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Larger Foraminiferal Biostratigraphy, Systematics And Paleoenvironments of The Avon Park Formation and Ocala Limestone, Highlands County, Florida

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LARGER FORAMINIFERAL BIOSTRATIGRAPHY, SYSTEMATICS AND PALEOENVIRONMENTS OF THE AVON PARK FORMATION AND OCALA LIMESTONE, HIGHLANDS COUNTY, FLORIDA

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by

Jacqueline Bowen Powell

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To: Dean Kenneth Furton
College of Arts and Sciences

This dissertation, written by Jacqueline Bowen Powell, and entitled Larger Foraminiferal Biostratigraphy, Systematics and Paleoenvironments of the Avon Park Formation and Ocala Limestone, Highlands County, Florida, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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The dissertation of Jacqueline Bowen Powell is approved.

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DEDICATION

I dedicate this dissertation to my parents and family. Their patience and support made it possible to complete this work.

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I would like to thank my committee for their support and patience. Dr. Kevin Cunningham was instrumental in helping us obtain the material for this study. Professor Edward Robinson's help was invaluable, and his expertise on larger foraminifera helped immensely, especially towards the end of the journey. Dr. Maurrasse, Dr. Draper and Dr. T. Collins were helpful in reviewing the manuscript and providing useful pointers. Roger Portell was nice enough to identify the echinoids from the Avon Park Formation. Jonathan Bryan provided expert knowledge on the Avon Park Formation and Ocala Limestone in the form of advice and offprints. Mark Jiang identified the calcareous nannofossils present in the Ocala Limestone. Ozlem G. Orhun's sample preparation and moral support were greatly appreciated. To all those who encouraged me to continue, thank you. Last and but not least I would like to thank my major professor Dr. Laurel Collins for her unwavering presence and guidance that kept me going; I could not have finished this work without out her dedication.

ABSTRACT OF THE DISSERTATION

LARGER FORAMINIFERAL BIOSTRATIGRAPHY, SYSTEMATICS AND PALEOENVIRONMENTS OF THE AVON PARK FORMATION AND OCALA LIMESTONE, HIGHLANDS COUNTY, FLORIDA

by

Jacqueline Bowen Powell

Florida International University, 2010

Miami, Florida

Professor Laurel Collins, Major Professor

This study investigates the use of larger foraminifera in determining the biostratigraphy of the Avon Park Formation and the Ocala Limestone in central Florida. Sedimentary rocks of the Avon Park Formation are the oldest exposed deposits in the state of Florida, and together with the Ocala Limestone comprise a part of the confining unit of the Floridan Aquifer, a major source of Florida's water supply.

Material from the ROMP 29A core collected by the U. S. Geological Survey was evaluated and compared to previous studies of the biostratigraphy of the formations. The larger foraminifera of the Avon Park Formation were examined in thin section, and those of the Ocala Limestone were free specimens. The larger foraminifera from both units were described and identified, and the biostratigraphy determined. The morphological features of the larger foraminifera of the Ocala Limestone were measured and analyzed at various depths within the ROMP 29A core.

The Avon Park Formation contains predominantly the shallow-water, conical foraminifera *Fallotella cookei, Fallotella floridana, Pseudochrysalidina floridana, Coleiconus christianaensis, Coleiconus* sp. A*, Coskinolina* sp. A*, Coskinolina* sp. B*, Fallotella* sp. A*, Fallotella* sp. B*, Fabularia vaughani* and larger miliolids.

The Ocala Limestone contains a different, deeper water assemblage that included the larger foraminifera *Heterostegina ocalana*, *Lepidocyclina ocalana* varieties, *Lepidocyclina chaperi*, *Lepidocyclina pustulosa*, *Nummulites willcoxi*, *Nummulites striatoreticulatus, Nummulites floridensis* and *Pseudophragmina* spp. A, B, and C. The age of the Avon Park Formation was corroborated by the occurrence of the biomarker echinoid *Neolaganum dalli* as Eocene, and the Ocala Limestone also contained Eocene larger foraminifera with Eocene to possibly Oligocene calcareous nannofossils. The distribution of the larger foraminifera of the Avon Park Formation was correlated with the subtidal and peritidal zones of the continental shelf. Analyses of variance showed that the changes in measurements of the morphology in *Heterostegina ocalana*, *Lepidocyclina* spp. and *Nummulites* spp. were correlated with change in the depositional environments.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This study explores the biostratigraphy and depositional environments of the Avon Park Formation and the Ocala Limestone with the use of larger foraminifera. The specimens were identified from the Regional Observation and Monitoring Program (ROMP) 29A core, which was collected by the U. S. Geological Survey in Highlands County, Florida (Fig. 1.1). The core represents the thickest, most continuous record of these units. The Avon Park Formation is the oldest exposed stratigraphic unit in Florida and is overlain by the Ocala Limestone. The geology of both units has been investigated previously because they constitute a part of the Floridan Aquifer, a significant source of the state's water supply. The widely accepted age for these deposits is Middle Eocene through Upper Eocene; however, conflicting dates of Upper Eocene through Lower Oligocene have been debated through the years (Applin and Applin, 1944; Bryan, 1998; this study).

The Avon Park Formation and the Ocala Limestone were shallow, carbonate-shelf environments on which larger foraminifera flourished and accumulated in large numbers, amid large deposits of carbonates. The larger foraminifera *Fallotella cookei* and *Fallotella floridana,* conical foraminifers of the Avon Park Formation, also occur with larger miliolids and subspherical *Alveolina* according to Vecchio and Hottinger (2007), who hypothesized that the taxa had inhabited the shallow upper photic zone (less than 40

m) of the inner shelf. The larger foraminifera of the Ocala Limestone are *Heterostegina ocalana; Lepiodocyclina ocalana* varieties A, B, C and D; *Lepidocyclina chaperi; Lepidocyclina pustulosa; Nummulites willicoxi; Nummulites striatoreticulatus; Nummulites floridensis;* and *Pseudophragmina* sp. varieties A, B and C. These taxa inhabited the deeper upper photic zone through lower photic zone (40-120 m) on the outer shelf to slope (Vecchio and Hottinger, 2007).

The Ocala Limestone was originally dated as Middle Eocene by Applin and Applin (1944), but they expressed concern for the conflicting occurrences of larger foraminifera of the Late Eocene and calcareous nannofossils of Lower Oligocene age. Bryan (2001) included the upper portion of the Avon Park Formation, covered in this study, as included in the Inglis Member; the lower part of the Ocala Limestone. The Ocala Limestone is considered to be of Upper Eocene age according to stratigraphic ranges of its larger foraminifera, but calcareous nannofossils *Ericsonia formosa, Reticulofenestra umbilica, Calcidiscus protoannulus, Chiasmolithus titus, Discoaster saipanensis*, and *Discoaster barbadiensis* suggest an age of uppermost Upper Eocene to Lower Oligocene.

1.2 Location of Study Area

The study area, where the ROMP 29A core was drilled, lies in Sebring, Florida, U. S. A. (Fig. 1.1), a small town in northern Highlands County, central Florida, approximately 60 km northeast of Lake Okeechobee. This study site is approximately 60 km south-southeast of Avon Park, Florida and 220 km south of Ocala, Florida, the areas

that contain the type sections of the Avon Park Formation and Ocala Limestone. The total length of the ROMP 29A core is 254.2 m, with the Avon Park Formation comprising 144.5 m, the Ocala Limestone 83.8 m and the Suwannee Limestone 10.1 m.

1.3 Regional Geologic Setting

The Florida peninsula is the emergent portion of a carbonate platform at the far southeastern edge of the North American plate. The platform is composed of a suite of Precambrian-Cambrian igneous basement rocks, Ordovician-Devonian sedimentary rocks and Triassic-Jurassic volcanic rocks (Arthur, 1988). The basement rocks were a part of the African Plate in the Paleozoic supercontinent Pangea (Smith, 1982). When Pangea broke apart in the early Mesozoic, the basement rocks became affixed to the North American plate (Smith, 1982). Mid-Jurassic to Holocene sediments were deposited unconformably on the basement suite; carbonate sedimentation was prevalent from the mid-Jurassic to mid-Oligocene, followed by siliciclastic-bearing carbonates dominating in the mid-Oligocene to Holocene (Scott, 1992).

Cenozoic sedimentation is thought to have been controlled by regional geological structures on the Florida platform (Scott, 1992; Fig. 1.2). The Gulf Trough/Apalachicola Embayment, Chattahoochee Anticline and Ocala Platform influenced the distribution of facies (Scott, 1992). The Gulf Trough/Apalachicola Embayment was a bathymetric high during the latest Eocene or earliest Oligocene to the Miocene which resulted in distinctly different Oligocene carbonate deposits from the east, siliciclastic-bearing carbonates and south, dolomitized and silicified fossiliferous limestones on either side (Scott, 1992).

1.4 Lithostratigraphy

This section provides an overview of the Paleogene units of Florida (Fig. 1.3).

1.4.1 Lithology of the Cedar Keys Formation

Characterization: According to Miller (1986) the unit can be divided into two subunits. The lower portion consists of tan to gray, fine-grained dolostone alternately bedded with white to clear anhydrite (Miller, 1986). The upper part is a gray to cream component of fine-grained gypsum and anhydrite (Miller, 1986).

Boundaries: The Cedar Keys Formation is overlain by the Oldsmar Formation with a sharp contact.

Fossils and Paleoenvironment: *Borelis gunteri* Cole and *Borelis floridanus* Cole characterized the undolomited areas of the Cedar Keys Formation (Cole, 1944). The paleoenvironmental setting of the Cedar Keys Formation is a tidal flat much larger than those of modern sabkha environments (Miller, 1986), with adjacent open-shelf marine conditions (Applin and Jordan, 1945).

Chronostratigraphic Position: The age is considered Paleocene by Cole (1944) based on the presence of *Borelis* spp.

Thickness: In central Florida the unit ranges from 305-670 m thick.

1.4.2 Lithology of the Oldsmar Formation

Characterization: According to Miller (1986) the Oldsmar Formation consists of two parts. The lower part is a gray-brown, dense, microcrystalline dolostone (Miller, 1986).

The upper portion consists of white to gray, interbedded layers of micrite to pelletal, glauconitic packstones, wackestones, mudstones and tan dolostones (Miller, 1986).

Boundaries: The Avon Park Formation - Oldsmar Formation contact is sharp, with the lithology changing from a white-gray, tan-light brown limestone and dolostones of the Oldsmar Formation to the darker (brown) colored deposits of the Avon Park Formation (Vernon, 1951). The Cedar Keys Formation - Oldsmar Formation boundary is also a sharp contact; the lighter grey dolostone of the upper Cedar Keys Formation meets the dark gray dolostones of the lower Oldsmar Formation (Vernon, 1951).

Fossils and Paleoenvironment: The Cedar Keys Formation is characterized by the index fossil *Helicostegina gyralis.* The larger foraminifera *Miscellanea nassauensis*, *Pseudophragmina (Proporocyclina) cedarkeysensis* and *Lockhartia* sp. are prevalent (Miller, 1986). The paleoenvironment is a shallow, marine setting which experienced much less restriction in water circulation than the Cedar Keys Formation (Miller, 1986).

Chronostratigraphic Position: The age is Lower Eocene, determined by the presence of the index fossil *Helicostegina gyralis* (Miller, 1986).

Thickness: The thickness of the Oldsmar Formation is 300-365 m in south Florida (Miller, 1986).

1.4.3 Lithology of the Avon Park Formation

Characterization: The Avon Park Formation is a group of light-brown limestones and dolostones of varying hardness. The unit is fossiliferous, and contains fluctuating concentrations of mollusks, foraminifera, echinoids, algae and carbonized plant remains.

Boundaries: The Oldsmar Formation - Avon Park Formation and the Avon Park Formation - Ocala Formation contacts are unconformable.

Fossils and Paleoenvironment: The Avon Park Formation is characterized by the larger foraminifera *Fabularia vaughani, Fallotella floridana, Fallotella cookei, Coskinolina* spp., and *Coleiconus christianeansis*.

Chronostratigraphic Position: A Middle Eocene age is based on the presence of *Fabularia vaughani* (Miller, 1986) and *Fallotella cookei* (Cole, 1944: Cole, 1945).

Thickness: The Avon Park Formation has a maximum thickness of 100-731m.

1.4.4 Lithology of the Ocala Limestone

Characterization: A review of the literature on the lithology of the Ocala Limestone indicates two main schools of thought: the Ocala Limestone is divided into two units (Applin and Applin, 1944; Scott, 2001) or the Ocala Limestone has three units (Puri, 1957, Ward et. al, 2003). The two-fold division is used by the U. S. Geological Survey and this study, whereas the Florida Bureau of Geology recognizes the three divisions. According to Miller (1986) and Scott (2001), the Ocala Limestone consists of limestone and dolostones. It can be divided into a lower and upper unit on the basis of its lithofacies. The lower lithofacies consists of white- to cream-colored, fine- to medium-grained, poorly to moderately indurated, highly fossiliferous limestone (grainstone and packstone). The upper lithofacies is a white, poorly to well indurated, poorly sorted, highly fossiliferous limestone (grainstone, packstone and wackestone).

Boundaries: The Avon Park Formation - Ocala Limestone contact is unconformable (Applin and Applin, 1944).

Fossils and Paleoenvironment: Fossils present in the Ocala Limestone are larger and small benthic foraminifera, echinoids, bryozoans and mollusks. The foraminifer *Lepidocyclina* sp. is abundant in the upper member and extremely sparse in the lower member, emphasizing a distinction in the larger foraminiferal content of the two lithofacies. The larger foraminifera are *Lepidocyclina ocalana, Heterostegina ocalana, Nummulites willcoxi, N. striatoreticulatus* and *N. floridensis*. The paleoenvironments of the Ocala Limestone are middle - to outer - shelf marine.

Chronostratigraphic Position: The Ocala Limestone was first thought to be Oligocene in age, but it was incorrectly correlated to the Vicksburg Limestone (in Hernando County, Florida), which was considered Eocene and now considered Oligocene (Heilprin 1882, Dall 1892). Cooke (1915) reassigned the Ocala Limestone to its present Upper Eocene stratigraphic position based on an equivalent stratigraphy and paleontology of the upper Jackson Formation of Alabama and Mississippi, and concluded that it overlay Vicksburgian Limestone of western Florida.

Thickness: The Ocala Limestone is 0-240 m thick (Winston, 1997).

1.4.5 Lithology of the Suwannee Limestone

Characterization: The Suwannee Limestone consists of two parts (Miller, 1986). The lower part is white to cream-colored, fine, pelletal limestone (Miller, 1986). The upper part is cream-colored to tan, crystalline, vuggy limestone (Miller, 1986).

Boundaries: The Ocala Limestone-Suwannee Limestone contact is gradational (Miller, 1986).

Fossils and Paleoenvironment: The upper part contains gastropod and pelecypod casts and molds (Miller, 1986). Characteristic larger foraminifera of the Suwannee Limestone are *Lepidocyclina leonensis, Lepidocyclina parvula, Miogypina* sp., *Discorinopsis gunteri, Fallotella cookei* and *Fallotella floridana* (Miller, 1986). Smaller benthic foraminifera present include *Pararotalia byramensis* and *Pararotalia mexicana mecatepecensis* (Miller, 1986). The paleoenvironments of the Suwannee Limestone are middle- to outer-shelf marine.

Chronostratigraphic Position: An age of Lower Oligocene is based on the occurrence of the echinoid *Rhyncholampas gouldii*, an index fossil (Green, et al., 2007).

Thickness: The Suwannee Limestone is 0-200 m thick (Winston, 1997).

1.5 Introduction to Larger Foraminifera

Larger foraminifera are unicellular protists housed within a hardened shell or test that is at least 3 mm^3 in volume, as opposed to the other foraminifera that do not exceed 1-2 mm^3 (Lee and Hallock, 1987; Ross, 1974). Eichwald (1830) named the order Foraminiferida for the numerous, tiny foramen (pores) in the test. The tests are made primarily of calcium carbonate but occasionally silica, organic compounds or particles cemented together (agglutinated). Their intricately designed interior is the taxonomical base used to describe the order. Larger foraminifera have complex and variable life cycles (Leutenegger, 1977). Most larger foraminifera reproduce by an alternation of generations through haploid-diploid life cycles. The haploid process involves the union of opposite sex gamonts resulting in the megalospheric type (A-form), whereas the diploid route entails asexual division into agamonts that produce the microspheric type (B-form).

The A-forms usually have a bigger test than the B-forms; however, the embryons of the A-forms are much bigger than the B-forms.

In this study three architectural kinds of larger foraminifers are described: 1) nummulitids and orbitoidforms; 2) miliolids; 3) conical forms. The details of the morphological features for the three larger foraminiferal groups will be reviewed in chapters 2 and 3. The term "well preserved" is used herin to describe specimens in which the fine features are visible with no crystal overgrowths or recrystallization.

1.6 Content of Dissertation Chapters 2 - 5

The chapters of this dissertation and their content are as follows:

Chapter 2, "Larger Foraminiferal Taxonomy and Biostratigraphy of the Avon Park Formation, Central Florida," investigates the taxonomy, biostratigraphy, paleoenvironments, and paleogeography of the larger foraminifera of the Avon Park Formation inferred from their occurrences in the ROMP 29A core.

Chapter 3, "Biostratigraphy and Larger Foraminiferal Taxonomy and Systematics of the Ocala Limestone," describes the taxonomy, biostratigraphy, paleoenvironments, and paleogeography of the larger foraminifera in the Ocala Limestone inferred from their occurrences in the ROMP 29A core.

Chapter 4, **"**Correlation of Changes in Larger Foraminiferal Features with Paleoenvironmental Variations in the Ocala Limestone" conducts a biometric analysis of *Heterostegina ocalana*, *Lepidocyclina* spp. and *Nummulites* spp. of the Ocala Limestone, for the purpose of detecting trends in the measurements of morphological features related to the depositional sequences of Ward et al. (2003). The correlation of changes in the

parameters of the morphological features to depositional environments determines the usefulness of larger foraminifera in biostratigraphy.

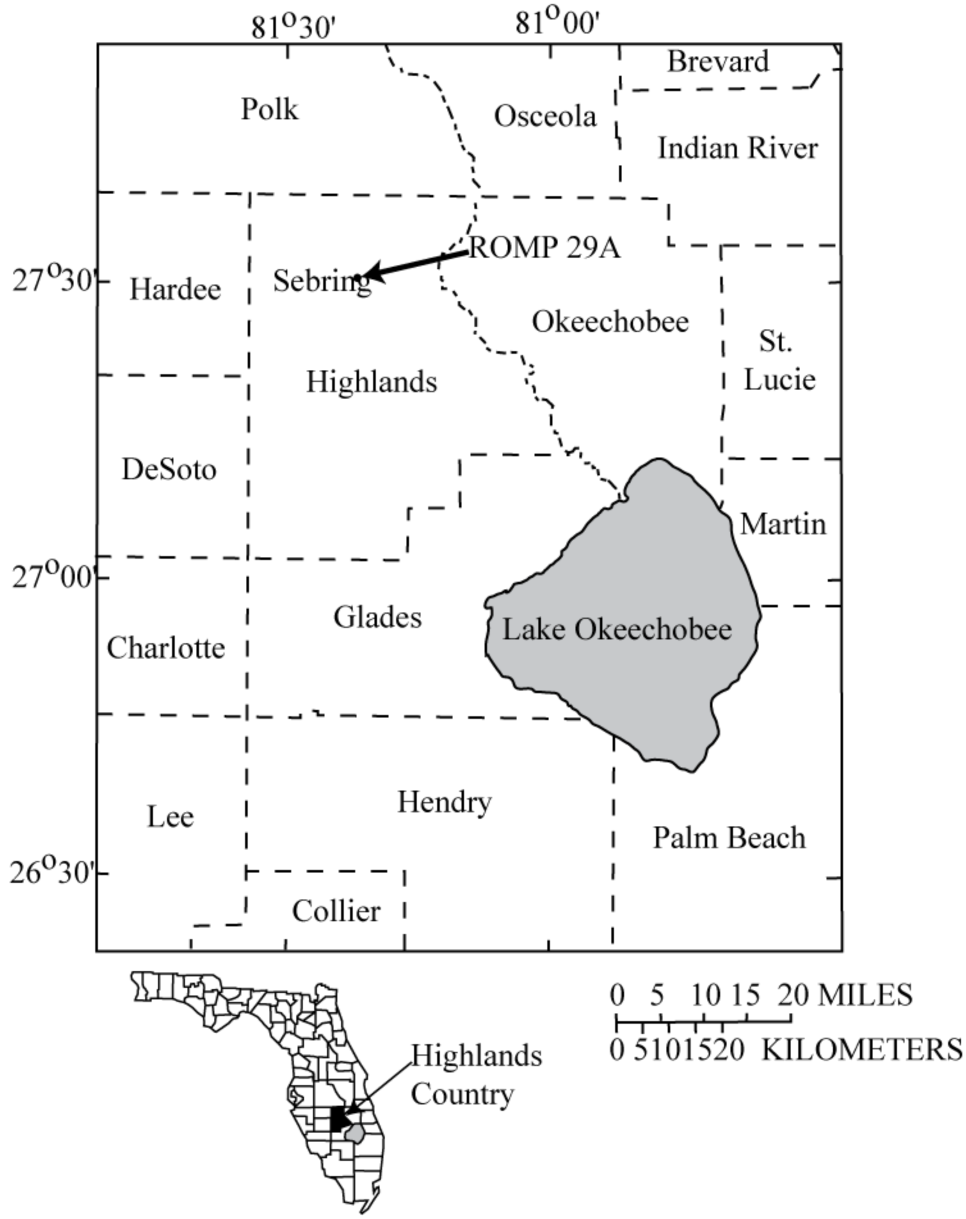


Figure 1.1 Location of ROMP29A test corehole in Highlands County, Florida (ROMP = Regional Observation and Monitoring Program). Adapted from Ward et al. (2003).

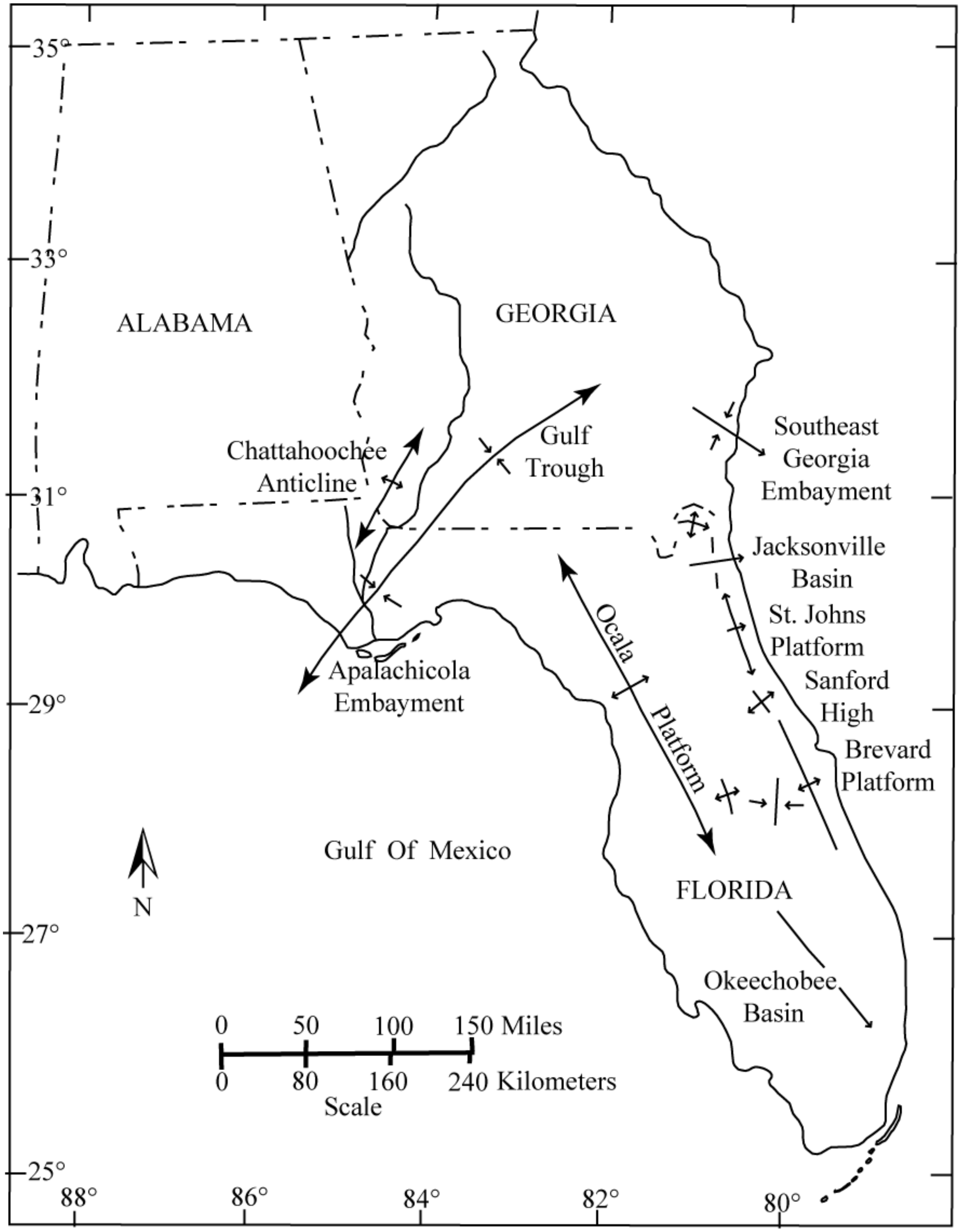


Figure 1.2 Geologic structures in Florida, redrawn from Scott (1992).

EPOCH	SERIES	STAGES	FLORIDA LITHO-STRATIGRAPHY	AGE (m.y.)
OLIGOCENE	LATE	CHATTIAN (CHICKASWHAYAN)	Hiatus	28.4
	EARLY	RUPELIAN (VICKSBURGIAN)	Suwannee Limestone	33.9
EOCENE	UPPER	PRIABONIAN (JACKSONIAN)	Ocala Limestone	37.2
	MIDDLE	BARTONIAN	Avon Park Formation	40.4
		LUTETIAN		48.6
	EARLY	YPRESIAN	Oldsmar Limestone	55.8
PALEOCENE		THANETIAN	Cedar Keys Formation	
		SELANDIAN		
		DANIAN		65.5

Figure 1.3 General chronostratigraphy and lithostratigraphy of the Florida peninsula (adapted from Loizeaux, 1995). Ages are according to the time scale of the International Commission on Stratigraphy (2008).

CHAPTER 2

LARGER FORAMINIFERAL TAXONOMY AND BIOSTRATIGRAPHY OF THE AVON PARK FORMATION, CENTRAL FLORIDA

2.1 Introduction

Sedimentary rocks of the Eocene Avon Park Formation comprise the oldest exposed rocks in the state of Florida (Fig. 1.1), occurring throughout peninsular Florida and the panhandle (Scott, 1992). The unit is a part of the Floridan Aquifer system and acts as a confining bed of low permeability which divides the aquifer into upper and lower segments in some areas (Scott, 1992). The Avon Park Formation generally consists of fossiliferous limestones interbedded with vuggy dolostones (Miller, 1986). Many of the earlier studies of the age and depositional setting of the formation were based on its larger foraminifera (Applin and Applin, 1944; Chen, 1965), the subject of this study.

The Regional Observational and Monitoring Program (ROMP) 29A core, the material for this study of the Avon Park Formation, was collected in northern Highlands County, south-central Florida (Fig. 1.1) by the South Florida Water Management District, which oversees the water resources of south Florida. The core was originally investigated by the U.S. Geological Survey to determine the sequence stratigraphy of the upper Floridan Aquifer and its relationship to carbonate porosity and regional transmissivity (Ward et al., 2003). The sequence of the Avon Park Formation, which spans 144.3 m between 234.7 m and 379 m within the core, has a high content of larger foraminifera.

In this study, the following problems are addressed:

1. The larger foraminiferal distribution in the Avon Park Formation as seen in the ROMP 29A core is compared to those of Miller (1986) and Applin and Applin (1944). The original descriptions of the stratigraphic unit were made on the basis of their larger foraminiferal content, contrary to traditional stratigraphic convention (Applin and Applin, 1944). Miller (1986) grouped the three limestones into one stratigraphic unit to form the Avon Park Formation, as he was unable to separate them stratigraphically according to the larger foraminiferal distribution of Applin and Applin (1944).
2. The larger foraminifera of the Avon Park Formation are compared to its paleoenvironments as documented by (Ward et al., 2003) who suggest that the environments of the Avon Park Formation were within the subtidal and peritidal zones (Fig. 2.1) based on the lithology. The ranges of the larger foraminifera of the Avon Park Formation are varied and their distribution may in part be explained by changes in depositional settings.

2.2 Historical Review of Lithology and Age of the Avon Park Formation

Applin and Applin (1944) established the name "Avon Park Limestone" based on chips from a well located at the Avon Park Bombing Range, Polk County, Florida, to describe the rocks of the upper part of the late Middle Eocene (Table 2.1). The fossil faunas and lithology of the Avon Park Limestone deposits distinguished them from the Tallahassee Limestone, Lake City Limestone, Oldsmar Limestone and Lawson Limestone, named in the same work. The Avon Park Limestone was originally described

as a cream-colored, highly microfossiliferous, chalky limestone with gypsum, chert, and dolomite, whereas the Lake City Limestone consisted of alternating layers of dark brown and chalky limestone with gypsum, chert and dolomite (Applin and Applin, 1944).

Cooke (1945) described the Middle Eocene Lake City Limestone as composed of alternating layers of dark-brown and chalky limestone, and containing gypsum in the central outcrop area of Tallahassee and southeast Georgia. The Lake City Limestone overlies the Oldsmar Limestone and is overlain by the Tallahassee Limestone. The larger foraminifera present in the Lake City Limestone were *Cushmania americana* Cushman (guide fossil), *Discocyclina (Asterocyclina) monticellensis* Cole and Ponton, *Fabularia vaughani* Cole and Ponton and *Lepidocyclina (Polylepidina) antillea* (Cooke, 1945).

Cooke (1945) found the upper surface of the cream-colored, chalky Avon Park Limestone to have an unconformable contact with the overlying Ocala Limestone. He proposed that the Avon Park Limestone was deposited on the submerged Floridan Plateau in an open-ocean setting that received little sand or clay. The larger foraminifera present were *Fallotella floridana* Cole and *Fallotella cookei* Moberg, and the small echinoid *Peronella dalli* Twitchell was locally common in the upper part of the Avon Park Limestone (Cooke, 1945).

Bishop (1956) identified additional larger foraminifera in the Lake City Limestone in Highlands County, Florida as *Discorbis inornatus* Cole, *Fabularia gunteri* Applin and Jordan, *Fabiania cassis* Oppenheim and Bermudez, *Lepidocyclina (Pliolepidina) cedarkeysensis* Cole, *Linderina floridensis* Cole, *Lockhartia cushmani* Applin and Jordan (1945), and *Operculinoides jennyi* Barker. He identified more larger foraminifera from the Avon Park Limestone in Highlands County deposits as *Cribrobulimina cushmani*

Applin and Jordan, *Fallotella cookei*, *Discorinopsis gunteri* Cole, *Flintina avonparkensis* Applin and Jordan, and *Coskinolina floridana* Cole.

Chen (1965) dated the upper boundary of the Lake City Limestone as lower Middle Eocene based on the first appearance of *Cushmania americana*, and pointed out that the unit had been originally defined biostratigraphically instead of lithologically by Applin and Applin (1944). In the Avon Park Limestone, Chen (1965) found abundant *Coskinolina, Cushmania* and *Fallotella*. As he was unable to divide the Lake City Limestone and Avon Park Limestone he combined them lithologically into a joint unit named the Claiborne Group, which he used in a study of the geology of the Florida Panhandle (Table 2.1).

Miller (1986) grouped the Avon Park Limestone and Lake City Limestone together as the Avon Park Formation because of the similarity of their faunal content and sediments, which can only be distinguished locally (Table 2.1). Both limestones were characterized by the larger foraminifera *Cushmania americana* and *Fabularia vaughani* (Miller, 1986).

Scott (1992) described the Avon Park Formation as a cream to light-brown, fossiliferous limestone that included grainstone, packstone, and mudstone with occasional vuggy dolostones. The fossils consist of mollusks, foraminifera, echinoids, and algal and other plant fragments.

Duncan et al. (1994) found that in Brevard County, the top of the Avon Park Formation was marked by a slight radioactive peak on the gamma-ray log, and this level also marked the first occurrence of *Dictyoconus* sp (equivalent to *Fallotella* sp. in this this study). The top of the Avon Park Formation consisted of light orange to white colored wackestones and packstones, with abundant *Dictyoconus* sp. All of the Avon

Park Formation beneath this horizon comprised interbedded dolostones and fossiliferous limestones containing foraminifera and echinoderm fragments. Midway through this larger, lower unit was another gamma-ray marker bed, designated the 'B" marker bed, separating the thinly bedded layers of the upper Avon Park Formation from the thickly bedded layers of the lower Avon Park Formation. A horizon of abundant *Operculina cookei* was recognized by Duncan et al. (1994) in most of the injection wells within the lower Avon Park Formation; however, this biotic marker was not recognized in this study of the ROMP 29A core. Duncan et al. (1994) identified a variety of carbonate depositional environments established by Scholle et al. (1983) including low-energy tidal flats, high-energy shoals, beach deposits, and the shoreface to foreshore.

Ward et al. (2003) identified twelve lithofacies in the ROMP29A core of the Avon Park Formation, all of which represent an inner ramp setting (Table 2.2). The lithofacies consisted of composite high-frequency cycles related to one transgression and two regressions, and representing three depositional settings: peritidal; open-shelf, shallow low tidal; and open-shelf, deeper subtidal.

2.3 Review of Morphological Terms Used to Describe Larger Foraminifera of the Avon Park Formation

The conical foraminifera in this study belong to the genera *Fallotella*, *Coskinolina* and *Coleiconus*. The approach to studying their interiors, which are diagnostic for identification, is by thin section in either axial, transverse or oblique orientation (Fig. 2.2a). Conical larger foraminifera have two types of embryonic apparatuses: a central proloculus, or a coiled proloculus and a nepiont (following the embryonic stage but

different in architecture from the adult stage; Fig. 2.3). The adult stage consists of uniserial chambers which increase in width with each successive chamber, forming a cone (Hottinger and Drobne, 1980).

In axial section, the embryonic apparatus is located at the top of the cone (Fig. 2.2b). The adult stage of the cone is divided into marginal and central zones (Fig. 2.2b). The marginal zone (exoskeleton) consists of chambers which may or may not possess horizontal partitions that can be present in several cycles (Fig. 2.2b). The central zone consists of horizontal chambers connected to each other by perforations (apertures), and vertical structures between each chamber wall are known as pillars (Fig. 2.2b).

In transverse section, the embryonic apparatus is present when the top of the cone is sectioned (Fig. 2.2d). The marginal zone may consist of no vertical partitions or multiple cycles of vertical partitions (Fig. 2.2c, 2.2d). The central zone in thin section consists of circular structures of cross-sectioned pillars (Fig. 2.2c, 2.2d).

According to Hottinger and Drobne (1980), conical foraminifera have four types of exoskeleton represented by the genera *Coskinolina, Coleiconus*, *Fallotella* and *Dictyoconus* (Hottinger and Drobne, 1980). *Coskinolina* has no vertical or horizontal partitions (Fig. 2.3). *Coleiconus* has one cycle of vertical partitions and no horizontal partitions (Fig. 2.3). *Fallotella* has one or two cycles of vertical partitions, and may or may not possess horizontal plates (Fig. 2.3). *Dictyoconus* has several cycles of vertical and horizontal partitions (Fig. 2.3).

Fabularid embryons consist of a larger proloculus (Fig. 2.4) in megalospheric forms, or a smaller proloculus in microspheric forms. Chambers are quinqueloculine in

the early stages, grading into triloculine and eventually biloculine chambers (Fig. 2.5). Chamber addition follows the axis of coiling, perpendicular to the aperture. The angle between the median plane of each successive chamber (Ponder, 1974; Hottinger 2006) is 72^{o} in the quinqueloculine stage (approximately five chambers), 120^{o} in the triloculine stage (approximately three chambers) and 180^{o} in the biloculine stage (two chambers). In axial section, the chambers form concentric bands around the proloculus and are subdivided into chamberlets (Fig. 2.4). The later chambers of the biloculine coiling stage may overlap slightly where they meet (Fig. 2.5). In equatorial section the quinqueloculine, triloculine and biloculine chamber arrangement is most evident (Figs. 2.4, 2.5).

2.4 Methods

2.4.1 Sampling Methods

One hundred eighty-eight rock samples were taken from a core of the Regional Observational and Monitoring Program (ROMP) 29A test corehole drilled by the South Florida Water Management District (Fig. 1.1). The core is archived at the Florida Geological Survey, Tallahassee, Florida. The core was sampled at regular intervals of 1.5 m or where there were visible changes in the color, or texture of the sedimentary rock. Each sample collected was approximately 5 cm in length. Of the 188 samples collected, 12 were selected for further study because they were collected from points where the lithology changed or where the larger foraminiferal content was representative of that core interval. In addition, 52 thin sections were provided by the U.S. Geological Survey. Echinoids that are potentially useful for biostratigraphy were collected at the core depths

of 236.6 m, 245.7 m, 272.8 m and 277.3 m (Fig. 2.1) to compare their distribution with that of the larger foraminifera. Samples of calcareous nannofossils, a primary age indicator, were collected at core depths of 254.5 m and 286.2-287.7 m.

2.4.2 Specimen Preparation and Identification

Limestone of the Avon Park Formation is indurated, so specimens were only examined in thin section. Epoxy-impregnated rock chips were cut from the core material with a water saw to fit on 50 x 75 mm glass slides. One side of each chip was sanded down on a lap glass sanding surface with #400 grit, then polished with #400 grit. The polished side of each chip was affixed to the frosted side of a glass slide using epoxy. Ninety-five percent of the chip was then cut off and ground down using a Hilquist thin-sectioning machine until the thin section was thin enough to transmit light under the polarized light microscope. The thin section was then polished on a lap glass sanding surface until smooth.

The larger foraminifera were viewed under a Leica petrographic microscope, and measured using a Lovin field finder micro slide. Larger foraminiferal taxa displaying internal structures were photographed with a digital camera mounted on the petrographic microscope. A total of 12 thin sections were made to supplement the 52 thin sections provided by the U. S. Geological Survey.

The echinoid samples were soaked in deionized water overnight to remove the surrounding matrix, then placed in an ultrasonic cleaner for 10 hours to clean the surface. Specimens were dried in an oven at 350^{o} C for approximately two hours.

The larger foraminiferal taxa were identified with the aid of the Catalogue of Foraminifera (Ellis and Messina, 1941-2009) and other literature. The echinoid specimens were identified by Roger Portell, Florida Museum of Natural History, University of Florida, Gainesville. Calcareous nannofossils specimens were identified by Mark Jiang of Ellington and Associates, Inc., Texas.

2.5 Results

The larger foraminifera identified in the Avon Park Formation sequence of the ROMP 29A core are listed in Table 2.3, defined in the Systematic Paleontology section (below), and shown according to the rock type in which they occurred in Table 2.4. Their biostratigraphic ranges (Fig. 2.1) use the uppermost and lowermost documented occurrences (Salvador, 1994). The upper and lower limits of a biohorizon are delineated by the lowermost and uppermost occurrences of the taxa. The assemblage zones are named for the most prominent and diagnostic of the fossils in the assemblage (Salvador, 1994).

The echinoids collected from the core were identified as *Neolaganum dalli* Twitchell (Fig. 2.1). Samples from depths 286.3 m and 254.5m investigated for calcareous nannofossils were barren.

2.5.1 Systematic Paleontology

Order Foraminiferida Eichwald, 1830

Family Dictyoconidae Moullade, 1965

Genus *Fallotella* Mangin, 1954

Fallotella cookei Moberg, 1928

Plate 1, Figs.1 – 11; Plate 2, Figs. 1- 8

Coskinolina cookei Moberg, 1928, p. 166, pl. 3, figs. 1- 8; pl. 5, fig. 3

Dictyoconus cookei (Moberg), *in* Cole, 1941, pl. 3, figs. 11 - 13; pl. 5, figs. 6 -10, 12, 13; pl. 6, figs.1-8; pl. 18, fig. 12

Dictyoconus cookei (Moberg), *in* Cole, 1942, pl. 3, fig. 10; pl. 4, fig. 8

Dictyoconus cookei (Moberg), *in* Cole, 1945, pl. 2, figs. 1, 2

Dictyoconus cookei (Moberg), *in* Robinson, 1974, pl. 1, figs. 3, 5

Fallotella (Fallotella) cookei (Moberg), *in* Hottinger and Drobne, 1980, pl. 16, figs. 1 – 14; text figs. 9D-E, 12A

Fallotella cookei (Moberg), *in* Robinson and Wright, 1993, figs. 9.1-9.7, 10.3-10.4

Fallotella cookei (Moberg), *in* Serra-Kiel et al., 2007, pl. 1, figs. 13-15

Description. Megalospheric and microspheric forms present, as follows.

Megalospheric forms: High, conical, uniserial test. Fourteen to eighteen saucer-shaped chambers. Average test height 2.0-3.5 mm. Average test diameter 2.75-4.0 mm. Prominent proloculus approximately 0.5 mm in diameter, centrally situated at apex of test (Plate 1, Figs. 1, 5, 8, 9). Marginal zone consists of three chamberlet types arranged in distinct layers (Plate 1, Figs. 1, 7). Outermost layer shows random partitions both vertically and horizontally, forming a web-like structure in axial sections (Fig. 2.2b). In transverse sections, vertical partitions bound chamberlets. Second marginal layer has two series of vertical partitions, with every alternate or third partition attached to first circle of columns. Third marginal layer has one series of vertical partitions, all attached to second

circle of columns. Central zone consists of alternately and correspondingly occurring columns (Fig. 2.2b). Each chamberlet has apertural openings along lower margin with approximately seven apertures per mm.

Microspheric forms: Larger forms are assumed to be microspheric when the proloculus was missed by the thin section. Low, conical, uniserial test. Test height approximately 2 mm, diameter 6 mm. Thirteen to twenty-seven saucer-shaped chambers. Proloculus not visible in available material (Plate 1, Figs. 10-11). Marginal zone consists of one series of horizontal partitions and at least one series of vertical partitions. Major partitions attached to first circle of columns. Central zone has alternately arranged columns. Each chamberlet has openings along lower margin, approximately 7 apertures per mm.

Material. Twenty specimens in two thin sections from depths 370 m and 367.2 m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida; Middle Eocene, Mexico; Lower Eocene-Lower Oligocene, Cuba; Lower Eocene to Lower Oligocene, Jamaica; Middle to Upper Eocene, Haiti; Middle Eocene, Dominican Republic; Lower Eocene to Lower Oligocene, Nicaragua. (See Appendix Ia for details.)

Comments. Moberg (1928) first identified *Fallotella cookei* as *Coskinolina cookei,* in which vertical (of varying lengths) and horizontal partitions characterized the periphery. *Coskinolina* (Stache, 1875) was initially described as an elliptical *Conulina* (d'Orbigny, 1839), but *Conulina* had rectangular chambers with no distinguishable periphery and

shared no similarities with *F. cookei*. In 1941, *Coskinolina cookei* Cole was placed in the genus *Dictyoconus* as it contained two cycles of horizontal and vertical partitions in the marginal zone. In 1980, Drobne and Hottinger placed *Dictyoconus cookei* in the genus *Fallotella* Mangin (1954). Mangin (1954) had distinguished between *Coskinolina*, *Fallotella* and *Dictyoconus* in both vertical and horizontal sections.

The embryonic apparatus of melogalospheric *Fallotella cookei* is much larger than that of other *Fallotella* species in the ROMP 29A core. *Fallotella* cookei can be readily distinguished by its greater width and characteristic bell shape with rounded apex, whereas *F. floridana* has a pointed apex. The microspheric forms are a low, flat cone reminiscent of the Lower Cretaceous *Orbitolina,* and comparatively, *F. floridana* is similar in width but at least 1.5 -2 times greater in height.

Fallotella floridana Cole, 1941

Plate 3, Figs.1-4; Plate 4, Figs. 1-15; Plate 5, Figs. 1-11; Plate 6, Figs. 1-11; Plate 7, Figs. 1-19; Plate 9, Figs. 1-26; Plate 10, Figs. 1-4, 6, 9-15, 17-26

Coskinolina floridana Cole, 1941, p. 24, pl. 3, figs. 1 - 7; pl. 4, figs. 1 - 9; pl. 5, figs. 1 - 5, 11; pl. 18, fig. 9

Coskinolina floridana Cole, *in* Cole, 1942, pl. 4, figs. 4 - 5

Coskinolina floridana Cole, *in* Cole, 1945, pl. 2, figs. 3 - 4

Coskinolina cookei Moberg, 1928, p.166-168, pl.3, fig. 6

Fallotella floridana (Cole), *in* Robinson and Wright, 1993, figs. 9.8, 10.1 - 10.2

Description. High, conical test. Megalospheric and microspheric forms present.

Megalospheric forms: Centrally positioned proloculus, 0.125 mm in diameter. Fourteen to twenty saucer-shaped chambers. Test height 2.0-2.5 mm. Test diameter 1.5-2.5 mm. Marginal zone, 0.25 mm wide with no horizontal partitions and one series of vertical partitions. Central zone with alternately distributed pillars.

Microspheric forms: Coiled initial chambers. Ten to twenty saucer-shaped chambers. Lower end of cone convex in shape. Test height 1.25 -2.5 mm, test diameter 0.5 – 2.0 mm. Marginal zone constitutes approximately 33% of the test diameter. Central zone with alternately distributed pillars.

Material. Eighty-two specimens. Six thin sections from ROMP 29A core at depths 370.0 m, 367.2 m, 351.7 m, 329.8 m, 283.8 m and 280.7 m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida; Middle Eocene, Mexico; Lower Oligocene, Bahamas; Lower-Middle Eocene, Cuba; upper Lower-Middle Eocene, Jamaica; Middle –Upper Eocene, Haiti; Middle Eocene, Nicaragua. (See Appendix Ib for details.)

Comments. *Fallotella floridana* was originally identified as *Coskinolina* by Cole (1941); Robinson (1993) subsequently classified it as *Fallotella*. *Fallotella floridana* and *Fallotella cookei* are similar, and they both have one cycle of partitions in horizontal section. However, in vertical section, no partitions are present in the former, but are present in the latter (Robinson, 1993).

Fallotella sp. A

Plate 10, Figs. 5, 7

Description. Coiled, centrally placed early chambers, 0.5mm in diameter, with indistinguishable details. Test 2-2.25 mm in height, 0.75-1.25 mm in width. Marginal zone with no horizontal partitions, 20 saucer-shaped chambers, 10 chambers per mm. Central zone with intricate arrangement of chambers.

Material. Two specimens in one thin section from 279.5m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida.

Comments. This species bears a similarity to *Barratolites* sp., which has an eccentric embryonic apparatus. The thin sections do not sample the embryonic chambers so no positive identification can be made. The test of *Fallotella* sp. A is higher and more elongated than that of other *Fallotella* in the ROMP 29A core, and Fallotella sp. A lacks distinct horizontal chamber walls in the central zone, which results in irregularly shaped chambers.

Fallotella sp. B

Plate 10, Figs. 8, 16

Description. High, conical test with 0.33 mm width and 0.50 mm height. Eccentric proloculus located at test apex, characterized by elongated, curled protrusions. Proloculus with 0.25 mm diameter occupies most of test apex. Marginal zone with no horizontal

partitions, and one cycle of vertical partitions. Central zone with pillars alternately spaced.

Material. Two specimens in one thin section from 279.5m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida.

Comments. *Fallotella* sp. B occurs with *F. floridana*, and both have high, conical tests, no horizontal partition and one cycle of vertical partitions in the marginal zone. However, the proloculus of *F. floridana* consists of a simple, circular structure, and in *Fallotella* sp. B the structure is aberrant, a possible result of borings by microscopic organisms.

Family Cosknolinidae Moullade, 1965

Genus *Coleiconus* Hottinger and Drobne, 1980

Coleiconus christianaensis Robinson, 1993

Plate 8, Fig. 3-5

Coleiconus christianaensis Robinson, 1993, p. 283 - 345, figs. 7.8, 7.9, 8.8

Description. Early chambers include prominent, coiled embryonic apparatus, which is half of entire specimen (Plate 8, Figs. 3, 5). Eighteen to nineteen saucer- shaped chambers. Marginal zone with no horizontal partitions. Central zone unclear. Height of test 0.5 mm, and width of test 0.5 mm.

Material. Three specimens. Two thin sections from 304.4m and 280.7 m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida; lower Middle Eocene-Upper Eocene, Jamaica; Middle Eocene Nicaragua. (See Appendix Ic for details.)

Comments. Hottinger and Drobne, 1980 considered *Coleiconus christianaensis* to be a subgenus of *Coskinolina elongata* (Cole, 1942). Robinson (1993) identified specimens from Jamaica with a diagnostically large, coiled early growth stage unlike any other conical form the ROMP 29A core.

Coskinolina sp. A

Plate 8, Fig. 1

Description. High, wide, conical test. Trochospiral juvenile growth stage, details not clear. Test 2.5 mm wide, 3 mm high.

Material. One specimen in one thin section from 351.7 m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida.

Comments. This species is similar to *Coskinolina (Coskinolina) roberti* Schlumberger (Hottinger and Drobne, 1980) because both have a discontinuity in the addition of chambers, resulting in a gap parallel to the bottom of the cone.

Coskinolina sp. B

Plate 8, Fig. 2

Description. Proloculus and early chambers not visible in material. Height of test 2.5 mm, width 2.25 mm. Thickness of outer wall 0.02 mm. Marginal zone with large, inflated, oval chambers and no horizontal partitions. Central zone obscured.

Material. One specimen in one thin section from 283.8 m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida.

Comments. The outer wall structure and chamber shape is similar to that in *Pseudochrysalidina floridana,* although the base of *Coskinolina* sp. B is much wider.

Family Chrysalidinidae Neagu, 1968

Genus *Pseudochrysalidina* Cole, 1941

Pseudochrysalidina floridana Cole, 1941

Plate 8, Figs. 6-12

Pseudochrysalidina floridana Cole, 1941, p. 36, pl. 1, figs. 10 - 11; pl. 2, fig. 4

Chrysalidina? sp., *in* Cushman, 1921, p. 44 - 45, pl. 1, figs. 6a - b

Pseudochrysalidina floridana (Cole), *in* Robinson, 1974, pl. 2, 6, 8

Chrysalidina (*Chrysalidina*) *floridana* (Cole), *in* Hottinger and Drobne, 1980, pl. 4, figs. 1 - 3

Pseudochrysalidina floridana (Cole), *in* Robinson, 1993, figs. 12.6 - 12.9

Description. Triserial test. Inflated chambers originate from small proloculus located at test apex. Proloculus 0.125 mm in diameter. Thick, agglutinated test wall. Small chambers 0.01 mm in diameter are located in specimen's center. Test height 3 mm, diameter 0.75-1.0 mm.

Material. Seven specimens in two thin sections from 289.2 m and 304.4 m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida; upper Lower – Middle Eocene Avon Park Formation, Florida (Cole, 1941); Middle Eocene to Upper Eocene, Jamaica; Middle to Upper Eocene, Nicaragua. (See details in Appendix Id.)

Comments. Pseudochrysalidina floridana in the ROMP 29A core is larger than the specimens originally described by Cole (1941). Transverse sections show inflated chambers and the lack of a differentiated central zone, which is common to the other conical foraminifera.

Suborder Miliolina Delage and Hérouard, 1896

Superfamily Alveolinacea Ehrenberg, 1839

Family Fabulariidae Ehrenberg, 1839

Genus *Fabularia* Defrance, 1820

Fabularia vaughani Cole and Ponton, 1934

Plate 11, Figs. 1-8; Plate 12, Figs. 1-5; Plate 14, Figs. 1-6; Plate 15, Fig.1-2; Plate 16, Figs. 1-9

Fabularia vaughani Cole and Ponton, 1934, p. 139, pl. 1, figs.1-9

Fabularia vaughani Cole and Ponton), *in* Cole, 1942, pl. 3, fig. 14; pl. 15, fig. 1

Fabularia vaughani (Cole and Ponton), *in* Robinson, 1977, fig. 1, nos. 3 - 6

Fabularia vaughani (Cole and Ponton), *in* Robinson and Wright, 1993, figs. 13.5 -13.7

Description. Megalospheric and microspheric forms present.

Megalospheric form. Test ovoid. Proloculus 0.25- 0.3 mm in diameter. Length 2-4 mm, width 1-3 mm. In axial section individual chambers 0.1-0.3 mm in width; rectangular chamberlets with rounded corners characterize each chamber. In equatorial section chambers 0.1-0.4 mm thick, thinner at center of chamber middle (Plate 16, Fig. 3). Two chambers occupy each whorl, overlapping slightly (Plate 16, Fig. 3).

Microspheric form. Proloculus diameter 0.1 mm. Test 7mm long, 5 mm wide. Eleven chambers, all subdivided into chamberlets increasing in size. Each whorl consists of one chamber divided into chamberlets which are rectangular with rounded edges.

Material. Thirty specimens in three thin sections from 318.2, 319.4 m and 329.8 m.

Geographic and stratigraphic distribution. Avon Park Formation, Hendry County, Florida; lower Middle Eocene-Upper Eocene, Jamaica; Middle Eocene, Nicaragua. (See Appendix Ie for details.)

Comments. The size of megalospheric specimens of *F. vaughani* from the ROMP 29A core are similar to that of the axial section of the holotype (Cole and Ponton, 1934). Equatorial and oblique thin sections are also included in this study. Although the

microspheric form is three to five times larger than the megalospheric form, the overall shape and appearance of the two forms is similar. The microspheric form is described for the first time in this study. Drobne and Cosovic (2009) correlate microspheric fabulariids with cooling events, a result of small ephemeral ice-sheets, which have also been reported in late Middle Eocene fabulariids of the Paris Basin.

Fabularia vaughani var. A

Plate 13, Figs. 1-4

Description. Test elongate, cylindrical. Proloculus 0.4-0.5 mm in diameter. In equatorial section, test width 2-3 mm, length 5-6 mm. Width of chamber 0.1 -0.5 mm thick, with thicker areas in center of chamber where folding to form a semi- circle (ends of entire specimen), and thinner areas at chamber ends. Two chambers occupy each whorl with slight overlap. First chamber undivided. Successive chambers divided into one row of irregularly shaped, rectangular chamberlets. In axial section, test diameter from 2-4 mm. Thickness of chambers 0.1-0.4 mm. Chambers uniform in thickness, except for final layer.

Material. Four specimens in two thin sections from 319.4 m and 329.8m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida.

Comments. Chambers of *F. vaughani* var. A are not uniform in thickness, whereas those of *F. vaughani* are. This species is similar to *Fabularia verseyi Cole* in their narrow, irregular chamberlets.

Large Miliolids

Plate 17, Figs. 1-3; Plate 18, Figs. 1-4

Description. Elongate, oval test. Test length 3.0-4.25 mm, test width 2.5-3.5 mm. External surface may be ribbed, with sutures created where chambers overlap (Plate 18, Figs. 1-4). Proloculus diameter 0.01- 0.02 mm. Chamber arrangement streptospiral. In axial section (Plate 18, Fig. 1), chamber width and length increase with each successive whorl; width 0.25-1.5 mm, depth 0.25 -0.50 mm. In equatorial section, chambers extend entire length of specimen (Plate 17, Figs. 1-3).

Material. Seven specimens in three thin sections from 317.6, 318.2 m and 329.8 m.

Geographic and stratigraphic distribution. Avon Park Formation, Florida.

Comments. Large miliolid specimens have the overall appearance of *Idalina* sp. and *Periloculina* sp., which are recognized from the Mediterranean Neotethys region (Drobne and Cosovic, 2009). No positive identification can be made at this time. However, the morphological features of the Avon Park Formation taxa miliods have similar chamber

arrangement and size as those from the Mediterranean, but occur in the Middle Eocene whereas the Mediterranean are Lower Eocene.

2.6 Discussion

2.6.1 Biostratigraphy of the Avon Park Formation in the ROMP 29A Core

The Avon Park Formation consists of three previously described units: the Avon Park Limestone, Tallahassee Limestone and Lake City Limestone (Table 1.3). When Applin and Applin (1944) initially described the Avon Park Limestone they found *Fallotella floridana* to be the most prevalent and consistent microfossil throughout, which also agrees with its distribution in the ROMP 29A core (Fig.2.1). Unusually large specimens of *Fallotella cookei* resembling *Cushmania americana* have been found at the top of the Avon Park Limestone and at the basal contact with the Lake City Limestone (Applin and Applin, 1944). In the ROMP 29A core *Fallotella cookei* was not found at the top of the Avon Park Formation, but specimens were found at the lower end which may be the contact with the Lake City Limestone as defined by Applin and Applin (1944). Although *Cushmania americana,* a key fossil for the Lake City Limestone, is absent, *Fabularia vaughani,* another lower Middle Eocene Lake City Limestone fossil, is present (Applin and Applin, 1944). *Fallotella floridana* and *F. cookei* were regarded as Middle Eocene by Applin and Applin (1944) and Cole (1942), but were later placed in the lower Ocala Limestone (Bryan, 2001); however, their presence in even earlier sediments of the Oligocene Suwannee Limestone was considered reworked (Applin and Applin 1944). The echinoid *Neolaganum dalli* Twitchell is endemic to the upper Avon Park Limestone

(Carter, 1987) and was found at four depths within the ROMP 29A core (Fig. 2.1). *Neolaganum dalli* is considered a Middle Eocene marker (Carter, 1987).

