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P. Kindler · R. J. Bain

Submerged Upper Holocene beachrock on San Salvador Island, Bahamas: implications for recent sea-level history

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Abstract Sedimentological, 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 1 m below low tide level yielded an average ^{14}C age of 965 ± 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 present beachrock position and the reported Late Holocene sea-level history in the Bahamas. A 1.5–2 m low stand of the sea about 1 000 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 workers might be overprinted by high frequency, low amplitude fluctuations. Recognition of these fluctuations is fundamental when calculating rates of sea-level rise and evaluating the coastal response to a marine transgression.

Key words Sea-level history – Bahamas – Beachrocks – Holocene – Carbonates

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 world-wide (e.g. Scholle et al., 1983). In contrast, the history of sea-level rise due to the melting of ice sheets 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 reports new information about the Late Holocene sea-level history of the Bahamas.

Setting and methods

Holocene sea levels 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 at any location in the Bahamas. Indeed, the Holocene sea-level curve of Boardman et al. (1989) shows a smooth, shoulder-like shape that trends towards the present stand, but never exceeds the modern datum. It is analogous to the curves proposed for neighbouring, but much more studied, south Florida (Scholl and Stuiver, 1967; Scholl et al., 1969; Wanless, 1982; Lidz and Shinn, 1991, Pirazzoli, 1991) and Jamaica (Digerfeldt and Hendry, 1987).

The important point to remember from these curves (Fig. 1) is that, after a rapid rise during the Mid-Holocene, the sea level reached a position within 1.5 m of its present elevation about 3 500 years ago and has risen at a steady rate of 3.5–4 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.

P. Kindler
Département de Géologie et de Paléontologie, Université de Genève, 13 rue des Maraîchers, 1211 Genève, Switzerland

R. J. Bain
Departement of Geology, University of Akron, Akron, Ohio, USA

Correspondence to: P. Kindler

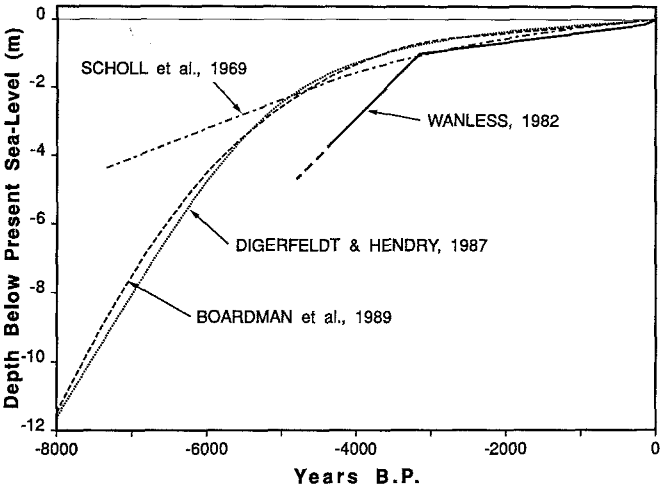


Fig. 1. A few of the Late Holocene sea-level curves that have been established for the south Florida – Bahamas region

