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The Cockburn Town Fossil Coral Reef and Modern Coral Reefs of Fernandez Bay, San Salvador Island, Bahamas: A Field Trip Guide

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INTRODUCTION

The Pleistocene coral reef located along the western coast of San Salvador northwest of the center of Cockburn Town is well exposed and is the best known and described ancient reef in the Bahamas. The Cockburn Town reef is an excellent fossil example of a bank/barrier reef as defined by Kaplan (1982); such reefs are common today on the narrow, wave-cut shelves of islands in tropical western Atlantic and Caribbean waters. Modern bank/barrier reefs normally are only hundreds of meters from a land mass, not thousands of meters offshore as is the case for true barrier reefs, and bank/barrier reefs are much shorter in linear extent than barrier reef complexes. This guide provides a general overview of the reef and more detailed information for ten field stops in the reef area. The locations of these stops and the stratigraphic profiles appearing herein are shown on the geologic map of the reef complex (Fig. 1). This map was prepared with the help of Smith College geology students, and topography was mapped using plane table and alidade. Reference starter points for the topographic survey were bench marks 1 and 2, which were originally tied directly to accurately measured mean sea level (Adams, 1980).

Recently 16 radiometric dates have been obtained from coral samples from the Cockburn Town reef. These ^{238}U-^{234}U-^{230}TH dates were determined by J.H. Chen and G.J. Wasserburg at the California Institute of Technology using newly developed mass spectrometric techniques for the measurement of ^{230}TH abundance (Edwards et al., 1987). Typical errors for dates from this method are ± 1.5 ky, permitting detailed chronologic study of the reef with time resolution sufficient to define stages of reef development. These stages and an overall discussion of the significance of the 16 dates have been given by Curran et al. (1988, 1989). Full information on the dating of corals from the Cockburn Town Fossil Reef may be obtained from Chen et al. (1991) (reprint copies of this article can be obtained from Allen Curran at Smith College). The oldest coral dated from the reef is an *Acropora palmata* specimen at 130.75 ± 1.5 ky from the oceanward end of Profile C-C' (Fig. 4). The youngest coral date is 119.2 ± 1.5 ky from a *Diploria strigosa* specimen between Profiles D and E. Thus we know that this reef arose and flourished during the Sangamon interglacial at the time of oxygen isotope substage 5e. The span of coral age dates indicates a minimum longevity for the reef of 12,000 years.

The main part of the Cockburn Town reef, the fossil reef crest zone, consists of coralstone composed of near *in situ Acropora palmata* and subordinate *A. cervicornis*. This part of the fossil reef bears close resemblance to the modern Gaulins Reef located off of the northern coast of San Salvador. The shallowing-upward sequence and diagenetic history of the reef complex and their significance with respect to reef development and sea level changes were described and discussed by White et al. (1984). Earlier, more extended versions of this field guide have been published by Curran and White (1984, 1985).

Location and Field Trip Procedure

The Cockburn Town fossil coral reef is exposed along coastal outcrops and in a small quarry located a short distance northwest of the center of Cockburn Town. Reefal rocks extend in a northwesterly direction from the old town dock for a distance of about 650 m, terminating near an abandoned cable trench

