The use of foraminifera and thecamoebians as reliable indicators of marine/freshwater transitions zones in natural environments of southern Florida

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Abstract

The mangrove environment of southern Florida is expansive, dominating the much of the southern coastline, including that of the southwestern Everglades. As such, it is a dynamic environment that is constantly readjusting the balance between marine and freshwaters. One major question is what has happened in the past; it is difficult to reliably distinguish marine and freshwater deposits of the past. Since 1995, the U.S. Geological Survey (USGS) has been engaged in a large-scale project to acquire high-quality, relevant information on the southern Florida ecosystem as part of the USGS's Placed-Based Studies Program. In conjunction with this project, various cores of unconsolidated sediment were collected. The portion of one core, Core 15-5, is examined in this study.

This study was designed to examine whether or not marine and freshwater Rhizopodia can be used as reliable indicators of marine/freshwater transition zones in the mangrove environment of southern Florida to help reconstruct past freshwater/marine transition zones. Three cores, Core 15-5 from Little Madeira Bay in Everglade National Park, Core L1011/Hwy 1 from south of Florida City, and Barnes Sound Core from the south end of Barnes Sound, were sampled, processed and analyzed under a stereomicroscope for freshwater thecamoebian and marine foraminifera faunal assemblages.

Results demonstrate marked differences between the peat environments of the three cores. Core 15-5 exhibits a transition from older freshwater peat to marine mud, evident in the transition from thecamoebian species and cysts to calcareous foraminiferal species. Core L1011/Hwy 1exhibits a transition from older mangrove peat to freshwater mud, evident in the transition from agglutinated foraminiferal species to thecamoebian species. The Barnes Sound Core is mangrove peat in the upper section, Section A. Section B of the Barnes Sound Core is marine mud, evident in the high percentages of calcareous foraminiferal species. Southern Florida is an important ecosystem to study as it contains assemblages of calcareous foraminifera with high diversity assemblages of thecamoebians, and thecamoebian cycts. This is the first time that calcareous foraminifera and thecamoebians have be reported together in high abundance (Core L1011). The fine scale of environmental differences that these organisms detect make them highly useful indicators of marine/freshwater transition zones in southern Florida.

Acknowledgements

Chapter 1: Introduction

1.1 General Statement

The ecological balance of Southern Florida is a particularly delicate one. It is a region that is subject to changes in sea level, overland water flow and various anthropogenic effects. The Everglade and mangrove environments of Southern Florida provide a natural laboratory for the study of past and present shoreline movements through the Holocene. Using testate rhizopods, this thesis will examine marine transition zones within these environments, to see whether testate rhizopods can be used to detect changes in paleo- marine/freshwater transitions.

1.2 Objectives and Scope

The objective of this thesis is to determine whether testate rhizopods, specifically foraminifera and thecamoebians, can be used as reliable indicators of marine transition zones in the mangrove and everglade environments of Southern Florida. Three cores will be considered (Figure 1); the first from Little Madeira Bay in Everglades National Park (Core 15-5), the second from a young mangrove community along Highway 1 south of Florida City (Core L1011), and the third from an established mangrove community along Highway 1 in Barnes Sound (Core sections A and B). The results are considered within the scope of historical and present water circulation in these environments and events affecting their natural patterns. Additionally, the merits of using recent foraminifera and thecamoebian tests to indicate the marine transition zone are discussed. This thesis is not taxonomic by nature, but utilizes taxonomic descriptions of previous studies for species identification.

84° 06' 01" West

28° 11' 19" North

23° 42' 52" North

84° 48' 25" West

1 cm=25 miles
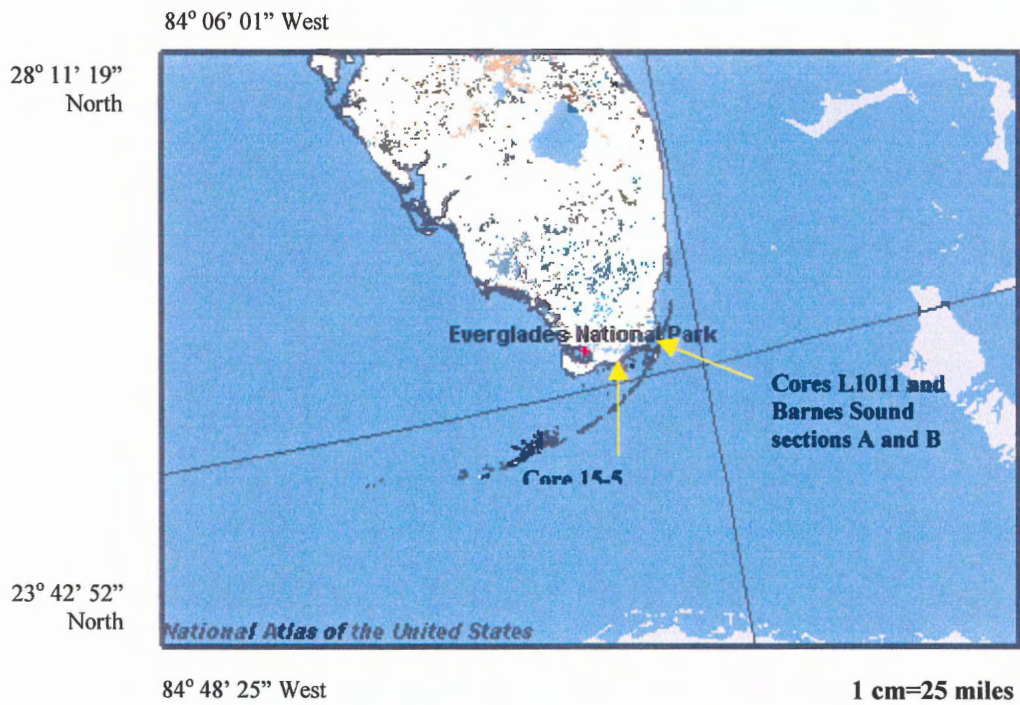
Figure 1. Lambert Azimuth Equal-Area Projection of region of interest in Southern Florida. Relative locations of core collection sites are depicted with labeled arrows.
(Adapted from: http://nationalatlas.gov)

1.3 Faunal Description and Definition of Terms

Among the most commonly studied microfossils are the testate rhizopods, foraminifera and thecamoebians. Classified in the Phylum Sarcodaria, these unicellular protozoa are particularly valuable environmental indicators in geologic and recent time. This is attributed to the fact that once dead, their tests are well preserved in sediments and allow for reconstruction of a site history without baseline data, and require only a small sample size to be statistically significant (Scott, *et al.*, 2001).

1.3.1 Foraminifera

Foraminifera are one of the most comprehensively studied and best known of all microfossils (Boersma,1978). They are heterotrophic, unicellular organisms that live in marine and marginal-marine environments. Higher taxonomic levels are determined by the materials that comprise their tests. Foraminifera can form tests by secreting calcium carbonate (resulting in calcareous tests), or by cementing detrital material to form the more primitive agglutinated test (Scott, *et al.*, 2001). Environments of higher salinity and warmer waters are most conducive to the formation and preservation of calcareous tests. Foraminifera with agglutinated tests can be found in these same environments, but are most prevalent and preserved at higher numbers in environments of lower salinity and/or colder waters (Scott, *et al.*, 2001). While foraminifera thrive in a marine environment, some species can occur in marginal-marine environments subject to significant freshwater input (Scott, *et al.*, 1991).

1.3.2. Thecamoebians

There are many similarities between foraminifera and thecamoebians. Thecamoebians are widely distributed, heterotrophic, unicellular organisms. The widespread distribution of thecamoebians is, however, within various fresh- to brackish water environments. The higher taxonomic levels of thecamoebians are also determined by the materials that form the test of the organism. Tests secreted by the organism are termed autogenous (resulting in calcareous or siliceous tests), while those composed of cemented foreign particles are termed xenogenous (Medioli and Scott, 1983).

The principal difference between these two groups of testate rhizopods that is relevant to this study is the freshwater environmental affinity of thecamoebians and inferred marine-influenced environment with the presence of foraminifera.

1.4 Previous Studies

While it is commonly understood that foraminifera and thecamoebians, when considered together, can be indicative of marine transition zones, the recent transition zones of Southern Florida are poorly understood, and little consideration has been given to the use of these testate rhizopods as indicators of a fluctuating environment. Table 1 lists relevant rhizopod studies.

Table 1. Chronological listing of relevant studies using testate rhizopods.

Study Location	Scope and Conclusions	Reference
Florida Bay and adjacent waters, Florida, U.S.A.	Examines and identifies benthic foraminiferal species found in the waters of this region from 108 cores around the South Florida Keys.	Bock (1971)
Lake Erie, Ontario, Canada	The transects across each of the three basins considered display distinctive patterns of agglutinated thecamoebian distribution, based on the differences in water quality and its associated features.	Medioli and Scott (1983)
General	Presents the merits of thecamoebians as reliable indicators of paleolimnological environments.	Medioli and Scott (1988)
Lower Mississippi Delta, U.S.A	Surface samples across the four representative vegetative zones. Brackish marshes were dominated by all agglutinated foraminiferal species. Emergent freshwater or intermediate marshes were dominated by thecamoebians, but significant numbers of foraminifera indicate occasional marine influences. Spatial distributions as a result of changing salinity were reflected by the foraminiferal and thecamoebian assemblages.	Scott, Suter and Kosters (1991)
Porter's Lake, Nova Scotia, Canada	The foraminiferal and thecamoebian fauna were determined to reflect distinct assemblages based on the water environment (fresh or estuarine).	Laidler and Scott (1996)
Kaipara Harbour, Miranda and Pauatahanui Inlet, New Zealand (all marsh environments)	Mangrove forest environments were dominated by *Ammonia* species along with some forms of *Elphidium excavatum*.	Hayward, Grenfell and Scott (1999)
Various sites, Bermuda (lagoon, reef, cave, mangrove and pond environments)	Mangrove environments exhibited low species diversity and variable abundance. Agglutinated species were most common, and a few specific calcareous species were present.	Javaux (1999)

As previously mentioned, the natural environments of Southern Florida are poorly

understood. Some work has been done in this region by the U.S. Geological Survey to

determine past transition zones, but most of this work is in the preliminary stage, and has

yet to be published. Techniques used include faunal and floral distributions, including palyntological studies (Brewster-Wingard *et al.*, 1999; Holmes *et al.*, 2000), carbon dating of organic material and fossils, and Pb-210 dating (Holmes *et al.*, 2000). These studies show that over the last 2,000 years, there have been long-term fluctuations related sea-level change, but in the last 50 years, significant changes can be attributed to anthropogenic effects through hydrologic management plans (Holmes *et al.*, 1999).

Related on-going studies include the use of Sediment Elevation Tables (SETs) to identify precise elevation changes over time, at a scale of ± 1 mm (Cahoon and Smith III, 1999), and geophysical mapping of salt water intrusions using helicopter electromagnetic, transient electromagnetic and borehole measurements (Fitterman and Deszcz-Pan, 1999).

