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FORAMINIFERA: THEIR DISTRIBUTION AND UTILITY IN THE INTERPRETATION OF CARBONATE SEDIMENTARY PROCESSES AROUND GRAND CAYMAN, BRITISH WEST INDIES

by

Chun Li

A thesis submitted to the Faculty of Graduate and Research in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY

DEPARTMENT OF EARTH AND ATMOSPHERIC SCIENCES

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October 17th, 1996

To my family and friends

ABSTRACT

An abundant, diverse foraminiferal biota including 136 species belonging to 50 genera is found in the sediment of ponds, lagoons, and open shelves around Grand Cayman. The foraminiferal tests form up to 30% of the sand in these settings. The 12 foraminiferal assemblages, based on 236,000 specimens, can be correlated to distinct environments that are defined by various ecologic (substrate, salinity, turbidity, temperature) and taphonomic parameters (abrasion, bioturbation, dissolution, transportation).

Species from known and aerally restricted ecological habitats can be used to trace sediment movement during storms. On the windward shelves, lagoonal and forereef tracer species are commonly winnowed after severe storms and hurricanes because of onshore and offshore sediment transportation. At the height of the storm, suspended sediment on the forereef is carried over the reef and deposited into the lagoon. When the storm wanes, back flow of piled-up water flushes suspended lagoonal and nearshore sediments out of the lagoon and deposits them on the forereef or down the shelf slope via channels.

The composition and origin of sediment on the shelves around Grand Cayman are partly controlled by the characters of foraminiferal assemblages and their distribution. On the windward east coast shelf, there is a diverse array of foraminiferal assemblages that are spread through the broad array of physiographic zones. The presence of shallow offshore reefs impedes sediment exchange, and hence, the mixing of foraminiferal tests between forereef and backreef will not happen unless severe storms and hurricanes take place. On the leeward shelf where shallow offshore reefs are absent, winter 'Nor-wester' storms move sediment across the entire shelf. As a result, foraminiferal assemblages on this shelf are mixed and less well defined. In lagoons, the character of the sediments reflects fair-weather lagoonal production, bioturbation, and the overprint of sediment import-export that takes place during tropical storms and hurricanes.

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CHAPTER 1 INTRODUCTION

INTRODUCTION

Foraminiferal studies play one of the most important roles in petroleum related economic geology and modern environmental issues. The need for more petroleum during the First World War led to renewed and extensive research on foraminiferal micropaleontology and biostratigraphy (Owen, 1975; Martin and Liddell, 1991). After the Second World War, the literature on tropical carbonate sedimentary petrology expanded rapidly because much of the world's petroleum has been found in ancient reefs and associated strata. Studies on foraminiferal ecology and distribution were renewed at the same time with emphasis on various aspects of carbonate sedimentology including sediment components, sediment transportation, carbonate production, facies analysis, and paleoenvironment reconstruction (e.g. Bandy, 1964; MacKenzie *et al.*, 1965; Muller, 1974; Poag, 1981; Reiss and Hottinger, 1984; Hallock and Glenn, 1986; Montaggioni *et al.*, 1986; Martin and Liddell, 1988). Recently, foraminiferal research has made substantial contributions to environmental assessment, environmental change, biodiversity, coastal processes, and global climate change (Hallock, 1995).

Foraminifera are found in virtually every environmental setting around isolated tropical oceanic islands that are surrounded by carbonate depositional regimes. In numbers, they are the most abundant organism found in the reef environments and one of the most important carbonate sediment producers in reefs. Their diversity may exceed 60 or 70 species in a sample of 300 individuals. Due to their small size, abundance, variety of test compositions, microstructures and morphologies, they can be recognized and identified to generic level in small sediment samples and thin sections. While living, specific species require specific ecologic conditions of salinity, temperature, and substrate. Before and after death, their tests are subjected to a variety of taphonomic pressures including abrasion, transportation, bioerosion and dissolution (Martin and Liddell, 1991). It is the combination of ecologic and taphonomic factors that ultimately controls the distribution of foraminiferal tests in the carbonate sediments that are found on and around these oceanic islands. Therefore, foraminiferal assemblages can provide valuable insights into past ecological and taphonomic conditions. For example, it should be possible to use foraminifera to trace carbonate sediment movement and to study the evolution of reefal environments caused by physical and biological processes under storm and fair-weather conditions.

Grand Cayman encompasses a diverse array of physiographic units that range from various types of ponds, to shore lines, to lagoons, to shelves, and to well-developed reef complexes that include unique habitats for various foraminifera. Sediments around Grand Cayman are formed entirely of carbonate because there is no river discharge or volcanic activity on the island. Its small size and narrow shelves mean that most of these environments are easily accessible. This tiny, isolated island is ideal for the study of natural and human impacts on a system that is ecologically and geologically fragile. Studies on foraminifera on Grand Cayman, however, are virtually non-existent. The only previous published work was by Hofker (1976) who identified 47 species from 9 randomly collected sand samples from several localities around the island. Furthermore, there have been no ecological and taphonomical studies on foraminifera distributions on Grand Cayman and foraminifera have rarely been used in carbonate studies. This thesis is an assessment of foraminiferal distribution in various environments around Grand Cayman and demonstrates that ecologically diagnostic foraminifera can be used as sediment tracers.

THESIS OBJECTIVES AND RATIONALES

Objective 1: Establishment of foraminiferal database for Grand Cayman

Goals

(a) To identify foraminiferal species extracted from fresh, surface sediment, and subsurface sediment samples collected from various environments around Grand Cayman,

(b) to describe any new species, and

(c) to create a database of foraminiferal distribution in different localities around Grand Cayman.

Rationale

The history of studying reef-related foraminifera can be traced back to Fichtel and Moll (1798), who described *Archaias angulatus*, which is the most common species in the Caribbean and Florida region at present. Subsequent detailed taxonomic works described numerous modern foraminifera that are found around reefs. The most important works include d'Orbigny (1826, 1839), Brady (1884), Cushman (1918, 1921, 1922a, b, 1923, 1924, 1929, 1930, 1931), Bermúdez (1935), and Hofker (1964, 1976). These classic works established the most common and well-known modern foraminiferal species in reefs throughout the Caribbean-Florida region and formed the basis of foraminiferal distributional studies.

Foraminifera distributional studies in the Caribbean-Florida region have concentrated on the total foraminiferal assemblages (living and dead) or the living foraminiferal assemblages. Studies of total foraminiferal assemblages can be traced back to Brady

(1884). Most subsequent works were summarized by Phleger (1960), Boltovskoy (1965), and Culver and Buzas (1980, 1981, 1982). Studies of living foraminiferal assemblages in the Caribbean-Florida region were pioneered by Cushman (1922b), who documented his observations on living foraminifera of the Dry Tortugas off Key West Florida. Since 1952, when the rose Bengal stain method was first used by Walton (1952), numerous studies on living foraminiferal assemblages have been published; these were summarized by Murray (1973, 1991), Boltovskoy and Wright (1976), and Poag (1981). The rose Bengal method, however, caused over-estimations of living populations because it also stained symbiotic algae. As a result, other methods have been suggested including Sudan Black B (Walker *et al.*, 1974), adenosine-5'-triphosphate (ATP) assay (DeLaca, 1986; Bernhard, 1988), and direct observation of the protoplasm (Martin and Steinker, 1973). Most studies on living assemblages, however, still use the rose Bengal method (Cebulski, 1969; Sen Gupta and Schafer, 1973; Brasier, 1975; Radford, 1976; Hallock *et al.*, 1986; Poag and Tresslar, 1981).

Compared to other areas in the Caribbean-Florida region, foraminifera on Grand Cayman have been overlooked apart from the work by Hofker (1976). Therefore, the first objective of the thesis is to accomplish a general taxonomic survey of foraminifera around the island and to create a database of living and total foraminiferal distributions based on rose Bengal stain method and sieve counting methods. This database is unique because it: 1) includes 235,960 specimens; 2) covers all types of environments on the island from deep forereef to seasonally dried ponds; 3) provides statistically reliable information (over 800 counts in each sample); and 4) includes 4–5 size splits in each sample that provide information on size distributions of foraminifera species and sediments. This database forms the basis of further studies in the rest of the thesis.

This objective is covered in chapter 2 and a synonymy is presented in Appendix A.

Objective 2: Foraminiferal distribution and comparison on the windward and leeward shelves of Grand Cayman — a taphonomical approach

Goals

(a) To delineate foraminiferal assemblages on the windward and leeward shelves using cluster analysis,

(b) to examine the diversity of foraminifera in each sample,

(c) to estimate the percentages of foraminiferal tests in the 0.25–2.00 mm size fractions of sediment samples, and

(d) to examine ecological and taphonomical factors that control foraminiferal diversity, foraminifera percentage in carbonate, and to compare the windward and leeward shelves.

Rationale

Over the last 20 years the value of reef foraminifera to paleoenvironmental interpretations of tropical carbonate sediments on windward barrier and fringing reef settings has been clearly demonstrated (Frost and Langenheim, 1974; Chaproniere, 1975; Reiss and Hottinger, 1984; Hallock and Glenn, 1985, 1986; Martin and Liddell, 1988, 1989, 1991). Conversely, studies based on leeward settings and the comparison between the windward and leeward shelves are rare. Grand Cayman is ideal for such a study because it is a small isolated island with well-defined windward and leeward shelves. Supported by systematic collections, a large database, faunal diversity indices, and cluster analysis, assemblage delineation and faunal diversity trends allow accurate and objective comparison of the windward and leeward shelves.

In carbonate component studies, foraminifera are third in importance in modern coral reefs, after corals and calcareous algae (Wells, 1957; Jell *et al.*, 1965; Muller, 1976; Sournia, 1976; Hallock, 1981; Hallock *et al.*, 1986). This part of the thesis will further demonstrate the contribution of foraminifera to carbonate sand and discuss the ecological and taphonomical factors that control the distribution and preservation of foraminiferal tests in carbonate sediments.

Taphonomical modification of carbonate sediment, including foraminiferal tests, is one of the most prominent activities in reef environments. In the last ten years, taphonomic experiments have been conducted in order to increase our understanding of the resistance of reefal foraminiferal tests to abrasion, transportation, dissolution, and bioerosion (Peebles and Lewis, 1988, 1991; Cottery and Hallock, 1988; Wetmore, 1988; Martin and Liddell, 1991; Kotler *et al.*, 1992). Detailed field observations to test those experimental results, however, have not been done, especially in comparison of the windward and leeward settings. Therefore, this part of the thesis will also examine the response of foraminiferal tests to variable taphonomic pressures on the windward and leeward shelves of Grand Cayman.

This objective is covered in chapter 3.

Objective 3: Storm sedimentary processes recognized by foraminiferal sediment tracers, windward coast of Grand Cayman

Goals

(a) To examine living and total foraminiferal assemblages with the view of finding ecologically diagnostic species that can be used as sediment tracers,

(b) to examine grain size distributions of tracer foraminiferal species and their variation along selected traverses, and

(c) to develop a model that explains the sedimentary processes on the windward shelf (onshore/offshore sediment movement) during tropical cyclones.

Rationale

In carbonate sedimentary studies, sediment tracers are critical because they can be used to interpret past sedimentary events. Sedimentary structures that are made by storms can be easily destroyed afterwards by physical and biological agents (High, 1969; Bonem and Stanley, 1977; Bonem, 1985; Riddle, 1988; Kobluk and Lysenko, 1992; Scoffin, 1993). Several types of skeletal grains such as the green alga *Halimeda*, corals and foraminifera have been used as indicators of sediment movement. There is, however, no absolute depth zonation of *Halimeda* species in the Caribbean (Hillis-Coinvaux, 1980, 1986) and they can, therefore, only give gross transportation direction between shallow- and deep-water such as down slope movement (Meaney, 1973; Johns and Moore, 1988). Due to the strong dependence on salinity, light and turbidity, hermatypic corals are only common in shallow normal-marine environments and rare in restricted lagoons and shelf slope. Furthermore, when broken, it is virtually impossible to identify coral fragments to species or genera. Due to their unstable chemical characters, the aragonitic skeletons of *Halimeda* and corals are prone to dissolution and replacement by more stable minerals after burial; thus, there is even less chance to recognize them in ancient sequences. Foraminifera tests are ideal sediment tracers and they have been proved superior to other particles (Emiliani, 1951; MacKenzie *et al.*, 1965; Meaney, 1973; Boss and Liddell, 1987). They are abundant in most carbonate environments and many species live in areally restricted habitats. The small size range, complicated morphologies, and more stable mineralogical characters (low- and high-Mg calcite) mean that they can be found and identified in even the smallest sediment samples or thin sections.

Onshore sediment movement by storms and hurricanes in reef environments has been documented by many studies (Ball *et al.*, 1967; Hernandez-Avila *et al.*, 1977; Graus *et al.*, 1984; Macintyre *et al.*, 1987; Jones and Hunter, 1992; Scoffin, 1993; Harmelin-Vivien, 1994). Conversely, offshore transportation by storms has rarely been considered (Hubbard, 1986, 1992). Without knowledge of the full-cycle of onshore-offshore sediment movement during storms, it is impossible to estimate the sediment budget and evaluate the evolution of lagoons. Therefore, using the East Coast of Grand Cayman as an example, this part of the thesis will demonstrate that ecologically diagnostic foraminiferal species can be used for tracing sediment movement. As such, sedimentary processes can be interpreted based on foraminiferal species distribution and size distribution of certain foraminiferal species.

This objective is covered in chapter 4.

Objective 4: Sediment origin and evolution in Frank Sound, Grand Cayman

Goals

(a) To determine the origin of sediment in Frank Sound, Grand Cayman based on foraminiferal assemblages in surface and subsurface samples,

(b) to examine the biological processes that control sediment component and fabric in the lagoon, and

(c) to determine the factors that control the sediment budget of the lagoon.

Rationale

The origin of carbonate sediment in lagoons has been examined from many different perspectives. Many studies, however, have shown that lagoonal sediments are skeletal debris derived from peripheral fringing- or barrier-reef or from neighboring lagoonal patch reefs (Emery *et al*., 1954; Guilcher, 1965; Swinchatt, 1965; Lewis, 1969; Basan, 1973; Milliman, 1973; Mallik, 1976; Scoffin *et al*., 1980). The possibility that a large portion of lagoonal sediments are in fact allochems that were transported from the forereef areas by storms and hurricanes has been overlooked. Furthermore, the idea that lagoonal sediments are periodically exported by storms and hurricanes and that those activities may be far more effective than the processes which export lagoonal fines during fair-weather conditions has been largely ignored.

Bioturbation is so active in lagoons that it effectively homogenizes sediments and complicates any study concerned with sediment origin. In Frank Sound, Grand Cayman, for example, grain size analysis based on surface samples showed a decreasing trend of sediment grain size shoreward from the reef crest. This has been used as the key evidence to demonstrate the onshore movement of imported sediments into the lagoon by storms and hurricanes (Kalbfleisch, 1995; Blanchon *et al*., in press). Due to intense bioturbation, however, grain size analysis of the subsurface sediment in Frank Sound has shown little variation (Kabfleisch, 1995). Consequently, it is difficult to determine the lithofacies and the origin of sediments that are buried below the lagoon sediment surface.

Using foraminifera as a tracer of sediment movement is an effective and reliable method for determining the origin of the surface and subsurface sediments. A 3-dimensional pattern of sediment facies in the lagoon can be based on the lateral and vertical distributions of various foraminiferal assemblages.

This objective is covered in chapter 5.

Objective 5: Foraminifera ecology in the restricted lagoons and ponds of Grand Cayman

Goals

(a) To examine living and total foraminiferal assemblages in environments under stressed conditions (restricted brackish lagoons and ponds),

(b) to determine the relationship of ecological factors (substrate, salinity, temperature, and turbidity) that control the distribution of various foraminifera species in these settings, and

(c) to determine the impact of human and natural activities on these environments.

Rationale

Environments with stressed ecological conditions are ideal for studying faunal distribution in response to harsh environmental pressures. These environments have never been surveyed on Grand Cayman.

The impact of human activities on reef environments around Grand Cayman is inevitable as the fast growing tourism industry on the island results in filling of low-lying land and sediment dredging. The natural impact of storms and hurricanes can also affect organisms and sediments in such areas by sediment transportation and heavy rainfall. It is necessary, therefore, to monitor the impact of these events and the response of biota to those processes. Past studies have shown that benthic foraminifera are specific to certain substrates such as *Thalassia*, fibrous green alga, and sediments (Bock, 1971; Brasier, 1975; Wantland, 1975; Steinker and Steinker, 1976; Poag, 1981; Hallock *et al.*, 1986; Hallock and Peebles, 1993; Martin, 1986; Martin and Wright, 1988). These results, therefore, can be applied to monitoring substrate modification based on foraminiferal assemblage distributions. This part of the thesis studies demonstrates how foraminiferal assemblages can uniquely serve to solve environmental problems.

This objective is covered in chapter 6.

Objective 6: Summary and Conclusions

Goals

To summarize ecologic and taphonomic information related to foraminiferal distributions and to develop an integrated foraminiferal distribution model for an isolated tropical oceanic island that is surrounded by carbonate sediments. This objective is covered in chapter 7.

SETTING

Grand Cayman, located southwest of Cuba and northwest of Jamaica, is the largest of three Cayman islands that are high points on the Cayman Ridge (Figs. 1.1, 1.2). It is a flat, low-lying tropical island that is 35 km long (east-west) and 6–14 km wide (Fig. 1.3). Most of the island is less than 3 m above sea-level. Fringing reefs are developed along windward shelves on the south, east and north coasts of Grand Cayman. Seaward from the fringing reefs, 1–2 km wide shelves are divided into the upper (0–10 m) and lower (12–40 m) terraces by a mid-shelf scarp (Blanchon and Jones, 1995)(Fig. 1.5). The edge of the shelf is bounded by an escarpment that typically begins at 55–80 m and extends vertically into waters 115–145 m deep (Messing and Platt, 1987). From there, the island slope extends into Yucatan Basin to the north, and Cayman trench to the south (Fig. 1.2).

Peripheral lagoons are developed on the windward shelves and bordered by fringing reefs (Fig. 1.3). North Sound, the largest lagoon on the island (12 by 8 km), is a broad saucer-shaped depression that has low-lying land on its west, south, and east coasts and a reef along its northern margin. Two relatively isolated water bodies, Little Sound and Duck Pond Bight (Fig. 1.3), located on the eastern margin of North Sound, are rimmed by dense mangroves. Other large lagoons on the windward coasts are East Sound, Frank Sound, and South Sound. On the western coast, isolated patch reefs and coral knobs do not impede onshore water movement and marine grasses are rare on the shelf (Figs. 1.3, 1.4). Ponds, which are located along the coastal parts of the island, are isolated from the open ocean by beach ridges (Fig. 1.3). They are shallow (<2 m), floored by mud, rimmed by mangrove, and commonly dry-up completely during the dry season.

Based on sediment grain size and *Thalassia* distribution, the lagoons are divided into (Fig. 1.5): 1) the Organic-rich Mud Zone, at the mangrove rimmed edges of lagoons, 2) the Bare Rock Zone at the nearshore, 3) the *Thalassia* and Sand Zone, in the inner part of lagoons, 4) the Bare Sand Zone, in the outer parts of lagoons, and 5) the Rubble and Knob Zone, at the landward side of fringing reefs.

Water temperature is 26–32°C throughout the year (Department of the Environment Protection and Conservation Unit, Grand Cayman, 1996). Along the mangrove rimmed borders of the lagoons and ponds, however, the water temperatures are extremely variable because of solar insolation (Fig. 1.6A). Rainfall varies between seasons and from year to year. Areas of high rainfall are found toward the west of the central mangrove swamps and in the George Town area (Burton, 1994)(Fig. 1.7A). Normal salinities (35–38 ‰) are

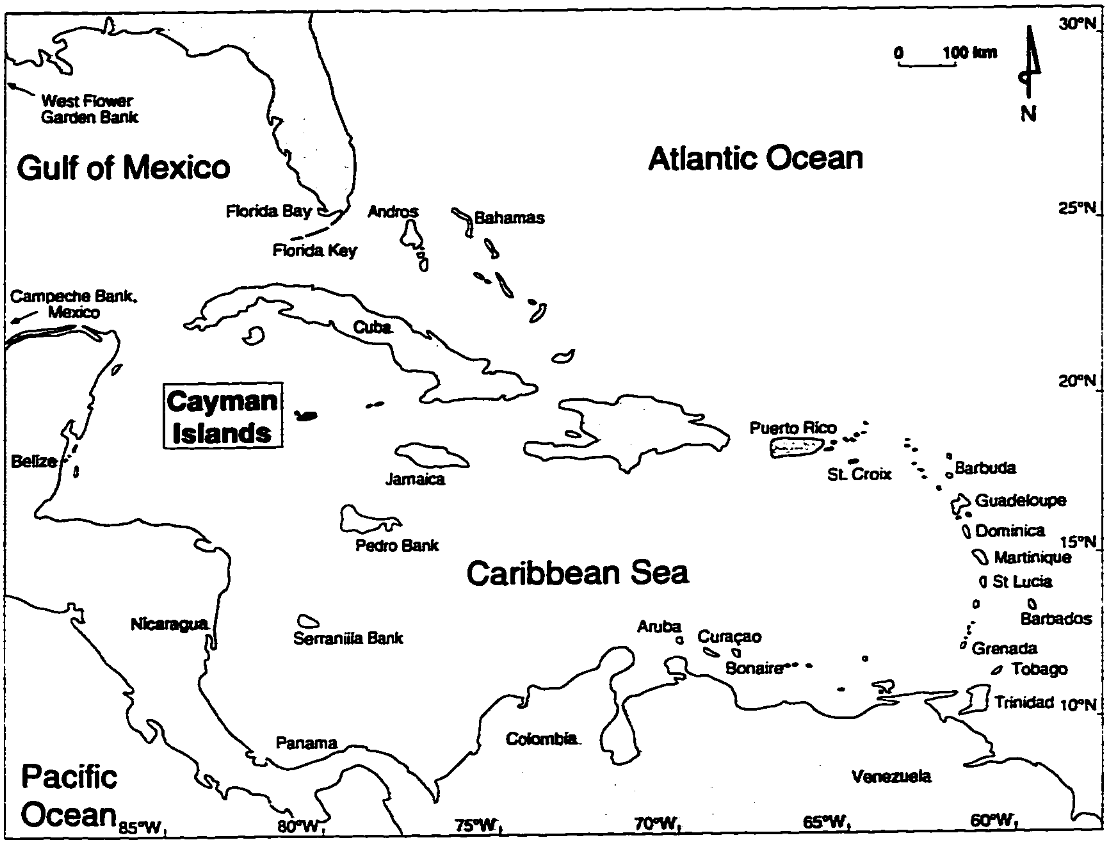

Figure 1.1—Map showing location of Grand Cayman.

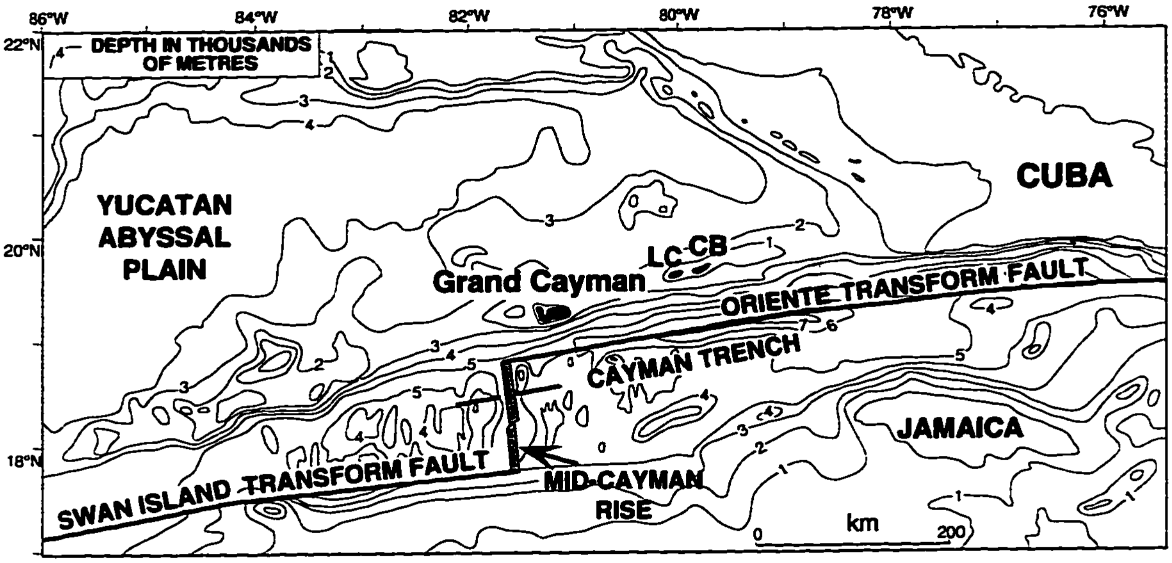

Figure 1.2—Tectonic setting of Grand Cayman (Based on information by Perfit and Heezen, 1978, and MacDonald and Holocomb, 1978). Modified after Pleydell *et al.* (1990).

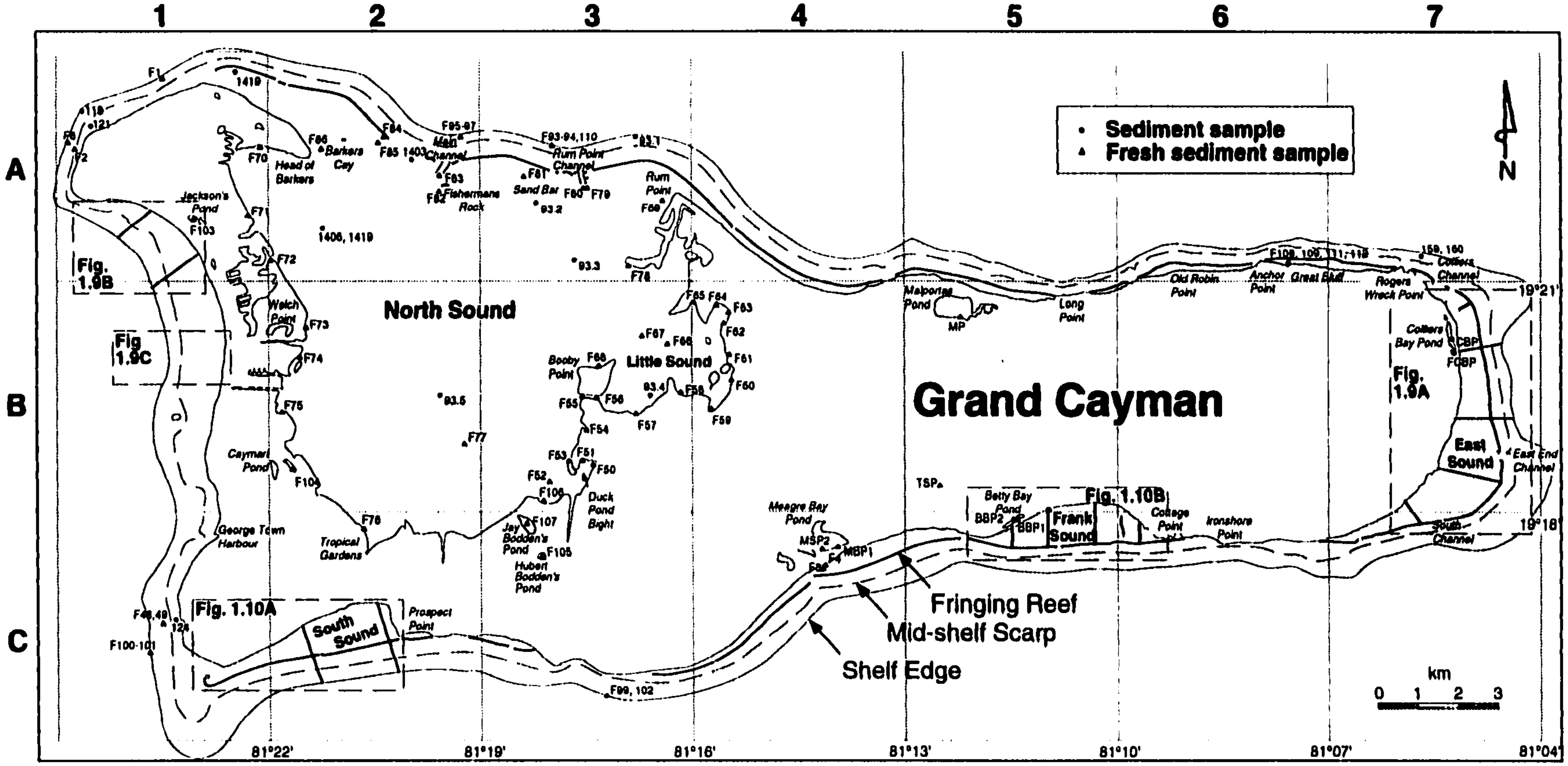

Figure 1.3—Map showing locations of lagoons, ponds, sample and traverse locations on Grand Cayman. (Capital letters and Arabic numbers outside the map are index for Appendix B.)

found in the north and central parts of North Sound and most parts of South Sound (Moore, 1973; Raymont *et al.*, 1976)(Fig. 1.6B). Along the east, south, and west borders of North Sound and northeast corner of South Sound, however, salinities are variably because of poor circulation. Salinity is elevated over 42‰ during the dry season, but can be 50% lower than normal during the rainy season because of the influx of brackish to fresh water from the soaked mangrove and offshore springs (Giglioli, 1994)(Fig. 1.7B). Many of the ponds on the island (*e.g.*, Colliers Bay Pond, Meagre Bay Pond) can be completely dried whereas they can be filled by fresh water after heavy rains. Some ponds (*e.g.*, Jackson Pond, Tarpon Spring Pond) are continuously flooded and appear to be connected to the sea through bedrock openings. As a result, salinities in these permanent ponds are characterized by brackish water. Waters near peripheral mangrove swamps and ponds are stagnant, organic rich, highly turbid, and tan in color.

Mixed diurnal and semi-diurnal tides have a maximum range of 1 m and generally produce only weak currents around the island (Burton, 1994). Consequently, shelf and coastal currents are largely driven by wind and waves. These waves are controlled by trade winds which blow from the east, northeast or southeast throughout most of the year (Fig. 1.7C). Waves are typically 1.25–2.5 m high on the windward side of the island but <0.5 m on the leeward side (Darbyshire *et al.*, 1976). As a result, there is good circulation of waters in the north part of North Sound and most other peripheral lagoons (Fig. 1.7D). In the east and south parts of North Sound and northeast part of South Sound, however, circulation is limited. Powerful waves generated by hurricanes can be many meters high and wash away roads and deposit cobbles and boulders on shore (Rigby and Roberts, 1976; Jones and Hunter, 1992). During hurricanes, sea water commonly floods the island; for example, hurricane-driven waves have crossed the narrow stretch of land that separates North Sound and South Sound (Burton, 1994). From 1886 to 1987, Grand Cayman experienced tropical storms (within 50 miles) on an average of once every 4.3 years, and suffered direct hits on an average of once every 12.5 years. Hurricanes pass within 50 miles of Grand Cayman every 3.7 years and over the island every 9.2 years. Over the last forty years, however, hurricanes have been infrequent apart from Hurricane Gilbert which passed over the island in 1988 (Clark, 1988)(Fig. 1.8). During the winter months, 'Nor-wester' gales generate strong onshore waves that have a deep wave base and the capacity to move substantial quantities of sand across the western shelf on an annual basis (Fig. 1.4).

Until 1978, when the Marine Conservation Law was passed, human activities had a tremendous impact on these natural environments. Large quantities of sediments were dredged from South Sound and western North Sound to fill low-lying land and some of the

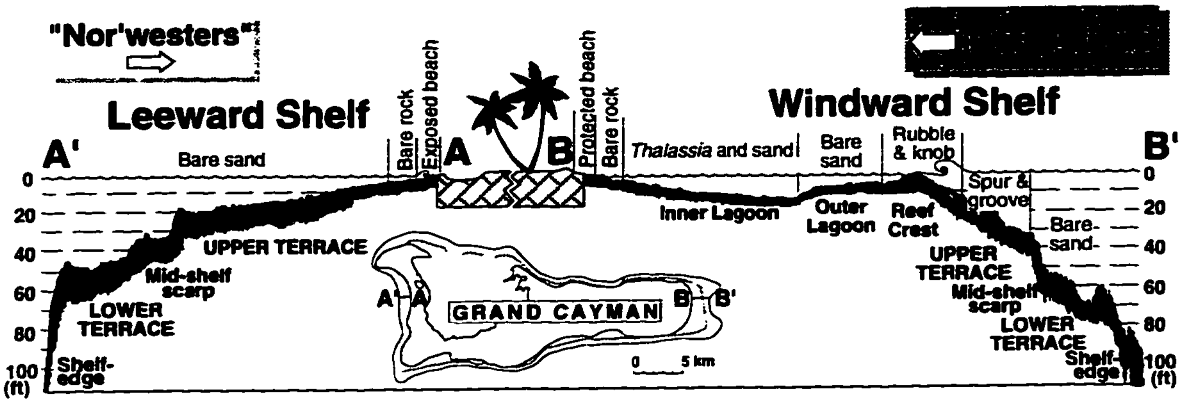

Figure 1.4—Comparison of the leeward shelf (A–A') and windward shelf (B–B') showing the distribution of the physiographic units.

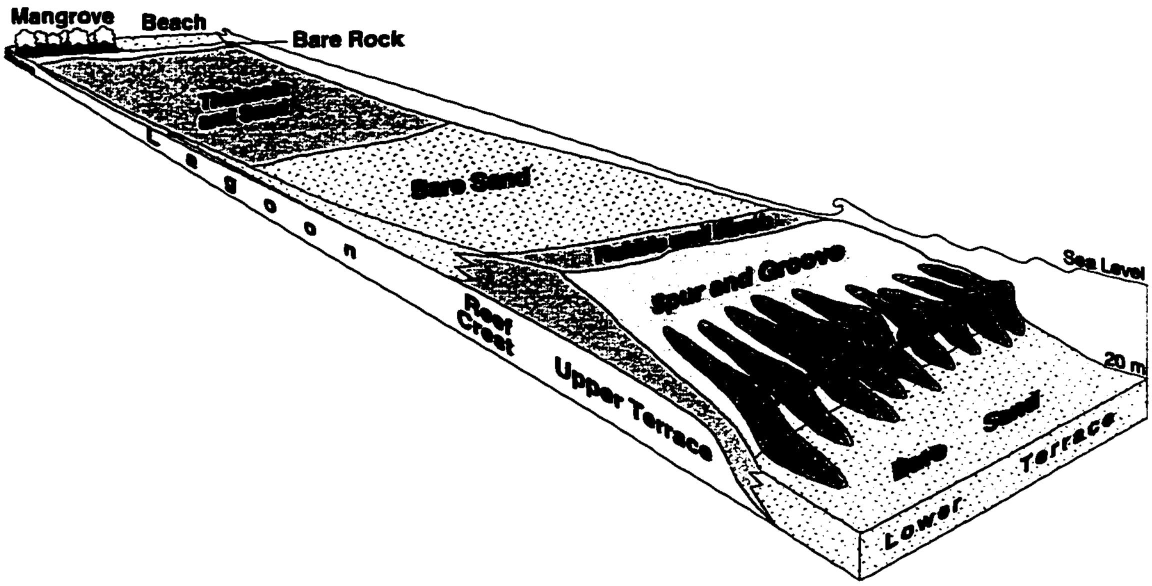

Figure 1.5—Block figure showing topography and substrate of different environments on the windward shelf of Grand Cayman. Modified after Blanchon and Jones (1995).

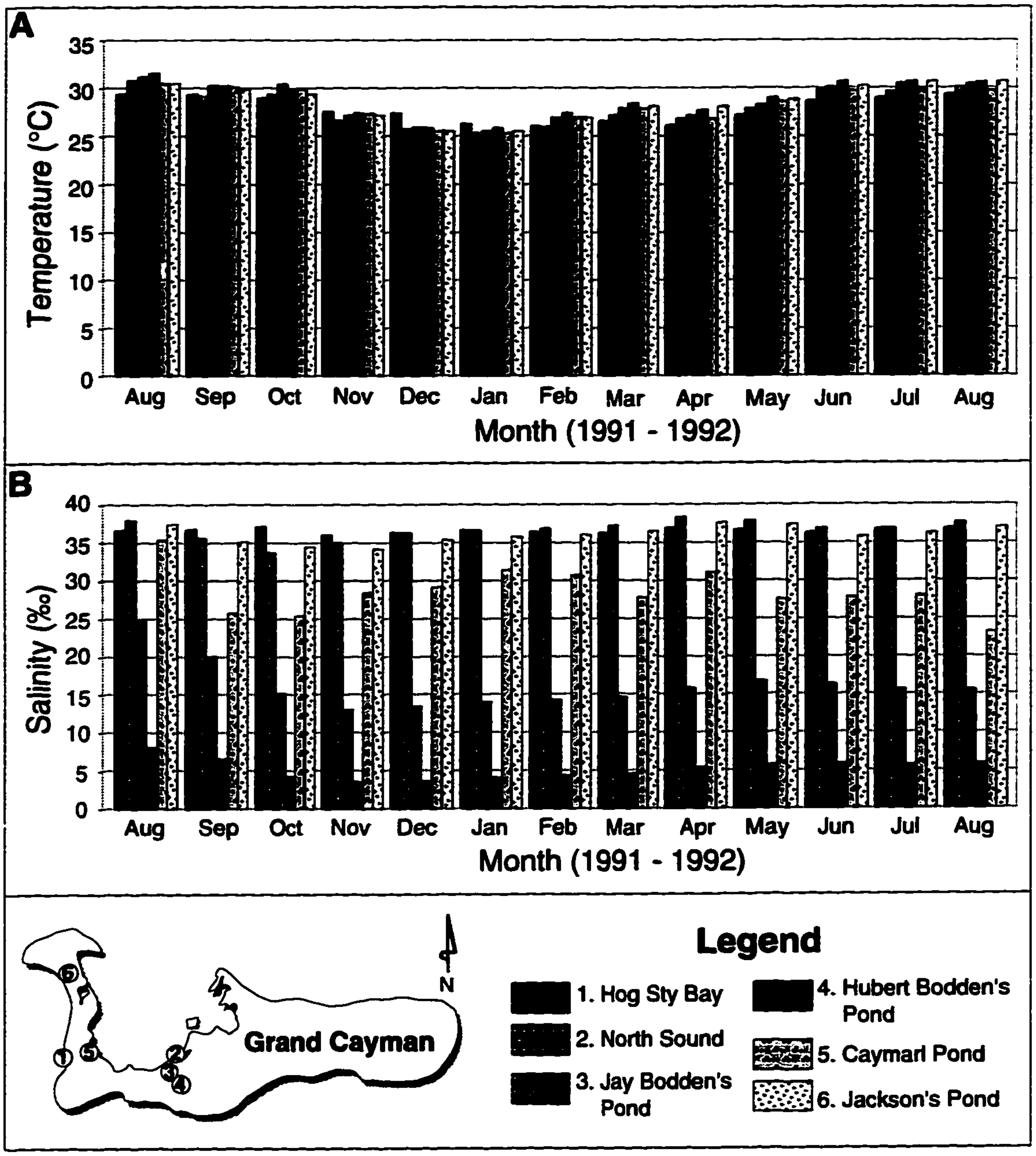

Figure 1.6—**A)** Temperatures and changes of sea water, lagoon water, and pond waters throughout the year. **B)** Salinities and changes of water bodies on Grand Cayman throughout the year (Modified after Department of the Environment Protection and Conservation Unit, Grand Cayman, 1996).

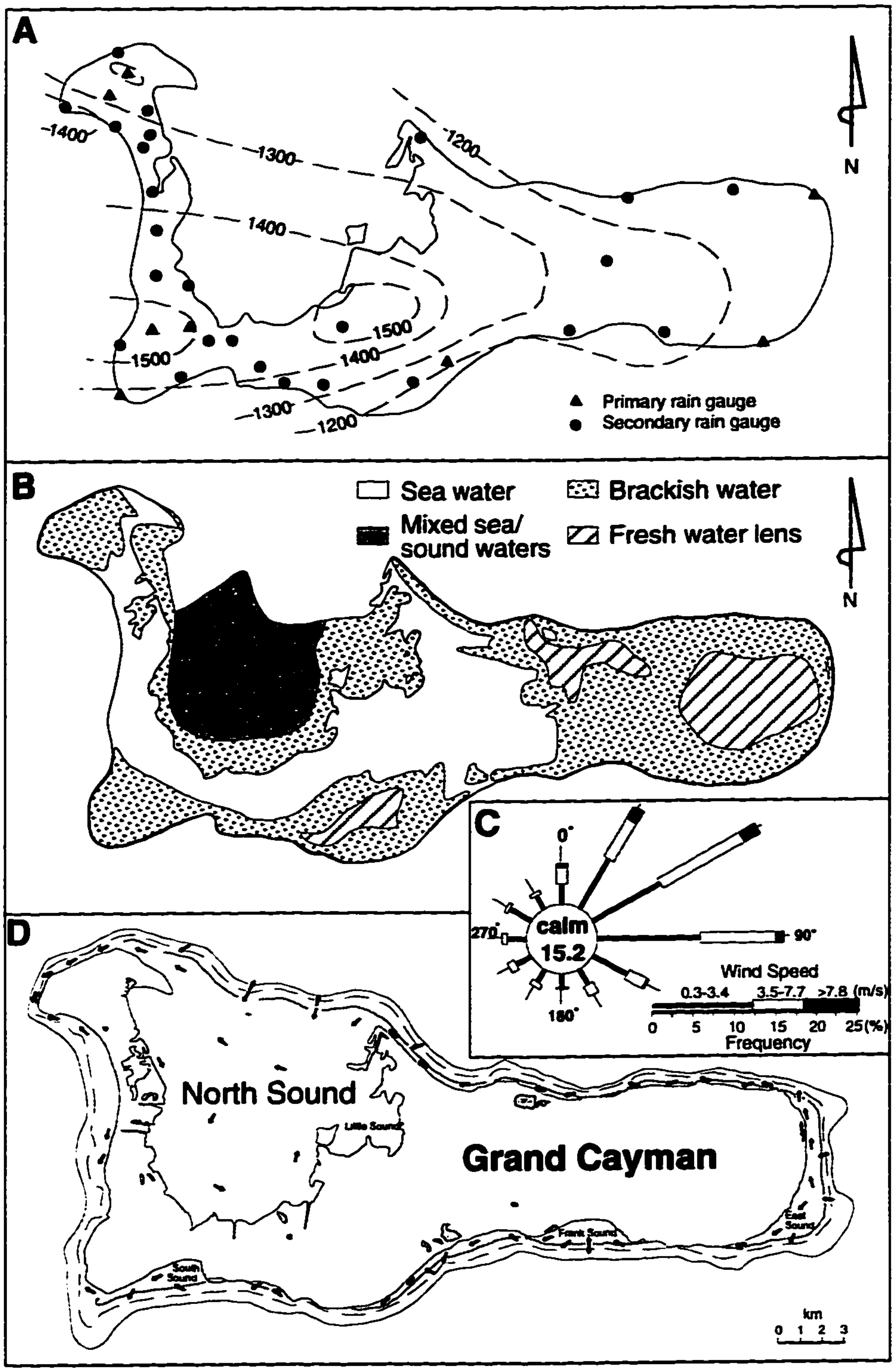

Figure 1.7—**A)** Map showing isohyet of Grand Cayman (from Burton, 1994). **B)** Map showing water characters of North Sound, South Sound, and proper areas (Department of the Environment Protection and Conservation Unit, Grand Cayman, 1996). **C)** Time-averaged annual wind rose graph (based on Darbyshire *et al.*, 1976). **D)** Map showing water circulation on Grand Cayman (from Rigby and Roberts, 1976).

natural ponds. The eastern part of North Sound, including Little Sound, however, was mainly untouched and is now protected by law.

METHODS

One hundred and eighty eight surface sediment samples (0.5–1 kg each) were collected by SCUBA or snorkeling along 14 traverses around the island during the summers of 1990 to 1993 by Blanchon, Kalbfleisch and others (Figs. 1.3, 1.9, and 1.10, labeled as solid circles; Appendix B). Subsequently, I collected 119 fresh sediment samples in the summer of 1994 to examine the living habitat of foraminifera in all kinds of environments around Grand Cayman (Figs. 1.3, 1.9, and 1.10, labeled as solid triangles; Appendix B). Transects were made using compass bearings and by lining up shoreline features with reference poles and buoys along the transect. Samples were located by using a tape to determine distances along a transect. Features evident on recent air photographs and in the field were used to check accuracy. Immediately after collection, each fresh sample was fixed by buffered formaldehyde which contains calcium chloride. Upon returning to the laboratory, they were washed over a 63μm sieve and immersed in a Rose Bengal solution for 30 minutes. After rewashing to remove excess stain, wet foraminifera were counted under a binocular stereo-microscope. Those stained pink in the last few chambers and/or displaying symbiont colors were considered living at the time of collection.

Seven sediment cores were collected from Frank Sound by driving 10 cm diameter PVC pipe into the sediment (Kalbfleisch, 1995)(Figs. 1.3, 1.10). The PVC pipe was cut using a saw and the core split using a thin wire and knife. 29 core sediment samples were taken at 10 or 20 cm intervals in these cores.

The sieve method of Martin and Liddell (1988, 1989) was used to obtain species abundances and size distributions of foraminifera tests from the sediment samples. This technique was used because it provides insights into the effects of transportation, sorting, and differential preservation of foraminifera in turbulent reef settings (Martin and Liddell, 1988). Initially, one split of each sediment sample (100–150 g) was divided into 1 ϕ intervals by sieving for 10 minutes. Then, where possible, 300 individuals were identified and counted from each fraction coarser than 3 ϕ (0.125 mm). In some cases, however, less than 300 specimens were identified and counted simply because the sediment fraction being examined contained less than 300 foraminifera tests. Each size fraction of sediment was spread on a small tray. Then, species were identified under a binocular microscope with each identification being recorded on tape. The number of specimens of each species was then determied from the information stored on the tape. These numbers were used to

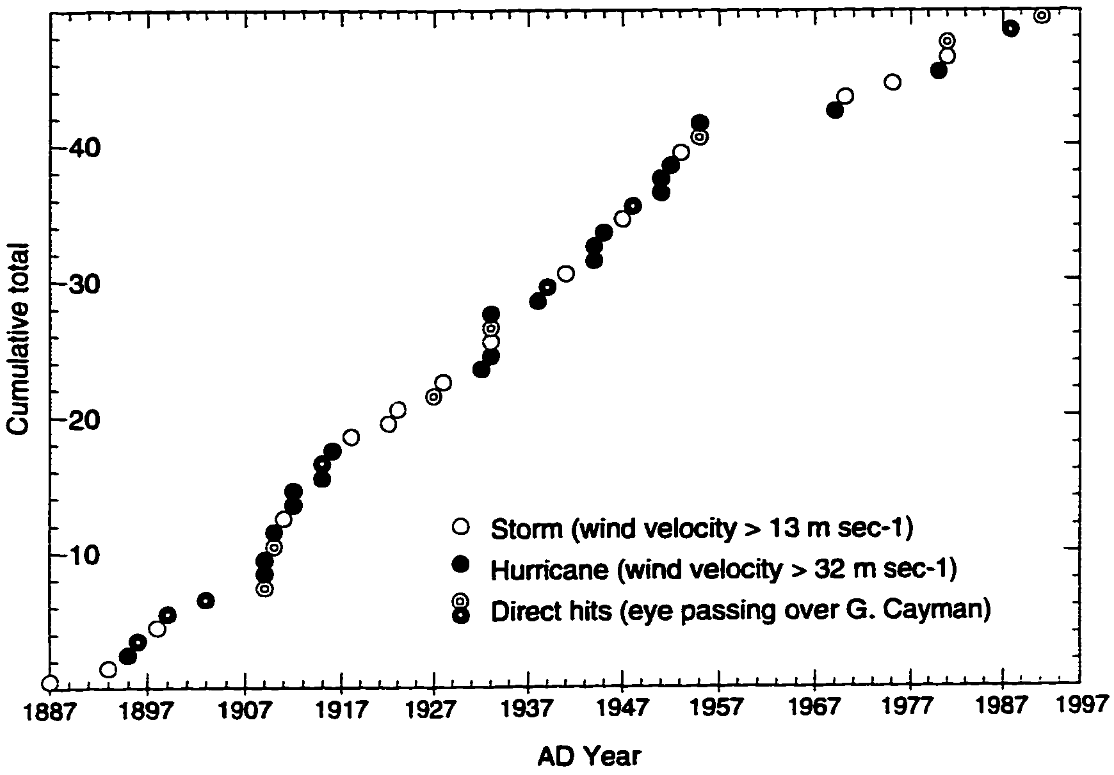

Figure 1.8—Tropical cyclones passing within 80 km of the Cayman Islands (Based on Clark, 1988).

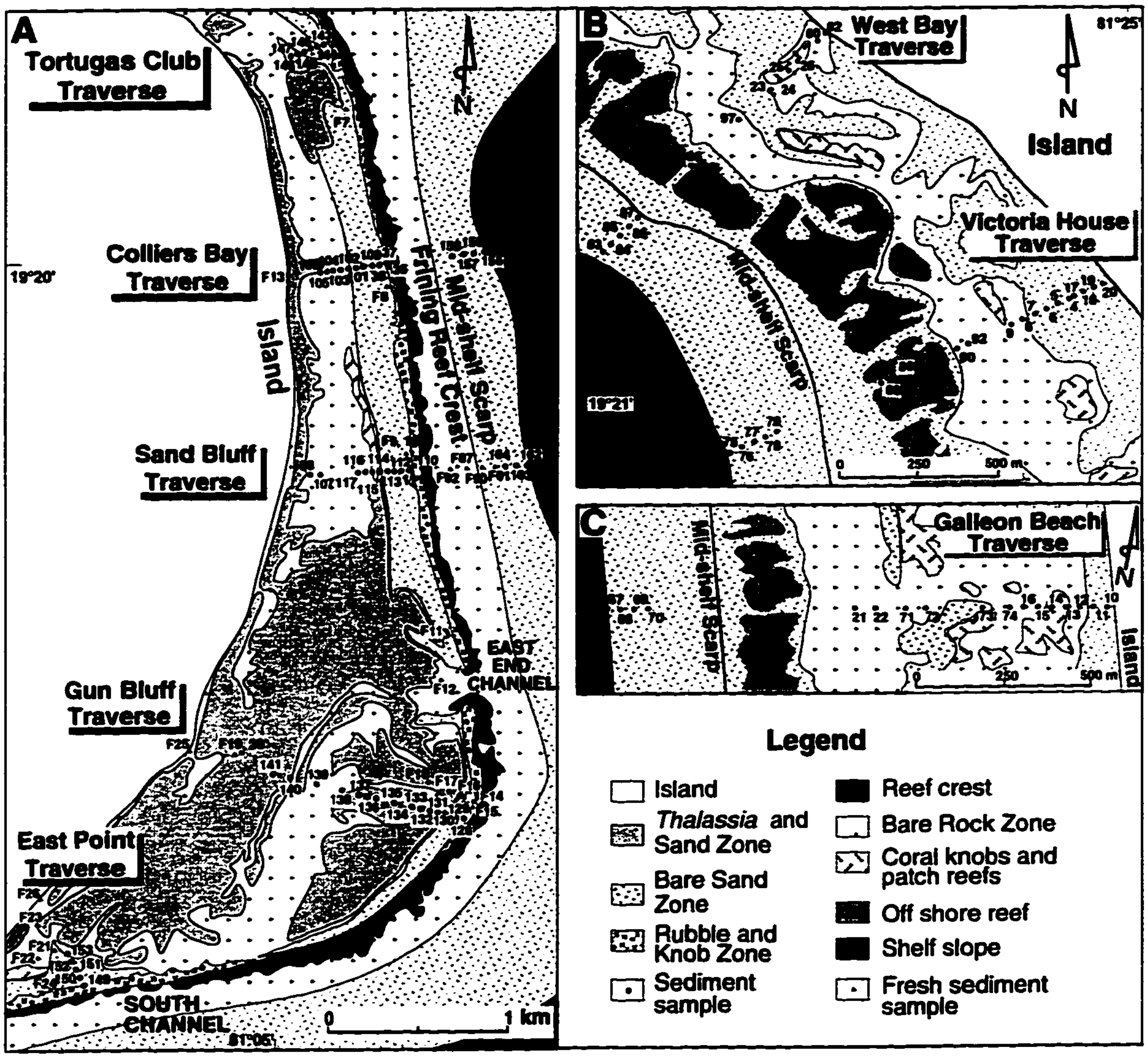

Figure 1.9—A) Map showing substrates and sample locations along traverses Tortugas Club, Colliers Bay, Sand Bluff, Gun Bluff, and East Point in East Sound of Grand Cayman. Substrates based on airphotos (1992). **B)** Map showing sample locations along traverses of West Bay and Victoria House on western coast of Grand Cayman. **C)** Map showing sample locations along Galleon Beach traverse on western coast of Grand Cayman. Substrates based on Rigby and Roberts (1976). Sample numbers are described in Appendix B.

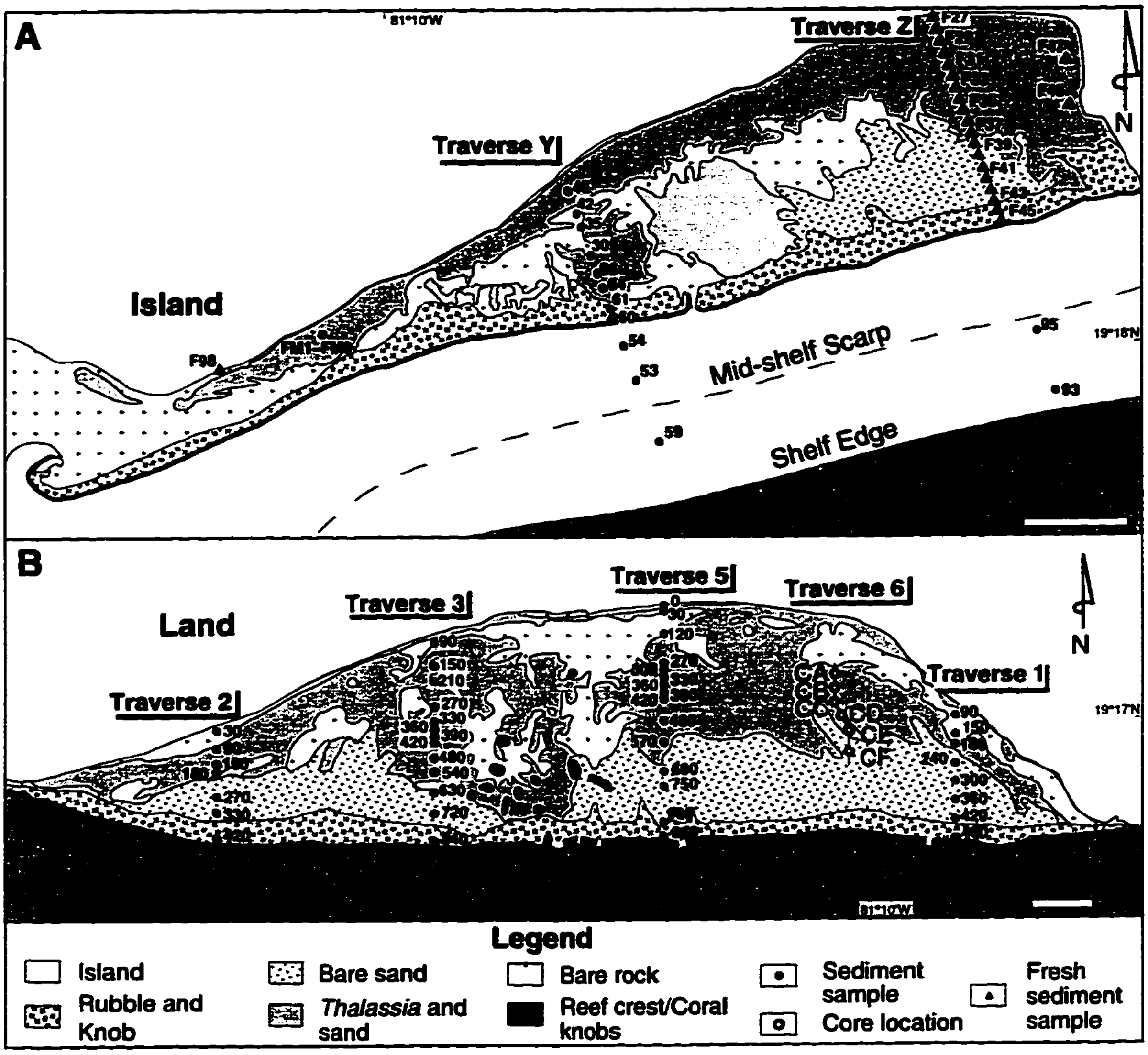

Figure 1.10—**A)** Map showing substrates and sample locations along traverses Y–Y' and Z–Z' in South Sound, Grand Cayman. **B)** Map showing substrates and sample locations along traverses 1, 2, 3, 5 and 6 in Frank Sound, Grand Cayman. Substrates in lagoons are based on airphotos (1992). Sample numbers are described in Appendix B.

construct the data base that was stored and manipulated using Microsoft Excel. For this study, 235,960 foraminifera tests were counted with the average number of specimens in each treated sample being >800. Such sample numbers mean that the recognition of assemblages using species that form >3% of any sample is statistically reliable at the 95% confidence limit (Patterson and Fishbein, 1989; Cerridwen and Jones, 1991).

Foraminiferal assemblage analysis of the surface and core samples was based on Q-mode cluster analysis that used species which formed ≥3% of the foraminiferal fauna in any sample. Dissimilarity indices (0 = minimum dissimilarity, or maximum similarity) between each pair of samples was calculated in Euclidean distance using abundance data. Binary data were not used because they consistently failed to give dendrograms that displayed foraminiferal assemblages. The dendrograms were derived using the between-groups method and the SPSS program.

Data for the grain-size analysis of surface and core sediment samples were extracted from Kalbfleisch (1995).

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CHAPTER 2 TAXONOMY

INTRODUCTION

During this study, 136 species and varieties belonging to 58 genera were identified from 235,960 specimens extracted from surface and core sediment samples from various environments on Grand Cayman (Table 2.1). The main aim of this study is to elucidate carbonate depositional processes under fair-weather and storm conditions by using ecologically sensitive foraminifera as tracers of sediment movement. Thus, very rare forms (3102 specimens, 1.3% of all specimens) were not identified. Of the identified species, only species (total 61) that form ≥3% of the foraminiferal fauna in each sample were used for data analysis. Only the 120 species and varieties that are common and/or ecologically diagnostic are illustrated (Figs. 2.1–2.12).

Species identifications relied on descriptions in Cushman (1918, 1921, 1922a, b, 1923, 1924, 1929, 1930, 1931), Bermudez (1935), Barker (1960), Hofker (1964, 1976), Bock (1971), Wantland (1975), and Poag (1981). Most species found during this study are well-known and do not need to be described herein. Abbreviated synonyms of identified species are provided in Appendix A. The only detailed description provided is that of an important new species of *Amphistegina*.

Amphistegina caymanensis sp. nov.

Fig 2.12a–i

1884 *A. lessonii* d'Orbigny; Brady 1884: pl. 111, fig. 2.
1931 *A. lessonii* d'Orbigny; Cushman 1931: pt. 8: p. 79, pl. 16, figs. 1–2.
1977 *A. gibbosa* d'Orbigny; Buzas *et al.*, 1977: p. 99, pl. 7, figs. 10–12.

Holotype and paratype. Holotype (Fig. 2.12a–d) and paratype (Fig. 2.12e, f) deposited at the Department of Earth and Atmospheric Sciences, University of Alberta. Numbers F50/3710 (Holotype) and F50/3706 (Paratype).

Type-locality. Recent samples from Duck Pond Bight, North Sound, Grand Cayman (Fig. 2.13).

Diagnosis. *Amphistegina* with flattened shape and carinate periphery. Aperture face wide. Sinistral coiling common.

Measurements. Holotype: maximum diameter – 1.02 mm. Minimum diameter – 0.91 mm. Axial diameter (thickness) – 0.34 mm. 11 chambers in last whorl. Paratype: Maximum diameter

Table 2.1. List of species found in modern sediment samples from Grand Cayman. Numbers of specimens refers to total number of specimens from all samples. Species with '*' are ≥3% of the foraminiferal fauna in any sample.

Species	Number of specimens	Figures
Ammobaculites exilis Cushman and Bronnimann, 1948	1	2.1b
Ammomassilina alveoliniformis (Millett), 1898	3	
*_Ammonia tepida_ (Linné), 1767	2377	2.9g, h
Amphisorus hemprichii Ehrenberg, 1838	4595	2.7g
*_Amphistegina gibbosa_ d'Orbigny, 1839	12555	2.10h–i
*_Amphistegina caymanensis_ sp. nov	1006	2.12a–i
*_Archaias angulatus_ (Fichtel and Moll), 1803	95195	2.7a, b
*_Archaias compressus_ (d'Orbigny), 1839	3653	2.7c, d
*_Articulina pacifica_ Cushman, 1944	725	2.6e
*_Asterigerina carinata_ d'Orbigny, 1839	13008	2.9d
*_Bigenerina irregularis_ Phleger and Parker, 1951	192	2.1f
Bolivina striatula Cushman, 1922	17	2.7j
Bolivina tortuosa Brady, 1884	12	2.7k
Bolivinita rhomboidalis (Millett), 1899	38	2.7l
*_Borelis pulchra_ (d'Orbigny), 1839	2691	2.7h, i
Bronnimannia palmerae (Bermudez), 1935	26	2.8h
Cancris sagra (d'Orbigny), 1839	7	2.9b
Cibicides mayori (Cushman), 1924	42	2.10j
*_Cibicides pseudoungeriana_ (Cushman), 1922	525	2.10k; 11a
Clavulina nodosaria d'Orbigny, 1839	70	2.1i
*_Clavulina tricarinata_ d'Orbigny, 1839	1249	2.1j, k
Clavulina cf. _tricarinata_ d'Orbigny, 1839	5	2.1l, m
Cribroelphidium discoidale (d'Orbigny), 1839	256	2.9j
*_Cribroelphidium poeyanum_ (d'Orbigny), 1839	1109	2.9k
Cymbaloporetta atlantica (Cushman), 1934	207	2.11e, f
*_Cymbaloporetta squammosa_ (d'Orbigny), 1826	7076	2.11g, h
*_Discorbis granulosa_ Heron-Allen and Earland, 1915	117	2.8c
*_Discorbis mira_ Cushman, 1922	6540	2.8d
Discorbis obtusa (d'Orbigny), 1826	8	2.8e
*_Discorbis rosea_ (d'Orbigny), 1826	12438	2.8f, g
*_Elphidium lanieri_ (d'Orbigny), 1839	308	2.9i
Elphidium sagrum (d'Orbigny), 1839	2	
*_Eponides antillarum_ (d'Orbigny), 1839	365	2.10e
*_Eponides repanda_ (Fichtel and Moll), 1798	422	2.10f
Eponides tubelifera canimarensis Palmer and Bermudezi, 1936	3	2.10g
Globigerina bulloides d'Orbigny, 1826	8	2.10b
*_Globigerinoides rubra_ (d'Orbigny), 1839	507	2.10c
Globorotalia menardii (d'Orbigny), 1826	118	2.10a
*_Gypsina vesicularis_ (Parker and Jones), 1860	94	2.11d
*_Hauerina bradyi_ Cushman, 1917	731	2.6b
Hauerina occidentalis Cushman, 1946	262	2.6c
*_Heterostegina antillarum_ d'Orbigny, 1839	575	2.9l
Islandiella laevigata (d'Orbigny), 1826	5	
Liebusella soldanii (Jones and Parker), 1860	73	2.1n
Massilina crenata (Karrer), 1868	5	2.3m
*_Massilina protea_ Parker, 1953	434	2.4a, b
*_Miliolinella circularis_ (Brönnimann), 1855	2772	2.5l

Table 2.1 (continued)

Species	Number of specimens	Figures
Miliolinella fichtelliana d'Orbigny, 1839	475	2.5m
Miliolinella labiosa (d'Orbigny), 1839	401	2.5n
*_Miliolinella subrotunda_ (Montagu), 1803	235	2.6a
Monalysidium politum Chapman, 1900	17	2.6m
*_Neoconorbina terquemi_ (Rzehak) 1888	482	2.8i, j
Nodosaria flintii Cushman, 1923	3	
Nonion grateloupi (d'Orbigny), 1826	188	2.11i
Orbulina universa d'Orbigny, 1839	34	2.10d
Patellina corrugata Williamson, 1858	29	2.9f
Pelosina rotundata Brady, 1884	1	2.1a
Peneroplis bradyi Cushman, 1930	546	2.6f
Peneroplis carinatus d'Orbigny, 1839	144	
*_Peneroplis discoideus_ Flint, 1897	1003	2.6g
Peneroplis pertusus (Forskål), 1775	497	2.6h
*_Peneroplis proteus_ d'Orbigny, 1839	2191	2.6i–k
*_Peneroplis_ cf. _proteus_ d'Orbigny, 1839	175	2.6l
*_Planorbulina acervalis_ Brady, 1884	1733	2.11b
Planorbulina mediterranensis d'Orbigny, 1826	63	2.11c
*_Pyrgo denticulata_ (Brady), 1884	492	2.4c
Pyrgo denticulata striolata (Brady), 1884	7	2.4d
Pyrgo johnsoni Cushman, 1935	4	2.4e
Pyrgo oeensis (Martinotti) 1920	6	2.4f
*_Pyrgo subsphaerica_ (d'Orbigny), 1839	1298	2.4g
*_Quinqueloculina agglutinans_ d'Orbigny, 1839	5094	2.2g
*_Quinqueloculina barbouri_ Bermudizi, 1935	450	2.2h, i
Quinqueloculina bicostata d'Orbigny, 1839	37	2.2j, k
*_Quinqueloculina bidentata_ d'Orbigny, 1839	2261	2.2l, m
Quinqueloculina bosciana d'Orbigny, 1839	33	2.3a
*_Quinqueloculina bradyana_ Cushman, 1924	1472	2.3b
Quinqueloculina candeiana d'Orbigny, 1839	199	2.3c
Quinqueloculina collumnosa Cushman, 1922	226	2.3d
Quinqueloculina collumnosa forma _excavata_ Poag, 1981	2	
*_Quinqueloculina funafutiensis_ (Chapman), 1901	893	2.3e
Quinqueloculina fusca Brady, 1865	2	
*_Quinqueloculina laevigata_ d'Orbigny, 1826	590	2.3f
*_Quinqueloculina lamarckiana_ d'Orbigny, 1839	899	2.3g
Quinqueloculina cf. _lamarckiana_ d'Orbigny, 1839	142	2.3h
Quinqueloculina parkeri occidentalis Cushman, 1922	172	2.3i
*_Quinqueloculina_ cf. _parkeri_ Brady, 1884	403	2.3j
*_Quinqueloculina poeyana_ d'Orbigny, 1839	894	2.3k
Quinqueloculina polygona d'Orbigny, 1839	287	2.3l
Quinqueloculina tipswordi Anderson, 1961	2	
Quinqueloculina vulgaris d'Orbigny, 1826	5	
Reussella atlantica Cushman, 1947	36	2.7m
Robertinoides bradyi Cushman and Parker, 1936	12	2.11l
Rosalina bulloides d'Orbigny, 1839	132	2.8k, l
*_Rosalina candeiana_ d'Orbigny, 1839	6684	2.8m
Rosalina concinna (Brady), 1884	110	
*_Rosalina floridana_ (Cushman), 1922	497	2.9a
Rosalina globularis d'Orbigny, 1826	36	

Table 2.1 (continued)

Species	Number of specimens	Figures
Sagrina pulchella d'Orbigny, 1839	31	2.8a
*_Schlumbergerina occidentalis_ Cushman, 1929	1384	2.6d
Siphonina pulchra Cushman, 1919	364	2.9c
Sorites marginalis (Lamarck), 1816	34	2.7e, f
Spirillina decorata Brady, 1884	44	
Spirillina vivipara Ehrenberg, 1841	101	2.9e
Spirolina acicularis (Batsch), 1791	2	2.6n
*_Spirolina arientina_ (Batsch), 1791	1092	2.6o
*_Spiroloculina antillarum_ d'Orbigny, 1839	508	2.2a, b
*_Spiroloculina arenata_ Cushman, 1921	364	2.2c
Spiroloculina caduca Cushman, 1922	70	2.2d
Spiroloculina communis Cushman and Todd, 1944	5	
Textularia agglutinans d'Orbigny, 1839	53	2.1c
Textularia candeiana d'Orbigny, 1839	9	2.1d
*_Textularia conica_ d'Orbigny, 1839	140	2.1e
Trifarina bella (Phleger and Parker), 1951	7	2.8b
*_Trichohyalus anuayoi_ (Bermudez), 1935	24	2.11j, k
Triloculina bermudezi Acosta, 1940	374	2.4h
Triloculina bicarinata d'Orbigny, 1839	421	2.4j, k
*_Triloculina bradyana_ (Cushman), 1917	737	2.4i
*_Triloculina carinata_ d'Orbigny, 1839	2982	2.4l, m
Triloculina gracilis d'Orbigny, 1839	58	
*_Triloculina laevigata_ (d'Orbigny), 1839	1257	2.4n
*_Triloculina linneiana_ d'Orbigny, 1839	4605	2.5a
Triloculina linneiana comis (Bandy), 1956	50	2.5b
Triloculina oblonga (Montagu), 1803	111	2.5c
Triloculina planciana d'Orbigny, 1839	280	
*_Triloculina quadrilateralis_ d'Orbigny, 1839	2065	2.5d
*_Triloculina rotunda_ d'Orbigny, 1826	2541	2.5e
*_Triloculina sidebottomi_ (Martinotti), 1920	230	2.5f
*_Triloculina simplex_ (Terquem), 1882	1947	2.5g
Triloculina sp.	236	
Troloculina transverstriata (Brady), 1881	18	2.5h
Triloculina tricarinata d'Orbigny, 1826	63	2.5i
Triloculina cf. _tricarinata_ d'Orbigny, 1826	2	2.5j
*_Triloculina trigonula_ (Lamarck), 1804	353	2.5k
*_Valvulina oviedoiana_ d'Orbigny, 1839	5776	2.1g, h
*_Vertebralina cassis_ d'Orbigny, 1839	303	2.2e
Vertebralina mucronata d'Orbigny, 1839	198	2.2f
Other unidentified foraminifera	3102	
Total number of specimens	235960	

EXPLANATION OF FIGURES

In the following plates, all photographs were taken with a Scanning Electron Microscope. All specimens are deposited in the Department of Earth and Atmospheric Sciences, University of Alberta. The number for each SEM photograph is composed of three parts that are separated by "/": 1) field number; 2) specimen number which is SEM stub number (01–39) plus location number on that stub (01–21); and 3) negative number which is the roll number (001–125) plus negative number (1–8).