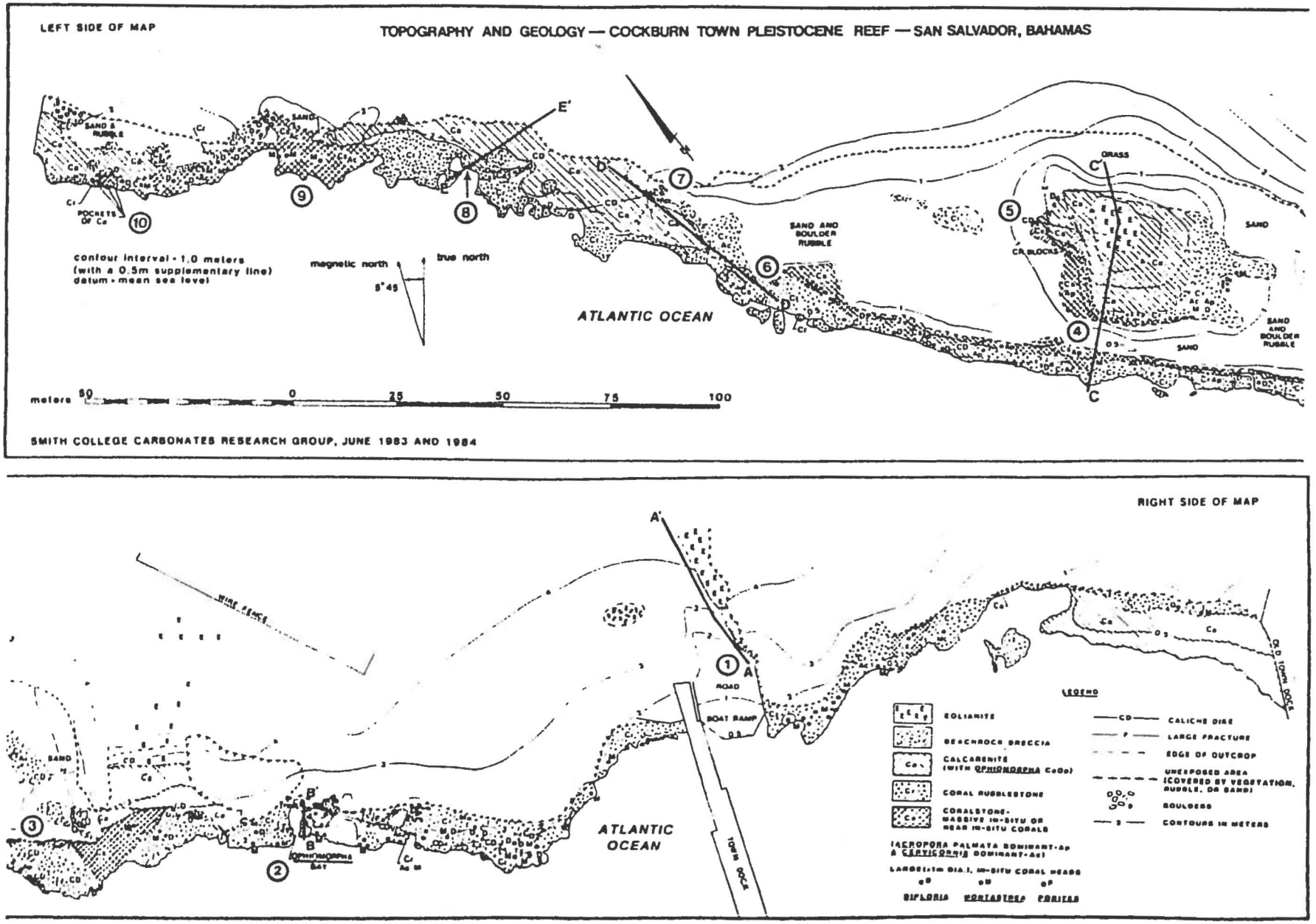

FIGURE 1 Geologic map of the Cockburn Town fossil reef complex, showing locations of the stratigraphic profiles and field trip stops (numbered areas).

cut into the Pleistocene shallow subtidal and beach calcarenites that flank and overtop the reef at its northern end.

This excursion will start from the parking area adjacent to the new town dock. The shallowing-upward sequence of calcarenites overlying reefal rocks is well exposed in the roadcut on the east side of the road leading to the dock and launch area (Stop 1). The main part of the reef can best be reached by walking WNW from the parking area through the woods to the coast in the vicinity of *Ophiomorpha* Bay (Stop 2, see map). The reefal facies are particularly well exposed in the quarry area a short distance beyond Stop 2.

Sturdy shoes with thick rubber soles are recommended for hiking over the reefal rocks; some exposures have rough surfaces with many sharp edges, particularly in the heavily bioeroded zone near the water. Wet, algae-covered surfaces in the intertidal zone are very slippery, so caution is advised. The quarry area of the reef can be hot and glary on sunny days; hats and sun glasses are recommended.

Because this fossil reef is an attraction of considerable geologic and biologic importance, every reasonable effort should be made to preserve it for future visitation and study. Accordingly, we ask that **no rock hammers** be used to collect samples from the reef exposures. Fossil corals and mollusks can be collected from rubble in the quarry area, but specimens should not be removed from outcrop. Your cooperation in preserving the reef will be appreciated by future visitors.

