ATOLL RESEARCH BULLETIN

NO. 466

ORIGIN OF THE PELICAN CAYS PONDS, BELIZE

BY

IAN G. MACINTYRE, WILLIAM F. PRECHT, AND RICHARD B. ARONSON

ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
MARCH 2000

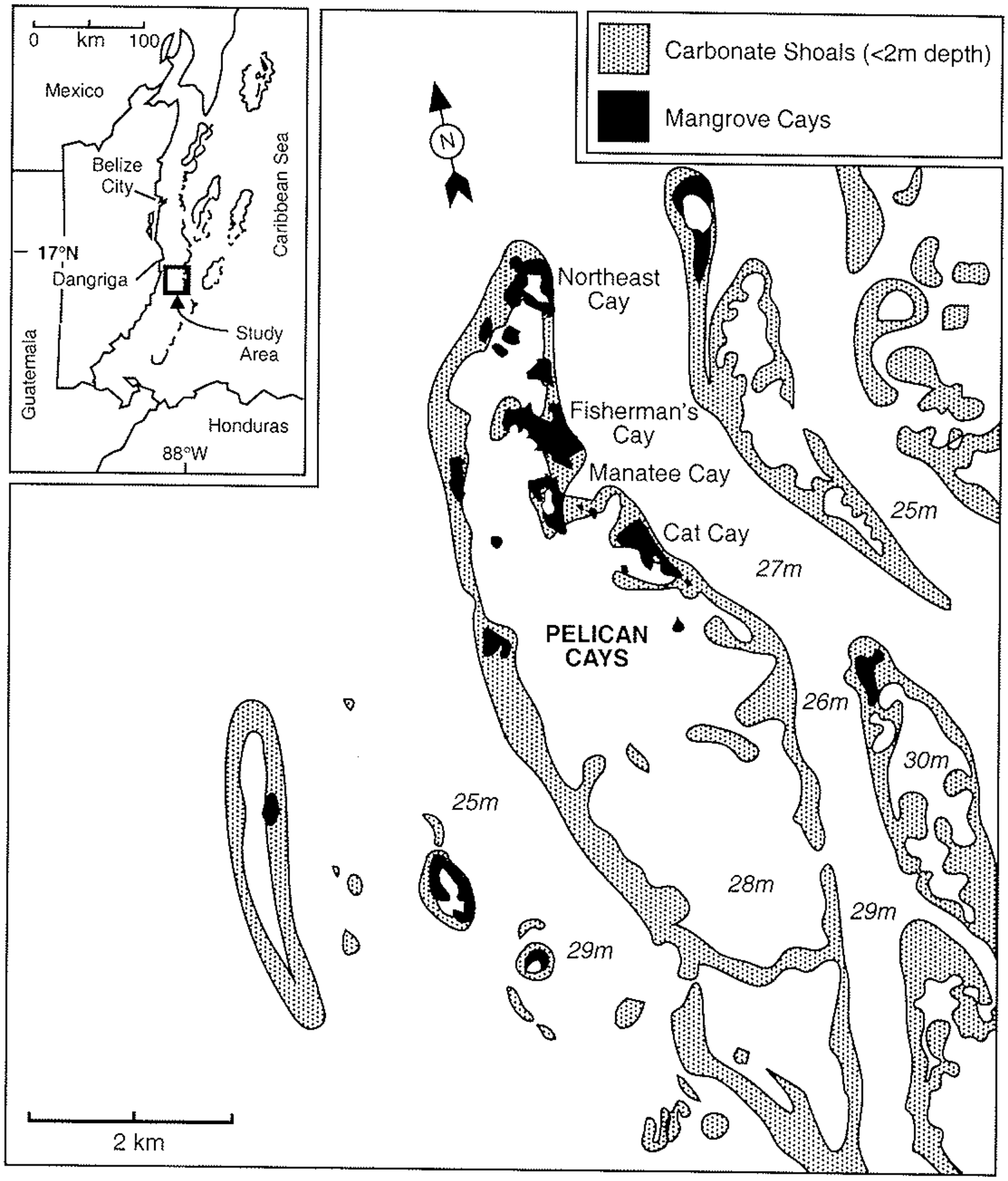

Figure 1. Index map showing the location of the Pelican Cays in the Belizean Barrier Reef Complex. Modified from a Landsat TM image acquired 18 September 1987.