When Applin and Applin (1944) defined the Tallahassee Limestone and the Avon Park Limestone they were considered equivalent in age to the Yegua Formation of the Claiborne Group of Texas which has an age of Middle Eocene based on the presence of the benthic foraminiferan *Nonionella cockfieldensis* Cushman and Ellisor (1933). *Nonionella cockfieldensis* has a last occurrence age of 36.90 Ma which is just above the 37.2 Ma, Middle/Upper Eocene boundary (Waterman, et al, 2009; Witrock, et al., 2003). The Tallahassee Limestone underlying the Avon Park Limestone was previously dated using the presence of *Discorbis yeguaensis,* which has a last occurrence of 37.34 Ma (Waterman, et al., 2009; Witrock, et al., 2003), just below the Middle/Upper Eocene boundary.

The five larger foraminiferal taxa recognized from the Avon Park Formation in this study give a possible age range of Lower Eocene through Lower Oligocene (Fig. 2.6). This agrees with the age of *Fallotella cookei* in Cuba, found to be Eocene – Oligocene based on the presence of planktic foraminifera (zones P7-P18; Beckmann, 1958). The age of *Fallotella floridana* in Jamaica was verified by Robinson and Wright (1993) and Robinson (2004) with diagnostic planktic foraminifera (zones P7-P19) and calcareous nannoplankton (zones NP18-NP23, Appendix Ib), which also give a range of Eocene to Oligocene.

In summary, the distribution of larger foraminifera in the ROMP 29A core does not agree with the larger foraminiferal occurrences used to distinguish the Avon Park Limestone and Lake City Limestone (Applin and Applin, 1944; Table 2.3). With the

exception of *Fallotella floridana* which was considered widespread (Applin and Applin, 1944), *Fallotella cookei* was found only once in the ROMP 29A core, but according to Applin and Applin (1944) it occurred twice. The absence of *Fallotella cookei* from the top boundary of the Avon Park Formation could be explained by its unconformable boundary with the Ocala Limestone (Applin and Applin, 1944) in which larger foraminifer deposits could have been eroded away. Another explanation is by Winston (1997) proposed the Suwannee Limestone-Ocala Limestone-Avon Park Formation contacts to be facies related, accounting for the difficulties in finding the distribution of larger foraminifera reported by Applin and Applin (1944) in other localities. Winston (1997) identified facies that interfingered because of the repetition of the Suwannee Limestone, Ocala Limestone and Avon Park Formation type units in cores from Indian River County, Florida, which may have resulted in the two occurrences of *Fallotella cookei* in Applin and Applin (1944) compared to the one occurrence found in this study.

The dating problems, in which fossils of Eocene through Oligocene age have been included in the Avon Park Formation (Applin and Applin, 1944; Bryan, 2001) can also be explained by treating the Avon Park Formation, Ocala Limestone and Suwannee Limestone as facies occurring between the Eocene to early Oligocene (Winston, 1997). However, the Avon Park Formation of the ROMP 29A core represents the Avon Park Formation described by Miller (1986), and considering the age determinations of its fauna and information from previous studies of the unit elsewhere, a general age of Eocene is appropriate.

2.6.2 Paleogeography in the Avon Park Formation

Larger foraminifera of the Avon Park Formation are apparently confined to the Caribbean region (Fig. 2.7). Previous work (Beckman, 1958; Bennett, 2001; Cole, 1941; Ituralde-Vincent et al., 2008; Robinson, 1974, 1977, 1995, 1996, 2004, 2009; Robinson and Wright, 1993; Quintas and Crepo, 2003; Serra-Kiel, 2007) shows that all five taxa were present to the extreme north and south in Florida, Jamaica and the Nicaraguan Rise (Fig. 2.7). The Nicaraguan Rise, Jamaica, Cuba, Haiti and the Dominican Republic were all much closer in middle Eocene time and were located west of their present location, accounting for today's broader distribution of the taxa. The absence of *Fabularia vaughani, Pseudochrysalidina floridana* and *Coleiconus christianaensis* in the central part of the distribution area (Cuba, Bahamas, Haiti and Dominican Republic) may be a result of deeper water conditions, which supports a suggested preference for back-reef and nearshore environments (Robinson, 1988; Vecchio and Hottinger, 2007).

The larger miliolids and microspheric *Fabularia vaughani* described herein have been reported only from the ROMP 29A core. Although other larger miliolids existed in the Late Cretaceous, and *Fabularia* was present in the Paleocene of the Neotethys region, they became extinct at the Mesozoic-Cenozoic boundary and Lower Eocene, respectively. The *Fabularia* species and larger miliolids that arose in the Caribbean region are considered endemic (Drobne and Cosovic, 2009); the Caribbean region lost its connection with the Neotethys in the Paleocene when it was separated from the shallow circumtropical seaway. The *Fabularia* species of similar age in the Neotethys and Caribbean regions are considered to have arisen in isolation but under similar ecologic conditions (Drobne and Cosovic, 2009). Drobne and Cosovic (2009) suggested that

microspheric forms of fabulariids in the Paris Basin were indicative of cooling, a result of short-lived ice sheets, which could also possibly account for the occurrence of the microspheric *Fabularia vaughani* and the larger miliolids in the ROMP 29A core, although no evidence of cooling in central Florida has been noted.

2.6.3 The Occurrence of Larger Foraminifera in Paleoenvironments of the Avon Park Formation

The presence of the small echinoid *Neolaganum dalli* Twitchell suggests a very shallow carbonate shelf, less than 5 m deep (Zachos, 1978), with carbonate tidal flats (Sharp, 1980). This echinoid is only definitively found in the Avon Park Formation, although there is a tentative occurrence of *Neolaganum dalli* Twitchell in the Eocene of Jamaica (Donovan and Lewis, 1993). It has been suggested that the shallow-water, high-energy environment of the Avon Park Formation deposits promoted low diversity and low ecological tolerance, based on the presence of the echinoid *Neolaganum dalli* (Carter, 1987). The larger foraminifera from the ROMP 29A core are assumed to have inhabited back-reef and nearshore environments as suggested by similar studies of Robinson (1988) and Vecchio and Hottinger (2007).

Ward et al. (2003) identified depositional environments of peritidal, subtidal and deeper subtidal (Fig. 2.1) in the ROMP 29A core based on the lithofacies. Considering this depositional sequence, *Fabularia cookei*, *F. vaughani, Coskinolina* sp. A and larger miliolids would be associated with peritidal; and *Pseudochrysalidina floridana, Coleiconus christianaensis, Coleiconus* sp. A, *Coleiconus* sp. B, *Fallotella* sp. A and *Fallotella* sp. B would be associated with subtidal (Fig. 2.1).

Consideration of the correspondence of the larger foraminifera occurrence to rock types (and thus, paleoenvironments) of the Avon Park Formation is herein restricted to those taxa that occur at least twice in the ROMP 29A core; this requirement excludes *Coskinolina* sp. A, *Coleiconus* sp. A, *Coskinolina* sp. B, *Fallotella* sp. A and *Fallotella* sp. B (Table 2.4). *Fallotella cookei* occurred in packstones two out of three times, in a grain-dominated packstone and a mud-dominated packstone (Table 2.4). *Fallotella floridana* occurred twelve times, throughout all rock types (Table 2.4). *Fabularia vaughani, Fabularia vaughani* var. A, and larger miliolids also occurred in an assortment of rock types (Table 2.4). *Pseudochrysalidina floridana* and *Coleiconus christianaensis* occurred in wackestone, packstone and grainstone (Table 2.4).

Although the occurrence of the Avon Park Formation larger foraminifera taxa shows no strong relationship to specific rock types, the taxa show some grouping according to depth in core: 1) 370.0 – 329.8 m, 2) 329.8- 314.2 m, and 3) 324.2-279.5 m (Table 2.4). The relationship between the three clusters is a transition from conical foraminifera in the lowest cluster, to enrolled planispiral larger foraminifera in the middle cluster. Overall, (Table 2.5) the larger foraminifera of the Avon Park Formation occur in packstones (containing little mud) 9 out of 15 times, wackestones (containing less than 90% mud) 4 out of 15 times, grainstones (containing no mud) 1 out of 15 times, and rudstone (containing no mud) 1 out of 15 times. Thus, they occur in rock types with little or no mud most of the time, which agrees with the high-energy, shallow-water setting suggested by Carter (1987) on the basis of an environment of low diversity and low ecological tolerance in which the echinoid *Neolaganum dalli* and seagrasses flourished.

2.7 Conclusions

Fallotella floridana, in conjunction with *Neolaganum dalli,* can be used as a marker for the Avon Park Formation in the ROMP 29A core. The age of the Avon Park Formation in the ROMP 29A core is accepted as Eocene on the basis of the known stratigraphic ranges of the larger foraminiferal taxa.

There was no connection between the Neotethys and waters under which the Avon Park Formation in ROMP 29A formed, so fabulariids and the larger miliolids arose in isolation in each region, resulting in endemic species.

The distribution of larger foraminifera in the Avon Park Formation are found in sediments of the peritidal and subtidal zones (Ward et al., 2003), of back-reef and nearshore environments (Robinson, 1988; Vecchio and Hottinger, 2007). Most of the larger foraminifera are concentrated in the subtidal and deeper subtidal zones, but this does not pertain to *Fallotella floridana,* which is equally distributed over rock types of the ROMP 29Acore sequence (Fig. 2.1).

<table>
<tr><th colspan="2"></th><th>Applin & Applin, 1944</th><th>Cooke, 1945</th><th colspan="2">Chen, 1965</th><th colspan="2">Miller, 1986</th><th>This Study</th></tr>
<tr><td rowspan="3">Middle Eocene</td><td rowspan="2">Bartonian</td><td>Avon Park Limestone</td><td>Avon Park Limestone</td><td rowspan="3">Claiborne Group</td><td rowspan="2">Avon Park Limestone</td><td rowspan="3">Avon Park Formation</td><td rowspan="2">Avon Park Limestone</td><td rowspan="3">Avon Park Formation</td></tr>
<tr><td>Tallahassee Limestone</td><td>Tallahassee Limestone</td></tr>
<tr><td>Lutetian</td><td>Lake City Limestone</td><td>Lake City Limestone</td><td>Lake City Limestone</td><td>Lake City Limestone</td></tr>
</table>

Table 2.1 Previous stratigraphic studies of the Middle Eocene Avon Park Formation of Florida.

Benthic foraminiferal grain-dominated packstone
Benthic foraminiferal wackestone/ mud-dominated packstone
Caliche
Collapse breccias
Intraclast floatstone/rudstone
Laminite
Planktic foraminiferal wackestone/mud-dominated packstone
Rip-up clast breccias
Skeletal-grain-dominated packstone/grainstone
Skeletal floatstone/rudstone
Skeletal wackestone/mud-dominated packstone
Stromatolite

Table 2.2 Lithofacies (in alphabetical order) from the Avon Park Formation identified by Ward et al. (2003).

Fallotella cookei Moberg, 1928	Pages 173-174, Plate 1, Figs. 1-11; Pages 175-176, Plate 2, Figs. 1-9
Fallotella floridana Cole, 1941	Pages 177-178, Plate 3, Figs. 1-4; Pages 179-180, Plate 4, Figs. 1-15; Pages 181-182, Plate 5, Figs. 1-11; Pages 183-184, Plate 6, Figs. 1-11; Pages 185-186, Plate 7, Figs. 1-19; Pages 189-190, Plate 9, Figs. 1-26 Pages 191-192, Plate 10, Figs. 1-4, 6, 9-15,17-26.
Fallotella sp. A	Pages 191-192, Plate 10, Figs. 5, 7
Fallotella sp. B	Pages 191-192, Plate 10, Figs. 8, 16
Coskinolina sp. A	Pages 187-188, Plate 8, Fig. 1
Coskinolina sp. B	Pages 187-188, Plate 8, Fig. 2
Coleiconus christianaensis Robinson,1933	Pages 187-188, Plate 8, Figs. 3-5
Pseudochrysalidina floridana Cole, 1941	Pages 187-188, Plate 8, Figs. 6-12
Fabularia vaughani Cole and Ponton, 1934	Pages 193-194, Plate 11, Figs. 1- 8 Pages 195-196, Plate 12, Figs. 1-5 Pages 199-200, Plate 14, Figs. 1-6 Pages 201-202, Plate 15, Figs. 1-2 Pages 203-204, Plate 16, Figs. 1-9
Fabularia vaughani var. A	Pages 197-198, Plate 13, Fig. 1-4
Large miliolids	Pages 206-207, Plate 17, Figs. 1-7

Table 2.3. Larger foraminifera recovered from the Avon Park Formation for this study.

Depth (m)	Rock Types	*Fallotella cookei*	*Fallotella floridana*	*Coskinolina* sp. A	*Fabularia vaughani*	*Fabularia vaughani* var. A	Larger miliolids	*Pseudochrysalidina floridana*	*Coleiconus christianaensis*	*Coleiconus* sp. A	*Coskinolina* sp. B	*Fallotella* sp. A	*Fallotella* sp. B
279.5	Skeletal grain-dominated packstone		1									1	1
280.7	Benthic foram grain-dominated packstone		1					1	1	1	1		
283.8	Skeletal grain-dominated packstone		1						Cluster 3				
289.2	Sketetal wackestone		1					1					
304.4	Coarse benthic foram grainstone		1					1	1				
314.2	Sketetal wackestone							1					
317.6	Skeletal grain-dominated packstone		1				1						
318.2	Sketetal wackestone		1		1		1						
319.4	Benthic foram grain-dominated packstone				1	1	Cluster 2						
329.8	Rudstone		1		1	1	1						
351.1	Benthic foram grain-dominated packstone		1	1									
351.4	Benthic foram grain-dominated wackestone		1										
351.7	Grain-dominated packstone	1		Cluster 1									
367.2	Mud-dominated packstone	1	1										
370.0	Grain-dominated packstone	1	1										

Table 2.4 Larger foraminiferal occurrence in rock types of the Avon Park Limestone.

Rock Type	Description
Grainstone	Grain supported, contains no mud.
Mudstone	Mud supported, contains, more than 90% mud and less than 10% grains.
Packstone	Grain supported, contains little mud.
Rudstone	Coarse limestone supported by grains larger than 2 mm in diameter.
Wackestone	Mud supported, consists of more than 10% grains and less than 90% mud.

Table 2.5 Description of rock types in ROMP 29A core. Adapted from Dunham (1962).

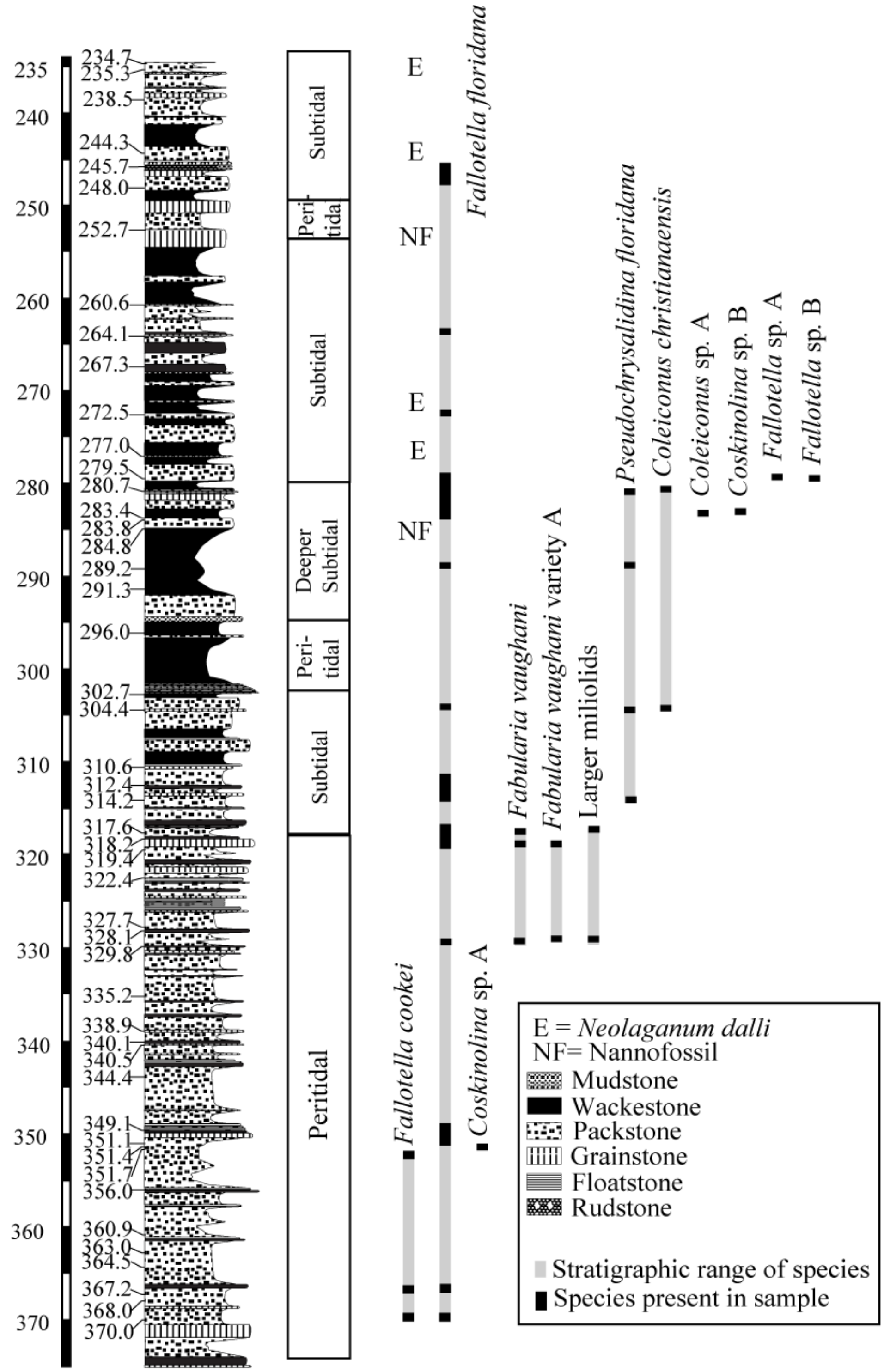


Figure 2.1 Stratigraphic distribution of larger foraminifera in the Avon Park Formation. Scale is m below surface. Lithology adapted from Ward et al. (2003).

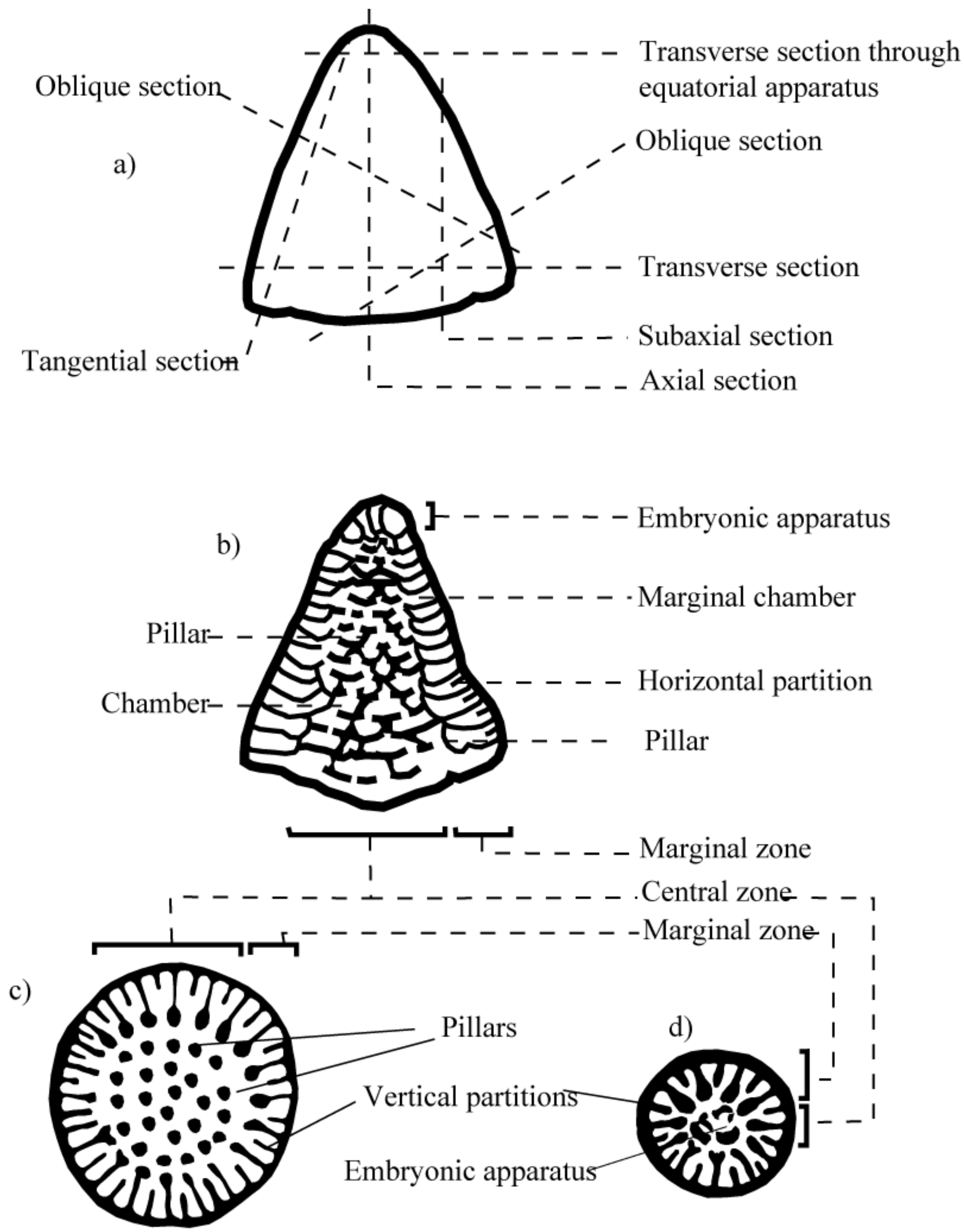


Figure 2.2 Features of conical foraminifera, a) thin section terminology; b) axial section; c) transverse section through base of cone; d) transverse section through embryonic apparatus.

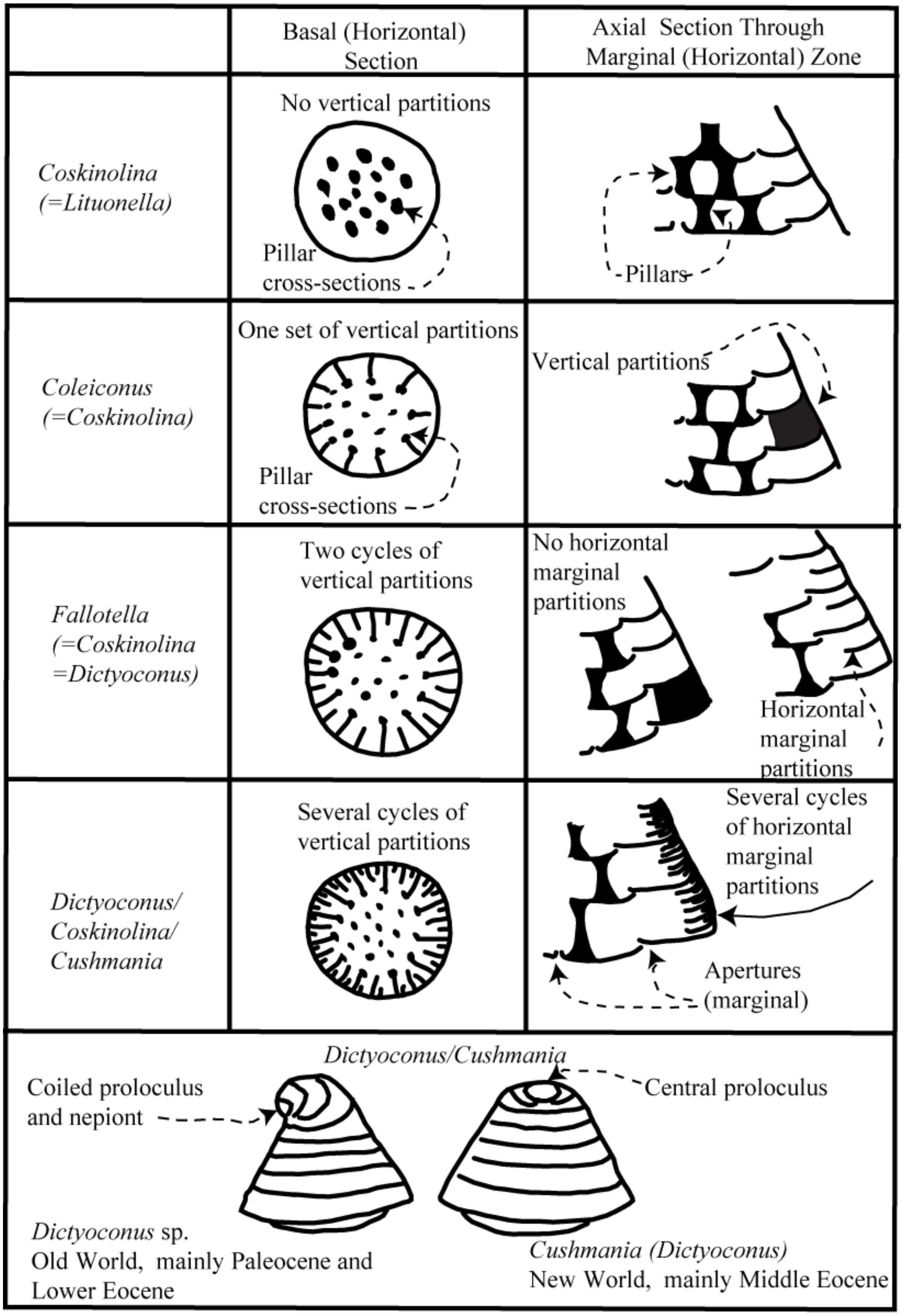


Figure 2.3 Horizontal and vertical section through conical larger foraminifera. Approximate magnification x 10. “=” indicates old terminology. Adapted from Robinson, unpublished research.

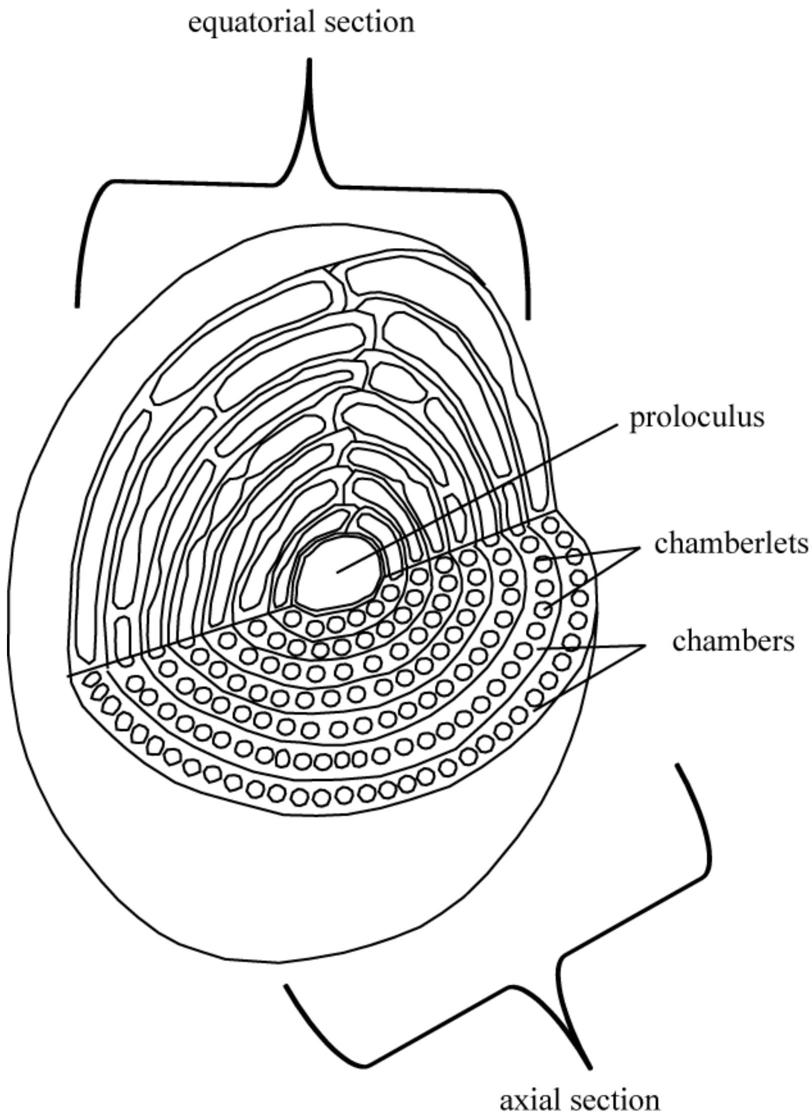
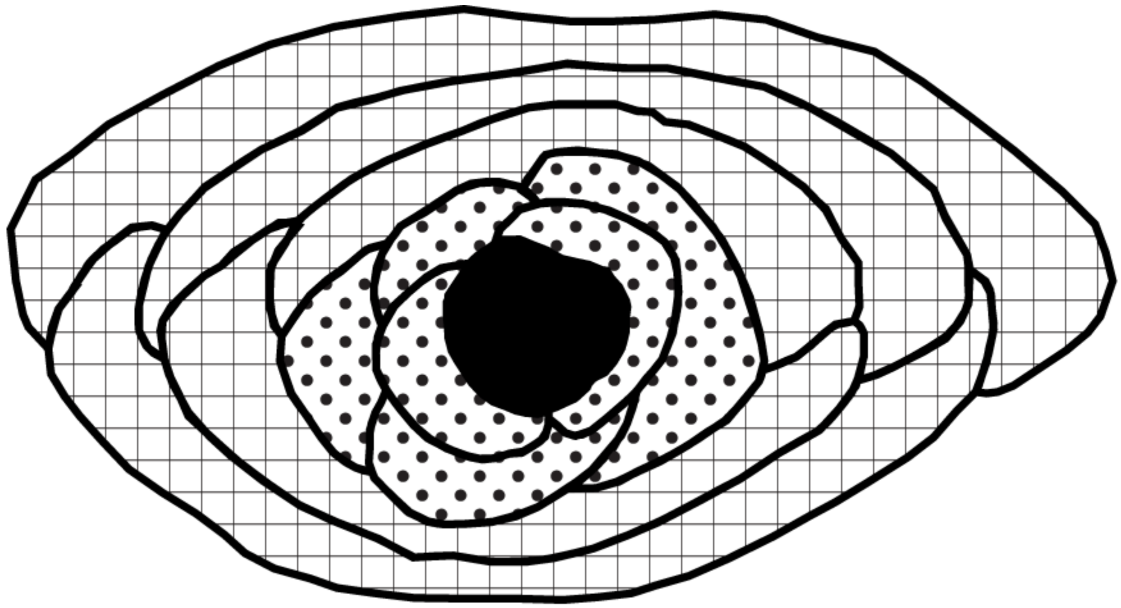


Figure 2.4 Three-dimensional sketch of a *Fabularia* sp. showing the morphological features used in the description of the tests.



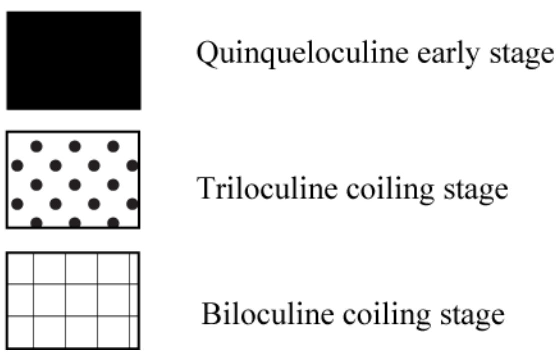


Figure 2.5 Sketch of equatorial section in *Fabularia* sp., showing coiling stages. Adapted from Drobne (2009).

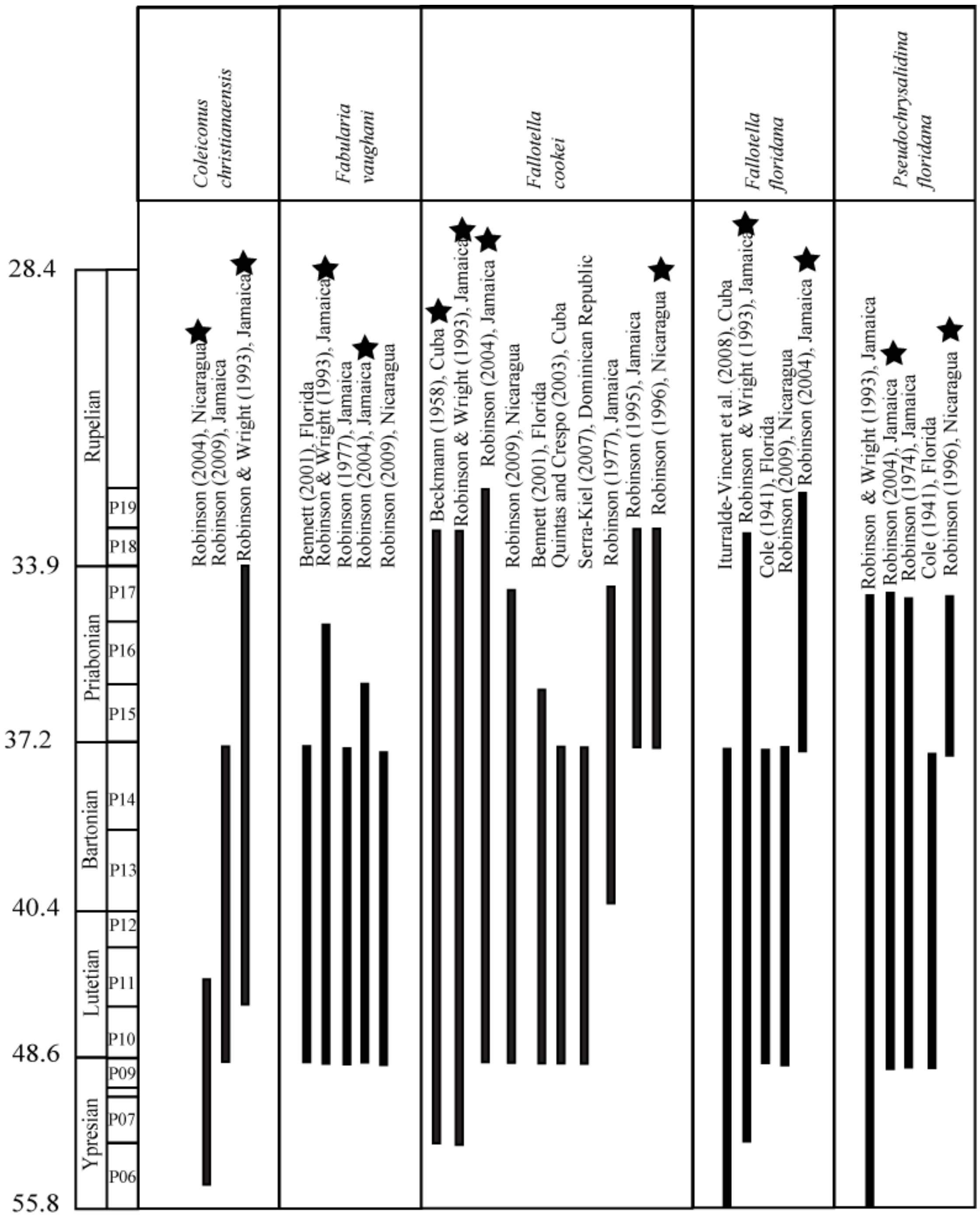


Figure 2.6 Stratigraphic ranges of the larger foraminifera in the Eocene of the Caribbean and the Americas, as reported by various authors. Star = species age confirmed by other zonation fossils.

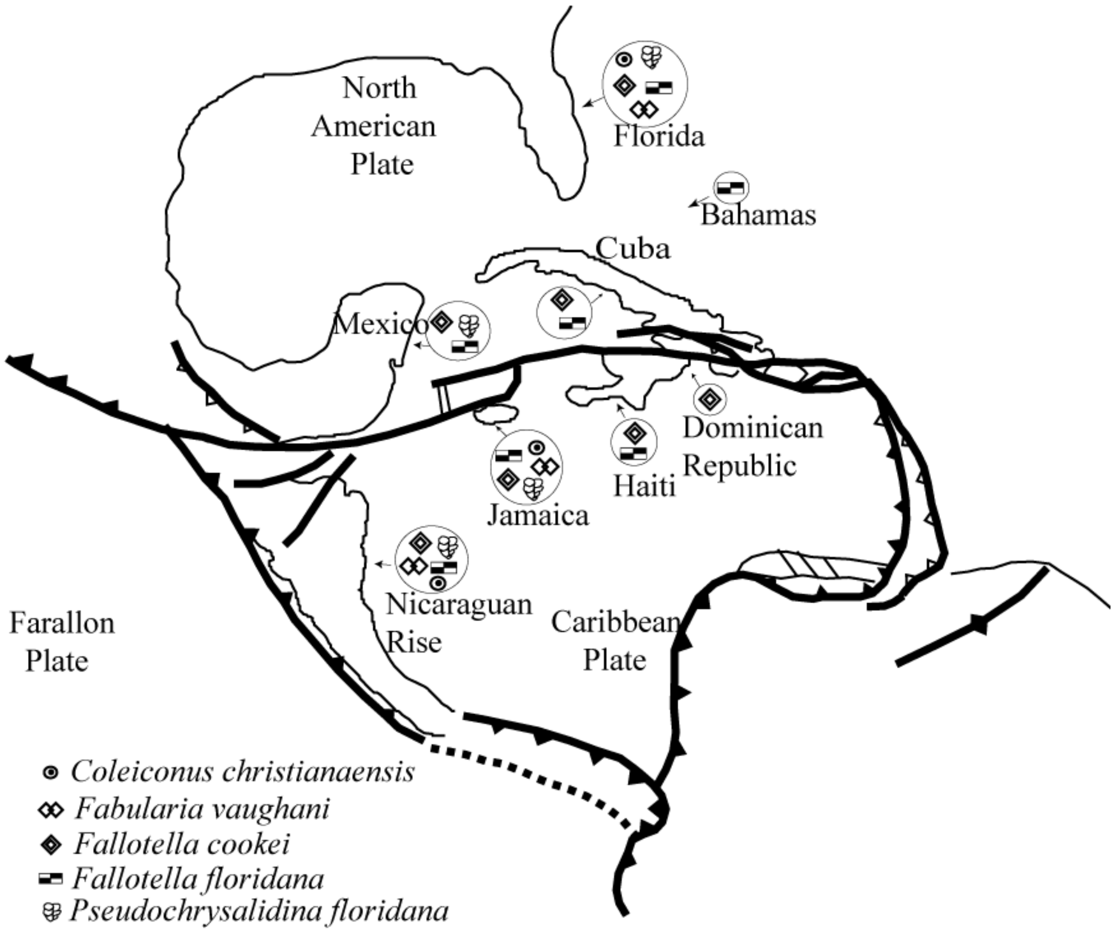


Figure 2.7 Geographic distribution of the Late Eocene larger foraminifera of the Avon Park Formation found in the ROMP 29A core. Map adapted from Pindell (2009).

CHAPTER 3

BIOSTRATIGRAPHY AND LARGER FORAMINIFERAL SYSTEMATICS OF THE OCALA LIMESTONE

3.1 Introduction

The Ocala Limestone is composed of Middle to Late Eocene carbonate deposits that crop out from the southern Florida Platform northward into Georgia (Cooke, 1915). The unit makes up part of the Floridan Aquifer, which houses a large part of Florida's groundwater reserves. The Regional Observational and Monitoring Program (ROMP) 29A core, the material for this study, was collected in northern Highlands County, south-central Florida (Fig. 1.1) by the Southwest Florida Water Management District, and originally investigated to determine the sequence stratigraphy of the upper Floridan Aquifer and its relationship to carbonate porosity and regional transmissivity (Ward et al., 2003). The sequence of the Ocala Limestone, which includes 85 m between 150 m and 235 m within the core, has a high content of larger foraminifera that are the subject of this study.

The ages of shallow-water, tropical Paleogene sediments are typically based on the biostratigraphy of larger foraminifera, and this study investigates the temporal and spatial distribution of larger foraminifera within the Ocala Limestone (ROMP 29A core), Highlands County, Florida, as compared to other localities in the U. S. Gulf states and Caribbean region. The biostratigraphic and geographic ranges of the species were compiled from comparative studies of the species from the Ocala Limestone (ROMP 29A

core), Highlands County, Florida; Ocala Limestone, Mayo Quarry, Lafayette County, Florida; and the Upper Eocene Lower Montpelier Formation (Dressikie, St. Mary Parish, Jamaica); and other reported occurrences in the region.

The larger foraminifera Nummulitidae have been shown to respond quickly to environmental changes and cyclical variations in conditions of sedimentation. This phenomenon was reported by Less et al. (2008), who observed the effects of differences in environmental conditions on the distribution, reduction in the number of operculinid (undivided) chambers, increase in the number of chamberlets and the partial increase in proloculus (first chamber) diameter in middle to late Eocene *Heterostegina* sp. and *Nummulites* sp. in the Western Tethys region. These morphologic changes are investigated quantitatively in Chapter 4, and the taxonomy and stratigraphic distribution of the taxa is presented in this chapter.

The rocks of the Ocala Limestone have a porosity of 30-40 % (Loizeaux, 1995). However, because of its non connected pores, the formation is considered a semiconfining unit of low hydraulic conductivity by Ward et al. (2003), who also identified three depositional units based on the sedimentology, larger foraminiferal genera and other skeletal content. The lowest depositional unit of the Ocala Limestone in the Romp 29A core overlies an unconformity bounding the top of the Avon Park Formation between 234.7 and 207 m, and consists of 27.7 m of a larger benthic foraminiferal wackestone. The middle unit is 28.4 m thick, lies between 207 and 178.6 m, and is composed predominantly of *Lepidocyclina* sp. wackestone, with a thin bed of packstone containing abundant *Lepidocyclina* sp. The uppermost unit is 26.4 m thick, lies between 178.6 and 152.2 m and consists of a mixed-skeletal wackestone with small

packstone lenses and a 0.6-m-thick layer of *Lepidocyclina* sp. floatstone. Loizeaux (1995) considered these same three units to be major coarsening- and shallowing-upward sequences within the Ocala Limestone. These depositional units are each 4.5 – 15.2 m thick, and together they comprise larger foraminiferal wackestone and larger foraminiferal packstone (Ward et al., 2003) lenses. The three divisions have also been previously identified (Vernon 1951, Puri 1957) as the Inglis, Williston and Crystal River formations; however, other studies (Applin and Applin, 1944; Miller, 1986) have not recognized these stratigraphic units, suggesting the divisions are localized.

Numerous echinoids are also present in the deposits of the ROMP 29A core. The echinoid taxon found in the ROMP 29A core, *Neolaganum dalli* Twitchell, has been shown to be a good age indicator (Oyen and Portell, 2001; Carter, 1990; Carter, 1987), and it aids in the biostratigraphy of the Ocala Limestone.

In this chapter, the following hypotheses are addressed:

1. There is a correspondence between the larger foraminiferal biostratigraphy and the lithologically defined depositional sequences identified recently in the Ocala Limestone sampled by the ROMP 29A core (Ward et al., 2003), which would suggest that the distribution of the taxa was ultimately controlled by local facies.
2. The stratigraphic ranges of the larger foraminiferal species identified in the ROMP29A core of the Ocala Limestone correlate to their ranges found elsewhere in the Americas and Caribbean. This knowledge strengthens the use of the taxa as a biostratigraphic tool.

3.2 Historical Review of the Lithology of the Ocala Limestone

Dall (1892) first used the name Ocala Limestone to describe the limestone in quarries found near Ocala, in Marion County, Florida (Table 3.1). He assumed the Ocala Limestone to be Eocene and associated with supposed Oligocene deposits described as "Nummulitic beds" by Heilprin (1882). Dall (1892) further divided the Eocene deposits in peninsular Florida into three units: 1) the lower "Miliolitic Limestone" (a part of the Vicksburg Group also found in Louisiana), 2) "Nummulitic Limestone" (Ocala Limestone) and 3) "Orbitoides Limestone". In 1903, Dall used the term "Peninsular Limestone" for the Orbitoides Limestone that lay between the Vicksburg Group and the Ocala Limestone.

In 1909, Matson and Clapp adopted the names Peninsular Limestone and Ocala Limestone, and added the name "Marianna Limestone" to describe the rock found in northwestern Florida. The "Marianna Limestone" was determined to be of Oligocene age according to the larger foraminifer *Lepidocyclina mantelli* it contained (Heilprin, 1882).

The Ocala Limestone was assigned to the Jackson Stage of the Upper Eocene by Cooke (1915). He found that the Peninsular Limestone and Ocala Limestone were equivalent units by correlating their faunal content with the Marianna Limestone overlying the Ocala Formation. Cooke and Mossom (1929) placed all of the exposed Eocene sediments in Florida into the "Ocala Formation," which included from oldest to youngest: the Peninsular Limestone, Miliolitic Beds, Nummulitic Limestone and Orbitoides Limestone.

Applin and Applin (1944) divided the Ocala Limestone into informal upper and lower members, based on faunal differences (Table 3.1). The lower member contained

the key smaller foraminifera *Amphistegina pinarensis* associated with the larger foraminifer *Camerina vanderstoki*, whereas the upper member was characterized by the larger foraminifer *Lepidocyclina ocalana.*

In 1951, Vernon reported Eocene deposits in Citrus and Levy counties, distinguishing the lower 24.3 m of the "Ocala Limestone" from the upper Moodys Branch Formation (Table 3.1). He then was able to divide the Moodys Branch Formation into two units; the lower unit he named the Inglis Member, which he correlated with the informally defined lower member of the Ocala Limestone (Applin and Applin, 1944). The upper member he named the Williston Member. These members were differentiated from each other by larger foraminifera, although the species overlapped considerably in their ranges.

Murray (1952) studied the carbonate facies of the Jackson Stage (Eocene) deposits, including the Moodys Branch Formation and the Ocala Limestone of Vernon (1951), and the lower and upper Ocala members of Applin and Applin (1944). He determined the Ocala Group to be a lithostratigraphic unit that contained all the characteristic sediment types of the Jackson Stage in Florida.

Puri (1957) raised the stratigraphic level of the Ocala Limestone to the Ocala Group based on fauna, which he divided into the Inglis, Williston and Crystal River Formations (Table 3.1). Faunizones (faunal zones) were established within each formation, as follows. The Inglis Formation included the *Periarchus lyelli floridanus - Plectofrondicularia? inglisiana* faunizone; the Williston Formation included the *Nummulites moodybranchensis* faunizone and *Operculinoides jacksonensis* faunizone; and the Crystal River Formation included the *Lepidocyclina (Nepurolepidina) chaperi*

faunizone, *Asterocyclina - Spirolaea veroni* faunizone, *Nummulites vanderstoki - Hemicythere* faunizone, and *Spiroloculina newberryensis* faunizone (Table 3.2).

Miller (1986) outlined the lithology of the Ocala Limestone (Table 3.1). The lower facies consisted of a "granular" limestone ranging from a grainstone to a packstone, whereas the upper unit consisted of a soft, friable, muddy, granular limestone, which varies from packstone to wackestone and contained numerous larger foraminifera.

Scott (1992) explained the reasons why the Florida Geological Survey had returned to the use of the Ocala Limestone terminology as follows: Puri (1957) had "raised the Ocala to a group and recognized formations based on the incorporated foraminiferal faunas," but these subdivisions because of their biostratigraphical nature were very hard to indentify and thus, not in keeping with the North American Code on Stratigraphic Nomenclature (2005). Scott (1992) outlined the newly adopted Ocala Limestone terminology in which the formation was to be divided into two units, lower and upper members, based on lithologic differences (Table 3.1). The lower subdivision is composed of a granular limestone (grainstone to packstone), whereas the upper unit consists of a granular limestone (packstone to wackestone with very little grainstone). The upper unit is usually soft and friable, containing abundant larger foraminifera (Scott, 1992). However, the entire Ocala Limestone in southern Florida consists of wackestone to pelletal limestone (Miller, 1986).

Bryan (2005, 2008) described the Ocala Limestone's lower member as having a shoal assemblage which was deposited in high-energy, nearshore waters. The upper part of the Ocala Limestone contained shelf faunal assemblages, including *Nummulites* sp. and *Lepidocyclina* sp., generally preserved in limestones, indicative of very shallow

environments. In sediments deposited in slightly deeper waters, *Lepidocyclina, Pseudophragmina* and *Asterocyclina* were most prevalent.

3.3 Review of Morphological Terms Used to Describe Larger Foraminifera of the Ocala Limestone

Lamarck (1801) initially described the genus *Nummulites* as lenticular with simple walls, and planispiral whorls separated into many chambers. The first two formed chambers are the protoconch and deuteroconch, and together constitute the embryon (Fig. 3.3). Chambers are added in a planispiral manner in whorls with a translation rate of zero along the vertical plane (Hottinger, 2006). The thickenings within the chamber walls are termed pillars, and chambers are separated by vertical partitions known as septa (Fig. 3.3). External ornamentation traces the position of the septa and pillars where they meet the external surface of the test (Fig. 3.3). Both sides of the test (spiral and umbilical) are identical and the test is bilaterally symmetrical. The marginal cord (Fig. 3.3) is a thickened area on the shell margin with an accumulation of canals, or interconnected spaces that were filled with protoplasm.

D'Orbigny (1826) characterized the genus *Heterostegina* as having chambers and chamberlets that are visible externally on the surface of the test. Chambers are added planispirally, and undivided chambers occurring after the proloculus and deuteroloculus are termed operculine (Fig. 3.4). Chambers increase in length away from the embryon and are subdivided into chamberlets (Fig. 3.4). Tests are normally thickest over the embryon and thin towards the periphery (Fig. 3.4). Surface ornamentation may occur

over the embryon in the form of papillae, indicating the position of the pillars externally on the test surface (Fig. 3.4).

The genus *Lepidocyclina* was described by Gumbel (1870) as a flattened test comprised of chambers that surround a column of roundish, median chambers (Fig. 3.5). The first row of chambers surrounding and in direct contact with the embryon are the peri-embryonic chambers (Fig. 3.6). Auxiliary chambers formed after the deuteroconch (Fig. 3.6) may be the largest of the peri-embryonic chambers, generally growing in the direction of the protoconch, and covering the wall that separates the protoconch and deuteroconch. The equatorial layer (Fig. 3.5) is a column of equatorial chambers which extends horizontally from both sides of the embryon. The equatorial chambers have various shapes including arcuate, ogival, rhombic, spatulate, and hexagonal, in equatorial section, and were considered by Adams (1987) as a morpholologic feature of taxonomic importance (Fig. 3.7). Lateral chambers are cuboid in axial section, lying above and below the equatorial layer and making up the remainder of the chambers in the beast. Areas of thickening that may occur amid the lateral chambers are termed pillars (Fig. 3.5), and tubercles (surface ornamentation) may be present where these pillars meet the test surface.

The structure of orthophragminids is centered around a two-chambered embryon (Figs. 3.8, 3.9). An equatorial layer developed in the horizontal plane around the embryon, consisting of square and rectangular chamberlets arranged in concentric bands (Fig. 3.8). Lateral chambers occur on either side of the equatorial layer, with scattered pillars (thickened structures) comprising the remainder of the foraminiferal test (Fig. 3.8). Surface ornamentation termed “granules” occur where the pillars meet the surface (Fig.

3.8). Auxillary chambers are the first row of the equatorial chamberlets that are in direct contact with the embryon (Fig. 3.9).

3.4 Methods

3.4.1 Sampling Methods Used in the Ocala Limestone

Three hundred ninety-eight rock samples were taken from a core of the ROMP 29A test corehole drilled by the Southwest Florida Management District (Fig. 1.1). The core is archived at The Florida Geological Survey, in Tallahassee, Florida. ROMP 29A penetrated the Upper Floridan Aquifer down to a depth of 234.7 m, including the Avon Park Formation, the Ocala Limestone and the Suwannee Limestone (Fig. 1.3). The core was sampled at regular intervals of 1.5 m or where there were visible changes in the lithology (including color, texture of the sediments). Each sample collected was approximately 5 cm in length. Of the 398 samples collected, 112 were selected for further study because they were located at lithology changes or from areas in which their larger foraminiferal content was representative of that core interval. Samples from Jamaica (Dressikie, St. Mary Parish) and Mayo Quarry (Lafayette County, Florida) were available, collected by Edward Robinson (sample ER176) and Jonathan Bryan, respectively, consisted of specimens previously processed (free of their rock matrix). Samples of calcareous nannofossils, a primary age indicator, were collected at core depths of 154.2 m, 188.1 m, 192.7 m and 230.0 m.

3.4.2 Specimen Preparation and Identification in the Ocala Limestone

The sedimentary rock removed from test core ROMP 29A is predominantly a soft, friable limestone with occasional areas of hard, indurated limestone. The procedures used to prepare the larger foraminifera so that their embryonic (first and second) chambers, (a key to taxonomic identification) could be studied are dependent on the sample type: for the hard, indurated samples, thin sections were made to reveal the larger foraminifera; and for the friable samples a washing and splitting technique was utilized. In the case of the free specimens of St. Mary Parish, Jamaica and Lafayette County, Florida this step was not necessary.

Thin sections were made from epoxy-impregnated chips to fit on 50 mm X 75 mm glass slides. The larger foraminifera were viewed using a petrographic microscope. Pictures displaying the morphology of the larger foraminifera for measurements were taken using a digital camera mounted on the petrographic microscope. A total of 25 thin sections were made, and an additional 3 thin sections were provided by the U. S. Geological Survey.

In non-indurated samples a system of washing and specimen splitting separated the foraminifera from the matrix in each sample. The samples were initially fragmented into approximately 1-cm-in-diameter pieces by hand or by using a rock hammer. The rock pieces were soaked in a beaker with deionized water until the sediments were disaggregated and the foraminifera freed from the matrix or cement. The samples were washed through a 0.045-mm mesh sieve until all of the clay sized and silt sized sediments were removed, and then dried in the air or oven.

The approach of sectioning the larger foraminiferal specimens to observe the interior structure (the basis of their species definitions) varied according to the taxa examined. In order to reveal the internal structure of *Nummulites* sp. and *Heterostegina ocalana,* the following technique of heating and chilling was used. The washed samples were either heated in an oven to temperatures of $\geq 400^{o}$ F, or boiled in water in a small pot on a hot plate until dry, depending on the ease at which the larger foraminifera split. This step could consist of both the oven and boiling water techniques being used alternatively multiple times, in order to successfully spilt specimens. The dry, hot samples were then dropped into cold water, because expansion with heat and contraction with cold helps promote splitting of the foraminifera across the equatorial plane. This process was repeated in some samples until a sufficient number for statistical analysis, approximately ≥ 15 were obtained. The samples were placed in an ultrasonic cleaner for at least 45 minutes to dislodge the clay sized and silt sized particles. The splitting process yielded clockwise- and anticlockwise-coiled sides of a specimen. These (complementary) split sides were sorted according to coiling direction to prevent duplication (i.e., measuring two sides of the same specimen) and fixed onto microscopic slides using gum tragacanth, a water-soluble glue.

Lepidocyclina sp. does not split using the heating and chilling method because the internal structure does not have a plane of weakness across the equatorial plane. Therefore, they were ground down to the middle of the embryonic chambers. The specimens were placed on the tip of the index finger and rubbed on #400 grit paper or rubbed across a glass plate containing #300 grade grit. To guarantee that each specimen was not ground down beyond the embryonic apparatus, it was viewed under the

microscope at successive stages of grinding. When the ground specimens showed the equatorial planes they were placed in an ultrasonic cleaner for at least 45 minutes or until clean, and then dried in the air or the oven at 300° C. The echinoid samples were soaked in deionized water overnight to remove the surrounding matrix, placed in an ultrasonic cleaner for 10 hours for further cleaning, and dried in an oven at 350° C for approximately two hours.

The larger foraminiferal taxa were identified with the aid of the Catalogue of Foraminifera (Ellis and Messina, 1941-2009) and other literature of the Caribbean - Florida region and tropical-subtropical northern Atlantic region. Larger foraminiferal species have a variety of life cycles which can result in different morphologies, but most exhibit two alterations in generations: A-generations produce A-forms and B-generations produce B-forms (Bryan, 1995). The A-generation results from haploid gamonts which reproduce sexually, while the B-generation results from a diploid agamont which reproduces asexually (Bryan, 1995). Both the A-forms and B-forms of the larger foraminifera in this study have been distinguished (Systematic Paleontology section).

Five echinoid specimens were identified by Roger Portell from the Florida Museum of Natural History, University of Florida, Gainesville, Florida. Calcareous nannofossils specimens were identified by Mark Jiang of Ellington and Associates, Inc., Texas.