Figure 2.1

a. *Pelosina rotundata* Brady, 1884. 67/23-03/063-3, Galleon Beach, side view, × 53.

b. *Ammobaculites exilis* Cushman and Brönnimann, 1948. BBP1/40-15, Betty Bay Pond, side view, × 100.

c. *Textularia agglutinans* d'Orbigny, 1839. 93.1/15-10/066-5, North Wall, side view, × 50.

d. *Textularia candeiana* d'Orbigny, 1839. 69/22-07/093-1, Galleon Beach, side view, × 72.

e. *Textularia conica* d'Orbigny, 1839. 93.1/15-10/066-6, North Wall, side view, × 65.

f. *Bigenerina irregularis* Phleger and Parker, 1951. 93.1/18-04/079-6, North Wall, side view, × 20.

g, h. *Valvulina oviedoiana* d'Orbigny, 1839. **g.** 1409/01-16/005-4, Gun Bluff, East Sound, side view, ×40. **h.** 137/3407/1081, side view, × 28.

i. *Clavulina nodosaria* d'Orbigny, 1839. 140/28-06/098-3, Gun Bluff, East Sound, side view, × 65.

j, k. *Clavulina tricarinata* d'Orbigny, 1839. **j.** 45/02-06/008-2, Central South Sound, side view, × 42. **k.** 45/02-06/010-6, Central South Sound, apertural view, × 72.

l, m. *Clavulina* cf. *tricarinata* d'Orbigny, 1839. **l.** 89/21-11/085-4, Victoria House, side view, × 37. **m.** 89/21-11/087-4, Victoria House, apertural view, × 55.

n. *Liebusella soldanii* (Jones and Parker), 1860. 93.1/18-03/079-5, North Wall, side view, × 11.

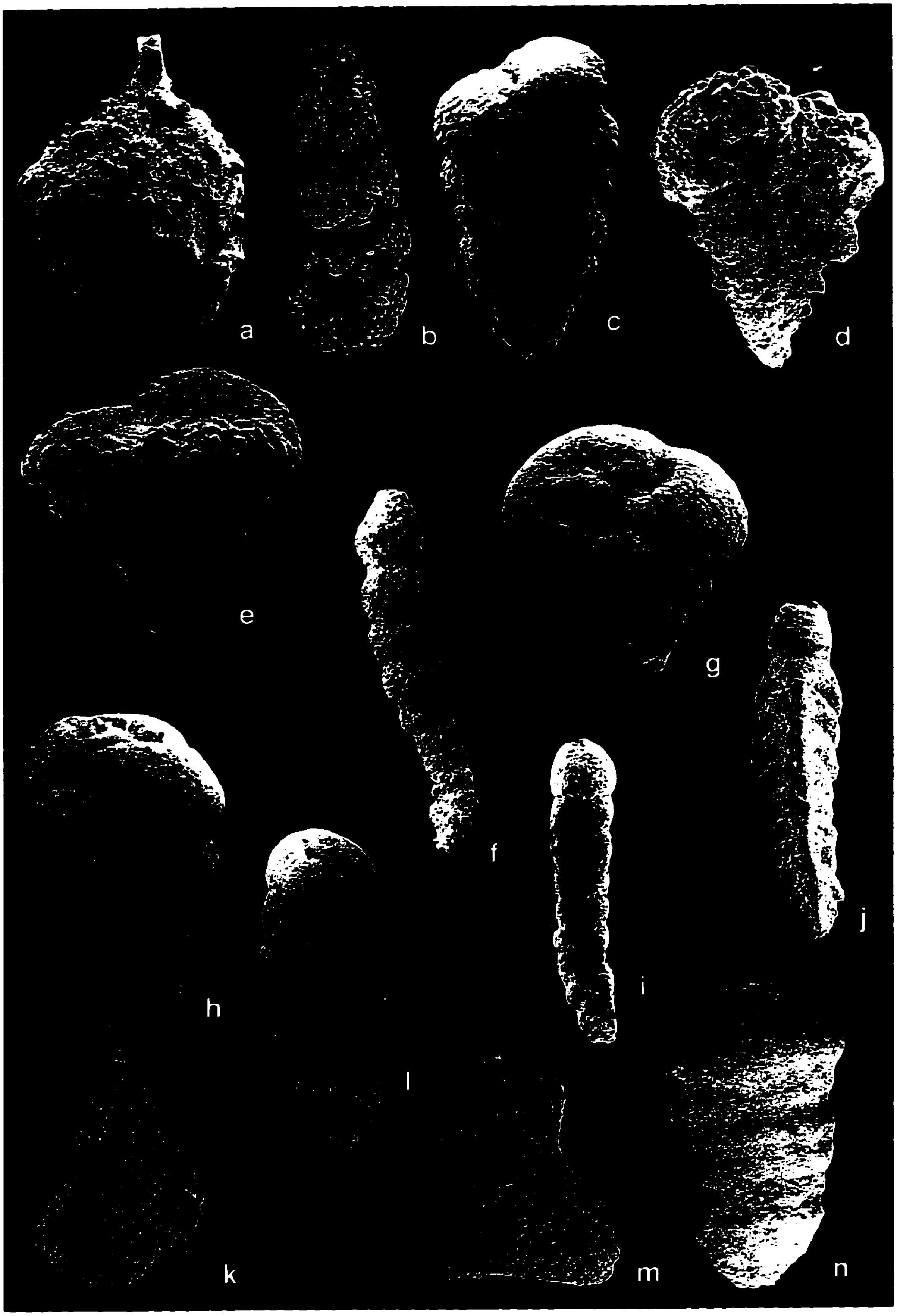
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Figure 2.2

a, b. *Spiroloculina antillarum* d'Orbigny, 1839. **a**. 93.1/16-05/067-5, North Wall, side view, × 50. **b**. 45/04-05/016-2, Central South Sound, side view, × 81.

c. *Spiroloculina arenata* Cushman, 1921. 140/28-04/098-2, Gun Bluff, East Sound, side view, × 70.

d. *Spiroloculina caduca* Cushman, 1922. 45/92-12/107-5, Central South Sound, side view, × 70.

e. *Vertebralina cassis* d'Orbigny, 1839. 93.1/16-02/075-2, North Wall, side view, × 65.

f. *Vertebralina mucronata* d'Orbigny, 1839. 45/09-01/033-2, Central South Sound, side view, × 62.

g. *Quinqueloculina agglutinans* d'Orbigny, 1839. FS5-960/32-09/105-7, Frank Sound, side view, × 33.

h, i. *Quinqueloculina barbouri* Bermudezi, 1935. **h**. 93.1/29-07/099-7, North Wall, side view, × 28. **i**. 93.1/29-07/101-2, North Wall, apertural view, × 40.

j, k. *Quinqueloculina bicostata* d'Orbigny, 1839. **j**. 88/21-10/085-1, Victoria House, side view, × 56. **k**. 45/03-09/013-7, Central South Sound, apertural view, × 175.

l, m. *Quinqueloculina bidentata* d'Orbigny, 1839. **l**. FS5-960/32-10/105-8, Frank Sound, side view, × 31. **m**. FS5-960/32-08/109-8, Frank Sound, apertural view, × 45.

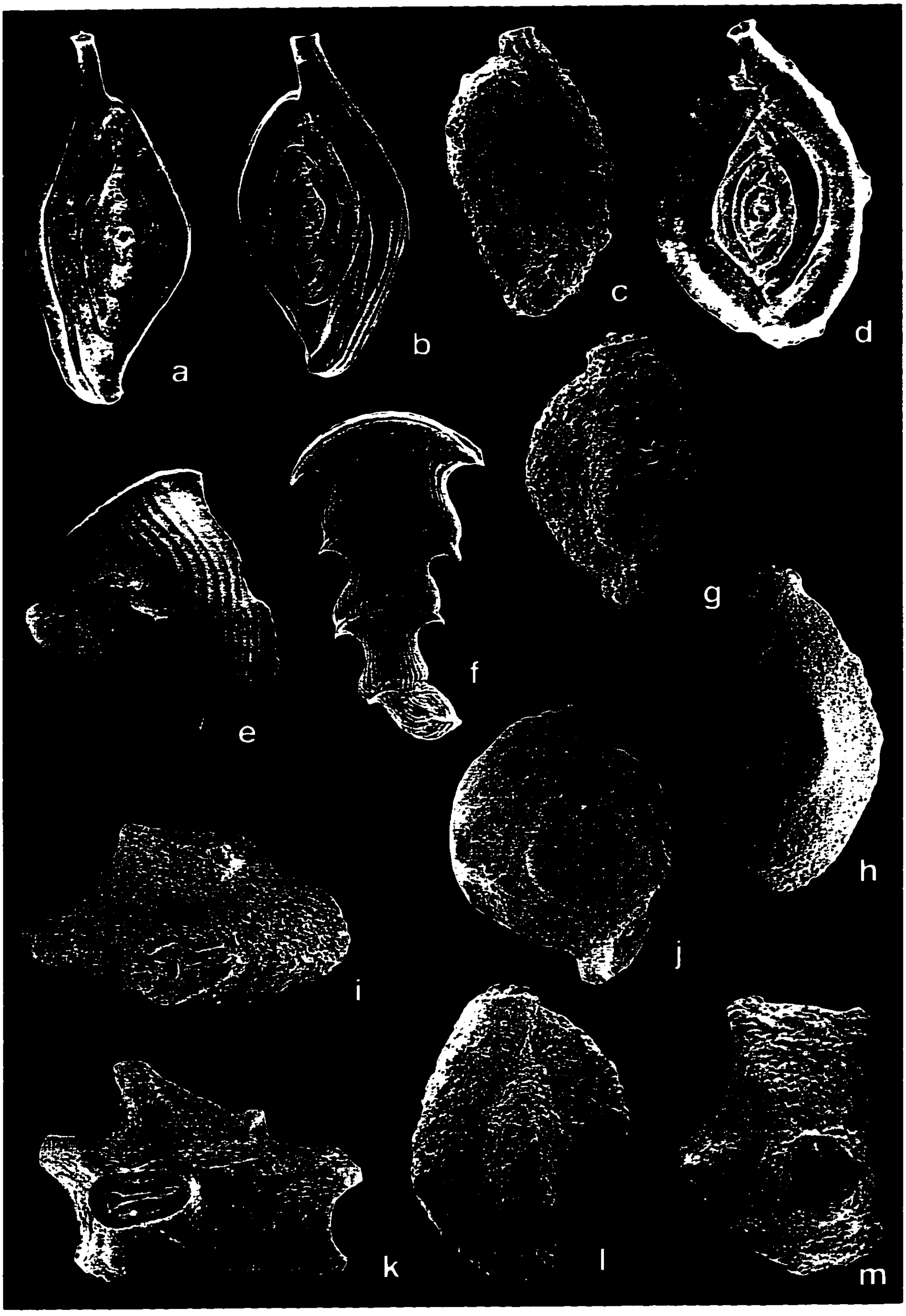
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Figure 2.3

a. *Quinqueloculina bosciana* d'Orbigny, 1839. 1409/13-01/047-6, Northwest North Sound, side view, × 165.

b. *Quinqueloculina bradyana* Cushman, 1924. 45/04-08/017-1, Central South Sound, side view, × 85.

c. *Quinqueloculina candeiana* d'Orbigny, 1839. 45/05-05/019-4, Central South Sound, side view, × 100.

d. *Quinqueloculina collumnosa* Cushman, 1922. 45/04-03/015-7, Central South Sound, side view, × 78.

e. *Quinqueloculina funafutiensis* (Chapman), 1901. 1409/13-05/048-1, Northwest North Sound, side view, × 115.

f. *Quinqueloculina laevigata* d'Orbigny, 1826. FM7/10-16/038-5, West South Sound, side view, × 115.

g. *Quinqueloculina lamarckiana* d'Orbigny, 1839. 18/24-01/070-1, Victoria House, side view, × 80.

h. *Quinqueloculina* cf. *lamarckiana* d'Orbigny, 1839. 45/08-06/031-6, Central South Sound, side view, × 105.

i. *Quinqueloculina parkeri occidentalis* Cushman, 1922. 128/21-07/086-1, Gun Bluff, East Sound, side view, × 53.

j. *Quinqueloculina* cf. *parkeri* (Brady), 1884. j. 70/23-10/064-5, Galleon Beach, side view, × 68.

k. *Quinqueloculina poeyana* d'Orbigny, 1839. 1409/02-04/007-5, Northwest North sound, side view, × 68.

l. *Quinqueloculina polygona* d'Orbigny, 1839. 155/26-01/056-6, Forereef of Colliers Bay, side view, × 95.

m. *Massilina crenata* (Karrer), 1868. 76/23-12/064-7, Victoria House, side view, × 125.

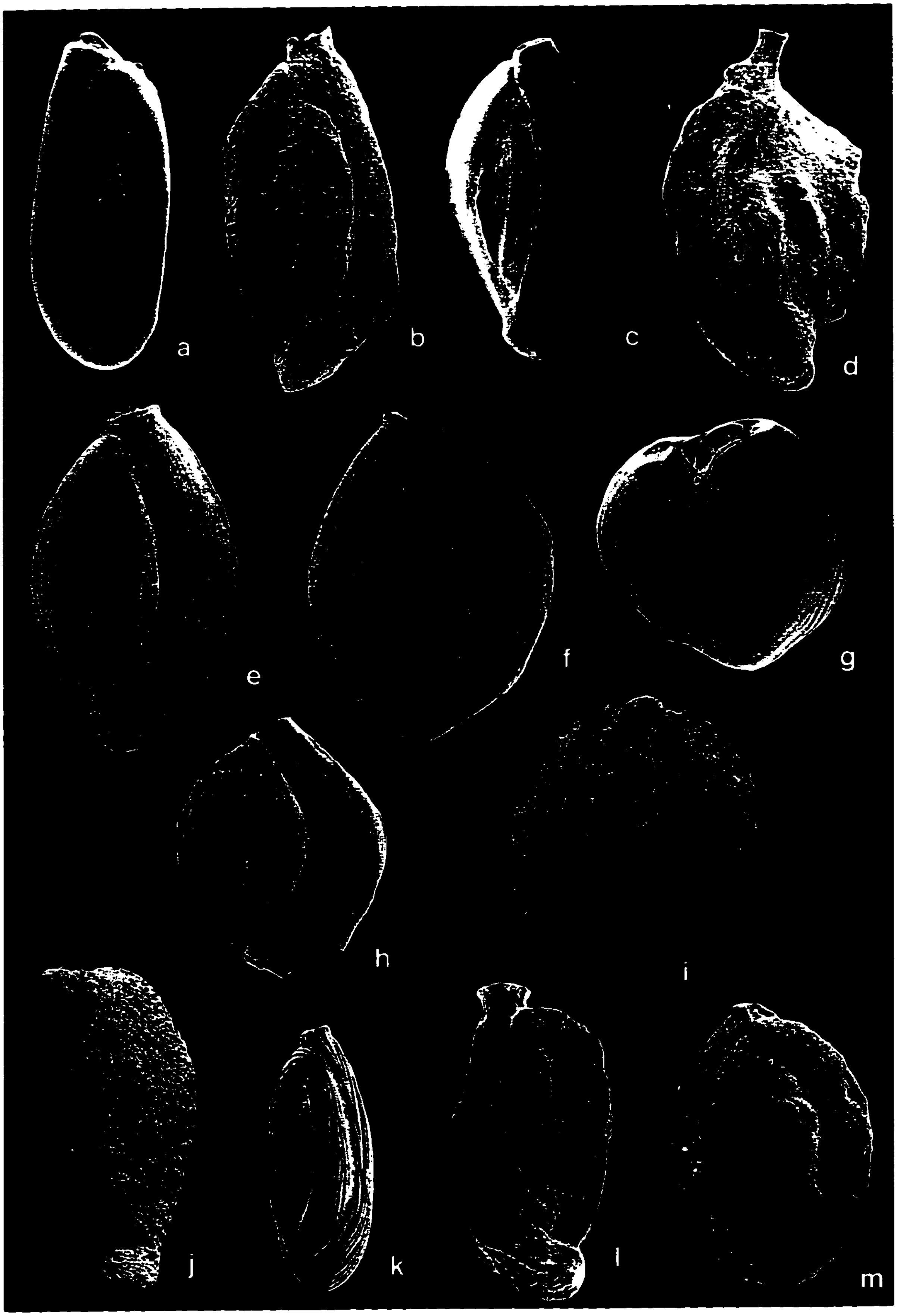
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Figure 2.4

a, b. *Massilina protea* Parker, 1953. **a**. CB/40-11, Western Cayman Brac, side view, × 160. **b**. CB/40-10, Western Cayman Brac, side view, × 150.

c. *Pyrgo denticulata* (Brady), 1884. 45/08-11/032-5, Central South Sound, side view, × 70.

d. *Pyrgo denticulata striolata* (Brady), 1884. 45/05-10/053-3, Central South Sound, side view, × 175.

e. *Pyrgo johnsoni* Cushman, 1935. 93.1/27-10/097-1, North Wall, side view, × 50.

f. *Pyrgo oeensis* (Martinotti), 1920. FS5-960/43-05/106-2, Frank Sound, side view, × 125.

g. *Pyrgo subsphaerica* (Brady), 1839, FM4/35-06/110-7, West South Sound, side view, × 90.

h. *Triloculina bermudezi* Acosta, 1940. 1409/11-06/039-6, Northwest North Sound, side view, × 140.

i. *Triloculina bradyana* (Cushman), 1917. 1409/01-08/003-4, Northwest North Sound, side view, × 40.

j, k. *Triloculina bicarinata* d'Orbigny, 1839. j. 45/34-11/107-8, Central South Sound, side view, × 43. **k**. 45/34-10/108-4, Central South Sound, apertural view, × 55.

l, m. *Triloculina carinata* d'Orbigny, 1839. **l**. 1409/01-11/004-1, Northwest North Sound, side view, × 63. **m**. 1409/02-13/011-6, Northwest North Sound, apertural view, × 90.

n. *Triloculina laevigata* (d'Orbigny), 1839. 132/25-13/056-1, Gun Bluff, East Sound, side view, × 95.

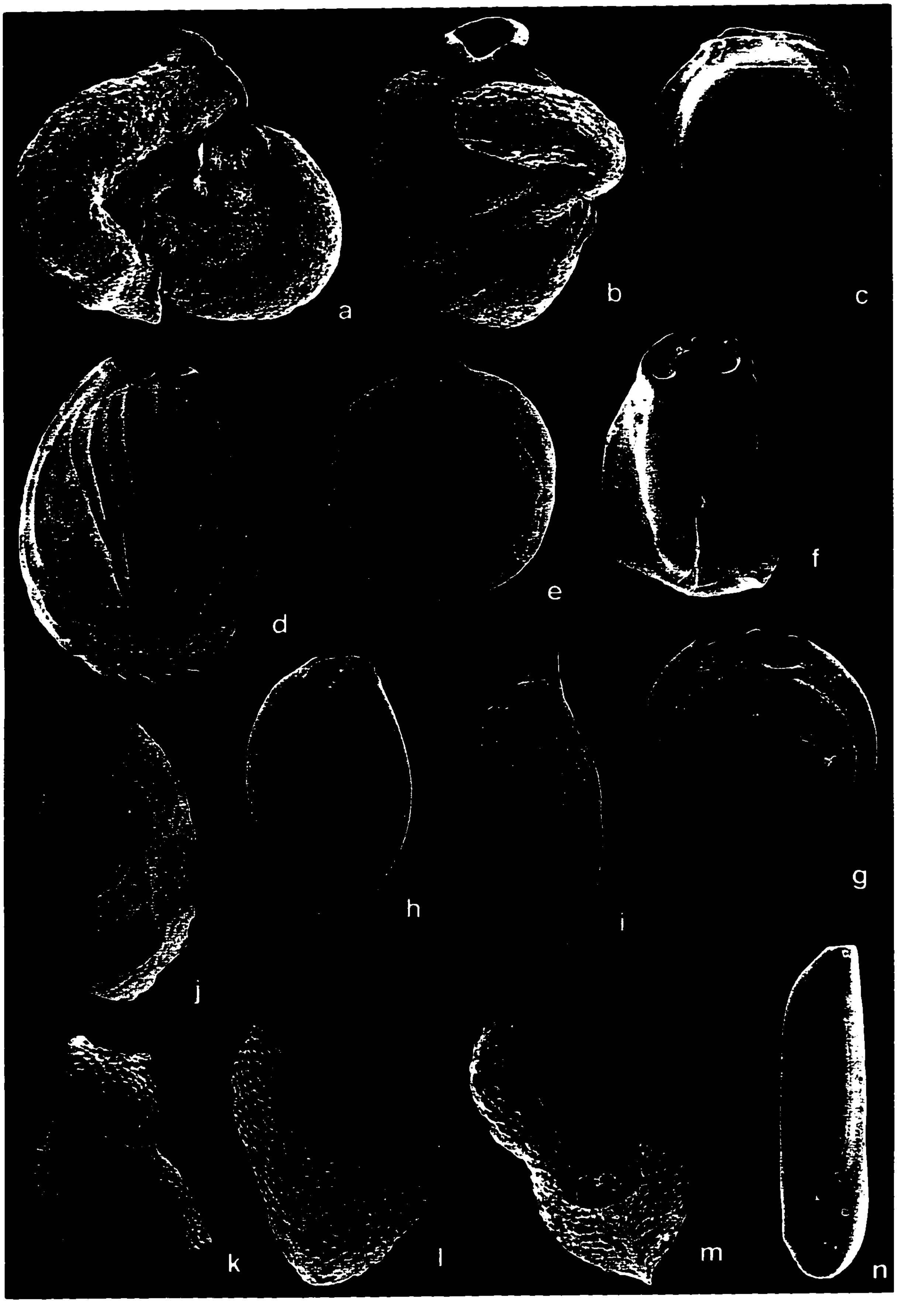
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Figure 2.5

a. *Triloculina linneiana* d'Orbigny, 1839. 1409/01-12/004-4, Northwest North Sound, side view, × 50.

b. *Triloculina linneiana comis* (Bandy), 1956. 118/26-13/071-8, Hepps Wall, side view, × 43.

c. *Triloculina oblonga* (Montagu), 1803. 93.1/17-10/09-22, North Wall, side view, × 46.

d. *Triloculina quadrilateralis* d'Orbigny, 1839. FM7/10-06/037-5, West South Sound, side view, × 130.

e. *Triloculina rotunda* d'Orbigny, 1826. 45/04-09/617-2, Central South Sound, side view, × 86.

f. *Triloculina sidebottomi* (Martinotti), 1920. 45/03-11/014-1, Central South Sound, side view, × 70.

g. *Triloculina simplex* (Terquem), 1882. CB/40-06, West Cayman Brac, side view, × 170.

h. *Triloculina transverstriata* (Brady), 1881. 22/25-04/054-4, Galleon Beach, side view, × 93.

i. *Triloculina tricarinata* d'Orbigny, 1826. 45/05-12/021-3, Central South Sound, side view, × 120.

j. *Triloculina* cf. *tricarinata* d'Orbigny, 1826. 140/28-01/097-7, Gun Bluff, East Sound, side view, × 65.

k. *Triloculina trigonula* (Lamarck), 1804. 21/23-14/065-1, Galleon Beach, side view, × 63.

l. *Miliolinella circularis* (Brönnimann), 1855. FM5/10-01/036-3, West South Sound, side view, × 155.

m. *Miliolinella fichtelliana* d'Orbigny, 1839. 45/03-14/014-5, Central South Sound, side view, × 130.

n. *Miliolinella labiosa* (d'Orbigny), 1839. 45/08-07/031-7, Central South Sound, side view, × 135.


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Figure 2.6

a. *Miliolinella subrotunda* (Montagu), 1803. F46/40-03, East South Sound, side view, × 250.

b. *Hauerina bradyi* Cushman, 1917. 121/29-01/099-2, Hepps Wall, side view, × 60.

c. *Hauerina occidentalis* Cushman, 1946. 45/04-16/018-3, Central South Sound, side view, × 100.

d. *Schlumbergerina occidentalis* Cushman, 1929. 45/09-04/033-7, Central South Sound, side view, × 90.

e. *Articulina pacifica* Cushman, 1944. FM7/09-15/036-2, West South Sound, side view, × 215.

f. *Peneroplis bradyi* Cushman, 1930. 45/07-08/026-6, Central South Sound, side view, × 80.

g. *Peneroplis discoideus* Flint, 1897. 93.2/33-05/106-7, North North Sound, side view, × 175.

h. *Peneroplis pertusus* (Forskål), 1775. 17/24-06/061-3, Victoria House, side view, × 35.

i-k. *Peneroplis proteus* d'Orbigny, 1839. **i.** 45/07-07/026-5, Central South Sound, side view, × 85. **j.** 93.1/16-09/068-3, North Wall, side view, × 30. **k.** 89/21-08/086-3, Victoria House, side view, × 45.

l. *Peneroplis* cf. *proteus* d'Orbigny, 1839. 93.1/16-11/068-6, North Wall, side view, × 60.

m. *Monalysidium politum* Chapman, 1900. FM4/12-15/047-1, West South Sound, side view, × 160.

n. *Spirolina acicularis* (Batsch), 1791. 88/21-12/085-5, Victoria House, side view, × 88.

o. *Spirolina arientina* (Batsch), 1791. FM7/35-07/110-8, West South Sound, side view, × 70.

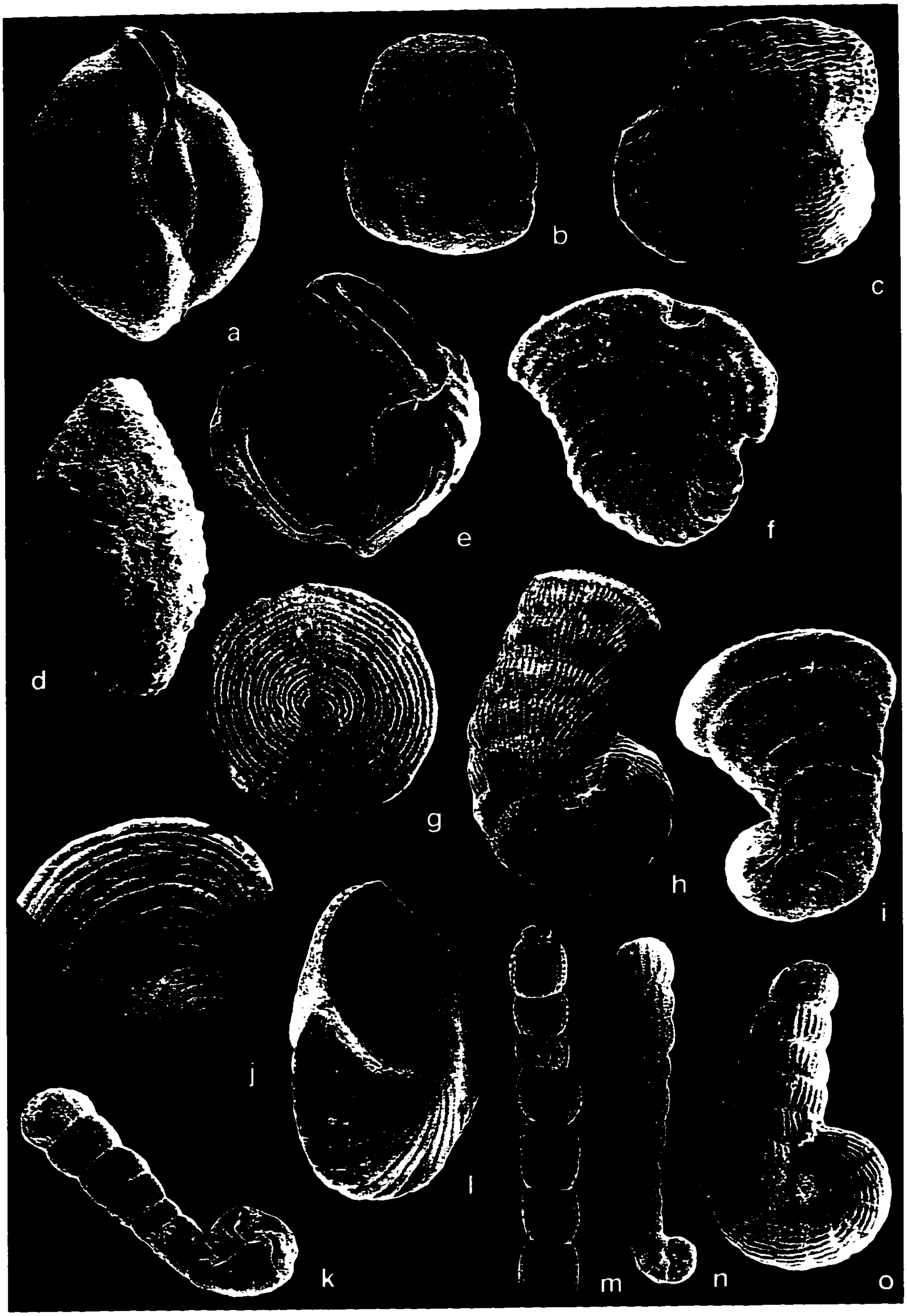
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Figure 2.7

a, b. *Archaias angulatus* (Fichtel and Moll), 1803. **a.** 1409/01-06/002-7, Northwest North Sound, side view, × 67. **b.** 93.2/33-06/106-8, North North Sound, side view, × 11.

c, d. *Archaias compressus* (d'Orbigny), 1839. **c.** 1409/01-01/001-1, Northwest North Sound, side views, × 12. **d.** 67/23-01/062-6, Galleon Beach, side view, × 40.

e, f. *Sorites marginalis* (Lamarck), 1816. **e.** 93.1/29-08/099-8, North Wall, side view, × 49. **f.** 67/23-11/064-6, Galleon Beach, side view, × 72.

g. *Amphisorus hemprichii* Ehrenberg, 1838. 45/06-01/022-3, Central South Sound, side view, × 37.

h, i. *Borelis pulchra* (d'Orbigny), 1839. **h.** 45/02-14/011-7, Central South Sound, apertural view, × 110. **i.** 158/26-06/057-3, Forereef Colliers Bay, apertural view, × 55.

j. *Bolivina striatula* Cushman, 1922. 67/23-05/063-8, Galleon Beach, side view, × 95.

k. *Bolivina tortuosa* Brady, 1884. 1409/11-12/041-1, Northwest North Sound, side view, × 230.

l. *Bolivinita rhomboidalis* (Millett), 1899. FM8/11-10/040-3, West South Sound, side view, × 280.

m. *Reussella atlantica* Cushman, 1947. FM3/05-09/020-6, West South Sound, side view, × 155.

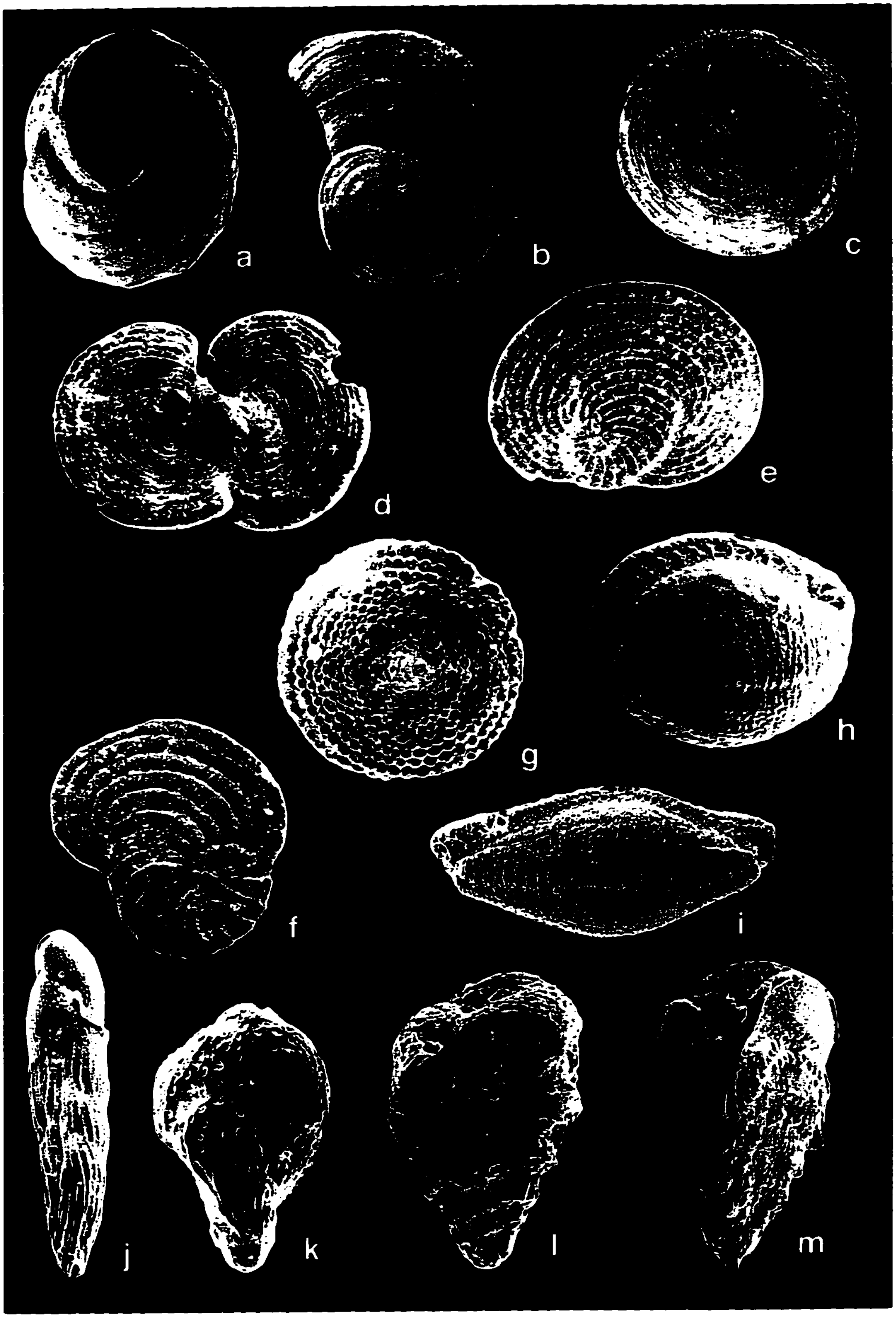
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Figure 2.8

a. *Sagrina pulchella* d'Orbigny, 1839. 11/24-09/062-5, Galleon Beach, side view, × 155.

b. *Trifarina bella* (Phleger and Parker), 1951. FM5/14-06/050-7, West South Sound, side view, × 188.

c. *Discorbis granulosa* (Heron-Allen and Earland), 1915. 18/25-03/054-3, Victoria House, ventral view, × 62.

d. *Discorbis mira* Cushman, 1922. 45/07-09/028-4, Central South Sound, dorsal view, × 70.

e. *Discorbis obtusa* (d'Orbigny), 1826. 46/11-21/042-8, West South Sound, ventral view, × 175.

f, g. *Discorbis rosea* (d'Orbigny), 1826. **f.** 140/27-01/096-1, Gun Bluff, East Sound, dorsal view, × 80. **g.** 140/27-03/096-2, Gun Bluff, East Sound, ventral view, × 80.

h. *Bronnimannia palmerae* (Bermudez), 1935. 93/26-15/059-5, East South Sound, dorsal view, × 70.

i, j. *Neoconorbina terquemi* (Rzchak), 1888. **i.** 45/03-01/012-1, Central South Sound, dorsal view, × 100. **j.** 45/03-02/012-2, Central South Sound, ventral view, × 100.

k, l. *Rosalina bulloides* d'Orbigny, 1839. **k.** 45/02-10/011-1, Central South Sound, dorsal view, × 145. **l.** 45/02-11/011-3, Central South Sound, ventral view, 150.

m. *Rosalina candeiana* d'Orbigny, 1839. 45/03-04/012-5, Central South Sound, dorsal view, × 140.


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Figure 2.9

a. *Rosalina floridana* (Cushman), 1922. 45/05-03/019-3, Central South Sound, ventral view, × 120.

b. *Cancris sagra* (d'Orbigny), 1839. 45/07-05/027-8, Central South Sound, dorsal view, × 70.

c. *Siphonina pulchra* Cushman, 1919. 93.1/16-10/068-4, North Wall, side view, × 70.

d. *Asterigerina carinata* d'Orbigny, 1839. FM7/09-06/034-4, West South Sound, ventral view, × 92.

e. *Spirillina vivipara* Ehrenberg, 1841. FM3/05-06/019-6, West South Sound, side view, × 150.

f. *Patellina corrugata* Williamson, 1858. 93.1/26-05/057-2, North Wall, side view, × 150.

g, **h**. *Ammonia beccarii* (Linné), 1767. **g**. 45/35-01/110-3, Central South Sound, dorsal view, × 70. **h**. 45/35-03/110-5, Central South Sound, ventral view, × 95.

i. *Elphidium lanieri* (d'Orbigny), 1839. 5/19-07/088-6, Victoria House, side view, × 103.

j. *Cribroelphidium discoidale* (d'Orbigny), 1839. 16/24-05/061-6, Galleon Beach, side view, × 50.

k. *Cribroelphidium poeyanum* (d'Orbigny), 1839. F104/36-07/113-3, Pond A, near George Town, side view, × 120.

l. *Heterostegina antillarum* d'Orbigny, 1839. 68/18-05/068-7, Galleon Beach, side view, × 18.

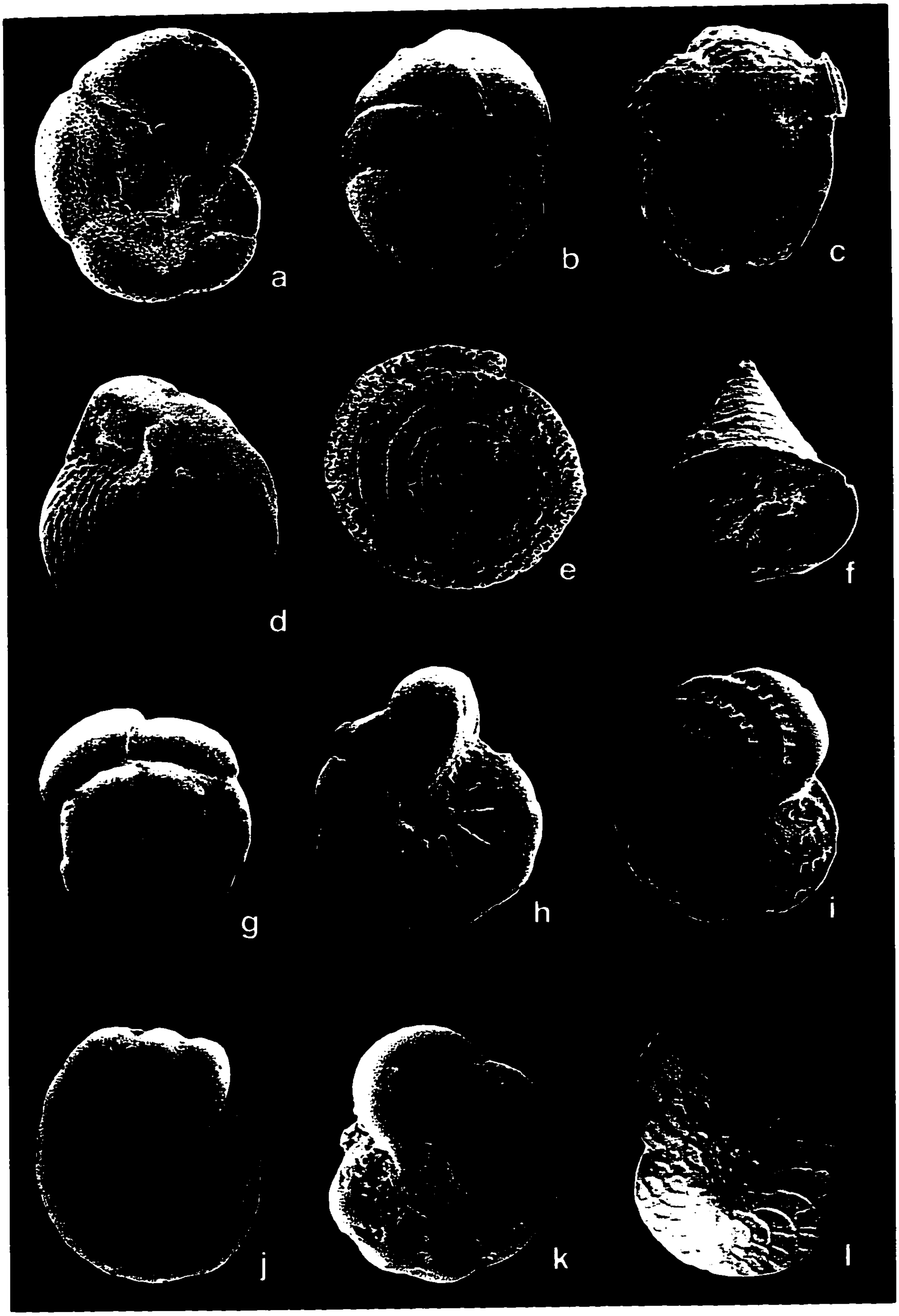
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Figure 2.10

a. *Globorotalia menardii* (d'Orbigny), 1826. 69/22-05/093-2, Galleon Beach, ventral view, × 48.

b. *Globigerina bulloides* d'Orbigny, 1826. 123/21-09/085-2, Smith Cove, spiral view, × 63.

c. *Globigerinoides rubra* (d'Orbigny), 1839. FM3/12-10/045-7, West South Sound, apertural view, × 250.

d. *Orbulina universa* d'Orbigny, 1839. 67/23-02/063-4, Galleon Beach, side view, × 65.

e. *Eponides antillarum* (d'Orbigny), 1839. 93.1/17-01/091-1, North Wall, dorsal view, × 50.

f. *Eponides repanda* (Fichtel and Mill), 1798. 93.1/17-06/091-7, North Wall, dorsal view, × 32.

g. *Eponides tubelifera canimarensis* Palmer and Bermudez, 1936. 133/25-12/055-7, Gun Bluff, East Sound, dorsal view, × 150.

h-i. *Amphistegina gibbosa* d'Orbigny, 1839. h. F89/39-03/115-8, Forereef Colliers Bay, ventral view, × 40. i. 93.1/31-01/102-8, North Wall, dorsal view, × 35.

j. *Cibicides mayori* (Cushman), 1924. 45/08-02/030-6, Central South Sound, ventral view, × 80.

k. *Cibicides pseudoungeriana* (Cushman), 1922. 46/03-05/012-7, West South Sound, ventral view, × 210.

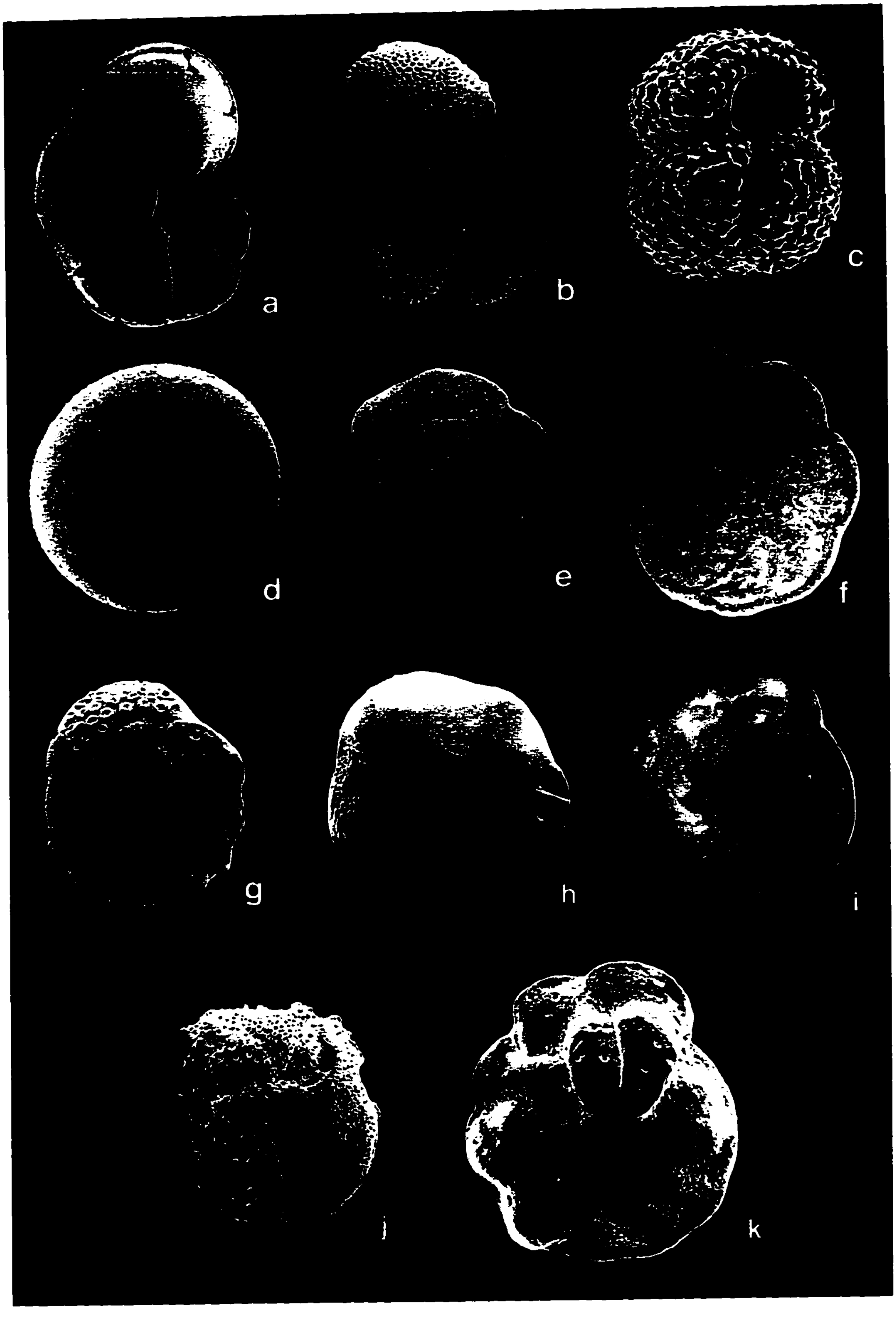
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Figure 2.11

a. *Cibicides pseudoungeriana* (Cushman), 1922. 45/03-06/013-1, Central South Sound, dorsal view, × 115.

b. *Planorbulina acervalis* Brady, 1884. 45/06-04/022-8, West South Sound, dorsal view, × 38.

c. *Planorbulina mediterranensis* d'Orbigny, 1826. 93.1/31-09/103-7, North Wall, dorsal view, × 40.

d. *Gypsina vesicularis* (Parker and Jones), 1860. F89/39-01/115-2, Forereef Colliers Bay, × 35.

e, f. *Cymbaloporetta atlantica* (Cushman), 1934. **e**. 45/06-14/026-1, Central South Sound, dorsal view, × 80. **f**. 45/06-15/026-3, Central South Sound, ventral view, × 88.

g, h. *Cymbaloporetta squammosa* (d'Orbigny), 1826. **g**. 45/03-17/015-1, Central South Sound, dorsal view, × 90. **h**. FM7/03-16/014-8, West South Sound, ventral view, × 110.

i. *Nonion grateloupi* (d'Orbigny), 1826. FM3/05-07/020-1, West South Sound, side view, × 200.

j, k. *Trichohyalus aguayoi* (Bermudez), 1935. **j**. BBP1/40-13, Betty Bay Pond, dorsal view, × 150. **k**. BBP/40-12, Betty Bay Pond, ventral view, × 150.

l. *Robertinoides bradyi* Cushman and Parker, 1936. 46/12-08/45-02, West South Sound, ventral view, × 500.

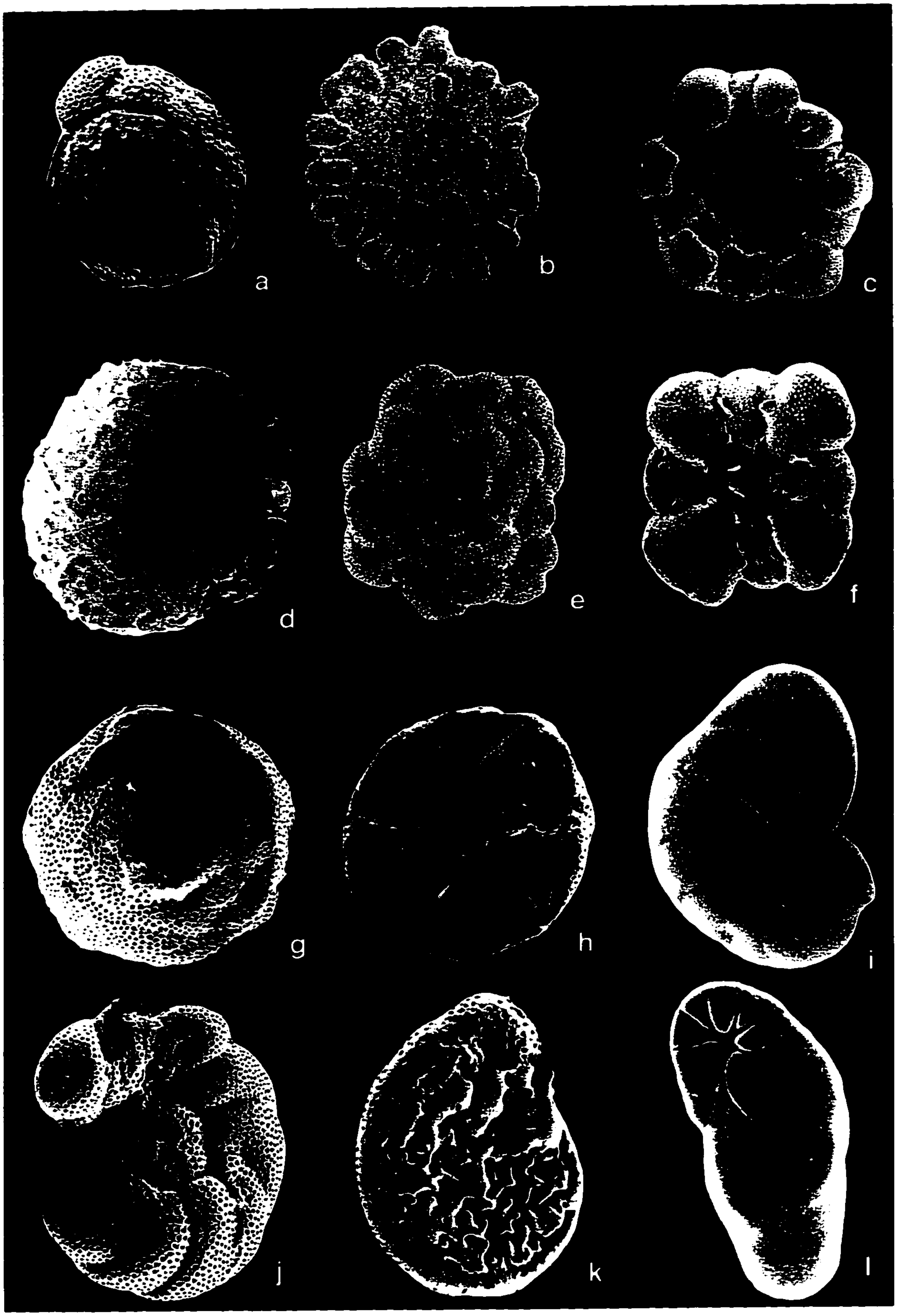
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Figure 2.12

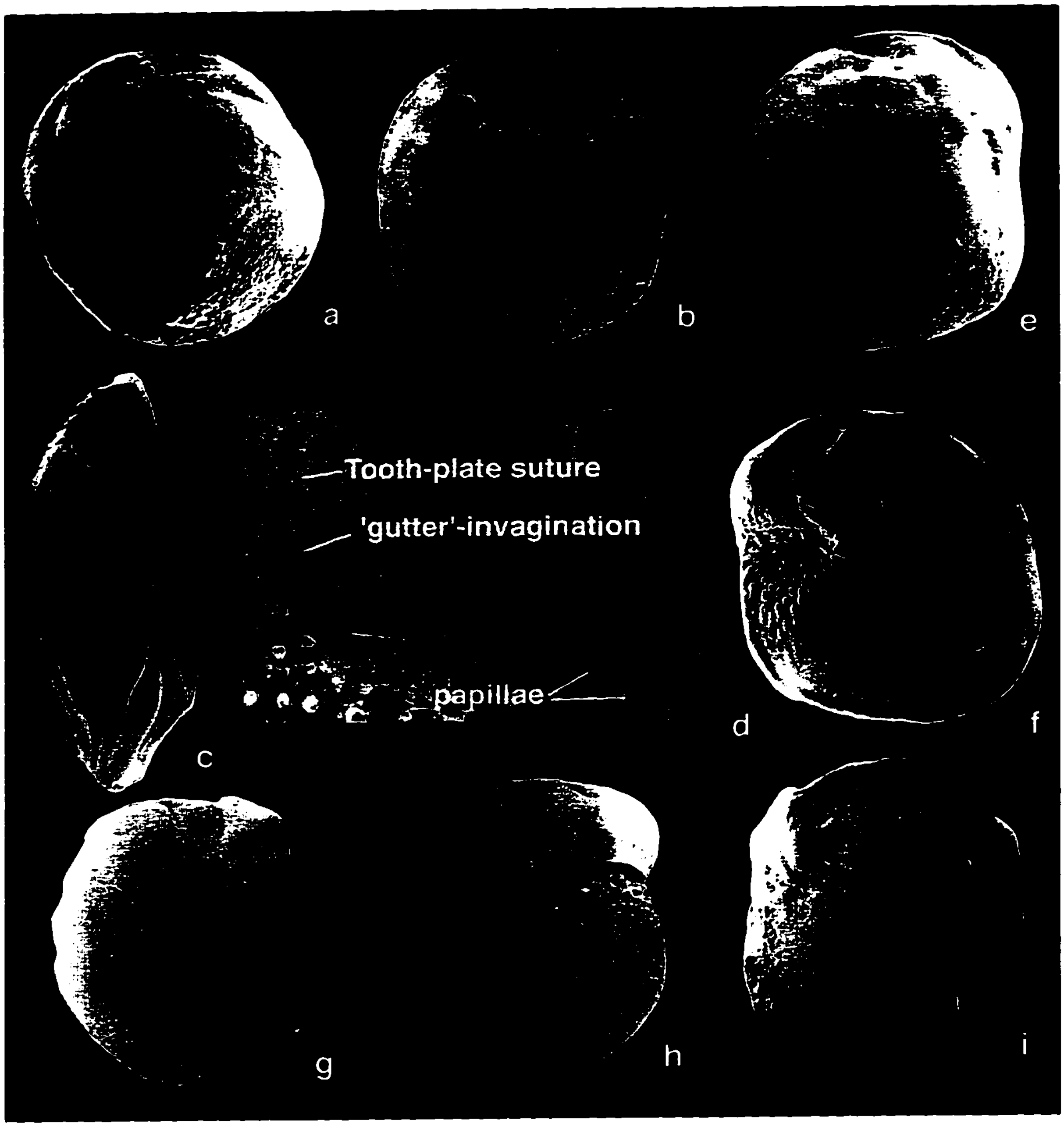
a-d. *Amphistegina caymanensis* sp. nov. Holotype. **a.** F50/37-10/119-1, Duck Pond Bight, dorsal view, × 41. **b.** F50/37-10/118-3, Duck Pond Bight, ventral view, × 41. **c.** F50/37-10/122-6, Duck Pond Bight, peripheral view, × 60. **d.** F50/37-10/118-5, Duck Pond Bight, closed view of aperture area, × 200.

e, f. *Amphistegina caymanensis* sp. nov. Paratype. **e.** F50/37-06/121-8, Duck Pond Bight, dorsal view, × 44. **f.** F50/37-06/117-5, Duck Pond Bight, ventral view, × 44.

g. *Amphistegina caymanensis* sp. nov. F50/37-08/117-7, Duck Pond Bight, ventral view, × 35.

h. *Amphistegina caymanensis* sp. nov. F50/38-03/114-5, Duck Pond Bight, ventral view, × 45.

i. *Amphistegina caymanensis* sp. nov. F50/37-08/122-3, Duck Pond Bight, dorsal view, × 38.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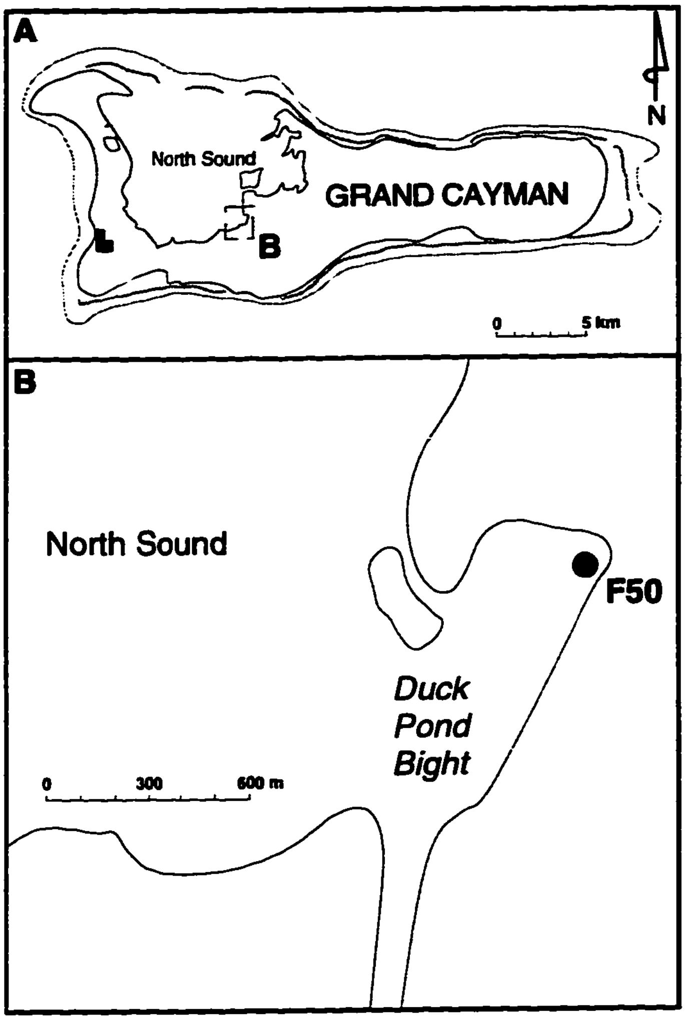

Fig. 2.13—Location of the site of collection of holotypes of *Amphistegina caymanensis* sp. nov.

– 1.11 mm. Minimum diameter – 0.93 mm. Axial diameter (thickness) – 0.36 mm. 11 chambers in last whorl.

Description. Test shape from plano-convex to more commonly biconvex. In plan view commonly square-shaped with rounded angles. Spiral side involute to evolute as test size increases. Umbilical side involute. Periphery carinated (keeled). On spiral side, sutures have pronounced angle in young involute forms. In more evolute adult forms angles less pronounced. Central part of chambers irregular. Short partition (interseptum) projects toward center of the test. On umbilical side, simple, narrow supplementary chambers extend half way to two-thirds of distance from umbilicus to periphery. Supplementary chambers star-shaped, or polygon-shaped when extension not well developed.

Slit-like and interiomarginal aperture situated on umbilical side, reaching from "gutter"-invagination (situating close to umbilicus) to periphery. Aperture face is papillate on final whorl in front of aperture, and papillae tend to be arranged in rows (up to 10) parallel to periphery. Aperture has narrow overhanging lip with single row of papillae. Tooth plate suture runs from "gutter"-invagination to chamber suture and indicates position of tooth plate complex. Near margin, aperture face is angled, giving that part of chamber on the spiral side a more anterior position with respect to growth direction than the remainder of the chamber.

Discussion. Most reports suggest that only one species of *Amphistegina, A. gibbosa*, is found in the Caribbean and Florida region (Hofker, 1964; Seiglie, 1967; Sen Gupta and Schafer, 1973; Wantland, 1975; Crouch and Poag, 1979; Poag, 1981; Poag and Tresslar, 1981; Hallock *et al.*, 1986; Galluzzo *et al.*, 1990; Triffleman *et al.*, 1991; Wetmore, 1992). Nevertheless, other species of *Amphistegina*, including *A. lessonii* (Cushman, 1931; Phleger and Parker, 1951; Albers, *et al.*, 1966; Cebulski, 1969; Bock, 1971; Todd and Low, 1971; Wright and Hay, 1971; Weis and Steinker, 1977), and *A. radiata* (Hofker, 1969) have been reported. Although many of the *A. lessonii* proved to be *A. gibbosa*, the status of *A. gibbosa* as the only species of *Amphistegina* in the Caribbean and Florida region is open to debate.

In 1826, d'Orbigny described *Amphistegina lessonii* from the Pacific Ocean. In the same year, he proposed *A. gibba* for the species he considered to be the Caribbean counterpart. This was, however, a *nomen nudum* until 1839 when d'Orbigny described and illustrated *A. gibbosa* from Cuba, a species that is generally regarded to be the same as *A. gibba*. In a summary paper, Larsen (1977) recognized six modern species of *Amphistegina* in the world: *A. lessonii* d'Orbigny, *A. gibbosa* d'Orbigny, *A. papillosa* Said, *A. radiata* (Fitchel and Moll), *A. lobifera* Larsen, and *A. bicirculata* Larsen. He pointed out that *A. gibbosa* is the valid and dominant species in the Caribbean region. He also noted that he had not found *A. gibbosa* and *A. lessonii* together. Compared to *A. lessonii, A. gibbosa* is much more irregular, with depressed lenticular to asymmetrically inflated tests, that are sharply carinate, less globose in shape, and that have more chambers in the last whorl.

A. gibbosa in the Caribbean and Florida region displays a wide range of morphological variation. *A. gibbosa* found on Grand Cayman, for example, are much flatter (low axial length) than the Florida specimens. As a result, most species of *Amphistegina* reported in Caribbean and Florida region belong to *A. gibbosa*.

The new species of *A. caymanensis* from Grand Cayman differs from *A. gibbosa* (Table 2.2) by having 1) a square shaped test in plane view, 2) a biconvex or lenticular test in periphery view, 3) less chambers in the last whorl, 4) dominance of sinistral coiling, 5) an inflated last few chambers, and 6) a light reddish non-transparent test. Ecologically, the environment where the new species is found (restricted lagoon with brownish-red, brackish water and high organic content) is different from that where typical *A. gibbosa* normally live (forereef with clean and normal marine water, hard substrate). Specimens reported by Cushman (1931) and Buzas *et al.* (1977), here included as synonyms of the new species, are also from shallow and restricted lagoonal environments. This different ecological distribution between different species/varieties has also been confirmed recently by Dr. P.H. Muller (personal communication).

This new species is similar to *A. lessonii* in terms of its axial view, fewer numbers of chambers on the last whorl, common coil direction, and aperture features. It is distinguished from *A. lessonii* by its test shape in plan view, carinate periphery, narrow spine-like extension of supplementary chambers, and non-transparent test (Table 2.2).

Table 2.2. Comparisons of *Amphistegina caymanensis* sp. nov. with *A. gibbosa* and *A. lessonii*

Characters	***A. caymanensis***	***A. gibbosa***	***A. lessonii***
Plan view	Square shaped with rounded angles	Circular or rounded	Circular or rounded
Periphery	Most are entirely carinate	May not be carinate	Not carinate
Axial diameter	Many biconvex or lenticular	Adult forms plano-convex or concavo-convex dominant.	Biconvex more common
Numbers of chambers in the last whorl (~ 1mm dia.)	Commonly ≤15	Commonly ≥15	Commonly <10
Supplementary chambers	Very narrow spine-like extension	Narrow fingerlike extension (digitus)	Simple, distinct star-shaped pattern
Aperture	Narrow slit located on umbilical side and extending from periphery toward umbo about 2/3 way. Aperture face wide, can extend inward up to umbilicus. Papillae tend to aligned parallel to periphery (up to 10 rows)	Narrow slit located near periphery, extending towards umbo about halfway. Apertural face small and low, commonly in sharp angle, several rows of rounded papillae aligned in front of aperture in first few chambers of final whorl.	Slit on umbilical side, extending from periphery toward umbo about 2/3 way. Aperture face wide. Papillae tend to aligned to 6 rows.
Coiling	Dominated sinistral (left handed)	Dominantly dextral (right-handed)	Dominantly sinistral
Intersepta	Irregular	Regular	Regular
Last few chambers	Somewhat inflated and observable more on spiral side	Not observable except the very last chamber. On spiral side mostly smooth and flat.	Not observable. Smooth.
Test	Not transparent and light reddish in color due to thick organic envelopes	Transparent	Transparent

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CHAPTER 3 COMPARISON OF FORAMINIFERAL ASSEMBLAGES IN SEDIMENTS ON THE WINDWARD AND LEEWARD SHELVES OF GRAND CAYMAN, BRITISH WEST INDIES

INTRODUCTION

Foraminiferal assemblages extracted from sediment samples are groups of species that reflect ecological preferences and post-mortem taphonomic signatures of abrasion, dissolution, transportation, and bioerosion (Martin and Liddell, 1989, 1991; Parsons, 1990). As emphasized by Martin and Liddell (1988, p. 299), the distribution of such assemblages "...should not be construed as exactly representing the biotic zonation of living foraminifera, but rather indicating the potentially preservable record." Nevertheless, the recognition and understanding of such patterns play a critical role in the interpretation and understanding of foraminifera distributions in ancient successions. Most islands in the Caribbean have an exposed windward coast and a protected leeward coast. Numerous studies on foraminiferal assemblages in the Caribbean and Florida region have focused on windward shelves, such as those on Cuba (Bandy, 1964), Belize (Cebulski, 1969; Wantland, 1975), Jamaica (Martin and Liddell, 1988) and Florida (Lidz and Rose, 1989; Levy, 1991). Foraminifera distributions on those shelves typically show distinctive, regular zones that parallel the reef crest. By comparison, foraminiferal assemblages on the leeward shelves are commonly less well-defined (Seiglie, 1971; Brasier, 1975a). Such studies, however, have tended to focus on a particular type of shelf; few have compared and contrasted the foraminiferal assemblages on the windward and leeward shelves.

On an intuitive basis, it might be expected that the foraminiferal assemblages and their distribution should be more clearly delineated and systematically distributed on the leeward shelf than on the windward shelf. This simplistic model is based on the premise that the foraminifera on the leeward shelf are protected from prevailing winds and should therefore be subjected to less physical stress and post-mortem redistribution. This hypothesis is tested by examining the foraminiferal assemblages recovered from sediments on the windward and leeward shelves of Grand Cayman. This island was selected because its biologic communities and geology are well known (e.g., Darbyshire *et al.*, 1976; Rigby and Roberts, 1976; Jones 1994; Blanchon and Jones, 1995). Furthermore, this island is devoid of rivers that could discharge clastic sediment onto the surrounding shelves. As a

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result, this influence on the foraminiferal assemblages does not have to be considered. By using sediment samples systematically collected from the leeward and windward shelves of Grand Cayman, this study (i) delineates the foraminiferal assemblages, (ii) establishes the foraminiferal diversity trends, (iii) examines the distribution of dominant species and foraminiferal assemblages, and (iv) determines the contribution of foraminifera to the medium and coarse-grained sand component of the sediment on the shelves. This data base allows comparison of the foraminiferal assemblages found in sediments on the windward and leeward shelves. By doing so, it assesses the usefulness of foraminifera for paleoecological interpretations in older deposits.

