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Deep-sea Coral: their use as climate change indicators

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Submitted in partial fulfillment of the requirements
For the Degree of Bachelor of Science (Honours)
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April 2003

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DATE MARCH 20, 2003

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TITLE DEEP-SEA CORAL: their use as climate change indicators

Degree BSc Honours Convocation MAY 20th Year 2003

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ABSTRACT

The need for accurate climate-change models is a major issue with the increasing concern of global warming. Recently, deep-sea corals have been calibrated for seawater temperatures using isotopic ratios since they record the surrounding seawater temperatures through element partitioning. The coral species, *Flabellum alabastrum*, found along the Atlantic coast on the continental slope, can be analyzed with an electron microprobe for Sr and Ca levels to calibrate bottom temperatures. This study compares seven corals off the coast of Nova Scotia along the Scotian Slope where temperatures over the past 50 years are known. Currents along the slope where deep-sea corals are found control the temperature variations recorded in *Flabellum alabastrum*. Cooler currents from the north lower water temperatures, while warmer currents from the south raise the water temperature. A temperature calibration curve has been created through the correlation of known temperature changes with variations in the Sr/Ca ratio. This curve can than be used to determine water temperatures that other *Flabellum* corals lived in using their Sr/Ca ratios. Although *Flabellum* provide a means of monitoring water temperature changes, extraction of this information may prove to be difficult because of the size and growth patterns they possess.

ACKNOWLEDGEMENTS

I would first like to thank my advisor Dr. David B. Scott for his time, knowledge, and funding of my honours thesis. Without Dave, this thesis would not have been possible. I would also like to thank Pal and Lene Mortensen from Bedford Institute of Oceanography (BIO) for their knowledge and several of the samples used in this study. Without the assistance of Dr. Mike Risk, Branwen Williams, and Owen Sherwood of McMaster University, this thesis would not have been possible. They gave me guidance for the methods and background required for this thesis. As well, I would like to acknowledge Bob MacKay of the electron microprobe laboratory at Dalhousie for assistance and knowledge during microprobe analyses, and Gordon Brown of the thin section laboratory at Dalhousie for the polished thin sections.

Lastly, I would like to thank the support group that I have had over the past four years. My fellow classmates have been there through the entirety of my thesis, making it easier to cope with the stress, and my parents, who have given continued support throughout my university education.

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1.0 INTRODUCTION

1.1 Background

The need for climate change modeling is currently a major issue, with increasing concern of global warming. Evidence for this concern can be seen in Canada, where the Kyoto Protocol has recently been ratified by Parliament. By reconstructing past climates, models for future changes in temperature can be made. Within the past 15 years, the use of deep-sea corals to measure changes in temperature has led to a new method of estimating changes in climate. Deep-sea corals record the surrounding seawater conditions through element partitioning (Smith, 1997). The deep-sea coral species, *Flabellum alabastrum*, found along the Atlantic coast on the continental slope, can be analyzed for Sr/ Ca ratios to calibrate bottom-water temperatures over the past 50 years on the slope. The corals in this study record bottom-water temperatures, which fluctuate seasonally, thereby allowing correlation between the variations in temperature and Sr/Ca ratios. Before corals were used, deep-sea and ice cores were used to reconstruct past climate changes. Corals may serve as better proxies for climate change than deep-sea or ice core records because the effects of temperature changes in corals are well known, and the resolution is much higher. Both currents and time of year determine the temperature changes along the Scotian Shelf and Slope. Cold North Atlantic water currents dominate along the Scotian Slope, but influxes of water from the Gulf Stream bring warmer water from the south to the slope (Petrie *et al*, 1987).

Flabellum alabastrum show annual banding that can be individually analyzed for Sr and Ca, using an electron microprobe. To ensure accuracy, several samples from the same area are compared in this study. Banding must be continuous, otherwise there is a possibility that dissolution has occurred and records will be lost. In addition to recording temperature, deep-sea corals may also yield valuable information for the oil and gas sector. It has been suggested that corals may feed from hydrocarbon sources at the ocean floor (Hovland *et al*, 1998).

1.1.1 Deep-sea Coral

There are two distinct types of deep-sea corals present today; gorgonians, some of which are soft corals, and scleractinia, or hard corals. Both types have been used as paleoclimate indicators, but the focus of this study is the scleractinia species *Flabellum alabastrum* (Moseley, 1873, fig.2, 3)). The Flabellidae order of scleractinia has existed since the Cretaceous (Veron, 1995), making *Flabellum alabastrum* an excellent coral to use to monitor climate change over long periods of time.

Flabellum alabastrum are also classified as azooxanthellate corals. These coral do not have photosynthetic, symbiotic algae (Best, 2001). They mainly exist in deep waters, below the photic zone, but can also grow in the photic zone. Most reef-forming coral are zooxanthellates, with a few exceptions. The exceptions are deep-sea reef corals such as *Lophelia pertusa*. *Lophelia* are the dominant species in deep-sea coral reefs off the coast of Norway, and are also found off the coast of Nova Scotia. *Flabellum alabastrum* differ from these in that they are solitary and do not form reefs. Uncommon to most coral, *Flabellum* do not attach themselves to a hard substrate; instead, they sit upright in soft sediment.

1.1.2 The Oceans

Covering approximately 70% of the earth's surface, and containing more than 95% of the world's water supply, the oceans play an essential role in earth systems, especially climate. The oceans are home to a large number of diverse species. One of these groups, Flabellidae, exists over wide range of water depths. Circulation of the ocean's waters replenishes nutrients in the water that are depleted by plants and animals. Off the coast of Nova Scotia, shallow water is circulated to the north, and deep water is circulated below to the south. Near Greenland, shallow water cools, becomes denser, sinks, and is recycled in the deeper flow to the south (Pollard, 1994). This water is replenished with many dissolved nutrients needed for animals and plants to survive. This deep flow continues south through the Atlantic and diverges to the east into the Indian Ocean, and to the west and then north in the Pacific (Figure 1.1). Upwelling of this deep water occurs along coastal areas, including the Scotian Shelf to the south of Nova Scotia during the summer (Petrie *et al*, 1987). These areas are highly productive as a result. Shallow water circulation also plays a role off the coast of Nova Scotia, as the Gulf Stream brings warmer water from the south up along the eastern margin of North America (Figure 1.2). This current dominates the upper portion of the Scotian Slope (Petrie *et al*, 1987). Although the warm Gulf Stream water is to the south of the Scotian Slope, warm-water gyres periodically travel northward (Richardson *et* al, 1978) to slope waters (Figure 1.3). The Labrador Current plays a more dominant role on the shelf, but it can also affect slope waters.

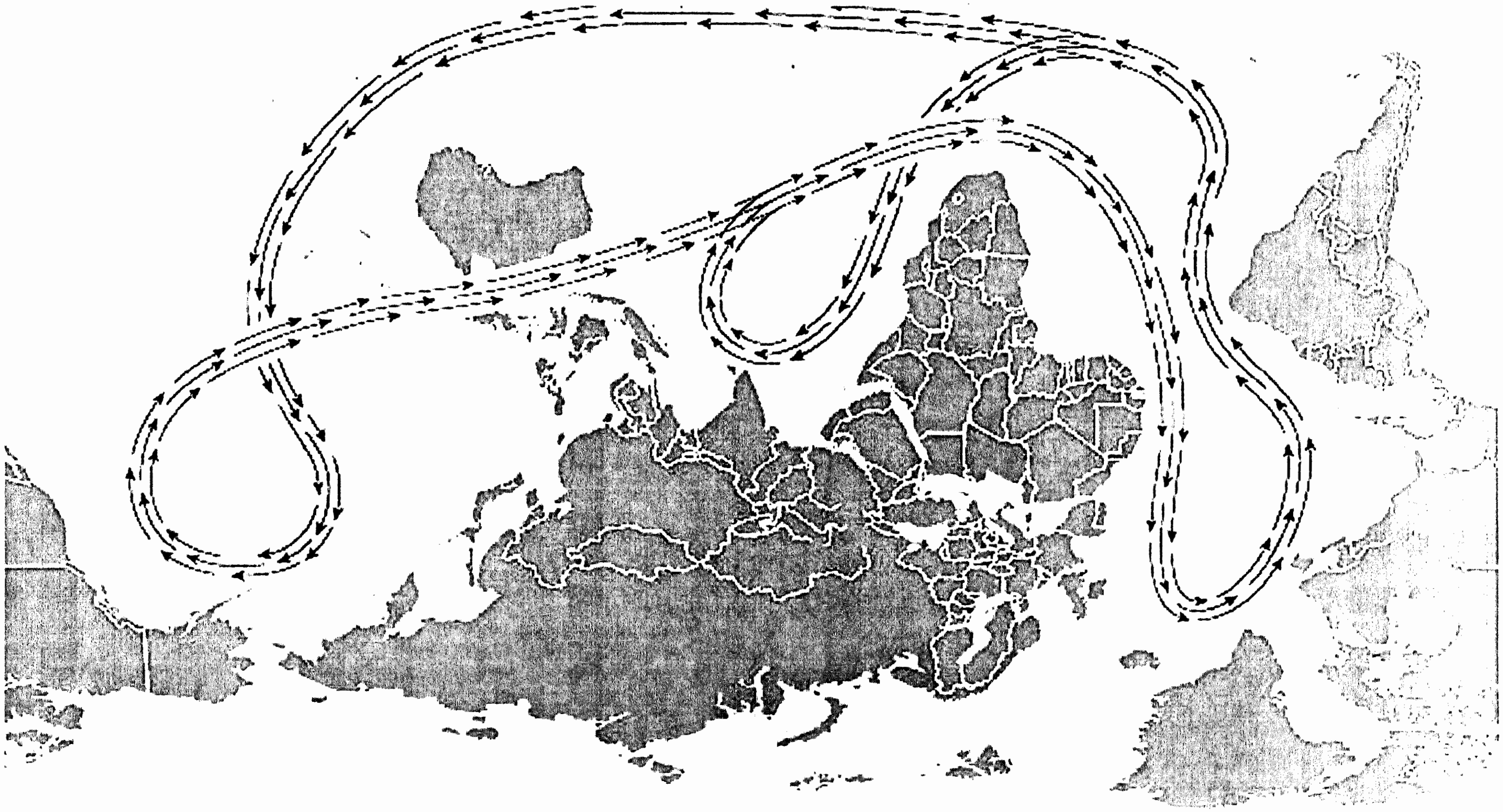


Figure 1.1. NADW Deep-water circulation. Modified from Duxbury and Duxbury, 1997.

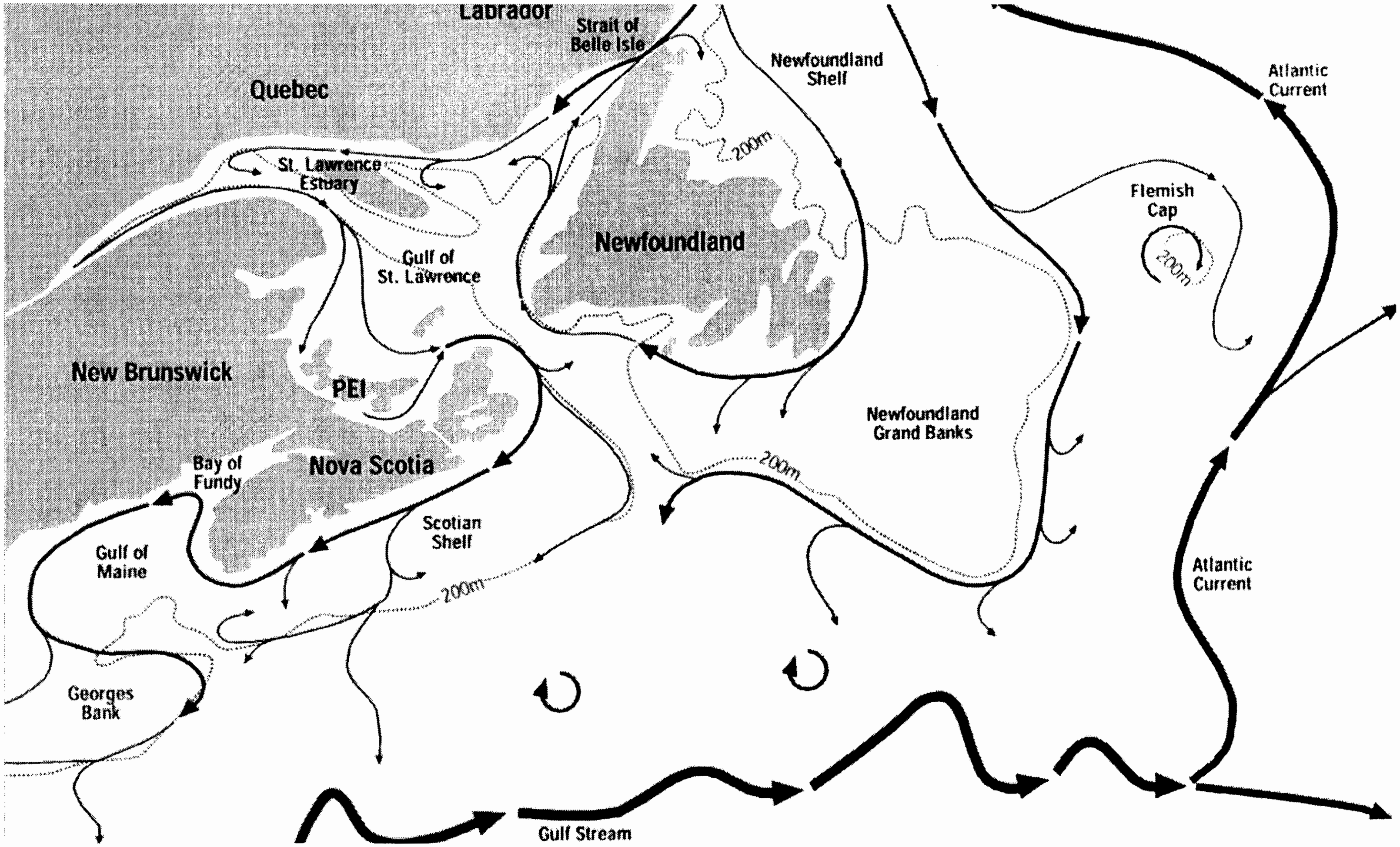


Figure 1.2. Shallow water currents off Nova Scotia. From http://museum.gov.ns.ca/mnh/nature/nhns/t6/t6-1.pdf

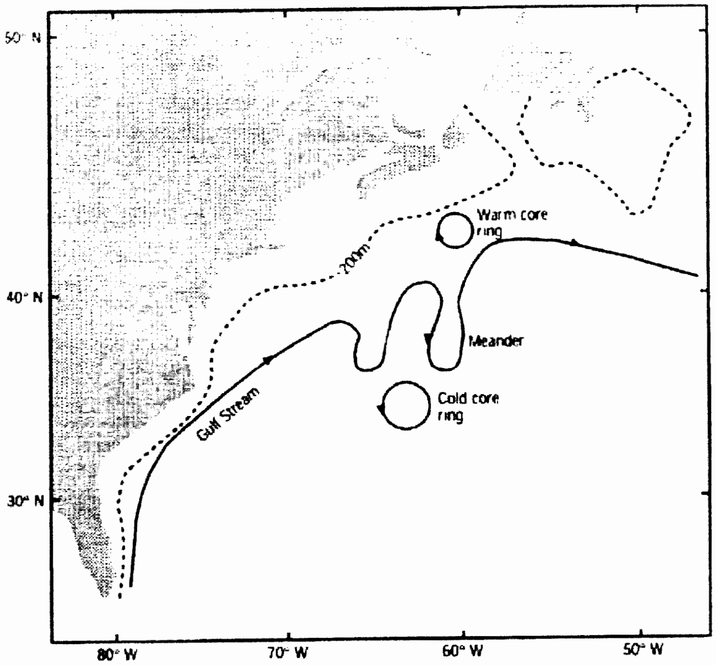


Figure 1.3. Influx of warm water to the slope from a warm-water gyre of the Gulf Stream. Modified from Mann and Lazier, 1996 and Richardson *et al*, 1978.

