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Geomorphology and community composition of two adjacent reef areas, Discovery Bay, Jamaica

by W. David Liddell and Sharon L. Ohlhorst

ABSTRACT

The north coast of Jamaica possesses a highly variable topography which reflects tectonic displacement of Pleistocene rock units. Holocene reef development is intimately related to the underlying Pleistocene rocks and reflects such variation in basement morphology. Underwater surveys have established that two adjacent reef areas, the East and West Fore Reefs at Discovery Bay, Jamaica, exhibit contrasting bottom profiles which are due to differential offset of the underlying Pleistocene shelf carbonates. The East Fore Reef is displaced 10 m relative to the West Fore Reef which has resulted in the lowering of such morphological zones as the fore reef escarpment, fore reef slope and the beginning of the deep fore reef wall. Displacement of the Pleistocene shelf post dates the cutting of several terraces in the 120,000-130,000 y. b. p. Falmouth Formation during Wisconsin stillstands.

The reefs of the East Fore Reef also differ from those of the West in exhibiting less relief on spur and groove structures and transects document differences in biotic composition of the two areas. These contrasts are probably linked to the differences in depth and geometry of the two fore reef terrace areas.

1. Introduction

Holocene reef development along the north coast of Jamaica is closely related to the topography of the underlying Pleistocene shelf carbonates (Gareau and Land, 1974; Land, 1974). Reef accretion rate information derived from cores taken from Holocene reef and underlying Pleistocene rocks demonstrate that the present Jamaican reefs represent relatively thin veneers of less than 10 m upon the Pleistocene basement. Thus, zones such as the fore reef terrace, fore reef escarpment, slope and deep fore reef (terminology after Gareau and Land, 1974) reflect coral mantling of erosional features formed at lower Pleistocene sea levels.

The subaerial topography of the north coast of Jamaica is highly variable and at
least some of the variation is due to tectonic offset of coastal blocks (Horsfield, 1972). Similarly, the morphologies of the reefs which fringe the north coast are also highly variable, even within the distance of only a few kilometers to the east or west of Discovery Bay (Woodley and Robinson, 1977). The current investigation examines the contrasting bottom topography and consequent reef development of two adjacent sites along the north coast of Jamaica—the much studied West Fore Reef area in the vicinity of Discovery Bay and the nearby, yet poorly known, East Fore Reef—and relates the observed features to the configuration of the underlying Pleistocene basement.

2. Methods

Studies were carried out at Discovery Bay, Jamaica (Fig. 1). Two areas, the West and East Fore Reefs, separated by a ship channel cut through the fringing reef,
were examined. Bottom profiles across each (Figs. 2, 3) were constructed using aerial photographs, bathymetric charts (Admiralty Chart 459, 1970) and underwater observations to depths of 55 m. Biotic composition of the two areas (Tables 1 and 2) were determined through the use of line transects (Loya, 1972; Porter, 1972) with points located at 20 m intervals and were conducted during 1977-1978 (Ohlhorst, 1980).

3. Results

a. West Fore Reef. The West Fore Reef exhibits the structural and ecological zones which characterize most Jamaican north coast reefs (Goreau, 1959; Goreau and Goreau, 1973) and has been described by Kinzie (1973), Goreau and Land (1974), Lang (1974) and Moore et al. (1976). The following succession of zones would be encountered along a transect across the West Fore Reef: reef crest, fore reef terrace, fore reef escarpment, fore reef slope and deep fore reef. The profile (A-A’, Fig. 3) presented herein is similar to those by others (Goreau and Wells, 1967; Kinzie, 1973; Dustan, 1975) for sites along the West Fore Reef.

The reef crest (0-7 m) consists of an upper zone dominated by the coral Acropora palmata. A slightly deeper, well developed mixed zone, dominated by Montastrea annularis and Acropora cervicornis, merges with the fore reef terrace. The fore reef
terrace (7-15 m) consists of large parallel lobes or buttresses oriented perpendicular to the reef crest and extending seaward at a moderate (15-20°) slope for approximately 200 m. These lobes are interrupted by large sand patches and channels resulting in spur and groove topography. These spurs often rise 5 m above the surrounding sand (Fig. 4B) and terminate in a steep (45°+) escarpment (15-25 m). The terrace is dominated by *A. cervicornis* with scattered heads of other corals, predominately *M. annularis* and *Colpophyllia natans*. The escarpment is less dominated by *A. cervicornis*, with a more even distribution of other coral species.

