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HIGH-FREQUENCY, LOW-AMPLITUDE FLUCTUATIONS DURING THE LATE HOLOCENE SEA-LEVEL RISE: NEW DATA FROM THE FRENCH BAY BEACHROCK, SAN SALVADOR, BAHAMAS.

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ABSTRACT

Sedimentologic, petrographic and radiometric data from a submerged beachrock on San Salvador Island, Bahamas, provide new information about the late Holocene sea-level history in this area.

At French Bay, on the southern shore of the island, samples of beachrock collected at a depth of one meter below low-tide level yielded a conventional ^{14}C age of 1120 $\pm$ 60 years before present. These samples further display a well-developed fenestral porosity and present an early generation of low-Mg calcite meniscus cement. These features characterize intertidal and supratidal settings. They are not consistent with the beachrock position and the reported late Holocene sea-level history in the Bahamas.

A 1.5 to 2 m low-stand of the sea some 1200 years ago would best explain the observed particularities of the French Bay beachrock. This example from San Salvador shows that the smooth trend of late Holocene sea-level rise proposed by previous authors might be overprinted by high-frequency, low-amplitude fluctuations. Recognition of these fluctuations is fundamental when calculating rates of sea-level rise and evaluating coastal response to a marine transgression.

INTRODUCTION

Modern sedimentary environments on the Bahama Platform have been extensively studied (e.g. Illing, 1954; Purdy, 1963; Ball, 1967; Bathurst, 1975; Schlager and Ginsburg, 1981) and used as a model for interpreting ancient carbonate sequences all over the world (e.g. Scholle et al., 1983). By contrast, the history of sea-level rise due to ice-sheet melting since the last glacial maximum is poorly constrained in this area.

Using sedimentary, petrographic and radiometric data from a submerged beachrock on San Salvador Island, this paper brings new information to the late Holocene sea-level history in the Bahamas.

SETTING AND METHODS

Holocene sea-level in the Bahamas

The Bahamian Islands lie within sea-level zone III of Clark et al. (1978) and should therefore present evidence of a slight (<0.75 m) marine emergence during the last few thousand years. To our knowledge, no record of a recent emergence, such as raised beaches or terraces, has been detected so far at any location in the Bahamas. Indeed, the Holocene sea-level curve published by Boardman et al. (1989) shows a smooth, shoulder-like shape that trends towards present stand but never exceeds modern datum. It is analogous to the curves proposed for neighboring, but much more studied, south Florida (Scholl and Stuiver, 1967; Scholl et al., 1969; Wanless, 1982; Pirazzoli, 1991) and Jamaica (Digerfeldt and Hendry, 1987).

The important point to remember from these curves (Fig. 1) is that, following a rapid rise during the mid-Holocene, sea-level reached a position within 1.5 m of its actual elevation some 3,500 years ago and has risen at a steady rate of 3.5 to 4 cm/100 years (Scholl et al., 1969; Wanless, 1982; Parkinson, 1989) since that time.

In the following sections we provide evidence from a submerged beachrock on San Salvador that the late Holocene sea-level history in the Bahamas might be more complicated than previously thought.

