamson)

Reophax fusiformis (Williamson) PARKER 1952a, p. 395, pl. 1, figs. 11-19.

Reophax guttifer Brady

Reophax guttifer Brady, 1881, pl. I, 8.

Reophax nana Rhumbler

Reophax nana Rhumbler, 1911, p. 182, pl. 8, figs. 6-12; Scott et al., 1977, p. 1579, pl. 3, figs. 1,2; Schafer and Cole, 1978, p. 29, pl. 2, Fig. 4; Scott and Medioli, 1980b, p. 43, pl. 2, Fig. 6.

Reophax nodulosus Brady

Reophax nodulosus Brady, 1879

Reophax scorpiurus (de Montfort)

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

Reophax scottii Chaster. (Appendix A, Figs. 13)

Reophax scottii Chaster, 1892, p. 57, pl. 1, Fig. 1; Miller et al., 1982a, p. 2362, pl. 1., Fig. 7.

Rhizammina algaeformis Brady

Rhizammina algaeformis Brady, 1879

Robertinoides charlottensis (Cushman)

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

Saccammina atlantica (Cushman)

Proteoina atlantica CUSHMAN 1944, p. 5, pl. 1, fig. 4.- PHLEGER 1952, p.85, pl. 13, figs. 1, 2.
Saccammina atlantica (Cushman).- VILKS 1962, p. 43, pl. 1, fig. 13.- BARBIERI and MEDIOLI 1969. p. 853, pl. 1, fig. 4.- COLE 1981, p. 13, pl. 1, fig. 14.

Saccammina difflugiformis (Brady). (Appendix A, Figs. 15)

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

Saccammina sphaerica (Sars)

Saccammina sphaerica Sars, 1872
Saccammina spp.

Spiroplectammina biformis (Parker and Jones). (Appendix A, Figs. 14)

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; 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.

Textularia earlandi Parker. (Appendix A, Figs. 16)

Textularia earlandi Parker, 1952, p. 458 (footnote), pl. 3, figs. 12a, 12b.

Thurammina spp.

Trifarina fluens (Todd)

Angulogerina fluens TODD in Cushman and Todd 1947, p. 67, pl. 16, figs. 6, 7.
Trifarina angulosa (Williamson).- GREGORY 1970, p. 217, pl. 11, fig. 5.
Trifarina fluens (Todd).- FEYLING-HANSSEN in Feyling-Hanssen et al. 1971, p. 242, pl. 7, figs. 12-15, pl. 18, fig. 10.- COLE and FERGUSON 1975, p.42, pl. 6, fig. 10.- SCOTT 1977a, p. 177, pl. 8, figs. 12, 13.- SCHAFER and COLE 1978, p. 29, pl. 7, fig. 3.

Trochammina compacta Parker

Trochammina compacta Parker, 1952.

Trochammina globigeriformis. (Appendix A, Figs. 17a, 17b)

Trochammina lobata Cushman

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

Trochammina pacifica Cushman

Trochammina pacifica Cushman, 1925.

Trochammina nana Brady. (Appendix A, Figs. 18a, 18b)

Trochammina nana Brady, 1881.

Trochammina nitida Brady

Trochammina nitida Brady, 1881.

Trochammina spp.