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ABSTRACT

Probing with interlocking steel rods and short cores indicates that the small ponds characteristic of the Pelican Cays are formed by differential coral accumulations on a polygonal karst pattern eroded into the underlying Pleistocene limestone. Rapidly accumulating *Acropora cervicornis*-dominated communities have been responsible for exaggerating the karst relief, forming steep-sided ridge patterns that commonly result in small restricted ponds. A shallowing-upward facies pattern is documented within the ridges and consists of an *Acropora cervicornis* facies grading into a *Porites divaricata* facies, which finally gives way to mangrove peat.

INTRODUCTION

The most striking topographic feature of the Pelican Cays (Fig. 1), in the south-central lagoon of the Belizean Barrier Reef, is the complex network of coral ridges, both submerged and exposed, some with mangrove cover. This unusual honeycomb topographic pattern, once colonized by the red mangroves *Rhizophora mangle*, forms the characteristic enclosed or partly enclosed ponds of this area of the barrier reef complex (Fig. 2). Similar ridge patterns have been reported in shallow lagoon areas in the Maldives by Purdy and Bertram (1993), who related them to the karst topography of the underlying limestone. The purpose of this study was to investigate the role of subsurface control in the formation of the Pelican Cays network of reef ridges, the extent to which Holocene differential reef accumulation contributes to the relief of these ridges, and the relationship of these ridge patterns to the origin of enclosed ponds.

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[1]Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560-0125.

[2]PBS & J Engineering Science, 2001 Northwest 107th Avenue, Miami, FL 33172.

[3]Dauphin Island Sea Lab, 101 Bienville Boulevard, Dauphin Island, AL 36528.

Figure 2. Aerial view of the Pelican Cays looking SSE: Fisherman's Cay (left), Manatee Cay (right), and Cat Cay (background). Note the characteristic enclosed and partially enclosed ponds in these islands and the network of shallow ridges in Pond C in Manatee Cay. (Photo by T. Rath)

METHODS

The research focused on the well-developed network of ridges in Pond C of Manatee Cay (Fig. 2). A 0.95-cm-diameter steel probe, in 3.05-m extensions, was used to establish the contact with the underlying rock substrate (Fig. 3). This contact was easy to detect because of the relative ease of penetrating the overlying open branching coral framework consisting predominantly of *Acropora cervicornis* (Shinn et al., 1979; Westphall, 1986; Aronson and Precht, 1997). In addition, three short cores were collected by pushing a 7.6-cm-diameter aluminum tube into the crests of reef ridges. Core logs were expanded to correct for compaction that occurred during coring.

Radiocarbon dates were determined by standard techniques by Beta Analytic Inc. (Miami, Florida). These dates are reported as radiocarbon years before A.D. 1950, conventionally termed "before present" (B.P.), using a Libby half-life of 5,568 yrs and a modern standard based on 95% of the activity of the National Bureau of Standards' oxalic acid. No corrections were made for the DeVries effect, reservoir effect, or natural isotopic fractionation.

RESULTS

Our probing and coring activities were limited to the complex ridge system around the opening to the large central pond in Manatee Cay, Pond C (Fig. 4). One transect of probe sites, including a core site, was established across the coral ridge that runs across the entrance to this

Figure 3. Probing open coral framework with connecting steel rods to locate depth of solid rock substrate.

pond, and a similar transect was set up across the northern inner ridge that cuts across the pond. In addition, a probe and core site, was also located on the crest of the southern inner ridge, an a 3-m probe section was pushed into the center of the southern pond and did not encounter a hard base.

As can be seen in Table 1, the two probe transects indicate that the ridges are established on minor relief (1 m and 0.7 m) at the edge of a significant drop in elevation of the hard rock substrate (8.6 m and 5.7 m). This is well illustrated in Fig. 5, which shows a transect across the ridge that extends across the mouth of Pond C. Although the hard substrate was not located in the southern pond probe, similar relief was encountered between this site and the site on the southern inner ridge. The accumulation of Holocene sections (Table 1) indicates that reef growth on the ridges is approximately twice that found in the interior of ponds.