All of the elements found on earth can be found dissolved in the oceans; of these, only 11 ions have significant concentrations (Table 1.1). Na and Cl are the most abundant elements found in the oceans, but Ca and Sr are found amounts much greater than 1ppm (Weyl, 1970). More importantly, the ratios between all major ions in the oceans are constant (Duxbury and Duxbury, 1997). Exceptions to this rule include stagnant water and river discharge areas (Duxbury and Duxbury, 1997) where water can become concentrated or diluted, respectively, with respect to some ions. Major ions are constantly replenished by rivers, and carried away by currents to areas where plants and animals incorporate them.

Constituent	Ion	Percent by Weight	Residence Time (My)
Chloride	Cl^-	55.07	79
Sodium	Na^+	30.62	260
Sulfate	SO_4^{2-}	7.72	8
Magnesium	Mg^{2+}	3.68	45
Calcium	Ca^{2+}	1.17	8
Potassium	K^+	1.10	11
Bicarbonate	HCO_3^-	0.40	
Bromide	Br^-	0.19	
Strontium	Sr^{2+}	0.02	
Boron	B^{3+}	0.01	
Fluoride	F^-	0.01	

Table 1.1. Major ions found in seawater. From Duxbury and Duxbury, 1997.

1.1.3 Climate Change

Climate change has become a major issue in the past 15 years, with increasing concern of global warming. The use of paleoclimate records can assist in the validation of current climate processes and models (Houghton *et al*, 1990). Only in the past 100 years have there been accurate measurements of temperature (Figure 1.4). Precision of instruments used to measure and calculate temperature change has greatly improved in recent years, giving rise to uncertainty about the validity of previous data (Houghton *et al*, 1990). Reconstructed temperature records for the last 1000 years have been created using ice cores, tree rings, and corals (Figure 1.5).

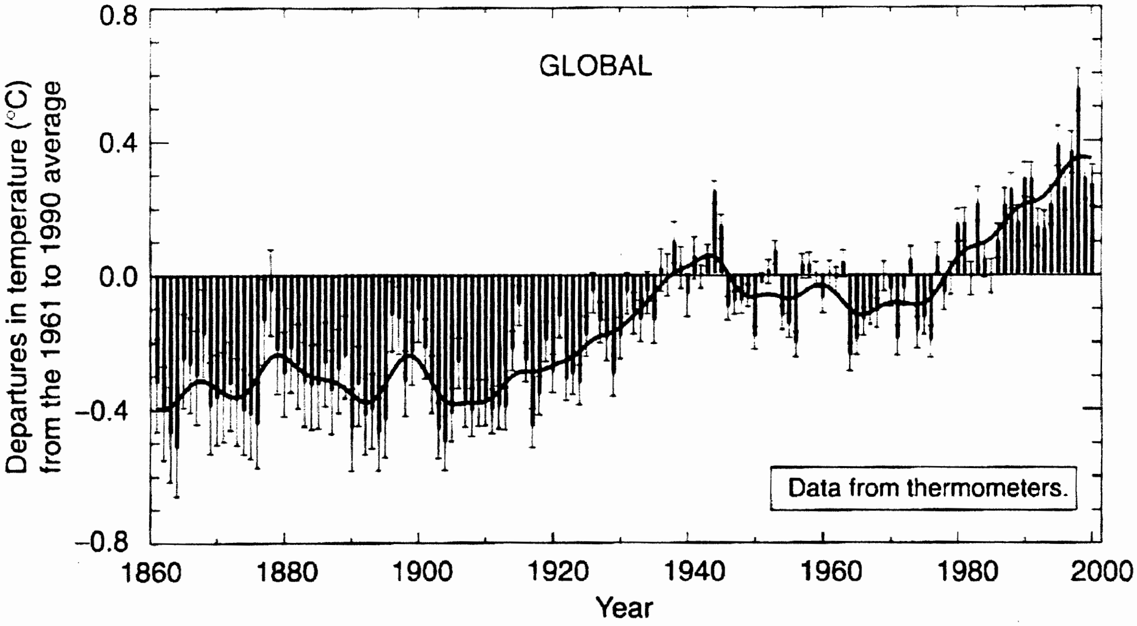


Figure 1.4. Change in temperature over the past 140 years. From Climate Change, 2001, modified from Folland *et al*, 2001.

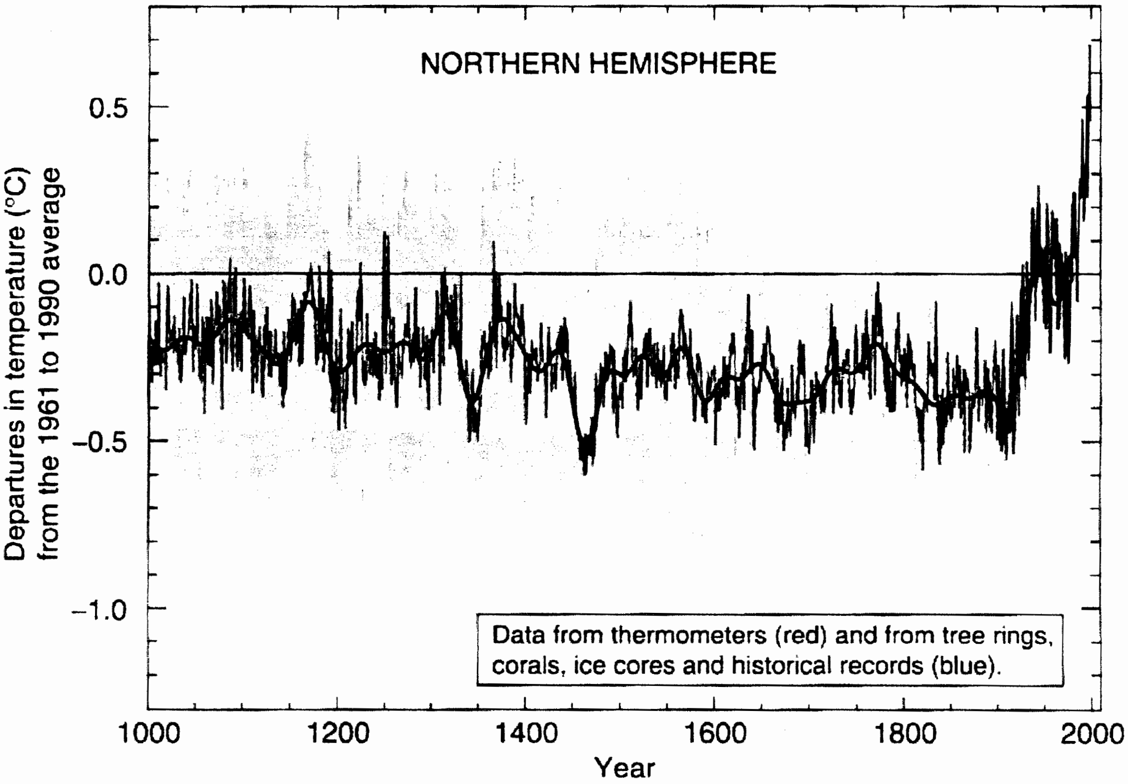


Figure 1.5. Climate change over the past 1000 years. Modified from Mann *et al*, 1999.

Most previous work on older paleoclimates has used glacial ice cores and more recently, corals and deep-sea sediments. Ice core records extend over the past 420 000 years (Climate Change 2001). The validity of these records has been debated because of numerous factors influencing glacial ice formation, including salinity, precipitation, temperature, wind, and humidity (Berger *et al*, 2000). Temperature-time graphs derived from ice cores all show large temperature changes recently and in the past.

The need for accurate paleoclimate records still exists. Uncertainty of near-future climates will continue as long as climate models are based on the large-scale changes detectable in ice and sediment cores. Corals are currently one of the ways this problem is being solved, since corals can resolve temperature changes on a much shorter scale, i.e. yearly. As the use of corals as paleoclimate monitors is recent, much more work is needed.

1.1.4 Previous Work

Corals have been used to determine variations in oceanic conditions. The most well-known documentation of this is the calculated sea-level curve of Fairbanks (1989). Using coral reefs off the coast of Barbados, Fairbanks created a sea-level curve for the last glacial period. The coral species *Acropora palmata* is restricted to the upper five meters of the ocean, allowing a correlation between current depth and age. The record shows an increase in sea level of 121.5 ± 5 meters over the past 17 000 years.

The skeleton of a coral can contain information about more that just sea-level however. Shen *et al* (1987) showed that corals could indicate past upwelling and industrial fallout through the presence of Cd in the skeleton of corals. As well, variation in coastal rainfall can be measured by fluorescent banding in massive corals (Isdale, 1984). Changes in temperature are recorded in the skeletons of corals through elemental and isotopic partitioning (Carriquiry *et al*, 1988 and Smith, 1997). Hydrothermal events at sea-floor ridges are recorded in coral skeletons, as metals such as Mn and Fe are taken up by corals (Smith, 1997).

Oxygen isotopes are one of the original methods used to measure temperature changes in coral environments. As the temperature of water increases, the δ^{18}O value decreases. The accuracy of this method has been argued by Mortensen and Rapp (1998) because the δ^{18}O values depend not only on temperature, but growth rate as well. In *Lophelia pertusa*, a negative correlation between δ^{18}O and width of the growth interval occurs in the septal regions. Along the theca of the coral the δ^{18}O and temperature data correlate much more so than in the septa (Mortensen and Rapp, 1998). Fairbanks (1989) also notes that δ^{18}O increases as sea level drops at a rate of approximately 0.011$^{0}/_{00}$ per meter change in sea level, due to increasing ice volume and salinity (more freshwater on land).

In 1997, the first extensive paleoceanographic work was done on deep-sea corals. Smith (1997) analyzed fossil *Desmophyllum cristigalli* from the Younger Dryas period. She concluded that the growth of the skeleton of *Desmophyllum cristigalli* shows annual banding that record large, rapid temperature changes. The corals provide accurate age dates from ^{230}Th/ ^{234}U dating techniques. The onset of the Younger Dryas period, from isotopic and age records of *Desmophyllum cristigalli*, was shown to be much shorter than previously thought.

Previous work on corals has shown that Sr/Ca ratio increases linearly with water temperature (Alibert and McCulloch, 1997, and Linsley *et al*, 2000). Similar behavior has been observed in laboratory experiments under equilibrium conditions. Unfortunately, corals precipitate inorganic material through biological processes, thus complicating the mechanism. Originally, it was assumed that the Sr/Ca ratios in corals were due to the variances in temperature causing a change in the partition coefficient between skeletal material and seawater (Beck *et* al, 1992). It is not as simple to say that the variation in Sr/Ca ratio is due solely to temperature changes. This would only be the case if both elements were precipitated in a non-biological manner. The mechanisms involved in the precipitation of skeletal material is still not fully known (Schrag and Linsley, 2002), adding the uncertainty of the accuracy of paleotemperatures calculated from Sr/Ca ratios. Cohen *et al* (2002) have shown that Sr/Ca ratios are not only caused by temperature differences in the coral species *Astrangia poculata*. This species occurs as both a symbiont-bearing and non symbiont-bearing coral. The non symbiont-bearing coral had Sr/Ca ratios that reflected temperature changes much more accurately than the symbiont-bearing coral, indicating a kinetic effect on the incorporation of Sr into the skeleton by the presence of symbiotic algae.

It is important to note that the relationship between Sr/Ca ratios and temperature is not the same for all organisms that precipitate calcitic skeletons. Stoll *et al* (2002) show how the Sr/Ca ratio in the coccolithophorid species *Emiliania huxleyi* is dependant on the growth rate. As the growth rate increases, so does the Sr/Ca ratio. This relationship is the dominant factor is Sr/Ca partitioning in coccolithophorids and foraminifera.

1.1.5 Overview of Structure of Flabellum

Flabellum are solitary coral, and only contain a single polyp per animal. This polyp is cup-shaped, with live tissue contained in the center of the cup. This live tissue contracts and expands in response to environmental stresses. Tissue most often covers the inside and upper outer edge of the coral (Figure 1.7). The hard calcareous skeleton of *Flabella* is divided into two sections, the theca and septa (Figure 1.8). The theca is the outer component of the skeleton, giving the cup-shape to *Flabellum*. The septa are thin, disc-shaped structures that grow inward from the theca. Septa grow in steps, doubling in number with each step. Starting with 6, most *Flabellum* have 48 or 96 septa. *Flabellum alabastrum* have a flattened cup shape (figure 1.8A), and are commonly found as whole samples.