3.5 Results

The larger foraminifera present in the ROMP 29A core of the Ocala Limestone are listed in Table 3.3 and defined in the Systematic Paleontology section (below). The

A-form test diameters are smaller than those of the B-forms (Plate 19, Fig. 3), whereas the A-form embryon diameters are larger than those of the B-forms (Plate 19, Fig. 4).

The distribution of the larger foraminifera in core ROMP 29A (Figs. 3.1, 3.2) showed the following biostratigraphic events (at m below ground surface):

- 154.2 m - uppermost occurrence of *Lepidocyclina* spp
- 163.6 m - uppermost occurrence of *Nummulites floridensis* and *Nummulites willcoxi*
- 170.0 m - uppermost occurrence of *Nummulites striatoreticulatus* and *Nummulites* sp. B
- 170.6 m - uppermost occurrence of *Heterostegina ocalana*
- 175.0 m - lowermost occurrence of *Nummulites* sp. B
- 178.0 m - uppermost occurrence of *Nummulites* sp. A
- 178.9 m - lowermost occurrence of *Nummulites striatoreticulatus* and *Lepidocyclina pustulosa*
- 188.0 m - lowermost occurrence of *Nummulites* sp. A
- 210.0 m - lowermost occurrence of *Lepidocyclina ocalana* var. D
- 225.0 m - lowermost occurrence of *Lepidocyclina ocalana* var. A, *Lepidocyclina* chaperi, *Lepidocyclina ocalana* var. B, and *Lepidocyclina ocalana* var. C
- 232.7 m - lowermost occurrence of *Heterostegina ocalana, Nummulites willcoxi and Nummulites floridensis*

The sequence also contained several non-foraminiferal age-diagnostic taxa. The echinoid *Neolaganum dalli* Twitchell was found at depths of 236.6 m, 245.7 m, 272.8 m

and 277.3 m in the upper portion of the Avon Park Formation in the ROMP 29A core (Fig. 3.1). Samples at depths 154.2 m and 188.1 m yielded the calcareous nannofossil *Ericsonia formosa,* the 192.7 m level yielded *Calcidiscus protannulus* and *Chiasmolithus titus,* and the 755 m level yielded *Discoaster saipanensis* and *Discoaster barbadiensis.*

3.5.2 Systematic Paleontology

Order Foraminiferida Eichwald, 1830

Family Nummulitidae de Blainville, 1827

Genus *Nummulites* Lamarck, 1801

Type species: *Camerina laevigata* Bruguière, 1792

Nummulites floridensis Heilprin, 1885

Plate 18, Fig. 1

Nummulites floridensis Heilprin, 1885, p. 321, text-fig.

Camerina jacksonensis Gravell and Hanna, 1935, p. 331, pl. 29, fig. 12.

Operculina vaughani (Cushman) *in* Gravell, 1935, pl. 29, figs. 12, 21.

Operculinoides floridensis (Heilprin) *in* Cole, 1941, p. 20-21, pl. 9, fig. 8; pl. 10, figs. 1-3.

Nummulites (Operculina) *floridensis* (Heilprin) *in* Frost and Langenheim, 1974, p. 78, pl. 12, figs. 5- 6, 8- 9.

Operculinoides vaughani (Cushman) *in* Cole, 1952, p.11, pl. 2, figs. 15, 16.

Operculinoides willcoxi (Heilprin) *in* Puri, 1957, p.135-136, pl. 7, figs. 4, 5.

Palaeonummulites floridensis (Heilprin) *in* Robinson, 1993, p. 333, pl. 30, 1-3.

Nummulites floridensis (Heilprin) *in* Bryan, 2005, p. 8, 22, pl. 3, figs. A, B.

Diagnostic features. Flattened, fragile (breaks easily during preparation) tests, average diameter of 8-12 mm. Whorls width increase rapidly in size.

External features: Test is flattened and fragile. Sutures form distinct grooves (septal filaments) towards middle and outer areas of test; towards embryonic areas raised grooves give rise to granules. Test diameter ranges from 1.5 to 4 mm.

Internal features: Chambers start with tight spire in embryonic area, then whorl width increases from first to second whorl (Table 3.4). Average number of chambers in each whorl increases with each successive whorl (Table 3.4). Protoconch ranges from 0.06 – 0.11 mm with mean of 0.09 mm (Table 3.4).

B-forms are much less abundant than A-forms, with A-forms consisting of more than 95% of each sample. Protoconch in A-forms is commonly much smaller than that of B-forms. Whorls of B-forms tend to increase more rapidly with each successive whorl than in A-forms, producing less tightly wound whorls.

Material. Specimens well-preserved. Ten specimens from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone, Highlands County, Florida; Upper Eocene, Panama; Middle Eocene, Costa Rica; Middle Eocene Mexico; Middle-Upper Eocene, Cuba; Upper Eocene, Trinidad; Upper Eocene, Brazil; Lower Middle - Upper Eocene, Jamaica; Upper Middle Eocene, Ecuador; Lower Middle Eocene, Jamaica; Upper Eocene, Louisiana (Gravell, 1935); Middle Eocene, French Lesser Antilles; Lower Middle Eocene, Cuba (see appendix IIa for details).

Comments. *Lepidocyclina floridensis* is widely distributed in the Upper Eocene (Fig. 3.10) and has the most southerly occurrence of the larger foraminifera included in this study.

Nummulites striatoreticulatus Rutten, 1928

Plate 18, Fig. 2

Nummulites striatoreticulatus Rutten, 1928, p. 1068-1070, text figs. 41-50, pl. figs. F- J.

Camerina vanderstoki (Rutten and Vermunt) *in* Cole, 1941, p. 28-29, pl. 8, figs. 5, 8.

Camerina vanderstoki (Rutten and Vermunt) *in* Cole, 1942, p. 27-28, pl. 8, fig. 10.

Camerina striatoreticulatus (Rutten) *in* Cushman, 1952, p. 8-9, pl. 3, figs. 16, 18- 20.

Operculinoides vanderstoki (Rutten and Vermunt) *in* Puri, 1957, p. 133-134, pl. 7, figs. 12-13.

Nummulites striatoreticulatus (Rutten) *in* Robinson and Wright, 1993, p.331, 333, pl. 30, fig. 6.

Diagnostic features. Rounded tests, closely wound whorls, with long chambers. Average number of whorls is 6. Distinctive retiform (net-like arrangement) or pseudo retiform structure.

External features. Rounded, smooth, translucent test, with suture lines forming straight, septal filaments. Test diameter ranges from 2 to 3.5 mm.

Internal features. Mean cross diameter of protoconch is less than that of deuteroconch (Table 3.4). Mean of deuteroconch/ protoconch ratio is 1.16. Specimens have 3 - 6 whorls, showing increase in mean number of chambers protoconch in successive whorls. Average whorl widths increase from first to fourth whorl (Table 3.4).

B-forms are less abundant than A-forms. Protoconch in A-forms is usually much smaller than that of B-forms. Whorls of B-forms tend to increase more rapidly with each successive whorl than in A-forms and result in specimens with larger test diameters.

Material. Specimens well-preserved. Twenty-nine specimens from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone, Highlands County, Florida; Upper Eocene, Trinidad; Upper Middle Eocene- Upper Eocene, Jamaica; Middle Eocene, Mexico; Middle Eocene, Mexico; Middle Eocene, Costa Rica; Upper Eocene, Panama; Middle Eocene, French Lesser Antilles; Lower Middle Eocene, Cuba (see appendix IIb for details).

Comments. N. striatoreticulatus has an average diameter of 0.07 mm which is much smaller than 0.2-0.3 mm in the description by Rutten (1928). The average test diameter was slightly smaller, 2.0-3.5 mm in this study compared to 3.8-4.7 mm in the description by Rutten (1928).

Nummulites willcoxi Heilprin, 1882

Plate 18, Fig. 3

Nummulites willcoxi Heilprin, 1882, p. 191, figs. 1, 2.

Camerina moodybranchensis Gravell and Hanna, 1935, p. 332, pl. 29, fig. 24.

Operculinoides willcoxi (Heilprin) *in* Cole, 1941, p. 32, pl. 9, fig. 2, 3.

Camerina vanderstoki (Rutten and Vermunt), *in* Cole, 1945, p. 103-104, pl. 13, fig. 1.

Operculinoides willcoxi (Heilprin) *in* Cole, 1945, p.106-107, pl 13, fig. 10; pl. 15, fig. 7.

Operculinoides moodybranchensis (Gravell and Hanna) *in* Cole, 1952, p. 10, pl. 1, figs. 14 -19.

Nummulites (*Paleonummulites*) *willcoxi* (Heilprin) *in* Frost and Langenheim,1974, p. 79-83; pl.13; pl. 14.

Paleonummulites willcoxi (Heilprin) *in* Robinson and Wright, 1993, p. 333, 335, pl. 29, fig. 6; pl. 30, figs. 4-5.

Diagnostic features. Test rounded, average diameter 8 mm. Average number of whorls is 8. Whorl width is generally constant except final whorl which may be slightly wider with larger chambers.

External features. Test rounded with smooth surface. Outline of septa shows through.

Internal features: A-form: First three chambers show slight increase in each whorl, but in 4th - 5th chambers increase is greater. Mean cross diameter of protoconch is less than that of deuteroconch. Deuteroconch/protoconch ratio is 1.26 (Table 3.4). Average number of chambers and whorl width show steady increase with each successive whorl (Table 3.4). B-forms are much less abundant than A-forms. Protoconch in A-forms is usually much smaller than in B-forms. Whorls of B-forms generally increase more rapidly with successive whorls than do those of in A-forms.

Material. Specimens well-preserved. One hundred and fifty-one specimens from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone Highlands County, Florida; Middle Eocene, Costa Rica; Middle to Upper Eocene, Dominican Republic; Upper Eocene, Mexico; Lower Middle Eocene to Upper Eocene, Brazil; Lower Middle-Upper Eocene, Jamaica; Upper Eocene, Mexico; Upper Eocene, Louisiana (see details in appendix IIc).

Comments. *Lepidocyclina willcoxi* is found widely in the Caribbean Basin (Fig. 3.10).

Nummulites sp. A

Plate 18, Fig. 4

Diagnostic features. Rounded, robust test. Large protoconch and deuteroconch (0.16 mm, 0.18 mm respectively). Average number of whorls is 3.

External features. Test white, robust, rounded and transparent. Test diameter > 3 mm.

Internal features: A form: Deuteroconch slightly larger than protoconch (Table 3.4). Mean of deuteroconch/protoconch ratio is 1.08. Mean number of chambers in each whorl increases from whorl 1 - 3 (Table 3.4). Specimens have on average 3 whorls.

B-forms are much less abundant than A-forms, with A-forms making up more than 95% of each sample. Protoconch in A-forms is usually much smaller than in B-forms. Whorls of B-forms tend to increase more rapidly with each successive whorl than in A-forms and result in specimens with larger test diameters.

Material. Specimens well-preserved. Thirteen specimens from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone, Highlands County, Florida.

Comments. Protoconch and deuteroconch of *Nummulites* sp. A have mean cross diameters that are twice those as of the other *Nummulites* sp in this study (Table 3.4). The number of chambers in *Nummulites* sp. A per whorl is similar to the other *Nummulites* sp. in this study (Table 3.4), however there are only three whorls, and this feature is similar to *Nummulites floridensis,* but less than the other species (Table 3.4). *Nummulites* sp. A whorl width is larger than that of *Nummulites floridensis, Nummulites striatoreticulatus,* and *Nummulites willcoxi* and with the exception of *Nummulites* sp. B other species (Table 3.4).

Nummulites sp. B

Plate 18, Fig. 5

Diagnostic features. Smooth test, pronounced septal ribs. Whorl width increase outward from embryon.

External features. Smooth, translucent test. Septal lines visible, showing thin semi-straight lines. Diameter of test > 4 mm.

Internal features. A forms: Protoconch mean cross diameter is equal to that of deuteroconch (Table 3.4). Deuteroconch/protoconch ratio has mean of 1.0. Specimens

have 3 - 4.5 whorls; whorl diameters and average chambers per whorl show steady increase with successive whorls (Table 3.4).

B-forms: None identified.

Material. Specimens well-preserved. Three specimens from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone, Highlands County, Florida.

Comments. The mean cross diameter and average range of the protoconch and deuteroconch of *Nummulites* sp. B are similar to those of *Nummulites floridensis, Nummulites striatoreticulatus,* and *Nummulites willcoxi* with the exception of the *Nummulites* sp. A which is larger (Table 3.4). *Nummulites* sp. B has the largest number of chambers per whorl and the largest whorl width in this study (Table 3.4).

Genus *Heterostegina* d'Orbigny, 1826

Type species: *Heterostegina depressa* d'Orbigny, 1826, Recent, L'île Sainte-Hélène, Montreal, Quebec, Canada.

Heterostegina ocalana Cushman, 1921

Plate 19, Figs. 1 – 3; Plate 20, Figs. 1 - 2

Heterostegina ocalana Cushman, 1921, p.130, pl. 21, figs. 15 – 18.

Heterostegina ocalana (Cushman), *in* Cole, 1941, p. 32-33, pl. 11, figs. 3-6.

Heterostegina ocalana (Cushman), *in* Cole, 1952, p. 13-13, pl. 4, figs. 2 - 18.

Heterostegina ocalana (Cushman), *in* Puri, 1957, p. 136, pl. 6, figs. 10, 11; pl. 7, fig. 16.

Heterostegina (*Vlerkina*) *ocalana* (Cushman), *in* Robinson and Wright, 1993, p. 335, 337, pl. 31, fig. 4.

Diagnostic features. Test flattened, central area thicker, biconvex, thins towards rounded periphery. External central portion of test is covered with costae (raised ribs or ridges), raised ribs along chamber and chamberlets (chamber subdivisions). Specimen diameters range from 5-8 mm.

External features. Test is involute (later whorls envelope the earlier whorls), biconvex, compressed and ranges in size from 2-4 mm with oval contour. The central portion in the vicinity of the embryonic chamber is thickest. The sutures (line where new chamber walls attach to previously formed test) chambers and chamberlets form distinctive reticulate (patterned ornamentation) texture of raised "ribs".

Internal features. Equatorial section of A-forms: Diameter of first chamber (proloculus) ranges from 0.06 to 0.11 mm, with mean diameter of 0.10 mm. Second chamber (deuteroloculus) ranges in size from 0.06 to 0.20 mm, with mean diameter of 0.12 mm. Second chamber/first chamber ratio ranges between 1.08 and 1.33. Number of operculine chambers (undivided chambers including first chamber) ranges from 2 to 12; mean number is 5.41. Number of chamberlets in chambers generally increases with chamber number (Table 3.5).

B-forms in the Ocala Limestone are much less abundant than A-forms, with A-forms making up more than 95% of each sample. First (proloculus) and second

(deuteroloculus) chambers are reduced in size to A-forms, and are at least 1.5 times larger than A-forms. A-forms in equatorial section from St. Mary Parish, Jamaica samples are similar in shape but vary slightly in size to Florida specimens. Average cross-diameter of first chamber is 0.07 mm, and mean cross-diameter of second chambers is 0.08 mm in Jamaican samples. First chamber/second chamber ratio is 1.28. Mean number of operculine (undivided chambers including proloculus) chambers is 7.25 in Jamaican samples. Average number of chamberlets in chambers increases with chamber number in Jamaican samples (Table 3.5).

Material. Well-preserved A-forms and B-forms. Eight specimens from Upper Eocene Lower Montpelier Formation, Dressikie, St. Mary Parish, Jamaica (E. Robinson sample ER176); 171 specimens from ROMP 29A core, Ocala Limestone, Highlands County, Florida; and one specimen from Ocala Limestone, Lafayette County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone, Highlands County and Lafayette County, Florida; Upper Eocene Jamaica; Upper Eocene, Panama; Red Bluff, Georgia; Upper Eocene, Carriacou Island of the Grenadines (see appendix IId for details).

Comments. Cole (1952) identified A-forms of *Heterostegina ocalana* from Panama using photographs (Cushman, 1921). He found that the Panama specimens had 8-14 operculine chambers, whereas the Florida specimens had 3-7; however, B-form specimens from Georgia also had 14 chambers. Highlands County, Florida specimens (this study) have 2-12 operculine chambers and those from St. Mary Parish, Jamaica have 5-12. Specimens

of *Heterostegina ocalana* from Highlands County, Florida had larger diameters than those from St. Mary Parish, Jamaica.

Family Lepidocyclinidae Scheffen, 1932

Subfamily Lepidocyclininae Scheffen, 1932

Genus *Lepidocyclina* Gümbel, 1870

Lepidocyclina chaperi Lemoine and Douvillé, 1904

Plate 21, Figs. 1; Plate 22, Figs. 1 - 2

Lepidocyclina chaperi Lemoine and Douvillé, 1904, p. 14, 22, 23.

Lepidocyclina (*Nephrolepidina*) *chaperi* (Lemoine and Douvillé) *in* Cole, 1952, p. 23-27, pl. 8, figs. 5-8; pl. 9, figs. 3-19; pl. 10, figs. 1-10; pl. 11, figs. 1-8; pl. 12, figs 3-10; pl. 20, figs. 8-9; pl. 23, figs.11-12.

Lepidocyclina (*Nephrolepidina*) *chaperi* (Lemoine and Douvillé) *in* Frost and Langenheim, 1974, p. 161-165; pl.45, figs. 1-6; Pl. 46, figs. 3, 4.

Lepidocyclina (*Nephrolepidina*) *chaperi* (Lemoine and Douvillé) *in* Butterlin, 1981 p. 73, 75; pl. 50, figs. 1-5.

Lepidocyclina (*Nephrolepidina*) *chaperi* (Lemoine and Douvillé) *in* Robinson and Wright, 1993, p. 321, figs. 22.5, 25.1-25.5.

Diagnostic features. Test diameter 1-2 centimeters. Deuteroconch (second chamber in embryonic apparatus) is wider than protoconch (first chamber in embryonic apparatus). Deuteroconch is semicircular in shape whereas protoconch is oval.

External features. A-forms: Test flattened, saddle–shaped. Test diameter 2-6 mm. Surface ornamentation obscured by abrasion.

Internal features. A-form in equatorial section: Mean cross diameter of protoconch is 0.38 mm and deuteroconch is 0.68 mm. Protoconch is circular, deuteroconch is bean-shaped. Rhombic chambers in equatorial section . Principal auxillary chambers are semicircular. Numbers of periembryonic (all chambers in direct contact with protoconch and deuteroconch, chambers are 16, 18 and 20.

B-form: None identified.

Material. Specimens well-preserved. Three specimens from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone, Highlands County, Lafayette County Florida; Upper Eocene of Trinidad; Upper, Panama; Upper Eocene, Dominican Republic; Upper Eocene, Brazil; lower Middle - Upper Eocene Jamaica; Upper Eocene, Carriacou Island of the Grenadines (see appendix IIe for details).

Comments: There has been some debate about the stratigraphic range of *Lepidocyclina chaperi*, as it was thought to be from Oligocene deposits of Panama (Douvillé, 1915). However this age has been refuted by later confirmation that these deposits were Eocene (Vaughan, 1926).

Lepidocyclina pustulosa Douvillé, 1917

Plate 21, Figs. 2; Plate 22, Figs. 1 - 2

Isolepidina pustulosa Douvillé, 1917, p. 843, text-figs. 1-4.

Lepidocyclina pustulosa (Douvillé) *in* Cole, 1952, p.16-17, pl. 14, figs. 4, 7, 8; pl. 15, fig. 11.

Lepidocyclina (*Pliolepidina*) *pustulosa* (Douvillé) *in* Cole 1960b, p. 135-136, vol. 6, no. 6, pl. 2, figs. 1, 4.

Diagnostic features. Test average diameter size is 10 mm. Deuteroconch and protoconch are subequal in size and shape. Average number of periembryonic chambers is 7, these chambers are curved and appear to wrap around the embryonic chambers.

External features. A-forms: Test saddle–shaped. Test diameter 4.5-5 mm.

Internal features. A-forms in equatorial section: Mean cross diameter of protoconch is 0.47 mm and of deuteroconch is 0.55 mm. Both are oval in outline, with straight walls separating them. Principal auxillary chambers are semicircular and wrapped around first two chambers. Number of periembryonic chambers is 7.

B-forms: None identified.

Material. Specimen well-preserved. One specimen from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone of Highlands County, Florida; Upper Eocene, Mexico; Upper Middle Eocene - Upper Eocene, Jamaica; Upper

Eocene, Panama; Upper Eocene of Trinidad; Middle Eocene, Costa Rica; Upper Eocene, Nicaragua; Upper Eocene, Colombia; Lower Middle Eocene to Upper Middle Eocene, Brazil; Upper Eocene, Trinidad; Upper Eocene, Cuba; Upper Eocene, Carriacou Island of the Grenadines; Upper Eocene, Trinidad; Middle and Upper Eocene, Margarita Island, Venezuela (see appendix IIf for details).

Comments. Lepidocyclina pustulosa was identified once in this study. However, because this species is part of previously recognized assemblage zones in Panama, Cuba, Hispaniola, Costa Rica and Jamaica (Fig. 3.10), it is important that its occurrence is included.

Lepidocyclina pustulosa from San Fernando, Trinidad was first reported as Lower Oligocene (Douvillé, 1917) and later placed in the Bartonian (Douvillé, 1924). It has also been found in Lower Miocene (Lower Aquitanian) deposits of San Fernando, Trinidad as reworked Eocene fossils (Eames, et. al, 1962).

Lepidocyclina ocalana Cushman, 1920, variety A

Plate 21, Figs. 3; Plate 22, Figs. 1 - 2

Lepidocyclina ocalana Cushman, 1920, p. 71.

Lepidocyclina (*Lepidocyclina*) *ocalana* (Cushman) *in* Cole, 1941, p. 41-42, pl, 13, figs. 1-7; pl. 16, figs. 1-4, 6-10, 15.

Diagnostic features. A variety of *Lepidocyclina ocalana* distinguished by number of periembryonic chambers, 11, 12, 13, 14 and 15. Test sides differ, from flat to convex. Protoconch and deuteroconch are almost equal in size and shape.

External features. A-forms in equatorial section: Test saddle–shaped. Test diameter 2- 6 mm. Surface ornamentation consists of regularly spaced papillae (small rounded protrusions), with papillae on central umbo (central pillar) much larger on outer rim. In some specimens outer rim is smooth, showing no visible papillae.

Internal features. A-forms: Mean cross diameter of protoconch is 0.51 mm and of deuteroconch is 0.56 mm, which are similar measurements, but chambers vary in height. Protoconch and deuteroconch are square or rectangular in shape with rounded edges. Principal auxillary chambers are semicircular and flattened in some instances. Numbers of periembryonic chambers are 11, 12, 13, 14 and 15. Arcuate or short, spatulate equatorial chambers.

B-forms: None identified.

Material. Specimens well preserved. Sixteen specimens from Ocala Limestone Highlands County, Florida, and two specimens from Ocala Limestone, Lafayette County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone of Highlands County and Lafayette County, Florida; Upper Middle Eocene Bateque Formation, Baja California Sur, Mexico; Upper Eocene, Jamaica.

Comments. *Lepidocyclina ocalana* specimens of Lafayette County, Florida (Maya Quarry) are smaller and more symmetrical in shape than those from Highlands County, Florida (ROMP 29A core).

Lepidocyclina ocalana Cushman 1920, variety B

Plate 21, Figs. 4; Plate 22, Figs. 1 - 2

Lepidocyclina (*Lepidocyclina*) *ocalana* (Cushman) variety *pseudomarginata* (Cushman), *in* Cole, 1941, p. 44-45, pl. 14, figs. 4-7.

Diagnostic features. A variety of *Lepidocyclina ocalana* distinguished by number of periembryonic chambers: 9, 10, 11 and 12.

External features. A-forms: Test flattened, saddle–shaped. Test diameter 2-7 mm. Surface ornamentation consists of regularly spaced papillae, with papillae on central umbo much larger than on outer rim.

Internal features. A-form in equatorial section: Mean cross diameter of protoconch is 0.41 mm and deuteroconch is 0.51 mm. Both embryonic chambers are oval-shaped and wall separating them varies from straight to slightly curved towards deuteroconch. Principal auxillary chambers are oval-shaped and semicircular. B form: None identified. Lateral chambers may be arranged in tiers and consist of approximately 7 layers of chambers. Deuteroconch and protoconch are subequal in size and shape.

Material. Specimens well-preserved. Twenty-four specimens from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone of Highlands County and Lafayette County, Florida.

Comments. Umbo ornamentation is similar to that described by Cole (1941) in possessing prominent papillae. Tiers or reinforced layers between rows of chambers are also another shared feature in equatorial section.

Lepidocyclina ocalana Cushman 1920 variety C

Plate 21, Figs. 5; Plate 22, Figs. 1 - 2

Lepidocyclina (*Lepidocyclina*) *ocalana* (Cushman) variety (Cushman) *in* Cole, 1941, p. 43-44, pl. 15, figs. 1-5; pl. 16, fig. 5.

Diagnostic features. A variety of *Lepidocyclina ocalana* distinguished by number of periembryonic chambers: 12, 13, 14, 15 and 16.

External features. A-forms: Test flattened, saddle shaped. Test diameter 2- 6 mm. Surface ornamentation consists of regularly spaced papillae, with papillae on central umbo is larger and denser than on outer rim, if not smooth.

Internal features. A-forms in equatorial section: Average cross diameter of protoconch is 0.45 mm, deuteroconch is 0.59 mm. Protoconch varies from oval to circular; deuteroconch is oval-shaped or in some cases almost bean-shaped. Wall separating them varies from straight to slightly curved towards deuteroconch. Principal auxillary chambers are oval-shaped and semicircular. Test small umbo, small papillae cover umbo, with outer rim smooth. Deuteroconch and protoconch are subequal in size and shape.

B-forms: None identified.

Material. Specimens well-preserved. Twenty-two specimens from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone, Highlands County and Lafayette County, Florida.

Comments. Average cross diameter of protoconch and deuteroconch are similar to those of Cole (1941). Papillae size and spacing are variable, and Cole (1941) described the papillae as small and concentrated on the umbo with a smooth outer rim.

Lepidocyclina ocalana Cushman 1920 variety D

Plate 21, Figs. 6; Plate 22, Figs. 1 - 2

Lepidocyclina (*Lepidocyclina*) *ocalana* (Cushman) variety *floridana* Cushman,1941, p. 44, pl, 14, figs. 1-3; pl. 16, fig. 17.

Diagnostic features. A variety of *Lepidocyclina ocalana* distinguished by number of periembryonic chambers: 16, 17, 18, 19, 20, and 21. Deuteroconch and protoconch subequal in size and shape.

External features. A-forms: Test flattened, strongly saddle – shaped. Test diameter 3-8 mm. Surface ornamentation consists of regularly spaced papillae, with papillae on central umbo much larger than on outer rim, if not entirely smooth.

Internal features. A-form in equatorial section: Mean cross diameter of protoconch is 0.56 mm and deuteroconch is 0.62 mm. Protoconch and deuteroconch are both

semicircular with rounded edges. Principal auxillary chambers are semicircular. Chambers in equatorial section are accurate.

B-forms: None identified.

Material. Specimens well-preserved. Fifteen specimens from Ocala Limestone, Highlands County, Florida.

Geographic and stratigraphic distribution. Ocala Limestone, Highlands County and Lafayette County, Florida.

Comments. Cole (1941) found this variety similar to *Lepidocyclina ocalana*, with the exception of possessing strongly saddle-shaped tests. This study recognizes the strongly saddle-shaped tests; however, the average cross diameter of the test diameter and protoconch and deuteroconch are larger.

Genus *Pseudophragmina* H. Douville, 1923

Pseudophragmina sp. A

Plate 23, Figs. 1 - 5

External features. Test diameter 4 mm. Coarse papillae.

Internal features. Embryonic chambers very small, apparently single chambers. Equatorial chambers narrowly rectangular, arranged in circles. Specimens extensively bored.

Material. Specimens well preserved. Two specimens from Ocala Limestone, Highlands County, Florida, from 229.2 m, in the ROMP 29A core.

Comments. Pseudophragmina sp. A has a diameter of 4 mm, similar to the 5 mm diameter in *Pseudophragmina (Proporocyclina) flintensis* Cushman, 1917. *Pseudophragmina* sp. A and *Pseudophragmina (Proporocyclina) flintensis* both have very small embryonic chambers and have been reported from the Ocala Limestone (Cushman, 1917).

Pseudophragmina (Proporocyclina) flintensis is similar to *Discocyclina (Discocyclina) citrensis* in appearance; however, *P. (Proporocyclina) flintensis* is twice the size of *D. (Discocyclina) citrensis*, and has smaller and less distinguishable embryonic chambers. *Pseudophragmina (Proporocyclina) flintensis* may be the microspheric form, whereas *D. (Discocyclina) citrensis* can be described as the megalospheric form.

Pseudophragmina sp. B

Plate 24, Figs. 1 – 6

External features. Test diameter 0.75-2 mm. Coarse papillae concentrated in middle of test, with no papillae on outer periphery (two chambers wide).

Internal features. Embryonic chambers, round protoconch, with bean- shaped deuteroconch which is 1.25 times wider than protoconch. Two semicircular chambers

surround protoconch and protoconch. Equatorial chambers rectangular, square and triangular, arranged in angular circles. Four to nine ribs.

Material. Specimens well-preserved. Six specimens from Ocala Limestone, Highlands County, Florida, from 185.9 m, 175.4 m, 175.0 m, and 173.4 m in the ROMP 29A core.

Comments. Pseudophragmina sp. B is similar to *Discocyclina (Discocyclina) citrensis* Vaughan, 1928 in the shape and orientation of the embryonic chambers, rectangular equatorial chambers, and diameters of 1.0-2.0 mm. However, *Pseudophragmina* sp. B has at least two growth phases, whereas in *Discocyclina (Discocyclina) citrensis* this phenomenon is absent. The first growth phase of *Pseudophragmina* sp. B is characterized by small chambers, giving the appearance of a compressed core, and the second phase has larger chambers creating a more inflated look. *Discocyclina (Discocyclina) citrensis* has chambers similar to those of the second phase. Another difference in *Pseudophragmina* sp. B is the hexagonally and pentagonally shaped circles of the chamber configuration; in *Discocyclina (Discocyclina) citrensis* the chambers are arranged in near-perfect circles.

Pseudophragmina sp. C

Plate 25, Figs. 1 - 4

External features. Test diameter 1-1.8 mm. Coarse papillae concentrated in middle of test; no papillae on outer periphery (two chambers wide).

Internal features. Embryonic chambers circular. Two semicircular chambers surround protoconch and deuteroconch. Equatorial chambers rectangular, arranged in circles.

Material. Specimens well-preserved. Four specimens from Ocala Limestone, Highlands County, Florida, from 164.6 m and 173.4 m in the ROMP29A core.

Comments. *Pseudophragmina* sp. C has similar characteristics to *Discocyclina (Discocyclina) citrensis.* Both have circular embryonic chambers of 2 mm or less in diameter.

3.6 Discussion

3.6.1 Ocala Limestone Biostratigraphy

Most of the larger foraminifera identified in the ROMP 29A core from Highlands County, Florida, including *Heterostegina ocalana, Lepidocyclina ocalana, Lepidocyclina pustulosa, Lepidocyclina chaperi, Nummulites willcoxi, Nummulites floridensis* and *Nummulites striatoreticulatus,* have a range of Middle Eocene through Upper Eocene. Their geographic range includes Georgia and Florida of the U. S., Mexico, the Caribbean Basin, Central America, and the northern countries of South America (Figs. 3.10, 3.11).

The echinoid *Neolaganum dalli* Twichell is an Avon Park Formation taxon which is restricted to the Middle Eocene (Oyen and Portell, 2001). The occurrence of *N. dalli* in

the core supports the boundary between Avon Park Formation and Ocala Limestone of 234.7m in the ROMP 29A core (Ward et al., 2003).

The calcareous nannofossil results suggest a latest Eocene age (NP 20/21) for the samples collected at 230 m and 192.7 m, and a Lower Oligocene age (NP 21) for the samples from depths 188.1 m and 154.2 m. These ages are based on relative abundances of taxa, so less conclusive than stratigraphic ranges (Jiang, 1997). This problem of the age discrepancy between calcareous nannofossils and larger foraminifera has been encountered previously by Applin and Applin (1944) in the Ocala Limestone.

Heterostegina ocalana and *Lepidocyclina chaperi* appear to be restricted to the Upper Eocene, a position confirmed by previous studies (Fig. 3.10). The Upper Eocene stratigraphic position of *Lepidocyclina chaperi* agrees with its lowermost documented occurrence, which coincides with its appearance at the beginning of the late Eocene in evolutionary lineages (Butterlin, 1984; Butterlin, 1987; Frost, et. al, 1974). The Upper Eocene stratigraphic range of *Heterostegina ocalana* has been confirmed by studies of specimens from Panama and the Caribbean (Vaughan, 1926, Robinson, 1993) (Fig. 3.11); however, its northern and southern geographic extent is limited by Jamaica and Panama (Fig. 3.10).

The *Heterostegina-Lepidocyclina-Nummulites* assemblage zone of the Ocala Limestone extends the entire length of the studied core section. The occurrences of these taxa are not isolated within any of the three depositional sequences defined by Ward et al. (2003; Figs. 3.1 - 3.2) and Bryan (2008), so these taxa were apparently not strictly controlled by the depositional environment that controlled the lithology of the three sequences. The Avon Park Formation, which unconformably underlies the Ocala

Limestone, contains a different larger foraminiferal assemblage, indicative of differences in the water depths (see Chapter 2).

The stratigraphy of the Ocala Limestone has been revised many times over the years (Table 3.1) and the terminology of Applin and Applin (1944) is presently being used (Blake and Portell, 2009). The Ocala Limestone's two divisions of the upper and lower members distinguished by their lithologic differences are now recognized. The lower member consists of white to cream-colored, granular fossiliferous limestone which is at least partially dolomitized, and the upper member is a soft, friable, variably muddy to granular limestone (Scott, 1991). The lower member is not present throughout Florida (Miller 1986), and is not present in the 29A core. The Ocala Limestone is highly fossiliferous and contains abundant larger and smaller foraminifera, echinoids, bryozoans and mollusks (Scott 2001). However, the larger foraminifer *Lepidocyclina* sp. is abundant in the upper member but limited in the lower member (Scott, 2001). In this study, the appearance of *Lepidocyclina* sp. was found at 210 m, which is 22.7 m above the Avon Park Limestone and the Ocala Limestone boundary. However, this 22.7m of the Ocala Limestone in this study does contain *Heterostegina ocalana*, *Nummulites willcoxi* and *Nummulites floridensis* and might be considered the lower member identified by Scott (2001).

3.7 Conclusions

Heterostegina ocalana and *Lepidocyclina chaperi* are apparently restricted to the late Eocene. *Lepidocyclina ocalana, Lepidocyclina pustulosa, Nummulites willcoxi, Nummulites floridensis* and *Nummulites striatoreticulatus* range in age from middle

through late Eocene. The total geographic range of larger foraminifera in this study includes the U. S. Gulf Coast and Florida, Caribbean Basin, Mexico, Central America and the northern coastlines of Ecuador, Colombia, Venezuela, Guyana and Brazil.

There is no relationship between the depositional sequences defined by Ward et al. (2003) within the Ocala Limestone and the larger foraminiferal biostratigraphy identified by this study. This indicates that their distribution was not facies-controlled, which strengthens their utility as biostratigraphic index fossils.

<table>
<tr><th></th><th>Heilprin,1882</th><th colspan="2">Dall, 1892</th><th colspan="2">Matson and Clapp, 1909</th><th colspan="2">Cooke, 1915 Cooke and Mossom, 1929</th><th colspan="2">Applin and Applin, 1944</th><th colspan="2">Vernon, 1951</th><th colspan="2">Puri, 1957</th><th colspan="2">Miller, 1986</th><th colspan="2">Scott, 1992</th></tr>
<tr><td rowspan="4">Eocene Deposits</td><td rowspan="4">Nummulitic beds assumed to be Oligocene in age</td><td>Vicksburg Group</td><td>Miliolitic Limestone</td><td rowspan="4">Vicksburg Group</td><td>Ocala Limestone</td><td rowspan="4">Ocala Formation</td><td>Orbitoides Limestone</td><td rowspan="4">Ocala Limestone</td><td rowspan="2">Informally Named Upper Members</td><td rowspan="4">Ocala Limestone/ Moodys Branch Formation</td><td rowspan="2">Williston Member</td><td rowspan="4">Ocala Group</td><td>Crystal Formation</td><td rowspan="4">Ocala Limestone</td><td rowspan="2">Upper Facies</td><td rowspan="4">Ocala Limestone</td><td rowspan="2">Upper Unit</td></tr>
<tr><td colspan="2">Nummulitic Limestone (Ocala Limestone)</td><td>Peninsular Limestone</td><td>Nummulitic Limestone</td><td>Williston Formation</td></tr>
<tr><td colspan="2" rowspan="2">Orbitoides Limestone</td><td rowspan="2">Marianna Limestone</td><td>Miliolitic Limestone</td><td rowspan="2">Informally Named Lower Members</td><td rowspan="2">Inglis Member</td><td rowspan="2">Inglis Member</td><td rowspan="2">Lower Facies</td><td rowspan="2">Lower Unit</td></tr>
<tr><td>Peninsular Limestone</td></tr>
</table>

Table 3.1 Previous studies of the stratigraphy of the Ocala Limestone.

Puri, 1957				Bryan, J. R., 2008			This Study
Crystal River Formation	*Lepidocyclina* (Nephrolepidina) *chaperi* faunizone	Shallow, warm water, no more than 30 feet.		*Lepidocyclina-Asterocyclina* in *Lepidocyclina* coquinas or bryozoan grainstones	Gulf Trough, southern flank		*Nummulites floridensis* *Lepidocyclina chaperi* *Lepidocyclina ocalana* var. A, B, C, & D
	Asterocyclina-Spirolaca veroni faunizone	Relatively deeper water					
	Nummulites vanderstoki – Hemicythere faunizone	Relatively deeper water		*Nummulites floridanus, Lepidocyclina chaperi* in bryozoan packstones	Middle-outer shelf		*Heterostegina ocalana* *Lepidocyclina chaperi* *Nummulites willcoxi,* *Lepidocyclina ocalana* var. A, C & D *Nummulites striatoreticulatus* *Lepidocyclina pustulosa* *Nummulites* sp. B
	Lepidocyclina – Pseudophragmina faunizone						
	Spiroloculina newberryensis faunizone	Shallow water, 60-150 feet, open seas		*Nummulites floridanus, Lepidocyclina ocalana, Pseudophragmina, Asterocyclina,* in packstones and grainstones	Mid-outer shelf deposits		*Heterostegina ocalana* *Lepidocyclina chaperi* *Nummulites willcoxi,* *Lepidocyclina ocalana* var. A, B, C & D *Nummulites* sp. B
Williston Formation	*Operculinoides moodybranchensis*			*Nummulites* sp. and *Lepidocyclina ocalana*, in packstones	Mid-shelf accumulations		*Heterostegina ocalana* *Nummulites willcoxi* *Lepidocyclina ocalana* var. A, B, C & D
	Operculina jacksonensis faunizone			*Nummulites* (*N. heilprini, N.willcoxi*) with miliolids, *Amphistegina*, rare *Lepidocyclina* in packstones	Inner to middle shelf facies		*Heterostegina ocalana* *Nummulites willcoxi* *Lepidocyclina ocalana* var. A, B & C *Lepidocyclina chaperi*
Inglis Formation	*Periarchus lyelli floridanus-Plectofrondicularia* ? *inglisiana* faunizone			*Fallotella-Discrinospsis-Fabularia* in chloralgal/miliolid grainstones	Subtidal facies on a restricted platform		*Heterostegina ocalana* *Nummulites willcoxi,* *Nummulites floridensis*

Table 3.2. Compilation of previous biostratigraphy and paleoenvironments of the Ocala Limestone, compared with this study.

Nummulites floridensis Heilprin, 1885	Pages 207-208, Plate 18, Figs. 1 – 2
Nummulites striatoreticulatus Rutten, 1928	Pages 207-208, Plate 18, Figs. 3 – 4
Nummulites willcoxi Heilprin, 1882	Pages 207-208, Plate 18, Figs. 5 –6
Nummulites sp. A	Pages 207-208, Plate 18, Figs. 7 – 8
Nummulites sp. B	Pages 207-208, Plate 18, Figs. 9 – 10
Heterostegina ocalana Cushman, 1921	Pages 209-210, Plate 19, Figs. 1 –3
Heterostegina ocalana Cushman, 1921	Pages 211-212, Plate 20, Figs. 1 –2
Lepidocyclina chaperi Lemoine and Douvillé, 1904	Pages 213-214, Plate 21, Fig. 1
Lepidocyclina ocalana Cushman, 1921 var. A	Pages 213-214, Plate 21, Fig. 3
Lepidocyclina ocalana Cushman, 1921 var. B	Pages 213-214, Plate 21, Fig. 4
Lepidocyclina ocalana Cushman, 1921 var. C	Pages 213-214, Plate 21, Fig. 5
Lepidocyclina ocalana Cushman, 1921 var. D	Pages 213-214, Plate 21, Fig. 6
Lepidocyclina pustulosa Douvillé,1917	Pages 213-214, Plate 21, Fig. 24
Lepidocyclina sp.	Pages 215-216, Plate 22, Figs 1-2.
Pseudophragmina sp. A	Pages 217-218, Plate 23, Figs. 1 – 5
Pseudophragmina sp. B	Pages 219-220, Plate 24, Figs. 1 – 6
Pseudophragmina sp. C	Pages 221-222, Plate 25, Figs. 1 - 4

Table 3.3. Larger foraminifera recovered from the Ocala Limestone.

	Proloculus (mm)		Deuteroconch (mm)		Deuteroconch/proloculus ratio	
	Mean	Range	Mean	Range	Mean	Range
Nummulites floridensis	0.10	0.06 – 0.11	0.13	0.10 – 0.18	1.42	1.05 – 1.77
Nummulites striatoreticulatus	0.07	0.05 – 0.09	0.08	0.06 – 0.09	1.16	0.97 – 1.53
Nummulites willcoxi	0.07	0.05 – 0.08	0.08	0.09 – 0.14	1.26	1.13 – 1.80
Nummulites sp. A	0.16	0.11 – 0.23	0.17	0.12 – 0.26	1.08	0.93 – 1.34
Nummulites sp. B	0.08	0.05 – 0.12	0.09	0.05 - 0.16	1.03	0.76 – 1.60

	Chambers in 1st Whorl		Chambers in 2nd Whorl		Chambers in 3rd Whorl		Chambers in 4th Whorl		Chambers in 5th Whorl	
	Mean	Range	mean	Range	Mean	Range	Mean	Range	Mean	Range
Nummulites floridensis	7.5	6 – 9	17.5	16 – 20	22.00	20 – 24				
Nummulites striatoreticulatus	7.80	7 – 8	14.27	12 – 17	18.13	15 – 22	21.43	19 – 24		
Nummulites willcoxi	8.40	6 – 12	16.53	12 – 21	21.12	17 – 33	23.45	19 - 27	26.06	21 – 29
Nummulites sp. A	8.13	7 – 11	17.15	13 – 21	18.13	15 – 22				
Nummulites sp. B	9.14	8 – 10	15.71	12 – 21	18.13	15 – 22	25.00	22 – 28		

	Width of 1st Whorl		Width of 2nd Whorl		Width of 3rd Whorl		Width of 4th Whorl		Width of 5th Whorl	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Nummulites floridensis	0.58	0.41 –0.82	1.46	1.21 – 2.03						
Nummulites striatoreticulatus	0.38	0.24-0.47	0.70	0.56-0.81	1.17	0.94-1.46	1.69	1.37-1.90		
Nummulites willcoxi	0.43	0.01-0.53	0.79	0.01-1.03	1.24	0.83-1.80	1.75	1.23-2.38	2.16	1.90-2.31
Nummulites sp. A	0.76	0.66-0.90	1.22	1.08-1.49	1.88	1.67-2.16				
Nummulites sp. B	0.53	0.41 -0.69	0.94	0.80 – 1.15	1.17	0.94 – 1.46	2.36	1.83 – 2.71		

Table 3.4 Measurements of species of *Nummulites*.

	Ocala Limestone		Jamaica	
Chamber No.	Mean	Range	Mean	Range
Operculine	5.41	2 – 12	7.25	5 – 12
4 + 5	2.42	2 – 8	2	2 – 2
10	2.61	1 – 6	2.25	1 – 4
14	3.54	1 – 6	3.00	2 – 5
18	4.61	1 – 12	3.88	2 – 5
22	5.59	1 – 13	5.25	3 – 7
26	6.7	2 – 14	6.13	5 – 8
30	8.01	1 – 16	7.88	6 – 9
34	9.53	2 – 19	10.20	8 – 12
38	11.84	1 – 20	11.00	11 – 11
42	9.71	6 – 15		
46	12.63	8 – 15		

Table 3.5. Number of chamberlets per chamber in *Heterostegina ocalana* from the Ocala Limestone and St. Mary Parish, Jamaica.

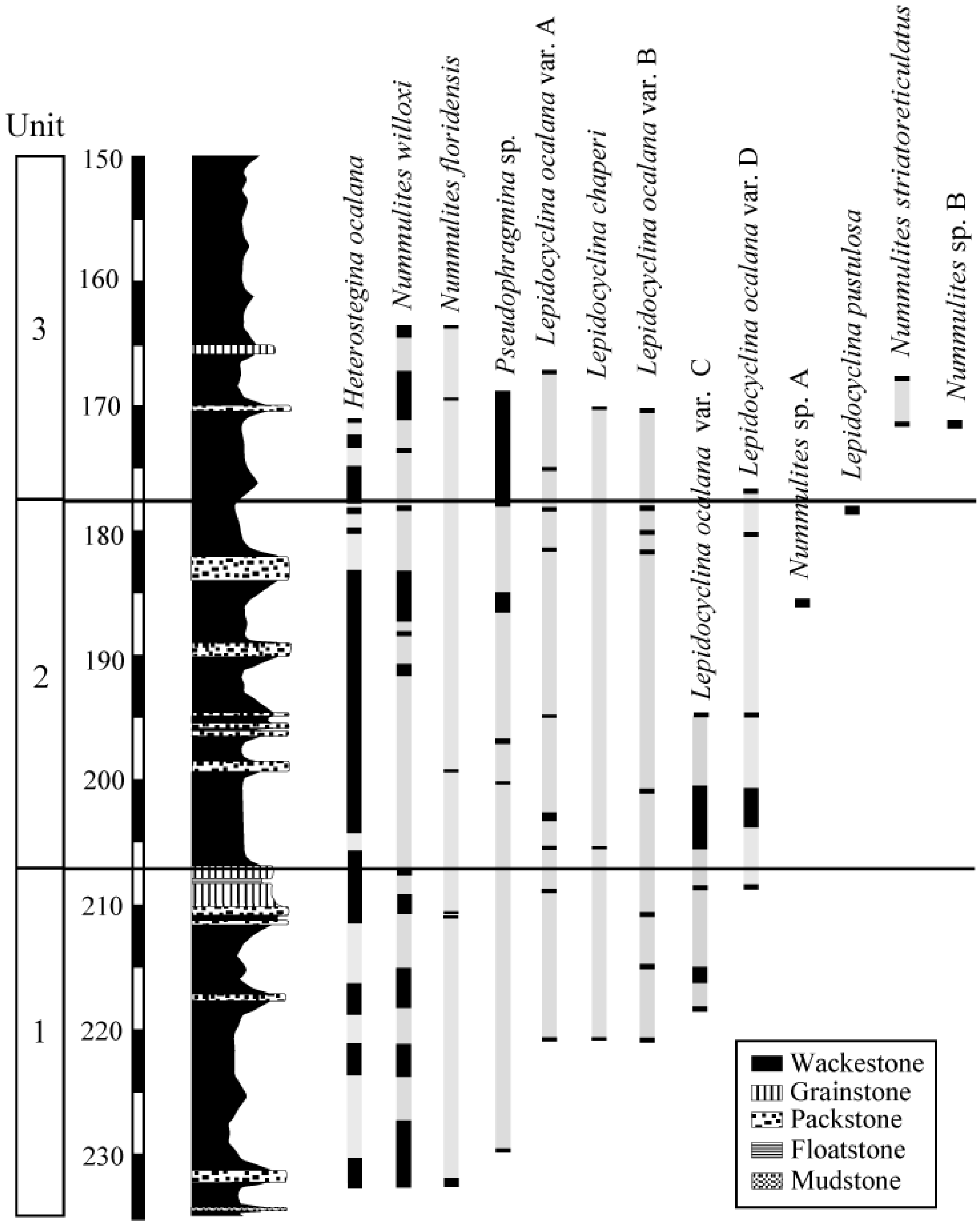


Figure 3.1 Stratigraphic ranges of the larger foraminifera in the Ocala Limestone. Scale is in m. Lithology and depositional units 1 – 3 adapted from Ward et al. (2003).

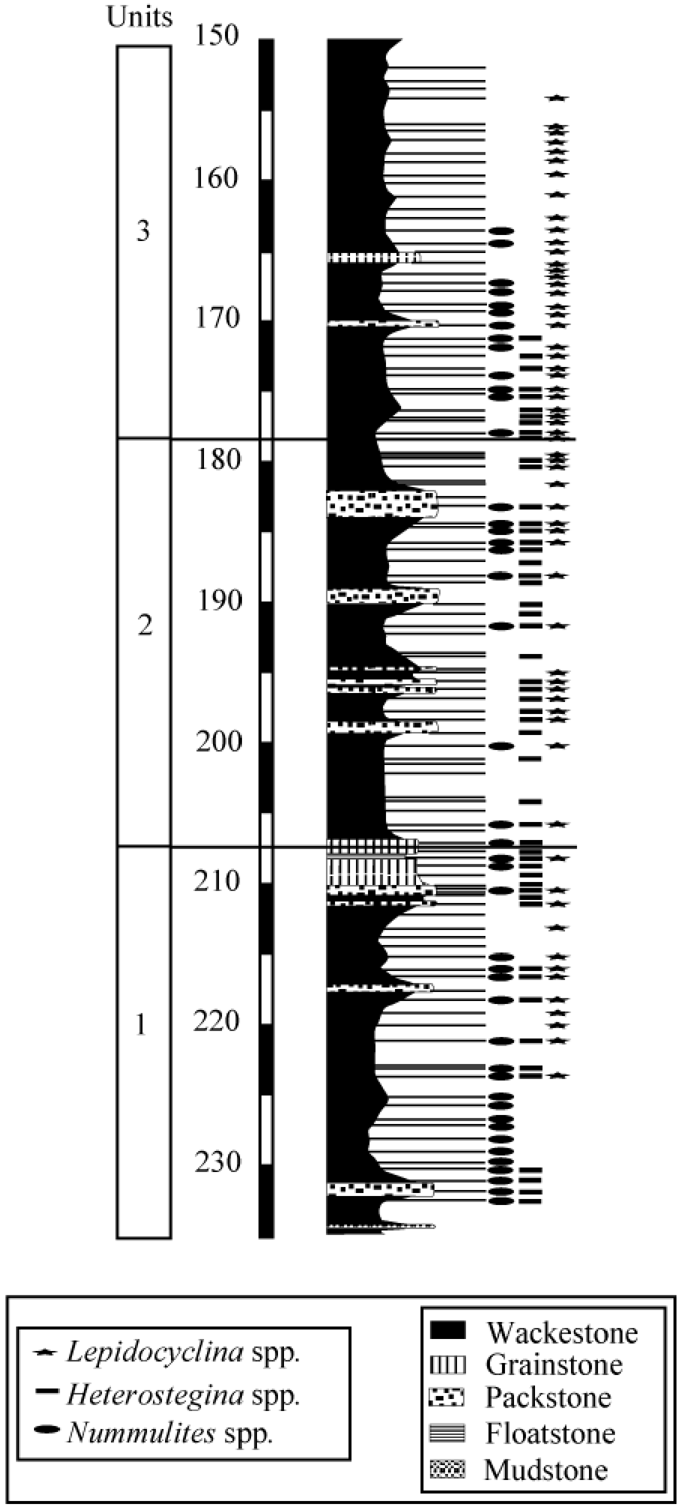


Figure 3.2 Summary of stratigraphic occurrences of genera of the larger foraminifera in the Upper Eocene Ocala Limestone. Scale is in m. Lithology and units 1 – 3 adapted from Ward et al. (2003).

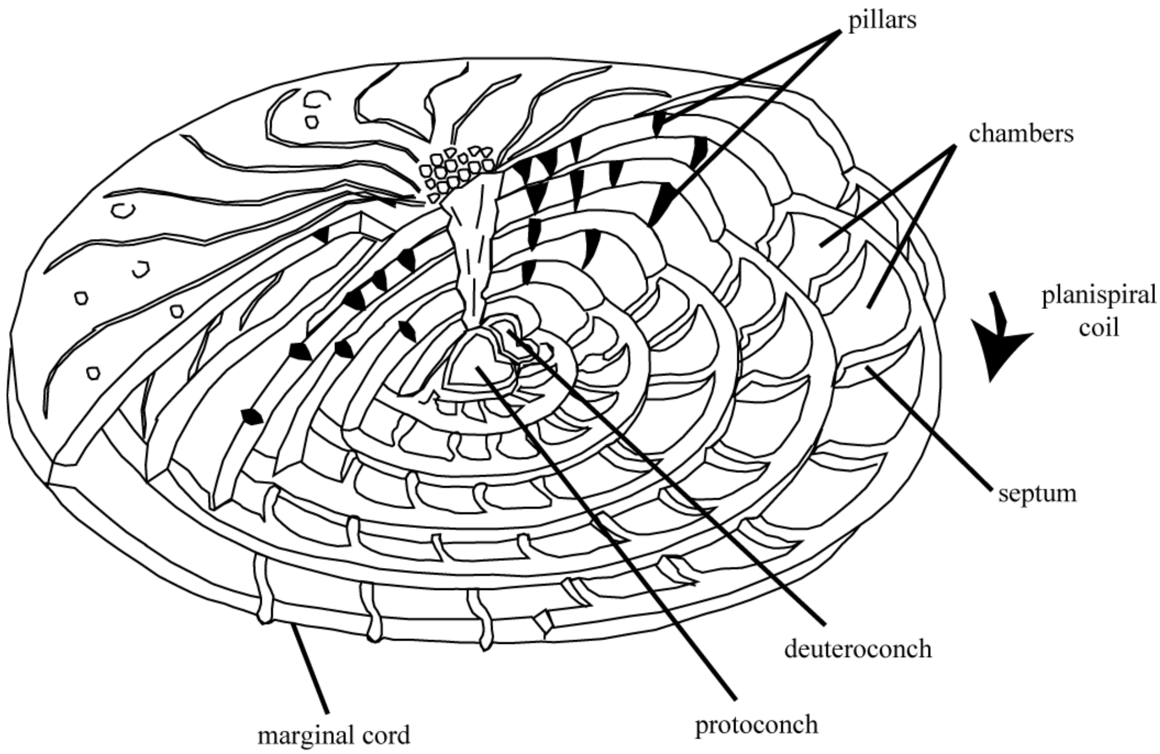


Figure 3.3 Three-dimensional, cut-away sketch of the *Nummulites* A-form morphology. The top portion represents the axial section, whereas the lower portion is the equatorial section. Redrawn from Racey (2001).

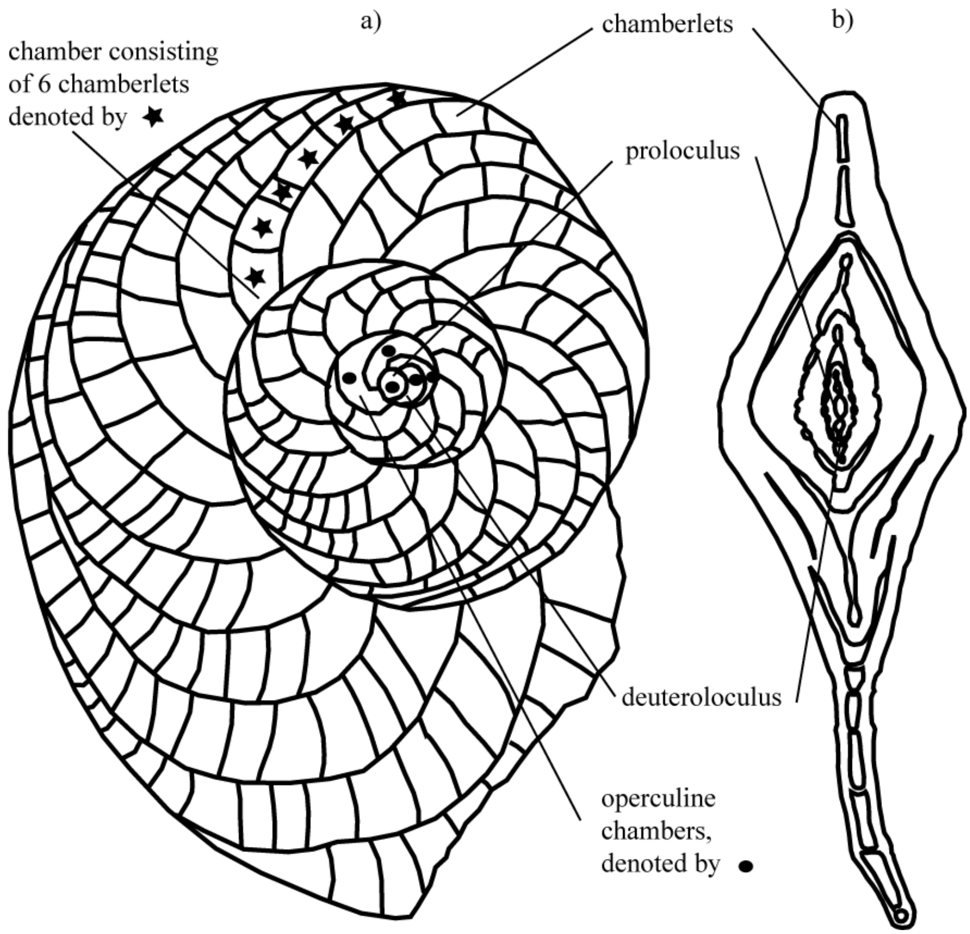


Figure 3.4 Sketch of *Heterostegina* showing the morphological features used in the description of the tests. a) equatorial section, b) axial section.