The landward portion of the fore reef slope, which begins at 25-30 m depth, usually consists of a low angle (5-20°) sand “moat” containing scattered coral heads. Coral cover increases at 30-35 m, often forming parallel fingers and occasional pinnacles which may rise up to 10 m above the sand. At approximately 35 m the slope increases to between 45-60°. Below 35 m the reefs are dominated by various sponges and plating *Agaricia* spp. Another slope break occurring between 45 and 65 m, typically at 55 m, marks the beginning of the deep fore reef “wall”. The effects of erosion and scleractinian growth on promontories have resulted in a variable upper depth for this structure. The steep (60-90°) escarpment
ends at approximately 122 m where the more gentle (20-45°) island slope begins (Moore et al., 1976).

The biotic composition of two West Fore Reef sites (15 m, 30 m) are presented in Table 1. Table 2 presents the relative abundances of various coral species at the two sites.

b. East Fore Reef. The East Fore Reef is briefly described by Woodley and Robinson (1977). Their description notes that the reef crest is not exposed, the terrace is very broad and constructional relief appears less than on the West Fore Reef. The description of the East Fore Reef is expanded upon herein; most importantly, it is noted that certain structural features are missing or offset relative to the West Fore Reef (B-B'; Fig. 3).

The reef crest is not well developed and possesses a reduced *A. palmata* zone. Just seaward is a barren zone of reef pavement with scattered colonies of predominately *Siderastrea radians* and *Diploria clivosa*. On the West Fore Reef this zone is poorly developed and much narrower. The following mixed zone merges with a very broad (approximately 800 m wide) fore reef terrace which extends from 7-28 m with a very shallow (0-5°) slope. *A. cervicornis* and *M. annularis* are the dominant corals of the terrace although diversity is high. Unlike the West Fore Reef, there are no pronounced coral buttresses rising above the sand, but rather extensive low-relief fields of coral and sand patches or channels (Fig. 4C), certain of which are organized into anastomosing fingers. Between 15-28 m the plain is broken by roughly parallel sand channels lacking steep sides. At 28 m the slope steepens to 45° or more, forming an escarpment which descends to 38 m.
Table 2. Coral composition at 4 Jamaican reef sites. Values are percentage of total corals. "*" indicates species present but not recorded under a transect point. (From Ohlhorst, 1980).

<table>
<thead>
<tr>
<th></th>
<th>WFR(15 m)</th>
<th>WFR(30 m)</th>
<th>EFR(15 m)</th>
<th>EFR(23 m)</th>
</tr>
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<tbody>
<tr>
<td>N (transect points) =</td>
<td>215</td>
<td>312</td>
<td>227</td>
<td>360</td>
</tr>
<tr>
<td>Acropora cervicornis</td>
<td>44.0</td>
<td>2.0</td>
<td>13.0</td>
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<tr>
<td>Agaricia agaricites</td>
<td>18.5</td>
<td>16.5</td>
<td>9.5</td>
<td>13.5</td>
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<tr>
<td>Agaricia lamarckii</td>
<td>—</td>
<td>9.5</td>
<td>3.0</td>
<td>—</td>
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<tr>
<td>Colpophyllia natans</td>
<td>1.0</td>
<td>1.0</td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Dendrogyra cylindrus</td>
<td>*</td>
<td>—</td>
<td>*</td>
<td>—</td>
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<tr>
<td>Dichococenia stokesi</td>
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<td>*</td>
<td>0.5</td>
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<tr>
<td>Diploria labiathiformis</td>
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<td>Eusmilia fastigiata</td>
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<td>*</td>
<td>*</td>
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<td>Helioseris cucullata</td>
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<td>6.5</td>
<td>0.5</td>
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<td>*</td>
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<td>Manicina areolata</td>
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<td>Meandrina meandrites</td>
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<tr>
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<td>0.5</td>
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<td>Montastrea annularis</td>
<td>7.0</td>
<td>45.5</td>
<td>39.5</td>
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<td>Montastrea cavernosa</td>
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<td>10.5</td>
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<td>*</td>
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<td>Mycetophyllia ferox</td>
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<td>0.5</td>
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<tr>
<td>Porites porites</td>
<td>4.0</td>
<td>—</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Scolymia cubensis</td>
<td>—</td>
<td>*</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Siderastrea siderea</td>
<td>1.0</td>
<td>2.0</td>
<td>7.0</td>
<td>9.5</td>
</tr>
<tr>
<td>Stephanocoenia michelinii</td>
<td>2.0</td>
<td>3.0</td>
<td>*</td>
<td>3.0</td>
</tr>
</tbody>
</table>