1.5 Methodology and Approach

As the sample cores considered here were taken in unconsolidated sediments of both the mangrove and everglade environments, the collection of samples was relatively straightforward. Core 15-5 was taken by field technicians of the U.S. Geological Survey in February 2000 using a hand-driven piston corer. This core was taken as a potentially interesting aside to their work presently being done on sediment supply, carbon and Pb-210 dating, macro-vertebrate and palyntological studies in the area to reliably indicate marine transition zones. The cores from both mangrove locations were sampled by Dr, Harold Wanless (University of Miami), Dr. David Scott and the Southeastern U.S.A. Honours Class 2000 Field Trip (both of Dalhousie University), on September 11, 2000 using hand-driven coring methods.

Core 15-5 was sampled in the U.S. Geological Survey laboratory in St. Petersburg, Florida and a portion was sent to Dalhousie University where it was

processed and subsequently analyzed using light microscopy. Both mangrove cores were

sampled, processed and analyzed, again by light microscopy, at Dalhousie University.

1.6 Organization of Thesis

After Chapter 1, Chapter 2 explores the regional physiography and geology of

Southern Florida, including the historical and present circulation of regional waters, and

the effect of short-term climatic events (e.g.: hurricanes) upon this natural system.

Following this, Chapter 3 presents the methodology used in the collection, preparation

and analysis of the samples considered, while Chapter 4 presents the results from each of

the three cores analyzed. Finally, Chapter 5 discusses the independent results of the

cores, the correlation of the results of the cores with each other, as well as with the results

of previous studies, implications for salt water intrusion detection, any conclusions

determined and recommendations for future work.

Chapter 2: Regional Physiography and Geology

2.1 Introduction

As a coastal region with elevation less than 7.5 metres above sea level (Scholl, 1964), Southern Florida consists of environments that are highly dependent on and reflective of water and its local chemical nature. Figure 2 illustrates different physiographic areas and emphasises the role that water and water chemistry play upon the bedrock and sediment of Southern Florida, from the limestone to mangrove to freshwater peat.

2.2 Physiography of Southern Florida

2.2.1 Everglade Features

The Everglades, often termed the "river of grass", is a wide and shallow, freshwater river that covers 1.4 million acres of southwestern Florida (Kern, 1992). This slow-moving, freshwater environment is home to a variety of floral habitats and their accompanying fauna. Common flora include sawgrass and *Conocarpus erectus*, or buttonwood mangrove (Tomlinson, 1994). The southern coast of the Everglades is non-continuously bounded by the Buttonwood Embankment, a 0.5m natural levee that traps freshwater on the landward side (Holmes *et al.*, 2000). The discontinuous portions of the southern coast consist of brackish and marine waters, juxtaposed to the freshwater regions behind the embankment (Holmes *et al.*, 1999). Little Madeira Bay, along the southern coast, is the site location of Core 15-5, and forms part of one of the discontinuous embankment regions (Figure 3).
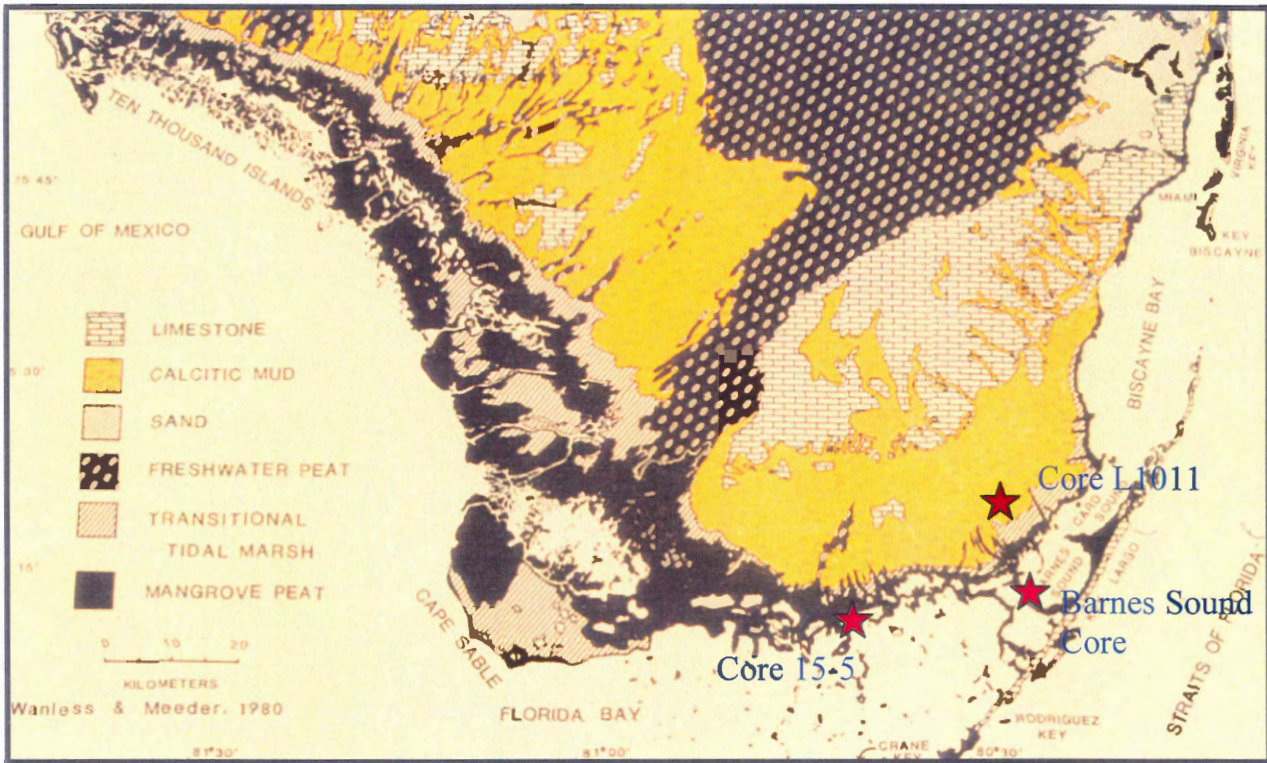
Figure 2. Surficial map of southern Florida, displaying Core 15-5, Core L1011 and Barnes Sound Core locations. Core L1011 was taken in a young red mangrove environment with a water depth of 1 foot. The Barnes Sound Core was taken near Lake Surprise in an established black mangrove environment with a water depth of 1.2 feet (Adapted from Wanless *et al.*, 1995).

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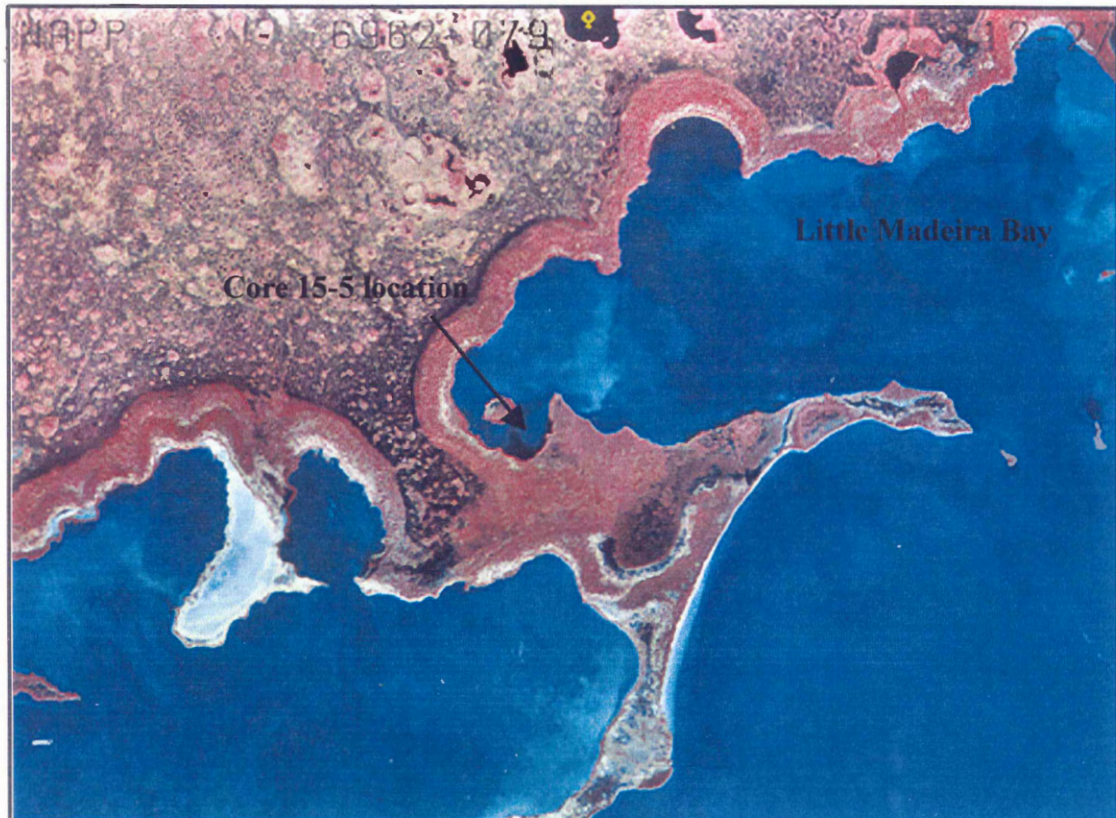
Figure 3. Satellite image of Core 15-5 location. The core was taken just southeast of the local mangrove island, in a water depth of 2.5 feet. Precise location was: 25° 10' 34.10" N, 80° 39' 32.49" W. Limestone bedrock was reached with the bottom of the core at a depth of 114.5 cm (Courtesy of the U.S. Geological Survey).

As shown on Figure 2 (Section 2.1), the Everglades is physiographically considered mangrove and transitional along the coast, and shallow marine mudbank in the bay island regions. The slope of the entire region is 2.5 cm/1.6 km, toward the coast.

2.2.2 Mangrove Features

The mangrove environment is one unique to semi-tropical to tropical coastal regions. It is an environment most notably dominated by the distinct mangrove trees, of which there are severalspecies. The predominant South Florida species in the mangrove study areas are *Rhizophora mangle* ("red mangrove"), *Laguncularia racemosa* ("white mangrove"), and *Avicennia germinans* ("black mangrove"; Tomlinson, 1994; Wanless, 2000; Scholl, 1964). Various species of cryptograms (algae, bryophytes and lichens) are associated with the mangrove trees, often forming mats on the sediment surface (Tomlinson, 1994). Features often considered when exploring the succession and occurrence of particular mangrove species are salinity, competitive ability and disturbance frequencies. Replacing the marsh environment of temperate regions, the salinity of waters in this environment can range up to 90 ‰ (Tomlinson, 1994). Each of these three species is considered salt tolerant. Zonation patterns are dependent on water depths (Tomlinson, 1994; Wanless, 2000), however, reliable zonation patterns can be difficult to determine due to disturbances of established systems and importation of seedlings via various means.

Observation of peat formed in mangrove environments reveals distinctly different peat characteristics between those of red mangrove and black mangrove (Wanless, 2000). Peat of the red mangrove is rich in dense, root hair mass and has little leaf detritus

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(Tomlinson, 1994). Peat of the black mangrove contains thick, brown root pieces and more leaf detritus than peat of the red mangrove (Wanless, 2000).

Core L1011 of this study was collected in a young, red mangrove environment where the mangrove trees had a maximum height of 0.75m. The Barnes Sound Core was collected in an established, black mangrove environment neighbouring an oceanically-connected lake, Lake Surprise, where the mangrove trees were well over 3 m tall .