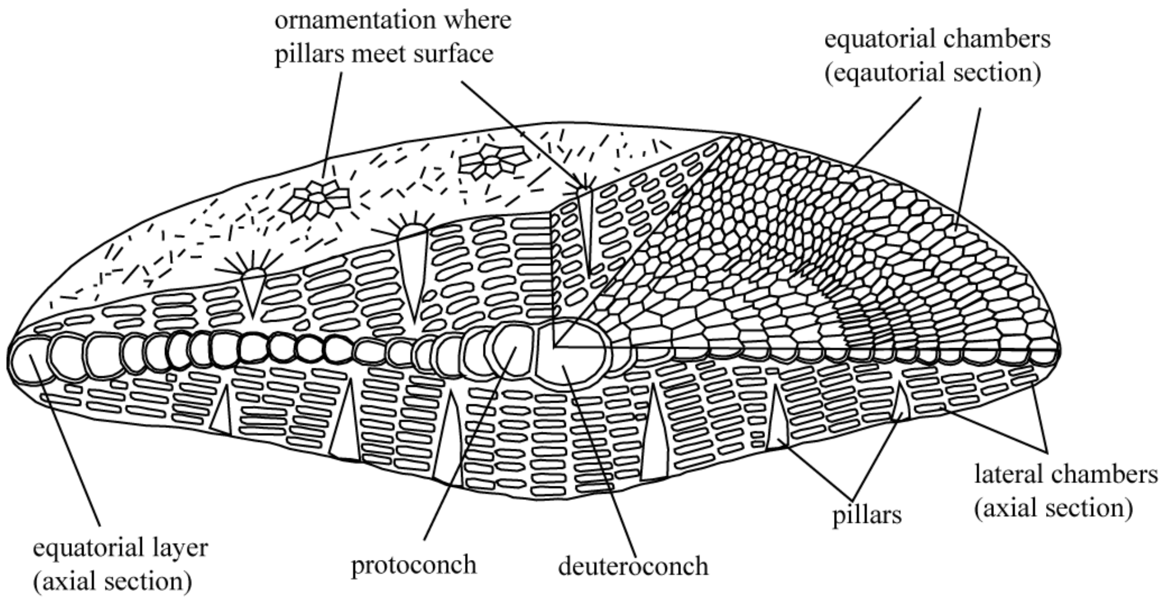


Figure 3.5 Three-dimensional, cut-away sketch of *Lepidocyclina* showing the morphological features used in the description of the tests. Adapted from Racey (2001).

Figure 3.6 Equatorial section of *Lepidocyclina* sp. showing the embryon and surrounding chambers.

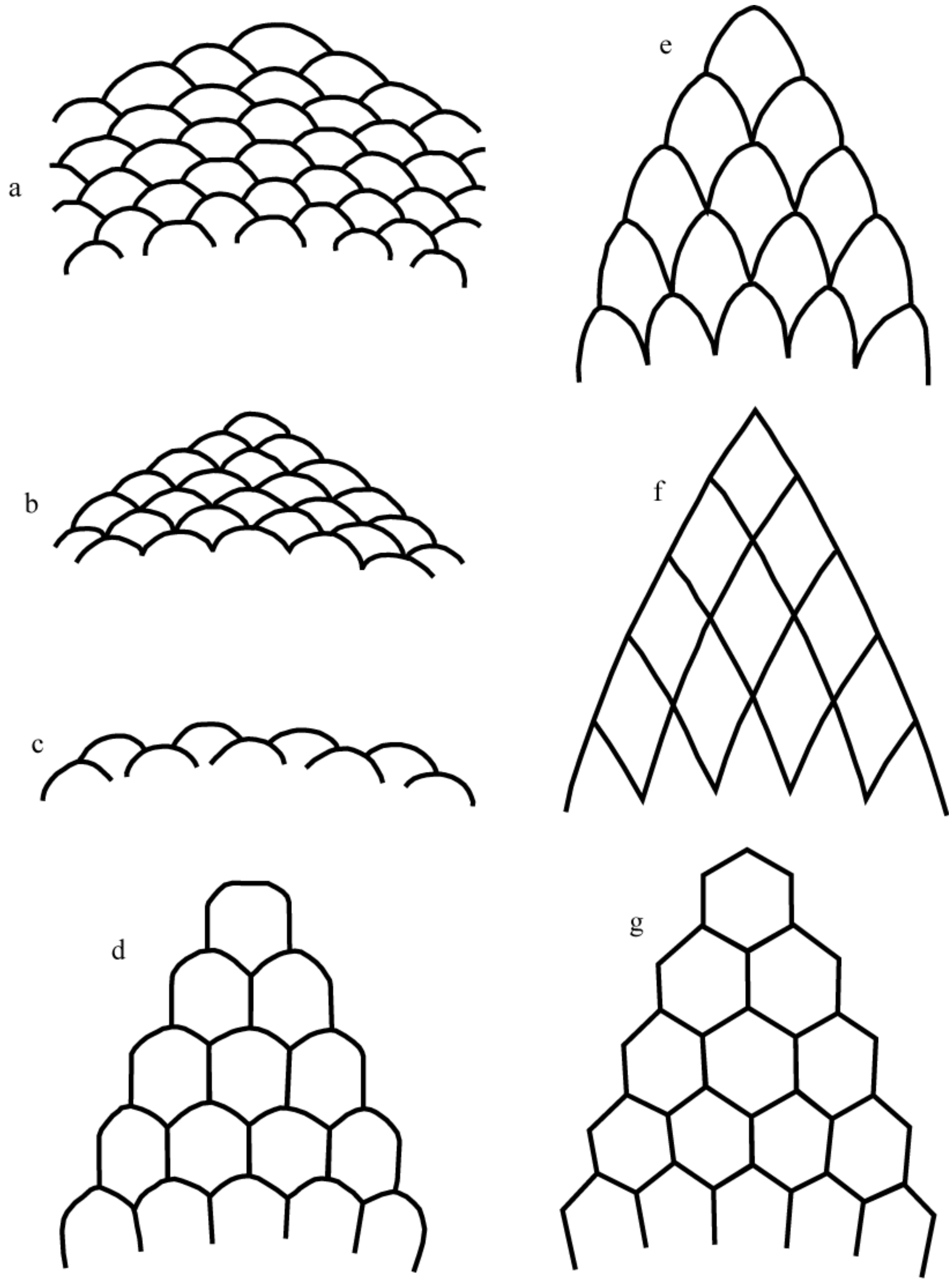


Figure 3.7 Schematic diagrams of equatorial chamber shapes in Lepidocyclinidae a) arcuate, with a pseudo-hexagonal appearance; b) simple arcuate in lateral contact, giving a compressed ogival appearance; c) arcuate, not in lateral contact; d) spatulate; e) elongate arcuate, producing a familiar ogival appearance; f) rhombic; g) hexagonal. Redrawn from van der Vlerk (1974).

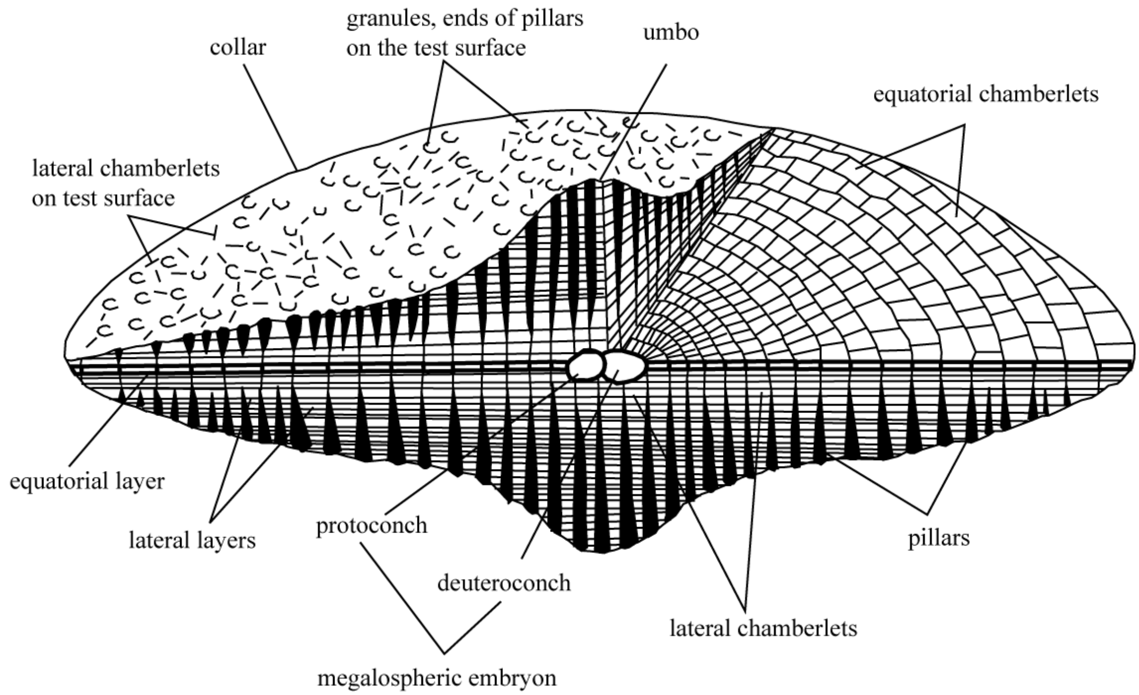


Figure 3.8 Three-dimensional sketch of an orthophragminid showing the morphological features used in the description of the tests. The upper right hand portion of the sketch represents the equatorial section, whereas the rest of the sketch is the axial section. Redrawn from Less and Kovacks (1996).

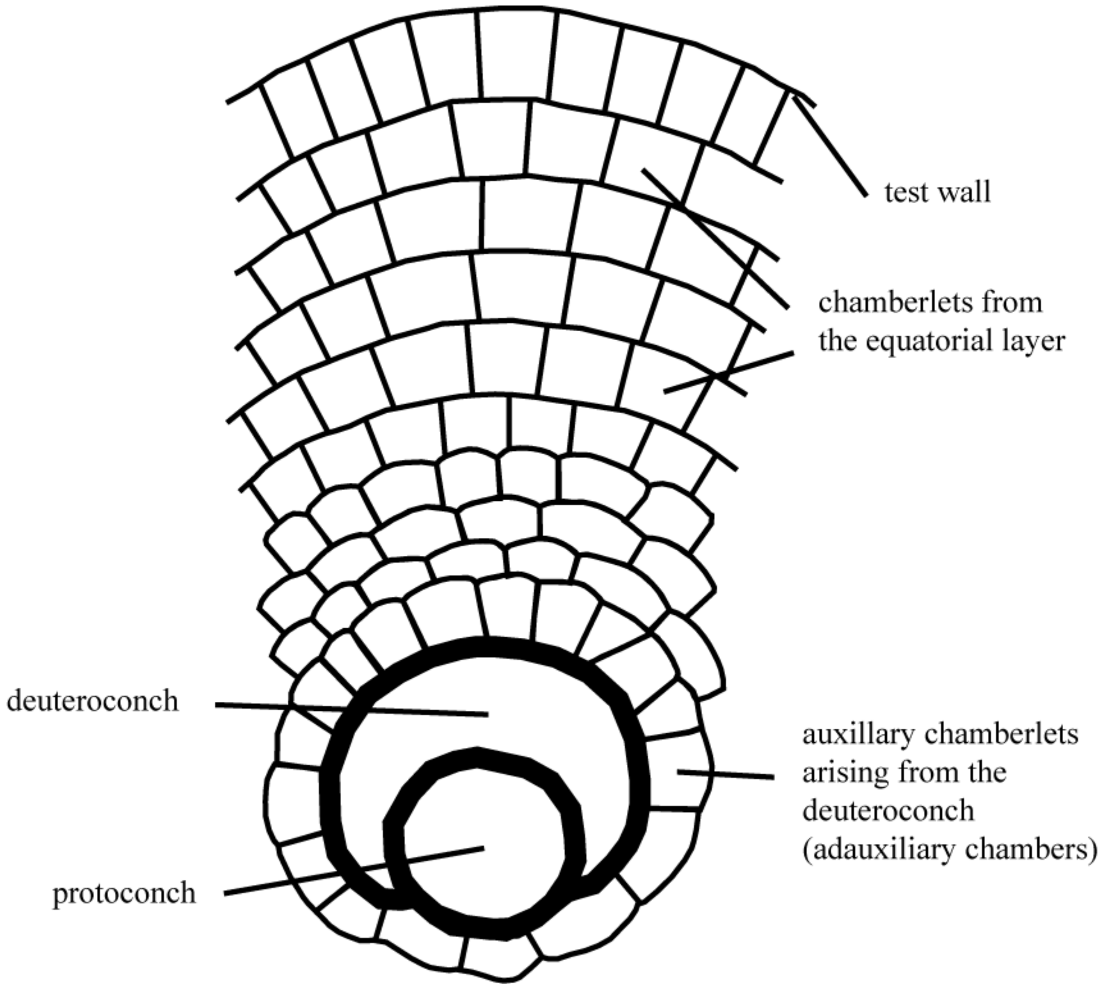


Figure 3.9 Slice of equatorial layer in equatorial section in orthophragminids, showing the morphological features used in the description of the tests. Adapted from Özcan et al. (2001).

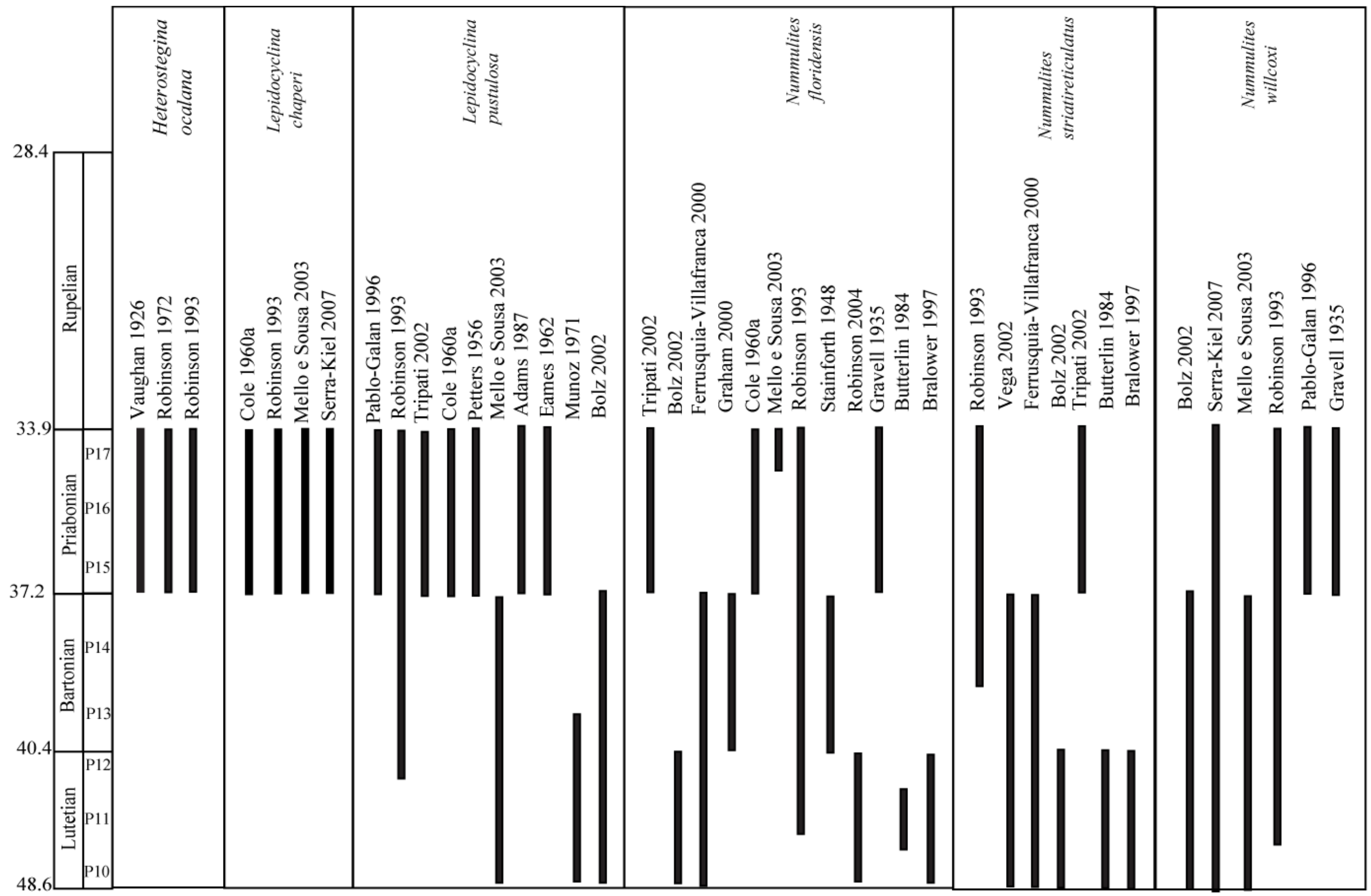


Figure 3.10 Stratigraphic ranges of the larger foraminifera in the Caribbean and the Americas.

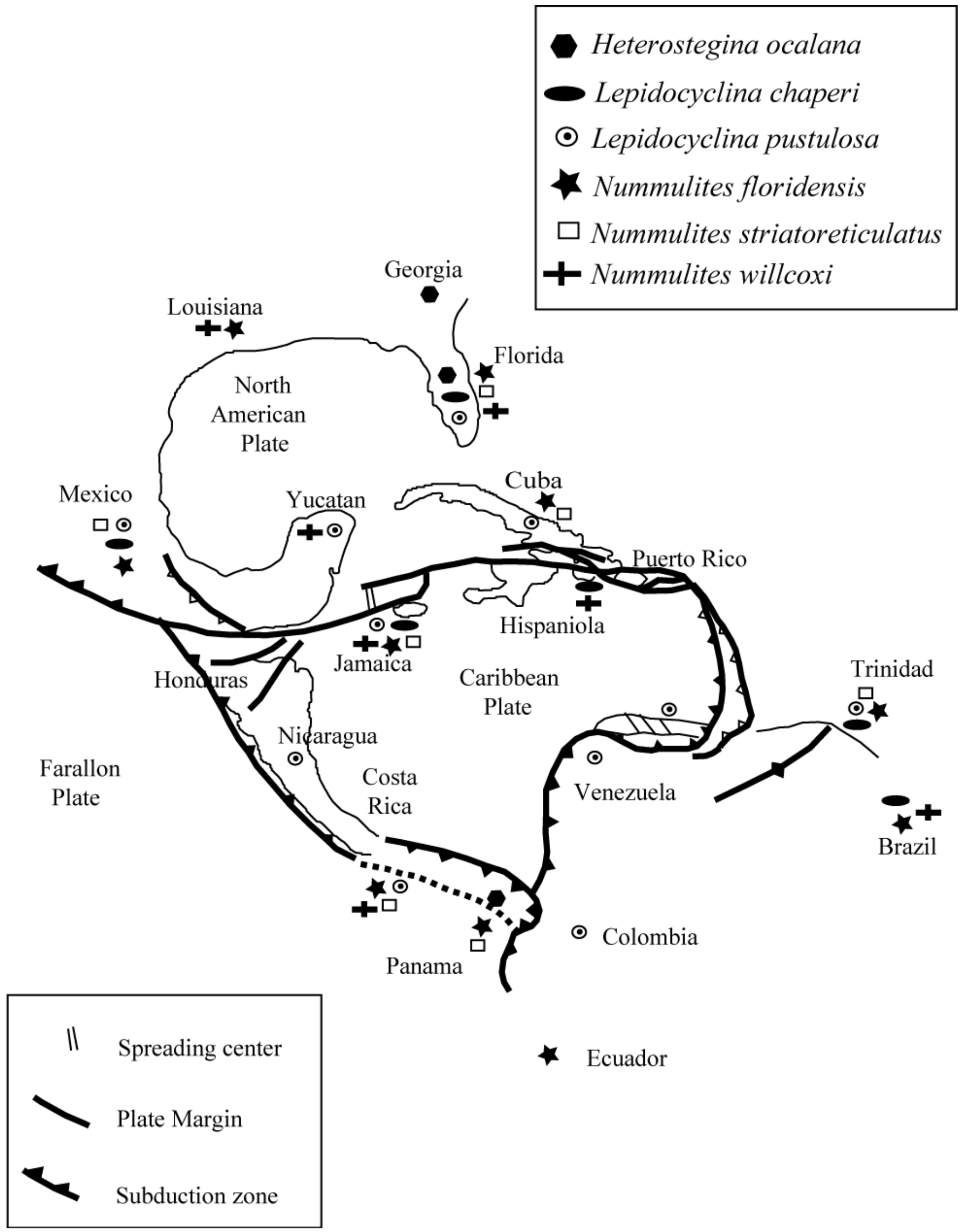


Figure 3.11 Geographical distribution of Late Eocene larger foraminifera found in the ROMP 29A core. Map adapted from Pindell (2009).

CHAPTER 4

CORRESPONDENCE OF LARGER FORAMINIFERAL MORPHOLOGY TO PALEOENVIRONMENTAL VARIATIONS IN THE OCALA LIMESTONE

4.1 Introduction

Foraminiferal taxa are classified in terms of morphological models; morphometrics seeks to express qualitative foraminiferal features and their variations quantitatively (Macleod, 2006). Morphometric studies help to explain the evolutionary-ecological processes affecting foraminifera, and foraminiferal researchers have applied these studies to taxonomic, systematic, stratigraphic, biogeographic and phylogenetic research.

Larger foraminiferal morphometry has been used by various authors to explain and demonstrate changes in temperature, water depth and symbionts. Larger foraminifers contain symbionts in their protoplasm, because the symbionts are light-dependent and their presence serves as an indicator for depth within the photic zone. The larger foraminiferal wall structure plays an important part in determining the amount and quality of light that is received by its cell, with thinner portions receiving more light (Hohenegger, 1994; Hohenegger et al., 1999). The structure and form of larger foraminiferal tests are also directly related to their proximity to nearshore regions and higher water energies, and are directly manifested in their test morphology as saddle shapes, test thickness and chamber walls (Hottinger, 1997; Hohenegger et al., 1999;

Bryan, 1995). The concentration of larger foraminifera has been correlated to down-shelf transport, which is controlled by traction, slope steepness and differences in test buoyancies (Hohenegger et al., 2001). These morphological relationships with environmental settings (Hottinger, 1983, 1977; Hallock and Glenn, 1986) have been used to estimate facies and water depths of paleoenvironments (Hottinger, 1978, 1997), although other factors such as possible post-mortem transportation of foraminiferal tests need to be considered when making these generalizations. For example, extant *Heterostegina depressa* inhabits upper slopes, and their low buoyancy should result in lower rates of displacement (Hohenegger et al., 2001). Similarly, the extant, thick, lenticular-walled *Nummulites* sp., a deeper water inhabitant, is minimally transported (Hohennegger et al., 2001).

Ward et al. (2003) identified three depositional sequences in the Ocala Limestone as seen in the ROMP 29A core (Table 4.1). These sequences contain characteristic high-frequency units of deposition associated with different paleoenvironments, and high concentrations of larger foraminifera. Larger foraminifera are known to be light-dependent because of their symbionts, which limit the water depths at which they occur to the photic zone (Hohenegger, 1994). Their test shape configurations accommodate light penetration for life in a deeper water by being thinner and wider. Increased strength to withstand high water energy results from having more chamber and chamberlet walls, and being saddle-shaped helps to withstand turbulent water in near shore environments (Hottinger, 1997; Bryan, 1995). Increase in the size of embryonic chambers and test diameter occurs with each phylogenetic generation (Bryan, 1995). This study tests a hypothesis concerning changes in larger foraminiferal features in response to

environmental changes in the Ocala Limestone as observed in the ROMP 29A core, namely the possible correlation of measured features observed in *Heterostegina ocalana, Nummulites,* and *Lepidocyclina* in the ROMP 29A core with the three depositional sequences of Ward et al. (2003).

4.2 Previous Research on Morphometry of Larger Foraminifera

Numerical values placed on the variations in the size and shape of larger foraminiferal features have been used to identify changes in paleoenvironmental conditions and to determine evolutionary successions useful in biostratigraphy. Below, the development of these approaches is reviewed.

Khan and Drooger (1971) examined Eocene *Nummulites partschi*, *N. burdigalensis* and *N. planulatus* from France and found them to show a great deal of variation in size and internal complexity. There was a significant number of intermediate states which did not fit any one taxon, according to measurements of the inner diameter of the protoconch, the outer diameter of the first two whorls and the number of chambers in the first two whorls. Based on the nature of the rocks from which they were collected, Khan and Drooger (1971) concluded that increases in the diameter of the protoconch, test size and number of whorls per median radius through time were a result of evolutionary changes in response to paleoenvironmental changes.

Chaproniere (1980) developed two parameters, N_o (the number of undivided chambers including the two initial chambers) and S_{4+5} (the number of chamberlets in the fourth and fifth chamber), in addition to the commonly used D_I (protoconch diameter) and D_{II} (deuteroconch diameter) in *Heterostegina borneensis*. He found that the

parameters N_o and S_{4+5} gave results that were consistent enough to make them useful in correlation. D_I and D_{II} differed considerably, suggesting environmental control.

Chaproniere (1980) also investigated the biometry of *Lepidocyclina (Eulepidina),* introducing the parameter LA, the length of the common wall between D_I and $D_{II,}$ as a percentage of the inner deuteroconch's circumference. LA is a measure of the "degree of enclosure" of the deuteroconch surrounding the protoconch. The LA value was found to decrease as the deuteroconch progressively surrounded the protoconch, characteristic of *Lepidocyclina* (*Nephrolepidina*). Chaproniere (1980) observed the diameter decrease in D_I and D_{II} in the North West Cape area *Lepidocyclina,* which was contrary to their expected increase up section (during ontogeny). In the Badjirrajirra Creek specimens of *Lepidocyclina,* D_I and D_{II} increase in diameter, but their test size did not lead to the conclusion that these trends were controlled by environmental conditions such as water depth.

Hottinger (1982) explained relationships between the intricate details of the biology of larger foraminifera and their morphology. As a k-strategist (adapted to living in an environment of limited resources) the shell morphology of larger foraminifera is determined by their biological processes of autecological adaptation (taxon response to the environment), ontogeny (growth pattern through time), protoplasmic streaming patterns (movement of the cytoplasm, transporting nutrients, protein and organelles within cells), and protoplasmic differentiation and patterns at the cell surface (Hottinger, 1982). The traits of larger foraminifera that make them useful as zonation markers in micropaleontology are as follows: abundance, allowing quantitative analysis because of a large amount of specimens; complex distinctive morphology, easily identified;

discontinuous chamber-wise growth reflecting the specimen's ontogenesis; extensive knowledge of the complex shell morphology, growth pattern and distribution in time and space indicative of phylogenetic history (Hottinger, 1982); and having living representatives or descendants from which generalizations can be made to decipher their life history in the geologic past (Hottinger, 1982).

It is clear that there are some correlations between larger foraminiferal growth patterns and their response to environmental conditions. Drooger (1983) has suggested that each species possesses a cline (a range) in all of the measurements of its morphometric features, and he embarked on an intensive, ten-year measuring program with the intention of defining intraspecific clines, especially in chamber arrangement and embryonic size. The term "nepionic acceleration" was used to explain the ontogenetic steps involved in embryon and nepiont development. It was concluded that in all orbitoidal groups a change from a spiral to globular chamber arrangement was expected during phylogeny. In size measurement, the use of embryonic size was favored, as test size was found to be a continuous variable tied to growth, and proved more easily susceptible to external influences of temperature, depth and symbionts. An irregular increase in embryonic size was found in all groups during phylogeny, but this trend was restricted to the megalospheric forms that possessed larger embryon sizes, a product of an association of reproductive cycles (Drooger, 1983). However, there is evidence of larger embryon size in *Planorbulinella, Miogypsinoides, Miogypsina bermudezi, Miogypsina complanatus, Planolinderina* and *Pseudorbitoides* associated with shallowing water conditions (Drooger, 1983).

Another approach to morphological variations in larger foraminifera was by Hallock (1985), who asked the question. ”Why are foraminifera large?” and concluded that delayed maturation and larger size were only beneficial in stable environments in which food resources were scarce. Dependence on algal symbiosis is advantageous where sunlight is available to compensate for oligotrophic conditions (Hallock, 1985). She linked increased proloculus and deuteroconch size and reduced occurrence of sexual reproduction to limited food resources and sunlight, which are characteristic of stable conditions (Hallock, 1985). However, adaptations to oligotrophic conditions can lead to extinction when conditions return to a more normal nutrient state (Hallock, 1985).

Hallock & Glenn (1986) outlined and highlighted the ecologic basis for paleoecologic interpretations based on larger foraminifera. They proposed an idealized distribution of modern, reef-associated foraminifera, supplying examples of standard facies types according to Wilson’s (1974) standard carbonate facies belts. Eight standards facies were defined: basin, open shelf, toe of slope, foreslope, ecologic reef, shelf sands, open platform, and restricted platform and lagoon (Hallock & Glenn, 1986). Four distinct facies were identified in two cores: a larger foraminiferal wackestone facies, of which 30% of the total fauna was characterized by lepidocyclinids, *Cycloclypeus* and planktic foraminifera; a coral boundstone facies containing low numbers but a high diversity of foraminifera including larger and smaller forms; a red algal-larger foraminiferal packstone facies containing miogypsinids, *Amphistegina*, *Lepidocyclina*, *Cycloclypeus* and small rotaliines and miliolids; and a small foraminiferal grainstone and packstone facies comprising at least 40% smaller rotaliines and miliolines, with *Lepidocyclina* and

Cycloclypeus representing less than 20% and miogypsinids and *Amphistegina* present in lower numbers (Hallock & Glenn, 1986).

A characteristic of larger benthic foraminifera is their ability to reproduce via an alternation of generations, forming microspheric forms through asexual reproduction and megalospheric forms by sexual reproduction. The microspheric embryons (proloculus and deuteroloculus) have diameters smaller in size than those of the megalospheric forms, and the microspheric tests are several times larger than those of the megalospheric forms (Bryan, 1995). The occurrences of the microspheric forms are usually uncommon, whereas the megalospheric forms are most prevalent. Bryan (1995) concluded that larger foraminifera are affected by low light intensity and water energy, which are inversely related to water depth in very shallow, oligotrophic, tropical to subtropical environments. He found that in deeper water, larger benthic foraminifera delay reproduction and grow for longer periods of time. Bryan (1995) proposed that the larger the juvenile, the more symbiont-rich protoplasm it contained, which put it at an advantage to survive under reduced light conditions. In shallow waters, delayed reproduction was also observed and interpreted as a response to juvenile demise in high-energy conditions (Bryan, 1995).

Hohenegger (1995) explained that larger foraminifera can be used to estimate relative depth in sublittoral coral reefs. He concluded that the restriction of larger foraminifera to the photic zone is a direct result of the relationship with symbiotic micro-algae. *Nummulites venosus* had a depth range of 10-80 m, with a normal distribution peaking at 40 m (Hohenegger, 1995). *Heterostegina depressa* had a depth range of 0-90 m, a normal distribution with its peak at 40 m (Hohenegger, 1995). Another control on depth distribution in larger foraminifera is the intensity of wave action. Larger

foraminifera respond to a high energetic environment by developing lenticular tests, thicker test walls, additional septulae and spines to protect themselves from abrasion and breakage (Hohenegger, 1994). Gradients defined by ecological factors control the spatial distribution, reproduction patterns and population size (Hohenegger, 1995).

Robinson (1996) used Middle Eocene Lepidocyclinidae to date extremely shallow marine paleoenvironments, which is especially useful where traditional planktonic microfossils (zonation species) are uncommon or missing. Most larger foraminifers flourish under optimum conditions of warm temperature, shallow seas, and low energy, and are found in large numbers on shallow marine platforms. The lepidocyclinids evolved from *Amphistegina* sp. through the intermediate species *Eulinderina* and *Polylepidina* in the Lower Eocene of the Gulf of Mexico and northern Caribbean. The *Amphistegina –Eulinderina – Polylepidina - Lepidocyclina* succession is characterized by the structure of the nepiont (with a different growth style that follows the embryonic stage preceding the adult stage) and the mode of nepionic acceleration (or the reduction of the nepiont), and was concluded to represent Lower Eocene deposits of the Gulf of Mexico and northern Caribbean (Robinson, 1996).

Less and Özcan (2008) found megalospheric forms of Priabonian *Spiroclypeus* sp. to have experienced a reduction in operculine (undivided), post–embryonic chambers and they used this criterion to divide them into the phylogentically linked species *S. sirottii* and *S. carpaticus*. Evolutionary trends were also seen in the increase in the number of secondary chamberlets, the diameter of the first whorls and the size of the proloculus, although the proloculus size has also been linked to ecological influence (Less and Özcan, 2008).

Boudagher-Fadel (2008) saw the Paleogene as a period of recovery after the Cretaceous-Paleogene catastrophe in which more than eighty percent of larger benthic foraminifera apparently migrated to other areas. In the Tethys region, the larger miliolines and rotaliines appeared in the Late Paleocene. The rotaliines developed a complex system of marginal cords, characteristic of the *Nummulites* spp., that eventually appeared and became abundant in the Eocene. They coexisted with the three-layered orthrophragmid *Discocyclina* sp. and its descendants in the forereef and shallow-marine, open platforms (Boudagher-Fadel, 2008). However, in the Americas, the rotallines did not appear until the Middle Eocene, evolving into the three-layered *Lepidocyclina* spp. and *Eulepidina* sp. Boudagher-Fadel (2008) concluded that these latter forms migrated through Tethys in the Oligocene, but a reverse migration of alveolines and discocylinids from Tethys to the Americas did not occur. Another important observation was that the American nummulitids did not attain sizes as large as those in the Mediterranean Tethys.

4.3 Methods

The methods for sampling the core, and for preparing and identifying the larger foraminifera, are described in Chapter 3, section 3.4.

4.3.1 Morphometry of Larger foraminifera in the Ocala Limestone

Specimens of *Heterostegina ocalana*, *Nummulites* sp. and *Lepidocyclina* sp. were viewed under a Leica MZ16 stereographic microscope, with a digital camera attached. Photographs were taken of each specimen and their morphologic features were measured using Leica Application Suite, version 2.8.1 software.

The morphologic features of 208 specimens of *Heterostegina ocalana* were measured (Fig. 4.1) as follows:

- p , diameter of the proloculus (first chamber formed), measured at right angles to the line joining the center points of the proloculus and next-formed chamber, or deuteroconch, d (Chaproniere, 1984)
- N_o, number of operculine (undivided) chambers, including the proloculus (Chaproniere, 1984)
- S_{4+5}, total number of chamberlets in chambers 4 and 5, added together, counting the proloculus as chamber 1 (Chaproniere, 1984)
- S_{10}, S_{14} , $S_{18,}$ $S_{22,}$ $S_{26,}$ $S_{30,}$ S_{34} (Fig. 2), $S_{38,}$ S_{42} and $S_{46,}$ total number of chamberlets in each particular chamber, counting the proloculus as chamber 1 (E. Robinson, oral communication, 2006; Less et al., 2008)
- Whorl-1, -2, - 3 or- 4, diameter of the first, second, third or fourth whorl parallel to the axis of the first two chambers.

In 192 specimens of *Nummulites* sp., the morphologic features were measured (Fig. 4.2) as follows:

- pxd, inner cross-diameter of protoconch
- pdd, depth diameter of protoconch
- dxd, inner cross-diameter of deuteroconch
- ddd, depth diameter of deuteroconch

- c, number of chambers in each of the first, second, third and fourth whorls (w1d, w2d, w3d, w4d and w5d), excluding first and second chambers
- w2d, w3d, w4d and w5d, diameter of first, second, third and fourth whorls, excluding first and second chambers

The morphologic features measured in 274 specimens of *Lepidocyclina* sp. specimens (Fig. 4.3) were as follows:

- a, inner cross-diameter of deuteroconch
- b, depth diameter of deuteroconch
- c, inner cross-diameter of protoconch
- d, depth diameter of protoconch
- e, number of periembryonic chambers (i.e., all chambers in direct contact with protoconch and deuteroconch)
- t, diameter of test

4.3.2 Analytic Methods

A one-way analysis of variance (ANOVA) was applied to the measured features to determine if the depositional environments of Ward et al. (2003) had a significant correlation with the morphology of *Heterostegina ocalana*, *Lepidocyclina* spp. and *Nummulites* spp. An ANOVA tests whether there is a significant difference between the means of groups. Here the groups are the depositional units. The variability about the mean within each group is compared to the variability between groups. The post-hoc Bonferroni multiple test correction was used to identify depositional sequences that were

significantly different; this test was selected from the others available because the number of dependent variables is low. If p-values are less than or equal to 0.05, there is a difference overall between groups (depositional units). The software used for the statistical analysis is SYSTAT version 13 (Systat, 2010).

4.4 Results

4.4.1 Morphometry

A summary of the measurements of *Heterostegina ocalana*, including the proloculus, deuteroconch, deuteroconch/proloculus ratio, whorl width (for the first, second and third whorls), number of operculine chambers (undivided chambers including the proloculus), and chamberlets per chamber in chambers 4+5, 10, 14, 18, 22, 26, 30, 34, and 38, are described below for the ROMP 29A core and Jamaica strata (Tables 4.2, 4.3, 4.4). There are no obvious trends except for an increase in the third whorl diameter and the chamberlets in whorls 30, 34 and 38 (Fig. 4.4).

In *Nummulites willcoxi* the cross diameter of the protoconch and deuteroconch; diameter of the first, second, and third whorls; and the number of chambers in the first, second and third whorls show no change between depths 232 m to 191.8 m, but between depths 191 m and 185.8 m there is a marked increase (Tables 4.5, 4.6, 4.7; Fig. 4.5). The deuteroconch/protoconch ratio shows no obvious trends. The number of chambers in the first, second, third and fourth whorls show a decrease from depths 232 m to 208.4 m, and a slight increase to 191.8 m, followed by a decrease from 191.8 m to 185.8 m.

In *Nummulites floridensis* the cross diameter of the protoconch and deuteroconch; deuteroconch/protoconch ratio; diameter of the first, second, and third whorls; and the

number of chambers in the first, second, and third whorls show no marked changes from the base to top of the formation (Tables 4.5, 4.6,4.7; Fig. 4.5).

In *Nummulites striatoreticulatus* the cross diameter of the protoconch and deuteroconch, and the deuteroconch/protoconch ratio show no marked changes between the two measured populations at depths 175 m and 171.3 m (Tables 4.5, 4.6, 4.7; Fig. 4.5). The measurements of the diameter and the number of chambers of the first, second, third whorls show an obvious increase from depths 175 m to 163.7 m (Tables 4.5, 4.6, 4.7; Fig. 4.5).

Six species of *Lepidocyclina* were identified using the criterion of the periembryonic chambers: *L. chaperi, L. pustulosa, L. ocalana* sp. A, *L. ocalana* sp. B, *L. ocalana* sp. C, and *L. ocalana* sp. D (Tables. 4.8, 4.9, 4.10, 4.11, 4.12, 4.13; Figs. 4.6, 4.7, 4.8, 4.9, 4.10, 4.11). Changes in the measurement of the features in the six *Lepidocyclina* spp. along the ROMP 29A show little variations because of insufficient data (Figs. 4.12, 4.13, 4.14, 4.15). More comparative information was seen in the changes of the combined measurements of the features in the *Lepidocyclina* spp. (Fig. 4.16).

4.4.2 Analysis of Variance

An analysis of variance was run for each morphologic feature of each of three taxa to test whether there were significant differences between morphologies within the three depositional sequences of Ward et al. (2003). The Bonferroni post-hoc test was used to identify which specific depositional sequences were different in each run. There were sufficient data for *Heterostegina ocalana*, but because the number of core depths for

the other taxa were few, species of *Nummulites* and *Lepidocyclina* were combined for each genus. The results are as follows (Table 4.14, APPENDICES III, IV, V):

- For *Heterostegina ocalana* all of the p-values were less than 0.05 with the exception of the deuteroloculus diameter and the number of chamberlets in the tenth chamber. In three of ten cases (30%) depositional sequences #1 and #2 were significantly different, five (50%) were significantly different for #1 and #3, and six (60%) were significantly different for #2 and #3.
- For *Nummulites* spp. all of the P-values were less than 0.05, with the exception of the number of chambers in the first and second whorls. In two of six cases (33%) depositional sequences #1 and #2 were significantly different, three (50%) were significantly different for #1 and #3, and one (17%) was significantly different for #2 and #3.
- For *Lepidocyclina* spp. both of the P-values were less than 0.05. In one of two cases (50%) depositional sequences #1 and #2 were significantly different, both (100%) were significantly different for #1 and #3, and both (100%) were significantly different for #2 and #3.

4.5 Discussion

4.5.1 Morphometry

Hallock (1985) and Bryan (1995) suggest that deeper water *Heterostegina* have larger tests, proloculus and deuteroconch diameters, and a smaller number of operculine chambers than those found in shallower water because of adaptation to oligotrophic

environments (Hallock, 1985; BouDagher-Fadel, 2008), in which organisms delay reproduction (and thus, death). Larger foraminifera increase in size by adding chambers and flattening their tests, and the originally cubic chambers become elongated, allowing more algae symbionts to concentrate around the peripheries. These adaptations are beneficial in adapting to water depth changes or extending the ecological niche vertically and laterally.

The ANOVA results indicate that the changes in the morphology of *Heterostegina ocalana,* with the exception of the deuteroloculus diameter and the number of the chamberlets in the tenth chamber, are overall significantly different between the depositional sequences of Ward et al. (2003), and there are more differences in morphology between depositional sequences #1 and #3 (50% mean) and between #2 and #3 (60% mean) than between #1 and #2 (30% mean). The results are in accordance with observations in Drooger (1983), in which depositional environments influenced the size of the diameters of the proloculus, but this influence was not always reflected in the deuteroloculus. He thought this was critical because traditionally, morphometric studies used embryon size (proloculus and deuteroloculus), which produced inconsistent trends, a result of different growth patterns in the proloculus and deuteroloculus.

The ANOVA results also indicate that the changes in the morphology of *Nummulites* spp., with the exception of the number of chambers in the first and second whorls, are significantly different between the depositional sequences of Ward et al. (2003). These results also support the morphologic-environmental trends suggested by Hallock (1985) and Bryan (1995). There are more differences in morphology between

depositional sequences #1 and #3 (50% mean) than between #2 and #3 (17% mean) or between #1 and #2 (33% mean).

The ANOVA results indicate that the average morphology of *Lepidocyclina* spp. is also significantly different between the depositional sequences of Ward et al. (2003). There are more differences in morphology between depositional sequences #1 and #3 (100% mean) and between #2 and #3 (100% mean) than between #1 and #2 (50% mean). Thus, the variation in morphology of all of the larger foraminifera corresponds to the depositional sequences of Ward et al. (2003), and the earliest and latest sequences are most different.

The morphometrics of the specimens of *Lepidocyclina* have implications for its taxonomy. The measurements of the periembryonic chambers used to differentiate species of *Lepidocyclina* produced results that are similar to that of the varieties of *Lepidocyclina ocalana* (Chapter 3) identified by Cushman (1920). The occurrences of *Lepidocyclina ocalana* in the ROMP 29A core (Figs. 4.12, 4.13, 4.14, 4.15) show changes of each species which are not trends, but the combined parameters show the overall response experienced by *Lepidocyclina* spp. (Table 4.12, Fig. 4.16). These observations suggest that the varieties of *Lepidocyclina ocalana* were ecophenotypes of one species.

The Jamaican specimens of *Heterostegina ocalana* are from one geographic site and stratigraphic level, unlike the Florida specimens. They are much smaller on average and coincide with the lower size range of the Florida specimens.

Nummulites willcoxi and *Nummulites* sp. A (Fig. 4.5) are similar in appearance, but *Nummulites* sp. A is much larger and thicker walled, and has a larger

concentration of chambers than does *Nummulites willcoxi*. *N. willcoxi* and *N.* sp. A could possibly be variants of the same species, where *N. willcoxi* experienced more favorable conditions which promoted rapid growth leading to additional and thicker chamber walls that were needed to support the larger test size of *N.* sp. A. However, more material would be required to investigate this possibility.

4.6 Conclusions

Variability within individual and group of species were significantly different between the three depositional units of Ward et al. (2003), suggesting some environmental control of morphology. Some changes in morphology were identified that can be used as tools for interpreting paleoenvironments. In *Heterostegina ocalana, Nummulites willcoxi* and *Lepidocyclina* (spp.), the test diameter, number of chambers per whorl and number of chamberlets increased with water depth, indicating their utility as a paleobathymetric indicator. The *Lepidocyclina ocalana,* the varieties named by Cushman (1920) are identified as environmental variants, and morphologies overlap too much to consider them further as separate taxa.

Depositional Sequences	Thickness (m)	Distance Along Core, below land surface (M)	Number of High Frequency units	Description
3	26.3	178.6-152.2	3	Mixed-skeletal wackestone; mud-dominated packstone, a 0.6-m-thick layer of *Lepidocyclina* floatstone
2	28.3	206.9-178.6	7	Each high frequency unit consists of *Lepidocyclina* wackestone with a thin layer of *Lepidocyclina* mud-dominated packstone.
1	27.7	234.7-206.9	0	The lower 16.8 m consists of alternating *Nummulites* wackestone. Above 217.9 m non-bedded *Lepidocyclina-Nummulites* wackestone coarsens up to *Lepidocyclina-Nummulites,* mud-dominated packstone. The top 2.4 m consists of large *Lepidocyclina* floatstone and mudstone.

Table 4.1 Depositional sequences of the ROMP 29A core, identified by Ward et al. (2003).

Parameter		Proloculus Cross-diameter (mm)			Deuteroconch Cross-diameter (mm)			Deuteroconch/Proloculus Ratio		
Depth		No.	mean ± s.e.	range	No.	mean ± s.e.	range	No.	mean ± s.e.	range
ROMP 29A	172.5	7	0.10 ± 0.01	0.07 – 0.12	7	0.13 ± 0.01	0.09 – 0.17	7	1.30 ± 0.10	0.94 ± 1.71
	175	8	0.10 ± 0.01	0.08 – 0.12	8	0.12 ± 0.01	0.09 – 0.14	8	1.19 ± 0.06	0.95 – 1.43
	184.7	15	0.10 ± 0.01	0.07- 0.13	15	0.13 ± 0.01	0.08- 0.16	15	1.27 ± 0.03	1.03 – 1.48
	186	17	0.09 ± 0.01	0.06- 0.15	17	0.12 ± 0.01	0.09 - 0.15	17	1.33 ± 0.06	0.75 – 1.79
	188	15	0.10 ± 0.01	0.07 – 0.13	15	0.13 ± 0.01	0.07 – 0.16	15	1.28 ± 0.06	0.93 – 1.85
	190.2	14	0.09 ± 0.01	0.07 – 0.12	14	0.12 ± 0.01	0.07 - 0.17	14	1.26 ± 0.06	0.68 - 1.51
	193.9	12	0.10 ± 0.01	0.08 – 0.14	12	0.12 ± 0.01	0.09 – 0.15	12	1.17 ± 0.09	0.62 – 1.70
	196.9	15	0.11 ± 0.01	0.08 – 0.17	15	0.13 ± 0.01	0.10 – 0.19	15	1.21 ± 0.04	0.83 – 1.46
	198.4	16	0.10 ± 0.01	0.08 – 0.14	16	0.13 ± 0.01	0.09 – 0.16	16	1.27 ± 0.03	1.10 – 1.45
	207.1	15	0.12 ± 0.01	0.07 – 0.19	15	0.14 ± 0.01	0.10 – 0.20	15	1.19 ± 0.05	0.73 – 1.53
	207.7	3	0.11 ± 0.01	0.10 – 0.12	3	0.12 ± 0.01	0.05 – 0.14	3	1.08 ± 0.13	0.83 - 1.24
	223	15	0.10 ± 0.01	0.08 – 0.19	15	0.13 ± 0.01	0.08 – 0.21	15	1.26 ± 0.04	0.99 – 1.58
	232	16	0.10 ± 0.01	0.07 - 0.18	16	0.12 ± 0.01	0.07 – 0.09	16	1.19 ± 0.06	0.91 – 1.51
	234	15	0.11 ± 0.01	0.09 - 0.16	15	0.13 ± 0.01	0.09 - 0.19	15	1.19 ± 0.04	0.79 – 1.33
Jamaica		8	0.07 ± 0.01	0.06 - 0.09	8	0.09 ± 0.01	0.07 – 0.10	8	1.28 ± 0.09	0.94 – 1.59

Table 4.2. Cross diameter of proloculus, deuteroconch and deuteroconch/proloculus in *Heterostegina ocalana.*

Parameter		1st Whorl Width (mm)			2nd Whorl Width (mm)			3rd Whorl Width (mm)		
Depth		n	mean ± s.e.	range	n	mean ± s.e.	range	n	mean ± s.e.	range
ROMP 29A	172.5	7	0.65 ± 0.05	0.42 – 0.86	7	1.78 ± 0.18	1.15 – 2.38	4	3.24 ± 0.39	2.59 – 4.38
	175	8	0.72 ± 0.03	0.59 – 0.86	8	1.77 ± 0.09	1.46 – 2.25	6	3.54 ± 0.32	2.55 – 4.61
	184.7	15	0.67 ± 0.03	0.49 – 0.86	15	1.43 ± 0.08	1.00 – 2.18	4	2.27 ± 0.18	2.02 – 2.77
	186	17	0.53 ± 0.04	0.25 – 0.79	17	1.20 ± 0.08	0.55 – 1.84	13	2.22 ± 0.16	1.08 – 3.06
	188	15	0.63 ± 0.03	0.47 – 0.93	15	1.45 ± 0.11	0.99 – 2.44	9	2.60 ± 0.16	2.05 – 3.69
	190.2	14	0.56 ± 0.02	0.43 – 0.73	14	1.21 ± 0.08	0.77 – 1.91	8	1.96 ± 0.12	1.62 – 2.53
	193.9	12	0.65 ± 0.03	0.47 – 0.83	12	1.32 ± 1.32	1.03 – 1.69			
	196.9	15	0.67 ± 0.03	0.52 – 0.84	15	1.41 ± 0.07	1.04 – 1.84	13	2.56 ± 0.12	1.71 – 3.21
	198.4	15	0.59 ± 0.02	0.44 – 0.74	16	1.23 ± 0.05	0.88 – 1.70	15	2.28 ± 0.12	1.62 – 3.09
	207.1	15	0.70 ± 0.03	0.49 – 0.54	15	1.38 ± 0.06	1.01 – 1.85	15	2.55 ± 0.11	1.42 – 1.82
	207.7	3	0.69 ± 0.06	0.60 – 0.82	3	1.53 ± 0.07	1.40 – 1.61			
	223	15	0.65 ± 0.02	0.53 – 0.83	15	1.40 ± 0.06	1.06 – 1.76			
	232	16	0.60 ± 0.03	0.30 – 0.76	16	1.40 ± 0.06	1.09 – 1.94	8	2.29 ± 0.06	2.00 – 2.60
	234	15	0.65 ± 0.03	0.43 – 0.84	15	1.28 ± 0.59	0.85 – 1.78	14	2.27 ± 0.13	1.29 – 3.13
Jamaica		8	0.49 ± 0.01	0.43 -- 0.54	8	1.04 ± 0.04	0.91 – 1.27	7	1.84 ± 0.04	1.71 – 1.99

Table 4.3. Diameter of whorls of *Heterostegina ocalana.*

Parameter		# of Operculine Chambers			# of Chamberlets: 4+5			# of Chamberlets: Chamber 10			# of Chamberlets: Chamber 14		
Depth		n	mean ± s.e.	range	n	mean ± s.e.	range	n	mean ± s.e.	range	n	mean ± s.e.	range
ROMP 29A	172.5	7	4.14 ± 0.26	3 – 5	7	2.86 ± 0.26	2 – 4	7	2.71 ± 0.49	2 – 3	7	4.00 ± 0.31	3 – 5
	175	7	4.43 ± 0.20	4 – 5	7	2.57 ± 0.20	2 – 3	7	3.14 ± 0.69	2 – 4	7	4.29 ± 0.36	3 – 6
	184.7	15	5.13 ± 0.34	3 – 8	15	2.40 ± 0.16	2 – 8	15	2.67 ± 0.23	2 – 6	15	3.13 ± 0.27	2 – 6
	186	16	5.19 ± 0.39	3 – 9	16	2.75 ± 0.25	2 – 5	16	3.00 ± 0.26	2 – 6	16	4.06 ± 0.30	2 – 6
	188	15	5.20 ± 0.37	4 – 9	15	2.40 ± 0.13	2 – 3	15	2.47 ± 0.17	2 – 4	15	3.80 ± 0.28	2 – 6
	190.2	14	5.36 ± 0.39	4 – 9	14	2.21 ± 0.43	2 – 3	14	2.64 ± 0.75	2 – 4	14	3.71 ± 0.35	2 – 6
	193.9	12	6.00 ± 0.69	2 – 11	12	2.25 ± 0.18	2 – 4	12	2.42 ± 0.24	1 – 4	12	2.50 ± 0.26	1 – 4
	196.9	15	5.73 ± 0.45	2 – 9	15	2.40 ± 0.16	2 – 4	15	2.73 ± 0.18	2 – 4	15	3.6 0 ± 0.21	2 – 5
	198.4	16	6.56 ± 0.43	5 – 10	16	2.00 ± 0.00	2 – 2	16	2.56 ± 0.18	1 – 4	16	3.63 ± 0.22	2 – 6
	207.1	15	4.93 ± 0.32	4 – 8	15	2.60 ± 0.16	2 – 4	15	2.73 ± 0.18	2 – 4	15	3.20 ± 0.26	2 – 5
	207.7	3	5.00 ± 1.00	4 – 7	3	2.67 ± 0.33	2 – 3	3	2.00 ± 0.00	2 – 2	3	3.00 ± 0.00	3 – 3
	223	15	5.20 ± 0.40	4 – 10	15	2.33 ± 0.13	2 – 3	15	2.47 ± 0.19	1 – 4	15	3.33 ± 0.29	2 – 6
	232	16	7.31 ± 0.60	5 – 12	16	2.06 ± 0.06	2 – 3	16	2.13 ± 0.18	1 – 3	16	3.19 ± 0.28	1 – 5
	234	15	5.60 ± 0.43	4 – 8	15	2.40 ± 0.16	2 – 4	15	2.80 ± 0.18	2 – 4	15	4.07 ± 0.28	3 – 6
Jamaica		8	7.25 ± 0.96	5 – 12	8	2.00 ± 0.00	2 – 2	8	2.25 ± 0.37	1 – 4	8	3.00 ± 0.42	2 – 5

Parameter		# of Chamberlets: Chamber 18			# of Chamberlets: Chamber 22			# of Chamberlets: Chamber 26		
Depth		n	mean ± s.e.	range	n	mean ± s.e.	range	n	mean ± s.e.	range
ROMP 29A	172.5	7	6.86 ± 0.67	4 – 9	7	7.86 ± 0.74	5 – 10	7	9.29 ± 0.84	6 – 12
	175	7	6.17 ± 1.14	3 – 12	6	7.33 ± 0.49	5 – 8	6	9.17 ± 0.60	8 – 11
	184.7	15	4.47 ± 0.42	2 – 7	15	5.60 ± 0.47	3 – 9	14	6.57 ± 0.53	3 – 10
	186	16	4.69 ± 0.25	3 – 6	16	6.06 ± 0.42	3 – 9	16	7.13 ± 0.44	4 – 10
	188	15	4.47 ± 0.24	3 – 6	15	6.73 ± 0.49	4 – 9	14	7.79 ± 0.61	5 – 11
	190.2	14	4.93 ± 0.50	2 – 9	14	5.79 ± 0.38	3 – 8	12	7.75 ± 0.83	3 – 14
	193.9	11	3.45 ± 0.31	2 – 6	10	4.20 ± 0.53	1 – 7	11	4.91 ± 0.48	2 – 7
	196.9	15	4.80 ± 0.36	3 – 7	15	6.00 ± 0.39	4 – 9	15	7.20 ± 0.69	4 – 13
	198.4	16	3.94 ± 0.35	1 – 6	16	4.56 ± 0.40	2 – 7	16	5.50 ± 0.41	2 – 8
	207.1	15	4.40 ± 0.42	2 – 7	15	4.87 ± 0.41	3 – 9	15	5.67 ± 0.53	2 – 10
	207.7	3	3.33 ± 0.33	3 – 4	3	4.00 ± 0.00	4 – 4	3	4.67 ± 0.33	4 – 5
	223	14	4.07 ± 0.50	1 – 8	15	4.73± 0.34	3 – 8	14	5.42 ± 0.37	4 – 8
	232	16	3.81 ± 0.40	1 – 7	16	4.56 ± 0.42	2 – 8	14	6.29 ± 0.58	4 – 12
	234	15	5.13 ± 0.31	3 – 7	15	5.93 ± 0.67	3 – 13	14	6.43 ± 0.45	3 – 9
Jamaica		8	3.88 ± 0.35	2 – 5	8	5.25 ± 0.56	3 – 7	8	6.13 ± 0.35	5 – 8

Parameter		# of Chamberlets: Chamber 30			# of Chamberlets: Chamber 34			# of Chamberlets: Chamber 38		
Depth		n	mean ± s.e.	range	n	mean ± s.e.	range	n	mean ± s.e.	range
ROMP 29A	172.5	3	10.00 ± 1.73	7 – 13	1	12.00 ± 0.00	12-12	1	13.00 ± 0.00	13-13
	175	5	11.60 ± 0.60	10- 13	4	14.75 ± 2.21	10-19	1	20.00± 0.00	20-20
	184.7	8	7.38 ± 0.53	4 – 9	2	9.50 ± 1.50	8 – 10			
	186	15	9.27 ± 0.41	6 – 12	12	10.42 ± 0.58	7 – 13			
	188	10	9.60 ± 0.93	6 – 16	4	9.00 ± 1.68	5 – 19	3	11.67 ±4.06	5 – 19
	190.2	8	7.00 ± 0.63	5 – 10	3	8.00 ± 1.00	6 – 9	1	11.00± 0.00	11- 11
	193.9	7	5.00 ± 0.95	1 – 8	6	6.83 ± 1.05	4 – 10			
	196.9	14	9.14 ± 0.70	4 – 14	13	10.62 ± 0.87	6 – 15	4	9.75 ± 1.89	6 – 15
	198.4	16	6.81 ± 0.65	3 – 12	16	8.79 ± 0.71	4 – 13	8	10.63 ± 1.80	4 – 19
	207.1	15	6.20 ± 0.72	2 – 11	15	7.27 ± 0.86	2 – 14	14	8.14 ± 0.95	1 – 15
	207.7									
	223	14	7.64 ± 0.45	5 – 12	10	7.80 ± 0.44	6 – 10			
	232	12	7.00 ± 0.67	3 – 11	10	7.80 ± 0.76	3 – 12			
	234	12	7.50 ± 0.60	5 – 12	9	11.11 ± 1.06	7 – 17	6	10.5 ± 0.85	8 – 13
Jamaica		8	7.88 ± 0.40	6 – 9	5	10.20 ± 0.66	8 – 12	1	11.00 ± 0.00	11-11

Table 4.4. The number of chamberlets per chamber in *Heterostegina ocalana*

Parameter		Proloculus Cross-diameter (mm)			Deuteroconch Cross-diameter (mm)			Deuteroconch/Proloculus Ratio		
Depth		n	mean ± s.e.	range	n	mean ± s.e.	range	n	mean ± s.e.	range
ROMP 29A	163.7	8	0.09 ± 0.01	0.06 – 0.11	8	0.14 ± 0.01	0.10 – 0.18	8	1.50 ± 0.08	1.05 – 1.77
	171.3	14	0.08 ± 0.01	0.05 – 0.12	14	0.09 ± 0.01	0.05 – 0.16	14	1.03 ± 0.06	0.76 – 1.60
	175	15	0.07 ± 0.00	0.05 – 0.09	15	0.08 ± 0.02	0.06 – 0.09	15	1.16 ± 0.04	0.97 – 1.54
	185.8	13	0.16 ± 0.01	0.12 – 0.23	13	0.17 ± 0.01	0.13 – 0.26	13	1.08 ± 0.03	0.93 – 1.35
	188	15	0.08 ± 0.01	0.07 – 0.10	15	0.09 ± 0.00	0.08 – 0.13	15	1.18 ± 0.05	0.81 – 1.47
	190.8	15	0.07 ± 0.00	0.06 – 0.09	15	0.09 ± 0.00	0.06 – 0.11	15	1.27 ± 0.04	1.07 – 1.57
	191.8	15	0.06 ± 0.00	0.04 – 0.08	15	0.07 ± 0.00	0.05 – 0.10	15	1.21 ± 0.04	0.97 – 1.56
	205.8	15	0.08 ± 0.00	0.06 – 0.10	15	0.09 ± 0.00	0.07 – 0.12	15	1.21 ± 0.05	0.80 – 1.54
	207.1	7	0.07 ± 0.00	0.06 – 0.09	7	0.09 ± 0.01	0.06 – 0.11	7	1.26 ± 0.04	1.13 – 1.46
	208.4	15	0.07 ± 0.00	0.05 – 0.09	15	0.09 ± 0.00	0.05 – 0.12	15	1.30 ± 0.05	0.91 – 1.50
	216.7	15	0.05 ± 0.00	0.04 – 0.06	15	0.07 ± 0.00	0.06 – 0.09	15	1.34 ± 0.05	0.96 – 1.67
	223	15	0.06 ± 0.00	0.05 – 0.08	15	0.08 ± 0.03	0.06 – 0.10	15	1.33 ± 0.03	1.09 – 1.09
	229.2	15	0.07 ± 0.00	0.05 – 0.08	15	0.09 ± 0.00	0.09 – 1.85	15	1.29± 0.06	0.93 – 1.85
	232 i	15	0.06 ± 0.00	0.04 – 0.08	15	0.08 ± 0.00	0.05 - 0.10	15	1.24 ± 0.05	0.84 – 1.52
	232 ii	2	0.10 ± 0.01	0.09 – 0.11	2	0.13 ± 0.01	0.13 – 0.14	2	1.34 ± 0.14	1.20 – 1.49

Table 4.5. Cross diameter of proloculus, deuteroconch and deuteroconch/proloculus ratio in *Nummulites* spp.

