Paleo-oceanography and paleo-ice cover of the Amundsen Gulf, Northwest Territories, using foraminiferal proxies from box cores

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ABSTRACT

Scientific research defining paleo-environments and paleo-ice cover of the Arctic Ocean is essential to the interpretation of current day trends within these regions. In 2004, the crew aboard the *NGCC Amundsen* collected box cores at stations within the Amundsen Gulf chosen carefully with the help of multi-beam sonar images, and sub-bottom profiles. This particular study is an investigation of the foraminifera in box cores 209B and 215, which transect through the Amundsen Gulf.

Both box core 209B and 215 show signs of an extremely low sedimentation rate, representing the entire Holocene. Recent research on benthic foraminifera completed on the Beaufort shelf indicate a high sedimentation rate. Box core 209B was taken at a water depth of 241 m in the Amundsen Gulf. Foraminifera from box core 209B were dominated by agglutinated species, which are common among the sediments of the Arctic shelf and shallow seas. The Late Holocene sediments (~1-5 cm interval) indicate less sea ice with few calcareous species in the sediment. Since anoxic conditions are not favorable to calcareous test preservation, this explains why other calcareous species were not more common in this core section. The presence of tintinnids near the surface indicate that there is a freshwater flux and no sea ice. Box core 215 is similar but has no foraminifera and a high concentration of sand, clay, and several large rock fragments near the base representing the glacial/interglacial boundary.

Key words: benthic foraminifera, paleo-environment, ice cover, Amundsen Gulf

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ACKNOWLEGEMENTS

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1 INTRODUCTION

As sea-ice continues to decrease in the Arctic regions, scientific research defining the paleo-environments and the extent of the decrease become crucial to understanding long-term trends. Global warming, an increase in the Earth's surface temperatures resulting from increased greenhouse gases, plays an active role in controlling the presence sea-ice, and consequently, physical oceanography. The annual freeze-ups and break-ups of the sea-ice create an effective platform for use in fishing and hunting. As the Arctic sea-ice continues to decrease in thickness and extent, these platforms become unstable, and nearby Inuit inhabitants struggle to keep their way of life. The multi-year sea-ice is decreasing, and during the summer, it is drifting further from the community, taking along with it access to the food that the community relies on. In the winter, the sea-ice is thin and broken, making it difficult for hunting (Ashford and Castleden, 2001). With continued yearly melting, the Inuit community will be affected, and with an open passage, ships will be able to take a more economic route to international markets. Sea-ice thickness variations are also important to the navigability as well as the insurability of ships. Reconstructions from tree rings, ice cores, and other long-term records indicate that the 20th century was the warmest century in the Arctic since 1600 (Overpeck et al., 1997). This warming is further evident in the recent finding of a grizzly/polar bear cross on Banks Island (Roach, 2006). The increases in temperatures are causing drastic ecological changes, and the once separated terrestrial and marine animals, now interbreed. An average increase of global temperature of 0.75^0C per hundred years is estimated by the Intergovernmental Panel on Climate Change (IPCC, 2002). Global average temperatures have regional highs and lows; however, there is an increase, and it is invariably affecting the Arctic environment. The interpretation of microfossil assemblages in core samples from the Arctic seafloor will help to determine paleo-environment and sea-ice cover in the area.

1.1 STATEMENT OF PURPOSE AND SCOPE OF WORK

In 2004, the crew aboard the Canadian Coast Guard Ship *NGCC Amundsen*, collected 51 box core samples from stations on transects in the Amundsen Gulf and Beaufort Shelf to ultimately determine the paleo-sea-ice variability in this region. Figure 1.1 is a regional map of an area including the Canadian Arctic Archipelago and northern mainland North West Territories to the West and Nunavut to the East. The area sampled by the Canadian Arctic Shelf Exchange Study (CASES) has been boxed in (Fig. 1.1). CASES is a project funded to investigate the Canadian Arctic Shelf, and more specifically, the Beaufort Shelf. CASES is, in part, a study encompassing modern ecology, water character, and health issues in this area, as well as collecting cores for paleoceanography. Figure 1.2 is a map showing the nine transects chosen for sampling. Each transect has numerous sampling stations, and the stations covered in this report are marked (Station 215 and 209). The Amundsen Gulf is a 300 to 400 km long embayment between Banks Island and Victoria Island and mainland NW Territories. The gulf has a width that varies from 75 to 100 km. In the north/north west the gulf terminates in the Beaufort Sea; in the southeast it is connected to the Dolphin and Union Strait, and in the northeast into the Prince of Wales Strait. Station 215 lies on the continental shelf off the south western tip of Banks Island, and station 209 is on the continental margin off the northern tip of Cape Perry, mainland NW Territories. My goals are to identify foraminiferal assemblages in box cores at two stations within the Amundsen Gulf, in an effort to uncover and interpret variations in the data with implications to sea-ice cover and paleo-environments of this region, and to compare to other data from nearby cores (Schell et al., in press).

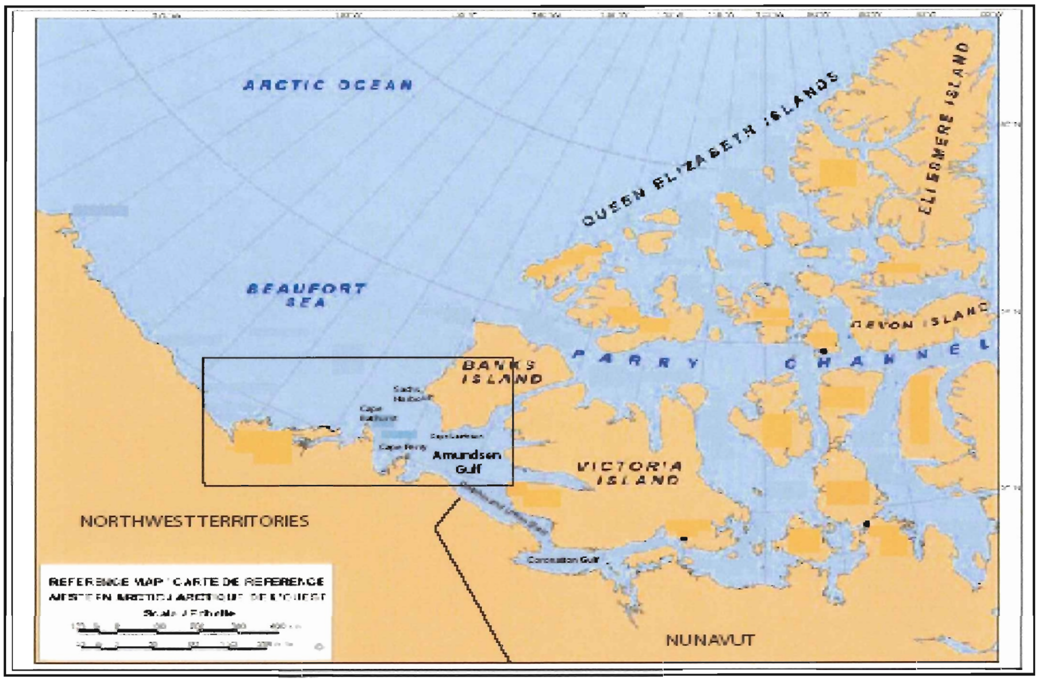

Figure 1.1 – Western Arctic Ocean. CASES research area, Southern Beaufort Shelf & Sea and the Amundsen Gulf, is boxed in (Modified from Canadian Ice Services, Environment Canada)

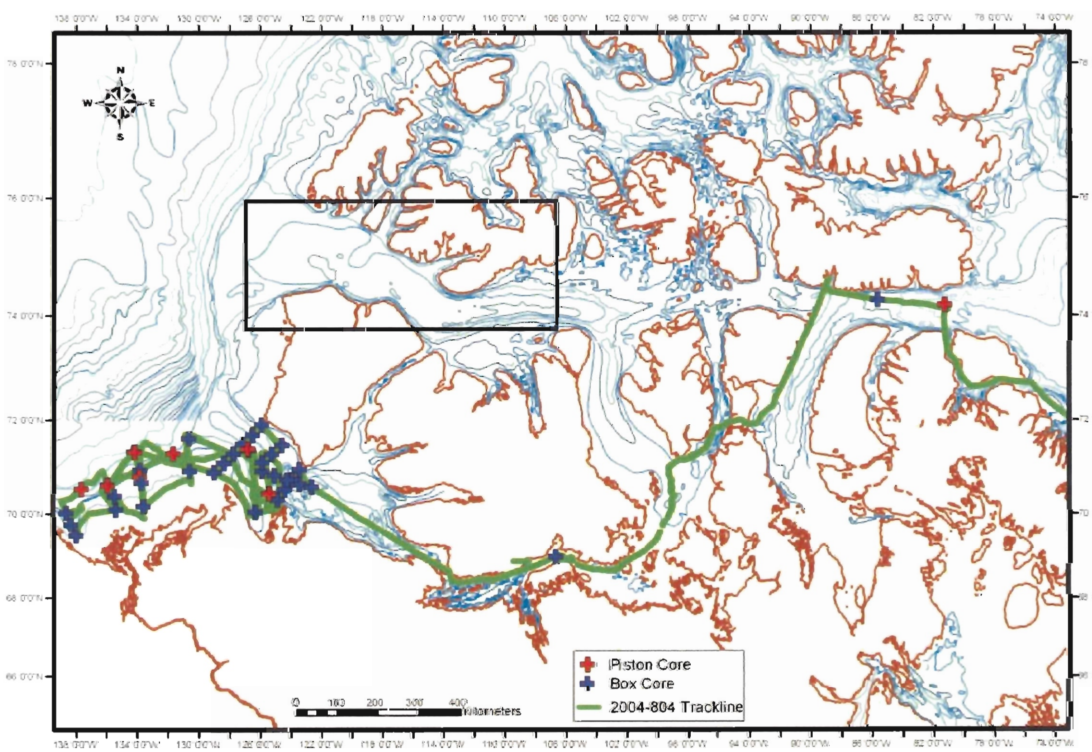

Figure 1.2 – The Beaufort Shelf and Sea and the Amundsen Gulf showing the ship's trackline and piston and box core locations (Modified from CASES cruise report, 2004)

1.2 BACKGROUND

This thesis is part of a larger study involving the interpretation of sea-ice cover and paleo-environments on the Beaufort Shelf and the Amundsen Gulf. By observing different trends in foraminiferal assemblages, a combination of results from various proxies will provide a more comprehensive knowledge of the environments and the ice cover present when the sediments were deposited. Fifty-one box cores, 10 piston cores, 9 plankton tows, and 6 drift sediment traps were recovered from different stations along preselected transects. Surficial foraminifera counts were completed by CASES (Scott et al., in press), and these data will be used for comparison with my data. Recent interpretive work completed on transects 800, 400 and 100 will also assist in my interpretations (Schell et al., in press).

1.3. PALEO-OCEANOGRAPHY

1.3.1 ICE COVER

Ice thickness at 29 stations in the Arctic Ocean as measured by submarine sonar, indicate that the mean ice volume at the end of the melt season in the 1990's had decreased by about 1.3 metres since the 1970's, representing a 40% reduction in ice volume (Rothrock et al., 1999). However, the decrease was greater in the central and eastern Arctic than in the Beaufort and Chukchi sea (Rothrock et al., 1999).

The Tara Damocles mission recovered scientific data on the Arctic sea-ice, to observe decreases in sea-ice extent. In 2007, the sea-ice summer extent measured 4.1 million square kilometres, but in 1998, it measured 6.6 million square kilometres (Gascard et al., 2008). This is a loss of 2.5 million square kilometres in less than 10 years (~40%). If it continues at this rate, there would likely only be seasonal rather than year-round ice in the Arctic ocean.

Perennial ice cover is that which exists year long, and survives the summer melt. Satellite measurements indicate the area of perennial ice cover had decreased by about 7% from 1978 to 1988 (Johannessen et al., 1999). More recent studies by NASA through satellite imaging, have given a slightly higher projection. They averaged the decrease in perennial ice cover to be about 9% from 1990 to 1999 (NASA news, 2002). With such high decreases in the sea-ice, continued observation and study are important to determine the causes, whether they be naturally or anthropogenically controlled, and to have an understanding of what the future might hold for this environment.

Barber and Hanesiak (2004) categorized the sea-ice within the Amundsen Gulf and Beaufort Sea into three separate regimes: (A) the offshore pack ice occurs in the basin beyond the landfast ice, (B) the landfast sea-ice forms along the continental shelf, and (C) the Cape Bathurst Polynya Complex consists of flaw leads and a polynya within the Amundsen Gulf. Boxcore 209 and 215 are near the boundary of the landfast ice and the Cape Bathurst Polynya Complex, as seen in Figure 1.3.

Barber and Hanesiak (2004) completed a study of the sea-ice concentrations in the southern Beaufort Sea from 1979 to 2000. Their study gives a comprehensive review of the freeze-up and break-up patterns of sea-ice around the Western Arctic Ocean.