Trochammina squamata Parker and Jones

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

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APPENDIX A

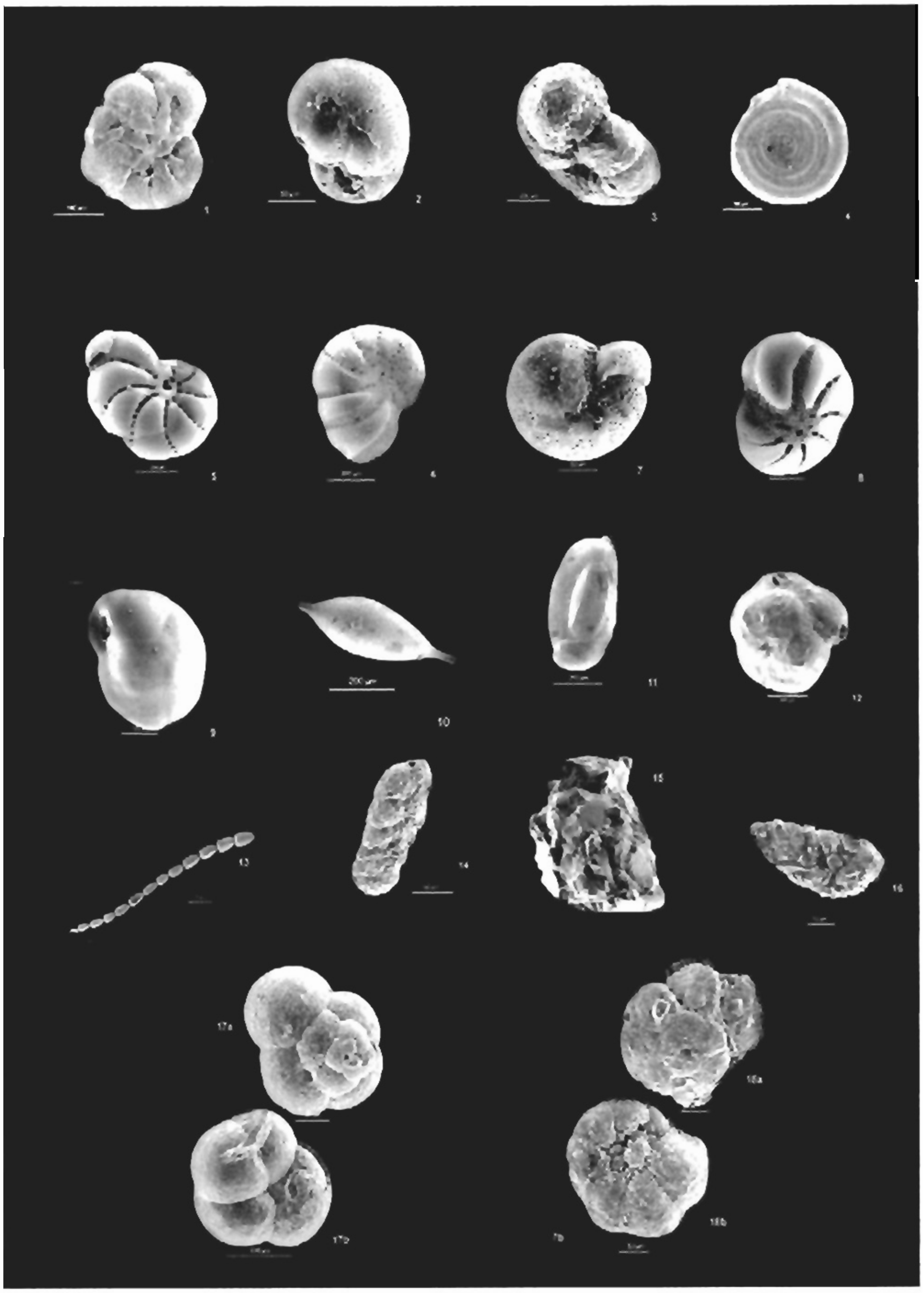

Plate 1. (1) *Astronion gallowayi*, side view. (2) *Cassidulina reniforme*. (3) *Cribrostomoides crassimargo*, side view. (4) *Cyclogyra involven*. (5) *Elphidium bartletti*, side view. (6) *Elphidium subarcticum*, side view. (7) *Elphidium exc. f. clavatum*, side view. (8) *Haynesina orbiculare*, side view. (9) *Islandiella teretis*, side view. (10) *Lagena spp.*, side view. (11) *Quinqueloculina seminulum*, side view. (12) *Recurvoides turbinatus*, dorsal view. (13) *Reophax scotti, side view.* (14) *Spiroplectammina biformis*, side view. (15) *Saccammina diffugiformis*, side view. (16) *Textularia earlandi*, side view. (17a) *Trochammina globigeriniformis*, dorsal view. (17b) *Trochammina globigeriniformis,* ventral view. (18a) *Trochammina nana*, dorsal view. (18b) *Trochammina nana*, ventral view.