Parameter		Chambers in 1st Whorl			Chambers in 2nd Whorl			Chambers in 3rd Whorl		
Depth		n	mean ± s.e.	range	n	mean ± s.e.	range	n	mean ± s.e.	range
ROMP 29A	163.7	8	8.50 ± 0.27	7 – 9	8	18.50 ± 0.27	18 – 20			
	171.3	14	9.14 ± 0.20	8 – 10	14	15.71 ± 0.67	12 – 21	12	20.33 ± 0.50	18 – 24
	175	15	7.80 ± 0.10	7 – 8	15	14.27 ± 0.34	12 – 17	15	18.13 ± 0.58	15 – 22
	185.8	13	8.13 ± 0.34	7 – 11	13	17.15 ± 0.66	13 - 21	6	20.67 ± 0.88	17 – 23
	188	15	9.13 ± 0.26	8 – 12	15	18.27 ± 0.34	16 – 21	15	20.73 ± 0.51	17 – 24
	190.8	15	8.07 ± 0.15	7 – 9	15	17.67 ± 0.54	14 – 23	15	21.73 ± 0.49	18 – 25
	191.8	15	8.00 ± 0.13	7 – 9	15	16.40 ± 0.34	15 – 19	15	20.53 ± 0.57	17 – 24
	205.8	15	7.80 ± 0.18	7 – 9	15	14.73 ± 0.36	12 – 17	15	20.13 ± 0.32	17 – 22
	207.1	7	8.57 ± 0.20	8 – 9	7	15.43 ± 0.71	13 – 18	7	19.71 ± 0.52	18 – 22
	208.4	15	7.53 ± 0.17	6 – 8	15	15.47 ± 0.29	14 – 18	15	20.60 ± 0.40	18 – 23
	216.7	15	7.40 ± 0.16	6 – 8	15	15.87 ± 0.38	14 – 18	15	22.20 ± 0.94	17 – 33
	223	15	9.53 ± 0.19	8 – 10	15	16.13 ± 0.35	14 – 18			
	229.2	15	9.13 ± 0.21	8 – 11	15	17.33 ± 0.44	14 – 20			
	232 i	12	8.83 ± 0.20	8 – 10	12	18.03 ± 0.48	15 – 20	12	23.33 ± 0.69	19 – 26
	232 ii	2	6.50 ± 0.50	6 – 7	2	16.50 ± 0.50	16 – 17	2	22.00 ± 2.00	20 – 24

Parameter		Chambers in 4th Whorl			Chambers in 5nd Whorl		
Depth		n	mean ± s.e.	range	n	mean ± s.e.	range
ROMP 29A	163.7						
	171.3	5	25.00 ± 1.10	22 – 28			
	175	14	21.43 ± 0.36	19 – 24			
	185.8						
	188	15	24.20 ± 0.54	21 – 27			
	190.8	13	24.31 ± 0.56	21 – 28			
	191.8	13	23.38 ± 0.43	21 – 26	2	28.00 ± 0.00	28 – 28
	205.8	15	21.67 ± 0.47	19 – 26	6	25.33 ± 0.99	22 – 29
	207.1	6	23.00 ± 0.37	22 – 24	2	25.00 ± 1.00	24 – 26
	208.4	15	23.53 ± 0.47	21 – 27	2	24.00 ± 3.00	21 – 27
	216.7	13	23.54 ± 0.56	20 – 27	1	28.00 ± 0.00	28 – 28
	223						
	229.2						
	232 i	10	25.80 ± 0.72	22 – 29	2	31.50 ± 4.50	27 – 36
	232 ii	5	25.00 ± 1.10	22 – 28	2	28.00 ± 0.00	28 – 28

Table 4.6. Chambers per whorl in *Nummulites* sp.

Parameter		1st Whorl Width (mm)			2nd Whorl Width (mm)			3rd Whorl Width (mm)		
Depth		n	mean ± s.e.	range	n	mean ± s.e.	range	n	mean ± s.e.	range
ROMP 29A	163.7	8	0.57 ± 0.04	0.41 – 0.82	8	1.50 ±0.13	1.21 – 2.03			
	171.3	14	0.53 ± 0.02	0.41 – 0.69	14	0.94 ± 0.03	0.80 – 1.15	11	1.48 ± 0.05	1.18 – 1.74
	175	15	0.31 ± 0.01	0.24 – 0.47	15	0.70 ± 0.01	0.56 – 0.81	15	1.17 ± 0.03	0.94 – 1.46
	185.8	13	0.76 ± 0.02	0.66 – 0.90	15	1.22 ± 0.03	1.08 – 1.49	5	1.88 ± 0.09	1. 67 –2.16
	188	15	0.50 ± 0.01	0.45 – 0.61	15	0.88 ± 0.01	0.77 – 1.03	15	1.39 ± 0.03	1.24 – 1.68
	190.8	15	0.47 ± 0.01	0.37 – 0.58	15	0.83 ± 0.32	0.66 – 0.99	15	1.27 ± 0.03	1.02 – 1.50
	191.8	15	0.41 ± 0.12	0.34 – 0.52	15	0.73 ± 0.02	0.61 – 0.86	15	1.16 ± 0.05	0.95 - 1.80
	205.8	15	0.49 ± 0.01	0.35 - 0.59	15	0.85 ± 0.02	0.67 – 1.00	15	1.30 ± 0.03	1.03 – 1.50
	207.1	7	0.45 ± 0.02	0.38 – 0.52	7	0.80 ± 0.03	0.70 – 0.93	7	1.24 ± 0.04	1.06 – 1.39
	208.4	15	0.46 ± 0.01	0.40 – 0.52	15	0.83 ± 0.01	0.73 – 0.92	15	1.31 ± 0.02	1.16 – 1.48
	216.7	15	0.35 ± 0.01	0.28 – 0.42	15	0.64 ± 0.01	0.51 – 0.74	15	1.07 ± 0.03	0.84 – 1.27
	223	15	0.40 ± 0.01	0.29 – 0.47	15	0.73 ± 0.02	0.83 – 0.90			
	229.2	15	0.41 ± 0.03	0.01 – 0.53	15	0.79 ± 0.06	0.01 – 1.00			
	232 i	15	0.39 ± 0.02	0.30 – 0.56	15	0.75 ± 0.03	0.58 – 1.02	15	1.20 ± 0.03	0.94 – 1.48
	232 ii	2	0.40 ±0.01	0.58 – 0.59	2	1.40 ± 0.07	1.33 – 1.48			

Parameter		4th Whorl Width (mm)			5nd Whorl Width (mm)		
Depth		n	mean ± s.e.	range	n	mean ± s.e.	range
ROMP 29A	163.7						
	171.3	6	2.36 ± 0.13	1.83 – 2.71			
	175	14	1.69 ± 0.05	1.37 – 1.90			
	185.8						
	188	15	2.01 ± 0.21	1.73 - 2.38			
	190.8	13	1.72 ± 0.05	1.47 – 2.08			
	191.8	13	1.59 ± 0.05	1.33 – 1.80	2	2.02 ± 0.12	1.99 – 2.14
	205.8	14	1.82 ± 0.06	1.41 – 2.15	4	2.22 ± 0.07	1.99 – 2.31
	207.1	6	1.68 ± 0.07	1.48 – 1.94			
	208.4	15	1.85 ± 0.06	1.50 - 2.09	2	2.24 ± 0.06	2.18 – 2.30
	216.7	15	1.65 ± 0.06	1.23 – 2.00			
	223						
	229.2						
	232 i	15	1.68 ± 0.04	1.40 – 1.99	2	2.10 ± 0.06	2.04 – 2.15
	232 ii						

Table 4.7. Diameter of whorls in *Nummulites* sp.

Depth (m)	No.	Average Proloculus (mm)	Pro-toconch Range (mm)	Average Deutero-conch (mm)	Deutero-conch Range (mm)	D/P	Average Test Diameter (mm)	Test Diameter (mm) Range	Average Peri-embryonic chamber	P C # Range
Mayo	2	0.48	0.44-0.51	0.46	0.44-0.47	1.04			14	14-14
167.42	1	0.49		0.47			5.90		15	
175.29	1	0.40		0.50			2.36		13	
178.06	1	0.42		0.43					12	
181.66	1	0.41		0.42					12	
193.70	4	0.53	0.50-0.56	0.58	0.53-0.64	1.09	4.29	4.01-4.52	12.75	12-14
195.07	1	0.64		0.74			3.87		13	
201.17	1	0.61		0.62					12	
204.06	2	0.52	0.52-0.53	0.60	0.58-0.61	1.15			14.5	14-15
205.75	1	0.60		0.67			4.75		16	
209.40	1	0.65		0.67			4.89		14	
221.28	2	0.50	0.46-0.53	0.58	0.58-0.58	1.16	3.69	3.44-3.93	13	13-13

Table 4.8. Parameters for *Lepidocyclina ocalana* var. A. D/P deuteroconch/protoconch diameter ratio; P C # , number of periembryonic chambers; n, number of specimens.

Depth (m)	No.	Average Pro-toconch (mm)	Protoconch Range (mm)	Average Deutero-conch (mm)	Deutero-conch Range (mm)	D/P	Average Test Diameter (mm)	Test Diameter Range (mm)	Average no. of Periembryonic chambers	No. of Periembryonic chamber Range
170.38	3	0.35	0.28-0.42	0.40	0.36-0.42	1.14			11.6	11 - 12
178.06	2	0.43	0.32-0.55	0.52	0.46-0.59	1.20	2.34 (1)		11	11-11
180.44	5	0.39	0.29-0.47	0.47	0.33-0.60	1.20	3.1 (1)	3.1	10.8	9 - 12
181.66	5	0.39	0.31-0.49	0.47	0.33-0.56	1.20			10.8	10 - 12
201.17	4	0.43	0.32-0.52	0.60	0.56-0.65	1.40			11	10 -12
208.48	1								10	
209.40	2	0.54	0.47-0.61	0.58	0.54-0.62	1.07	5.77	4.87-6.67	9.5	9 - 10
215.19	1								9	
221.28	1								10	

Table 4.9. Parameters for *Lepidocyclina ocalana* var. B.

Depth (m)	No.	Average Proloculus (mm)	Proloculus Range (mm)	Average Deutero-conch (mm)	Deutero-conch Range (mm)	Average Test Diameter (mm)	Test Diameter Range (mm)	Average no. of Peri-embryonic chamber	No. of Peri-embryonic chamber Range
195.07	3	0.49	0.43-0.56	0.60	0.49-0.63	3.50	2.84-3.90	12.3	12-13
201.17	1								
204.06	2	0.59	0.57-0.60	0.90	0.90-0.91			15	15-15
205.75	2	0.51	0.48-0.54	0.70	0.66-0.73	4.83	4.67-5.0	13	12-14
208.48	3	0.59	0.57-0.61	0.81	0.76-0.90			13.3	12-16
215.19	4	0.42	0.38-0.47	0.54	0.52-0.56			13.75	13-14
216.16	2	0.55	0.42-0.68	0.70	0.59-0.82	3.99 (1)		16.5	15-18
218.23	5	0.48	0.40-0.63	0.57	0.50-0.64	3.83	3.83	14	13-15

Table 4.10. Parameters for *Lepidocyclina ocalana* var. C.

Depth (m)	n	Average Pro-loculus (mm)	Pro-loculus (mm) Range	Average Deutero-conch (mm)	Deutero-conch (mm) Range	D/P	Average Test Diameter (mm)	Test Diameter (mm) Range	Average Periembryonic chamber #	P C # Range
167.42	2	0.43	0.38-0.49	0.53	0.42-0.64	1.23	4.00 (1)		16.5	16-17
180.44	2	0.51	0.47-0.55	0.62	0.60-0.64	1.21	3.02 (1)		17.5	17-18
193.70	1									
195.07	3	0.64	0.53-0.80	0.70	0.64-0.86	1.09	4.11	3.87-4.60	18	17-19
201.17	4	0.55	0.56-0.66	0.61	0.51-0.73	1.10			17	16-18
204.06	2	0.56	0.51-0.62	0.59	0.51-0.67	1.05			17.5	16-19
209.40	1									

Table 4.11. Parameters for *Lepidocyclina ocalana* var. D.

		Lepidocyclina pustulosa	*Lepidocyclina ocalana* sp. A	*Lepidocyclina ocalana* sp. B	*Lepidocyclina ocalana* sp. C	*Lepidocyclina ocalana* sp. D	*Lepidocyclina chaperi*
Protoconch	Number	1	23	40	18	15	3
	Mean ± s.e.	0.470 ± 0.000	0.417 ± 0.019	0.454 ± 0.017	0.517 ± 0.017	0.561±0.034	0.385±0.060
	Range		0.242 – 0.619	0.233 – 0.676	0.404 – 0.650	0.379-0.902	0.301-0.504
	Standard Deviation		0.095	0.108	0.075	0.135	0.105
Deuteroconch	Number	1	23	40	18	15	3
	Mean ± s.e.	0.550 ± 0.000	0.510 ± 0.021	0.593 ± 0.148	0.568 ± 0.020	0.627±0.041	0.676±0.902
	Range		0.330 – 0.693	0.305 – 0.911	0.423 – 0.746	0.424-1.028	0.545-0.854
	Standard Deviation		0.105	0.148	0.087	0.160	0.159
Deuteroconch/ protoconch ratio	Number	1	23	40	18	15	3
	Mean ± s.e.	1.170 ± 0.000	1.241 ± 0.035	1.315 ± 0.029	1.099 ± 0.017	1.022±0.024	1.777±0.161
	Range		1.002 – 1.732	1.018 - 1.703	1.013 – 1.261	1.007-1.316	1.548-1.089
	Standard Deviation		0.169	0.189	0.075	0.094	0.280
Test Diameter	Number		23	5	12	6	1
	Mean ± s.e.		4.721 ± 0.740	2.393 ± 0.842	4.061 ± 0.295	3.761±0.235	2.181±0.000
	Range		2.959 – 6.567	0.362 – 4.670	2.232 – 5.901	3.029-4.609	
	Standard Deviation		1.481	1.883	1.024	0.577	

Table 4.12. Measured parameters for all identified *Lepidocyclina* spp.

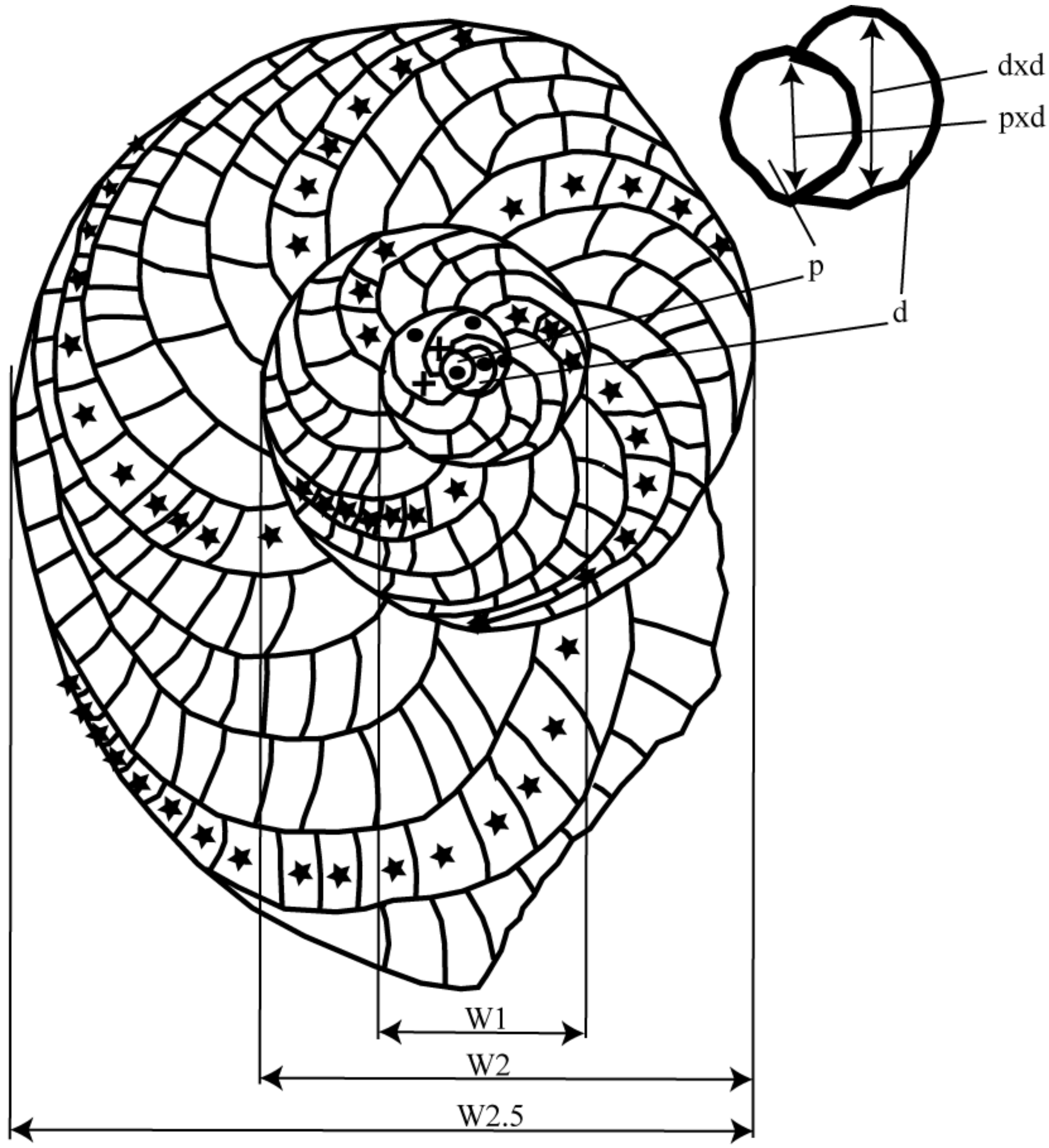
Depth (m)	Protoconch				Deuteroconch			
	n	Mean ± s.e.	range	s.d.	n	Mean ± s.e.	range	s.d.
156.7	4	0.462 ± 0.057	0.311 – 0.584	0.115	4	0.505 ± 0.068	0.339 – 0.667	0.115
166.7	10	0.468 ± 0.034	0.264 – 0.678	0.107	10	0.593 ± 0.021	0.471 – 0.686	0.069
167.4	11	0.451 ± 0.015	0.377 – 0.555	0.052	11	0.526 ± 0.029	0.385 – 0.657	0.098
170.4	13	0.350 ± 0.020	0.233 – 0.498	0.073	13	0.440 ± 0.019	0.357 – 0.545	0.072
173.4	14	0.356 ± 0.015	0.294 – 0.466	0.058	14	0.451 ± 0.019	0336 – 0.578	0.073
175.2	1	0.404 ± 0.000			1	0.500 ± 0.000		
178.0	15	0.439 ± 0.017	0.328 – 0.552	0.069	15	0.526 ± 0.016	0.438 – 0.656	0.069
180.5	15	0.421 ± 0.022	0.253 – 0.555	0.086	15	0.517 ± 0.023	0.331 – 0.659	0.092
181.7	13	0.439 ± 0.033	0.249 – 0.616	0.120	13	0.512 ± 0.032	0.330 – 0.726	0.116
184.8	12	0.470 ± 0.018	0.379 – 0.588	0.063	12	0.559 ± 0.023	0.431 – 0.705	0.082
193.5	17	0.549 ± 0.022	0.418 – 0.796	0.094	17	0.649 ± 0.029	0.453 – 0.897	0.120
195.0	16	0.551 ± 0.032	0.394 – 0.866	0.131	16	0.645 ± 0.032	0.485 – 0.970	0.129
201.1	16	0.514 ± 0.026	0.322 – 0.708	0.105	16	0.634 ± 0.030	0.492 – 0.873	0.122
204.0	16	0.534 ± 0.027	0.248 – 0.652	0.111	16	0.689 ±0.040	0.305 – 0.934	0.162
205.8	15	0.527 ± 0.020	0.381 – 0.667	0.527	15	0.686 ± 0.028	0.506 – 0.854	0.109
208.5	13	0.581 ± 0.030	0.375 – 0.740	0.108	13	0.752 ± 0.044	0.450 – 1.115	0.160
209.4	15	0.641 ± 0.030	0.476 – 0.902	0.116	15	0.780 ± 0.039	0.545 – 1.120	0.153
215.2	5	0.389 ± 0.039	0.242 – 0.468	0.087	5	0.505 ± 0.042	0.337 – 0.565	0.094
216.1	7	0.471 ± 0.038	0.376 – 0.676	0.102	7	0.595 ± 0.052	0.420 – 0.823	0.139
218.2	14	0.487 ± 0.023	0.390 – 0.691	0.089	14	0.592 ± 0.017	0.455 – 0.698	0.066
221.3	15	0.516 ± 0.022	0.301 – 0.649	0.088	15	0.647 ± 0.027	0.504 – 0.914	0.276

Depth (m)	D/P				Test Diameter			
	n	Mean ± s.e.	range	s.d.	n	Mean ± s.e.	range	s.d.
156.7	4	1.090 ± 0.018	1.057 –1.142	0.036				
166.7	10	1.316 ± 0.087	1.012 – 1.784	0.277				
167.4	11	1.159 ± 0.037	0.963 – 1.326	0.123	3	7.079 ± 2.196	4.004 – 11.333	3.804
170.4	13	1.286 ± 0.065	1.002 – 1.708	0.236				
173.4	14	1.279 ± 0.048	1.039 – 1.615	0.904	9	4.428 ± 0.301	2.855 – 5.380	0.904
175.2	1	1.239 ± 0.000			1	2.363 ± 0.000		
178.0	15	1.213 ± 0.034	1.031 – 1.456	0.135	9	2.879 ± 0.183	2.217 – 3.814	0.549
180.5	15	1.241 ± 0.033	1.078 – 1.505	0.128	3	3.544 ± 0.476	3.029 – 4.495	0.824
181.7	13	1.190 ± 0.049	1.021 - 1.607	0.177				
184.8	12	1.190 ± 0.028	1.038 – 1.359	0.099				
193.5	17	1.189 ± 0.041	1.033 – 1.732	0.171	17	4.020 ± 0.194	3.164 – 6.044	0.801
195.0	16	1.180 ± 0.020	1.078 – 1.360	0.081	16	4.109 ± 0.267	2.843 – 7.667	1.071
201.1	16	1.271 ± 0.054	1.020 – 1.732	0.217				
204.0	16	1.303 ± 0.062	1.007 – 1.848	0.248				
205.8	15	1.313 ± 0.053	1.050 – 1.694	0.207	8	4.275 ± 0.230	3.122 – 5.188	0.651
208.5	13	1.300 ± 0.047	1.067 – 1.529	0.171				
209.4	15	1.229 ± 0.054	1.009 – 1.787	0.210	12	4.554 ± 0.250	3.323 – 6.567	0.867
215.2	5	1.312 ± 0.059	1.129 – 1.479	0.132				
216.1	7	1.260 ± 0.048	1.092 – 1.433	0.128	5	3.687 ± 0.179	3.045 – 4.038	0.401
218.2	14	1.241 ± 0.055	0.914 – 1.650	0.055	12	3.774 ± 0.186	2.701 – 4.628	0.636
221.3	15	1.281 ± 0.071	1.022 – 2.090	0.276	14	3.217 ± 0.141	2.181 – 3.966	0.536

Table 4.13. Measured parameters for *Lepidocyclina* sp. per depth in ROMP 29A core.

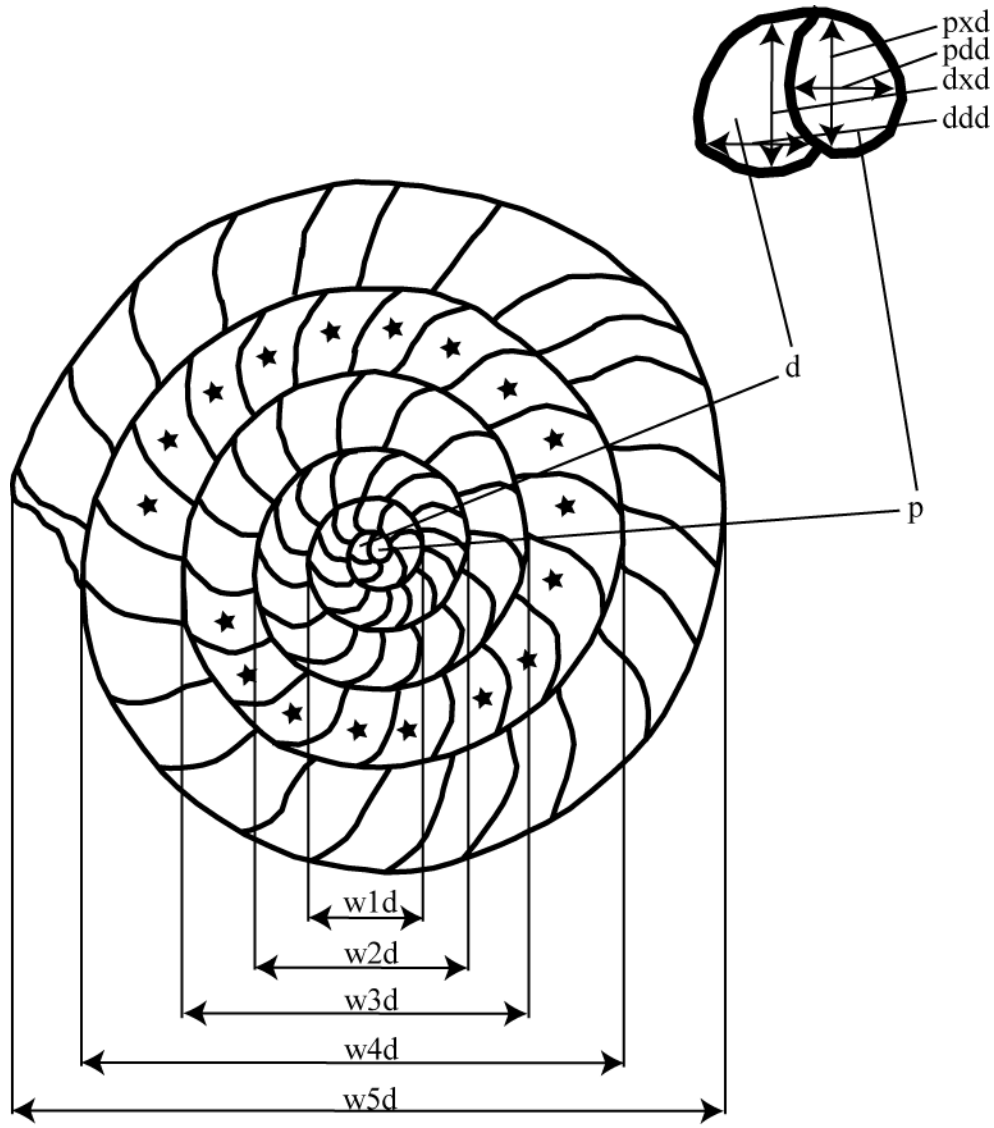
Heterostegina Ocalana			*Nummulites* spp.			*Lepidocyclina* spp.	
Measured Morphological Feature	P-value		Measured Morphological Feature	P-value		Measured Morphological Feature	P-value
Proloculus diameter	0.025		Protoconch diameter	0.000		Protoconch diameter	0.000
Deuteroloculus diameter	0.238		Deuteroconch diameter	0.000		Deuteroconch diameter	0.000
No. of operculine chambers	0.005		No. of chambers in 1st whorl	0.575			
No. of chamberlets in fourth and fifth chamber	0.094		No. of chambers in 2nd whorl	0.057			
No. of chamberlets in tenth chamber	0.265		Diameter of 1st whorl	0.000			
No. of chamberlets in fourteen chamber	0.011		Diameter of 2nd whorl	0.000			
No. of chamberlets in eighteen chamber	0.000						
No. of chamberlets in Twenty-second chamber	0.000						
No. of chamberlets in Twenty-sixth chamber	0.000						
Diameter of second whorl	0.000						

Table 4.14. Analysis of variance P-values for the significance of the three depositional environments by Ward et al. (2003) for size changes in the measured morphological features of *Heterostegina ocalana, Nummulites* spp. and *Lepidocyclina* spp.



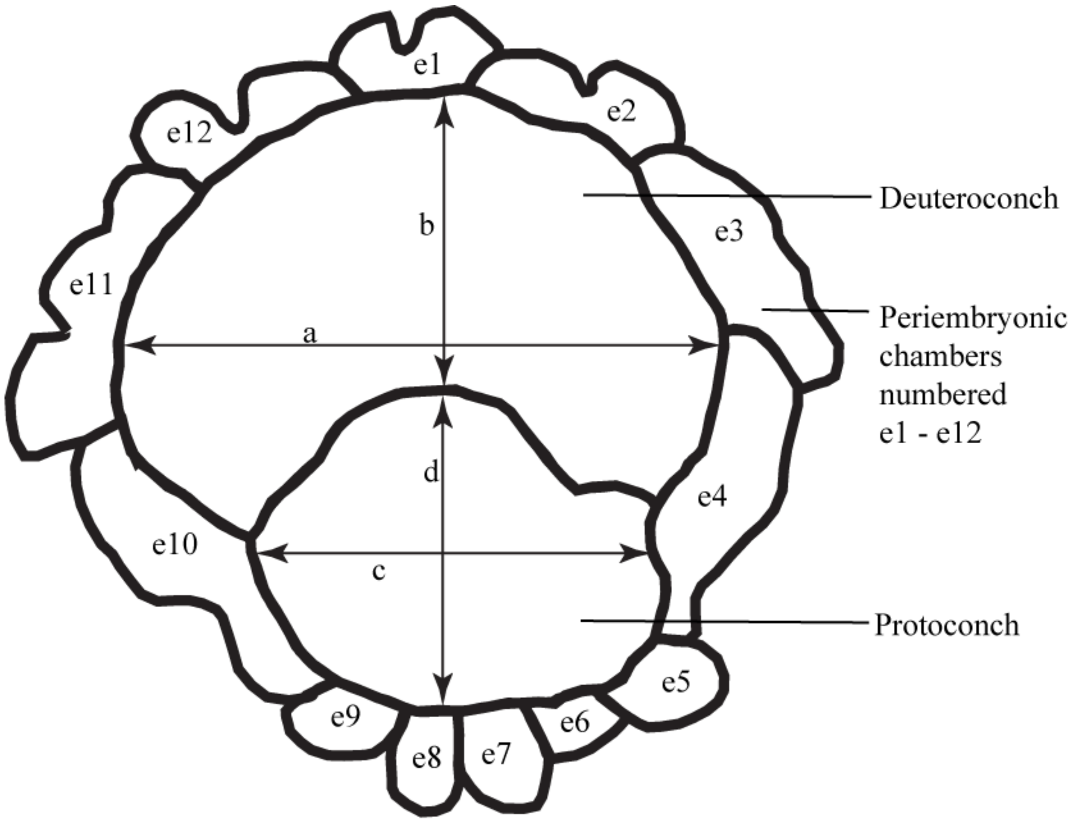
W1, first whorl; W2, second whorl; W2.5, two and a half whorls
p, proloculus; d, deuteroloculus; pxd, proloculus cross diameter
dxd, deuteroloculus cross diameter
★ , denotes # of chamberlets in chamber #s 10, 14, 18, 22, 26, 30, 34 & 38
● , denotes # of operculine (undivided) chambers including proloculus and deuteroloculus
+ , denotes chambers 4+5

Figure 4.1 Schematic drawing of *Heterostegina ocalana*, illustrating features used in the morphometric analysis.



w1d, first whorl; w2d, second whorl; w3d, third whorl
w4d, fourth whorl; w5d, fifth whorl
p, protoconch; d, deuteroconch
pxd, protoconch cross diameter
pdd, protoconch depth diameter
dxd, deuteroconch cross diameter
ddd, deuteroconch depth diameter
★, denotes # of chambers in the fourth whorl

Figure 4.2 Schematic drawing of *Nummulites* sp., illustrating features used in the morphometric analysis.



a, inner cross-diameter of deuteroconch
b, depth diameter of deuteroconch
c, inner cross-diameter of protoconch
d, the depth diameter of protoconch
e, # of periembryonic chambers

Figure 4.3 The embryonic apparatus of *Lepidocyclina* sp. illustrating features used in the morphometric analysis.

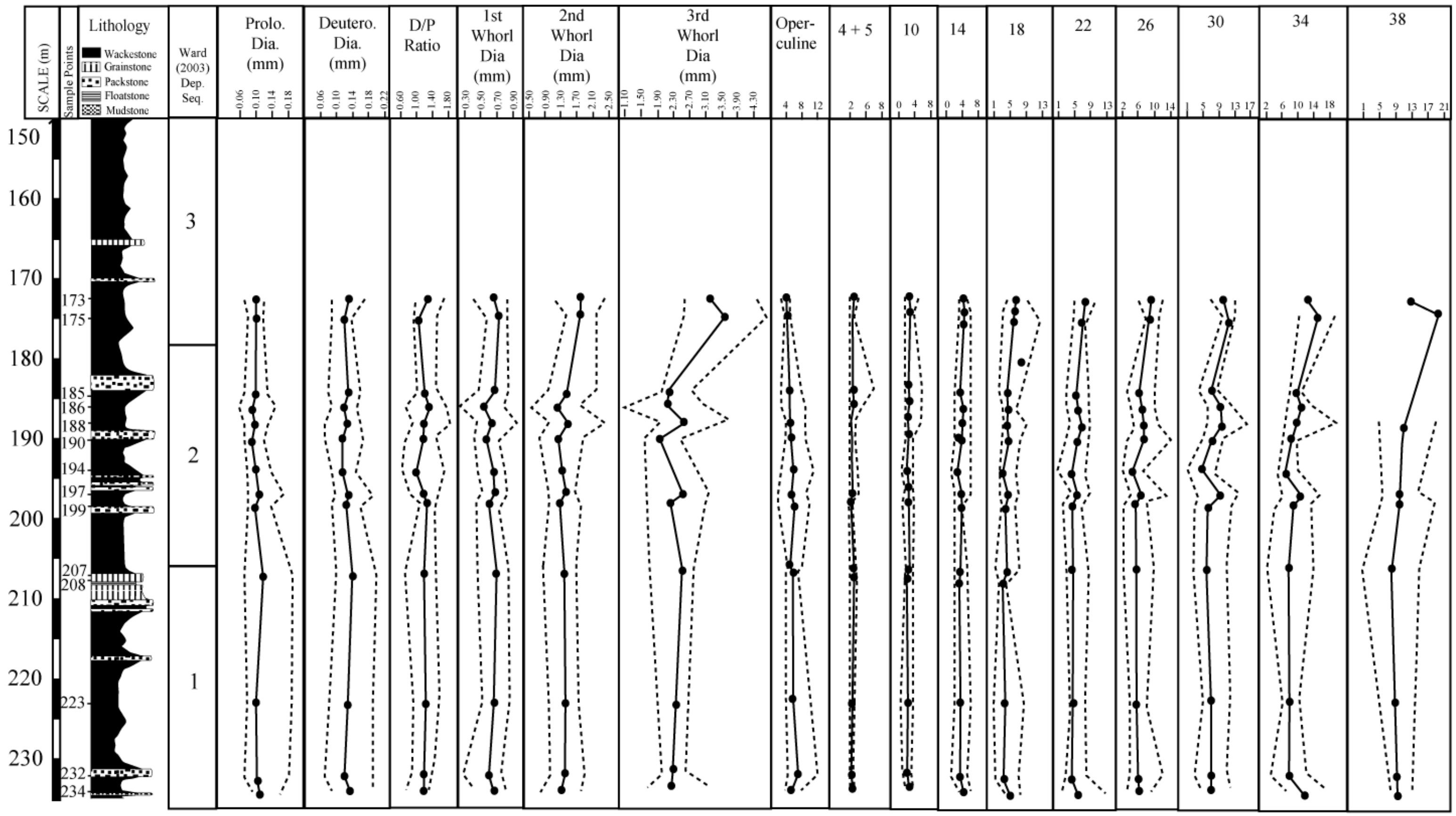


Figure 4.4 Changes in the morphometric features of *Heterostegina ocalana* along ROMP 29 A core. The solid lines represent the averaged measured features. Dashed lines indicate the range of the measured features.

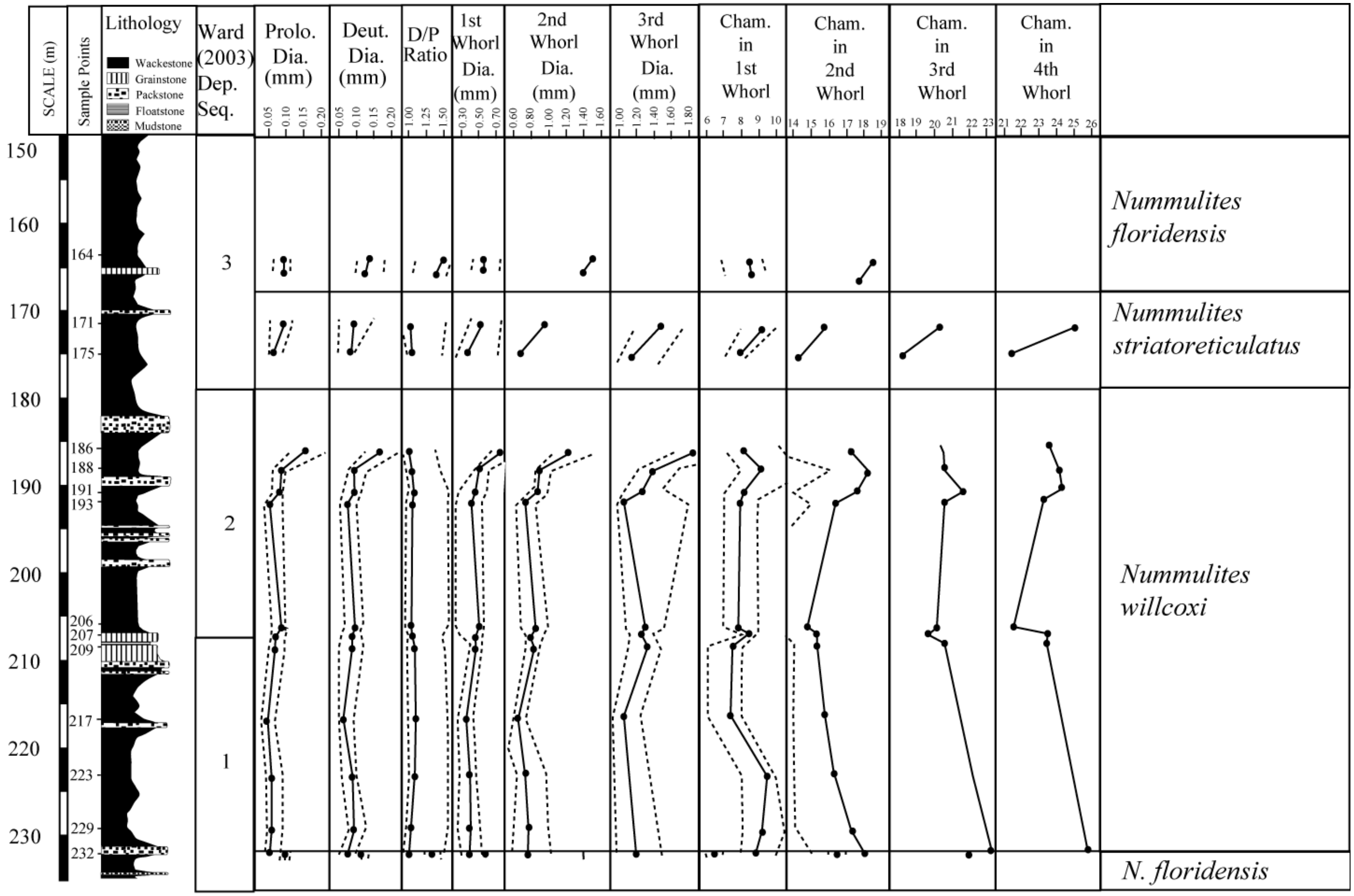


Figure 4.5 Changes in the measurement of the combined morphometric features of *Nummulites* spp. along ROMP29 A. The solid lines represent the averaged measured features. Dashed lines indicate the range of the measured features.

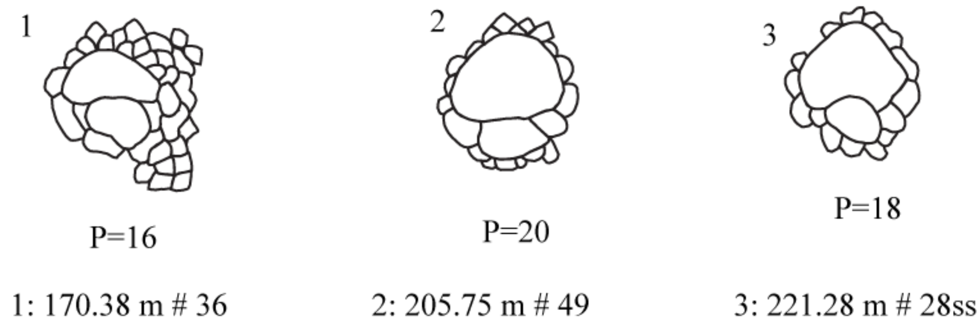


Figure 4.6 Outlines of embryonic apparatus and periembryonic chambers (P) for *Lepidocyclina chaperi*. Depth and sample number provided about.

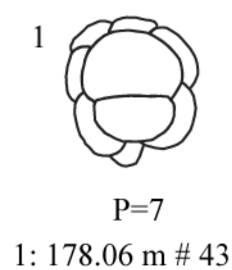
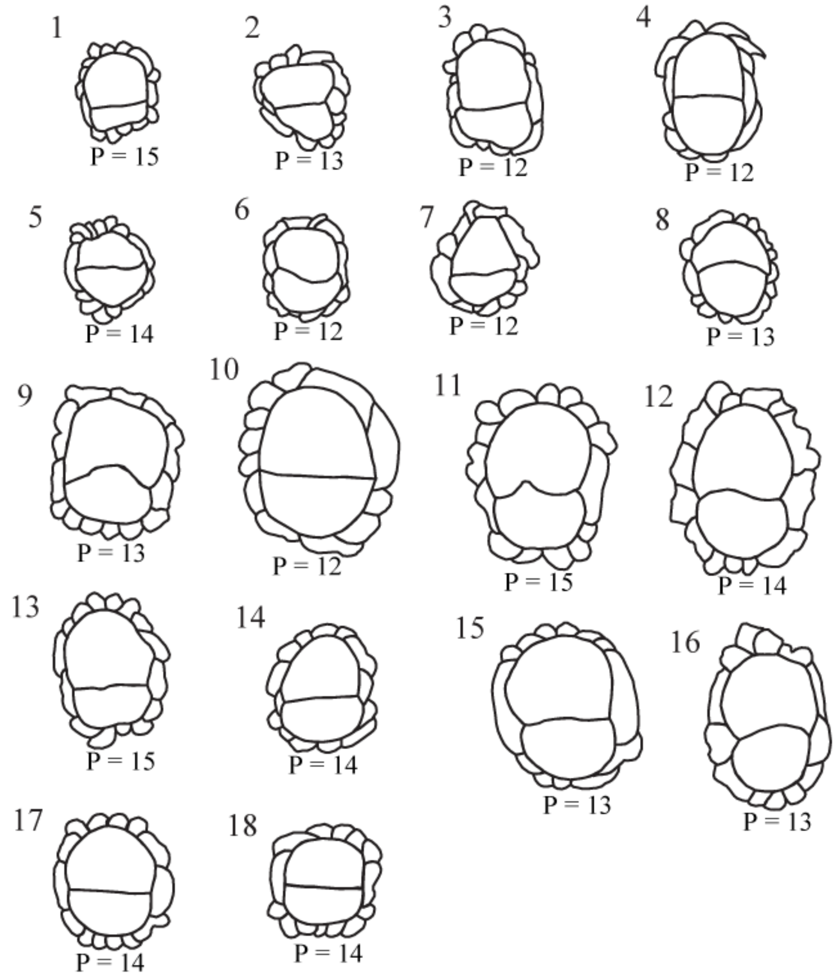
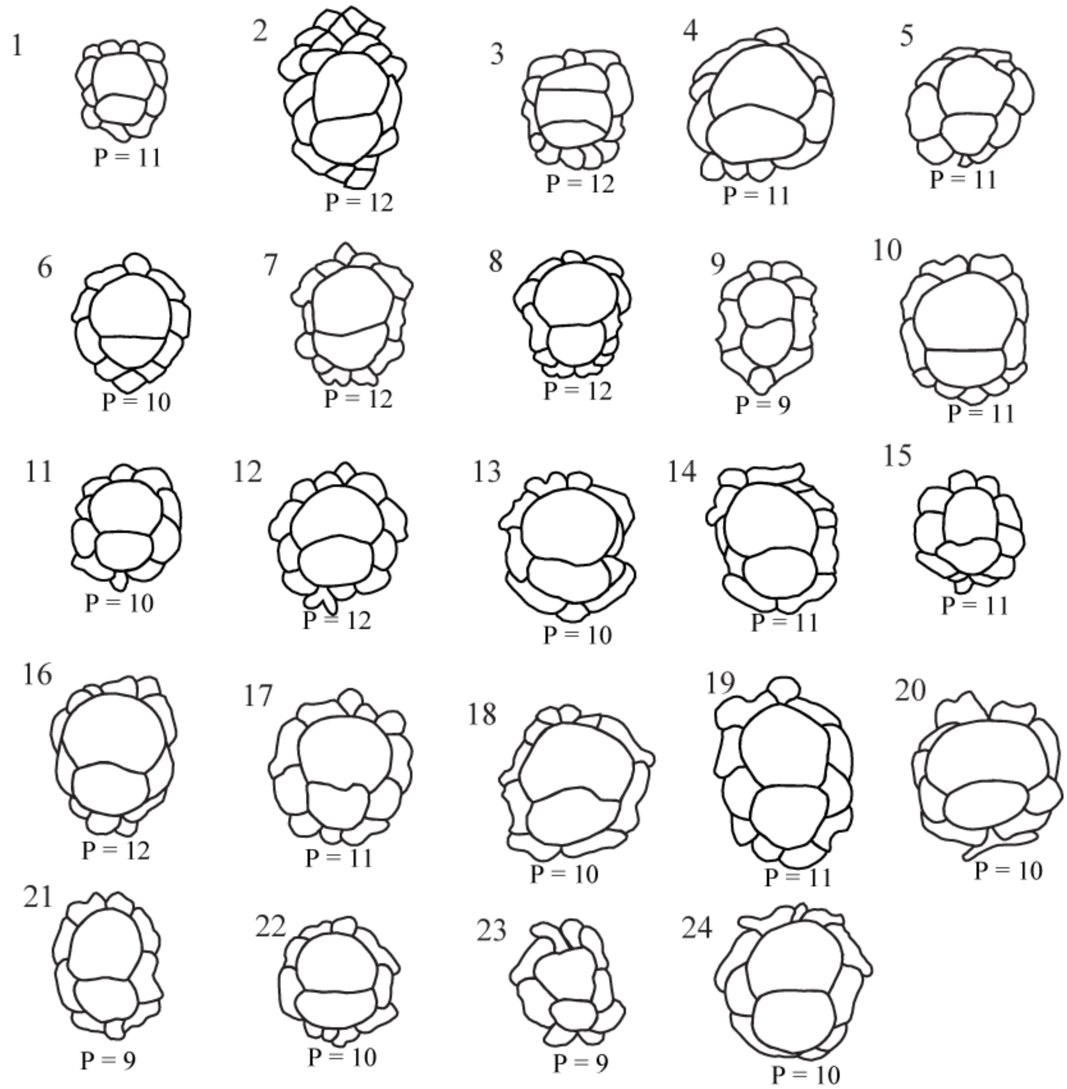


Figure 4.7 Outline of embryonic apparatus and periembryonic chambers (P) for *Lepidocyclina pustulosa*. Depth and sample number provided above.



1: 167.42 m # 1
2: 175.29 m # 13
3: 178.06 m # 3
4: 181.66 m # 6
5: 193.70 m # 10
6: 193.70 m # 22
7: 193.70 m # 23
8: 193.70 m # 30
9: 195.07 m # 28
10: 201.17 m # 26
11: 204.06 m # 13
12: 204.06 m # 30
13: 205.75 m # 5
14: 209.40 m # 4
15: 221.28 m # 27ss
16: 221.28 m # 31ss
17: Mayo # 1
18: Mayo # 13

Figure 4.8 Outlines of embryonic apparatus and periembryonic chambers (P) for *Lepidocyclina ocalana* var. A. Depth and sample number provided above.