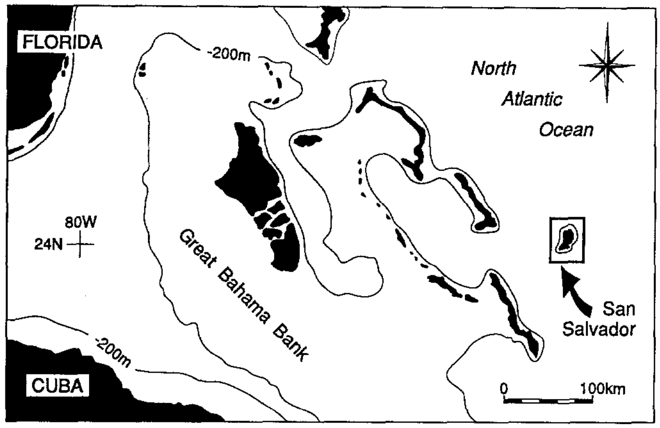


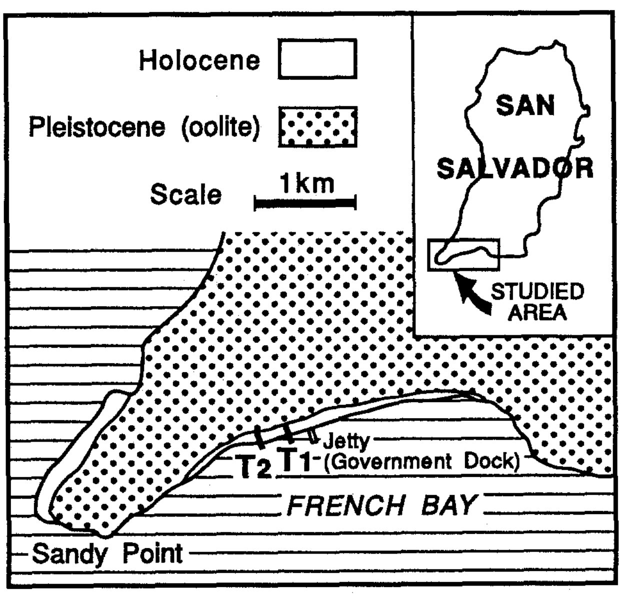
Fig. 3. Location of the French Bay beachrock. T1 and T2 indicate the transects studied

Study area

San Salvador is a small (19 × 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 north-western 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, the limited volume of sediment, 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 north-western Bahamas.

The pattern of tides in the Bahamas is semi-diurnal. The 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).

Fig. 2. Location of San Salvador Island



Owing 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 petrological 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 the 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-upwards sequence from subtidal to aeolian 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 (Fig. 3). Collected samples were impregnated with blue epoxy resin, slabbed, thin sectioned and analysed qualitatively and quantitatively under a petrological microscope. Additional petrographic investigations included staining of thin sections with Titan-yellow and Fiegl's solutions for carbonate mineral identification, and examination of polished surfaces with a JEOL 6400 scanning electron microscope. Lastly, whole rock ^{14}C dating analyses were performed on three selected samples by Beta Analytic (Miami, FL, USA).

Results

Field observations

Depending on oceanic and weather conditions, the French Bay beachrock may be largely exposed within the