2.3 Bedrock Geology

Southern Florida has always been a coastal environment, however, the position of the coastline has fluctuated throughout time. When sea level was +6-8 m relative to present sea level during the late Pleistocene, a submerged reef formed between Miami and Key West (Wanless *et al.*, 1995). This reef is now exposed as a ridge and termed the Key Largo Limestone (Vernon and Puri, 1964). The bedrock west of the Key Largo Limestone is also limestone of Pleistocene age, but it is not a reef; it is a shallow marine oolitic limestone (Vernon and Puri, 1964). This Miami Limestone (or Miami oocite) is comprised of two facies: ridge-forming oocite and adjacent lagoonal deposits (Wanless *et al.*, 1995). Cross-bedding is evident. Figure 2 shows the relationship between the two limestone ridges (see Section 2.1).

2.4 Circulation of Waters

2.4.1 General Statement

It is the continuous circulation of marine, brackish and freshwater throughout Southern Florida that results in this regions' dynamism. It is important, however, to distinguish the characteristics of natural, or on-going water circulation, so alteration due

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to anthropogenic effects or natural distruptions (e.g.: hurricanes, tropical storms), can be readily detected.

2.4.2 Natural Circulation of Waters

In this context, 'natural' water circulation is a somewhat ambiguous term. The ecologically natural water circulation system of Southern Florida involves overland and groundwater flow from the Kissimmee River and Lake Okeechobee water system in the central portion of the state, out across the Everglades in the southwestern region of the state and into Florida Bay (Figure 4). The present-day natural water circulation system follows a similar pattern to that of the ecologically natural system, but has been subjected to extreme anthropogenic alteration through the implementation of a massive-scale levee and channel system. This channel system controls surface water flow, and subsequently groundwater flow, in a strictly regulated manner managed by the U.S. Army Corps of Engineers and the South Florida Water Management District (Figure 5). The channel system, begun in 1948 and completed by 1960, was designed to provide a mechanism for controlling the periodic large-volume flooding that was common, and to divert freshwater to populated centres and agricultural areas (Wanless *et al.*, 1995).

Tidal influence is also an important element of water circulation in southern Florida. The eastern coast, including all of the Barnes Sound coastal area, experiences regular, semidiurnal tides (Fernald, 1981). The western coast and majority of the southern coast experience mixed tides, of two unequal high tides and/or two unequal low tides per day (Fernald, 1981).

Figure 4. Historic (pre-1900) overland freshwater flow pattern of the Lake Okeechobee water system in Southern Florida. The majority of flow was directed south and slightly west, flooding what are now heavily populated areas in the southern region of the state. The Everglade environment, depicted as green in the figure, covered a significantly large land area (http://www.evergladesplan.org/theplan/p11.htm #flowmap).
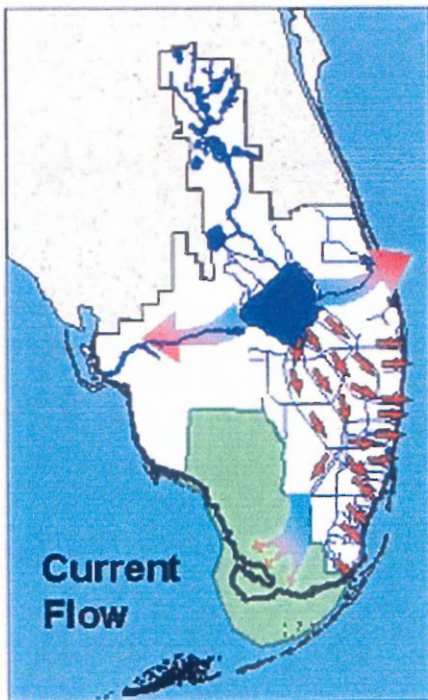
Figure 5. Current overland freshwater flow pattern of the Lake Okeechobee water system of Southern Florida. The redirection of the natural flow pattern is the result of a levee built around the southern portion of Lake Okeechobee, and the installation and development of a large-scale series of channels and canals. The movement of water through these canals is regulated by the South Florida Water Management District and the U.S. Army Core of Engineers. The larger arrows and darker red colour indicate more intense flow. The freshwater is directed away from or toward populated regions as is necessary to fulfill freshwater requirements. Note the significantly reduced land area considered to be Everglade environment as a result of this redirection of freshwater flow (http://www.evergladesplan.org/theplan/p11.htm #flowmap).

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Due in part to the shallow depth to bedrock in the southern portion of the state (<80cm to bedrock at Core L1011 location), groundwater recharge rates are high, and flow is often artesian (Fernald, 1981).

2.4.3 Factors Altering Natural Circulation

Groundwater/surface water interaction has been noticeably affected by the implementation of the channel and levee system. This is due to the maintenance of water-level differences across levees that force water down into the permeable limestone (Harvey *et al.*, 1999). Harvey *et al.* (1999) also have shown significant flux occurs between surface waters and surrounding peat.

Hurricanes and tropical storms can also have significant impacts on water circulation patterns. Although storms occur over a finite period of time, the results of the storms can have lasting effects. Major flooding as a result of high winds can either redistribute freshwater from surface reservoirs, or in conjunction with tidal waves, can cause an influx of seawater or overwash into localities otherwise cut-off from marine input. The most recent major storm to hit southern Florida was Hurricane Andrew, August 24, 1992. Although flooding was not extremely widespread, a +5 meter flood surge did affect the mainland portion of Biscayne Bay (Wanless *et al.*, 1995), in the region of core locations of Core L1011 and Barnes Sound Core. Hurricane-force winds occur in any given area of southern Florida once/7.5 years (Neumann *et al.*, 1978, as cited by Wanless *et al.*, 1995).

Change in relative sea level is another factor altering natural water circulation. Relative sea-level increase may result due to increase in ocean volume, or due to

continued subsidence of the land as it continues its isostatic subsidence from the last glacial period. Relative sea-level rise, within the last hundred years only, may also occur due to the decreased amount of freshwater flow into Florida Bay resulting from the installation of the levee and channel system. With an average rate of relative sea-level rise of 4cm/100 year for the past 1,000 years, changing sea level will, over time, affect the natural water patterns of Southern Florida (Wanless *et al.*, 1995).

Chapter 3: Methods

3.1 Sample Collection

The core segments addressed in this paper were taken in unconsolidated sediments of the major natural environments of Southern Florida: the Everglade and mangrove environments.

The representative core of the Everglade environment, Core 15-5, was taken by technicians of the U.S. Geological Survey (USGS) in February 2000 using a hand-driven piston corer (Figure 6). The core tube was 10.8 cm in diameter and had a polycarbonate liner. Immediately after collection, the core was capped and sealed, and transported to cold storage in the USGS laboratory in St. Petersburg, Florida. The full length of core collected was 114.5 cm, but only the section from 80-114.5 cm is considered within the scope of this project.

Both representative cores of the mangrove environments, Cores L1011/Highway 1 and Highway 1/Barnes Sound were taken by Dr. David Scott, Dr. Harold Wanless and the Southeastern U.S.A. Honours Class 2000 Field Trip (which included myself), on September 11, 2000 using hand-driven coring methods (Figure 7). Both core tubes were 10 cm in diameter. The length of core L1011/Highway 1 collected (and examined) from the young mangrove was 70 cm. This core was immediately capped and sealed after collection. The core of Highway 1/Barnes Sound collected from the established mangrove was approximately 2.8 m in total length, using three lengths of tubing. The core was extruded on site, and the two sections considered in this project, sections A and B, were collected at this time and sealed in plastic sample bags. The upper sampled section of this core, Section A, was 0.5 m below the surface and 15 cm in length. The
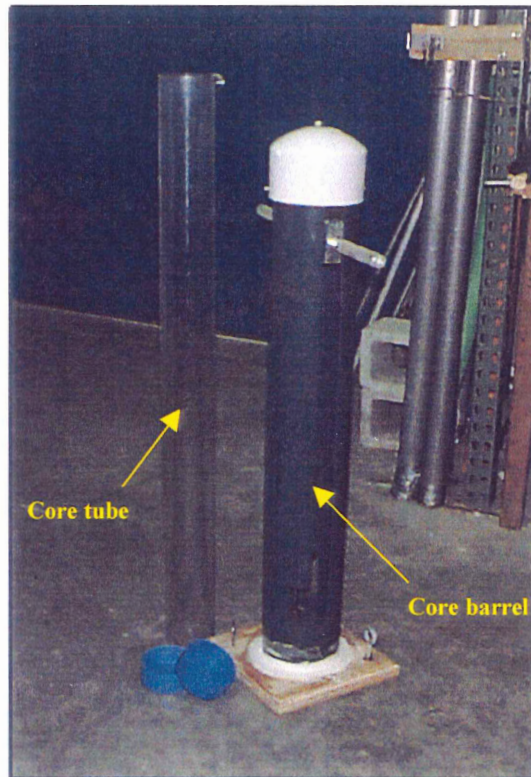
Figure 6. Apparatus used to collect Core 15-5. The 10.8 cm diameter polycarbonate core barrel is inserted over a piston with the coring device inside. The corer is set on the sediment surface and manually pushed into the sediment. A vitron gasket and the piston act to form a vacuum to keep the sediment in place while the core tube is extracted from the surrounding sediment. Immediately after extraction, the core tube is capped at both ends and stored vertically to minimize the disturbance to the collected sediments (Marot, 2001).

Figure 7. Materials used in the collection of Core L1011/Hwy 1 and Barnes Sound Core was a 10 cm aluminum core tube. This was pushed by hand into the sediment, and capped immediately once removed from the water. This photo is of the collection location for Core L1011/Hwy 1.

lower sampled section, Section B, was 0.5 m above the base of the core and 15 cm in length. The remainder of the core was discarded.

3.2 Sample Preparation and Processing

After the cores were collected, the core tube was sawed in half lengthwise; the Everglade core in St. Petersburg, Florida at the USGS laboratory, and the young mangrove core at Dalhousie University (as the core from the established mangrove was extracted from the core tube on site, this step applies only to the other two cores considered in this project). At this point, the cores were logged and one half was set aside in cold storage for archival purposes.

From the remaining half of each of the cores, samples were selected and extracted. Those of the Everglade core were sampled in 2 cm widths, while those of the mangrove cores were sampled in 1 cm widths. In this state, the samples of the Everglades core were sent to Dalhousie University for processing and examination.

All samples were processed by washing them through three stacked sieves of sizes 45, 63, and 500 μm. To effectively separate the tests from the sediment, a small amount of detergent was added to some samples and the washing procedure was repeated. The material remaining on each sieve after washing was then transferred to appropriately labeled individual containers and alcohol was added. From the time the cores were collected until the samples were washed and alcohol was added, the core materials were kept refrigerated.