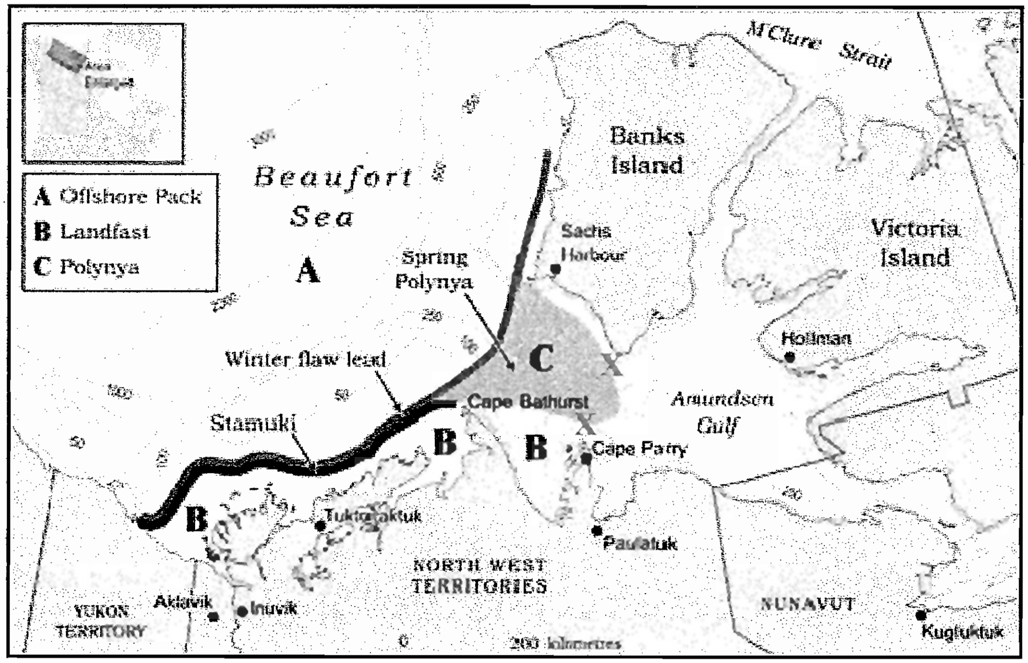

Figure 1.3 - The CASES study region showing the location and shape of the three sea-ice regimes (A) The offshore pack ice (B) The landfast sea-ice (C) The Cape Bathurst Polynya complex. Station 209 and 215 are marked with red X's. (Modified from Barber and Hanesiak, 2004)

1.3.2 SEDIMENTATION RATE

Recent radiocarbon dating indicated that sedimentation rates east of the Mackenzie Delta on the Beaufort Shelf were averaging about 1.35 millimetres per year (Andrews and Dunhill, 2003). The depositional rates in the Arctic Ocean during the Holocene have been well documented by radiocarbon chronology with results indicating higher sedimentation rates near continental margins (e.g., Polyak et al., 2004).

Pb^{210} dating indicates that the sedimentation rate at Station 206 (Fig. 2.2) is 1.6 millimetres per year (Schell et al., in press). This station is less than 100 metres deep, while box cores at station 209 and 215 were taken at depths greater than 200 metres. Since this station is in a shallower environment on the continental shelf, it likely has a higher sedimentation rate than those at station 209 and 215.

1.3.3 FORAMINIFERAL ASSEMBLAGES AND PALEOCEANOGRAPHIC IMPLICATIONS

The temporal distribution of foraminifera shows peaks during the interglacial/interstadial periods and strong decreases during glacial times, which are assumed to be correlated with the drastic reduction in organic productivity (Darby et al., 2006).

Although the controls on the habitats of benthic foraminifera in the Arctic Ocean are not completely understood, distinct patterns have been recognized in the modern distribution of foraminiferal assemblages reflecting a bathymetric zonation, changes in water masses (ie. salinity and temperature variations) and/or sea-ice conditions (Lagoe, 1977; Scott et al., 1989; Scott and Vilks, 1991; Ishman and Foley, 1996).

1.4 A REVIEW OF PREVIOUS STUDIES

Parker and Jones (1860, 1865) completed taxonomic work and developed much of the nomenclature for foraminifera of the North Atlantic and Arctic Oceans. They were the first to study and document Arctic foraminiferal life forms. Cushman (1948) completed taxonomic work and established foraminiferal assemblages in the region from Bering Sea to Greenland including Hudson Bay. He made great advances to taxonomy and he founded the Cushman Laboratory for Foraminiferal Research which still exists today. Phleger (1952) studied the distribution of foraminifera in the Canadian Arctic as well as in the Greenland Arctic. Vilks (1969, 1989) and Iqbal (1973) explored the assemblages of benthic foraminifera on the Canadian Arctic Shelf.

Marlowe and Vilks (1963) and Vilks (1969) explored the foraminifera of the Canadian Arctic Archipelago, and Vilks (1989) reported on the ecology of foraminifera on the Canadian Arctic Shelves. Green (1960) and Lagoe (1977, 1979) also reported on the ecology of benthic foraminifera species in the Arctic Ocean. More recently, Ishman and Foley (1996) studied foraminiferal distributions within the Amerasian Basin, Arctic Ocean.

Markussen and colleagues (1985) completed studies in the Eastern Arctic Ocean and calculated ratios of planktonic to benthic foraminifera. Scott and Vilks (1991) found ratios of 1:1 planktonic to benthic distributions,which contradicted the previous results of Markussen et al. (1985). They determined that two deep-sea foraminiferal species which have long gone unnoticed were common on the Beaufort Shelf by observing the normally overlooked size fractions (>63microns and >45 microns). These improvements in data sampling processes increase the species counts and also provide more reliable data for paleo-oceanographic interpretation (Scott et al., 1989).

More recently, Scott and Schell and their colleagues (Scott et al., and Schell et al., in press) reported on the distribution of Arctic foraminifera within the Beaufort Sea, and made implications from core data to paleo-environments and paleo-ice cover of this region.

2 METHODS

2.1 MISSION OF THE CCGS AMUNDSEN

Canadian Coast Guard Ship (CCGS) Amundsen (Fig. 2.1) went to the Canadian Arctic in 2003/04 on a one year expedition for the purposes of the Canadian Arctic Shelf Exchange Study. This was in part to determine the environment and sea-ice cover changes on the Beaufort Shelf and Sea and to attempt to recover details of the impacts of climate change in these environments. A wide array of sampling was completed in an attempt to help with the future interpretation of these data, and in turn, understand the dynamics of the sea-ice and snow cover. Leg 8 took place during the summer ice break-up of June to August 2004, and sampling was completed along transects in the Amundsen Gulf and Beaufort Sea. (Fig. 2.2)

Figure 2.1 – *CCGS Amundsen* is a class 3 icebreaker refitted for arctic research (CASES, 2004)

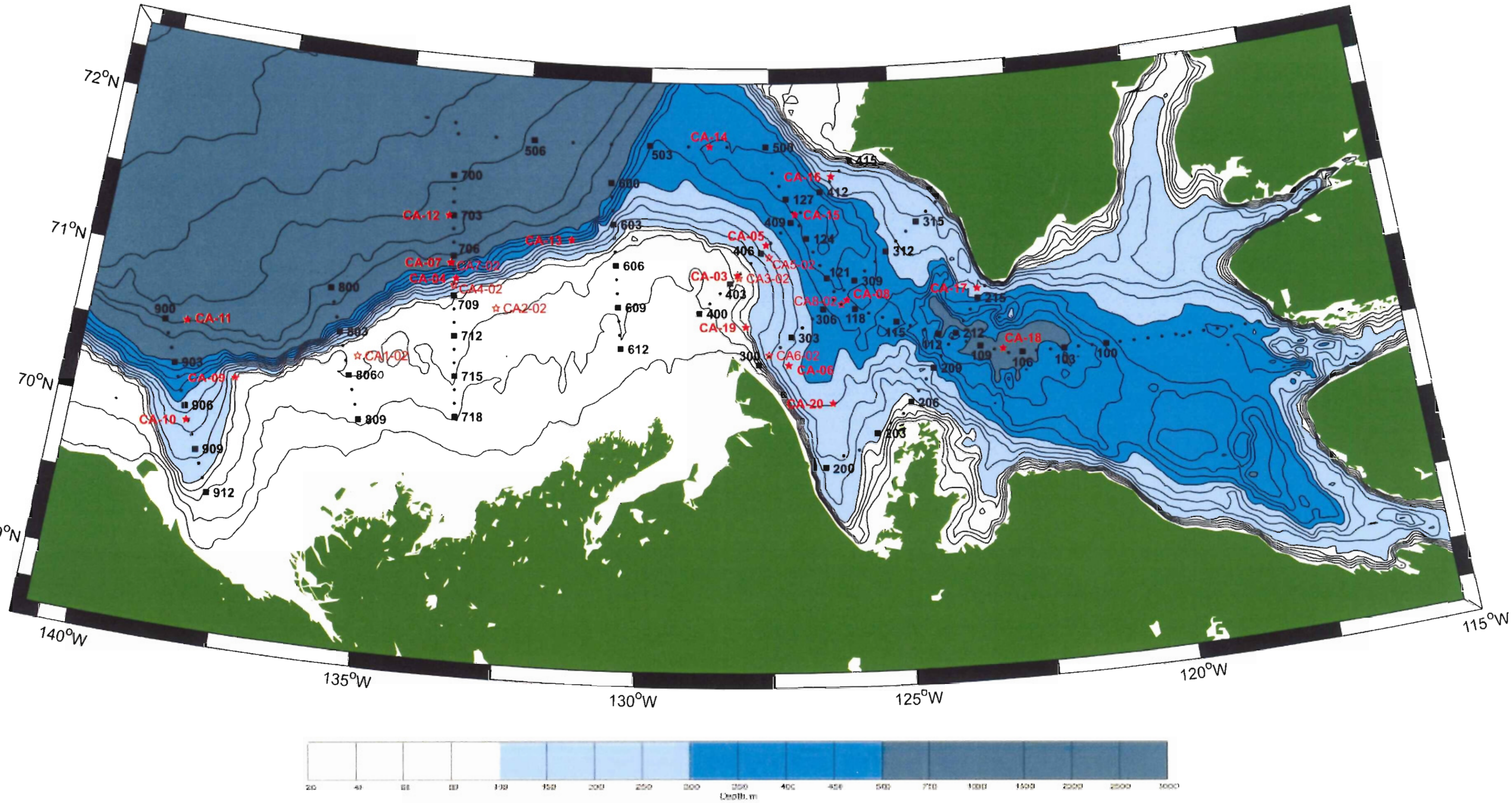

Figure 2.2 – Box cores, piston cores, plankton tows and drifting sediment traps were collected at stations along transects throughout the Amundsen Gulf and Beaufort Sea (modified from CASES, 2004)

2.2 ON-BOARD SAMPLING TECHNIQUES

2.2.1 MULTI-BEAM SONAR IMAGES AND SUB BOTTOM PROFILER

Multi-beam sonar images (Fig. 2.3) and sub-bottom profiler images were taken of the sea floor. The Kongsberg-Simrad EM 300 multibeam echosounder system and the Knudsen 320R deep water echosounder were used on the *CCGS Amundsen* to assist the crew in choosing suitable coring and sampling locations and to help in avoiding areas of low sedimentation and slumping. The multi-beam profile is a 3-D image of the seafloor, and shows any elevated or slumped features (Fig. 2.3). The sub-bottom profiler is a depth section with shallow sub-bottom penetration (Fig. 2.4).

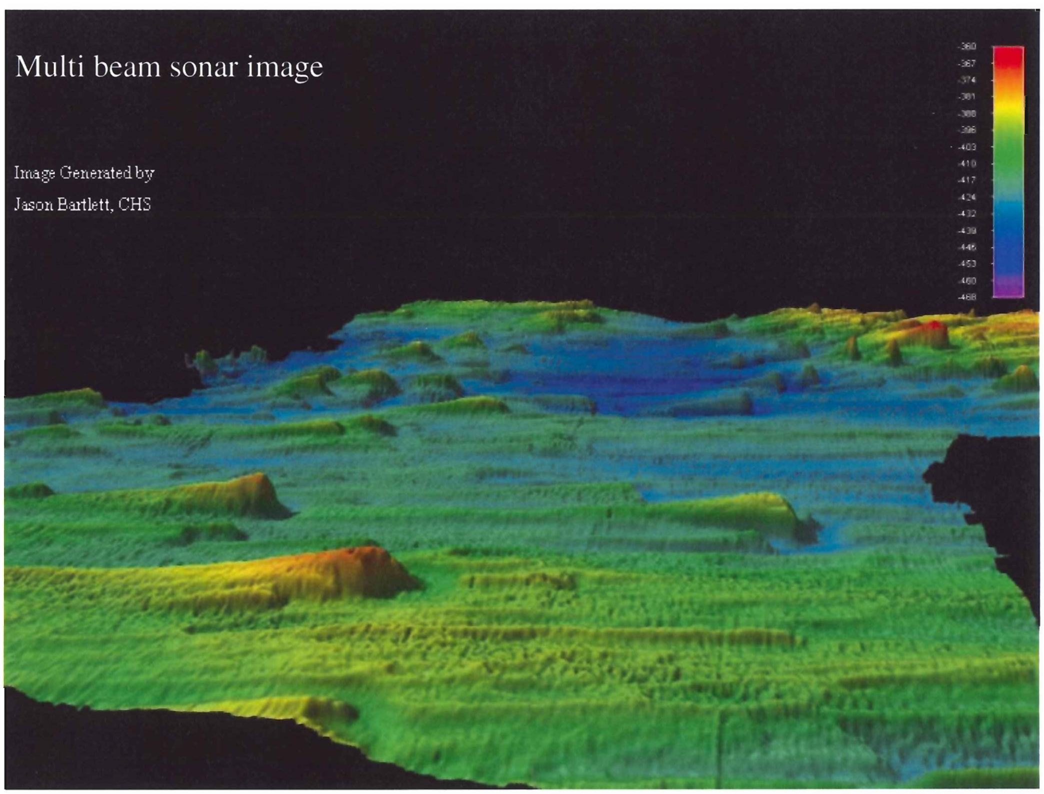

Figure 2.3 – Multi beam sonar image of the Amundsen Gulf originating at Transect 100 and directed northwest. Glaciers created the drumlins (large mounds) and glacial scours (Modified from Clark, 2004)