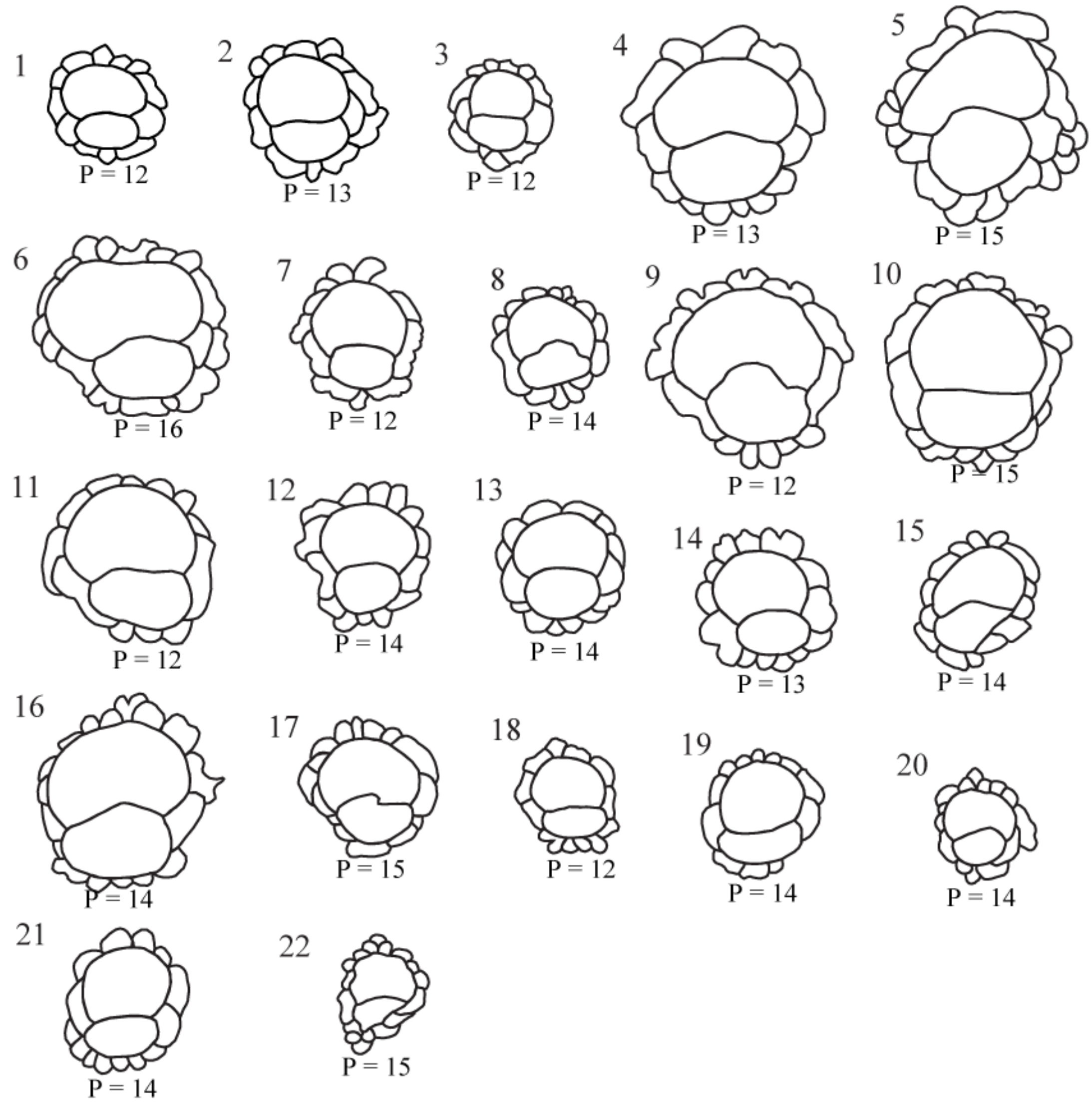


1: 170.39 m # 8
2: 170.39 m #14
3: 170.39 m # 17
4: 178.06 m # 29
5. 178.06 m # 42
6. 180.44 m # 1
7: 180.44 m # 21
8: 180.44 m # 23

9: 180.44 m # 27
10: 180.44 m # 37
11: 181.66 m # 2
12: 181.66 m # 15
13: 181.66 m # 17
14: 181.66 m # 27
15: 181.66 m # 29
16: 201.17 m # 2

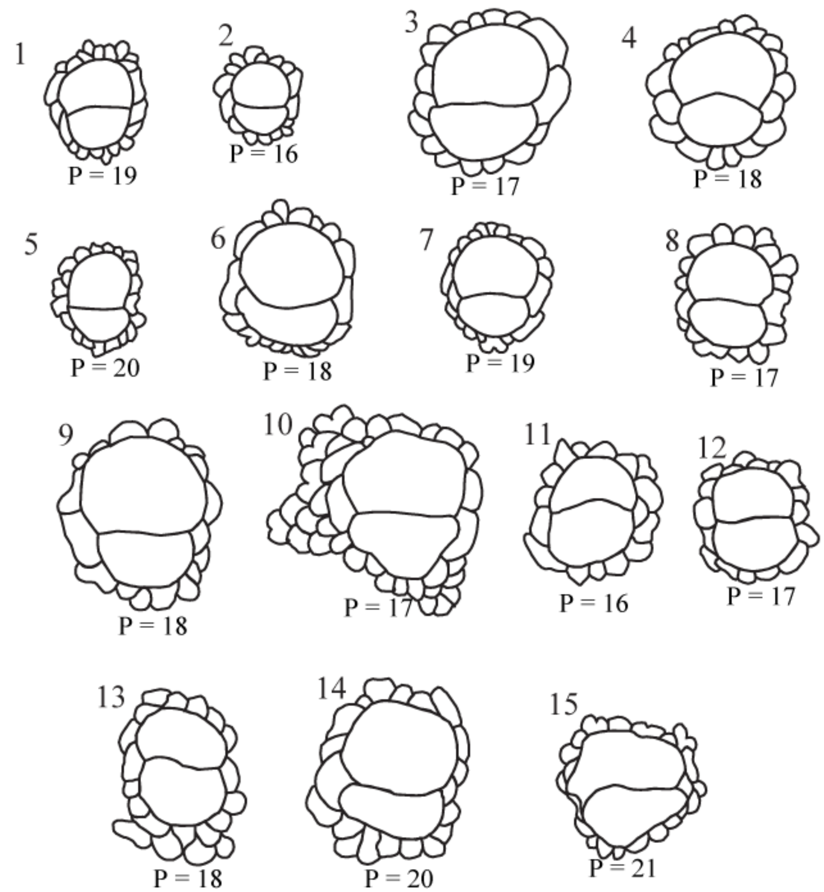
17: 201.17 m # 4
18: 201.17 m # 5
19. 201.17 m # 8
20: 208.48 m # 25
21: 209.40 m # 2
22: 209.40 m # 34
23: 215.19 m # 13
24: 221.28 m # 1ss

Figure 4.9 Outlines of embryonic apparatus and periembryonic chambers (P) for *Lepidocyclina ocalana* var. B. Depth and sample number provided above.



1: 195.07 m # 22
2: 195.07 m # 23
3: 195.07 m # 31
4: 201.17 m # 40
5: 204.06 m # 25
6: 204.06 m # 48
7: 205.75 m # 9
8: 205.75 m # 33
9: 208.48 m # 4
10: 208.48 m # 5
11: 208.48 m # 13
12: 215.19 m # 1
13: 215.19 m # 3
14: 215.19 m # 15
15: 215.19 m # 40
16: 216.16 m # 14
17: 216.16 m # 16
18: 218.23 m # 1
19: 218.23 m # 3
20: 218.23 m # 5
21: 218.23 m # 7
22: 218.23 m # 13

Figure 4.10 Outlines of embryonic apparatus and periembryonic chambers (P) for *Lepidocyclina ocalana* var. C. Depth and sample number provided above.



1: 167.42 m # 3
2: 167.42 m # 25
3: 180.44 m # 4
4: 180.44 m # 7
5: 193.70 m # 2
6: 195.07 m # 7
7: 195.07 m # 27
8: 195.07 m # 30

9: 201.17 m # 25
10: 201.17 m # 29
11: 201.17 m # 44
12: 201.17 m # 45
13: 204.06 m # 27
14: 204.06 m # 31
15: 209.40 m # 6

Figure 4.11 Outlines of embryonic apparatus and periembryonic chambers (P) for *Lepidocyclina ocalana* var. D. Depth and sample number provided above.

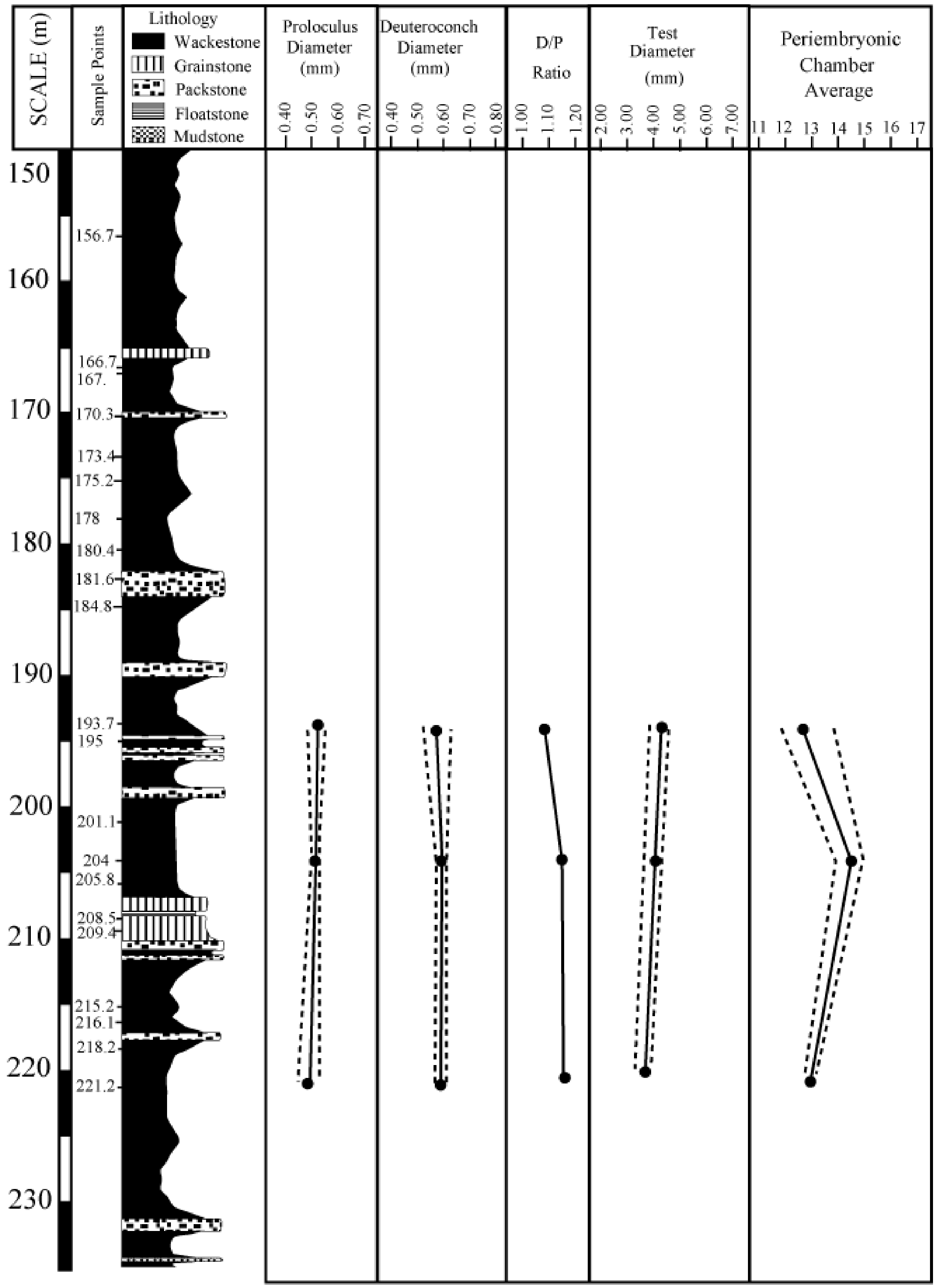


Figure 4.12 *Lepidocyclina ocalana* var. A measurements compared to stratigraphy of ROMP 29A core. Solid lines represent averages of measurements. Dashed lines indicate the range of the measured feature.

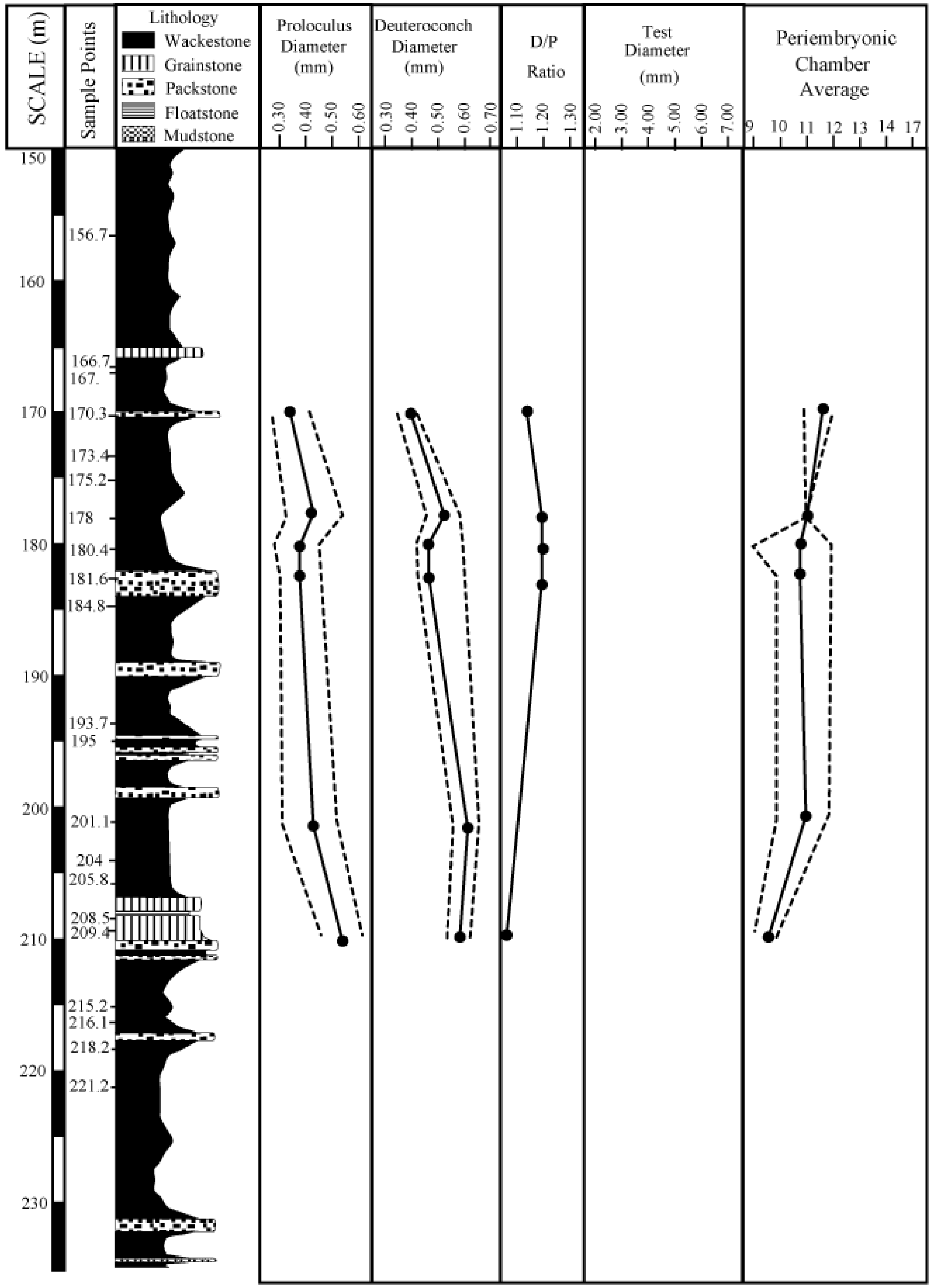


Figure 4.13 *Lepidocyclina ocalana* var. B measurements compared to stratigraphy of ROMP 29A core. Solid lines represent averages of measurements. Dashed lines indicate the range of the measured feature.

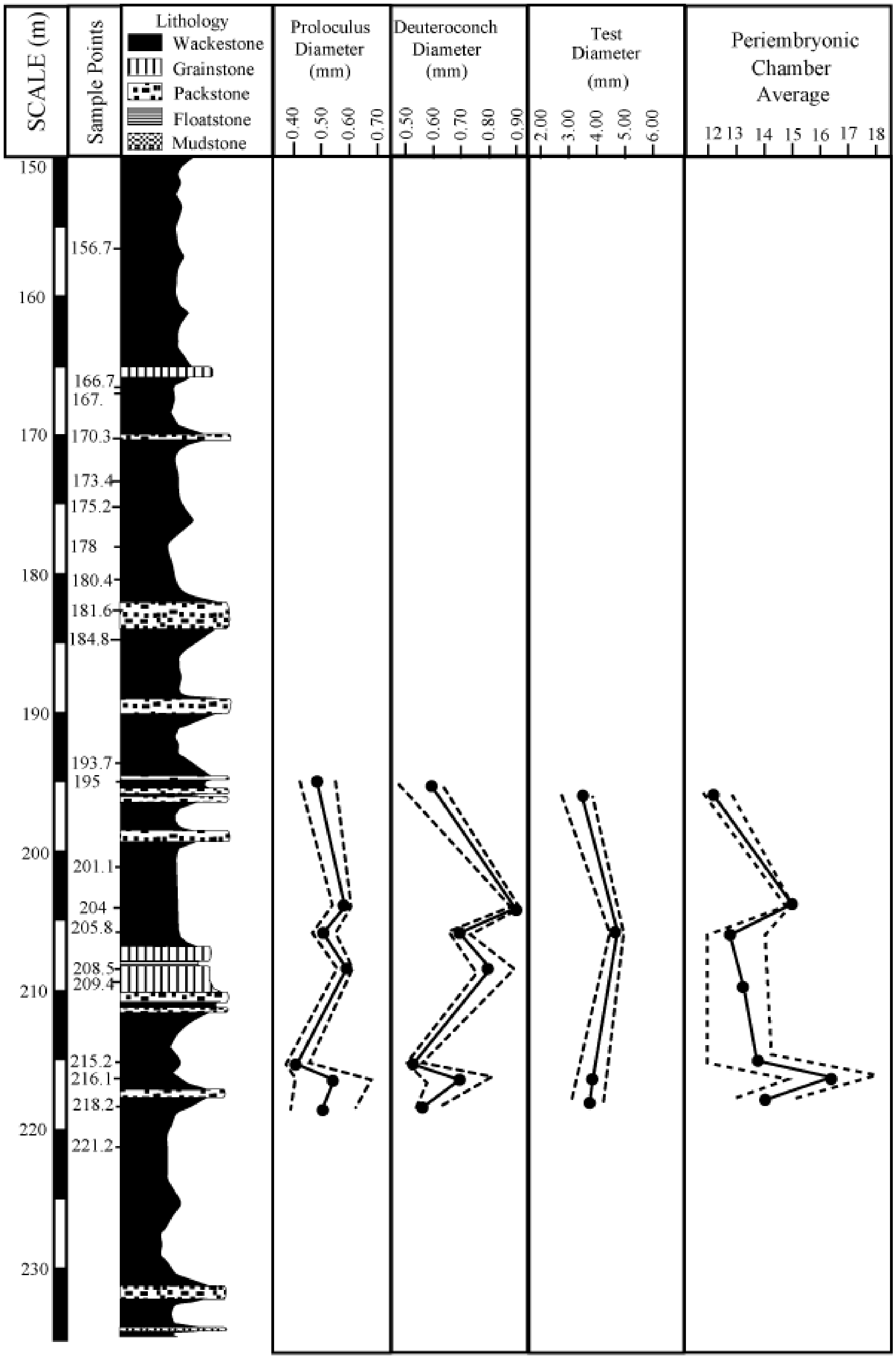


Figure 4.14 *Lepidocyclina ocalana* var. C measurements compared to stratigraphy of the ROMP 29A core. Solid lines represent averaged measurements. Dashed lines indicate the range of the measured feature.

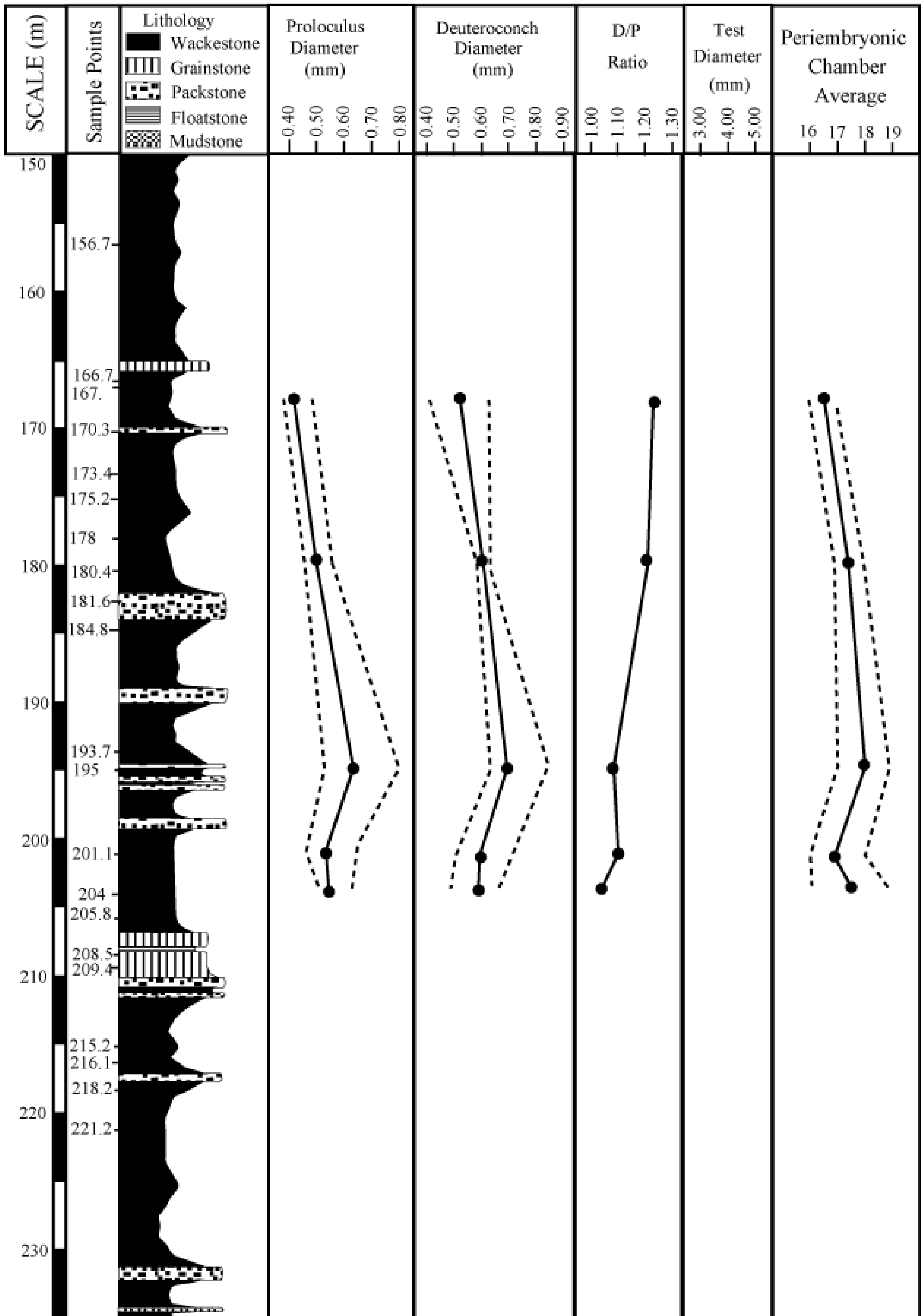


Figure 4.15 *Lepidocyclina ocalana* var. D measurements compared to stratigraphy of the ROMP 29A core. Solid lines represent averaged measurements. Dashed lines indicate the range of the measured feature.

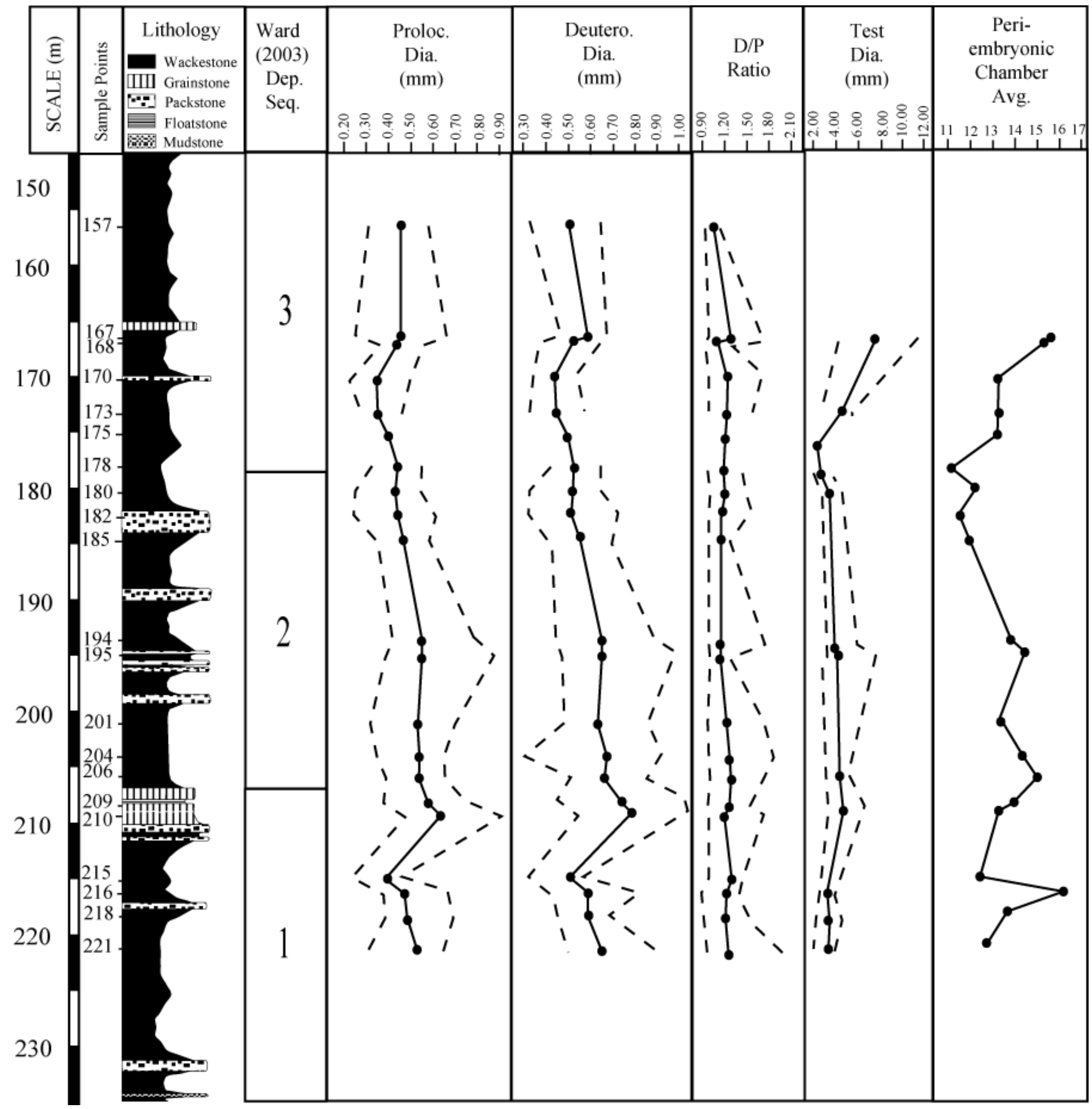


Figure 4.16 Changes in the morphometric features of *Lepidocyclina* spp. along ROMP29 A core. The solid lines represent the averaged measured features. Dashed lines indicate the range of the measured features.

CHAPTER 5

CONCLUSIONS

5.1 Main Conclusions from Chapters 2-4

The taxonomy, biostratigraphy and morphometrics of identified taxa of the Ocala Limestone and the Avon Park Limestone were described in this study. The composite stratigraphic column showing the distribution of the foraminiferal taxa is shown in Figure 5.1. The main conclusions of each chapter are listed below.

Chapter Two. The larger foraminifera of the Avon Park Formation occur in sediments of the peritidal and subtidal zones. Most of the larger foraminifera are concentrated in the subtidal and deeper subtidal zones, except for *Fallotella floridana,* which is equally distributed over the ROMP 29A sequence. *Fallotella floridana,* in conjunction with the echinoid *Neolaganum dalli*, can be used as a marker for the Avon Park Formation in the ROMP 29A core. The age of the Avon Park Formation in the ROMP 29A core can be accepted as Eocene on the basis of the larger foraminifera taxa. There was apparently no migration route between the Neotethys Sea and waters under which sediments of the Avon Park Formation in the ROMP 29A core were deposited, because fabulariids and the larger miliolids of the Americas and Europe are endemic to the two regions.

Chapter Three. *Heterostegina ocalana* and *Lepidocyclina chaperi* are apparently restricted to the Late Eocene, according to their distribution in the ROMP 29A core and other regional occurrences. *Lepidocyclina ocalana, Lepidocyclina pustulosa, Nummulites willcoxi, Nummulites floridensis* and *Nummulites striatoreticulatus* range in age from middle through late Eocene. The total geographic range of all of these larger foraminifera includes the U. S. Gulf Coast and Florida, Mexico, Caribbean Basin, Central America and the northern coastlines of Ecuador, Colombia, Venezuela, Guyana and Brazil. There is no relationship between the depositional sequences defined by Ward et al. (2003) within the Ocala Limestone and the larger foraminiferal distribution identified by this study, indicating that their occurrence was not controlled by facies.

Chapter Four. The means of the measured features of *Heterostegina ocalana, Nummulites,* and *Lepidocyclina* through the ROMP 29A core are significantly different in the three depositional sequences of Ward et al. (2003) according to analyses of variance. Some changes in morphology were identified that can be used as tools for interpreting paleoenvironments,: In *Heterostegina ocalana, Nummulites willcoxi* and *Lepidocyclina* spp., the test diameter, number of chambers per whorl and number of chamberlets increased with water depth. *Lepidocyclina ocalana* varieties identified using the number of periembryonic chambers are the same varieties of *L. ocalana* identified by Cushman (1920). Although the differences among the varieties are real, they may be a result of environmental adaptation and should not be considered true species.

5.2 Comparisons of Larger Foraminifera of the Avon Park Formation and Ocala Limestone

5.2.1 Paleobiogeography

The larger foraminifera of the Avon Park Formation are concentrated within the Caribbean Basin, whereas those of the Ocala Limestone have been reported from a wider area that includes the northern Gulf Coast states of the U. S., Mexico, Central America and South America (Figs. 2.7, 3.11). This paleogeographical difference is related to the ecological niches of larger foraminifera. The assemblages from the Avon Park Formation consist of enrolled miliolids and conical larger foraminifera, and the Ocala Limestone assemblages contain nummulitids, lepidocyclinids and orthophragminids. Malvia (2009) suggested that the Avon Park Formation and Ocala Limestone were deposited on a wide, flat carbonate ramp that was gently sloped towards the Gulf of Mexico. The depositional environment of the Avon Park Formation was interpreted as occupying the inner ramp, whereas the Ocala Limestone was deposited on the middle to outer ramp below storm-wave base (Ward et al., 2003).

The sediments of the Avon Park Formation may also have been deposited under shallow-water, sheltered conditions. Robinson (1972) and Eva (1980) proposed that enrolled miliolids and conical larger foraminifera have been restricted to sheltered environments and experienced limited dispersal, in comparison to the open, deeper water taxa which are subjected to higher dispersal. In support of this, Ivany (1990) inferred from the rare occurrence of seagrass in the Avon Park Formation of west-central peninsular Florida that the sediments had accumulated at depths of 1-10 m in low-energy,

warm waters in a nearshore or wide protected flat, and these waters may have covered the entire peninsula.

5.2.2 Transition Between the Studied Formations

According to Ward et al (2003) the contact between the Avon Park Formation and Ocala Limestone has been identified as an unconformity, which is formed by a period of nondeposition of sediments or erosion. Loizeaux (1995) identified this unconformity near the Peninsula Arch as truncated Avon Park sediments, a biostratigraphic hiatus, and Avon Park deposits that had been subjected to compression, diagenesis, and lithification before the deposition of the Ocala Limestone. This time gap in the sedimentary record would account for the abrupt paleontological transition in larger foraminiferal assemblages from the Avon Park Formation to the Ocala Limestone and the absence of overlap in taxa between the two units. A co-occurrence of larger foraminiferal taxa in both units would indicate a gradual transition from one depositional setting to the other, which is possible as these larger foraminifera are known to co-exist, for example, in Jamaica (Robinson, 1993).

5.3 Suggestions for Future Research

The larger miliolids found in sedimentary rocks of the Mediterranean Neothethys have a wide variety of taxa that include *Fabularia, Periloculina, Idalina, Lacazina, Lacazinella, Pseudolacazina, Helenalveolina*, and *Pseudonummuloculina.* Of these species, only *Fabularia* has been reported in the Caribbean and Americas. Larger miliolids similar to *Idalina* and *Periloculina* have been found in the Avon Park

Formation in this study. An investigation into other occurrences of these specimens in Florida and similarly aged sediments of the region might explain their migration or, evolution.

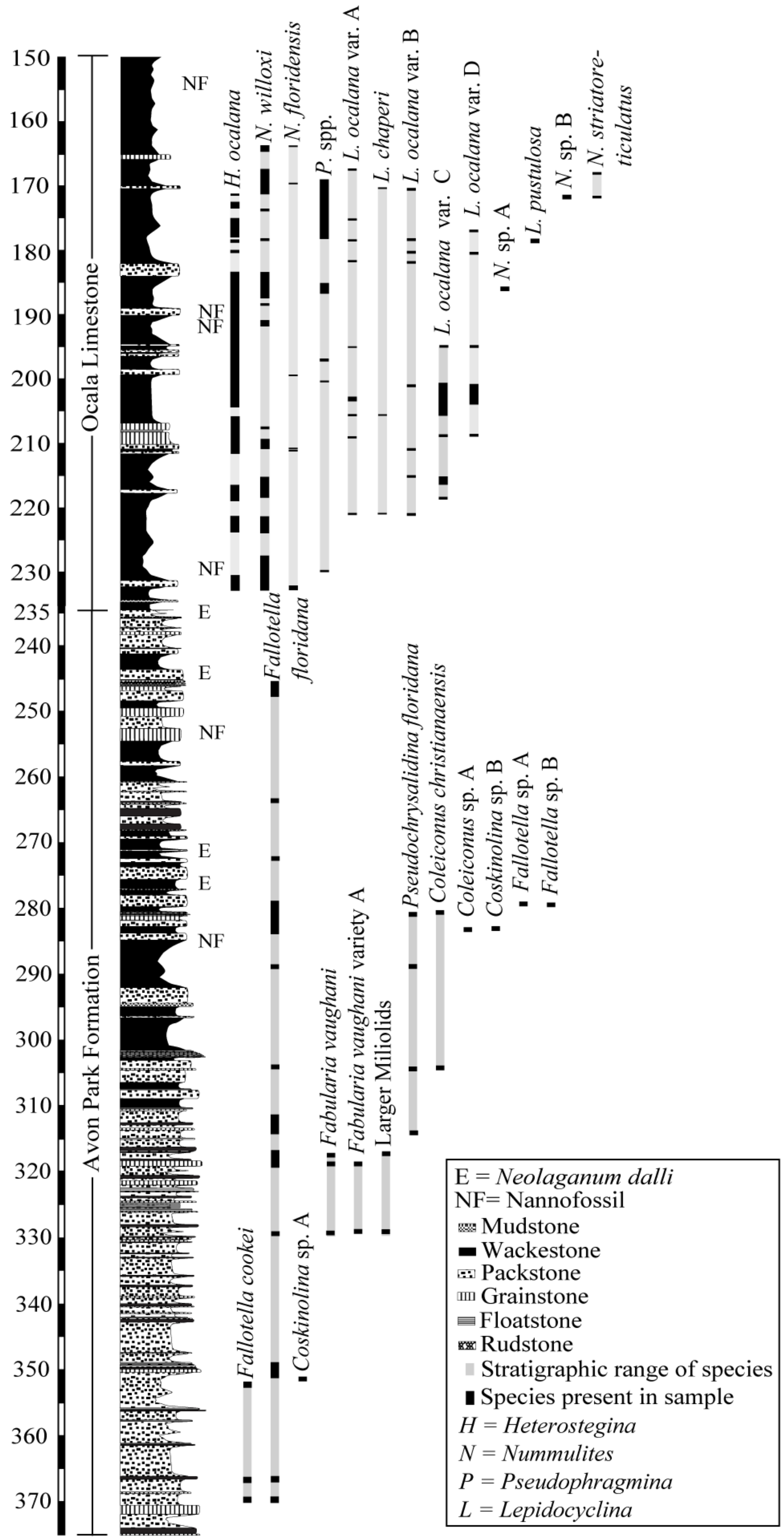


Figure 5.1 Stratigraphic distribution of larger foraminifera in the Avon Park Formation and the Ocala Limestone. Scale is m below surface. Lithology from Ward et al. (2003).

PLATES

PLATE 1

Fallotella cookei Moberg

The type of thin section and core depth are listed.

1. Axial section, 367.2 m.
2. Axial section, 370.0 m.
3. Axial section, 367.2 m.
4. Axial section, 370.0 m.
5. Axial section, 351.7 m.
6. Axial section, 370.0 m.
7. Transverse section, 367.2 m.
8. Axial section, 370.0 m.
9. Axial section, 370.0 m.
10. Axial section, 370.0 m.
11. Axial section, 367.2 m.

PLATE 1

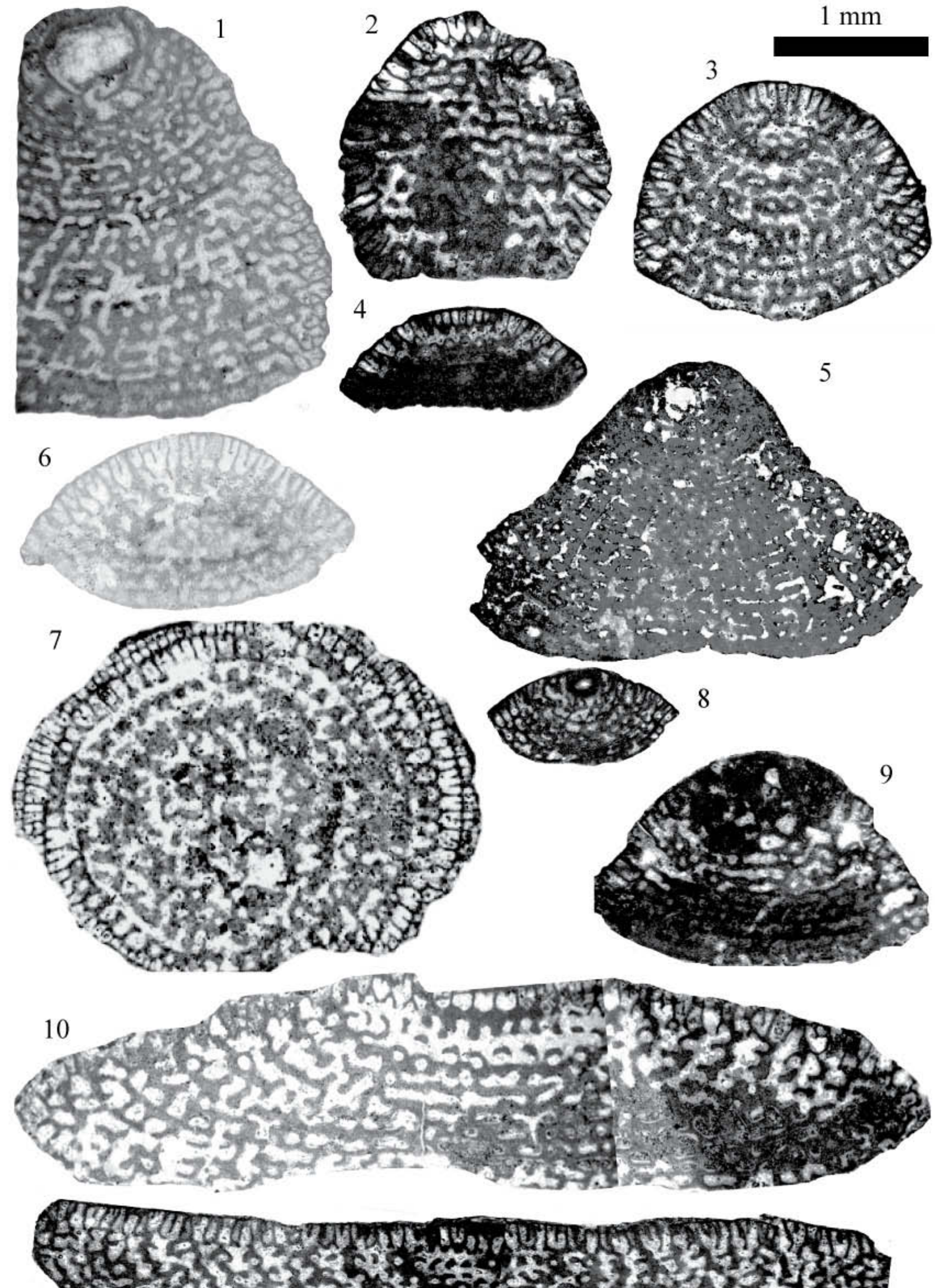


PLATE 2

Fallotella cookei Moberg

The type of thin section and core depth are listed.

1. Axial section, 367.2 m.
2. Axial section, 367.2 m.
3. Axial section, 367.2 m.
4. Axial section, 367.2 m.
5. Axial section, 367.2 m.
6. Axial section, 367.2 m.
7. Axial section, 367.2 m.
8. Transverse section, 367.2 m.
9. Transverse section, 367.2 m.

PLATE 2

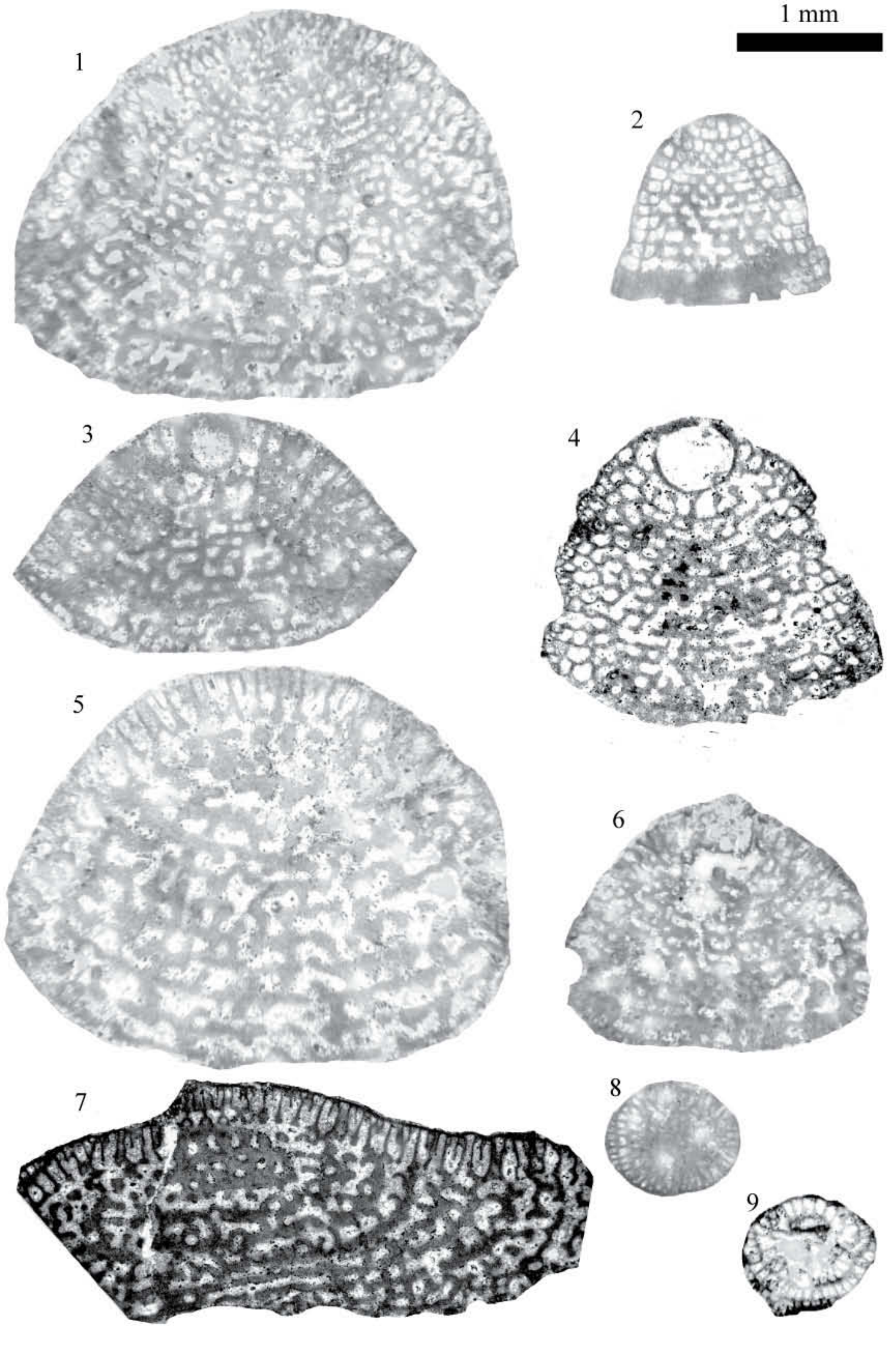


PLATE 3

Fallotella floridana Cole

The type of thin section and core depth are listed.

1. Axial section, 367.2 m.
2. Axial section, 370.0 m.
3. Axial section, 367.2 m.
4. Axial section, 367.2 m.

PLATE 3

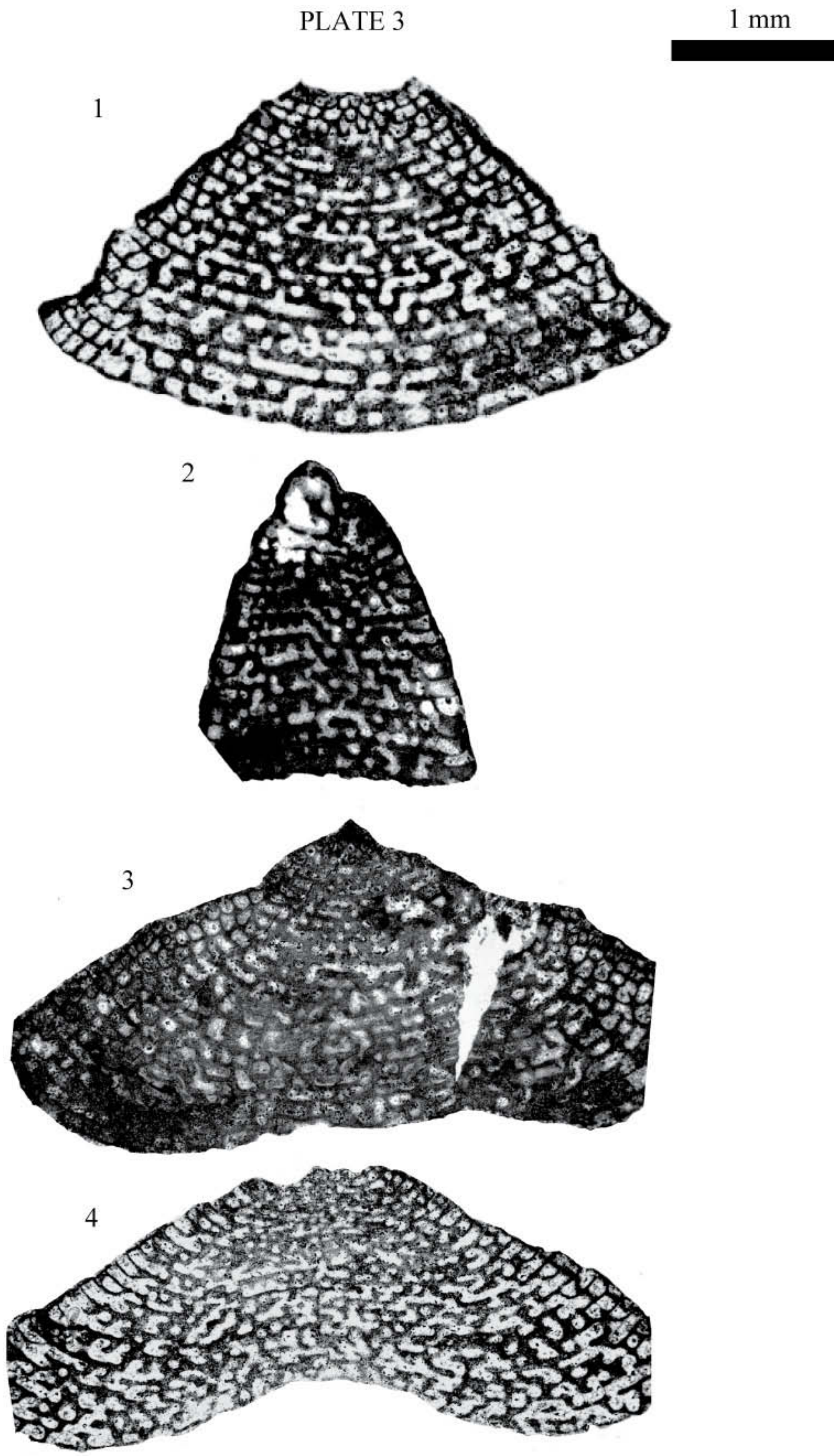


PLATE 4

Fallotella floridana Cole

The type of thin section and core depth are listed.

1. Axial section, 370.0 m.
2. Axial section, 370.0 m.
3. Axial section, 370.0 m.
4. Axial section, 370.0 m.
5. Axial section, 370.0 m.
6. Axial section, 370.0 m.
7. Axial section, 370.0 m.
8. Oblique section, 370.0 m.
9. Axial section, 370.0 m.
10. Transverse section, 370.0 m.
11. Oblique section, 370.0 m.
12. Axial section, 370.0 m.
13. Axial section, 370.0 m.
14. Axial section, 370.0 m.
15. Transverse section, 370.0 m.

PLATE 4

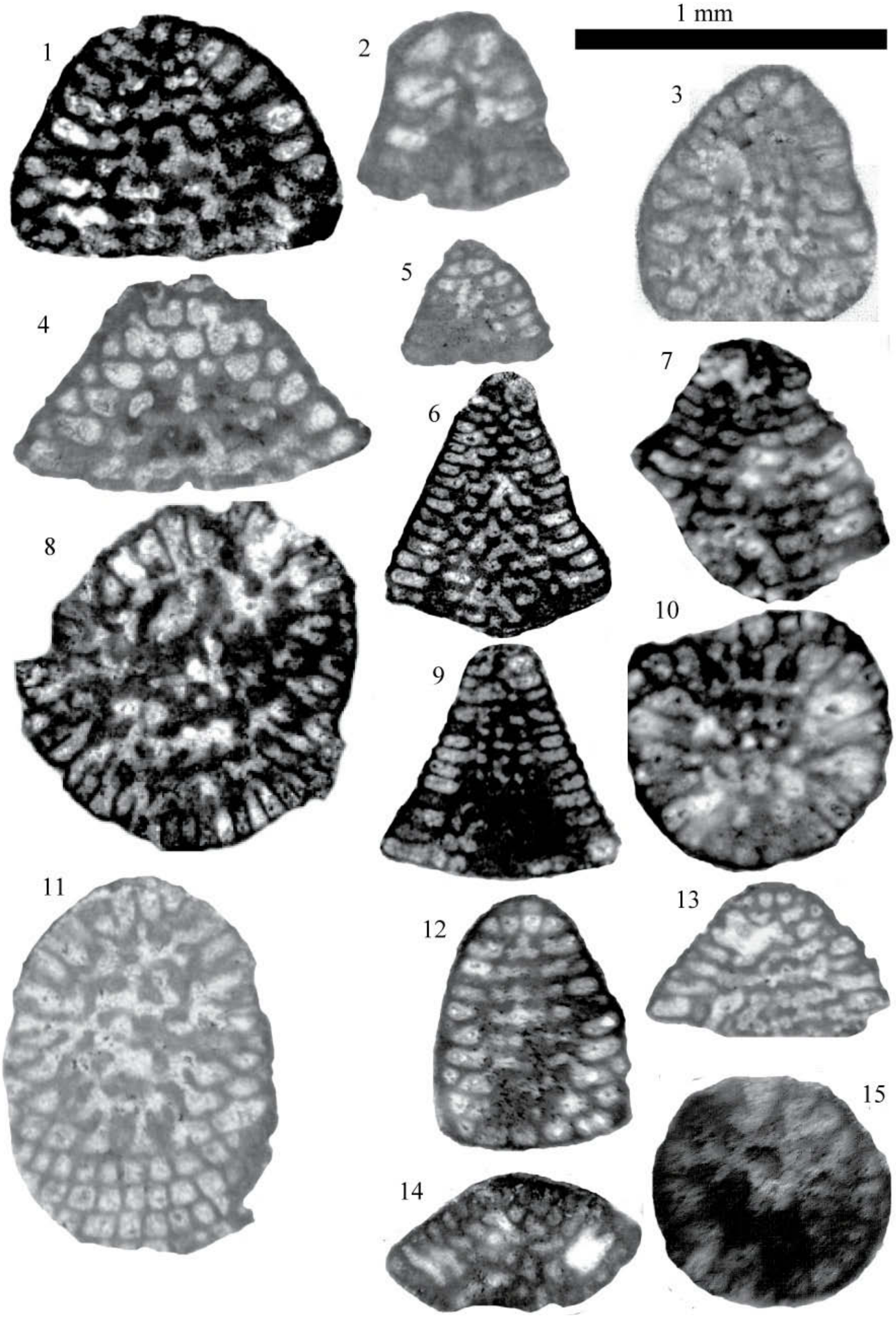


PLATE 5

Fallotella floridana Cole

The type of thin section and core depth are listed.

1. Axial section, 351.4 m.
2. Axial section, 351.4 m.
3. Oblique section, 351.4 m.
4. Axial section, 351.4 m.
5. Transverse section, 351.4 m.
6. Oblique section, 351.1 m.
7. Transverse section, 351.4 m.
8. Transverse section, 329.8 m.
9. Transverse section, 351.1 m.
10. Transverse section, 329.8 m.
11. Transverse section, 329.8 m.

PLATE 5

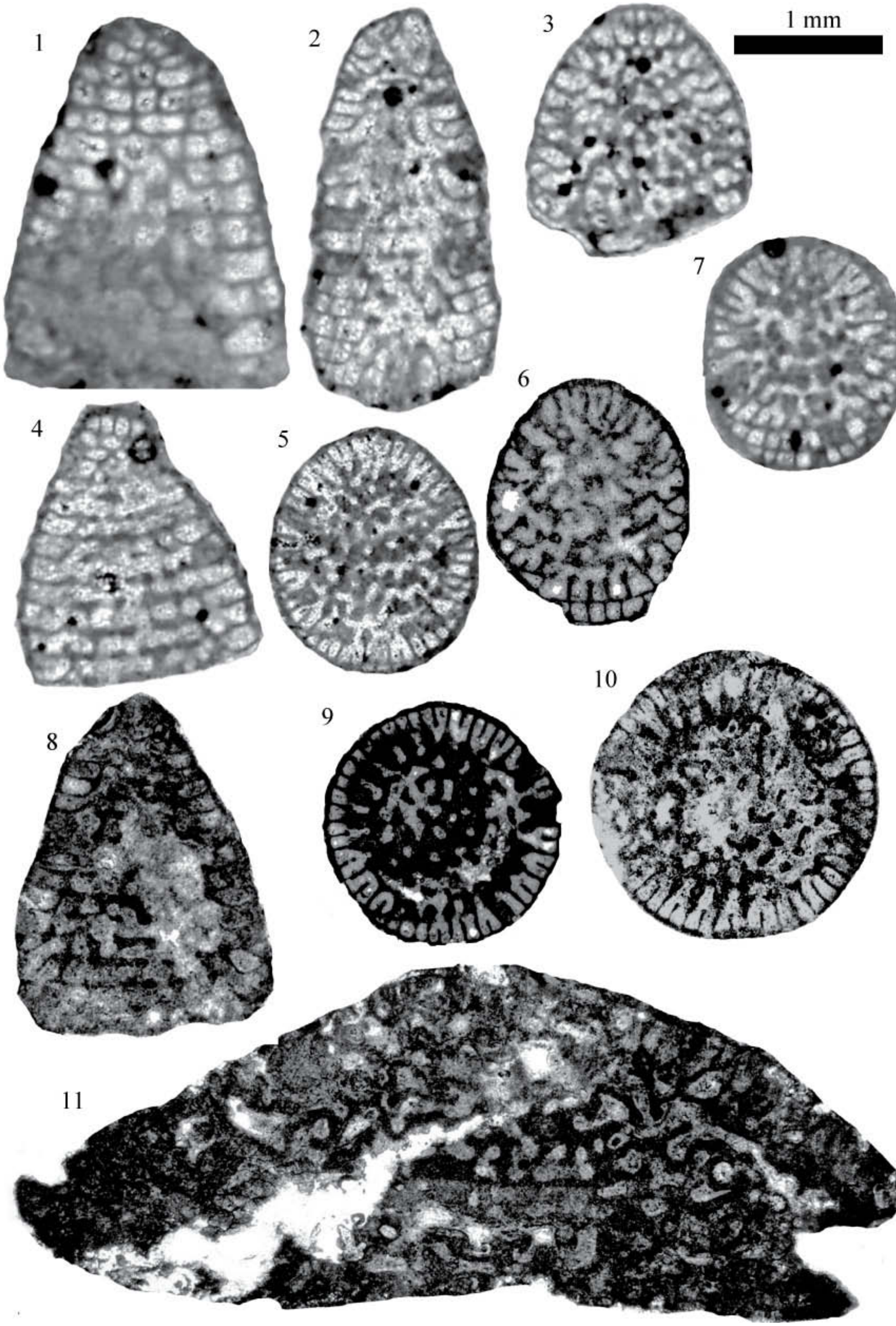


PLATE 6

Fallotella floridana Cole

The type of thin section and core depth are listed.

1. Axial section, 318.2 m.
2. Transverse section, 318.2 m.
3. Axial section, 318.2 m.
4. Oblique section, 318.2 m.
5. Axial section, 318.2 m.
6. Axial section, 318.2 m.
7. Axial section, 318.2 m.
8. Axial section, 318.2 m.
9. Transverse section, 318.2 m.
10. Axial section, 318.2 m.
11. Transverse section, 318.2 m.