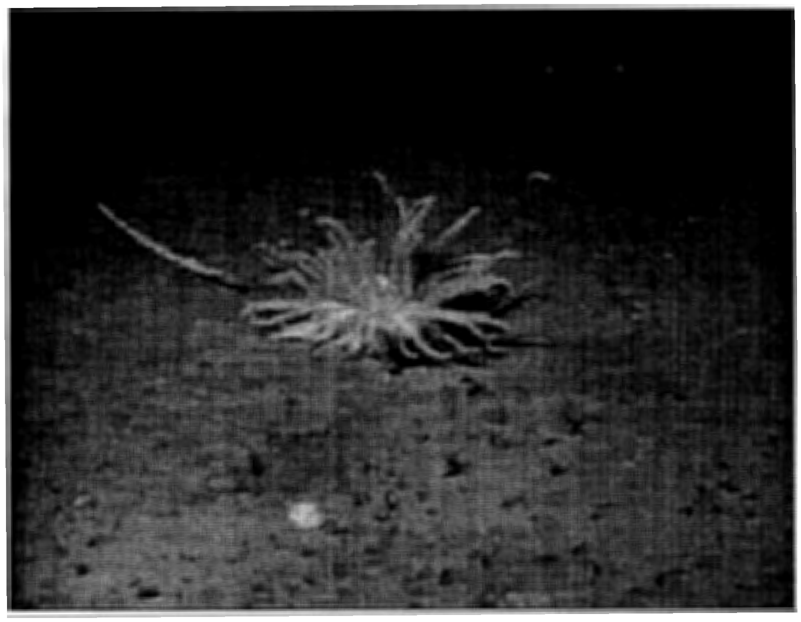


Figure 1.6. Image of a live Flabellum, illustrating the location of soft tissue. The cup-shaped skeleton is below the tissue (From ROPOS, 2001).

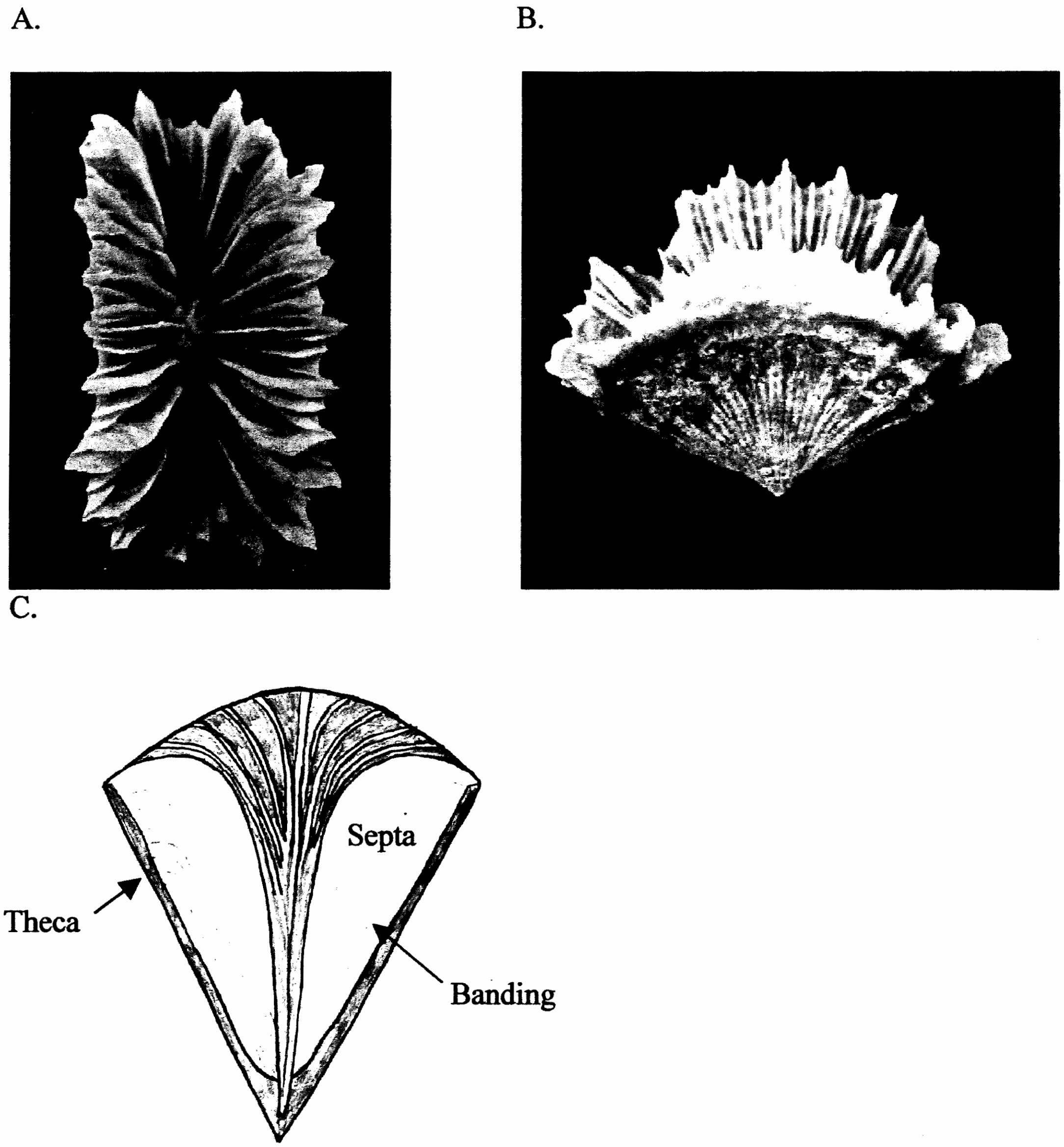


Figure 1.7. A. Top view of a *Flabellum*. B. Side view. C. Sketch of a cross-section.

1.2 Study Areas

The area of interest in this study is off the southern coast of Nova Scotia along the upper portion of the continental slope. The slope surface is predominantly soft Tertiary, rock-covered sediment. Samples were collected from Verrill Canyon, at a depth of approximately 450m, to the south-west in 250-400m of water, and from the eastern side of the Laurentien Channel (Figure 1.8). The average water temperatures in the study areas averaged 4-10^{0}C with a range of 0.5-16^{0}C, with a salinity of ~35$^{0}/_{00}$ (DFO Database, 2003a). The samples collected from Verrill Canyon lie along the Northern Scotian Slope, and the more westerly samples along the Central Slope. Temperature and salinity profiles can be seen in figure 1.9.

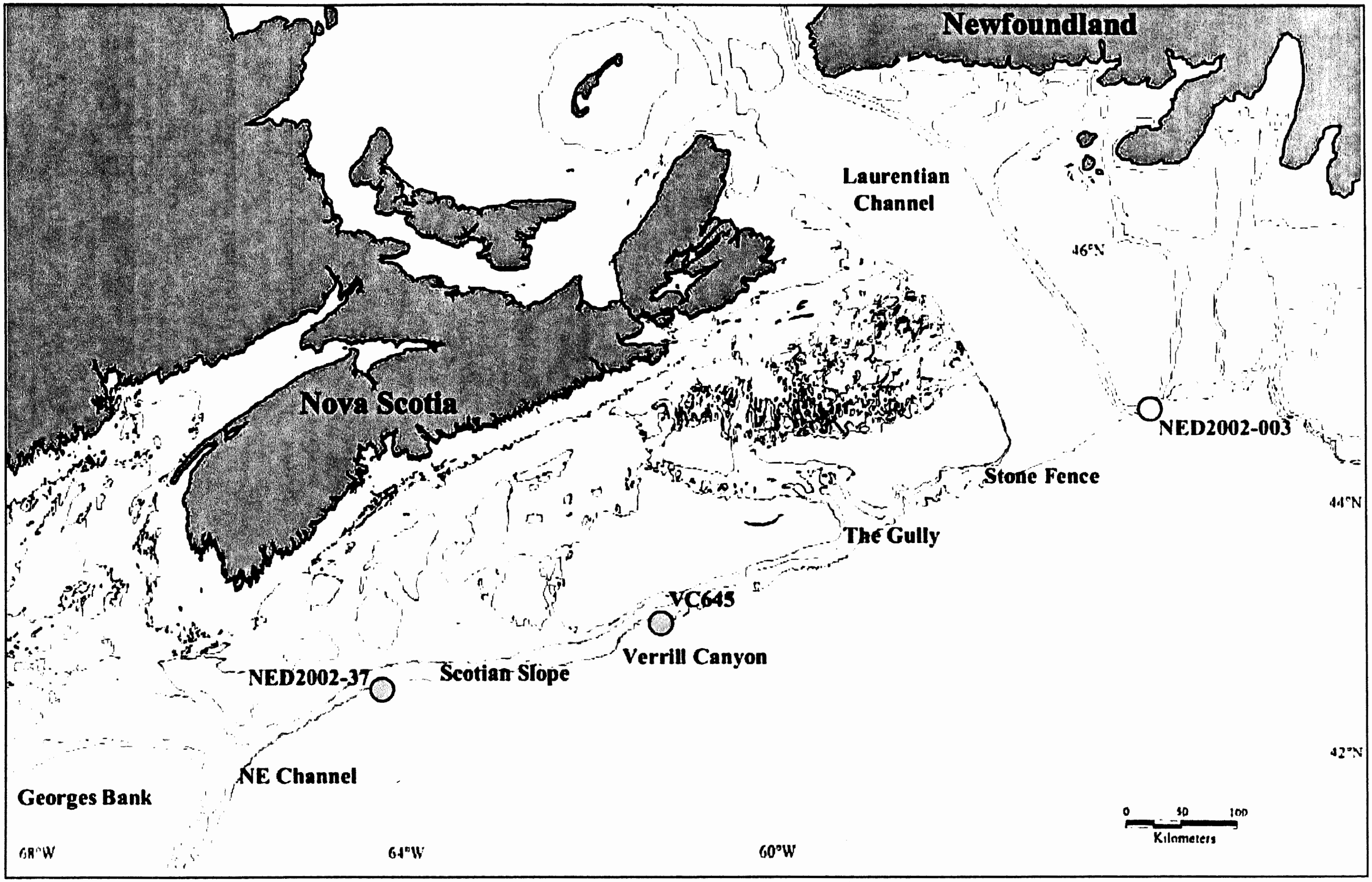


Figure 1.8. Study area and location of samples.

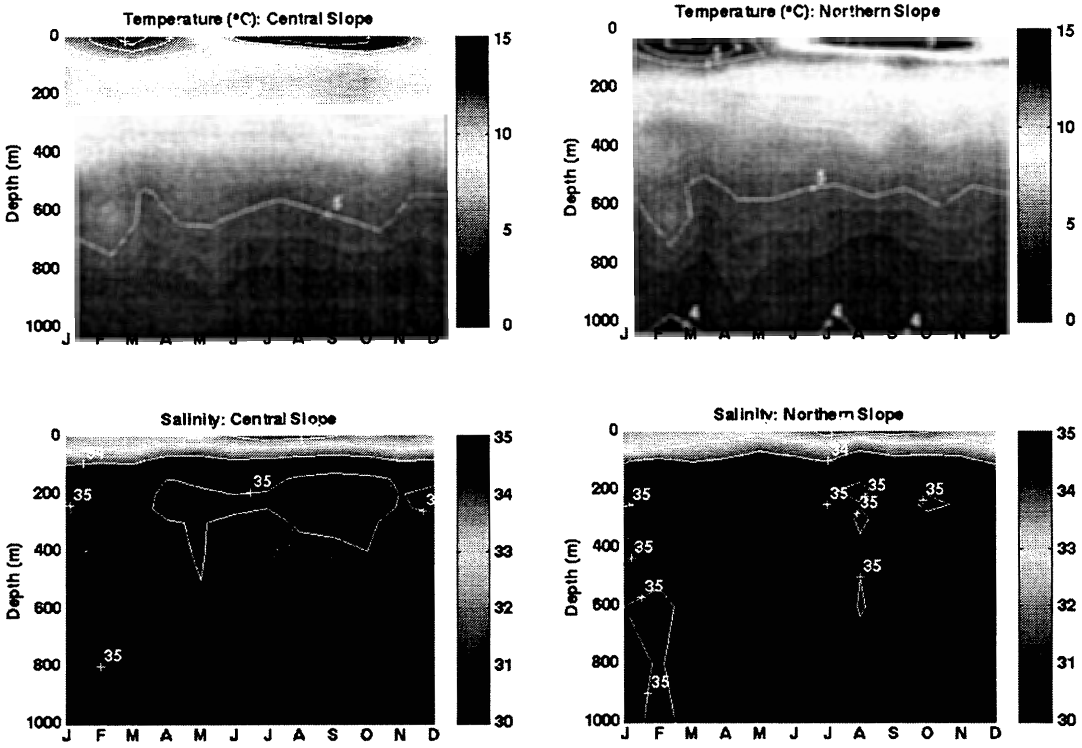


Figure 1.9. Temperature (top) and salinity (bottom) profiles of two of the study areas. From DFO, 2003b, http://www.mar.dfo-mpo.gc.ca/science/ocean/tsdata.html

1.3 Objectives

1) To analyze the growth patterns of *Flabellum alabastrum*; see if they are the same within individual samples, and between different coral from the same area.

2) To calibrate bottom temperatures in the areas where the coral samples were collected using Sr/Ca elemental ratios.

3) To determine whether or not *Flabellum* can be used for paleoclimate records.

1.4 Organization of Thesis

This thesis is divided into three sections. The second chapter discusses the methods involved in the thesis. Chapter three is the results, where the analysis of thin sections to determine the growth patterns of *Flabellum alabastrum* and temperature and Sr/Ca ratios are plotted and temperature calibration curves determined. A discussion of the results follows in chapter 4, analyzing the suitability of the coral for oceanic climate studies. The conclusion summarizes major findings of the thesis.

2.0 METHODS

Samples of *Flabellum alabastrum* were collected during one research cruise and two DFO random drags off the coast of Nova Scotia. The research cruise was a joint Dalhousie/ DFO cruise in August 2001 using the ROV ROPOS. The joint cruise and two random DFO drags collected coral samples in areas along the Scotian Shelf and Slope. Selection of specimens from these samples is based on location and size of coral. Several coral from any one area are taken for comparison within that area. Several areas are compared in this thesis. The size of the specimens is also important. Since *Flabellum* are small and grow slow, the largest ones are chosen, allowing for data from a longer time frame.