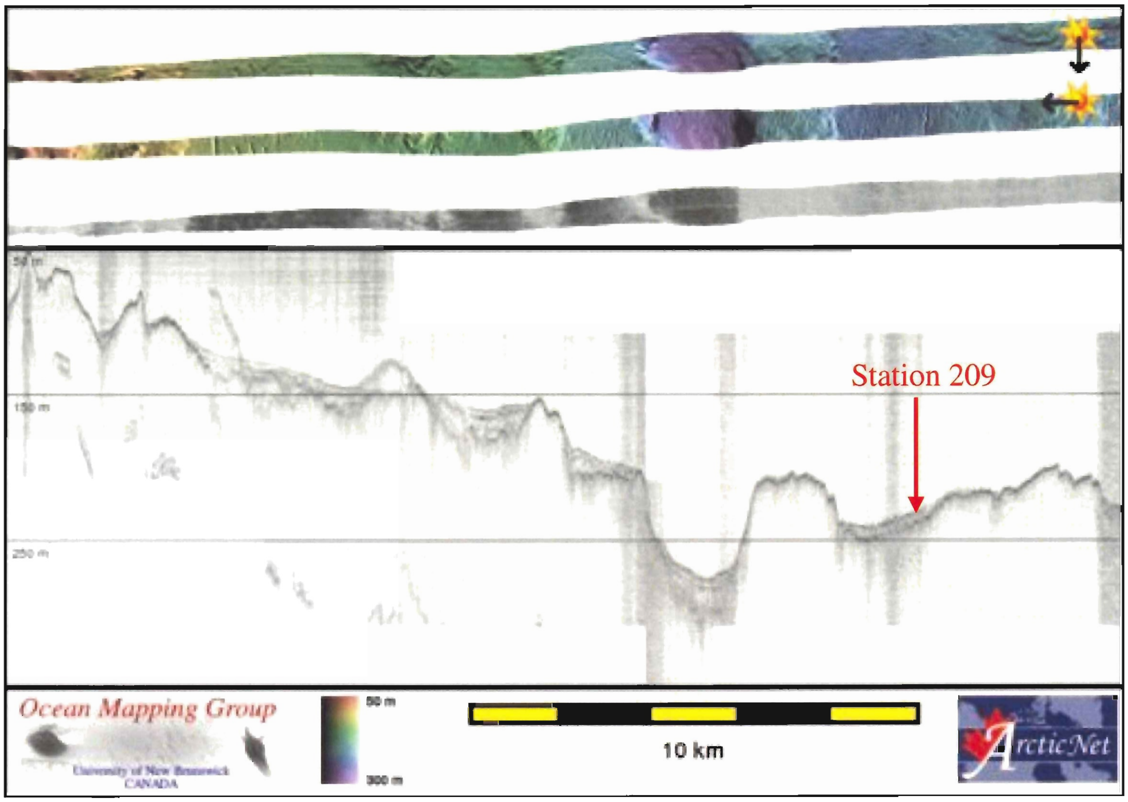

Figure 2.4 – Multi beam and sub-bottom profile originating near station 209
(Modified from Clark, 2004)

2.2.2 BOX CORES

Box cores are undisturbed samples of seafloor sediment. They help in determining living and total populations of microfossils, which assist in the interpretation of the paleo-environment and paleo-ice cover. Box cores were taken from many locations (Fig. 2.2) within the Amundsen Gulf and Beaufort Shelf to aid in the interpretation of this area. Box cores were taken from Stations 209 and 215 on July 31st, 2004. From each box core, two surface samples and two push cores were taken (Fig. 2.5). They were noted for any variations and then were stored and refrigerated at +4^{o}C until further processing at the Bedford Institute of Oceanography (BIO).

Figure 2.5 – Box core with push cores and surficial samples (CASES, 2004)

2.2.3 CONDUCTIVITY, TEMPERATURE AND DEPTH (CTD) DATA

CTD profiles together with fluorescence and transmissometry data were acquired by lowering the CTD device to the seafloor; it collects data at programmed intervals within the water column. CTD data are also useful in understanding the factors that control sedimentation and circulatory patterns within the ocean, as well as factors controlling the preservation of foraminiferal tests: temperature, salinity and depth. This sampling also provides results for fluorescence and transmissometry, which are controlled by the amount of organic matter and debris present in the water column. These data will be discussed in the results and discussion.

2.3 PROCESSING OF THE CORE SAMPLES

Storage and initial sampling of the CASES Arctic core samples were completed at BIO and processing of samples was done at Dalhousie University's core laboratory.

2.3.1 BEDFORD INSTITUTE OF OCEANOGRAPHY (BIO) CORE PROCESSING

The push cores were brought initially to the BIO, where they were split into vertical halves. One half was for sampling; one half was for archiving. Photography, Munsell color matching and photospectrometry were completed shortly after the cores were split because the core begins to oxidize immediately, and this is noticeable in the color changes around the edges of the core after about 3-4 hours. The archived section of each core was X-rayed to help in the description of layering, bioturbation, shells, pebbles, and inner structure of the core column. Core descriptions include lithology, sedimentary structures, grain size, shells, rock fragments, laminations, colour and bioturbation. Core descriptions will be discussed in the results.

The working half of the core was used to provide 10 cm^3 samples. Working halves were marked at every centimetre so that samples could be taken at 1 centimetre intervals for the entire core column. Once marked, a horizontal slab was taken out and 10cm^3 was stored in a sample bag. Samples at the same interval and quantity were also collected for dinoflagellate analysis by André Rochon.

2.3.2 DALHOUSIE UNIVERSITY CORE LAB MATERIAL PROCESSING

The 10 cm^3 samples are taken from BIO and brought to Dalhousie University, where they are kept in cold storage until further processing.

2.3.2.1 SIEVING

The samples are sieved to concentrate the foraminifera into two or three size fractions, and to remove the clay & mud particles and decaying organic matter. The 10 cm^3 samples are sieved in the core lab using sieves >45 µm and >63 µm mesh sizes. It is important to get both of these sizes because some foraminifera do not reach the 63 µm size. In some cases, the material is also sieved at >850 µm or >250 µm mesh sizes because the foraminifera are very large and difficult to observe under a microscope with the smaller-sized individuals. The sieved material is stored in a sealable container with a water and alcohol mixture to preserve the foraminiferal tests.

2.3.2.2 SPLITTING

Once the material was sieved, it was observed under the microscope to determine the approximate concentration of foraminifera. Samples closer to the surface tend to have more individuals, so the material was split into fractions for ease of examination. The 8- and 6-wet splitters (Scott and Hermelin, 1993) were used to split the material, so that populations of 300 to 500 foraminifera could be counted, as this is sufficient to have a good understanding of the species assemblages. The 8-wet splitter (Fig. 2.6) is a large column of water resting on eight separate compartments. For the best results, the sample was poured into a turbulent water column to ensure a uniform distribution in the compartments.

Once the material was sieved and washed, Chloe Younger, Dalhousie University's Core Laboratory curator, completed initial microfossil content descriptions at 1 cm intervals, based on the presence or absence of calcareous and agglutinated species. Calcareous species were not observed at some intervals. Also noted were the presence of other microfossils, such as diatoms and radiolarians.

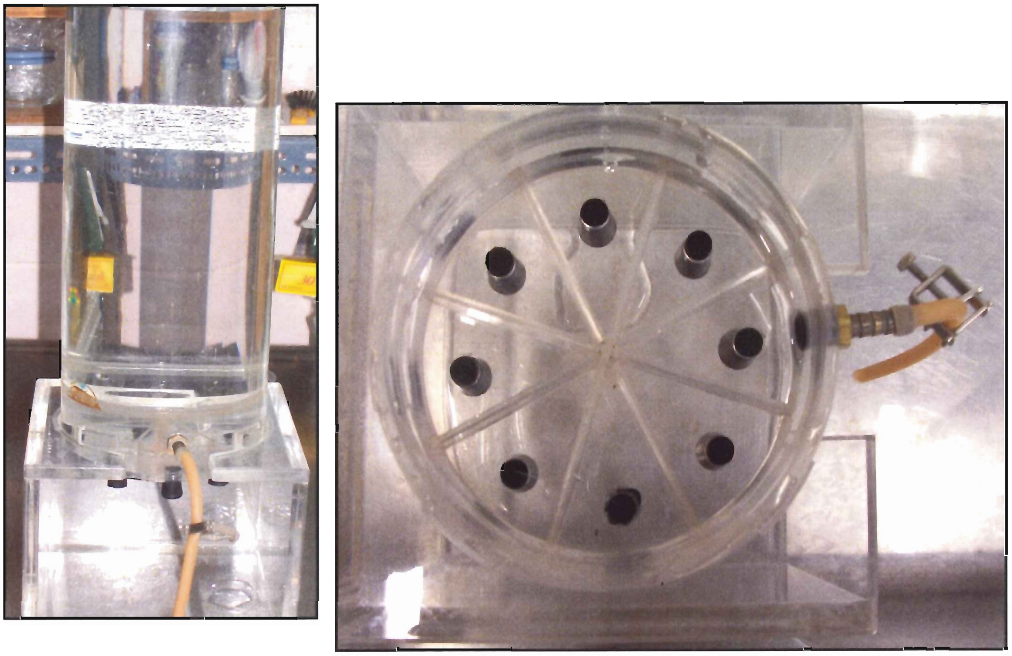

Figure 2.6 – Large water column (left) overlying 8-splitter compartments (right). Sample is poured into the top of the column and settles into the plugged compartments at the bottom of the column. (Photo by Julie Griffiths)

2.3.2.3 IDENTIFICATION, DIFFERENTIATION, AND COUNTING

Each sample is then placed into a gridded petri dish with distilled water, and species are identified through a light microscope. A few representative individuals from each species were placed on slides for easier identification, and for future reference. The individuals in the petri dish were counted to obtain individual totals for each species. Data was logged into a data sheet, and percentage of total species were determined for all species at every centimetre interval in the push core. These totals were used to construct foraminiferal assemblages. Assemblages will be further discussed in Chapter 3.

Select foraminifera species were carbon coated and photographed using a Scanning Electron Microscope (SEM) at the Sexton Campus Facility. The SEM is an effective tool in observing morphological features on foraminiferal tests and are shown in Appendix 2. Not only did these images provide a much better depth perception of the individuals, but they will also be an aid in future identifications.

2.3.2.4 FURTHER PRESERVATION

After the individuals have been identified and counted, the samples were transferred into a smaller vial. A Formaldehyde solution (5-10 ml) is added for long-term preservation. Since formaldehyde is acidic, borax is added to prevent a decrease in the pH, which would cause foraminifera shells to deteriorate. The samples are stored at Dalhousie University's Core Laboratory.

3 RESULTS

Ten cm^3 samples taken at centimetre intervals in the core column were collected, sampled, sieved, and split, and foraminifera were counted. Results for foraminiferal counts for box cores 209B and 215 are in Appendix 1 and are listed as percents of total foraminifera. The results include the smaller (>45-63 micron) size fraction as a percent of total. These data were used to determine assemblages and create genus/species total graphs for easier interpretation. Common species were photographed using an SEM microscope at the SEM-FIB facility at Dalhousie University, and are shown in Appendix 2.

3.1 STATION 209

3.1.1 CTD DATA

CTD data are shown in figure 3.1 as graphs showing temperature, salinity, transmissometry, and fluorescence versus depth, where pressure is on a linear scale with depth. The surface temperature at station 209 is 6.5°C, it rapidly drops to -1°C at a 25 m depth, and goes to a minimum of -1.5°C at 100 m, then gradually increases to -0.8°C at 241 m. The salinity value at the surface is 28.5 PSU, it increases rapidly in the first few m then more slowly as depth increases. The salinity at the seafloor is 34 PSU. The transmissometry and fluorescence data of the sea water aids in determining the concentration of plankton and suspended particles in the seawater. The fluorometer at this station indicates a minor flux of organic matter from 10 to 55 m, and the transmissometer values are fairly consistent throughout the water column.