(SEM photographs by Frank Thomas, Bedford Institute of Oceanography, Dartmouth, Nova Scotia)

APPENDIX B

403B Core Depth (cm)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29
Total number of individuals (10cc)	59	219	110	96	64	114	124	130	162	64	56	426	108	84	120	48	30	9	6	24	12	12	18	102	240	213	201	189	270
Total number of species (10cc)	14	15	20	11	11	12	13	12	15	10	8	11	10	8	11	6	4	3	1	1	1	1	2	9	9	9	11	8	7
Astracolis sp.							1.6	3.1	1.2			1.4													1.3				
Astrononion galloway									1.2			4.2																	
Bolivina arctica	5.1	5.5					1.6																			1.4			
Brizalina spathulata			1.8																										
Cassidulina reniforme		2.7	10.9	8.3	34.4	18.4	8.1	21.5	9.9	7.4	28.6	16.9	13.9	14.3	32.5	25.0	20.0							38.2	43.8	23.9	29.9	33.3	12.2
Cibicides lobatulus	2.5	2.7	9.1	6.3			8.1	16.9	11.1	7.4	10.7	7.0	11.1	21.4	7.5	12.5	10.0							8.8				1.6	1.1
Cribrostomoides crassimargo	2.5	1.4		2.1																				8.8			1.5	1.6	
Cyclogyra involvens	2.5																												
Eggerella advena			1.8																										
Elphidium bartletti			1.8		6.3		1.6				7.1	5.6		7.1	5.0			33.3											
Elphidiumcrisbum																												1.6	
Elphidium etavatum				2.1		2.6																							
Elphidium exc. F. clavata				2.1		7.9	8.1	4.6	8.6	1.2	7.1	2.8	2.8		10.0	6.3								11.8	1.3		1.5		3.3
Elphidium sp.										1.2																2.8			
Elphidium subarctica			5.5	4.2	3.1	10.5	9.7	9.2	14.8	3.7	7.1	16.9	13.9	3.6	7.5	12.5	20.0							8.8	18.8	21.1	28.4	15.9	22.2
Fissurina spp		1.4	1.8			5.3		3.1	4.9	1.2		2.8		3.6	2.5										1.3				
Fursenkoina fusiformis						2.6	3.2	4.6				1.4																	
Glandulina sp.									1.2																				
Glomospira gordalis									2.5				2.8																
Haplophragmoides canariensis	2.5	1.4	5.5		3.1																					1.4			
Haynesina orbiculare			3.6	14.6		2.6	4.8	6.2	2.5	2.5	3.6	4.2	5.6	7.1	2.5									2.9	3.8		4.5		5.6
Hyperammina sp.	5.1																												
Islandiella teretis		28.8	18.2	20.8	12.5	26.3	33.9	15.4	32.1	8.6	25.0	33.8	30.6	35.7	17.5	37.5	50.0	33.3					33.3	14.7	25.0	42.3	25.4	36.5	54.4
Nodosaria sp.								1.5																					
Nonionellina labradorica			1.8		3.1										2.5														
Oridorsalis umbonatus															2.5										2.5	4.2	3.0		
Pseudopolymorphina novangliae									1.2	1.2																			
Quinqueloculina agglutinans	2.5								1.2																				
Recurvoides turbinatus		5.5	1.8		6.3	2.6	1.6		2.5																			3.2	1.1
Reophax arctica	12.7		1.8		3.1	2.6	1.6																						
Reophax fusiformis	7.6	1.4																											
Reophax scorpiurus	5.1	1.4																											
Reophax sp.	20.3	35.6		22.9	9.4	5.3	9.7	12.3	4.9	4.9	10.7	2.8	13.9	7.1	10.0	6.3		33.3	100.0	100.0	100.0	100.0	66.7	5.9			1.5		
Saccammina atlantica	2.5		7.3																										
Saccammina difflugiformis		1.4																											
Saccammina sp.																										2.8			
Saccammina sphaerica													2.8																
Spiroplectammina biformis	25.4	8.2	16.4	14.6	15.6	13.2	6.5						2.8												2.5		1.5	6.3	
Textularia earlandi	2.5		3.6	2.1	3.1																								
Trochammina globigeriniformis			3.6																										
Trochammina nana		2.7	1.8					1.5																			1.5		
Trochammina sp.			1.8																								1.5		
Agglutinated fragments		x		x	x																				x				
Ostracods																													
Pebbles	x																												
Burrow casts																			x	x	x	x	x	x	x	x	x	x	x
Coral/Sponge fragments													x	x	x														
Shell fragments						x	x	x	x	x	x	x	x	x	x														
Calcareous fragments					x	x									x									x	x			x	