Initially, the coral specimens are cut in half, while frozen, allowing half to be used in future studies. This is done perpendicular to the long axis, from top to bottom (figure 1.8C). The samples are then thawed, and the soft tissue is removed using tweezers. The hard calcareous skeleton is then soaked in bleach until the samples are white; this can take up to a week. Once the samples are white they are washed using super-Q water (extremely pure water) in an ultrasonic bath three times, 15 minutes for each washing. This ensures that the bleach is removed as well as any other surficial impurities. Since the element Sr is being measured, large errors may result from unclean samples.

Septa from the samples are then cut, using a microsaw with a diamond-bit blade. Septa are chosen on the basis of how straight they are, and size. Many septa are not straight, making it difficult to get a good polished thin section. Once several septa are cut they are washed again once, and then dried for 8-10 hours at 50-60^{0}C. The septa are then taken to the thin section lab, where they are made into polished thin sections. Since the septa are very thin, a polished section across the whole of each septum is rare. This often results in part of the septum being immersed in resin, and rendering it useless for microprobe analysis.

Once the thin sections are made, the septa are analyzed under a light reflecting microscope. Growth banding occurs in the samples, similar to tree growth rings. Size of the banding is looked at, to see if there are times of increased or decreased growth rates as faster rates are represented by larger band width. Counting of the bands to determine the age of the coral is done, with the age assumed to be half the number of bands present (Smith, 1997). The coral were collected live, so the last band present represents either the year 2001 or 2002. Ensuring that the banding is continuous is important, otherwise some dissolution has occurred, which could result in lost of bands. Comparison of banding in septa of the same sample is done to ensure that the banding present is the same in all septa of the same polyp. As well, comparing of banding of septa of different samples in the same location, and other locations will allow for comparing the differences in growth patterns in different areas.

Once the thin sections have been prepared, they are analyzed for Sr and Ca using the electron microprobe at Dalhousie University. The electron microprobe at Dalhousie University is a JEOL JXA-8200 with five wavelength dispersive spectrometers (WDS) capable of analyzing elements from boron to uranium. For elemental analysis, the instrument is operated at 15Kv with 20na of probe current. Counting times for Ca is 20s and Sr is 60s on WDS. Geological samples and oxides are used as standards and are initially analyzed for Sr and Ca, reducing any error caused from background. Measured wavelengths for both elements includes a spectrum from 10nm on either side of the peak wavelength. In the case of specimens NED2002-37-01 and NED2002-37-02, the spectrum measured for Sr ranges from 5nm on either side of the peak to reduce background noise. Measurement of Sr and Ca allow for calculation of the Sr/Ca ratios in the coral samples, and from these, Sr/Ca ratio vs. age graphs are made. By comparing the calculated ratios with the known bottom water temperatures, a calibration curve relating the two can be made. The Sr/Ca ratio is dependant upon temperature, so variation in this ratio can be attributed to a change in temperature.

Banding cannot be seen readily under the electron microprobe, so a straight line analysis with a set number of measurements is done. The number of readings for each run varies with the length of the area to be measured, so that each measurement is spaced at approximately 100μm. In two cases, continuous data is taken so that the spacing between measurements is 10μm, the width of the microprobe beam. Measurement is from the youngest part of the septa, the outer edge, to the oldest, the inner area near the theca. The graphs made of Sr/Ca vs. measurement number give plots over time from young to old. These are compared with measured bottom water temperatures for the past 50 years.

After the microprobe measurements are completed, the thin sections are then analyzed under a light transmitting microscope to see the data points where measurements are taken. Any outliers can be looked at, to see if there is an explanation why. Reasons for outliers may include cracks in the samples from thin section preparation, resin covering the sample, and pore spaces in the corals. If a measurement is made over a crack, resin, or pore space, the data may be erratic and these data can then be excluded.

3.0 RESULTS

3.1 Growth Patterns

3.1.1 Banding in individual septa

Within each septum, older bands occur continuously from the top of the *Flabellum* to the bottom. Younger bands rarely extend from top to bottom and generally are only present on the upper portions of the septa. Towards the bottom of the septa, calcite appears to be reabsorbed, forming a more massive calcite structure without any composition or density differences. Banding curves along the same line as the curvature of the septum. Older bands have less curvature near the top while younger septa curve around the tops of older septa.

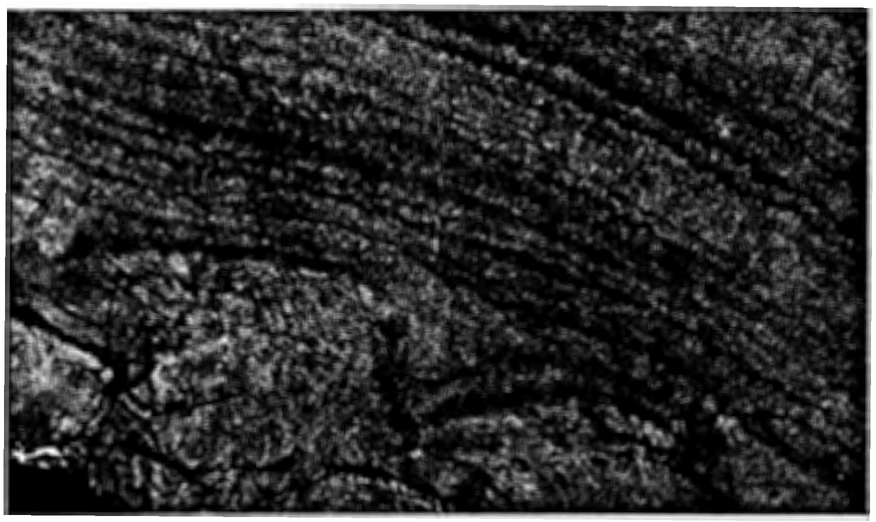


Figure 3.1. Microprobe image of banding in one septum.

Alternating light and dark bands are present; darker layers being denser than the lighter layers (Figure 3.1). Thicknesses of the layers are highly variable, but lighter layers are most often wider than darker layers. Layering is on the order of 50μm in thickness, but ranges from roughly 10μm up to more than 100μm in thickness. Darker layers can be difficult to discern in some cases, and have variable band width. Banding is jagged, as seen in figure 3.1, with some wavy undulations. Some undulations are not seen in figure 3.1 because they are in a plane perpendicular to the surface of the polished thin section.

3.1.2 Growth along the theca

Growth along the theca is not as obvious as in the septa. The theca are denser than the septa and growth is upward in a cone shape, giving rise to bands that run perpendicular to the banding in the septa. This banding is most obvious near the top of the coral where the theca is thinner and white in color. The bands are not seen in thin section, indicating that the theca is homogeneous and that the banding seen is due to the uneven surfaces. Lower portions of the outer coral are darker in color and this material is not part of the coral skeleton. The thecal growth is equal to that of upward septal growth, as both have banding of equal thicknesses at the top.

3.1.3 Comparison of septa of single polyps

Septa from the same polyps have a similar growth pattern. Starting with the youngest rings, thickness of banding is common among septa of each polyp. As some septa are younger than others, they are smaller and have fewer bands present. Alternating bands of high and low density calcite are common among all septa. Wavy undulations are present in each septum, but no attempt to correlate the undulations of differing septa has been done.

3.1.4 Comparison of banding in coral of the same/different areas

Banding in corals of the same area, i.e. NED2002-37-01 and NED2002-37-02, is similar. Banding in both of these samples averages 50μm, with thinner bands common within larger bands. The thinner bands are not commonly present, but average less than 10μm. In samples VC645-01 and VC645-02, banding also averages 50μm, but thinner bands are even less common. Samples NED2002-03-01 and NED2002-03-02 have banding similar to that of all the other samples, with larger bands averaging 50μm, although some thinner bands can be seen. Overall, the specimens have similar banding in the same areas, as well as compared to other areas.

3.2 Calibration of bottom temperatures

3.2.1 Bottom water temperatures

Bottom water temperatures in the study areas vary seasonally as well as locally. Specimens VC654-01 and VC645-02 are located in Verrill Canyon at a depth of about 450m along the northern part of the Scotian Slope. The average temperature of the water that the coral were living in is approximately 5.5^{0}C. This value based on a constant thermal gradient from 400 to 500 meters of water, and is the average of recorded temperatures at 400 and 500 meters depth along the northern slope (Appendix IA). Specimens NED2002-37-01, NED2002-37-02, and NED2002-37-03 were collected along the central Scotian Slope in 250-400m of water on July 6, 2002. The temperature range from 250 to 400 meters of water along the central slope is approximately 6-9^{0}C (Appendix IB). Samples NED2002-003-01 and NED2002-003-02 were collected from the margin of the Laurentian Channel, but no depth was recorded; best estimates from a bathymetry map range from 200-500m of water.

Monthly temperature variations along the slope range from as low as 0.5^{0}C, up to more than 16^{0}C. From Appendix I, standard deviations of the recorded monthly temperatures during 2002 are as high as 2.41^{0}C in February and March on the Central Slope. This is a large variation considering that 280 measurements were taken in the month of March. Two S.D.'s are high along the Halibut Channel, but no microprobe work was conducted on these samples.

Yearly variations in the study areas appear to be cyclic, with a period of ~10y since 1970 (Appendix II). Temperature records from 1950-1970 also show a cyclic pattern, but have a period closer to ~5y along the Central Slope (Appendix IIB). Data for the Northern Slope from 1950-1970 is sporadic, but there definitely appears to be a sharp decrease in temperature from 1960-1965 (Appendix IIA), similar to the same drop in temperature along the Central Slope during the same time period. This drop is significantly lower (~1^{0}C) than any other temperature drop over the past 50 years in either slope area. Periodic temperature changes of slope water in the past have been as great as 3^{0}C over a several year period.

3.2.2 Sr/ Ca ratios

Samples from the Northern and Southern Scotian Slopes are analyzed using a straight line traverse across the septal and/or thecal regions. A sketch of each thin section that was analyzed is shown on the next page to illustrate where transects of the measurements are taken (Figure 3.2).

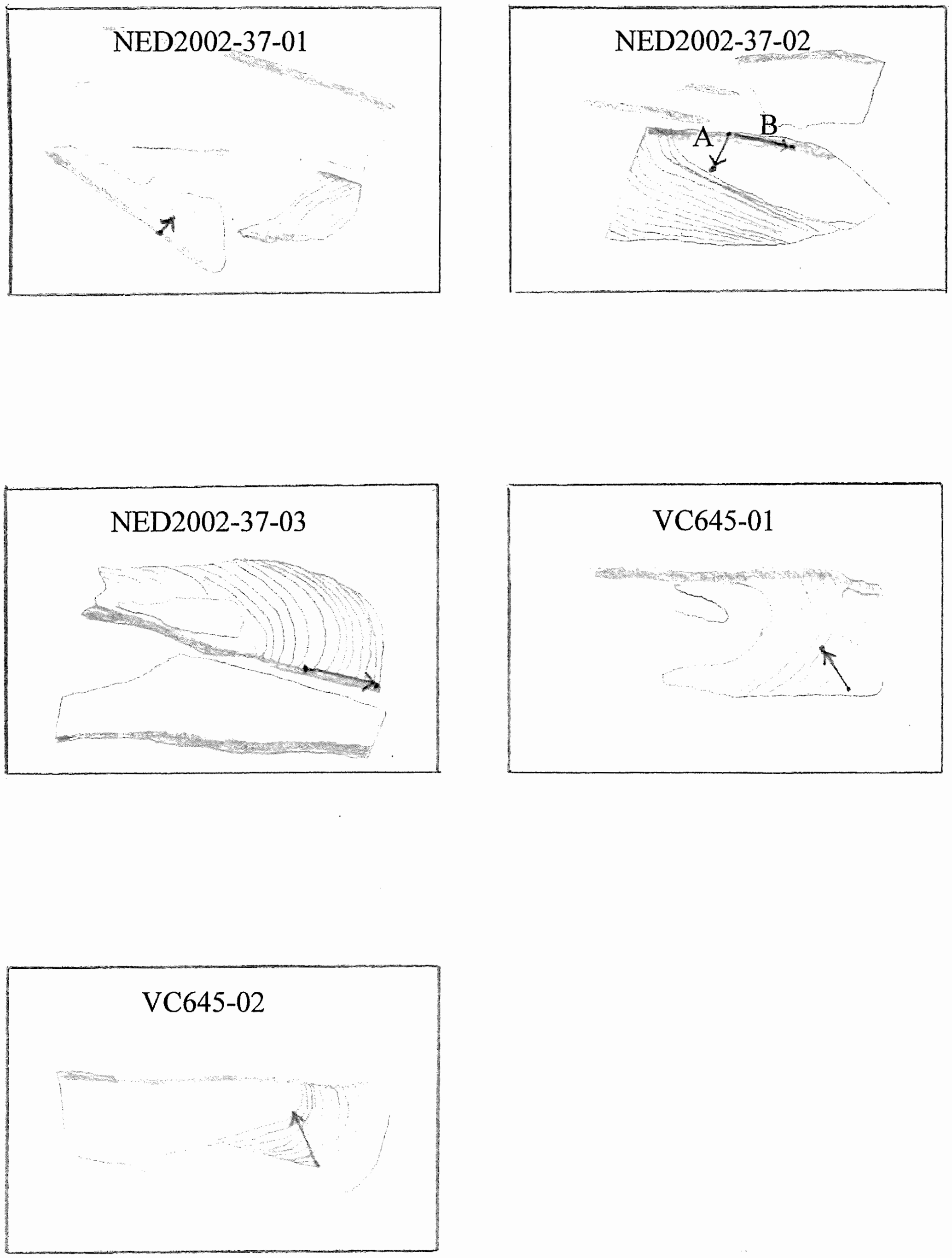


Figure 3.2. Sketches showing the location of the microprobe transects for the measurement of Sr and Ca. In NED2002-37-02, there are two transects, A and B, one of which is through septal material (A), and the other is through thecal material (B).