Due to the large amount of material in the samples, most samples were divided into subsamples using a settling column splitter (or wet-splitter) immediately prior to the examination of the samples, dividing each sample into six equal parts (Figure 8; Scott *et*
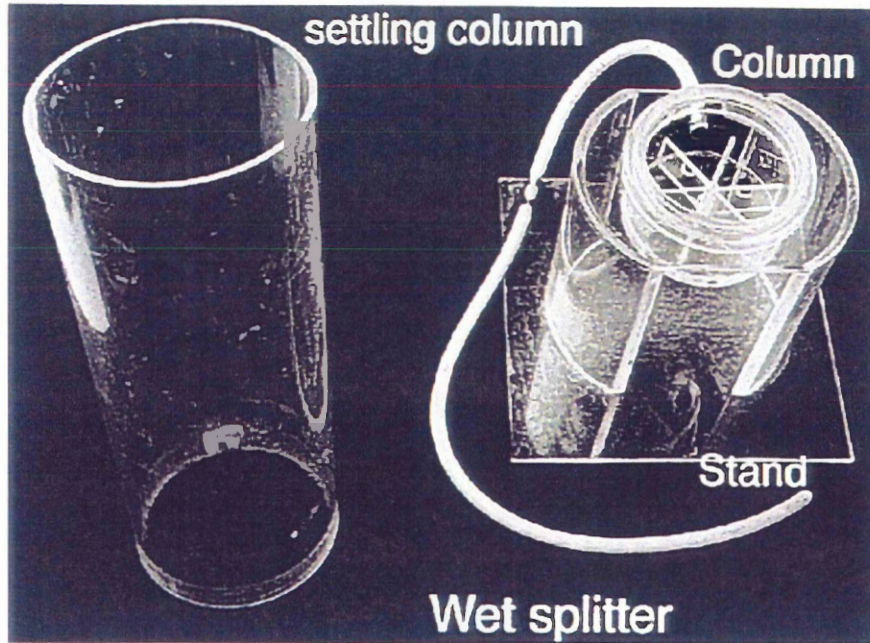
Figure 8. Apparatus used to divide samples into six equal parts, for ease of analysis. Column is placed on stand, filled with water, and sample is settled through (Scott *et al.*, 2001).
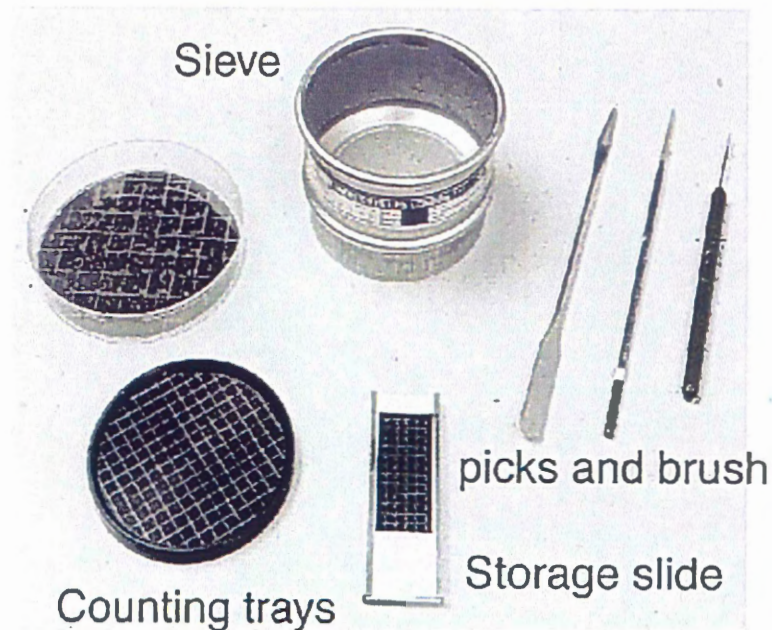
Figure 9. Tools used in to aid light microscopy examination of testate rhizopods (Scott *et al.*, 2001).

al., 2001). Those samples of extremely large material volume, often in the 63-500 μm range, were split twice. Only those samples with low material volume were not split. One of each sample's subsample, or the entire sample in the case of those non-split samples, was then placed into a gridded petri dish in preparation for examination.

3.3 Foraminifera and Thecamoebian Examination

All samples were examined on a gridded petri using a Zeiss binocular stereomicroscope with magnification of power 20-80x. Tools used to aide in examination included fine watercolour brushes and fine picks (Figure 9). Thecameobian and foraminiferal plates of line drawings, scanning electromicrograph photographs, black-and-white and colour photographs from various sources were used in the identification process (Scott *et al.*, 2001; Medioli and Scott, 1983; Javaux, 1999; Collins, 1996; complied plates of the Dalhousie University Earth Science Department). Those specimens that required further study were picked from the petri dish with the watercolour brush, and mounted on a storage slide coated with water-soluble tragancanth gum glue. These isolated specimens were then re-examined under the light microscope.

Chapter 4: Results

4.1 Little Madeira Bay, Core 15-5

4.1.1 Lithology

The total length of Core 15-5 was 115.5 cm, of which the 80-115.5 cm segment is considered here as this segment included the marine/freshwater transition. Sediment of the upper section, 80-90 cm, was light gray to light brown calcareous mud, while sediment of the lower portion of the core, 90-115.5 cm, was dark brown peat. Leaf detritus and root hair mass increased with depth from 94-114 cm. Percent coarse/fines (>0.063mm/<0.063mm) dry weight data reflects this transition from upper layer mud to peat in the 90-92 cm interval. The calcareous mud, above 90cm, has a coarse dry weight of 23.02-29.93%. From 92-112 cm, the peat has a coarse dry weight of 1.07-8.85%. Coarse and fine values were not acquired for the segment 112-115.5 cm as high organic content inhibited sieving (Figure 10).

4.1.2 Distribution of Foraminifera and Thecamoebians

The 18 samples examined from this core exhibited moderate to high species numbers of 9 to 17. Total abundance was variable with highest total numbers present in the 80-92 cm interval at 45,180 to 91,944 individuals/10cc, and significantly lower abundance in the 92-115.5 cm interval with 5,652 to 17,928 individuals/10cc (Fig.11, Appendix A, Table 2). Calcareous foraminifera such as *Ammonia beccarii*, and *Elphidium* and *Quinqueloculina* species dominate the interval 80-90 cm, while thecamoebian cysts and agglutinated thecamoebians, particularly *Difflugia* species, are the dominant organisms of the interval 90-115.5 cm. The agglutinated foraminiferal species *Trochammina inflata* and *Trochammina macrescens* are dominant but not abundant in relation to thecamoebians over calcareous species in the interval 90-115.5cm. *Polysaccammina ipohalina* occur only in this lower interval.

Figure 10. Profile of percent sand, total number of thecamoebian cysts, total species number, total number of individuals, and percentage of thecamoebians, *Difflugia* species and *Cucurbitella tricuspis*, *Ammonia beccarii*, *Elphidium* species, and *Polysaccammina ipohalina* of Core 15-5, Little Madeira Bay.

Core 15-5, Little Madeira Bay

| | gray, brackish calcareous mud | | brown freshwater peat | | black freshwater peat | | organic materials |
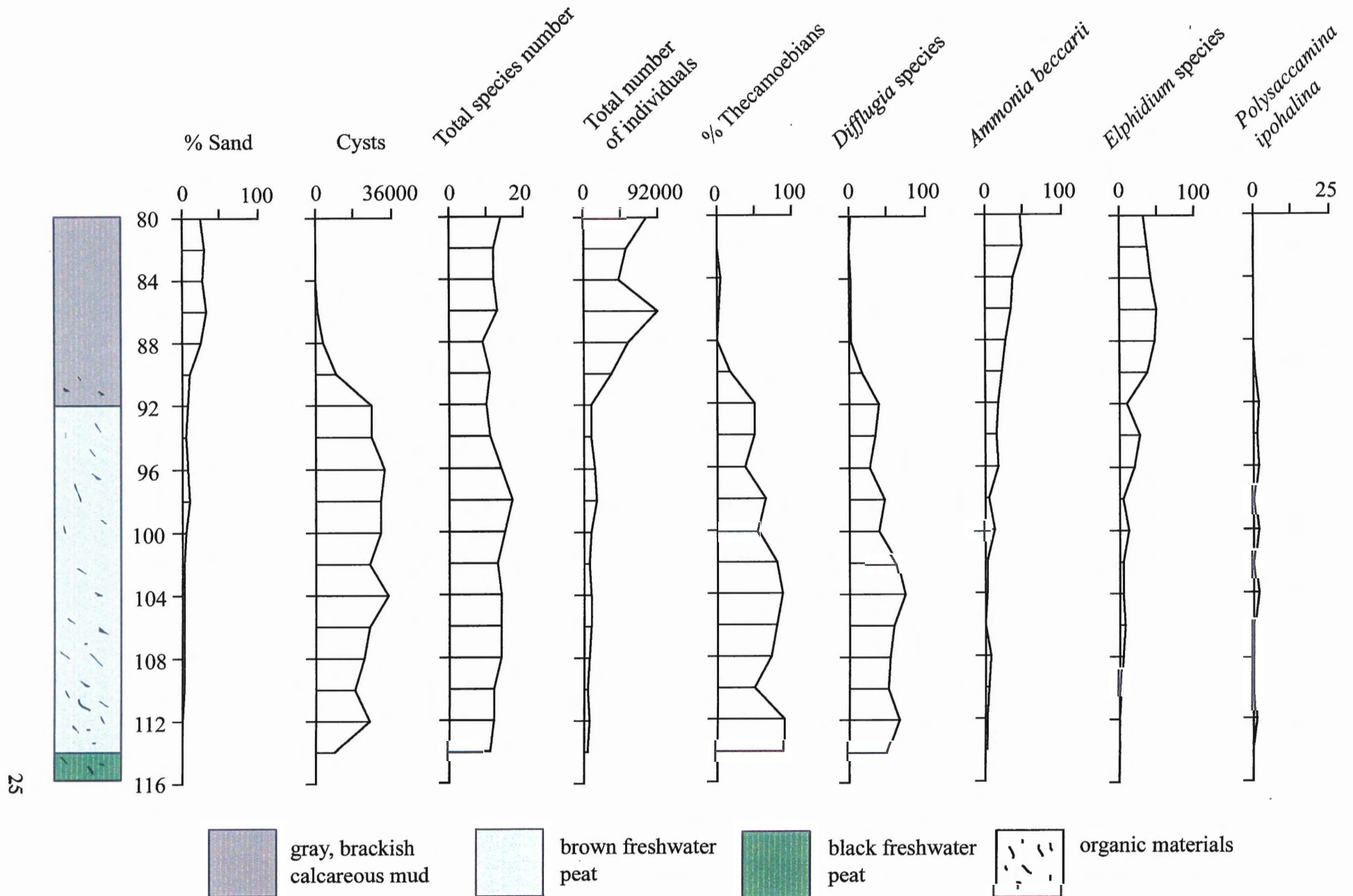
4.2 Southeastern Florida/Highway 1 Specimens

4.2.1 Young Mangrove, Core L1011

4.2.1.1 Lithology

The total length of Core L1011 was 70 cm. Sediments graded from light gray calcareous mud to dark brown peat, the peat appearing first at 30cm depth (Figure 11). Abundance of root hairs, root fragments and leaf detritus increased with depth.