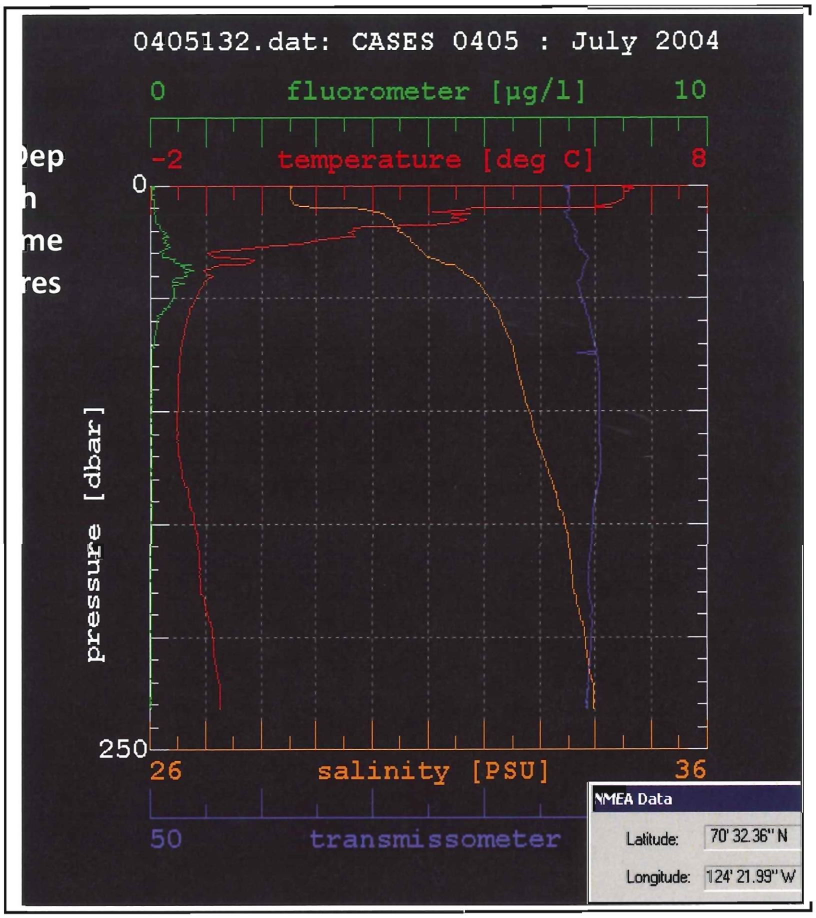

Figure 3.1– CTD (Conductivity, temperature and depth), transmissometry and fluorescence data for station 209 (Modified from Miller, 2004)

3.1.2 LITHOLOGICAL DESCRIPTION

Box core 209B (70° 32.35/124° 22.01) was taken at a water depth of 241 m and measured 14 cm in length. Figure 3.2 is a photograph of box core 209B. The sediment is a brownish gray mud. There are large clay balls and clasts at the 6 to 10 cm interval, and several large stones were found in the 9-11 cm interval. There are higher quantities of sand and clay in the 10 to 14 cm interval. When X-ray photographs are available from BIO, these features will be more visible.

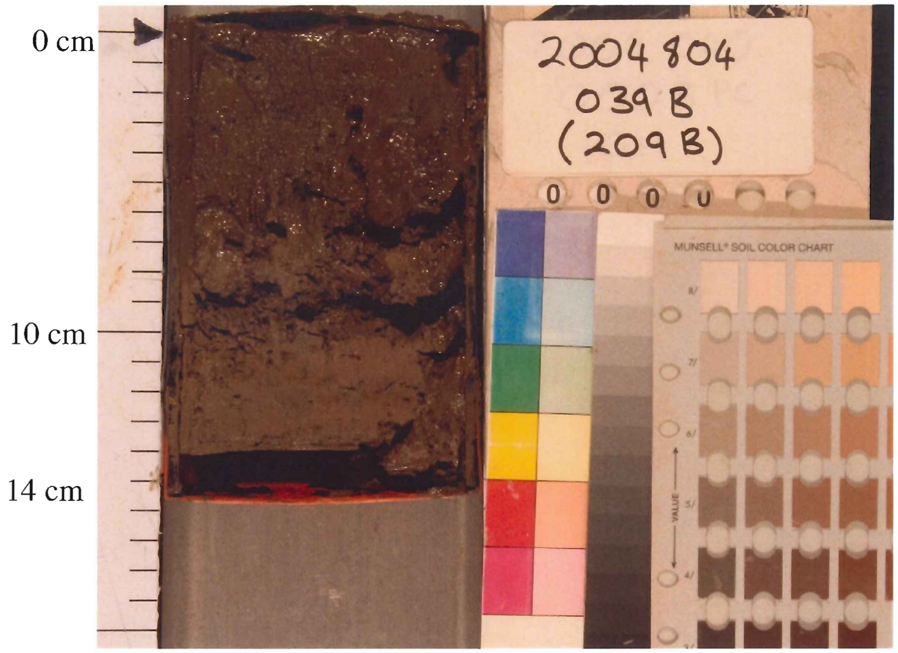

Figure 3.2 – Photograph of box core 209B taken at the Bedford Institute of Oceanography (BIO, 2007)

3.1.3 MICROFOSSIL CONTENT

Agglutinated species are those that cement pieces of sand and debris externally to form a shell, and they were the most abundant throughout the entire core section. The calcareous species, those that secrete their own shell, were not abundant in either push core, but are more useful as indicator species to paleo-ice cover.

Initial surficial counts of foraminifera in box core 209B were completed by Scott et al. (in press). The total number of individual foraminifera in $10cm^3$ of sediment is 5688 individuals of 39 different species, and 66.5% of these are in the 45-63 micron range; the rest are larger. *Bulimina hensoni* and *Stetsonia arctica* are the most common of the smaller size range. These core results will differ from the first interval (surface) of the box core because the surface samples were not a true distribution between the 0 cm and 1 cm section, as in the box core sample. The 0-1 cm interval of the box core column contains 3156 individuals of 30 different species, and 53% are in the 45-63 micron range.

Figure 3.3 shows graphs with the total percentage of individuals of calcareous species in 10 cm^3 of sediment at centimetre intervals in the core. The most abundant calcareous species in this core were *Fursenkoina fusiformis, Bulimina exilis* and *Cyclogyra involvens*. The calcareous species show two peaks; one at the surface and one at the 6-7 cm interval. *Cyclogyra involvens* totals show a minor peak at the 10 to 11 cm interval.

Figure 3.4 shows the genus/species counts created from foraminiferal counts in centimetre intervals for total agglutinated species in 10 cm^3 of sediment (refer to Appendix 1 for tables). The most common agglutinated species were *Trochammina nana*, *Trochammina pseudoinflata*, *Trochammina globigeriniformis*, *Textularia torquata,* and *Textularia earlandi*. These species have been grouped into the *Trochammina spp.* and *Textularia spp.* groups for purposes of interpreting the data, and because there are no major environmental distribution differences between species, but rather by genera. These two groups dominated the entire core section. *Textularia spp.* values are higher (~40-50%) from 0-5 cm, but decrease steadily to 15% by the bottom of the core. *Cribrostomoides species* were present throughout most of the core section in small quantities, and showed a small peak at the 10-11 cm interval, similar to *Spiroplectammina biformis*, and *Reophax spp.* There are also small peaks at 2-3 cm, and 4-5 cm intervals.

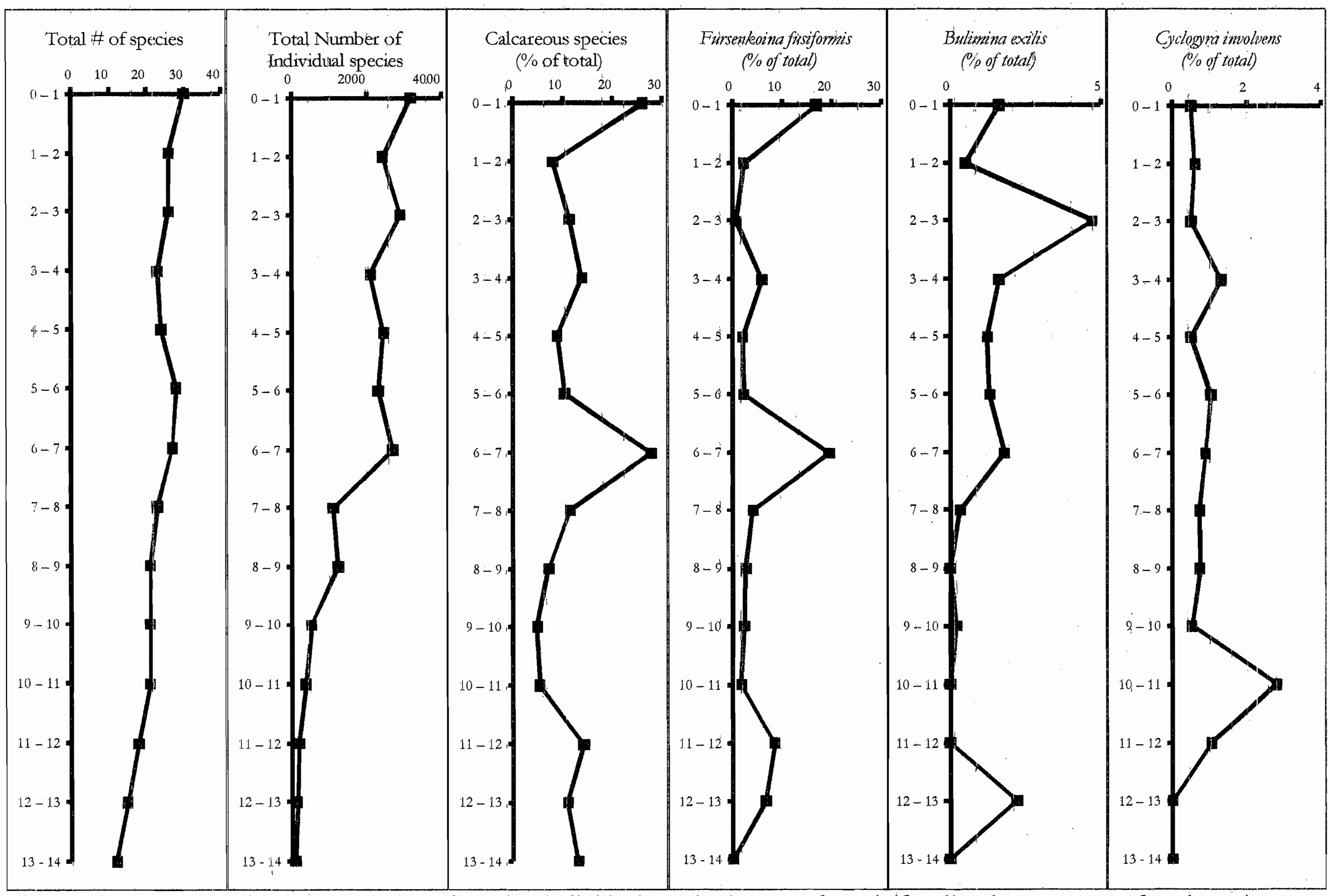

Figure 3.3 - Box core 209B: Total number of species, individuals, and calcareous foraminifera listed as a percent of total species

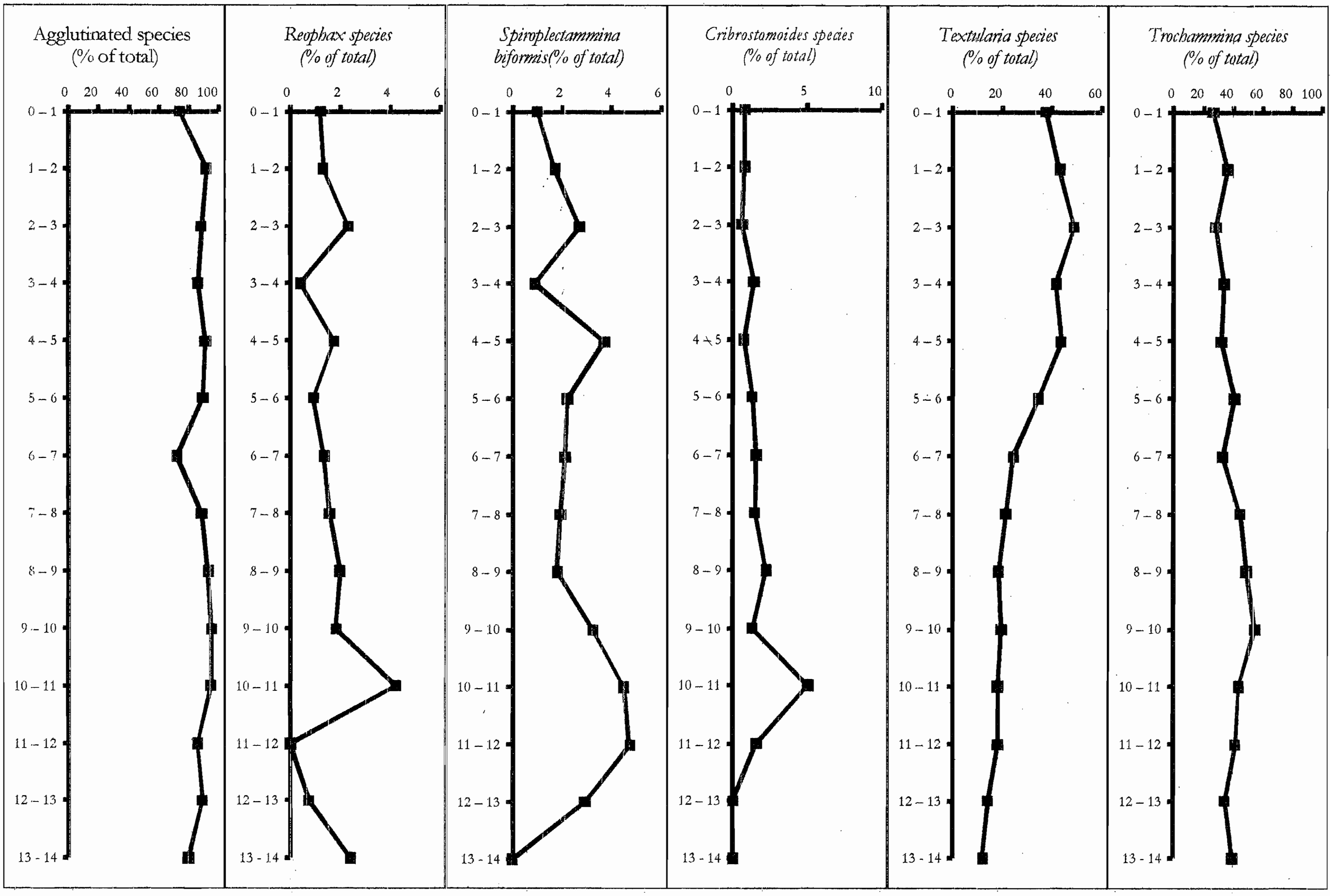

Figure 3.4 – Box core 209B: Total Agglutinated foraminifera expressed as a percent of total species

Some of the agglutinated species (*R. scorpiurus, S. confusa, C. crassimargo*) in the core were very large, reaching sizes of 750 microns, and even larger species (*R. dentaliniformis*) reaching 1 mm in length.