Core 1 was collected on the crest of the ridge at the mouth of Pond C and consisted of two core intervals. The first interval reached a depth of 1.5 m and had a core recovery of 80%. The second core interval was from 1.5 m to 4.1 m and had a recovery of 72%.

As the core log (Fig. 6) indicates, most of the coral recovered was *Acropora cervicornis*, with smaller amounts of *Agaricia tenuifolia, Porites furcata,* and *Millepora* spp. There was a marked increase in the amount of *A. tenuifolia* and *Millepora* spp. in the top section of the core. This transition in reef facies is related to the colonization of *A. tenuifolia* following the 1986–1992 mass mortality of *A. cervicornis* throughout this area of the lagoon (Aronson and Precht, 1997). A light grey mud matrix was found throughout both core intervals.

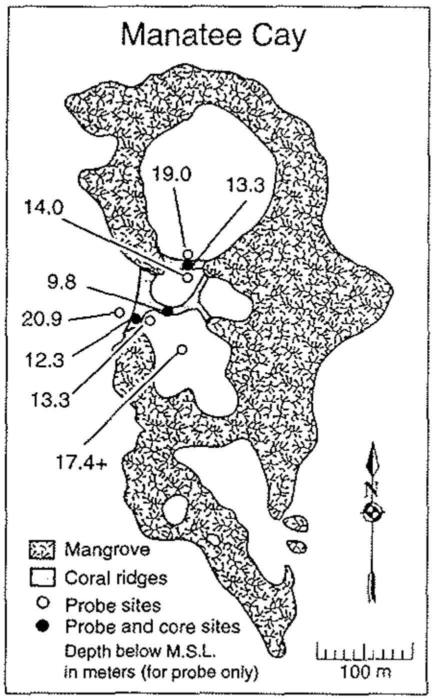

Figure 4. Map showing probe and core locations in the central area of Pond C, Manatee Cay.

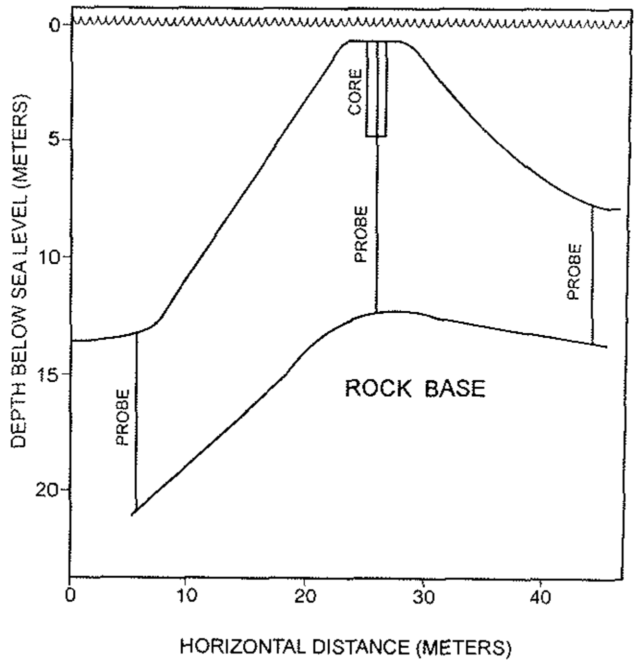

Figure 5. Probe transect across ridge at mouth of Pond C, Manatee Cay. The hard rock substrate shows a slight elevation in relief before a significant increase in depth. Note the exaggeration of this rim relief by the differential accumulation of the overlying section.