| H = | 1.86 | 1.82 | 2.02 | 2.23 |
| J = | 0.67 | 0.64 | 0.73 | 0.77 |

1 A hydrozoan included because it produces a calcified skeleton
2 Shannon and Weaver, 1948 (H' calculated using log e)
3 Pielou, 1968

Figure 4. A. Offset in subaerially exposed Pleistocene terraces located approximately 4 km west of Discovery Bay, Jamaica.
B. High relief spur and groove structure (top of terrace at 15 m), West Fore Reef, Discovery Bay.
C. Low relief contact between reef and sand plain at 15 m, East Fore Reef, Discovery Bay.
Seaward of the fore reef escarpment, morphological features are very similar to those of the West Fore Reef, however, they appear to be lowered by approximately 10 m. A low angle (5-10°) sand moat extends seaward from 38 m and increases in slope at 45 m to approximately 45°. Increased coral cover, including pinnacle formations, begins at 39 m and plating corals, largely Agaricia spp., persist with increasing depth. At approximately 66 m the fore reef slope terminates at the nearly vertical wall of the deep fore reef.

A second East Fore Reef profile (C-C', Fig. 2) resembles that described above with a low angle fore reef terrace, a 45° escarpment from 28-38 m, and a low angle sand moat from 38-43 m with parallel pinnacles appearing at 40 m. The slope steepens to 45° at approximately 43 m although it flattens again in areas of reef growth from 55-66 m. At 66 m the deep fore reef wall begins.

A third East Fore Reef profile (D-D', Fig. 2) differs from the previous two in that the slope of the fore reef escarpment from 24-36 m is only 20°. At 36 m the slope increases to 45° and continues to 64 m, the beginning of the deep fore reef wall. A sand moat is absent along this profile and both reefs and sand channels are uninterrupted in their seaward continuation.

The 800 m wide fore reef terrace of the East Fore Reef is greatly extended relative to the West Fore Reef and appears to continue subaerially as the wide Pleistocene terrace forming the east side of Discovery Bay. This terrace of Falmouth Formation limestone extends southward from the shore for over 1 km before terminating at a wave-cut cliff in the older Hopegate Formation. On the west side of Discovery Bay the subaerial Falmouth terrace extends southward for only approximately 100 m before abutting against a Hopegate Cliff. The explanation for the breadth of this shelf is unknown at this time although reef growth at approximately 120,000-130,000 y. b. p. on an earlier (Pliocene or Miocene) broad fluvial “prism” represents one possibility (L. S. Land, personal communication).

Several differences exist between the communities inhabiting similar depths on the East and West Fore Reefs (Table 1), especially at 15 m. Corals are more abundant at 15 m on the East than on the West Fore Reef and species composition is quite different with Montastrea spp. predominating on the East Fore Reef and Acropora cervicornis predominating on the West Fore Reef (Table 2). Fleshy sponges are also more abundant at 15 m on the East Fore Reef while boring sponges and coralline algae are more evident at 15 m on the West Fore Reef.

The deeper sites differ in that the West Fore Reef (30 m) has a higher coral cover and few algae while on the East Fore Reef (23 m) fleshy algae predominate in addition to corals (Table 1). Coral species composition is more similar between these sites with both dominated by Montastrea annularis. The abundance of fleshy algae at 23 m on the East Fore Reef (30.5% of all points) is somewhat anomalous as all other sites (both sides of the channel) exhibit very low algal abundances (0.7-
c. Physical and chemical factors. Over the range of 10-30 m, the parameters of temperature, dissolved carbon, oxygen, and salinity do not vary significantly with depth or between the East and West Fore Reef sites. (Ohlhorst, 1980) Examination of sedimentation patterns at equivalent depths also failed to show significant differences between the East and West Fore Reefs. (Ohlhorst, 1980) Nonquantitative evidence (e.g. Woodley, 1980) suggests that the energy regimes of the two areas may differ, with sites on the East Fore Reef receiving greater amounts of storm energies than sites at comparable depths on the West.