Figure 3.3 also contains graphs of the total number of calcareous and agglutinated individuals and total number of species. These data show a prominent decrease downcore with a small peak in the number of individuals at the 2-3 cm, and 6-7 cm intervals, and practically no individuals at the bottom of the core (12 – 14 cm interval). Some larger calcareous forms, such as *Nonion barleeanum*, were present in small quantities, with most in the 8-10 cm interval of the core column.

3.2 STATION 215

3.2.2 CTD DATA

The water depth at station 215 is 356 metres. Surficial temperature, as shown by the CTD graph (Fig.3.5), is about 2^0C and decreases to about -1.5^0C at 100 m, and then begins to increase to just above 0^0C at the seafloor (~350 m). Salinity at Station 215 has a surficial (0-10 m) low, and the rest of the water column ranges from 29 - 34.5 PSU reaching the maximum value at the seafloor. Fluorescence values have near surface variations with peaks at 10-20 m. Station 215 shows fairly constant values for suspended particles through the entire column.

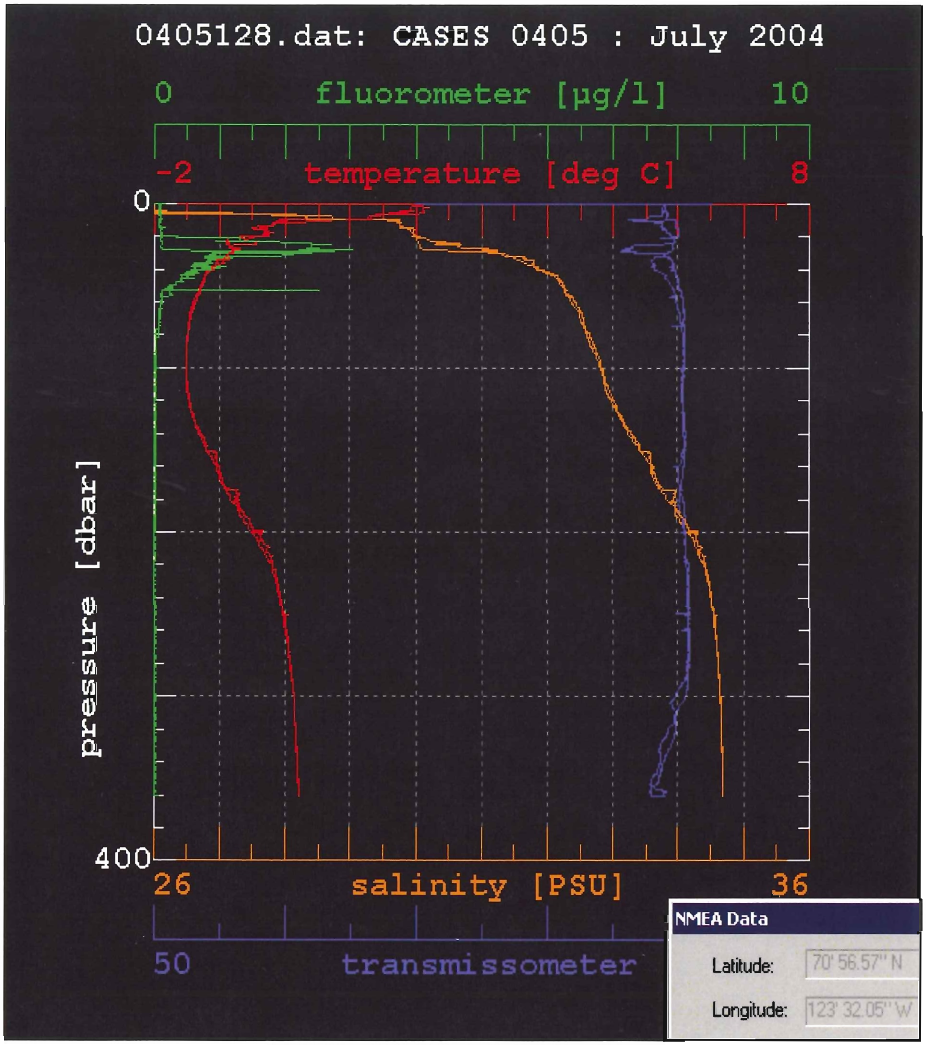

Figure 3.5 - CTD (Conductivity, Temperature and Depth), transmissometry and fluorescence data for station 215 (Modified from Miller, 2004)

3.2.2 LITHOLOGICAL DESCRIPTION

Box core 215 (70°56.59/123°31.37) was taken at a water depth of 365 m and measured 22 cm in length. Figure 3.6 is a photograph of box core 215. The lithology consists of a reddish-brown mud (0-5 cm) and a uniform mixture of medium-grained sand in an olive-grey mud (5-22 cm). Box core 215 has pebbles with a diameter of ~2 cm at the bottom of the core section (14-17 cm).

0 cm

10 cm

Figure 3.6 – Photograph of archived half of box core 215
taken at Bedford Institute of Oceanography (BIO, 2007)

3.2.3 MICROFOSSIL CONTENT

Initial surficial foraminifera species counts for box core 215 were completed by CASES (Scott et al., in press) There were a total of 7464 individual foraminifera of 28 different taxa in 10 cm^3 of sediment, and 55.1% of the total population are in the 45-63 micron range. *Bulimina hensoni* and *Textularia earlandi* were the most common foraminifera of the smaller size fraction. In the are in the >45-63 micron range. At the 1-2 cm interval, there is an increase in both species and individuals, to 6726 individuals and to 25 different species. From 2 cm to the bottom of the core species diversity, and individual species totals decrease gradually.

Graphs of genus/species totals for agglutinated and calcareous foraminifera for box core 215 were created and are shown in figure 3.7. The dominant calcareous species are *Fursenkoina fusiformis, Bolivina arctica, and Cyclogyra involvens. Bulimina exilis and Buliminella hensoni* were both present in small quantities throughout the core.

The graph (Fig.3.7) of total calcareous species shows two peaks: an increase in calcareous species at the 7-8 cm interval, and a minor peak at 10 to 11 cm interval, where there is a sudden appearance of planktic foraminifera (10%). *Islandiella teretis* is present (5%) at the 7-8 cm interval, but was not found in any other sections of the box core, and this also happens to be the interval where *Buliminella hensoni* populations are highest.

The agglutinated faunas dominate this core, and the abundant species, *Textularia spp* and *Trochammina spp*, are the same as those found in box core 209B. *Trochammina spp* show a large drop in totals at the 7-8 cm interval, as well as a smaller drop at the 19-20 cm interval. Other agglutinated species were present in smaller quantities throughout the section such as, a variety of *Reophax spp* (*R. dentaliniformis*, *R. fusiformis*, *R. guttifer*, *R. scottii*, and *R. scorpiurus*), *Saccammina difflugiformis*, *Psammosphaera fusca*, and *Cribrostomoides spp* (*C. crassimargo & C. jeffreysii*). As in box core 209B, this box core was populated by very large foraminifera, reaching lengths of 750 microns to 1 mm.

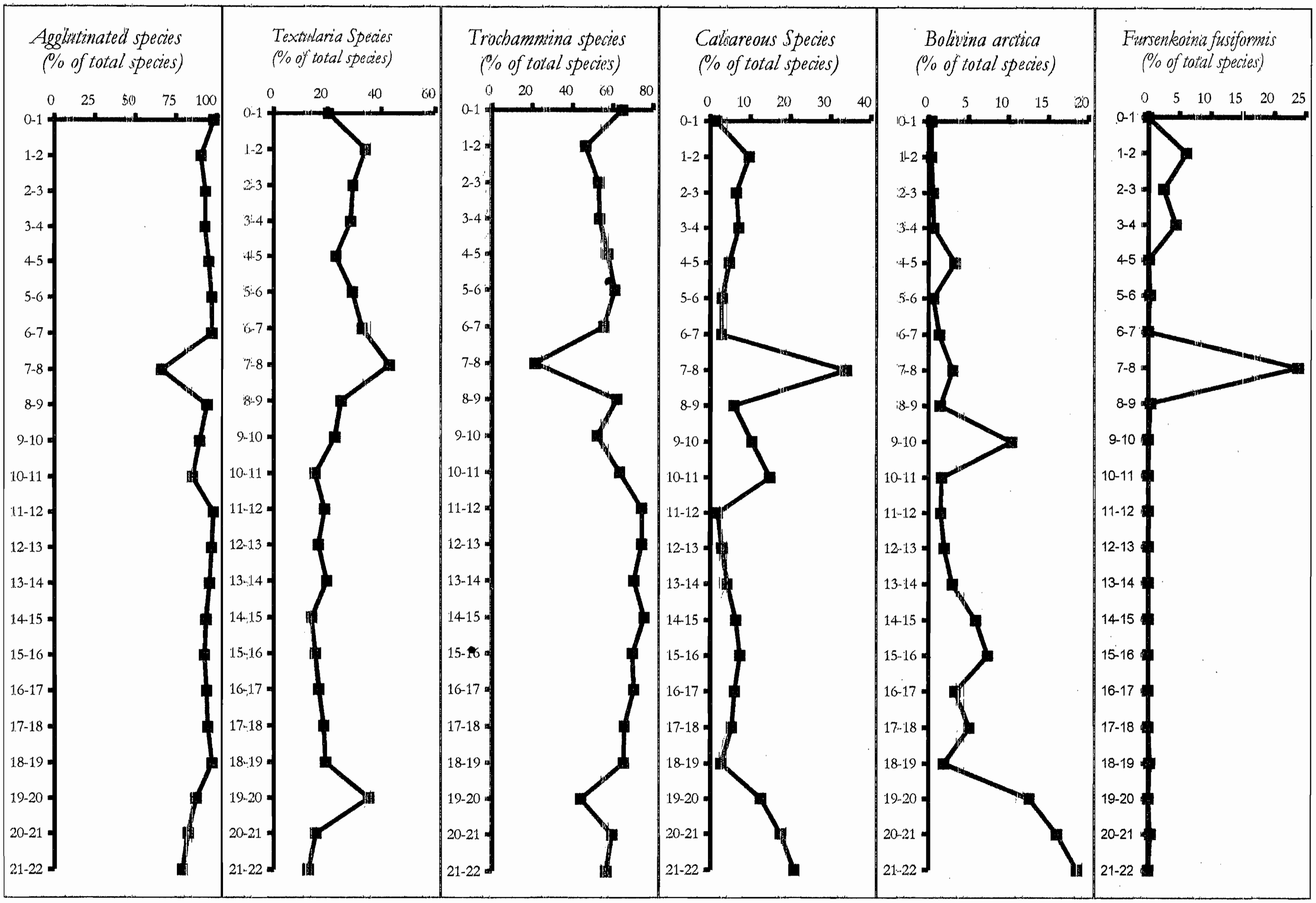

Figure 3.7 – Box core 215: Calcareous and Agglutinated foraminifera listed as a percent of total species

4 DISCUSSION

The 22 cm box core at Station 215 off Banks Island was taken at a depth of 360 m, and the 14 cm long box core at Station 209 off Cape Perry was taken at a depth 241 m. Both box cores contain higher values of agglutinated foraminifera than calcareous foraminifera. This could in part be due to the depth at which the samples were taken but also the higher productivity from the open water over this shown by low salinity at the surface. At a depth of approximately 200 m, the warmer and less saline Arctic Surface Waters (ASW) interface with the colder and more saline Arctic Intermediate Waters (AIW).

Common to Arctic shallow areas are *Textularia earlandi, Trochammina* spp, and *Spiroplectammina biformis* (Schell et al, in press). These species are present in both box cores, and both *Textularia* spp and *Trochammina* spp have the highest percentage of individual totals in both box cores. With such high values of ASW-associated foraminifera, it is likely that this area is dominated by more seasonally open waters, and this could be an effect of surface temperatures during the summer sea-ice break-up. This also increases surface productivity which causes dissolution of $CaCO_3$.