METHODS

The foraminifera were identified using Cushman (1921, 1922a, 1922b, 1924, 1929, 1930, 1931), Bermúdez (1935), Barker (1960), Hofker (1964, 1976), Bock (1971), Wantland (1975), and Poag (1981). Synonyms of the species are listed in Appendix C.

Foraminiferal tests were obtained from 63 sediment samples collected by SCUBA or snorkeling during the summers of 1990 to 1994. They were collected at 40–60 m intervals along four traverses on the windward and leeward shelves of Grand Cayman (Fig. 3.1). After collection, each sample was washed with distilled water and then allowed to air dry.

For this study, the "sieve counting method" as outlined by Martin and Liddell (1988, p. 299) was used to construct the abundance data base. This technique was used because it provides insights into the effects of transportation, sorting, and differential preservation of foraminifera in turbulent reef settings (Martin and Liddell, 1988, 1989). Accordingly, one split of each sample (100–150 g) was divided into the >2 mm, 1–2 mm, 0.5–1 mm, 0.25–0.5 mm, 0.125–0.25 mm, 0.063–0.125 mm, and <0.063 mm fractions by sieving for 10 minutes. Then, if possible, at least 300 individuals were identified and counted from each fraction coarser than 0.125 mm. In many cases, however, less than 300 specimens were identified and counted simply because the sediment fraction being examined contained less than 300 specimens. Accordingly, the total number of specimens counted for each sample varies (Tables 1, 2) because of the natural differences in the density of foraminifera from sample to sample. This is especially true in the >2 mm fraction because it usually contains numerous *Halimeda* plates but relatively fewer foraminifera tests. The total percent abundance of each species was calculated by adding the number of specimens found in all size-fractions from each locality (Tables 3.1, 3.2).

Analyses of the 63 samples used in this study produced a database formed of 142 species and 52,993 specimens. Locality groups were defined by performing Q-mode

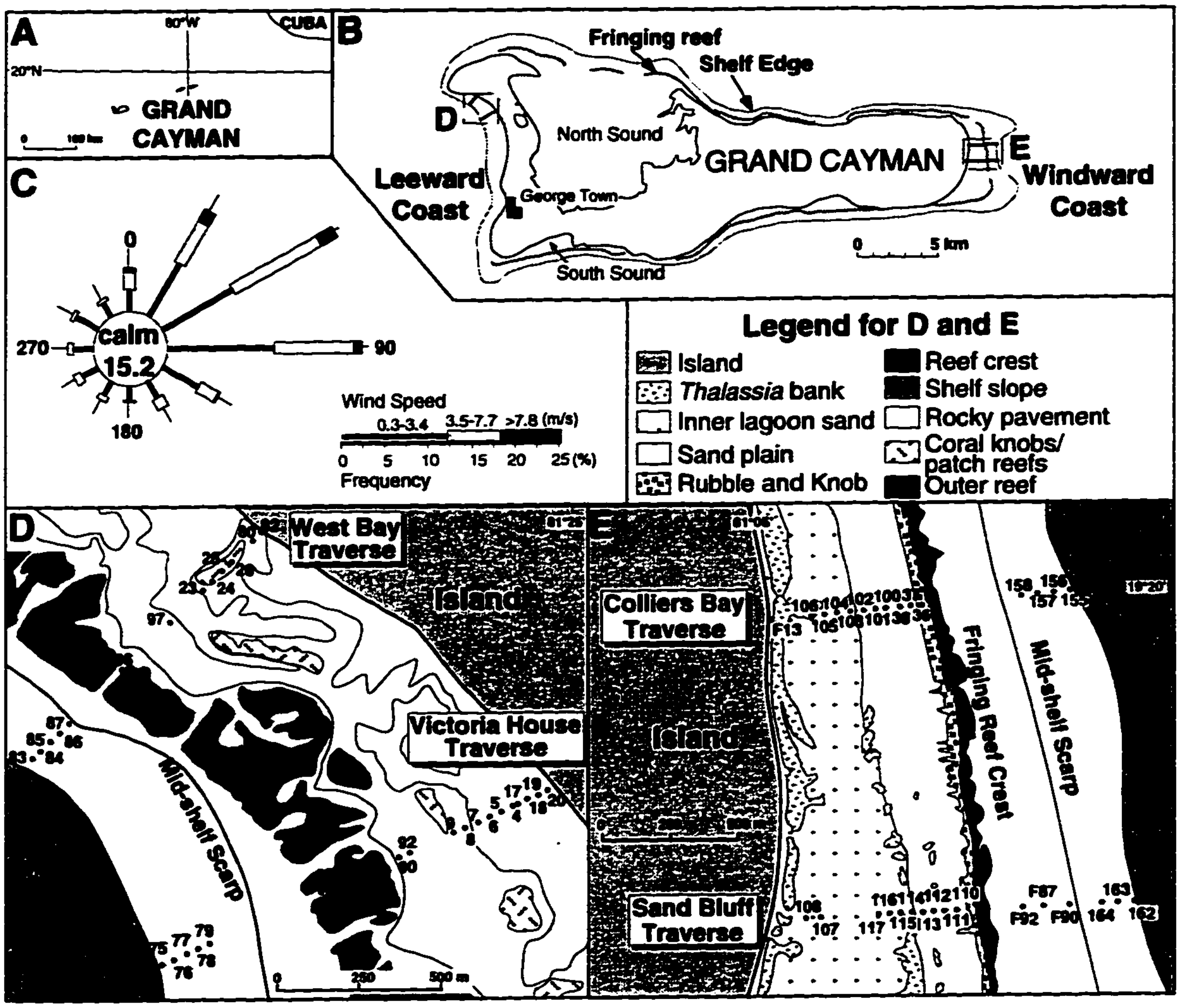

Figure 3.1—A) Location of Grand Cayman in northern Caribbean Sea. B) Map showing study areas, Grand Cayman. C) Time-averaged annual wind rose graph (based on Darbyshire *et al.*, 1976). D) Leeward shelf showing positions of West Bay and Victoria House traverses, locations of samples, and substrate (from Rigby and Roberts, 1976). E) Windward shelf showing positions of the Colliers Bay and Sand Bluff traverses, locations of samples, and substrate (from air photos, 1979).

Table 3.1. Distribution data expressed as percentage of total number of the foraminifera recovered from each locality on the windward shelf. Those species that form less than 3% of the fauna at each locality are collectively listed as "other species". S = number of species; N = number of specimens.

	LOCALITIES															
SPECIES	36	37	38	100	101	102	103	104	105	106	107	108	110	111	112	113
Amphisorus hemprichii	7.4	4.6	1.5	2.3	5.2	5.4	0.9	0.9	0.1	0.4	1.0	1.3	1.6	5.2	2.4	1.6
Amphistegina gibbosa	14.9	20.4	20.9	8.1	2.5	2.4	0.3	0.1	0.4	0.2	0.5	0.5	18.7	9.5	6.6	5.3
Archaias angulatus	7.1	15.8	17.5	50.7	57.6	57.9	63.9	62.6	56.5	56.0	64.8	61.8	24.1	42.8	49.8	59.3
Archaias compressus	0.0	0.3	0.4	0.0	2.0	0.8	3.6	4.8	7.5	7.6	0.8	2.0	0.8	0.6	0.8	0.2
Asterigerina carinata	16.7	8.9	8.6	0.0	4.7	3.6	3.1	1.6	1.1	1.0	1.8	0.9	4.7	5.5	5.8	4.4
Borelis pulchra	2.6	3.0	2.6	0.5	0.4	0.7	1.2	2.2	2.5	2.8	1.9	2.1	1.6	2.3	0.7	0.6
Cymb. squammosa	0.6	3.9	1.1	4.5	4.5	3.2	2.6	1.2	0.9	1.4	0.9	0.8	3.9	2.3	5.1	2.6
Discorbis granulosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Discorbis mira	3.2	1.3	1.5	0.5	0.3	0.6	0.4	0.2	0.1	0.3	1.1	1.1	1.2	1.4	0.7	0.2
Discorbis rosea	11.5	12.5	19.0	4.3	1.3	1.8	0.9	1.0	1.0	1.0	2.4	2.0	15.2	11.5	6.8	2.9
Miliolinella circularis	2.2	3.6	1.5	2.7	0.9	1.1	0.8	0.8	0.4	0.4	0.5	0.7	1.6	1.4	1.2	1.1
Peneroplis proteus	1.5	0.3	0.4	0.5	0.7	0.4	0.4	0.1	0.2	0.2	0.9	1.0	0.8	1.1	0.8	0.4
Quin. agglutinans	0.9	1.6	1.1	3.6	3.3	4.7	7.0	5.7	7.3	5.8	1.6	3.1	0.8	1.7	1.7	1.6
Quin. barbouri	0.0	0.7	1.1	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.2	1.2	0.3	0.2	0.6
Quin. bidentata	0.0	0.7	0.7	0.9	0.4	2.4	3.6	2.9	2.1	3.5	3.5	3.5	1.9	2.6	1.2	1.5
Rosalina candeiana	8.2	1.0	4.5	4.7	2.8	3.5	2.0	5.3	4.9	4.0	2.4	1.3	5.8	0.6	3.2	4.0
Triloculina linneiana	0.4	1.6	1.9	3.4	2.3	1.2	1.7	1.6	2.1	3.2	2.3	3.5	1.2	0.3	2.5	2.2
Other species	22.8	19.8	15.7	12.8	11.1	10.3	7.5	9.0	12.9	12.2	13.5	14.2	14.9	10.9	10.5	11.5
S	54	46	47	47	54	57	55	54	51	50	57	57	46	42	48	56
N	503	324	270	588	1197	944	1525	1519	1385	1221	1273	921	257	348	590	823

	LOCALITIES														
SPECIES	114	115	116	117	155	156	157	158	162	163	164	F13	F87	F90	F92
Amphisorus hemprichii	3.7	4.0	1.3	1.6	0.4	0.0	0.3	0.3	0.0	0.8	0.3	0.2	0.2	1.4	0.4
Amphistegina gibbosa	2.2	1.4	1.8	0.4	48.5	63.4	37.1	45.3	52.3	47.0	64.1	1.7	36.6	29.4	30.3
Archaias angulatus	55.8	53.6	52.4	54.4	5.3	6.1	22.6	15.5	4.3	14.1	16.3	77.9	10.3	8.2	8.3
Archaias compressus	1.0	1.0	1.3	2.0	0.0	0.5	0.4	0.0	0.0	1.1	0.0	0.0	0.5	0.2	0.6
Asterigerina carinata	4.5	6.2	5.1	4.3	8.2	4.0	7.0	6.9	8.4	5.9	1.7	1.1	11.7	15.4	14.8
Borelis pulchra	0.6	1.3	0.7	1.2	2.0	1.9	3.9	3.0	1.9	2.2	1.1	0.6	2.1	2.8	1.5
Cymb. squammosa	3.4	3.4	2.9	2.3	0.0	0.0	0.0	0.3	0.3	0.0	0.0	6.3	0.7	0.7	0.6
Discorbis granulosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0
Discorbis mira	0.6	0.5	0.5	0.3	1.6	0.7	0.4	1.0	1.2	0.5	0.3	1.5	2.1	3.0	1.7
Discorbis rosea	1.7	2.4	1.0	2.2	1.3	3.3	3.1	4.6	0.9	1.9	2.5	1.7	11.2	6.1	14.6
Miliolinella circularis	1.9	1.1	0.5	0.5	0.9	0.5	0.1	0.0	0.3	0.0	0.0	0.0	1.1	0.7	0.6
Peneroplis proteus	0.6	0.6	1.2	1.3	2.2	2.3	4.5	1.3	3.1	2.4	0.3	0.0	0.2	2.3	0.8
Quin. agglutinans	3.0	4.8	3.6	2.2	2.5	2.6	2.1	3.8	1.2	1.1	0.6	0.8	0.2	0.7	0.4
Quin. barbouri	0.3	0.0	0.1	0.1	1.1	0.7	0.9	1.2	2.2	4.1	4.1	0.0	1.8	1.2	0.9
Quin. bidentata	0.8	2.6	5.3	2.8	0.4	0.0	0.0	0.4	0.3	0.8	0.6	0.4	0.2	1.2	0.0
Rosalina candeiana	1.8	2.4	7.2	7.1	2.0	1.2	0.6	1.3	1.2	1.6	0.3	0.2	3.2	2.3	5.1
Triloculina linneiana	2.6	0.6	2.1	3.5	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.2	0.2	0.7	0.0
Other species	15.5	14.1	13.0	13.8	23.6	12.8	16.9	14.5	22.4	16.5	7.8	4.4	17.7	23.7	19.4
S	66	55	63	56	54	35	44	43	41	38	26	27	56	56	56
N	1341	871	769	743	550	426	668	677	324	370	362	474	437	429	528

Table 3.2. Distribution data expressed as percentage of total number of the foraminifera recovered from each locality on the leeward shelf. Those species that form less than 3% of the fauna at each locality are collectively listed as "other species". S = number of species; N = number of specimens.

	LOCALITIES															
SPECIES	4	5	6	7	8	9	17	18	19	20	23	24	25	26	75	76
Amphisorus hemprichii	4.1	2.0	1.7	0.4	2.9	0.8	3.9	1.0	0.3	0.0	0.4	0.0	0.4	1.4	1.0	0.4
Amphistegina gibbosa	1.4	0.0	0.0	4.0	1.6	2.9	1.8	2.2	1.6	1.4	5.8	5.6	4.9	5.1	4.9	9.3
Archaias angulatus	24.5	38.8	17.7	50.8	23.4	39.9	33.8	43.2	60.1	62.6	36.7	42.3	33.6	29.6	51.7	50.4
Archaias compressus	0.3	0.7	1.0	0.4	0.5	0.4	0.3	0.1	1.1	0.6	0.0	0.6	0.3	0.2	2.3	2.3
Asterigerina carinata	16.0	14.8	20.3	7.2	12.7	11.9	12.2	6.6	2.1	2.9	9.5	9.6	9.3	12.3	9.2	9.7
Borelis pulchra	1.6	3.0	2.0	3.8	2.4	3.8	2.2	4.4	2.8	2.3	2.1	1.9	2.5	3.4	0.9	0.6
Cymb. squammosa	6.4	5.9	6.3	1.9	4.3	6.1	7.4	5.3	1.1	1.2	4.5	3.0	3.9	3.9	2.6	1.1
Discorbis mira	3.8	2.5	4.6	1.7	2.5	2.3	2.2	0.7	0.3	0.7	2.4	0.7	2.8	3.3	0.9	0.0
Discorbis rosea	6.9	5.5	3.1	9.4	5.3	9.8	6.6	14.3	9.8	14.9	15.5	14.9	17.0	11.3	1.0	1.0
Peneroplis discoideus	0.9	0.2	0.5	0.0	0.6	0.1	1.1	0.0	0.0	0.0	0.3	0.1	0.0	0.2	0.2	0.0
Peneroplis proteus	0.4	1.0	2.5	0.4	1.1	0.8	0.6	0.1	0.0	0.1	0.5	0.2	0.6	0.4	1.2	0.1
Quin. agglutinans	2.3	1.9	3.1	4.7	2.9	2.1	3.0	4.4	3.4	2.7	1.4	1.6	0.9	1.3	2.6	3.3
Quin. bidentata	2.5	0.8	1.3	0.4	0.8	0.8	1.0	0.8	1.7	0.8	0.1	0.1	0.2	0.1	0.5	0.1
Rosalina candeiana	2.8	1.7	5.5	0.5	5.5	1.4	3.2	1.1	3.2	3.0	8.2	8.0	10.5	11.9	2.7	2.1
Triloculina carinata	0.7	1.1	0.7	0.1	2.9	0.7	2.7	3.7	0.0	0.1	0.3	0.9	0.2	1.0	0.9	0.5
Triloculina linneiana	2.8	1.9	3.6	1.1	6.1	0.9	3.3	1.7	0.7	0.4	0.1	0.2	0.5	0.6	0.8	0.8
Valvulina oviedoiana	2.3	2.5	5.2	4.0	6.9	2.5	3.5	1.5	6.5	1.6	0.8	2.1	0.6	1.1	3.6	2.3
Other species	20.3	15.7	20.9	9.2	17.6	12.8	11.2	8.9	5.3	4.7	11.4	8.2	11.8	12.9	13.0	16.0
S	50	46	54	41	55	42	42	34	33	34	40	43	51	47	59	55
N	981	1008	1346	839	1079	767	901	722	917	853	759	810	997	1126	1247	798

	LOCALITIES															
SPECIES	77	78	79	80	82	83	84	85	86	87	88	89	90	92	96	97
Amphisorus hemprichii	0.5	0.3	0.8	0.4	0.0	0.3	0.4	0.5	0.4	0.4	2.2	0.8	2.5	1.5	0.4	0.3
Amphistegina gibbosa	7.7	8.0	8.6	8.8	8.8	5.0	5.2	5.6	3.6	5.4	6.3	9.2	1.1	2.9	5.6	5.0
Archaias angulatus	45.8	48.1	29.1	56.6	73.9	36.5	52.0	51.4	39.6	50.8	23.6	29.3	42.4	44.7	39.9	48.5
Archaias compressus	1.3	4.4	2.6	1.1	0.0	1.5	2.2	4.7	1.9	1.7	0.0	0.2	0.0	0.1	1.4	5.3
Asterigerina carinata	7.9	8.2	16.7	2.4	0.4	12.2	10.6	7.2	14.1	12.0	13.9	10.7	8.8	15.5	10.0	5.0
Borelis pulchra	0.7	1.0	1.8	1.2	0.4	0.7	1.2	1.7	1.4	1.3	1.4	4.1	2.9	3.4	2.2	2.7
Cymb. squammosa	1.8	1.6	2.0	1.6	0.0	0.9	1.4	2.2	3.0	2.2	2.7	2.5	3.1	3.1	3.4	1.8
Discorbis mira	0.5	0.3	1.0	1.2	0.0	1.2	0.6	0.9	1.3	0.5	1.5	0.6	1.6	2.7	0.6	0.4
Discorbis rosea	1.5	1.3	1.8	15.0	16.1	3.4	4.5	5.4	3.0	4.7	2.9	5.7	2.5	4.6	11.3	14.4
Peneroplis discoideus	0.4	0.3	0.6	0.2	0.0	0.2	0.2	0.3	3.4	2.6	4.5	0.6	0.7	1.0	1.7	0.3
Peneroplis proteus	0.6	0.9	2.4	0.4	0.0	0.7	0.8	0.9	0.6	0.8	3.4	2.1	2.0	1.4	1.4	0.1
Quin. agglutinans	3.3	3.7	1.8	0.0	0.4	1.7	2.8	2.1	2.4	2.1	2.8	3.5	2.1	1.5	1.3	2.3
Quin. bidentata	0.2	0.1	0.0	0.2	0.0	0.5	0.4	0.2	0.1	0.4	0.9	0.6	0.5	0.0	0.4	4.2
Rosalina candeiana	1.9	2.0	6.2	5.2	0.0	8.3	2.2	3.1	4.7	2.6	7.0	3.3	8.4	0.0	2.2	0.8
Triloculina carinata	0.7	0.6	0.2	0.2	0.0	0.4	0.3	0.6	0.4	1.0	0.9	0.8	2.3	1.2	0.8	1.2
Triloculina linneiana	1.5	0.6	1.2	0.3	0.0	1.4	0.7	0.6	1.4	0.7	1.7	1.2	2.5	1.8	0.8	0.5
Valvulina oviedoiana	3.3	2.0	1.1	1.1	0.0	1.7	1.3	0.3	0.8	0.8	2.0	1.8	1.2	0.8	1.2	3.7
Other species	20.4	16.6	22.1	4.1	0.00	23.4	13.2	12.3	17.9	10.0	22.3	23.0	22.3	13.8	15.4	3.5
S	57	52	61	35	6	74	53	47	62	52	67	54	63	48	56	40
N	847	792	930	1142	249	1173	993	877	985	1114	1024	513	1542	1230	772	1293

cluster analysis that used all the species which form ≥3% of the foraminiferal fauna at one locality. This selection process was done because Koch (1987) demonstrated that large samples with a high diversity may have many more rare species than smaller samples (cf. Martin and Liddell, 1988). As a result, the analyses for the leeward and windward shelves of Grand Cayman are each based on 17 species (Table 3.1, 3.2). Dissimilarity indices (0 = minimum dissimilarity, or maximum similarity) between each pair of samples were calculated in Euclidean distance (= square root of the sum of the squared differences in values for each variable) using the abundance data (Tables 3.1, 3.2). Binary (presence-absence) data were not used because they consistently failed to give dendrograms that displayed foraminiferal zonations. This parallels the experience of Martin and Liddell (1988). The dendrogram was derived using the between groups method and the SPSS program. Each locality group was equated to a foraminiferal assemblage that is named according to its most common species or genera.

The diversity of each sample is expressed by the *Richness index* (S) and the *Shannon-Weaver index* (H'). S equals the number of species in a sample and can, therefore, be a function of sample size. The Shannon-Weaver Index is given by $H'=-\Sigma[(n_i/N)\log(n_i/N)]$, where n_i is the number of specimens of species *i* and N is the total number of specimens counted. This index considers the number of species and their relative abundances. The maximum value of H' occurs when all species are equally distributed (Buzas, 1972). Therefore, high H' means high evenness or low dominance.

An assessment of the contribution of foraminiferal tests to the sediment budget was made by calculating the percentage of foraminifera in the 0.25-2.00 mm size fraction of each sediment sample from the West Bay traverse on the leeward shelf and the Colliers Bay traverse on the windward shelf (Fig. 3.1). The >2 mm size fraction was not included because most of it is formed of *Halimeda* plates and other bioclasts. The <0.25 mm size fraction was excluded because it was impossible to identify the foraminifera that form these small grains. For the medium and coarse-sand fractions, however, the percentage of foraminiferal tests was calculated by counting the number of foraminifera in 1,200–2,000 grains collected from the 0.25–0.5 mm, 0.5–1 mm, and 1–2 mm size fractions of each sample.

THE STUDY AREA

Grand Cayman, located in the northern Caribbean Sea, is a flat, low-lying island that is 35 km long (east-west) and 6 km to 14 km wide (Figs. 3.1A, 3.1B). Winter temperatures are 23.9–26.7°C, whereas summer temperatures are 28.5–28.6°C (Hsu *et al.*, 1972).

Waters in the peripheral lagoons have annual maximum surface temperatures of 32°C in July and August (Raymont *et al.*, 1976) and normal open marine salinities (35 to 38‰) with a chlorinity of 19.9 to 20.9‰ (Moore, 1973). There is no river discharge from the island and the ocean waters surrounding Grand Cayman are remarkably clear. Mixed diurnal and semi-diurnal tides around Grand Cayman have a maximum range of 1 m (Burton, 1994). Most shelf and coastal currents are driven by onshore wind and waves. Trade winds are from the east or slightly northeast or southeast throughout most of the year (Fig. 3.1C), and waves are typically 1.25–2.5 m high on the windward side and <0.5 m on the leeward side (Darbyshire *et al.* 1976). In winter, the winds come from the north and northwest in response to the cold fronts from North America. These winds, known locally as 'Nor-westers' commonly produce severe, storm conditions on the west, leeward coast of the island. Over the last forty years hurricanes have been infrequent apart from Hurricane Gilbert which passed over the island in 1988 (Clark, 1988).

In the forereef, the upper (0–15 m) and lower (20–25 m) terraces are separated by the mid-shelf scarp (Blanchon and Jones, 1995). Peripheral lagoons are developed on the inner (restricted) part of the upper terraces of the windward shelves on the east, south and north coasts of Grand Cayman (Figs. 3.1B, 3.2). The lagoons, which are a few hundred meters to 1.6 km wide, are divided into inner and outer zones. The inner zone is typically characterized by *Thalassia* banks. The outer zone incorporates a sand plain and a narrow, shallow band of loose rubble and sand behind the reef crest (Figs. 3.1E, 3.2). The reef crests, which are formed of growing corals and/or boulders of dead corals, can be emergent during low tide. The reef crest on the windward shelf commonly impedes sediment movement between the lagoon and the forereef area. The leeward shelf of Grand Cayman is exposed to the open ocean because there is no offshore barrier reef that reaches sea level. On this shelf, isolated patch reefs and coral knobs do not impede onshore water movement and marine grasses are rare (Figs. 3.1D, 3.2). Thus, loose sediments above normal wave base, including those on the exposed beach sand, are prone to abrasion, sorting, transportation, and mixing when energy levels allow. This is especially true during the winter months when 'Nor-wester' gales generate strong onshore waves that have a deep wave base and the capacity to move substantial quantities of sand across the shelf on an annual basis.

RESULTS OF Q-MODE CLUSTER ANALYSES

The foraminifera on the windward shelf belong to four locality groups (Fig. 3.3) whereas those on the leeward shelf belong to two locality groups (Fig. 3.4). Each group

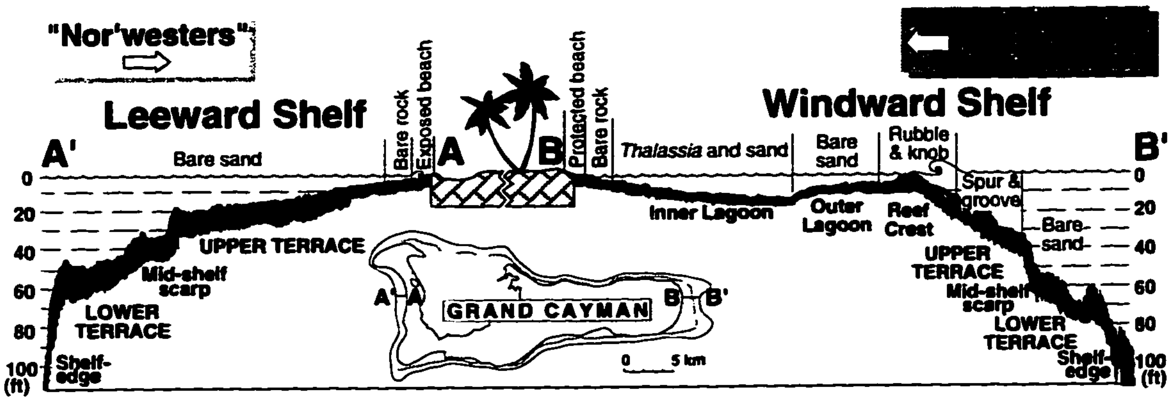

Figure 3.2—Comparison of the leeward shelf (A–A') and windward shelf (B–B') showing the distribution of the physiographic units.

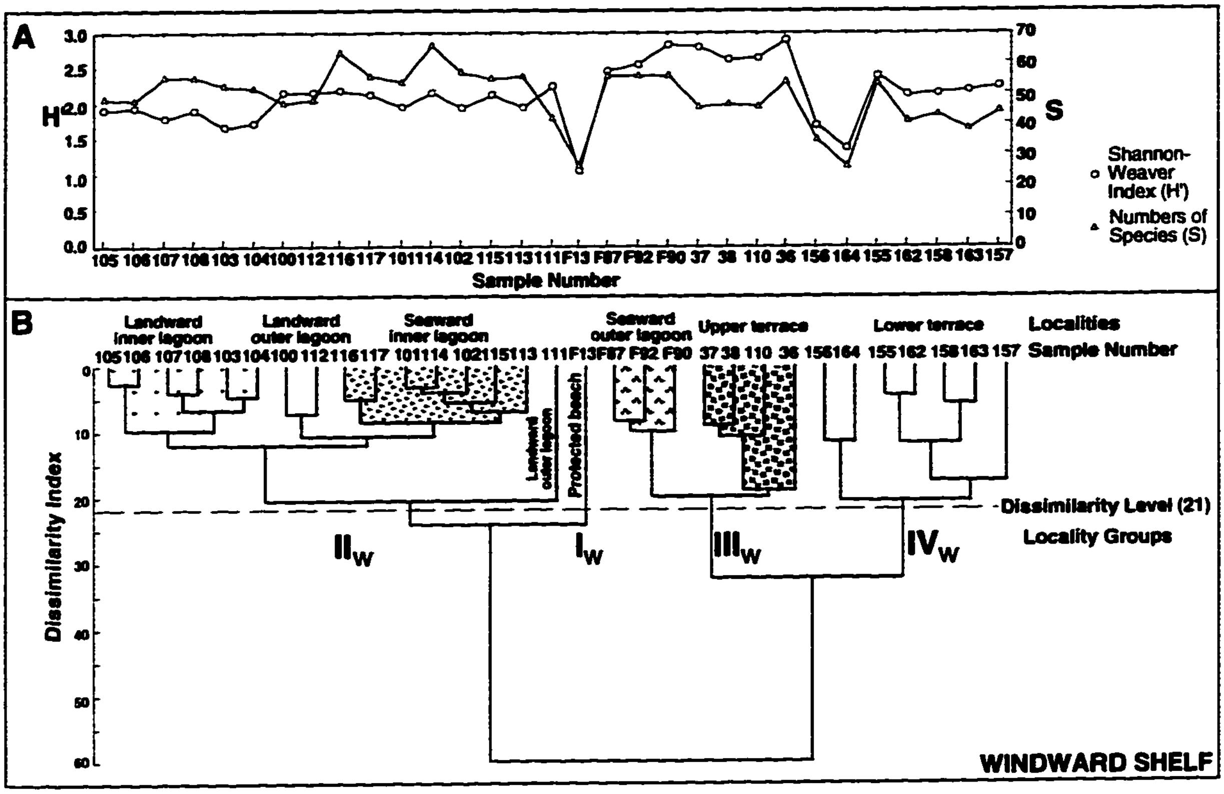

Figure 3.3—Windward shelf—statistical data from the Colliers Bay and Sand Bluff traverses. **A)** Plot of Shannon-Weaver index (H') and number of species (S) for each sample. **B)** Q-mode cluster analysis of samples, based on foraminifera that form ≥3% of the fauna on any site (Between Groups Method and Euclidean Distance), showing major groups.

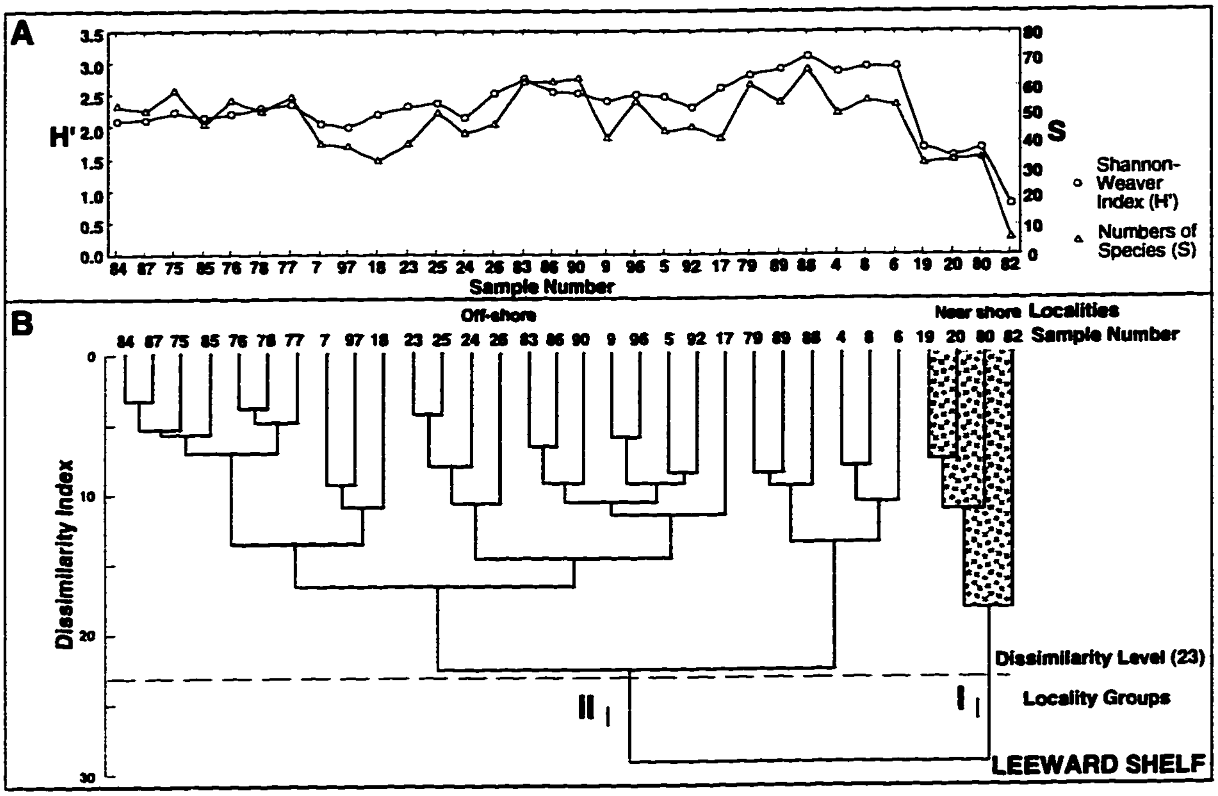

Figure 3.4—Leeward shelf—statistical data from the West Bay and Victoria House traverses. **A)** Plot of Shannon-Weaver index (H') and number of species (S) for each sample. **B)** Q-mode cluster analysis of samples, based on foraminifera that form ≥3% of the fauna on any site (Between Groups Method and Euclidean Distance), showing major groups.

occupies a distinct physiographic unit. On the windward shelf they are the protected beach (I_w), the inner lagoon and landward part of the outer lagoon (II_w), seaward part of the outer lagoon plus upper terrace (III_w), and the lower terrace (IV_w). On the leeward shelf they correspond to the near-shore (I_l) and off-shore (II_l) zones.

On the windward shelf, group II_w is further divided into the landward part of the inner lagoon, the seaward part of the inner lagoon, and the landward part of the outer lagoon. Similarly, group III_w on the windward side can be divided into the seaward part of the outer lagoon and upper terrace (Fig. 3.3). On the leeward shelf, the nearshore group (I_l) is divided into the exposed beach and nearshore zones. Group II_l on the leeward shelf, however, cannot be divided into smaller units that correspond to any physiographic units (Fig. 3.4). Although different coefficients and methods of cluster analysis were tried, the results were the same: samples from windward shelf can be grouped into mappable units, whereas those from leeward side (except a few from nearshore) cannot be arranged into clusters that correspond to defined physiographic units.

PERCENTAGE OF FORAMINIFERAL TESTS IN THE MEDIUM- AND COARSE-GRAINED SANDS

The medium- and coarse-grained sands on the windward shelf generally contain more foraminiferal tests (5–15%) than those on the leeward shelf (1–8%). Sample 97 on the leeward shelf, which contains ~30% foraminifera, is the exception to this trend. This sample contains the most foraminifera of any sample examined (Fig. 3.5).

On the windward shelf, the highest percentage of foraminiferal tests is found in the medium- and coarse-grained sands collected from the *Thalassia* bank in the inner lagoon (11–17%). From there, the percentage of foraminifera decreases toward the protected beach (5%) and the outer lagoon (7–11%). The lowest percentages (3–4%) are on the lower terrace (Fig. 3.5). On the leeward shelf, the percentages are low on the nearshore upper terrace (1–6%), relatively high on the lower terrace (5–8%), and exceptionally high locally (30% in Sample 97) on the off-shore upper terrace.

FORAMINIFERAL ASSEMBLAGES OF THE WINDWARD SHELF

Archaias angulatus-Cymbaloporetta squammosa-Discorbis granulosa Assemblage (I_w)

Composition.— The nominal species form up to 90% of the foraminiferal tests; *Discorbis granulosa* is unique in this assemblage (Fig. 3.6).

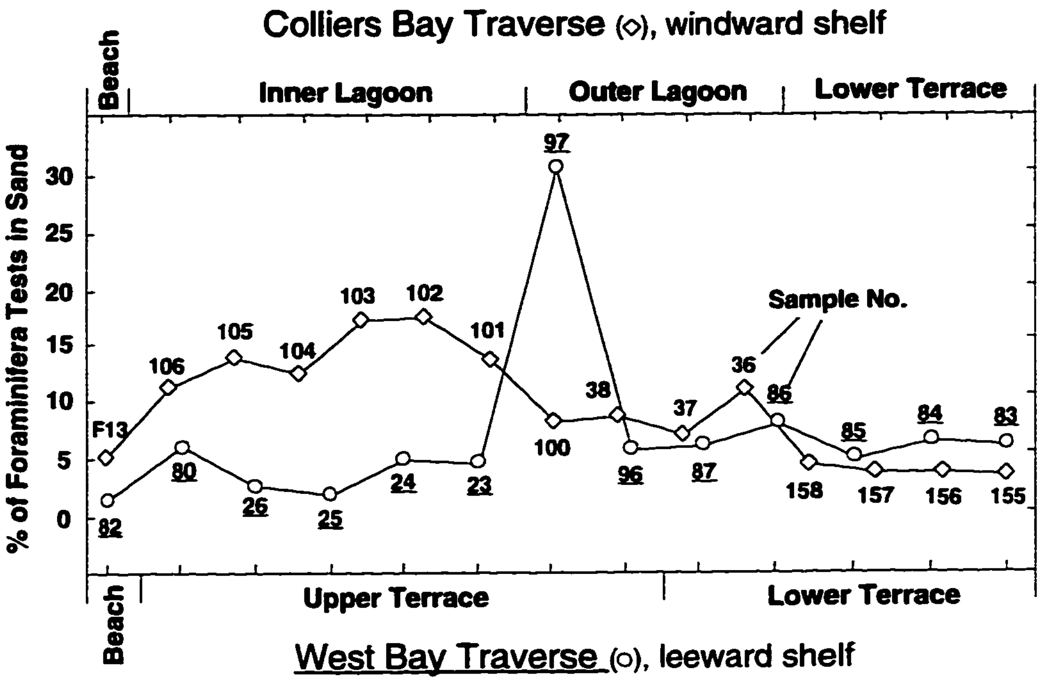

Figure 3.5—Comparison of the percentages of foraminifera tests in the medium- and coarse-grained sand (-1 to 2ϕ) along the Colliers Bay (windward) and West Bay (leeward) traverses.

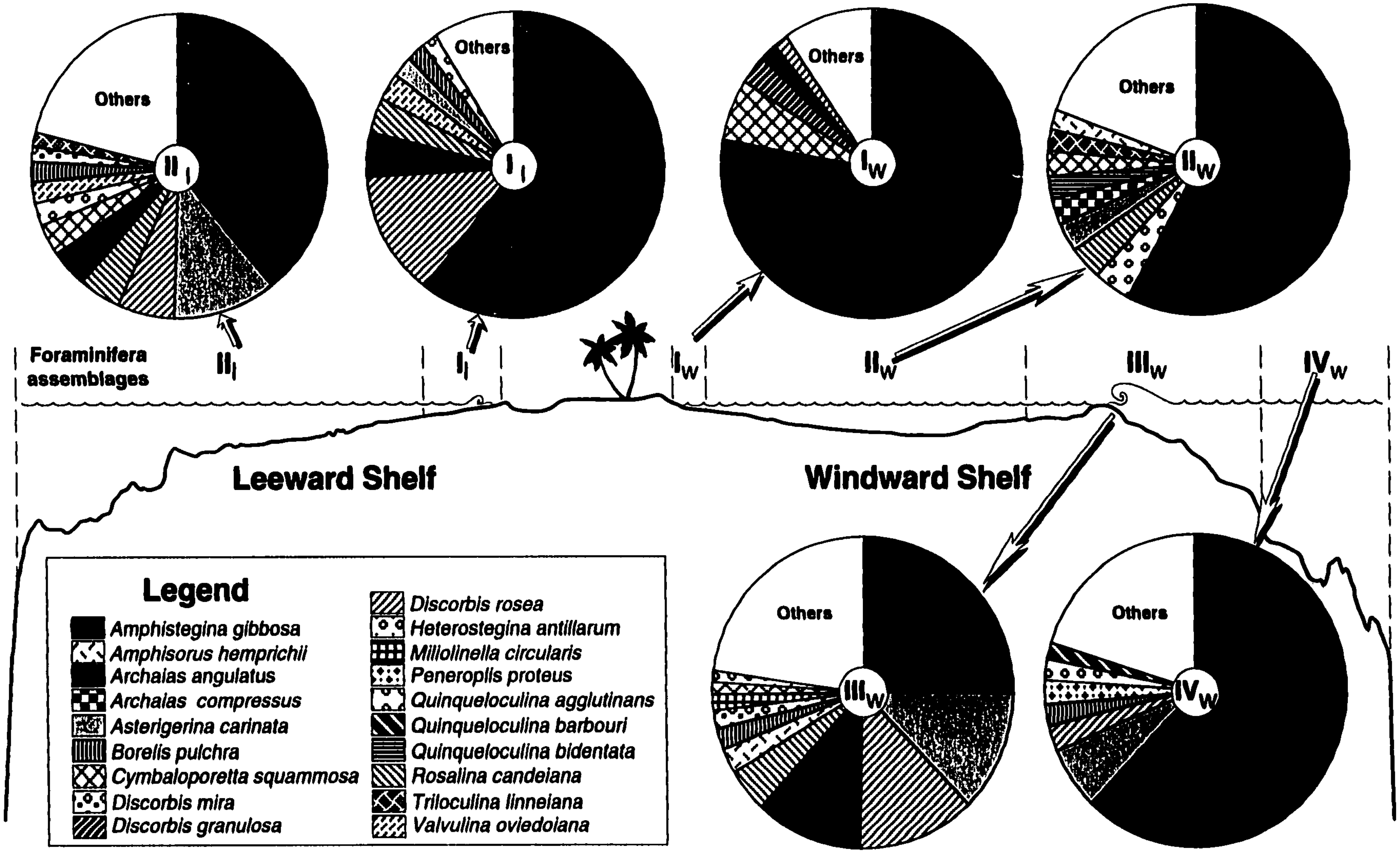

Figure 3.6—Spatial distribution and composition of the six foraminifera assemblages on the windward and leeward shelves of Grand Cayman.

Diversity.— Very low S (27) and H' (1.11).

Distribution.— Protected beach.

Comments.— This assemblage contains the fewest species (S=28) of all the assemblages on the windward shelf. It is characterized by high dominance and low evenness (H'=1.11). The dominant species in this assemblage have thick and/or large shells that can resist abrasion caused by the high energy conditions operating on the beaches. Tests of small and fragile species that flourish in the lagoon are not found in this assemblage.

Archaias-Quinqueloculina-Triloculina Assemblage (II_w)

Composition.— *Archaias angulatus* and *A. compressus* form >60% of the total tests. Up to 40 species of *Quinqueloculina* and *Triloculina* form the second important (>16% overall) and unique part of this assemblage. Species ubiquitously present in this assemblage, commonly in high frequencies, are *Amphisorus hemprichii, Discorbis mira, Peneroplis discoideus, Planorbulina acervalis, Pyrgo subsphaerica, Rosalina candeiana, Schlumbergerina occidentalis,* and *Valvulina oviedoiana.* Of these, *Peneroplis discoideus, Planorbulina acervalis,* and *Valvulina oviedoiana* are unique to this assemblage. Although *Amphistegina gibbosa, Asterigerina carinata,* and *Discorbis rosea* are present in most samples, they are only significant in samples from the landward part of the outer lagoon.

Diversity.— Collectively 110 species, with 42 to 66 (average 54) present in any one sample. Moderate H' (1.74–2.31).

Distribution.— Inner lagoon and landward part of outer lagoon.

Comments.— This assemblage is characterized by: 1) the highest richness of all assemblages in the study area; 2) moderate evenness; 3) dominance of epiphytic and sediment-dwelling species; and 4) samples from the landward part of the outer lagoon (e.g., 100, 111, 112) that are transitional in character with the neighboring *Amphistegina gibbosa-Asterigerina carinata-Discorbis rosea* Assemblage (III_w).

Comparison.— This assemblage is comparable to the "backreef" assemblage on Barbuda (Brasier, 1975a), the "Open interior fauna" on the Florida shelf (Rose and Lidz, 1977; Lidz and Rose, 1989), and the "High-diversity miliolid assemblage" on the Belize shelf (Wantland, 1975).

Amphistegina gibbosa-Asterigerina carinata-Discorbis rosea Assemblage (III_w)

Composition.— *Amphistegina gibbosa* dominates this assemblage. *Asterigerina carinata* and *Discorbis rosea,* which are almost equally abundant, are the second most dominant species. Although *Archaias angulatus* is present in all the samples, its overall percentage is low, especially when compared with other assemblages in the study area.

Other species ubiquitously present and locally abundant are *Rosalina candeiana, Amphisorus hemprichii, Borelis pulchra,* and *Discorbis mira.*

Diversity.— Collectively 103 species, with 46 to 56 (average 52) in any one sample. High H' (2.52–2.98).

Distribution.— Seaward part of outer lagoon and upper terrace.

Comments.— This assemblage is characterized by a high richness (average S=51), that is only surpassed by that in the lagoon assemblage (II_w), and the highest evenness of all assemblages in the study area. The high evenness of this assemblage is caused by low and even percentages of the common species, including the two most abundant species (*Archaias angulatus* and *Amphistegina gibbosa*) on Grand Cayman (Fig. 3.6).

Comparison.— This assemblage can be divided into two subassemblages that correspond, respectively, to the seaward part of the outer lagoon (Samples 36–38, 110) and the upper terrace (F87, F90, F92). The former is comparable to the "Backreef zone", Discovery Bay, Jamaica (Martin and Liddell, 1988), the "*Archaias-Asterigerina* assemblage" on the Belize shelf (Wantland, 1975), the "sand barrier fauna" of the windward Buccoo reefs, Tobago (Radford, 1976a), and the "Platform margin assemblage" and "back-reef assemblage" on the Florida shelf (Rose and Lidz (1977) and Moore (1957) respectively). The latter is akin to the "Fore-Reef Terrace" assemblage on the north coast fringing reefs at Discovery Bay, Jamaica (Liddell *et al.*, 1986, Martin and Liddell, 1988, 1989), and the "Reef Foraminiferal Facies" of southeastern Puerto Rico (Seiglie, 1970).

Amphistegina gibbosa-Archaias angulatus-Asterigerina carinata Assemblage (IV_w)

Composition.— *Amphistegina gibbosa* dominates the assemblage with even higher frequency (up to 50%) than in III_w (25%). Besides the nominal species, other ubiquitous species that dominate locally are *Discorbis rosea, Borelis pulchra, Peneroplis proteus, Quinqueloculina agglutinans,* and *Q. barbouri.* Species unique to this assemblage are *Bigenerina irregularis, Eponides repanda, Globigerinoides rubra, Heterostegina antillarum, Quinqueloculina barbouri,* and *Q. lamarckiana.*

Diversity.— Collectively 82 species, with 26 to 54 (average 40) species in any one sample. Moderate H' (1.43–2.47).

Distribution.— Lower terrace.

Comments.— This assemblage is characterized by the dominance of *Amphistegina gibbosa*, subdominance of *Asterigerina carinata, Discorbis rosea,* and *Archaias angulatus*, and the ubiquitous presence, in high numbers, of the diagnostic forereef or deep species, *Bigenerina irregularis, Eponides repanda, Globigerinoides rubra, Heterostegina antillarum, Quinqueloculina barbouri,* and *Q. lamarckiana.*

Comparison.— This assemblage is comparable to the "30 m site" of northern Jamaica, especially that on the Zingorro traverse (Martin and Liddell, 1988, 1989).

FORAMINIFERAL ASSEMBLAGES OF THE LEEWARD SHELF

Archaias angulatus-Discorbis rosea Assemblage (I_l)

Composition.— The nominal species and other 6 species form >90% of the assemblage (Fig. 3.6).

Diversity.— Collectively 53 species, with 6 to 35 (27 in average) in any one sample. Low H' (0.8–1.71).

Distribution.— Near shore and exposed beach.

Comments.— As with the windward protected beach assemblage, this assemblage is characterized by the dominance of abrasion-resistant species and low S and H'.

Comparison.— This assemblage is comparable to the "Beach Facies" on the western coast of Puerto Rico (Seiglie, 1971) and the "Thanatotope VI" on the southern coast of Puerto Rico (Brooks, 1973).

Archaias angulatus-Asterigerina carinata-Discorbis rosea Assemblage (II_l)

Composition.— The nominal species along with *Rosalina candeiana, Amphistegina gibbosa, Cymbaloporetta squammosa, Quinqueloculina agglutinans, Valvulina oviedoiana, Borelis pulchra, Discorbis mira,* and *Triloculina linneiana* form up to 80% of this assemblage. Ubiquitous species that are rarely significant in terms of their numbers are *Amphisorus hemprichii, Globigerinoides rubra, Heterostegina antillarum, Peneroplis discoideus, Quinqueloculina bidentata, Q. lamarckiana, Triloculina carinata,* and *T. quadrilateralis.*

Diversity.— Collectively 100 species, with 34 to 74 (average 52) in any one sample. High H' (2.0–3.13).

Distribution.— Off-shore area of upper terrace plus lower terrace.

Comments.— This assemblage has a higher S and H' values than the leeward nearshore assemblage.

Comparison.— This assemblage is comparable to the "Sand blanket" assemblage on the leeward western shelf of Barbuda (Brasier, 1975a), the "Thanototope III" on the southern coast of Puerto Rico (Brooks, 1973), and "Group IV" on the western leeward side of the Serranilla Bank (Triffleman *et al.*, 1991).

DOMINANT SPECIES

Archaias angulatus, *Amphistegina gibbosa*, *Asterigerina carinata*, and *Discorbis rosea* are the four most common species around Grand Cayman. Fluctuations in their abundance (Tables 1, 2) strongly influence the delineation of the foraminiferal assemblages (Fig. 3.7).

Archaias angulatus is the most abundant species in the study area (Figs. 3.6, 3.7). Samples dominated by this species (>50% of total foraminifera counted) come from the *Thalassia* banks and beaches. In the outer lagoon, this species is relatively rare because of the reduced size of the living population in that area and the increased number of other species. *Archaias angulatus* is less abundant in samples from the upper terrace and lower terrace on the windward shelf. On the leeward shelf of Grand Cayman, *Archaias angulatus* is consistently the most dominant species; its percentage only decreases at the shelf edge.

Amphistegina gibbosa is the second most abundant species in the study area. It outnumbers *Archaias angulatus* on the upper and lower terraces on the windward shelf (Figs. 3.6, 3.7). Its numbers are severely reduced in the outer lagoon and it is rare in the inner lagoon. Similar distribution patterns have been found on other windward shelves throughout the Caribbean and Florida Keys (Bandy, 1964; Wright and Hay, 1971; Wantland, 1975; Martin, 1986; Martin and Liddell, 1988; Martin and Wright, 1988; Lidz and Rose, 1989). On the leeward terraces of Grand Cayman, *Amphistegina gibbosa* never dominates the biota; instead, it ranks as the fourth most abundant species after *Archaias angulatus*, *Discorbis rosea*, and *Asterigerina carinata* (Fig. 3.7). *Amphistegina gibbosa* is prominent in the nearshore assemblage on the leeward shelf because its strong tests can withstand the abrasion generated by the high energy conditions (Fig. 3.6).

Asterigerina carinata is the third most abundant species found in the study area. It is abundant on the forereef terraces but relatively rare in the lagoon. It commonly follows a parallel trend in abundance with *Amphistegina gibbosa* along any given traverse (Fig. 3.7).

Discorbis rosea, the fourth most abundant species, is most common on the upper terraces of the windward and leeward coasts (Fig. 3.7). Although abundant in the outer lagoon on the windward shelf, it never forms more than 2% of total foraminiferal tests in the inner lagoon. On the beaches where abrasion dominates, however, it becomes prominent due to its resistant test (Figs. 3.6, 3.7).

DISCUSSION

The distributions of foraminiferal assemblages, dominant species, faunal diversity, and the percentages of foraminiferal tests in the medium- and coarse-grained sands on the windward and leeward shelves around Grand Cayman are fundamentally related to the

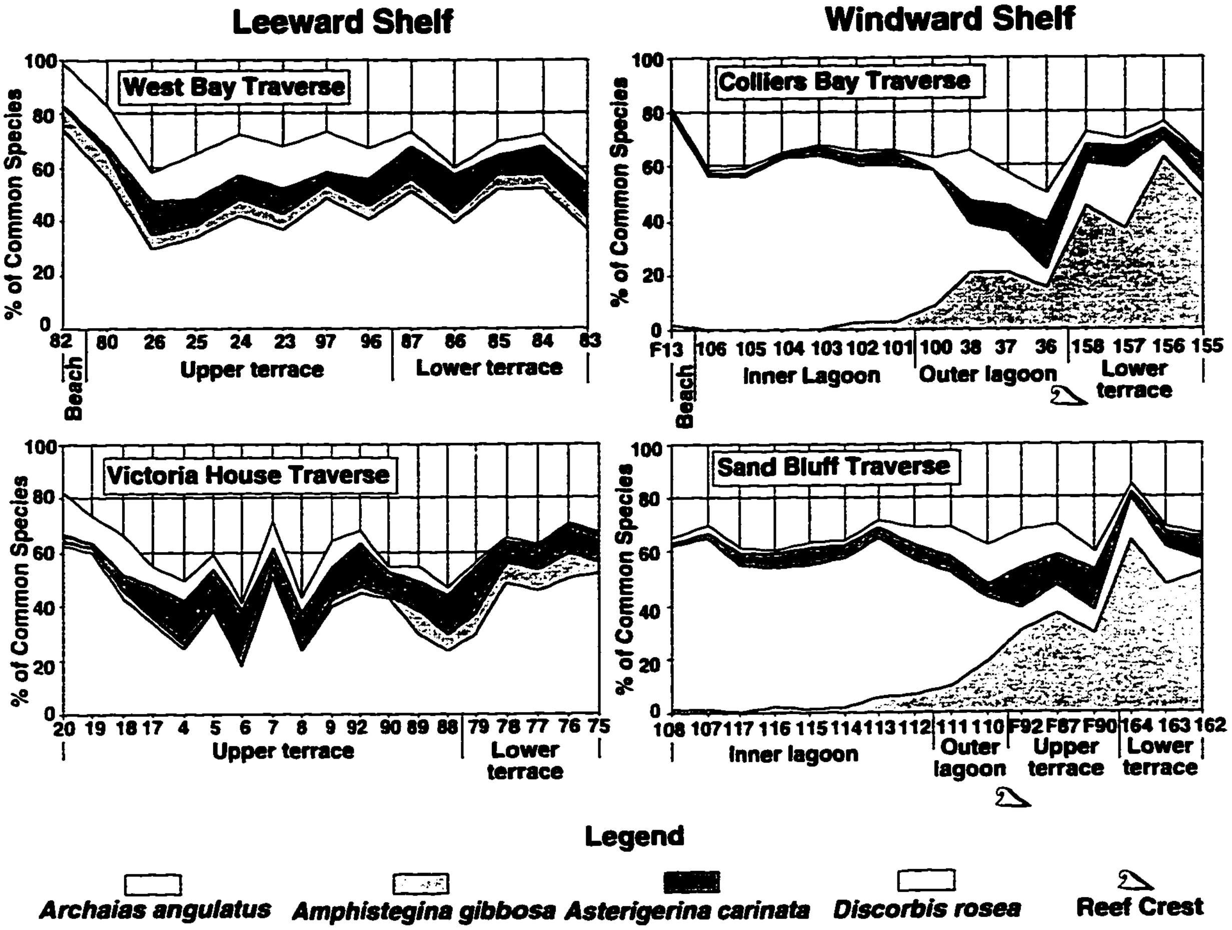

Figure 3.7—Comparison of the abundance fluctuations of the most abundant species (*Archaias angulatus, Amphistegina gibbosa, Asterigerina carinata* and *Discorbis rosea)* on the windward and leeward shelves of Grand Cayman.

physiographic features of the shelves. Three aspects are of particular importance in this regard. First, similar physiographic units on the leeward and windward shelves are subjected to different intensities of wind-induced waves. As a result, there are different physical stresses on the foraminiferal populations that inhabit those physiographic units on different shelves. Second, the different topographies of the two shelves mean that different ecological niches are available for the foraminifera — this has an impact on overall faunal diversity trends. Third, the mixing of the living and dead foraminifera populations has a profound effect on the foraminifera distributions now found in the sediments.

The upper and lower terraces on the windward shelf receive higher and more enduring energy levels than the terraces on the leeward shelf (Stoddart, 1969; Roberts, 1974; Blanchon and Jones, 1995). On the leeward shelf, the upper terrace is subjected to strong erosion whereas the lower terrace is the site of moderate sedimentation. The terraces on the leeward shelf are much flatter and shallower than those on the windward shelf (Fig. 3.2), primarily because the former is a site of net sedimentation whereas the latter is a site of sediment erosion. Medium- and coarse-grained sands from the lower terrace on the windward shelf contain fewer foraminifera tests (<5%) than those from lower terrace on the leeward shelf (mostly >5%). The severe physical conditions on the windward terrace limit the living foraminiferal population and destroy the tests of dead foraminifera assemblages at the same time. As a result, fewer recognizable foraminifera tests can be recovered from the sediments of that area. With the intense physical stresses on the windward shelf, it might be expected that medium- and coarse-grained sands from the beach would contain fewer foraminifera than the beach sands on the leeward shelf. There are, however, fewer foraminifera in the medium- and coarse-grained sands from the beach on the leeward coast (1.36%) than on the windward coast (4.72%). The fundamental reason for this is the existence of an offshore reef on the windward shelf. This means that the beach sediments on the windward shelf are largely derived from the lagoon and that the beach sediments are protected from severe physical damage (compared to those on the exposed leeward beaches) because most of the onshore waves have been dissipated by the reef crest. In this context, it is interesting to note that Spencer (1985) demonstrated that erosion rates on the open coasts are at least six times greater than that on the reef-protected shores of Grand Cayman.

The number of foraminiferal assemblages on each shelf is closely linked to the physiographic zones found on that shelf. Different physiographic zones with different intensities of ecologic and taphonomic processes are inhabited by a variety of foraminifera assemblages. The windward shelf is characterized by a diverse array of physiographic zones each with its own set of ecologic and taphonomic constraints. Conversely, conditions on the open leeward shelf are essentially constant except for the very shallow nearshore zone where high-energy conditions prevail. Consequently, sediments on the leeward shelf are characterized by fewer foraminiferal assemblages than the sediments on the windward shelf. Obviously, the presence of a shallow off-shore reef on the windward shelf is responsible for the greater diversity of assemblages on that shelf. Furthermore, each assemblage on the windward shelf is characterized by its own unique species. In assemblage $\mathrm{I_w}$, for example, *Discorbis granulosa* is a diagnostic and common species. Similarly, assemblage $\mathrm{II_w}$ is characterized by the presence of epiphytic species. For the two assemblages recognized on the leeward shelf, however, there are no significant differences in terms of species; the assemblages simply reflect differences in abundance of the same species.

Any physiographic unit that has conditions favorable for living foraminifera and the accumulation of dead foraminifera will be characterized by high diversity (S). Conversely, physiographic units with stressed ecological conditions will be characterized by fewer living foraminifera. Similarly, fewer tests of foraminiferal species and/or individuals will be preserved in areas characterized by adverse taphonomic conditions. In general, physiographic units with stressed ecologic and taphonomic conditions will produce assemblages with low evenness (H'). Thus. different physiographic zones, each with their own set of ecologic and taphonomic conditions that are operating at various intensities, will produce assemblages that have different diversity levels and variable percentages of foraminiferal tests in the sands. The *Thalassia* banks in the inner lagoon on the windward shelf, for example, provide an environment with slight water motion, good light penetration, flourishing marine plants, and a rich food supply. This is an ideal habitat for foraminifera, especially the epiphytic forms. Small and fragile foraminiferal tests survive in this area because they are protected from severe abrasion and transportation by the marine grasses. Dissolution is minimal due to the normal salinity and low organic content of the water. As a result, assemblage $\mathrm{II_w}$ has the highest average richness (S=54) and the medium- and coarse-grained sands contain numerous foraminifera (11–17%; Fig. 3.5). Conversely, the exposed beach on the leeward coast is an area of stressed ecologic and taphonomic conditions. Consequently, medium- and coarse-grained sands from that area have relatively few foraminiferal tests (1.36%) and the foraminiferal assemblage has low richness (S=6) and evenness (H'=0.8).

Sediment mixing, which has different intensity on the windward and leeward shelves has a profound effect on foraminiferal distributions. On the open leeward shelf, only local transportation of sediments, including foraminiferal tests, takes place during normal weather conditions. Winter storms and hurricanes, however, have a profound effect on foraminiferal distribution and mixing of the sediments. Nearly every year, this shelf is swept by strong onshore currents that are generated by the 'Nor-wester' storms. The lack of an offshore reef that reaches sea-level means that there is no impediment to water and/or current movement across the shelf. The annual movement of these sands means that they are homogenized and little cross-shelf variance can be expected. On the windward shelf, however, the offshore reef effectively impedes sediment exchange between the lagoon and fore-reef area under normal weather conditions — only the waves generated by the most severe storms or hurricanes can carry the sediment over the reef crest. As a result, sediment mixing is only evident in the outer lagoon area (Fig. 3.8).

Evidence of sediment mixing can be demonstrated by comparing the abundance of the two most common species, *Archaias angulatus* and *Amphistegina gibbosa*. *Archaias angulatus* is the most abundant species in shallow, quiet, normal marine, and oxygenated environments that are typical of lagoons (Seiglie, 1970; Wright and Hay, 1971; Martin, 1986; Martin and Liddell, 1988, 1991; Murray, 1991), bays (Bock, 1971; Smith, 1971), the shallow interiors of banks (Todd and Low, 1971; Marshall, 1976; Rose and Lidz, 1977; Lidz and Rose, 1989; Triffleman *et al.*, 1991), and patch reefs (Davis, 1964; Brooks, 1973). This species prefers to live on marine plants, especially *Thalassia* (Davis, 1964; Lee and Zucker, 1969; Lee *et al.*, 1974; Wantland, 1975; Lee and Bock, 1976; Marshall, 1976; Steinker and Steinker, 1976; Duguay and Taylor, 1978; Poag, 1981; Duguay, 1983; Hallock *et al.*, 1986a; Martin, 1986; Levy, 1991; Murray, 1991; Hallock and Peebles, 1993). It can, however, live on the sediment (Wright and Hay, 1971; Brasier, 1975b; Lidz and Rose, 1989). *Amphistegina gibbosa* prefers to live on algal-veneered hard substrates (e.g., rubbles or rocky substrate) in clear, normal marine water with appropriate light conditions (Poag and Tresslar, 1981; Hallock *et al.*, 1986b; Hallock and Talge, 1993). Thus, *Amphistegina gibbosa* is most common in water deeper than 10 m on forereef terraces or slopes (Bandy, 1964; Seiglie, 1966, 1971; Brooks, 1973; Sen Gupta and Schafer, 1973; Brasier, 1975a; Radford, 1976b). *Amphistegina gibbosa* (living and/or dead populations) is also common on submerged banks (~ 40 m or deeper) in the Caribbean Sea and the Gulf of Mexico (Lowman, 1949; Ludwick and Walton, 1957; Davis, 1964; Seiglie, 1968; Bock, 1971; Marshall, 1976; Poag, 1972, 1981; Poag and Sweet, 1972; Poag and Tresslar, 1979, 1981; Triffleman *et al.*, 1991). Compared to *Archaias angulatus*, *Amphistegina gibbosa* can easily attach itself to the hard substrate, has low metabolic requirements, and can reproduce itself very successfully in more turbulent settings (Hallock *et al.*, 1986a, b; Martin, 1986; Hallock and Peebles, 1993). On the windward shelf of Grand Cayman and other windward shelves in the Caribbean, the two species always show a distinct inverse relationship — *Archaias angulatus* dominates the

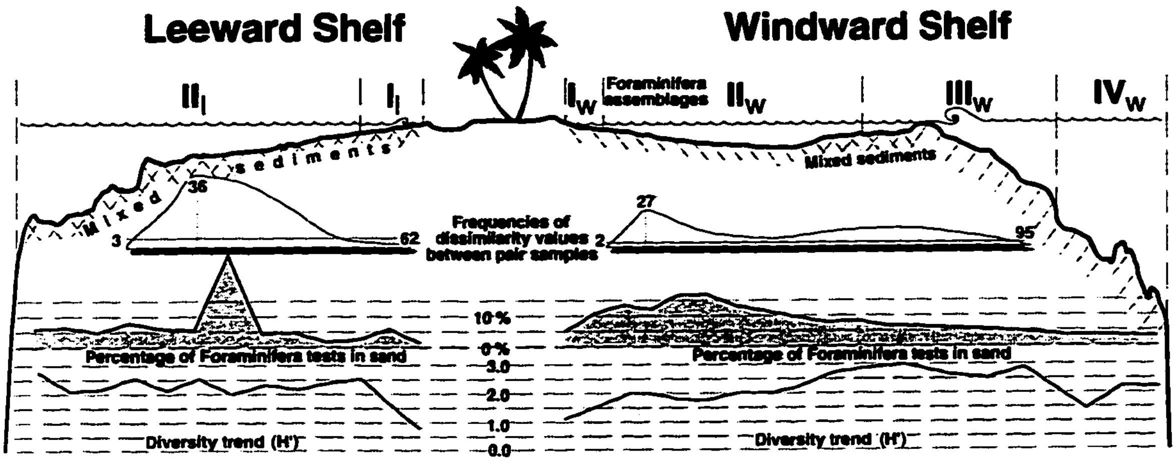

Figure 3.8—Summary diagram showing the distribution of the foraminifera assemblages on the windward and leeward shelves of Grand Cayman (same scale as in Fig. 3.2). Inset graphs show the frequency distributions of the dissimilarity indices between samples, the contribution that the foraminifera make to the medium- and coarse-grained sand, and the diversity trends (H') in the foraminifera on each shelf.

lagoon area whereas *Amphistegina gibbosa* dominates the forereef area. On the leeward shelf, however, frequencies of these two species fluctuate side by side across the entire shelf because of the intense mixing of the sediments (Figs. 3.6, 3.7).

Evidence of sediment mixing is also demonstrated by the foraminifera assemblages and their distributions. On the leeward shelf, intense sediment redistribution has thoroughly mixed the sediments. As a result, cluster analyses failed to delineate any foraminiferal assemblages that can be directly correlated to the major physiographic features. On the windward shelf, however, the foraminiferal assemblages are easily delineated and correlate directly to the major physiographic units. This difference can also be highlighted by determining the frequency distribution of the dissimilarity values between each pair of samples (Fig. 3.8). The curve for the leeward shelf has a high amplitude, is leptokurtic, nearly symmetrical, and has a maximum dissimilarity values of 62. By comparison, the curve for the windward shelf has a low amplitude, is platykurtic, bimodal, and has a maximum dissimilarity value of 95. These curves show that the mutual dissimilarity indices for the windward shelf are much higher than those on the leeward shelf.

CONCLUSIONS

Study and comparison of foraminifera assemblages found in the sands on the windward and leeward shelves, Grand Cayman demonstrate the following points.

1. The windward shelf is characterized by four foraminiferal assemblages whereas the leeward shelf has only two assemblages. Assemblages on the windward shelf are well defined and can be divided into mappable groups. Conversely, foraminiferal assemblages on the leeward shelf are less defined because they are recognized by slight differences in abundance of the same species.
2. The character of the foraminiferal assemblages and their distribution on the windward and leeward shelves are closely tied to the shelf topography and the operative sedimentary processes. The windward shelf, with an off-shore reef which reaches sea level, is characterized by a diverse array of physiographic zones, each with its own set of ecologic and taphonomic processes. The leeward shelf, however, is characterized by relatively constant conditions except for the very shallow nearshore zones where high energy conditions are prevalent. As a result, the leeward shelf is characterized by fewer physiographic zones, thus fewer ecologic niches for foraminifera, than the windward shelf.
3. Sediment mixing, which differs in intensity on the windward and leeward shelves, has a profound effect on foraminiferal distributions. On the open leeward shelf, local

transportation of sediments under normal weather conditions is minimal. 'Nor-wester' storms in the winter months, however, are capable of moving vast quantities of sediment across the shelf very quickly. On the windward shelf, the off-shore reef effectively impedes sediment exchange between back- and fore-reef areas under normal weather conditions. Only the most severe tropical storms and hurricanes can carry sediment over the reef crest. Consequently, on the windward shelf the foraminifera assemblages tend to retain their distinctive character apart from those in the outer lagoon area. On the leeward shelf, however, foraminiferal assemblages are mixed because the sediments on that shelf are mixed on an annual basis.

4. The peripheral lagoon is an ideal habitat for living foraminifera. In addition, small and fragile foraminiferal tests in those areas are protected from taphonomic damage. Medium- and coarse-grained sands from the *Thalassia* bank in the inner lagoon generally contain the highest percentage of foraminiferal tests (11–17%) and the most diverse array of foraminifera. On the contrary, the exposed beach on the leeward shelf is an area of highly stressed ecologic and taphonomic conditions. Thus, medium- and coarse-grained sands from that area have the fewest foraminiferal tests (1.36%) and the lowest diversity of foraminifera.

