Characterization of Depositional Environments in Isolated Carbonate Platforms Based on Benthic Foraminifera, Belize, Central America

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Tests of benthic foraminifera were analyzed quantitatively in 43 surface sediment samples collected along E–W traverses across the modern isolated carbonate platforms of Glovers Reef (N=14), Lighthouse Reef (N=14), and Turneffe Islands (N=15), offshore Belize, Central America. Water depths of sample stations range from 0 m (beach) to 40 m (fore reef). Each sample was sieved in the size classes 2–1, 1–0.5, 0.5–0.25, and 0.25–0.125 mm (ϕ=1–0, 0–1, 1–2, and 2–3, respectively) and 300 foraminiferal identifications were attempted for each sieve fraction (i.e., 1,200 individuals per sample, totaling 46,003 specimens). Cluster analyses of samples characterized platform environments and distinguished four benthic foraminifera associations. Fore reef samples were characterized by abundant Amphistegina gibbosa *and the occurrence of* Asterigerina carinata, *both rotaliids. In high-energy, marginal-reef areas the encrusting rotaliid* Homotrema rubrum *predominated. Platform-interior environments were marked by a variety of common taxa, the most common of which include Miliolina such as* Archaias angulatus, Quinqueloculina *sp., and* Triloculina *sp., as well as the rotaliid* Cribroelphidium poeyanum, *the latter indicating low-energy or deep-lagoonal regimes. Diversity, expressed as numbers of identified taxa, appears to be a function of relative degree of circulation. The highest number (147) of taxa was found in the shallow, high-energy platform of Lighthouse Reef, followed by Glovers Reef (78), both of which are open to the Caribbean Sea. The lowest number of taxa (66) occurred in Turneffe Islands where large parts of the platform are characterized by the restricted circulation imposed by dense mangrove growth behind platform margins. The occurrence of tests of common foraminiferal species outside their original habitats, coupled with trends towards smaller grain-sizes and better sorting of tests away from original habitats along parts of the sample traverses, indicates sediment transport across platform margins. In the great majority of samples, however, sediment redeposition did not significantly alter characteristic taxonomic compositions. This result has important implications for the use of benthic foraminifera as facies indicators in fossil carbonate platforms.*

INTRODUCTION

Benthic foraminifera have been used repeatedly as facies indicators in both modern and ancient carbonate depositional environments (e.g., Frost and Langenheim, 1974; Hallock and Glenn, 1986). Distribution of modern benthic foraminifera as found in reefal and shallow-water carbonate environments have significantly contributed to the Cenozoic foraminiferal distribution model of Hallock and Glenn (1986). Studies in the Caribbean are numerous (e.g., Hofker, 1964, 1969, 1971, 1976; Bock et al., 1971; Brooks, 1973; Sen Gupta and Schafer, 1973; Rose and Lidz, 1977; Lidz and Rose, 1989), however, the number of investigations in benthic foraminifera on modern isolated carbonate platforms and atolls of the same area is limited. Streeter (1963) investigated the distribution of foraminifera on Great Bahama Bank. Davis (1964) gave a brief report on benthic foraminiferal distribution on the atoll-like Alacran Reef, Campeche Bank. Foraminiferal distribution on deep isolated platforms of the Nicaraguan Rise was studied by Triffleman et al. (1991) and Peebles et al. (1997). Similarly, investigations on the use of foraminifera as tracers of sediment transport in reef and platform systems are limited. Coulbourn and Resig (1975) used population densities of certain taxa to show directions of sediment transport in Kahana Bay, Oahu, Hawaii. More recently, Li (1997) and Li et al. (1997, 1998) investigated live and death distributions of benthic foraminifera among the reefs of Grand Cayman Island. Patterns of textural parameters of foraminiferal tests, such as grain-size and sorting, were used as proxies of sediment transport by these authors.

These studies are particularly important because they provide answers to the questions as to whether foraminiferal distributions in fossil carbonate platforms may be interpreted as reflecting realistic pictures of original distributions of taxa or whether these patterns could have been changed significantly by sediment redeposition. This study presents results concerning both the distribution of tests of benthic foraminifera and the degree of sediment redeposition as seen in the granulo-

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FIGURE 1—Study area and locations of data loggers that were used to record temperature and salinity (Table 1). (a) Location of Belize and the three isolated offshore carbonate platforms. Black dots within Glovers and Lighthouse Reefs are lagoonal patch reefs. Wind data from Gischler and Hudson (1998). Note that a large part of Turneffe Islands is located in the lee of Lighthouse Reef. Depth contours are in meters. (b) Locations of the sediment samples analyzed: MR=Middle Reef, BH=Blue Hole, Turneffe Islands. HJP=Harry Jones Point. Platform interior patch reefs in Glovers and Lighthouse Reefs not shown; only Middle Reef patch reef-trend shown in Lighthouse Reef. All islands shown are mangrove dominated.

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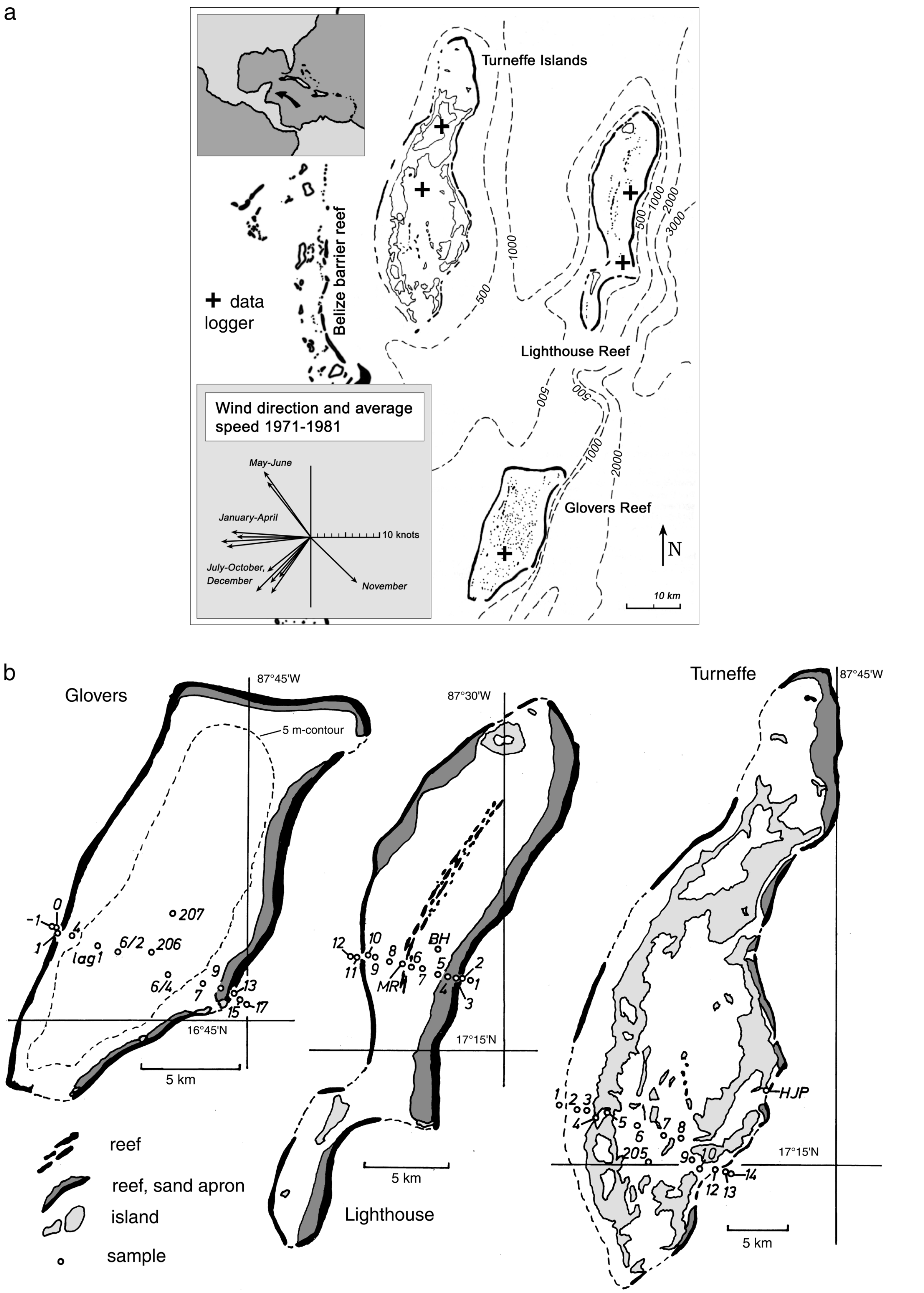

a
Turneffe Islands
Belize barrier reef
data logger
Lighthouse Reef
Glovers Reef
Wind direction and average speed 1971-1981
May-June
January-April
10 knots
July-October, December
November
N
10 km
500
1000
2000
3000
b
Glovers
87°45'W
5 m-contour
16°45'N
5 km
207
6/2
206
lag1
6/4
87°30'W
BH
MR
17°15'N
5 km
Lighthouse
Turneffe
87°45'W
HJP
205
17°15'N
5 km
reef
reef, sand apron
island
sample

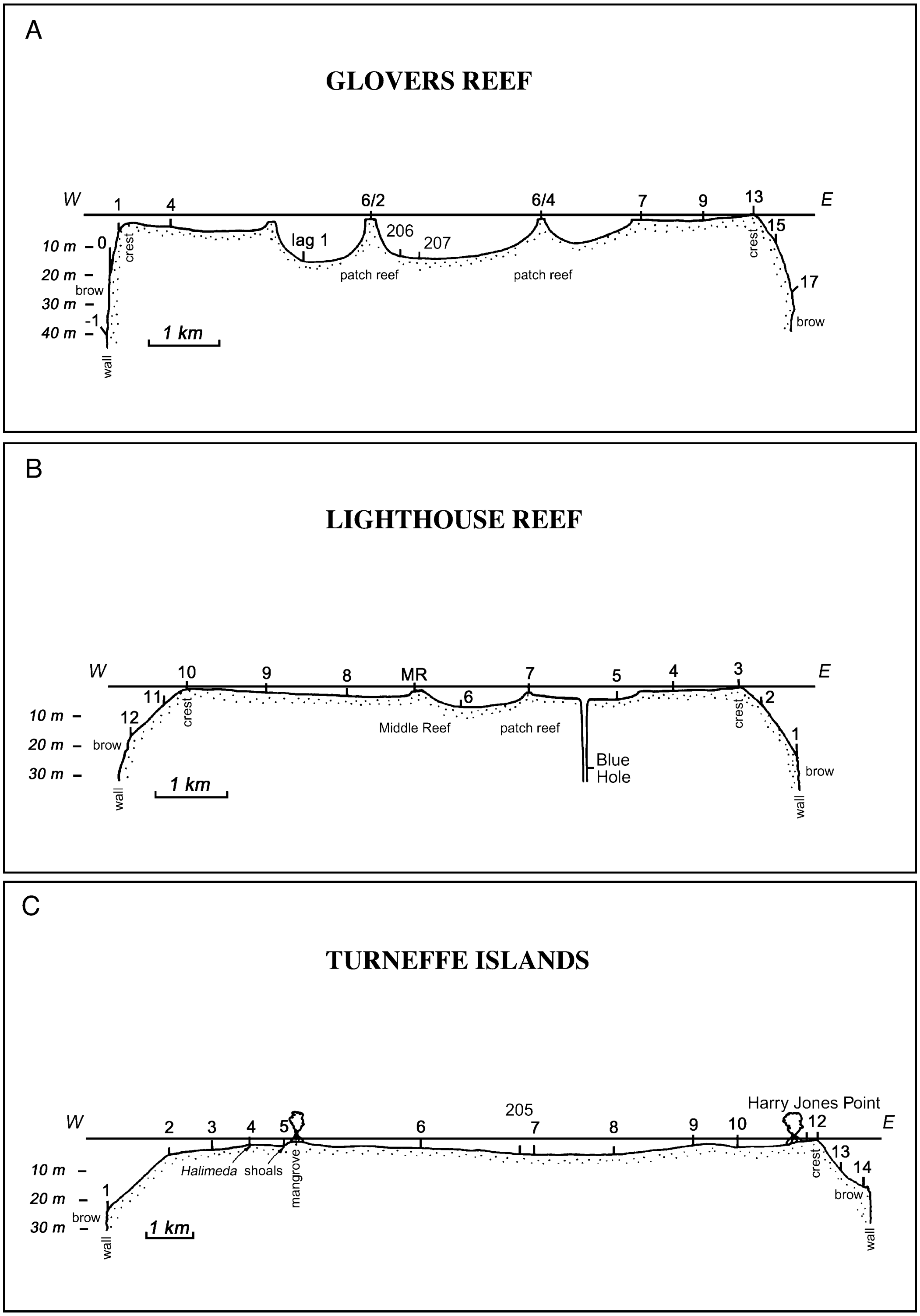


FIGURE 2—Cross-sections through the Belize carbonate platforms along the sample transects. (A) Glovers Reef. (B) Lighthouse Reef. Note positions of Middle Reef and Blue Hole. (C) Turneffe Islands. Note position of Harry Jones Point.

metry of these tests in isolated offshore carbonate platforms of Belize, Central America. These platforms are well-suited for such a study because they include a variety of different reef and platform environments. Also, in combination with the published results from the Belize shelf (Cebulski, 1969; Wantland, 1975), this study provides a detailed picture of distribution of benthic foraminifera in this major Atlantic reef system including nearshore, lagoonal, open-shelf, barrier-reef, and offshore isolated platform environments.

TABLE 1—Bottom-water temperature and salinity ranges in the Belize isolated platform lagoons, as measured from December 2000 to December 2001 on a daily basis using temperature and conductivity data loggers (R. Brancker, model XL210). For locations of loggers see Figure 1.