4.2.1.2 Distribution of Foraminifera and Thecamoebians

Total number of species ranges between 7 and 21 species, the maximum number of species occurring at 30cm depth. Total abundance is highest in the upper 30cm of the core, peaking at 9,168 individuals/10cc (Figure 11, Appendix A, Table 3). Thecamoebians are abundant throughout the core, particularly *Centropyxis* species. Calcareous *Elphidium* species and *Ammonia beccarii* are the dominant foraminifera of the upper 20cm. Agglutinated foraminifera ("marsh species"; Fig. 11), such as *Trochammina inflata, Trochammina macrescens* and *Haplophragmoides wilberti*, are first evident at 15cm depth, and are the dominant foraminiferal species in 20-70 cm depth. Calcareous foraminiferal species are present throughout this range, but occur in significantly lower numbers. *Polysaccammina ipohalina* also found in this lower range of the core.

Figure 11. Profile of total number of individuals, total species number, and percentage of thecamoebians, *Centropyxis* species, *Ammonia beccarii*, *Elphidium* species, marsh species and *Polysaccammina ipohalina* of Core L1011/Highway 1. Marsh species include *Haplophragmoides wilberti*, *Discorinopsis aguayoi*, *Trochammina macrescens*, *Trochammina inflata*, *Haplophragmoides manilianensis*, *Tiphotrocha comprimata*, *Pseudothurammina limnetis*, and *Miliammina fusca*.

Core L1011/Highway 1
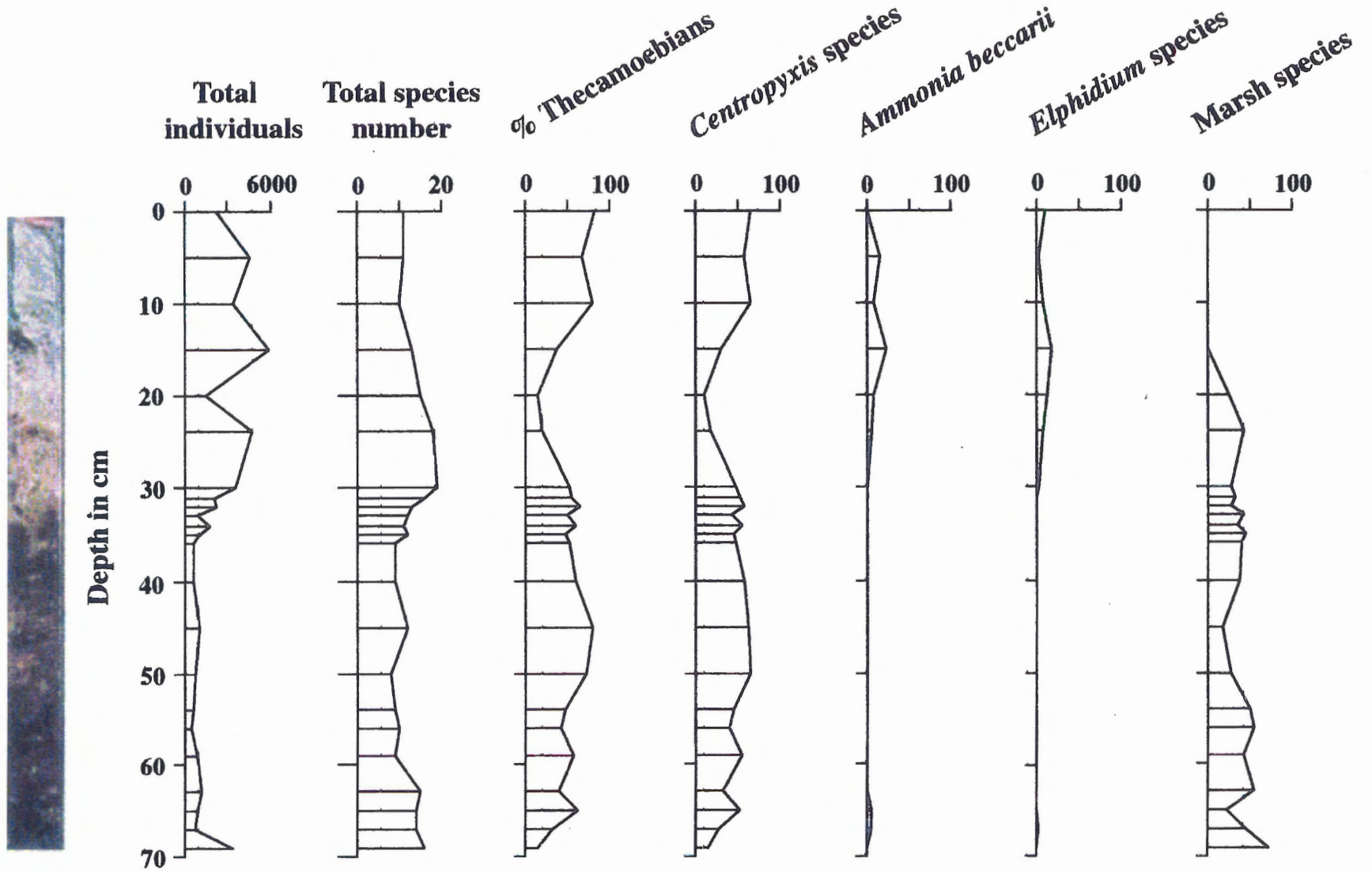
4.2.2 Established Mangrove, Barnes Sound Core (Sections A and B)

4.2.2.1 Lithology

The total length of the Barnes Sound/Highway 1 core was 3.0 m. Sediment of Section A, 0.5-0.65 cm, was dark brown peat with dense, fibrous root mass and leaf detritus. Sediment of Section B, 2.5-2.65 m was fine gray-beige mud and included some large gastropod shells.

4.2.2.2 Distribution of Foraminifera and Thecamoebians

Total species number of Section A, 11 species, was significantly lower than that of Section B, 20 species. The dominant foraminifera of Section A, with 36% thecamoebians, were *Trochammina macrescens* and *Polysaccammina ipohalina*. Section B, with 11% thecamoebians, was dominated by calcareous foraminiferal species, particularly *Elphidium poeyanum*, *Pygro subsphaerica*, and *Quinqueloculina polygona* (Appendix A, Table 4).

Chapter 5: Discussion and Conclusions

5.1 Introduction

The most striking aspect of the combined results from the three cores considered here are the differences in peat and calcareous mud characteristics, not evident through lithological consideration alone. These differences between the cores, their relevance to other studies of the region, and implications for detection of saltwater intrusion are discussed below, and conclusions are presented.

5.2 Comparison of Sample Sites

In each of the three cores, a total of 12 foraminiferal species and 5 thecamoebian species are found. Segments of fibrous peat and calcareous mud are also represented in each (by analyzed transitions in Cores L1011 and 15-5). The differences between the depositional environments of these sediments become evident in the small-scale analysis of thecamoebian and foraminiferal tests.

A direct comparison of Core L1011 and the Barnes Sound Core (Section A) reveals a similar species composition in the peat of both cores. This assemblage, dominated by *Trochammina macrescens*, exhibits moderate percentages of thecamoebians, low species numbers and low numbers of total individuals. Considering the proximity of the two coring locations to each other, 50cm depth in the Barnes Sound Core (Section A) can be assumed comparable in elevation to that of Core L1011 at 50cm. As the Barnes Sound Core was taken in an established mangrove environment, the similarities in assemblages between these cores suggest that the peat of Core L1011 is in

fact mangrove peat. Characteristic of mangroves is their ability to tolerate tidal conditions. Hence, the peat of Core L1011 represents a tidal marsh section.

In contrast, the peat segment of Core 15-5, 90-115.5 cm, shows a different species assemblage than that of the Barnes Sound mangrove peat. Core 15-5 shows a high average percentage of thecamoebians at 67%, almost double the 34% of thecamoebians in the Barnes Sound Core. Unlike Core L1011, these high percentages of thecamoebians are of *Difflugia* spp. which always live in freshwater, as opposed to the *Centropyxis* spp. which can tolerate brackish conditions. In addition, Core 15-5 exhibits many more calcareous foraminifera species and fewer typical mangrove species in the peat than does either the Barnes Sound core or Core L1011. One characteristic species that occurs at low, but significant numbers, is the agglutinated species, *Polysaccammina ipohalina*. *P. ipohalina* commonly occurs in non-tidal, highly-stressed environments such as inland saline ponds in Bermuda (Javaux, 1999), and salt springs in Manitoba (Patterson *et al.*, 1990). The correlation between highest percentages of *Polysaccammina ipohalina* and marine/freshwater transition zones in both Core 15-5 and Core L1011, is excellent evidence of stressed environments.

The high numbers of thecamoebian cysts in the 90-115.5cm segment of Core 15-5 is unique to this core, relative to the other two cores. Thecamoebian encystment is a natural, acyclical part of thecamoebian life histories as a mechanism of rest and self-preservation until more suitable environmental conditions are present (Medioli and Scott, 1988). Keeping in mind the central location of Little Madeira Bay along the southern coast of Florida, this is an area susceptible to high-frequency sea-level oscillations, in addition to overall sea-level changes. The late Holocene sediments of Southern Florida

exhibit an overall relative sea-level rise (Wanless *et al.*, 1995; Scholl, 1964). According to Wanless *et al.* (1995), radiometric and radiocarbon data from previous studies of Southern Florida give strong evidence for a major high-frequency sea-level oscillation which spanned approximately 3,200 to 2,400 years before present (YBP). The segment of Core 15-5 in which the cysts are present, 90-115.5cm, corresponds with an age of approximately 3,000-2,600 YBP (Scholl, 1964) or 3,250-2,700 YBP (Wanless *et al.*, 1995). Therefore, it is reasonable to propose that the rapid transgression-regression at 3,200 to 2,400 YBP caused less than optimal fresh- to brackish water conditions, resulting in high numbers of encysted thecamoebians. This transgression-regression model is supported by the increase in percent sand that occurs at the point where the thecamoebian cysts have significantly decreased, as regressions are characterized by the deposition of coarser sediments in the local section (Fichter and Poché, 2001). With the section of core studied in this project, a comparison cannot be made between this oscillation and the Barnes Sound Core (Sections A or B), as only the segments of 50-51cm and 256-257cm were analyzed. The depth to bedrock in the area from which Core L1011 was sampled is at <80cm depth, and therefore would have no record in the sediment of this event.

With a transition from mangrove peat to freshwater mud, the Core L1011 environment has undergone very different processes. Comparison with the Barnes Sound Core (Section B) has shown the peat in the basal portion of the core to be mangrove peat. However, since the area of Core L1011 is not tidally influenced, the explanation of the carbonate mud is more speculative. As recently as 1981, the Core L1011 region was classified as freshwater marl prairie in a physiographic analysis (Fernald, 1981). This is

supported by the high percentages of thecamoebians. This freshwater environment can be attributed to the implementation of the levee and canal system in the region between 1948 and 1960. The core site of Core L1011 was less than 20 m from Canal L1011/Highway 1. Seepage through the permeable bottoms of the levees and into surrounding wetlands has been shown to extend for kilometers from the levees (Harvey *et al.*, 1999). The seepage in this location was enough to allow thecamoebians to become dominant over marsh foraminifera; calcareous species remained present in low percentages. Due to the minimal change in sea level since 1960 (Wanless *et al.*, 1995), the present conditions that foster mangroves are not the result of a passive influx of seawater, tidal or otherwise. It can, however, be attributed to an isolated influx of material caused by Hurricane Andrew, August 24, 1992. The high winds of this storm transported mangrove seedlings, resulting in present mangroves of less than 9 years of age in the Core L1011 region (Wanless, 2000).