PLATE 6

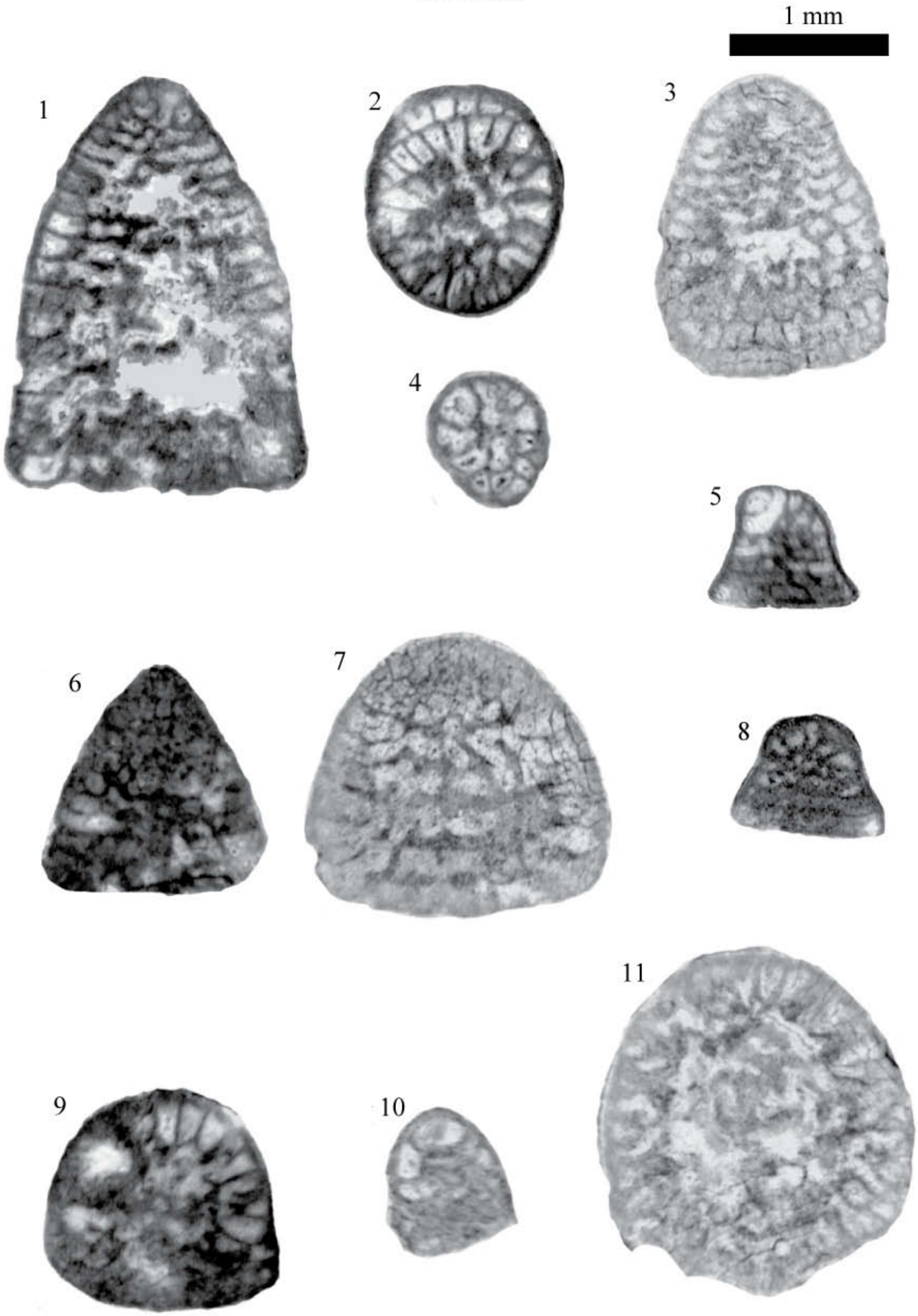


PLATE 7

Fallotella floridana Cole

The type of thin section and core depth are listed.

1. Axial section, 317.6 m.
2. Axial section, 317.6 m.
3. Oblique section, 283.8 m.
4. Oblique section, 283.8 m.
5. Axial section, 283.8 m.
6. Axial section, 283.8 m.
7. Axial section, 317.6 m.
8. Axial section, 283.8 m.
9. Oblique section, 304.4 m.
10. Oblique section, 304.4 m.
11. Oblique section, 283.8 m.
12. Axial section, 283.8 m.
13. Transverse section, 283.8 m.
14. Transverse section, 283.8 m.
15. Transverse section, 283.8 m.
16. Transverse section, 317.6 m.
17. Transverse section, 283.8 m.
18. Axial section, 283.8 m.
19. Axial section, 289.2 m.

PLATE 7

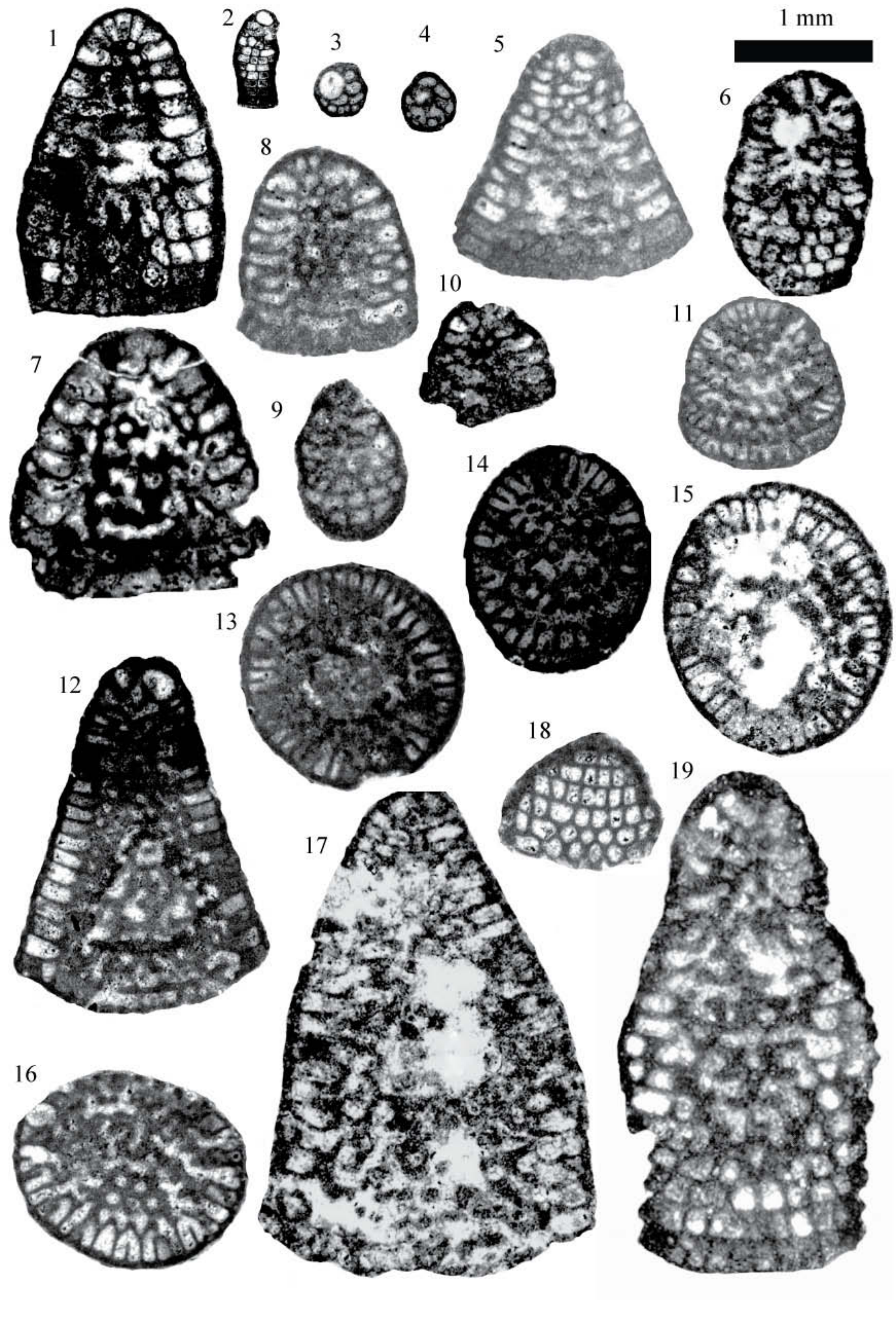


PLATE 8

The type of thin section and core depth are listed.

1. Coskinolina sp. A, axial section, 351.7 m.
2. *Coskinolina* sp. B, axial section, 283.8 m.
3. *Coleiconus christianaensis* Robinson, axial section, 280.7 m.
4. *Coleiconus christianaensis* Robinson, transverse section, 280.7 m.
5. *Coleiconus christianaensis* Robinson, axial section, 304.4 m.
6. *Pseudochrysalidina floridana* Cole, transverse section, 289.2 m.
7. *Pseudochrysalidina floridana* Cole, transverse section, 280.7
8. *Pseudochrysalidina floridana* Cole, transverse section, 289.2 m.
9. *Pseudochrysalidina floridana* Cole, axial section, 289.2 m,
10. *Pseudochrysalidina floridana* Cole, axial section, 314.2 m.
11. *Pseudochrysalidina floridana* Cole, axial section, 304.4 m.
12. *Pseudochrysalidina floridana* Cole, axial section, 304.4 m.

PLATE 8

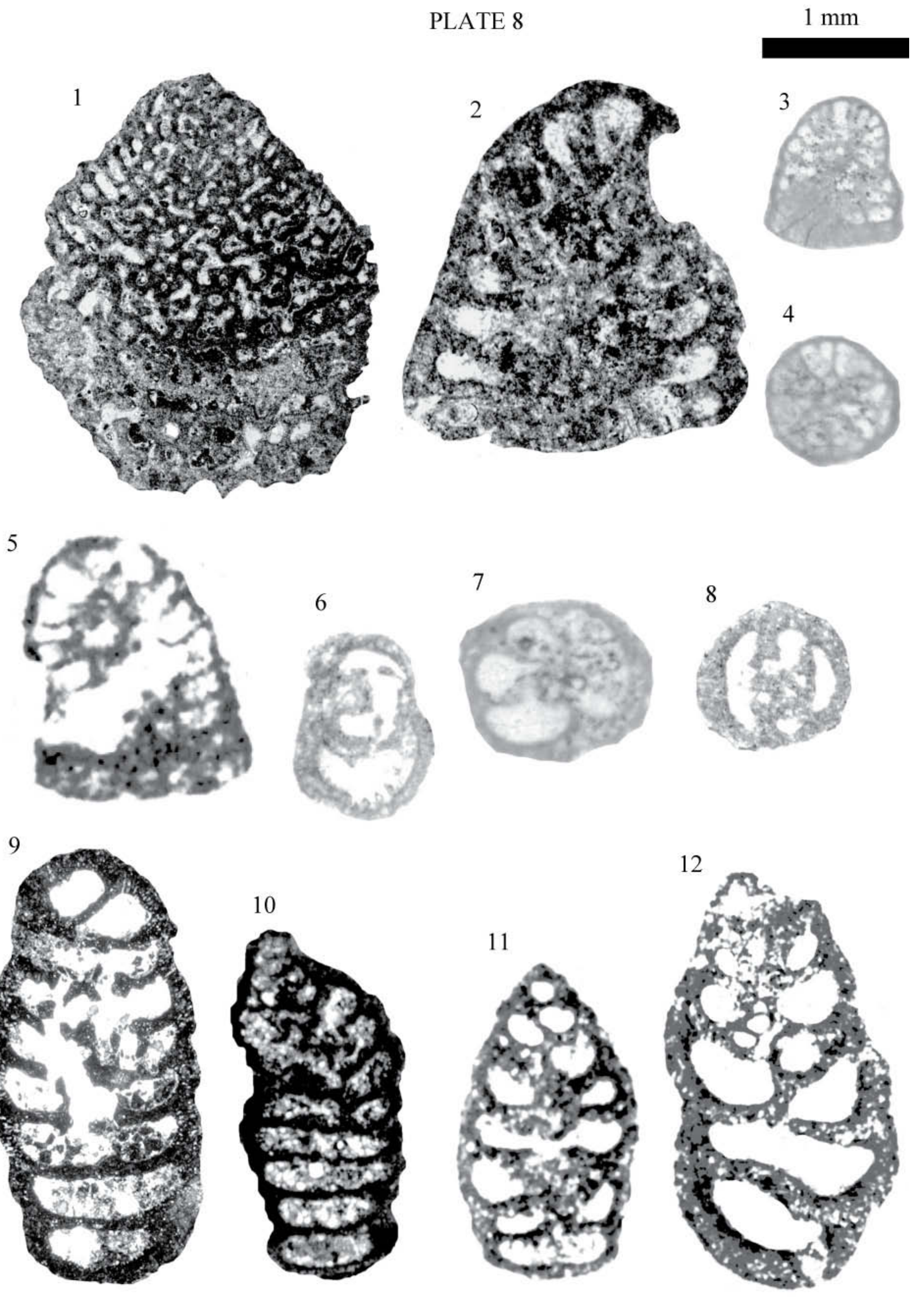


PLATE 9

Floridana floridana Cole

The type of thin section and core depth are listed.

1. Axial section, 280.7 m.
2. Axial section, 280.7 m.
3. Axial section, 280.7 m.
4. Axial section, 280.7 m.
5. Axial section, 280.7 m.
6. Transverse, 280.7 m.
7. Oblique section, 280.7 m.
8. Oblique section, 280.7m.
9. Transverse section, 280.7 m.
10. Transverse section, 280.7 m.
11. Axial section, 280.7 m.
12. Axial section, 280.7 m.
13. Axial section, 280.7 m.
14. Axial section, 280.7 m.
15. Axial section, 280.7 m.
16. Axial section, 280.7 m.
17. Transverse section, 280.7 m.
18. Transverse section, 280.7 m.
19. Axial section, 280.7 m.
20. Axial section, 280.7 m.
21. Axial section, 280.7 m.
22. Axial section, 280.7 m.
23. Oblique section, 280.7 m.
24. Axial section, 280.7 m.
25. Transverse section, 280.7 m.
26. Axial section, 280.7 m.

PLATE 9

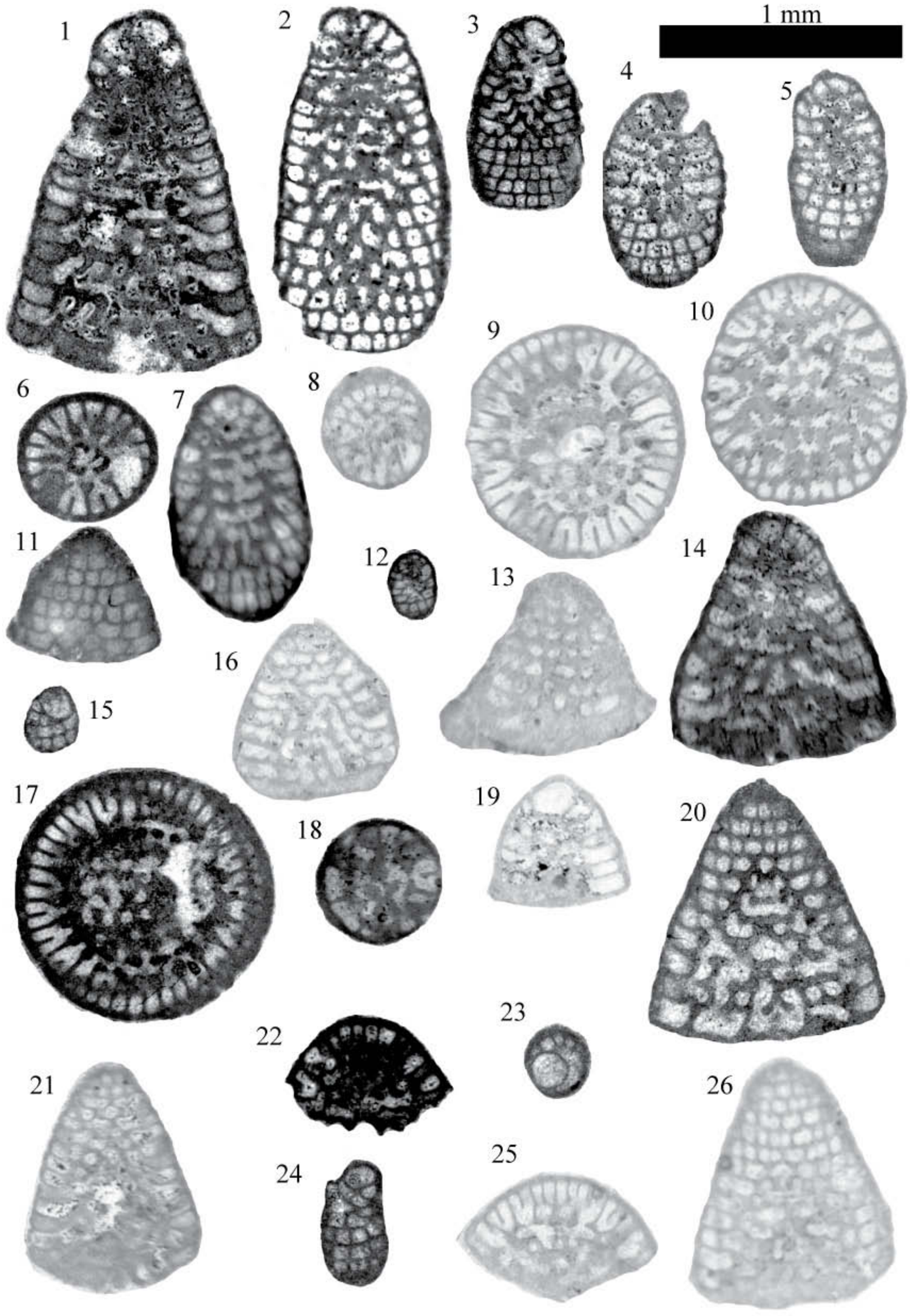


PLATE 10

The type of thin section and core depth are listed.

Fallotella floridana Cole

1. Axial section, 279.5 m.
2. Oblique section, 279.5 m.
3. Oblique section, 279.5 m.
4. Transverse section, 279.5 m.
6. Transverse section, 279.5 m.
9. Transverse section, 279.5 m.
10. Transverse section, 279.5 m.
11. Axial section, 279.5 m.
12. Transverse section, 279.5 m.
13. Transverse section, 279.5 m.
14. Axial section, 279.5 m.
15. Axial section, 279.5 m.
17. Oblique, 279.5 m.
18. Axial section, 279.5 m.
19. Transverse section, 279.5 m.
20. Axial section, 279.5 m.
21. Axial section, 279.5 m.
22. Transverse section, 279.5 m.
23. Axial section, 279.5 m.
24. Transverse section, 279.5 m.
25. Axial section, 279.5 m.
26. Axial section, 279.5 m.

Fallotella sp. A

5. Axial section, 279.5 m.
7. Axial section, 279.5 m.

Fallotella sp. B

8. Axial section, 279.5 m.
16. Axial section, 279.5 m.

PLATE 10

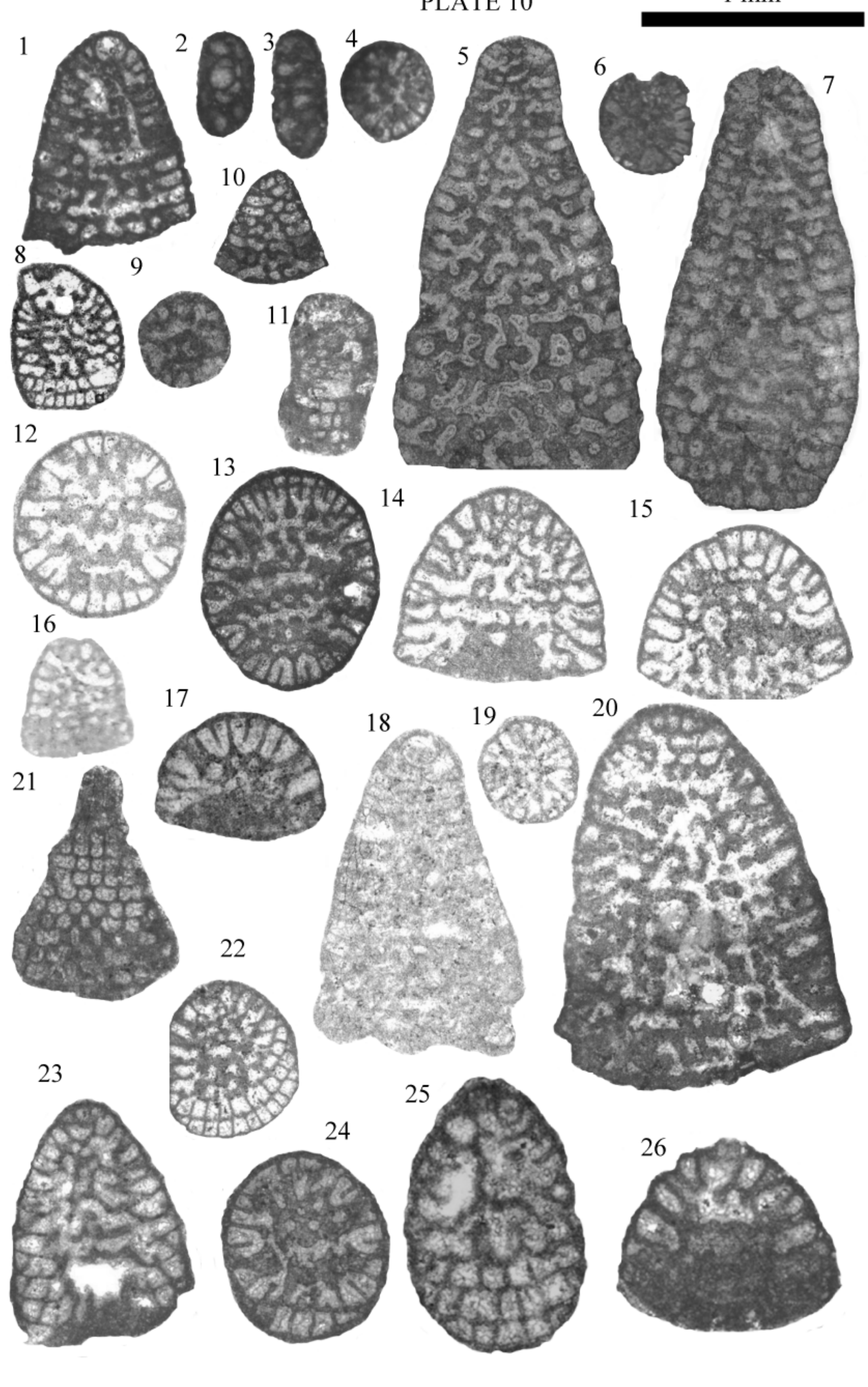


PLATE 11

Fabularia vaughani Cole.

The type of thin section and core depth are listed.

1. Oblique section, 329.8 m.
2. Oblique section, 329.8 m.
3. Near-equatorial section, 329.8 m.
4. Near-equatorial section, 318.2 m.
5. Near-equatorial section, 329.8 m.
6. Near-equatorial section, 329.8 m.
7. Oblique section, 329.8 m.
8. Axial section, 329.8 m.

PLATE 11

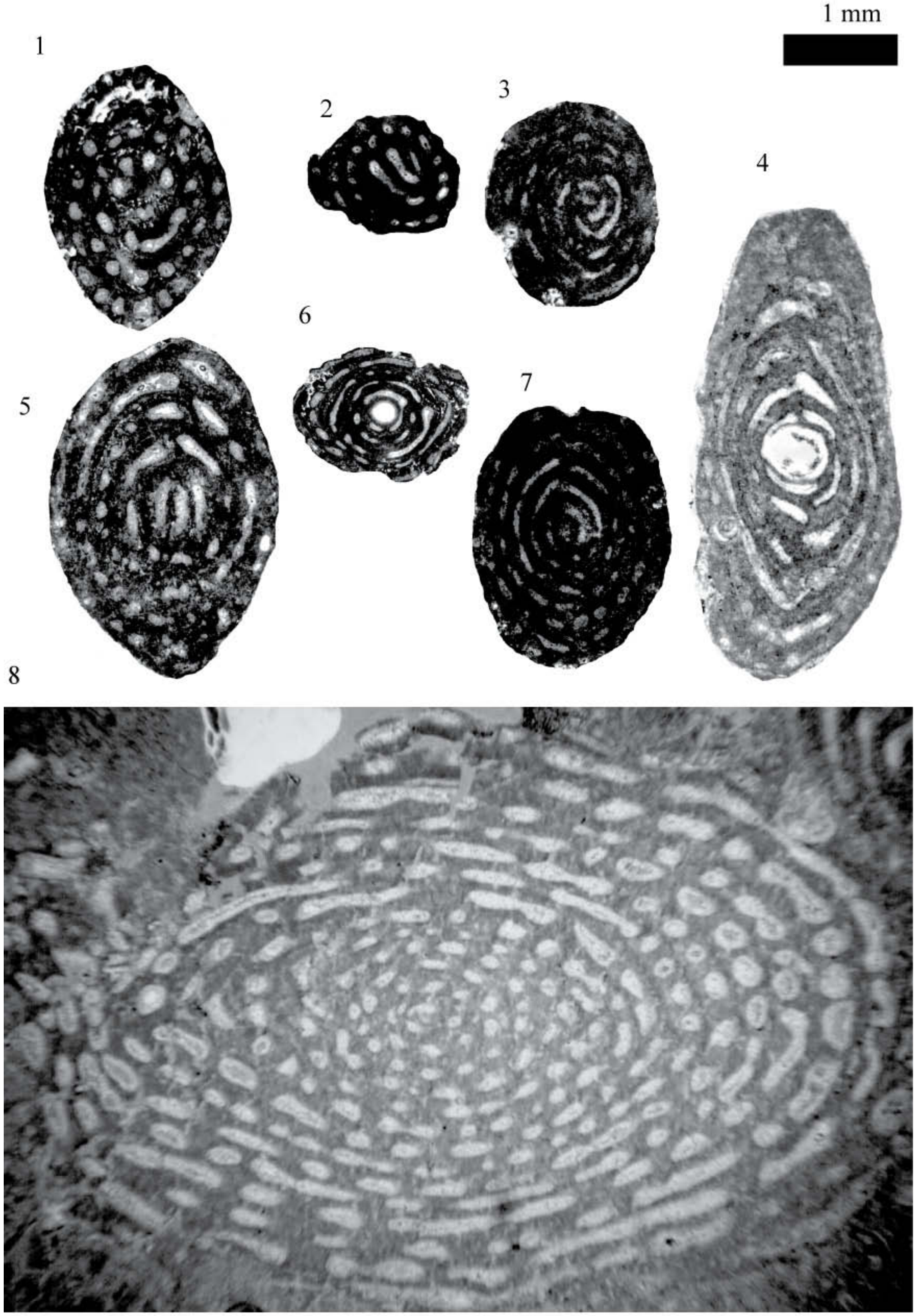


PLATE 12

Fabularia vaughani Cole.

The type of thin section and core depth are listed.

1. Oblique section, 329.8 m.

2. Axial section, 329.8 m.

3. Oblique section, 329.8 m.

4. Oblique, 329.8 m.

5. Axial section, 329.8 m.

PLATE 12

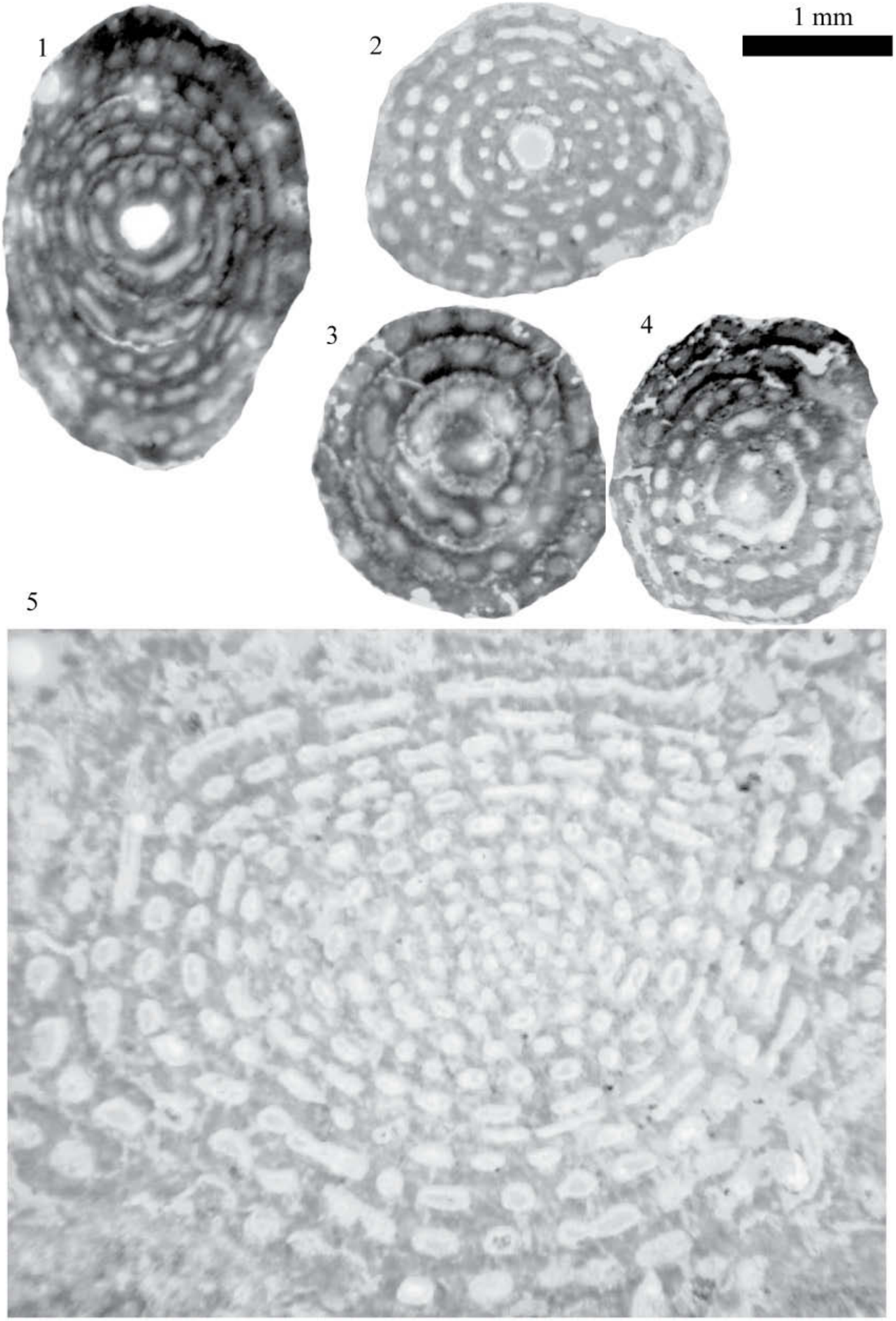


PLATE 13

Fabularia vaughani Cole var. A.

The type of thin section and core depth are listed.

1. Oblique section, 329.8 m.

2. Oblique section, 329.8m.

3. Near-equatorial section, 329.8 m.

4. Near-equatorial section, 319.4 m.

PLATE 13

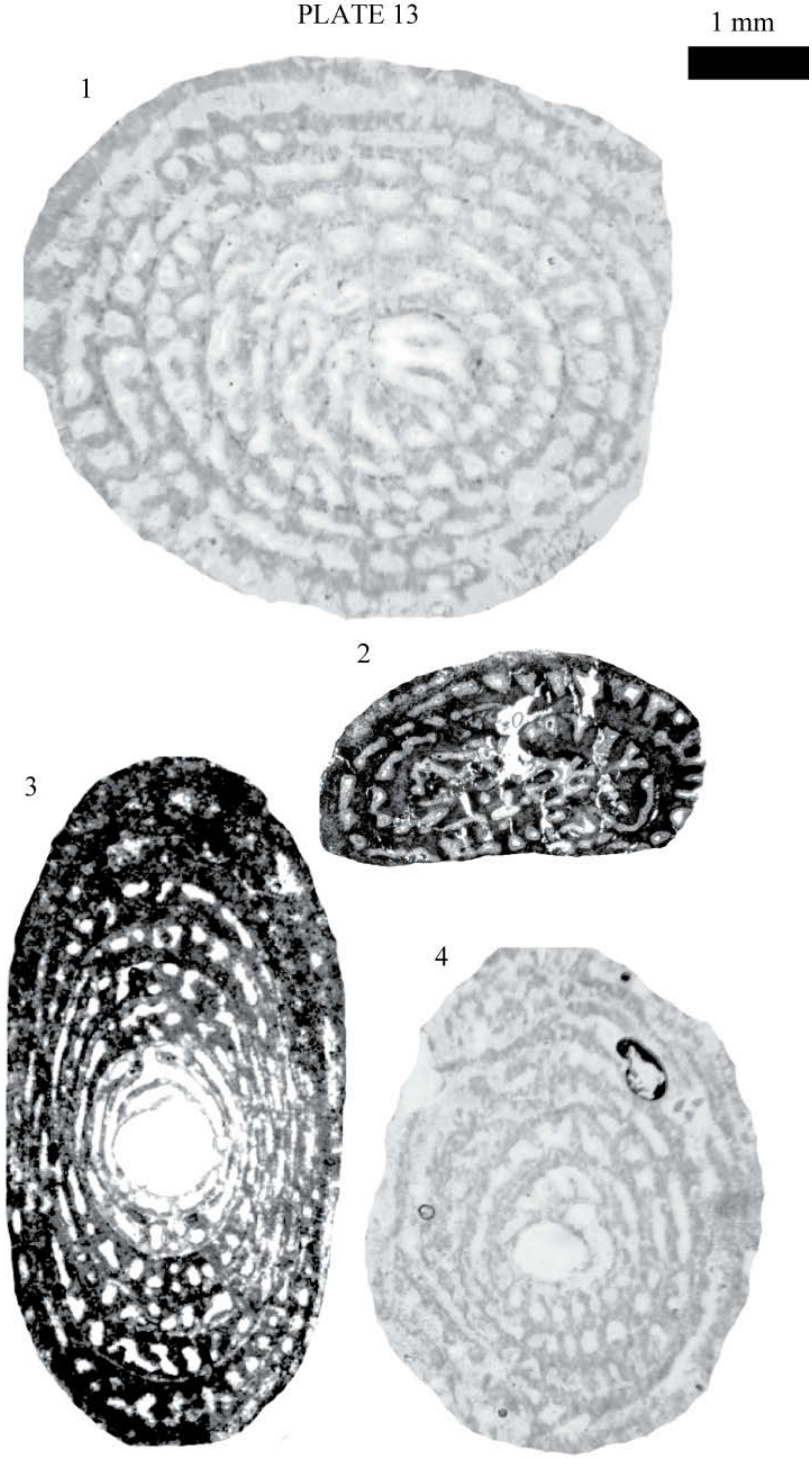


PLATE 14

Fabularia vaughani Cole.

The type of thin section and core depth are listed.

1. Oblique section, 319.4 m.
2. Near-equatorial section, 319.4 m.
3. Oblique section, 319.4 m.
4. Axial section, 319.4 m.
5. Oblique section, 319.4 m.
6. Microspheric form, axial section, 319.4 m.

PLATE 14

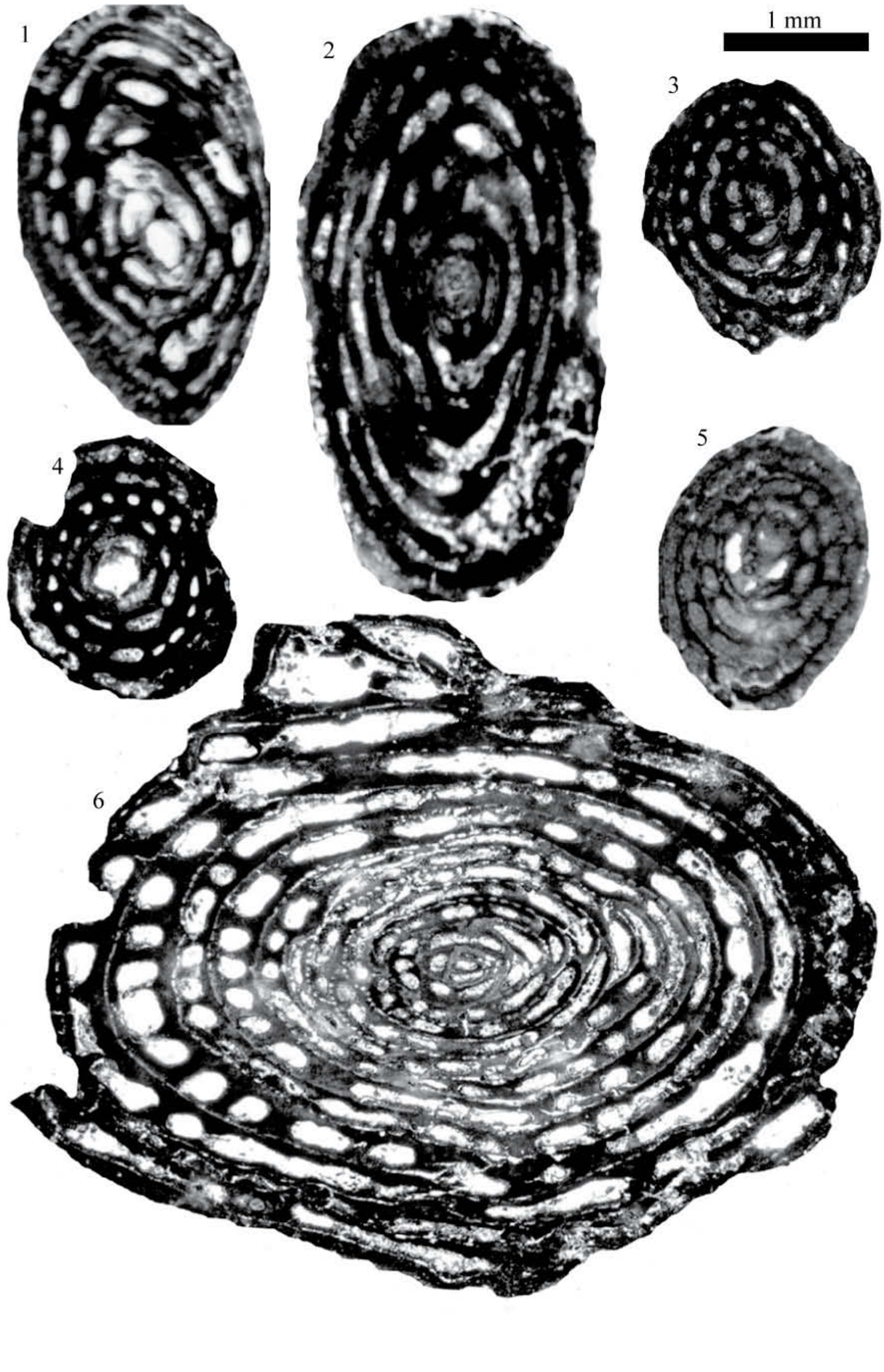


PLATE 15

Fabularia vaughani Cole.

The type of thin section and core depth are listed.

1. Near-equatorial section, 319.4 m.

2. Near-equatorial section, 319.4 m.

PLATE 15

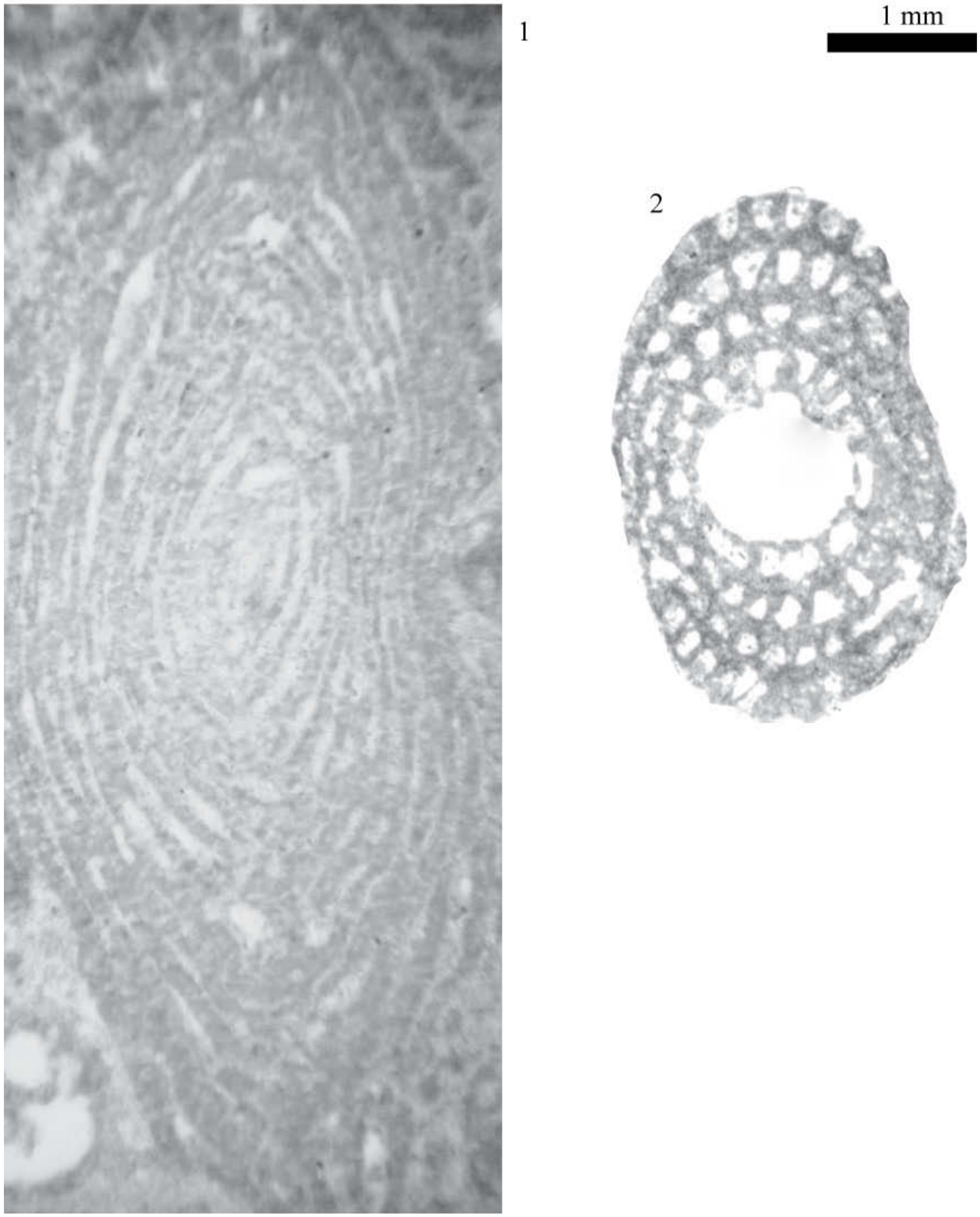


PLATE 16

Fabularia vaughani Cole.

The type of thin section and core depth are listed.

1. Axial section, 318.2 m.
2. Oblique, 318.2 m.
3. Near-equatorial section, 318.2 m.
4. Oblique section, 318.2 m.
5. Oblique 318.2 m.
6. Oblique section, 318.2 m.
7. Oblique section, 318.2 m.
8. Axial section, 318.2 m.
9. Axial section, 318.2 m.

PLATE 16

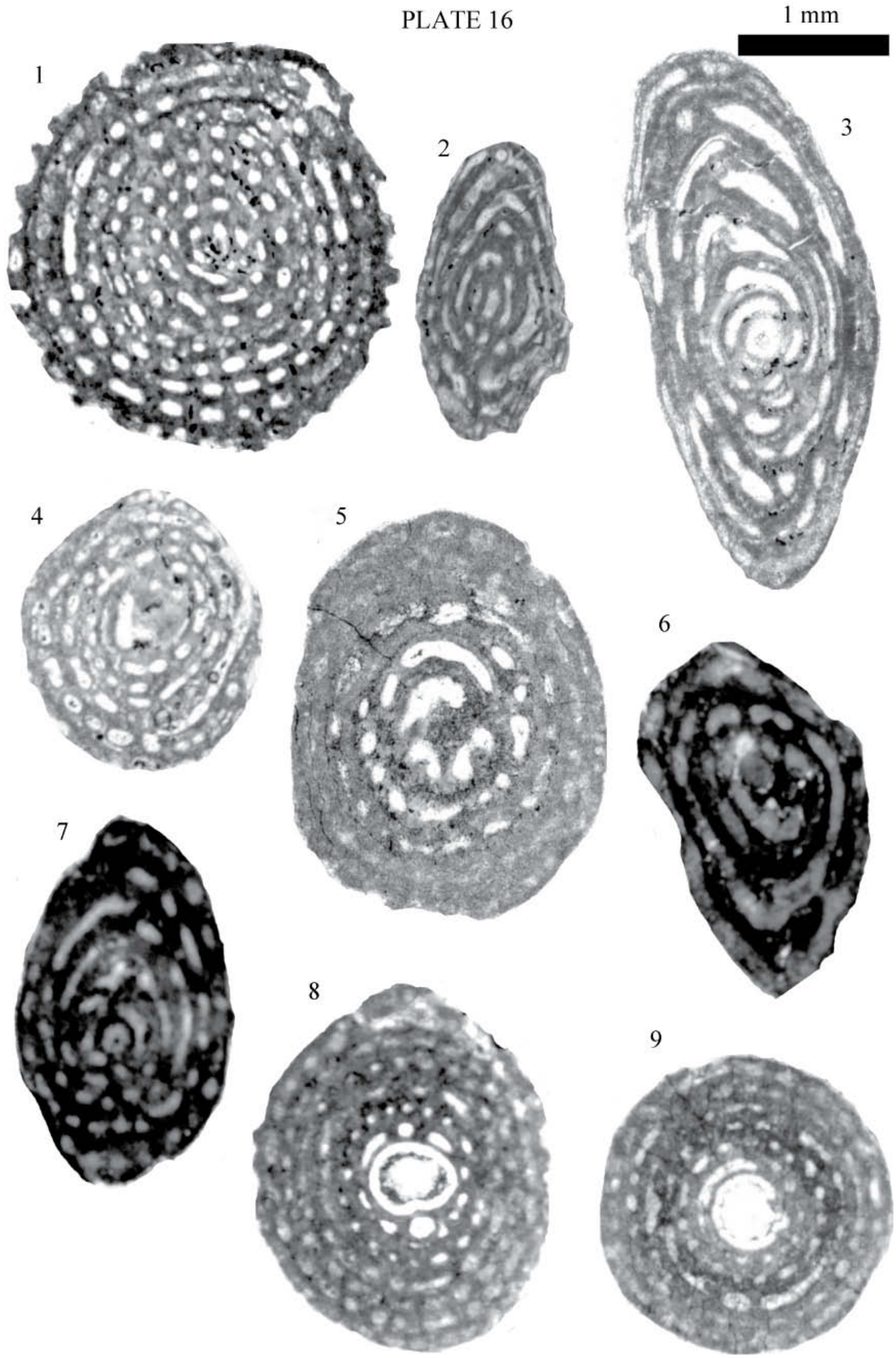


PLATE 17

Larger Miliolids.

The type of thin section and core depth are listed.

1. Equatorial section, 318.2 m.
2. Equatorial section, 329.8 m.
3. Axial section, 329.8m
4. Axial section, 329.8 m
5. Axial section, 317.6 m
6. Axial section, 329.8 m
7. Equatorial section, 329.8 m.

PLATE 17

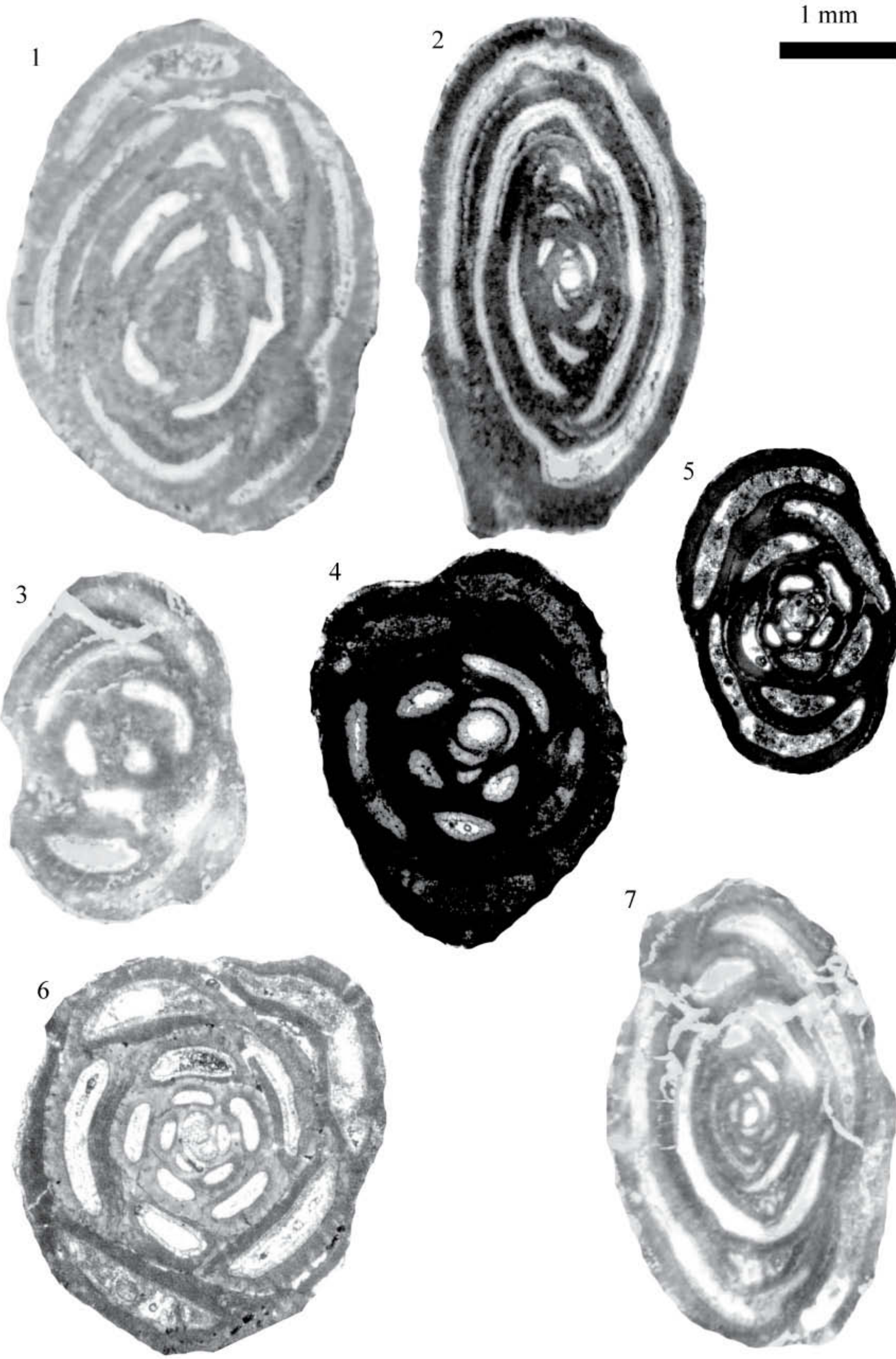


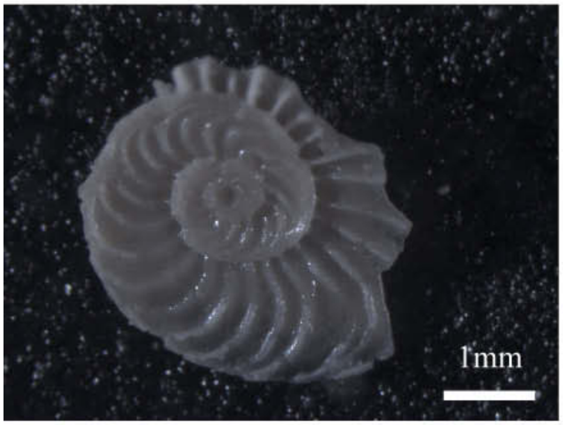
PLATE 18

Nummulites spp.

The type of section and core depth are listed.

1. *Nummulites floridensis*, equatorial section, 163.7 m
2. *Nummulites striatoreticulatus*, equatorial section, 175.0 m
3. *Nummulites willcoxi*, equatorial section, 207.2 m
4. *Nummulites* sp. A, equatorial section, 185.9 m
5. *Nummulites* sp. B, equatorial section, 171.2 m

PLATE 18



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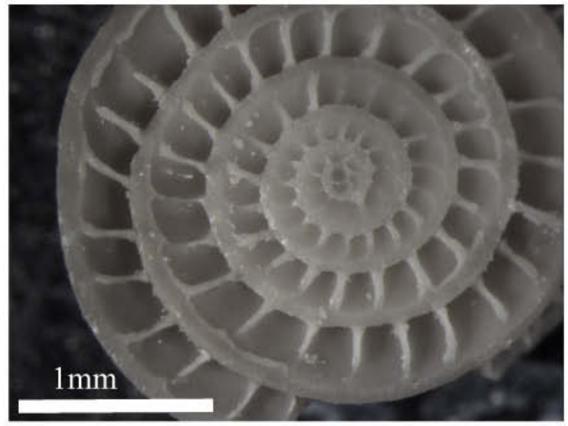

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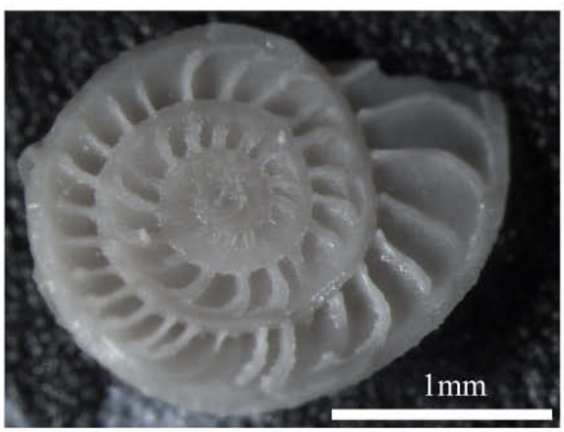


5

PLATE 19

Heterostegina ocalana

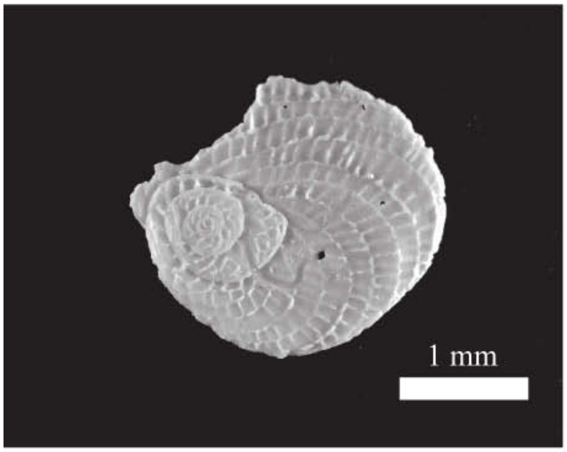
The type of section and core depth are listed.

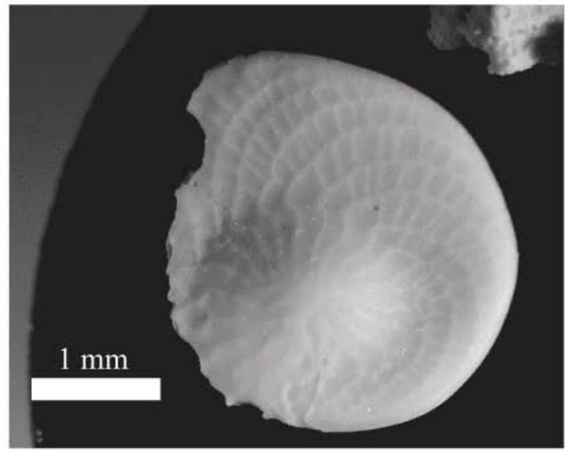
1. *Heterostegina ocalana*, microspheric form, equatorial section, 193.9 m

2. *Heterostegina ocalana*, external test, equatorial section, 193.9 m

3. *Heterostegina ocalana,* equatorial section, 223 m

PLATE 19





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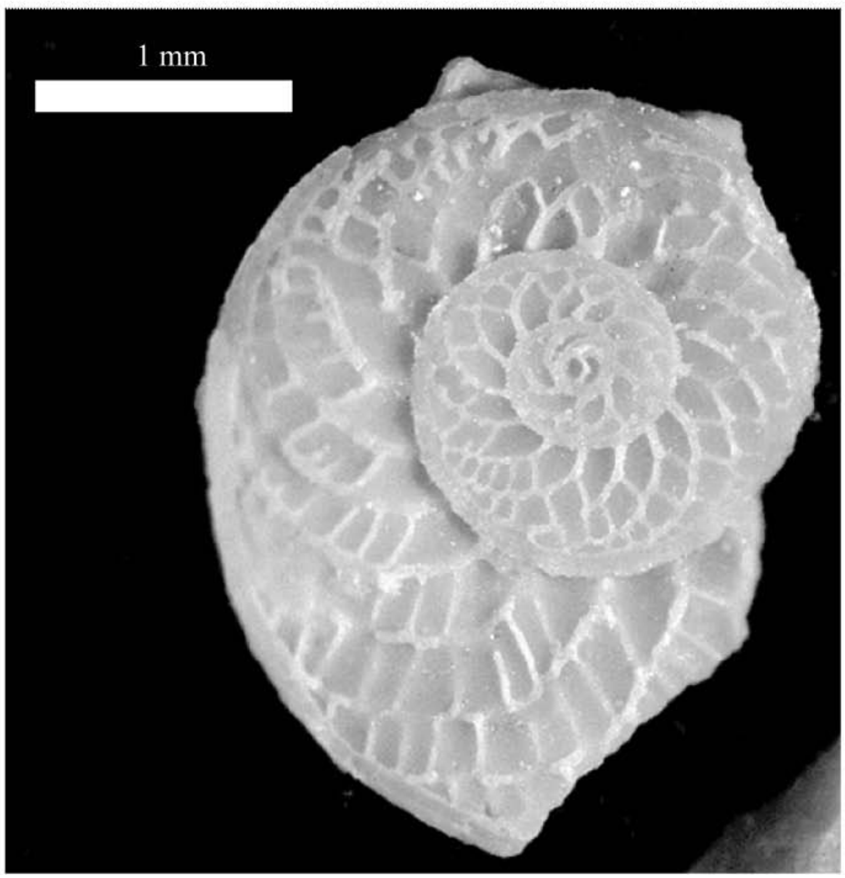


PLATE 20

Heterostegina ocalana

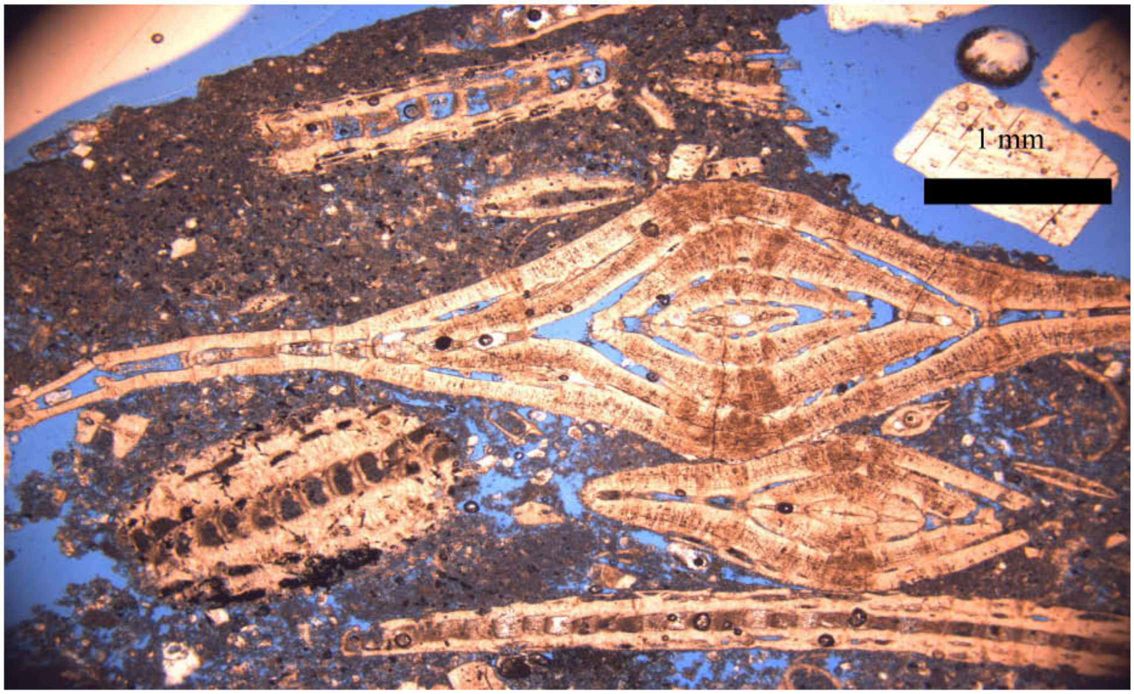
The type of thin section and core depth are listed.