Boxcore 403B (> 63 µ) total number of individuals, total number of species, foraminiferal percentage abundance, and accessory distributions in 10 cc versus core depth.

APPENDIX C

Station	403B		415B	
Water Depth (m)	59		45	
Size	>63 µ	>45-63 µ	>63 µ	>45-63 µ
Total Species (10 cc)	33	10	34	9
Total Individuals (10cc)	1020	900	324	102
Ammodiscus catinus			0.3	
Astrononion galloway			0.3	
Astrorhiza arenaria			0.3	
Bolivina arctica		2.7		
Buccella frigida	2.9		1.5	
Buliminella hensoni	3.5	29.3	0.0	17.6
Cassidulina reniforme	2.1		4.9	5.9
Cibicides lobatulus	3.8		3.1	
Cribrostomoides crassimargo	1.8		0.3	
Cribrostomoides jeffreysi	1.8		0.3	
Cyclogyra involvens	0.6	1.3	0.3	
Discorbis squamata	0.3		1.9	5.9
Eggerella advena	0.3		0.3	
Elphidium bartletti			0.6	
Elphidium exc. f. clavatum	12.6		6.2	
Elphidiella arctica	0.3			
Eoeponides pulchella	4.1	14.7		
Epistominella takayanagii	1.2	9.3		
Fissurina spp.	0.6		3.4	
Fursenkoina fusiformis	3.8	1.3	0.3	
Haynesina orbiculare	6.5		1.2	
Hemisphaerammina bradyi	0.3		2.5	
Hyperammina frabilis	0.6			
Islandiella teretis	10.0		38.0	
Jacullena acuta			3.1	
Nonionellina labradorica	0.3			
Oolina borealis			0.3	
Psamosphaera fusca	0.9		0.6	
Pseudopolymorphina novangliae			0.3	
Quinqueloculina agglutinans	0.3			
Quinqueloculina seminulum	0.6		2.8	
Recurvoides turbinatus	0.6		0.6	
Reophax arctica	4.7		3.7	5.9
Reophax dentaliformis	2.1			
Reophax scorpiurus	2.6		2.8	
Reophax scottii				5.9
Rhizammina algaeformis	0.3		0.3	
Robertinoides charlottensis			0.3	
Saccammina difflugiformis	5.3	5.3	8.3	
Spiroplectammina biformis	7.4	1.3	6.8	23.5
Stetsonia arctica		5.3		5.9
Textularia earlandi	16.2	29.3	1.5	23.5
Trifarina fluens			0.3	
Trochammina nana	0.9		2.5	5.9
Ptbbs			0.3	
Tintinnids	1.5	41.3		
Agglutinated frags	some small		abundant	
Molluscs			many fragments	
ostracods	many		abundant	

Surface foraminiferal sample percentages for 403B and 415B in 10 cc (after CASES, 2004).