Table 1. Probe Holes in Pond C , Manatee Cay (depths in meters)

Location	Water depth	Probe depth	Depth of Pleistocene (below MSL)
Pond Entrance Ridge			
Base outer slope	13.3	7.6	20.9
Ridge crest	0.6	11.7	12.3
Base inner slope	7.3	6.0	13.3
Northern Inner Ridge			
Base northern slope	10.1	8.9	19.0
Ridge crest	1.0	12.3	13.3
Base southern slope	8.8	5.2	14.0
Southern Inner Ridge			
Ridge crest	0.8	9.0	9.8
Southern Inner Pond			
Center of pond	14.3	3.1+	17.4+

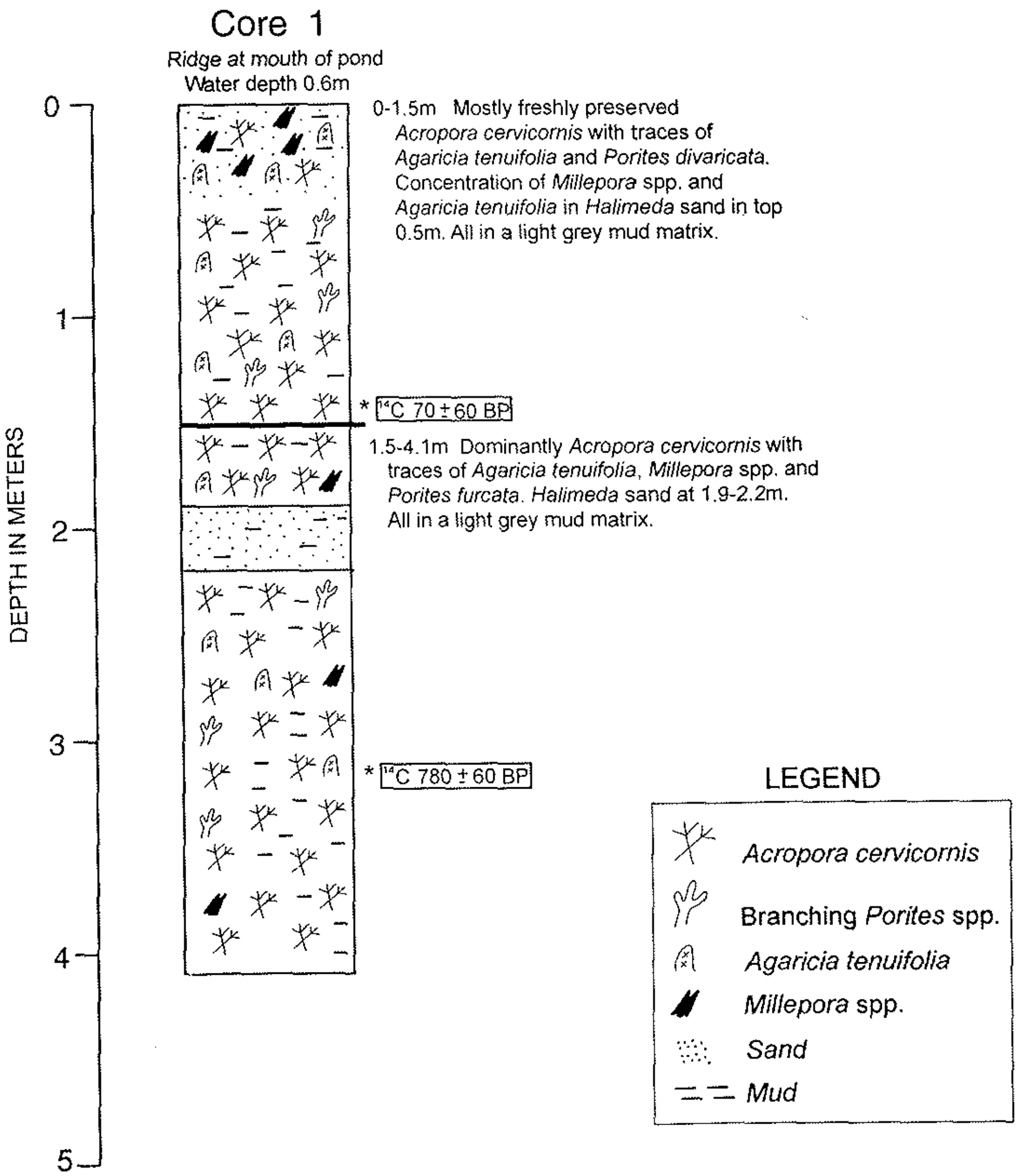

Figure 6. Graphic summary of data from the two core intervals of Core 1.