While Hurricane Andrew was also a contributing factor to the carbonate mud of the upper core section, the relative uniformity within the mud section implies continual deposition of sediment; these sediments are also dissolution and erosional products of the regional limestone. The calcareous foraminifera have been present longer; they may be transported by birds. However, this is the first time calcareous foraminifera have been found living within a high diversity thecamoebian fauna.

5.3 Correlation with previous studies

Considering the high percentage of thecamoebians in each of the long cores, it may seem unreasonable that any of the sediments analyzed were anything other than

freshwater in origin. Scott *et al.* (1991), through their study of Mississippi Delta surface samples, show some of the diversity of thecamoebians regarding water composition. Their results show a higher proportion of *Difflugia* species than *Centropyxis* species in freshwater environments; conversely, a higher proportion of *Centropyxis* species occur in brackish water environments. This is comparable with the results from the cores of this study; Core L1011, with a more brackish sedimentological history, has a higher proportion of *Centropyxis* species, while the higher proportion of *Difflugia* species are found in the peat of Core 15-5.

Correlation of the results presented here with marine/freshwater transition zone studies in Nova Scotia is not very strong as the number and type of different species found in Florida are numerous.

The transition of Core 15-5 from freshwater peat to high-salinity brackish mud complements the U.S. Geological Survey's conceptual model of Buttonwood Embankment development in the Florida Bay region. This model is a step-wise development from freshwater lakes and ponds, to estuarine deposits encroached upon by mangroves, through an overwash stage and drying, ending, as it began, with a freshwater environment, but one that contains some mangrove communities (Holmes *et al.*, 2000). The mechanism for the transition to a brackish mud environment from a freshwater peat is, evidently, the inferred transgressive-regressive event discussed in section 5.2. The regressive portion of the sequence ensures the maintenance of a freshwater environment for lakes and ponds in close proximity to the coastline. The transgressive segment provides the mechanism for coarser, marine influenced sediments to be superimposed on the existing freshwater deposits.

Believed to have originally been a marine mud bank, the Barnes Sound Core area also concurs with the bank development model discussed in the previous paragraph. The two sections analyzed from this core, however, represent the later stages of development, those being the marine mud and final mangrove encroachment stages.

5.4 Implications for saltwater intrusion detection

The level of precision achieved through analysis of rhizopod tests, for interpreting the marine/freshwater characteristics of mangrove and everglade environments in Southern Florida, is such that there are a broad spectrum of practical applications for this technique. Agglutinated rhizopods make good study subjects for determining sediment-water interface conditions due to their benthic nature and resilience to dissolution, unlike many pollen, spores and diatoms (Scott and Medioli, 1983). This technique is particularly applicable for studies such as The South Florida Land Characterization Project, a project designed to map the distribution of vegetation and related hydrologic variables through time and space (Desmond, 1999). A fine scale understanding of the water characteristics allows for a more accurate assignment of land type, and the potential to interpret hydrologic sources.

In addition, the use of rhizopod tests to monitor saltwater intrusion into areas of Southern Florida is relatively inexpensive. Ease in collection of samples and analysis are other benefits to using rhizopod tests. Geophysical mapping, and subsequent modeling, of saltwater intrusion using helicopter electromagnetic, transient electromagnetic and borehole measurements, can provide good baseline data of saltwater intrusion (Fitterman and Deszcz-Pan, 1999). However, this is a very expensive technique, where a model is

created from a snapshot in time. Periodic analysis of rhizopod assemblages in the areas of interest would allow for the observance, perhaps anticipation, of saltwater intrusion via new or changing means.

5.5 Conclusions

Through the analysis of rhizopod assemblages from three core locations from natural environments of southern Florida, distinct transition zones were found and plausible correlations made between the various locations. Analysis in this manner allows for interpretation of water quality and ecosystems on a much finer scale than achieved by previous studies of this area. In addition, the discovery of calcareous foraminifera with thecamoebian assemblages is the first finding of its kind, and illustrates the need to conduct more studies of this area.

5.6 Recommendations for future work

While the results of this project provide some insightful indications as to the water environments and rhizpod assemblages in the Everglade and mangrove environments of southern Florida, much more research is needed. Surficial sediment baseline data of present rhizopod assemblages in the Everglade and mangrove environments is of particular importance. This baseline data will prove useful in interpreting both past and present environments and will aide in understanding the relationship between rhizopods and their environments. This includes a better understanding of how salinity and temperature of the water can affect rhizopod assemblages.

In addition, accurate dating of sediments and sedimentation rates is needed. While this is being done by the U.S. Geological Survey in Everglade National Park, it is necessary to obtain this information for the mangrove environments at various locations along or near the coastline of southern Florida. Accurate dates and sedimentation rates will assist in correlating the transition zone results determined by rhizopod analysis with dated events such as hurricanes, channel development and general sea level rise.

Chapter 6: Systematic Taxonomy

Listed are the abbreviated systematic taxonomy of benthic foraminifera and thecamoebians of the study area. Taxonomy is taken from Javaux (1999), and Scott *et al.* (2001). Only the most common species are represented on Plates I and II.

BENTHIC FORAMINIFERA

Ammonia beccarii (Linné)
Plate I, Figure 1

Nautilus beccarii Linné, 1758, p. 710.

Ammonia beccarii (Linné). Brünnich, 1772, p. 232; Scott and Medioli, 1980, p. 35, pl. 5, figs. 8, 9.

Discorinopsis aguayoi (Bermudez)
Plate I, Figure 2

Discorbis aguayoi Bermudez, 1935, p. 204, pl. 15, figs. 10-14.

Discorinopsis aguayoi (Bermudez). Phleger, Parker and Peirson, 1953, p. 7, pl.4, figs. 23, 24; Arnold, 1954, p. 6-12, pl. 1, figs. 1-10; Bock, 1971, p. 50, pl. 18, fig. 42; Stienker, 1980, p. 135, pl. 2, fig. 6.

Trichohayalus aguayoi (Bermudez). Bermudez and Seiglie, 1963, p. 176, pl. 26, fig. 4.

Elphidium excavaturm (Terquem) forma *excavatum* (Terquem)

Polystolmella excavata Terquem, 1876, p. 429, pl. 2, fig 2.

Elphidium excavaturm (Terquem). Cushman, 1930b, p. 21, pl. 8, figs. 1-7; Cushman, 1944, p. 26, pl. 2, fig. 40.

Elphidium excavatum f. *gunteri* (Cole)
Plate I, Figure 3

Elphidium gunteri Cole 1931, p. 34, pl. 4, figs. 9, 10; Phleger, 1954, p. 639, pl. 2, figs. 3, 4.

Elphidium excavatum (Terquem) forma *gunteri* Cole; Scott et al., 1991, p. 385, pl. 2, Fig. 15.

Elphidium   poeyanum (d'Orbigny)

Plate I, Figure 4

Polystomella poeyana d'Orbigny, 1839, p. 55, pl. 6, figs. 25, 26.

Elphidium poeyanum (d'Orbigny). Cushman, 1930b, p. 25, pl. 10, figs. 4, 5; Phleger, 1954, p. 639, pl. 2, figs. 8, 9; Hansen and Lykke-Andersen, 1976, p. 13, pl. 9, figs. 9-12; pl. 10, figs. 1-5.

Elphidium translucens Natland. Scott, 1976a, p. 170.

Fissurina spp.

The species of this genus were rare and were not identified.

Fursenkoia complanata (Egger)

Virgulina schreibersiana Czzjec var. *complanata* Egger, 1893, p. 292, pl. 8, figs. 91, 92; Bock, 1971, p. 62, pl. 23, fig 6.

Haplophragmoides manilaensis (Andersen)

Haplophragmoides manilaensis Andersen, 1953, p. 22, pl. 4, Fig. 8; Scott et al., 1990, p. 730, pl. 1, figs. 9a,b; Scott et al., 1991, p. 385, pl. 1, figs. 18, 19; Scott et al., 1995, p. 292, pl. 1, figs. 3,4.

Haplophragmoides bonplandi Todd and Brönnimann, 1957, p. 23, pl. 2, Fig. 2; Scott and Medioli, 1980b, p. 40, pl. 2, figs. 4, 5.

Haplophragmoides wilberti (Andersen)

Plate I, Figure 5

Haplophragmoides wilberti Andersen, 1953, p. 21, pl 4, fig. 7; Zaninetti *et al.*, 1977, pl. 1, figs. 12, 13; Boltovskoy, 1984, fig. 7; Scott *et al.*, 1991, p. 385, pl. 1, figs 20-21.

Helenina anderseni (Warren)

Plate I, Figure 6

Psuedoeponides anderseni Warren, 1957, p. 39, pl. 4, figs. 12-15.

Helenina anderseni (Warren) Saunders, 1961, p. 148; Scott and Medioli, 1980, p. 40, pl. 5, figs. 10,11; Scott et al., 1991, p. 385, pl. 2, figs. 19, 20; Steinker, 1980, p. 136, pl. 3 fig. 3.

Homotrema rubrum (Lamarck)

Milipora rubra Lamarck, 1816, p. 202.

Polytrema rubra Dujardin, 1841, p. 259.

Homotrema rubrum Hickson, 1911, p. 445, 454, pl.30, fig. 2; pl. 31, fig 9; pl. 32, figs. 19, 22, 28; Bock, 1971, p. 61, pl. 23, fig. 3; Javaux, 1999, p. 3, fig. 19.

Miliammina fusca (Brady)

Quinqueloculina fusca Brady, 1870, p. 286, pl. 11, figs. 2, 3.

Miliammina fusca (Brady) Phleger and Walton, 1950, p. 280, pl. 1, figs. 19a,b; Phleger, 1954, p. 642, pl. 2, figs. 22, 23; Scott et al., 1977, p. 1579, pl. 2, figs. 8,9; Schafer and Cole, 1978, p. 28, pl. 12, Fig. 2; Scott and Medioli, 1980, p. 40, pl. 2, figs. 1-3; Scott et al. 1991, p. 386, pl. 1, Fig. 14.

Miliaolinella labiosa (d'Orbigny)

Triloculina labiosa d'Orbigny. 1839, p. 178, pl. 10, figs 12-14.

Miliolian labiosa Brady, 1884, p. 170, pl. 6, figs. 3-5.

Miliolinella labiosa Said, 1950, p. 5, pl. 1, fig. 10; Bock, 1971, p. 29, pl. 12, fig. 7; Steinker, 1980, p. 136, pl. 3 fig. 9.

Polysaccammina ipohalina (Scott)

Plate I, Figure 7

Polysaccammina ipohalina Scott. 1976b. p. 316, pl. 2 figs. 1-4; text-fig. 4; Scott and
  Medioli, 1980 p. 43, pl. 2, figs. 8-11; Scott et al., 1991, p. 386, pl.2, fig. 3; Javaux,
  1999, p.4, fig. 19.

Pseudothurammina limnetis (Scott and Medioli)

Plate I, Figure 8

Astrammina sphaerica (Heron-Allen and Earland), Zaninetti et al., 1977, pl. 1, Fig. 9.

Thurammina (?) *limnetis* Scott and Medioli, 1980, p. 43, pl. 1, figs. 1-3.

Pseudothurammina limnetis Scott and others, *In* Scott et al., 1981, p. 126; Scott et al.,
  1991, p. 386, pl. 2, Fig. 4; Scott et al., 1995, p. 292, Fig. 6.2.