APPENDIX D

403B Core Depth (cm)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	11-12	15-16	19-20	23-24	28-29
Total number of individuals (10cc)	47	51	17	27	32	40	61	76	191	25	8	53	8	80	39
Total number of species (10cc)	4	13	6	3	8	9	5	7	17	3	3	5	2	11	9
Adercotyma glomerata			5.9				41.0								
Ammotium cassis	12.8														
Astracolis spp.									1.6						
Bolivina arctica	63.8	43.1	47.1	66.7	37.5	35.0	44.3	27.6	21.2	48.0	25.0	45.3	75.0	30.0	7.7
Brizalina subaenariensis		3.9					20.5								
Cassidulina reniforme									2.1						
Cyclogyra involvens		2.0			6.3			3.9							
Eggerella advena	10.6	7.8	17.6	14.8	9.4	10.0	24.6	3.9	3.1		12.5	5.7		5.0	
Elphidium exc. f. clavatum								9.2	7.9					11.3	2.6
Elphidium spp.									1.6	16.0				2.5	
Elphidium subarctica									0.5					3.8	
Eoeponides pulchella														0.0	38.5
Fissurina spp.									5.5	36.0				7.5	
Fursenkoina fusiformis								39.5	33.8					15.0	12.8
Globigerina bulloides									3.9						
Haplophragmoides canariensis		3.9							0.5						7.7
Hemisphaerammina bradyi		2.0				2.5									
Hyperammina spp.		2.0													
Islandiella teretis														8.8	10.3
Pseudopolymorphina novangliae							41.0								
Reophax arctica		2.0			6.3	7.5		3.9	1.6			17.0		6.3	
Reophax nana		2.0													
Reophax scotti		5.9			12.5	17.5	24.6	11.8	5.5		25.0	9.4	25.0	6.3	7.7
Reophax spp.					6.3		61.5								
Saccammina diffugiformis		2.0													
Spiroplectammina biformis			5.9	7.4		7.5			5.5					3.8	
Textularia earlandi	12.8	9.8	5.9		15.6	10.0	3.3		1.6		37.5	22.6			5.1
Trochammina nana						5.0			0.8						
Trochammina spp.		13.7	17.6	11.1	6.3	5.0	3.3		3.1						7.7

Boxcore 403B (> 45-63 µ) total number of individuals, total number of species, foraminiferal percentage abundance, and accessory distributions in 10 cc versus core depth.

APPENDIX E

415B Core Depth (cm)	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**
Total number of individuals (10cc	501	393	396	912	909	819	578	305	726	840	1008	807	512	368	339	338	573	723	470	195	432	170
Total number of species (10cc)	34	25	29	27	28	27	28	35	32	25	28	25	23	20	20	22	20	20	18	18	12	13
Adercotyma glomerata	0.3																					
Ammobaculites exiquus															0.4							
Ammotium cassis		0.4																				
Astracolis spp.										0.4												
Astrononion galloway	0.3			0.7	1.3	1.1	0.7	1.6	0.3			1.9										
Bolivina arctica	11.7	10.7	10.3	8.6	4.3	7.3	5.5	11.4	10.2	13.1	19.9	12.3	15.8	7.1	15.9	7.1	13.6	16.2	15.3	20.8	9.7	15.9
Botellina spp.										0.4				1.6								
Brizalina spathulata	2.4											1.1								0.8		
Brizalina subaenariensis								0.8														
Cassidulina reniforme	0.6					0.4		4.7	1.4	1.9	0.3		4.1	5.4		6.5	2.6	3.3				
Cibicides lobatulus	2.4		0.6	1.0	1.7	2.9	3.1	2.8	0.8	1.9	1.2	1.1	3.5	3.8		4.7	1.0	2.1				
Cribrostomoides crassimargo	1.2	1.1	0.3	0.3	1.0	1.5	1.0	1.2	0.6	1.1	1.5	2.2	1.5	2.2	0.4	3.0	1.6		0.4	0.8		
Cyclogyra involvens	0.3	1.1	0.6	1.0	0.3	0.7	0.7	0.4	0.8	0.4	0.6	1.1	1.2			0.6		0.8	0.4	0.8		
Dentelina spp.					0.3																	
Eggerella advena	0.3	1.5	1.5	1.3	1.0	1.1			1.7	2.2	0.6	1.1	1.2	2.2	1.3	1.2	2.6	2.5	2.1	0.8		0.9
Elphidiella arctica											0.3											
Elphidium bartletti					1.3	0.4	0.3				0.3											
Elphidium etavatum						0.4	0.3		1.1													
Elphidium exc. f. clavatum	0.3				0.3	1.1	3.5	0.4														
Elphidium spp.				0.3					0.3													
Elphidium subarcticum		0.8	0.3			0.7	0.7	1.6	0.6		0.3		0.6	1.1								
Eoeponides pulchella	0.3			1.3				0.8	1.7													
Epistominella takayanagii								0.4														
Fissurina spp.					0.3	1.5	1.0															
Fursenkoina fusiformis	0.9				0.3	2.2	0.7	1.2			0.3	1.1										
Globigerina bulloides							0.3	2.8														
Glomospira chorodies									0.6													
Glomospira gordalis			0.3					0.4		0.4												
Haplophragmoides canariensis	3.6	3.1	2.7	2.3	2.3	3.3	4.8	2.8	5.0	3.0	2.7		7.6	2.2	6.2	4.7	6.8	9.1	8.5	9.2	5.6	5.3
Haynesina orbiculare	1.5		0.3			3.3		2.0			0.3	0.4										
Hemisphaerammina bradyi	0.3		0.3					0.4														
Hiarbiculare							0.3		0.3													
Hyperammina frabilis		0.8																				
Hyperammina spp.	13.8	6.5	0.9	0.3																		
Islandiella teretis	7.8	0.8	6.7	14.8	20.8	24.2	22.1	0.8	5.0	2.2	0.3	5.9	5.6		0.4	0.6		3.3				
Langena spp.				0.3																		