Warm and low salinity environments characterize the shallow water fauna (up to ~100 metres), whereas, colder and higher salinity sea water characterizes the deep water fauna (~200 metres). Deep water species such as *Stetsonia arctica, Bolivina arctica,* and *Buliminella hensoni* were present as a small percentage of total individuals throughout both box cores.

Another interesting feature noted earlier, is that both Station 209 and 215 lie on the boundary of the Cape Bathurst Polynya Complex (Barber and Hanesiak, 2004). This boundary would have an increased number of flaw leads and thus more openings of the sea-ice in the proximity of the box cores on a yearly basis.

The rounded pebbles and high concentration of sand in box core 215 just below the 18-19 cm interval could indicate that it is within the glacial/interglacial boundary. Box core 209B is only 14cm long, this is likely because the sediment below was too hard to core. This could be the contact with glacial sediment, as glacial scours are visible throughout the basin on the multi-beam sonar images, and contacts with this sediment have been found in previous work. The glacial sediment is the reason for the abundance of sand at the bottom of both cores.

Both box core 215 and 209B have some very large agglutinated foraminifera in the size range of 750 microns to 1 mm. *Reophax dentaliniformis, Rhizammina algaeformis, Hyperammina sp., Saccorhiza difflugiformis* and *Psammosphaera fusca* all had specimens greater than 850 microns. These specimens were giants compared to others of their form. These larger sized foraminifera obviously had lots of time to grow, without reproducing, because smaller sizes of the same foraminifera were not present. This may indicate low reproduction rates because of little food and colder temperatures.

Box core 215 shows population peaks in the subsurface higher than those found in the surface sample (0-1cm). This could have been caused by a recent change in the environment that wasn't favorable to foraminiferal growth.

Some calcareous species, such as *Fursenkoina fusiformis*, could have been overlooked if the smaller size fractions (>45<63microns) had not been counted. It shows how crucial this may be if smaller calcareous species are only present in fractions less than 63 microns, as current results show for box core 215.

Numerous studies suggest that a 1:1 ratio between benthic and planktonic foraminifera is exhibited in environments of permanent or perennial ice cover (e.g. Schell et al., in press). Only a few planktonic foraminifera were recovered from box core 209B, however, box core 215 had a peak in the abundance of planktonic foraminifera at the 10 to 11 cm interval. Since there is not a 1:1 ratio in the data, then it is likely that this area is not covered by perennial ice, and is characterized by a seasonally open basin.

Other microfossils were also noted in the cores. Radiolarians, and diatoms were noted based on their presence and relative abundance. Tintinnids were also counted for both box cores to determine populations at centimetre intervals throughout the core. Box core 209B has higher values of tintinnids, which could be explained by the influx of freshwater from either of two small rivers that flow into the Amundsen Gulf near Cape Perry. Box core 215 has very small values for tintinnids, and this indicates that there is not much freshwater input into this environment on the opposite side of the Gulf.

Box core 209B and 215 represent two similar benthic/pelagic environments. Both box cores likely have a low sedimentation rate, as they are much deeper than the high sedimentation rates of the shallow continental shelf environments, which on average accumulate 1.5 mm per year.

5 CONCLUSIONS

Both box cores exhibited typical Arctic shelf species and some deep water Arctic species. Since both deep and shallow water species are present, this is considered to be a transitional enviroment, where both species co-exist. The presence of dominant agglutinated foraminifera throughout the box cores could indicate that these are presently seasonally open waters.

Station 209 is characterized by the presence of specific species assemblages characteristic of a shallow sea and deep continental shelf with permanent ice cover. The lack of tintinnids indicates less freshwater influence to this environment in the Early Holocene. The presence of both shallow Arctic shelf species and deep Arctic species at station 215 indicate a transitional environment where both species co-exist. The Late Holocene sediment indicate that this environment is becoming more anoxic.

Some intervals in the push cores only had calcareous species in the less than 63 micron sieve fraction; only recently have scientists discovered their value, but this study substantiates it. The smaller sized species are sometimes only found in the smaller size fractions. Without these data, species ratios could be inaccurate.

SYSTEMATIC TAXONOMY

Astrohiza arenaria Carpenter

Astrorhiza arenara Carpenter in Norman, in 1877, p.213, pl. 19, figs. 1.13

Bolivina arctica Herman

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

Buccella frigida (Cushman)

Eponides frigida (Cushman) var. *calida* Cushman and Cole, 1930, p. 98, pl.13, fig. 13a-c.

*Bulimina exilis (*Brady, 1884)

Bulimina elegans var. exilis Brady, 1884, *Eubuliminella exilis* (Brady) Regets, 1993a.

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.

Cribrostomoides crassimargo (Norman)

Haplophragmium crassimargo Norman, 1892, p.17

Cribrostomoides crassimargo (Norman).- Leslie, 1965, p. 158, pl. 2, figs. 2a, b Williamson 1984, p. 209, pl. 1, figs. 6-7.

Cribrostomoides jeffreysi (Williamson)

Nonionina jeffreysi Williamson 1858, p. 34, pl. 3, figs. 72, 73.

Cribrostomoides jeffreysi (Williamson).- Vilks 1969, p. 45, pl. 1, figs. 17a, b.

Cyclogyra involvens (Reuss).

Operculina involvens Reuss 1851, v. 2, p. 370, pl. 46, fig. 20; Cornuspira involvens (Reuss) Loeblich and Tappan, 1953, p. 49, p.. 7, figs. 4,5

Dendrophyra arborescens Norman

Dendrophyra arborescens, Brady, 1884:262, pi. 28. figs. 12, 13.

Eggerella advena (Cushman)

Verneuilina advena Cushman, 1922b, p. 141; *Eggerella advena* (Cushman). Cushman, 1937, p. 51, pl. 5, figs. 12-15.

*Eoeponides pulchella (*Parker)

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

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.

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.

Haplophragmoides bradyi (Robertson)

Trochammina bradyi, Robertson, 1891, p. 388.

Hemispaerammina bradyi Loeblich and Tappan

Hemisphaerammina bradyi Loeblich and Tappan *in* Loeblich and Collaborators, 1957, p. 224, pl. 72, fig 2.

Islandiella teretis (Tappan).

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, p. 35, pl. 3, figs. 12, 13.

Neogloboquadrina pachyderma (Ehrenberg)

Aristospira pachyderma Ehrenberg, 1861, p. 276, 277, 303, *Globerigerina pachyderma* (Ehrenberg) Be, 1960, p. 66, text fig. 1; *Globorotalia pachyderma* (Ehrenberg), Vilks, 1973, pl 1-4; *Neogloboquadrina pachyderma* (Ehrenberg), Rogl and Boili, 1973, p.571, pt.11, figs.2-6, pl.16, fig. 12.

Nonion barleeanum (Williamson)

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

Oridorsalis umbonatus Reuss

Oridorsalis umbonatus Reuss, 1851, p. 75, pl. 5, figs. 35a-c.

Psammosphaera fusca Schulze

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

Quinqueloculina seminulum (Linné)

Serpula seminulum Linné, 1758, p. 786.
Quinqueloculina seminulum (Linné), d'Orbigny, 1826, p. 301.

Recurvoides turbinatus (Brady)

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.

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 scorpiurus de Montfort

Reophax scorpiurus De Montford 1808, p. 330.

Reophax scottii Chaster

Reophax scottii Chaster, 1892, p. 57, pl. 1, fig. 1.

Rhabdammina Abyssorum Sars

Rhabdammina abyssorum Sars in Carpenter, 1869, p. 60.

Rhizammina algaeformis Brady

Rhizammina algaeformis Brady, 1879, p. 39, p. 4, fig. 16, 17.

Saccammina difflugiformis (Brady)

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.

Saccorhiza ramosa (Brady)

Hyperammina ramosa Brady, 1879, Quart. Jour. Micr. Sci., n. ser., vol. 19, p.33, pl. 3, figs 14-15

Sorosphaera confusa Brady, 1879

Sorosphaera confusa Brady, 1879, p. 18, figs. 9, 10.

Spiroplectammina biformis (Parker and Jones)

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.

Stetsonia arctica Green

Epistominella arctica Green, 1960, p. 71, pl. 1, figs. 4a, b.

Textularia earlandi Parker.

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

Textularia torquata Parker, 1952a

Textularia torquata Parker, 1952a, p. 458

Trochammina globigeriformis (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 nana (Brady)

Haplophragmium nana Brady, 1881b, p. 50: *Trochammina nana* (Brady). Loeblich and Tappan, 1953, p.50, pl. 8, fig.5a-c.

Trochammina pseudoinflata Scott and Vilks

Trochammina nitida Brady. Lagoe, 1977, p. 116, pl1, figs. 3,4,7; *Trochammina inflata* Brady. Schroeder et al.,1990, p. 36, pl. 3, figs. 9, 10, pl. 9, figs. 24-26, *Trochammina pseudoinflata* Scott and Vilks, 1991, p. 35, pl. 2, figs. 3-6.

Tintinnopsis rioplatensis Souto

Tintinnopsis rioplatensis Sonto, 1973, p. 251, figs. 5-8, *Difflugia elegans* Penard, 1890. Scott and Martini, 1982, listed in tables 1 and 2. *Difflugia bacillariarum* Perty, 1849. Medioli and Scott, 1983, p. 20, pl. 5, figs. 16-19, pl.6, figs. 1-4.

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APPENDIX 1
Foraminifera Counts for Boxcore 209b and 215

Table 1 – Foraminifera counts for boxcore 209B (0 – 14 cm) shown as a percentage of total species

CASES 2004 – Amundsen Gulf – Box Core 209B - Foraminifera (all size fractions) – Julie Griffiths														
Water depth	**241 m**													
Total # species	30	26	26	23	24	28	27	23	21	21	21	18	15	12
species >45μ	16	13	16	13	13	18	17	15	10	10	9	10	8	6
Total # of individuals/10cc >45μ-63μ	1641	819	1782	888	966	987	1627	341	231	142	50	71	36	20
Total # of individuals/10cc >63μ	1515	1602	1106	1200	1476	1317	1059	758	960	372	307	120	101	64
Total # of individuals/10cc	3156	2421	2889	2088	2442	2304	2688	1099	1217	514	357	191	137	84
Total % >45μ<63μ total	52.0	33.8	61.7	42.5	39.56	42.84	60.53	31.03	18.98	27.63	14.01	37.17	26.28	23.81
Interval	**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**
Astrorhiza arenaria	0.4	0.0	0.0	0.0	0.5	0.0	0.3	0.0	0.1	0.3	0.0	0.0	0.0	0.0
Bolivina arctica	1.7	1.6	0.1	1.1	0.1	0.9	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
>45μ-63μ %	1.6	1.2	0.0	0.6	0.1	0.9	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Buccella frigida	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.6	0.0	0.0
>45μ-63μ %	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bulimina exilis	1.6	0.5	4.7	1.6	1.2	1.3	1.8	0.3	0.0	0.2	0.0	0.0	2.2	0.0
>45μ-63μ %	1.3	0.4	0.3	1.4	1.2	1.3	1.2	0.3	0.0	0.2	0.0	0.0	2.2	0.0
Buliminella hensoni	0.0	0.0	0.2	0.4	0.0	1.0	1.5	0.7	0.4	0.0	0.0	1.6	0.0	0.0
>45μ-63μ %	0.0	0.0	0.2	0.4	0.0	1.0	1.5	0.7	0.4	0.0	0.0	1.6	0.0	0.0
Cribrostomoides crassimargo	0.3	0.2	0.1	0.1	0.2	0.3	0.7	0.7	1.5	0.8	2.2	0.5	0.0	0.0
Cribrostomoides jefreysi	0.5	0.6	0.5	1.3	0.5	1.0	0.9	0.7	0.7	0.5	2.8	1.0	0.0	0.0
Cyclogyra involvens	3.4	2.5	4.8	4.6	4.9	4.4	3.3	5.5	3.3	1.8	2.2	1.6	0.7	2.4
>45μ-63μ %	1.5	1.1	3.7	2.2	2.7	2.7	1.8	2.2	0.8	1.0	1.1	1.6	0.0	0.0
Dendrophyra arborescens	0.2	1.1	1.1	1.4	1.0	1.2	1.7	2.5	2.0	1.6	6.4	3.1	8.8	6.0
>45μ-63μ %	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eggerella advena	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eponides Pulchella	0.6	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45μ-63μ %	0.6	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fursenkoina fusiformis	16.8	2.2	0.6	5.9	2.0	2.2	19.4	4.0	2.6	2.3	1.7	8.4	6.6	0.0
>45μ-63μ %	16.5	2.0	0.4	5.9	2.0	2.2	19.4	4.0	2.6	2.3	1.7	8.4	6.6	0.0
Glomospira gordialis	0.5	0.6	0.0	0.0	0.6	0.1	0.6	0.1	0.1	0.0	0.0	0.0	0.0	4.8
>45μ-63μ %	0.5	0.5	0.0	0.0	0.6	0.1	0.6	0.1	0.1	0.0	0.0	0.0	0.0	4.8
Haplophragmoides canariensis	0.2	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haynesia orbiculare	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemisphaerammina bradyi	0.3	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Islandiella teretis	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4	0.0	0.2	0.8	1.0	1.5	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.2	0.0	1.0	1.5	0.0
Jaculella acuta	0.1	0.1	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nonion barleeanum	1.2	0.0	0.0	0.1	0.0	0.1	0.2	0.0	0.7	0.3	0.0	0.0	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Psammosphaera fusca	1.1	0.9	0.2	1.4	0.7	0.9	1.9	5.8	5.7	4.7	4.8	3.1	8.8	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quinqueloculina seminulum	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recurvoides turbinatus	2.9	3.0	3.1	2.6	1.7	1.8	1.7	4.0	2.2	1.8	1.7	1.0	0.0	0.0
>45μ-63μ %	0.9	0.5	0.6	0.1	0.2	1.0	1.0	1.1	0.0	0.0	0.8	1.0	0.0	0.0
Reophax dentaliniformis	0.1	0.6	0.3	0.1	0.2	0.3	0.1	0.2	0.0	0.0	0.6	0.0	0.0	2.4
>45μ-63μ %	0.0	0.1	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reophax scorpiurus	1.0	0.7	0.9	0.3	1.2	0.4	1.1	1.4	2.0	1.8	3.6	0.0	0.7	0.0
>45μ-63μ %	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reophax scotti	0.1	0.0	1.1	0.0	0.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45μ-63μ %	0.1	0.0	1.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhizammina algaeformis	0.5	1.1	0.4	1.3	1.5	1.6	1.9	1.9	3.0	1.6	1.7	0.5	0.7	0.0
Saccammina difflugiformis	1.1	1.2	0.6	1.4	3.1	3.1	2.1	3.0	4.7	4.4	4.5	12.6	19.0	0.0
>45μ-63μ %	0.1	0.2	0.6	0.4	0.4	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	1.2
Saccorhiza acuta	0.1	0.9	0.3	0.0	0.5	0.0	0.1	0.4	1.5	0.3	0.0	0.0	0.0	19.0
Sorosphaera confusa	0.1	0.2	0.1	0.1	0.0	0.4	0.2	0.2	0.5	0.5	0.3	0.0	0.0	1.2
Spiroplectammina biformis	1.0	1.7	2.7	0.9	3.7	2.2	2.1	1.9	1.8	3.2	4.5	4.7	2.9	0.0
>45μ-63μ %	0.5	0.4	1.9	0.7	1.0	1.0	0.6	0.1	0.3	0.4	0.0	0.0	0.0	0.0
Stetsonia arctica	0.0	0.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	6.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0