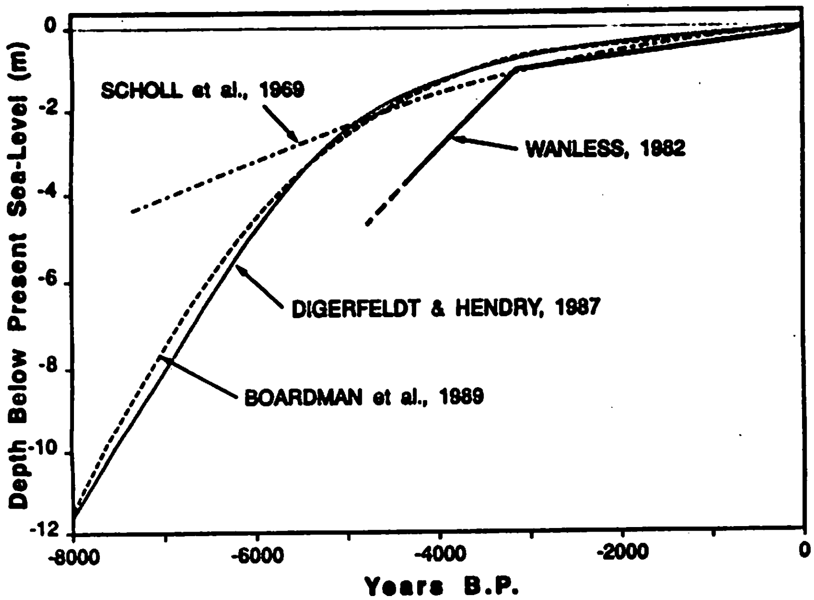

Fig. 1 Comparison of the late Holocene sea-level curves that have been established for the south Florida-Bahamas region.

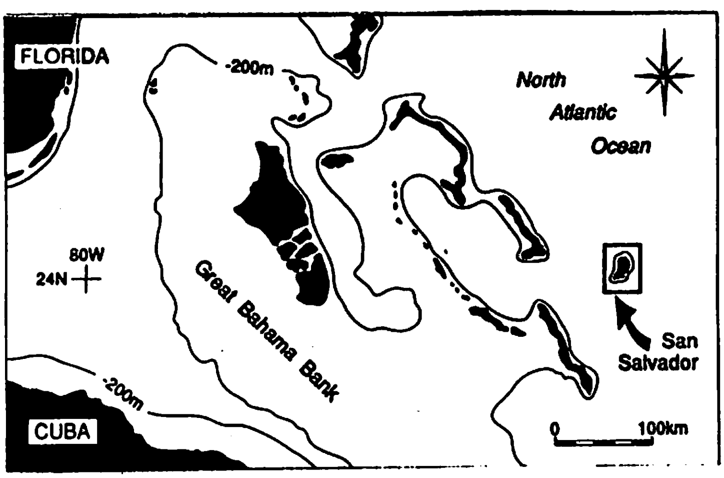

Fig. 2 Situation map of San Salvador Island

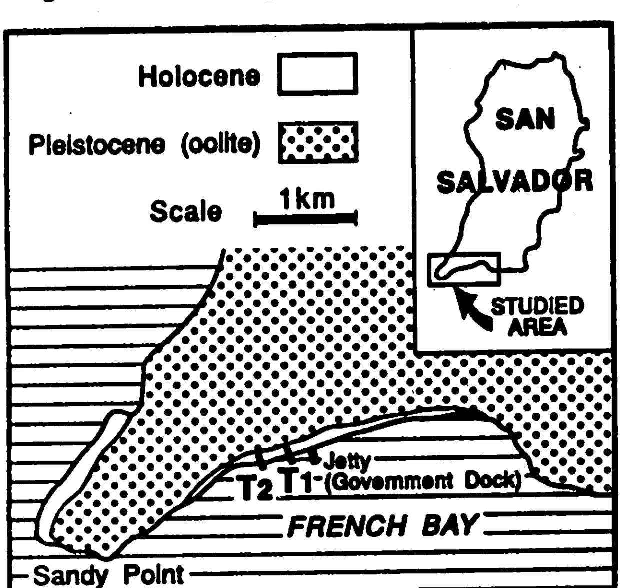

Fig. 3 Location map of the French Bay beachrock. T1 and T2 indicate the studied transects.

Area of Study

San Salvador is a small (19 x 11 km) rectangular island located on an isolated carbonate platform off the eastern margin of the Great Bahama Bank (Fig. 2). It belongs to the tectonically passive northwestern Bahamas (Sheridan et al., 1988) that appear to be affected by slow (1.6 cm/10^3 years; Lynts, 1970; Mullins and Lynts, 1977) subsidence largely due to thermally induced sedimentary loading (Pindell, 1985). However, limited amount of sediment volume, platform size (Mullins et al., 1991), and proximity to the North American-Caribbean plate boundary suggest that the subsidence history of San Salvador could differ from that of other islands in the northwestern Bahamas.

The pattern of tides in the Bahamas is semi-diurnal. Mean tidal range varies between 0.7 and 0.9 m and may increase to 1.2 m after new and full moons (Fields, 1989).