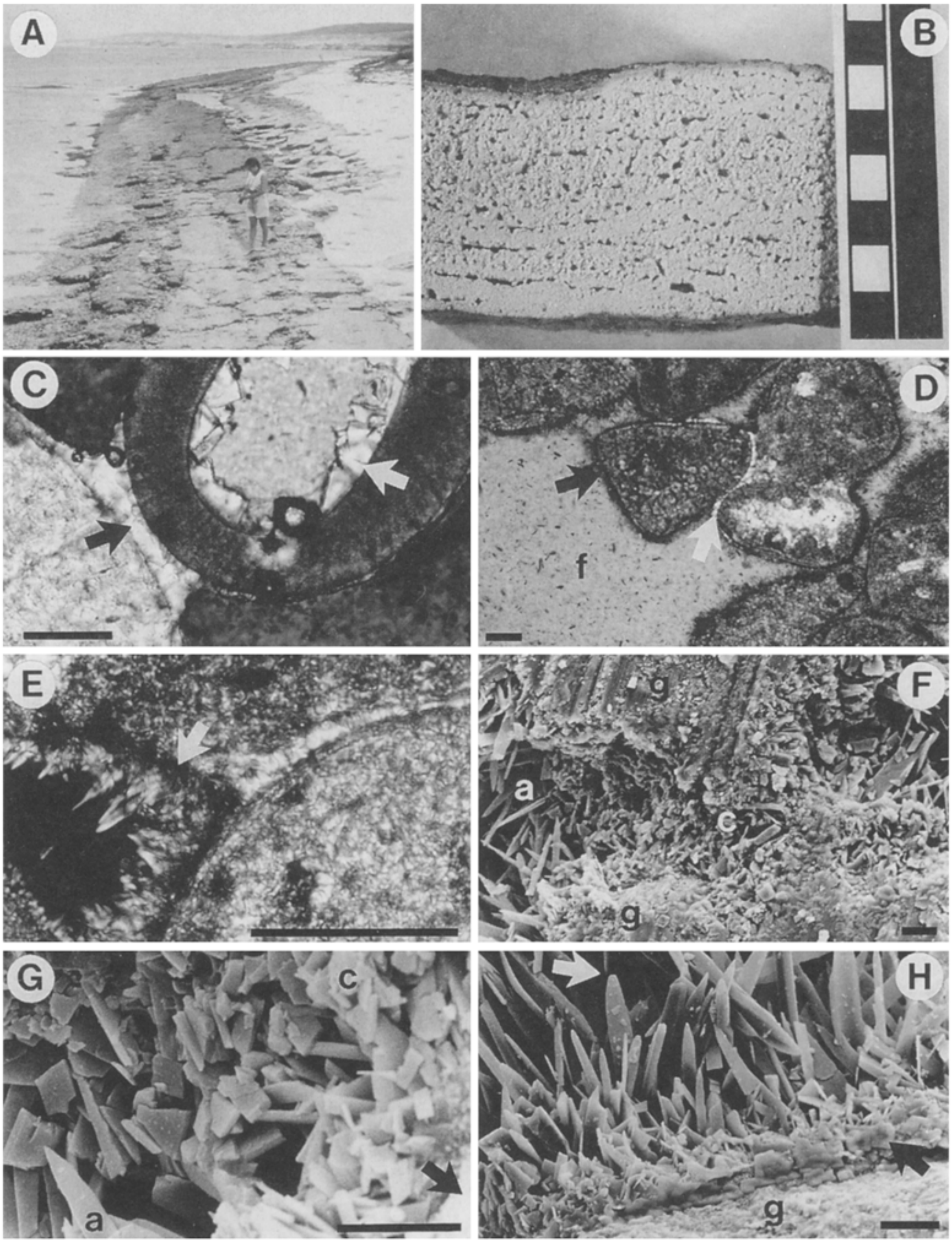


Fig. 4. (A) Exposure of the French Bay beachrock west from Government Dock. Photograph taken at solstice and spring low tide in June 1990. Cliffs in the background are made of Pleistocene oolite. **(B)** Slabbed sample of fenestrae-rich beachrock collected 1 m below low tide level at French Bay. Scale in centimetres. **(C)** Thin section of a beachrock fragment collected below loose sand in the lower supratidal zone. Grains are bound by low Mg calcite cement forming menisci at grain contacts (dark arrow); blocky spar also occurs within bioclasts (white arrow). Scale bar = 50 μm. **(D)** Thin section of a porous beachrock sample gathered from the subtidal zone. Note the large fenestral pore (f) and the two phases of cementation: equant spar occurring at grain contacts (white arrow) and isopachous rims of fibrous aragonite surrounding the grains (black arrow). Scale bar = 50 μm. **(E)** Close-up view showing both generations of cement. Note the dark layer at the base of the aragonite needles that may have originated from an organic mucus in which micrite was precipitated and trapped (Strasser et al., 1989). Scale bar = 50 μm. **(F)** Same view as 4 E seen through the scanning electron microscope; g = grain, c = calcitic meniscus, a = aragonite. Scale bar = 5 μm. **(G)** Detail of 4 F; c = calcitic meniscus, a = aragonite, arrow points to grain. Scale bar = 5 μm. **(H)** Close-up view of aragonitic cement. Note the presence a few square-ended crystals (white arrow) and of the micritic layer at the base of the needles (black arrow); g = grain. Scale bar = 5 μm

modern subtidal to lower supratidal zones, or it may be almost totally covered by loose sand. When exposed, it displays several sets of 5–15 cm thick laminated calcarenite beds that lie perfectly parallel to the present beach face and dip seawards at an angle of 8°–10° (Fig. 4 A). 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 exposed lower surfaces contain pelecypods, barnacles, worms and sponge borings.

Internally, the beachrock beds show a well developed fenestral porosity from the middle part of the intertidal zone to a depth of 1 m below low tide level. Observed fenestrae (Fig. 4 B) 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 sands.

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, mollusc fragments, benthic foraminifera; Fig. 4 D; Table 1). The remaining grains consist of superficial ooids, peloids and aggregates. The

Table 1. Petrographic database of ^{14}C dated samples from the French Bay beachrock, San Salvador, Bahamas

Sample	Grains (%)	Cement %		Porosity (%)	Bioclasts (%)	Ooids (%)	Peloids (%)	Others (%)	Age (years BP)
		Meteoric	Marine						
SS 73	64.8	1.0	0.0	34.2	72.8	8.6	12.1	6.5	1220 ± 60
SS 71	54.9	1.3	16.2	27.6	68.9	6.8	11.0	13.3	810 ± 50
SS 34a	57.0	0.8	19.2	23.0	62.1	15.2	14.9	7.8	1120 ± 60
SS 34b	60.5	1.0	16.8	21.7	62.1	13.9	14.5	9.5	1120 ± 60

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, 1992); 'Holocene biopelsparite II', North Bimini (Gifford, 1973; Davaud and Strasser, 1984)].