Table 1 (Cont'd.)

Interval	**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**
Textularia earlandi	32.3	41.8	44.7	38.4	41.2	31.3	21.3	19.7	17.1	18.2	17.6	16.2	13.1	0.0
>45μ-63μ %	16.5	17.0	29.9	15.8	17.3	14.7	19.4	8.8	5.5	7.0	2.8	8.4	4.4	0.0
Textularia torquata	5.0	1.0	3.9	3.0	2.3	3.0	2.9	1.5	1.2	1.2	0.3	1.6	0.7	11.9
>45μ-63μ %	2.5	1.0	3.9	3.0	2.3	3.0	2.9	1.5	1.2	1.2	0.3	1.6	0.7	7.1
Trochammina globigeriniformis	7.6	11.3	8.9	11.1	14.3	11.5	10.7	13.8	12.2	13.2	9.2	12.0	8.8	3.6
>45μ-63μ %	2.7	2.7	4.2	4.5	2.9	3.6	3.1	4.4	2.4	3.3	1.4	5.8	2.9	3.6
Trochammina nana	16.3	22.8	16.9	18.0	10.7	23.3	19.9	22.8	28.0	34.8	26.6	23.6	19.0	7.1
>45μ-63μ %	6.0	6.7	8.5	5.6	7.5	8.7	7.0	5.8	4.6	10.7	4.8	4.7	6.6	2.4
Trochammina pseudoinflata	2.7	2.2	2.4	4.6	7.4	6.0	2.5	8.0	8.7	6.5	7.8	5.8	6.6	28.6
>45μ-63μ %	0.7	0.0	1.2	1.9	1.2	1.0	0.8	1.1	1.1	1.4	0.8	3.1	1.5	4.8
Foram fragments	P-A	P-A	P	P-A	P	P	P-A	P	P	P	P	P-R	P-R	7.1
Total Tintinnids	66	57	36	36	33	42	42	1	0	0	3	0	0	0
Diatoms	P	P	P	P	P	P	P	N	P-R	N	N	R	N	N
Radiolarians	P-R	P-R	P	P	P	P-R	R	N	N	R	N	P-R	R	N
N=None R=Rare P=Present A=Abundant														

Table 2 – Foraminifera counts for boxcore 215 (intervals 0-11cm & 11-22cm) shown as a percent of total species

CASES 2004 – Amundsen Gulf – Box Core 215 - Foraminifera (all size fractions) {1cm-11cm}											
Water depth	360 m										
Total # species	21	24	26	19	19	21	20	16	17	17	17
species >45μ-63μ	10	13	13	10	9	10	11	9	11	5	10
Total # of ind./10cc >45μ-63μ	1618	3240	1632	1770	999	759	765	552	372	276	297
Total # of ind./10cc >63μ	3240	3486	2760	1783	1620	2148	1002	1430	849	504	795
Total # of ind./10cc	4858	6726	4392	3553	2619	2907	1767	1982	1221	780	1092
Total % >45μ<63μ total	33.3	48.2	37.2	49.8	38.1	26.1	43.3	27.9	30.5	35.4	27.2
Interval (Centimetres)	**0 – 1**	**1 – 2**	**2 – 3**	**3 – 4**	**4 – 5**	**5 – 6**	**6 – 7**	**7 – 8**	**8 – 9**	**9 – 10**	**10 – 11**
Astrorhiza arenaria	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Bolivina arctica	0.4	0.4	0.5	0.7	3.3	0.6	1.4	3.0	1.5	10.4	1.6
>45μ-63μ %	0.1	0.4	0.6	0.7	3.3	0.6	1.4	1.4	1.5	10.4	1.7
Bulimina exilis	0.1	0.2	0.3	0.0	0.0	0.0	0.5	0.6	0.8	0.0	1.1
>45μ-63μ %	0.0	0.2	0.1	0.0	0.0	0.0	0.5	0.5	0.6	0.0	1.1
Buliminella hensoni	0.0	0.4	0.4	0.0	0.0	0.0	0.0	2.0	0.3	0.0	0.0
>45μ-63μ %	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Cribrostomoides crassimargo	0.4	0.0	0.0	0.3	0.2	0.1	0.0	0.0	0.5	0.0	0.3
Cribrostomoides jeffreysii	0.1	0.0	0.1	0.3	0.5	0.0	0.3	0.0	0.2	0.0	0.3
Cyclogyra involvens	0.2	2.0	2.3	2.0	1.1	1.7	1.0	0.5	2.9	0.0	0.5
>45μ-63μ %	0.0	1.1	0.5	0.8	0.5	0.2	0.2	0.0	0.0	0.0	0.3
Dendrophyra arborescens	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.5
Fursenkoina fusiformis	0.0	6.1	2.5	4.4	0.1	0.3	0.0	23.8	0.4	0.0	0.0
>45μ-63μ %	0.0	6.1	2.0	4.4	0.1	0.3	0.0	0.3	0.4	0.0	0.0
Glomospira gordialis	0.0	0.5	0.2	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.5
>45μ-63μ %	0.0	0.5	0.1	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Haplophragmoides canariensis	0.0	0.0	0.0	0.0	0.9	0.0	0.2	0.0	0.0	0.8	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.5	0.0	0.2	0.0	0.0	0.0	0.0
Islandiella teretis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jaculella acuta	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nonion Barleeanum	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Psammosphaera fusca	1.6	0.4	0.5	1.7	0.2	1.4	0.5	0.2	0.2	3.8	0.5
Quinqueloculina seminulum	0.1	0.2	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Recurvoides turbinatus	5.9	5.6	6.7	5.2	8.7	0.4	4.6	0.5	3.7	1.3	1.1
>45μ-63μ %	2.6	1.6	1.5	1.4	1.6	0.4	1.5	0.0	0.0	0.0	0.0
Reophax dentaliniformis	0.0	0.2	0.1	0.3	0.2	0.1	0.2	0.0	0.0	0.0	0.0
Reophax guttifer	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reophax scorpiurus	0.5	0.1	0.3	0.2	0.2	0.5	0.3	0.0	0.5	0.3	0.5
Reophax scotti	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0

Table 2 (Cont'd.)

Interval	**0 – 1**	**1 – 2**	**2 – 3**	**3 – 4**	**4 – 5**	**5 – 6**	**6 – 7**	**7 – 8**	**8 – 9**	**9 – 10**	**10 – 11**
Rhabdammina species	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhizammina algaeformis	0.1	0.2	0.2	0.3	0.0	0.1	0.1	0.0	0.0	0.5	0.0
Saccammina difflugiformis	3.0	2.2	1.6	2.2	2.3	3.6	1.7	0.1	1.7	5.6	3.0
>45µ-63µ %	0.6	0.0	0.5	0.7	0.0	0.0	0.0	0.0	0.2	0.0	0.3
Saccorhiza acuta	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.3	0.0
Sorosphaera confusa	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.0
Spiroplectammina biformis	1.5	0.6	0.8	0.2	1.1	0.4	0.7	0.8	0.0	1.5	0.0
>45µ-63µ %	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Textularia earlandi	10.3	26.0	14.1	19.6	14.7	16.2	22.6	34.4	14.8	12.8	8.8
>45µ-63µ %	1.1	22.7	12.2	17.9	13.3	13.5	21.4	9.7	11.9	10.0	4.1
Textularia torquata	10.1	8.0	15.3	9.0	8.4	13.0	10.4	8.6	10.2	9.9	6.6
>45µ-63µ %	5.9	3.6	6.3	3.9	4.9	4.5	6.3	2.7	4.8	3.5	2.2
Trochammina globigeriniformis	29.3	24.4	26.9	25.0	27.9	27.2	27.5	7.6	19.1	11.5	16.2
>45µ-63µ %	8.9	5.2	5.6	10.0	5.5	4.1	5.3	3.6	3.1	2.3	0.8
Trochammina nana	31.1	19.0	21.4	23.3	24.4	27.5	23.3	12.7	35.4	38.7	41.8
>45µ-63µ %	10.6	5.7	6.3	9.1	7.0	1.3	5.8	8.6	7.4	9.2	5.5
Trochammina pseudoinflata	4.2	3.0	4.6	5.1	5.2	6.2	4.8	1.2	7.5	2.1	5.5
>45µ-63µ %	0.0	0.7	1.0	1.0	1.3	0.6	0.8	0.6	0.2	0.0	0.3
Planktics	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0
Foram fragments	P-R	R	R	R	R	R	R	R	R	R	R
Total Tintinnids	0	24	18	12	15	6	3	1	0	1	1
Diatoms	R	R	R	R	R	R	R	R	P	N	N
Radiolarians	P	P	P	P	P	P	P	P	P	P	P
N=None R=Rare P=Present A=Abundant											

CASES 2004 – Amundsen Gulf – Box Core 215 - Foraminifera (all size fractions) {11cm – 22 cm)											
Water depth	360 m										
Total # species	12	15	16	11	14	17	15	17	14	13	14
species >45µ-63µ	7	7	6	4	3	5	6	4	5	3	4
Total # of ind./10cc >45µ-63µ	207	237	159	225	198	174	210	138	117	75	57
Total # of ind./10cc >63µ	762	678	546	942	532	716	498	634	169	205	153
Total # of ind./10cc	969	915	705	1167	730	890	708	772	286	280	210
Total % >45µ<63µ total	21.4	25.9	22.6	19.3	27.1	19.6	29.7	17.9	40.9	26.8	27.1
Interval	**11 – 12**	**12 – 13**	**13 – 14**	**14 – 15**	**15 – 16**	**16 – 17**	**17 – 18**	**18 – 19**	**19 – 20**	**20 -21**	**21 – 22**
Astrorhiza arenaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Bolivina arctica	1.5	2.0	3.0	5.9	7.4	3.4	5.1	1.9	12.6	16.1	18.6
>45µ-63µ %	1.6	2.0	3.0	4.9	7.4	3.4	5.1	1.9	12.6	16.1	18.6
Bulimina exilis	0.3	0.3	0.3	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0
>45µ-63µ %	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Buliminella hensoni	0.0	0.0	0.4	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0
>45µ-63µ %	0.0	0.0	0.4	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
Cribrostomoides crassimargo	0.6	0.7	0.6	0.3	1.9	0.9	2.0	0.8	1.7	0.7	2.9
Cribrostomoides jeffreysii	0.0	0.9	0.3	0.0	0.0	0.4	0.3	0.8	0.7	0.4	1.0
Cyclogyra involvens	0.0	0.7	0.0	0.5	0.0	0.0	0.3	0.3	0.0	0.4	0.5
>45µ-63µ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dendrophyra arborescens	0.6	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0
Fursenkoina fusiformis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4	0.0
>45µ-63µ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glomospira gordialis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45µ-63µ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haplophragmoides canariensis	0.0	0.0	0.0	0.0	0.0	0.4	0.0	1.0	0.0	0.0	0.0
>45µ-63µ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Islandiella teretis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45µ-63µ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jaculella acuta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45µ-63µ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nonion Barleeanum	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.3	0.0	0.7	1.9
>45µ-63µ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Psammosphaera fusca	0.9	0.9	1.1	2.6	2.2	1.8	2.8	4.1	0.7	1.8	2.4
Quinqueloculina seminulum	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>45µ-63µ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2 (Cont'd.)