Due to active support from the Bahamian Field Station, the surficial geology of San Salvador is better known than that of most Bahamian Islands (Teeter, 1985; Curran, 1987; Mylroie, 1989; Bain, 1991). Complementing earlier works (e.g. Carew and Mylroie, 1985; Titus, 1987) and using new petrologic and amino-acid racemization data, Hearty and Kindler (1992) recognize eight limestone units that were deposited in shallow marine and terrestrial environments during a time interval stretching from middle Pleistocene to late Holocene.

First described by Bain (1989), the studied beachrock is exposed at French Bay, a 4 km wide embayment on the southern shore of the island (Fig. 3). Two stratigraphic units can be found around the bay: (1) upper-Pleistocene oolitic limestones (French Bay Member; Carew and Mylroie, 1985; Hearty and Kindler, 1992) that form a shallowing-upward sequence from subtidal to eolian deposits, and (2) poorly consolidated, subrecent beach-dune sediments that include the studied beachrock.

Methods

Beachrock morphology and sedimentary structures were studied along two transects, separated by 500 m, on the west side of Government Dock (Fig3). Collected samples were impregnated with blue epoxy resin, slabbed, thin-sectioned and analyzed qualitatively and quantitatively under a petrographic microscope. A whole-rock ^{14}C-dating analysis was performed on a selected sample by Beta Analytic Inc., of Miami, FL.

RESULTS

Field Observations

Depending on ocean and weather conditions, the French Bay beachrock may be largely exposed within the modern subtidal to lower supratidal zones, or it may be almost totally covered by loose sand. When exposed, it displays several sets of 5 to 15 cm-thick, laminated calcarenite beds that lie perfectly parallel to the present beach face and dip seaward at an angle of 8 to 10 degrees (Fig. 4). Beachrock beds also display an abundant encrusting fauna on their upper surfaces (e.g. vermetid gastropods, red algae; for more details, see Bain, 1989), whereas lower exposed surfaces are repleat with pelecypods, barnacles, worms and sponges borings.

Internally, beachrock beds show a well-developed fenestral porosity from the middle part of the intertidal zone to a depth of one meter below low-tide level. Observed fenestrae (Fig. 5) may be classified as "irregular" or slightly "laminoid" (Tebbutt et al., 1965; Logan, 1974; Tucker and Wright, 1990). They measure from 1 to 10 mm in length, up to 2 mm in height, and seem to occur preferentially within coarse-grained laminae. Surprisingly, beachrock fenestrae may be found more than 1.5 m below the presently forming fenestrae in modern sand.

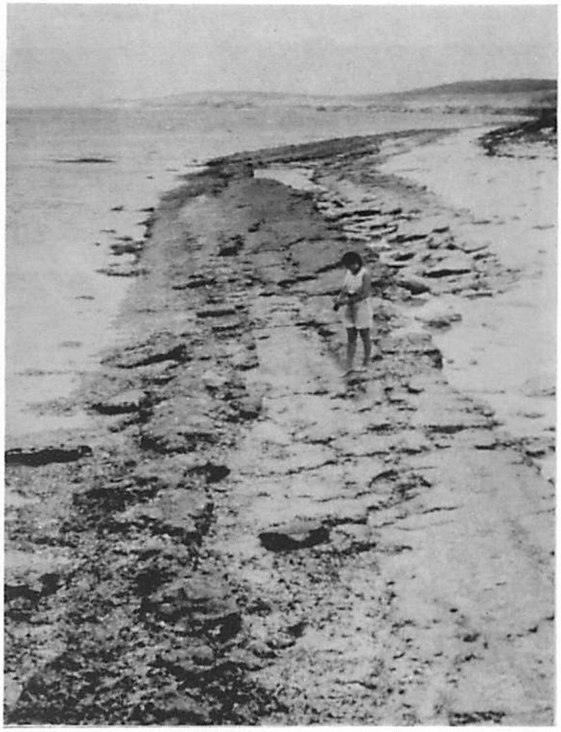

Fig. 4 View of the French Bay beachrock looking west from Government Dock. Picture was taken at solstice and spring low-tide in June 1990. Cliffs in the background are made of Pleistocene oolite.