Recovery was only 21% for Core 2, which was located on the crest of the northern inner ridge. This core (Fig. 7) showed a sharp transition in reef facies at a depth of 2.14 m. The upper section consisted of scattered *Porites divaricata*, with only a trace of *A. cervicornis* fragments in a brown organic-rich mud matrix; in contrast, the lower section is dominantly *A. cervicornis,* with some *Agaricia sp.* and *Porites spp.* in a light grey mud matrix. A similar transition of reef facies was also noted in Core 3 (Fig. 8), which was collected on the crest of the southern inner ridge. The upper 0.5 m consisted predominantly of *P. divaricata* with only traces of *A. cervicornis*, over a dominantly *A. cervicornis* lower interval.

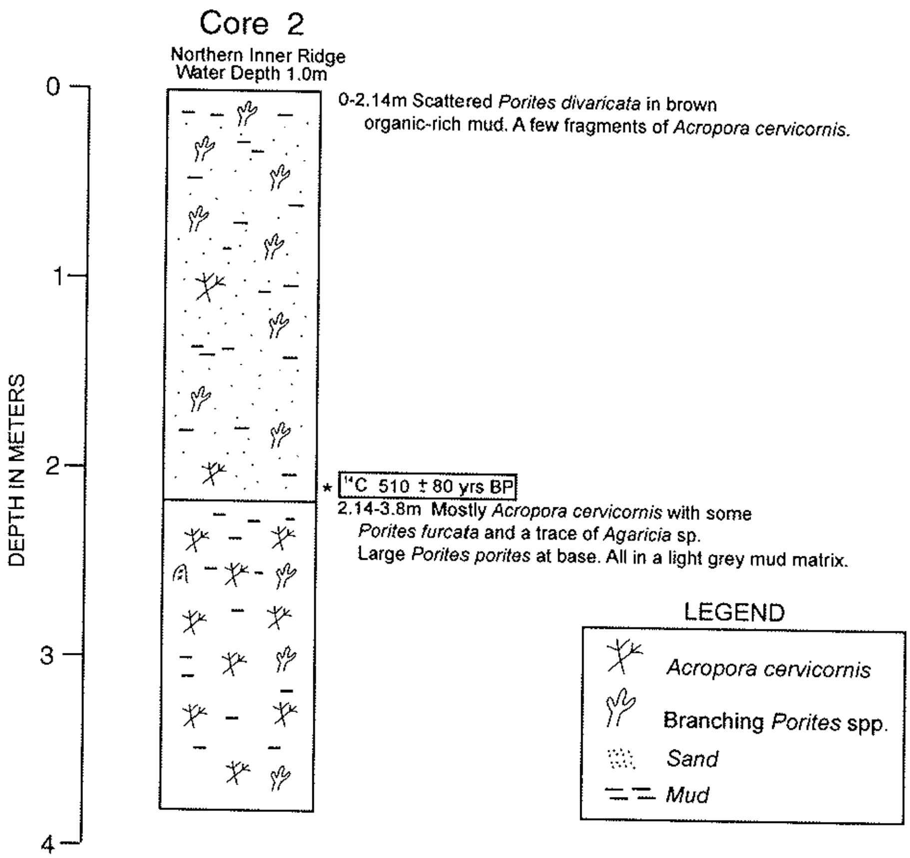

Figure 7. Graphic summary of data from Core 2.