Samples collected below loose sand in the lower supratidal zone (e.g. SS 73, Table 1) are characterized by a very low proportion of finely crystallized low Mg calcite cement forming sutured menisci at grain contacts (Fig. 4C). Samples gathered from the intertidal and subtidal zones (e.g. SS 34, Table 1) show two generations of cement (Fig. 4D – G): (1) an older calcitic cement that also displays a meniscus morphology and (2) younger rims of fibrous aragonite crystals that surround the constituent grains. Although scanning electron microscopy views of aragonite needles do not always show square-ended crystal terminations (Scoffin, 1987; Fig. 4H), the mineralogy has been confirmed by the appearance of a black taint after immersing the thin sections in Fiegl's solution. The former calcitic cement is typical of a fresh water vadose environment (Halley and Harris, 1979; James and Choquette, 1984), whereas the aragonitic rims characterize an active marine phreatic setting (Longman, 1980).

Radiometric dating

Radiocarbon dating on one beachrock fragment collected below loose sand in the lower supratidal zone (SS 73, Table 1) yielded an uncorrected age of 1220 ± 60 years before present (YBP). Moreover, two fenestrae-rich samples gathered from the subtidal zone (SS 71, SS 34, Table 1), more than 1 m below low tide level, were dated at 810 ± 50 and 1120 ± 60 YBP, respectively. These young ages and the intertidal and lower supratidal features observed on the French Bay beachrock are not consistent with its position and with the known Late Holocene sea-level history in the Bahamas. Indeed, according to established curves (Fig. 1), the sea level was at most 0.5 m lower 1000 years ago than it is today. Consequently, if the ^{14}C ages are correct, fenestrae and low Mg calcite cements should be found at a higher elevation within the beachrock.

This inconsistency could be resolved if one of the following hypotheses is verified: (1) San Salvador is subsiding at a very fast rate; (2) the French Bay beachrock has been displaced into the subtidal zone; (3) the ^{14}C ages obtained are not reliable; (4) fenestrae and calcitic meniscus may form underwater; or (5) the sea level was about 1.5 – 2 m lower 1000 years ago than it is today.

Discussion

Subsidence and beachrock displacement

A subsidence rate of about 1.5 cm/10 years 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 north-western Bahamas (Lynts, 1970; Mullins and Lynts, 1977). Moreover, if San Salvador is subsiding at such a fast rate, reefs formed during the +6 m Sangamon highstand would be submerged today. Instead, they are 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 constant and agree with values measured on modern beaches around the island.

Radiocarbon dating errors

The radiometric ages obtained might not be reliable. Errors could result from isotopic fractionation, reservoir effects, secular variations in ^{14}C production and contamination by either old or modern carbon. Corrections for isotopic fractionation and reservoir effects have not been made. It should be noted, however, that these errors often compensate each other in 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 ages 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 amount of Early Holocene grains within our sample would shift the maximum age of beachrock cementation towards the present day. This in turn would indicate that marine conditions started to prevail much later than previously thought, giving further support to hypothesis 5 (subrecent sea-level lowstand, see following section). Providing that the aragonitic cement binding the grains is modern, the porous samples from the subtidal zone could then be about 200 years older than measured, according to the correction table presented by Geyh and Schleicher (1990). Corrected values between 1010 and 1320 YBP are coherent with the 1220 YBP age obtained on the beachrock fragment collected from the lower supratidal zone.

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.

Significance of fenestrae

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 or 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, submitted) 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 instance 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 and algae) following burial by modern oolitic sand.

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

Significance of freshwater cements

Freshwater cements can precipitate within subtidal sediments following rapid shoreline progradation and concomitant seawards migration of the freshwater lens (Davaud and Strasser, 1984). On a stable shoreline, reduced freshwater discharge coupled with pronounced tidal fluctuations may also lead to the precipitation of low Mg calcite in subtidal sands by degassing of carbondioxide-rich meteoric waters (Hanor, 1978).

However, the regular occurrence of an early cement showing a meniscus morphology clearly indicates that the diagenesis of the French Bay beachrock began in the freshwater vadose environment (Halley and Harris, 1979; Longman, 1980), i.e. in a subaerial setting.

Sea-level history

The foregoing discussion shows that a lowstand of the sea about 1 000 years ago would best explain the sedimentological and petrographic characteristics of the French Bay beachrock.

A lowstand at about 1 000 YBP is supported by other studies. Palaeosalinity variations derived from Mg concentrations in fossil ostracod shells from saline lakes on San Salvador point to a lowering of the sea around 1 360 YBP (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 south-eastern shoreline of the island (Winter, 1987) provides additional evidence of a 1 000–1 300 YBP lowstand 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) reports 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 amplitude of Late Holocene sea-level variations in the Bahamas.