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CHAPTER 4 LAGOON-SHELF SEDIMENT EXCHANGE BY STORMS — EVIDENCE FROM FORAMINIFERAL ASSEMBLAGES, EAST COAST OF GRAND CAYMAN, BRITISH WEST INDIES

INTRODUCTION

Carbonate shelves throughout the Caribbean and the Bahamas are vulnerable to storm- and hurricane-generated high-energy events. Although the impact of storms are dramatic and undeniable, their recognition in sedimentary deposits can be difficult. To a large extent, this problem arises because the storm deposits and associated sedimentary structures are reworked during the subsequent fair-weather homogenization of the sediment by physical and biological agents (High, 1969; Bonem and Stanley, 1977; Bonem, 1985; Kobluk and Lysenko, 1992; Scoffin, 1993). Studies documenting the onshore transport of sediment by storm processes are common (e.g., Ball *et al.*, 1967; Hernandez-Avila *et al.*, 1977; Graus *et al.*, 1984; Macintyre *et al.*, 1987; Jones and Hunter, 1992; Scoffin, 1993). Conversely, studies considering offshore sediment transport due to storms are rare (Hubbard, 1986, 1992). Thus, there is a need to identify easily preserved and recognizable allochems that can act as tracers of sediment movement across a shelf during storms.

Allochems such as *Halimeda* (Meaney, 1973; Moore *et al.*, 1976; Johns and Moore, 1988), corals (Meaney, 1973), and *Homotrema* (Emiliani, 1951; MacKenzie *et al.*, 1965; Meaney, 1973; Boss and Liddell, 1987) have been used for tracing sediment movement in various carbonate depositional regimes. The usefulness of these allochems as tracers is limited, however, by the difficulty of their identification in sand-sized sediment and poor knowledge of their original habitat (e.g., *Halimeda*, Hillis-Coinvaux, 1980, 1986). Normally, these allochems can only provide information about the gross transportation directions between shallow- and deep water, such as down slope transportation (Moore *et al.*, 1976; Land and Moore, 1977; Johns and Moore, 1988). Benthic foraminifera are ideal candidates for tracing sediment movement because they are abundant in most carbonate environments and many species live in areally restricted habitats (Bandy, 1964; Wantland, 1975; Radford, 1976a, b; Rose and Lidz, 1977; Martin and Liddell, 1988). Their small size also means that they are found in even the smallest sediment samples. By using diagnostic lagoonal and forereef foraminiferal species, as well as their size distributions, it

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should be possible to track sediment movement caused by storm activity. We test this hypothesis by examining sediments found on the windward east shelf of Grand Cayman. Specifically, this study (i) identifies the foraminiferal species that can be used for tracing sediment movement, (ii) considers the size distributions of those species across the shelf, and (iii) develops a model that explains the movement of sediment on this shelf during severe storm conditions.

STUDY AREA

Grand Cayman is a flat, low-lying tropical island that is 35 km long (east-west) and 6–14 km wide (Fig. 4.1). It is surrounded by a narrow shelf, up to 3 km wide, that is divided into two parts by a fringing reef (Rigby and Roberts, 1976). Landward of the reef, narrow peripheral lagoons parallel the shore. Seaward of the reef, the shelf is divided into upper (0–10 m) and lower (12–40 m) terraces by a mid-shelf scarp (Blanchon and Jones, 1995). The edge of the shelf is bounded by an escarpment that typically begins at 55–80 m and extends vertically into waters 115–145 m deep (Messing and Platt, 1987). From there, the island slope extends into the abyssal depths of the Caribbean Sea.

Waters in the lagoons have a maximum surface temperature of 32°C, normal open marine salinities (35 to 38‰), and chlorinity of 19.9 - 20.9‰ (Moore, 1973; Raymont *et al.*, 1976). The open shelf waters are remarkably clear, partly because no rivers discharge from the island. Mixed diurnal and semi-diurnal tides have a maximum range of 1 m and generally produce only weak currents (Burton, 1994). Consequently, shelf and coastal currents are largely driven by wind and waves. These waves are controlled by trade winds which blow from the east, northeast, or southeast throughout most of the year. Waves generated are typically 1.25–2.5 m high on the windward side of the island but < 0.5 m on the leeward side (Darbyshire *et al.*, 1976). Waves are also generated by tropical cyclones which frequently affect the island. From 1886 to 1987, Grand Cayman experienced tropical storms (within 50 miles) on an average of once every 4.3 years, and suffered direct hits on an average of once every 12.5 years. On average, hurricanes pass within 50 miles of Grand Cayman every 3.7 years and over the island every 9.2 years (Clark, 1988). Powerful waves generated by hurricanes can be many meters high and wash away roads and deposit cobble and boulders on shore (Rigby and Roberts, 1976; Jones and Hunter, 1992).

On the windward shelf of Grand Cayman, which is the focus of this study, sediment deposition is restricted to the lagoon and lower terrace of the open shelf. The lagoon,

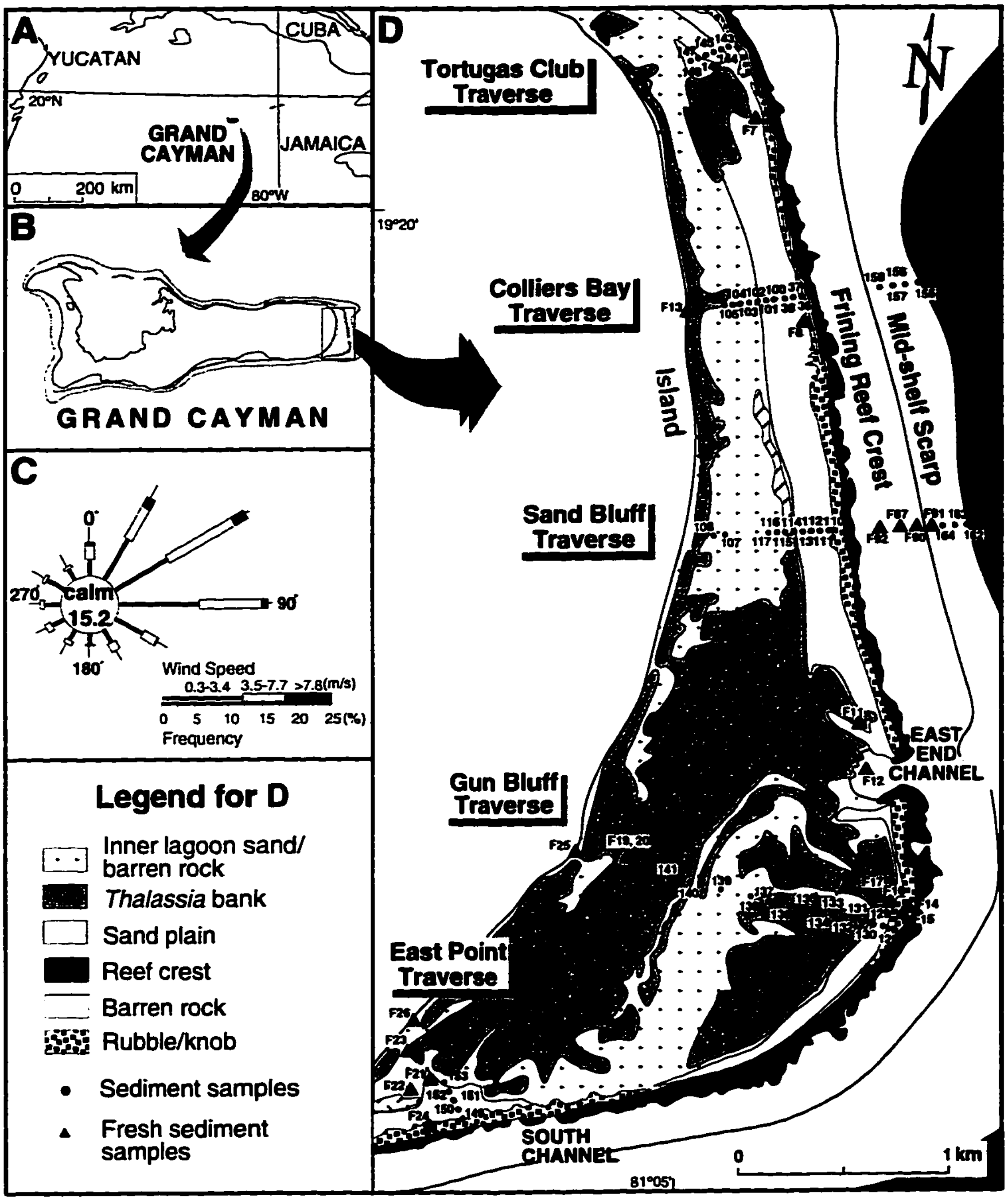

Figure 4.1—**A)** Location of Grand Cayman in northern Caribbean Sea. **B)** Map showing study area, Grand Cayman. **C)** Time-averaged annual wind rose graph (based on Darbyshire *et al.*, 1976). **D)** Positions of traverses, locations of samples and substrate (from airphoto, 1979).

which is 200 m to 1.6 km wide, is divided into the inner and outer zones (Fig. 4.1). The inner zone is typically characterized by *Thalassia* banks and thin sediment cover (< 2 m). The outer zone consists of a sand apron and a narrow tract of loose rubble and sand behind the reef crest (Fig. 4.2). This tract of sediment, which parallels the reef crest, has a variable width along its length. The reef crest, which consists of an emergent ridge of growing corals and/or boulders of dead corals, is cut by narrow channels. Although the reef acts as a significant barrier to onshore wave energy, water is exchanged via the channels during every tidal cycle. On the open shelf, the upper terrace is swept by wave swell and little sediment accumulates. On the lower terrace, however, which is the site of active sediment accumulation, the sediment is up to 10 m thick (Blanchon, 1995).

METHODS

Fifty-two surface sediment samples, collected at 40–60 m intervals by Scuba or snorkeling, were taken along five traverses on the eastern shelf of the island during the summers of 1990 and 1991. In addition, 22 fresh sediment samples were collected from vegetation, rubble, and the upper few centimeters of sediment from the lagoonal and open shelf environments in the summer of 1994 (Fig. 4.1). Immediately after collection, the living foraminifera were fixed by buffered formaldehyde which contained calcium chloride. Upon returning to the laboratory, they were washed over a 63 µm sieve and immersed in a Rose Bengal solution for 30 minutes. After rewashing to remove excess stain, wet foraminifera were counted under a binocular stereo-microscope. Those that had the last few chambers stained pink and/or displaying symbiont colors were considered living at the site of collection.

Species abundances and size distributions of foraminiferal tests from sediment samples were obtained using the sieve counting method of Martin and Liddell (1988, 1989). This technique was used because it provides insights into the effects of transportation, sorting, and differential preservation of foraminifera in turbulent reef settings (Martin and Liddell, 1988). Initially, one split of each sediment sample (100–150 g) was divided into 1 ϕ intervals by sieving for 10 minutes. Then, where possible, 300 individuals were identified and counted from each fraction coarser than 3 ϕ (0.125 mm). In many cases, however, < 300 specimens were identified and counted simply because the sediment fraction being examined contained < 300 foraminifera tests. The average number of specimens in each sample is > 800. Such sample numbers mean that the recognition of

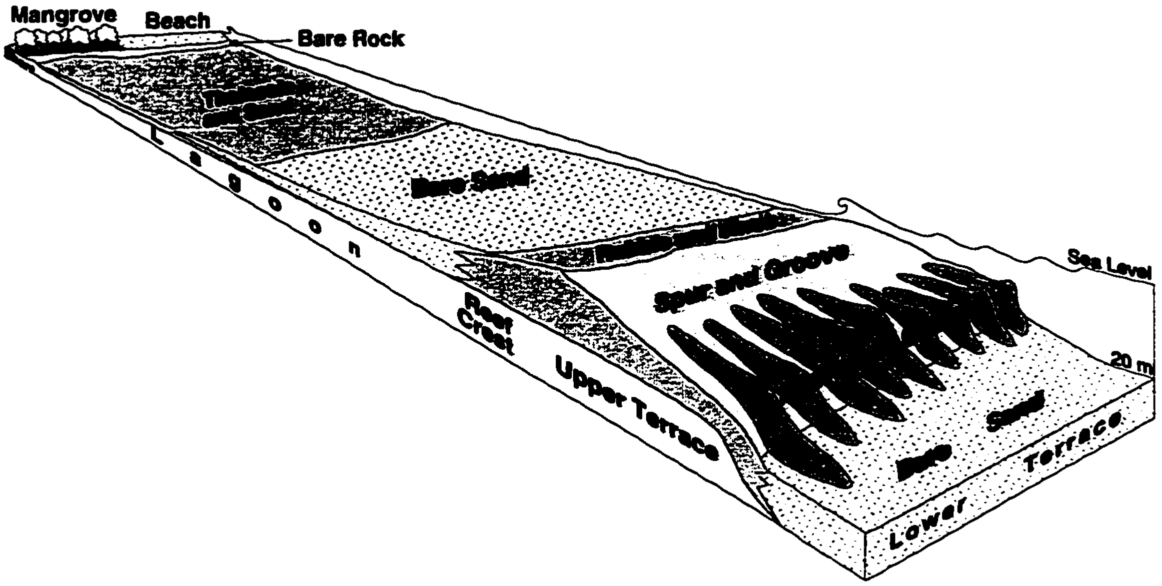

Figure 4.2—Block figure showing topography and substrate of different environments on windward shelf of eastern Grand Cayman. Note that there are two carbonate sediment bodies (filled by dotted pattern) concentrated in the inner lagoon and on the inner part of the lower terrace (modified after Blanchon and Jones, 1995).

assemblages using species that form >3% of any sample is statistically reliable at the 95% confidence limit (Patterson and Fishbein, 1989; Cerridwen and Jones, 1991).

Standard grain-size analysis was used to examine the size distributions of foraminifera tests across the shelf. Accordingly, representative samples from the beach, the *Thalassia* banks of the inner lagoon, the sand plain of the outer lagoon, the landward edge of the sand plain on the lower terrace, and the seaward edge of the sand plain on the lower terrace were sieved into 0.25ϕ intervals. Subsequently, all specimens of *Archaias angulatus* and *Amphistegina gibbosa* were counted for each fraction coarser than 1.5ϕ (0.354 mm). Tests smaller than 1.5ϕ (juveniles) were omitted because they are poorly preserved due to poor calcification (cf. Hallock *et al.*, 1986). The median, mean, and sorting of each species population and the host sediments were calculated for each sample.

DISTRIBUTION OF TRACER SPECIES

Sediment samples from the east coast of Grand Cayman yielded ~50,000 foraminifera belonging to 150 species. Of those species, *Archaias angulatus*, *Amphistegina gibbosa*, *Asterigerina carinata*, and *Discorbis rosea* have the best potential for tracing sediment movement across the shelf because their original life habitat is restricted and they are common components in the sediment samples. For brevity these four species are collectively referred to as "tracer species".

Living (stained) *Archaias angulatus* are most abundant on *Thalassia* banks in the inner lagoon, but are significantly reduced in numbers on the sands from the inner and outer lagoon zones, and rare in the forereef area. Conversely, living *Amphistegina gibbosa* and *Asterigerina carinata* are most abundant on algal-veneered rubble in the forereef area. *Discorbis rosea* is most common on the upper terrace. Living specimens of *Asterigerina carinata*, *Discorbis rosea*, and *Amphistegina gibbosa*, however, are rare in the lagoon.

In total foraminiferal assemblages (stained plus dead), *Archaias angulatus* is abundant in the sands found in the inner lagoon (47% — here and elsewhere, percentages are averages derived from a set of samples) and beaches (61%), and less common in sands of the outer lagoon (30%), upper terrace (9%), and lower terrace (13%)(Fig. 4.3). *Amphistegina gibbosa* is most abundant in sediments on the lower (50%) and upper terraces (32%). Significantly fewer tests are found in sediments from the outer lagoon (13%), and they are rare in the inner lagoon (<2%). *Asterigerina carinata* is most abundant in sediments on the upper (13%) and lower terraces (6%). *Discorbis rosea* is most

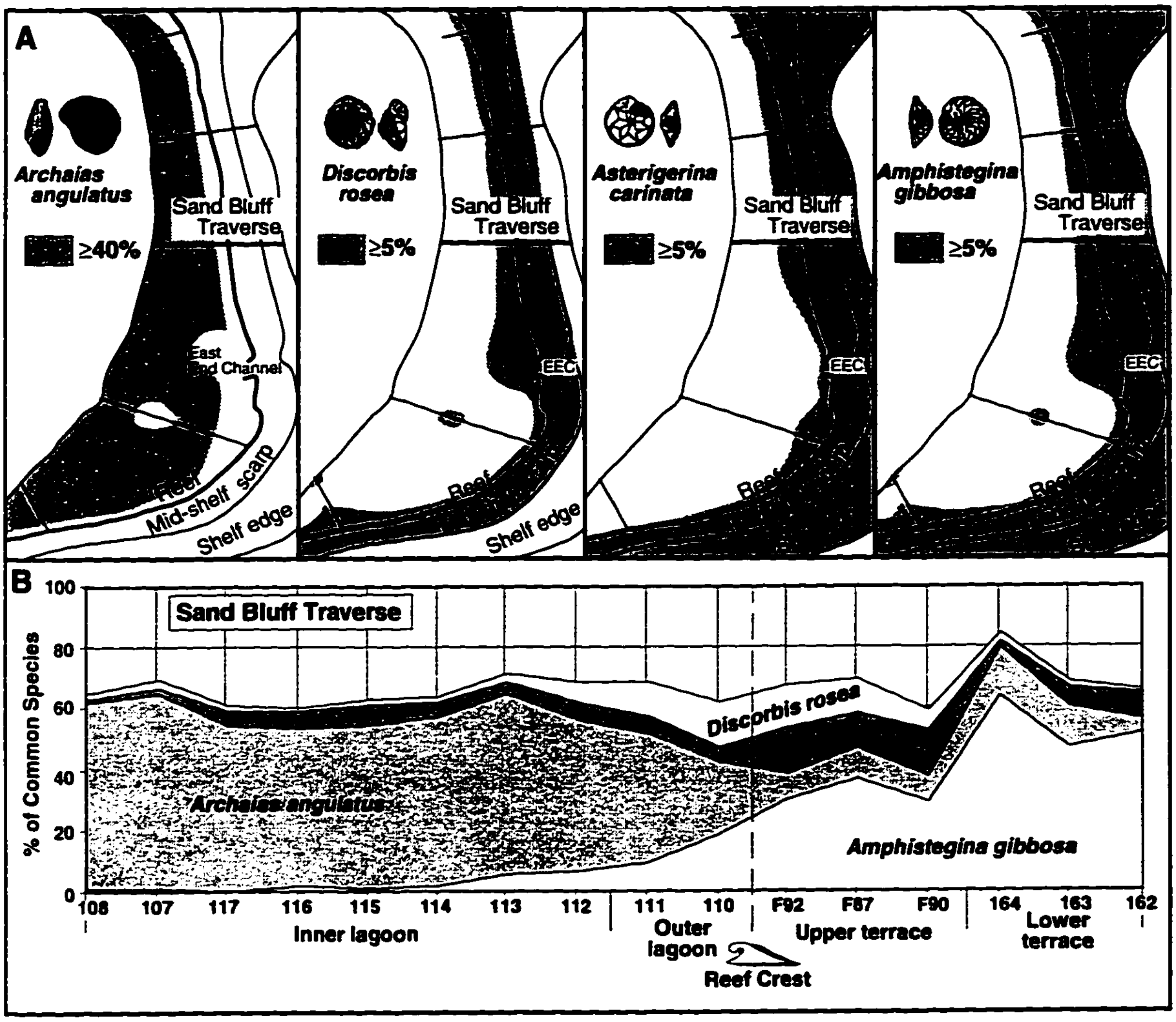

Figure 4.3—**A)** Maps showing the most abundant zones of tracer foraminiferal species, eastern Grand Cayman. **B)** Graph showing the change in abundance of the tracer species along Sand Bluff Traverse, eastern Grand Cayman.

common in sediments from the upper terrace (11%), less common in sediments from the lower terrace (3%) and outer lagoon (10%), and rare in the inner lagoon (2%).

In general, the distribution of the lagoonal species *Archaias angulatus* is inversely proportional to that of the forereef species *Amphistegina gibbosa*, *Discorbis rosea*, and *Asterigerina carinata* (Fig. 4.3). The distribution of forereef species, however, does extend landward of the reef crest such that the ≥40% contour for the lagoonal species coincides with the ≤5% contour for the forereef species (Fig. 4.3). Significantly, this boundary is the junction between outer and inner zones of the lagoon (Figs. 4.1, 4.3). There are, however, two exceptions to this general trend. First, some samples near to the East End Channel have disproportionately higher percentages of forereef species (Fig. 4.3). Second, on the East End traverse the ≥40% abundance contour for the lagoonal species and the ≤5% abundance contour for the forereef species *Asterigerina carinata* are located close to the reef crest rather than the landward boundary of the sand apron.

SIZE DISTRIBUTION OF TRACER SPECIES

Size distributions of the most common tracer species, *Archaias angulatus* and *Amphistegina gibbosa*, display several interesting features. In areas where these species live (e.g., inner lagoon for *Archaias angulatus* and forereef for *Amphistegina gibbosa*), their populations contain few tests smaller than 1 ϕ (0.5 mm)(Fig. 4.4). Conversely, in areas outside of their original habitats, small tests are so abundant that the size distributions of the two species are skewed towards the smaller tests.

Standard grain size analyses show that the mean and median sizes of the lagoonal species *Archaias angulatus* increase from the beach into the lagoon and the forereef terrace (Fig. 4.5). The largest mean test size (0.94 ϕ)(0.521 mm) of this species is found in sands from the inner part of the lower terrace sand plain. Conversely, the mean and median values of *Amphistegina gibbosa*, increases from the shelf-edge into the lagoon. Thus, both lagoon and forereef tracer species have winnowed assemblages in their original habitats and have test sizes that become smaller as the distance from the original habitat increases.

For both species, sorting is poorest in their original habitats and best in physically-dominated environments such as the beach.

ONSHORE SEDIMENT TRANSPORT DURING STORMS

Field data from Grand Cayman show that living *Archaias angulatus* are most abundant in the inner lagoon. *Amphistegina gibbosa* and *Asterigerina carinata* are most common on the forereef terraces, and *Discorbis rosea* dominates the upper terrace channels.

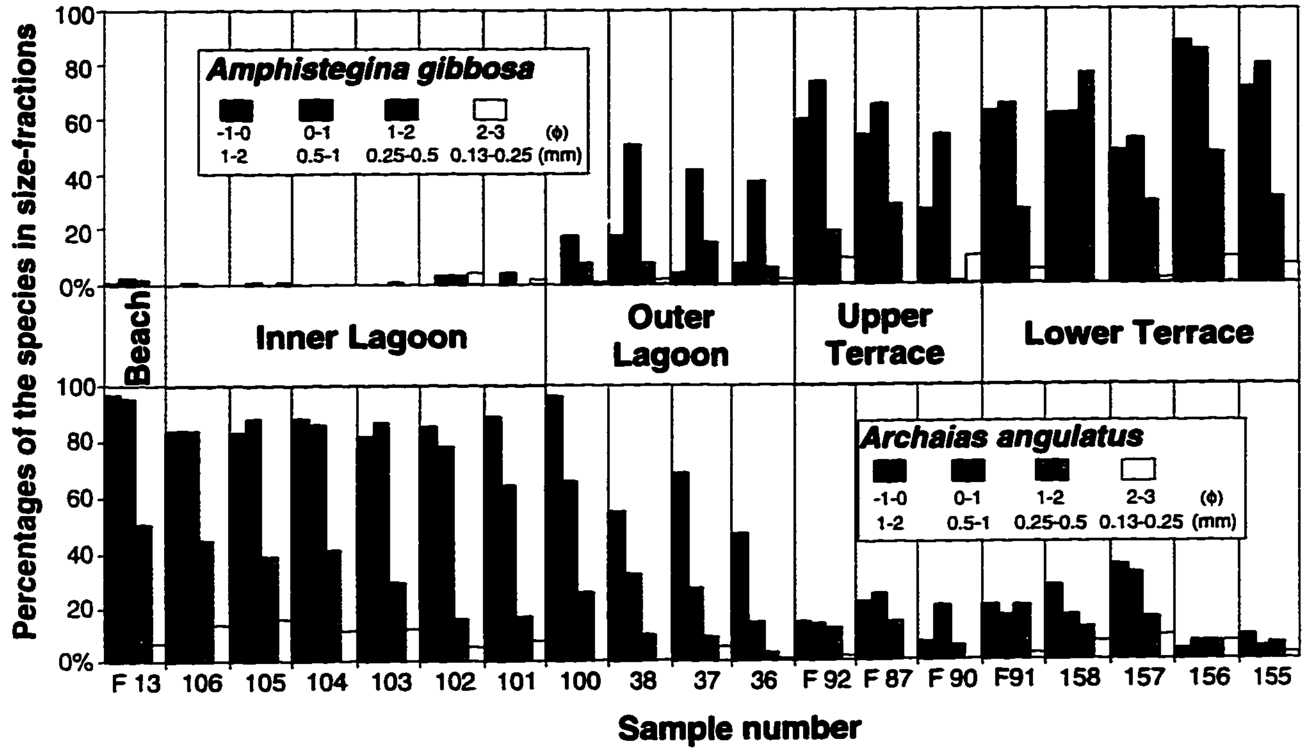

Figure 4.4—Relative abundance (in each size fraction) of forereef species *Amphistegina gibbosa* and lagoonal species *Archaias angulatus* along the Colliers Bay traverse, eastern Grand Cayman (Fig. 4.1D).

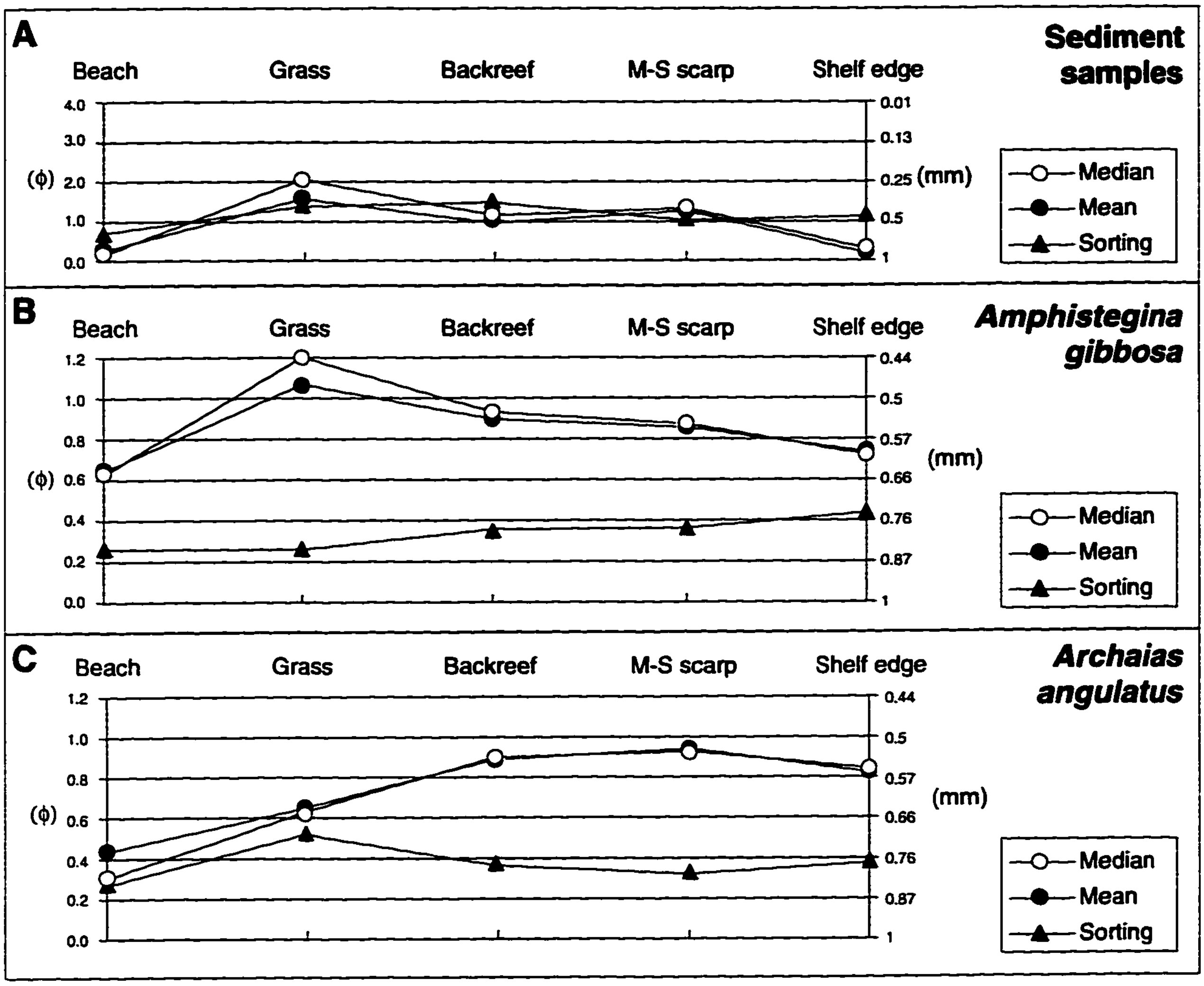

Figure 4.5—Plots showing the values of median, mean, and sorting of sediment samples from different environments **(A)**, *Amphistegina gibbosa* tests **(B)**, and *Archaias angulatus* tests **(C)**, along the Colliers Bay Traverse (Fig. 4.1D).

Similar trends in the distribution of these species are also evident throughout the Caribbean-Florida region (Brasier, 1975; Radford, 1976a, b; Hallock *et al.*, 1986; Lidz and Rose, 1989; Martin, 1986; Martin and Wright, 1988; Wantland, 1975; Wright and Hay, 1971).

Under fair-weather conditions the areal distributions of the total (living plus dead) foraminiferal assemblages should not be significantly different from those of the living specimens because the fringing reef provides an effective barrier to wave energy and prevents exchange of sediments between the lagoon and forereef shelf (Roberts *et al.*, 1975). Nevertheless, the presence of forereef species in the outer lagoonal sediments demonstrates that forereef sediment is being transported over the reef crest and into the lagoon. Clearly, if sediment cannot be transported into the lagoon during fair-weather conditions, it must be accomplished during storms and hurricanes.

By showing that the fringing-reef complex was composed entirely of boulder- to sand-grade detritus, Blanchon (1995) suggested that storms play a major role in the architectural development of reefs around Grand Cayman. This model of over-the-reef sediment transport during storms is consistent with the presence of forereef foraminifera in back reef areas. Other studies have also shown that forereef foraminiferal species are commonly found in back-reef deposits. The presence of *Amphistegina gibbosa*, *Discorbis rosea*, and *Asterigerina carinata* along the windward reef of Discovery Bay (N. Jamaica), for example, has been attributed to washover deposits caused by storms (Martin and Liddell, 1988, 1989, 1991; Kotler *et al.*, 1992). Similarly, on the Belize Shelf, dead tests of *Amphistegina gibbosa* are found in the "High-diversity miliolid assemblage" and the "*Archaias-Asterigerina* assemblage" that are located on the sand flat behind the reef crest. In those assemblages, tests of *Amphistegina gibbosa* form up to 50% of the total foraminifera assemblages despite the fact that no living specimens have been found in the area (Wantland, 1975). A similar phenomenon is apparent in the Gulf of Batabano (SW Cuba) where Bandy (1964) found *Amphistegina gibbosa* concentrated in the sand shoals behind the reef crest: he suggested that they may have been rafted into that area from water that was more than 80 ft deep. On Baccoo reef, SW Tobago Island, living *Amphistegina gibbosa* is found on the forereef, the shelf edge, and forereef slope. Dead tests, however, are also common in the sand barrier assemblage that accumulated behind the reef crest where *Amphistegina gibbosa* is mixed with lagoonal species (Radford, 1976a). These studies show that forereef species, along with forereef sediment, are commonly transported into lagoons by onshore currents during storms.

OFFSHORE SEDIMENT TRANSPORT DURING STORMS

The distribution of the tracer species shows that sediment is exported from the lagoon and subsequently deposited in forereef environments. Size-distribution data show that in the inner lagoon, where living populations of *Archaias angulatus* are well established, small tests are rare. Conversely, numerous small tests are found in the forereef, where living populations of *Archaias angulatus* are rare (Figs. 4.4, 4.6). These anomalous distributions of small tests are comparable to trends in the mean test size of *Archaias angulatus*, which is greater at the shelf edge (0.83ϕ)(0.563 mm) than in the inner lagoon (0.63ϕ)(0.646 mm). These size trends indicate that significant winnowing of lagoonal sediment has taken place and that fine fractions have been exported and deposited on the lower forereef terrace.

Winnowed lagoonal assemblages are difficult to explain under fair-weather conditions. From biological and ecological perspectives, the best habitat for a species should have the largest population with numerous small juvenile tests. This situation is confirmed by the living collections from peripheral lagoons of Grand Cayman, where most *Archaias angulatus* found in the inner lagoon are small (<1.0 mm in diameter).

Similarly, the presence of lagoonal species such as *Archaias angulatus* on the forereef is also difficult to explain by fair-weather processes. *Archaias angulatus* is also found in forereef sediments in other areas of the Caribbean (Martin and Liddell, 1988, 1989; Triffleman *et al.* 1991). On fore-reef spurs or lobes, the size distribution of *Archaias angulatus* is skewed towards small individuals on the northern windward margin of Jamaica (Martin and Liddell, 1988, 1989). Winnowed *Archaias angulatus* assemblages found in other lagoons and on bank interiors throughout the Caribbean have been attributed to fair-weather processes or ecological requirement of the species (e.g., Streeter, 1963; Bandy, 1964; Wright and Hay, 1971; Brasier, 1975; Wantland, 1975; Lidz and Rose, 1989).

The presence of lagoonal tracers in forereef deposits around Grand Cayman and in other areas of the Caribbean shows that storms export foraminifera and sediment from lagoons into the forereef and deeper settings. Other studies have shown that sediments in lagoons have been winnowed and fine sediment moved out of lagoons and settled on outer shelf settings immediately after storms. Flood and Jell (1977), for example, noted that a decrease in the percentage of fine particles and increase of percentage of coarse sediment in the lagoon on Heron Island, Great Barrier Reef, after the passage of cyclone "David". In Florida Strait, a 6-inch layer of mud and silt was found at a depth of 50 m one month after Hurricane Donna (Ball *et al.*, 1967). Similarly, after Hurricane Betsy, muddy water extended from the mainland to the edge of the Gulf Stream a short distance beyond the outer reef (Perkins and Enos, 1968).

DISCUSSION

The distribution and size characteristics of tracer foraminifera around Grand Cayman are controlled largely by the processes that take place during storms and hurricanes (Fig. 4.7). Generally, these sedimentary processes can be divided into the: 1) storm approach stage; 2) storm waning stage, and 3) fair-weather inter-storm stage. The distributions of tracer foraminifera provide valuable insights into the processes that operate during each of these stages.

Under peak storm conditions sediments in the lagoon and forereef shelf are placed into suspension by the large storm waves. Broken corals and rubbles will be moved shoreward by wind-driven onshore currents that overtop the reef crest. Sand or finer-sized sediment from the forereef is moved landward and deposited as a bare sand blanket in the outer part of the lagoon (Blanchon *et al.*, in press). The smaller tests of the forereef species *Amphistegina gibbosa* moved into the lagoon along with the sand. This produces a winnowed forereef assemblage of *Amphistegina gibbosa* that is dominated by larger tests and explains why the mean and median sizes of *Amphistegina gibbosa* tests progressively increase from the shelf-edge into the inner lagoon (Figs. 4.4–4.6).

As the storm begins to abate and wave overtopping decreases, water level setup in the lagoon is released, and starts to drain via the channels. During this phase, lagoonal sediments that include foraminifera tests are carried out of the lagoon and deposited on the forereef terrace and down the shelf escarpment. This process produces winnowed sediment in the lagoon because suspended fine sediments that include smaller lagoonal foraminifera tests will be preferentially transported. Sediment located close to reef channels will be subjected to the maximum current reworking and suffer the most erosion.

After storms, fair-weather conditions are once again established and lagoonal organisms start to recolonize the substrates. Sediment exchange between the lagoon and forereef will be limited because the fringing reef effectively blocks most of the onshore wave energy. Under these conditions there is no source for sand-sized sediment that can be imported into the lagoon because the upper terrace is devoid of sediment. Potentially, fine sediment (silt and mud) that is placed into suspension by the bioturbation activities of organisms such as *Callianassa* could be exported from the lagoon by day-to-day currents induced by overwash waves and tides (Roberts *et al.*, 1975; Roberts, 1980, 1983; Roberts *et al.*, 1981; Roberts and Suhayda, 1983; Roberts *et al.*, 1992). Nevertheless, the fair-weather export of lagoonal fines was excluded from this study because the foraminiferal

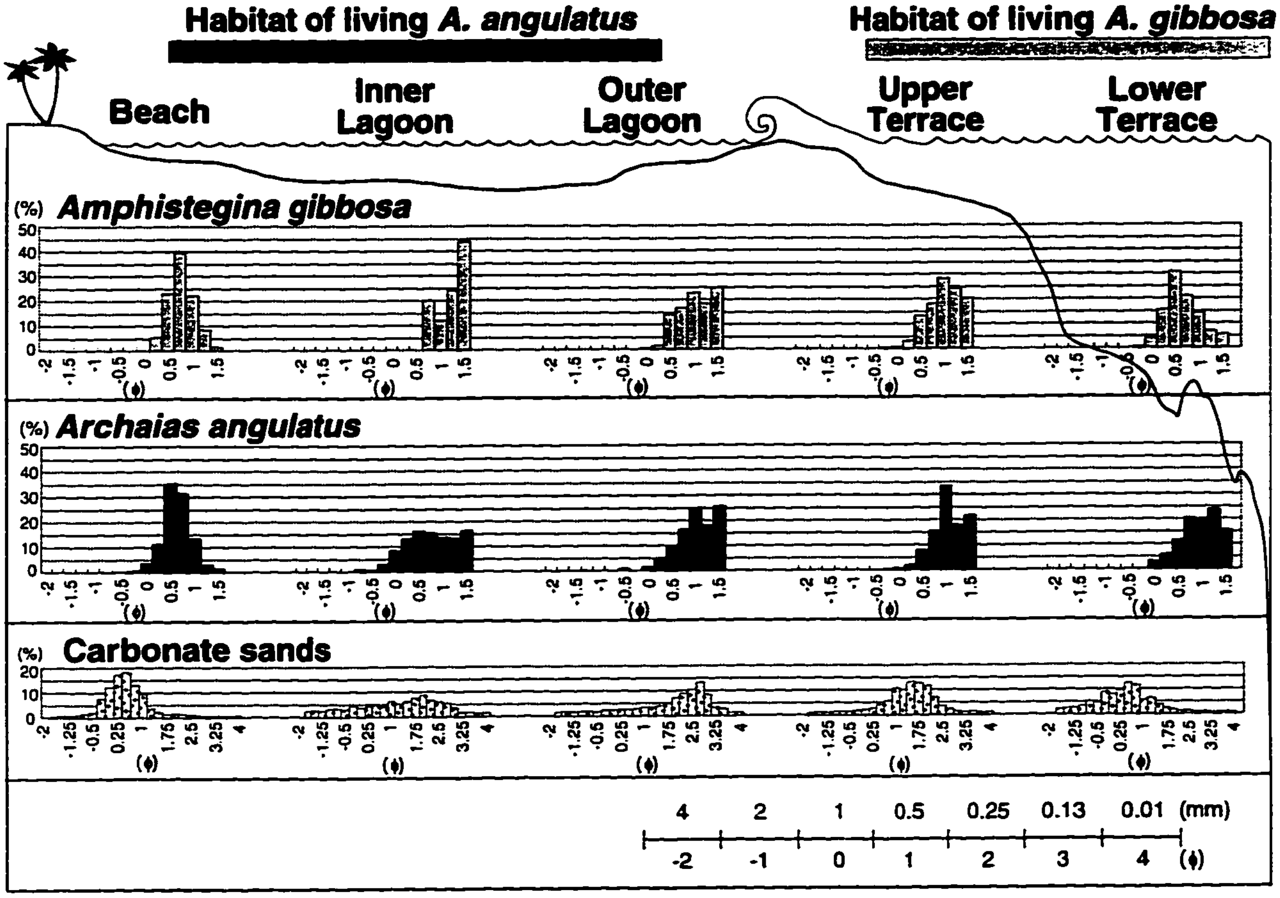

Figure 4.6—Histograms showing size distributions of *Amphistegina gibbosa* tests, *Archaias angulatus* tests, and sediments across the eastern shelf of Grand Cayman.

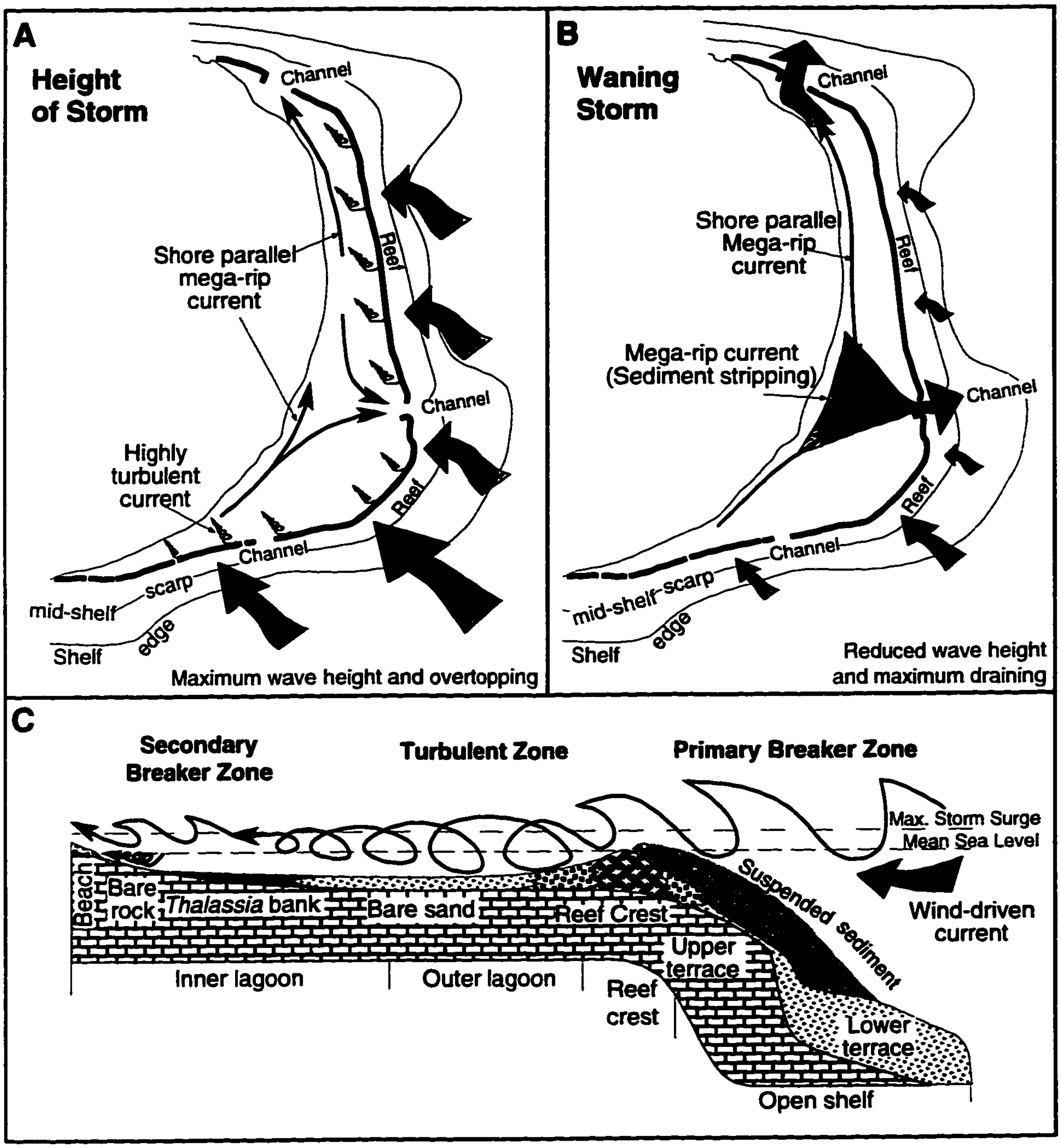

Figure 4.7—A model of storm processes on eastern shelf, Grand Cayman. **A)** At the height of the storm. **B)** As the storm wanes. **C)** A profile across the shelf during a severe storm (based on Kalbfleisch, 1995).

assemblages are based on specimens that are > 0.125 mm in size and hence coarser than the silt- and mud-sized grains that can be transported under "normal" conditions. Similarly, the effects of dissolution on lagoonal foraminifera (cf. Martin and Liddell, 1991) can be excluded because the water around Grand Cayman has normal marine salinity and is not impacted by river discharge as in other areas.

Although fair-weather export of sediment from lagoons is relatively minor, the burrowing organisms do cause extensive vertical mixing of the sediments. This process is so effective that sedimentary structures in the storm deposited sediments can be destroyed within a few weeks (Riddle, 1988). Vertical mixing of sediment will not, presumably, affect the distribution of the lithofacies and biofacies because there is little lateral movement of sediment under fair-weather conditions. During this calm period, progressive recolonization of the substrates in the *Thalassia* zone leads to progressive increases in the amounts of sediment produced by lagoonal organisms. In the bare sand zone, however, recolonization is much slower and the addition of lagoon-produced sediment is correspondingly slower due to the harsh substrate conditions. Accordingly, the character of the sediments in the bare sand zone is, at least in part, inherited from the storm deposited sediment that originated in the forereef zone (Blanchon *et al.*, in press). These contrasts explain why the boundary between the bare sand and *Thalassia* zones coincides with the contours of foraminifera abundances that denote significant decreases in the quantities of forereef tracer species (Fig. 4.3A).

In each cycle, the factors that control the composition and fabrics of the lagoon sediments are: 1) productivity and bioturbation of the lagoonal organisms, 2) topography of the lagoon, and 3) the intensity and frequency of storms. The recolonization by new lagoonal organisms and mixing of surface/subsurface sediments during the inter-storm stage will produce sediments with a progressively increasing proportion of lagoonal components. In channel-adjacent areas, however, the limited thickness of sediment and barren nature of the seafloor means that recolonization and recovery of the lagoonal sediment producers is slow. Thus, sediments in those areas contain fewer lagoonal components but elevated proportions of forereef components as shown in the area opposite the East End Channel (Fig. 4.3). Sediment behind the reef is prone to winnowing and sorting even under fair-weather conditions because the reef crest is broken by a series of poorly-developed channels. This explains why the ≥40% abundance contour for *Archaias angulatus* and ≤5% abundance contour for *Asterigerina carinata* are parallel to the reef crest rather than the landward boundary of the sand plain as in other areas. As might be expected, the foraminifera in this area are dominated by abrasion-resistant species. This is consistent with earlier taphonomic experiments which showed that *Archaias angulatus* is resistant to abrasion whereas *Asterigerina carinata* are prone to destruction by physical abrasion (Martin, 1986; Martin and Wright, 1988;

Peebles and Lewis, 1988, 1991; Wetmore and Plotnick, 1988; Martin and Liddell, 1991; Kotler *et al.*, 1992). Storm frequency and intensity play crucial roles in controlling sediment composition in the lagoon. High frequency and/or intensity of storms will produce sediments over the entire lagoon that are dominated by less lagoonal components. Less frequent and/or weak storms will leave the sediments in the lagoon more "lagoonal" in composition.

CONCLUSIONS

This study demonstrates that certain species of foraminifera can be used to trace sediment movement and thereby provide unique insights into storm processes on the windward shelf of Grand Cayman. Under peak storm conditions, sediment including foraminifera tests in the lagoon and forereef shelf are placed into suspension by the large storm waves. Wind-driven onshore currents carry the sediment over the reef crest and deposit it in the back-reef. As a result, the forereef assemblage of *Amphistegina gibbosa* is dominated by larger tests, which decrease in size from the shelf-edge to the inner lagoon. In addition, size distributions of the lagoonal tracer species demonstrate that water drains out of the lagoon through channels as the storm starts to abate and deposits finer suspended lagoonal sediment, including foraminifera tests, in the forereef area and down the shelf slope. Consequently, the total population of the lagoonal species *Archaias angulatus* is winnowed in the lagoon whereas numerous small tests of the same species are found in the forereef area.

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CHAPTER 5 SEDIMENT COMPOSITION AND EVOLUTION IN LAGOON BASED ON FORAMINIFERA TRACER SPECIES, FRANK SOUND, GRAND CAYMAN, BRITISH WEST INDIES

INTRODUCTION

Peripheral lagoons around Grand Cayman are characterized by shallow, tranquil normal-marine waters that are separated from the open ocean by fringing reefs. Similar lagoons are present around most islands in the Caribbean region. Little work has been done, however, on the processes that govern the formation of the substrates and sediments in those lagoons (Kalbfleisch, 1995). Little is known about the origin of sediments in these lagoons and it is therefore difficult to analyze lagoonal sediment budgets and assess their evolution through time. This problem can be approached by identifying tracer grains that can be used to track the temporal and spatial movement of sediments.

Benthic foraminifera are used in this study to track sediment movement because many species live in specific, ecologically diagnostic environments. By tracing the movement of those species, we can identify the origin of sediments in the lagoon, gain an understanding of sediment transportation directions under different physical conditions, and determine the evolution of the lagoon. Using Frank Sound on Grand Cayman (Fig. 5.1) as an example, this study (i) delineates foraminiferal assemblages in the surface and subsurface sediments, (ii) outlines the physical processes that control sediment transportation during storm conditions, (iii) examines the biological processes that control sediment composition and fabric, and (iv) determines the factors that control the sediment budget in the lagoon.

THE STUDY AREA

Grand Cayman is a flat, low-lying tropical island that is 35 km long and 6–14 km wide (Fig. 5.1). It is surrounded by a narrow shelf, up to 3 km wide, that is divided by a fringing reef (Rigby and Roberts, 1976). Landward of the reef, narrow peripheral lagoons parallel the shore. Seaward of the reef, the shelf is divided into the upper (0–10 m) and lower (12–40 m) terraces by a mid-shelf scarp (Blanchon and Jones, 1995). The edge of the shelf is bounded by an escarpment that typically begins at 55–80 m and extends vertically into waters 115–145 m deep (Messing and Platt, 1987). From there, the island slope extends into the abyssal depths of the Caribbean Sea.

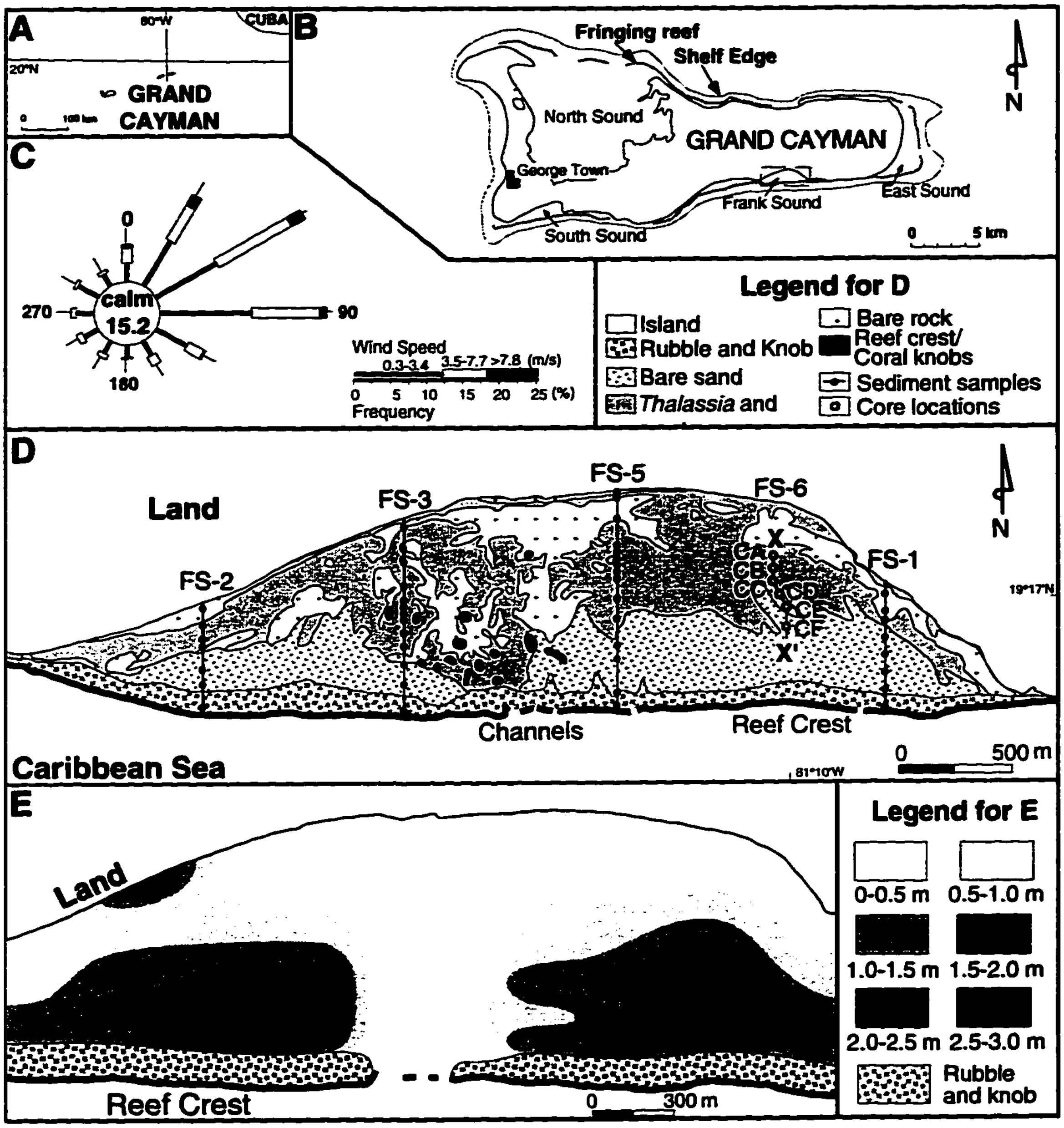


Figure 5.1—**A)** Location of Grand Cayman in northern Caribbean Sea. **B)** Map showing study area on Grand Cayman. **C)** Time-averaged annual wind rose graph (based on Darbyshire *et al.*, 1976). **D)** Map of Frank Sound showing substrates, locations of traverses, and locations of samples (from satellite photo, 1992). **E)** Sediment thickness for Frank Sound (from Kalbfleisch, 1995).

Waters in Frank Sound have a maximum surface temperature of 32°C, normal open marine salinities (35 to 38‰), and chlorinity of 19.9 - 20.9‰ (Moore, 1973; Raymont *et al.*, 1976). The open shelf waters are remarkably clear, partly because no rivers discharge from the island. Mixed diurnal and semi-diurnal tides have a maximum range of 1 m and generally produce only weak currents (Burton, 1994). Consequently, shelf and coastal currents are largely driven by wind and waves that are controlled by trade winds which blow from the east, northeast, or southeast throughout most of the year. Waves generated are typically 1.25–2.5 m high on the windward side of the island but < 0.5 m on the leeward side (Darbyshire *et al.*, 1976). Waves are also generated by the tropical cyclones that frequently affect the island. Powerful waves generated by hurricanes can be many meters high and have washed away roads and deposited cobbles and boulders on shore (Rigby and Roberts, 1976; Jones and Hunter, 1992).

Frank Sound is on the exposed-windward margin of the south coast of Grand Cayman (Fig. 5.1D). It is ~ 4 km long and up to 1 km wide. It is bounded by land to the north and a fringing reef to the south. One major break in the reef has been widened for navigation purposes. Although the water is typically about 2 m deep, it attains a maximum depth of 3 m. Over most of the lagoon, the sediment is about 1 m thick. Local changes in sediment thickness are due to variations in the topography of the underlying bedrock (Kalbfleisch, 1995). Exceptions to this general pattern are found on the east and west sides of the channel where sediment is concentrated in two major lobes (Fig. 5.1E). North of the channel there is a triangular-shaped region where sediment is <0.5 m thick.

METHODS

Forty-four surface sediment samples (0.5–1 kg each), collected at 30-60 m intervals by SCUBA or snorkeling, were taken along traverses 1, 2, 3, and 5 in Frank Sound in the summer of 1993 (Fig. 5.1D). Six sediment cores (CA–CF) were collected on traverse 6 (X–X') by driving 10 cm diameter PVC pipe into the sediment (cf. Jones *et al.*, 1992) (Fig. 5.1D). The PVC pipe was cut using a saw and the core split using a thin wire and knife. Twenty-nine sediment samples were taken at 10 or 20 cm intervals in these cores.

The sieve method of Martin and Liddell (1988, 1989) was used to obtain species abundances and size distributions of foraminifera tests from the sediment samples. This technique was used because it provides insights into the effects of transportation, sorting, and differential preservation of foraminifera in turbulent reef settings (Martin and Liddell, 1988). Initially, one split of each sediment sample (100–150 g) was divided into 1 ϕ intervals by sieving for 10 minutes. Then, where possible, 300 individuals were identified and counted from each fraction coarser than 3 ϕ (0.125 mm). In some cases, however, less than 300 specimens were identified and counted simply because the sediment fraction being examined contained less than 300 foraminifera tests. For this study, 58,796 foraminifera tests were counted with the average number of specimens in each sample being >800. Such sample numbers mean that the recognition of assemblages using species that form >3% of any sample is statistically reliable at the 95% confidence limit (Cerridwen and Jones, 1991; Patterson and Fishbein, 1989).

Of the 117 species identified from the samples in Frank Sound, *Archaias angulatus* (lagoonal), *Amphistegina gibbosa*, *Asterigerina carinata*, and *Discorbis rosea* (forereef) are used as "tracer species" for tracking sediment movement across the shelf. These species were selected because their original habitat is restricted and they are common components in all of the sediment samples.

Foraminiferal assemblage analysis of the surface and core samples was based on Q-mode cluster analysis that used 24 species which form ≥3% of the foraminiferal fauna in any sample (Table 5.1). Dissimilarity indices (0 = minimum dissimilarity, or maximum similarity) between each pair of samples was calculated in Euclidean distance using abundance data. Binary data were not used because they consistently failed to give dendrograms that displayed foraminiferal assemblages. The dendrograms were derived using the between groups method and the SPSS program.

Data for the grain-size analysis of 20 surface sediment samples and 18 core sediment samples were extracted from Kalbfleisch (1995).

ZONATIONS OF LAGOON SUBSTRATES

Substrates in Frank Sound are divided into the 1) Rubble and Knob Zone; 2) Bare Sand Zone; 3) *Thalassia* and Sand Zone; 4) Bare Rock Zone and 5) Coral Knob Zone (Kalbfleisch, 1995). The Rubble and Knob Zone, located behind and parallel to the reef crest, is dominated by coral rubble that is colonized by brown and red algae, corals, and gorgonians. The Bare Sand Zone, landward of the Rubble and Knob Zone, is dominated by medium to fine skeletal sand with sparse sea grass and green algae. The *Thalassia* and Sand Zone, which extends from the Bare Sand Zone to near shore, is characterized by dense *Thalassia* banks. The Bare Rock Zone, dominated by stripped bedrock, is found as a shore-parallel pavement and in a triangle-shaped area that spreads out northwards from the channels that cut through the reef (Fig. 5.1D). Coral knobs are scattered throughout the bare rock, Rubble and Knob and Bare Sand Zones.

Table 5.1 Distribution data of total number of the foraminifera recovered from each samples. Those species that form <3% of the assemblage at each locality are collectively listed as "other species".