DESCRIPTIONS OF THE FIELD STOPS

Stop 1. Shallowing-upward Sequence

This exposure demonstrates clearly the shallowing-upward nature of the reef complex and associated facies as described by White et al. (1984). Near the water's edge, several large coral heads (*Diploria strigosa, Montastrea annularis,* and *Porites asteroides*) are preserved in near growth position in a matrix of shelly, coarse to very coarse calcarenite (Fig. 2, Profile A-A', 0-8 m).

Moving along the outcrop, coral rubblestone gives way to shelly, medium to coarse calcarenite. The most prominent shells are single valves and valve fragments of the bivalve *Chione cancellata.* Gently seaward-dipping bedding begins to become apparent here, and there is some weakly developed trough cross bedding. A few clasts of beachrock breccia also are present.

Farther up along the outcrop, the calcarenite becomes progressively finer-grained and less shelly. The last shell fragments occur at about the 23 m mark on Profile A-A'. The uppermost part of the outcrop is composed of fine to very fine calcarenite beds (=eolianite), which contain some rhizomorphs.

The facies present here represent three distinct environments of a regressive sequence: a shallow subtidal environment with corals such as *Diploria, Montastrea,* and *Porites,* all characteristic of patch reefs; a very nearshore to beach environment with gently seaward-dipping beds and beachrock breccia clasts; and a coastal dune environment with fine to very fine calcarenites containing rhizomorphs.

The area of coastal exposure to the southeast of the new town dock is rugged and not easily traversed by groups, but it does display good outcrops of coral rubblestone with many prominent heads of *Montastrea annularis* and *Diploria strigosa.* Less common are heads of *M. cavernosa, D. labryinthiformis,* and *Porites asteroides.* In the vicinity of the old town dock, the coral rubblestone is overlain by ancient beachrock beds that terminate the reefal exposure.

Stop 2. *Ophiomorpha* Bay

A small, wave-cut re-entrant is located about 100 m northwest along the coast from the new town dock. The stratigraphic profile here is shown in Figure 3. This is one of the best trace fossil localities found to date on San Salvador. Coral rubblestone dominated by fragments of *Acropora cervicornis* forms the lower and middle part of the re-entrant exposure. These beds are overlain by and interfinger with shelly, coarse calcarenites containing the trace fossils *Ophimorpha* sp. and *Skolithos linearis.* These trace fossils have been described and their paleoenvironmental significance discussed by Curran (1983, 1984).