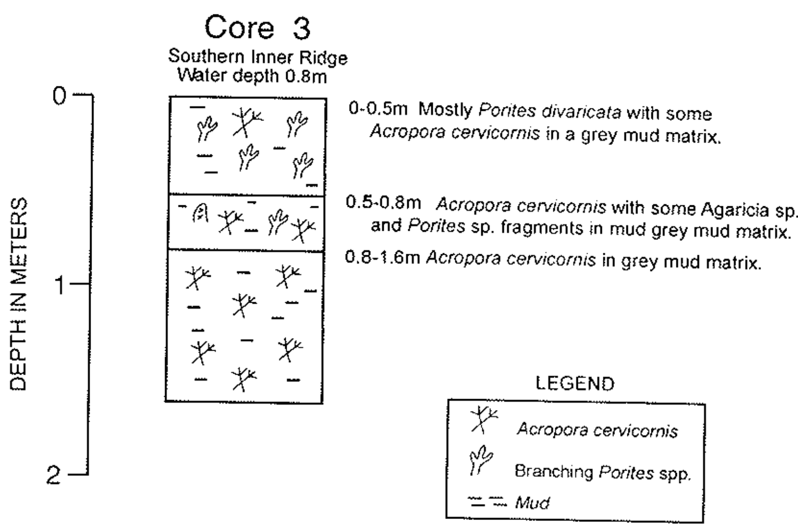

Figure 8. Graphic summary of data from Core 3.

Coral samples from both core holes and the base of peat sections exposed in undercut edges of ponds (Fig. 9) were radiocarbon dated (Table 2). Dates ranged from 780 ± 60 yrs B.P. to 70 ± 60 yrs B.P.

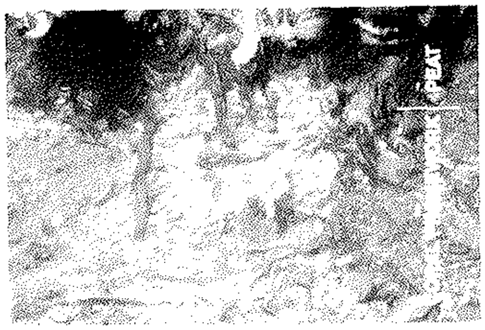

Figure 9. Undercut exposure in the edge of Pond C, Manatee Cay, showing mangrove peat overlying coral framework.

Table 2. Radiocarbon Dates

Location	Material dated	Depth below MSL	Date
From base of mangrove undercut, east side of Pond A, Cat Cay	*P. divaricata*	1.33m	190 ±60
Core from ridge at entrance to Pond C, Manatee Cay	*A. cervicornis*	2.1m	70 ±60
	A. cervicornis	3.8m	780 ±60
Core from northern inner ridge, Pond C, Manatee Cay	*A. cervicornis*	3.1m	510 ±80
From base of mangrove undercut, east side of Pond A, Cat Cay	*P. divaricata*	1.33m	190 ±60
From base of mangrove undercut, south side of Pond C,	*A. cervicornis*	1.28m	590 ±60

DISCUSSION

The Pelican Cays are characterized by an unusual network of reef ridges that are both submerged and emergent, some with mangrove overgrowths. This network of ridges is responsible for the formation of the ponds in this area, which are the habitat of a great diversity of marine life.

The distinctive feature of the network pattern is that the ridges commonly intersect at right angles. This pattern is identical to the polygonal karst pattern that Williams (1972) documented on the exposed surface of Miocene limestones in Papua, New Guinea (Fig. 10). Indeed, Purdy and Bertram (1993) used this figure to explain the "peculiar honeycomb pattern" (p. 40) that they observed in shallow lagoon areas in the Maldives. Purdy and Bertram were convinced that preferential reef colonization on polygonal karst relief formed on limestone surfaces during Pleistocene subaerial exposure was responsible for the "honeycomb shoals" (p. 41) in the

Maldives. Purdy (1974a, 1974b) also hypothesized that elevated karst Pleistocene relief was responsible for the location and initiation of many of the Holocene lagoon reefs in Belize.