Boxcore 415B (> 63 μ) total number of individuals, total number of species, foraminiferal percentage abundance, and accessory distributions in 10 cc versus core depth.

APPENDIX E

Miliolina spp.		0.4																				
Nonion barleeanum								0.4														
Nonionellina labradorica												0.7										
Oolina borealis	0.3																					
Oridorsalis umbonatus	0.3	0.8	0.6		0.3		0.3	1.2	0.6		0.6		0.6		0.4	0.6	1.0	3.7	0.9	3.1		
Planulina wuellerstorfi				0.3																		
Pseudopolymorphina novangliae							1.0															
Pyrgo williamsoni					0.3																	
Quinqueloculina lamarckina	0.3																					
Quinqueloculina seminulum	1.2		1.5	1.3		0.4		0.8	0.3													
Recurvoides turbinatus	0.3	0.4	3.0	0.7	1.7	0.4	1.7	2.0	1.7	0.7	0.9	1.9	2.1	1.6	0.4	2.4	1.6	1.7	2.1	2.3	5.6	1.8
Reophax arctica	1.5	5.7	6.4	2.0	1.7	7.7	2.1	2.8	6.9	6.3	3.6	0.7	0.6	6.0	7.5	8.3	11.5	7.5	10.2	11.5	2.8	9.7
Reophax fusiformis	2.4	5.7	0.6	0.7	1.0	1.5	0.3	1.6	2.8	0.7	2.4	3.7	2.3	2.7	2.2	4.7	1.6	1.2	3.0	3.1	5.6	6.2
Reophax guttifer		0.4																				
Reophax nana	0.3		0.3								0.3											
Reophax nodulosa		0.4																	0.4			
Reophax scorpiurus	3.6	3.1	1.2	1.0	1.3	0.7	1.4	1.6	0.6	1.5	1.5	0.4	1.2	1.1	0.4	0.6	1.0	2.9	0.9	0.8	2.1	
Reophax scottii			0.6	0.7															0.4			
Reophax sp.			0.6		1.3	3.3		0.4	2.8	3.4	2.4	0.4	1.8	3.3	2.2						2.8	4.4
Saccammina atlantica	7.8	8.8	11.8	6.9	8.6	9.2	15.2	12.6	11.3	14.6	10.1	3.0	7.6	12.0	15.5	13.0	6.3	5.8	3.8	12.3	6.3	1.8
Saccammina difflugiformis	2.1	1.1	0.9		0.3		1.7		0.3	0.4	0.9	0.4	0.3		0.4	1.8	3.1	2.9	3.0	1.5		2.6
Saccammina spp.											0.6											
Saccammina sphaerica	3.0	0.8	0.6	0.7	0.7		0.3	0.4		1.5	2.1	0.7		0.5	0.4	2.4						
Spiroplectammina biformis	15.0	26.3	26.1	26.0	21.8	16.5	13.5	20.9	26.4	27.6	28.3	23.0	16.7	21.7	21.2	21.3	29.8	18.3	31.9	9.2	45.1	36.2
Textularia earlandi	5.4	9.2	10.9	13.8	12.5	0.4	6.2	6.3	5.0	5.6	5.7	17.8	7.0	6.5	11.5	5.9	6.3	7.5	7.2	10.0	8.3	5.3
Thurammina spp.	0.6																					
Trochammina compacta				0.3																		
Trochammina globigerinformis	7.2	9.5	8.8	10.5	10.9	6.6	10.0	8.3	9.1	14.2	11.9	16.0	15.5	15.2	11.1	7.1	3.7	7.5	9.4	9.2	3.5	6.2
Trochammina lobata			0.3	0.3					0.3		0.3	0.4				1.2						
Trochammina nana				0.7	1.0			1.2	0.3				2.1		0.9	1.2	3.7	1.7		2.3	2.8	3.5
Trochammina nitida									0.6	0.4							0.5					
Trochammina pacifica								1.2		0.7		1.5	0.3	1.6		1.2	0.5	2.1				
Trochammina spp.	0.9	0.8	0.9	2.0	1.3	1.5	0.7	1.2	1.4			1.1	0.9	2.2	0.9		1.0			1.5		
Trochammina squamata								1.2														
Ostracods							x	x	x	x	x											
Pebbles	x						x	x	x	x	x					x	x	x	x			x
Burrow casts														x	x	x	x					
Organic clasts							x	x	x	x	x					x	x	x	x			x
Shell fragments														x	x	x	x					
Spicule-like fragments	x	x	x	x	x	x	x	x														