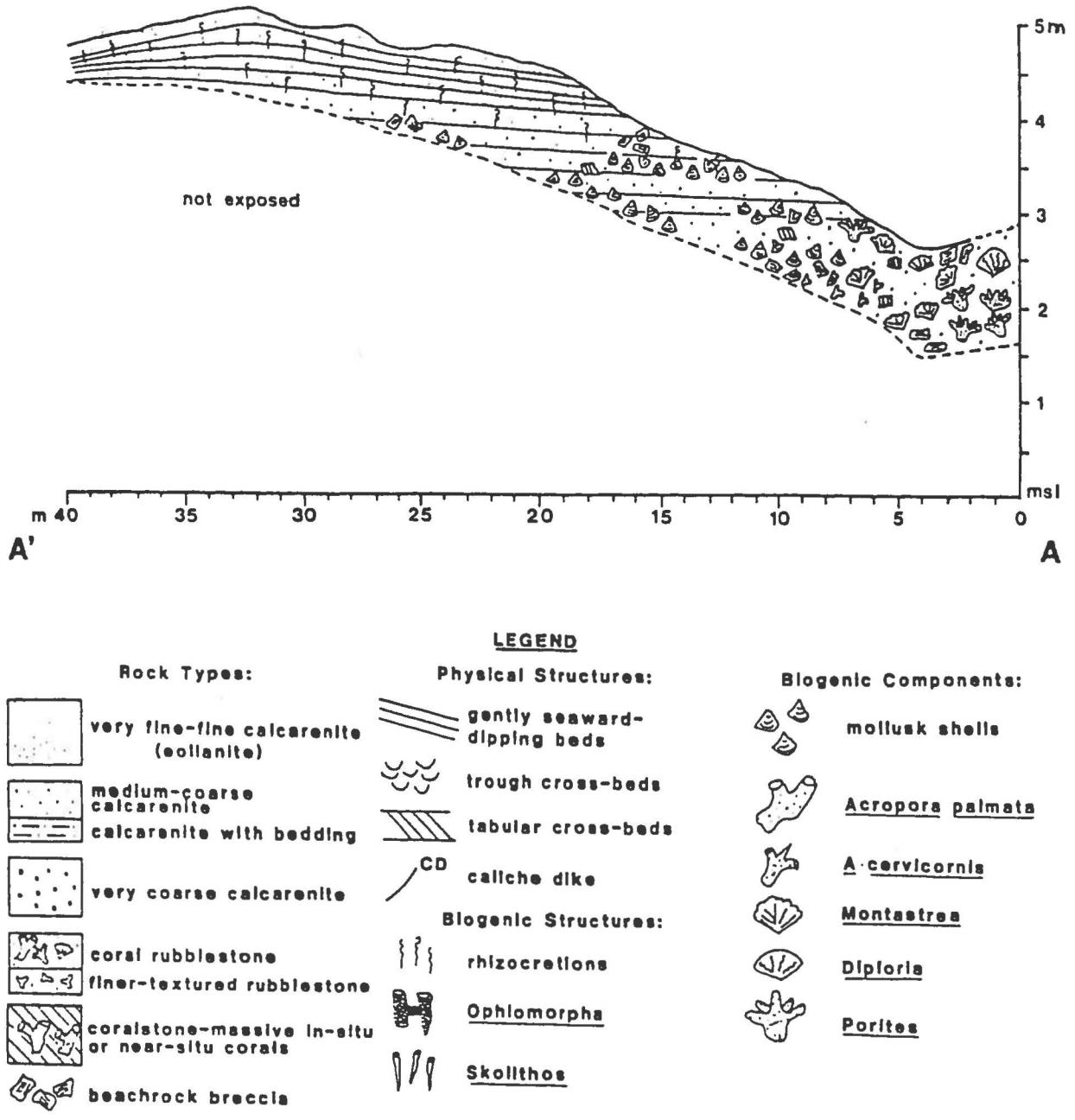

FIGURE 2 Stratigraphic profile A-A'; exposure along road leading to Cockburn Town dock and launch area. Lower part of the figure presents the legend of symbols used in the stratigraphic profiles.

Tunnels and shafts of *Ophiomorpha sp.* are particularly abundant and well developed here. The interfingering of the coral rubblestone and *Ophiomorpha*-bearing calcarenites indicates the contemporaneous subtidal nature of the coral reef and the surrounding environment of current-bedded carbonate sands. Burrowing of the subtidal sands by callianassid shrimp produced the *Ophiomorpha sp.* burrows, the dwelling tubes of the shrimp.

The *Ophiomorpha*-bearing calcarenites are overlain by a shelly, coarse to very coarse calcarenite that contains clasts of beachrock breccia and some rhizomorphs. Patches of a generally well sorted, coarse to very coarse

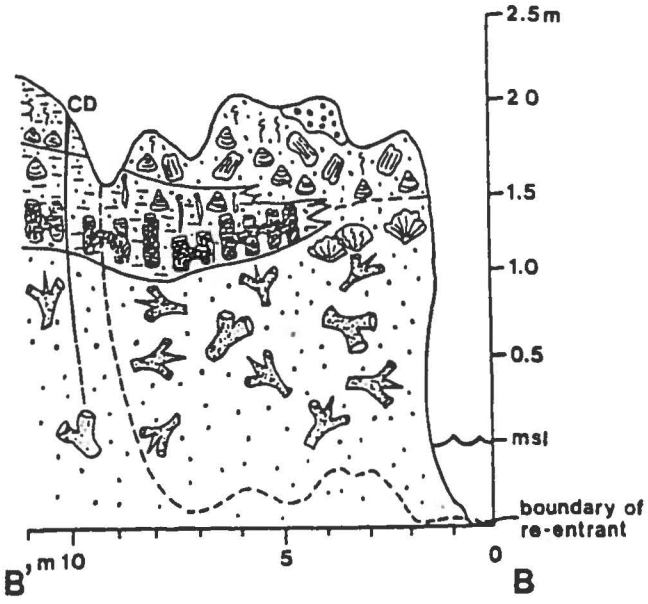

FIGURE 3 Stratigraphic profile B-B'; exposure along southeast wall of *Ophiomorpha Bay*.

calcarenite overlie the beachrock-bearing calcarenite. Both units suggest a near beach environment; thus, the shallowing-upward sequence again is demonstrated.