Petrographic analysis

The French Bay beachrock is composed of well-lithified, medium to coarse-grained limestones that essentially contain heavily micritized, reef-derived allochems (coral and algal debris, mollusks fragments, benthic foraminifers; Fig. 6). The remaining grains consist of superficial ooids, peloids and aggregates. The petrographic composition of the studied beachrock is analogous to that of modern sand at French Bay, and also to that of upper Holocene units described at other locations in the Bahamas (Hanna Bay Member, San Salvador, Carew and Mylroie, 1985; Hearty and Kindler, 1992; Unit B, Lee Stocking Island, Kindler, 1993; "Holocene biopelsparite II", North Bimini, Gifford, 1973; Davaud and Strasser, 1984).

Samples collected below loose sand in the lower supratidal zone are characterized by a very low proportion of finely crystallized low-Mg calcite cement forming sutured menisci at grain contacts. Samples gathered in the intertidal and subtidal zones show two

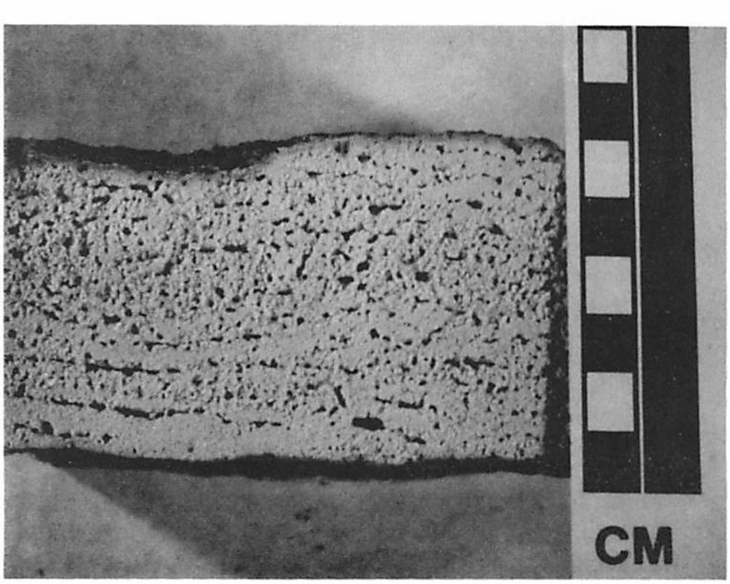

Fig. 5 Slabbed sample of fenestrae-rich beachrock collected one meter below low-tide level at French Bay.

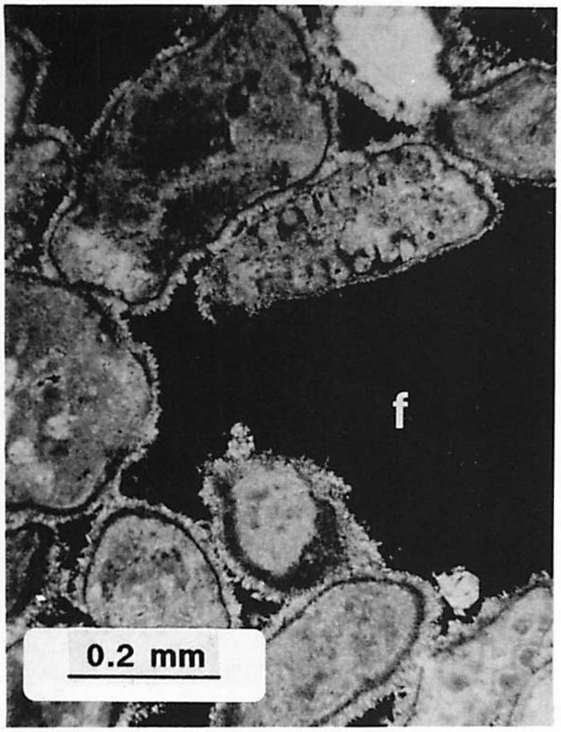

Fig. 6 Microfacies of the French Bay beachrock. Note the large fenestral pore (f) and the isopachous rims of fibrous aragonite. Note the dark layer at the base of the aragonite cement that may have originated from an organic mucus in which micrite was precipitated and trapped (Strasser et al., 1989).