d. Summary. In summary, the West and East Fore Reefs in the vicinity of Discovery Bay differ in the following features: (1) several of the prominent breaks in slope of the West Fore Reef (at 15, 33, and 55 m) appear to be displaced (lowered) by 10 m on the East Fore Reef, (2) the fore reef terrace of the East Fore Reef is greatly lengthened relative to that of the West, (3) the reefs of the East Fore Reef show less relief (on the order of several meters) above sand channels than those of the West and, finally, (4) certain faunal elements, particularly scleractinian species, exhibit greater abundance at one site than at the other.

4. Discussion

a. Pleistocene history. The chronology of deposition and erosion of Pleistocene rock units in the Discovery Bay area in response to fluctuations in sea level provides a framework in which the timing of displacement of the East Fore Reef may be determined. At 120,000-130,000 y.b.p. the Falmouth Formation was deposited on an eroded terrace in the 300,000 y.b.p. Hopegate Formation at a +10 to +20 m sea level during the Sangamon Interglacial (Land, 1973). A lowering of sea level to a stillstand at +3 m heralded the Wisconsin Glaciation and resulted in truncation of the Falmouth Formation and cutting of a notch in the cliffs of the Hopegate Formation at 105,000 y.b.p. (Land and Epstein, 1970). These features are now exposed subaerially and may be observed along the coastline near Discovery Bay. With the onset of the Wisconsin Glaciation the Falmouth Formation was further exposed as sea level descended and other lower terraces, now mantled by Holocene reef growth, were cut at various stillstands. These terraces are responsible for the characteristic submarine profiles of the modern Jamaican reefs. One such stillstand near present sea level, occurring at approximately 80,000 y.b.p., is reported by...
several authors (Mesolella et al., 1969). Other (now) subaqueous terraces were probably cut between 80,000 and 20,000 y.b.p. although eustatic changes during this interval are poorly documented (Momer, 1971).

At 15,000 y.b.p. sea level was at −130 m (Emery, 1969). This depth corresponds to the base of the deep fore reef and the beginning of the island slope (Moore et al., 1976). From approximately 15,000 to 5,000 y.b.p. sea level rapidly rose to within a few meters of the present sea level (Emery, 1969; Goreau, 1969) and at this time reef organisms became established upon the newly flooded substrate. Isostatic adjustment from the last glaciation has resulted in the subsequent sea level “rise” to the present level (Bloom, 1971). Figure 5 illustrates the relationships of the Pleistocene rock units and Holocene reefs in the vicinity of Discovery Bay, Jamaica.

b. Late Pleistocene shelf movements and reef geomorphology. As the prominent breaks in the submarine profile of the West Fore Reef (Fig. 3A) represent Pleistocene erosional features (Goreau and Land, 1974; and Land, 1974), the apparent lowering of these features on the East Fore Reef can best be explained by a dropping of the East Fore Reef block relative to the West, through faulting and/or tilting. Several authors present evidence for Late Pleistocene faulting on the north coast of Jamaica. Land and Epstein (1970) mention an offset of 8 m in the subaerial Pleistocene in the vicinity of Discovery Bay. Horsfield (1972, 1973) documents offsetting of several meters in the Falmouth Formation and of the 105,000 y.b.p. erosional notch cut into the Hopegate Formation to the west of Discovery Bay. Cant (1972) cites offsetting of Pleistocene terraces (Falmouth and Hopegate Formations) in the area of Oracabessa, 45 km east of Discovery Bay. These examples of Late Pleistocene movements are consistent with the suggestion that a displacement of 10 m has occurred between the West Fore Reef and the East Fore Reef blocks. From the previous Pleistocene chronology, it is apparent that the
relative lowering of the East Fore Reef must have occurred after several truncations of the Falmouth terrace since these surfaces are now offset. Therefore, the movement was most likely initiated sometime after 80,000 y.b.p. and completed prior to the 15,000-5,000 y.b.p. Holocene transgression and subsequent mantling of the Pleistocene rocks by coral growth.