Conclusions

Detailed sedimentological, petrographic and radiometric studies of the French Bay beachrock indicates that, in the Bahamas, the sea level was probably 1.5–2 m below modern datum about 1 000 years ago. It appears that the smooth trend of sea-level rise proposed by previous workers (Scholl et al., 1969; Wanless, 1982; Digerfeldt and Hendry, 1987; Boardman et al., 1989; Lidz and Shinn, 1991; Pirazzoli, 1991) might be overprinted by high frequency, low amplitude fluctuations.

The recognition of such fluctuations is fundamental in calculating rates of sea-level rise and in evaluating coastal responses to a marine transgression.

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References

Bain RJ (1985) Eolian dune, Watling roadcut. In: Curran HA (ed) Pleistocene and Holocene Carbonate Environments on San Salvador Island, Bahamas. Guidebook for the Geological Society of America, Orlando Annual Meeting Field Trip, Bahamian Field Station, Fort Lauderdale: 129–132

Bain RJ (1989) Exposed beachrock: its influence on beach processes and criteria for recognition. In: Mylroie JE (ed) Proceedings of the Fourth Symposium on the Geology of the Bahamas. Bahamian Field Station, Fort Lauderdale: 33–44

Bain RJ (ed) (1991) Proceedings of the Fifth Symposium on the Geology of the Bahamas. Bahamian Field Station, San Salvador: 247 pp

Bain RJ, Kindler P. Irregular fenestrae in Bahamian eolianites: a rainstorm-induced origin. J Sedim Petrol, submitted

Ball MM (1967) Carbonate sand bodies of Florida and the Bahamas. J Sedim Petrol 37: 556–591

Bathurst RBG (1975) Carbonate Sedimentology and Diagenesis. Elsevier, Amsterdam: 658 pp

Beier JA (1985) Diagenesis of Quaternary Bahamian beachrock: petrographic and isotopic evidence. J Sedim Petrol 55: 755–761

Boardman M, Neumann AC, Rasmussen KA (1989) Holocene sea level in the Bahamas. In: Mylroie JE (ed) Proceedings of the Fourth Symposium on the Geology of the Bahamas. Bahamian Field Station, Fort Lauderdale: 45–52

Bowen DQ (1985) Quaternary Geology – A Stratigraphic Framework for Multidisciplinary Work. Pergamon Press, Oxford: 237 pp

Carew JL, Mylroie JE (1985) The Pleistocene and Holocene stratigraphy of San Salvador Island, Bahamas, with reference to marine and terrestrial lithofacies at French Bay. In: Curran HA (ed) Pleistocene and Holocene Carbonate Environments on San Salvador Island, Bahamas. Guidebook for the Geological Society of America, Orlando Annual Meeting Field Trip. Bahamian Field Station, Fort Lauderdale: 11–61

Chen JH, Curran HA, White B, Wasserburg GJ (1991) Precise chronology of the last interglacial period: ^{234}U-^{230}Th data from fossil coral reefs in the Bahamas. Geol Soc Am Bull 103: 82–97

Clark JA, Farrell WE, Peltier WR (1978) Global changes in postglacial sea level: a numerical calculation. Quaternary Res 9: 265–287

Curran HA (1987) Proceedings of the Third Symposium on the Geology of the Bahamas. Bahamian Field Station, Fort Lauderdale: 254 pp

Davaud E, Strasser A (1984) Progradation, cimentation, érosion: évolution sédimentaire et diagénétique récente d'un littoral carbonaté (Bimini, Bahamas). Eclog Geol Helv 77: 449–468

Digerfeldt G, Hendry MD (1987) An 8000 year Holocene sea-level record from Jamaica: implications for interpretation of Caribbean reef and coastal history. Coral Reefs 5: 165–169

Dill RF, Shinn EA, Jones AT, Kelly K, Steinen RP (1986) Giant subtidal stromatolites forming in normal salinity waters. Nature 324: 55–58

Dunham RJ (1970) Keystone vugs in carbonate beach deposits [abstract]. Am Assoc Petrol Geol 54: 845

Fields MH (1989) Yachtsman's guide to the Bahamas. Tropic Isle Publishers, Red Bank: 454 pp

Geyh MA, Schleicher H (1990) Absolute Age Determination. Physical and Chemical Dating Methods and their Application. Springer, Berlin Heidelberg New York: 503 pp

Gifford JA (1973) A description of the geology of the Bimini Islands, Bahamas. Unpublished MS Thesis. University of Miami: 88 pp