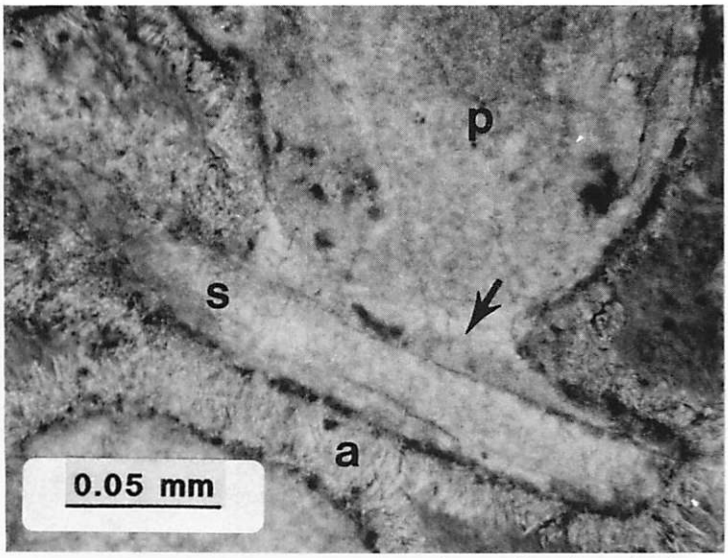

Fig. 7 Detailed microscopic view showing both generations of cement. Arrow points to early fresh-water calcitic meniscus. Younger rims of marine aragonite are indicated by an a; p = peloid, s = shell fragment.

generations of cement (Fig. 7): (1) an older calcitic cement that also displays a meniscus morphology, and (2) younger rims of fibrous aragonite crystals that surround the constituent grains. The former cement is typical of a fresh-water vadose environment (Halley and Harris, 1979; James and Choquette 1984), whereas the latter characterizes a active marine phreatic setting (Longman, 1980).

Radiometric Dating

^{14}C dating on a fenestrae-rich sample collected in the subtidal zone, more than one meter below low-tide level, yielded an uncorrected age of 1120 $\pm$ 60 years before present (YBP). This young age is not consistent with the known late Holocene sea-level history in the Bahamas. Indeed, according to established curves (Fig. 1), sea-level was at most 0.5 m lower 1100 years ago than it is today. This inconsistency could be resolved if one of the following hypothesis were correct:

(1) San Salvador is subsiding at a very fast rate;
(2) the French Bay beachrock has been displaced into the subtidal zone;
(3) the obtained ^{14}C age is not reliable;
(4) fenestrae and calcitic menisci may form underwater;
(5) sea-level was about 2 m lower 1100 years ago than it is today.

DISCUSSION

Subsidence and Beachrock Displacement

A subsidence rate of about 1.5 cm/10 yrs could explain the features of the French Bay beachrock. However, this rate is about 100 times greater than the values reported from other places in the northwestern Bahamas (Lynts, 1970; Mullins and Lynts, 1977). Moreover, if San Salvador was subsiding at such a fast rate, reefs formed during the +6 m Sangamon highstand would be submerged today. Instead, they can be found in life position up to 3 m above sea-level (Chen et al. 1991).

We do not have any field evidence that the beachrock has been displaced or slumped. As mentioned before, dip measurements are very constant and agree with values measured on modern beaches all around the island.

^{14}C Dating Errors

The obtained radiometric age of 1120 years might not be reliable. Errors could result from isotopic fractionation, reservoir effect, secular variations in ^{14}C production and contamination by either old or modern carbon.

Corrections for isotopic fractionation and reservoir effect have not been made. It should be noted however that these errors frequently compensate each other in the case of marine carbonates (Bowen, 1985, p. 117; Geyh and Schleicher, 1990, p. 175). Precise calibration with dendrochronology cannot be applied because the constituent grains and the cement of our sample probably have a different age. Approximate calibration based on a table published by Geyh and Schleicher (1990) indicates that the studied beachrock could be a hundred years younger than measured because of variations in ^{14}C production. The measured age of 1120 years could be biased by old carbon from the Pleistocene bedrock and/or from grains formed during the early Holocene. In the French Bay area, the bedrock is composed of oolitic limestones (French Bay Member; Carew and Mylroie, 1985; Hearty and Kindler, 1992) containing thickly-coated ooids that are clearly absent from the beachrock samples. The presence of a significant quantity of early Holocene grains within our sample would shift the maximal age of beachrock cementation towards present times. This in turn would indicate that marine conditions started to prevail much later at modern datum than previously thought, giving thus further support to hypothesis #5 (subrecent sea-level low-stand, see following section). Providing that the aragonitic cement binding the grains is modern, our sample could then be some 200 years older than measured, according to a correction table presented by Geyh and Schleicher (1990).