	LOCALITIES														
SPECIES	1090	1150	1180	1240	1300	1360	1420	1480	2030	2090	2150	2180	2270	2330	2420
Amphisorus hemprichii	5.92	3.61	0.92	0.21	1.61	2.16	4.10	4.03	1.04	2.37	2.04	0.81	0.91	1.39	3.54
Amphistegina gibbosa	2.88	3.07	6.26	8.18	5.89	8.93	4.50	4.87	2.09	10.13	7.25	0.41	5.91	7.11	3.66
Archaias angulatus	51.97	57.39	60.22	61.22	49.26	38.33	36.90	33.72	77.91	37.18	33.86	69.96	48.03	34.00	22.05
Archaias compressus	0.61	0.00	0.00	0.00	0.00	0.00	0.26	1.34	0.60	0.95	1.25	6.22	0.61	0.15	0.12
Asterigerina carinata	3.19	0.77	2.39	5.45	6.29	8.93	10.19	10.07	0.60	1.42	3.28	1.96	8.48	10.36	13.09
Clavulina tricarinata	0.38	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.15	1.11	0.91	0.07	0.00	0.00	0.00
Cymb. squammosa	1.44	1.97	2.58	2.52	7.90	9.65	9.92	8.56	1.04	0.79	1.47	1.56	8.18	7.88	5.66
Discorbis mira	2.20	2.52	0.92	0.42	1.07	1.15	2.38	1.01	1.79	9.49	6.23	0.61	0.76	1.39	2.36
Discorbis rosea	3.57	5.26	4.24	5.03	7.63	5.04	3.97	8.39	4.93	9.97	11.33	1.22	7.12	6.65	18.87
Elphidium lanieri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.07	0.30	0.00	0.24
Miliolinella circularis	1.67	0.77	1.29	0.84	2.01	3.31	4.76	3.69	0.30	1.90	2.15	1.42	0.91	4.33	5.07
Peneroplis discoideus	0.23	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.16	0.11	0.00	0.00	0.00	0.24
Planorbulina acervalis	6.75	8.32	0.37	0.00	0.00	0.00	0.00	0.17	0.45	0.47	0.79	0.27	0.00	0.00	0.00
Pyrgo subsphaerica	0.23	0.11	0.37	0.00	0.67	0.29	0.53	0.17	0.00	0.00	0.23	0.00	0.45	0.46	0.59
Quin. agglutinans	1.29	0.66	1.29	1.47	0.40	0.86	0.53	1.01	1.94	1.11	1.47	2.44	2.58	2.16	0.24
Quin. bidentata	0.83	0.33	0.55	0.42	0.27	0.00	0.26	0.34	0.45	0.79	0.79	0.27	0.61	0.00	0.24
Quin. bradyana	1.37	0.77	1.29	0.00	0.40	0.43	0.40	0.17	0.45	0.47	0.34	0.20	0.15	0.00	0.47
Rosalina candeiana	1.67	1.97	3.50	2.94	3.48	3.31	4.63	4.87	0.00	1.27	2.72	2.03	1.67	4.95	7.55
Schlum. occidentalis	0.46	0.11	0.74	0.21	0.67	1.15	0.53	0.67	0.30	0.32	1.25	0.00	0.00	0.93	0.71
Tr. carinata	0.68	0.22	0.18	0.00	0.67	0.43	0.79	0.84	0.15	0.63	0.23	0.20	1.52	1.70	1.06
Tr. laevigata	0.76	1.20	0.92	0.00	0.13	0.14	0.00	0.00	0.30	1.58	0.34	0.20	0.00	0.31	0.00
Tr. linneiana	2.43	1.42	2.03	2.94	3.48	3.75	1.98	2.35	0.75	3.48	4.08	2.50	2.27	2.47	1.89
Tr. quadrilateralis	1.06	0.44	0.55	0.00	0.13	0.14	0.66	0.34	0.15	0.95	0.23	0.34	0.91	0.93	0.94
Valvulina oviedoiana	0.99	0.88	0.74	1.89	1.47	2.74	2.25	3.52	0.60	1.42	1.81	1.01	2.12	2.47	1.06
Other species	7.44	7.89	8.66	6.29	6.56	9.22	10.19	9.90	4.03	12.03	15.74	6.22	6.52	10.36	10.38

	LOCALITIES														
SPECIES	3030	3090	3150	3210	3270	3330	3360	3390	3420	3480	3540	3630	3720	3840	5000
Amphisorus hemprichii	1.88	2.20	0.65	1.34	3.90	3.49	1.44	3.52	7.26	7.06	4.19	4.05	2.10	5.43	2.23
Amphistegina gibbosa	4.69	0.00	0.65	0.00	0.00	0.12	0.11	0.10	0.14	0.17	1.31	0.23	1.61	2.77	2.63
Archaias angulatus	52.11	38.83	73.23	58.18	62.83	63.51	77.90	54.10	40.31	51.43	53.01	45.43	53.71	41.38	49.80
Archaias compressus	0.00	0.00	0.00	0.27	2.46	2.62	2.10	2.54	1.71	2.35	5.37	2.54	4.19	0.24	0.00
Asterigerina carinata	1.41	0.73	0.65	0.27	0.00	0.25	0.77	1.27	1.14	2.69	4.58	6.59	5.81	9.89	2.50
Clavulina tricarinata	0.47	1.10	0.65	0.54	0.41	0.25	0.11	0.49	0.71	0.34	0.13	0.00	0.16	0.00	0.53
Cymb. squammosa	2.82	1.10	0.32	0.80	0.82	1.00	0.77	1.27	2.28	2.86	4.58	6.94	5.32	5.07	7.88
Discorbis mira	7.51	4.40	0.65	0.54	0.82	0.87	0.55	0.20	1.14	0.34	0.00	0.46	0.81	1.09	2.37
Discorbis rosea	0.47	0.37	1.29	0.80	0.21	0.25	0.33	0.98	0.43	1.01	0.92	1.50	2.90	10.25	3.29
Elphidium lanieri	3.29	1.83	0.00	0.00	0.00	0.12	0.11	0.00	0.00	0.17	0.00	0.35	0.00	0.12	0.13
Miliolinella circularis	0.94	1.47	0.00	0.00	0.21	0.75	0.22	0.88	1.28	1.34	1.96	5.09	0.81	2.41	0.66
Peneroplis discoideus	0.00	0.00	0.00	0.27	0.62	0.50	0.77	0.98	1.00	1.18	1.05	0.92	0.48	0.00	0.00
Planorbulina acervalis	0.00	0.37	0.32	0.80	3.90	5.98	3.31	8.69	8.40	4.71	0.92	0.46	0.00	0.12	0.00
Pyrgo subsphaerica	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.10	0.00	0.34	0.52	0.58	1.13	0.60	0.66
Quin. agglutinans	1.41	7.33	3.23	6.70	2.05	1.74	2.21	5.86	3.28	2.18	2.75	2.43	1.45	1.69	1.45
Quin. bidentata	1.88	4.03	3.55	7.77	3.29	1.37	1.55	2.54	1.99	0.00	1.05	0.92	1.45	0.48	1.71
Quin. bradyana	2.82	6.59	0.32	0.54	1.44	1.37	0.44	1.95	1.85	0.67	0.13	0.35	0.48	0.36	1.31
Rosalina candeiana	0.00	0.73	0.00	0.80	0.41	1.00	0.11	0.59	1.57	0.50	1.44	4.62	3.39	3.02	2.37
Schlum. occidentalis	0.00	0.37	1.94	1.61	0.82	0.37	0.11	0.10	0.71	0.67	0.00	0.23	0.16	0.60	1.58
Tr. carinata	2.35	1.47	1.61	2.14	1.64	0.37	0.55	1.37	1.71	4.71	2.23	1.27	1.94	0.84	0.66
Tr. laevigata	1.88	4.76	0.32	1.61	3.29	1.74	1.55	1.27	4.13	1.34	1.31	1.27	0.65	0.24	0.00
Tr. linneiana	0.94	2.20	0.97	1.88	1.85	1.62	0.77	2.05	2.42	3.19	1.96	1.97	1.61	1.09	1.71
Tr. quadrilateralis	0.94	0.37	1.29	1.34	0.41	0.37	0.33	0.10	1.00	0.84	1.18	1.16	0.81	0.72	1.97
Valvulina oviedoiana	0.47	0.37	0.32	0.54	0.00	0.37	0.22	0.20	1.00	0.34	0.65	0.69	0.81	1.21	0.53
Other species	11.74	19.41	8.06	11.26	8.62	9.96	3.54	8.89	14.53	9.58	8.77	9.94	8.23	10.37	14.06

Table 5.1 (Continued)

	LOCALITIES														
SPECIES	5030	5120	5240	5270	5300	5330	5360	5390	5480	5570	5690	5750	5900	5960	CA0
Amphisorus hemprichii	0.28	2.57	0.92	1.33	3.71	2.55	2.62	2.71	2.15	3.26	2.51	1.14	2.59	5.93	2.18
Amphistegina gibbosa	0.09	0.37	0.50	1.46	1.35	2.55	5.59	4.27	0.31	0.79	0.46	1.39	3.41	3.21	23.75
Archaias angulatus	61.88	49.02	60.64	47.74	37.91	48.29	42.10	60.38	64.35	57.65	50.34	62.15	35.56	21.60	29.90
Archaias compressus	0.47	0.25	3.52	2.32	1.52	3.75	5.11	2.38	0.61	1.18	1.37	2.91	0.54	0.12	3.03
Asterigerina carinata	0.28	0.49	0.42	1.00	1.94	1.91	2.21	1.15	1.43	7.90	6.61	5.82	4.22	14.07	1.23
Clavulina tricarinata	1.31	3.06	2.09	3.39	3.29	1.83	2.62	1.48	0.51	0.00	0.00	0.00	0.00	0.00	2.65
Cymb. squammosa	0.19	0.12	0.42	0.73	1.94	1.20	0.14	1.07	2.35	5.53	8.09	3.92	3.68	7.28	3.88
Discorbis mira	2.91	3.19	1.76	3.39	4.13	4.38	2.83	2.54	0.82	0.89	0.57	0.25	0.82	1.36	3.03
Discorbis rosea	0.47	0.86	0.67	1.99	0.84	2.07	0.97	1.07	0.41	0.99	0.80	1.52	10.08	11.36	1.70
Elphidium lanieri	0.00	0.00	0.08	0.00	0.00	0.16	0.07	0.16	0.00	0.00	0.00	0.00	0.00	0.12	0.00
Miliolinella circularis	0.09	0.37	0.17	0.40	1.18	1.20	0.48	0.49	0.61	2.17	2.05	0.89	0.27	2.84	0.66
Peneroplis discoideus	0.00	0.12	0.17	0.53	0.51	0.64	1.38	0.82	1.23	0.39	2.05	1.14	7.90	0.12	1.61
Planorbulina acervalis	0.00	0.37	0.67	1.06	2.78	3.19	3.11	2.13	2.35	0.00	0.00	0.13	0.14	0.49	0.57
Pyrgo subsphaerica	0.00	0.12	0.00	0.27	0.17	0.00	0.14	0.08	0.31	0.49	0.46	1.27	3.13	0.99	0.47
Quin. agglutinans	3.19	3.55	3.43	3.25	2.78	2.95	2.00	2.21	3.98	2.47	1.94	2.41	1.50	2.10	2.08
Quin. bidentata	4.79	4.90	2.26	2.99	0.67	1.12	1.45	2.21	2.15	1.97	0.11	0.51	0.95	0.74	1.04
Quin. bradyana	1.88	3.31	1.01	1.79	3.29	1.75	2.76	0.00	0.10	0.20	0.11	0.13	0.27	0.62	0.95
Rosalina candeiana	0.00	0.49	0.50	0.13	1.68	1.20	1.59	0.82	1.02	3.26	4.67	3.29	2.45	4.81	0.76
Schum. occidentalis	5.82	1.35	0.67	0.53	0.51	1.04	0.00	0.49	0.20	0.30	0.00	0.25	0.95	1.11	0.57
Tr. carinata	0.00	2.70	3.52	1.86	3.03	1.43	2.14	1.07	2.55	1.48	0.57	0.38	0.95	0.37	2.18
Tr. laevigata	0.00	1.59	0.75	0.33	0.34	0.64	0.48	0.08	0.82	0.20	0.34	1.01	0.95	0.25	0.47
Tr. linneiana	0.75	2.33	2.01	2.32	3.03	2.39	1.31	1.72	1.94	1.88	4.10	1.77	3.41	1.73	2.55
Tr. quadrilateralis	2.91	1.72	1.09	1.73	3.20	1.35	1.59	0.49	0.61	1.18	1.94	0.38	1.23	1.85	1.23
Valvulina oviedoiana	1.50	3.31	7.04	8.63	9.44	4.46	6.56	3.45	4.09	1.48	1.37	0.89	0.82	1.11	3.88
Other species	11.17	13.85	5.70	10.82	10.78	7.97	10.77	6.73	5.11	4.34	9.57	6.46	14.17	15.80	9.65

	LOCALITIES														
SPECIES	CA20	CA40	CB0	CB20	CB40	CC0	CC30	CC50	CD0	CD20	CD40	CD60	CD77	CE0	CE20
Amphisorus hemprichii	2.48	1.40	2.24	2.17	1.51	5.11	3.16	1.19	2.05	1.21	2.06	3.23	2.48	1.83	2.25
Amphistegina gibbosa	23.16	9.43	1.82	1.76	1.85	2.49	2.83	3.06	2.05	2.68	1.84	1.94	1.74	1.94	4.21
Archaias angulatus	38.60	59.95	35.01	58.86	62.86	53.12	55.07	68.59	55.63	64.97	46.85	50.32	49.69	60.73	58.18
Archaias compressus	4.88	6.05	2.52	2.57	0.34	1.12	0.17	1.02	0.51	0.13	0.65	0.52	0.87	0.43	0.20
Asterigerina carinata	1.33	1.28	4.48	2.30	6.39	5.11	6.32	2.21	4.09	2.55	4.23	4.90	7.95	4.85	4.90
Clavulina tricarinata	0.62	0.81	0.84	0.27	0.00	0.50	0.17	0.00	0.13	0.13	0.00	0.13	0.00	0.00	0.00
Cymb. squammosa	1.69	3.38	4.62	7.04	4.20	5.61	4.99	5.09	13.68	6.71	13.02	3.74	9.32	5.18	4.11
Discorbis mira	1.42	0.58	5.32	0.68	2.02	0.62	0.83	1.02	0.90	0.40	1.41	0.65	0.25	0.86	0.78
Discorbis rosea	1.33	1.51	1.12	0.81	1.68	0.75	1.16	0.34	1.28	1.07	2.49	1.81	1.74	0.43	0.49
Elphidium lanieri	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.13	0.00	0.11	0.13	0.00	0.22	0.10
Miliolinella circularis	0.89	0.35	2.52	0.81	2.18	0.87	5.66	1.19	0.77	1.07	1.52	3.35	1.86	2.70	3.33
Peneroplis discoideus	1.95	0.58	0.42	0.81	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.11	0.10
Planorbulina acervalis	0.44	0.23	6.30	0.81	0.17	4.49	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00
Pyrgo subsphaerica	0.53	0.00	0.28	0.54	0.50	0.50	0.00	0.00	0.77	0.54	0.22	0.90	0.50	0.22	0.49
Quin. agglutinans	2.40	1.75	3.22	2.03	2.02	2.49	1.66	1.70	2.94	3.09	3.36	2.19	2.24	1.73	0.98
Quin. bidentata	0.89	1.16	0.70	1.08	0.50	0.50	1.50	1.02	1.15	1.48	1.41	1.29	1.37	0.11	0.49
Quin. bradyana	0.71	0.35	1.82	0.27	0.50	0.50	0.50	0.17	0.38	0.13	0.22	1.03	0.12	0.22	0.10
Rosalina candeiana	0.53	1.51	1.68	3.25	3.19	2.37	4.66	2.89	2.30	2.28	5.86	4.39	4.10	3.34	3.13
Schlum. occidentalis	0.27	0.00	0.42	0.14	0.00	0.12	0.00	0.00	0.13	0.00	0.33	0.00	0.00	0.22	0.29
Tr. carinata	1.06	1.28	2.52	0.81	0.84	1.00	0.00	0.34	0.64	0.81	0.98	2.19	0.75	0.32	0.59
Tr. laevigata	0.27	0.12	0.56	0.27	0.17	0.37	0.00	0.00	0.51	0.13	0.00	0.13	0.75	0.54	0.69
Tr. linneiana	2.84	1.98	2.66	3.11	2.86	2.62	2.66	2.04	1.92	2.55	3.04	4.13	2.24	2.91	3.43
Tr. quadrilateralis	0.44	0.12	1.26	0.54	0.67	1.12	0.83	0.85	0.51	0.54	0.65	0.77	1.24	0.97	1.57
Valvulina oviedoiana	5.50	2.79	7.70	3.92	1.18	3.12	1.16	1.53	1.41	3.09	3.58	2.32	1.49	2.59	1.67
Other species	5.77	3.38	9.94	5.01	4.37	5.24	6.66	5.77	5.88	4.43	6.18	9.81	9.32	7.55	7.93

Table 5.1 (continued)

	LOCALITIES												
SPECIES	CE40	CE60	CE80	CE100	CE113	CF0	CF20	CF40	CF60	CF80	CF100	CF120	CF134
Amphisorus hemprichii	1.81	2.32	1.17	1.80	1.32	6.98	3.67	4.85	3.57	3.33	4.67	2.72	1.73
Amphistegina gibbosa	2.36	3.22	1.52	3.04	3.95	2.50	1.83	1.73	3.23	5.28	2.75	3.14	2.60
Archaias angulatus	54.66	59.54	57.73	55.22	54.68	30.52	36.70	29.29	36.05	38.16	46.15	47.49	39.27
Archaias compressus	0.28	0.13	0.00	0.09	0.13	0.83	0.92	1.04	0.68	0.59	0.55	0.21	0.17
Asterigerina carinata	5.42	4.38	5.50	4.93	4.74	6.15	5.39	3.99	7.82	7.63	4.53	5.44	6.40
Clavulina tricarinata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cymb. squammosa	8.48	8.51	6.21	7.31	5.93	14.58	16.51	20.28	12.93	13.89	13.87	9.21	15.22
Discorbis mira	0.42	0.39	1.99	0.95	1.19	0.73	0.46	0.35	0.68	0.20	0.69	0.63	1.56
Discorbis rosea	1.53	1.68	1.05	1.04	1.05	1.04	1.49	1.73	0.85	1.76	0.96	2.09	0.69
Elphidium lanieri	0.28	0.13	0.12	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.17
Miliolinella circularis	2.78	1.68	3.16	2.09	2.24	4.17	3.21	2.43	3.23	3.52	1.51	2.93	5.54
Peneroplis discoideus	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planorbulina acervalis	0.00	0.00	0.00	0.00	0.00	0.31	0.23	0.00	0.00	0.00	0.14	0.00	0.00
Pyrgo subsphaerica	0.28	0.13	0.47	0.38	0.13	1.56	1.15	0.52	0.51	0.39	0.69	0.21	0.17
Quin. agglutinans	2.64	2.19	2.22	2.66	2.77	2.19	2.98	4.33	2.89	2.15	3.57	3.35	3.11
Quin. bidentata	0.00	0.00	0.35	0.38	0.53	0.73	1.15	0.87	1.19	0.78	0.82	1.05	0.17
Quin. bradyana	0.14	0.39	0.12	0.28	0.13	0.31	0.00	0.00	0.00	0.20	0.14	0.21	0.00
Rosalina candeiana	3.06	3.48	4.33	4.55	5.14	7.29	5.05	3.99	6.63	5.09	2.34	5.86	3.81
Schlum. occidentalis	0.28	0.26	0.23	0.09	0.26	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00
Tr. carinata	0.70	0.64	0.35	0.28	0.26	1.35	0.92	0.69	1.02	0.78	1.24	0.84	1.04
Tr. laevigata	0.70	0.26	0.47	0.00	0.79	0.10	0.57	0.17	0.85	0.00	0.27	0.42	0.17
Tr. linneiana	4.17	1.42	2.11	3.42	3.16	4.06	3.44	4.16	4.76	3.72	4.67	4.81	4.15
Tr. quadrilateralis	0.97	0.90	1.41	0.85	1.45	1.56	1.26	1.39	1.02	0.98	0.82	0.84	1.73
Valvulina oviedoiana	2.50	1.55	1.76	1.71	2.11	1.98	1.38	4.16	1.36	1.76	2.61	1.46	1.73
Other species	6.54	6.83	7.73	8.92	8.04	10.83	11.70	14.04	10.54	9.78	6.87	7.11	10.55

FORAMINIFERAL ASSEMBLAGES

Foraminifera in Frank Sound belong to two assemblages (1 and 2) and Assemblage 1 is subdivided into 3 subassemblages (1A, 1B, and 1C). They are: *Archaias angulatus-Cymbaloporetta squammosa-Asterigerina carinata* Assemblage (1A), *Archaias angulatus-Valvulina oviedoiana-Discorbis mira* Assemblage (1B), *Archaias angulatus-Quinqueloculina agglutinans-Discorbis rosea* Assemblage (1C), and *Archaias angulatus-Cymbaloporetta squammosa-Amphistegina gibbosa* Assemblage (2).

Assemblage 1A is dominated by lagoonal species whereas Assemblage 2 is characterized by abundant forereef species (Fig. 5.2). Assemblage 1A, characterized by its high diversity and numerous epiphytic species, is found on the *Thalassia* and Sand Zone and the inner part of the Bare Sand Zone near the channel (Figs. 5.3, 5.4A). Assemblage 1B, dominated by abrasion-resistant species such as *Archaias angulatus, Valvulina oviedoiana*, and *Planorbulina acervalis* (cf. Peebles and Lewis, 1991; Kotler, *et al.*, 1992), is found in the triangular-shaped Bare Rock Zone area north of the channel (Fig. 5.4A). Assemblage 1C, characterized by exceptionally high percentage (up to 77% of the fauna) of the lagoonal species *Archaias angulatus* that has abrasion-resistant test, has been winnowed. It is typically found on the Bare Rock Zone or around coral knobs. Assemblage 2, characterized by abundant forereef species and the lowest percentage of lagoonal species *Archaias angulatus*, is typically found in the Rubble and Knob Zone and the seaward part of the Bare Sand Zone. This assemblage, however, is also found in small areas in the inner part of the *Thalassia* and Sand Zone. Overall, the surface distribution of the assemblages (Fig. 5.4A) closely mimics the lagoon substrates that were defined by other biotic and sedimentologic parameters (Fig. 5.1D).

Subsurface samples along traverse 6 further confirm the surface distribution of these assemblages. Assemblage 1A is found in the *Thalassia* and Sand Zone near the surface, but extends landward and seaward in the subsurface (cores CA, CB, and CF, Fig. 5.4B). Although assemblage 1B is found near the surface in core CB, it is replaced seaward by Assemblage 1A and landward by Assemblage 2. Assemblage 2 is found in the top and bottom parts of core CF, and in the upper part of core CA (Fig. 5.4B).

DISTRIBUTION OF TRACER SPECIES

Sediment in the *Thalassia* and Sand Zone is characterized by numerous tests (>50% of the foraminifera assemblage) of the lagoonal species *Archaias angulatus*. The abundance of the forereef species *Amphistegina gibbosa, Discorbis rosea*, and *Asterigerina carinata*

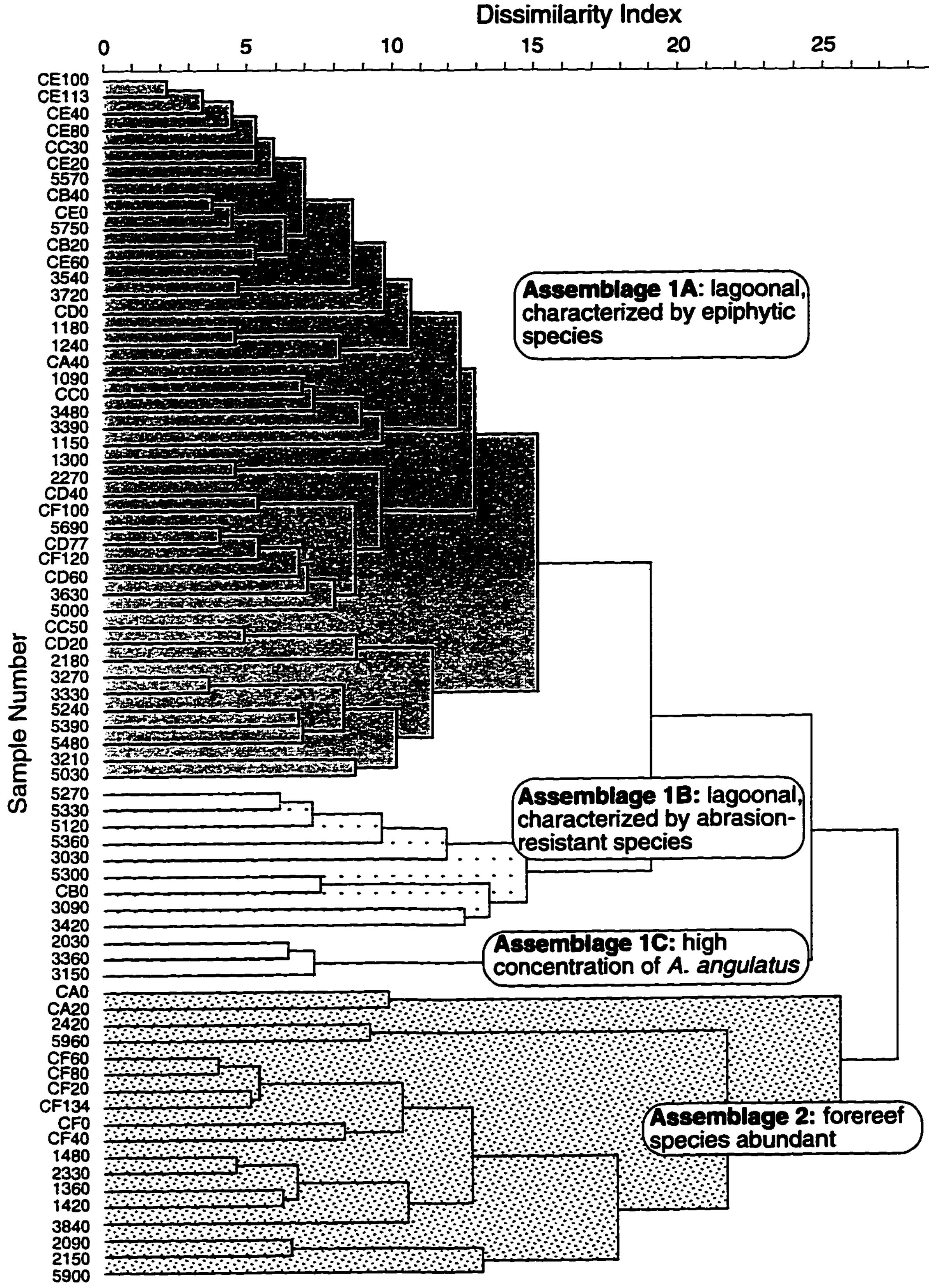


Figure 5.2—Dendrogram of Q-mode cluster analysis of samples, based on foraminifera that form ≥3% of the fauna on any site (Between Groups Method and Euclidean Distance), showing assemblages 1A, 1B, 1C and 2.

Substrate	*Thalassia* and sand zone/ Bare sand zone		Bare rock zone				Rubble and knob zone/ Bare sand zone	
Assemb.	Assemblage 1A		Assemblage 1B		Assemblage 1C		Assemblage 2	
Most abundant species	Species	%	Species	%	Species	%	Species	%
	Archaias angulatus	56.72	*Archaias angulatus*	43.55	*Archaias angulatus*	77.14	*Archaias angulatus*	40.77
	Cymb. squammosa	5.02	*Valvulina oviedoiana*	5.96	*Q. agglutinans*	2.28	*Cymb. squammosa*	5.33
	Asterigerina carinata	3.79	*Discorbis mira*	3.65	*Discorbis rosea*	2.12	*Amphistegina gibbosa*	5.26
	Rosalina candeiana	2.66	*Q. agglutinans*	3.03	*Planorbulina acervalis*	1.80	*Asterigerina carinata*	4.55
	Triloculina linneiana	2.48	*Planorbulina acervalis*	2.98	*Q. bidentata*	1.49	*Discorbis rosea*	4.12
	Amphisorus hemprichii	2.44	*Amphisorus hemprichii*	2.86	*Archaias compressus*	1.22	*Valvulina oviedoiana*	3.28
	Q. agglutinans	2.41	*Archaias compressus*	2.54	*Amphisorus hemprichii*	1.17	*Amphisorus hemprichii*	3.12
	Amphistegina gibbosa	2.32	*Q. bradyana*	2.53	*Discorbis mira*	1.01	*Rosalina candeiana*	2.67
	Valvulina oviedoiana	1.89	*Clavulina tricarinata*	2.35	*Amphistegina gibbosa*	0.90	*Triloculina linneiana*	2.59
	Discorbis rosea	1.71	*Triloculina linneiana*	2.25	*T. laevigata*	0.90	*Discorbis mira*	2.41
	Other 104 species	18.56	**Other 87 species**	28.30	**Other 42 species**	9.97	**Other 95 species**	22.10

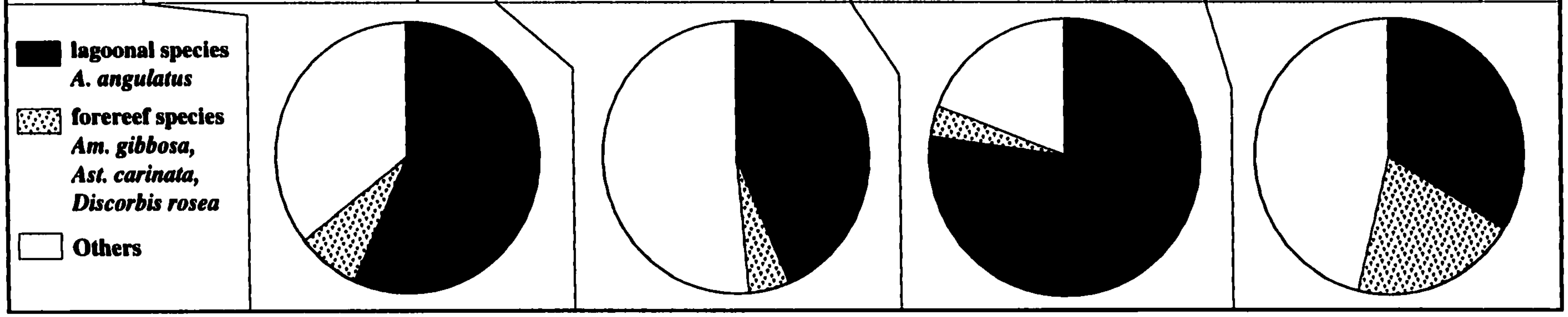


Figure 5.3—Summary of the four foraminiferal assemblages, showing the percentages of the ten most common species in each assemblage, total percentage of lagoonal tracer species (*Archaias angulatus*) and forereef tracer species (*Amphistegina gibbosa, Asterigerina carinata,* and *Discorbis rosea)* in each assemblage, and correlation of these assemblages to substrate zones.

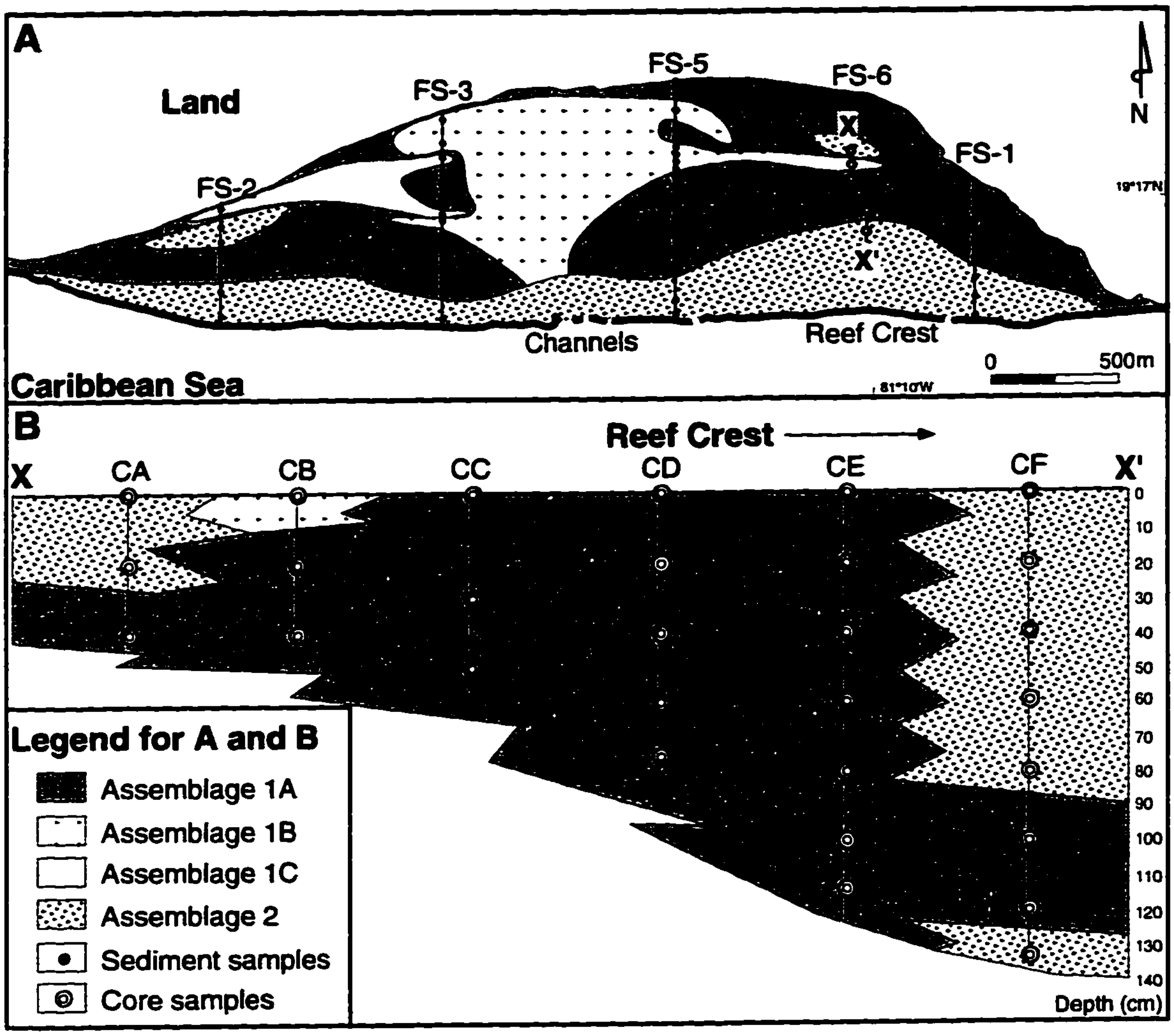


Figure 5.4—A) Distribution of assemblages in Frank Sound based on surface samples. B) Distribution of assemblages based on subsurface samples along traverse 6, Frank Sound. From the shore to the reef crest, there is a alternative pattern of assemblage zones, characterized by the alternative prominence of forereef-lagoon-forereef components.

fluctuates from 1–5% in the *Thalassia* and Sand Zone to ≥10% in the Bare Sand Zone on traverses 1, 3, and 5 (Figs. 5.5D, 5.5B, and 5.5C). On traverse 2, however, the abundance of forereef species in the *Thalassia* and Sand Zone is 1–10% (Fig. 5.5A).

In general, from the reef crest to the shore, the abundance of forereef species decreases whereas the lagoonal species increases. From the landward edge of the *Thalassia* and Sand Zone to the Bare Rock Zone, however, the percentage of the forereef species become higher as the number of lagoonal species decreases. This 'abnormal' abundance of forereef species in a nearshore setting means that several samples in this area have been grouped into Assemblage 2 which is characterized by abundant forereef foraminifera.

GRAIN SIZE ANALYSIS

The mean grain-size (in Phi) of the sediment increases slightly from reef crest to the shore but decreases slightly on the beach (Fig. 5.5E). The sediment on the beach is well-sorted whereas the sediment in the Rubble and Knob Zone is very poorly sorted. Sediment in the Rubble and Knob Zone is strongly fine skewed whereas most sediment in the Bare Sand Zone and the *Thalassia* and Sand Zone is coarsely skewed (Kalbfleisch, 1995).

Little variation in grain size was found in the sediment cores apart from: 1) a layer of gravel (40–60 cm below the surface) in cores CE and CF; and 2) a strong fine skewed trend at the bottom of core CA.

DISCUSSION

Analysis of the foraminifera in the surface and subsurface sediment samples of Frank Sound indicates that the sediment in the lagoon is a mixture of material derived from the lagoon and the forereef. The sediments from these sources are mixed in variable proportions throughout the lagoon with the degree of the mixing reflecting the substrate type. Subsurface sediment analysis indicates that the sediment blanket in the lagoon has evolved through multiple cycles of sediment transportation.

The dominance of forereef foraminifera in the Rubble and Knob Zone and the Bare Sand Zone of Frank Sound shows that there has been a considerable amount of onshore sediment transportation. Furthermore, all samples collected from Frank Sound, including the beach sands, contain forereef foraminifera. Movement on this scale can only happen at the peak of a storm when waves cross the reef crest (Fig. 5.6A). Under fair-weather conditions such transportation is impossible. Sediment thickness data support the idea that sediment accumulation is largely controlled by storm activity. The thickest sediment in Frank Sound is concentrated in two lobes located to the east and west of the channel

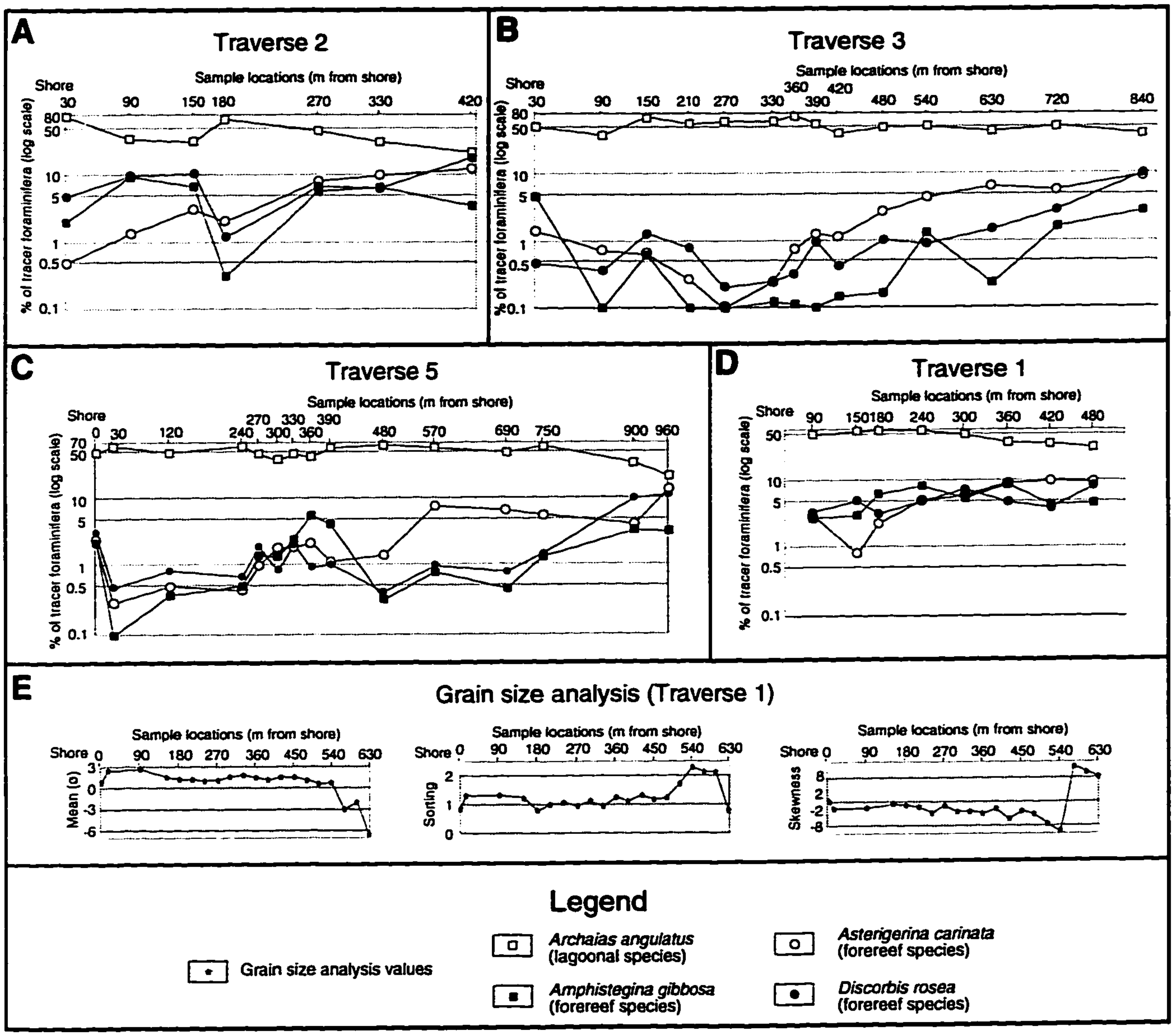


Figure 5.5—Abundance and fluctuations of the tracer species (***Archaias angulatus, Amphistegina gibbosa, Asterigerina carinata,*** and ***Discorbis rosea)*** along Traverse 2 (**A**), Traverse 3 (**B**), Traverse 5 (**C**), and Traverse 1 (**D**), Frank Sound. Note that the peaks of the abundance of lagoonal species ***Archaias angulatus*** are at the inner part of the lagoon. One high peak for the abundance of forereef species occurs near the reef crest, whereas another small peak occurs near the landward edge of the *Thalassia* and Sand Zone. **E**) Change in grain size distribution along Traverse 1, Frank Sound (from Kalbfleisch, 1995).

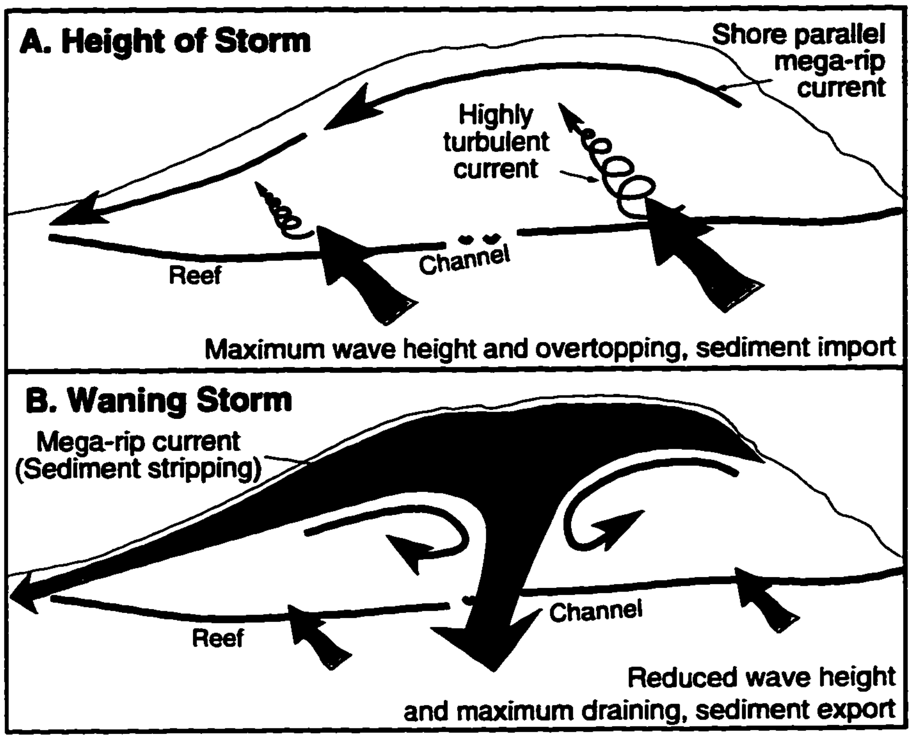


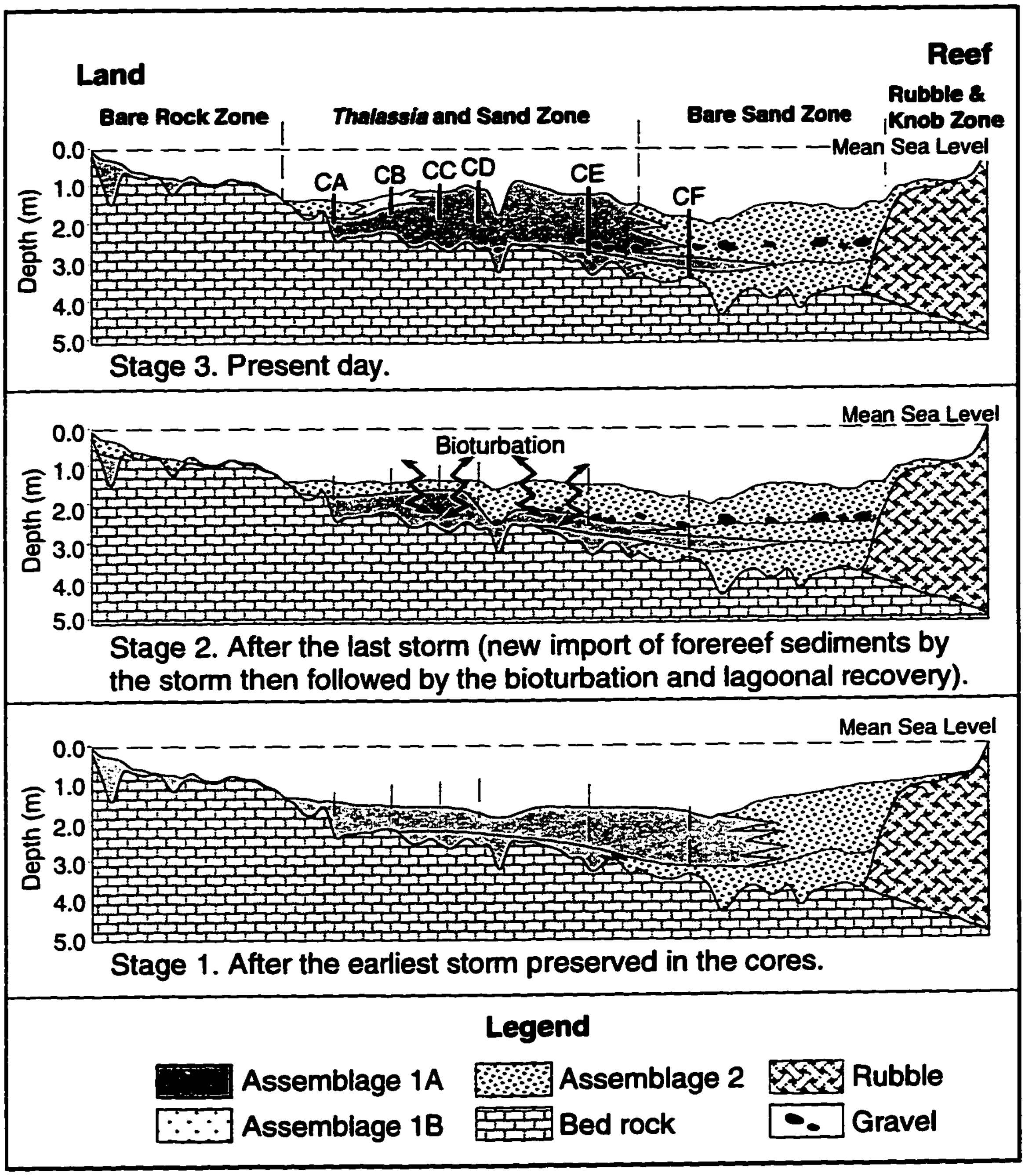
Figure 5.6—Model of waves, currents, and sediment transportation at storms. **A)** At the height of the storm. **B)** At waning stage of the storm (modified after Kalbfleisch, 1995). Note that when storm wanes, piled water drains out from the main channel and west end of the lagoon. At the same time, suspended sediment is carried away through the same passes by currents.

opening landward of the reef crest (> 4 m). Sediment in these lobes corresponds to Assemblage 2 which is dominated by forereef foraminifera. In the inner lagoon that is covered by *Thalassia*, however, sediment is, on average, only 1 meter thick (Kalbfleisch, 1995). In many other areas, process of over-reef sediment transportation during storms has also been documented (e.g., Ball *et al.*, 1967; Hernandez-Avila *et al.*, 1977; Macintyre *et al.*, 1987; Jones and Hunter, 1992; Scoffin, 1993).

During the height of a storm, water and sediment are driven onshore, and then piled and held onshore by the strong onshore winds and the constant flow of water over the reef and across the lagoon. As the storm wanes, however, the water that was piled onshore will start to flow offshore and back into the open ocean. This process generates strong rip currents that ultimately flow out of the main channel in the reef and, to a lesser extent, from the west end of the lagoon (Fig. 5.6B). Such currents strip sediment from the nearshore zone and the central part of the lagoon so that bare rock surfaces are exposed (Figs. 5.1D, 5.6). In addition, these currents winnow the sediment and place small grains in suspension. The suspended sediment is then swept out of the lagoon via channels and the west corner of the lagoon as the piled water drains out (5.6B). Evidence for this process lies in the configuration of the foraminiferal assemblages, the distribution of the tracer species, and the distribution of bare rock along the near shore area and in the triangular area north of the channel. Sediment is stripped from those areas, whereas sediment close to the *Thalassia* and Sand Zone is only partially removed because it is stabilized by the sea grasses. Lag deposits left in these areas are winnowed and larger and abrasion-resistant grains (lagoonal and forereef origin) are preferentially preserved. Consequently, samples in these locations show disproportionately higher percentage of forereef grains compared to the seaward samples in the *Thalassia* and Sand Zone. This nearshore belt of sediment with disproportionally high amounts of forereef species indicates the track of shore parallel rip current during storms.

Subsurface foraminiferal assemblage distributions indicate an alternating storm-interstorm history for the evolution of the lagoon sediments (Fig. 5.7). Assemblage 1A in core CE passes seaward into Assemblage 2 (base of core CF). This records the earliest storm event that affected the lagoon. Above this layer, the seaward progradation of Assemblage 1A is the record of the lateral expansion of the *Thalassia* and Sand Zone during an inter-storm period. The results of at least other two storm events are evident in the upper parts of cores, whereas the base of the last storm deposit can be defined by the gravel layer that is present 40–60 cm below the surface in cores CE and CF.

In the periods between storms, vertical bioturbation by shrimps and other burrowers effectively modifies the storm deposited sediments (cf. Bonem and Stanley, 1977; Riddle,



Stage 3. Present day.

Stage 2. After the last storm (new import of forereef sediments by the storm then followed by the bioturbation and lagoonal recovery).

Stage 1. After the earliest storm preserved in the cores.

Figure 5.7—Model of sediment evolution in the lagoon throughout of the time. Notice the thin veneer of the sediment at the Bare Rock Zone near the core CA, and how bioturbation mixed the subsurface and surface sediment at the *Thalassia* and Sand Zone near cores CC to CE.

1988; Jones and Pemberton, 1989). Modification of the surface sediment depends on the characteristics of the subsurface sediment and the rate of recolonization and expansion of the lagoonal biota. During the inter-storm period, surface sediments in the *Thalassia* and Sand Zone are formed by mixing of older lagoonal subsurface sediment and renewed production from organisms that live on and between the *Thalassia* leaves. In the landward part of the *Thalassia* and Sand Zone transitional to the Bare Rock Zone, it is characterized by a thin veneer of sediment. Lagoonal production and bioturbation are therefore less active because of the paucity of sediment. As a result, the surface sediment retains the characters of the original storm-deposited material (Figs. 5.5, 5.7).

In the long term, the sediment budget in the lagoon is balanced between the intensity and frequency of tropical storms and sediment production by lagoonal organisms. Storms play a major role because of their influence on sediment import and export. The intensity and frequency of storms control the rate and efficiency of lagoonal carbonate production because they control the amount of damage to the reef and lagoon substrates and the degree of recovery from that damage. In the Caribbean-Florida region, carbonate sediment produced in lagoons has been estimated at ~ 400 g/ m^2·yr (e.g., Land, 1970; Patriquin, 1972; Bach, 1979; Hallock, 1981; Bosence *et al.*, 1985; Hallock *et al.*, 1986; Nelsen and Ginsburg, 1986; Bosence, 1989; Frankovich and Zieman, 1994). Given that major storms or hurricanes pass over Grand Cayman on an average of once every 10 years, the maximum sediment production in the inter-storm periods is on the order of millimeters. During these periods, lagoonal *in situ* production is limited and sediment transportation is minimal. Therefore, given normal storm frequency and intensity, sediment in Frank Sound will be dominated by forereef components at most of the time. Over the last forty years, however, storm and hurricanes have been infrequent apart from Hurricane Gilbert which passed over the island in 1988 with yet minor impact (Clark, 1988). This means that what we see at present the relative abundance of lagoonal sediment in lagoon is exceptional as in most of the lagoon history.

CONCLUSIONS

Analysis of foraminiferal assemblages in the surface and subsurface sediments of Frank Sound yields the following conclusions:

1. Sediments in the lagoon come from forereef and lagoonal production. During storms, forereef sediment is moved over the reef into the lagoon. During inter-storm periods, sediment is produced in the lagoon. Sediments from these different sources are mixed in variable proportions throughout the lagoon.

2. Near the Bare Sand Zone and Bare Rock Zone, two parallel belts were found with elevated proportions of the forereef species. The former demonstrates that forereef sediment has been imported during the height of storms whereas the latter shows that lagoonal sediment has been stripped from the lagoon as storms wane respectively.
3. Subsurface sediments record an alternating history of storm and inter-storm deposited sediments. Such trends, however, can only be recognized by foraminiferal assemblage studies because there is little variation in grain size throughout the sediment pile.
4. During inter-storm periods, vertical bioturbation effectively modified the storm-induced sedimentary structures and modified the character of the surface sediment.
5. Sediment composition in the lagoon is balanced by the intensity and frequency of the storms and production by lagoonal organisms during the inter-storm periods. With frequent and intense storms that induce massive sediment import and export, sediments in the lagoon will be dominated by forereef components.

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CHAPTER 6 FORAMINIFERAL ASSEMBLAGES OF NORTH SOUND, SOUTH SOUND AND PONDS, GRAND CAYMAN

INTRODUCTION

North Sound, South Sound and various ponds on Grand Cayman contain water that is different from the water found on the open shelves around the island. As a result, unique aquatic communities are found in these diverse environments. Until 1978, when the Marine Conservation Law was passed, human activities had a tremendous impact on these natural environments. Large quantities of sediments were dredged from South Sound and western North Sound to fill low-lying lands and some of the natural ponds. The eastern part of North Sound including Little Sound, however, was largely untouched and is now protected by law. During storm and hurricane seasons, organisms and sediments in many areas of these lagoons and ponds can be greatly affected by sediment transportation and heavy rainfall. Little work has been done, however, to examine the microfauna communities and sediments found in these unique environments. Without this, it is difficult to measure the natural and human impact on these environments.

Benthic foraminifera can be used to examine the evolution of these areas. Living specimens are present in these waters with specific species requiring specific salinity, temperature, and substrate conditions. As a result, they are very sensitive indicators of environment changes. Due to their small size, complex shell structures and abundance, they can also be used to trace sediment movement and to monitor natural and human activities. To test this possibility, this study: (i) examines the distribution of ecologically diagnostic species, (ii) delineates foraminiferal assemblages from very restricted lagoons rimmed by mangroves, (iii) analyses the unique foraminiferal assemblages found in the ponds, and (iv) determines the impact of natural and human activities on the foraminifera.

THE STUDY AREA

Grand Cayman is a flat, low-lying tropical island that is 35 km long (east-west) and 6–14 km wide (Fig. 6.1A). North Sound, the largest lagoon on the island (12 by 8 km), is a broad saucer-shaped depression, that has low-lying land on its west, south, and east coasts and a reef along its northern margin. Two relatively isolated water bodies, Little Sound and Duck Pond Bight, located on the eastern margin of North Sound, are rimmed by dense mangroves. South Sound, located on the southwest corner of the island, is 5.5 km long, 1

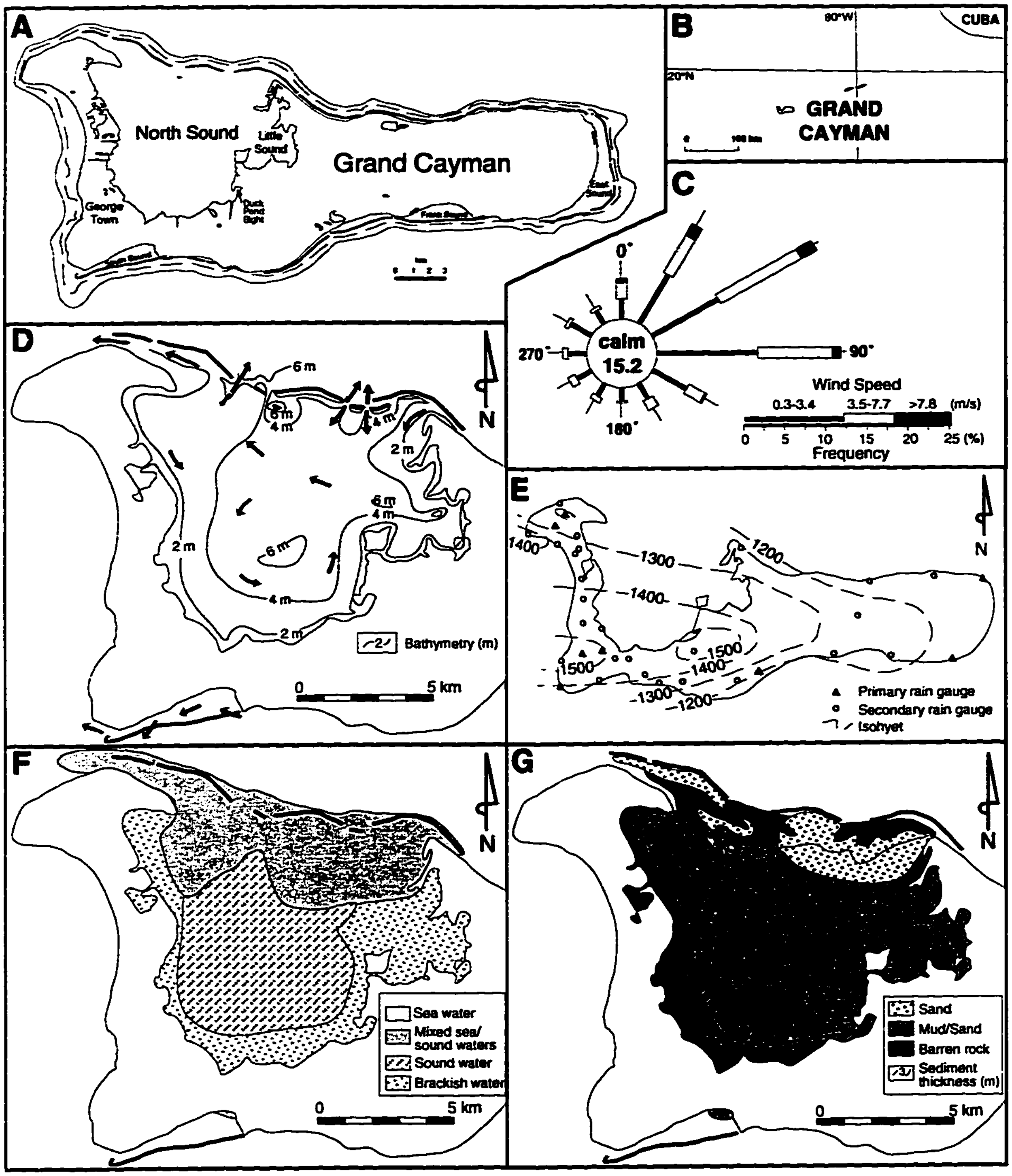


Figure 6.1—A) Map showing study area on Grand Cayman. B) Location of Grand Cayman in northern Caribbean Sea. C) Time-averaged annual wind rose graph (based on Darbyshire *et al.*, 1976). D) Map showing bathymetry and water circulation of North Sound (from Rigby and Roberts, 1976). E) Map showing isohyet of Grand Cayman (from Burton, 1994). F) Map showing water characters of North Sound, South Sound, and proper area (from Roberts, 1976). G) Map showing sediment characters of North Sound (from Rigby and Roberts, 1976).

km wide at the eastern end, and 200 m wide at the west end (Fig. 6.1A). The northeast margins of South Sound are rimmed by mangrove swamps, whereas its southern margin is delineated by a fringing reef. Along the seaward margins of North and South sounds, 1 km wide shelves are located seaward of the fringing reefs. The shelf is divided into the upper (0–10 m) and lower (12–40) terraces by a mid-shelf scarp (Blanchon and Jones, 1995). The edge of the shelf is bounded by an escarpment that typically begins at 55–80 m and extends vertically into waters 115–145 m deep (Messing and Platt, 1987). From there, the island slope extends into Yucatan Basin to the north, and the Cayman Trench to the south. Ponds, which are located on the coastal parts of the island, are isolated from the open ocean by beach ridges. They are shallow (<2 m), floored by mud, rimmed by mangrove, and may dry-up completely in the dry season.

Mixed diurnal and semi-diurnal tides have a maximum range of 1 m and generally produce only weak currents around the island (Burton, 1994). Consequently, shelf and coastal currents are largely driven by wind and waves. These waves are controlled by trade winds which blow from the east, northeast or southeast throughout most of the year. Waves are typically 1.25–2.5 m high on the windward side of the island but <0.5 m on the leeward side (Darbyshire *et al.*, 1976)(Fig. 6.1C). As a result, there is good circulation of waters in the north part of North Sound and most of South Sound (Fig. 6.1D). In the east and south parts of North Sound and northeast part of South Sound, however, circulation is limited. Powerful waves generated by hurricanes can be many meters high and wash away roads and deposit cobble and boulders on shore (Rigby and Roberts, 1976; Jones and Hunter, 1992). During hurricanes, sea water commonly floods the island; for example, hurricane-driven waves have crossed the narrow stretch of land that separates South Sound and North Sound (Burton, 1994). Rainfall varies between seasons and from year to year. Areas of high rainfall are found toward the west of the central mangrove swamps and in the George Town area (Burton, 1994)(Fig. 6.1E).

Water temperature is 26–32°C throughout the year in most parts of water bodies on the island (Department of the Environment Protection and Conservation Unit, Grand Cayman, 1996)(Fig. 6.2A). Along the mangrove rimmed borders of these sounds and ponds, water temperatures are extremely variable. Normal salinities (35–38 ‰) are found in the north and central parts of North Sound and most parts of South Sound (Moore, 1973; Raymont *et al.*, 1976) (Fig. 6.1F). Along the east, south, and west borders of North Sound and northeast corner of South Sound, however, salinities are variable due to poor circulation (Fig. 6.2B). Salinity is elevated to ≥42‰ during the dry season, but it can be 50% lower than normal during the rainy season because of the influx of brackish to fresh water from the soaked mangrove and offshore springs (Giglioli, 1994). Water in many of the ponds

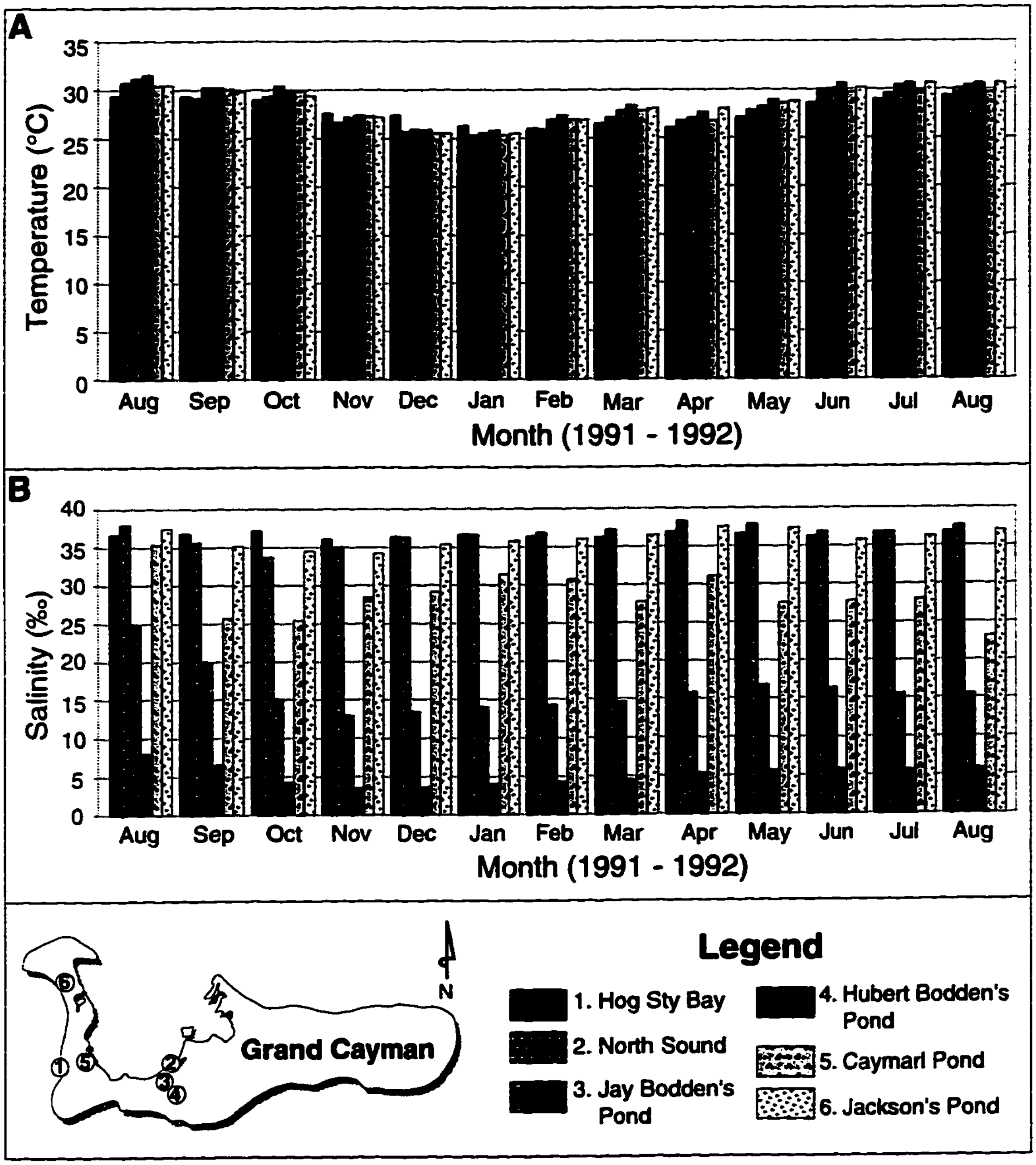


Figure 6.2—**A)** Temperatures and changes of sea water, lagoon water, and pond waters throughout the year. **B)** Salinities and changes of water bodies on Grand Cayman throughout the year (Modified after Department of the Environment Protection and Conservation Unit, Grand Cayman, 1996).

(*e.g.*, Colliers Bay Pond, Meagre Bay Pond) can be completely dried whereas other are filled by fresh water after heavy rains. Some ponds (*e.g.*, Jackson Pond, Tarpon Spring Pond) are continuously flooded and appear to be connected to the sea through bedrock openings. As a result, these permanent ponds are characterized by brackish water (Fig. 6.2B). Waters near peripheral mangrove swamps and ponds are stagnant, organic rich, highly turbid, and tanned in color.

METHOD

Nineteen surface sediment samples were collected by SCUBA or snorkeling from North and South Sounds, open shelves and Colliers Bay Pond during the summers 1990 to 1993. In addition, 70 fresh sediment samples were collected from these lagoons and 9 ponds in the summer of 1994 (Figs. 6.3, 6.4). Immediately after collection, each sample was fixed by buffered formaldehyde which contains calcium chloride. Upon returning to the laboratory, they were washed over a 63μm sieve and immersed in a Rose Bengal solution for 30 minutes. After rewashing to remove excess stain, wet foraminifera were counted under a binocular stereo-microscope. Those stained pink and/or displaying symbiont colors were considered living at the site of collection.

Species abundances and size distributions of foraminifera tests in the sediment samples were obtained using the sieve counting method of Martin and Liddell (1988, 1989). This technique was used because it provides insights into the effects of transportation, sorting, and differential preservation of foraminifera in turbulent settings (Martin and Liddell, 1988). Initially, one split of each sediment sample (100–150 g) was divided into 1 ϕ intervals by sieving for 10 minutes. Then, where possible, 300 individuals were identified and counted from each fraction coarser than 3 ϕ (0.125 mm). In many cases, however, <300 specimens were identified and counted simply because the sediment fraction being examined contained < 300 foraminifera tests.

Analyses of 89 samples in this study produced a database formed of 128 species and 66,213 specimens. No living specimens or foraminifera tests were found in samples F59 and F105. Locality groups (= assemblages) were defined by Q-mode cluster analysis that used all the species which form ≥5% of the foraminiferal fauna at one locality. As a result, the cluster analyses are based on 35 species and 87 samples from the lagoons and ponds. Dissimilarity indices between each pair of samples was calculated in Euclidean distance using the abundance data (Table 6.1). The dendrogram was derived using the between-groups method and the SPSS program. Each locality group was equated to a foraminiferal assemblage that is named according to its most common species or genera.

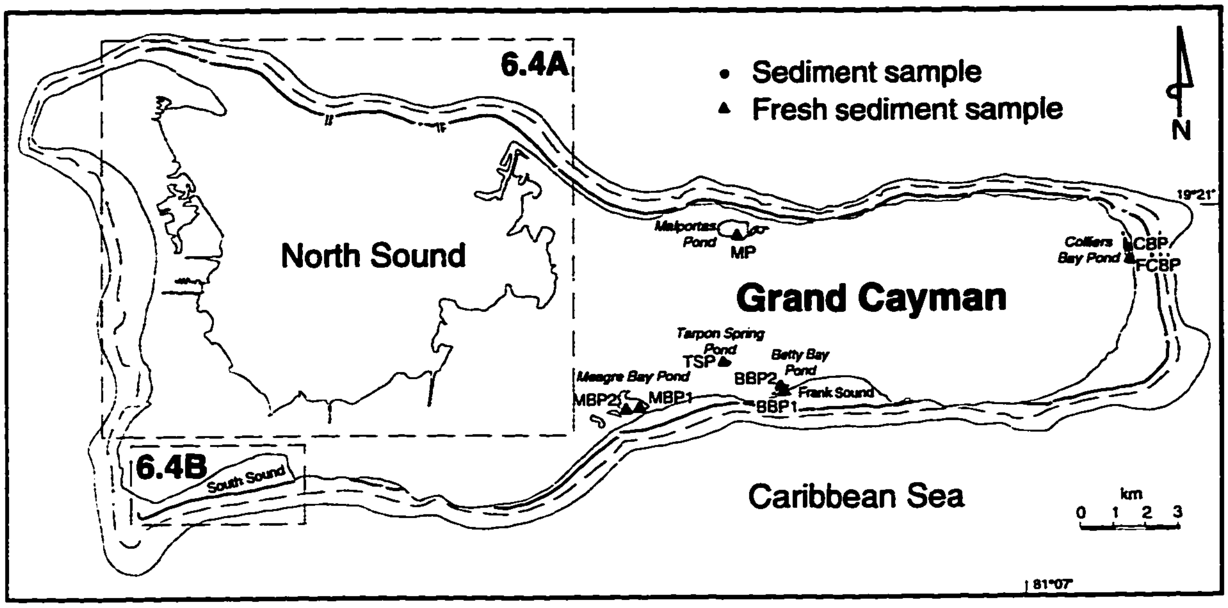


Figure 6.3—Map showing locations of North Sound, South Sound, ponds on eastern island and some sample locations.

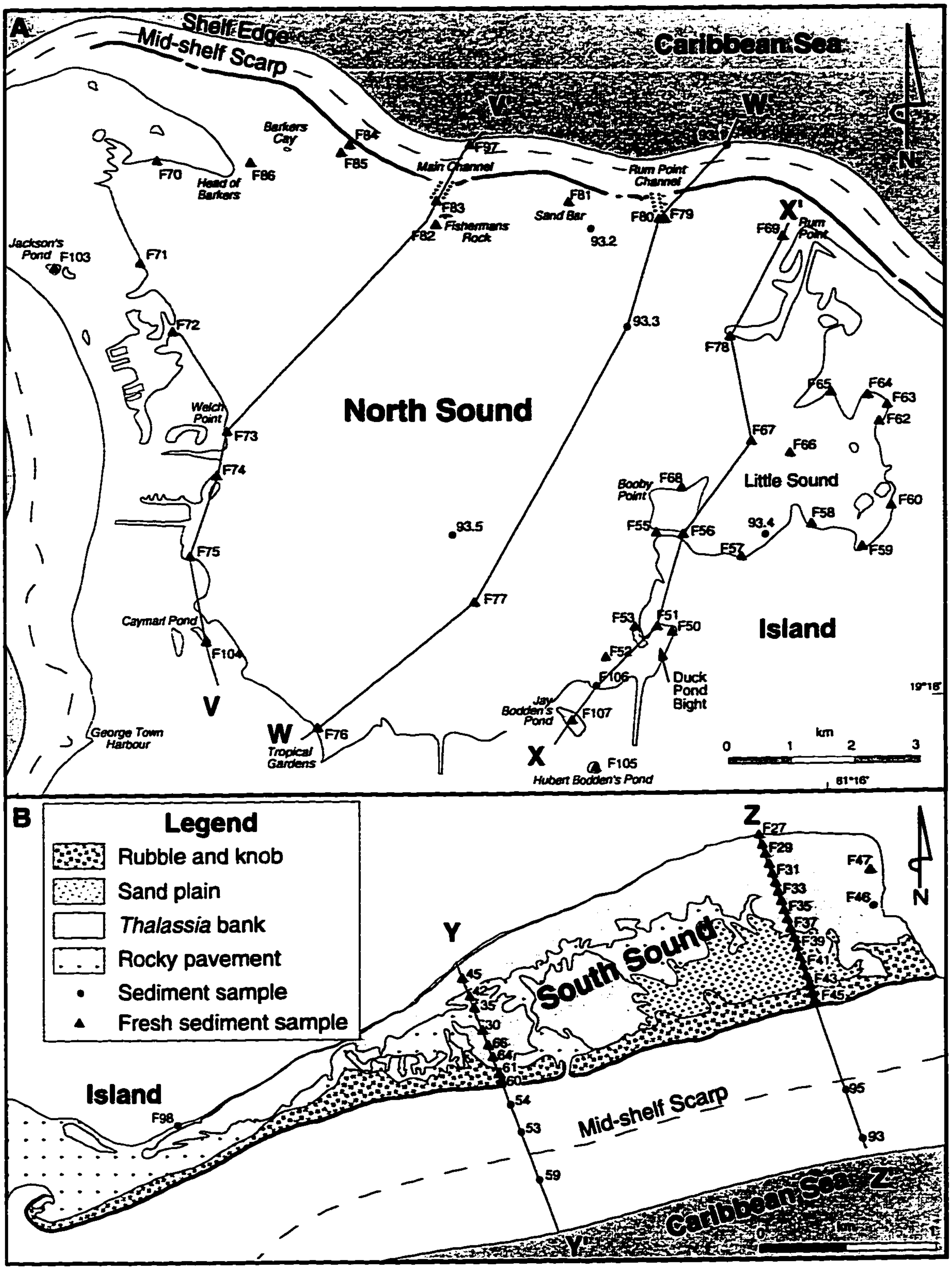


Figure 6.4—**A)** Map showing sample locations in North Sound and ponds around North Sound, and traverses V–V', W–W', and X–X' across North Sound. **B)** Map showing samples, locations of traverses Y–Y' and Z–Z', and substrate zonations in South Sound (substrates based on airphotos, 1992).

Table 6.1 Distribution data of total number of the foraminifera (≥5% of the fauna) recovered from each locality from North Sound, South Sound and various ponds.