Boxcore 415B (> 63 µ) total number of individuals, total number of species, foraminiferal percentage abundance, and accessory distributions in 10 cc versus core depth.

APPENDIX F

415B Core Depth (cm)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22
Total number of individuals (10cc)	266	31	28	24	6	83	220	108	24	92	53	48	34	19	10	54	48	34	47	13	54	38
Total number of species (10cc)	10	6	4	3	3	6	8	5	3	6	4	5	4	5	3	5	5	4	2	3	3	5
Bolivina arctica	55.6	38.7	10.7	50.0	50.0	73.5	43.6	38.9	50.0	32.6	69.8	37.5	35.3	21.1	60.0	46.3	45.8	35.3	89.4	46.2	55.6	36.8
Cyclogyra involvens	1.1					4.8	1.4															
Eggerella advena		6.5			16.7									10.5								
Elphidium spp.					33.3																	
Haplophragmoides canariensis							2.7															
Hyperammina spp.						1.2																
Quinqueloculina seminulum	0.4																					
Reophax arctica			32.1				11.4	5.6		13.0	11.3	22.9	35.3	47.4			18.8				33.3	28.9
Reophax guttifer	2.3																					
Reophax scotti	2.3		42.9	45.8		7.2	5.0	16.7						5.3	30.0	24.1	8.3					
Spiroplectammina biformis	4.5	9.7				6.0	5.5		25.0	8.7		12.5	11.8			11.1	12.5	14.7	10.6	46.2		7.9
Stetsonia arctica	2.3																					
Textularia earlandi	11.3	9.7	14.3	4.2		7.2	22.3	33.3	25.0	26.1	11.3	16.7	17.6	15.8	10.0	7.4	14.6	35.3		7.7		7.9
Trochammina globigerinformis	18.0	25.8																				
Trochammina nana							8.2	5.6		18.5												
Trochammina spp.	2.3	9.7								1.1	7.5	10.4				11.1		14.7			11.1	18.4

Boxcore 415B (>45-63 µ) total number of individuals, total number of species, foraminiferal percentage abundance, and accessory distributions in 10 cc versus core depth.