In summary, the corrected age of the French Bay beachrock is roughly equal to its conventional age because errors resulting from the de Vries effect and contamination by modern carbon practically cancel each other.

Fenestrae Significance

Also called bird's eyes or keystone vugs (Dunham, 1970), fenestrae (Tebbutt et al., 1965; Logan, 1974) are primary voids in rocks or sediments that can result from the trapping of air, sediment shrinkage, biogenic gas production, decay of organic matter. They most commonly occur in the intertidal zone but have been recognized in terrestrial settings (Stieglitz and Inden 1969; Bain, 1985; Kindler, 1991; Bain and Kindler, 1993) and also underwater.

Shinn (1983) observed such voids within a Holocene hardground at a depth of 7 m on the Bahama Platform, off New Providence Island. In this case they result from the loose packing of irregular grains. Fenestrae may also occur within subtidal stromatolites (Dill et al., 1986), where they are produced by the decay of epiphytic organisms (e.g. sponges, algae) following burial by modern oolitic sand.

Therefore, although the French Bay beachrock does not have the same morphology as the coastal stromatolites recently discovered on nearby Stocking Island (Reid and Browne, 1991), we must remember that fenestrae may form in a subtidal environment.

Significance of Fresh-water Cements

Fresh-water cements can precipitate within subtidal sediments following rapid shoreline progradation and concomitant seaward migration of the fresh-water lens (Davaud and Strasser, 1984). On a stable shoreline, reduced fresh-water discharge coupled with pronounced tidal fluctuations may also lead to the precipitation of low-Mg calcite in subtidal sands by degassing of CO_2-rich meteoric waters (Hanor, 1978). However, the occurrence of an early cement showing a meniscus morphology clearly indicates that the diagenesis of the French Bay beachrock began in the fresh-water vadose environment (Halley and Harris, 1979; Longman, 1980), i.e. in a subaerial setting.

Sea-level History

The foregoing discussion shows that a low-stand of the sea some 1200 years ago would best explain the sedimentologic and petrographic characteristics of the French Bay beachrock.

A low-stand at about 1200 years is supported by other studies. Paleosalinity variations derived from Mg concentrations in fossil ostracodes from saline lakes on San Salvador point to a lowering of the sea around 1.36 ka (Teeter and Quick, 1990). Also, a 950 $\pm$ 70 year-old peat sample collected at a depth of 0.7 m below the sediment/water interface of a brackish water pond on the southeastern shoreline of the island (Winter, 1987) provides additional evidence of a 1-1.3 ka low-stand of the sea in this region.

No other beachrock presenting fenestrae and early low-Mg calcite meniscus cement in the modern subtidal zone has been uncovered on San Salvador (Beier, 1985). However, Illing (1954) mentions a similar, but unfortunately undated, exposure on Hog Cay (Ragged Islands). Further investigation of submerged beachrocks appears to be necessary to better understand the extension and the amplitude of late

Holocene sea-level variations in the Bahamas.

CONCLUSIONS

Detailed sedimentologic, petrographic and radiometric study of the French Bay beachrock indicates that, in the Bahamas, sea-level was probably 1.5 to 2 meters below modern datum some 1200 years ago. It appears then that the smooth trend of sea-level rise proposed by previous authors (Boardman et al., 1989; Digerfeldt and Hendry, 1987; Scholl et al. 1969; Pirazzoli, 1991; Wanless, 1982) might be overprinted by high-frequency, low-amplitude fluctuations.

Recognition of such fluctuations is fundamental while calculating rates of sea-level rise and for evaluating coastal responses to a marine transgression.

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