	LOCALITIES																
SPECIES	30	35	42	45	53	54	59	60	61	64	66	93	93.1	83.2	93.3	93.4	93.5
Ammonia tepida	0.22	0.00	0.13	0.53	0.00	0.00	0.59	0.00	0.07	0.09	0.00	0.81	0.20	0.23	0.35	0.00	0.44
Archaias angulatus	54.50	43.74	57.40	26.46	13.76	25.64	27.86	15.40	50.41	43.76	58.30	11.18	4.85	32.32	49.29	20.76	43.05
Archaias compressus	4.50	0.56	0.39	0.00	1.28	0.99	0.88	0.42	0.34	0.00	2.20	0.16	0.10	3.28	6.18	0.07	4.49
Amphistegina gibbosa	1.21	6.10	0.52	0.71	6.27	10.76	20.97	3.85	1.36	1.81	0.73	26.58	27.70	3.98	0.53	0.07	0.44
A. caymanensis sp. nov.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphisorus hemprichii	1.54	0.40	4.85	1.76	1.43	0.42	0.44	0.42	0.68	3.53	1.37	0.16	1.29	0.94	2.47	1.06	1.03
Asterigerina carinata	2.08	2.33	0.39	0.71	9.27	2.55	5.87	8.64	4.34	6.12	4.31	14.42	3.86	4.22	4.06	0.07	0.07
Borelis pulchra	2.30	6.02	2.88	0.88	1.43	0.71	1.61	3.54	2.99	1.46	0.92	1.94	0.99	1.87	2.47	0.00	0.15
Cribroelphidium poeyanum	0.11	0.08	0.00	0.18	0.14	0.00	0.15	0.00	0.00	0.52	0.09	0.00	0.30	0.00	0.18	1.06	1.10
Cymbaloporetta squammosa	0.77	0.00	1.31	0.88	5.35	1.13	0.73	4.06	3.60	4.39	4.49	0.81	0.89	3.75	1.41	0.00	0.00
Discorbis granulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Discorbis mira	0.33	1.04	0.79	10.76	2.00	0.28	1.32	1.56	0.81	0.26	0.09	1.78	0.69	0.94	1.94	12.92	4.78
Discorbis rosea	1.10	3.21	0.79	0.00	40.70	50.57	30.65	45.37	14.79	5.68	1.92	6.32	1.78	6.09	1.59	0.00	0.00
Elphidium lanieri	0.00	0.00	0.00	1.06	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.20	0.00	0.00	0.14	0.07
Massilina protea	0.33	0.00	0.00	0.18	0.00	0.00	0.00	0.21	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Peneroplis discoideus	0.66	1.28	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.46	0.00	0.00	7.26	0.35	0.00	0.44
Planorbulina acervalis	0.00	0.08	0.00	0.88	0.00	0.00	0.00	0.00	0.07	0.69	0.00	0.00	0.40	0.00	0.71	0.00	0.07
Pyrgo denticulata	0.00	0.00	0.00	0.00	0.00	0.14	0.29	0.10	0.07	0.00	0.00	0.65	0.10	0.47	0.00	1.48	1.40
Pyrgo subsphaerica	0.99	1.28	1.57	0.00	0.29	0.28	0.15	1.35	1.02	0.95	0.82	2.76	1.48	3.75	0.18	0.07	0.29
Quinqueloculina agglutinans	3.18	4.57	5.11	1.94	0.07	0.00	0.00	1.04	0.61	1.81	1.37	2.76	0.10	1.17	3.53	0.28	4.49
Quinqueloculina bidentata	1.75	3.29	4.98	0.53	0.07	0.00	0.15	0.00	0.61	0.00	1.83	0.32	0.00	0.23	1.06	0.14	0.00
Quinqueloculina bradyana	0.22	1.28	0.26	7.94	0.07	0.00	0.00	0.10	0.34	0.26	0.09	0.00	0.40	0.23	0.18	1.06	2.94
Quinqueloculina funafutiensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	11.41
Quinqueloculina laevigata	0.00	0.00	0.13	1.06	0.07	0.00	0.00	0.00	0.07	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quinqueloculina poeyana	1.75	0.64	0.26	0.35	0.00	0.00	0.00	0.00	0.00	0.86	0.46	0.00	0.10	0.23	0.53	1.27	0.96
Rosalina candeiana	2.19	1.69	1.18	0.18	5.84	0.99	0.73	2.39	3.05	2.33	3.57	0.81	4.06	5.85	3.00	0.28	0.15
Rosalina floridana	0.44	0.32	0.92	1.59	0.07	0.00	0.00	0.00	0.07	0.26	0.00	0.00	0.40	0.00	0.00	0.00	0.07
Spiroloculina arenata	0.11	0.08	0.00	4.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.18	0.78	1.18
Trichohyalus aguayoi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina carinata	0.55	2.17	1.57	1.94	0.21	0.00	0.15	0.21	0.61	1.81	1.37	0.00	0.40	1.41	1.77	1.91	2.87
Triloculina laevigata	0.66	0.64	0.26	2.12	0.00	0.00	0.00	0.00	0.00	0.34	0.64	0.00	0.10	1.17	0.53	1.84	0.52
Triloculina linneiana	2.96	0.72	0.92	1.59	0.64	0.00	0.00	0.21	0.34	2.33	1.65	1.13	0.99	4.45	3.00	11.94	2.94
Triloculina rotunda	0.00	0.08	0.00	0.35	0.07	0.00	0.00	0.10	0.07	0.00	0.09	0.00	0.40	1.17	0.71	20.55	0.15
Triloculina sidebottomi	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.23	0.00	0.85	0.00
Triloculina simplex	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina trigonula	0.33	0.24	0.26	0.00	0.00	0.00	0.00	0.00	0.14	0.95	0.37	0.16	0.20	0.00	0.18	0.14	0.07
Valvulina oviedoiana	0.22	1.61	1.70	3.00	1.14	1.42	0.59	0.52	0.61	1.03	1.83	1.13	2.27	0.47	2.47	5.44	3.38
Other Species	15.02	16.53	11.01	27.87	9.84	4.11	6.89	10.51	12.75	18.26	11.00	26.09	45.80	14.05	11.13	15.11	11.04

Table 6.1 (Continued)

	LOCALITIES																	
SPECIES	95	F27	F28	F29	F30	F31	F32	F33	F34	F35	F36	F37	F38	F39	F40	F41	F42	F43
Ammonia tepida	0.62	5.31	0.30	1.36	0.47	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
Archaias angulatus	31.59	7.96	40.49	52.66	60.98	48.23	30.04	25.38	34.51	39.05	50.42	56.45	61.54	67.17	44.10	29.47	23.74	25.45
Archaias compressus	0.62	0.00	1.32	0.48	1.50	0.39	1.43	1.38	3.92	2.03	0.76	0.72	0.54	1.10	1.12	1.47	1.56	2.88
Amphistegina gibbosa	25.12	0.44	0.20	0.39	0.63	0.20	2.34	0.75	1.31	1.94	3.87	4.96	3.90	2.00	3.98	6.08	5.37	3.12
A. caymanensis sp. nov.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphisorus hemprichii	0.77	1.33	2.73	3.29	3.00	4.03	5.33	5.15	3.40	2.21	2.02	1.35	1.19	2.40	1.86	1.29	1.91	3.72
Asterigerina carinata	5.55	2.65	0.51	2.13	2.61	2.95	2.60	1.76	1.44	2.56	5.81	4.42	4.66	5.59	9.94	12.89	9.53	9.60
Borelis pulchra	2.31	0.00	0.00	0.29	0.00	0.00	0.13	0.25	0.26	0.44	0.67	0.63	0.76	0.70	1.86	3.13	2.77	1.56
Cribroelphidium poeyanum	0.00	1.33	0.10	0.00	0.32	0.00	0.00	0.25	0.39	0.00	0.34	0.09	0.11	0.00	0.00	0.00	0.00	0.00
Cymbaloporetta squammosa	0.15	3.54	0.10	0.77	1.66	1.08	1.82	1.88	1.31	2.74	2.86	2.61	3.36	3.79	4.10	4.24	6.41	6.96
Discorbis granulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Discorbis mira	1.23	25.22	5.16	2.32	1.03	2.46	4.55	3.64	5.36	4.06	1.26	0.72	1.19	1.00	1.24	1.47	3.81	2.16
Discorbis rosea	15.56	0.00	0.00	0.00	0.16	0.59	0.26	0.88	3.66	4.86	2.36	3.25	5.09	4.89	14.78	25.05	26.52	25.81
Elphidium lanieri	0.00	1.33	0.81	0.97	0.47	0.20	0.13	0.00	0.13	0.09	0.00	0.00	0.11	0.00	0.12	0.18	0.00	0.00
Massilina protea	0.00	0.00	3.24	0.19	0.24	0.10	1.82	0.38	0.65	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Peneroplis discoideus	0.31	0.00	0.00	0.00	0.16	0.29	0.52	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.18	0.00	0.24
Planorbulina acervalis	0.00	0.00	0.10	0.19	0.16	0.39	2.99	3.64	2.48	1.77	5.05	3.88	0.11	0.00	0.50	0.00	0.00	0.24
Pyrgo denticulata	0.77	0.00	1.32	0.77	0.32	0.20	0.39	0.00	0.00	0.00	0.08	0.09	0.00	0.00	0.00	0.18	0.00	0.00
Pyrgo subsphaerica	0.46	0.00	1.21	2.81	0.39	0.59	0.13	0.63	0.52	0.88	1.01	0.63	0.11	0.10	0.37	0.55	0.35	0.60
Quinqueloculina agglutinans	1.85	0.00	0.51	1.74	1.11	1.57	4.03	2.14	0.78	3.00	1.68	1.71	1.08	0.90	0.62	0.37	0.17	0.36
Quinqueloculina bidentata	0.46	0.00	1.52	2.71	4.11	4.13	4.29	5.78	3.53	1.24	1.09	0.54	0.22	0.30	0.00	0.18	0.17	0.24
Quinqueloculina bradyana	0.00	1.77	1.42	2.03	0.55	1.08	1.17	1.51	2.48	2.21	0.76	0.27	0.22	0.20	0.37	0.18	0.00	0.00
Quinqueloculina funafutiensis	0.00	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quinqueloculina laevigata	0.00	0.44	0.00	0.10	0.00	0.20	0.13	0.25	0.00	0.62	0.34	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Quinqueloculina poeyana	0.00	0.88	0.30	0.00	0.08	0.29	0.39	0.25	0.13	0.62	0.34	0.18	0.43	0.20	0.25	0.00	0.00	0.00
Rosalina candeiana	0.46	0.00	0.20	0.48	1.03	1.87	1.04	2.14	1.31	2.30	3.28	2.16	2.71	1.80	2.73	3.68	5.89	5.76
Rosalina floridana	0.00	3.10	1.42	0.19	0.08	0.20	0.78	0.88	1.31	1.06	0.42	0.54	0.11	0.00	0.00	0.00	0.17	0.00
Spiroloculina arenata	0.00	0.00	2.13	1.74	1.26	0.88	1.17	1.01	0.13	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trichohyalus aguayoi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina carinata	0.15	3.54	4.25	2.13	3.79	4.81	1.82	2.14	1.31	1.59	0.76	0.99	0.33	0.90	0.37	0.18	0.17	0.60
Triloculina laevigata	0.00	3.98	1.21	0.68	0.16	0.98	0.78	1.26	0.65	1.15	0.93	0.36	0.11	0.00	0.00	0.00	0.00	0.00
Triloculina linneiana	0.31	0.44	0.10	0.48	0.39	2.16	2.60	2.26	2.48	1.33	1.35	2.52	2.38	0.70	0.62	0.37	0.52	0.36
Triloculina rotunda	0.00	3.98	10.63	4.36	3.16	2.46	5.20	6.66	2.88	0.53	0.08	0.27	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina sidebottomi	0.00	0.44	0.40	0.29	0.55	0.29	0.00	0.63	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina simplex	0.00	1.77	0.20	0.10	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina trigonula	0.15	0.44	0.20	0.48	0.47	0.10	0.26	0.00	0.00	0.44	0.17	0.27	0.00	0.00	0.00	0.00	0.00	0.00
Valvulina oviedoiana	1.69	6.64	2 94	0.87	1.34	3.63	3.38	7.16	3.27	2.92	2.61	3.52	1.63	1.20	1.49	0.37	0.52	2.04
Other Species	9.86	22.57	14.98	12.97	7.82	13.65	18.34	19.47	20.00	17.67	9.51	6.76	8.13	5.09	9.44	8.47	10.40	8.16

Table 6.1 (Continued)

	LOCALITIES																	
SPECIES	F44	F45	F46	F47	F50	F51	F52	F53	F55	F56	F57	F58	F60	F63	F64	F65	F66	F67
Ammonia tepida	0.00	0.00	0.00	0.00	8.05	12.00	0.00	0.87	0.00	0.00	0.00	0.00	0.19	0.00	0.50	27.05	0.16	0.00
Archaias angulatus	17.55	8.90	3.85	38.38	0.48	0.00	42.42	2.09	15.10	33.15	20.35	35.71	30.20	56.01	12.57	0.00	40.58	27.89
Archaias compressus	1.16	0.65	0.00	0.00	0.00	0.00	1.69	0.17	2.96	14.02	3.81	0.23	1.52	2.44	7.20	0.00	9.97	0.91
Amphistegina gibbosa	3.97	3.07	0.28	2.18	0.00	0.00	0.00	0.00	1.06	0.00	0.00	1.39	0.00	0.00	0.08	0.00	0.31	0.00
A. caymanensis sp. nov.	0.00	0.00	0.00	0.00	70.43	56.00	1.55	4.01	7.18	3.90	0.73	0.00	0.95	0.38	2.32	8.51	5.22	1.51
Amphisorus hemprichii	0.33	13.59	2.06	5.08	0.00	0.00	0.70	0.00	1.27	2.31	1.02	0.77	0.09	0.06	0.33	0.00	0.00	0.60
Asterigerina carinata	9.60	5.83	0.69	4.48	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Borelis pulchra	2.15	3.24	0.14	0.24	0.00	0.00	0.00	0.00	0.11	0.88	0.15	0.08	0.00	0.00	0.00	0.00	0.08	0.00
Cribroelphidium poeyanum	0.00	0.00	0.00	0.00	9.50	25.00	1.13	3.66	1.37	0.64	0.00	0.15	0.47	0.31	3.39	51.98	3.35	1.74
Cymbaloporetta squammosa	4.97	13.75	1.38	3.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Discorbis granulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Discorbis mira	3.31	5.02	0.96	3.87	8.77	0.00	7.12	18.50	17.74	7.09	33.82	26.80	31.53	12.95	13.15	1.52	11.68	13.08
Discorbis rosea	44.70	21.84	6.46	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elphidium lanieri	0.00	0.16	0.00	0.12	0.36	5.00	0.35	2.27	1.48	0.48	0.29	0.39	0.00	0.00	0.00	2.74	1.95	0.76
Massilina protea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.32	0.00	0.29	0.00	0.00	0.69	17.29	0.00	0.00	0.08
Peneroplis discoideus	0.00	0.16	0.00	0.12	0.00	0.00	0.07	0.00	0.11	0.88	0.00	0.00	0.09	0.25	0.17	0.00	0.00	0.08
Planorbulina acervalis	0.00	0.97	52.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Pyrgo denticulata	0.00	0.32	0.00	0.00	0.00	0.00	2.11	3.84	4.65	5.42	0.59	1.63	0.28	0.00	0.00	0.00	1.71	2.57
Pyrgo subsphaerica	0.00	0.32	1.10	0.24	0.00	0.00	0.00	0.00	0.32	0.16	0.29	1.16	0.47	0.25	0.25	0.00	0.00	0.08
Quinqueloculina agglutinans	0.50	1.13	0.14	1.33	0.00	0.00	4.02	1.05	1.58	0.64	0.00	0.00	0.00	0.38	1.74	0.30	1.87	2.65
Quinqueloculina bidentata	0.00	0.00	0.28	6.17	0.00	0.00	0.35	0.17	0.21	0.64	0.00	0.00	0.00	0.00	0.58	0.00	0.08	0.08
Quinqueloculina bradyana	0.33	0.49	0.69	1.21	0.00	0.00	1.90	1.05	0.32	0.48	0.59	0.70	0.00	0.00	1.16	0.00	0.62	2.27
Quinqueloculina funafutiensis	0.00	0.00	0.00	0.00	0.12	0.00	11.21	3.49	5.81	5.66	0.00	0.23	0.00	0.00	0.00	0.00	4.52	7.11
Quinqueloculina laevigata	0.00	0.00	0.00	0.00	0.12	0.00	0.00	1.75	0.11	0.08	0.00	0.08	0.00	0.06	1.08	0.30	0.16	0.15
Quinqueloculina poeyana	0.00	0.00	0.00	0.00	0.00	0.00	0.21	3.14	0.63	0.48	0.44	0.08	0.00	0.38	1.32	0.00	0.00	0.15
Rosalina candeiana	4.30	4.69	3.30	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Rosalina floridana	0.00	0.00	1.24	0.00	0.36	1.00	0.28	2.27	0.21	0.24	2.05	2.63	4.65	7.07	0.91	2.74	0.31	0.91
Spiroloculina arenata	0.00	0.00	0.14	0.85	0.00	0.00	0.42	2.27	0.53	0.00	1.46	0.62	0.00	0.00	0.41	0.00	0.16	0.30
Trichohyalus aguayoi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.00
Triloculina carinata	0.66	2.10	0.69	3.03	0.00	0.00	2.75	1.92	5.17	2.15	0.44	1.39	1.80	0.63	2.56	0.00	2.73	3.63
Triloculina laevigata	0.00	0.00	0.28	4.00	1.20	0.00	0.14	7.33	0.32	0.80	1.17	0.39	0.19	1.69	7.61	0.00	0.16	1.44
Triloculina linneiana	0.00	0.32	0.69	1.45	0.00	0.00	5.14	7.50	7.39	6.37	2.78	6.51	1.90	2.57	4.05	0.00	2.02	5.06
Triloculina rotunda	0.00	0.00	0.00	3.15	0.00	0.00	0.70	5.76	3.38	1.59	1.61	1.63	7.41	0.88	5.71	0.00	0.23	0.76
Triloculina sidebottomi	0.00	0.00	0.14	0.61	0.00	0.00	0.07	0.52	0.00	0.08	0.15	0.62	0.19	0.06	1.49	0.00	0.00	0.23
Triloculina simplex	0.00	0.00	0.00	0.48	0.12	0.00	0.00	0.17	0.00	0.00	0.00	0.31	3.51	0.13	0.99	0.00	0.31	0.23
Triloculina trigonula	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.87	0.74	0.00	0.15	0.08	0.00	0.00	0.00	0.00	0.08	0.60
Valvulina oviedoiana	0.66	2.27	0.55	3.87	0.00	0.00	4.58	8.55	4.44	1.75	9.66	8.21	5.98	3.44	7.11	0.00	5.53	8.24
Other Species	5.79	11.17	22.70	14.04	0.48	1.00	10.71	15.71	15.42	10.12	18.16	8.13	8.55	9.39	6.04	4.26	6.23	16.86

Table 6.1 (Continued)

	LOCALITIES																
SPECIES	F68	F69	F70	F71	F72	F73	F74	F75	F76	F77	F78	F79	F80	F81	F82	F83	F84	F85
Ammonia tepida	0.00	0.00	11.90	32.91	0.00	5.66	11.54	0.00	0.00	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Archaias angulatus	4.99	7.77	55.34	20.66	14.75	1.81	15.38	11.98	1.37	39.40	69.62	38.99	27.44	66.84	38.54	9.65	20.21	26.86
Archaias compressus	0.00	0.35	0.00	0.26	0.00	0.00	0.00	0.00	0.00	2.18	2.96	3.56	2.70	0.00	1.08	0.00	0.71	4.00
Amphistegina gibbosa	0.00	5.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.43	8.81	7.28	8.74	1.44	1.49	8.16	7.14
A. caymanensis sp. nov.	0.76	1.77	0.00	0.00	6.01	0.00	0.00	0.98	2.05	1.13	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00
Amphisorus hemprichii	0.87	5.65	0.20	0.00	0.55	1.13	0.00	1.18	0.68	0.16	0.22	2.10	0.83	1.03	0.60	0.00	2.13	2.57
Asterigerina carinata	0.11	11.31	0.61	0.00	0.00	0.00	0.00	0.20	0.00	0.00	3.97	4.19	6.24	1.29	9.24	9.41	7.80	3.71
Borelis pulchra	0.22	3.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.14	2.31	2.49	1.03	2.04	1.98	2.13	1.71
Cribroelphidium poeyanum	0.00	0.00	5.60	15.31	4.37	5.43	0.00	2.55	1.37	1.21	0.14	0.42	0.00	0.00	0.12	0.00	0.00	0.29
Cymbaloporetta squammosa	0.00	6.01	1.32	2.30	0.55	0.00	0.00	0.00	0.23	0.00	1.08	2.94	5.20	0.00	2.64	2.48	2.84	5.14
Discorbis granulosa	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.42	0.00	0.00	0.00	0.00	0.00	0.00
Discorbis mira	34.20	4.24	1.12	3.32	39.34	1.58	0.00	16.50	20.73	7.44	0.36	0.00	1.04	0.51	1.92	3.22	3.19	2.57
Discorbis rosea	0.65	28.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.75	16.14	16.42	17.48	19.93	46.78	27.30	22.29
Elphidium lanieri	0.33	0.00	0.00	0.51	4.37	0.45	0.00	0.98	0.23	0.73	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Massilina protea	0.11	0.00	1.93	0.26	0.00	3.39	0.00	4.72	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Peneroplis discoideus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.62	0.00	0.12	0.00	0.00	0.00
Planorbulina acervalis	0.22	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.21	0.00	0.00	0.12	0.00	0.00	0.00
Pyrgo denticulata	1.41	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.42	0.00	0.12	0.00	0.00	0.29
Pyrgo subsphaerica	0.54	0.71	0.00	0.00	0.00	0.23	0.00	0.20	0.46	0.00	0.14	0.00	1.46	0.00	0.84	0.00	1.42	0.86
Quinqueloculina agglutinans	0.00	1.77	1.22	0.51	0.00	0.45	0.00	1.96	0.46	3.16	1.44	2.73	1.46	1.29	1.20	0.99	1.06	1.14
Quinqueloculina bidentata	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.23	0.08	0.72	1.26	0.21	0.00	0.36	0.00	0.35	0.29
Quinqueloculina bradyana	1.63	0.35	0.00	0.00	0.55	2.04	0.00	2.55	1.37	2.59	0.00	0.42	0.00	0.00	0.00	0.00	1.42	0.00
Quinqueloculina funafutiensis	0.11	0.00	0.00	1.02	1.09	0.00	0.00	1.38	2.28	14.08	1.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quinqueloculina laevigata	0.11	0.00	0.10	8.16	0.00	1.13	23.08	3.14	24.37	0.24	0.07	0.00	0.21	0.00	0.00	0.00	0.00	0.00
Quinqueloculina poeyana	0.11	0.00	1.42	1.53	0.00	8.82	0.00	1.77	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29
Rosalina candeiana	0.00	2.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.63	4.78	0.00	5.52	13.61	5.32	3.71
Rosalina floridana	2.71	0.71	0.20	0.00	3.83	1.58	3.85	3.54	0.68	0.65	0.00	0.21	0.21	0.00	0.00	0.50	0.71	0.00
Spiroloculina arenata	0.43	0.00	0.00	0.00	0.00	3.17	7.69	1.18	0.23	1.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trichohyalus aguayoi	0.00	0.00	0.00	0.00	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina carinata	2.82	1.06	1.42	1.53	2.19	5.66	3.85	5.50	1.59	2.27	0.36	1.05	2.91	0.00	0.84	0.25	0.71	0.57
Triloculina laevigata	0.00	0.00	2.14	0.26	1.09	2.94	11.54	3.14	0.00	0.65	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina linneiana	5.32	0.35	2.14	2.04	1.09	3.62	3.85	2.95	4.33	2.27	0.94	1.05	1.25	0.00	1.80	0.99	0.35	2.57
Triloculina rotunda	6.30	0.00	1.12	2.30	0.55	16.52	11.54	10.22	19.82	0.81	0.14	0.00	0.00	0.00	0.00	0.00	0.35	0.29
Triloculina sidebottomi	0.43	0.00	0.00	0.00	0.00	1.36	0.00	1.18	4.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina simplex	0.00	0.00	3.05	1.02	0.00	0.00	0.00	2.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina trigonula	0.00	0.00	0.92	1.28	0.00	3.62	0.00	0.39	0.00	0.00	0.07	0.00	0.21	0.00	0.00	0.00	0.00	0.00
Valvulina oviedoiana	16.40	2.83	3.05	1.02	1.09	0.23	0.00	2.95	5.69	2.75	1.59	4.19	6.86	0.26	2.04	0.00	2.48	1.71
Other Species	19.22	13.78	4.37	3.83	17.49	29.19	7.69	16.70	7.06	12.46	2.31	8.18	9.77	1.54	9.48	8.66	10.64	12.00

Table 6.1 (Continued)

	LOCALITIES													
SPECIES	F86	F97	F98	F103	F104	F106	F107	MPP	MBP2	FCBP	BBP2	BBP1	CBP	TSP	MBP1
Ammonia tepida	0.00	0.16	0.00	0.00	25.37	2.91	0.00	15.36	72.39	1.01	99.87	80.08	1.85	89.26	91.32
Archaias angulatus	53.02	1.56	67.47	0.00	0.00	18.02	5.93	0.00	0.00	0.00	0.00	2.44	60.19	2.01	2.52
Archaias compressus	0.37	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphistegina gibbosa	0.07	33.96	9.64	0.00	0.00	0.87	0.40	0.00	0.00	0.00	0.00	0.41	8.33	0.00	0.28
A. caymanensis sp. nov.	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphisorus hemprichii	2.31	0.00	0.00	0.00	0.00	0.29	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Asterigerina carinata	1.19	14.87	2.41	0.09	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Borelis pulchra	0.45	1.25	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cribroelphidium poeyanum	0.00	0.16	0.00	0.38	17.91	6.40	2.37	0.00	0.00	0.00	0.00	0.41	0.00	1.34	0.00
Cymbaloporetta squammosa	1.27	0.31	10.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.48	0.00	0.28
Discorbis granulosa	0.00	0.00	2.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.81	9.26	0.00	0.00
Discorbis mira	3.13	1.88	0.00	0.09	0.00	3.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Discorbis rosea	3.20	1.25	3.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.19	0.00	0.00
Elphidium lanieri	0.15	0.00	0.00	0.00	0.00	0.87	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Massilina protea	0.00	0.31	0.00	2.07	7.71	2.62	3.16	0.00	0.37	0.00	0.00	0.00	0.00	0.67	0.00
Peneroplis discoideus	0.07	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planorbulina acervalis	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pyrgo denticulata	0.00	0.78	0.00	0.00	0.00	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pyrgo subsphaerica	0.67	0.78	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34	0.00
Quinqueloculina agglutinans	4.10	1.41	0.00	0.09	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.93	0.00	0.00
Quinqueloculina bidentata	0.30	0.31	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00
Quinqueloculina bradyana	1.64	0.63	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quinqueloculina funafutiensis	0.15	0.00	0.00	0.09	0.00	6.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quinqueloculina laevigata	0.07	0.00	0.00	1.88	0.00	1.16	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quinqueloculina poeyana	0.30	0.00	0.00	0.56	0.75	0.58	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rosalina candeiana	0.74	5.48	2.41	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rosalina floridana	0.52	1.25	0.00	0.47	0.00	1.74	1.58	0.00	0.00	0.14	0.13	1.63	0.00	0.00	0.00
Spiroloculina arenata	0.00	0.00	0.00	0.09	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trichohyalus aguayoi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.32	0.00	0.00	0.00
Triloculina carinata	2.01	0.31	0.00	14.85	0.00	8.72	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28
Triloculina laevigata	0.37	0.31	0.00	2.82	3.23	0.29	17.00	0.00	0.00	0.00	0.00	2.85	0.00	0.00	0.00
Triloculina linneiana	2.90	0.94	0.00	0.00	0.25	9.30	3.56	0.00	0.00	0.00	0.00	0.81	0.00	0.00	0.00
Triloculina rotunda	0.45	0.00	0.00	60.43	28.11	7.85	15.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina sidebottomi	0.00	0.00	0.00	5.73	3.23	0.87	3.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina simplex	0.00	0.00	0.00	1.03	12.44	0.00	39.13	84.64	27.24	98.85	0.00	0.81	0.00	0.00	5.32
Triloculina trigonula	0.15	0.00	0.00	0.66	0.00	9.59	0.00	0.00	0.00	0.00	0.00	0.00	0.93	0.00	0.00
Valvulina oviedoiana	7.15	0.63	0.00	3.76	0.00	5.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Species	13.10	30.99	0.00	4.79	1.00	9.59	3.56	0.00	0.00	0.00	0.00	2.03	1.85	5.37	0.00

SUBSTRATE ZONATIONS

Based on sediment grain size, the lagoon floors of North Sound and South Sound are divided into: 1) the Organic-rich Mud Zone, along the mangrove rimmed edges of lagoons, 2) the *Thalassia* and Sand Zone, in the central part of the North Sound and landward part of South Sound, 3) the Bare Rock Zone along the western margin of North Sound and nearshore South Sound, 4) the Bare Sand Zone, in the northern part of North Sound and southern part of South Sound, and 5) the Rubble and Knob Zone, along the landward side of the fringing reefs and the seaward margins of the lagoons. Five distinctive macrofauna and macroflora communities generally correspond to these substrates: organic sediment community, deep lagoon community, shallow sediment community, pre-reef plain community, and back-reef community (Swain and Hull, 1977). Two types of substrates are common in the ponds: 1) organic-rich mud in seasonally dried ponds, and 2) bare rock bottom floored by pebble-sized sediments in the man-made permanently flooded ponds.

FORAMINIFERAL ASSEMBLAGES

Eight foraminiferal assemblages are defined (Figs. 6.5, 6.6). These are named according to their most common species.

Discorbis rosea-Archaias angulatus-Asterigerina carinata *Assemblage (1A)*

Characters.— The assemblage is dominated by the forereef species, *Discorbis rosea, Asterigerina carinata,* and *Amphistegina gibbosa*, which collectively form > 40% of the foraminiferal tests. Other common and unique forereef species present in this assemblage are *Heterostegina antillarum, Quinqueloculina barbouri, Globigerinoides rubra,* and *Gypsina vasicularis*. Lagoonal species having abrasion-resistant tests such as *Archaias angulatus*, however, are also abundant (15%). Species that are commonly found in backreef areas such as *Cymbaloporetta squammosa, Rosalina candeiana, Amphisorus hemprichii*, and *Borelis pulchra* are also abundant in this assemblage. Living (stained) specimens of *C. squammosa* and *R. candeiana* are common in this assemblage.

Distribution.— All samples of this assemblage come from the seaward margin of the lagoons, close to the fringing reefs. Specifically, they are 1) on the channel or rocky floors, 2) in the Rubble and Knob Zone that lies behind the reef crest, 3) on the upper and lower terraces of open shelf, and 4) on the rippled sand plain that belongs to the seaward part of the Bare Sand Zone. The substrates are typically medium to coarse-sand or barren rocky floor that is covered by brown algae, gorgonians, and sparse green algae. Even

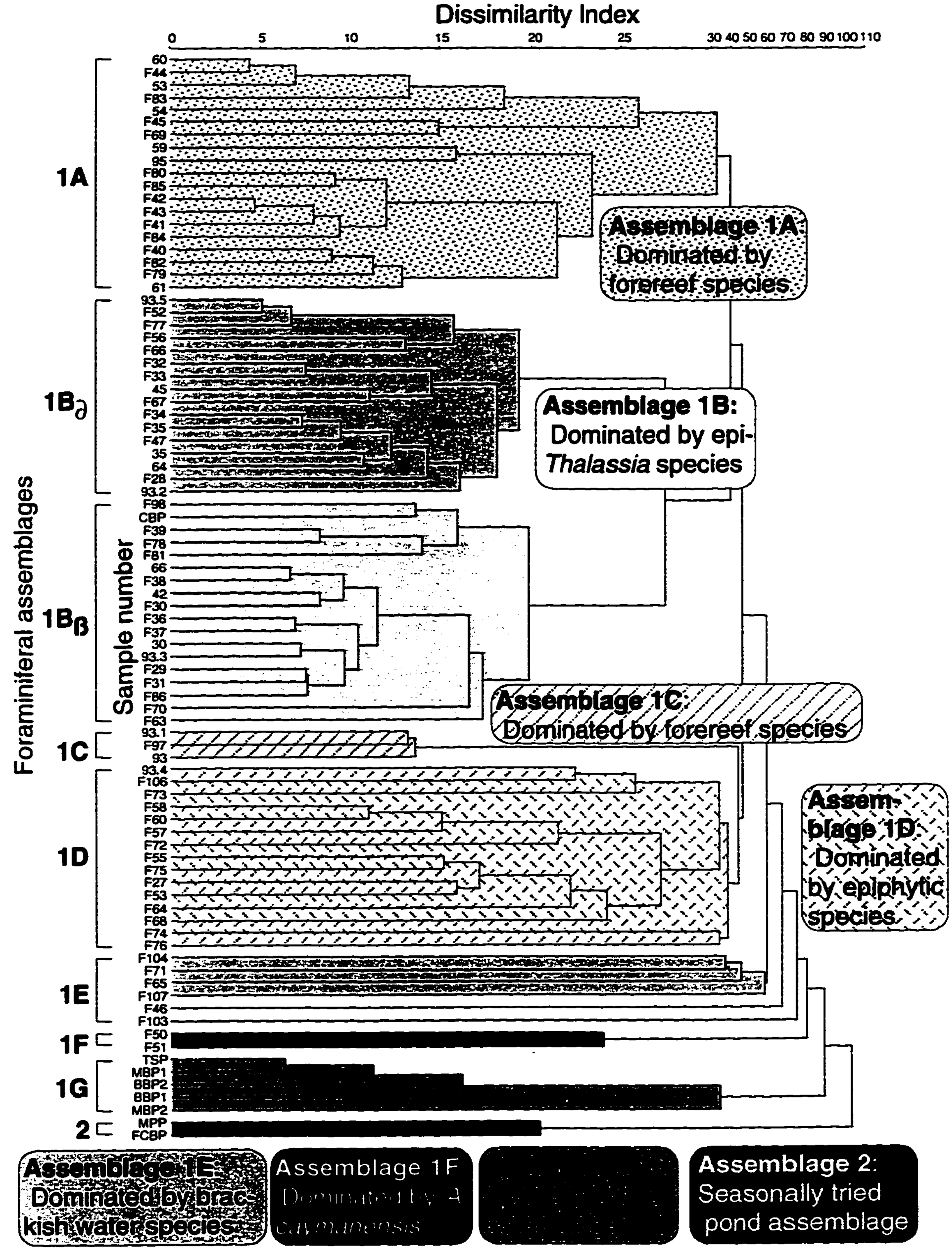


Figure 6.5—Dendrogram of Q-mode cluster analysis of samples, based on foraminifera that form ≥5% of the fauna on any site (Between Groups Method and Euclidean Distance), showing 9 assemblages and subassemblages.

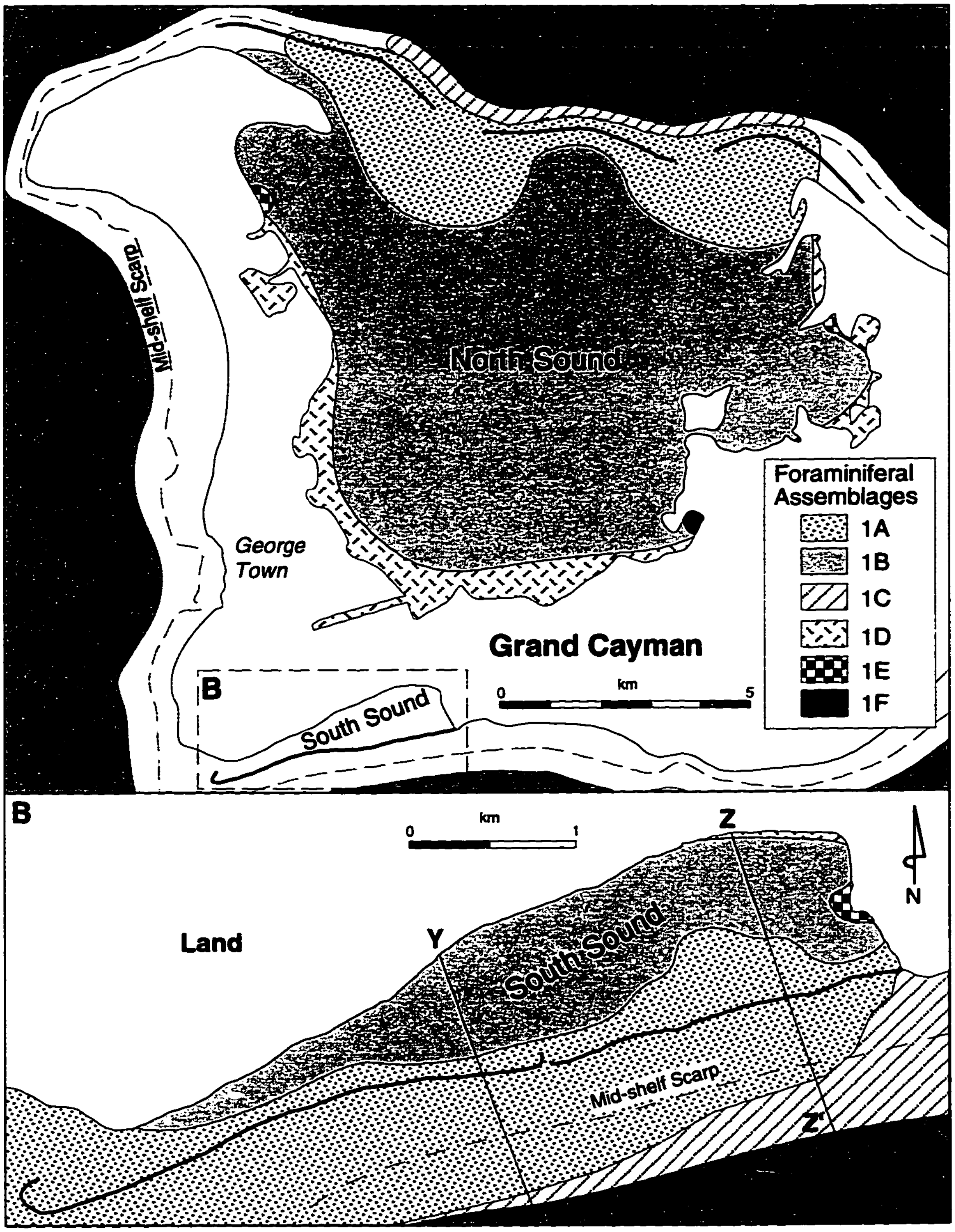


Figure 6.6—Distribution of assemblages (1A to 1F) in North Sound (A) and South Sound (B) based on Q-mode cluster analysis.

under fair-weather conditions, these areas are characterized by turbulent water due to wave and current activity.

Comparison.—This assemblage is comparable to the Assemblage III_w dominated by *Amphistegina gibbosa, Asterigerina carinata,* and *Discorbis rosea* on the east coat of Grand Cayman, especially the sub-assemblage found in the seaward part of the outer lagoon (Li and Jones, in press). It is also similar to the "Backreef zone", Discovery Bay, Jamaica (Martin and Liddell, 1988), the "*Archaias-Asterigerina* assemblage" on the Belize shelf (Wantland, 1975), the "sand barrier fauna" of the windward Buccoo reefs, Tobago (Radford, 1976), and the "Platform margin assemblage" and "back-reef assemblage" on the Florida shelf (Rose and Lidz (1977) and Moore (1957) respectively).

Archaias angulatus-Discorbis mira-Valvulina oviedoiana *Assemblage (1B)*

Characters.—*Archaias angulatus* and other epiphytic species that are commonly associated with *Thalassia* form up to 80% of the foraminiferal tests in this assemblage. Conversely, forereef species form <5% of the assemblage.

This assemblage can be divided into two subassemblages, that correspond to the *Thalassia* and Sand Zone in the inner part of the sounds and landward part of the Bare Sand Zone in the outer part of the sounds. Subassemblage $1B_{\alpha}$ 1) is dominated by epiphytic species that are typically found on *Thalassia* grasses, 2) has high diversity, and 3) is characterized by epiphytic species such as *Archaias angulatus, Archaias compressus, Cribroelphidium poeyana,* and *Discorbis mira*. Subassemblage $1B_{\beta}$ 1) is dominated by *Archaias angulatus, Discorbis rosea,* and other abrasion-resistant species, 2) contains few living specimens, and 3) contains numerous forereef species.

Distribution.— Assemblage $1B_{\alpha}$ is found on the substrates that have a dense cover of *Thalassia,* numerous shrimp mounds and green algae in the *Thalassia* and Sand Zone in the landward sides of the North Sound, South Sound, and Little Sound. Assemblage $1B_{\beta}$ is typically found on well sorted sands on the beaches, and in the Bare Sand Zone (*e.g.*, Sand Bar), and in very poorly sorted, bimodal sediments (mud and pebbles) at the northwestern part of North Sound.

Comparison.— Subassemblage $1B_{\alpha}$ is comparable to Assemblage II_w in the inner lagoon of east coast which is dominated by *Archaias, Quinqueloculina,* and *Triloculina* (Li and Jones, in press). It is also comparable to Assemblage 1A from the *Thalassia* and Sand Zone of Frank Sound, Grand Cayman (Chapter 5). In other parts of the Caribbean and Florida region, this assemblage is similar to the "backreef" assemblage on Barbuda (Brasier, 1975a), the "Open interior fauna" on the Florida shelf (Rose and Lidz, 1977; Lidz and Rose, 1989), and the "High-diversity milliolid assemblage" on the Belize shelf

(Wantland, 1975). Subassemblage $1B_8$ is comparable to the *Archaias angulatus-Discorbis rosea* Assemblage from the nearshore zone on the western leeward shelf (Li and Jones, in press) and Assemblage 1C from the Bare Rock Zone of Frank Sound (chapter 5).

Amphistegina gibbosa-Asterigerina carinata-Archaias angulatus *Assemblage (1C)*

Composition.—This assemblage is dominated by typical forereef species that form up to >60% of the assemblage.

Distribution.— This assemblage is found on the Bare Sand Zone on the lower terrace.

Comparison.— The assemblage is comparable to Assemblage III_w on the east coast of the island which is dominated by *Amphistegina gibbosa, Archaias angulatus,* and *Asterigerina carinata* (Li and Jones, in press). It is also similar to the assemblage found on the "30 m site" of northern Jamaica (Martin and Liddell, 1988, 1989).

Discorbis mira-Archaias angulatus-Triloculina rotunda *Assemblage (1D)*

Composition.—This assemblage is characterized almost exclusively by epiphytic species. Two groups of species are common — those commonly found on leaves of *Thalassia* (*Discorbis mira, Archaias angulatus, Valvulina oviedoiana),* and those commonly found on fibrous green alga (*i.e., Penicillus*) such as *Triloculina rotunda.* Typical euryhaline species such as *Massilina protea, Ammonia tepida*, and *Triloculina simplex* become common compared to Assemblage 1B. Living specimens of *Discorbis mira, Archaias angulatus, Rosalina floridana*, and *Cribroelphidium poeyana* are common in this assemblage.

Distribution.— This assemblage is typically found in the Organic-rich Mud Zone and Bare Rock Zone along the landward margins of North Sound and South Sound that are within 10 m of the mangroves. The substrates are characterized by: 1) abundant green algae (especially *Penecillus* and *Halimeda)* and *Thalassia*, 2) numerous jelly fish *(Cassiopea xamachana)*, 3) sponges and some head corals that can withstand high turbidity conditions (F53, F64, F68), 4) abundant mangrove fragments with organic-rich mud, and rare sand sized sediment, 5) bimodal grain size distribution of pebble-sized rock fragments and mud. The low sand content in these areas prevents *Thalassia* spreading thus only green algae can grow.

Comparison.—This assemblage is comparable to the "offshore lagoon assemblage" on the south coast of Puerto Rico (Culver, 1990), the "low diversity *Cribroelphidium* Assemblage" at the landward side of the Belize lagoon (Wantland, 1975), the "Bay fauna" or "Restricted Interior Fauna" in Florida Bay (Bock, 1971; Rose and Lidz, 1977).

Triloculina rotunda-Ammonia tepida-Cribroelphidium poeyanum *Assemblage (1E)*

Composition.—This assemblage is dominated by species that are commonly found on restricted mud-bank environments with brackish water conditions. The nominal species, which form up to 50% of the assemblage, are accompanied by other epiphytic species that commonly live on green alga and *Thalassia* leaves. Of the living specimens, *Triloculina simplex, Ammonia tepida, Cribroelphidium poeyanum* and *Massilina protea* are common.

Distribution.— Samples belonging to this assemblage come from areas 1) close to the mangrove on substrates that are characterized by green algae, jelly-fish and *Thalassia* as with Assemblage 1C, and 2) artificial brackish-water ponds surrounded by mangrove swamps where the substrates are characterized by mud and rocky bottom covered with green algae.

Comparison.—This assemblage is comparable to the "*Quinqueloculina-Cribroelphidium* Assemblage" that is found along the mainland margin of southern Belize (Wantland, 1975).

Amphistegina caymanensis *sp. nov.*-Cribroelphidium poeyanum-Ammonia tepida *Assemblage (1F)*

Composition.—This low diversity assemblage is dominated by *Amphistegina caymanensis* sp. nov. which commonly forms ≥90% of the assemblage. No living foraminifera were found with this assemblage.

Distribution.— The assemblage is concentrated along the north edge of Duck Pond Bight, eastern North Sound. It is found close to the mangrove where the substrates are characterized by abundant green algae, *Thalassia*, and numerous jelly fishes. Mollusk fragments on the lagoon floor are covered by loose, brownish, plant fragments.

Comparison.—This assemblage does not appear to be comparable to any other described assemblages.

Ammonia tepida-Triloculina simplex-Trichohyalus auguayoi *Assemblage (1G)*

Composition.—The assemblage is dominated by *Ammonia tepida* (up to 86% of assemblage), *Triloculina simplex,* and *Trichohyalus aguayoi.* Living specimens of *Ammonia tepida* were found with the assemblage. Tests of other species, which form a minor portion of the assemblage, are transported from other environments.

Distribution.— This assemblage is found in three ponds close to Frank Sound and Pease Bay (Fig. 6.3). These ponds are surrounded by mangroves and the locations where samples were collected are commonly desiccated during the dry season. During the rainy season, however, they are flooded by brackish waters. Water in the ponds may be connected to the sea through bedrock openings.

Comparison.—This assemblage is comparable to the "Additional marginal-marine Assemblage" of nearshore Belize that is influenced by river discharges (Wantland, 1975).

Triloculina simplex-Ammonia tepida ***Assemblage (2)***

Composition.—The assemblage is characterized, almost exclusively, by the nominal species. Living specimens were found with this assemblage.

Distribution.—This assemblage was found in Malportas Pond and Colliers Bay Pond on the northeast part of the island (Fig. 6.3). These ponds are commonly dried out during the dry seasons.

Comparison.— This assemblage is comparable to the "Additional marginal-marine Assemblage" found in nearshore Belize in areas that are influenced by river discharges (Wantland, 1975).

DISCUSSION

In North Sound and South Sound, and several ponds on Grand Cayman the composition of the foraminiferal assemblages is strongly related to substrate conditions, water quality, and taphonomic factors that are controlled by natural forces and/or human activities (Fig. 6.7).

Many foraminifera species in the lagoons are related directly to the substrate conditions. *Triloculina rotunda*, for example, is typically found living on "fibrous weed" substrates such as those provided by *Penicillus* and *Batophora* (Brasier, 1975a). The Organic-rich Mud Zone along the eastern margins of North Sound and the northeast corner of South Sound, which is flanked by mangroves, is characterized by variable salinities due to the influx of fresh to brackish water from the interior of the island and evaporation. On the western margin of North Sound, the substrate lacks sand-sized sediment because it has been modified by sediment dredging. As a result, vegetation in these marginal areas is dominated by algae (especially *Penecillus, Halimeda*) rather than *Thalassia*. This explains the dominance of *Triloculina rotunda* in assemblages 1D and 1E.

Thalassia becomes abundant in the *Thalassia* and Sand Zone where the environment is more open and sand-sized sediment is common. Common species in this area (Assemblage 1B) include *Archaias angulatus, Discorbis mira, Valvulina oviedoiana, Archaias compressus, Quinqueloculina funafutiensis, Planorbulina acervalis, Rosalina floridana*, and *Triloculina linneiana*. All of these species prefer to live on *Thalassia* leaves in shallow,

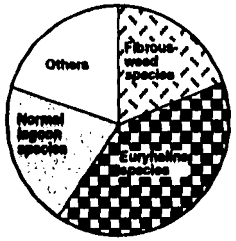
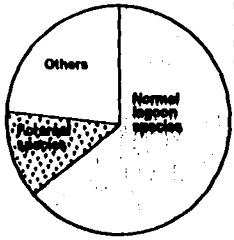
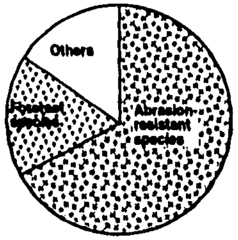
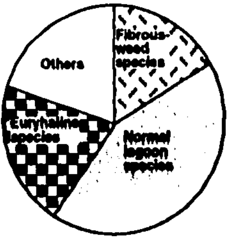
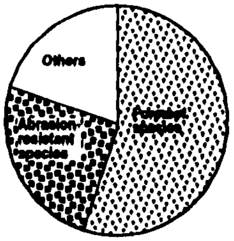
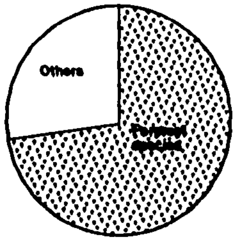
Foraminiferal Assemblages	1E, 1F		$1B_{\partial}$	$1B_{\beta}$	1D	1A	1C
Diversity	1E	1F	$1B_{\partial}$	$1B_{\beta}$	1D	1A	1C
	53	8	87	75	78	94	88
Substrate Zonations			*Thalassia* and Sand Zone	Bare Sand Zone	Bare Rock Zone	Rubble & Knob Zone	Bare Sand Zone, Lower Terrace
Main composition of assemblages							
Macrofauna-macroflora Comminities (Swain and Hull, 1976)	Organic Sediment Community		Deep Lagoon Community	Pre-reef Plain Community	Shallow Sediment Community	Back-reef Community	Fore-reef Community?

Figure 6.7—Summary of assemblages and subassemblages from sounds, showing diversity of each assemblages, main composition of assemblages/subassemblages, and correlation of these assemblages to substrate zones and macrofauna communities.

normal marine and oxygenated environments (cf. Davis, 1964; Bock, 1971; Lee and Zucker, 1969; Brasier, 1975a; Wantland, 1975; Steinker and Steinker, 1976; Lutze and Wefer, 1980; Poag, 1981; Hallock *et al.*, 1986a, Hallock and Peebles, 1993; Martin, 1986; Martin and Wright, 1988).

In the Bare Sand Zone, the substrate is characterized by barren, mud-free, loose carbonate sand. Sand-sized sediment becomes rare near channels or the Rubble and Knob Zone where the water is turbulent because of currents and breaking waves. Most sediment in these areas was transported from the forereef during storms and hurricanes. Lagoonal components are present but are mixed with the imported forereef grains. Foraminiferal assemblage 1A, which is found in this area, is dominated by *Discorbis rosea, Asterigerina carinata, Amphistegina gibbosa* , species that prefer to live on algal-veneered hard substrates in the forereef area under turbulent energy conditions, and by *Archaias angulatus, Cymbaloporetta squammosa*, and *Rosalina candeiana*, which typically live in the *Thalassia* and Sand Zone of the inner lagoon (Bandy, 1964; Wantland, 1975; Sen Gupta and Schafer, 1973; Radford, 1976; Weis and Steinker, 1977; Poag and Tresslar, 1981; Hallock *et al.*, 1986b). Due to their robust tests, these lagoonal species are prominent on the mixed bare sand plain (Seiglie, 1970; Wright and Hay, 1971; Martin and Liddell, 1988).

Dramatic changes in species abundance take place along traverses from the muddy and brackish mangrove-margin of the lagoon to the normal marine open shelves (Figs. 6.8, 6.9). *Archaias angulatus*, the most abundant species on the *Thalassia* banks dominates in the middle lagoon area. Landward, euryhaline species or fibrous-weed species become dominant (Fig. 6.7). Seaward from the Bare Sand Zone to the open forereef terraces, however, forereef species are most abundant. This trend indicates that most of the sediment in the Bare Sand Zone was transported from forereef areas by storms and hurricanes (ref. Li *et al.*, in press). Similar trends were also found elsewhere on Grand Cayman and from other areas such as Gulf of Batabano, Cuba (Bandy, 1964), Barbuda (Brasier, 1975b), Belize shelf (Wantland, 1975), the north coast fringing reef, Discover Bay, Jamaica (Martin and Liddell, 1988), and Florida Bay and adjacent waters (Bock, 1971; Rose and Lidz, 1977).

Ponds on Grand Cayman are divided into those that may be completely desiccated during the dry seasons (Colliers Bay Pond, part of Malportas Pond, Meagre Bay Pond, and Tarpon Spring Pond), and those that are always flooded because they are connected to the sea via bedrock openings (Jackson's Pond, Caymarl Pond, Jay Bodden Bay Pond, and part of Betty Bay Pond). The ponds that periodically desiccate are characterized by Assemblage 2 which is dominated by *Ammonia tepida* and *Triloculina simplex*. Laboratory

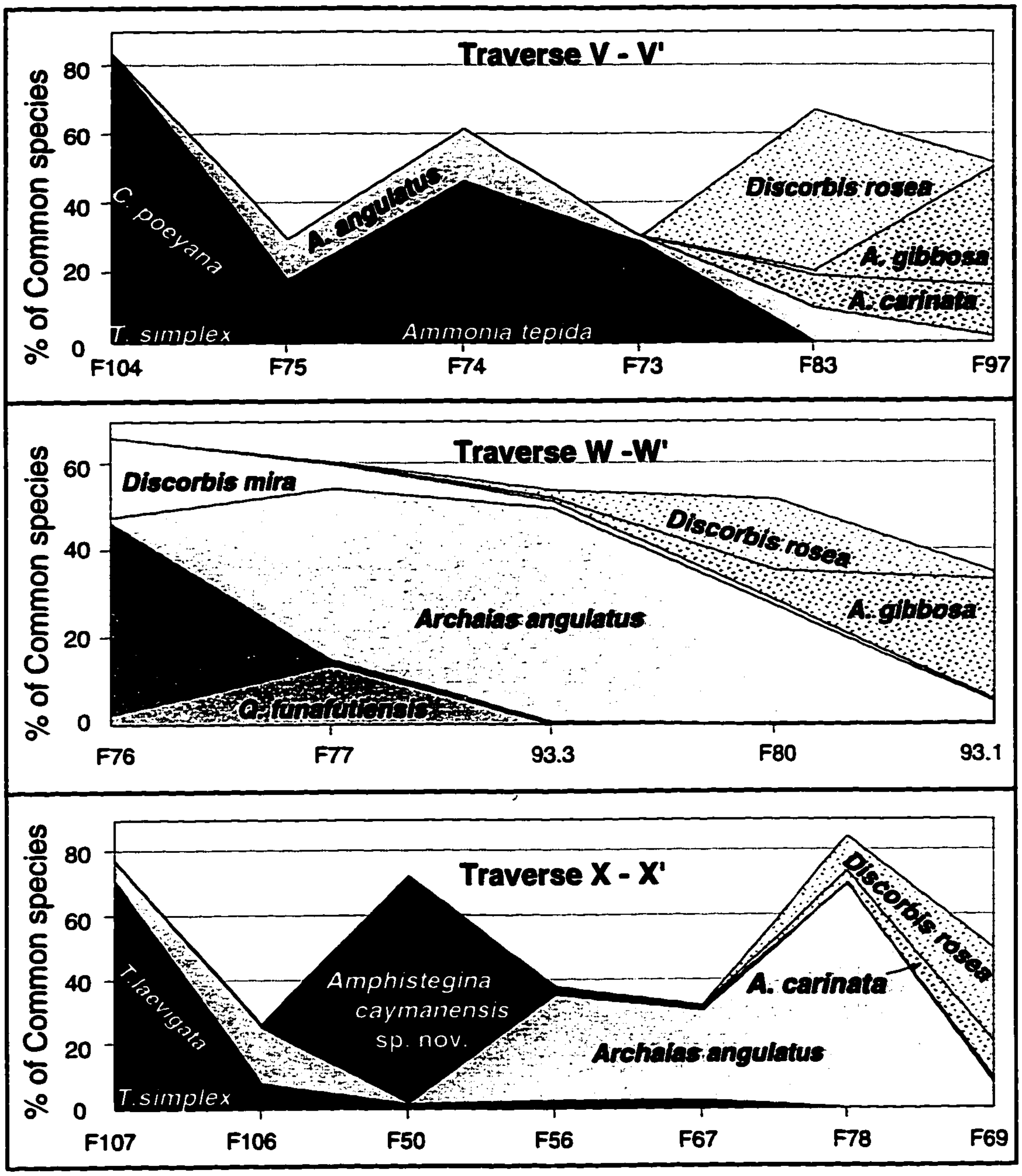


Figure 6.8—Abundance and fluctuations of dominant species along traverses V–V', W–W', and X–X' in North Sound. Note the dramatic changes in abundance of species from restricted mangrove edge (left side of charts) to the open shelves (right side of charts).

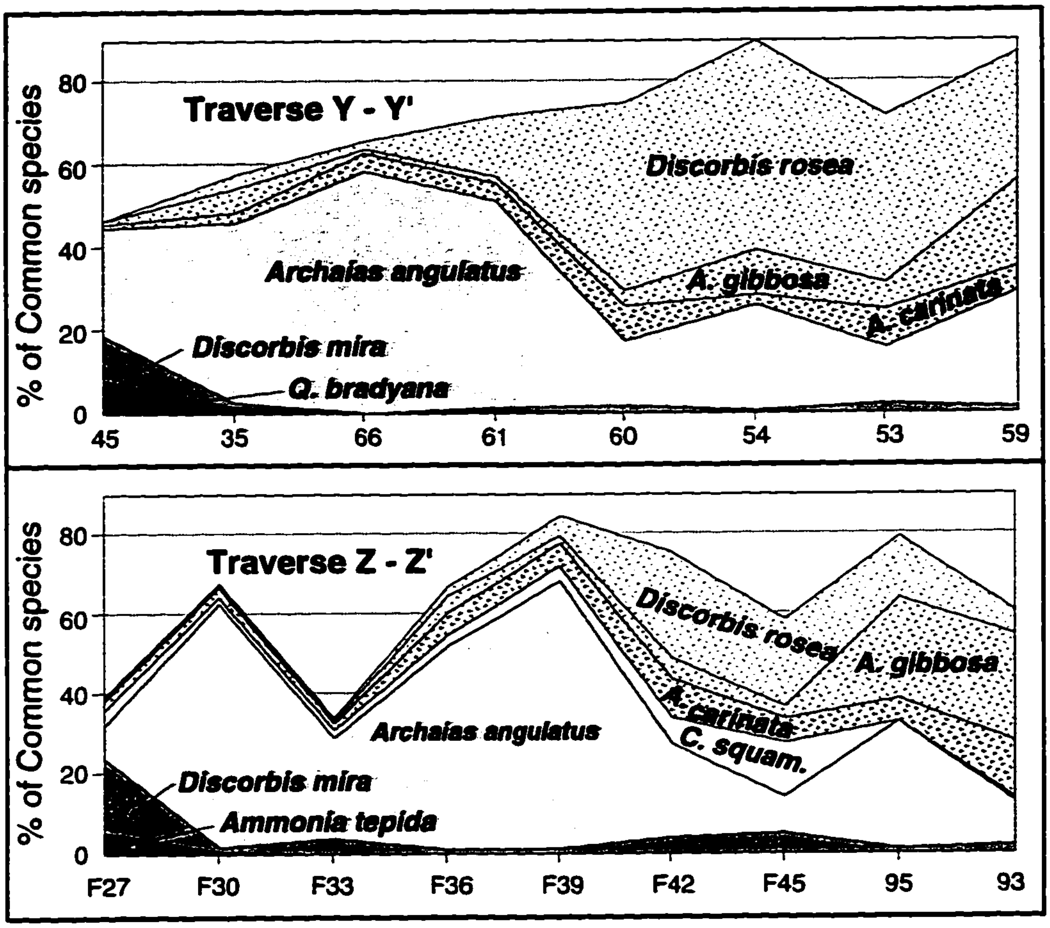


Figure 6.9—Abundance and fluctuations of dominant species along traverses Y–Y' and Z–Z' in South Sound. Note dramatic changes of species and abundance occur at the eastern traverse (Y–Y') of South Sound.

experiments and field observations have shown that *A. tepida* can survive in temperatures from -2 to 45°C, salinity from 2 to 67‰, pH as low as 2.0, and has the ability to recalcify damaged tests (Bradshaw, 1961). As a result, *Ammonia tepida* and its varieties (*A. parkinsoniana, A. ornata, A. beccarii)* are commonly found in brackish to hypersaline waters in bays, estuaries, lagoons, deltas throughout the Caribbean and Gulf of Mexico (Bandy, 1964; Seiglie, 1970, 1971; Poag, 1981; Lidz and Rose, 1989; Culver, 1990; Murray, 1991). *T. simplex* has been found in the "Low-diversity miliolid Assemblage" from restricted lagoonal areas of Belize where hypersaline conditions may develop (Wantland, 1975). Other components found with *A. tepida* and *T. simplex* in ponds on Grand Cayman are ostracods, gastropods, charophyta, and plant fragments. In the permanently flooded ponds, where the water is brackish and the substrates are characterized by bare rock and bimodal-distributed grains, green algae are commonly present. As a result, the foraminiferal assemblages are characterized by fibrous-weed species and small numbers of lagoonal species.

Different parts of the same pond may have different ecological conditions. Along the landward sides of the ponds, fresh to brackish water influx will affect the area during rainy periods but may dry out completely during the dry season. On the seaward side of the same ponds, however, the water has greater interaction with the sea. During storms and hurricanes. marine sediment can be transported into the seaward side of the pond. This explains why samples MBP2 and BBP2 from landward sides of Meagre Bay Pond and Betty Bay Pond contain virtually only *Ammonia tepida* and *Triloculina simplex*, whereas samples MBP1 and BBP1 from the seaward sides of the same ponds also contain tests of open lagoonal species such as *Archaias angulatus, Cymbaloporetta squammosa*, and *Rosalina floridana*. Similarly, normal marine species have been reported from sediment core samples of Salt Pond, an evaporite lake on eastern San Salvador Island, Bahamas, and have been used to recognize washover events by tropical storms (Diaz and Fluegeman, 1993).

Modification of sediment along the west side of North Sound by dredging is reflected by the foraminiferal assemblages. Hydraulic dredging preferentially removed the sand-sized sediment from the lagoon floor with the result that only pebble-sized sediment remains. On the other hand, the suspended mud generated during the dredging process flows into the mangrove swamps, back into the lagoon, or further to the sea. These fines can be re-suspended by storms and redistributed many years after the dredging (Giglioli, 1994). The recolonization of vegetation on such substrates is difficult or impossible (Giglioli, 1994). As a result, *Thalassia* is sparse in these areas and green algae are common as pioneer colonizers. Consequently, foraminifera assemblages found in these areas are characterized by fibrous-weed species such as *Triloculina rotunda*. Sample F86, located 100 m east of Head of Barkers (Fig. 6.4A), was collected from a substrate that is characterized by abundant algae and mud. Northward from this location strong western currents occur as the sound water including suspended sediments exits from the lagoon during both fair-weather and storm conditions (Fig. 6.1D). Mud suspended by continuous dredging was dispersed from North Sound via this pass out into the Caribbean Sea. High turbidity prevents any foraminifera from living in that area; and the dead tests are dominated by *Archaias angulatus* and other abrasion-resistant species.

Taphonomic constraint, especially physical abrasion, may impact the distribution of foraminiferal tests. The sediment on the Sand Bar (Fig. 6.4A) is typically abraded and sorted by fishes (especially stingrays) and tourists on a daily basis. Samples collected from this area contain no living foraminifera and the foraminiferal tests have been abraded. Foraminifera from this area belong to Assemblage $1B_8$ which is dominated by *Archaias angulatus* and *Discorbis rosea*. Living *A. angulatus* has only been found common on *Thalassia* leaves in the *Thalassia* and Sand Zone in the central lagoon. On the Bare Sand Zone, however, this species forms up to 67% of the fauna; the second highest concentration in the study area after beach samples. Taphonomic experiments have demonstrated that *A. angulatus* has one of the strongest tests of all reefal foraminifera in the Caribbean and Florida region (Peebles and Lewis, 1988, 1991; Martin and Liddell, 1991; Kotler *et al.*, 1992). Among the smaller reefal species, *D. rosea* has the most robust test (Wetmore, 1988). Time-averaging effect results in the strongest foraminiferal tests surviving longest in these taphonomic stressed conditions. Consequently, *A. angulatus* is prominent although the location is not the favorite habitat for the species to live. As a result, although located in the Bare Sand Zone, the sample was grouped with those from the *Thalassia* and Sand Zone of the inner lagoon (Figs. 6.5, 6.6A).

CONCLUSIONS

Studies on living and total foraminiferal assemblages from North Sound, South Sound and various ponds on Grand Cayman result in the following conclusions:

1. Eight distinctive foraminiferal assemblages were found and each is characterized by specific dominant species. The distributions of these assemblages are strongly related to the substrate and water conditions and taphonomic factors that are controlled by natural forces and/or human activities.
2. The dominance of fibrous-weed species such as *Triloculina rotunda* is an indicator of the environment that is characterized by brackish water and substrate lacking sand-

sized sediment. Fibrous green algae are common in this environment and they provide a special habitat for the indicator species.

3. In the ponds that are periodically desiccated during the dry season only *Ammonia tepida* and *Triloculina simplex* are found living and dominating the foraminiferal assemblages in the environment with extreme variable conditions in temperature and salinity.
4. During storms marine foraminifera tests can be imported with other shelf sediment onto the island. This is demonstrated by the observation that tests of open lagoonal species were found in the seaward side of the ponds.
5. Human activities have a strong impact on biota and environmental deterioration can be demonstrated by the distribution of foraminiferal assemblages. At the west side of North Sound, hydraulic dredging results in the suspension of mud and loss of sand-sized sediment. As a result, the foraminiferal assemblages found in these areas are dominated by fibrous-weed dwelling species and very few living specimens. On the Sand Bar where sediment abrasion is prevalent, the foraminiferal assemblage is dominated by tests of abrasion-resistant species.

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CHAPTER 7 DISCUSSION AND CONCLUSIONS

INTRODUCTION

Grand Cayman, an isolated oceanic island, encompasses a diverse array of physiographic units that ranges from various types of ponds, to shorelines, to lagoons, to shelves, and to well developed reef complexes that include unique habitats for various foraminifera. As sediment grains, foraminiferal tests are subjected to various taphonomical constraints after their death. Potentially, therefore the distribution patterns of individual foraminifera and foraminiferal assemblages provide valuable tools for paleoenvironment reconstruction and for the deciphering of various sedimentological processes. On a large scale, they can be used to detect different types of shelves (Li and Jones, in press) and the evolution of lagoonal sediment (chapter 5). This chapter i) summarizes the most important ecologic and taphonomical factors that control foraminifera distribution, and ii) presents an integrated foraminiferal distribution model that could be used in comparative studies of other similar islands in the Caribbean region as well as in paleoecological studies of ancient successions.

ECOLOGIC FACTORS CONTROLLING FORAMINIFERA DISTRIBUTION

Of 136 species identified from Grand Cayman, 55 are diagnostic of specific ecological domains (Fig. 7.1). These diagnostic species are the key to understanding paleoecologic conditions. Among ecologic factors that control the living foraminifera in the study area, substrate, salinity, turbidity, light quality and temperature are the most important.

Substrate

The textural, chemical, and biological nature of the substrates can influence the distribution and morphology of benthic foraminifera (Brasier, 1975; Boltovskoy and Wright, 1976; Langer, 1993). The most common types of substrate around Grand Cayman are: 1) fibrous alga surfaces; 2) flat grass surfaces; 3) sediment surfaces; and 4) hard surfaces (e.g., dead coral, molluscs, rock). Those foraminifera on fibrous algae and flat grass surfaces have little risk of detachment, whereas those on loose sediment surfaces are prone to detachment. Although hard rock substrates may include caverns and overhangs that could protect foraminifera from detachment, most hard surfaces are smooth and subjected to high agitation due to their locations. Consequently, only sessile forms (cemented attachment) such as *Homotrema rubrum* can survive. In the *Thalassia* and Sand

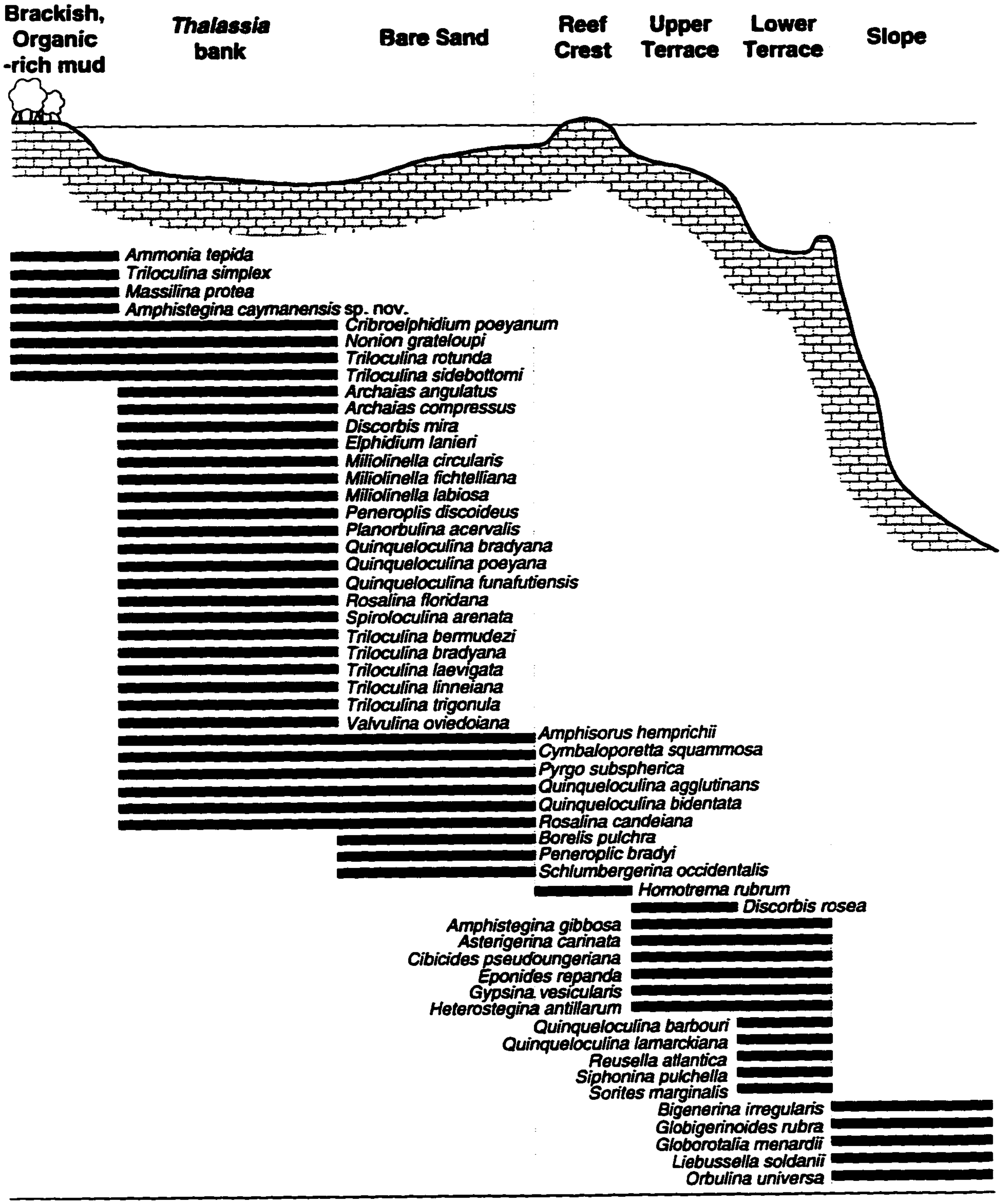


Figure 7.1—Ecological diagnostic species and their preferred habitats (based on studies of Grand Cayman and other areas of Caribbean-Florida region).