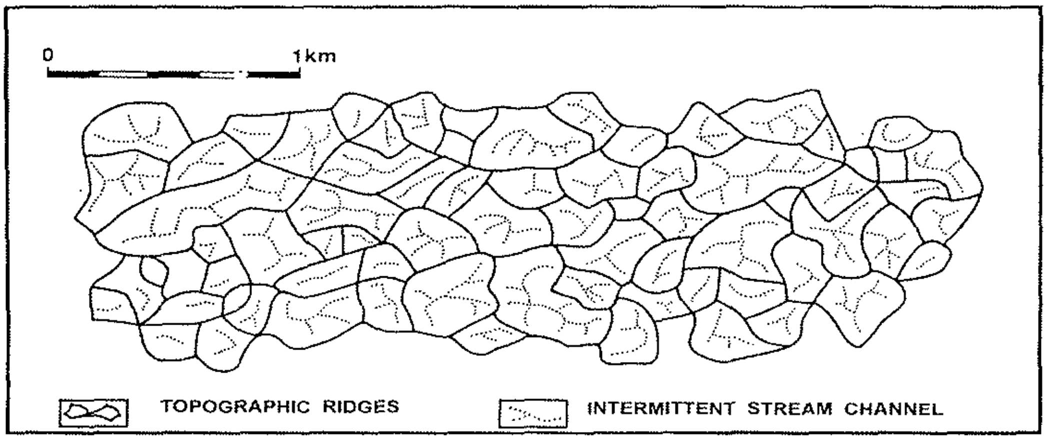

Figure 10. Plan view of polygonal karst pattern on the surface of Miocene limestones, Papua, New Guinea (Purdy and Bertram, 1993; modified from Williams, 1972).

Such honeycomb shoals are common features of shallow lagoon areas and have also been well documented in the Cocos (Keeling) Islands (Searle, 1994). Searle noted that the "central southeastern part of the lagoon is occupied by steep-sided 'blue holes,' some over 15 m deep" (p. 5), and 100 m wide (Fig. 11). These, Searle suggested, are related to "multi-generational dolins" (p. 5), although he emphasized that both differential accretion and erosional relief are responsible for atoll lagoon morphology.

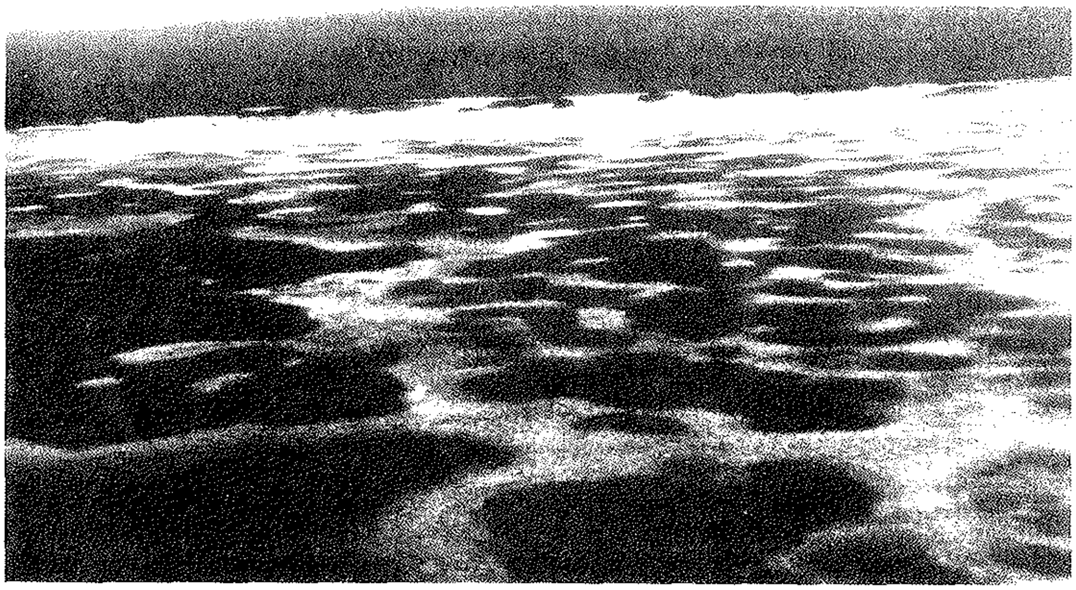

Figure 11. Aerial view of southern area of Cocos (Keeling) Islands lagoon. Note honeycomb ridge pattern (Searle, 1994).