The Sr/Ca ratios in the specimens are often erratic on a small scale, but as more data points are selected, a larger scale shows noticeable variations. In specimen NED2002-37-02A there are three distinct ratios present in the septa. The three distinct Sr/Ca ratios are 0.022±0.002, 0.020±0.002, and 0.018±0.002 (Figure 3.4). There is a cyclic pattern that arises from the Sr/Ca values that alternates from high to low. The oldest region analyzed in specimen NED2002-37-02A had the lowest ratio values averaging 0.018, while adjacent younger material showed highly variable Sr/Ca ratios. The thecal material in NED2002-37-02B showed a similar cyclic variability in the Sr/Ca ratio (Figure 3.5). NED2002-37-01 also showed similar ratios of 0.022±0.001 and 0.020±0.001 (Figure 3.3). Both NED2002-01 and NED2002-02 were analyzed using a 10µm beam at 10µm intervals. This yields a continuous data set over the width of septum measured.

Specimens VC645-01 and VC645-02 also showed a tri-variant Sr/Ca ratio. Ratios for VC645-01, from oldest to youngest, are 0.013±0.003, 0.007±0.003, and 0.012±0.02 (Figure 3.6). VC645-02 varies in that the oldest ratio is 0.015±0.03 (Figure 3.7). Both of these samples were analyzed using a 10µm beam with 100µm spacing. This does not represent a continuous path. It should be noted that the background level is high on either side of the Sr peak, and so these values are lower than expected from the high background noise. Specimens NED2002-37-01 and NED2002-37-02 have less background noise due to the reduced range of wavelengths measured.

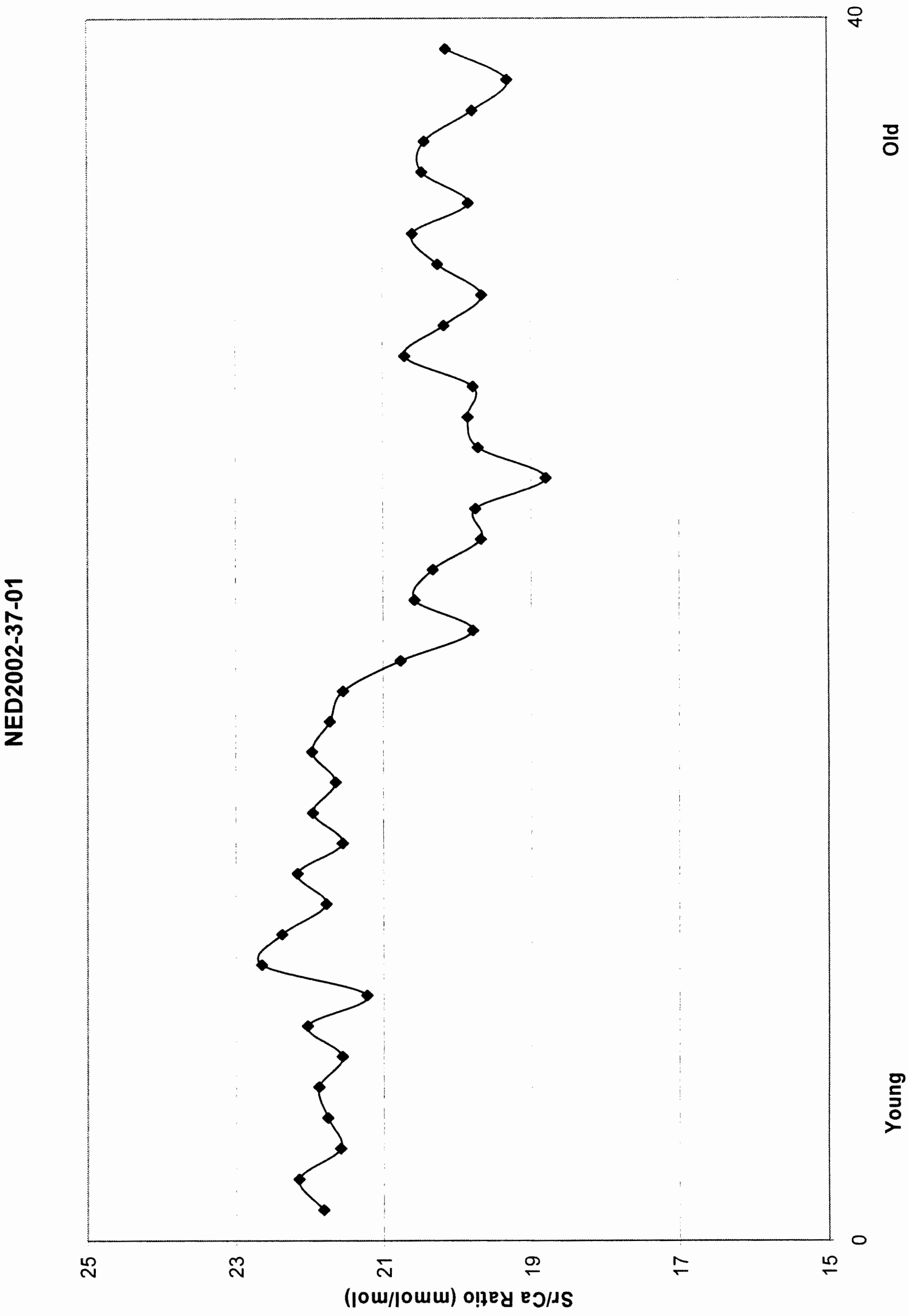


Figure 3.3. Data for NED2002-37-01 (septal material). Smoothed using a three point average.

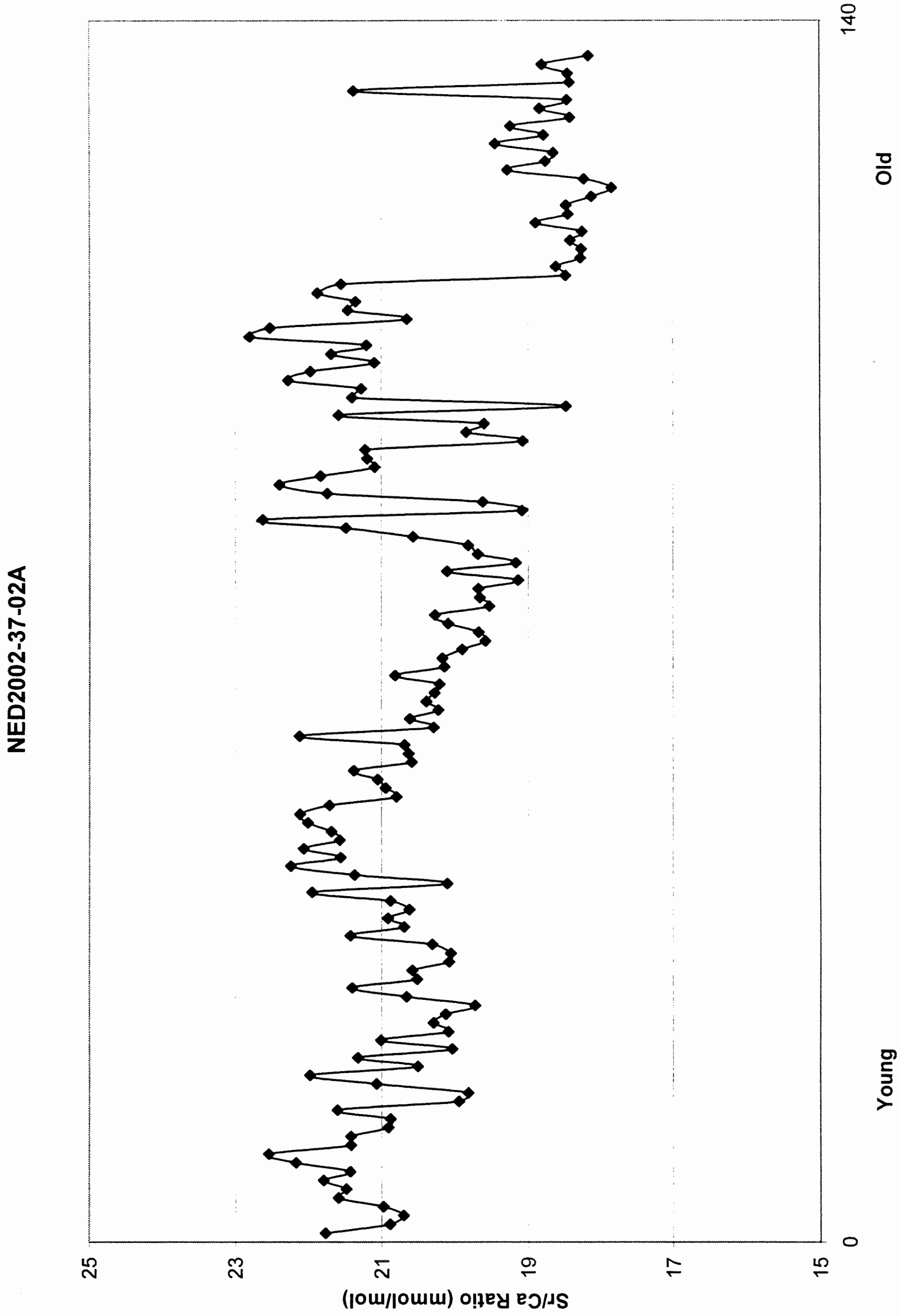


Figure 3.4. Data for NED2002-37-02A (septal material). Smoothed using a three point average.

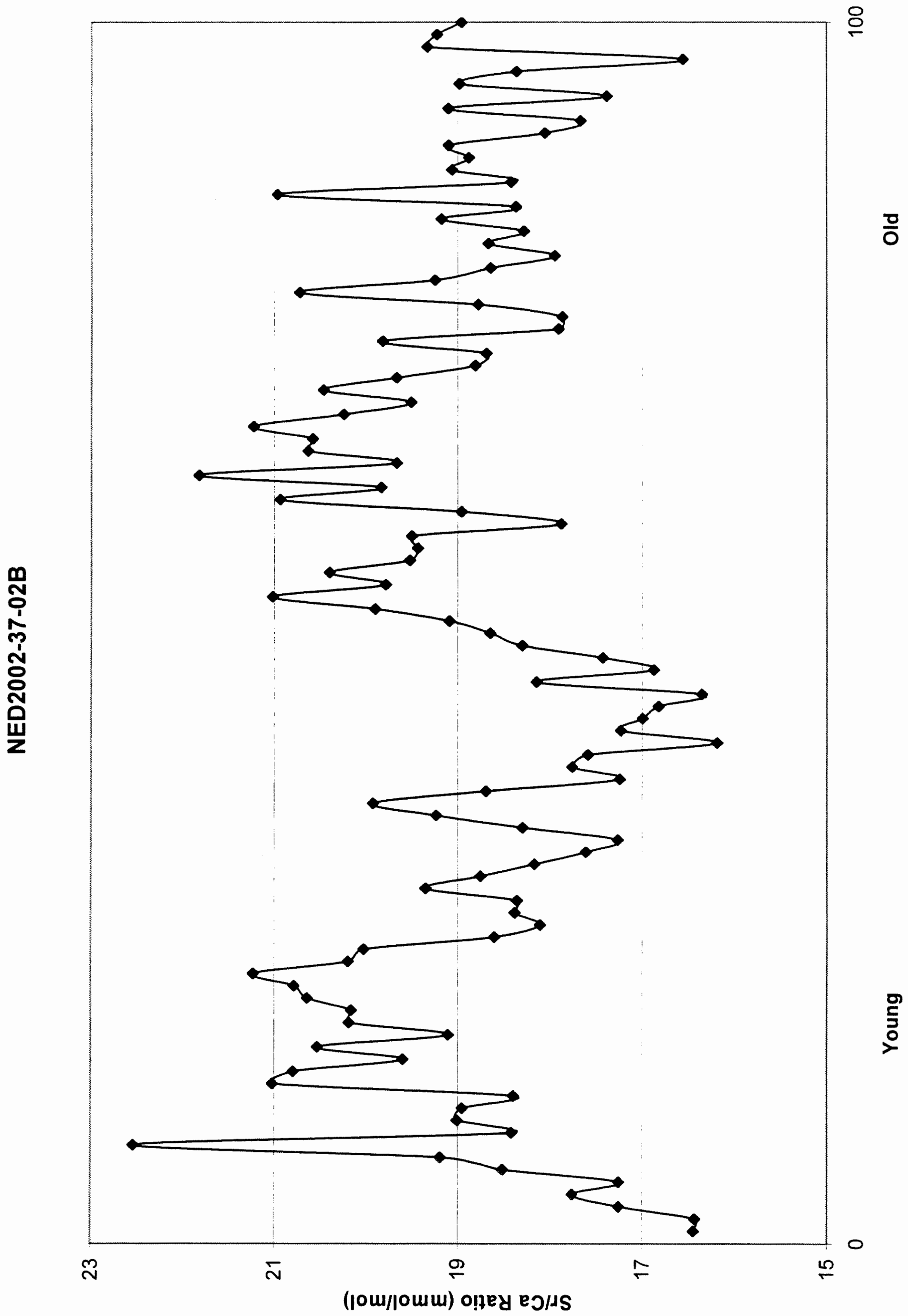


Figure 3.5. Data for NED2002-37-02B (thecal material).