The outcrop area immediately southwest of the re-entrant contains many well-preserved *in situ* coral heads of *Diploria strigosa*, *Montastrea annularis*, and *Porites porites* in coral rubblestone. A prominent caliche dike can be traced from immediately behind the re-entrant for a distance of about 60 m southeast to the water's edge.

Walk-by Stop

The shallowing-upward sequence again is well exposed about 35 m northwest of Stop 2 on an unvegetated slope upwards from the water's edge. Here an amphitheater-like, wave-cut re-entrant, with boulders in and just above the intertidal zone, exposes coral rubblestone containing several large *Diploria* and *Montastrea* heads. On the northwestern side of the exposure, *Acropora palmata* appears for the first time as an important constituent of the rubblestone, a change that continues into the quarry area. Shelly, medium to coarse calcarenite overlies the coral rubblestone. As seen earlier at Stop 1, the calcarenites show a fining-upward trend to eolianite toward the top of the hill slope.

Stop 3. More *Ophiomorpha*

A pocket of shelly, coarse to very coarse calcarenite with coral clasts and several *Ophiomorpha* sp. shafts and tunnels is exposed on an interior face of the quarry, about 13 m beyond its south entrance. The calcarenite is surrounded by *Acropora cervicornis* and *A. palmata*-dominated rubblestone. Some of the calcarenite may have been deposited as void fill in the rubblestone, but at least the upper part of the calcarenite appears to interfinger with the rubblestone, again indicating the contemporaneous deposition of the two facies.

Stop 4. Profile C-C'

Particularly good exposures of coralstone dominated by large, near *in situ* chunks of *Acropora palmata* are found here along the first 20 to 25 m of Profile C-C' (Fig.4). Coralstone makes up the major part of the rock forming the oceanside quarry wall and parallels the N50°W strike of the wall, a trend that may well reflect the life orientation of the *A. palmata* crest of the Cockburn Town reef. A large, bifurcating caliche dike is prominently exposed on the top of the wall, and several large heads of *Diploria* also occur here.

Move across the quarry floor to the front (oceanward) face of the prominent knoll located within the quarry area. This knoll largely has been created by quarrying operations on all sides. The front face (15-20 m on Profile C-C') reveals a zone of *Acropora palmata*-dominated coralstone overlain by coarse, *A. cervicornis*- dominated rubblestone. Beds of shelly, coarse to very coarse calcarenite overlie the rubblestone on this front face of the knoll.

Stop 5. The Knoll

The full range of facies occurring in the Cockburn Town fossil reef complex can be seen in this exposure on the flank of the knoll (Profile C-C', 20-50 m). *Acropora palmata*-dominated coralstone forms the lower part of the exposure, and the overlying rubblestone can be traced along the side of the knoll to about the 30 m point on Profile C-C'; in this