A core hole drilled in the Pelican Cays by the University of Miami in 1984 recovered Pleistocene limestone at a depth of about 20 m (R. N. Ginsburg, personal communication, 1994). This depth coincides with the depth at which our probe encountered hard rock on the outside of Pond C. It is therefore not unreasonable to assume that our probe was recording the Pleistocene limestone surface substrate when we hit hard rock at the base of our probes.

These probes confirm the hypothesis that the Pleistocene karst relief is controlling the honeycomb patterns of reef-ridge growth in the Pelican Cays, which commonly results in the formation of ponded areas. The short cores suggest that *Acropora cervicornis* colonized the areas of slightly elevated relief on the Pleistocene limestone surface when it was flooded by the rising seas of the Holocene Transgression. Differential growth of this fast-growing branching coral community, reported to be accumulating in this area at a rate of up to 8 m/1,000 yrs by Westphall (1986), then formed steep-sided ridges, which on catching up with sea level in some areas, were overgrown by mangrove communities. Although the ponded network pattern of reef ridges is related to polygonal karst relief on a Pleistocene limestone substrate, their relief is mainly the result of differential reef accumulation (Fig. 5). The origin and growth of these Holocene lagoon reefs is therefore related to a combination of karst control (Purdy, 1974a; 1974b) and differential reef growth (Halley et al., 1977).

This honeycomb pattern is superimposed on a larger rhombohedral configuration of the shelf atolls, including the one on which the Pelican cays are located (Fig. 1). The parallelism of these rhomboidal atolls suggests that pre-Holocene reef accumulation occurred along the edges of fault blocks (Purdy, 1974a, 1974b; Precht, 1997).

The cores from inside Pond C show a distinct transition from a predominantly *Acropora cervicornis* facies to a predominantly *Porites divaricata* facies, dating to probably about 500 yrs B.P. This facies change documents a shallowing-upward reef sequence similar to that reported in this area by Westphall (1986), where a "catch-up" reef community is being replaced by a very shallow "keep-up" community (Neumann and Macintyre, 1985). The *Porites divaricata* community was killed off on the ridges inside the pond when water conditions became restricted following an almost complete closure of the mouth of the pond. A date of 70 ± 60 yrs B.P., if valid, indicates that the present restricted conditions within Pond C are recent. Outside of ponds, *Porites divaricata* is most common at depths shallower than 1 m.

Radiocarbon dates (Table 2) indicate that red mangrove, *Rhizophora mangle,* communities became established on the Pelican Cays reef ridges at approximately 600 yrs B.P., and there has been a continuum of mangrove colonization ever since. They can be seen in the process of establishing themselves on some submerged ridges today (Fig. 12).

Figure 12. Mangroves at the initial stage of colonization of a shallow submerged reef-ridge crest, Cat Cay. Note the mangrove roots penetrating a surface cover of *Porites divaricata*, *Thalassia testudinum*, and *Dictyota* sp.

CONCLUSIONS

The Pelican Cays, located in the south-central lagoon of the Belize Barrier Reef, consist of mangrove-covered islands with a network of circular ponds. Probing and coring studies indicate that the ponds are formed by differential sediment accumulation, with the faster accumulating reef facies growing on the positive karst relief on the underlying Pleistocene limestone.

Acropora cervicornis-dominated communities, with documented accumulation rates in this area of Belize of up to 8 m/1,000 yrs, have been responsible for accentuating the positive polygonal karst relief. On catching up with sea level, these reef ridges show a transition from an *A. cervicornis* facies to a very shallow water *Porites divaricata* facies. Reef growth is terminated when these ridges become shallow enough for colonization by *Rhizophora mangle.* Islands are eventually formed when these ridges become capped with mangrove peat. The distribution of ponds in the islands reflects the original polygonal relief pattern of the Pleistocene surface.

ACKNOWLEDGMENTS

Special thanks go to Victoria E. Macintyre Saville for field assistance. We would also like to thank William T. Boykins for his valuable help with graphics and text layout, and Thad Murdock for additional assistance with graphics. Fieldwork for this project was supported by the National Museum of Natural History's Caribbean Coral Reef Ecosystem Program (CCRE Contribution No. 576).

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