Interval	**11 – 12**	**12 – 13**	**13 – 14**	**14 – 15**	**15 – 16**	**16 – 17**	**17 – 18**	**18 – 19**	**19 – 20**	**20 -21**	**21 – 22**
Recurvoides turbinatus	0.9	0.0	0.0	0.0	0.3	0.0	0.8	2.1	2.1	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reophax dentaliniformis	0.0	0.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Reophax guttifer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reophax scorpiurus	0.0	0.9	0.6	0.0	0.5	0.0	0.3	0.3	0.7	0.7	1.0
Reophax scotti	0.0	0.0	0.4	0.0	0.0	0.3	0.4	0.5	1.0	0.0	0.0
>45μ-63μ %	0.0	0.0	0.4	0.0	0.0	0.3	0.4	0.0	0.0	0.0	0.0
Rhabdammina species	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhizammina algaeformis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Saccammina difflugiformis	1.9	2.4	2.3	0.8	1.6	0.9	3.1	3.1	0.7	3.6	1.9
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Saccorhiza acuta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sorosphaera confusa	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Spiroplectammina biformis	0.0	0.2	0.3	0.0	0.3	1.3	0.6	0.0	0.0	0.0	0.0
>45μ-63μ %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Textularia earlandi	14.2	8.2	9.6	8.0	13.3	12.8	7.1	12.8	20.3	10.7	7.6
>45μ-63μ %	9.9	5.6	5.1	5.1	8.6	7.4	4.2	8.2	12.6	6.4	4.3
Textularia torquata	4.6	8.4	10.1	6.2	2.2	4.0	11.6	6.5	15.0	5.0	5.2
>45μ-63μ %	1.9	4.3	6.4	0.5	0.0	0.0	7.6	3.1	12.6	4.3	2.9
Trochammina globigeriniformis	18.9	16.6	10.8	10.0	13.2	12.6	12.0	15.8	10.1	11.4	17.6
>45μ-63μ %	0.6	2.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0
Trochammina nana	48.9	54.0	57.2	60.9	53.0	55.2	51.7	47.9	32.2	37.1	36.7
>45μ-63μ %	6.2	11.1	7.2	8.7	11.1	7.1	11.0	4.7	2.1	0.0	1.4
Trochammina pseudoinflata	6.5	3.7	2.6	4.6	3.6	2.7	2.0	1.6	1.7	11.1	2.4
>45μ-63μ %	0.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Planktics	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Foram fragments	R	R	R	R	R	R	R	P	P	P	P
Total Tintinnids	2	1	0	0	0	0	0	2	0	0	0
Diatoms	N	N	N	R	N	N	N	N	N	R	N
Radiolarians	P	R	R	P	P	P	R	R	P	P	P
N=None R=Rare P=Present A=Abundant											

Appendix 2 – SEM Photographs

Plate 1

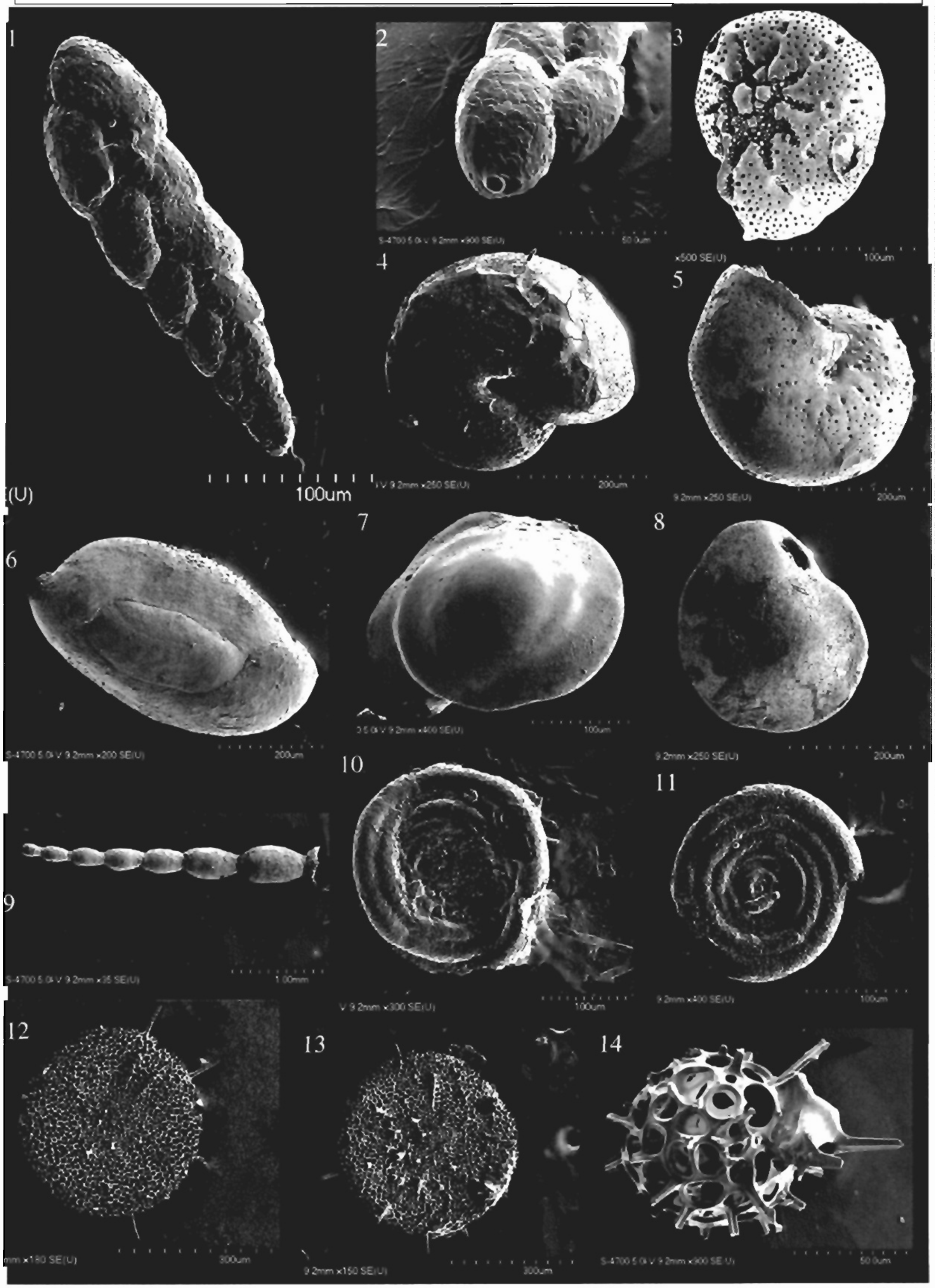
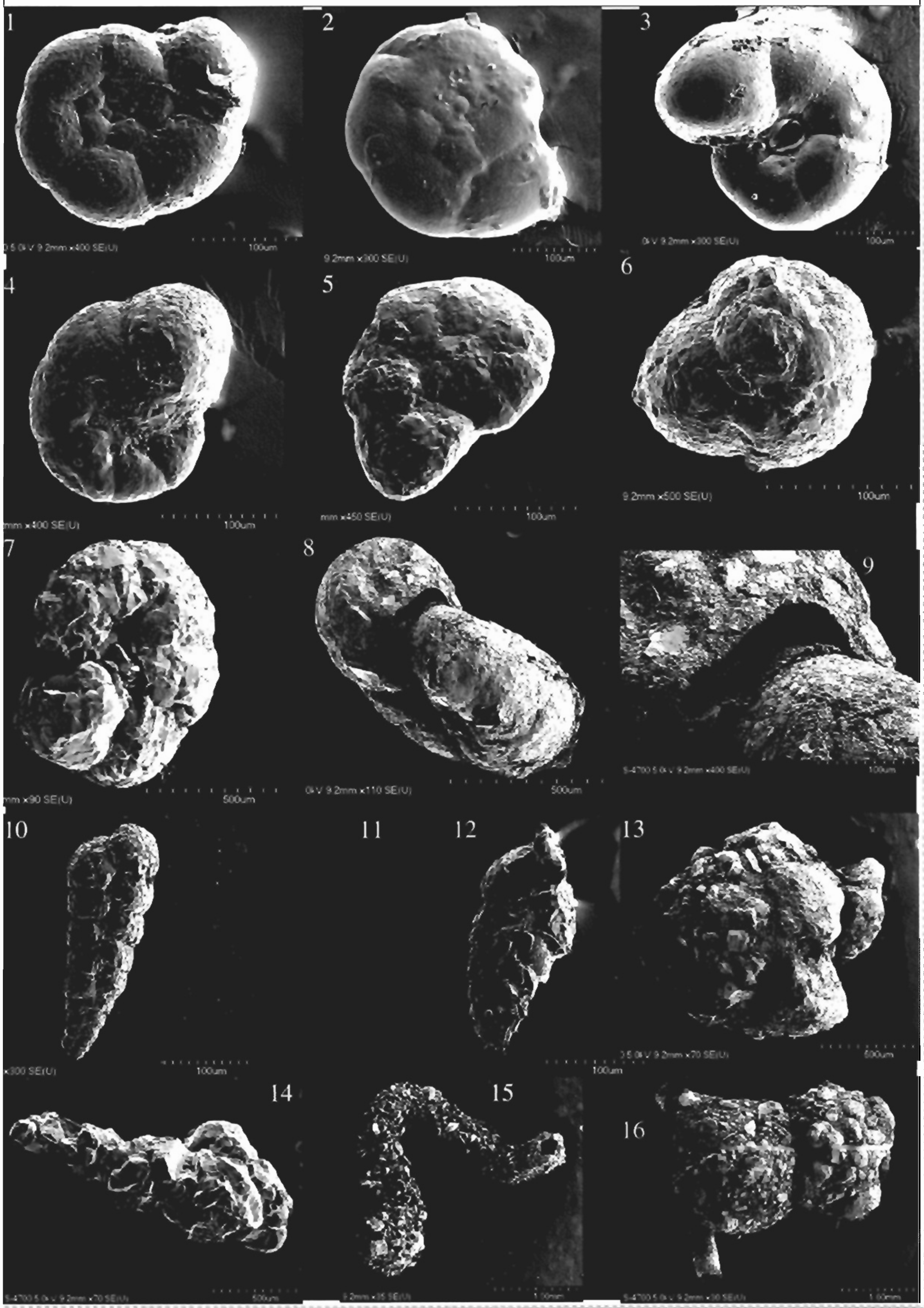


Plate 2



APPENDIX – SEM Photographs

Plate 1

1 – *Bolivina arctica*	Calcareous species, 100 μm scale
2 – *Bolivina arctica*	Apertural view,100 μm scale
3 – *Elphidium excavatum*	Calcareous species, 100 μm scale
4 – *Nonion barleeanum*	Calcareous species, 200 μm scale
5 – *Nonion barleeanum*	200 μm scale
6 – *Quinqueloculina seminulum*	Calcareous species, chambers visible, 200 μm scale
7 – *Oridorsalis umbonatus*	Calcareous species, 200 μm scale
8 – *Islandiella teretis*	Calcareous species, aperture visible, 200 μm scale
9 – *Reophax dentaliniformis*	Large agglutinated species, 1 mm scale
10 – *Cyclogyra involvens*	Planispiral calcareous species, 100 μm scale
11 – *Glomospira gordialis*	Planispiral agglutinated species, 100 μm scale
12 – Radiolarian (Spumellaria)	Radial symmetry, siliceous test
13 – Radiolarian (Spumellaria)	
14 – Radiolarian (Spumelaria)	Spherical with radial symmetry

Plate 2

1 – *Trochammina pseudoinflata*	Dorsal view, agglutinated species, 100 μm scale
2 – *Trochammina pseudoinflata*	Dorsal view, 100 μm scale
3 – *Trochammina pseudoinflata*	Ventral view, 100 μm scale
4 – *Trochammina nana*	Ventral view, agglutinated species, 100 μm scale
5 – *Trochammina nana*	Dorsal view, 100 μm scale
6 – *Trochammina globigeneriformis*	Dorsal view, agglutinated species, 100 μm scale
7 – *Cribrostomoides crassimargo*	Ventral view, agglutinated species, 500 μm scale
8 – *Cribrostomoides crassimargo*	Apertural view, 500 μm scale
9 – *Cribrostomoides crassimargo*	Apertural view, 100 μm scale
10 – *Textularia earlandi*	Biserial agglutinated species, 100 μm scale
11 – *Spiroplectammina biformis*	Agglutinated species, 200 μm scale
12 – *Textularia torquata*	Agglutinated species, 100 μm scale
13 – *Psammosphaera fusca*	Large spherical agglutinated species, 500 μm scale
14 – *Reophax scorpiurus*	Agglutinated species, 500 μm scale
15 – *Saccorhiza ramosa*	Large agglutinated species, 1mm scale
16 – *Sorosphaera confusa*	Large agglutinated species, 1 mm scale