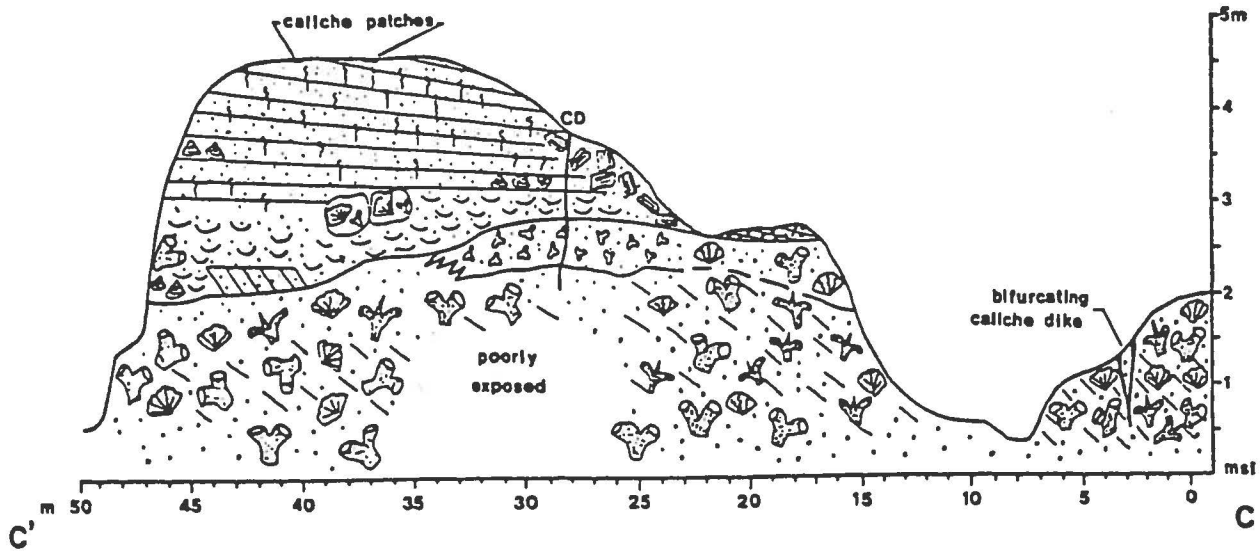

FIGURE 4 Stratigraphic profile C-C' in the quarry area; exposure from the water's edge along the northwest face of the knoll.

area, the rubblestone has a distinctly finer texture.

Shelly, medium to coarse, tabular and trough cross bedded calcarenites overlie the coralstone and coral rubblestone and are well exposed on the sides of the knoll, particularly between 25-50 m along Profile C-C' and to the rear of the knoll (northeast side). The most prominent set of tabular cross beds dips in a westerly direction, essentially perpendicular to the flow direction of currents that produced the surrounding trough cross beds. Our interpretation is that the tabular cross beds were deposited by a storm event, possibly a hurricane. The trough cross beds were deposited by northerly flowing, longshore currents possibly created by wave refraction around the south end of ancient San Salvador Island (White et al., 1984). Two blocks of coral rubblestone, probably deposited by storm waves, are prominent in the exposure and are completely surrounded by the trough cross bedded calcarenites.

Stop 6. *Acropora palmata* Reef Crest

Move toward the northwest end of the quarry, at water's edge along Profile D-D' (Fig. 5, 0-17 m). Exposed here is a large mass of coralstone on a base of *Acropora palmata*-dominated coral rubblestone similar to that found elsewhere in the quarry. The exceptional aspect here is the coralstone which is formed of large trunk sections of *A. palmata*. Although the coral heads are collapsed, they are essentially *in situ* and represent the palisades of *A. palmata* typical of a reef crest zone. This reef crest zone appears to extend at least for the full length of the oceanside quarry exposure (about 200 m).

The top of the *Acropora palmata*-dominated coralstone mass is at an elevation of just over +2m. Assuming a growth height of 3 to 4 m for living, fully mature *A. palmata* heads and assuming that the tips of the fronds rose to mean low sea level, this suggests minimum sea level of +5to +6m above present at the time of coral growth. This time now is known, because two specimens of *A. palmata* have been dated from this area of the reef, and they yielded ages of 122.5 ±1.5 ky and 121.2 ±1.4 ky (Curran et al., 1989).

The interstices of the *Acropora palmata* coralstone mass are filled with poorly lithified, shelly, coarse to very coarse calcarenite. Here molluscan fossils can be well preserved; the fauna is dominated by ark shells of the species *Arca imbricata*, *Barbatia cancellaria*, and *B. domingensis*. These bivalves today are common inhabitants in and around living coral heads.