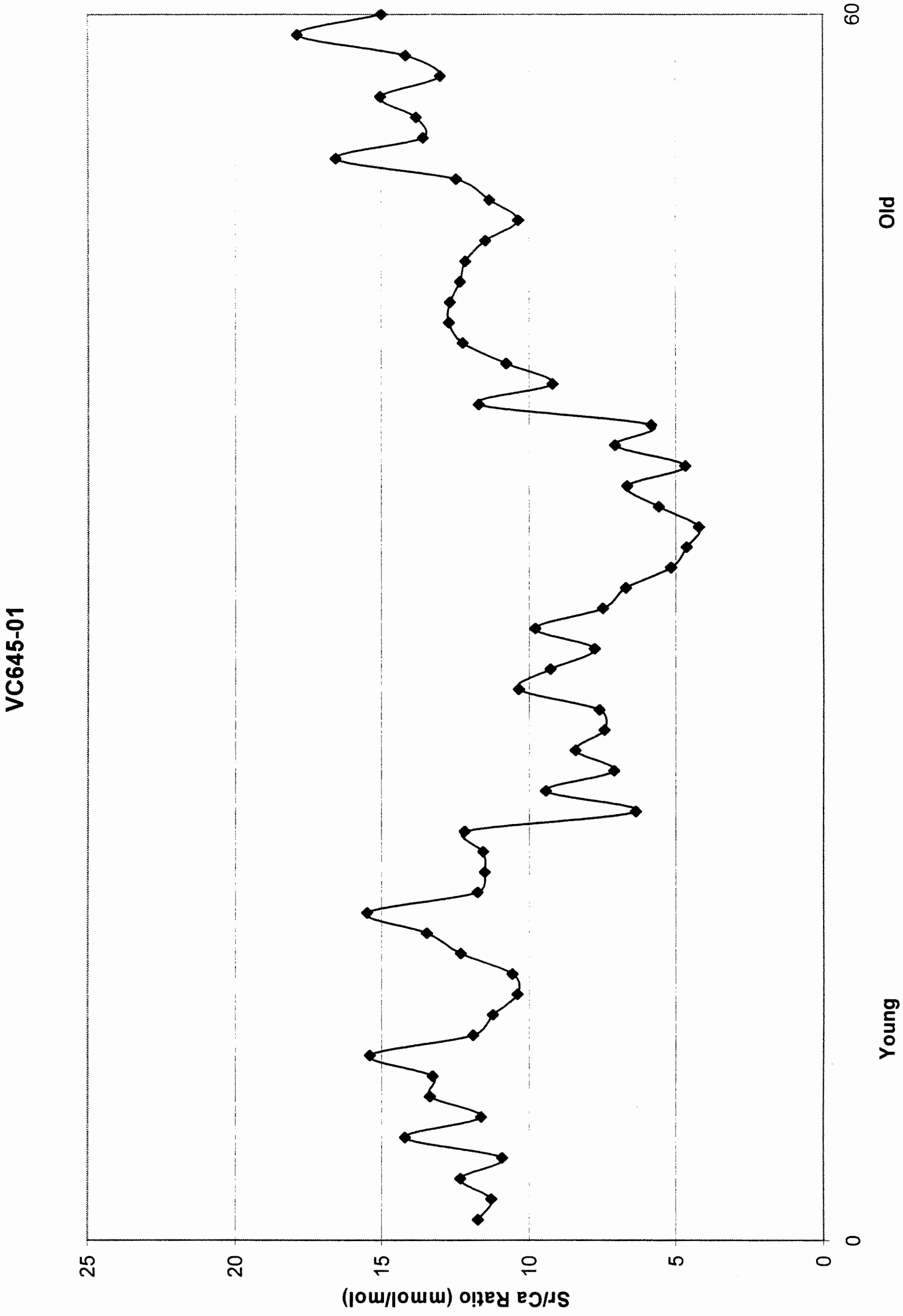


Figure 3.6. Data for VC645-01 (septal material).

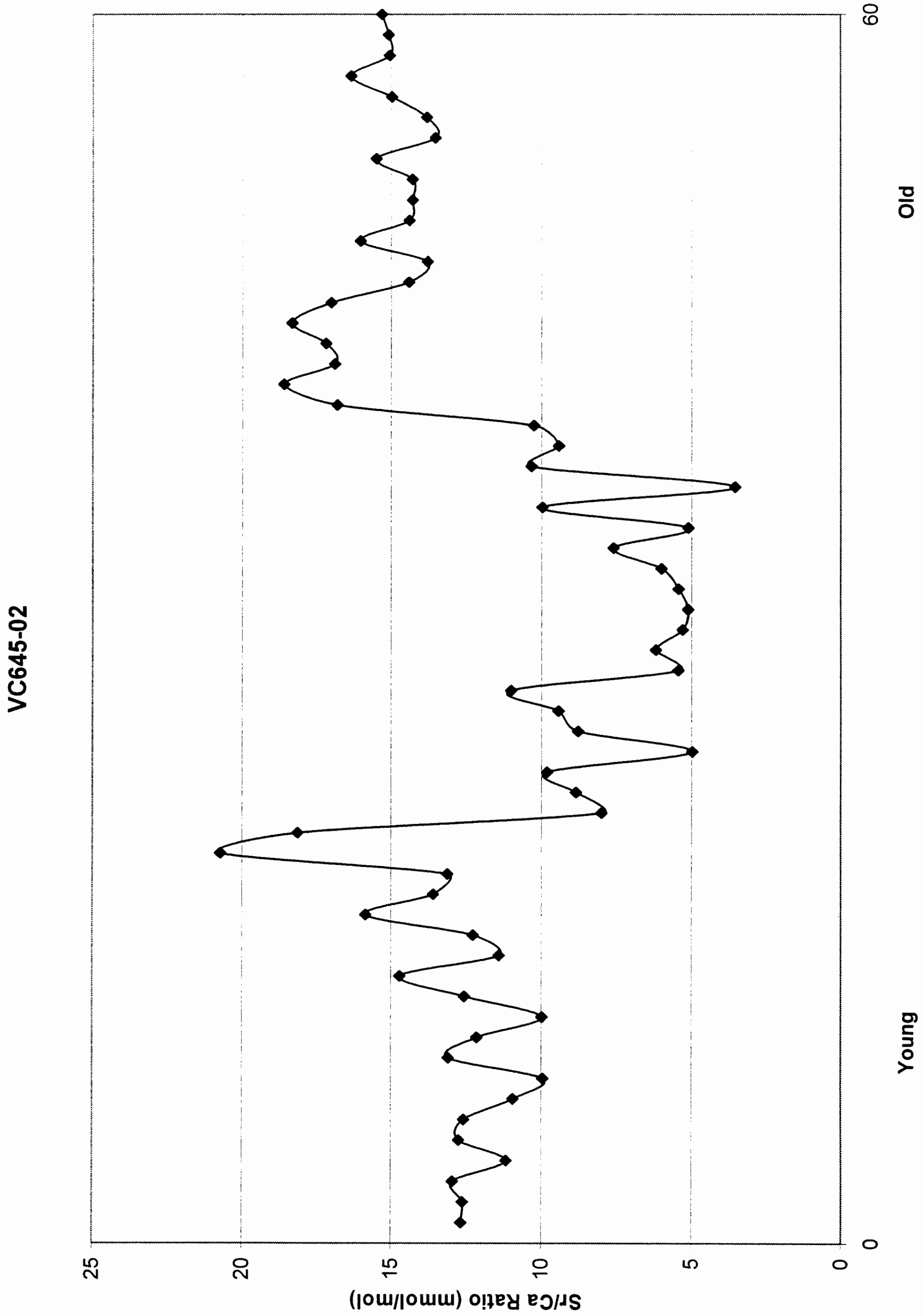


Figure 3.7. Data for VC645-02 (septal material).

3.2.3 Calibration of Sr/ Ca ratios to temperature

Correlating the recorded temperature data and the calculated Sr/Ca ratios, a calibration curve is made. Specimen NED2002-37-02A has the most continuous record and provides the longest record of temperature on the slope. Through counting bands, and assuming banding is biannual, an approximation of the age of the bands measured is made. These ages are correlated with the known temperatures on the Central Scotian Slope (Figure 3.8). Values of Sr/Ca are then plotted versus the average temperatures they represent to form a calibration curve (Figure 3.9). From this curve, Sr/Ca ratios that have been calculated from *Flabellum* of unknown water temperatures can be converted to temperature. The calibration curve shown in figure 3.9 has been calculated from Sr/Ca ratios and temperatures from two *Flabellum* specimens, NED2002-37-01 and NED2002-37-02A. The microprobe analyses from these two specimens are continuous across the septa, and the background noise has been reduced. High Sr/Ca ratios have been correlated with lower temperatures, as calibration work done by Alibert and McCulloch, 1997, and Linsley *et al*, 2000 has shown this relationship in corals. An average temperature of 8.25 ± 1.00^0C for a high and 6.25 ± 1.25^0C for a low is used.

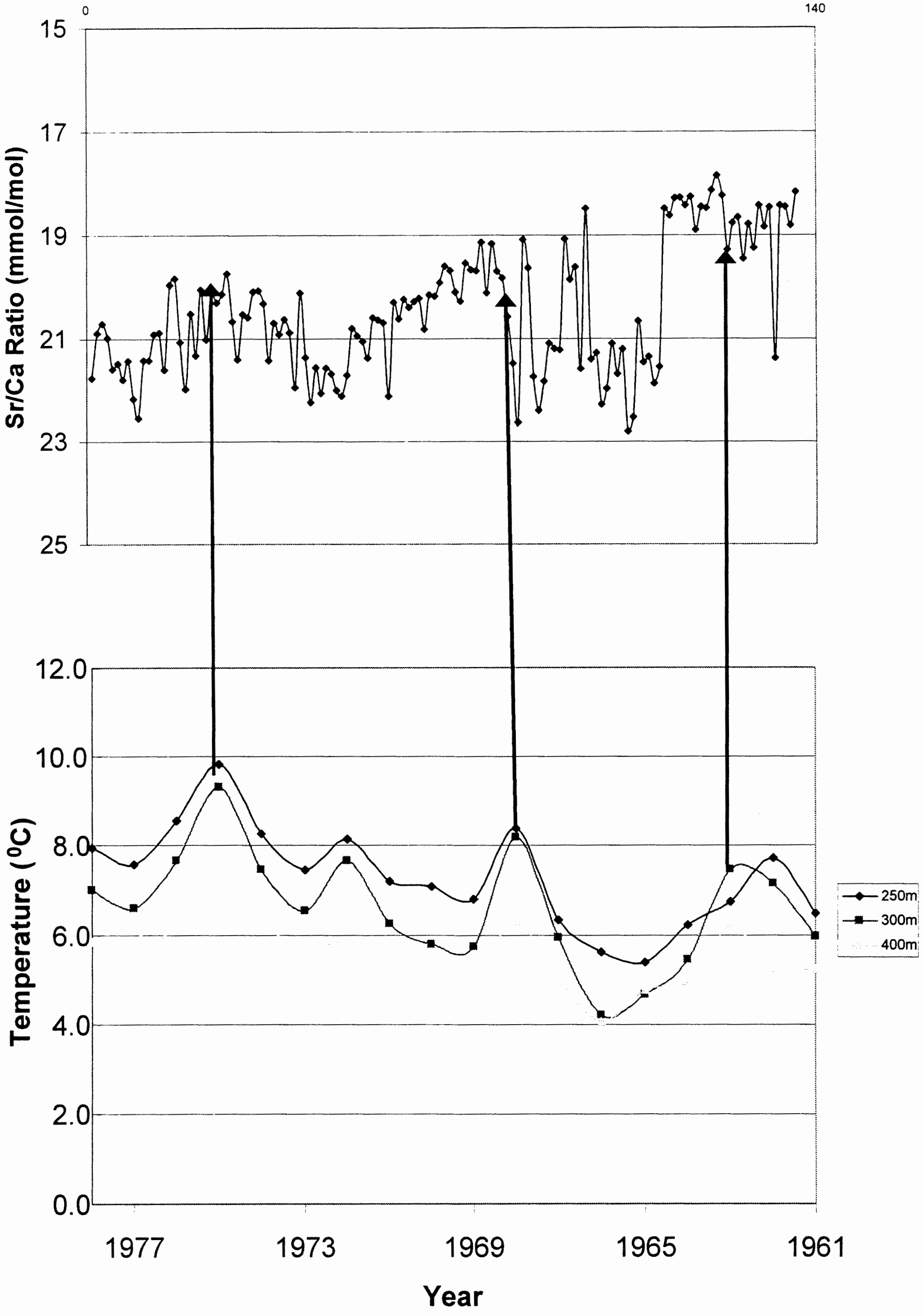


Figure 3.8. Correlation of Sr/Ca ratios from specimen NED2002-37-02B with temperature data for the Central Scotian Slope.

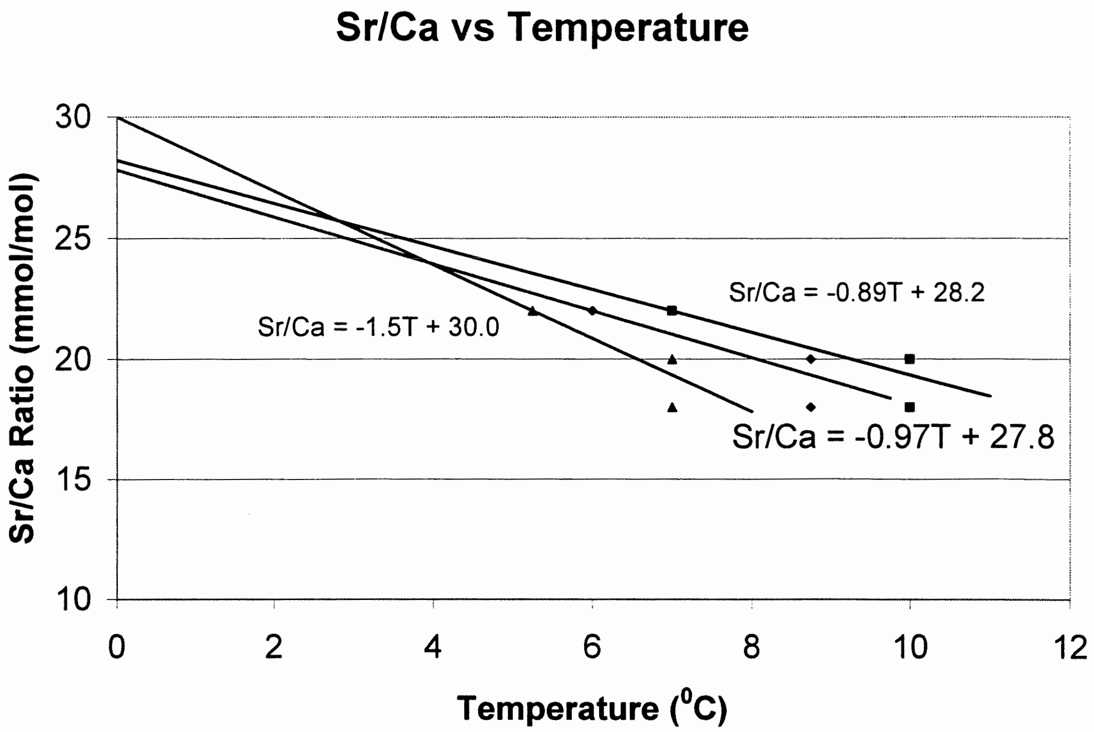


Figure 3.9. Sr/Ca vs. Temperature calibration curve for *Flabellum alabastrum*. The three slopes represent varying water depth (and hence temperatures). The steepest curve is based on a depth of 250m, the middle curve is at 300m, and the top curve is at 400m.