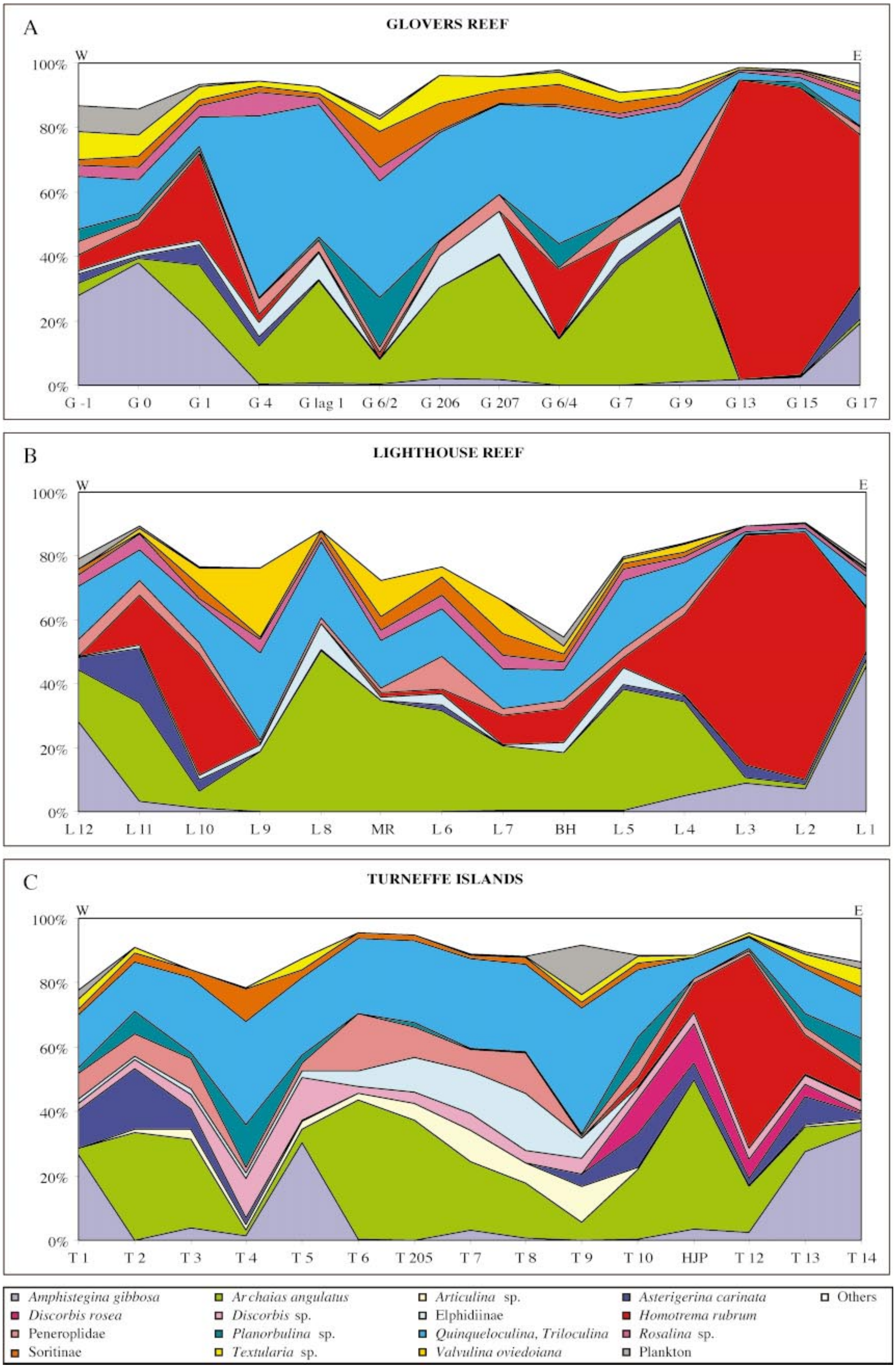
Position	Depth	Temp., °C	δT, °C	Salinity, ‰	δS, ‰
Glovers Reef	10.5 m	23.5–30.4	6.9	38.6–42.0	3.4
Lighthouse Reef N	6.0 m	23.1–29.8	6.7	no data	no data
Lighthouse Reef S	3.0 m	23.9–31.3	7.4	37.7–41.7	3.9
Turneffe Islands N	3.6 m	21.7–31.8	10.1	34.2–42.2	8.0
Turneffe Islands S	7.8 m	22.5–30.8	8.3	37.5–42.5	5.0

TABLE 2—Numbers of foraminifera in sediment fractions of the samples.

Sample number	2–1 mm	1–0.5 mm	0.5–0.25 mm	0.25–0.125 mm	Total (N)
G-1	73	300	300	300	973
G0	228	300	300	300	1128
G1	74	240	107	97	518
G4	12	55	300	300	667
Glag1	168	300	300	300	1068
G6/2	62	300	300	300	962
G6/4	109	300	300	300	1009
G206	218	300	300	300	1118
G207	300	300	300	300	1200
G7	284	300	300	300	1184
G9	300	300	300	300	1200
G13	300	300	300	300	1200
G15	134	300	300	300	1034
G17	300	300	300	300	1200
L1	300	300	300	300	1200
L2	300	300	206	117	923
L3	300	300	300	300	1200
L4	300	300	300	300	1200
L-BH	71	300	300	300	971
L5	169	300	300	300	1069
L6	300	300	300	300	1200
L7	300	300	300	300	1200
L-MR	300	300	300	300	1200
L8	300	300	300	300	1200
L9	286	300	300	300	1186
L10	300	300	300	300	1200
L11	300	300	300	300	1200
L12	270	300	300	300	1170
T1	173	300	300	300	1073
T2	300	300	300	300	1200
T3	300	300	300	300	1200
T4	4	66	168	300	538
T5	13	300	300	300	913
T6	137	300	300	300	1037
T205	70	300	300	300	970
T7	39	300	300	300	939
T8	34	300	300	300	934
T9	0	300	300	300	900
T10	81	300	300	300	981
HJP	300	300	300	300	1200
T12	300	300	300	300	1200
T13	240	300	300	300	1140
T14	298	300	300	300	1198
Total	8647	12361	12481	12514	46003
Average	201	287	290	291	1070

TABLE 3—Environments, water depths, percentages of fine and coase size-fractions of sediment samples, as well as number of taxa and percentages of foraminifera in individual samples. Data, except for numbers of taxa, are from Gischler (1994) and Gischler and Lomando (1999). Deep- and shallow-lagoon environments were distinguished by water depths greater or less than ~5 m, respectively.

Sample	Environment	Depth in m	% <63 µm	% >2 mm	Number of taxa	% Forams in sediment
G-1	fore reef	40	2.4	16.4	57	2.9
G0	fore reef	18	0.9	5.1	60	5.7
G1	reef	4	0.3	7.1	32	0
G4	sand apron	3	9.8	0.3	44	2.9
Glag1	deep lagoon	17	20.8	1.0	47	4.3
G6/2	patch reef	1	0.5	5.0	50	2.6
G6/4	patch reef	1	0.9	5.2	39	0
G206	deep lagoon	18	29.5	1.0	39	8.1
G207	deep lagoon	17	33.1	2.0	40	10.0
G7	sand apron	2	1.6	0.2	46	0
G9	sand apron	2	2.0	0.1	44	2.9
G13	reef	0.5	0.1	15.0	12	2.3
G15	fore reef	11	1.4	8.3	19	5.7
G17	fore reef	27	0.3	18.4	42	4.3
L1	fore reef	13	0	9.4	63	2.9
L2	fore reef	8	0	5.4	31	12.4
L3	reef	0.5	0	8.8	42	10.0
L4	sand apron	2	0.3	1.6	69	6.2
L-BH	Blue Hole, wall	30	0.9	21.0	83	0
L5	deep lagoon	5	12.0	0.4	71	4.3
L6	deep lagoon	7	6.7	12.4	75	3.7
L7	patch reef	3	5.0	9.3	72	5.7
L-MR	patch reef	2	1.8	11.2	66	8.1
L8	shallow lagoon	3	10.2	0.7	52	2.9
L9	shallow lagoon	2	3.9	0.5	67	4.3
L10	reef	1	0.8	5.3	69	3.0
L11	fore reef	7	0.2	1.1	60	5.7
L12	fore reef	18	3.3	5.0	68	8.6
T1	fore reef	23	0.9	8.5	42	3.0
T2	fore reef	5	0.1	7.3	33	5.7
T3	shallow lagoon	3	0.5	3.2	41	9.2
T4	mangrove pond	1	1.2	52.6	40	1.4
T5	mangrove pond	1.5	0.5	60.2	42	0
T6	restricted lagoon	4	16.0	2.5	33	7.2
T205	restricted lagoon	3	6.0	2.4	33	2.1
T7	restricted lagoon	6	13.3	3.7	31	10.9
T8	restricted lagoon	6	1.9	6.7	38	5.7
T9	restricted lagoon	2.5	3.3	6.5	37	7.2
T10	restricted lagoon	3	0.4	8.4	43	4.9
HJP	cay (beach)	0	0.1	1.5	30	7.8
T12	reef	0.5	0	13.8	29	7.2
T13	fore reef	12	0.3	4.0	43	2.9
T14	fore reef	17	3.9	6.5	45	5.7


A
GLOVERS REEF
W
E
100%
80%
60%
40%
20%
0%
G -1 G 0 G 1 G 4 G lag 1 G 6/2 G 206 G 207 G 6/4 G 7 G 9 G 13 G 15 G 17
B
LIGHTHOUSE REEF
W
E
100%
80%
60%
40%
20%
0%
L 12 L 11 L 10 L 9 L 8 MR L 6 L 7 BH L 5 L 4 L 3 L 2 L 1
C
TURNEFFE ISLANDS
W
E
100%
80%
60%
40%
20%
0%
T 1 T 2 T 3 T 4 T 5 T 6 T 205 T 7 T 8 T 9 T 10 HJP T 12 T 13 T 14
Amphistegina gibbosa
Archaias angulatus
Articulina sp.
Asterigerina carinata
Others
Discorbis rosea
Discorbis sp.
Elphidiinae
Homotrema rubrum
Peneroplidae
Planorbulina sp.
Quinqueloculina, Triloculina
Rosalina sp.
Soritinae
Textularia sp.
Valvulina oviedoiana
Plankton

STUDY AREA

Glovers Reef, Lighthouse Reef, and Turneffe Islands (Figs. 1, 2) are small (200–525 km^2) isolated carbonate platforms located to the east of the Belize shelf and barrier reef. Their geomorphology was first described by Stoddart (1962) and their sediment distribution and environments by Gischler (1994) and Gischler and Lomando (1999). Surface-breaking marginal reefs, sloping fore reefs, and wide sand aprons behind the windward reefs are present on all three platforms; however, platform interiors are markedly different. Glovers Reef has an 18 m deep lagoon with more than 860 coral patch reefs. Lighthouse Reef has an 8 m deep eastern and ≥ 3 m deep western part divided by a trend of coalescing coral patch reefs. On both of these platforms, the existence of abundant coral patch reefs, clear water, and light-colored bottom sediment suggests open-marine circulation. Seagrasses *Thalassia testudinum* and *Syringodium filiforme* cover lagoon floors in a patchy manner. The interior lagoons of Turneffe Islands are up to 8 m deep and in contrast are largely surrounded by marginal mangrove areas. Moreover, a low number of coral patch reefs and the presence of both darkly stained bottom sediments and lagoon mangrove rims suggest that restricted circulation characterizes the Turneffe interior lagoons. Lagoon floors are densely covered by the *Thalassia testudinum*.

Belize has a tropical climate with air temperatures from 24–27°C (Purdy et al., 1975), and is in the trade wind belt with winds blowing from E and NE for most of the year (Fig. 1). However, winds from the NW predominate during the winter months. Hurricanes repeatedly hit Belize, mainly from the E and SE (Gischler and Hudson, 1998). Precipitation on the Belize platforms is estimated to be 175 mm/year with May to November being the wettest and February to April being the driest time periods. The tidal range is 30 cm (Stoddart, 1962). Water temperature in the Belize isolated platform lagoons ranges from 23–31°C in Glovers and Lighthouse Reefs and from 22–32°C in Turneffe Islands. Salinity fluctuates from 38.6–42.0‰ in Glovers Reef, from 37.7–41.6‰ in Lighthouse Reef, and from 34.2–42.5‰ in Turneffe Islands (Table 1).

MATERIALS AND METHODS

Foraminifera in thirty-nine surface sediment samples from the study of Gischler (1994) and four surface sediment samples from the work of Gischler and Lomando (1999) were analyzed during the present study. The 43 sediment samples were collected along E–W traverses across the isolated carbonate platforms of Belize by free and/or SCUBA diving. Average abundances of foraminifera in the size-classes >0.125 mm range from 4.8–16.5% as determined by point-counting of thin-sections (Gischler, 1994; Gischler and Lomando, 1999). After washing in a dilute solution of Clorox, the samples were sieved into the size-classes >2, 2–1, 1–0.5, 0.5–0.25, 0.25–0.125, and <0.125 mm.

Three hundred foraminiferal tests were picked whenever possible from each of the four fractions 2–1, 1–0.5, 0.5–0.25, and 0.25–0.125 mm (ϕ=1–0, 0–1, 1–2, 2–3, respectively), for a total of 1,200 tests from each sediment sample (sieve method or standard method of Martin and Liddell, 1988, 1989). In a number of samples, however, the size classes yielded fewer than 300 foraminifera per size class (Table 2). This was particularly the case for the larger size fractions. In the smaller size classes, more than 300 tests were frequently present, necessitating the use of a sample-splitter in order to obtain smaller, statistically similar sub-samples.