Pyrgo subsphaerica (d'Orbingy)

Biloculina subphaerica d'Orbigny, 1839, pl. 162, figs. 25-27.

Pyrgo subsphaerica Cushman, 1929, p. 68, pl. 18, figs, 1,2; Bock, 1971, p. 24, pl. 8, fig.
  15

Quinqueloculina laevigata (d'Orbigny)

Quinqueloculina laeigata d'Obigny, 1826, p. 301, no.6 Cimmerman and Langer, 1991,
  figs. 8-11.

Quinqueloculina poeyana (d'Orbingy)

Quinqueloculina poeyana d'Orbigny, 1839, p. 191, pl. 11, figs. 25-27; Bock, 1971 p. 20,
  pl. 6, figs. 13-15; Steinker, 1980, p. 136, pl. 6, fig.1.

Quinqueloculina polygona (d'Orbingy)

Quinqueloculina polygona d'Orbingy, 1839, p. 198. pl. 12, figs. 21-23. Cushman, 1921, p. 66, pl. 16, figs. 3,4; Cushman, 1929, p. 28, pl. 3, fig. 5; Bock, 1971, p. 20, pl. 7, figs. 1-3; Todd and Low, 1971, p. 8, pl. 2, fig. 5; Steinker, 1980, p. 136, pl. 6, fig. 2; Javaux, 1999, p.5, figs. 17, 18.

Quinqueloculina seminulum (Linné)
Plate I, Figure 9

Serpula seminulum Linné, d'Orbigny, 1826, p. 301. Cushman, 1929, p. 24, pl. 2, figs. 1,2; Parker, 1952a, p. 456, pl. 2, fig. 7; Bock, 1971, p. 21, pl. 7, figs. 7-9; Steinker, 1980, p. 136, pl. 6, fig. 3; Javaux, 1999, p. 5, fig. 20.

Textularia earlandi (Parker)

Textularia earlandi Parker, 1952, p. 458 (footnote).

Tiphotrocha comprimata (Cushman and Brönnimann)

Trochammina comprimata Cushman and Brönnimann, 1948b, p. 41, pl. 8, figs. 1-3; Phleger, 1954, p. 646, pl. 3, figs. 20, 21.

Tiphotrocha comprimata (Cushman and Brönnimann). Saunders, 1957, p. 11, pl. 4, figs. 1-4; Scott et al., 1977, p. 1579, pl. 4, figs. 3,4; Scott and Medioli, 1980, p. 44, pl. 5, figs. 1-3; Scott et al., 1990, pl. 1, figs. 10a,b; Scott et al., 1991, p. 388, pl. 2, figs. 5, 6.

Trochammina inflata (Montagu)

Plate I, Figure 10

Nautilus inflatus Montagu, 1808, p. 81, pl. 18, Fig. 3.

Rotalina inflata Williamson, 1858, p. 50, pl. 4, figs. 93, 94.

Trochammina inflata (Montagu). Parker and Jones, 1859, p. 347. Phleger, 1954, p. 646,
    pl. 3, figs. 22, 23; Scott et al., 1977, p. 1579, pl. 4, figs. 6,7; Scott and Medioli,
    1980b, p. 44, pl. 3, figs. 12-14; pl. 4, figs. 1-3, Scott et al., 1990, p. 733, pl. 1, figs.
    3a,b; Scott et al., 1991, p. 388, pl. 2, figs. 7, 8; Scott et al., 1995d, p. 294, figs. 6.10-
    17; Javaux, 1999, p. 8, figs. 10-15.

Trochammina macrescens (Brady)

(forma *macrescens*)

Plate I, Figure 11

Trochammina inflata (Montagu) var. *macrescens* Brady, 1870, p. 290, pl. 11, Fig. 5.
    Scott, 1976b, p. 320, pl. 1, figs. 4-7; Scott et al., 1977, pl. 4, figs. 6,7.

Jadammina polystoma Bartenstein and Brand, 1938, p. 381, figs. 1, 2.

Trochammina macrescens Brady. Parker, 1952a, p. 460, pl. 3, Fig. 3. Phleger, 1954, p.
    646, pl. 3, Fig. 24; Scott and Medioli, 1980b, p. 44, pl. 3, figs. 1-12; Scott et al.,
    1990, p. 733, pl. 1, figs. 1a,b,2a-c; Scott et al., 1991, p. 388, pl. 2, figs. 10, 11; Scott
    et al., 1995d, p. 294, figs. 6.6-8; Javaux, 1999, p. 8, fig. 16.

THECAMOEBIANS

Centropyxis aculeata   (Ehrenberg) ab (Ehrenberg)

Plate II, Figure 1

Arcella aculeata Ehrenberg, 1832 (ab Ehrenberg, 1830, p. 60, nomen nudum), p.
91.

    Centropyxis excentricus (Cushman and Brönnimann). Scott, 1976b, p. 320, pl. 1,
figs. 1, 2; Scott et al., 1977, p. 1578, pl. 1, figs. 1,2; Scott et al.,1980, p. 224, pl. 1, figs. 1-
3.

    Centropyxis aculeata (Ehrenberg). Stein, 1859, p. 43. Medioli and Scott, 1983, p.
39, pl. 7, figs. 10-19; Scott and Medioli, 1983, p. 819, Fig. 9I; Patterson et al., 1985, p.
134, pl. 4, figs. 1-7; Scott et al., 1991, p. 384, pl. 1, figs. 7-9.

Centropyxis constricta (Ehrenberg)

Plate II, Figure 2

Arcella constricta Ehrenberg, 1843, p. 410, pl. 4, Fig. 35, pl. 5, Fig. 1.

Difflugia constricta (Ehrenberg). Leidy, 1879, p. 120, pl. 18, figs. 8-55.

Urnulina compressa Cushman, 1930a, p. 15, pl. 1, Fig. 2. Parker, 1952, p. 460, pl. 1, Fig. 9; Scott et al., 1977, p. 1578, pl. figs. 7,8; Scott et al., 1980, p. 224, pl. 1, figs. 13-15.

Centropyxis constricta (Ehrenberg). Deflandre, 1929, p. 340, text-figs. 6-67. Medioli and Scott, 1983, p. 41, pl. 7, figs. 1-9; Scott and Medioli, 1983, p. 819, Fig. 9K; Patterson et al., 1985, p. 134, pl. 4, figs. 8-14; Scott et al., 1991, p. 384, pl. 1, Fig. 4.

Cucurbitella tricuspis (Carter)

Plate II, Figure 4

Difflugia tricuspis Carter, 1856, p. 221, pl. 7, Fig. 80. Medioli and Scott, 1983, p. 28, pl. 4, figs. 5-19; Scott and Medioli, 1983, p. 818, Fig. 9Q,R; Patterson et al. 1985, p. 134, pl. 2, figs. 15, 16; Haman, 1986, p. 47, pl. 1, figs. 1-14; pl. 2, figs. 1-12.

Cucurbitella tricuspis (Carter). Medioli et al., 1987, p. 42, pl. 1, figs. 1-10; pl. 2, figs. 1-10; pl. 3, figs. 1-7; pl. 4, figs. 1-9.

Difflugia globulus (Ehrenberg)

Plate II, Figure 3

(?) *Difflugia proteiformis* Lamarck. Ehrenberg, 1848, p. 131 (part), pl. 9, figs. 1a, b.

Difflugia globulus (Ehrenberg). Cash and Hopkinson, 1909, p. 33, textfigs. 52-54, pl. 21, figs. 5-9.

Difflugia globulus (Ehrenberg), Medioli and Scott, 1983, pl. 5, figs. 1-15

Difflugia urceolata (Carter)

Plate II, Figure 5

Difflugia urceolata Carter, 1864, p. 27, pl. 1, Fig. 7; Scott et al., 1977, p. 1578, pl. 1, figs. 3,4;   Scott et al., 1980, p. 224, pl. 1, figs. 10-12. Medioli and Scott, 1983, p. 31, pl. 3, figs. 1-23; pl. 4, figs. 1-4; Scott and Medioli, 1983, p 818, Fig. 9F, G; Patterson et al., 1985, p. 134, pl. 2, figs. 11,12.

Lagunculina vadescens Cushman and Brönnimann, 1948a, p. 15, pl. 3, figs. 1, 2. Parker, 1952a, p. 451, Fig. 8.

Plate 1

Figure 1. *Ammonia beccarri* (Linné), ventral view

Figure 2. *Discorinopsis aguqyoi* (Bermudez), dorsal view

Figure 3. *Elphidium excavatum* f. *gunteri* (Cole)

Figure 4. *Elphidium poeyanum* (d'Orbigny)

Figure 5. *Haploidphragmoides wilberti* (Andersen), a) side view; b) apertural view

Figure 6. *Helenina anderseni* (Warren), a) ventral view; b) dorsal view

Figure 7. *Polysaccammina ipohalina* (Scott)

Figure 8. *Pseudothurammina limnetis* (Scott and Medioli)

Figure 9. *Quinqueloculina semilunum* (Linné)