Stop 7. Channel Exposure

The exposure along the north end of

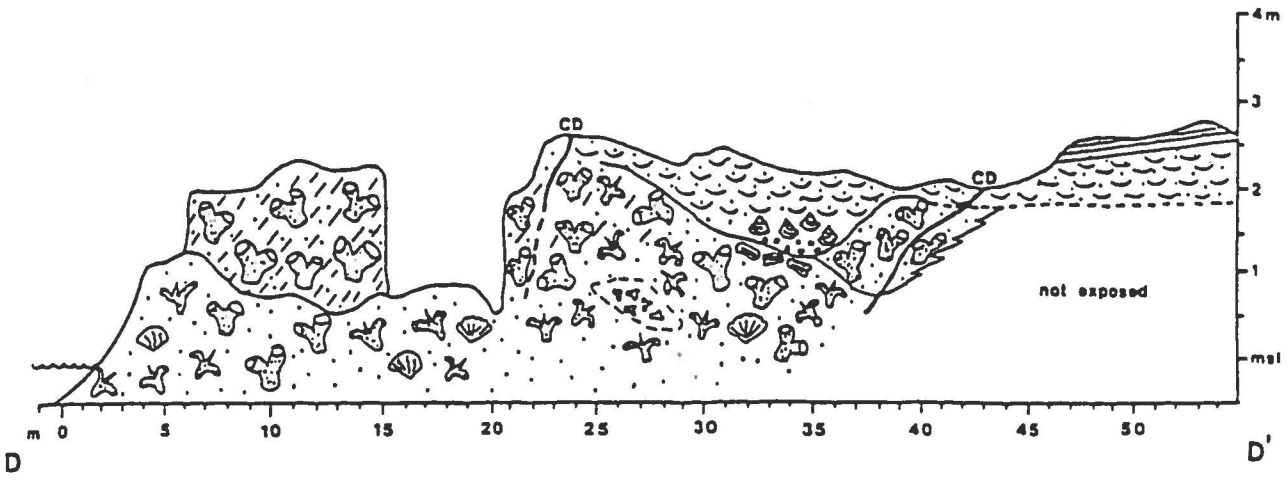

FIGURE 5 Stratigraphic profile D-D', northwest end of quarry area; exposure includes the main part of the zone of *Acropora palmata* in near growth position.

Profile D-D' (Fig. 5, 20-55 m) reveals *Acropora palmata*-dominated coralstone continuing to overlie coral rubblestone. The new feature of interest here is a well developed channel cut into the rubblestone and filled with calcarenite. Fill at the base of the channel consists of shelly, coarse to very coarse calcarenite. Upwards in the channel, trough cross bedding is obvious and the calcarenite texture becomes finer.

The north side of the channel is bounded by *Acropora palmata*-dominated coralstone which has a different character from that seen previously. Here the coralstone consists primarily of tightly lithified fronds of *A. palmata*; coral trunk pieces are much less abundant than elsewhere. Again, we interpret the rock as representing coral head fronds that collapsed, were compacted, and then were lithified essentially *in situ*. Several large boulders of this type of *A. palmata*-dominated coralstone can be seen in this area on the floor of the quarry.

Stop 8. Profile E-E'

The exposures of Profile E-E' (Fig. 6) are located about 50 m beyond the northwest end of the quarry. The oceanward half of the profile consists of coral rubblestone exposures dominated by *Acropora cervicornis*. Fragments of *Diploria* and *Montastrea* are common, and the importance of *A. palmata* has decreased markedly from its dominant levels in the rock of the quarry area.

The principal features of interest along this profile are the overlying calcarenite beds and their sedimentary structures (Profile E-E', 25-45 m). Particularly prominent is a set of steeply dipping tabular cross beds up to 1 m thick in places. These tabular cross beds dip in a westerly direction as do the similar beds described earlier at Stop 5 (Profile C-C'), and we interpret them as representing deposition by the same large-scale storm event.

The overlying trough cross bedded calcarenites were deposited by northerly flowing, perhaps longshore, currents (White et al., 1984). Overlying the trough cross bedded calcarenites are westerly dipping calcarenites with low angle cross beds and beachrock clasts. These beds progressively overstep the trough cross bedded, subtidal calcarenites and represent the deposits of a westerly facing and westward migrating beach formed during sea regression (White et al., 1984).

Stop 9. *Acropora cervicornis* Thicket

Move to an area of coralstone and coral rubblestone about 40 m northwest of Stop 8 (Profile E-E'). Here medium to coarse