4.0 DISCUSSION

4.1 Factors influencing growth

There are several factors affecting the growth of *Flabellum alabastrum*. The first is the temperature of the water. The colder the water, the slower the growth of coral (Vaughan and Wells, 1943). Coral in the tropics and shallow water tend to be in warmer water, and these coral grow at rates on the order of cm's to tens of cm's per year. Corals in colder waters, such as those off of Nova Scotia's coast, grow on the order of mm's per year. The temperature of water is roughly proportional to depth and so depth plays a major indirect role in the growth rate. Latitude affects temperature in that warmer water is present near the equator, and colder water nearer the poles.

The amount of food present for the corals affects the animals' growth rates. More food results in a higher growth rate (Vaughan and Wells, 1943). Ocean currents replenish nutrients removed from the oceans by animals and plants (Mann and Lazier, 1996), and these play a major role on the Scotian Slope. In coral, C, O, Ca, and Mg are all major nutrients in a coral's diet. Without these, corals could not form a hard calcareous skeleton. Depth plays a crucial role in whether or not Ca or Mg is taken up by the corals. At greater depths, Mg's presence in coral skeletons diminishes because Mg becomes much more soluble than Ca with increased depth (Drever, 1988).

Extended periods of lack of nutrient input may result in dissolution of the coral along the top edge of the theca and septa. This can cause a net reduction in size of the coral, as soft tissue contracts to conserve energy.

4.2 Variations in temperature and Sr/Ca ratios

Although yearly changes in the temperature of water on the Scotian Slope have been looked at, there are also seasonal and even daily changes in temperature that occur. These changes have not been looked at because the temperature records off the coast of Nova Scotia are not continuous. Many months have no temperature data, making it nearly impossible to correlate Sr/Ca ratios to monthly changes in temperature. This may add to the irregularities in the Sr/Ca ratios measured, as water temperatures have changed on the order of 10^0C or more in less than a month. The most likely cause of these rapid changes are pulses of warm Gulf Stream water circulating up to the slope through warm-water gyres.

The Sr/Ca variations seen in *Flabellum alabastrum* seem to follow a cyclic trend like the temperature changes in slope water temperature, indicating that the partitioning of these two elements is dominated by temperature variations. However, on a smaller scale there are many deviations from the averages. These may be caused by daily to monthly changes in temperature, or perhaps by biological processes.

4.3 Future Work

Obtaining good thin sections of specimens from Verrill Canyon where the depth of collection is known should be the next step in work on paleoclimate interpretation using *Flabellum alabastrum*. The use of thin sections of these samples will enable measurement of accurate Sr/Ca ratios that can be compared to accurate Sr/Ca measurements done on specimens from the Central Slope. As well, with an exact depth and not a range of depths, the slope of the calibration curve can then be adjusted. These corals have good potential as paleoclimate indicators, once the problem of creating thin sections is solved. This is not trivial because the septa of *Flabellum* are not flat in most cases, allowing for only a portion of the bands to be analyzed.

Etching of all thin sections with HCl (Smith, 1997) may also help reveal the banding present in the septa of *Flabellum*. Grinding down samples during thin section preparation makes banding less visible; etching may help to improve this.

Comparison of *Flabellum alabastrum* off the coast of Nova Scotia with *Flabellum* from other areas in the Atlantic may also show differences or similarities in banding and/or Sr/Ca ratios. This would help to eliminate any factors acting on corals of the Scotian Slope that may not be affecting corals elsewhere.

5.0 CONCLUSIONS

1) Banding in the coral species *Flabellum alabastrum* is continuous and similar among coral in the same geographic areas. Compared to other areas, these coral still show distinct similarities among one another.

2) Using maximum and minimum recorded temperatures and average Sr/Ca ratios for *Flabellum* on the Central Slope, the equation for the calibration curve is:

$$\mathrm{Sr/Ca} = -1.33T + 30.33$$

which can be rearranged to:

$$T = 1.33(30.33 - \mathrm{Sr/Ca})$$

where T is in degrees Celsius, and Sr/Ca is in mmol/mol.

3) *Flabellum* may prove to be good paleoclimate indicators because banding is continuous and Sr/Ca ratios are easily measured. The utility of *Flabellum* depends on the degree to which temperature variations can be correlated to banding. Variation in banding can be attributed to both seasonal and yearly temperature changes, overcoming this may prove to be the biggest step to understanding the climate record containing in these coral.

APPENDIX I

A) 2002 Temperature Data for the Northern Scotian Slope (From DFO, 2003).

	January			February			March			April		
Depth	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs
0	4.27	1.88	262	2.58	1.48	359	2.30	1.42	423	3.98	2.26	271
10	4.25	1.44	225	2.91	1.40	312	2.74	1.72	289	4.21	2.57	279
20	4.47	1.58	232	2.96	1.62	343	2.84	2.04	284	3.89	2.03	284
30	4.66	1.63	244	3.17	1.63	349	3.04	2.02	318	4.05	2.13	285
50	5.18	1.92	286	3.77	2.05	354	3.46	2.53	471	4.19	2.44	305
75	5.61	2.38	389	4.92	2.48	393	4.71	3.02	476	5.74	3.02	315
100	6.01	2.53	588	6.22	3.11	631	5.43	3.17	694	6.80	3.00	485
150	7.63	2.06	347	7.37	2.96	312	7.59	2.68	379	8.08	2.49	253
200	7.91	2.08	244	7.07	2.49	248	7.50	2.27	261	6.95	2.57	202
250	7.23	1.34	119	6.70	1.97	131	6.85	1.77	210	6.88	1.63	123
300	6.60	1.46	33	5.82	1.52	22	6.31	1.35	86	6.70	1.35	71
400	**6.23**	**0.58**	**19**	**5.67**	**1.16**	**20**	**5.21**	**0.94**	**50**	**5.70**	**0.67**	**46**
500	**5.18**	**0.43**	**8**	**5.14**	**1.19**	**6**	**4.86**	**0.71**	**14**	**5.11**	**0.45**	**23**
600	4.63	0.42	5	5.73	1.09	4	4.54	0.46	13	4.86	0.30	20
800	4.30	0.25	5	4.28		2	4.24	0.25	7	4.48	0.19	12
1000	4.05	0.16	4	3.87		1	4.01	0.04	5	4.29	0.19	9

	May			June			July			August		
Depth	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs
0	5.94	2.24	597	9.99	2.72	696	14.94	1.85	841	18.37	1.53	749
10	5.90	2.26	665	9.73	2.48	1010	13.64	1.97	1465	17.16	1.93	1305
20	5.61	2.17	756	8.73	2.94	1475	11.10	1.79	2186	14.16	3.38	2501
30	5.51	2.24	708	7.42	2.90	1263	8.56	1.57	1684	10.35	3.11	2157
50	5.19	2.54	756	5.96	2.70	983	6.15	1.98	935	7.03	2.90	1065
75	6.37	2.49	736	6.13	3.00	790	6.56	2.35	647	6.93	3.03	750
100	7.47	2.49	1079	7.49	2.72	1162	7.65	2.22	1118	8.00	2.65	1130
150	8.46	2.25	529	8.81	2.46	758	8.27	1.84	562	9.02	2.14	770
200	8.04	1.95	423	8.17	2.05	577	8.41	1.59	363	8.47	1.90	658
250	7.16	1.50	272	7.65	1.60	424	7.79	1.16	195	7.74	1.72	485
300	6.42	1.51	167	6.87	1.38	352	6.88	1.29	115	7.51	1.43	370
400	**5.68**	**1.09**	**109**	**5.70**	**0.93**	**261**	**5.80**	**1.26**	**77**	**6.32**	**1.02**	**209**
500	**5.11**	**0.60**	**48**	**5.02**	**0.63**	**95**	**4.97**	**0.50**	**24**	**5.20**	**0.55**	**68**
600	4.86	0.28	28	4.79	0.35	69	4.62	0.24	7	4.61	0.21	22
800	4.38	0.18	11	4.40	0.22	33	4.25	0.15	8	4.09	0.33	10
1000	4.25	0.10	8	4.08	0.16	36	3.87	0.14	3	4.14	0.04	10

	September			October			November			December		
Depth	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs
0	17.60	1.31	572	14.19	1.91	458	10.78	2.20	641	7.51	2.55	294
10	17.20	1.55	588	14.12	2.21	316	11.14	2.13	409	7.73	2.30	182
20	15.57	2.07	1695	13.97	2.27	542	11.39	2.33	470	7.79	2.39	179
30	11.44	3.31	2707	12.94	2.68	1152	11.19	2.33	713	8.14	2.69	197
50	6.53	3.56	1242	8.73	3.63	1297	9.53	2.88	1888	7.20	2.62	414
75	5.35	3.05	632	6.51	4.13	639	6.75	2.89	990	5.81	2.52	482
100	6.54	2.77	1050	7.08	3.33	882	7.20	3.03	1305	7.15	3.80	568
150	8.38	2.26	545	9.08	2.79	425	8.51	2.21	772	8.10	3.54	113
200	8.34	1.94	406	8.66	2.22	314	8.54	1.79	581	7.73	2.68	80
250	7.34	1.83	276	8.05	1.80	242	7.74	1.53	431	6.95	2.48	50
300	6.50	1.57	273	7.42	1.77	145	7.05	1.17	183	6.96	2.35	16
400	**5.72**	**1.19**	**189**	**6.01**	**1.13**	**88**	**5.74**	**0.64**	**86**	**6.04**	**1.51**	**16**
500	**5.03**	**0.51**	**112**	**5.25**	**0.90**	**34**	**4.99**	**0.35**	**33**	**5.17**	**1.05**	**8**
600	4.52	0.37	78	4.88	0.52	27	4.83	0.45	19	4.53	0.22	3
800	4.29	0.09	15	4.33	0.13	12	4.38	0.12	6	4.41	0.52	7
1000	3.99	0.11	18	4.11	0.11	7	4.19	0.20	5	4.14		

B) 2002 Temperature Data for the Central Scotian Slope (From DFO, 2003)

	January			February			March			April		
Depth	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs
0	6.30	2.77	318	4.55	2.59	359	3.51	2.28	569	4.63	1.86	649
10	6.28	2.77	327	4.55	2.50	238	3.76	2.14	528	4.81	1.73	716
20	6.69	3.11	369	4.77	2.75	266	3.89	2.33	553	5.06	1.85	848
30	7.23	3.27	407	5.22	2.75	282	4.07	2.32	637	5.42	1.97	901
50	7.71	3.12	486	6.01	2.68	317	5.04	2.39	721	6.31	2.22	955
75	8.87	2.93	472	7.34	2.93	386	6.98	2.65	702	7.78	2.57	846
100	9.97	2.93	691	8.76	2.81	606	8.19	2.48	1036	9.02	2.47	1267
150	10.08	2.68	374	9.26	3.06	212	9.09	2.55	483	9.54	2.41	749
200	9.58	2.22	206	9.17	2.55	200	9.01	2.21	421	8.94	2.20	656
250	**9.08**	**1.93**	**173**	**8.08**	**2.41**	**88**	**8.36**	**2.41**	**280**	**8.24**	**1.74**	**471**
300	**8.42**	**1.99**	**198**	**7.67**	**2.07**	**40**	**7.30**	**1.75**	**165**	**7.46**	**1.84**	**681**
400	**6.98**	**1.67**	**136**	**6.48**	**1.96**	**20**	**5.93**	**1.13**	**109**	**6.24**	**1.38**	**538**
500	5.34	0.62	24	5.55	1.81	14	4.87	0.60	68	5.42	0.77	287
600	5.28	0.54	14	5.88	2.20	7	4.69	0.45	35	5.02	0.49	174
800	4.29	0.04	3	4.30	0.01	3	4.34	0.25	21	4.42	0.21	104
1000	4.20	0.00	1	4.11	0.00	1	4.07	0.14	15	4.25	0.09	70

	May			June			July			August		
Depth	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs
0	7.33	1.74	941	11.27	1.75	930	16.11	1.69	1286	18.41	1.45	776
10	7.08	1.60	1040	10.34	1.99	1359	14.37	2.32	2807	17.49	2.39	1652
20	6.91	1.73	1156	9.10	1.88	1608	11.85	2.40	3512	14.49	2.80	2584
30	6.78	1.78	1267	8.49	2.00	1633	9.63	2.79	3072	11.41	3.41	2342
50	7.43	2.05	1181	8.09	2.42	1191	8.02	2.47	1953	8.60	3.16	1265
75	8.29	2.02	1019	8.49	2.61	1016	8.56	2.19	1604	8.48	2.78	874
100	9.29	1.77	1516	9.39	2.19	1424	9.45	1.97	2302	9.48	2.64	1197
150	9.73	1.99	855	9.98	1.59	712	10.03	1.50	1011	10.10	2.05	717
200	9.16	1.49	693	9.24	1.68	580	9.47	1.50	813	9.33	1.58	623
250	**8.17**	**1.51**	**471**	**8.34**	**1.63**	**395**	**8.15**	**1.37**	**565**	**8.44**	**1.43**	**416**
300	**7.50**	**1.22**	**437**	**7.37**	**1.37**	**288**	**7.41**	**1.16**	**569**	**7.61**	**1.20**	**437**
400	**6.32**	**0.73**	**338**	**6.17**	**1.11**	**188**	**6.15**	**0.92**	**385**	**6.27**	**0.82**	**322**
500	5.45	0.44	82	5.28	0.56	56	5.09	0.60	193	5.34	0.44	181
600	5.03	0.38	56	4.83	0.41	44	4.71	0.34	65	4.73	0.27	121
800	4.56	0.05	33	4.35	0.14	20	4.40	0.17	34	4.41	0.11	43
1000	4.15	0.11	29	4.15	0.16	18	4.12	0.11	43	4.17	0.06	19