Zone, dense sea grass provides ideal habitats for epiphytic species and some species (*Planorbulina acervalis*) can survive on the grass leaves even after they are broken and transported. In the Organic-rich Zone and Bare Rock Zone, however, the fibrous green algae *Penicillus* flourish because the brackish water and the barren rocky substrate prevent the growth of sea grasses. As a result, *Triloculina rotunda* that prefer to living on fibrous alga dominates in this zone whereas other epiphytic species that are common on sea grasses are rare (chapter 6).

Salinity, temperature and turbidity

Salinity, turbidity, light quality, and temperature are other important water characters that control the foraminifera distribution around Grand Cayman. Most species found on Grand Cayman are stenohaline forms that prefer normal marine salinity. Some species such as *Ammonia tepida, Triloculina simplex* and *Massilina protea*, however, can tolerate extreme conditions of salinities and temperatures. Therefore, they can thrive in ponds that are flooded with brackish to fresh water, or even dried out during the dry season (chapter 6). Like corals, many foraminifera species host algae as symbionts. As a result, turbidity as well as intensity and quantity of light are crucial factors that control their distribution. *Amphistegina gibbosa*, for example, has been found "bleached" due to the death of its symbiont and has been used to indicate hazardous events (e.g., volcano eruption) that have affected local light quality (Hallock *et al.*, 1993).

TAPHONOMICAL FACTORS CONTROLLING FORAMINIFERAL DISTRIBUTION

Besides ecologic factors, taphonomical factors (physical, chemical, and biological) also strongly control the distribution of foraminiferal assemblages. Consequently, each foraminiferal assemblage is the product of ecologic and taphonomical forces. Due to different morphological, structural, behavioral, mechanical, and mineralogical characters, tests of different species respond uniquely to variable taphonomical constraints. Therefore, the condition of the tests, the species composition, and the size distribution of the total assemblage can provide valuable insights into paleoenvironmental conditions when living foraminiferal associations changed to fossil assemblages. Generally, in terms of space and time, two magnitudes of taphonomical pressures can be considered: 1) abrasion, bioerosion, and dissolution, which are locally operative on individual foraminiferal tests during fair-weather conditions, and 2) transportation, which controls foraminiferal assemblage distribution between different physiographic units during storm conditions.

Taphonomical constraints during fair-weather conditions

Abrasion is prevalent in surf zones where waves break near the shoreline and sand particles are lifted into suspension. On the protected beach, most foraminifera tests are derived from the lagoon or forereef areas, and only those with large or strong tests will survive and be recognizable. Due to the more severe breaking energy on the leeward coast, the foraminifera tests on the exposed beach have even less chance of being preserved and recognized (Li and Jones, in press). Abrasion under fair-weather conditions also takes place on the bare sand zone in the outer lagoons behind poorly developed reef crests or near channels. Foraminiferal assemblages found in those areas are dominated by abrasion-resistant species (Li *et al.*, in press; chapters 4, 6).

Dissolution is the main taphonomical force in mangrove rimmed brackish to fresh waters where variable salinity and pH are found. Stressful chemical conditions allow only a few species to survive and may dissolve other empty tests thereby masking true assemblage patterns. In these environments, euryhaline species such as *Ammonia tepida, Massilina protea*, and *Triloculina simplex* dominate because they can tolerate a wide range of salinity, pH, and temperatures and have the ability to recalcify their tests when damaged (chapter 6). Other species have less chance to survive or reproduce. Similarly, their calcareous tests, together with any other storm imported allochthonous tests, will not be preserved due to dissolution. Most lagoons on Grand Cayman contain normal marine water with low organic content because there is no river discharge nor terrigenous sediment. Therefore, unlike other areas such as Jamaica (Martin and Liddell, 1991), dissolution is minimal.

Bioerosion (boring, encrusting, and bioturbation) can affect the preservational potential of foraminifera tests and mask spatial distributional patterns. Boring and encrusting can reduce the chance of recognition of foraminifera species on the sediment surface. Vertical bioturbation is effective in mixing foraminifera tests between different layers and modifying sedimentary structures. In the *Thalassia* and Sand Zone, for example, vertical bioturbation results in surface foraminiferal assemblages similar to the subsurface assemblages. As a result, foraminiferal assemblages retained the same lagoonal character, although storms and hurricanes can temporarily modify the surface assemblages (chapter 5). Similar active bioturbation would also allow lower terrace assemblages to retain the original characters in spite of modifications by storms and hurricanes.

Taphonomical constraints during storm conditions

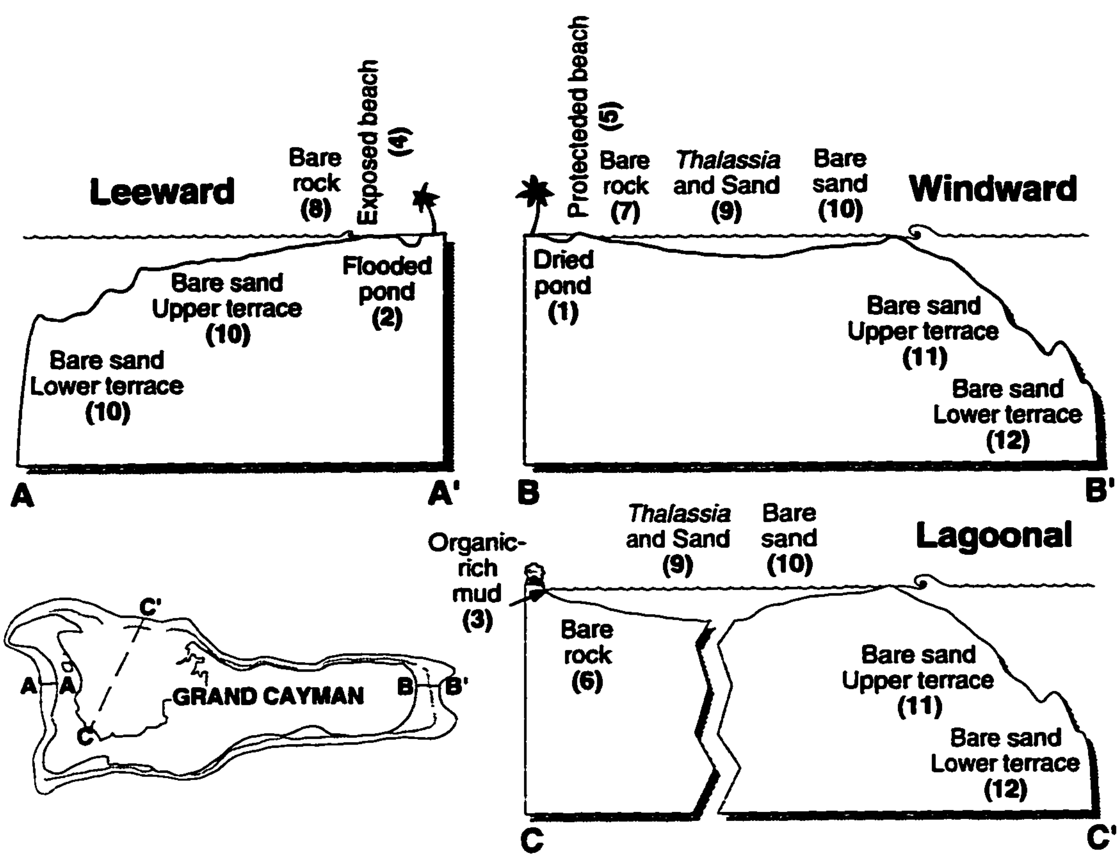
Due to their low density and small size, foraminiferal tests are more liable to be transported than other bioclasts under turbulent conditions in reefal environments. During fair-weather conditions, physical transportation of foraminifera tests only takes place above normal wave base — on surf zones and/or upper terrace on the leeward shelf. Those on the lower terraces and in the lagoons remained intact. During storms and hurricanes, however, all foraminifera tests on the shelves of Grand Cayman are subjected to transportation and mixing of foraminifera tests between different environments will take place (Li and Jones, in press; Li *et al.*, in press; chapters 3 to 5).

When a storm or hurricane arrives, foraminifera tests are placed into suspension by storm waves and then transported onshore by strong currents. Those species that grow on the lower terraces are moved landward and deposited on the upper terraces, in the lagoons, or carried onto the beaches or even into the ponds. Partial removal of the forereef foraminifera tests by onshore storm waves produces winnowed forereef assemblages that are dominated by larger tests (Li *et al.*, in press). During the waning stage of storms or hurricanes, the water that was piled onshore starts to drain out. The mega rip-up currents along the nearshore bare rock zones and channels strip foraminifera tests and deposit them on the lower terrace and down the shelf escarpment. In peripheral lagoons, this process produces winnowed lagoonal foraminifera assemblage because suspended small foraminifera tests will be preferentially transported seaward.

Onshore-offshore transportation during storms and hurricanes causes mixing of foraminifera tests from different habitats. On the bare rock zones in lagoons it also produces assemblages with disproportionately lower numbers of lagoonal species compared to those in the *Thalassia* and Sand Zone. On the leeward shelf, due to the annual winter storms, mixing of foraminifera tests is even more intense and frequent that foraminiferal assemblages are recognized by slight differences in abundance of the same species, and thus assemblages are less well defined (Li and Jones, in press).

FORAMINIFERAL DISTRIBUTIONAL MODEL

By considering the most dominant species and faunal diversity, 12 total foraminiferal assemblages can be delineated on Grand Cayman (Fig. 7.2; Table 7.1). The composition and spatial distribution of these assemblages are primarily determined by ecologic parameters (substrate, salinity, turbidity, light, temperature) and taphonomic pressures (abrasion, bioturbation, dissolution, transportation). Recognition of these total foraminiferal assemblages are even more useful than living assemblages because they are analogues to the fossil assemblages that may be found in ancient deposits. They have good potential for paleoecological interpretations and facies correlation because most of the common modern species can be traced back to as early as the Miocene.



Foraminiferal Assemblages

1. *Triloculina simplex-Ammonia tepida* Assemblage.
2. *Triloculina rotunda-Cribroelphidium poeyanum-Ammonia tepida-Triloculina simplex* Assemblage.
3. *Triloculina rotunda-Ammonia tepida-Cribroelphidium poeyanum-Amphistegina caymanensis* sp. nov. Assemblage.
4. *Archaias angulatus-Discorbis rosea* Assemblage.
5. *Archaias angulatus-Cymbaloporetta squammosa-Discorbis granulosa* Assemblage.
6. *Discorbis mira-Archaias angulatus-Triloculina rotunda* Assemblage.
7. *Archaias angulatus-Valvulina oviedoiana-Discorbis mira-Amphistegina gibbosa* Assemblage.
8. *Archaias angulatus-Discorbis rosea-Amphistegina gibbosa* Assemblage.
9. *Archaias angulatus-Archaias compressus-Quinqueloculina-Triloculina* Assemblage.
10. *Archaias angulatus-Amphistegina gibbosa-Discorbis rosea* Assemblage.
11. *Amphistegina gibbosa-Discorbis rosea-Asterigerina carinata* Assemblage.
12. *Amphistegina gibbosa-Asterigerina carinata-Archaias angulatus* Assemblage.

Figure 7.2—Distribution of foraminiferal assemblages (Arabic numbers) in different environments on Grand Cayman: a model for isolated oceanic islands in the Caribbean and Florida region.

Table 7.1 Foraminiferal assemblages and corresponding environments on Grand Cayman.

Assem -blage	Dominant species	Diver-sity	Other diagnostic components	Environment	Primary ecologic factor(s)	Primary taphonomic factor(s)
1	*Triloculina simplex*, *Ammonia tepida*	low	ostracods, gastropods, mangrove fragments	seasonally dried ponds	salinity, temperature	dissolution
2	*Triloculina rotunda*, *Cribroelphidium poeyanum*, *A. tepida*, *T. simplex*	low	rock fragments and mud, sessile pelecypods, algae	flooded ponds	salinity, substrate	dissolution
3	*T. rotunda*, *A. tepida*, *C. poeyanum*, *Amphistegina caymanensis* sp. nov.	moderate	organic-rich mud, mollusks, alga, mangrove fragments	mangrove-rimmed organic-rich mud zones	salinity, substrate	dissolution
4	*Archaias angulatus*, *Discorbis rosea*	low	well sorted sand	exposed beach	substrate	abrasion, transportation
5	*Archaias angulatus*, *Cymbaloporetta squammosa*, *Discorbis granulosa*	moderate	well sorted sand, fragments of alga and *Thalassia*	protected beach	substrate	abrasion, transportation
6	*Discorbis mira*, *A. angulatus*, *T. rotunda*	moderate	rock fragments and mud, algae	mangrove-rimmed bare rock zone	substrate, turbidity	dissolution, transportation
7	*A. angulatus*, *Valvulina oviedoiana*, *D. mira*, *Amphistegina gibbosa*	high	*Thalassia*, algae, mollusks, beach sand	nearshore lagoonal bare rock zone	substrate	transportation, abrasion
8	*A. angulatus*, *Discorbis rosea*, *A. gibbosa*	high	beach sand	nearshore bare rock zone on the leeward shelf	substrate	transportation, abrasion
9	*A. angulatus*, *Archaias compressus*, *Quinqueloculina*, *Triloculina*	high	*Thalassia*, mollusks and other epiphytic organisms	*Thalassia* and sand zone	substrate	bioerosion
10	*A. angulatus*, *Amphistegina gibbosa*, *Discorbis rosea*	high	rubble and knobs, coral fragments	bare sand zone in the outer lagoon and on the leeward shelf	substrate	transportation, abrasion, bioturbation
11	*A. gibbosa*, *D. rosea*, *Asterigerina carinata*	moderate	rubbles and sand in channels	bare rock zone on windward shelf	substrate	abrasion, transportation
12	*A. gibbosa*, *A. carinata*, *A. angulatus*	moderate	coral fragments, planktonic species	bare sand zone on lower terrace	substrate	bioturbation, transportation

***Triloculina simplex-Ammonia tepida* Assemblage.** A low-diversity assemblage, dominated (or only represented) by the euryhaline species *Triloculina simplex* and *Ammonia tepida*, indicates an environment with extremely variable temperature, salinity and pH such as seasonally dried ponds (chapter 6). It has the lowest diversity both as living assemblage or total assemblage because of the highly stressed ecological and taphonomical conditions.

***Triloculina rotunda-Cribroelphidium poeyanum-Ammonia tepida-Triloculina simplex* Assemblage.** A low-diversity assemblage, dominated by the euryhaline species *Triloculina rotunda, Cribroelphidium poeyanum, Ammonia tepida*, and *Triloculina simples*, indicates an environment with variable water characters but not as extreme as those for Assemblage 1. Examples of this environment are the permanently flooded ponds on the island, in which waters are connected to the sea as well as affected by fresh water influx during the rainy season (chapter 6). Various algae that survive in this environment provide substrates for fibrous-weed species to live.

***Triloculina rotunda-Ammonia tepida-Cribroelphidium poeyanum-Amphistegina caymanensis* sp. nov. Assemblage.** A moderate-diversity assemblage, dominated by the euryhaline species *Triloculina rotunda, Ammonia tepida, Cribroelphidium poeyanum*, and *Amphistegina caymanensis* sp. nov. indicates an organic-rich mud environment around the margins of the mangrove-rimmed lagoons (chapter 6). The environment is similar to that represented by Assemblage 2 but it is more open and transitional to the normal lagoonal environment. Thus, the assemblage has higher diversity and contains normal marine species.

***Archaias angulatus-Discorbis rosea* Assemblage.** A low-diversity assemblage, dominated by the abrasion-resistant species *Archaias angulatus* and *Discorbis rosea*, indicates an extremely high-energy environment such as exposed beach on the leeward side of Grand Cayman (Li and Jones, in press). Physical abrasion by broken waves on the open beach prevents foraminifera from living in that unstable environment. Also, the persistent daily abrasion demolishes any allochthonous species with weak or small tests, and leaves only those with the strongest shells. This is consistent with the results of taphonomical experiments that all the dominating species in the Assemblage 4 have the strongest shells of all common species in Caribbean reefs (Peebles and Lewis, 1988, 1991; Martin and Liddell, 1991; Kotler *et al.*, 1992).

***Archaias angulatus-Cymbaloporetta squammosa-Discorbis granulosa* Assemblage.** A moderate-diversity assemblage, dominated by the abrasion-resistant species *Archaias angulatus, Cymbaloporetta squammosa*, and *Discorbis granulosa*, indicates an environment with high energy conditions such as the protected beach behind the lagoon on the windward shelf of Grand Cayman, where the agitation is milder than on the exposed beach. Lagoonal species with large or strong tests are also present in this assemblage. As a result, the assemblage has much higher diversity than Assemblage 4 and contains typical lagoonal species (Li and Jones, in press).

***Discorbis mira-Archaias angulatus-Triloculina rotunda* Assemblage.** A moderate-diversity assemblage, dominated by the epiphytic species *Discorbis mira*, *Archaias angulatus*, and *Triloculina rotunda*, indicates an environment characterized by water with variable salinities and rocky substrate, such as on the west and south sides of North Sound. The assemblage is a mixture of *in situ* fibrous-weed species with species that are common on *Thalassia*.

***Archaias angulatus-Valvulina oviedoiana-Discorbis mira-Amphistegina gibbosa* Assemblage.** A high-diversity assemblage, dominated by *Archaias angulatus*, *Valvulina oviedoiana*, *Discorbis mira*, and *Amphistegina gibbosa*, indicates another bare rock environment commonly found in the nearshore part of peripheral lagoons, such as Frank Sound. The assemblage, formed of a mixture of numerous lagoonal species and a few forereef species, is formed during tropical storms and hurricanes. The presence of this assemblage may indicate the location of shore-parallel mega rip-up currents that operate in lagoons during storm and hurricanes (chapter 5).

***Archaias angulatus-Discorbis rosea-Amphistegina gibbosa* Assemblage.** A high-diversity assemblage, dominated by abrasion-resistant species *Archaias angulatus*, *Discorbis rosea*, and *Amphistegina gibbosa*, indicates an agitated environment such as nearshore bare rock zone on the leeward shelf of Grand Cayman (Li and Jones, in press). This assemblage, formed of a mixture of lower and upper terrace species, is formed by shoreward transportation by winter storms and there is no typical epiphytic lagoonal species.

***Archaias angulatus-Archaias compressus-Quinqueloculina-Triloculina* Assemblage.** A high-diversity assemblage, dominated by epiphytic species *Archaias angulatus*, *Triloculina*, and *Quinqueloculina*, indicates a lagoonal environment typically characterized by dense *Thalassia* banks (Li and Jones, in press; chapters 5 and 6). The assemblage normally has the highest diversity due to the ideal habitat for the living assemblage as well as a tranquil condition that allows good preservation of the fragile tests.

***Archaias angulatus-Amphistegina gibbosa-Discorbis rosea* Assemblage.** A moderate-diversity assemblage, dominated by *Archaias angulatus*, *Amphistegina gibbosa* and *Discorbis rosea*, indicates an outer lagoon (backreef) environment. This assemblage is characterized by a mixture of autochthonous lagoonal species (*Archaias angulatus*) and allochthonous forereef species (*Amphistegina gibbosa* and *Discorbis rosea*)(Li and Jones, in press; Li *et al.*, in press). Foraminiferal assemblages on the terraces of the leeward shelf of Grand Cayman also belong to this group.

***Amphistegina gibbosa-Discorbis rosea-Asterigerina carinata* Assemblage.** A moderate-diversity assemblage, dominated by *Amphistegina gibbosa, Discorbis rosea, Asterigerina carinata,* and *Archaias angulatus,* indicates a turbulent environment of upper terrace on the windward shelf. The assemblage, found only in sand pockets or channels, is characterized by the dominance of abrasion-resistant forereef species and *Archaias angulatus* (Li and Jones, in press).

***Amphistegina gibbosa-Asterigerina carinata-Archaias angulatus* Assemblage.** A moderate-diversity assemblage, dominated by *Amphistegina gibbosa, Asterigerina carinata,* and *Archaias angulatus,* indicates a forereef environment such as the Bare Sand Zone on lower terrace on windward shelves of Grand Cayman. The assemblage is characterized by the dominance of forereef species (Li and Jones, in press; Li *et al.*, in press).

Distributions of these assemblages are closely related to the physiographic features on Grand Cayman. Assemblage 4, for example, is distinguished from Assemblage 5 by its low diversity and high proportion of abrasion-resistant forereef species, because the former is on the leeward exposed beach whereas the latter is on the windward protected beach. Similarly, three different assemblages (6, 7 and 8) representing distinct bare rock substrates have been recognized due to the different physiographical features.

CONCLUSIONS

Studies of foraminifera on Grand Cayman demonstrate the following points:

1. There are 136 common foraminiferal species and varieties belonging to 58 genera in the sediments from Grand Cayman. A new species, *Amphistegina caymanensis* that lives in restricted lagoons under stressful ecological conditions, was established.
2. Four foraminiferal assemblages are found on the windward shelf and two assemblages on the leeward shelf. Assemblages on the windward shelf are well defined and can be divided into mappable groups. Conversely, foraminiferal assemblages on the leeward shelf are less well defined because they differ only by slight changes in abundance of the same species. The character of foraminiferal assemblages and their distributions are closely tied to the shelf topography and the operative taphonomical processes. Sediment transportation and mixing are prevalent on the leeward shelf of Grand Cayman because there is no fringing reef that can impede onshore waves and currents. Winter storms from the northwest move vast quantities of sediment across the shelf on an annual basis. Sediment on the exposed beach on the leeward shelf is also subjected

to more severe abrasion and sorting than that on the protected beaches on the windward shelf.

3. Sediment transportation during storms and hurricanes can be reconstructed based on the composition of total assemblages and size distribution of tracer species found on the windward shelf of Grand Cayman. At the height of a storm, suspended sediment on the forereef is carried onshore and deposited into the lagoon. When the storm wanes, back flow of piled-up water flushes suspended lagoonal and nearshore sediments out of the lagoon and deposits them onto the forereef or down the shelf slope via channels. This results in both winnowed lagoonal and forereef total foraminiferal assemblages after storms and hurricanes.
4. Studies on sediments of Frank Sound demonstrated that sediments are derived from the lagoon or forereef. During fair-weather conditions, biological activities are prevail in lagoons that include recolonization, expansion, and bioturbation by lagoonal organisms. Vertical bioturbation effectively masks any storm-induced sedimentary structure in the sediment. The characteristics of the surface sediment in these areas are strongly controlled by the characteristics of the old sediment below due to the vertical mixing by burrowers.
5. In the ponds and restricted lagoons that are under extreme ecological and taphonomical conditions, distinctive foraminiferal assemblages are found with very low diversity. On the seaward side of the same pond, however, assemblages with normal marine species and higher diversity indicate the landward transportation of normal marine sediments by storms or hurricanes.

   The distribution of the foraminiferal assemblages also reflects human activities that have severely modified natural environments. In the western part of North Sound, sediment dredging has produced a substrate that is characterized by pebbles and mud without sand-sized grains. As a result, fibrous-weed dwelling species dominate the foraminiferal assemblage because green algae have recolonized that area more successfully than sea grasses.
6. Fifty-six ecologically diagnostic species were found that can be used for habitat studies. Twelve distinctive total foraminiferal assemblages can be used to indicate unique environments on Grand Cayman. Distributions of the total foraminiferal assemblages are controlled by both ecological and taphonomical factors. Among ecological factors, substrate, salinity, temperature, turbidity, quality and intensity of light are the most important parts. Transportation is the dominant taphonomical factor during storm periods, whereas abrasion, dissolution, and bioturbation are prominent taphonomical factors during inter-storm periods.

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APPENDIX A SPECIES AND THEIR SYNONYMS

Family Saccammininae Brady, 1884

***Pelosina rotundata* Brady, 1884** *Pelosina rotundata* Brady, 1884, pl. 25, figs. 18, 20;—Cushman, 1918, pt. 1, p. 55, pl. 21, figs. 4–6.

Family Lituolidae de Blainville, 1825

***Ammobaculites exilis* Cushman and Bronnimann, 1948** *Ammobaculites exilis* Cushman and Bronnimann, 1948, p. 39, pl. 7, fig. 9.—Wantland, 1975, Fig. 4: e–g.

Family Textulariidae Ehrenberg, 1838

***Textularia agglutinans* d'Orbigny, 1839** *Textularia agglutinans* d'Orbigny, 1839, p. 144, pl. 1, figs. 17, 18, 32–34.—Brady, 1884, pl. 43, figs. 1–3.—Cushman, 1921, p. 49, pl. 11, figs. 1–3.—Cushman, 1922a, pt. 3, p. 7, pl. 1, figs. 4, 5.—Cushman, 1922b, p. 22, pl. 1, fig. 6.—Cebulski, 1961, pl. I, figs. B. C.—Cebulski, 1969, pl. II, fig. 3.—Bock, 1971, p. 8, pl. 2, fig. 1.—Sen Gupta and Schafer, 1973, pl. 1, fig. 1.—Wantland, 1975, Fig. 3: h.—Weis and Steinker, 1977, Fig. 3: e.—Triffleman *et al.*, 1991, pl. 1, fig. 1;*Valvotextularia agglutinans* Hofker, 1976, p. 69, Fig. 39.

***Textularia candeiana* d'Orbigny, 1839** *Textularia candeiana* d'Orbigny, 1839, p. 143, pl. 1, figs. 25–27.—Cushman, 1921, p. 50, pl. 11, figs. 7, 8.—Cushman, 1922a, pt. 3, p. 8, pl. 1, figs. 1–3.—Cushman, 1922b, p. 23, pl. 2, fig. 2.—Bandy, 1954, p. 139, pl. 29, fig. 2.—Cebulski, 1969, pl. III, fig. 4.—Bock, 1971, p. 8, pl. 2, fig. 2;*Valvotextularia candeiana* Hofker, 1964, p. 72, Figs. 193–196.

***Textularia conica* d'Orbigny, 1839** *Textularia conica* d'Orbigny, 1839, p. 143, pl. 1, figs. 19, 20.—Brady, 1884, pl. 43, figs. 13, 14.—Cushman, 1921, p. 50, pl. 11, figs. 4–6.—Cushman, 1922a, pt. 3, p. 22, pl. 5, figs. 5–7.—Cushman, 1922b, p. 24, pl. 2, fig. 4.—Phleger and Parker, 1951, p. 5, pl. 1, fig. 27.—Bock 1971, p. 8, pl. 2, fig. 3.—Sen Gupta and Schafer, 1973, pl. 1, fig. 2.

***Bigenerina irregularis* Phleger and Parker, 1951** *Bigenerina irregularis* Phleger and Parker, 1951, p. 4, pl. 1, figs. 16–21.—Bandy, 1954, p. 135, pl. 29, figs. 8, 9.—Cebulski, 1969, pl. III, fig. 1.—Bock, 1971, p. 9, pl. 2, fig. 5.—Brooks, 1973, pl. 9, fig. 3.—Poag, 1981, p. 43, pl. 33, fig. 3; pl. 34, fig. 3; *Bigenerina nodosaria* Cushman, 1922b, p. 25, pl. 2, figs. 5, 6.

Family Ataxophragmiidae Schwager, 1877

***Valvulina oviedoiana* d'Orbigny, 1839** *Valvulina oviedoiana* d'Orbigny, 1839, p. 103, pl. 2, figs. 21, 22.—Cushman, 1921, p. 51, pl. 11, figs. 11–14.—Cushman, 1922a, pt. 3, p. 64, pl. 11, figs. 2–5.—Cushman, 1922b, pl. 2, figs. 7, 8.—Bermudez, 1935, p. 154, pl. 11, figs. 1–3.—Cushman, 1941, p. 1, pl. 1, fig. 24.—Hofker, 1964, p. 65, Figs. 168–174.—Cebulski, 1969, pl. I, fig. 8.—Bock 1971, p. 10, pl. 2, fig. 11.—Todd and Low, 1971, p. C7, pl. 1, fig. 4.—Wantland, 1975, Fig. 16: l.—Weis and Steinker, 1977, Fig. 3: l; *Cribrobulimina polystoma* Todd and Low, 1971, p. C8, pl. 1, fig. 3.

***Clavulina nodosaria* d'Orbigny, 1839** *Clavulina nodosaria* d'Orbigny, 1839, p. 110, pl. 2, figs. 19, 20.—Cushman, 1921, p. 53, pl. 12, fig. 3; p. 54, fig. 1.—Cushman, 1941, p. 2, pl. 1, fig. 2.—Hofker, 1964, p. 72, Fig. 192.—Todd and Low, 1971, p. C7, pl. 2, fig. 1.—Wantland, 1975, Fig. 11: f; *Clavulina* sp.? Cushman, 1922b, pl. 3, fig. 4; *Clavulina tricarinata* Cushman, 1941, p. 2, pl. 1, fig. 1.

***Clavulina tricarinata* d'Orbigny, 1839** *Clavulina tricarinata* d'Orbigny, 1839, p. 111, pl. 2, figs. 16–18.—Cushman, 1921, p. 52, pl. 12, figs. 1, 2.—Cushman, 1922a, pt. 3, p. 89, pl. 17, figs. 3, 4.—Cushman, 1922b, p. 29, pl. 3, fig. 3.—Bermudez, 1935, p. 154, pl. 11, figs. 4–6.—Cebulski, 1961, pl. I, fig. D.—Hofker, 1964, p. 69, Figs. 179–185.—Bock 1971, p. 11, pl. 2, fig. 14.—Brooks, 1973, pl. 1, figs. 3, 4.—Wantland, 1975, Fig. 11: e.—Buzas *et al.*, 1977, p. 68, pl. 1, figs. 13, 14.—Weis and Steinker, 1977, Fig. 3: a.

***Liebusella soldanii* (Jones and Parker), 1860** *Lituola soldanii* Jones and Parker, 1860, p. 307; *Haplostiche soldanii* Brady, 1884, p. 318, pl. 32, figs. 14–18; *Liebusella soldanii* Bock 1971, p. 11, pl. 2, fig. 15.—Brooks, 1973, pl. 1, figs. 10, 11.—Wantland, 1975, Fig. 7: n.

Family Nubeculariidae Jones, 1875

***Spiroloculina antillarum* d'Orbigny, 1839** *Spiroloculina antillarum* d'Orbigny, 1839, p. 166, pl. 9, figs. 3, 4.—Cushman, 1921, p. 63, pl. 14, figs. 14, 15.—Cushman, 1929, pt. 6, p. 43, pl. 9, fig. 3.—Cushman, 1941, p. 4, pl. 1, figs. 12–15.—Cebulski, 1961, pl. I, fig H.—Hofker, 1964, p. 19, Figs. 5–7.—Bock, 1971, p. 13, pl. 3, fig. 7.—Brooks, 1973, pl. 6, fig. 7.—Weis and Steinker, 1977, Fig. 3: h; *Sigmoilina antillarum* Bandy, 1954, p. 138, pl. 29, fig. 1.

***Spiroloculina arenata* Cushman, 1921** *Spiroloculina arenata* Cushman, 1921, p. 63, pl. 14, fig. 17.—Cushman, 1922b, p. 62.—Cushman, 1929, pt. 6, p. 44, pl. 9, fig. 5.—Cushman, 1941, p. 63, pl. 14, fig. 7.—Cebulski, 1961, pl. I, fig. I.—Bock 1971, p. 13, pl. 3, fig. 8; *Sigmoilopsis arenata* Hofker, 1964, p. 29, Fig. 23.

***Spiroloculina caduca* Cushman, 1922** *Spiroloculina caduca* Cushman, 1922b, p. 61, pl. 11, figs. 3, 4.—Cushman, 1929, p. 42, pl. 9, figs. 1, 2; *Spiroloculina ornata* Bock 1971, p,. 14, pl. 3, fig. 9.

***Spiroloculina communis* Cushman and Todd, 1944** *Spiroloculina grateloupi* d'Orbigny, 1826, p. 298; *Spiroloculina excavata* Brady, 1884, pl. 9, figs. 5, 6; *Spiroloculina communis* Cushman and Todd, 1944, p. 63.—Bock, 1971, p. 14, pl. 3, fig. 10.

***Spiroloculina grateloupi* d'Orbigny, 1826** *Spiroloculina grateloupi* d'Orbigny, 1826, v.7, p. 298.—Cushman, 1922c, p. 101, pl. 25, fig. 2.

***Spiroloculina eximia* Cushman, 1922** *Spiroloculina eximia* Cushman, 1922b, p. 61, pl. 11, fig. 2.—Cushman, 1929, pt. 6, p. 42, pl. 8, fig. 7.—Brooks, 1973, pl. 6, fig. 8.

***Vertebralina cassis* d'Orbigny, 1839** *Vertebralina cassis* d'Orbigny. 1839, p. 51, pl. 7, figs. 14, 15.—Cushman, 1921, p. 64, pl. 15, fig. 1, 4.—Cushman, 1922b, p. 62.—Cushman, 1929, pt. 6, p. 96, pl. 22, fig. 4.—Brooks, 1973, pl. 7, figs. 5, 10.—Wantland, 1975, Fig. 9: i; *Articulina cassis* Cushman, 1941, p. 4, pl. 1, figs. 17–19; *Nodobaculariella cassis* Phleger and Parker, 1951, p. 8, pl. 4, figs. 12–14.—Bock 1971, p. 15, pl. 4, fig. 2.—Poag, 1981, p. 73, pl. 61, fig. 4; pl. 62, fig. 4.—Triffleman *et al.*, 1991, pl. 1, fig. 2; *Vertebralina mucronata* Todd and Low, 1971, p. C10, pl. 1, fig. 1.

***Vertebralina mucronata* d'Orbigny, 1839** *Vertebralina mucronata* d'Orbigny, 1839, p. 72, pl. 7, figs. 16–19; *Vertebralina cassis* Cushman, 1921, pl. 15, figs. 2, 3, 5–8; *Vertebralina cassis* var. *mucronata* Cushman, 1922b, p. 63.—Cushman, 1929, pt. 6, p. 96, pl. 22, fig. 5.—Cebulski, 1961, pl. II, fig. E; *Articulina cassis* Cushman, 1941, pl. 1, figs. 20–23; *Articulina mucronata* Cushman, 1944, p. 12, pl. 10, figs. 11–18.—Hofker, 1964, p. 33, Figs. 49–57.—Cebulski, 1969, pl. I, fig. 1.—Bock, 1971, pl. 13, fig. 4.—Weis and Steinker, 1977, Fig. 4: 1.

Family Miliolidae Ehrenberg, 1839

***Quinqueloculina agglutinans* d'Orbigny, 1839** *Quinqueloculina agglutinans* d'Orbigny, 1839, p. 195, pl. 12, figs. 11–13.—Cushman, 1921, p. 65, pl. 15, figs. 3, 9, 10.—Cushman, 1922b, p. 63.—Cushman, 1929, pt. 6, p. 22, pl. 1, fig. 1.—Cushman, 1941, pl. 1, fig. 3.—Cebulski, 1961, pl. I, fig. E.—Hofker, 1964, p. 24, Figs. 27–30.—Bock 1971, pl. 4, figs. 3–5—Weis and Steinker, 1977, Fig. 3: m.—Poag, 1981, pl. 59, fig. 1; pl. 60, fig. 1a; *Quinqueloculina (Dentostomina) agglutinans* Todd and Low, 1971, p. C9, pl. 1, fig. 7; *Quinqueloculina bradyana* Brooks, 1973, pl. 1, figs. 17–19.

***Quinqueloculina barbouri* Bermudez, 1935** *Quinqueloculina barbouri*, Bermudez, 1935, p. 156, pl. 13, figs. 4–6.

***Quinqueloculina bicostata* d'Orbigny, 1839** *Quinqueloculina bicostata* d'Orbigny, 1839, p. 195, pl. 12, figs. 8–10.—Bock 1971, p. 17, pl. 4, figs. 9–11.—Wantland, 1975, Fig. 3: a, b; Fig. 13: n; *Quinqueloculina bidentata* Cushman, 1929, pt. 6, pl. 1, fig. 2; *Quinqueloculina bicostata* forma *garretti* Poag, 1981, p. 77, pl. 63, fig. 1; pl. 64, fig. 1; *Quinqueloculina bicostata* forma *typica* Poag, 1981, p. 77, pl. 63, fig. 2; pl. 64, fig. 2.

***Quinqueloculina bidentata* d'Orbigny, 1839** *Quinqueloculina bidentata* d'Orbigny, 1839, p. 197, pl. 12, figs. 18–20.—Cushman, 1921, p. 65, pl. 15, figs. 11, 12.—Cushman, 1922b, p. 64.—Bermudez, 1935, p. 155, pl. 12, figs. 4, 5.—Hofker, 1964, p. 23, Figs. 14–17.—Bock 1971, p. 17, pl. 4, fig. 12; pl. 5, figs. 1–2.—Sen Gupta and Schafer, 1973, pl. 1, fig. 3.—Wantland, 1975, Fig. 3: e.—Poag, 1981, pl. 60, fig. 1b; ?*Quinqueloculina* sp.B, Brooks, 1973, pl. 7, figs. 8, 9.

***Quinqueloculina bosciana* d'Orbigny, 1839** *Quinqueloculina bosciana* d'Orbigny, 1839, p. 191, pl. 11, figs. 22–24.—Bock 1971, p. 17, pl. 5, figs. 3–5.—Weis and Steinker, 1977, Fig. 3: k.—Poag and Tresslar, 1981, p.54, pl. 9, figs. 3–5; *Quinqueloculina* cf. *seminulum* Sen Gupta and Schafer, 1973, pl. 1, fig. 5.

***Quinqueloculina bradyana* Cushman, 1924** *Miliolina undosa* (Not *M. u.* Karrer) Brady, 1884, pl. 6, fig. 8; *Quinqueloculina bradyana* Cushman 1922b, p. 67.—Cushman, 1924, pl. 21, figs. 4–7.—Cushman, 1929, pt. 6, p. 23, pl. 1, fig. 3.—Wantland, 1975, Fig. 8: g.—Weis and Steinker, 1977, Fig. 3: g; *Q.* cf. *bradyana* Bock 1971, p. 17, pl. 5, figs. 6–8.

***Quinqueloculina candeiana* d'Orbigny, 1839** *Quinqueloculina candeiana* d'Orbigny, 1839, p. 170, pl. 12, figs. 24–26.—Cushman, 1922b, p. 65, pl. 13, fig. 1.—Cushman, 1929, pt. 6, p. 27, pl. 3, fig. 1.—Brooks, 1973, pl. 6, figs. 14, 15.—Wantland, 1975, Fig. 8: c; Fig. 13: 1.—Hofker, 1976, p. 121, Fig. 115.—Poag, 1981, p. 77, pl. 55, fig. 4; pl. 56, fig. 4; *Miliolina venusta* Brady, 1884, pl. 5, fig. 7.

Quinqueloculina collumnosa **Cushman, 1922** *Quinqueloculina collumnosa* Cushman, 1922b, p. 65, pl. 10, fig. 10.—Cushman, 1929, pt. 6, pl. 3, fig. 2.—Bock 1971, p. 18, pl. 5, figs. 9–11.

Quinqueloculina collumnosa **forma *excavata* Poag, 1981** *Quinqueloculina collumnosa* forma *excavata* Poag, 1981, p. 78, pl. 63, fig. 3; pl. 64, fig. 3.

Quinqueloculina funafutiensis **(Chapman), 1901** *Miliolina funafutiensis* Chapman, 1901, p. 178, pl. 9, fig. 6; *Quinqueloculina funafutiensis* Cushman, 1922b, p. 67, pl. 13, fig. 3.—Cushman, 1929, pt. 6, p. 30, pl. 4, fig. 4.—Wantland, 1975, Fig. 3: d; *Q. lamarckiana* Bock, 1971, pl. 6, figs. 7–9;*Quinqueloculina poeyana* Sen Gupta and Schafer, 1973, pl. 1, fig. 7.

Quinqueloculina fusca **Brady, 1865** *Quinqueloculina fusca* Cushman, 1929, pt. 6, p. 23, pl. 1, fig. 4.

Quinqueloculina laevigata **d'Orbigny, 1826** *Quinqueloculina laevigata* d'Orbigny, 1826, p. 301.—d'Orbigny, 1839, p. 143, pl. 3, figs. 31–33.—Cushman, 1922b, p. 65, pl. 13, fig. 2.—Cushman, 1929, pt. 6, p. 30, pl. 4, fig. 3.—Wantland, 1975, Fig. 8: b; Fig. 13: m; *Quinqueloculina compta* Bandy, 1954, pl. 28, fig. 2.

Quinqueloculina lamarckiana **d'Orbigny, 1839** *Quinqueloculina lamarckiana* d'Orbigny, 1839, p. 189, pl. 11, figs. 14, 15.—Cushman, 1921, p. 65, pl. 15, figs. 13, 14; p. 66, Fig. 5.—Cushman, 1922b, p. 64.—Cushman, 1929, pt. 6, p. 26, pl. 2, fig. 6.—Phleger and Parker, 1951, p. 17, pl. 4, fig. 1.—Bandy, 1954, p. 138, pl. 28, fig. 3.—Hofker, 1964, p. 22, Figs. 10–12.—Todd and Low, 1971, p. C8, pl. 2, fig. 10.—Sen Gupta and Schafer, 1973, pl. 1, fig. 6.—Wantland, 1975, Fig. 8: f.—Hofker, 1976, p. 122, Fig. 116.—Weis and Steinker, 1977, Fig. 3: i.—Boltovskoy, *et al.*, 1980, p. 46, pl. 28, figs. 9–12; *Miliolina cuvieriana* Brady, 1884, pl. 5, fig. 12.

Quinqueloculina **cf. *parkeri* (Brady), 1884** *Quinqueloculina parkeri* var. *occidentalis* Bock 1971, p. 19, pl. 6, figs. 10–12.—Poag, 1981, p. 79, pl. 55, fig. 2; pl. 56, fig. 2.

Quinqueloculina parkeri **var. *occidentalis* Cushman, 1922** *Quinqueloculina parkeri* var. *occidentalis* Cushman, 1922b, p. 68, pl. 12, fig. 3.—Cushman, 1929, pt. 6, p. 35, pl. 6, fig. 9.

Quinqueloculina poeyana **d'Orbigny, 1839** *Quinqueloculina poeyana* d'Orbigny, 1839, p. 191, pl. 11, figs. 25–27.—Cushman, 1921, p. 67, pl. 16, figs. 7, 8.—Cushman, 1922b, p. 66.—Cushman, 1929, pt. 6, p. 31, pl. 5, fig. 2.—Cebulski, 1961, pl. I, figs. F, G.— ? Bock 1971, p. 20, pl. 6, fig. 13–15.—Todd and Low, 1971, p. C8, pl. 2, fig. 4.—Wantland, 1975, Fig. 8: a; Fig. 15: q, r.—Hofker, 1976, p. 124, Fig. 119—Weis and Steinker, 1977, Fig. 3: b; *Quinqueloculina laevigata* Bock 1971, pl. 6, figs. 4–6.

Quinqueloculina polygona **d'Orbigny, 1839** *Quinqueloculina polygona* d'Orbigny, 1839, p. 198, pl. 12, figs. 21–23.—Cushman, 1921, p. 66, pl. 16, figs. 3, 4.—Cushman, 1922b, p. 68.—Cushman, 1929, pt. 6, p. 28, pl. 3, fig. 5.—Hofker, 1964, p. 22, Fig. 13.—Bock 1971, p. 20, pl. 7, figs. 1–3.—Todd and Low, 1971, p. C8, pl. 2, fig. 5.—Brooks, 1973, pl. 6, figs. 19, 20.—Wantland, 1975, Fig. 8: h.—Weis and Steinker, 1977, Fig. 3: f.

Quinqueloculina seminulum **(Linnaeus), 1767** *Serpula seminulum* Linné, 1767, p. 1264, no. 791; *Quinqueloculina seminulum* Brady, 1884, pl. 5, fig. 6.—Cushman, 1929, pt. 6, p. 24, pl. 2, figs. 1, 2.—Bock 1971, p. 21, pl. 7, figs. 7–9.—Murray, 1971, p. 65, pl. 24, figs. 1–6.—Wantland, 1975, Fig. 3: g.—Boltovskoy *et al.*, 1980, p. 47, pl. 29, figs. 7–13;*Quinqueloculina seminula* Hofker, 1976, p. 120, Fig. 114.

Quinqueloculina tenagos **Parker, 1954** *Quinqueloculina tenagos* Rose and Lidz, 1977, pl. 5, figs. 1, 2.

Quinqueloculina tipswordi **Anderson, 1961** *Quinqueloculina tipswordi* Anderson, 1961, p. 31, pl. 5, fig. 2.—Poag, 1981, p. 79, pl. 63, fig. 4; pl. 64, fig. 4;*Quinqueloculina candeiana* Sen Gupta and Schafer, 1973, pl. 1, fig. 4.

Quinqueloculina vulgaris **d'Orbigny, 1826** *Quinqueloculina vulgaris* d'Orbigny, 1826, p. 302.—d'Orbigny, 1839, p. 207, pl. 2, figs. 65, 66, text figs. 13, 14.—Cushman, 1929, pt. 6, p. 25, pl. 2, fig. 3.—Sen Gupta and Schafer, 1973, pl. 1, fig. 8; *Quinqueloculina* cf. *vulgaris* Phleger and Parker, 1951, p. 8, pl. 4, fig. 2.

Massilina crenata **(Karrer), 1868** *Spiroloculina crenata* Karrer, 1868, p. 135, pl. 1, fig. 9.—Brady, 1884, pl. 10, figs. 24–26; *Massilina crenata* Cushman, 1922b, p. 69, pl. 11, fig. 6.—Cushman, 1929, p. 38, pl. 7, fig. 5.

Massilina protea **Parker, 1953** *Massilina protea* Wantland, 1975, Fig. 15: a–e.

Pyrgo denticulata **(Brady), 1884** *Biloculina ringens* (Lamarck) var. *denticulata* Brady, 1884, p. 143, pl. 3, figs. 4, 5; *Biloculina denticulata* Cushman, 1921, p. 74, Fig. 12; *Pyrgo denticulata* Cushman, 1922b, p. 78.—Cushman, 1929, pt. 6, p. 69, pl. 18, figs. 3, 4.—Bock 1971, p. 23, pl. 8, fig. 11.—Todd and Low, 1971, p. C11.—Brooks, 1973, pl. 3, figs. 16, 17.—Weis and Steinker, 1977, figs. 3: d.—Poag and Tresslar, 1981, p. 52, pl. 9, figs. 1, 2; *Pyrgo denticulatus* Hofker, 1976, p. 116, Fig. 111.

Pyrgo denticulata striolata **(Brady), 1884** *Biloculina ringens* (Lamarck) var. *striolata* Brady, 1884, pl. 3, figs. 7, 8; *Pyrgo denticulata striolata* Cushman, 1922b, p. 78.—Cushman, 1929, pt. 6, p. 69, pl. 18, fig. 5; *Pyrgo comata* Bock 1971, p. 23, pl. 8, fig. 10.

Pyrgo johnsoni **Cushman, 1935** *Pyrgo johnsoni* Cushman, 1935, p. 6, pl. 2, figs. 6–8.—Bermudez, 1935, p. 173; pl. 13, figs. 1–3.

Pyrgo oeensis **(Martinotti), 1920** *Biloculina oeensis* Martinotti, 1920, p. 253, pl. 1, figs. 1–3.—*Pyrgo oeensis* Seiglie, 1965, p. 72, pl. 8, figs. 5, 6.

Pyrgo subsphaerica **(d'Orbigny), 1839** *Biloculina subsphaerica* d'Orbigny, 1839, p. 162, pl. 8, figs. 25–27.—*Biloculina subsphaerica* Cushman, 1922b, p. 77; *Biloculina* sp.? Cushman, 1922c, p. 105, pl. 28, figs. 5, 6.—*Pyrgo subsphaerica* Cushman, 1929, pt. 6, p. 68, pl. 18, figs. 1, 2.—Hofker, 1964, p. 31, Figs. 34, 35.—Bock 1971, p. 24, pl. 8, fig. 15—Todd and Low, 1971, p. C11.—Brooks, 1973, pl. 3, figs. 18–20.—Boltovskoy, *et al.*, 80, p. 45, pl. 26, figs. 10–13; *Pseudopyrgo subsphaerica* Hofker, 1976, p. 112, Fig. 107.

Sigmoilina schlumbergeri **Silvestri, 1904** *Sigmoilina schlumbergeri* Silvestri, 1904, p. 267.—Brady, 1884, pl. 8, figs. 1–4.—Cushman, 1929, pt. 6, p. 49, pl. 11, figs. 1–3.—Phleger and Parker, 1951, p. 8, pl. 4, fig. 6.—Bock 1971, p. 25, pl. 9, figs. 1, 2.—Brooks, 1973, pl. 2, figs. 20–22.—Hofker, 1976, Fig. 128.

Triloculina bermudezi **Acosta, 1940** *Triloculina bermudezi* Acosta, 1940a, p. 37, pl. 4, figs. 1–5.—Bock, 1971, p. 25, pl. 9, figs. 9–11.—Wantland, 1975, Fig. 14: n–s; *Triloculina oblonga* Bock, 1971, p. 27, pl. 11, figs. 2–4.

Triloculina bradyana **(Cushman), 1917** *Quinqueloculina tricarinata* d'Orbigny, 1839, p. 187, pl. 11, figs. 7–9, 11.—Cushman, 1921, p. 68, pl. 16, figs. 11, 12.—Cushman, 1929, pt. 6, p. 29, pl. 14, fig. 1.—Bock 1971, p. 22, pl. 8, figs. 1, 2.—Brooks, 1973, pl. 6, figs. 1, 2.—Wantland, 1975, Fig. 8: i.—Weis and Steinker, 1977, Fig. 3: c; *Quinqueloculina bradyana* Cushman, 1917, p. 52, pl. 18, fig. 2.—Cushman, 1922b, p. 67.—Cushman, 1941, p. 3, pl. 1, figs. 5, 6; *Quinqueloculina* cf. *kerimbatica* var. *philippinensis* Cushman, 1941, pl. 2, figs. 2, 3; *Miliola tricarinata* Hofker, 1964, p. 17, Figs. 2–4; *Triloculina bradyana* Hofker, 1976, p. 128, Fig. 124.

Triloculina bicarinata **d'Orbigny, 1839** *Triloculina bicarinata* d'Orbigny, 1839, p. 158, pl. 10, figs. 18–20.—Cushman, 1922b, p. 76, pl. 12, fig. 7.—Cushman, 1929, pt. 6, p. 66, pl. 17, fig. 5.—Bock 1971, p. 25, pl. 9, figs. 12–13; pl. 10, fig. 1.—Brooks, 1973, pl. 6, figs. 11, 12.—Wantland, 1975, Fig. 8: l; *Quinqueloculina antillarum* Cushman, 1921, p. 67, pl. 16, figs. 9, 10; *Quinqueloculina carinata* Hofker, 1976, p. 124, Fig. 120b; *Triloculina variolata* Poag, 1981, p. 84, pl. 57, fig. 1; pl. 58, fig. 1.

Triloculina carinata **d'Orbigny, 1839** *Triloculina carinata* d'Orbigny, 1839, p. 179, pl. 10, figs. 15–17.—Cushman, 1921, p. 71, pl. 17, figs. 9, 10.—Cushman, 1922b, p. 75, pl. 12, fig. 6.—Cushman, 1929, pt. 6, p. 65, pl. 17, fig. 4.—Bermudez, 1935, p. 69, pl. 12, figs. 1–3.—Cushman, 1941, p. 6, pl. 1, figs. 10, 11.—Cebulski, 1961, pl. I, fig. N.—Hofker, 1964, p. 25, Fig. 20.—Cebulski, 1969, pl. I, fig. 6.—Bock 1971, p. 26, pl. 10, figs. 2–4.—Todd and Low, 1971, p. C10, pl. 2, fig. 2; *Quinqueloculina carinata* Hofker, 1976, p. 124, Fig. 120a.

Triloculina fitteri **Acosta, 1940** *Triloculina fitteri* Acosta, 1940b, p. 25, pl. 4, figs. 6–8.—Wantland, 1975, Fig. 15: h–k; *Triloculina fitteri* var. *menigoi* Bock, 1971, p. 26, pl. 10, figs. 5–7.—Todd and Low, 1971, p. C9, pl. 2, fig. 6.

Triloculina gracilis **d'Orbigny, 1839** *Triloculina gracilis* d'Orbigny, 1839, p. 181, pl. 11, figs. 10–12.—Cushman, 1922b, p. 74.—Cushman, 1929, pt. 6, p. 59, pl. 14, fig. 4.

Triloculina laevigata **(d'Orbigny), 1839** *Quinqueloculina laevigata* d'Orbigny, 1839, p. 143, pl. 3, figs. 31–33; *Triloculina laevigata* Boltovskoy, *et al.*. 1980, p. 52, pl. 33, figs. 8–10. *Triloculina* sp., Poag and Tresslar, 1981, p. 62, pl. 15, figs. 10–12.

Triloculina linneiana **d'Orbigny, 1839** *Triloculina linneiana* d'Orbigny, 1839, p. 172, pl. 9, figs. 11–13.—Cushman, 1921, p. 70, pl. 17, figs. 3, 4.—Cushman, 1922b, p. 75.—Cushman, 1929, pt. 6, p. 61, pl. 16, figs. 1, 2.—Cebulski, 1961, pl. II, fig. A.—Hofker, 1964, p. 28, Figs. 21, 22.—Cebulski, 1969, Pl. I, fig. 7.—Schnitker, 1967, pl. 1.—Bock 1971, p. 26, pl. 10, figs. 8–10.—Todd and Low, 1971, p. C9, pl. 1, fig. 15.—Brooks, 1973, pl. 7, figs. 3, 4.—Wantland, 1975, Fig. 12: m.—Weis and Steinker, 1977, Fig. 4: k.

Triloculina linneiana **var. *comis* Bandy, 1956** *Triloculina linneiana* var. *comis* Bandy, 1956, p. 198, pl. 29, fig. 12.—Bock, 1971, p. 27, pl. 10, figs. 11–12; pl. 11, fig. 1.

Triloculina oblonga **(Montagu), 1803** *Vermiculum oblongum* Montagu, 1803, p. 522, pl. 14, fig. 9; *Miliolina oblonga* Brady, 1884, pl. 5, fig. 4; *Triloculina laevigata* Fornasini, 1905, pl. 1, fig. 10; *Triloculina oblonga* Cushman, 1922b, p. 73.—Cushman, 1929, pt. 6, p. 57, pl. 13, figs. 4, 5.

***Triloculina planciana* d'Orbigny, 1839** *Triloculina planciana* d'Orbigny, 1839, p. 173, pl. 9, figs. 17–19.—Cushman, 1921, p. 70, pl. 17, figs. 7, 8.—Cushman, 1922b, p. 74.—Cushman, 1929, pt. 6, p. 62, pl. 15, figs. 5, 6.—Bock 1971, p. 27, pl. 11, figs. 5–7.—Brooks, 1973, pl. 2, figs. 4–6.—Poag and Tresslar, 1981, p. 60, pl. 15, figs. 4–6.

***Triloculina quadrilateralis* d'Orbigny, 1839** *Triloculina quadrilateralis* d'Orbigny, 1839, p. 173, pl. 9, figs. 14–16.—Cushman, 1921, p. 71, fig. 11.—Cushman, 1922b, p. 76.—Cushman, 1929, pt. 6, p. 64.—Bock 1971, p. 25, pl. 9, figs. 3–8.—Brooks, 1973, pl. 2, figs. 10–12.—Wantland, 1975, Fig. 8: m; *Quinqueloculina quadrilateralis* Hofker, 1964, p. 24, Fig. 18; *Triloculina bassensis* Poag and Tresslar, 1981, p. 60, pl. 14, figs. 7–9.—Todd and Low, 1971, p. C9, pl. 2, fig. 8.—Weis and Steinker, 1977, Fig. 3: j.

***Triloculina rotunda* d'Orbigny, 1826** *Triloculina rotunda* d'Orbigny, 1826, p. 299.—Cushman, 1922b, p. 73.—Cushman, 1929, pt. 6, p. 59, pl. 14, fig. 3.—Cebulski, 1961, pl. II, figs. B, C.—Hofker, 1964, p. 27, Fig. 19.—Bock 1971, p. 27, pl. 11, figs. 8–10.—Brooks, 1973, pl. 3, fig. 1–3.—Weis and Steinker, 1977, Fig. 4: m.—Poag and Tresslar, 1981, p. 62, pl. 15, figs. 7–9.

***Triloculina sidebottomi* (Martinotti), 1920** *Sigmoilina sidebottomi* Martinotti, 1920, p. 59, pl. 2, fig. 29; *Miliolina subrotunda* Sidebottom, 1904, pl. 3, figs. 1–7; *Triloculina sidebottomi* Bock 1971, p. 28, pl. 11, figs. 11–13.—Todd and Low, 1971, p. C10, pl. 2, fig. 14.

Triloculina simplex* (Terquem), *1882 *Quinqueloculina simplex* Terquem, 1882, pl. 18, figs. 5–13 (part); *Triloculina* sp., Wantland, 1975, Fig. 15: l–p.

***Triloculina transverstriata* (Brady), 1881** *Miliolina transverstriata* Brady, 1881, p. 45; *Triloculina transverstriata* Cushman, 1929, pt. 6, p. 62, pl. 16, fig. 3.

***Triloculina tricarinata* d'Orbigny, 1826** *Triloculina tricarinata* d'Orbigny, 1826, p. 299, pl. 1, fig. 8.—Cushman, 1922b, p. 72.—Cushman, 1929, pt. 6, pl. 13, fig. 3.—Bock 1971, p. 28, pl. 12, figs. 1, 2.—Hofker, 1976, p. 129, Fig. 126.—Poag, 1981, p. 84, pl. 57, fig. 3; pl. 58, fig. 3; *Miliolina tricarinata* Brady, 1884, pl. 3, fig. 17.

***Triloculina trigonula* (Lamarck), 1804** *Miliola trigonula* Lamarck, 1804, p. 351; *Triloculina trigonula* Brady, 1884, pl. 3, figs. 15, 16.—Cushman, 1922b, p. 72.—Cushman, 1929, pt. 6, p. 56, pl. 12, fig. 11; pl. 13, figs. 1, 2.—Bandy, 1954, pl. 28, fig. 5.—Cebulski, 1961, pl. II, fig. D.—Bock 1971, p. 28, pl. 12, fig. 34.—Todd and Low, 1971, p. C10.—Brooks, 1973, pl. 2, figs. 13–16.—Poag, 1981, p. 84, pl. 57, fig. 2; pl. 58, fig. 2.

***Miliolinella circularis* (Brönnimann), 1855** *Triloculina circularis* Brönnimann, 1855, p. 349.—Cushman, 1922b, p. 73.—Cushman, 1929, pt. 6, p. 58, pl. 13, figs. 6, 7; pl. 14, figs. 1, 2.—Cebulski, 1961, pl. I, figs. O, P; *Miliolina circularis* Brady, 1884, pl. 4, fig. 3: pl. 5, figs. 13, 14; *Miliolinella circularis* Hofker, 1976, p. 105, Fig. 103.—Bock 1971, p. 29, pl. 12, fig. 5.—Sen Gupta and Schafer, 1973, pl. 1, fig. 9.—Wantland, 1975, Fig. 15: f, g.—Weis and Steinker, 1977, Fig. 4: b.—Poag, 1981, p. 72, pl. 59, fig. 3; pl. 60, fig. 3;

***Miliolinella fichtelliana* d'Orbigny, 1839** *Triloculina fichtelliana* d'Orbigny, 1839, p. 171, pl. 9, figs. 8–10.—Cushman, 1921, p. 70, pl. 17, figs. 1, 2.—Cushman, 1922b, p. 75.—Cushman, 1929, pt. 6, p. 63, pl. 17, fig. 1.—Cushman, 1941, p. 6, pl. 1, figs. 7–9; *Miliolinella fichtelliana* Bock 1971, p. 29, pl. 12, fig. 6.—Todd and Low, 1971, p. C11.—Brooks, 1973, pl. 8, figs. 17, 18.—Weis and Steinker, 1977, Fig. 4: a.—Poag, 1981, p. 72, pl. 59, fig. 4; pl. 60, fig. 4.

***Miliolinella labiosa* (d'Orbigny), 1839** *Triloculina labiosa* d'Orbigny, 1839, p. 178, pl. 10, figs. 12–14.—Cushman, 1921, p. 70, pl. 16, figs. 13, 14.—Cushman, 1922b, p. 77, pl. 12, fig. 1.—Cushman, 1929, pt. 6, p. 60, pl. 15, figs. 2, 3; *Miliolina labiosa* Brady, 1884, pl. 6, figs. 3–5; *Miliolinella labiosa* Bock, 1971, p. 29, pl. 12, fig. 7.—Hofker, 1964, p. 29, Figs. 24–26.—Todd and Low, 1971, p. C11.—Wantland, 1975, Fig. 9: a–g.—Hofker, 1976, p. 107, Fig. 105; *Miliolinella dilatata* Brooks, 1973, pl. 3, figs. 21–23.

***Miliolinella subrotunda* (Montagu), 1803** *Miliolinella subrotunda* Brook, 1973, pl. 8, figs. 6, 9.

***Ammomassilina alveoliniformis* (Millett), 1898** *Ammomassilina alveoliniformis* Wantland, 1975, Fig. 8p.

***Hauerina bradyi* Cushman, 1917** *Hauerina compressa* Brady, 1884, pl. 11, figs. 12, 13; *Hauerina bradyi* Cushman, 1917, p. 62, pl. 23, fig. 2.—Cushman, 1921, p. 72.—Cushman, 1922b, p. 71.—Cushman, 1929, pt. 6, p. 47, pl. 10, figs. 4–9.—Cushman, 1941, p. 5, pl. 1, figs. 25–27.—Hofker, 1964, p. 61, Figs. 166, 167.

***Hauerina occidentalis* Cushman, 1946** *Hauerina ornatissima* Cushman, 1929, pt. 6, p. 47, pl. 10, figs. 10–12; *Hauerina occidentalis* Cushman, 1946, p. 9, pl. 1, figs. 23, 24.—Brooks, 1973, pl. 8, figs. 4, 5.—Wantland, 1975, Fig. 8: q; *H(?) ornatissima* Hofker, 1964, p. 60, Figs. 162–165.

Schlumbergerina occidentalis **Cushman, 1929** *Schlumbergerina alveoliniformis* var. *occidentalis* Cushman, 1929, pt. 6, p. 36, pl. 7, fig. 2; *Schlumbergerina occidentalis* Hofker, 1976, p. 133, Fig. 129.—Bock 1971, p. 30, pl. 12, fig. 12.—Todd and Low, 1971, p. C11.

Articulina pacifica **Cushman, 1944** *Articulina sulcata* (not Reuss) Brady, 1884, pl. 12, figs. 12, 13.—Cebulski, 1961, pl. I, figs. L, M; *Articulina pacifica* Cushman, 1944, p. 17, pl. 14, figs. 14–18.—Cebulski, 1969, pl. II, fig. 2.—Bock 1971, p. 32, pl. 13, fig. 6.—Brooks, 1973, pl. 7, figs. 11, 16.—Poag, 1981, p. 42, pl. 61, fig. 3; pl. 62, fig. 3.—Triffleman *et al.*, 1991, pl. 1, fig. 3.

Articulina sagra **d'Orbigny, 1839** *Articulina sagra* d'Orbigny, 1839, p. 183, pl. 9, figs. 23–26.—Cushman, 1921, p. 73, pl. 18, figs. 2–5.—Cushman, 1922b, p. 70.—Cushman, 1929, pt. 6, p. 51, pl. 11, fig. 7.—Cushman, 1941, p. 4, pl. 1, fig. 16.—Phleger and Parker, 1951, p. 7, pl. 3, figs. 8–10.—Cebulski, 1961, pl. I, fig. K.—Hofker, 1964, p. 35, Figs. 37–42.—Cebulski, 1969, pl. II, fig. 3.—Bock 1971, p. 33, pl. 13, fig. 7.—Todd and Low, 1971, p. C10, pl. 1, fig. 9.—Wantland, 1975, Fig. 7: s, t; *Articulina sagrai* Brooks, 1973, pl. 7, figs. 12, 13; *Articulina conico–articulata* Brady, 1884, pl. 12, figs. 17, 18.

Family Soritidae Ehrenberg, 1839

Peneroplis bradyi **Cushman, 1930** *Laevipeneroplis bradyi* (Cushman) Hallock and Peebles, 1993, p. 285, pl. 2, figs. 3, 4; *Peneroplis pertusus* var. g. Brady, 1884, pl. 13, figs. 12, 13; *Peneroplis planatus* Cushman, 1921, p. 75, pl. 18, fig. 9; *Peneroplis bradyi* Cushman, 1930, p. 40, pl. 14, figs. 8–10.—Cushman, 1941, p. 8, pl. 1, fig. 28.—Bock 1971, p. 33, pl. 13, fig. 8.—Levy, 1977, p. 402, pl. 1, fig. 10.—Todd and Low, 1971, p.C11, pl. 2, fig. 12.

Peneroplis carinatus **d'Orbigny, 1839** *Peneroplis (Peneroplis) carinatus* d'Orbigny, 1839, pl. 3, figs. 7, 8; *Peneroplis dubius* Levy, 1977, p. 402, pl. 1, figs. 8, 9; *Peneroplis pertusus* var. f. Brady, 1884, pl. 13, fig. 14; *Peneroplis pertusus carinatuts* Cushman, 1917, p. 87, pl. 37, fig. 4; *Peneroplis carinatus* Cushman, 1921, p. 75, pl. 18, fig. 12.—Cushman, 1922b, p. 79.—Cushman, 1930, pt. 7, p. 36, pl. 12, figs. 7–10.—Bock 1971, p. 33, pl. 13, fig. 9.—Brooks, 1973, pl. 5, figs. 1, 2; *Peneroplis proteus* Sen Gupta and Schafer, 1973, pl. 1, fig. 10.

Peneroplis discoideus **Flint, 1899** *Peneroplis pertusus* var. *discoideus* Flint, 1899, p. 304, pl. 49, figs. 1–2; *Cyclorbiculina americana* Levy, 1977, p. 416, pl. 5, figs. 1–9.—Levy *et al.*, 1988, pl. 1, figs. 4, 5; *Peneroplis discoideus* Cushman, 1921, p. 76, pl. 18, fig. 20; pl. 19, figs. 1–4, 6.—Cushman, 1922b, p. 80—Cushman, 1930, pt. 7, p. 41, pl. 15, figs. 6–8; *Peneroplis proteus* Poag, 1981, pl. 47, fig. 3; pl. 38, fig. 3a; *Puteolina (Sorites?) discoidea* Hofker, 1964, p. 49, Figs. 87, 91; *Boreckina discoidea* Levy, 1977, p. 421, pl. 7, figs. 1–7.—Levy *et al.*, 1988, pl. 1, fig. 10; *Boreckina orbitolitoides* ?Brook, 1973, pl. 8. figs. 14, 15.

Peneroplis pertusus **(Forskål), 1775** *Nautilus pertusus* Forskål, 1775, p. 125, no. 65; *Peneroplis (Peneroplis) elegans* d'Orbigny, 1839, p. 61, pl. 7, figs. 1, 2; *Peneroplis pertusus* var. b Brady, 1884, pl. 13, fig. 16, 17, 23; *Peneroplis pertusus* Cushman, 1917, p. 86, pl.. 1, figs. 1, 3; pl. 37, figs. 1, 2, 6.—Cushman, 1921, p. 75, pl. 18, figs. 7, 8.—Cushman, 1922b, p. 78.—Cushman, 1930, pt. 7, p. 35, pl. 12, figs. 3–6.—Cebulski, 1961, pl. II, fig. H.—Cebulski, 1969, pl. II, fig. 8.—Bock 1971, p. 34, pl. 13, fig. 10.—Brooks, 1973, pl. 7, fig. 15.—Levy, 1977, p. 399, pl. 1, fig. 11.—Wantland, 1975, Fig. 9: l.—Weis and Steinker, 1977, Fig. 4: c; *Dendritina elegans* Hofker, 1964, p. 56, Figs. 149–151, 153–155; *Cribrospirolina antillarum* (d'Orbigny) Crouch and Poag, 1987, p. 167, pl. 2, figs. 1–2.