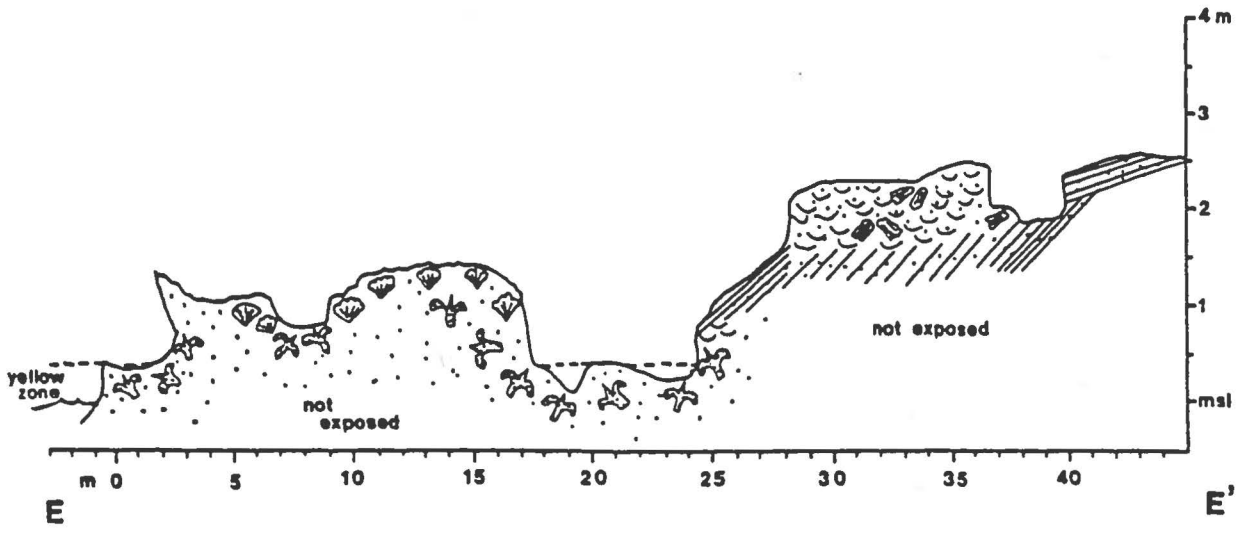

FIGURE 6 Stratigraphic profile E-E', northwest of the quarry area.

calcarenite is packed in and around exposures of coralstone and coral rubblestone; the calcarenites clearly overlie the coralstone on the landward side of the outcrop area.

The main point of interest here is the nature of the coralstone. It is dominated by *Acropora cervicornis* in what we think is essentially growth position; also present are several large heads of *Montastrea annularis*, smaller heads of *Diploria*, and clumps of the finger coral *Porites furcata*, all in growth position. This marks the first common occrrence of *P. furcata* in growth position seen in the reef complex. Although *A. cervicornis* is widespread in the coral-bearing rocks of the reef complex, it usually occurs fragmented and in rubblestone. We interpret the coralstone of this area of the reef as representing an *A. cervicornis* thicket with its associated coral species. Thus we see here another aspect of the Cockburn Town reef complex.

Stop 10. Northwest End of the Cockburn Town Reef

Exposures in the northwestern-most area of the reef are located about 20-70 m beyond Stop 9 across a small stone bridge. This is an area of coralstone and coral rubblestone exposure, and once again, the coralstone is composed largely of *Acropora cervicornis*. Several large heads of *Montastrea annularis* and *Diploria* are prominently exposed in growth position. Calcarenite is packed in and around the coral heads, and calcarenite beds overlying the reefal rocks are well exposed on the landward side of the outcrop area.

The reef proper ends very abruptly. The final visible exposures of coral rubblestone are virtually surrounded by calcarenites. Looking northwestward along the coast from the last coral rubblestone exposures, one sees only gently seaward dipping calcarenites. The texture and bedding of these calcarenites is well exposed in vertical section in the cable trench immediately beyond the last rubblestone outcrop. This trench marks the northwestern boundary of the geologic map and the study area.

MODERN CORAL REEFS OF FERNANDEZ BAY

Following the tour of the Cockburn Town Fossil Coral Reef, we will head south along the coast road from Cockburn Town to Fernandez Bay. Here we will have an optional snorkel dive on Telephone Pole Reef. In addition to cooling off and enjoying the beautiful, clear offshore waters of San Salvador, this stop will enable participants to view a living patch reef and to make some comparisons with the fossil coral communities seen at the Cockburn Town reef site. If one follows the line of the double telephone poles in swimming offshore, there is a distinct

zonation of communities as one traverses from the beach to the major part of the reef and beyond. The various zones will be discussed briefly prior to entering the water.

The Telephone Pole Reef is a large patch reef complex, and, therefore, is somewhat different from much of the *Acropora palmata*-dominated bank-barrier fossil reef complex exposed at Cockburn Town. Formerly Telephone Pole reef was dominated by thickets of *Acropora cervicornis*, but, beginning in the early 1980's, virtually all of the *A. cervicornis* died. In more recent years, there has been a very noticeable expansion of heads of *Porites porites*. During this time, the large heads of *Montastrea annularis*, the other major constituent of this reef community, have remained seemingly unchanged.

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