1. *Heterostegina ocalana,* axial section, 210.6 m

2. *Heterostegina ocalana,* axial section, 210.6 m

PLATE 20

1



2

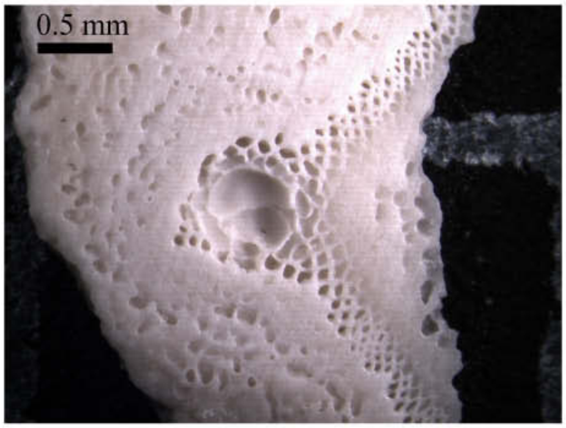
PLATE 21

Lepidocyclina spp.

The type of section, core depth (or location) and specimen number are listed.

1. *Lepidocyclina chaperi,* equatorial section, 178 m # 43
2. *Lepidocyclina pustulosa,* equatorial section, 170.3 m # 36
3. *Lepidocyclina ocalana* var. A, equatorial section, mayo # 1
4. *Lepidocyclina ocalana* var. B, equatorial section, 180.4 m # 37
5. *Lepidocyclina ocalana* var. C, equatorial section, 208.4 m # 5
6. *Lepidocyclina ocalana* var. D, equatorial section, 201.2 m # 29

PLATE 21



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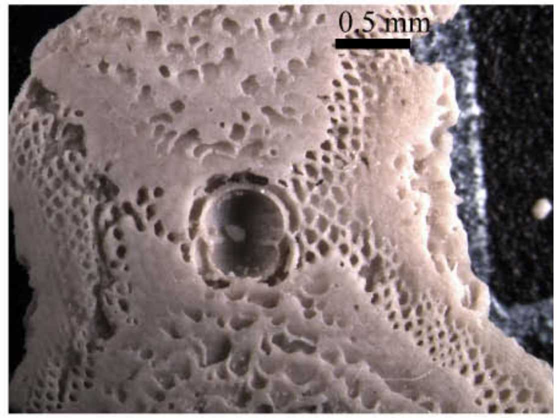

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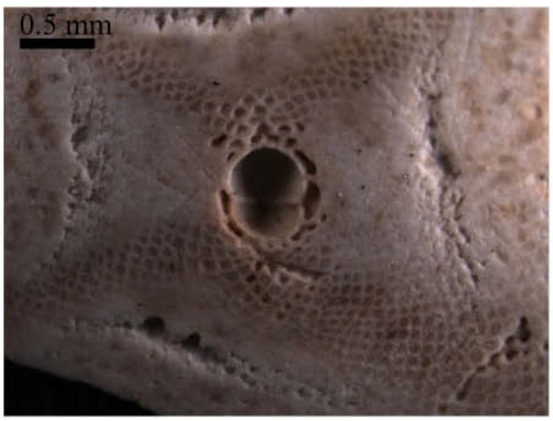

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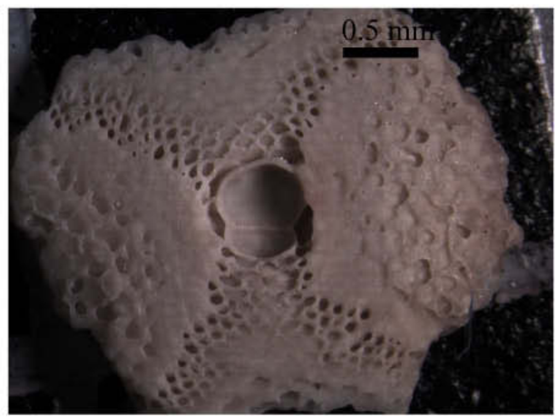

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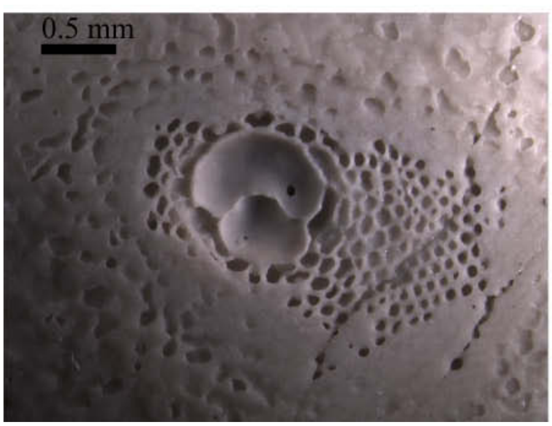

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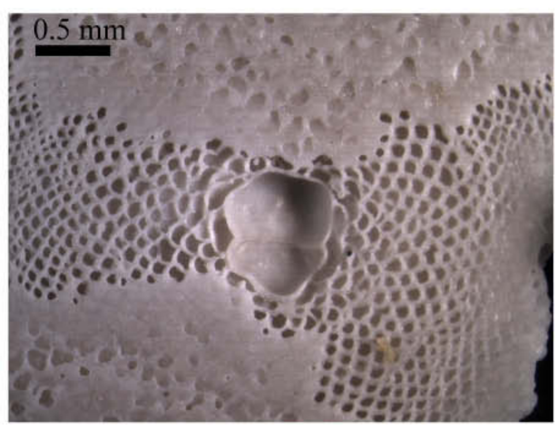


PLATE 22

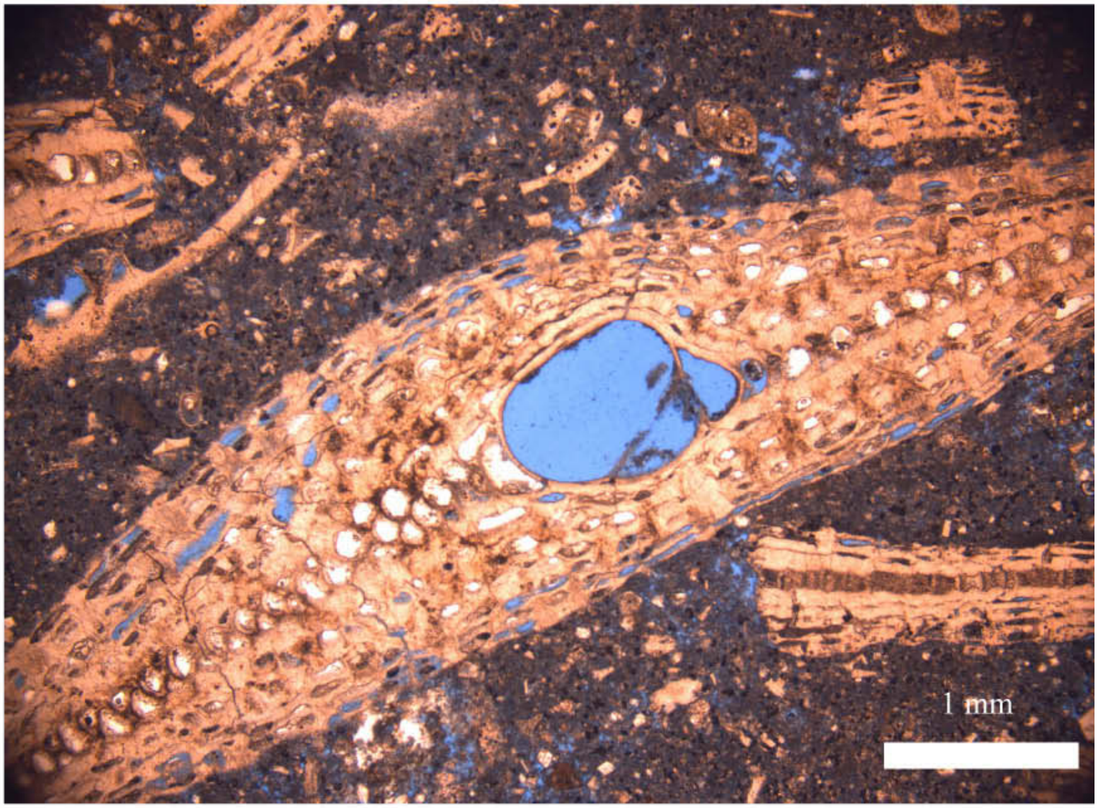
Lepidocyclina sp.

The type of thin section and core depth are listed.

1. *Lepidocyclina* sp., axial section, 210.6 m
2. *Lepidocyclina* sp., axial section, 210.6 m

PLATE 22

1



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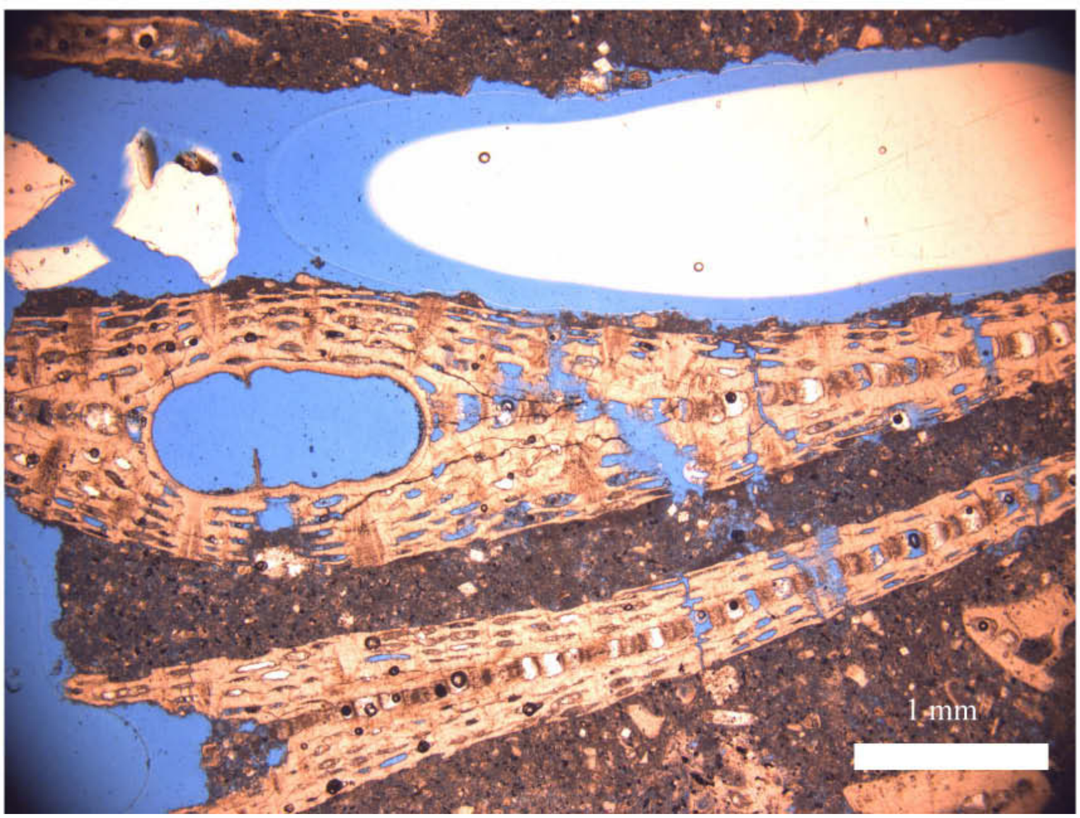


PLATE 23

Pseudophragmina sp. A

The type of section and core depth are listed.

1. *Pseudophragmina* sp. A, equatorial section, 229.2 m

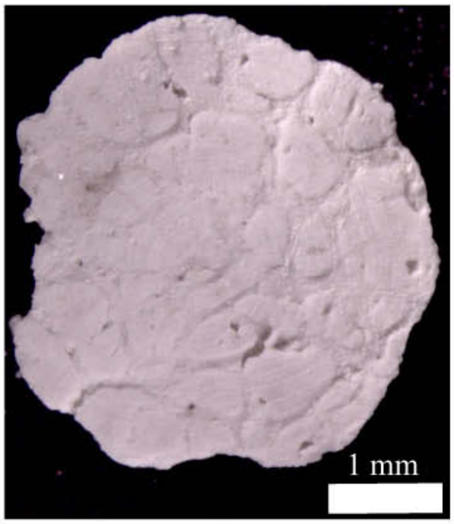
2. *Pseudophragmina* sp. A, equatorial section, 229.2 m

3. *Pseudophragmina* sp. A, equatorial section, 229.2 m

4. *Pseudophragmina* sp. A, equatorial section, 229.2 m

5. *Pseudophragmina* sp. A, equatorial section, 229.2 m

PLATE 23



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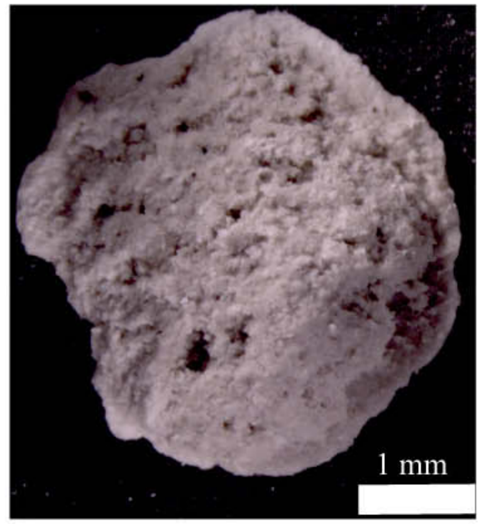

3

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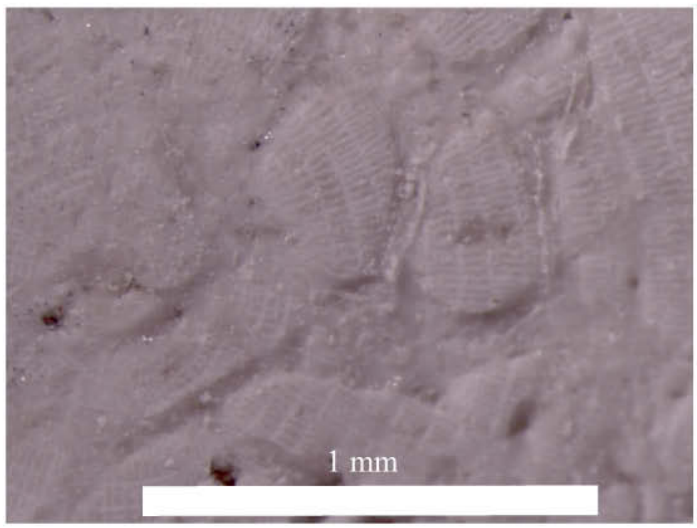
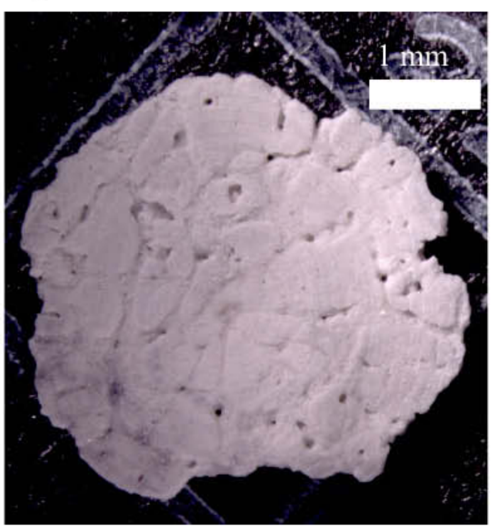


4



5

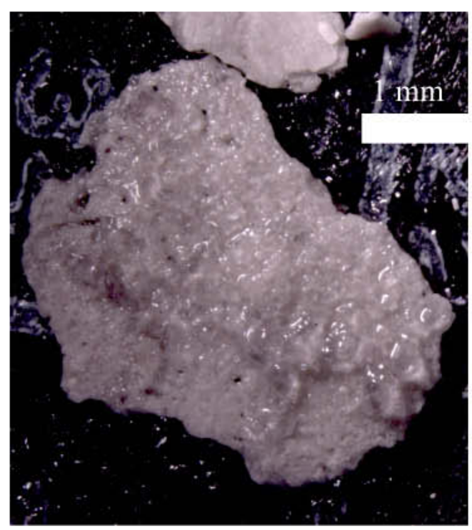


PLATE 24

Pseudophragmina sp. B

The type of section and core depth are listed.

1. *Pseudophragmina* sp. B, 173.4 m.

2. *Pseudophragmina* sp. B, 173.4 m.

3. *Pseudophragmina* sp. B, 175 m.

4. *Pseudophragmina* sp. B, 175.3 m

5. *Pseudophragmina* sp. B, 185.9 m

6. *Pseudophragmina* sp. B, 185.9 m

PLATE 24

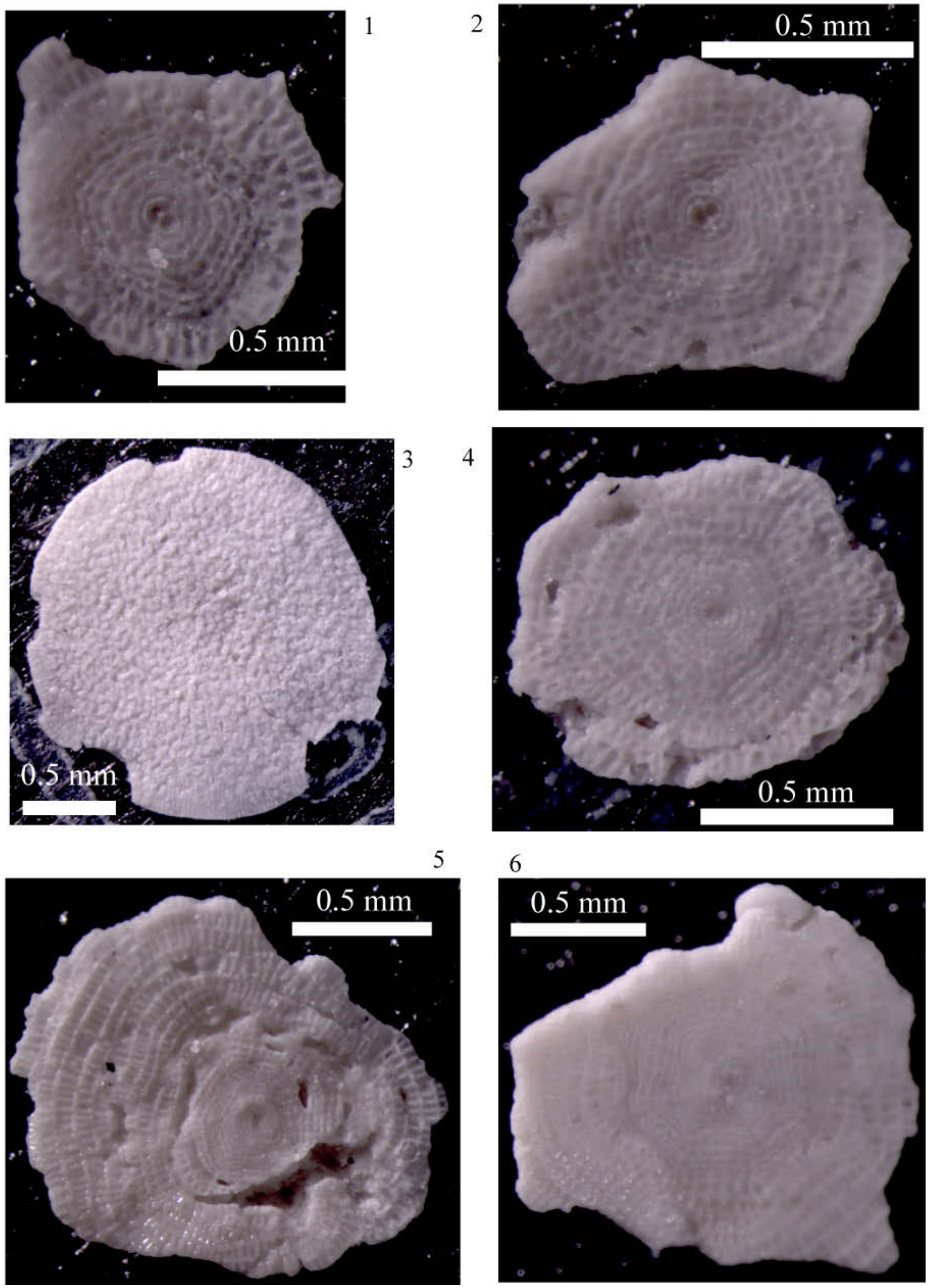


PLATE 25

Pseudophragmina sp. C

The type of section and core depth are listed.

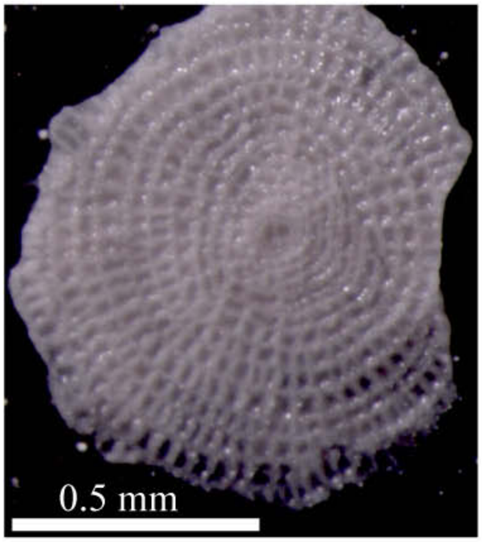
1. *Pseudophragmina* sp. C, equatorial section, 173.4 m

2. *Pseudophragmina* sp. C, equatorial section, 164.6 m

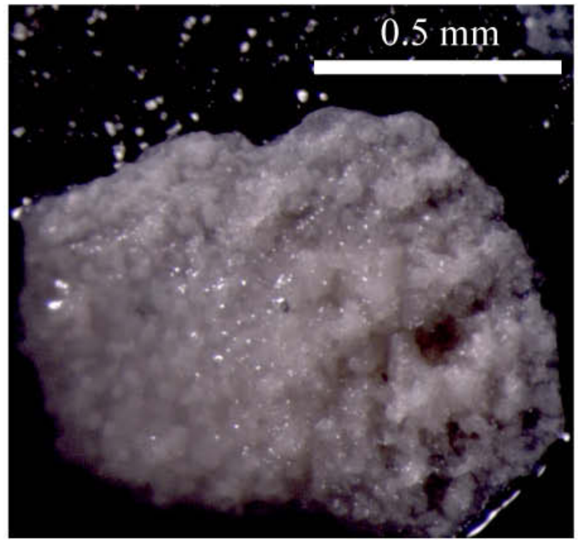
3. *Pseudophragmina* sp. C, equatorial section, 173.4 m

4. *Pseudophragmina* sp. C, equatorial section, 164.6 m

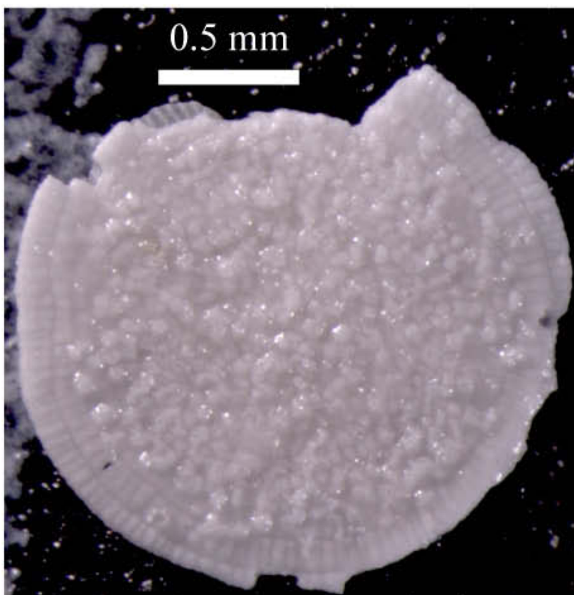
PLATE 25



1

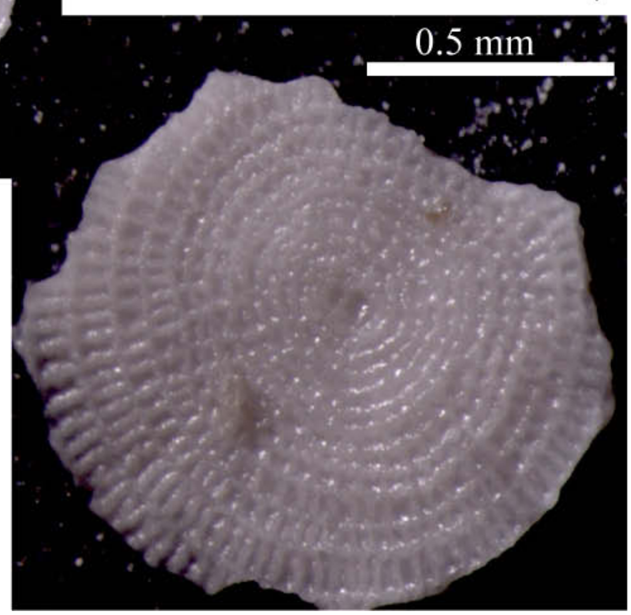


2



3

4



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APPENDICES

Appendix I. Geographic and stratigraphic distribution of taxa for Avon Park Formation

Appendix Ia. *Fallotella cookei* Moberg.	
Florida	Middle Eocene Avon Park Formation, Highlands County; middle-lower Upper Eocene Ocala Limestone and Avon Park Formation, Hendry and Suwannee counties (Bennett, 2001; Moberg, 1928); Middle Eocene Avon Park Formation, Pinecrest, Monroe County, and Lakeland, Polk County (Cole, 1941).
Mexico	Middle Eocene Xbacal and Piste member of Chihen Itza Formation (Butterlin and Moullade, 1968).
Cuba	Lower Eocene-Middle Eocene Vigía Formation, Gibara (Iturralde-Vincent et al., 2008); Middle Eocene Charco Redondo Formation, La Gran Piedra, Santiago de Cuba, and Mayari, Arriba (Quintas and Crespo, 2003); Lower Eocene – Lower Oligocene (planktic foraminiferal zones P7-P18) (Beckmann, 1958).
Jamaica	Upper Middle Eocene Swanswick Limestone (Robinson and Wright, 1993); lower Middle Eocene- Lower Oligocene (planktic foraminiferal zones P7-18), Middle Chapleton Formation through Lower Walderston Limestone (Robinson and Wright, 1993); upper Lower Eocene (planktic foraminiferal zones P9) Richmond Formation (Robinson and Wright, 1993); Upper Eocene- Lower Oligocene Somerset Limestone and

	Walderston Limestone, Walderston, Red Gal Ring and Mocho area (Robinson, 1977; Robinson, 1995; Robinson and Mitchell, 1999); lower Middle Eocene (Upper Claremont Formation and Upper Claremont) to Upper Eocene Somerset Formation, Red Gal Ring (Robinson, 1974); planktic foraminiferal zones P10-P19/calcareous nannoplankton zones NP14b-NP22 (Robinson, 2004).
Haiti	Middle –Upper Eocene (Butterlin and Moullade, 1968)
Dominican Republic	Middle Eocene Upper Neiba Formation, Catanamatías Formation and Rio Yabón Formation, Galván, Banica, Miches and Aurroyo Limón (Serra-Kiel et al., 2007).
Nicaragua	Upper Eocene – Lower Oligocene, 0.70785 $^{87}S/^{86}Sr$ isotopic ratio, respectively (Robinson, 1996); Middle Eocene Touche-1 and Punta Gorda-1 wells (Robinson, 2009).

Appendix Ib. *Fallotella floridana* Cole.	
Florida	Middle Eocene Avon Park Formation, Pinecrest, Monroe County and Lakeland, Polk County (Cole, 1941).
Mexico	Middle Eocene Xbacal and Piste member of Chihen Itza Formation, (Butterlin and Moullade, 1968).
Bahamas	Lower Oligocene P19-P20 planktonic foraminifera zones (Fourcade and Butterlin, 1988)

Cuba	Lower-Middle Eocene Embarcadero Formation, Sierra de Cubitas (Iturralde-Vincent et al., 2008); Lower-Middle Eocene Lesca Formation, north of Camagüey (Iturralde-Vincent et al., 2008).
Jamaica	upper Middle Eocene Swanswick Limestone (Robinson, 1993); lower Middle Eocene- Lower Oligocene (planktic foraminiferal zones P7-18), Middle Chapleton Formation through Lower Walderston Limestone (Robinson and Wright, 1993); upper Lower Eocene (planktic foraminiferal zones P9) Richmond Formation (Robinson, 1993); Upper Middle Eocene Upper Claremont Formation to Upper Eocene Somerset Formation and White Limestone, Red Gal Ring, St. Andrew Parish (Robinson, 1977 Robinson, 1974; planktic foraminiferal zones P15-P19/ calcareous nannoplankton zones NP18-NP23 (Robinson, 2004).
Haiti	Middle –Upper Eocene (Butterlin and Moullade, 1968).
Nicaragua	Middle Eocene Touche-1 well (Robinson, 2009).

Appendix Ic. *Coleiconus christianaensis* Robinson.	
Florida	Middle Eocene Avon Park Formation.
Jamaica	lower Middle Eocene-Upper Eocene (planktic foraminiferal zones P11-P17) Albert Town Member of Chapleton Formation (Robinson, 1993); planktic foraminiferal zones P11-P15/ Calcareous nannoplankton zones

	NP15-NP15 (Robinson, 2004).
Nicaragua	Middle Eocene Punta Gorda-1 well, Nicaragua (oral communication, Robinson, 2009).

Appendix Id. *Pseudochrysalidina floridana* Cole	
Florida	Upper Lower – Middle Eocene Avon Park Formation, Highlands County; Middle Eocene Avon Park Formation, Pinecrest, Monroe County (Cole, 1941).
Mexico	Middle Eocene Xbacal and Piste member of Chihen Itza Formation, (Butterlin and Moullade, 1968).
Jamaica	Middle Eocene Claremont Formation to Upper Eocene Somerset Formation (Robinson, 1974); Lower - Upper Eocene Swanswick Limestone (Robinson and Wright, 1993); Upper Eocene (Priabonian) Somerset Limestone, Walderston area, Mocho area and Red Gal Ring (Robinson, 1995; Robinson and Mitchell, 1999); planktic foraminiferal zones P13-P17/ calcareous nannoplankton zones NP17-21 (Robinson, 2004).Upper Eocene, 0.70785 $^{87}S/^{86}Sr$ isotopic ratio (Robinson, 1996).
Nicaragua	Upper Eocene, 0.70785 $^{87}S/^{86}Sr$ isotopic ratio (Robinson, 1996); Middle Eocene Touche-1 well (Robinson, 2009).

Appendix Ie. *Fabularia vaughani* Cole	
Florida	Eocene Avon Park Formation, south Jackson (Cole and Ponton, 1934); Middle Eocene Avon Park Formation, Hendry County (Bennett, 2001).
Jamaica	lower Middle Eocene-Upper Eocene (planktic foraminiferal zones P10-P16) Chapleton Formation, Swanswick Limestone and Lower Claremont Limestone (Robinson and Wright, 1993); planktic foraminiferal zones P10-P15/ calcareous nannoplankton zones NP14b-P15 (Robinson, 2004); Middle Eocene Gentle Hill, St. Elizabeth-Manchester Parish boundary, Red Gal Ring, Dallas Mountain and Stony Hill, St. Andrew (Robinson, 1977).
Nicaragua	Middle Eocene Touche-1 well, Nicaragua (oral communication, Robinson, 2009).

Appendix II. Geographic and stratigraphic distribution of taxa for the Ocala Limetone

Appendix IIa. *Nummulites floridensis* Heilprin	
Florida U.S.A.	Upper Eocene (Priabonian) Ocala Limestone, Highlands County, Florida.
Louisiana	Upper Eocene Moody’s Branch Formation, Caldwell Parish, Louisiana (Gravell, 1935).

Mexico	Middle Eocene San Juan Formation at La Mesa de Copaya, Tuxtla Gutiérrez-Chiapa de Corzo-Suchiapa area, west-central Chiapas, southeastern Mexico (Ferrusquia-Villafranca, 2000).
Cuba	Middle-Upper Eocene El Capatz Member of Maraguán Formation, Cameguey, Cuba (Graham, 2000); Lower Middle Eocene Loma Candela Formation, Cuba (Bralower, 1997).
Jamaica	Lower Middle - Upper Eocene (P11-P17) Font Hill Formation, Bonny Gate Limestone, Troy/Claremont Limestone, and Swanswick Limestone, Jamaica (Robinson, 1993); Lower Middle Eocene (NP 14b and NP 15), Yellow Limestone Group, central and eastern Jamaica (Robinson, 2004).
Trinidad	Upper Eocene of Trinidad, from dark grey-brown calcareous siltstone (Cole, 1960a).
French Lesser Antilles	Middle Eocene (Lutetian, P11), Gustavia-Baie des Flamands, French Lesser Antilles (Butterlin, 1984).
Costa Rica	Middle Eocene (Lutetian) Parritilla Formation, Costa Rica (Bolz, 2002).
Panama	Upper Eocene (Shallow Benthic Zone 19-20) Gatuncillo Formation, Panama (Tripati, 2002).

Ecuador	Upper Middle Eocene Clay Pebble Beds near Ancon, Ecuador (Stainforth, 1948).
Brazil	Upper Eocene (P17) Amapá Formation, Brazil (Mello e Sousa, 2003).

Appendix IIb. *Nummulites striatoreticulatus* Rutten.	
Florida U.S.A.	Upper Eocene (Priabonian) Ocala Limestone, Highlands County, Florida.
Mexico	Middle Eocene San Juan Formation at La Mesa de Copaya, Tuxtla Gutiérrez-Chiapa de Corzo-Suchiapa area, west-central Chiapas, southeastern Mexico (Ferrusquia-Villafranca, 2000); Middle Eocene, middle Sandstone-Grit Member of San Juan Formation, Tuxtla Gutiérrez, Mexico (Vega, 2001).
Cuba	Lower Middle Eocene Loma Candela Formation, Cuba (Bralower, 1997).
Jamaica	Upper Middle Eocene- Upper Eocene (P13-P17) Swanswick Limestone, Font Hill Limestone and lower part of Bonny Gate Limestone (Gibraltar facies), Jamaica (Robinson, 1993).
Trinidad	Upper Eocene of Trinidad.

French Lesser Antilles	Middle Eocene (Lutetian P12), Plateau de Lurin, French Lesser Antilles (Butterlin, 1984).
Costa Rica	Middle Eocene (Lutetian) Parritilla Formation, Costa Rica (Bolz, 2002).
Panama	Upper Eocene (Priabonian, Shallow Benthic Zones 19-20) Gatuncillo Formation, Panama (Tripati, 2002).

Appendix IIc. *Nummulites willcoxi* Heilprin	
Florida, U.S.A.	Upper Eocene (Priabonian) Ocala Limestone Highlands County, Florida.
Louisiana, U.S.A.	Upper Eocene Moody's Branch Marl, Louisiana (Gravell, 1935).
Mexico	Upper Eocene Chumbec Member of Chichén-itzá Formation, Yucatan, Mexico (Pablo-Galán, 1996); Upper Eocene Caliza Formation, Mexico; Lower Middle Eocene (P15).
Jamaica	Lower Middle-Upper Eocene (P11-P17) Font Hill Limestone, Swanswick Limestone and Bony Limestone, Jamaica (Robinson, 1993).
Dominican	Middle to Upper Eocene, upper Neiba Formation, Dominican Republic

Republic	(Serra-Kiel, 2007).
Costa Rica	Middle Eocene Parritilla Formation, Costa Rica (Bolz, 2002).
Brazil	Lower Middle Eocene (P10-P12) to Upper and terminal Eocene (P13-P14) Amapá Formation, Brazil (Mello e Sousa, 2003).

Appendix IId. *Heterostegina ocalana* Cushman.	
Florida U.S.A.	Upper Eocene (Priabonian) Ocala Limestone, Highlands County and Lafayette County, Florida.
Georgia, U.S.A.	Red Bluff, Georgia (Cole, 1952).
Jamaica	Upper Eocene, St. Mary, Jamaica; Upper Eocene (Planktic foraminiferal zones P15-P17) Swanswick Limestone, Jamaica (Robinson, 1993).
Carriacou	Upper Eocene, Anse la Roche Formation, Carriacou Island of the Grenadines, eastern Caribbean (Robinson, 1972).
Panama	Upper Eocene, San Juan de Pequañi, Haut Chagres, Panama (Vaughan, 1926).

Appendix IIe. *Lepidocyclina chaperi* Lemoine and Douvillé

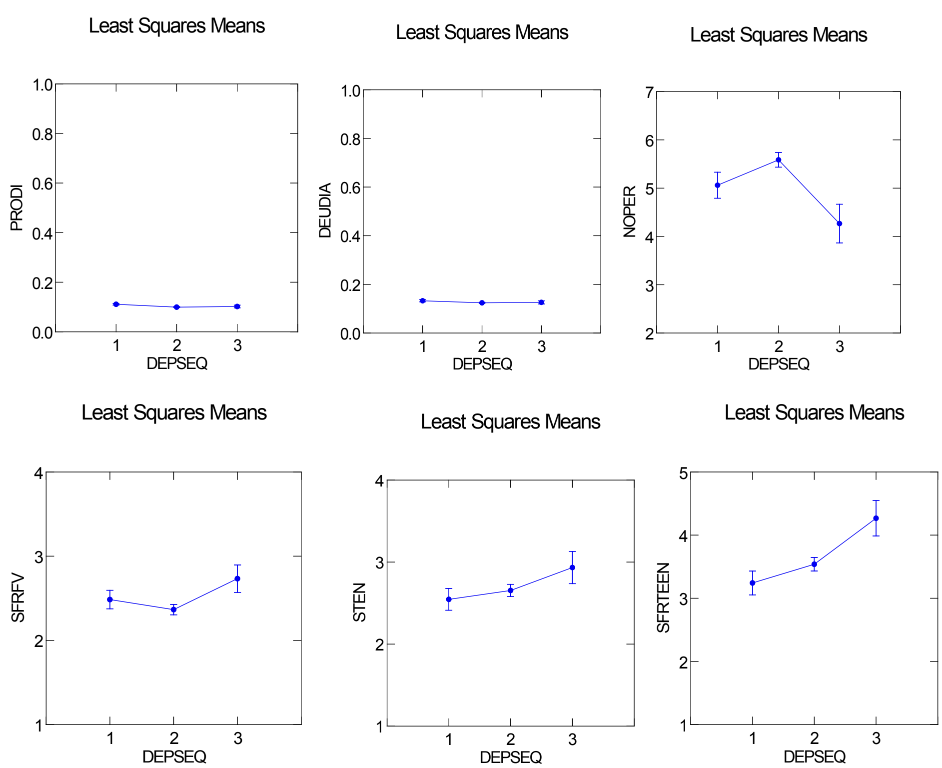
Florida U.S.A.	Upper Eocene (Priabonian) of Highlands County, Lafayette County Florida, Ocala Limestone.
Jamaica	Upper Eocene (P15-P17) Swanswick Limestone, Bonny Gate Limestone, White Limestone Group, Jamaica (Robinson, 1993); lower Middle - Upper Eocene Somerset Formation (White Limestone), Red Gal Ring, St. Andrew Parish, Jamaica (Robinson, 1977).
Dominican Republic	Upper Eocene Cantanamatías Formation breccias, Dominican Republic (Serra-Kiel, 2007).
Trinidad	Upper Eocene of Trinidad from dark grey-brown calcareous siltstone (Cole, 1960a).
Carriacou	Upper Eocene, Anse la Roche Formation, Carriacou Island of the Grenadines, eastern Caribbean (Robinson, 1972).
Panama	San Juan Pequañi, Haut Chagres, Panama; Upper Eocene (Shallow Benthic Zones 19-20) Gatuncillo Formation, Panama (Tripati, 2002).
Brazil	Upper Eocene (P15-P17) Amapá Formation, Brazil (Mello e Sousa, 2003).

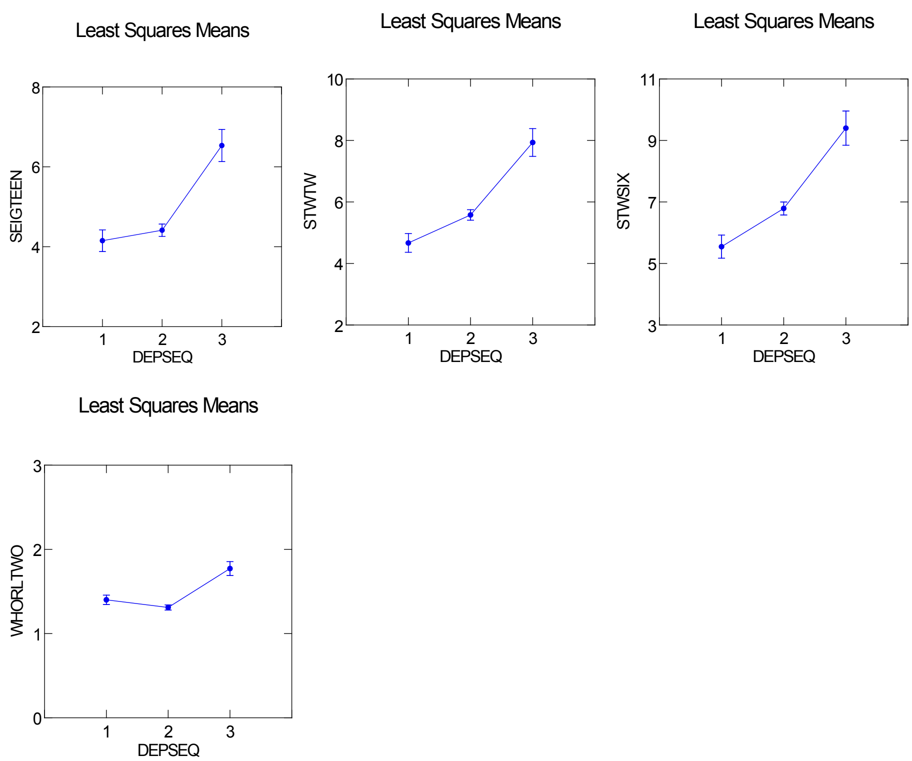
Appendix IIf. *Lepidocyclina pustolosa.* Douvillé	
Florida	Upper Eocene (Priabonian) Ocala Limestone of Highlands County,

U.S.A.	Florida.
Mexico	Upper Eocene of the Isthmus of Tehuantepec and Rio Vinazco, Chicontepec, state of Veracruz, Mexico; Upper Eocene Chumbec Member of Chichén-itzá Formation, Yucatan, Mexico (Pablo-Galán, 1996).
Jamaica	Upper Middle Eocene - Upper Eocene (P12-P17) Swanswick Limestone, Jamaica (Robinson, 1993).
Carriacou	Upper Eocene Anse la Roche Formation, Carriacou Island of the Grenadines, eastern Caribbean (Robinson, 1972).
Margarita Island	Upper Eocene of Cuba (Eames, 1962); Upper Middle Eocene Punta Mosquito Formation, Isle of Margarita, Venezuela (Muñóz, 1971); Middle and Upper Eocene, Margarita Island (Caudri, 1975; Kugler, 1975).
Trinidad	Upper Eocene, Soldado Rock and San Fernando, Trinidad (Caudri, 1975; Kugler, 1975); Upper Eocene Soldado Formation, Soldado Rock and Vistabella, San Fernando, Trinidad (Adams, 1987); Upper Eocene of Trinidad, from dark grey-brown calcareous siltstone (Cole, 1960a).
Nicaragua	Parritilla Formation (Middle Eocene, Lutetian) and Caraigres Formation (Middle Eocene, Bartonian), Costa Rica (Bolz, 2002) and Nicaragua.

Costa Rica	Parritilla Formation (Middle Eocene, Lutetian) and Caraigres Formation (Middle Eocene, Bartonian), Costa Rica (Bolz, 2002) and Nicaragua.
Panama	Upper Eocene (Shallow Benthic Zones 19-20) Gatuncillo Formation, Panama (Tripati, 2002).
Colombia	Upper Eocene limestones of the Carmen-Zambrano area, Colombia (Petters, 1956).
Brazil	Lower Middle Eocene (P10-P12) to Upper Middle Eocene (P13-P14) Amapá Formation, Brazil (Mello e Sousa, 2003).

APPENDIX III ANOVA graphs of means and variance for measurements of *Heterostegina ocalana*, and tables.





Heterostegina ocalana ANOVA tables and post-hoc Bonferroni tests of significance DEPSEQ (3 levels) = three depositional sequences of Ward et al. (2003).

Proloculus diameter (PRODI), N: 152, Multiple R: 0.220, Squared multiple R: 0.048

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	0.003	2	0.002	3.796	0.025
Error	0.066	149	0.000		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	0.020	1.000	
3	0.513	1.000	1.000

Deuteroloculus diameter (DEUDIA), N: 152, Multiple R: 0.138, Squared multiple R: 0.019

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	0.002	2	0.001	1.448	0.238
Error	0.093	149	0.001		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	0.273	1.000	
3	1.000	1.000	1.000

Number of operculine chambers (NOPER), N: 152, Multiple R: 0.261, Squared multiple R: 0.068.

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	26.177	2	13.089	5.447	0.005
Error	358.033	149	2.403		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities.

	1	2	3
1	1.000		
2	0.275	1.000	
3	0.306	0.007	1.000

The number of chambers in the fourth and fifth chambers (SFRFV), N: 152, Multiple R: 0.177, Squared multiple R: 0.031.

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	1.913	2	0.956	2.403	0.094
Error	59.291	149	0.398		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities.

	1	2	3
1	1.000		
2	1.000	1.000	
3	0.624	0.109	1.000

The number of chambers in the tenth chamber (STEN), N: 152, Multiple R: 0.133, Squared multiple R: 0.018.

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	1.557	2	0.778	1.339	0.265
Error	86.654	149	0.582		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities.

	1	2	3
1	1.000		
2	1.000	1.000	
3	0.314	0.560	1.000

The number of chambers in the fourteenth chamber (SFRTEEN), N: 152, Multiple R: 0.242, Squared multiple R: 0.058.

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	10.838	2	5.419	4.618	0.011
Error	174.840	149	1.173		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities.

	1	2	3
1	1.000		
2	0.520	1.000	
3	0.008	0.048	1.000

The number of chambers in the eighteenth chamber (SEIGTEEN), N: 152, Multiple R: 0.393, Squared multiple R: 0.154.

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	66.145	2	33.073	13.568	0.000
Error	363.197	149	2.438		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities.

	1	2	3
1	1.000		
2	0.275	1.000	
3	0.000	0.000	1.000

The number of chambers in the twenty second chamber (STWTW), N: 152, Multiple R: 0.443, Squared multiple R: 0.196.

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	110.447	2	55.224	18.218	0.000
Error	451.651	149	3.031		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities.

	1	2	3
1	1.000		
2	0.029	1.000	
3	0.000	0.000	1.000

The number of chambers in the twenty sixth (STSIX), N: 152, Multiple R: 0.426, Squared multiple R: 0.182.

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	153.267	2	76.633	16.521	0.000
Error	691.128	149	4.638		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities.

	1	2	3
1	1.000		
2	0.013	1.000	
3	0.000	0.000	1.000

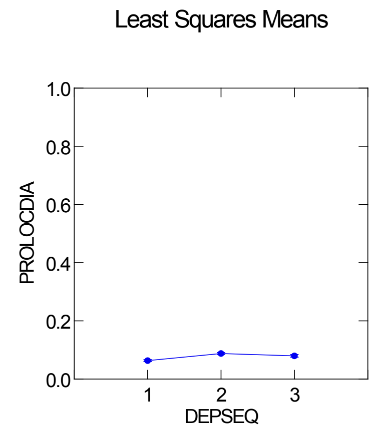
Diameter of the second whorl (WHORLTWO), N: 152, Multiple R: 0.399, Squared multiple R: 0.159.

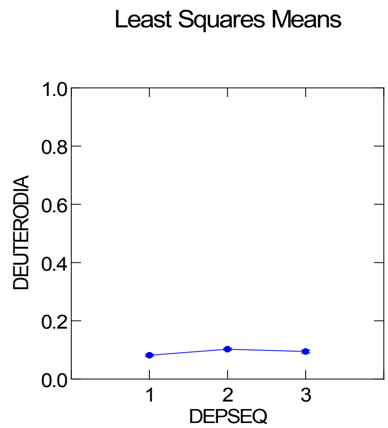
Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	2.824	2	1.412	14.087	0.000
Error	14.933	149	0.100		

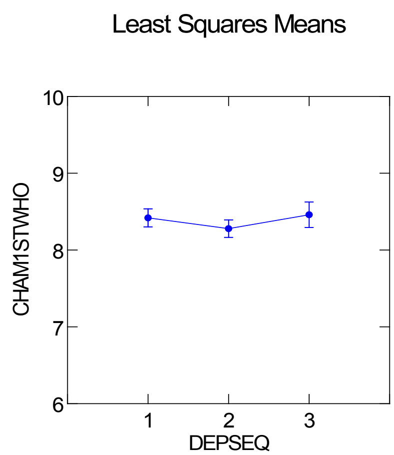
Bonferroni Adjustment: Matrix of pairwise comparison probabilities.

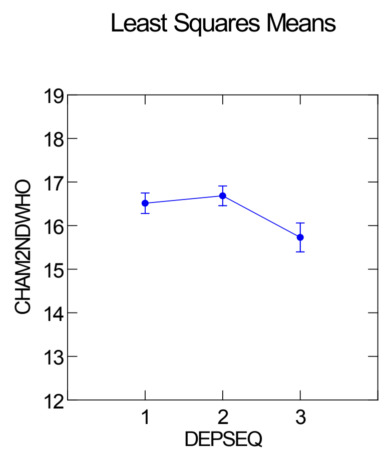
	1	2	3
1	1.000		
2	0.463	1.000	
3	0.001	0.000	1.000

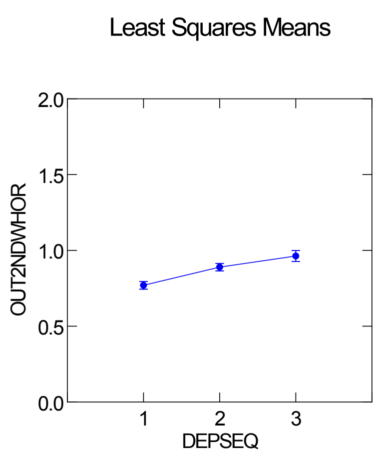
APPENDIX IV ANOVA graphs of means and variance for measurements of *Nummulites,* and tables

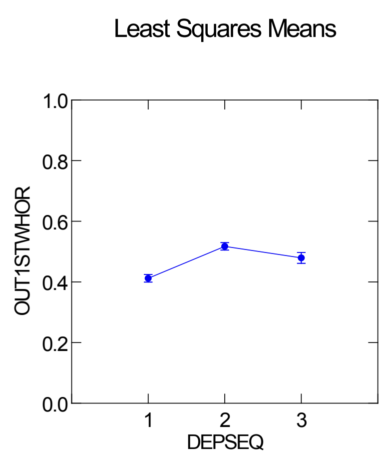












Protoconch diameter (PROLODIA), N: 190, Multiple R: 0.381, Squared multiple R: 0.145

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	0.023	2	0.012	15.868	0.000
Error	0.137	187	0.001		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	0.000	1.000	
3	0.009	0.397	1.000

Deuteroconch diameter (DEUTERODIA), N: 190, Multiple R: 0.296, Squared multiple R: 0.088

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	0.017	2	0.008	9.009	0.000
Error	0.172	187	0.001		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	0.000	1.000	
3	0.107	0.592	1.000

Number of chambers in 1^{st} whorl (CHAM1STWHO), N: 190, Multiple R: 0.077, Squared multiple R: 0.006

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	1.134	2	0.567	0.555	0.575
Error	191.076	187	1.022		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	1.000	1.000	
3	1.000	1.000	1.000

Number of chambers in second whorl (CHAM2STWHO), N: 190, Multiple R: 0.174, Squared multiple R: 0.030

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	23.738	2	11.869	2.917	0.057
Error	760.872	187	4.069		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	1.000	1.000	
3	0.165	0.056	1.000

Diameter of 1st whorl (OUT1STWHOR), N: 190, Multiple R: 0.401, Squared multiple R: 0.161

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	0.423	2	0.214	17.900	0.000
Error	2.238	187	0.012		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	1.000	1.000	
3	0.008	0.251	1.000

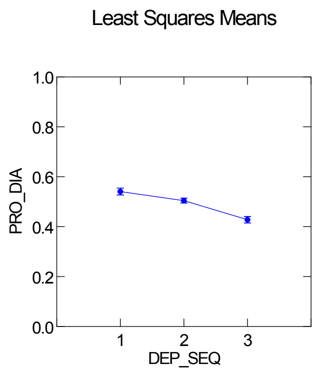
Diameter of 2nd whorl (OUT2STWHOR), N: 190, Multiple R: 0.324, Squared multiple R: 0.105

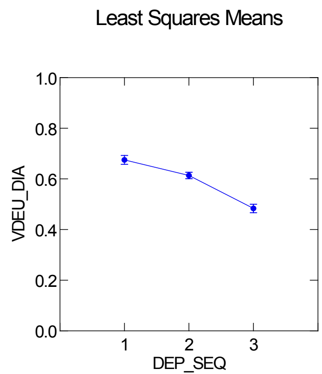
Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	1.062	2	0.531	10.997	0.000
Error	9.028	187	0.048		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	1.000	1.000	
3	0.000	0.288	1.000

APPENDIX V ANOVA graphs of means and variance for measurements of *Lepidocyclina*, and tables





Protoconch diameter (PRO_DIA), N: 250, Multiple R: 0.371, Squared multiple R: 0.137

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	0.449	2	0.224	19.6664	0.000
Error	2.818	247	0.011		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	0.093	1.000	
3	0.000	0.000	1.000

Deuteroconch diameter (VDEU_DIA), N: 250, Multiple R: 0.462, Squared multiple R: 0.213

Source	Sum of Squares	df	Mean-Square	F-ratio	P
DEPSEQ	1.295	2	0.647	33.514	0.000
Error	4.771	247	0.019		

Bonferroni Adjustment: Matrix of pairwise comparison probabilities

	1	2	3
1	1.000		
2	0.015	0.000	
3	0.000	0.000	1.000

VITA

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