Halley RB, Harris PM (1979) Fresh-water cementation of a 1000-year-old oolite. J Sedim Petrol 49: 969–988

Hanor JS (1978) Precipitation of beachrock cements: mixing of marine and meteoric waters vs. CO_2 degassing. J Sedim Petrol 48: 489–501

Hearty PJ, Kindler P (1992) The geological evolution of San Salvador, Bahamas. Abstracts and Program of the Sixth Symposium on the Geology of the Bahamas. Bahamian Field Station, Fort Lauderdale: 11–12

Illing LV (1954) Bahaman calcareous sands. Am Assoc Petrol Geol Bull 38: 1–95

James NP, Choquette PW (1984) Limestones – the meteoric diagenetic environment. Geosci Can 11: 161–194

Kindler P (1991) Keystone vugs in coastal dunes: an example from Eleuthera, Bahamas. In: Bain RJ (ed) Proceedings of the Fifth Symposium on the Geology of the Bahamas. Bahamian Field Station, Fort Lauderdale: 117–123

Kindler P (1992) Coastal response to the Holocene transgression in the Bahamas: episodic sedimentation versus continuous sea-level rise. Sedim Geol 80: 319–329

Lidz BH, Shinn EA (1991) Paleoshorelines, reefs, and a rising sea: south Florida, USA. J. Coastal Res 7: 203–229

Logan BW (1974) Inventory of diagenesis in Holocene-Recent carbonate sediments, Shark Bay, Western Australia. In: Logan BW (ed) Evolution and Diagenesis of Quaternary Carbonate Sequences, Shark Bay, Western Australia. Am Assoc Petrol Geol Mem No 22: 195–249

Longman MW (1980) Carbonate diagenetic textures from nearsurface diagenetic environments. Am Assoc Petrol Geol Bull 64: 461–487

Lynts GW (1970) Conceptual model of the Bahamian Platform for the last 135 million years. Nature 225: 1226–1228

Mullins HT, Lynts GW (1977) Origin of the northwestern Bahama Platform: review and reinterpretation. Geol Soc Amer Bull 88: 1447–1461

Mullins HT, Dolan J, Breen N, Andersen B, Gaylord M, Petruccione JL, Wellner RW, Melillo AJ, Jurgens AD (1991) Retreat of carbonate platforms: response to tectonic processes. Geology 19: 1089–1092

Mylroie JE (ed) (1989) Proceedings of the Fourth Symposium on the Geology of the Bahamas. Bahamian Field Station, Fort Lauderdale: 381 pp

Parkinson RW (1989) Decelerating Holocene sea-level rise and its influence on Southwest Florida coastal evolution: a transgressive/regressive stratigraphy. J Sedim Petrol 59: 960–972

Pindell JL (1985) Alleghenian reconstruction and subsequent evolution of the Gulf of Mexico, Bahamas, and proto-Caribbean. Tectonics 4: 1–39

Pirazzoli PA (1991) World Atlas of Holocene Sea-level Changes. Elsevier, Amsterdam: 300 pp

Purdy EG (1963) Recent calcium carbonate facies of the Great Bahama Bank. J Geol 71: 472–497

Reid RP, Browne KM (1991) Intertidal stromatolites in a fringing Holocene reef complex, Bahamas. Geology 19: 15–18

Schlager W, Ginsburg RN (1981) Bahama carbonate platforms – the deep and the past. Mar Geol 44: 1–24

Scholl DW, Stuiver M (1967) Recent submergence of Southern Florida: a comparison with adjacent coasts and other eustatic data. Geol Soc Am Bull 78: 437–454

Scholl DW, Craighead FC Sr, Stuiver M (1969) Florida submergence curve revised: its relation to coastal sedimentation rates. Science 163: 562–564

Scholle PA, Bebout DG, Moore CH (1983) Carbonate depositional environments. Am Assoc Petrol Geol Mem No 33: 708 pp

Scoffin TP (1987) An Introduction to Carbonate Sediments and Rocks. Blackie, Glasgow and London: 274 pp

Sheridan RE, Mullins HT, Austin JA Jr, Ball MM, Ladd JW (1988) Geology and geophysics of the Bahamas. In: Sheridan RE, Grow JA (eds) The Geology of North America. Vol. 1–2. Geological Society of America, Boulder: 329–364

Shinn EA (1983) Birdseyes, fenestrae, shrinkage pores, and loferites: a reevaluation. J Sedim Petrol 53: 619–628

Stieglitz RD, Inden RF (1969) