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Cover photo: *Diploria strigosa*, the common brain coral, preserved in growth position at the Cockburn Town fossil coral reef site (Sangamon age) on San Salvador Island. Photo by Al Curran.

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SEDIMENTOLOGICAL AND FORAMINIFERAL CHARACTERIZATION
OF SHELF AND SLOPE ENVIRONMENTS (1-234 m),
NORTH JAMAICA

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ABSTRACT

Holocene carbonate sediments from fringing reefs and adjacent, deeper-water environments along the north coast of Jamaica display variation in texture, grain constituents, and foraminifera which can be utilized in the delineation of several distinct facies. Q-mode cluster analyses of samples collected along traverses from the shore out to 234 m depth resulted in six distinct groupings: back reef (1-5 m), fore reef terrace (1-14 m), fore reef escarpment and slope (24-55 m), upper deep fore reef wall (70 m), and upper island slope (137-234 m). Bathymetric trends contributing to this zonation include: (1) A decrease in sorting (IGSD) from 0.77 on the shallow (5 m) fore reef terrace to 2.01 on the upper island slope and a decrease in mean grain size from 0.83 phi at 5 m to 2.62 phi on the upper island slope. (2) Shifts in constituent proportions with changing depth. Coral and *Homotrema* decrease from 63% and 8%, respectively, on the shallow fore reef terrace, to 24% and <0.1% on the upper island slope, while *Halimeda* and nonencrusting foraminifera increase from <1% and 2%, respectively, on the shallow fore reef terrace, to 15% and 11% on the upper island slope. (3) Changes in diversity and proportions of foraminifera species and larger taxonomic groupings. Foraminifera species diversity (H' , \log_e) increases from 2.9 on the shallow reef to 3.9 on the upper island slope. Textulariine and planktonic rotaliine species increase from 3% and <1% of individuals, respectively, on the shallow reef to 10% and 20% on the upper island slope.

INTRODUCTION

Fringing coral reefs along the north coast of Jamaica display a striking pattern of biological zonation which is related to the environmental tolerances of the reef biota (Goreau, 1959; Goreau and Goreau, 1973; Kinzie, 1973; Lang, 1974; Liddell and Ohlhorst, in press). The continual degradation of the calcareous skeletons of these organisms by biological and mechanical processes produces sediment which accumulates in reef interstices and in sand channels (grooves) adjacent to reef spurs. Sampling and analyses of these Holocene carbonates were undertaken in order to better understand the relationship of sediment composition to reef community structure, to determine the magnitude of sediment flux, and to evaluate what parameters could be most effectively used to delineate reef facies over the range from 1-234 m.

METHODS

Due to length requirements of this volume, aspects of the methods employed and results generated must be kept brief. For further details refer to Boss (1985), Nelson (1986), Boss and Liddell (in press), and Martin and Liddell (in prep. a).

Location of Study

Field work was conducted from the Discovery Bay Marine Laboratory of the University of the West Indies during the summers of 1982 and 1984. This facility is located on the Jamaican north coast (Fig. 1),

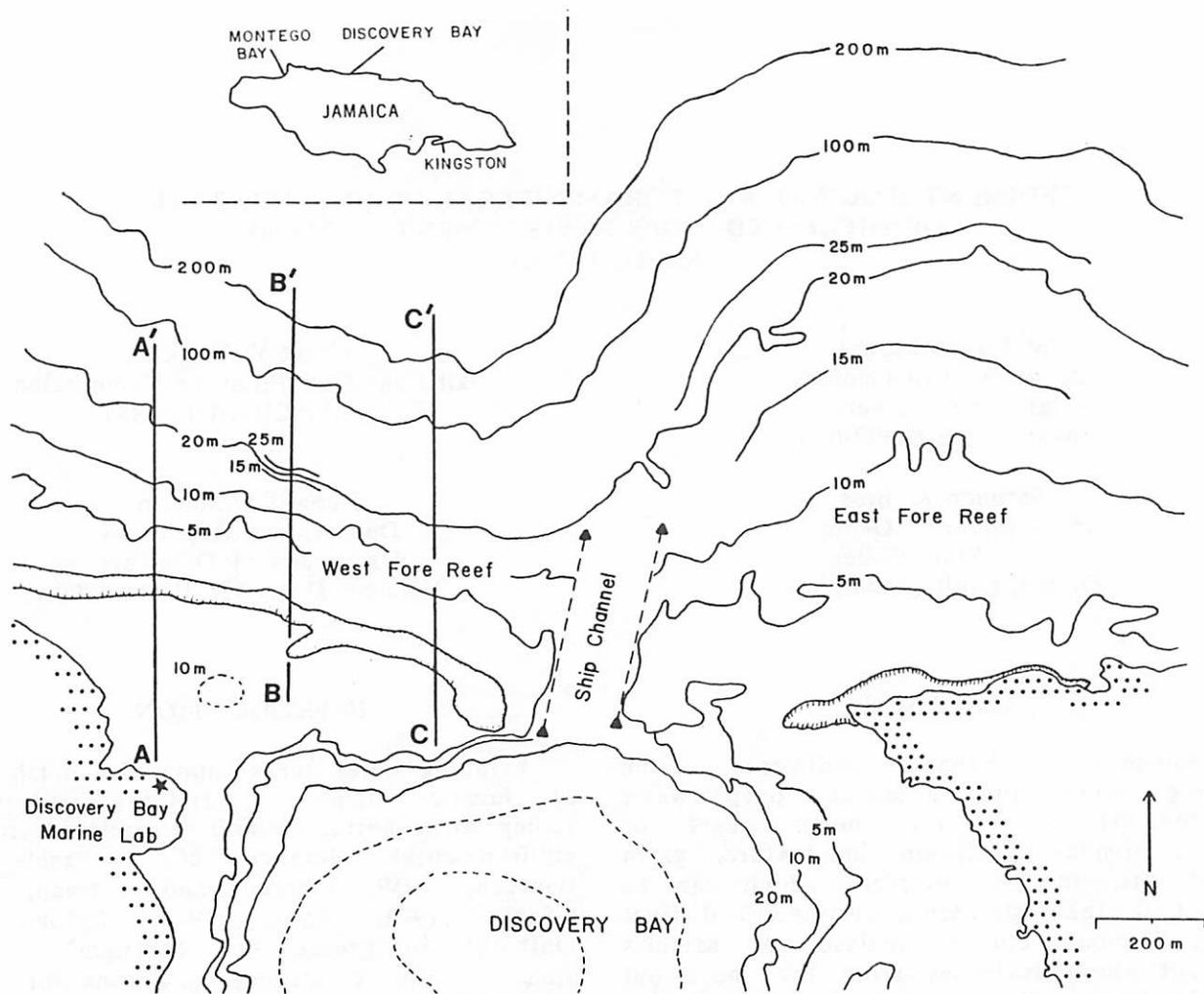


Fig. 1. Index map of Jamaica and Discovery Bay showing location of sample traverses, A-A' = LTS, B-B' = Zingorro, C-C' = Mooring One. Modified from Liddell and others, 1984.

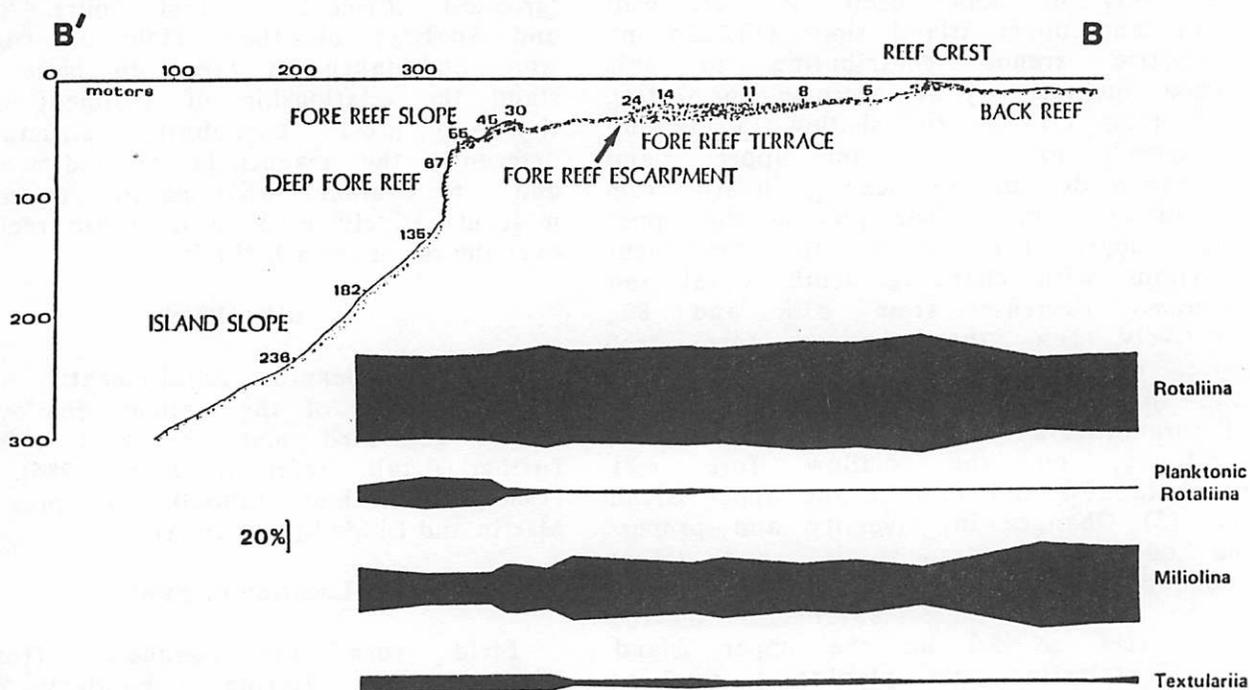


Fig. 2. Profile of Zingorro reef with sample locations. Relative abundance of larger foraminifera groups (Table 3) shown below. Modified from Moore and others, 1976.

at Discovery Bay (lat. 18°30'N, long. 77°20'W).

Sample Collection

Samples were collected from parallel traverses on the fringing reef which extended from near shore across the back reef (1-5 m) and reef crest, fore reef terrace (1-14 m), fore reef escarpment (14-24 m), fore reef slope (24-55 m), upper deep fore reef (55-75 m), and upper island slope (137-234 m) (Figs. 1-2; terminology after Goreau and Goreau, 1973; and Goreau and Land, 1974). Over the range of 1-70 m, shallow sediment was collected by SCUBA divers, while the upper island slope (130-234 m) was sampled by the Research Submersibles Ltd.'s Perry PC-8 submersible.

Sample Processing

Sediment samples were rinsed twice with distilled water and dried at 105°C. The supernatant was filtered to determine the amount of fines lost through rinsing, which was found to be insignificant (e.g. 0.01-0.15% per sample). All samples were mechanically quartered for various analyses with a riffle splitter.

Sediment grain-size distributions were determined and various textural parameters calculated through standard techniques (Folk, 1974). The relative abundance of sediment constituents was determined by point counting resin impregnated thin-sections with 600 points counted per slide. Quantitative X-ray analysis was performed to determine bulk sediment carbonate mineralogy using the technique of Stehli and Hower (1961).

Foraminifera Counting

Sediment samples were separated into four size fractions (1-2mm, 0.5-1mm, 0.25-0.5mm, and 0.125-0.25mm) through wet sieving. Five hundred to six hundred foraminifera were counted from each size fraction, except in cases where all individuals were picked before that limit was reached, and averaged to produce relative abundance values. This technique was employed in order to reduce the "swamping" of samples caused by certain very abundant foraminifera species occurring in particular size fractions (Martin and Liddell, in prep. b).

Location (depth)	N	Phi Mean (Hz)	Phi Sorting (IGSD)	Skaeness (SKI)	Kurtosis (KG)
Back Reef (1-5m)	(na) 3	0.91 ±0.3	1.19 ±0.4	0.08 ±0.0	0.98 ±0.3
	(th) 4	1.08 ±0.3	1.17 ±0.6	0.05 ±0.4	1.15 ±0.2
	(ca) 6	1.11 ±0.7	1.44 ±0.2	-0.03 ±0.0	0.94 ±0.2
Fore Reef Terrace	(cr) 5	0.55 ±0.0	1.03 ±0.3	0.00 ±0.2	1.28 ±0.5
	(5m) 6	0.83 ±0.6	0.77 ±0.1	-0.02 ±0.1	1.01 ±0.2
	(8m) 6	1.04 ±0.6	0.71 ±0.3	0.04 ±0.1	1.15 ±0.2
	(11m) 7	0.93 ±0.3	0.88 ±0.1	0.03 ±0.1	1.07 ±0.0
Fore Reef Escarpment	(14m) 6	0.74 ±0.4	0.92 ±0.2	0.02 ±0.1	1.10 ±0.1
	(24m) 7	1.16 ±0.3	1.31 ±0.1	0.02 ±0.1	1.12 ±0.2
Fore Reef Slope	(32m) 6	1.09 ±0.4	1.18 ±0.1	-0.04 ±0.0	1.20 ±0.1
	(46m) 6	1.53 ±0.5	1.64 ±0.1	-0.08 ±0.2	1.07 ±0.2
	(55m) 7	1.27 ±0.4	1.67 ±0.4	-0.07 ±0.2	1.00 ±0.2
Deep Fore Reef	(70m) 11	0.85 ±0.5	1.79 ±0.3	-0.01 ±0.3	0.98 ±0.2
Island Slope	(137m) 4	2.04 ±2.8	1.93 ±2.6	-0.22 ±0.1	1.08 ±1.7
	(188m) 3	2.62 ±5.9	1.32 ±1.6	-0.03 ±0.3	1.13 ±1.8
	(234m) 4	1.71 ±2.2	2.01 ±3.3	0.29 ±0.5	0.92 ±1.1

Table 1. Mean sediment textural parameters over the range of 1-234 m with 95% confidence intervals. For back reef sites, ns = near shore, th = *Thalassia* bed, ca = *Callianassa* area, cr = near reef crest. Data from 1-70 m (average of 3 traverses, Fig. 1) from Boss (1985), data from 137-234 m (average of 2 traverses, B-B' and C-C', Fig. 1) from Nelson (1986).

RESULTS

Texture

Due to the *in situ* generation of carbonate grains by bioerosion and biosynthesis, textural "inversions" occur along parts of the bathymetric profile (e.g. mean grain size, Mz, actually increases from 1.09 - 1.27 phi on the fore reef escarpment and slope (24-55 m) to 0.85 phi on the upper deep fore reef (70 m) due to the quantity of coarse grains produced by the calcareous alga *Halimeda* on the latter). Over the range of 1-234 m, however, Mz and sorting significantly decrease (Table 1; Spearman Rank Correlation Coefficient, SRC, $p < 0.01$; Fig. 3). Q-mode cluster analysis of textural parameters (utilizing the Euclidean proportional dissimilarity coefficient and the unweighted pair group with arithmetic averages algorithm; Romesburg and Marshall, 1984) resulted in the dendrogram shown in Figure 4.

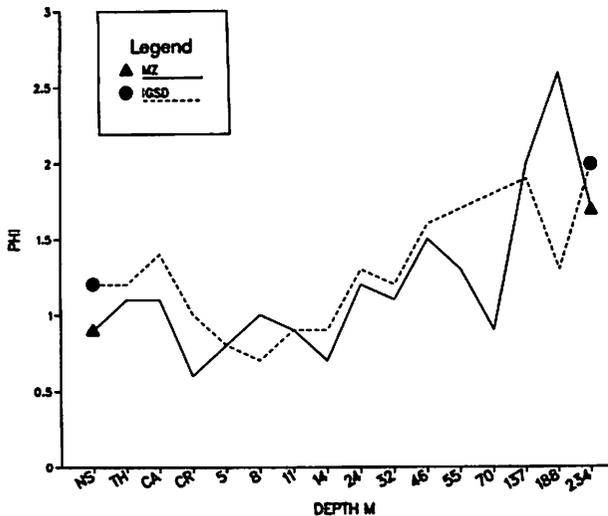


Fig. 3. Plot of mean grain size (MZ) and sorting (IGSD) versus depth (Table 1).

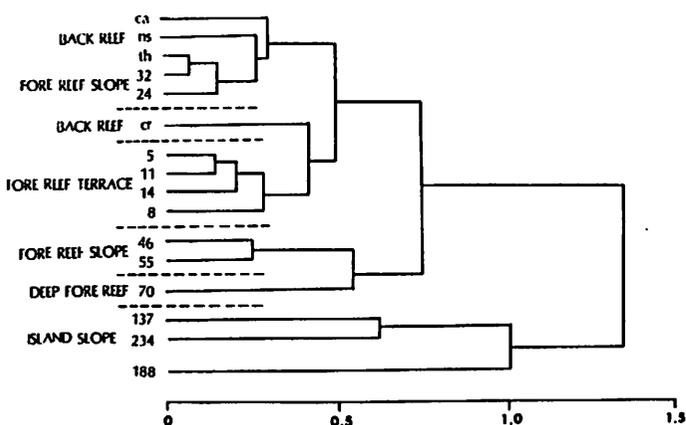


Fig. 4. Q-mode cluster dendrogram (Euclidean Distance, UPGMA) of sediment textural parameters from 1-234 m (Table 1). Dashed lines separate clusters which are significantly different (X^2 , $p < 0.05$).

Constituents

Coral, the encrusting foraminiferan *Homotrema*, non-encrusting foraminifera, and *Halimeda* display the most striking bathymetric trends (Fig. 5). Coral and *Homotrema* abundance are negatively correlated with depth (SRC, $p < 0.001$) while nonencrusting foraminiferal abundance is positively correlated with depth (SRC, $p < 0.001$). *Halimeda* has a bimodal distribution, being most abundant in the back reef (1-5 m)

sediment and in sediment from ≥ 24 m. This corresponds well to the distribution of living *Halimeda* on the reef (Liddell and Ohlhorst, 1986, and in press). Along with coralline algae, the above grains comprise over 80% percent of the sediment at most reef sites. Q-mode cluster analysis of the ten most abundant grain types (Table 2) resulted in the dendrogram shown in Figure 6.

Mineralogy

Total $CaCO_3$ in these sediments is generally greater than 95%. X-ray analysis of carbonate mineralogy indicates that aragonite is the primary carbonate phase (70%) with lesser amounts of high-Mg calcite (22%) and low-Mg calcite (8%). No statistically significant bathymetric trends occur, with the exception of an increase in the amount of high-Mg calcite (27%) occurring on the fore reef terrace (5-14 m). The amount of insoluble material on the island slope is double (4%) that on the fringing reef (2%), which most likely corresponds to the increase in fine-grained sediment on the former.

Foraminiferal Abundance

Over 180 species of foraminifera were identified by this study; of these, only 32 were "common" (i.e. comprised $\geq 1\%$ of at least one sample; Table 3). Species diversity (H' , \log_e ; Shannon and Weaver, 1948) is

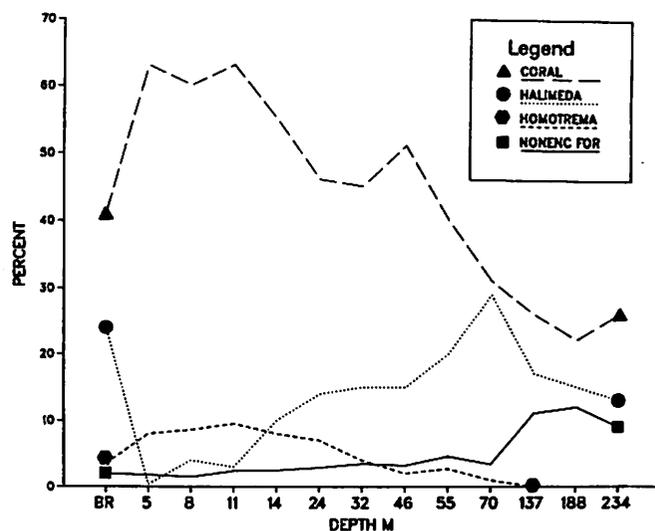


Fig. 5. Plot of sediment constituents (coral, *Halimeda*, *Homotrema*, nonencrusting foraminifera) versus depth (Table 2).

Location	N	Coral	Halimeda	Coralline Algae	Homotrema	Non-enc. Forams	Molluscs	Echinoderms	Other	Composite	Inid./Matrix
BR 1-5m	18	41.3 ± 6.8	24.0 ± 9.6	13.2 ± 1.9	3.5 ± 3.5	2.1 ± 0.7	3.5 ± 1.0	2.8 ± 1.4	0.4 ± 0.2	1.2 ± 0.6	7.7 ± 1.7
FRT 5m	6	62.6 ± 6.8	0.4 ± 0.4	13.5 ± 6.7	8.1 ± 5.6	1.8 ± 1.6	1.4 ± 0.8	1.7 ± 1.7	0.4 ± 0.4	3.2 ± 3.6	7.0 ± 3.8
FRT 8m	6	60.3 ± 6.8	3.6 ± 3.6	13.7 ± 10.1	8.6 ± 6.0	1.5 ± 1.4	2.7 ± 1.7	2.0 ± 1.0	0.5 ± 0.5	1.5 ± 1.2	5.6 ± 3.7
FRT 11m	6	63.1 ± 6.8	3.0 ± 1.6	8.4 ± 3.8	9.5 ± 5.9	2.4 ± 1.2	2.4 ± 1.5	3.3 ± 2.7	0.4 ± 0.3	1.2 ± 0.6	6.4 ± 3.1
FRT 14m	6	54.5 ± 3.6	10.1 ± 9.5	5.8 ± 3.0	8.3 ± 5.6	2.5 ± 2.2	4.6 ± 2.7	2.2 ± 0.4	0.3 ± 0.3	2.2 ± 1.2	9.5 ± 5.7
FRE 24m	7	46.2 ± 9.7	14.0 ± 12.0	8.7 ± 6.0	7.2 ± 2.3	2.9 ± 0.9	4.5 ± 3.0	1.8 ± 1.0	0.4 ± 0.2	1.9 ± 1.8	10.4 ± 6.2
FRS 32m	5	44.9 ± 5.6	15.0 ± 7.2	9.3 ± 6.2	4.3 ± 4.5	3.5 ± 0.7	5.1 ± 3.7	1.8 ± 1.0	0.4 ± 0.5	4.9 ± 3.9	10.8 ± 0.7
FRS 46m	6	50.8 ± 4.8	15.0 ± 6.4	4.7 ± 1.9	2.0 ± 0.9	3.2 ± 0.4	4.5 ± 2.2	1.4 ± 0.4	0.6 ± 0.3	3.8 ± 2.1	14.2 ± 4.2
FRS 55m	7	39.9 ± 8.1	19.5 ± 10.6	7.5 ± 6.1	2.7 ± 3.2	4.6 ± 2.1	4.3 ± 1.1	2.0 ± 1.7	0.7 ± 0.4	3.9 ± 2.3	15.0 ± 4.8
DFR 70m	11	30.9 ± 4.1	29.2 ± 9.2	5.3 ± 2.5	1.1 ± 0.8	3.4 ± 1.8	3.5 ± 1.2	1.6 ± 0.4	0.7 ± 0.4	8.1 ± 4.8	16.1 ± 2.5
IS 137m	4	25.8 ± 21.8	17.4 ± 3.7	9.7 ± 7.5	0.1 ± 0.0	11.1 ± 9.6	4.7 ± 2.9	3.8 ± 1.4	1.7 ± 1.6	1.7 ± 4.0	21.4 ± 15.6
IS 188m	4	21.5 ± 7.4	14.8 ± 4.9	11.3 ± 8.4	0.0 ± 0.0	12.1 ± 1.6	3.5 ± 1.3	2.7 ± 1.6	2.2 ± 0.9	1.6 ± 1.8	30.4 ± 16.1
IS 234m	4	25.6 ± 5.7	13.2 ± 4.2	14.8 ± 6.1	0.0 ± 0.0	9.0 ± 1.9	4.5 ± 0.8	2.8 ± 1.9	2.3 ± 1.0	3.1 ± 1.7	24.8 ± 9.3

Table 2. Sediment constituent composition (%) with 95% confidence intervals. Depths in meters; BR = back reef, FRT = fore reef terrace, FRE = fore reef escarpment, FRS = fore reef slope, DFR = deep fore reef, IS = island slope. Data from 1-70 m (average of 3 traverses, Fig. 1) from Boss and Liddell (in press), data from 137-23 m average of 2 traverses, B-B' and C-C', Fig. 1) from Nelson (1986).

positively correlated with depth (SRC, $p < 0.05$), increasing from 2.9 on the shallow fore reef terrace to 3.9 on the upper island slope. Species number is also positively correlated with depth (SRC, $p < 0.01$), increasing from 70 on the shallow fore reef terrace to 118 on the upper island slope. This increase in diversity may be due to a combination of factors including increased addition of pelagic species with increasing depth, less taphonomic destruction of fragile tests with increasing depth, and possible mixing of fore reef slope with island slope species.

Overall, species fidelity is low. Most species occur over a broad bathymetric range, with relative shifts in abundance occurring with changing depth (Table 3). Benthic rotaliine species are ubiquitous, displaying no statistically significant trends when plotted against depth (Fig. 2). The abundances of planktonic rotaliine and textulariine species are positively correlated with depth (SRC, $p < 0.001$), as both groups occur most abundantly in island slope sediments. In contrast, the abundance of milioline species is negatively correlated with

depth (SRC, $p < 0.01$), as these species are most common in back reef environments. Q-mode cluster analysis based on common ($\geq 1\%$) foraminifera species (Table 3) produced the dendrogram shown in Figure 7.

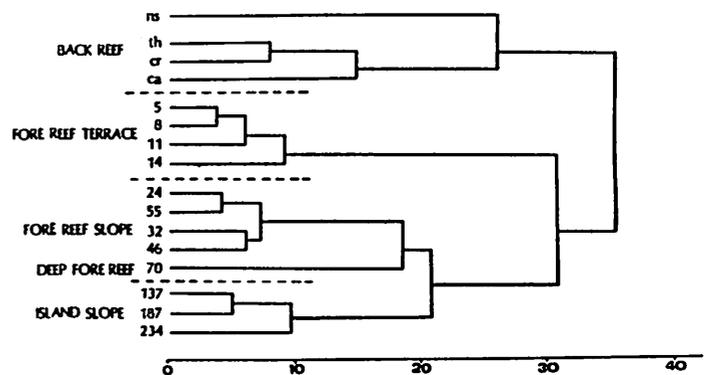


Fig. 6. Q-mode cluster dendrogram (Euclidean Distance, UPGMA) of sediment constituents from 1-234 m (Table 2). Dashed lines separate clusters which are significantly different (X^2 , $p < 0.05$).

Species (Group)	Back Reef			Fore Reef Terrace			Fore Reef Escarpment			Fore Reef Slope			Deep Fore Reef		Island Slope	
	BR-2	BR-4a	BR-4b	FRT-5	FRT-8	FRT-11	FRT-14	FRE-24	FRS-30	FRS-45	FRS-55	DFR-67	IS-135	IS-182	IS-236	
<i>Ammonia beccarii</i> (R)	0.0	10.2	6.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	
<i>Ampistegina gibbosa</i> (R)	7.8	8.7	11.9	25.8	22.4	31.9	20.6	31.7	22.2	27.8	24.2	20.6	16.3	8.3	17.9	
<i>Archaeas angulatus</i> (M)	14.1	16.1	11.8	2.5	8.2	4.6	6.8	1.7	6.8	2.4	4.4	2.7	2.1	2.1	4.1	
<i>Asterigerina carinata</i> (R)	5.3	3.8	6.7	8.8	11.8	7.4	16.1	5.3	11.2	6.4	6.9	6.7	4.5	4.4	3.0	
<i>Bigennerina irregularis</i> (T)	0.0	0.1	0.0	0.3	0.1	0.3	0.6	1.0	0.6	2.0	2.3	4.0	3.7	2.1	3.4	
<i>Borellis pulchra</i> (M)	1.1	2.7	1.1	2.0	5.7	3.4	2.6	1.3	1.7	0.5	0.6	0.5	0.3	0.2	0.4	
<i>Cibicides floridanus</i> (R)	0.2	0.3	0.4	0.3	0.1	0.2	0.1	0.2	0.9	0.7	1.2	1.4	5.4	7.4	6.6	
<i>Cibicides lobatulus</i> (R)	1.4	0.1	0.3	0.0	0.2	1.4	0.5	0.9	1.4	0.6	1.6	0.7	1.1	1.2	1.2	
<i>Cyclorbiculina compressa</i> (M)	3.1	0.4	0.2	1.9	1.4	2.3	1.7	2.6	6.1	3.4	3.1	2.8	1.1	0.7	4.0	
<i>Cymbaloporeta squamosa</i> (R)	8.3	2.7	2.5	1.6	3.9	1.3	2.4	1.0	2.1	1.7	3.1	1.0	0.8	0.6	0.9	
<i>Discorbis rosea</i> (R)	12.4	4.8	4.6	16.8	15.3	14.6	6.5	5.7	10.4	6.5	8.1	6.6	3.0	4.3	4.9	
<i>Eponides repandus</i> (R)	0.0	0.2	0.1	2.5	2.2	1.5	1.3	0.7	0.3	1.5	0.8	1.9	3.0	1.0	1.0	
<i>Globigerinoides quadrilobatus</i> (RP)	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	
<i>Globigerinoides ruber</i> (R)	0.1	0.3	0.3	1.1	0.3	0.5	0.6	2.3	1.3	3.0	3.8	3.8	1.9	5.7	3.2	
<i>Globigerinoides trilobus</i> (RP)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	4.9	3.3	
<i>Globorotalia menardii</i> (RP)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.2	2.6	2.0	
<i>Haverina bradyi</i> (M)	1.4	2.9	2.6	0.8	0.7	0.6	1.7	0.8	1.1	0.4	1.4	0.3	0.3	0.4	0.8	
<i>Heterostegina depressa</i> (R)	0.1	0.0	0.0	1.8	1.2	0.2	1.0	1.3	0.9	1.3	0.3	1.8	0.6	0.3	0.5	
<i>Miliolinella suborbicularis</i> (M)	0.4	0.0	1.0	0.1	0.2	0.2	0.1	0.2	0.0	0.2	0.3	0.2	0.5	0.8	1.0	
<i>Orbulina universa</i> (RP)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.3	6.1	4.2	0.4	
<i>Peneropolis bradyi</i> (M)	0.0	0.7	0.4	0.0	0.0	0.2	0.2	0.2	0.6	0.4	0.6	1.0	1.2	1.4	1.4	
<i>Peneropolis proteus</i> (M)	2.8	4.9	5.4	3.4	4.4	3.2	4.3	2.3	4.7	2.4	2.5	3.2	2.7	2.0	2.3	
<i>Planorbulina acervalis</i> (R)	3.4	3.8	5.4	1.1	0.0	0.8	1.9	2.1	0.4	2.4	0.6	0.7	0.9	0.6	0.4	
<i>Pyrgo fornasinii</i> (M)	1.8	0.8	0.4	1.6	0.5	0.4	1.7	0.6	0.8	1.0	0.4	0.9	1.7	0.7	0.5	
<i>Quinqueloculina bidentata</i> (M)	2.1	3.1	2.6	0.7	0.5	1.1	1.2	0.7	2.0	0.5	1.2	0.6	0.1	0.1	0.7	
<i>Quinqueloculina bradyana</i> (M)	0.9	1.3	0.8	1.6	4.1	3.3	4.2	2.9	2.2	3.0	3.3	2.9	0.8	0.8	0.5	
<i>Quinqueloculina lamarckiana</i> (M)	0.2	0.4	0.7	0.6	0.8	0.6	0.4	2.2	1.5	1.9	1.4	2.1	0.9	0.4	1.3	
<i>Q. parkeri</i> var. <i>occidentalis</i> (M)	0.1	0.2	0.5	0.1	0.4	0.4	0.7	0.2	1.7	0.4	0.2	0.9	0.2	0.4	0.6	
<i>Quinqueloculina seminulum</i> (M)	0.3	0.2	0.2	0.9	1.4	1.2	0.9	1.2	0.6	0.8	0.7	0.2	1.3	0.6	1.4	
<i>Siphonina pulchra</i> (R)	0.2	0.1	0.1	2.4	2.1	0.8	0.7	0.9	0.4	2.9	0.7	2.2	2.2	5.5	2.9	
<i>Sorites marginalis</i> (M)	5.0	6.1	6.4	0.3	0.1	0.1	0.6	0.8	0.2	0.0	0.5	0.7	0.6	0.5	0.8	
<i>Textularia conica</i> (T)	0.0	0.0	0.3	0.0	0.3	0.2	0.9	0.9	0.1	2.1	4.7	2.1	0.5	1.2	1.7	
GROUP (key)																
<i>Rotalina</i> (R)	47.72	46.00	43.90	71.38	63.86	66.19	58.12	59.56	55.28	60.59	55.87	55.09	50.98	49.71	51.49	
<i>Miliolina</i> (M)	48.11	50.16	53.41	24.49	33.16	29.78	36.86	31.09	39.37	26.30	29.61	30.16	20.55	19.68	28.57	
<i>Rotalina</i> (Planktonic) (RP)	0.10	0.32	0.30	1.08	0.42	0.48	0.69	2.79	1.54	3.58	4.47	4.85	15.28	20.14	9.93	
<i>Textularia</i> (T)	4.07	2.70	2.40	3.13	3.36	3.55	4.34	6.48	3.85	9.53	10.06	9.90	10.69	10.48	10.02	

Table 3. Foraminifera species and group abundance for Zingorro traverse (B-B', Fig. 1; 2-236 m). Table based on the 32 most common species ($\geq 1.0\%$) and 21,770 specimens from 18 sites. Data from 2-70 m from Martin and Liddell (in prep. a), data from 136-236 m from Nelson (1986).

DISCUSSION AND CONCLUSIONS

All of the above parameters (texture, constituents, carbonate mineralogy, insoluble content, foraminifera species and larger foraminifera groups) exhibit utility in facies delineation over the range of 1-234 m. However, constituents, foraminifera species, and textural characteristics offer the finest facies resolution.

The reef biota exhibits a well-defined zonation which is reflected in the distribution of sediment constituent grains (Boss and Liddell, in press). Q-mode clustering of constituents (Table 2, Fig. 6) results in a dendrogram containing the following statistically significant (X^2 , $p < 0.05$) clusters: back reef (1-5 m), fore reef terrace (5-14 m), fore reef escarpment, slope and upper deep fore reef (24-70 m), and upper island slope (137-234 m).

While exhibiting low fidelity (restriction) to particular environments or depths, the abundances of most foraminifera species vary with depth (Table 3). In addition, the

relative abundances of larger foraminifera groups (suborders and planktonic versus benthic forms) vary with depth. From a practical standpoint, the latter shows great potential as these categories can be identified by non-specialists, even in thin-section. Q-mode clustering of the common ($\geq 1\%$) foraminifera species yields three statistically significant (X^2 , $p < 0.05$) clusters representing back reef (1-5 m), fore reef (5-70 m) and island slope (137-234 m) environments. Within the fore reef cluster, there is a general separation of shallow and deep sites.

Texture (Table 1) is perhaps the weakest of the three suites of parameters which were utilized in cluster analysis as indicated by the relatively low range for the dissimilarity coefficient (Fig. 4). Nonetheless, the deeper fringing reef and island slope environments are distinct while the back reef and shallow fringing reef sites are generally (but not completely) separated. This reflects non-linearly changing energy conditions (low, high, low) along the reef profile and textural

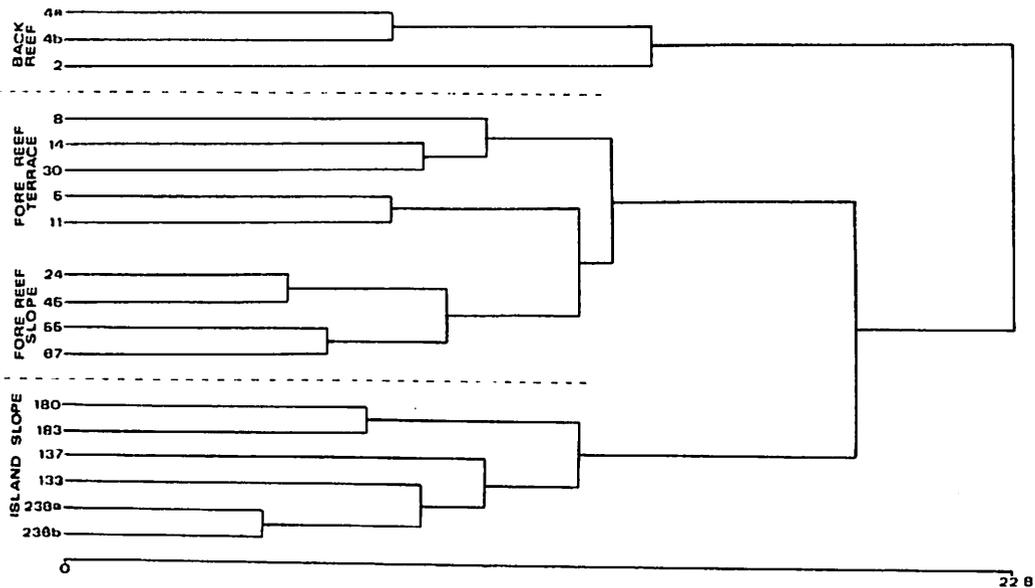


Fig. 7. Q-mode cluster dendrogram (Euclidean Distance, UPGMA) of common ($\geq 1\%$) foraminifera species from 2-236 m (Table 3). Dashed lines separate clusters which are significantly different (X^2 , $p < 0.05$).

"inversions" produced by the *in situ* generation of grains by biosynthesis.

With regard to the magnitude of transport or mixing of sand-sized sedimentary components in the reef environment, it is of interest to examine Figure 6. Note that fore reef slope, deep fore reef and island slope sites are more similar to each other than to any of the shallower fore reef terrace or back reef environments. This suggests that transport from the gently sloping, shallow reef zones into deeper water environments is somewhat restricted, whereas the more steeply sloping fore reef slope and the vertical to overhanging deep fore reef (Fig. 2) appear to be supplying much of the sediment occurring on the island slope. This supports the idea that sill reefs, occurring at the top of the fore reef slope, act as sediment traps, thereby limiting off-reef transport of sediment from the shallow reef (Goreau and Goreau, 1973; Moore, and others, 1976). The high degree of separation of back reef sites from all others (Figs. 6-7) demonstrates the relative effectiveness of the reef crest as a barrier to sediment transport into or out of the back reef. These trends are further supported by Boss and Liddell's (in press) study which demonstrates that no significant (X^2 , $p < 0.05$) differences in sand-sized constituents exist between

sediment samples from sand channels and sites on the adjacent reef. The steady decline in *Homotrema* abundance (Table 2, Fig. 5) from shallow water, where it lives (Mackenzie and others, 1965) and comprises up to 9.5% of the sediment, onto the island slope also indicates the limited nature of sediment flux in the shallow reef system.

We believe that this paper demonstrates the potential utility of quantitative studies of sediment in microfacies analysis and in evaluating sediment flux in reef environments. We caution that the results are from a single reef at Jamaica and should be tested elsewhere before extrapolation to other settings or back in time.

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