c. Other factors controlling Holocene reef development. Gareau (1969) theorized that the uneven development of coral communities along coastlines where there are no obvious differences in environmental parameters reflects chance phenomena and that the 5,000 years since the attainment of near modern sea levels is an insufficient amount of time for random effects to be damped out. Certain of the differences in coral species composition of the East and West Fore Reefs (Table 2) may be due to such stochastic processes, however, differences in reef terrace depths and geometries are capable of influencing physical parameters, such as light, sediment dispersal and water movement, and, thus, reef construction. In this context several possible controls of reef development are discussed.

The greater depth of the lowered East Fore Reef relative to the West Fore Reef following the relatively rapid Holocene sea level rise would result in greater light attenuation and, thus, possibly lower coral growth rates as suggested by Adey et al. (1977) for reefs at St. Croix. The differences in vertical accretion rates found by Land (1974) for two depths on the West Fore Reef are not greatly dissimilar (1.0 m/1000 yrs at 26 m on the fore reef escarpment and 0.6 m/1000 yrs at 36 m on fore reef pinnacles) but are sufficient to account for differences in reef accretion of approximately 2 m over 5,000 years. It should be noted, however, that Wethey and Porter (1976) present evidence suggesting that the relationships between photosynthesis and growth rates and depth may not be as clear cut as generally assumed and demonstrate that at least certain scleractinians are capable of depth "acclimatization", thereby compensating for reduced light intensities.

Although deeper flooding of large portions of the East Fore Reef relative to the West following the Holocene transgression might result in less constructional activity in the deeper zones, it is not sufficient to explain the lower constructional relief of shallow portions of the East Fore Reef; therefore other parameters related to the geometry of the East Fore Reef terrace must be considered. Gareau and Wells (1967) suggest that broad areas of low slope (such as the East Fore Reef) may experience hindered sediment drainage and, thus, interference with reef growth. However, as cited earlier, sedimentation rates are not shown to differ significantly between the two areas.

Roberts et al. (1975) have demonstrated that certain aspects of reef morphology are intimately linked to the distribution of wave power. The differences exhibited by the East Fore Reef relative to the West (less constructional relief on spur and groove structures, broader gently sloping terrace, greater seaward extension of the
East Fore Reef block) may be related to different wave energy regimes. Also, the greater seaward extension of the East Fore Reef results in greater susceptibility to storm damage, particularly as the majority of hurricanes tend to cross the Caribbean from the East (Neumann and Hill, 1976). The West Fore Reef, particularly the more eastern portions, is to some degree sheltered from waves by the East Fore Reef terrace. This was graphically displayed in August, 1980 when Hurricane Allen struck the north coast of Jamaica (Woodley, 1980). Storm wave damage to the East Fore Reef was extensive, in places reducing the terrace to a level plain of coral rubble, while the West Fore Reef was affected to a lesser degree (J. D. Woodley, personal communication). While the frequency of such catastrophic events as major storms striking a particular site is low by human standards, such events occur with a frequency which is significant over both geological and ecological time. For example, Hayes (1967) stresses the importance of hurricanes as geological agents and cites the frequency of hurricanes striking the Texas coast during this century (0.67/yr) as supporting evidence. It is felt that the periodic leveling of the East Fore Reef by major storms is in large part responsible for the low topographic relief exhibited and may even exert an effect on species differences between the two areas (e.g. lessened abundance of *Acropora cervicornis* on the East Fore Reef, Table 2).

5. Conclusions

Underwater surveys have established that submarine features such as the fore reef escarpment, slope and deep fore reef wall of the East Fore Reef at Discovery Bay, Jamaica, are lowered by 10 m relative to the West. Displacement occurred as the result of late Pleistocene faulting and/or tilting of the East Fore Reef block. The East Fore Reef also differs in exhibiting less relief between sand channels and reef patches than does the West. Although the two areas are generally comparable in terms of living bottom cover and species diversity, differences in relative abundances of scleractinian species and other organisms do occur. While stochastic processes may play some role in the determination of reef community composition, it is more likely that the interaction between its terrace morphology and periodic severe storm events exert the major control on both community structure and constructional relief of the East Fore Reef.

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