According to Patterson and Fishbein (1989) the statistical error depends on the abundance of a taxon and ranges from approximately 1–6% for 300 individuals and from about 0.4–2% for 1,200 specimens. In the present study, 46,003 foraminifera were picked with small brushes and glued onto Plummer-type slides with 60 numbered fields using gelatin (Table 2). Individuals were identified using the standard reference of Loeblich and Tappan (1988a, b) and other literature illustrating shallow-water Caribbean foraminifera (e.g., Streeter, 1963; Hofker, 1964, 1969, 1971, 1976; Bock et al., 1971; Brooks, 1973; Sen Gupta and Schafer, 1973; Rose and Lidz, 1977; Lidz and Rose, 1989; Li, 1997) and foraminifera from the Belize shelf (Cebulski, 1969; Wantland, 1975). Living versus dead individuals were not differentiated because the samples were not stained after collection. Consequently, the foraminiferal distribution patterns represent the potential preservable rock record of foraminifera, not zonations of living taxa. The conspicuous red encrusting rotaliid *Homotrema rubrum* also was included in the analysis because each *Homotrema* fragment certainly would contribute to the potential rock record. Cluster analyses using abundance data (percentages) of foraminifera (linkage: unweighted pair-group average, distance measure: Euclidean) were used to obtain dissimilarity measures between samples and between taxa, and to delineate foraminiferal associations. Mean grain-size and sorting of foraminiferal tests were calculated using the formulas of Folk and Ward (1957).

RESULTS

Abundance, Occurrence, and Diversity of Foraminifera

Foraminiferal abundance in surface sediments of the Belize carbonate platforms averages 4.9% (Table 3). This value is based on point-counting of constituent particles in thin-sections of the sediment size-fraction >125 μm (Gischler, 1994; Gischler and Lomando, 1999). Values are highest in Lighthouse Reef (5.6%), followed by Turneffe Islands (5.4%), and Glovers Reef (3.7%). There appears to be no correlation between foraminiferal abundance and certain reef environments (Table 3). There is also no statistically significant correlation between foraminiferal abundance and water depth ($r = -0.026$; $p<0.870$). There are

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FIGURE 3—Distribution of most common and planktonic (''Plankton'') foraminifera across the carbonate platforms of Belize. *Quinqueloculina* sp. and *Triloculina* sp. have been combined because they have similar patterns of distribution. (A) Glovers Reef. (B) Lighthouse Reef. MR=Middle Reef, BH=Blue Hole. (C) Turneffe Islands. HJP=Harry Jones Point. Note that distances between sample locations are equidistant. For exact distances, please refer to Figure 2.

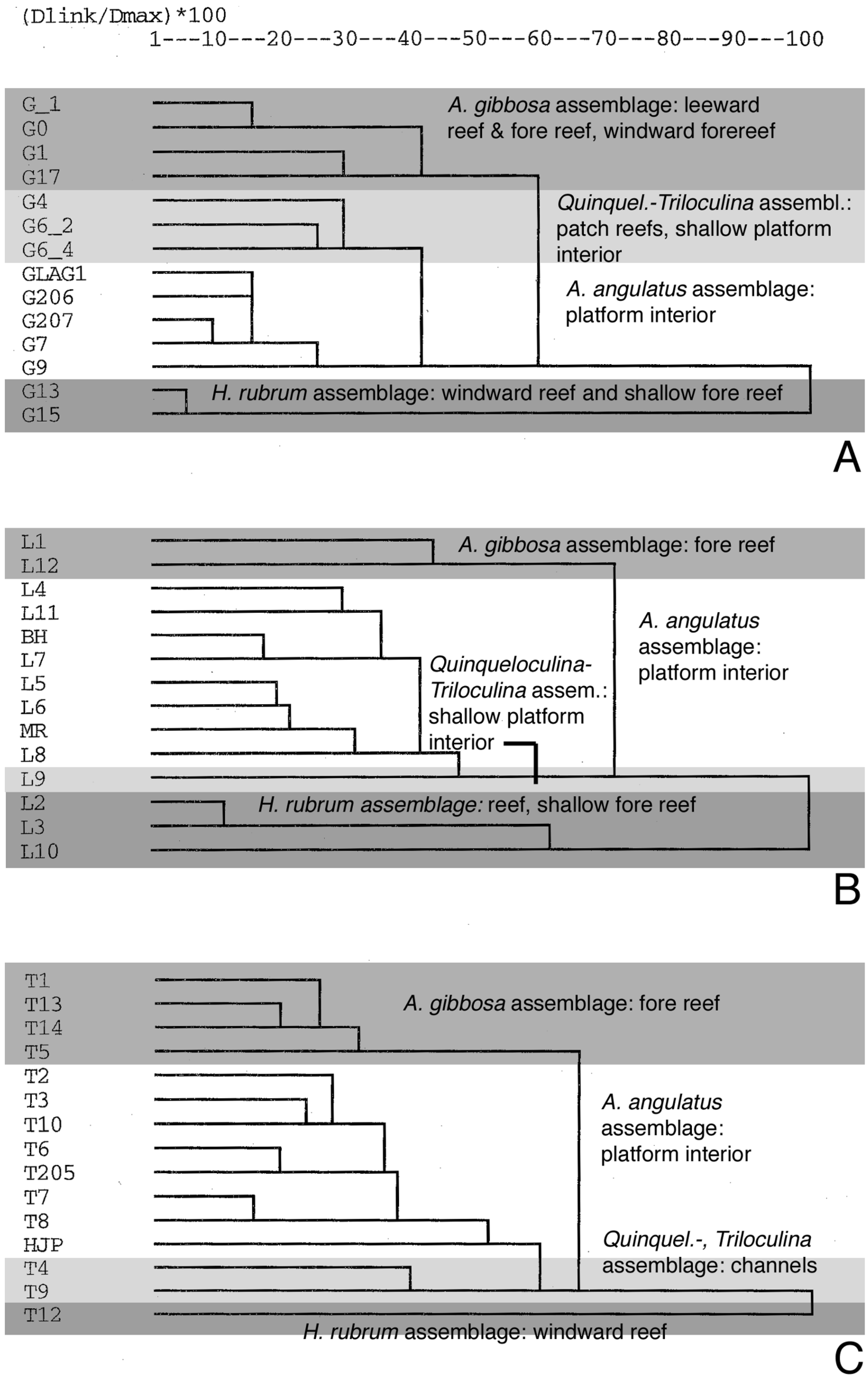

FIGURE 4—Q-mode cluster analysis dendrograms of samples based on abundance data (percentages) of individual taxa in the samples. The data are not normally distributed. Unweighted pair-group average and Euclidean distances were used because they produced the most meaningful dendrogram entities; 0 = minimum dissimilarity; 100 = maximum dissimilarity. Only the most common taxa and ''Plankton,'' shown on Figures 3 and 5, were included in the cluster analysis. ''Others'' were excluded from the analysis. (A) Glovers Reef (N=12). (B) Lighthouse Reef (N=11). (C) Turneffe Islands (N=14).

TABLE 4—Taxonomic composition of foraminiferal assemblages on Glovers Reef.

Homotrema rubrum assemblage		*Amphistegina gibbosa* assemblage	
Homotrema rubrum	91.1%	*Amphistegina gibbosa*	27.0%
Amphistegina gibbosa	2.1%	*Homotrema rubrum*	22.2%
Quinqueloculina sp. and *Triloculina* sp.	2.0%	*Quinqueloculina* sp. and *Triloculina* sp.	8.2%
Rosalina sp.	1.1%	*Textularia* sp.	5.2%
Planorbulina sp.	0.8%	*Asterigerina carinata*	4.7%
Textularia sp.	0.5%	Plankton	4.7%
Archaias angulatus	0.2%	*Archaias angulatus*	4.4%
Others	2.0%	*Rosalina* sp.	3.3%
		Peneroplidae	2.6%
		Soritinae	1.8%
		Planorbulina sp.	1.8%
		Elphidiinae	0.9%
		Others	13.3%
N = 2,234		N = 3,819	
***Archaias angulatus*-*Quinqueloculina*-*Triloculina* assemblage**		***Quinqueloculina*–*Triloculina* assemblage**	
Archaias angulatus	37.4%	*Quinqueloculina* sp. and *Triloculina* sp.	43.5%
Quinqueloculina sp. and *Triloculina* sp.	29.9%	*Archaias angulatus*	11.2%
Elphidiinae	8.3%	*Homotrema rubrum*	9.4%
Peneroplidae	5.6%	*Planorbulina* sp.	8.1%
Soritinae	4.0%	Soritinae	6.6%
Textularia sp.	4.0%	*Rosalina* sp.	3.7%
Rosalina sp.	1.2%	*Textularia* sp.	3.5%
Amphistegina gibbosa	1.1%	Peneroplidae	2.1%
Asterigerina carinata	0.6%	Elphidiinae	1.2%
Homotrema rubrum	0.3%	*Asterigerina carinata*	0.9%
Planorbulina sp.	0.3%	Plankton	0.6%
Others	7.4%	*Amphistegina gibbosa*	0.2%
		Others	9.0%
N = 5,570		N = 2,638	

TABLE 5—Taxonomic composition of foraminiferal assemblages on Lighthouse Reef.

Homotrema rubrum assemblage		*Amphistegina gibbosa* assemblage	
Homotrema rubrum	61.3%	*Amphistegina gibbosa*	37.0%
Amphistegina gibbosa	5.6%	*Quinqueloculina* sp. and *Triloculina* sp.	13.0%
Quinqueloculina sp. and *Triloculina* sp.	5.1%	*Archaias angulatus*	9.2%
Archaias angulatus	3.0%	*Homotrema rubrum*	7.0%
Asterigerina carinata	3.0%	*Asterigerina carinata*	3.3%
Valvulina oviedoiana	2.0%	Peneroplidae	2.7%
Soritinae	1.6%	*Rosalina* sp.	2.6%
Peneroplidae	1.6%	Soritinae	2.5%
Rosalina sp.	1.4%	Plankton	2.4%
Elphidiinae	0.5%	Elphidiinae	1.0%
Plankton	0.3%	*Valvulina oviedoiana*	0.2%
Others	14.6%	Others	19.2%
N = 3,323		N = 2,370	
***Archaias angulatus*-*Quinqueloculina*-*Triloculina* assemblage**		***Quinqueloculina*-*Triloculina* assemblage**	
Archaias angulatus	32.1%	*Quinqueloculina* sp. and *Triloculina* sp.	27.0%
Quinqueloculina sp. and *Triloculina* sp.	15.1%	*Valvulina oviedoiana*	21.3%
Homotrema rubrum	8.2%	*Archaias angulatus*	18.9%
Valvulina oviedoiana	4.2%	*Rosalina* sp.	2.3%
Peneroplidae	3.6%	Elphidiinae	2.0%
Soritinae	3.1%	Peneroplidae	0.8%
Rosalina sp.	3.1%	Soritinae	0.8%
Asterigerina carinata	3.0%	*Homotrema rubrum*	0.4%
Elphidiinae	2.8%	*Asterigerina carinata*	0.2%
Amphistegina gibbosa	1.2%	*Amphistegina gibbosa*	0.1%
Plankton	0.5%	Others	26.2%
Others	23.1%		
N = 9,240		N = 1,186	

weak correlations, however, between abundance and amount of the coarse size-fraction >2 mm ($r = -0.34$; $p<0.027$) and between abundance and amount of fine sediment <63 μm ($r = +0.29$; $p<0.057$).

A total of 163 foraminiferal taxa have been identified on the Belize platforms in this study. Occurrence of all foraminiferal taxa in each grain-size category in each sample was recorded, and these raw data are available in electronic form from the PALAIOS data pages (http://www.ngdc.noaa.gov/mgg/sepm/archive). Appendix 1 records the distribution of foraminifera from Glovers Reef, Appendix 2 records distribution of foraminifera from Lighthouse Reef, and Appendix 3 records distribution of foraminifera from Turneffe Islands.

The highest number of foraminiferal taxa are present in Lighthouse Reef (147 identified taxa) and the lowest in Turneffe Islands (66 identified taxa). Glovers Reef is intermediate with 78 taxa identified. The average number of taxa per sample is 47.0 (Table 3). Mean values are highest in Lighthouse Reef (63.4), followed by Glovers Reef (40.8), and Turneffe Islands (37.3). There are no statistically significant correlations between number of taxa in individual samples and water depth ($r = +0.23$; $p<0.137$), between number of taxa and amount of fine-grained sediment in the samples ($r = -0.04$; $p<0.780$), or between number of taxa and foraminiferal abundance ($r = -0.16$; $p<0.320$). There is a discernible trend, however, in that numbers of foraminiferal taxa in individual samples are lowest in samples from reef crests and shallow fore reef environments (Table 3).

Distribution of Foraminifera

Distribution of the most-common foraminiferal taxa is shown on Figure 3. These taxa occur in mean abundances exceeding 1.5–2.0% and are characteristic of certain platform environments. On Glovers Reef, these include *Archaias angulatus*, *Asterigerina carinata*, *Amphistegina gibbosa*, Elphidiinae, *Homotrema rubrum*, *Quinqueloculina* sp. and *Triloculina* sp. (undifferentiated), Peneroplidae, *Planorbulina* sp., *Rosalina* sp., Soritinae, and *Textularia* sp. (N=11). On Lighthouse Reef, these include *Archaias angulatus*, *Asterigerina carinata*, *Amphistegina gibbosa*, *Homotrema rubrum*, Elphidiinae, Peneroplidae, *Quinqueloculina* sp. and *Triloculina* sp. (undifferentiated), Soritinae, *Rosalina* sp., and *Valvulina oviedoiana* (N=10). On Turneffe Islands, the most common taxa are *Archaias angulatus*, *Asterigerina carinata*, *Amphistegina gibbosa*, *Articulina* sp., *Discorbis* sp., *Discorbis rosea*, Elphidiinae, *Homotrema rubrum*, Peneroplidae, *Planorbulina* sp., *Quinqueloculina* sp. and *Triloculina* sp. (undifferentiated), Soritinae, and *Textularia* sp. (N=13).

Amphistegina gibbosa and *Asterigerina carinata* char-

TABLE 6—Taxonomic composition of foraminiferal assemblages on Turneffe Islands.

Homotrema rubrum assemblage		*Amphistegina gibbosa* assemblage	
Homotrema rubrum	60.3%	*Amphistegina gibbosa*	29.6%
Archaias angulatus	14.3%	*Quinqueloculina* sp. and *Triloculina* sp.	16.4%
Discorbis rosea	5.8%	*Asterigerina carinata*	5.7%
Discorbis sp.	3.6%	*Homotrema rubrum*	5.6%
Quinqueloculina sp. and *Triloculina* sp.	3.3%	*Discorbis* sp.	4.9%
Amphistegina gibbosa	2.4%	*Planorbulina* sp.	4.3%
Asterigerina carinata	2.3%	*Archaias angulatus*	4.1%
Textularia sp.	1.1%	*Textularia* sp.	3.9%
Peneroplidae	0.9%	Peneroplidae	3.7%
Planorbulina sp.	0.8%	Soritinae	2.4%
Soritinae	0.3%	*Discorbis rosea*	1.3%
Articulina sp.	0.2%	Plankton	1.3%
Plankton	0.1%	Elphidiinae	1.0%
Others	4.5%	*Articulina* sp.	0.9%
		Others	14.8%
N = 1,200		N = 4,324	
Archaias angulatus-Quinqueloculina-Triloculina **assemblage**		***Quinqueloculina-Triloculina*** **assemblage**	
Archaias angulatus	31.6%	*Quinqueloculina* sp. and *Triloculina* sp.	36.4%
Quinqueloculina sp. and *Triloculina* sp.	20.8%	Plankton	9.7%
Peneroplidae	8.6%	*Articulina* sp.	7.7%
Elphidiinae	5.8%	*Discorbis* sp.	7.4%
Asterigerina carinata	5.6%	*Planorbulina* sp.	5.4%
Discorbis rosea	4.8%	Soritinae	5.0%
Discrobis sp.	4.8%	Elphidiinae	4.7%
Articulina sp.	3.2%	*Archaias angulatus*	4.0%
Planorbulina sp.	2.3%	*Asterigerina carinata*	3.3%
Soritinae	1.8%	*Textularia* sp.	1.5%
Homotrema rubrum	1.6%	Peneroplidae	0.9%
Amphistegina gibbosa	1.5%	*Amphistegina gibbosa*	0.6%
Textularia sp.	0.7%	Others	13.3%
Others	9.8%		
N = 8,461		N = 1,438	

acterize the fore-reef environment. *Amphistegina gibbosa* is also abundant in one of the samples (T5) from the leeward mangrove rim in Turneffe Islands (Fig. 3C). The high-energy windward margins and shallow fore-reef areas of all three platforms, and the leeward margins of Glovers and Lighthouse Reefs, are characterized by a predominance of the encrusting rotaliid *Homotrema rubrum*. On Turneffe Islands, *Discorbis rosea* is also abundant on the windward margin. The leeward margin of that same platform, however, shows no *Homotrema*-predominance as seen in Glovers and Lighthouse Reefs, which reflects the absence of a shallow-water, high-energy, reef-margin environment. The most common taxa in platform interiors include *Archaias angulatus*, other soritid genera such as *Sorites* and *Amphisorus*, peneroplids, and hauerinid genera such as *Quinqueloculina* and *Triloculina*. Low-energy environments in all platforms are characterized by Elphidiinae, especially by *Cribroelphidium poeyanum*. Whereas *Articulina* is common only in the interior of Turneffe Islands, abundant *Rosalina* and *Textularia* are found only in Glovers and Lighthouse interior lagoons. Additionally, *Valvulina oviedoiana* is common in the interior of Lighthouse Reef.

Q-mode cluster analyses of samples were made for each platform in order to measure dissimilarity between samples and to test whether or not platform depositional environments can be characterized by specific foraminiferal assemblages (Fig. 4). Interestingly, cluster analyses using all identified taxa and analyses based on only the 10–13 most commonly occurring taxa listed above produced similar dendrograms, suggesting that depositional environments in the Belize carbonate platforms may be characterized by a few abundant foraminifers.

In Glovers Reef, there is a separation into four dendrogram entities (Fig. 4A). High-energy samples from the windward reef and shallow fore reef (G13, G15) have abundant *H. rubrum*. Leeward fore-reef and deep windward fore-reef samples (G–1, G0, G1, G17) are characterized by elevated numbers of *A. gibbosa*. Among platform interior sediments, samples from patch reefs (G6–2, G6–4) and from the shallow leeward platform interior (G4) that contain abundant *Quinqueloculina* and *Triloculina* form one dendrogram entity. Deep lagoon-floor (Glag1, G206, G207) and windward sand-apron samples (G7, G9), which have high numbers of *Quinqueloculina*, *Triloculina*, *A. angulatus*, and Elphidiinae, form another cluster.

In Lighthouse Reef, there are four dendrogram entities as well (Fig. 4B). Samples from the deeper fore reef (L1, L12) are characterized by abundant *A. gibbosa*, whereas samples from the reef margin (L3, L10) and shallow fore reef (L2) are predominated by the encruster *H. rubrum*. Platform-interior samples (L5–L8, BH, MR) have abundant *A. angulatus*, *Quinqueloculina*, *Triloculina*, Elphidiinae, and *V. oviedoiana*. Samples L4 and L11 contain foraminifers indicative of both the lower-energy platform interior (e.g., *A. angulatus*, *Quinqueloculina*, *Triloculina*) and the marginal and high-energy environments (e.g., *H. rubrum*, *A. gibbosa*, *A. carinata*) as a result of sediment transport. Sample L9 forms a fourth cluster with *Quinqueloculina* and *Triloculina* being most abundant.

In Turneffe Islands, windward reef sample T12 with abundant *H. rubrum* forms one dendrogram entity (Fig. 4C). Fore-reef samples (T1, T13, T14) build another cluster characterized by the occurrence of *A. gibbosa*, *A. carinata*, and *H. rubrum*. Sample T5 from the leeward mangrove rim falls into the same cluster because of the abundance of *A. gibbosa*. Lower-energy, platform-interior lagoon samples form a third cluster. Samples T6, T7, T8, T205, and T3, the latter of which comes from the lagoon-like area west of the leeward mangrove rim, form a fourth cluster that is characterized by *A. angulatus*, peneroplids, Elphidiinae, and *Articulina*. Samples T2, T10, and HJP contain a mixture of marginal (e.g., *A. carinata*, *H. rubrum*, *D. rosea*) and platform interior (e.g., *A. angulatus*) taxa reflecting sediment transport. Samples T4 and T9 from channels through mangrove rims have elevated abundances of *Quinqueloculina* and *Triloculina*.

Foraminiferal Assemblages

Based on cluster analyses (Fig. 4), four foraminiferal assemblages are recognized in the Belize carbonate platforms (Tables 4–6). Results of r-mode cluster analyses, which show relationships between taxa, using the same data matrix (10–13 most-common foraminiferal taxa), confirm the results of the Q-mode analyses. The taxa *A. gibbosa*, *H. rubrum*, *A. angulatus*, as well as *Quinqueloculina* and *Triloculina* form

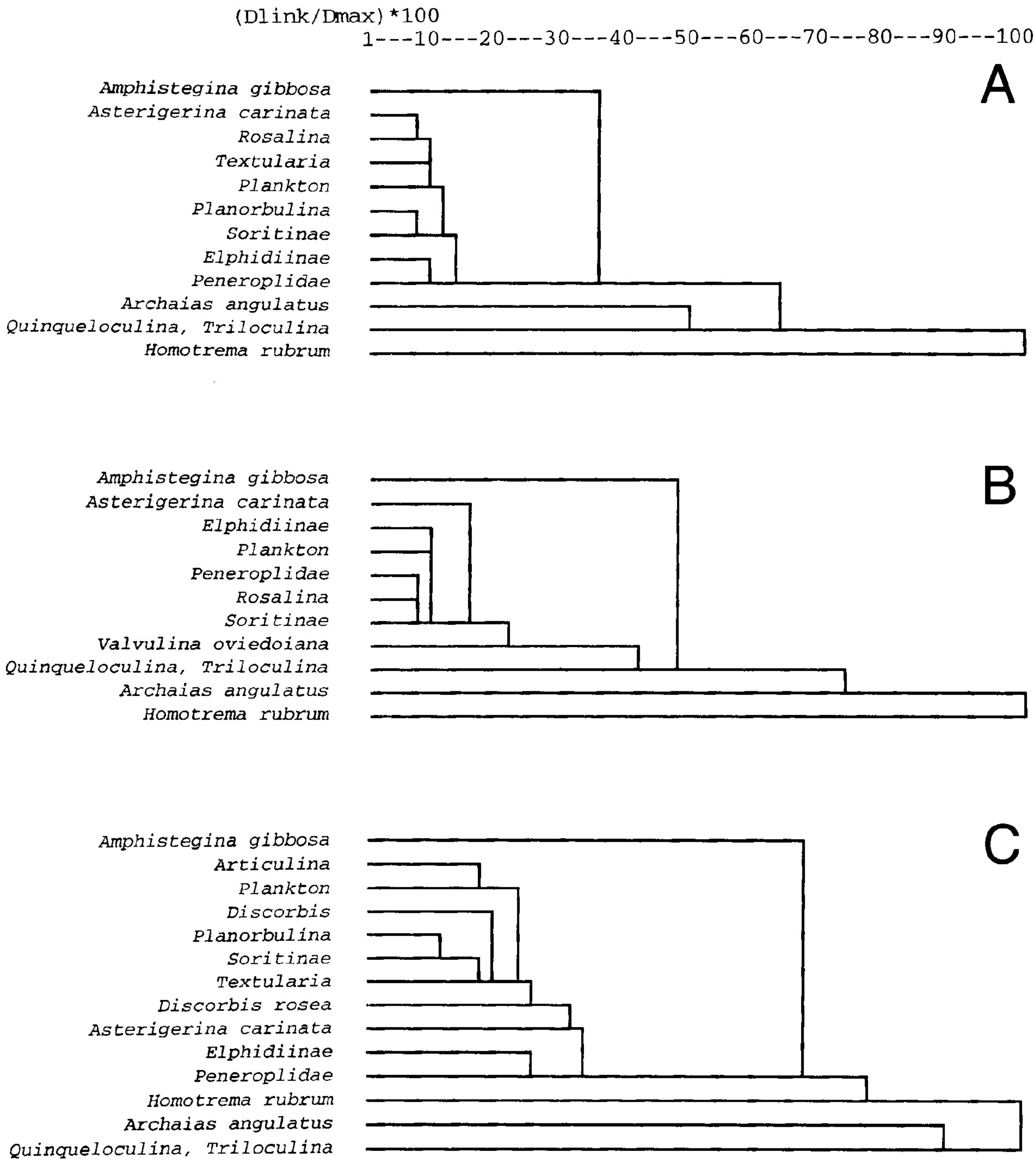

FIGURE 5—R-mode cluster analysis dendrograms of taxa based on the same data matrix as used for Q-mode analyses (see Fig. 4). "Plankton"=planktonic foraminifera. *Quinqueloculina* sp. and *Triloculina* sp. have been combined as they have similar patterns of distribution. (A) Glovers Reef (N=12). (B) Lighthouse Reef (N=11). (C) Turneffe Islands (N=14).

well-defined dendrogram entities, whereas the other common taxa exhibit significantly lower dissimilarity (Fig. 5). Each foraminiferal assemblage is characterized by the abundance of one to three different taxa.

Amphistegina gibbosa assemblage: The *Amphistegina gibbosa* assemblage is characteristic of the fore-reef environment. *Amphistegina gibbosa* reaches abundances of 27–37% on the platforms (Tables 4–6). *Quinqueloculina* sp. and *Triloculina* sp. are the second most common taxa in this assemblage. *Homotrema rubrum* also may be common (5.6–22.2%). *Asterigerina carinata* is present and reaches abundances of 3.3–5.7%. Planktonic forms and *Textularia* are abundant on Glovers Reef; *Archaias angulatus* is abundant on Lighthouse Reef in this assemblage.

Homotrema rubrum assemblage: High abundances (60–90%) of the red encrusting foram *H. rubrum* characterize the *Homotrema rubrum* assemblage, which is indicative of the high-energy platform margins. Other common taxa in

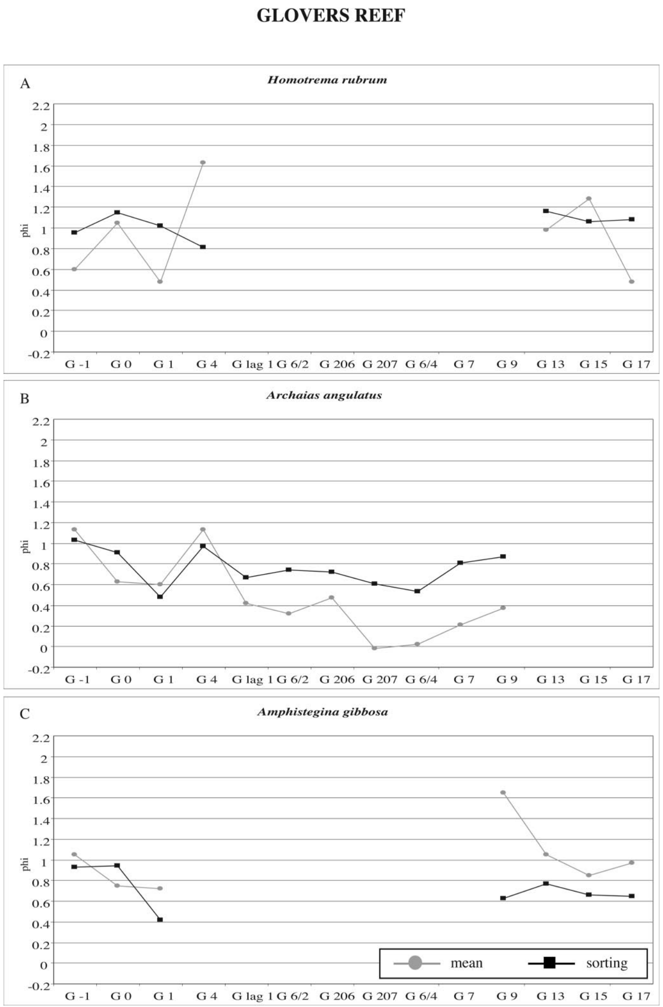

FIGURE 6—Mean and sorting of some common foraminifera along the Glovers Reef transect. (A) *Homotrema rubrum*. (B) *Archaias angulatus*. (C) *Amphistegina gibbosa*.

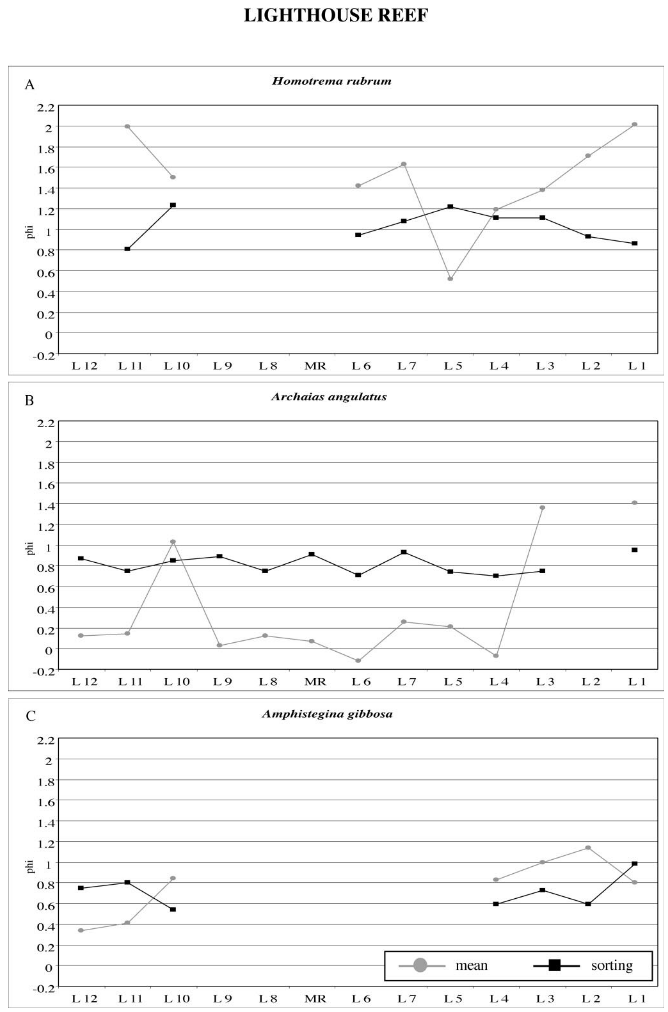

FIGURE 7—Mean and sorting of some common foraminifera along the Lighthouse Reef transect. (A) *Homotrema rubrum*. (B) *Archaias angulatus*. (C) *Amphistegina gibbosa*.

this assemblage include *A. gibbosa*, *A. angulatus*, *Discorbis rosea*, *Quinqueloculina* sp., and *Triloculina* sp., as well as *Discorbis* sp. in Turneffe Islands.

Archaias angulatus-Quinqueloculina-Triloculina assemblage: The *Archaias angulatus-Quinqueloculina-Triloculina* assemblage indicates platform interiors. It generally characterizes rather low-energy areas, but may also extend to higher-energy areas such as the windward sand aprons on Glovers and Lighthouse Reefs, and to the channels through the windward mangrove rim and the windward beaches on Turneffe Islands. The three nominate taxa predominate with *A. angulatus* being most abundant (32–37%) (Tables 4–6). Other common foraminifera are *Cribroelphidium poeyanum*, Soritinae, Peneroplidae, *H. rubrum*, and *Valvulina oviedoiana* on Lighthouse Reef, as well as *Discorbis* sp. and *A. carinata* on Turneffe Islands.

Quinqueloculina-Triloculina assemblage: The *Quinqueloculina-Triloculina* assemblage also is characteristic of platform interiors, however, it is not as well defined as the other three assemblages. The assemblage appears to characterize patch reefs and carbonate shoals. Other common taxa aside from *Quinqueloculina* and *Triloculina*, which reach abundances of 27–44%, include *A. angulatus*, *H. rubrum*, *Planorbulina* sp., and Soritinae on Glovers Reef, *V. oviedoiana* and *A. angulatus* in Lighthouse Reef, and planktonic forms, *Articulina* sp., and *Discorbis* sp. in Turneffe Islands (Tables 4–6).

Granulometry of Foraminiferal Tests

Trends in mean grain-size and sorting of tests of selected common species such as *A. gibbosa* (most common in the fore reef), *H. rubrum* (most common in the reef environment), and *A. angulatus* (most common in platform interior) are shown on Figures 6–8. *Amphistegina gibbosa* shows a trend of improved sorting away from its original habitat in the fore reef towards the reef, back reef, and platform interior. Mean grain-size is usually smaller in platform-interior areas, however, there is no clear trend on the leeward sides of Glovers Reef and Turneffe Islands. *Archaias angulatus* shows no sorting trend along the sample transects. Even so, mean grain-sizes are usually greater in the original habitat, the platform interior, as compared to the reef and fore-reef areas. Within its narrow range of occurrence, *H. rubrum* exhibits

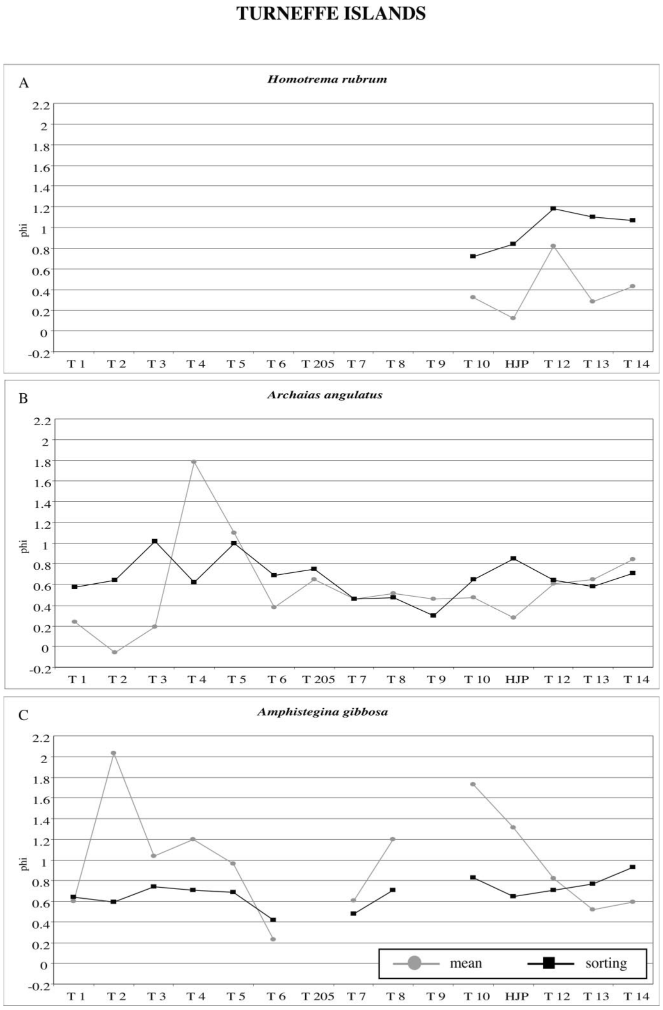

FIGURE 8—Mean and sorting of some common foraminifera along the Turneffe Islands transect. (A) *Homotrema rubrum*. (B) *Archaias angulatus*. (C) *Amphistegina gibbosa*.

trends towards better sorting away from its habitat of high-energy reef crests. *Homotrema* fragments do not show clear trends in grain-size distribution.

DISCUSSION

Occurrence and distribution of the most common foraminifera in the Belize isolated carbonate platforms (see Fig. 3) are comparable to other Caribbean shallow-water locations. Symbiont-bearing porcellaneous Miliolina and hyaline Rotaliina are the most abundant foraminifera (compare Davis, 1964; Hallock, 1984; Hallock and Peebles, 1993). Among these, *Amphistegina gibbosa* and *Asterigerina carinata* are characteristic of Caribbean fore-reef slope environments (Martin and Liddell, 1988; Li et al., 1998). *Archaias angulatus* is the most abundant form in lower-energy back-reef and lagoonal areas of the Belize platforms, and is present, for example, around Barbuda (Brasier, 1975), in south Florida (Martin, 1986), Discovery Bay, Jamaica (Martin and Liddell, 1988, 1989), and around Grand Cayman (Li and Jones, 1997; Li et al., 1997, 1998). *Discorbis rosea*, which is present in the windward side of Turneffe Islands, is usually found in similar Caribbean higher-energy environments (Streeter, 1963; Li et al., 1977), including tops of submerged carbonate platforms on the Nicaraguan Rise that are affected by strong currents (Triffleman et al., 1991; Peebles et al., 1997). *Cribroelphidium*, which is characteristic of low-energy lagoonal settings on the Belize platforms, is common in similar depositional environments in the Caribbean, such as on the Belize shelf (Cebulski, 1969; Wantland, 1975) and in the Gulf of Batabano, Cuba (Bandy, 1964). *Homotrema rubrum* is well known for its abundance in high-energy and cryptic Caribbean reef- and platform-margin habitats (Streeter, 1963; Murray, 1991; Gischler and Ginsburg, 1996).

Murray (1991, p. 96) defined two lagoonal associations for the Gulf of Mexico and Caribbean Sea—an *Archaias angulatus*-association and a *Quinqueloculina* spp. association—that correspond to the two platform-interior assemblages defined in this study. Both assemblages reflect a 9–38°C temperature range, water depths <12 m, and substrates of turtle grass, carbonate sands and muds (Murray, 1991). However, the salinity range given by the same author for the *A. angulatus*-association, is much narrower (34–37‰) than for the *Quinqueloculina* spp. association (10–47‰). The Belize salinity data indicate that *A. angulatus* may thrive in salinities from 34–42‰ (Table 1). For the open shelf, slope, and deep sea of the Gulf of Mexico and Caribbean Sea, Murray (1991, p. 104) delineated an *Asterigerina carinata* association, which corresponds to the Belize *Amphistegina gibbosa* assemblage in the fore reef. Environmental parameters include temperatures of 18–31°C, a narrow salinity range from 35–37‰, water depths below 12 m, and sandy substrates.

Comparing foraminiferal distribution across the three carbonate platforms reveals mainly similarities. However, there also are certain differences, which remain to a large part enigmatic. For example, *Discorbis rosea* is quite common on the windward margin of Turneffe Islands, but not on the other two platforms. *Valvulina oviedoiana* is much more common in the interior of Lighthouse Reef as compared to Glovers Reef and Turneffe Islands. Hauerinids such as *Quinqueloculina* and *Triloculina* are more abundant in the interior lagoon of Glovers Reef than in Lighthouse Reef and Turneffe Islands. The abundance of these forms in the Glovers Reef lagoon was observed previously by Wallace and Schafersman (1977) in their study of patch reefs and areas surrounding patch-reefs on the same platform. The abundance of *Homotrema rubrum* on the windward margin of Turneffe Islands is not as prominent as on the other two platforms. This observation, however, is a consequence of the fact that Turneffe Islands is protected largely by Lighthouse Reef to the east, whereas Glovers and Lighthouse Reefs are open to the Caribbean Sea. Furthermore, *Homotrema* is not present on the leeward margin of Turneffe Islands (T1, T2) because shallow, surface-breaking marginal reefs are developed here only rarely.

Differences in foraminiferal diversity, as seen in numbers of identified taxa among the three Belize platforms, may be explained by variations in circulation, salinity, temperature, and in habitat diversity. Lighthouse Reef has the highest number of foraminiferal taxa (147) and appears to have active circulation because the platform is open to the Caribbean Sea and its interior is relatively shallow. Annual salinity and temperature variations amount to 3.9‰ and 7.4°C, respectively (Table 1). Glovers Reef, which is intermediate with regard to identified taxa (78), also is open to the Caribbean Sea. Because this platform has a deep interior lagoon, circulation is probably slightly reduced as compared to Lighthouse Reef. Measured annual salinity and temperature variation are comparable to Lighthouse Reef, reaching 3.4‰ and 6.9°C, respectively (Table 1). A large part of Turneffe Islands, which exhibits the lowest numbers of foraminiferal taxa (66), is protected from the Caribbean Sea by Lighthouse Reef to the east, and the interior lagoons probably have sluggish circulation because of the presence of marginal mangrove rims (Fig. 1). Annual salinity and temperature variations are as high as 10.1‰ and 8.0°C, respectively (Table 1). Thus, lagoonal salinity fluctuations that influence foraminiferal distribution are significantly stronger in Turneffe Islands as compared to Lighthouse and Glovers Reefs. On the Belize shelf, Wantland (1975) found that highest diversities of benthic foraminifera occurred in well-circulated areas of normal and constant marine salinities. Conversely, low diversities were encountered in variable or low-salinity environments with restricted circulation. Recently, Bicchi et al. (2002) also found a positive correlation between the degree of lagoonal circulation and benthic foraminiferal species richness in the lagoons of ten small atolls in the Tuamoto Archipelago. Finally, habitat diversity might be another factor controlling diversity differences among the Belize platforms. With the existence of variably vegetated lagoon floors and coral patch reefs, Glovers Reef and Lighthouse Reef have relatively higher habitat diversities as compared to Turneffe Islands, the lagoon of which is covered by *Thalassia* throughout and which largely lacks reefs.

Combining data from Wantland (1975) from the Belize shelf with this study, the entire spectrum of foraminiferal distribution in this major Atlantic reef system is visible. On the southern Belize shelf, Wantland (1975) delineated a nearshore *Quinqueloculina-Cribroelphidium* assemblage in quartzose muddy sands in shallow water with less than normal-marine salinity. Large parts of the deeper, offshore shelf lagoon are covered by low-diversity and high-diversity *Cribroelphidium* assemblages, which reflect normal-marine salinity, low energy, and somewhat restricted regimes. On the shallow northern Belize shelf and southern part of Chetumal Bay, which has variable salinities, a low-diversity miliolid assemblage with common genera *Heterillina* and *Triloculina* predominates. From north to south, the barrier-reef platform is characterized by a high-diversity miliolid assemblage with *Quinqueloculina* and *Triloculina* predominating. Samples from the outer shelf edge have abundant *Archaias angulatus* and *Asterigerina carinata*. Only these two latter assemblages, which are present in shallow, normal-marine, clear waters with pure carbonate sedimentation, are somewhat similar to the assemblages found within the offshore isolated carbonate platforms of Belize.

There are several indications of transport of foraminiferal tests across platform margins. First, there are trends towards smaller grain-sizes and higher degrees of sorting away from original habitats in selected common species such as *A. gibbosa*, *H. rubrum*, and *A. angulatus* (Figs. 6–8). In general, sorting is poorest in the original habitat where all sizes of foraminifers occur. Smaller tests are preferentially winnowed away from original habitats, and tests become better sorted away from their point of origin. Li et al. (1997, 1998) made similar observations around the island of Grand Cayman. Sorting trends are better defined in the Li et al. (1997) study, probably reflecting the much shorter distances between samples as compared to our study. Second, some common foraminifers also occur outside their typical habitats. Examples are the presence of *H. rubrum*, *A. gibbosa*, and *A. carinata* in eastern platform-interior areas, and the occurrences of *A. angulatus*, hauerinids, and *Elphidium* in leeward fore-reef environments (Fig. 3), indicating eastward transport with the prevailing trade winds. Sediment movement towards the east as seen in low numbers of platform-interior species such as *A. angulatus*, *Quinqueloculina*, and *Triloculina* in windward fore-reef areas, occurs to some degree, probably during the winter months when winds blow predominantly from the NW (Fig. 1). It has to be stressed, however, that portions of transported tests in individual samples are generally low as compared to tests that were not transported, so that characteristic taxonomic compositions of individual samples are usually only slightly to moderately altered. Mixing of taxa originating from marginal and platform-interior environments led to significant changes in characteristic taxonomic compositions (Figs. 3, 4) in only five marginal samples (L4, L11, T2, T10, HJP) from Lighthouse Reef and Turneffe Islands.

CONCLUSIONS

Marginal and interior depositional environments of the three isolated carbonate platforms of Belize are characterized by 10–13 common benthic foraminifera, the most common of which include *Amphistegina gibbosa* in the fore reef, *Homotrema rubrum* in the high-energy marginal areas, and *Archaias angulatus*, *Quinqueloculina* sp., and *Triloculina* sp. in platform interiors.

Following the above, four characteristic foraminiferal assemblages can be differentiated. These are the fore-reef *Amphistegina gibbosa* assemblage, the reef-margin *Homotrema rubrum* assemblage, and the platform-interior *Archaias angulatus-Quinqueloculina-Triloculina* and *Quinqueloculina-Triloculina* assemblages.

Occurrence, grain-size, and sorting of three common species of foraminifera in the Belize carbonate platforms indicate sediment transport around the platform margins to some degree, predominantly from east to west. Mixing of marginal and platform-interior foraminiferal taxa is significant only in five samples from the platform margins of the Lighthouse and Turneffe platforms. This finding has important implications for studies investigating foraminiferal distributions in fossil carbonate platforms.

Diversity of benthic foraminifera appears to be a function of circulation and salinity fluctuations as the most-exposed platform exhibits the highest numbers of taxa, whereas the least-exposed platform has the lowest number of taxa. Another controlling factor of foraminiferal diversity might be habitat diversity, which is higher in Glovers and Lighthouse Reefs as compared to Turneffe Islands.

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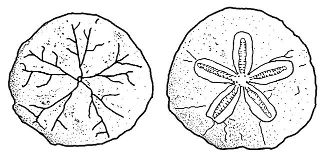

APPENDIX 1

Distribution of foraminifera in samples from Glovers Reef. Numbers are in %.

	G −1	G 0	G 1	G 4	G lag 1	G 6/2	G 6/4	G 206	G 207	G 7	G 9	G 13	G 15	G 17
Ammodiscus anguillae	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphisorus hemprichii	1.23	3.28	1.93	1.35	1.31	11.23	6.34	0.27	0.08	0.42	1.50	0	0.48	0.58
Aphistegina gibbosa	27.75	37.85	20.08	0.45	0.75	0.31	0.00	1.97	1.67	0	1.08	1.67	2.61	19.08
Archaias angulatus	4.11	1.68	17.37	11.69	31.74	7.80	14.17	28.18	38.83	37.33	49.83	0.17	0.29	1.58
Articulina lineata	0.00	0.09	0.00	0.30	0.09	0.00	0.00	0.18	0.08	0.25	0.00	0.00	0.00	0.08
Articulina mayori	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
Articulina mexicana	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.25	0.17	0.00	0.00	0.08
Articulina pacifica	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.08
Articulina sp.	0.00	0.00	0.19	0.00	0.28	0.00	0.00	0.00	1.17	0.00	0.00	0.00	0.00	0.00
Asterigerina carinata	2.57	0.44	5.98	3.00	0.09	0.21	0.30	0.27	0.25	1.18	1.25	0.00	0.10	9.75
Asterigerinata sp.	0.41	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bigenerina irregularis	0.10	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bigenerina nodosaria	1.03	0.71	0.00	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bigenerina textularoidea	0.41	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bolivina lanceolata	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bolivina pulchella	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bolivinita sp.	0.10	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Borelis pulchra	0.21	0.27	0.58	0.00	0.00	1.35	0.40	0.00	0.08	1.44	1.33	0.42	0.39	2.08
Clavulina nodosaria	0.10	0.09	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clavulina tricarinata	0.51	0.62	0.39	0.75	0.94	0.10	0.20	0.00	0.42	0.25	0.00	0.00	0.00	0.00
Cribroelphidium poeyanum	0.82	0.62	1.16	3.00	7.30	0.10	0.10	6.89	11.42	6.33	3.00	0.00	0.00	0.00
Cyclorbiculina compressa	0.51	1.06	0.00	0.00	3.46	0.21	0.10	1.43	0.92	2.03	2.83	0.00	0.00	0.92
Cymbaloporetta sp.	0.92	0.18	0.97	0.75	0.28	0.21	0.10	0.18	0.50	0.59	0.33	0.08	0.97	0.17
Discorbis sp.	0.92	1.86	0.97	0.15	0.09	0.42	0.00	0.00	0.00	0.08	0.08	0.08	0.00	0.58
Elphidium sp.	0.21	0.80	0.19	1.35	1.12	0.00	0.00	2.77	1.92	0.08	0.58	0.00	0.00	0.08
Eponides sp.	0.31	0.89	0.00	0.30	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Florilus sp.	0.31	0.09	0.00	0.00	0.56	0.00	0.00	0.27	0.33	0.08	0.00	0.00	0.00	0.00
Globigerinella sp.	1.23	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Globigerinoides ruber	1.54	2.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Globigerinoides sp.	5.45	3.99	0.58	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
Hauerina speciosa	0.51	0.44	0.58	0.00	0.19	0.73	0.10	0.09	0.00	0.08	0.33	0.00	0.10	0.33
Hauerinidae	7.81	3.19	4.44	25.04	26.31	19.65	31.81	7.16	8.33	15.71	8.58	2.08	0.97	3.17
Heterostegina depressa	1.44	1.86	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.08
Homotrema rubrum	4.83	8.16	26.83	2.55	0.37	1.77	21.21	0.00	0.00	0.76	0.25	92.83	89.17	47.33
Massilina protea	0.21	0.00	0.00	0.75	0.00	0.10	0.00	0.45	0.83	0.51	0.00	0.00	0.00	0.00
Miliolinella fichtelliana	0.51	0.27	0.58	0.00	0.00	0.31	0.10	0.00	0.08	0.25	0.17	0.00	0.00	0.08
Miliolinella labiosa	1.75	1.60	0.39	0.75	0.28	0.83	0.30	0.27	0.08	1.27	1.00	0.00	0.19	0.25
Neoconorbina orbicularis	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
Nodobaculariella cassis	0.10	0.09	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.08	0.25	0.00	0.25
Nonion sp.	0.00	0.09	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orbulina universa	0.00	0.00	0.00	0.00	0.00	0.73	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Parasorites orbitolitoides	0.21	0.09	0.00	0.30	0.09	0.00	0.00	8.14	3.92	3.13	0.92	0.00	0.00	0.00
Peneroplis bradyi	0.41	0.27	0.00	0.60	0.47	0.21	0.10	1.16	1.17	0.59	0.33	0.00	0.00	0.58
Peneroplis perfusus	0.21	0.09	0.00	0.45	0.37	0.31	0.20	0.27	0.00	0.84	1.25	0.00	0.00	0.25
Peneroplis proteus	3.70	1.60	1.16	3.75	2.62	1.14	0.50	3.04	3.75	5.07	7.75	0.00	0.10	1.50
Peneroplis sp.	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.08	0.17	0.00	0.00	0.00	0.00
Planorbulina acervalis	2.67	0.98	1.35	0.45	0.66	14.24	6.14	0.27	0.08	0.17	0.33	0.00	0.97	0.25
Planorbulina mediterranensis	1.03	0.98	0.00	0.00	0.19	1.14	1.29	0.00	0.00	0.00	0.00	0.00	0.77	0.08

APPENDIX 1

Continued.

	G −1	G 0	G 1	G 4	G lag 1	G 6/2	G 6/4	G 206	G 207	G 7	G 9	G 13	G 15	G 17
Pyrgo sp.	1.13	0.98	0.77	0.15	0.09	1.04	0.10	0.00	0.25	0.08	0.00	0.00	0.00	0.17
Quinqueloculina bicostata	0.10	0.27	0.00	0.90	0.37	0.42	0.00	4.65	1.00	0.76	1.33	0.08	0.10	0.25
Quinqueloculina bidentata	0.31	0.09	0.00	1.05	0.66	0.42	0.69	0.72	1.33	1.27	0.58	0.00	0.00	0.25
Quinqueloculina bradyana	0.92	0.44	0.00	1.50	0.28	0.62	0.69	0.09	0.42	0.68	0.50	0.00	0.00	0.83
Quinqueloculina candeiana	0.00	0.00	0.00	0.00	0.37	0.21	0.00	0.00	0.50	0.17	0.25	0.00	0.00	0.17
Quinqueloculina laevigata	0.31	0.89	0.19	4.50	1.87	0.62	0.20	0.63	0.58	1.35	1.33	0.00	0.00	0.00
Quinqueloculina lamarckiana	0.10	0.09	0.00	1.50	0.66	3.01	0.79	0.81	0.08	0.00	1.08	0.00	0.10	0.00
Quinqueloculina poeyana	0.72	0.09	0.58	4.05	0.09	0.00	0.10	0.27	0.50	1.60	0.25	0.00	0.00	0.00
Quinqueloculina polygona	1.64	0.27	0.97	1.65	1.22	1.14	1.68	0.45	0.25	0.68	0.00	0.00	0.00	0.00
Quinqueloculina seminulum	0.00	0.00	0.00	0.60	0.00	0.94	0.00	0.36	0.00	0.08	0.42	0.00	0.00	0.08
Quinqueloculina sp.	2.36	2.04	1.74	9.45	5.52	5.61	4.36	12.16	11.33	5.41	3.92	0.33	0.19	1.83
Quinqueloculina subpoeyana	0.00	0.09	0.00	0.15	0.09	0.10	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Quinqueloculina tenagos	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.27	0.00	0.17	0.08	0.00	0.00	0.00
Quinqueloculina tricarinata	0.51	0.98	0.39	0.30	0.00	0.10	0.10	0.00	0.00	0.00	0.08	0.00	0.00	0.58
Reophax sp.	0.41	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rosalina sp.	3.70	4.08	3.28	7.35	1.97	4.37	0.69	0.72	0.42	1.35	1.42	0.83	1.45	2.33
Siphonina pulchra	0.62	0.09	0.00	0.00	0.00	0.21	0.10	0.00	0.00	0.00	0.17	0.25	0.19	0.42
Sorites marginalis	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00
Spirolina acicularis	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spiroloculina antillarum	0.31	0.53	0.39	1.05	0.19	0.10	0.10	0.09	0.00	0.08	0.00	0.00	0.00	0.00
Spiroloculina sp.	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Textularia agglutinans	4.83	2.39	1.74	1.20	1.97	0.21	0.40	8.32	4.17	0.76	0.25	0.00	0.00	0.75
Textularia conica	2.26	3.10	1.93	0.30	0.09	3.43	2.87	0.09	0.08	2.20	1.75	0.50	0.48	0.83
Textularia mayori	1.13	0.98	0.39	0.00	0.00	0.10	0.30	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Textularia sp.	0.51	0.18	0.00	0.15	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
Triloculina bassensis	0.10	0.35	0.00	0.60	0.28	1.56	0.50	0.54	0.42	0.68	0.92	0.00	0.00	0.08
Triloculina bicarinata	0.62	0.27	0.39	2.25	0.84	0.83	1.29	1.16	1.83	1.27	0.08	0.00	0.19	0.50
Triloculina linneiana	0.92	0.62	0.58	1.35	2.15	0.42	0.20	0.72	1.33	0.51	0.42	0.00	0.00	0.00
Triloculina sp.	0.00	0.44	0.00	0.90	0.56	0.42	0.10	3.67	0.00	0.08	0.75	0.00	0.00	0.08
Valvulina oviedoiana	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	1.10	0.08	0.00	0.00	0.00
Vertebralina cassis	0.21	0.27	0.00	0.15	0.19	0.10	0.10	0.00	0.25	0.08	0.00	0.00	0.00	0.08
Others	0.10	0.09	0.39	0.45	0.19	10.19	0.30	0.81	0.08	0.68	1.00	0.42	0.19	0.50

APPENDIX 2

Distribution of foraminifera in samples from Lighthouse Reef. Numbers are in %.

	L1	L2	L3	L4	BH	L5	L7	L6	MR	L8	L9	L10	L11	L12
Acervulinidae	0.33	0.00	0.08	0.42	0.82	0.00	1.67	0.50	1.17	0.08	1.18	3.42	0.25	0.17
Ammodiscus sp.	0.00	0.00	0.08	0.00	0.00	0.19	0.00	0.00	0.00	0.08	0.08	0.00	0.00	0.00
Ammonia beccarii	0.00	0.11	0.00	0.00	0.31	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Ammonia sp.	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphisorus hemprichii	0.17	0.00	0.00	0.25	0.10	0.00	0.00	0.16	0.25	0.08	0.00	0.50	0.00	0.00
Amphistegina gibbosa	45.33	6.93	8.92	4.92	0.41	0.19	0.25	0.08	0.08	0.08	0.08	1.17	3.25	27.95
Amphistegina lessonii	0.58	0.11	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 sp.	0.17	0.22	0.08	0.08	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77
Archaias angulatus	2.25	1.63	1.83	29.50	18.02	38.17	20.16	32.67	35.00	50.92	18.88	5.17	30.75	16.32
Archaiasinae	0.00	0.00	0.00	0.17	0.00	0.28	1.00	0.08	0.58	0.00	0.34	0.00	0.08	0.34
Articulina lineata	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.08	0.00	0.67	0.00	0.00	0.08	0.00
Articulina mucronata	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.08	0.08	0.08	0.00	0.08	0.00	0.00
Articulina pacifica	0.58	0.00	0.00	0.00	0.10	0.09	0.25	0.00	0.17	0.00	0.08	0.00	0.00	0.34
Articulina sarga	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Articulina sp.	1.33	0.00	0.00	0.00	0.00	0.65	0.75	0.17	0.42	0.08	0.08	0.08	0.33	0.17
Asterigerina carinata	2.67	1.30	3.83	2.00	0.00	1.40	0.08	1.92	0.08	0.58	0.17	3.58	17.17	3.93
Bigeneria irregularis	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bigeneria nodosaria	0.42	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bigeneria sp.	0.00	0.00	0.17	0.00	0.72	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Bigeneria textularoidea	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	1.37
Borelis pulchra	1.33	0.43	0.50	0.00	0.00	0.09	0.75	0.50	1.83	0.00	0.17	1.58	1.17	0.34
Borelis sp.	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
Cancris oblonga	0.00	0.11	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.09
Caribeanella sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00
Cibicides cicatriosus	0.00	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cibicides robustus	0.08	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cibicides rugosa	0.67	0.87	142	0.25	0.00	0.19	0.25	0.00	0.00	0.00	0.00	0.17	0.08	0.00
Cibicides sp.	0.75	0.33	0.58	0.00	0.21	0.09	0.33	0.08	0.25	0.00	0.00	0.33	0.08	0.00
Clavulina difformis	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.08	0.08	0.08	0.00	0.00
Clavulina tricarinata	0.17	0.00	0.00	0.00	2.78	0.00	0.33	0.08	0.25	0.75	0.59	0.25	0.00	0.09
Cribroelphidium poeyanum	0.00	0.00	0.08	0.25	3.09	5.33	0.58	3.33	0.50	8.17	2.02	0.92	0.75	0.00
Cycloputeolina sp.	0.00	0.00	0.00	0.08	0.00	0.56	0.08	0.83	0.00	0.08	0.08	0.08	0.00	0.00
Cyclorbiculina compressa	0.16	0.00	0.16	0.00	0.72	0.93	3.42	1.08	1.50	0.25	0.17	0.83	0.58	2.74
Cyclorbiculina sp.	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
Cymbaloporetta sp.	0.00	0.00	0.58	0.67	0.10	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cymbaloporetta squammosa	0.08	0.11	1.08	2.50	0.82	2.15	3.08	0.33	0.33	0.33	0.42	1.00	0.83	0.60
Dentostomina bermudiana	0.17	0.00	0.00	0.00	0.10	0.09	0.00	0.42	0.50	0.00	1.77	0.25	0.00	1.11
Dentostomina sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00
Discorbis mira	0.25	0.11	0.00	0.08	0.72	0.19	3.42	0.58	3.08	1.25	1.18	2.00	0.00	1.28
Discorbis rosea	0.00	0.11	0.42	0.08	0.00	0.00	0.08	0.00	0.08	0.00	0.00	0.00	0.00	0.00
Discorbis sp.	0.58	0.11	0.83	0.50	0.51	0.28	0.50	0.42	0.50	0.00	0.42	0.33	0.00	0.00
Elphidium advenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.08	0.00
Elphidium discoidale	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elphidium lanieri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.26
Elphidium sargum	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00
Elphidium sp.	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Eponides antillarum	0.08	0.00	0.00	0.00	5.77	0.00	0.25	0.08	0.00	0.00	0.08	0.00	0.08	0.51
Eponides repandus	1.41	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.17	0.60
Eponides sp.	0.25	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
Eponides turgidus	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	0.09
Glabratellina sp.	0.00	0.00	0.58	0.00	0.00	0.00	0.08	0.25	0.00	0.00	0.34	0.00	0.00	0.00
Globigerinella sifonifera	0.17	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
Globigerinoides ruber	0.67	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43
Globigerinoides sp.	0.17	0.00	0.00	0.08	0.10	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
Globigerinoides trilobus	0.08	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.08	0.00	0.00	0.00	2.22
Globorotalia sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.60
Gypsina planta	1.58	0.00	0.00	0.00	4.43	0.00	0.17	0.00	0.08	0.00	0.00	0.17	0.08	0.17
Hauerina bradyi	0.00	0.00	0.08	0.25	0.41	0.28	0.25	0.33	0.25	0.00	0.00	0.59	1.33	0.09
Hauerina sp.	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.08	0.00	0.00	0.17	0.17	0.09
Hauerina speciosa	0.33	0.00	0.00	0.08	0.31	0.00	0.92	0.08	0.17	0.00	0.00	0.83	0.25	0.17
Hauerinidae	0.00	0.65	0.33	2.00	4.63	3.18	4.25	6.92	7.58	3.42	6.24	3.17	2.08	3.16
Heterostegina depressa	1.83	0.00	0.08	0.00	0.72	0.00	0.25	0.00	0.08	0.00	0.00	0.00	0.00	0.60
Homotrema rubrum	13.75	77.79	71.91	25.66	10.50	2.99	9.00	1.42	1.42	0.00	0.42	37.92	15.83	0.17
Massilina protea	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00
Masslinia sp.	0.25	0.00	0.00	0.25	0.00	0.37	0.17	0.08	0.34	0.00	0.34	0.08	0.00	0.00
Miliolinella circularis	0.00	0.00	0.00	0.58	0.20	1.03	1.08	0.17	0.08	0.08	0.95	0.08	0.00	0.17

APPENDIX 2

Continued.

	L1	L2	L3	L4	BH	L5	L7	L6	MR	L8	L9	L10	L11	L12
Miliolinella fichteliana	0.17	0.00	0.00	0.08	0.21	0.09	0.67	0.33	0.17	0.00	0.25	0.00	0.08	0.00
Miliolinella labiosa	0.17	0.00	0.00	1.17	0.62	1.78	2.75	1.92	1.25	0.25	2.19	0.42	0.17	0.43
Miliolinella orbicularis	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
Miliolinella sp.	0.25	0.11	0.67	0.92	0.72	1.50	0.92	0.83	0.75	0.00	0.76	0.00	0.00	0.17
Neoconorbina orbicularis	0.08	0.00	0.08	0.08	0.31	0.09	0.17	0.42	0.08	0.00	0.00	0.17	0.08	0.09
Nonion grateloupi	0.00	0.00	0.00	0.08	0.62	0.28	0.00	0.50	0.08	0.50	0.00	0.00	0.42	0.17
Nonion sp.	0.00	0.00	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	1.71
Orbulina universa	0.00	0.43	0.08	0.17	2.57	0.00	0.08	0.00	0.00	0.00	0.00	0.42	0.67	0.00
Parasorites sp.	0.00	0.00	0.00	0.00	0.31	0.37	0.00	2.75	0.00	0.58	0.17	0.33	0.08	0.43
Peneroplidae	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Peneroplis carinatus	0.00	0.00	0.00	0.17	0.00	0.00	0.25	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Peneroplis perfusus	0.00	0.00	0.17	1.00	0.51	0.47	0.50	1.42	0.83	0.00	0.17	0.92	1.50	0.77
Peneroplis proteus	0.17	0.11	0.08	1.17	2.06	2.06	1.58	7.92	0.42	1.67	0.67	2.33	2.83	4.27
Peneroplis sp.	0.08	0.00	0.08	0.42	0.21	0.28	0.00	0.50	0.17	0.00	0.00	0.17	0.33	0.17
Planogypsina acervalis	1.25	0.33	0.00	0.17	2.68	1.59	1.25	1.17	0.25	0.92	1.43	2.00	0.25	0.09
Planorbulina mediterranensis	0.17	0.00	0.25	0.67	4.12	0.19	0.50	0.00	0.83	0.08	0.25	0.42	0.17	0.00
Planorbulina sp.	0.00	0.00	0.17	0.25	0.21	0.00	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Planorbulinoides sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00
Planulina exorna	0.00	0.22	0.00	0.25	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.08	0.00	0.43
Planulina sp.	0.08	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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Pyrgo elongata	0.00	0.00	0.08	0.08	0.10	0.09	0.25	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Pyrgo sp.	0.50	0.43	0.00	0.58	0.72	0.47	2.08	0.83	1.67	0.17	0.17	1.33	0.17	0.17
Quinqueloculina agglutinans	0.25	0.00	0.00	2.08	0.51	0.84	0.75	0.17	1.33	0.50	1.18	0.67	0.08	1.45
Quinqueloculina bertelotiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.08	0.00
Quinqueloculina bicarinata	0.17	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
Quinqueloculina bicornis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.58	0.77
Quinqueloculina bicostata	0.00	0.00	0.00	0.25	0.10	0.28	0.08	0.08	0.37	0.00	0.68	0.16	0.00	0.00
Quinqueloculina bidentata	0.00	0.00	0.17	0.33	0.21	1.87	0.16	0.50	1.08	0.16	1.94	0.50	0.17	0.26
Quinqueloculina brady	0.00	0.00	0.00	0.00	0.10	0.00	0.08	0.58	0.00	0.00	0.08	0.17	0.00	0.00
Quinqueloculina bradyana	1.58	0.00	0.00	0.00	1.65	1.03	2.67	2.17	0.66	0.50	3.12	1.25	0.41	0.43
Quinqueloculina candeiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.16	0.00	0.00	0.00
Quinqueloculina collumnosa	0.25	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
Quinqueloculina horrida	0.00	0.00	0.00	0.08	0.00	0.09	0.00	0.08	0.17	0.25	0.00	0.58	0.08	0.00
Quinqueloculina irregularis	0.08	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
Quinqueloculina laevigata	0.00	0.00	0.00	0.25	0.00	0.65	0.00	0.08	0.00	0.67	0.93	0.58	0.00	0.00
Quinqueloculina lamarckiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.75	0.67	0.00	0.00	0.00
Quinqueloculina parkeri	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.08	0.00	0.00	0.25	0.00	0.00	0.00
Quinqueloculina poeyana	0.00	0.00	0.00	1.58	0.00	0.09	0.00	0.08	0.00	0.33	0.08	0.08	0.42	0.77
Quinqueloculina polygona	0.00	0.00	0.00	0.17	0.10	0.84	0.00	0.00	0.00	0.91	0.25	0.00	0.00	0.17
Quinqueloculina seminulum	0.00	0.00	0.00	0.50	0.00	0.09	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
Quinqueloculina sp.	2.83	0.54	0.42	1.50	1.44	1.96	1.17	2.15	4.25	7.33	5.23	3.58	2.00	4.79
Quinqueloculina subpoeyana	0.17	0.00	0.00	0.17	0.10	0.09	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
Quinqueloculina tricarinata	2.00	0.00	0.00	0.00	0.51	0.00	0.08	0.08	0.00	0.25	0.08	0.67	0.25	0.34
Reophax sp.	0.17	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rosalina floridana	0.42	0.43	0.67	1.33	1.34	2.62	2.42	3.75	1.83	0.92	2.11	0.83	3.42	2.22
Rosalina floridensis	0.71	0.00	0.17	0.17	0.21	0.00	0.75	0.25	0.17	0.08	0.17	0.25	0.92	0.68
Rosalina sp.	0.83	0.76	0.83	0.42	1.03	1.03	0.83	0.25	1.00	0.33	2.28	0.17	0.58	0.85
Sigmoilopsis sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.17
Siphonina pulchra	0.50	0.11	0.17	0.00	1.65	0.00	0.17	0.17	0.25	0.00	0.00	0.08	0.17	0.09
Sorites marginalis	0.50	0.11	0.08	0.92	1.75	1.22	6.42	2.83	3.50	1.33	0.59	3.17	0.25	1.03
Sorites sp.	0.00	0.00	0.00	0.17	0.21	0.09	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soritinae	0.00	0.00	0.00	0.00	0.00	0.19	0.33	0.00	0.42	0.00	0.00	0.17	0.00	0.00
Spirillina obconica	0.33	0.00	0.00	0.00	0.31	0.00	0.08	0.08	0.00	0.00	0.00	0.08	0.00	0.00
Spirillina sp.	0.00	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
Spirillina vivipara	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
Spirolina orientinus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00
Spirolina sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.17	0.00
Spiroloculina antillarum	0.00	0.00	0.00	0.17	0.00	0.09	0.25	0.00	0.16	1.17	0.51	0.42	0.08	0.09
Spiroloculina sp.	0.17	0.00	0.08	0.00	0.41	0.00	0.08	0.00	0.25	0.08	0.17	0.00	0.08	0.09
Textularia agglutinans	0.00	0.00	0.08	0.00	0.21	0.00	0.00	0.00	0.33	0.00	0.08	0.08	0.17	0.77
Textularia candeiana	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	0.17
Textularia conica	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00

APPENDIX 2

Continued.

	L1	L2	L3	L4	BH	L5	L7	L6	MR	L8	L9	L10	L11	L12
Textularia mayori	0.00	0.00	0.00	0.00	2.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Textularia sp.	0.00	0.00	0.00	0.17	0.21	0.00	0.00	0.00	0.08	0.00	0.08	0.08	0.00	0.00
Tifarina bella	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tretomphalus atlanticus	1.42	0.87	0.08	0.25	0.20	0.28	0.08	0.00	0.00	0.00	0.16	0.00	0.00	0.17
Tretomphalus sp.	0.00	0.33	0.00	0.25	0.41	0.28	0.08	0.25	0.00	0.00	0.00	0.08	0.25	0.00
Triloculina bassensis	0.00	0.00	0.00	0.66	1.13	3.00	1.38	2.17	1.41	6.67	4.22	1.25	1.33	2.23
Triloculina bermudezi	0.00	0.00	0.00	0.00	0.10	0.47	0.75	0.17	0.00	0.25	0.33	0.00	0.00	1.37
Triloculina bicarinata	0.00	0.00	0.00	0.50	0.51	0.47	1.00	0.42	1.25	0.33	0.67	0.50	0.08	0.26
Triloculina carinata	0.00	0.00	0.00	0.33	0.10	0.09	0.58	0.58	0.58	0.33	0.76	0.25	0.08	1.03
Triloculina conica	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tirloculina fiterei	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.17	0.00	0.08	0.00	0.00	0.00	0.00
Triloculina lamarckiana	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina linneiana	0.08	0.00	0.08	2.25	0.21	2.81	0.25	1.91	0.58	1.75	2.95	0.92	2.17	0.00
Triloculina planciana	0.00	0.00	0.00	0.25	0.10	0.28	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina quadrilateralis	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
Triloculina sidebottomi	0.00	0.00	0.00	0.00	0.00	0.56	0.25	0.00	0.00	0.00	0.42	0.08	0.00	0.00
Triloculina sp.	1.42	0.33	0.08	2.08	1.54	5.24	2.50	2.08	3.00	2.58	3.04	1.25	1.50	2.82
Triloculina tricarinata	0.75	.0.11	0.00	0.08	0.62	0.00	0.25	1.00	0.25	0.00	0.25	0.08	0.17	0.00
Triloculina tirgonula	0.00	0.00	0.00	0.00	0.20	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valvulina oviedoiana	0.25	0.00	0.00	1.50	2.57	1.40	10.25	3.08	11.50	0.00	11.80	5.25	0.75	0.09
Valvulina oviedoiana (MG)	0.00	0.00	0.00	1.08	0.00	0.09	0.00	0.00	0.00	0.00	9.53	0.25	0.75	0.00
Valvulina sp.	0.00	0.00	0.00	0.17	0.00	0.00	0.08	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Vertebralina cassis	0.08	0.00	0.00	0.00	0.21	0.19	0.25	0.17	0.08	0.08	0.00	0.00	0.00	0.09
Vertebralina sp.	0.00	0.00	0.00	0.00	0.10	0.37	0.00	0.25	0.17	0.00	0.08	0.00	0.00	0.00
Others	4.00	2.71	1.50	1.83	2.06	1.78	0.42	1.58	1.00	0.58	2.28	2.17	0.33	0.77

APPENDIX 3

Distribution of foraminifera in samples from Turneffe Islands. Numbers are in %.

	T 1	T 2	T 3	T 4	T 5	T 6	T 205	T 7	T 8	T 9	T 10	HJP	T 12	T 13	T 14
Ammodiscus sp.	0.00	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.08
Amphisorus hemprichii	1.40	2.50	0.75	5.58	1.53	0.29	0.62	0.64	0.54	1.89	1.63	0.00	0.17	1.05	2.75
Amphistegina gibbosa	26.65	0.17	3.67	1.49	30.23	0.29	0.00	3.30	0.86	0.00	0.51	3.33	2.42	27.37	34.06
Archaias angulatus	1.77	33.42	27.67	1.49	4.16	43.39	37.42	21.09	17.02	5.56	21.51	46.33	14.33	7.89	2.67
Archaias or *Cyclorbiculina*	5.22	2.50	3.83	0.19	0.77	0.29	0.72	1.49	0.11	0.00	1.73	3.75	0.00	0.35	0.67
Articulina lineata	0.09	0.25	0.42	0.37	0.77	0.10	0.82	0.85	1.82	2.89	0.10	0.00	0.00	0.00	0.00
Articulina mayori	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Articulina mexicana	0.00	0.17	2.17	1.12	0.33	0.48	1.65	4.05	3.21	2.89	0.31	0.00	0.00	0.26	0.25
Articulina pacifica	0.00	0.33	0.42	0.56	0.66	0.58	2.06	2.66	0.86	3.44	0.20	0.00	0.08	0.26	0.33
Articulina sp.	0.09	0.00	0.08	0.00	0.66	0.68	0.52	2.13	0.32	1.89	0.00	0.00	0.08	0.18	0.17
Asterigerina carinata	11.74	18.83	6.42	2.04	0.33	0.00	0.10	0.00	0.00	4.00	10.50	5.42	2.25	8.51	1.75
Bigenerina nodosaria	1.40	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00
Bolivinita sp.	0.09	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Borelis pulchra	0.93	0.00	0.25	0.19	0.11	0.10	0.00	0.00	0.00	0.00	0.82	0.25	0.58	2.37	1.25
Clavulina nodosaria	0.00	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
Clavulina tricarinata	0.47	0.33	0.25	0.56	0.99	0.87	0.21	0.32	0.11	0.11	0.41	0.58	0.17	0.09	0.42
Cribroelphidium poeyanum	1.68	1.08	1.58	1.30	1.75	4.24	10.52	12.57	16.49	5.11	0.31	0.17	0.00	0.09	0.17
Cyclorbiculina compressa	2.61	0.75	5.00	0.37	0.33	0.29	0.62	2.24	0.21	0.00	0.82	0.50	0.25	1.75	2.34
Cymbaloporetta sp.	0.84	0.83	0.42	0.00	0.44	0.00	0.00	0.11	0.00	0.89	1.63	1.50	1.08	0.53	0.33
Discorbis rosea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.61	12.33	5.84	3.86	1.00
Discorbis sp.	2.05	2.83	4.42	12.08	13.36	2.03	3.20	5.22	3.64	4.67	3.36	3.25	3.67	2.89	3.01
Elphidium sp.	0.00	0.00	0.17	0.56	0.22	0.58	0.41	0.53	1.39	1.33	0.41	0.00	0.00	0.18	0.25
Fissurina marginata	0.09	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	0.00
Florilus sp.	1.03	0.08	0.08	0.37	0.22	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.35	0.17
Globigerinella sp.	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	0.08
Globigerinoides sp.	1.77	0.08	0.08	0.19	0.00	0.00	0.00	0.00	0.00	0.11	0.10	0.08	0.00	0.44	1.84
Gypsina sp.	0.37	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
Hauerinidae	10.16	10.92	11.83	9.85	8.00	9.06	14.33	8.73	10.39	24.33	12.33	5.17	2.50	11.58	8.68
Hauerina speciosa	0.65	0.33	0.08	0.00	0.11	0.00	0.10	0.00	0.00	0.11	0.10	0.00	0.00	0.35	0.33
Heterostegina depressa	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.08	0.08	0.26	1.00
Homotrema rubrum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.65	8.92	60.33	12.28	8.51
Massilina protea	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.21	0.11	0.44	0.10	0.00	0.00	0.00	0.00
Miliolinella fichtelliana	0.00	0.00	0.00	1.86	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00
Miliolinella labiosa	0.00	0.00	0.00	2.23	0.55	0.10	0.41	0.21	0.32	0.67	0.92	0.25	0.00	0.26	0.58
Nodobaculariella cassis	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.22	0.00	0.00	0.00	0.18	0.42
Nonion sp.	0.93	0.00	0.17	0.19	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00
Orubulina universa	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.33	0.00	0.00	0.08	0.18	0.00
Parasorites orbitolitoides	0.65	0.50	1.50	0.19	0.00	1.06	0.41	0.00	1.50	0.00	0.31	0.00	0.17	0.00	0.00
Peneroplidae	0.47	0.08	0.00	0.00	0.00	2.31	0.41	0.85	0.54	0.00	0.10	0.08	0.00	0.18	0.08
Peneroplis bradyi	1.77	0.50	1.00	0.19	0.77	0.39	0.82	0.00	2.14	0.00	0.61	0.50	0.08	0.35	0.08
Peneroplis perfusus	0.56	1.17	1.00	0.19	0.77	0.77	1.13	1.06	1.61	0.22	1.63	0.58	0.50	0.26	0.08
Peneroplis proteus	5.22	5.42	7.42	1.12	1.10	14.46	7.11	4.69	8.46	0.33	2.65	0.33	0.33	1.49	1.84
Planorbulina acervalis	0.47	6.42	1.58	11.90	1.97	0.00	1.24	0.11	0.21	0.22	7.54	0.08	0.67	3.51	8.26
Planorbulina mediterranensis	1.12	0.50	0.08	1.49	0.33	0.00	0.00	0.21	0.11	0.44	0.00	0.00	0.17	0.70	0.17
Pyrgo sp.	0.28	0.08	0.00	0.19	0.00	0.10	0.00	0.32	0.32	0.78	0.00	0.08	0.17	0.44	0.75
Quinqueloculina laevigata	0.09	0.00	0.08	0.00	0.11	1.45	0.72	2.34	1.18	0.89	0.10	0.50	0.00	0.00	0.00
Quinqueloculina poeyana	0.09	1.83	0.75	3.53	3.61	2.99	5.36	4.15	3.85	4.56	0.41	0.17	0.00	0.44	0.17
Quinqueloculina polygona	0.28	0.25	0.42	0.74	0.11	0.96	0.82	1.92	0.64	0.33	0.71	0.00	0.08	0.18	0.08
Quinqueloculina sp.	1.30	0.92	1.17	4.28	1.20	1.06	2.06	1.17	2.36	0.89	1.12	0.17	0.00	0.35	0.33
Quinqueloculina subpoeyana	0.09	0.00	0.17	1.67	0.33	0.19	0.10	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.08
Quinqueloculina tenagos	0.09	0.00	0.08	0.37	0.00	0.00	0.00	0.11	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Quinqueloculina tricarinata	0.65	0.42	3.25	0.74	3.07	0.00	0.00	0.00	0.00	0.00	2.85	0.08	0.50	0.26	0.33
Reophax sp.	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	0.09	0.50
Rosalina sp.	0.28	0.00	0.25	1.49	0.55	0.10	0.82	0.00	0.54	0.33	0.41	0.00	0.58	0.18	0.67
Sorites marginalis	0.00	0.00	0.00	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sorites or *Amphisorus*	0.00	0.00	0.00	2.79	0.77	0.39	0.72	0.53	0.00	0.11	0.10	0.17	0.00	0.44	0.42
Spirillina obconica	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	0.17
Spiroloculina antillarum	0.00	0.00	0.42	0.74	2.08	0.10	0.21	0.00	0.75	0.22	0.41	0.42	0.00	0.09	0.08
Spiroloculina sp.	0.00	0.00	0.17	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Textularia agglutinans	2.52	1.25	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.11	1.12	0.08	0.08	1.40	2.34
Textularia conica	0.00	0.00	0.00	0.00	3.61	0.00	0.21	0.21	0.11	2.11	0.82	0.58	1.00	1.05	2.92
Textularia mayori	0.56	0.17	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.61	0.42
Textuaria sp.	0.00	0.25	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 bassensis	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triloculina bicarinata	0.28	0.00	0.67	0.19	2.19	0.48	1.34	4.26	2.46	3.67	0.51	0.17	0.00	0.00	0.33
Triloculina carinata	0.00	0.17	0.08	0.00	0.11	0.00	0.00	0.00	0.11	0.11	0.41	0.00	0.00	0.00	0.00
Triloculina linneiana	0.00	0.33	0.33	0.56	0.33	1.35	0.10	0.64	1.39	0.67	0.92	0.00	0.00	0.00	0.00
Triloculina planciana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.44	0.10	0.00	0.00	0.00	0.00
Triloculina sp.	3.17	0.33	4.67	9.85	5.04	5.69	0.62	4.58	4.07	3.11	1.83	0.08	0.17	1.32	2.92
Vertebralina cassis	0.28	0.08	1.75	2.60	1.10	0.87	1.03	4.79	4.18	3.11	0.41	0.00	0.33	0.70	0.25
Others	6.71	3.92	3.33	10.59	4.38	1.45	0.82	1.49	4.82	1.44	3.26	3.83	1.25	2.19	3.59