Peneroplis proteus **d'Orbigny, 1839** *Peneroplis (Peneroplis) proteus* d'Orbigny, 1839, p. 60, pl. 7, fig. 7–11; *Laevipeneroplis protea* (d'Orbigny) Hallock and Peebles, 1993, p. 285, pl. 2, figs. 1, 2; *Peneroplis (Peneroplis) dubius* d'Orbigny, 1839, p. 62, pl. 6, figs. 21, 22; *Peneroplis protea* Levy, 1977, p. 40, pl. 1, figs. 1–7;*Orbiculina adunca* Brady, 1884, pl. 14, figs. 3, 4; *Peneroplis bradyi* Wantland, 1975, Fig. 9: m; *Peneroplis proteus* Cushman, 1921, p. 75, Figs. 13–16, pl. 18, figs. 13–19.—Cushman, 1922b, p. 79.—Cushman, 1930, p. 37, pl. 13, figs. 1–17.—Phleger and Parker, 1951, p. 11, pl. 6, fig. 6.—Cebulski, 1961, pl. II: fig. I.—Cebulski, 1969, pl. II, fig. 7.—Bock 1971, p. 34, pl. 13, fig. 11.—Levy, 1991, pl. 1, figs. 1, 2.—Todd & Low, 1971, p. C11. pl. 1, fig. 10.—Brooks, 1973, pl. 7, fig. 20.—Weis and Steinker, 1977, Fig. 4: g.—Poag, 1981, p. 74, pl. 47, fig. 3; pl. 48, fig. 3a.—Poag and Tresslar, 1981, p. 50, pl. 8, figs. 7, 8; *Puteolina protea* Hofker, 1964, p. 51, Figs. 135–146;

Monalysidium politum **Chapman, 1900** *Peneroplis (Monalysidium) polita* (Funafuti) Chapman, 1900, v.28, p. 4, pl.. 1, fig. 5; *Peneroplis pertusus* Brady, 1884. pl. 13, figs. 24, 25 (Cape Verde Is.); *Monalysidium politum* Cushman, 1930, pt. 7, p. 44, pl. 15, figs. 11, 12.—Bock 1971, p. 34, pl. 13, figs. 12.

Spirolina acicularis **(Batsch), 1791** *Nautilus (Lituus) acicularis* Batsch, 1791, p. 4, pl. 6, fig. 16; *Peneroplis pertusus* v. *cylindraceus* Brady, 1884. pl. 13, figs. 20, 21; *Peneroplis cylindraceus*

Cushman, 1921, p. 75, pl. 18, fig. 11; *Monalysidium polita* Cushman, 1922b, p. 80, pl. 13, fig. 4; *Spirolina acicularis* Cushman, 1930, pt. 7, p. 42, pl. 15, figs. 1–3.

Spirolina arientina **(Batsch), 1791** *Nautilus (Lituus) arientinus* Batsch (part), 1791; *Peneroplis pertusus* var. c Brady, 1884, pl. 13, figs. 18, 19, 22; *Peneroplis arientinus* Cushman, 1921, p. 75, pl. 18, fig. 10; *Spirolina arientina* Cushman, 1922b, p. 29.—Bock 1971, pl. 13, fig. 14.—Levy, 1977, p. 403, pl. 1, figs. 12, 13.—Levy, 1991, pl. 1, fig. 3; *Spirolina arientinus* Cushman, 1930, p. 43, pl. 15, figs. 4, 5; *Dendritina elegans* Hofker, 1964, p. 56, Fig. 152.

Archaias angulatus **(Fichtel and Moll), 1798** *Nautilus angulatus* Fichtel and Moll, 1798, p. 113, pl. 22, figs. a–e; *Androsina lucasi* Levy, 1977, p. 418, pl. 6, figs. 1–15; *Orbiculina adunca* Brady, 1884, pl. 14, figs. 1, 2, 5, 6, 10–13.—Cushman, 1917, p. 91, pl. 37, figs. 7, 8; *Archaias angulatus* Cushman, 1930, p. 46, pl. 16, figs. 1–3; pl. 17, figs. 3–5.—Bock 1971, p. 35, pl. 14, figs. 1–3.—Brooks, 1973, pl. 9, figs. 16–20.—Hallock and Peebles, 1993, p. 280, pl. 1, figs. 5–8.—Levy, 1977, p. 404, pl. 2, figs. 1–12.—Levy *et al.*, 1988, pl. 1, figs. 3, 6.—Levy, 1991, pl. 1, figs. 4, 5.—Sen Gupta and Schafer, 1973, pl. 1, fig. 11. —Todd and Low, 1971, p. C12, pl. 1, fig. 5.—Wantland, 1975, Fig. 9: o–r; Fig. 12: b; Fig. 16: j, k, m–t.—Weis and Steinker, 1977, Fig. 4: e.—Poag, 1981, p. 41, pl. 48, figs. 4b, c.—Triffleman *et al.*, 1991, pl. 1, fig. 4; *Archaias compressus* Phleger and Parker, 1951, p. 42, pl. 6, fig. 4; *Puteolina angulata* Hofker, 1964, p. 42. Figs. 58–62, 71–76, 100–108, 111–113; *Peneroplis carinatus* Cebulski, 1969, pl. II, fig. 6; *Cyclobiculina compressa* Brooks, 1973, pl. 8, fig. 11.

Archaias compressus **(d'Orbigny), 1839** *Orbiculina compressa* d'Orbigny, 1839, p. 66, pl. 8, figs. 4–7; *Orbiculina adunca* Brady, 1884, pl. 14, fig. 9; *Archaias compressus* Cushman, 1930, pt. 7, p. 48, pl. 17, figs. 1, 2.—Phleger and Parker, 1951, p. 11, pl. 6, figs. 3.—Bock 1971, pl. 14, fig. 4; *Puteolina compressus* Hofker, 1964, Figs. 86, 109, 114–118; *Cyclorbiculina compressa* Hallock and Peebles, 1993, p. 282, pl. 1, figs. 9–12.—Loeblich and Tappan, 1964, C495, figs. 383: 1–3.—Levy, 1977, p. 408, pl. 3, figs. 1–13; pl. 4, figs. 1–13.—Levy *et al.*, 1988, pl. 1, figs. 1, 2.—Levy, 1991, pl. 1, fig. 7.—Todd and Low. 1971, p. C12, pl. 1, fig. 8.—Sen Gupta and Schafer, 1973, *Cyclobiculina c.*, pl. 1, fig. 12.—Triffleman *et al.*, 1991, pl. 1, fig. 5; *Sorites marginalis* Cebulski, 1969, pl. II: fig. 10; *Archaias angulatus* Poag, 1981, pl. 47, fig. 4; pl. 48, fig. 4a.

Sorites marginalis **(Lamarck), 1816** *Sorites marginalis* Cushman, 1930, pt. 7, p. 49, pl. 18, fig. 2.—Phleger and Parker, 1951, p. 11, pl. 6, fig. 5.—Brook, 1973, pl. 8, figs. 13, 16.—Sen Gupta and Schafer, 1973, pl. 1, fig. 13.—Wantland, 1975, Fig. 11: a; *Broeckina orbitolitoides* Bock, 1971, p. 35, pl. 13, fig. 15.—Levy, 1977, p. 423, pl. 7, figs. 8–14.—Levy *et al.*, 1988, pl. 1, fig. 17; *Broeckina/Parasorites orbitolitoides* (Hofker) Hallock and Peebles, 1993, p. 284, pl. 2, figs. 5, 6; *Orbitolites marginalis* (Lamarck, 1816) Brady, 1884, pl. 15, fig. 4; *Orbulina compressa* Cushman, 1921, pl. 19, fig. 5; *Praesorites orbitilitoides* Bandy, 1954, p. 137, pl. 29, fig. 5. *Puteolina (Sorites) marginalis* Hofker, 1964, p. 45, Figs. 77–84, 88;

Amphisorus hemprichii **Ehrenberg, 1838** *Amphisorus hemprichii* Ehrenberg, 1838, p. 134, pl. 3, fig. 3.—?Cushman, 1921, p. 9, pl. 2, fig. 1.—Cushman, 1930, pt. 7, p. 51, pl. 18, figs. 5–7.—Cushman, 1941, p. 9, pl. 2, fig. 1.—Cebulski, 1961, pl. II, fig. k.—Brooks, 1973, pl. 8, fig. 12.—Levy, 1977, p. 428, pl. 8, figs. 11–17.—levy *et al.*, 1988, pl. 1, fig. 11.—Levy, 1991, pl. 1, figs. 8, 9.—Wantland, 1975, Fig. 11: c.—Crouch and Poag, 1987, p. 165, pl. 1, fig. 1; *Sorites marginalis* Bock 1971, pl. 14, figs. 5, 6.—Levy, 1977, p. 426, pl. 8, figs. 1–10; *Sorites orbiculus* Cole, 1965; *Orbitolites (Amphisorus) hemprichii.* Hofker, 1964, p. 52–55, Figs. 68, 69, 119–128.—Hofker, 1976, p. 137, Figs. 131, 161, 162.

Family Aveolinidae Ehrenberg, 1839

Borelis pulchra **(d'Orbigny), 1839** *Alveolina pulchra* d'Orbigny, 1839, p. 70, pl. 8, figs. 19, 20.—Cushman, 1921, p. 77, pl. 19, figs. 7, 8; *Borelis pulchra* Cushman, 1922b, p. 82.—Cushman, 1930, pt. 7, p. 55, pl. 15, figs. 9, 10.—Cebulski, 1969, pl. I, fig. 2.—Bock 1971, p. 37, pl. 14, fig. 7.—Brooks, 1973, pl. 8, fig. 1.—Weis and Steinker, 1977, Fig. 4: d—Crouch and Poag, 1987, p. 167, pl. 1, fig. 5; *Neoalveolina pulchra* Hofker, 1964, p. 55, Fig. 161.

Family Nodosariidae Ehrenberg, 1838

Nodosaria flintii **Cushman, 1923** *Nodosaria obliqua* Brady, 1884, pl. 64, figs. 20–22; *Nodosaria flintii* Cushman, 1923, p. 85, pl. 14, fig. 1.—Bock, 1971, p. 37, pl. 14, fig. 11.

Lenticulina iota **(Cushman), 1923** *Lenticulina iota* Bock, 1971, p. 40, pl. 15, fig. 7; *Cristellaria iota* Cushman, 1923, p. 111, pl. 29, fig. 2; pl. 30, fig. 1; *Cristellaria cultrata* Brady, 1884, pl. 70, figs. 4–6.

Family Bolivinitidae Cushman, 1927

***Bolivina canimarensis* Palmer and Bermudez, 1936** Palmer and Bermudez, 1936, p. 247, pl. 20, figs. 1, 2.

***Bolivina paula* Cushman and Cahill, 1933** *Bolivina paula* Cushman and Cahill, 1933, p. 84, pl. 12, fig. 6.

***Bolivina striatula* Cushman, 1922** *Bolivina striatula* Cushman, 1922b, p. 27, pl. 3, fig. 10.—Bandy, 1954, p. 135, pl. 31, fig. 9.—Bock 1971, p. 46, pl. 17, fig. 2.—Buzas *et al.*, 1977, p. 75, pl. 2, figs. 5–10.—Todd and Low, 1971, p. C13.—Boltovskoy *et al.*, 1980, p. 18, pl. 3, figs. 9–13; *Brizalina striatula* Wantland, 1975, Fig. 3: k; Fig. 5: j; Fig. 6: l; Fig. 13: k.

***Bolivina tortuosa* Brady, 1884** *Bolivina tortuosa* Brady, 1884, pl. 52, figs. 31–34.—Cushman, 1922b, pt. 3, p. 49, pl. 9, fig. 5.—Hofker, 1964, p. 77, Fig. 208.—Boltovskoy *et al.*, 1980, p. 18, pl. 3, figs. 14–17; *Bolivina alvarezi* Sellierde and Civrieux, 1976.—Crouch and Poag, 1987, p. 165, pl. 1, fig. 2; *Sigmavirgulina tortuosa* Loeblich and Tappan, 1964, C733, Fig. 601: 1–3.

***Bolivinita rhomboidalis* (Millett), 1899** *Textularia rhomboidalis* Millett, 1899, p. 559, pl. 7, fig. 4; *Bolivina rhomboidalis* Hofker, 1964, p. 77, Figs. 205, 206; *Bolivinita rhomboidalis* Lynts, 1965, p. 69, pl. 7, figs. 5, 6.—Todd and Low, 1971, p. C13.—Wantland, 1975, Fig. 10: s.—Buzas *et al.*, 1977, p. 74, pl. 2, figs. 3, 4.

Family Islandiellidae Loeblich and Tappan, 1964

***Islandiella laevigata* (d'Orbigny), 1826** *Cassidulina laevigata* d'Orbigny, 1826, p. 282, pl. 15, figs. 4, 5; *Islandiella laevigata* Poag, 1981, p. 70, pl. 17, fig. 2; pl. 18, fig. 2.

Family Buliminidae Jones, 1875

***Reussella atlantica* Cushman, 1947** *Verneuilina spicubsa* (non Reuss) Cushman, 1922b, p. 28, pl. 3, fig. 11; *Reussella spinulosa* var. *atlantica* Cushman, 1947, p. 91, pl. 20, figs. 6, 7; *Reussella atlantica* Phleger and Parker, 1951, pl. 8, figs. 8, 9.—Wantland, 1975, Fig. 5: l; Fig. 7: g; Fig. 13: i.—Bandy, 1954, p. 138, pl. 31, fig. 7.—Bock 1971, p. 48, pl. 17, fig. 1.—Brooks, 1973, pl. 8, fig. 19.

Family Uvigerininae Haeckel, 1894

***Sagrina pulchella* d'Orbigny, 1839** *Sagrina pulchella* d'Orbigny, 1839, pl. 150, pl. 1, figs. 23, 24.—Sen Gupta and Schafer, 1973, pl. 1, fig. 14.—Wantland, 1975, Fig. 5: m; *Bolivina pulchella* Cushman, 1922b, pt. 3, p. 41, pl. 7, fig. 4.

***Trifarina bella* (Phleger and Parker), 1951** *Trifarina bella* Bock 1971, p. 49, pl. 17, fig. 13.—Sen Gupta and Schafer, 1973, pl. 1, fig. 16.—Wantland, 1975, Fig. 7: c, d; Fig. 12: l; *Agulogerina bella* Phleger and Parker, 1951, p. 12, pl. 6, figs. 7, 8; *Trifarina occidentalis* Buzas *et al.*, 1977, p. 82, pl. 3, fig. 7–10.

Family Discorbidae Ehrenberg, 1838

***Discorbis granulosa* (Heron-Allen and Earland), 1915** *Discorbina valvulata* var. *granulosa* Heron-Allen and Earland, 1915, p. 695, pl. 52, figs. 1–6; *Discorbina granulosa* Buzas *et al.*, 1977, p. 83, pl. 3, figs. 11–13; *Rotorbinella granulosa* Hofker, 1964, p. 108, Fig. 262.—Hofker, 1976, p. 150, Fig. 144; *Rotorboides granulosum* Crouch and Poag, 1987, p. 171, pl. 4, figs. 1–2.

***Discorbis mira* Cushman, 1922** *Discorbina turbo* Brady, 1884, pl. 87, fig. 8; *Discorbis mira* Cushman, 1922b, p. 39, pl. 6, figs. 10, 11.—Cushman, 1931, pt. 8, p. 25, pl. 5, figs. 5, 6.—Cushman, 1941, p. 11, pl. 2, figs. 4–6.—Bock 1971, p. 51, pl. 18, figs. 3, 4.—Wantland, 1975, Fig. 10: a, b.—Buzas *et al.*, 1977, p. 82, pl. 3, figs. 14–16.—Weis and Steinker, 1977, Fig. 4: i; *Discorbis floridensis* Cebulski, 1961, pl. II: fig. l; *Neoconorbina floridensis* Cebulski, 1969, pl. II, fig. 5; *Rotorbinella mira* Hofker, 1964, p. 107, Figs. 258–261.—Todd and Low, 1971, p. C14, pl. 2, fig. 16.—Hofker, 1976, p. 150, Fig. 145; *Rotorbinella* cf. *mira* Hofker, 1964, p. 108, Fig. 261; *Discorbis mirus* Sen Gupta and Schafer, 1973, pl. 2, fig. 10, 11.—Brooks, 1973, pl. 10, figs. 1, 2.

***Discorbis obtusa* (d'Orbigny), 1826** *Rosalina obtusa* d'Orbigny, 1826, pl. 11, figs. 4–6; *Discorbis obtusa* Bermudez, 1935, p. 202, pl. 17, figs. 1–3.

***Discorbis rosea* (d'Orbigny), 1826** *Rotalia rosea* d'Orbigny, 1826, p. 272.—d'Orbigny, 1839, p. 72, pl. 3, figs. 9–11.—Todd and Low, 1971, p. C15; *Truncatulina rosea* Brady, 1884, pl. 96, fig. 1.—Cushman, 1921, p. 56, pl. 13, figs. 1–3.—Cushman, 1922b, p. 46, pl. 14, figs. 3–5; *Discorbis rosea* Cushman, 1931, pt. 8, p. 62, pl. 13, fig. 5.—Bock 1971, p. 50, pl. 17, figs. 15, 16.—Wantland, 1975, Fig. 12: e, f.—Weis and Steinker, 1977, Fig. 4: h, j; *Rotorbinella rosea* Hofker, 1964, p. 109, Fig. 263–265.—Crouch and Poag, 1987, p. 171, pl. 3, figs. 9–10.—Hofker, 1976, p. 151, Fig. 143; *Discorbis roseus* Brooks, 1973, pl. 10, figs. 3, 4.—Sen Gupta and Schafer, 1973, pl. 2, figs. 12, 13.

***Discorbis aguayoi* Bermudez, 1935** *Discorbis aguayoi* Bermudez, 1935, p. 204, pl. 15, figs. 10–14.—Bock, 1971, p. 50, pl. 18, figs. 1, 2; *Trichohyalus aguayoi* Wantland, 1975, Fig. 4: n, 0.

***Bronnimannia palmerae* (Bermudez), 1935** *Discorbis palmerae* Bermudez, 1935, p. 207; *Bronnimannia palmerae* Wantland, 1975, Fig. 10:k, l.

***Neoconorbina terquemi* (Rzehak), 1888** *Rosalina orbicularis* Terquem, 1876, p. 75, pl. 9, fig. 4; *Discorbina orbicularis* Brady, 1884, pl. 88, figs. 5–8.—Cushman, 1922b, *Discorbis orbicularis?* p. 38, pl. 5, fig. 10; *Neoconorbina orbicularis* Hofker, 1964, p. 79, Figs. 211, 212.—Bock 1971, p. 51, pl. 18, figs. 7, 8; *Neoconorbina terquemi* Cebulski, 1969, pl. I, fig. 4.—Todd and Low, 1971, p. C14.—Brooks, 1973, pl. 9, figs. 7, 8.—Wantland, 1975, Fig. 6:k; Fig. 12: k.—Triffleman *et al.*, 1991, pl. 1, fig. 7.

***Rosalina bulloides* d'Orbigny, 1839** *Rosalina bulloides* d'Orbigny, 1839, p. 104, pl. 3, figs. 2–5; *Tretomphalus planus* Brady, 1884, pl. 102, figs. 7, 8, 12; *Tretomphalus bulloides* Cushman, 1921, p. 58, pl. 13, fig. 13.—Cushman, 1922b, p. 42.—Cushman, 1931, pt. 8, p. 86, pl. 16, fig. 5.—Cushman, 1934, p. 86, pl. 1, figs. 1–3.—Hofker, 1964, p. 85, Fig. 216.—Wantland, 1975, Fig. 13: r, s.

***Rosalina candeiana* d'Orbigny, 1839** *Rosalina candeiana* d'Orbigny, 1839, p. 97, pl. 4, figs. 2–4.—Cushman, 1931, pt. 8, p. 19, pl. 7, fig. 4.—Phleger and Parker, 1951, p. 20, pl. 10, fig. 3.—Buzas *et al.*, 1977, p. 85, pl. 4, figs. 1–3.—Wantland, 1975, Fig. 10: c, d; Fig. 12: n.—Galluzzo *et al.*, 1990, pl. 2, figs. 27, 28; *Truncatulina candeiana* Cushman, 1921, p. 57, pl. 13, figs. 4, 5.—Cushman, 1922b, p. 47, pl. 6, figs. 7–9; *Discorbis candeiana* Cebulski, 1961, pl. II, fig. M.—Cebulski, 1969, pl. II, fig. 4; *Valvulinerina candeiana* Hofker, 1964, p. 102, Fig. 251; *Rosalina floridana* Bock 1971, p. 52, pl. 18, figs. 9, 10.—Triffleman *et al.*, 1991, *Rosalina floridana*, pl. 1, fig. 9; *Rosalina bahamaensis* Todd and Low, 1971, p. C14, pl. 3, fig. 2; *Discorbis floridana* Cushman, 1922b, p. 39, pl. 5, figs. 11, 12; *Rosalina floridana* Cushman, 1931, pt. 8, p. 21, pl. 4, figs. 7, 8.—Phleger and Parker, 1951, pl. 10, fig. 4.—Todd and Low, 1971, p. C14.—Brooks, 1973, pl. 5, figs. 12–14.—Wantland, 1975, Fig. 10: e.—Buzas, *et al.*, 1977, p. 86, pl. 4, fig. 7–9.—Weis and Steinker, 1977, Fig. 4: f; *Discopulvinulina floridana* Hofker, 1964, p. 81, Fig. 213.

***Rosalina concinna* (Brady), 1884** *Discorbis concinna* Brady, 1884, pl. 90, figs. 7, 8; *Discorbis concinnus* Bandy, 1956, pl. 31, fig. 4; *Rosalina concinna* Buzas et al., 1977, p. 85, pl. 4, figs. 4–6.

***Rosalina floridana* (Cushman), 1922** *Discorbis floridana* Cushman, 1922b, p. 39, pl. 5, figs. 11, 12.—Cushman, 1931, pt. 8, p. 21, pl. 4, figs. 7, 8.—Cushman and Parker, 1932, p. 18, pl. 4, fig. 5.

***Rosalina globularis* d'Orbigny, 1826** *Rosalina globularis* d'Orbigny, 1826, p. 271, pl. 13, figs. 1, 2.—Cushman, 1931, pt. 8, p. 22, pl. 4, fig. 9.—Murray, 1971, p. 135, pl. 56, figs. 1–6.

***Cancris sagra* (d'Orbigny), 1839** *Rotalina sagra* d'Orbigny, 1839, p. 17, pl. 5, Figs. 13–15; *Pulvinulina semipunctata* Cushman, 1922b, p. 51, pl. 8, figs. 5–6; *Cancris Sagra* Cushman, 1931, pt. 8, p. 74, pl. 15, figs. 2a–c.—Bock, 1971, p. 53, pl. 19, figs. 6–7.—Wantland, 1975, Fig. 6: q.

***Physalidia earlandi* Bermudez, 1935** *Physalidia earlandi* Bermudez, 1935, p. 212, pl. 14, figs. 1–3.

Family Siphoninidae Cushman, 1927

***Siphonina pulchra* Cushman, 1919** *Siphonina pulchra* Cushman, 1919, p. 42, pl. 14, fig. 7.—Cushman, 1922b, p. 49, pl. 7, figs. 11, 12.—Cushman, 1931, pt. 8, p. 69, pl. 14, figs. 2, 3.—Phleger and Parker, 1951, p. 24, pl. 12, fig. 15.—Bock 1971, p. 54, pl. 19, figs. 10, 11.—Brooks, 1973, pl. 8, figs. 7, 8.

Family Asterigerinidae d'Orbigny

***Asterigerina carinata* d'Orbigny, 1839** *Asterigerina carinata* d'Orbigny, 1839, p. 118, pl. 5, figs. 1, 2.—Cushman, 1921, p. 60, pl. 14, figs. 6–8.—Cushman, 1922b, p. 54, pl. 9, figs. 4–6.—Cushman, 1931, pt. 8, p. 77, pl. 15, figs. 4, 5.—Bandy, 1954, p. 135, pl. 31, fig. 5.—Hofker, 1964, p. 88, Figs. 222, 223.—Bock 1971, p. 54, pl. 19, fig. 12, pl. 20, fig. a.—Todd and Low, 1971, p. C15, pl. 3, fig. 3.—Brooks, 1973, pl. 10, figs. 6, 7.—Wantland, 1975, Fig. 12: a.—Weis and Steinker, 1977, Fig. 5: a.—Poag, 1981, p. 42, pl. 47, fig. 1; pl. 48, fig. 1.—Triffleman *et al.*, 1991, pl. 1, fig. 8.

Family Spirillinidae Reuss, 1862

***Spirillina decorata* Brady, 1884** *Spirillina decorata* Brady, 1884, pl. 85, figs. 22, 25.—Cushman, 1931, pt. 8, p. 9, pl. 2, fig. 3.

***Spirillina vivipara* Ehrenberg, 1840** *Spirillina vivipara* Ehrenberg, 1840, p. 422, pl. 3, sec. 7, fig. 41.—Brady, 1884, pl. 85, figs. 1–5.—Cushman, 1922b, p. 37, pl. 5, fig. 7.—Cushman, 1931, pt. 8, p. 3, pl. 1, figs. 1–4.—Phleger and Parker, 1951, p. 25, pl. 13, figs. 3, 4.—Bock 1971, p. 55, pl. 20, fig. 4.—Murray, 1971, p. 145, pl. 60, figs. 1–2.—Todd and Low, 1971, p. C13.—Buzas, *et al.*, 1977, p. 93, pl.

6, figs. 4–6.—Boltovskoy *et al.*, 1980, p. 50, pl. 31, figs. 16–18; *Spirillina vivipara* var. Cushman, 1922b, p. 37, pl. 5, fig. 6.

Patellina corrugata **Williamson, 1858** *Patellina corrugata* Williamson, 1858, p. 46, pl. 3, figs. 86–89.—Cushman, 1931, pt. 8, p. 11, pl. 2, figs. 6, 7.—Cushman, 1941, p. 11.—Phleger and Parker, 1951, p. 23, pl. 12, fig. 4.—Poag and Tresslar, 1981, p. 50, pl. 8, figs. 5, 6.

Family Rotaliidae Ehrenberg, 1839

Ammonia tepida **Cushman, 1926** *Rotalia beccarii tepida* Cushman, 1926, p. 79, pl. 1.—Todd and Low, 1971, p. C15; *"Rotalia" beccarii tepida* Cushman, 1931, pt. 8, p. 61, pl. 13, fig. 3.—Phleger and Parker, 1951, p. 23, pl. 12, fig. 7; *Streblus beccarii* Cebulski, 1969, pl. III, fig. 4; *Streblus tepidus* Hofker, 1964, p. 96, Figs. 236, 239–240; *Ammonia tepida* Sen Gupta and Schafer, 1973, pl. 2, figs. 6, 7; *Ammonia beccarii* Brooks, 1973, pl. 10, figs. 5, 10.—Wantland, 1975, Fig. 4: c, d; *Ammonia parkinsoniana tepida*, Poag, 1981, p. 37, pl. 45, fig. 2; pl. 46, fig. 2.

Family Elphidiidae Galloway, 1933

Elphidium lanieri **(d'Orbigny), 1839** *Polystomella lanieri* d'Orbigny, 1839, p. 54, pl. 7, figs. 12, 13; *Elphidium lanieri* Cushman, 1930, pt. 7, p. 23, pl. 9, fig. 7.—Brooks, 1973, pl. 10, fig. 8.

Elphidium sagrum **(d'Orbigny), 1839** *Polystomella sagra* d'Orbigny, 1839, p. 55, pl. 6, figs. 19, 20; *Elphidium sagrum* Cushman, 1930, pt. 7, p. 24, pl. 9, figs. 5, 6.—Cushman, 1939, p. 55, pl. 15, figs. 1–3.—Weis and Steinker, 1977. fig. 5, 6; *Elphidium sagra* Todd and Low, p. C16, pl. 3, fig. 7; *Elphidium lanieri* Poag, 1981, p. 62, pl. 37, fig. 4; pl. 38, fig. 4.—Wantland, 1975, Fig. 10: q.

Cribroelphidium discoidale **(d'Orbigny), 1839** *Polystomella discoidalis* d'Orbigny, 1839, p. 56, pl. 6, figs. 23, 24; *Polystomella discoidalis* Cushman, 1922b, p. 56, pl. 10, figs. 3, 4; *Elphidium discoidale* Cushman, 1930, pt. 7, p. 22, pl. 8, figs. 8, 9.—Cushman, 1939, p. 56, pl. 15, figs. 5–7.—Phleger and Parker, 1951, p. 10, pl. 5, figs. 10, 11.—Bandy, 1954, p. 136, pl. 30, fig. 4.—Bock, 1971, p. 56, pl. 20, figs. 9, 10.—Todd and Low, 1971, p. C16, pl. 3, fig. 9.—Sen Gupta and Schafer, 1973, pl. 2, fig. 1; *Cribroelphidium discoidale* Cebulski, 1969, pl. III, fig. 1.—Boltovskoy *et al.*, 1980, p. 29, pl. 13, figs. 5–7; *Elphidium poeyanum* Hofker, 1964, p. 110, Fig. 268; *Cellanthus discoidalis* Brooks, 1973, pl. 10, fig. 9; *Elphidium discoidalis* forma *kugleri* Seiglie, 1975, p. 476, pl. 2, figs. 17, 18; *Elphidium discoidalis* forma *typica* Seiglie, 1975, p. 476, pl. 2, figs. 19, 20; *Elphidium discoidalis* forma *translucens* Poag, 1981, pl. 35, fig. 2; pl. 36, fig. 2; *Elphidium discoidalis* forma *typicum* Poag, 1981, pl. 35, fig. 1; pl. 36, fig. 1.

Cribroelphidium poeyanum **(d'Orbigny), 1839** *Polystomella poeyana* d'Orbigny, 1839, p. 55, pl. 6, figs. 25, 26.—Cushman, 1922b, p. 55, pl. 9, figs. 9, 10; *Cribroelphidium poeyanum* Bock 1971, p. 57, pl. 21, figs. 1, 2.—Todd and Low, 1971, p. C16, pl. 3, fig. 8.—Brooks, 1973, pl. 10, fig. 13.—Wantland, 1975, Fig. 3: m; Fig. 4: i; Fig. 5: b, c; Fig. 6: g–h; Fig. 7: h; Fig. 13: a; Fig. 16: i; *Elphidium poeyanum* Cushman, 1939, p. 54, pl. 14, figs. 25, 26.—Cebulski, 1961, pl. II, fig. G.—Hofker, 1964, p. 110, Figs. 266, 267, 269.—Cebulski, 1969, pl. III, fig. 2.—Sen Gupta and Schafer, 1973, pl. 2, fig. 2.—Poag, 1981, p. 63, pl. 39, fig. 3; pl. 40, fig. 3.

Family Nummulitidae de Blainville, 1825

Heterostegina antillarum **d'Orbigny, 1839** *Heterostegina antillarum* d'Orbigny, 1839, p. 121, pl. 7, figs. 24, 25.—Cushman, 1922b, p. 57, pl. 10, fig. 5.—Cushman, 1930, pt. 7, p. 33, pl. 12, figs. 1, 2.—Hofker, 1964, Fig. 273.—Brooks, 1973, pl. 5, figs. 15, 16.—Poag and Tresslar, 1981, p. 46, pl. 7, figs. 1, 2; *Heterostegina depressa* Bock 1971, p. 57, pl. 21, fig. 3.

Family Globorotaliidae Cushman, 1927

Globorotalia menardii **(d'Orbigny), 1826** *Rotalia menardii* d'Orbigny, 1826, p. 273, no. 26, Model, no. 10; *Globorotalia menardii* Phleger and Parker, 1951, p. 36, pl. 20, figs. 1, 2; *Pulvinulina menardii* Brady, 1884, pl. 103, figs. 1, 2.—Cushman, 1921, p. 60.

Family Globigerinidae Carpenter, Parker and Jones, 1862

Globigerina bulloides **d'Orbigny, 1826** *Globigerina bulloides* Jones, 1971, p. 180, pl. 27, fig. 4.

Globigerinoides conglobatus **(Brady), 1879** *Globigerinoides conglobatus* Jones, 1971, p. 181, pl. 25, fig. 5.

Globigerinoides rubra **(d'Orbigny), 1839** *Globigerina rubra* d'Orbigny, 1839, p. 94, pl. 4, figs. 12–14.—Brady, 1884, pl. 79, figs. 11, 16.—Cushman. 1921, p. 55, pl. 12, fig. 6.—Cushman, 1924, pt. 5, p. 15, pl. 3, figs. 4–7; *Globigerinoides rubra* Phleger and Parker, 1951, p. 35, pl. 19, fig. 16.—Bandy, 1954,

p. 136, pl. 31, fig. 6.—Wantland, 1975, Fig. 13, q.—Weis and Steinker, 1976, Fig. 5:i.—Jones, 1971, p. 181, pl. 25, fig. 10.

***Orbulina universa* d'Orbigny, 1839** *Orbulina universa* d'Orbigny, 1839, p. 3, pl. 1, fig. 1.—Jones, 1971, p. 181, pl. 26, fig. 1.—Wantland, 1975, Fig. 7: v.

Family Eponididae Hofker, 1951

***Eponides antillarum* (d'Orbigny), 1839** *Rosalina antillarum.* d'Orbigny, 1839, p. 75, pl. 5, figs. 4–6; *Eponides antillarum* Cushman, 1931, pt. 8, p. 42, pl. 9, fig. 2.—Bock 1971, p. 57, pl. 21, figs. 4, 5.

***Eponides repanda* (Fichtel and Moll), 1798** *Nautilus repandus* Fichtel and Moll, 1798, p. 35, pl. 3, figs. a–d; *Eponides repanda* Brady, 1884, pl. 104, fig. 18.—Cushman, 1931, pt. 8, p. 49, pl. 10, fig. 7.—Phleger and Parker, 1951, p. 21, pl. 11, figs. 5, 6.—Bock, 1971, p. 58, pl. 21, figs. 6, 7.

***Eponides tubelifera* var. *canimarensis* Palmer and Bermudez, 1936** *Eponides tubelifera* var. *canimarensis* Palmer and Bermudez, 1936, p. 251, pl. 20, figs. 8–10; *"Alabamina" tubelifera* (Heron-Allen and Earland) Poag and Tresslar, 1981, p. 39, pl. 2, figs. 1–3; *Svratkina tubelifera* (Heron-Allen and Earland) Crouch and Poag, 1987, p. 173, pl. 4, figs. 8–9.

Family Amphisteginidae Cushman, 1927

***Amphistegina gibbosa* d'Orbigny, 1839** *Amphistegina gibbosa* d'Orbigny, 1839, p. 120, pl. 8, figs. 1–3.—Hofker, 1964, Figs. 224–226.—Cebulski, 1969, pl. II, fig. 1.—Seiglie, 1967, Fig. 70.—Sen Gupta and Schafer, 1973, pl. 2, figs. 14, 15.—Poag, 1981, p. 41, pl. 47, fig. 2; pl. 48, fig. 2.—Poag and Tresslar, 1981, p. 39, pl. 2, figs. 4–7.—Galluzzo *et al.*, 1990, pl. 3, fig. 24.—Triffleman *et al.*, 1991, pl. 1, fig. 11.—Wetmore, 1992, pl. 1, figs. 1, 2; *Amphistegina lessonii* Brandy, 1884, pl. 111, fig. 7.—Cushman, 1931, pt. 8, p. 79, pl. 16, fig. 3.—Phleger and Parker, 1951, p. 26, pl. 13, figs. 13. 14; pl. 14, fig. 1.—Bock 1971, p.58, pl. 21, fig.10.—Todd and Low, 1971, p. C15.—Weis and Steinker, 1977, Fig. 5: e.

Family Cibicididae Cushman, 1927

***Cibicides mayori* (Cushman), 1924** *Truncatulina mayori* Cushman, 1924, pt. 5, p. 39, pl. 12, figs. 3, 4; *Cibicides mayori* Wantland, 1975, Fig. 10: o.

***Cibicides pseudoungeriana* (Cushman), 1922** *Truncatulina pseudoungeriana* Cushman, 1922b, p. 97, pl. 20, fig. 9; *Truncatulina ungeriana* Brady, 1884, pl. 94, fig. 9; *Cibicides pseudoungeriana* Cushman, 1931, pt. 5, p. 123, pl. 22, figs. 3–7; *Cibicides pseudoungerianus* Brooks, 1973, pl. 10, figs. 19, 20.

***Planulina edwardiana* (d'Orbigny), 1839** *Rosalina edwardiana* d'Orbigny, 1839, pl. 6, figs. 8–10.

Family Planorbulinidae Schwager, 1877

***Planorbulina acervalis* Brady, 1884** *Planorbulina acervalis* Brady, 1884, p. 657, pl. 92, fig. 4.—Cushman, 1922b, p. 45, pl. 6, fig. 3.—Cushman, 1931, pt. 8, p. 130, pl. 25, fig. 1.—Cushman, 1941, p. 13, pl. 2, figs. 7, 8.—Cebulski, 1961, pl. II, fig. N.—Hofker, 1964, p. 216, Figs. 217–219.—Cebulski, 1969, pl. II, fig. 9.—Bock 1971, p. 60, pl. 22, figs. 9, 10.—Todd and Low, 1971, p. C17.—Wantland, 1975, Fig. 11: d.—Hofker, 1976, p. 141, Fig. 134.—Buzas, *et al.*, 1977, p. 100, pl. 6, figs. 19–21.

***Planorbulina mediterranensis* d'Orbigny, 1826** *Planorbulina mediterranensis* d'Orbigny, 1826, p. 280, no. 2, pl. 14, figs. 4–6.—Brady, 1884, pl. 92, fig. 1–3.—Cushman, 1922b, p. 45, pl. 6, figs. 1, 2.—Cushman, 1931, pt. 8, p. 129, pl. 24, figs. 6–8.—Cushman, 1941, p. 13, pl. 12, fig. 9.—Bandy, 1954, pl. 31, fig. 3.—Bock 1971, p. 60, pl. 22, figs. 11, 12.—Murray, 1971, p. 179, pl. 75, figs. 1–6.—Brooks, 1973, pl. 9, fig. 10, 15.—Wantland, 1975, Fig. 11–b.—Hofker, 1976, Figs. 132, 133.—Boltovskoy *et al.*, 1980, p. 43, pl. 25, figs. 1–3.—Triffleman *et al.*, 1991, pl. 1, fig. 10; *Planorbulina acervalis* Weis and Steinker, 1977, Fig. 5: f.

Family Acervulinidae Schultze, 1854

***Gpysina rubra* (d'Orbigny), 1826** *Planorbulina rubra* d'Orbigny, 1826, p. 280, no. 4; *Gpysina rubra* Heron-Allen and Earland, 1915, pl. 53, figs. 35–37.—Cushman, 1931, pt. 8, p. 137; *Sporadotrema rubrum* Hofker, 1976, p. 143, Fig. 137.

***Gypsina vesicularis* (Parker and Jones), 1860** *Gypsina vesicularis* Brooks, 1973, pl. 8, fig. 10.—Wantland, 1975, Fig. 12: c.

***Cymbaloporetta atlantica* (Cushman), 1934** *Tretomphalus bulloides* Cushman 1931, pt. 8, p. 86, pl. 16, figs. 5a–c; *Tretomphalus atlanticus* Cushman, 1934, p. 86, pl. 11, fig. 3; pl. 12, fig. 7.—Bock 1971, p. 53, pl. 19, figs. 1, 2; *Cymbaloporetta atlantica* Buzas *et al.*, p. 101, pl. 7, figs. 22–24.

Cymbaloporetta squammosa **(d'Orbigny), 1826** *Rotalina squammosa* d'Orbigny, 1826, p. 272.—d'Orbigny, 1839, p. 91, pl. 3, figs. 12–14; *Cymbaloporetta squammosa* Brady, 1884, pl. 102, fig. 13.—Cushman, 1922b, p. 41, pl. 6, figs. 4–6.—Cushman, 1931, pt. 8, p. 83, pl. 16, fig. 4.—Hofker, 1964, p. 84, Fig. 215.—Cebulski, 1969, pl. I, fig. 3.—Bock 1971, p. 60, pl. 23, figs. 1, 2.—Buzas *et al.*, 1977, p. 101, pl. 8, figs. 1–3; *Cymbaloporetta poeyi* Cushman, 1921, p. 58, pl. 13, figs. 9–12.

Family Homotrematidae Cushman, 1927

Homotrema rubrum **(Lamarck), 1816** *Millepora rubra* Lamarck, 1816, p. 202; *Homotrema rubrum* Cushman, 1922b, p. 53, pl. 14, figs. 6–8.—Cushman, 1931, pt. 8, p. 143.—Hofker, 1964, Figs. 220–221.—Bock 1971, pl. 23, fig. 3.—Wantland, 1975, Fig. 12: d.—Weis and Steinker, 1977, Fig. 5: g; *Homotrema rubra* Poag and Tresslar, 1981, p. 48, pl. 7, figs. 4, 5.

Family Nonioninae Schultze, 1854

Nonion grateloupi **(d'Orbigny), 1826** *Nonionina grateloupi* d'Orbigny, 1826, p. 46, pl. 6, figs. 6, 7.—Cushman, 1921, p. 61, pl. 14, figs. 9–11.—Cushman, 1922b, p. 55, pl. 9, figs. 7, 8; *Nonion grateloupi* Bock 1971, p. 65, pl. 23, fig. 15.—Cushman, 1930, pt. 7, p. 10, pl. 3, figs. 9–11; pl. 4, figs. 1–4.—Cushman, 1939, p. 21, pl. 6, figs. 1–7.—Phleger and Parker, 1951, p. 11, pl. 5, fig. 18.—Cebulski, 1961, pl. II, fig. 8.—Cebulski, 1969, pl. II: fig. 3.—Weis and Steinker, 1977, Fig. 5: h; *Florilus grateloupi* Brooks, 1973, pl. 9, fig. 6.—Seiglie, 1975, p. 476.—Boltovskoy *et al.*, 1980, p. 33, pl. 16, figs. 11–13; *Pseudononion grateloupi* Galluzzo *et al.*, 1990, pl. 4, fig. 2.

Trichohyalus aguayoi **(Bermudez), 1935** *Discorbis aguayoi* Bermudez, 1935, p. 204, pl. 15, figs. 10–14; *Trichohyalus aguayoi* Wantland, 1975, Fig. 4: n, o.

Family Robertinidae Reuss, 1850

Robertinoides bradyi **Cushman and Parker, 1936** *Bulimina substeres* Brady, 1884, pl. 50, figs. 18a, b; *Robertinoides bradyi* Cushman and Parker, 1936.—Bock, 1971, p. 67, pl. 24, fig. 11.

Appendix B Sample locations

No.	Location	Keys*	Distance (m)	Depth (ft)
4	Victoria House U. Terrace	Fig.1.9B	120 from Shore	10
5	Victoria House U. Terrace	Fig.1.9B	160 from Shore	10
6	Victoria House U. Terrace	Fig.1.9B	200 from Shore	10
7	Victoria House U. Terrace	Fig.1.9B	240 from Shore	10
8	Victoria House U. Terrace	Fig.1.9B	280 from Shore	14
9	Victoria House U. Terrace	Fig.1.9B	320 from Shore	16
10	Galleon Beach U. Terrace	Fig.1.9C	20 from Shore	5
11	Galleon Beach U. Terrace	Fig.1.9C	60 from Shore	10
12	Galleon Beach U. Terrace	Fig.1.9C	100 from Shore	10
13	Galleon Beach U. Terrace	Fig.1.9C	140 from Shore	8
14	Galleon Beach U. Terrace	Fig.1.9C	180 from Shore	8
15	Galleon Beach U. Terrace	Fig.1.9C	220 from Shore	9
16	Galleon Beach U. Terrace	Fig.1.9C	260 from Shore	10
17	Victoria House U. Terrace	Fig.1.9B	120 from Shore	9
18	Victoria House U. Terrace	Fig.1.9B	80 from Shore	6
19	Victoria House U. Terrace	Fig.1.9B	40 from Shore	8
20	Victoria House U. Terrace	Fig.1.9B	1 from Shore	3
21	Galleon Beach U. Terrace	Fig.1.9C	690 from Shore	45
22	Galleon Beach U. Terrace	Fig.1.9C	730 from Shore	44
23	West Bay U. Terrace	Fig.1.9B	250 from Shore	9
24	West Bay U. Terrace	Fig.1.9B	210 from Shore	10
25	West Bay U. Terrace	Fig.1.9B	170 from Shore	7
26	West Bay U. Terrace	Fig.1.9B	130 from Shore	6
30	S. Sound Lagoon Central	Fig.1.10A	460 from Shore	5
35	S. Sound Lagoon Central	Fig.1.10A	300 from Shore	5
36	Colliers Bay Lagoon	Fig.1.9A	20 from Reefcrest	5
37	Colliers Bay Lagoon	Fig.1.9A	60 from Reefcrest	6
38	Colliers Bay Lagoon	Fig.1.9A	100 from Reefcrest	6
42	S. Sound Lagoon Central	Fig.1.10A	210 from Shore	6
45	S. Sound Lagoon Central	Fig.1.10A	90 from Shore	6
53	S. Sound C., U. Terrace	Fig.1.10A	95 from M-S Scarp	18
54	S. Sound C., U. Terrace	Fig.1.10A	175 from M-S Scarp	9
59	S. Sound C., U. Terrace	Fig.1.10A	140 from Shelf Edge	45
60	S. Sound Lagoon Central	Fig.1.10A	20 from Reefcrest	4
61	S. Sound Lagoon Central	Fig.1.10A	60 from Reefcrest	5
64	S. Sound Lagoon Central	Fig.1.10A	180 from Reefcrest	6
66	S. Sound Lagoon Central	Fig.1.10A	260 from Reefcrest	6
67	Galleon Beach L. Terrace	Fig.1.9C	0 from Shelf Edge	55
68	Galleon Beach L. Terrace	Fig.1.9C	40 from Shelf Edge	58
69	Galleon Beach L. Terrace	Fig.1.9C	80 from Shelf Edge	53
70	Galleon Beach L. Terrace	Fig.1.9C	120 from Shelf Edge	50
71	Galleon Beach U. Terrace	Fig.1.9C	600 from Shore	21
72	Galleon Beach U. Terrace	Fig.1.9C	540 from Shore	20

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* Figure numbers in chapter 1.

Appendix B (continued)

No.	Location	Keys	Distance (m)	Depth (ft)
73	Galleon Beach U. Terrace	Fig.1.9C	380 from Shore	15
74	Galleon Beach U. Terrace	Fig.1.9C	300 from Shore	10
75	Victoria House L. Terrace	Fig.1.9B	40 from Shelf Edge	55
76	Victoria House L. Terrace	Fig.1.9B	80 from Shelf Edge	52
77	Victoria House L. Terrace	Fig.1.9B	120 from Shelf Edge	50
78	Victoria House L. Terrace	Fig.1.9B	160 from Shelf Edge	50
79	Victoria House L. Terrace	Fig.1.9B	200 from Shelf Edge	50
80	West Bay U. Terrace	Fig.1.9B	30 from Shore	6
82	West Bay U. Terrace	Fig.1.9B	0 from Shore	3
83	West Bay L. Terrace	Fig.1.9B	0 from Shelf Edge	60
84	West Bay L. Terrace	Fig.1.9B	40 from Shelf Edge	55
85	West Bay L. Terrace	Fig.1.9B	80 from Shelf Edge	52
86	West Bay L. Terrace	Fig.1.9B	120 from Shelf Edge	49
87	West Bay L. Terrace	Fig.1.9B	160 from Shelf Edge	47
88	Victoria House U. Terrace	Fig.1.9B	760 from Shore	47
89	Victoria House U. Terrace	Fig.1.9B	720 from Shore	40
90	Victoria House U. Terrace	Fig.1.9B	500 from Shore	19
92	Victoria House U. Terrace	Fig.1.9B	460 from Shore	14
93	South Sound East	Fig.1.10A	20 from Shelf Edge	95
95	South Sound East	Fig.1.10A	120 from Shelf Edge	65
96	West Bay U. Terrace	Fig.1.9B	600 from Shore	42
97	West Bay U. Terrace	Fig.1.9B	350 from Shore	10
100	Colliers Bay Lagoon	Fig.1.9A	150 from Reefcrest	6
101	Colliers Bay Lagoon	Fig.1.9A	190 from Reefcrest	10
102	Colliers Bay Lagoon	Fig.1.9A	230 from Reefcrest	10
103	Colliers Bay Lagoon	Fig.1.9A	270 from Reefcrest	9
104	Colliers Bay Lagoon	Fig.1.9A	310 from Reefcrest	8
105	Colliers Bay Lagoon	Fig.1.9A	350 from Reefcrest	7
106	Colliers Bay Lagoon	Fig.1.9A	390 from Reefcrest	6
107	Sand Bluff Lagoon	Fig.1.9A	180 from Shore	8
108	Sand Bluff Lagoon	Fig.1.9A	120 from Shore	6
109	Sand Bluff Lagoon	Fig.1.9A	40 from Shore	3
110	Sand Bluff Lagoon	Fig.1.9A	80 from Reefcrest	6
111	Sand Bluff Lagoon	Fig.1.9A	120 from Reefcrest	5
112	Sand Bluff Lagoon	Fig.1.9A	160 from Reefcrest	6
113	Sand Bluff Lagoon	Fig.1.9A	200 from Reefcrest	7.5
114	Sand Bluff Lagoon	Fig.1.9A	240 from Reefcrest	15
115	Sand Bluff Lagoon	Fig.1.9A	280 from Reefcrest	14
116	Sand Bluff Lagoon	Fig.1.9A	320 from Reefcrest	14
117	Sand Bluff Lagoon	Fig.1.9A	360 from Reefcrest	11
118	Hepps Wall L. Terrace	Fig.1.3-1A	0 from Shelf Edge	84
121	Hepps Wall L. Terrace	Fig.1.3-1A	120 from Shelf Edge	80
123	Smith Cove U. Terrace	Fig.1.3-1C	210 from Shore	48
128	Gun Bluff Lagoon	Fig.1.9A	50 from Reefcrest	5

Appendix B (continued)

No.	Location	Keys	Distance (m)	Depth (ft)
129	Gun Bluff Lagoon	Fig.1.9A	100 from Reefcrest	8
130	Gun Bluff Lagoon	Fig.1.9A	150 from Reefcrest	9
131	Gun Bluff Lagoon	Fig.1.9A	200 from Reefcrest	23
132	Gun Bluff Lagoon	Fig.1.9A	250 from Reefcrest	24
133	Gun Bluff Lagoon	Fig.1.9A	300 from Reefcrest	20
134	Gun Bluff Lagoon	Fig.1.9A	350 from Reefcrest	17
135	Gun Bluff Lagoon	Fig.1.9A	450 from Reefcrest	16
136	Gun Bluff Lagoon	Fig.1.9A	550 from Reefcrest	14
137	Gun Bluff Lagoon	Fig.1.9A	650 from Reefcrest	14
138	Gun Bluff Lagoon	Fig.1.9A	750 from Reefcrest	12
139	Gun Bluff Lagoon	Fig.1.9A	900 from Reefcrest	9
140	Gun Bluff Lagoon	Fig.1.9A	1050 from Reefcrest	7
141	Gun Bluff Lagoon	Fig.1.9A	1150 from Reefcrest	7
143	Tortuga Club Lagoon	Fig.1.9A	40 from Reefcrest	5
144	Tortuga Club Lagoon	Fig.1.9A	80 from Reefcrest	6
145	Tortuga Club Lagoon	Fig.1.9A	120 from Reefcrest	6
146	Tortuga Club Lagoon	Fig.1.9A	160 from Reefcrest	6
147	Tortuga Club Lagoon	Fig.1.9A	200 from Reefcrest	6
148	Tortuga Club Lagoon	Fig.1.9A	240 from Reefcrest	6
148	East Point Lagoon	Fig.1.9A	0 from Reefcrest	3–5
149	East Point Lagoon	Fig.1.9A	50 from Reefcrest	5
150	East Point Lagoon	Fig.1.9A	100 from Reefcrest	7.5
151	East Point Lagoon	Fig.1.9A	150 from Reefcrest	8
152	East Point Lagoon	Fig.1.9A	200 from Reefcrest	8
153	East Point Lagoon	Fig.1.9A	250 from Reefcrest	9
155	Colliers Bay L. Terrace	Fig.1.9A	0 from Shelf Edge	78
156	Colliers Bay L. Terrace	Fig.1.9A	60 from Shelf Edge	73
157	Colliers Bay L. Terrace	Fig.1.9A	120 from Shelf Edge	70
158	Colliers Bay L. Terrace	Fig.1.9A	180 from Shelf Edge	65
159	Black Hole L. Terrace	Fig.1.9A	0 from Shelf Edge	55
160	Black Hole L. Terrace	Fig.1.9A	50 from Shelf Edge	70
162	Gun Bluff L. Terrace	Fig.1.9A	0 from Shelf Edge	80
163	Gun Bluff L. Terrace	Fig.1.9A	60 from Shelf Edge	75
164	Gun Bluff L. Terrace	Fig.1.9A	120 from Shelf Edge	70
1090	Frank Sound Tran. 1	Fig.1.10B	90 from Shore	5.16
1150	Frank Sound Tran. 1	Fig.1.10B	150 from Shore	6
1180	Frank Sound Tran. 1	Fig.1.10B	180 from Shore	5.85
1240	Frank Sound Tran. 1	Fig.1.10B	240 from Shore	5.85
1300	Frank Sound Tran. 1	Fig.1.10B	300 from Shore	5.4
1360	Frank Sound Tran. 1	Fig.1.10B	360 from Shore	5.4
1420	Frank Sound Tran. 1	Fig.1.10B	420 from Shore	4.8
1480	Frank Sound Tran. 1	Fig.1.10B	480 from Shore	6.3
2030	Frank Sound Tran. 2	Fig.1.10B	30 from shore	1.5
2090	Frank Sound Tran. 2	Fig.1.10B	90 from Shore	3.9

Appendix B (continued)

No.	Location	Keys	Distance (m)	Depth (ft)
2150	Frank Sound Tran. 2	Fig.1.10B	150 from Shore	5.25
2180	Frank Sound Tran. 2	Fig.1.10B	from Shore180	5.7
2270	Frank Sound Tran. 2	Fig.1.10B	270 from Shore	5.4
2330	Frank Sound Tran. 2	Fig.1.10B	330 from Shore	5.85
2420	Frank Sound Tran. 2	Fig.1.10B	420 from Shore	3.3
3030	Frank Sound Tran. 3	Fig.1.10B	30 from Shore	3.9
3090	Frank Sound Tran. 3	Fig.1.10B	90 from Shore	6
3150	Frank Sound Tran. 3	Fig.1.10B	150 from Shore	6.9
3210	Frank Sound Tran. 3	Fig.1.10B	210 from Shore	7.8
3270	Frank Sound Tran. 3	Fig.1.10B	270 from Shore	7.5
3330	Frank Sound Tran. 3	Fig.1.10B	330 from Shore	7.8
3360	Frank Sound Tran. 3	Fig.1.10B	360 from Shore	8.4
3390	Frank Sound Tran. 3	Fig.1.10B	390 from Shore	8.1
3420	Frank Sound Tran. 3	Fig.1.10B	420 from Shore	7.2
3480	Frank Sound Tran. 3	Fig.1.10B	480 from Shore	5.85
3540	Frank Sound Tran. 3	Fig.1.10B	540 from Shore	6
3630	Frank Sound Tran. 3	Fig.1.10B	630 from Shore	6.15
3720	Frank Sound Tran. 3	Fig.1.10B	720 from Shore	4.95
3840	Frank Sound Tran. 3	Fig.1.10B	840 from Shore	3.9
5000	Frank Sound Tran. 5	Fig.1.10B	0 from Shore	0
5030	Frank Sound Tran. 5	Fig.1.10B	30 from Shore	3
5120	Frank Sound Tran. 5	Fig.1.10B	120 from Shore	5.85
5270	Frank Sound Tran. 5	Fig.1.10B	270 from Shore	4.5
5300	Frank Sound Tran. 5	Fig.1.10B	300 from Shore	4.8
5330	Frank Sound Tran. 5	Fig.1.10B	330 from Shore	5.25
5360	Frank Sound Tran. 5	Fig.1.10B	360 from Shore	5.4
5390	Frank Sound Tran. 5	Fig.1.10B	390 from Shore	5.25
5480	Frank Sound Tran. 5	Fig.1.10B	480 from Shore	6.3
5570	Frank Sound Tran. 5	Fig.1.10B	570 from Shore	6
5690	Frank Sound Tran. 5	Fig.1.10B	690 from Shore	6.9
5750	Frank Sound Tran. 5	Fig.1.10B	750 from Shore	7.8
5900	Frank Sound Tran. 5	Fig.1.10B	900 from Shore	6.75
5960	Frank Sound Tran. 5	Fig.1.10B	960 from Shore	3.9
CA0	Frank Sound Tran. 6	Fig.1.10B	Surface	
CA20	Frank Sound Tran. 6	Fig.1.10B	0.2 from surface	
CA40	Frank Sound Tran. 6	Fig.1.10B	0.4 from surface	
CB0	Frank Sound Tran. 6	Fig.1.10B	Surface	
CB20	Frank Sound Tran. 6	Fig.1.10B	0.2 from surface	
CB40	Frank Sound Tran. 6	Fig.1.10B	0.4 from surface	
CC0	Frank Sound Tran. 6	Fig.1.10B	Surface	
CC30	Frank Sound Tran. 6	Fig.1.10B	0.3 from surface	
CC50	Frank Sound Tran. 6	Fig.1.10B	0.5 from surface	
CD0	Frank Sound Tran. 6	Fig.1.10B	Surface	
CD20	Frank Sound Tran. 6	Fig.1.10B	0.2 from surface	

Appendix B (continued)

No.	Location	Keys	Distance (m)	Depth (ft)
CD40	Frank Sound Tran. 6	Fig.1.10B	0.4 from surface	
CD60	Frank Sound Tran. 6	Fig.1.10B	0.6 from surface	
CD77	Frank Sound Tran. 6	Fig.1.10B	0.77 from surface	
CE0	Frank Sound Tran. 6	Fig.1.10B	Surface	
CE20	Frank Sound Tran. 6	Fig.1.10B	0.2 from surface	
CE40	Frank Sound Tran. 6	Fig.1.10B	0.4 from surface	
CE60	Frank Sound Tran. 6	Fig.1.10B	0.6 from surface	
CE80	Frank Sound Tran. 6	Fig.1.10B	0.8 from surface	
CE100	Frank Sound Tran. 6	Fig.1.10B	1 from surface	
CE113	Frank Sound Tran. 6	Fig.1.10B	1.13 from surface	
CF0	Frank Sound Tran. 6	Fig.1.10B	Surface	
CF20	Frank Sound Tran. 6	Fig.1.10B	0.2 from surface	
CF40	Frank Sound Tran. 6	Fig.1.10B	0.4 from surface	
CF60	Frank Sound Tran. 6	Fig.1.10B	0.6 from surface	
CF80	Frank Sound Tran. 6	Fig.1.10B	0.8 from surface	
CF100	Frank Sound Tran. 6	Fig.1.10B	1 from surface	
CF120	Frank Sound Tran. 6	Fig.1.10B	1.2 from surface	
CF134	Frank Sound Tran. 6	Fig.1.10B	1.34 from surface	
93.1	North Wall L. Terrace	Fig.1.3-3A	5 from Shelf Edge	145
93.2	North of N. Sound	Fig.1.3-3A		6
93.3	NE of S. Sound	Fig.1.3-3A		10
93.4	South Edge of L. Sound	Fig.1.3-3B	40 from Shore	6
93.5	S. Central of N. Sound	Fig.1.3-2B		12
FM1	South Sound West	Fig.1.10A		
FM2	South Sound West	Fig.1.10A		
FM3	South Sound West	Fig.1.10A		
FM4	South Sound West	Fig.1.10A		
FM5	South Sound West	Fig.1.10A		
FM6	South Sound West	Fig.1.10A		
FM7	South Sound West	Fig.1.10A		
FM8	South Sound West	Fig.1.10A		
1403	North Edge of N. Sound	Fig.1.3-2A		
1406	Central W. of N. Sound	Fig.1.3-2A		
1409	Central W. of N. Sound	Fig.1.3-2A		
1419	NW of N. Sound	Fig.1.3-1A		
F1	Spanish Bay L. Terrace	Fig.1.3-1A	200 from Shore	85
F2	Turtle Farm L. Terrace	Fig.1.3-1A	70 from Shore	60
F3	Pease Bay Lagoon	Fig.1.3-4C	30 from Shore	3
F4	Pease Bay Lagoon	Fig.1.3-4C	0 from Shore	0.5
F5	Frank Sound Beach	Fig.1.3-5B	0 from Shore	0.5
F6	Turtle Farm L. Terrace	Fig.1.3-1A	200 from Shore	97
F7	Tortugas Club Lagoon	Fig.1.9A	50 from Reefcrest	1.5
F8	Colliers Bay Lagoon	Fig.1.9A	100 from Reefcrest	5
F9	Sand Bluff Lagoon	Fig.1.9A	160 from Reefcrest	5

Appendix B (continued)

No.	Location	Keys	Distance (m)	Depth (ft)
F10	Sand Bluff Lagoon	Fig.1.9A	200 from Reefcrest	6
F11	Near E.E. Channel	Fig.1.9A	100 from Reefcrest	2
F12	East End Channel	Fig.1.9A	150 m from reef	15
F13	Colliers Bay Beach	Fig.1.9A	0 fromShore	0.5
F14	Gun Bluff Lagoon	Fig.1.9A	30 from Reefcrest	6
F15	Gun Bluff Lagoon	Fig.1.9A	30 from Reefcrest	5
F16	Gun Bluff Lagoon	Fig.1.9A	100 from Reefcrest	6
F17	Gun Bluff Lagoon	Fig.1.9A	150 from Shore	6
F18	Gun Bluff Lagoon	Fig.1.9A	130 from Reefcrest	6
F19	Gun Bluff Lagoon	Fig.1.9A	170 from Shore	7
F20	Gun Bluff Lagoon	Fig.1.9A	170 from Shore	7
F21	East Point Lagoon	Fig.1.9A	150 from Shore	6
F22	East Point Lagoon	Fig.1.9A	150 from Shore	6
F23	East Point Lagoon	Fig.1.9A	120 from Shore	6
F24	East Point Lagoon	Fig.1.9A	50 from Shore	5
F25	East Point Lagoon	Fig.1.9A	0 from Shore	
F26	Gun Bluff Lagoon	Fig.1.9A	0 from Shore	
F27	South Sound East	Fig.1.10A	0 from Shore	0.99
F28	South Sound East	Fig.1.10A	60 from Shore	4.8
F29	South Sound East	Fig.1.10A	120 from Shore	5.55
F30	South Sound East	Fig.1.10A	180 from Shore	5.1
F31	South Sound East	Fig.1.10A	240 from Shore	4.5
F32	South Sound East	Fig.1.10A	300 from Shore	3.6
F33	South Sound East	Fig.1.10A	360 from Shore	3
F34	South Sound East	Fig.1.10A	420 from Shore	3.6
F35	South Sound East	Fig.1.10A	480 from Shore	3.9
F36	South Sound East	Fig.1.10A	540 from Shore	4.35
F37	South Sound East	Fig.1.10A	600 from Shore	4.2
F38	South Sound East	Fig.1.10A	660 from Shore	4.8
F39	South Sound East	Fig.1.10A	720 from Shore	4.8
F40	South Sound East	Fig.1.10A	780 from Shore	4.65
F41	South Sound East	Fig.1.10A	840 from Shore	5.1
F42	South Sound East	Fig.1.10A	900 from Shore	3.9
F43	South Sound East	Fig.1.10A	930 from Shore	3.3
F44	South Sound East	Fig.1.10A	960 from Shore	3
F45	South Sound East	Fig.1.10A	980 from Shore	3
F46	South Sound East	Fig.1.10A	150 from E Shore	3
F47	South Sound East	Fig.1.10A	30 from E Shore	1–1.5
F48	Smith Cove U. Terrace	Fig.1.3-1C	400 from Shore	47
F49	Smith Cove U. Terrace	Fig.1.3-1C	400 from Shore	48
F50	Duck Pond Bight	Fig.1.3-3B	5 from Mangrove	3
F51	Duck Pond Bight	Fig.1.3-3B	Edge of Mangrove	2.1
F52	SE of N. Sound	Fig.1.3-3B		9
F53	SE of N. Sound	Fig.1.3-3B	NW of Canal	3

Appendix B (continued)

No.	Location	Keys	Distance (m)	Depth (ft)
F54	SE of N. Sound	Fig.1.3-3B	100 into the Creek	3
F55	SE of N. Sound	Fig.1.3-3B	W End of the Canal	9
F56	Little Sound	Fig.1.3-3B	E End of the Canal	9
F57	Little Sound	Fig.1.3-3B	SW Edge	3
F58	Little Sound	Fig.1.3-3B	South Edge Central	3
F59	Little Sound	Fig.1.3-4B	SE Corner	3.75
F60	Little Sound	Fig.1.3-4B	SE Edge	1.2
F61	Little Sound	Fig.1.3-4B	East Edge Central	13.5
F62	Little Sound	Fig.1.3-4B	NE Edge	3
F63	Little Sound	Fig.1.3-4B	NE Corner	3
F64	Little Sound	Fig.1.3-4B	W of NE Corner	5.1
F65	Little Sound	Fig.1.3-4B	NW Corner	6
F66	Little Sound	Fig.1.3-3B	Central L. Sound	7.5
F67	Little Sound	Fig.1.3-3B	Mouth of L. Sound	9
F68	East N. Sound	Fig.1.3-3B	Booby Cay N. Central	3
F69	Rum Point Nearshore	Fig.1.3-3A	100 from Shore	3
F70	NW of N. Sound	Fig.1.3-1A	Edge of Mangrove	3
F71	Little Salt Creek	Fig.1.3-1A	10 from Shore	3
F72	Governers creek	Fig.1.3-2A	100 inside the Creek	3
F73	Safe Heaven	Fig.1.3-2A	10 from Shore	3
F74	Safe Heaven	Fig.1.3-2A	5 from mangrove	1.2
F75	Safe Heaven	Fig.1.3-2A	Near mangrove	10.5
F76	Airport Proper	Fig.1.3-2C	Edge of mangrove	3
F77	Central S. of N. Sound	Fig.1.3-2A		9
F78	Water Cay	Fig.1.3-3A	0 from Shore	0
F79	Rum Point channel	Fig.1.3-3A	5 east of polar	9
F80	Rum Point channel	Fig.1.3-3A	10 west of polar	9
F81	Sand bar	Fig.1.3-3A		3.6
F82	Fishman's Rock	Fig.1.3-3B	20 SW from the Rock	7.5
F83	Main Channel	Fig.1.3-3B		10.5
F84	Stingrey City	Fig.1.3-3B	30 from Reefcrest	6
F85	Stingrey City	Fig.1.3-3B	70 from Reefcrest	7.5
F86	Head of Barkers	Fig.1.3-3B	100 from the Head	0.9
F87	Gun Bluff U. Terrace	Fig.1.9A	200 from Reefcrest	50
F90	Gun Bluff U. Terrace	Fig.1.9A	250 from Reefcrest	70
F91	Gun Bluff U. Terrace	Fig.1.9A	270 from Reefcrest	72
F92	Gun Bluff U. Terrace	Fig.1.9A	200 from Reefcrest	40
F93	Chinese Wall L. Terrace	Fig.1.3-3A	0 from Shelf Edge	90
F94	Chinese Wall L. Terrace	Fig.1.3-3A	100 from Shelf Edge	85
F95	North Wall L. Terrace	Fig.1.3-2A	Lemon Drop off	70
F96	North Wall L. Terrace	Fig.1.3-2A	Lemon Drop off	70
F97	North Wall L. Terrace	Fig.1.3-2A	Lemon Drop off	60
F98	South Sound West	Fig.1.10A	0 from Shore	0
F99	Pedro Castle L. Terrace	Fig.1.3-3C	5 from Shelf Edge	95

Appendix B (continued)

No.	Location	Keys	Distance (m)	Depth (ft)
F100	Black forest L. Terrace	Fig.1.3-1C		70
F101	Black forest L. Terrace	Fig.1.3-1C		75
F102	Pedro Castle L. Terrace	Fig.1.3-3C	10 from Shelf Edge	123
F103	Jackson Pond	Fig.1.3-1A	Central pond	5
F104	Caymarl Pond	Fig.1.3-2B	5 from Shore	6
F105	Hubert Bodden's Pond	Fig.1.3-3C	5 from Shore	6
F106	SE of N. Sound	Fig.1.3-3B	10 m from Shore	6
F107	Jay Bodden's Pond	Fig.1.3-3C	10 m from Shore	6
F108	Greet Bluff lagoon	Fig.1.3-6A	5 from Reefcrest	5.4
F109	Greet Bluff lagoon	Fig.1.3-6A	80 from Reefcrest	5.1
F110	Chinese Wall L. Terrace	Fig.1.3-3A	Chinese wall	92
F111	Greet Bluff lagoon	Fig.1.3-6A	50 from Shore	4.8
F112	Greet Bluff lagoon	Fig.1.3-6A	1 from Shore	0.3
BBP1	Betty Bay Pond South	Fig.1.3-5C	0 from Shore	6
BBP2	Betty Bay Pond North	Fig.1.3-5C	0 from Shore	3
TSP	Tarpon Spring Pond	Fig.1.3-5B	3 from Shore	1.5
MBP1	Meagre Bay Pond South	Fig.1.3-4C	1 from Shore	3
MBP2	Meagre Bay Pond North	Fig.1.3-4C	0 from Shore	3
FCBP	Collisers Bay Pond	Fig.1.3-7B	2 from Shore	3
MP	Malportas Pond	Fig.1.3-5B	1 from Shore	6
CBP	Collisers Bay Pond	Fig.1.3-7B	5 from Shore (core)	