Figure 10. *Trochammina inflata* (Montagu), a) dorsal view; b) ventral view

Figure 11. *Trochammina macrescens* (Brady), a) ventral view; b) dorsal view

Plate I
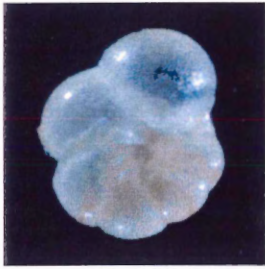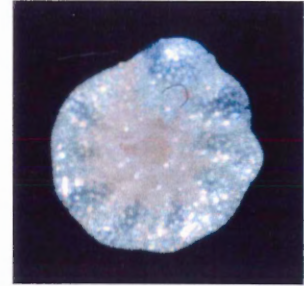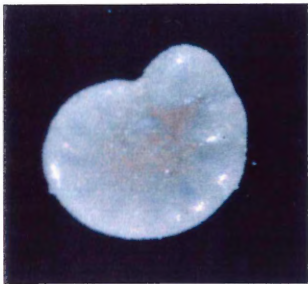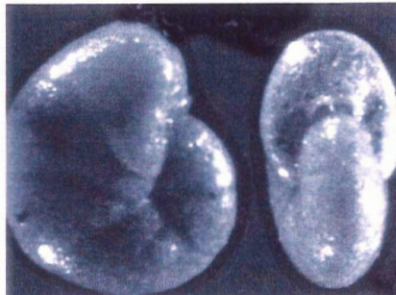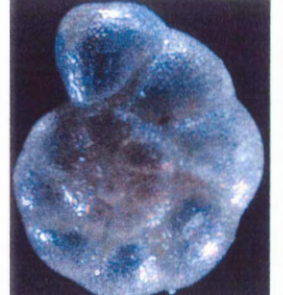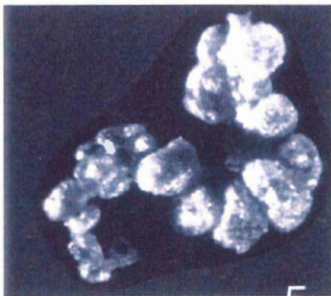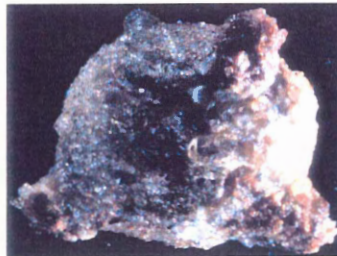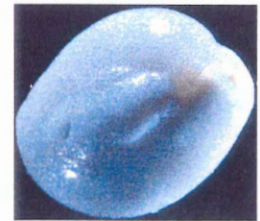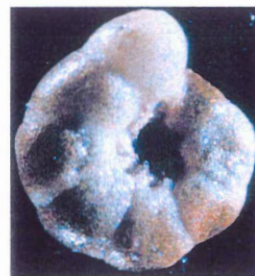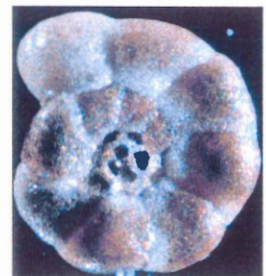
Plate II
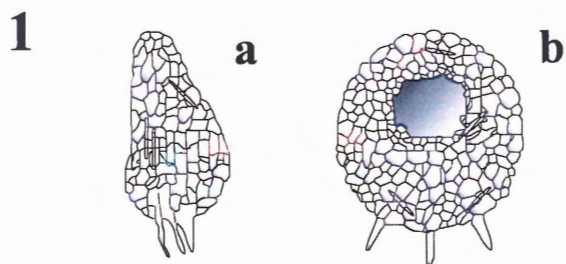
1. *Centropyxis aculeata* Ehrenberg:
   a) edge view
   b) apertural view
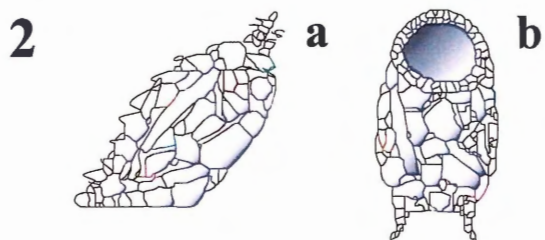
2. *Centropyxis constricta* Ehrenberg:
   a) latero-aperture view
   b) edge view
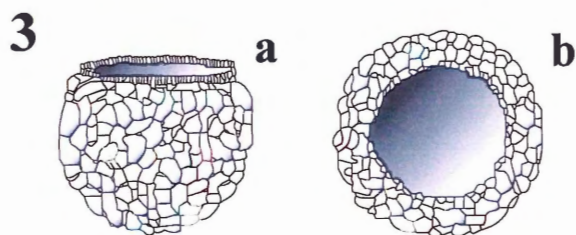
3. *Difflugia globulus* Ehrenberg:
   a) side view
   b) apertural view
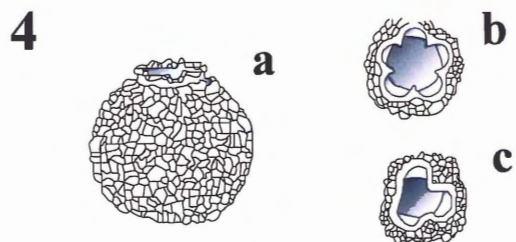
4. *Cucurbitella tricuspis* (Carter):
   a) lateral view showing collar
   b) and c) apertural variation
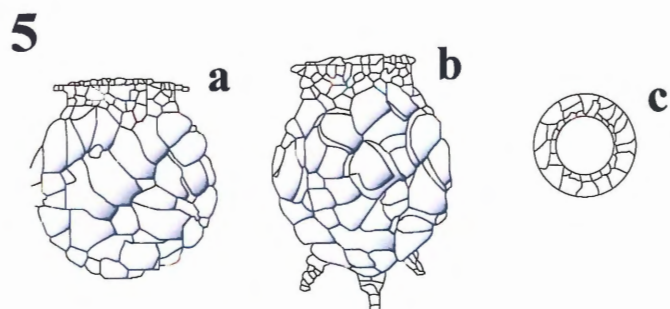
5. *Difflugia urceolata* Carter:
   a) and b) morphological variation
      of side view
   c) apertural view
   (Figures 1-5 after Scott *et al.*,2001)
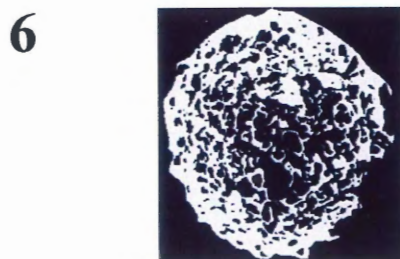
6. Representative of a cyst of *D. urceolata*
   (after Medioli and Scott, 1983, SEM photo).
   The cysts found in core 15-5 are very similar
   in appearance to these.

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Appendicies

Table 2. Percentage occurrences of foraminifera and thecamoebian species from Core 15-5, Little Maderia Bay, where * denotes abundance of less than 1%. All total numbers are per unit sample (10 cc).

Depth (cm)	80-82	82-84	84-86	86-88	88-90	90-92	92-94	94-96	96-98	98-100	100-102	102-104	104-106	106-108	108-110	110-112	112-114	114-115.5
Total species number	12	10	11	13	9	12	10	10	14	17	15	13	14	14	14	12	12	11
Total number of individuals	79224	52644	45180	91944	55440	36144	9108	9108	15084	17928	11160	8676	10728	10368	8460	5652	8280	6336
Ammonia beccarii	46	49	37	34	26	21	17	15	16	5	12	2	2	*	8	5	3	2
Discornopsis aguayoi			*	*		1			*	*	*							
Elphidium excavatum f. excavatum	*																	
Elphidium galvenstonense	16	22	12	16	11	10	3	5	6	*	2	1		*	3			
Elphidium excavatum f. gunteri	7	10	90	14	16	10	4	4	*	2	4	*	1	2	2		*	
Elphidium poeyanum	10	6	21	20	20	18	4	17	13	2	7	3	3	5	3	2		
Fissurina species	*			*														
Fursenkoia species	*	*	*	*	*	*												
Haplophragmoides wilberti										*								1
Helenina anderseni	1	*	7	8	24	20	12	9	6	3	8	3	1	3	7	5	2	
Homotrema rubrum										*			*			*		1
Miliammina fusca																		*
Polysaccammina ipohalina						*	2	*	2	*	2	*	2	*	*	*	*	
Pseudothurammina limnetis									4	3	2	1	*	2	*		*	
Quinqueloculina species	17	11	9	4														
Trochammina inflata					*				12	11	5	4	1	6	2	6	2	3
Trochammina macrescens									4	7	4	6	2	3	1	1	1	3
Centropyxis aculeata	*	*		*							2	*		2	*	2	2	9
Centropyxis constricta	*	*	2	1	*	3	10	13	8	24	16	17	13	19	20	25	21	30
Cucurbitella tricuspis	2	*	1	2	1	8	17	15	11	17	17	30	33	26	18	25	31	21
Difflugia globulus			*	*		2	7	5	5	5	8	11	16	13	9	6	10	8
Difflugia urceolata						6	15	15	11	16	13	22	26	19	26	20	25	22
Thecamoebian cysts	0	0	0	360	3024	9252	26820	26568	33048	30744	30456	25776	34776	25848	22500	18288	25992	8280

Table 3. Percentage occurrences of foraminifera and thecamoebian species from Core L1011/Highway 1, where * denotes abundance of less than 1%. All total numbers are per unit sample (10 cc).

Depth (cm)	0-1	5-6.	10-11	15-16	20-21	24-25	30-31	31-32	32-33	33-34	34-35	35-36	36-37	40-41	45-46	50-51	54-55	56-57	59-60	63-64	65-66	67-68	69-70
Total species number	11	11	10	14	16	18	21	16	13	12	11	13	9	7	12	8	8	10	9	15	13	14	16
Total number of individuals	2217	9168	6528	5562	3192	4686	3522	2010	2184	1674	3768	2328	1104	1536	1704	1416	1640	1564	2868	3525	882	712	3438
Ammonia beccarii	2	23	13	23	10	6	2		*					2						1	5	7	*
Discornopsis aguayoi				2	*	1	1	*			*				1						*	3	
Elphidium excavatum f. excavatum	4		*	1	1	1	*	*															
Elphidium excavatum f. gunteri	3	3	2	3	1	1	1	*				2								1		3	*
Elphidium poeyanum	4	11	11	16	14	8	2	1	*	1												*	*
Elphidium species	3	1		1																			
Fissurina species				*	*			*													*		
Haplophragmoides manilianesis							1	1	*	1		2											
Haplophragmoides wilberti					6	3	3	4	6	5	2	16	1	10	11	8	11	8	13	10	4	4	4
Helenina anderseni					34	9	4	3	2	*	*	3			1					2	3	2	*
Homotrema rubrum						*	2													*	1		1
Miliammina fusca										5		*		2	*		2						3
Polysaccammina ipohalina						6	3	4	3	*	5	5	9		2			2	*	*			4
Pseudothurammina limnetis								1	8	3	5	6	9	4	2	3	9	5	4	4	2	3	3
Quinqueloculina poeyana	1	*	2	*			2																
Quinqueloculina polygona	1	*	*	6	1		*																
Textularia agglutinans						*																	4
Textularia earlandi		2					2								*		1						
Tiphotrocha comprimata					1	1	*	*										2	2	3		2	1
Trochammina inflata				*	11	12	6	5	11	19	30	20	19		4	12	25	24	19	33	10	19	22
Trochammina macrescens					13	16	8	10	5	18	3	6	12	25	10	23	21	27	24	17	8	12	34
linings					13	7	10	3	4	4	1	9	2		*								6
Centropyxis aculeata	4	5	9	12	3	2	5	7	10	*	11	2	3	34	21	33	20	20	21	11	29	11	6
Centropyxis constricta	61	50	47	22	3	18	42	46	48	43	34	32	35	17	31	17	9	10	16	10	22	23	11
Cucurbitella tricuspis				*											2	14	4	3	1	*	6	10	6
Difflugia globulus	5	2	3	1		1	4	2	4	2	*	1	2		*			1			*		
Difflugia urceolata	12	4	13	7	1	2	2		3	2	6		5							*	*	1	*

Table 4. Percentage occurrences of foraminifera and thecamoebian species from Barnes Sound/Highway 1, Sections A and B, where * denotes abundance of less than 1%. All total numbers are per unit sample (10 cc).

Depth (cm)	50-51 (Section A)	256-257 (Section B)
Total species number	11	20
Total number of individuals	7776	32976
Ammonia beccarii	1	3
Discornopsis aguayoi		1
Elphidium excavatum f. excavatum		*
Elphidium galvenstonense		2
Elphidium excavatum f. gunteri		1
Elphidium poeyanum		14
Fissurina species		3
Fursenkoia complanata		4
Haplophragmoides wilberti	*	
Helenina anderseni		5
Homotrema rubrum	6	
Miliammina labiosa		8
Polysaccammina ipohalina	8	
Pyrgo subsphaerica		21
Quinqueloculina laevigata		8
Quinqueloculina poeyana		2
Quinqueloculina polygona		13
Quinqueloculina semilunum		7
Trochammina inflata	3	
Trochammina macrescens	28	
Inner linings	17	
Centropyxis aculeata	*	2
Centropyxis constricta	12	4
Cucurbitella tricuspis	11	1
Difflugia globulus		1
Difflugia urceolata	13	1

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