	September			October			November			December		
Depth	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs
0	18.11	1.48	791	15.33	1.91	660	11.93	2.42	748	9.30	2.49	221
10	17.60	2.09	1066	15.18	1.72	559	12.05	2.46	628	9.54	2.48	222
20	16.53	2.90	1763	15.11	1.78	792	11.90	2.51	784	9.50	2.44	268
30	14.69	3.11	2614	14.12	2.15	1596	11.52	2.70	1151	9.34	2.43	314
50	10.34	4.00	2160	11.43	2.79	2096	10.20	3.02	1813	9.42	2.65	587
75	9.20	3.09	1358	9.17	2.78	1035	8.15	2.95	1520	8.80	3.13	419
100	10.21	2.60	2017	10.26	2.46	1343	8.50	2.96	1880	9.29	3.52	623
150	10.53	1.84	1118	10.63	1.65	756	9.58	2.23	1031	9.31	2.50	311
200	10.16	1.83	916	10.08	1.38	614	9.28	1.91	701	9.00	1.95	262
250	**9.02**	**1.65**	**613**	**9.19**	**1.45**	**492**	**8.42**	**1.77**	**492**	**8.29**	**1.71**	**193**
300	**8.22**	**1.60**	**764**	**8.36**	**1.16**	**707**	**7.45**	**1.45**	**340**	**7.35**	**1.94**	**253**
400	**6.43**	**0.87**	**608**	**6.57**	**0.76**	**577**	**6.09**	**1.10**	**276**	**6.49**	**1.52**	**216**
500	5.52	0.84	385	5.55	0.53	242	5.02	0.50	46	5.02	0.62	138
600	4.96	0.27	63	5.11	0.51	193	4.79	0.37	32	4.80	0.32	111
800	4.38	0.07	26	4.42	0.23	123	4.36	0.21	16	4.53	0.05	76
1000	4.10	0.17	14	4.12	0.16	52	4.07	0.16	8	4.21	0.01	31

C) 2002 Temperature Data for the Halibut Channel Slope (From DFO, 2003)

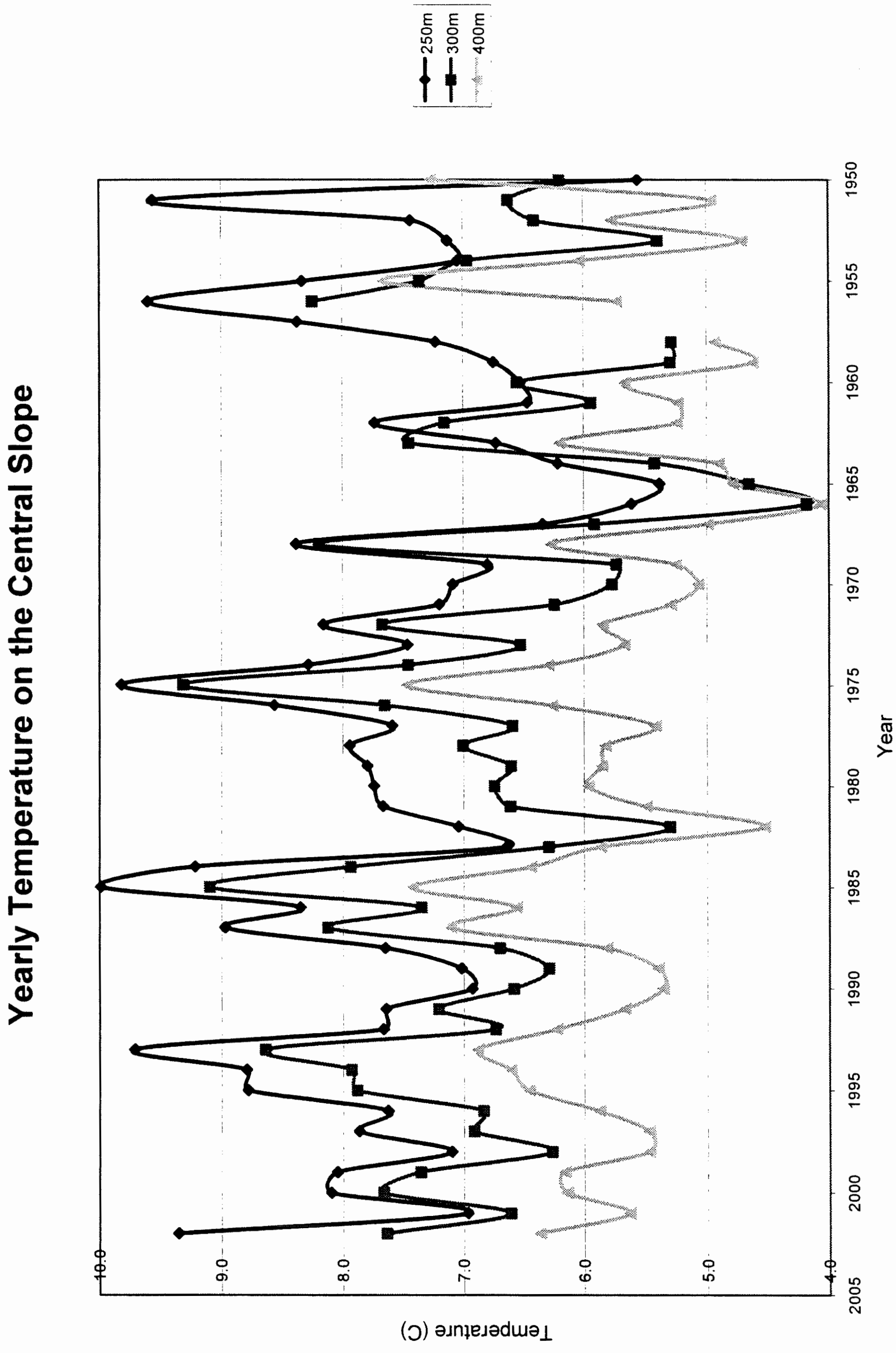
	January			February			March			April		
Depth	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs
0	2.82	1.30	42	1.61	0.83	139	1.01	1.66	208	2.20	1.13	105
10	2.88	1.29	28	1.50	1.01	64	1.20	1.42	120	1.95	0.88	79
20	2.97	1.34	18	1.88	0.94	44	1.11	1.65	143	2.00	1.19	89
30	2.85	1.48	22	1.95	1.08	52	1.16	1.66	147	2.05	1.19	96
50	3.01	1.56	38	2.00	1.26	118	1.14	1.70	184	1.87	1.17	131
75	2.66	1.34	72	1.88	1.01	109	1.35	1.75	302	2.31	1.88	171
100	2.84	1.44	152	1.94	1.24	229	2.25	2.39	638	3.59	2.32	306
150	3.76	1.48	77	3.70	2.35	176	4.14	2.92	449	6.48	2.56	246
200	**5.07**	**1.43**	**53**	**4.47**	**2.31**	**143**	**5.20**	**2.29**	**215**	**7.10**	**1.80**	**115**
250	**5.13**	**1.07**	**28**	**4.79**	**2.21**	**54**	**5.42**	**1.99**	**92**	**6.80**	**1.35**	**86**
300	**5.51**	**0.85**	**24**	**4.72**	**2.00**	**87**	**5.34**	**1.58**	**103**	**6.20**	**1.20**	**81**
400	**4.73**	**0.58**	**16**	**5.16**	**0.80**	**58**	**4.93**	**0.96**	**40**	**5.04**	**0.72**	**31**
500	**3.68**		**6**	**4.60**	**0.36**	**5**	**4.58**	**0.68**	**21**	**4.62**	**0.17**	**6**

	May			June			July			August		
Depth	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs
0	4.83	2.20	124	7.07	2.36	259	12.93	2.09	73	16.40	1.53	208
10	4.83	1.91	148	7.08	2.39	248	11.48	1.35	183	15.50	1.37	308
20	4.57	1.92	194	5.94	2.10	400	9.80	2.07	231	12.05	2.28	887
30	4.23	2.04	202	4.83	1.61	468	6.78	1.85	206	8.66	2.54	733
50	3.19	1.97	201	2.57	1.39	473	3.38	1.90	137	3.17	1.57	304
75	2.88	2.68	173	1.86	2.16	361	2.27	1.97	86	2.16	1.64	215
100	3.29	2.62	345	2.89	1.97	659	3.95	2.82	153	2.86	2.02	367
150	5.83	2.93	166	5.89	2.26	421	6.20	1.71	148	5.16	1.68	333
200	**5.73**	**2.27**	**80**	**6.34**	**2.09**	**137**	**6.86**	**1.23**	**64**	**6.49**	**1.20**	**197**
250	**6.41**	**1.62**	**73**	**6.36**	**1.13**	**72**	**6.49**	**1.21**	**21**	**6.02**	**0.94**	**161**
300	**5.98**	**1.02**	**47**	**5.79**	**1.23**	**59**	**5.43**	**0.71**	**9**	**5.69**	**0.83**	**67**
400	**5.47**	**1.01**	**18**	**4.82**	**0.57**	**13**	**4.83**	**0.68**	**4**	**5.38**	**0.22**	**10**
500	**4.89**	**0.50**	**4**	**4.01**	**0.13**	**4**	**5.07**		**2**	**4.48**		**4**

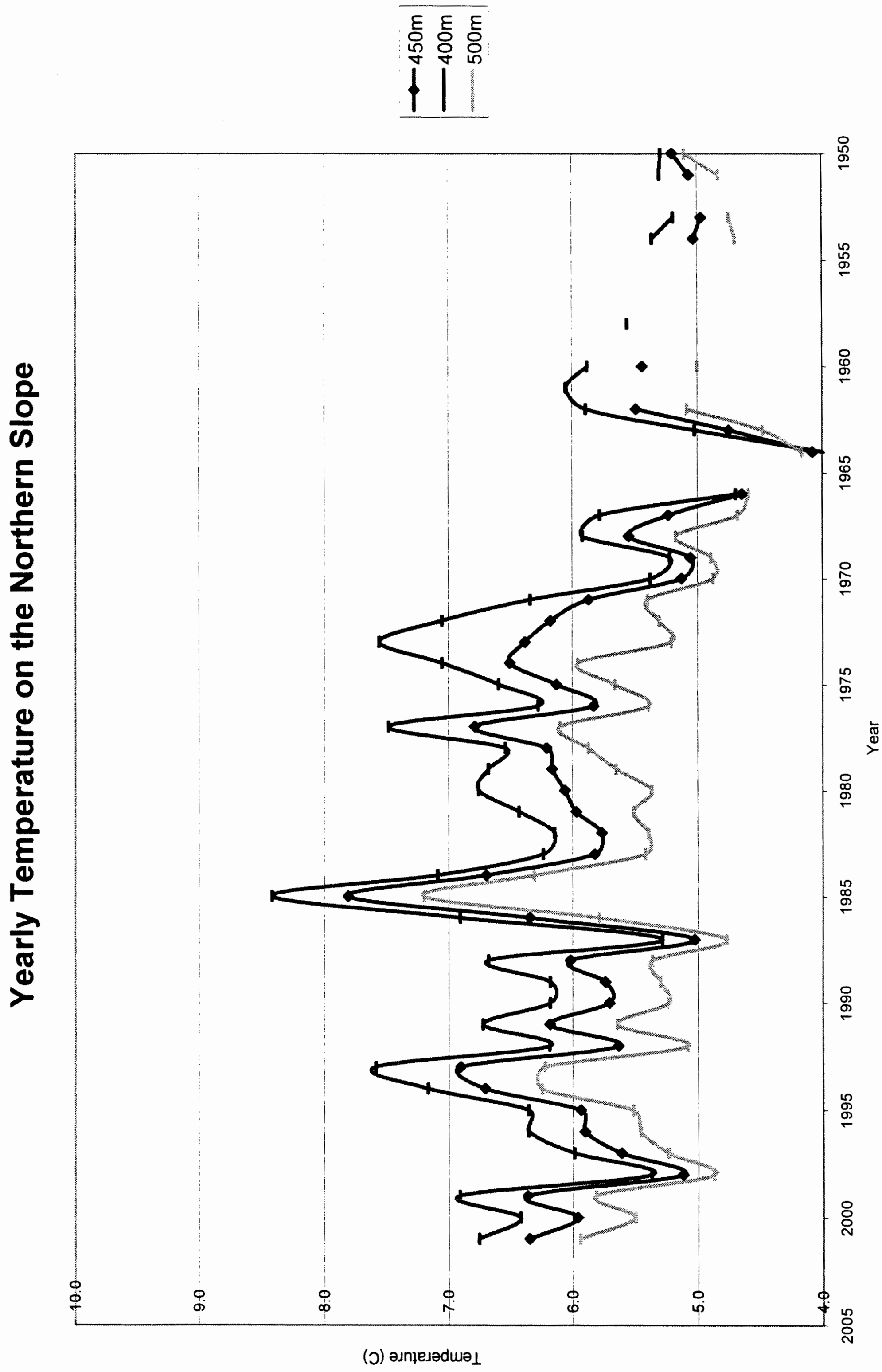
	September			October			November			December		
Depth	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs	Mean	S.D.	#Obs
0	15.33	1.02	55	12.32	2.11	28	8.81	1.19	33	6.63	1.81	30
10	15.18	1.26	43	13.30	2.29	12	8.77	1.04	24	7.04	1.98	16
20	14.71	1.52	88	12.49	1.93	19	8.94	1.18	27	6.84	2.21	11
30	11.40	2.51	422	9.83	2.43	79	8.96	1.37	38	6.82	2.15	16
50	4.59	3.60	93	4.42	2.21	59	4.86	1.77	94	5.53	2.15	67
75	2.78	4.03	64	4.46	2.27	18	2.01	2.31	31	5.00	2.54	64
100	3.74	3.96	109	4.69	2.52	34	2.69	2.14	36	4.36	2.63	57
150	5.49	4.19	23	8.06	1.06	15	4.81	3.38	22	6.38	2.52	34
200	**6.77**	**3.00**	**21**	**7.73**	**0.63**	**12**	**6.32**	**2.37**	**16**	**6.54**	**1.96**	**18**
250	**6.32**	**2.59**	**22**	**7.41**	**1.18**	**14**	**4.92**	**2.28**	**8**	**5.52**	**2.31**	**7**
300	**6.21**	**2.25**	**14**	**6.37**	**0.94**	**10**	**6.21**	**0.35**	**10**	**5.30**	**1.87**	**12**
400	**5.12**	**1.45**	**7**	**5.58**	**0.65**	**10**	**5.60**		**1**	**5.43**	**0.36**	**9**
500	**4.82**	**1.03**	**6**	**4.67**		**1**	**5.00**		**1**	**4.27**		**4**

APPENDIX II

A) Average Water Temperatures over the Past 50 Years on the Central Slope (From DFO, 2003).



B) Average Water Temperatures over the Past 50 Years on the Northern Slope (From DFO, 2003).



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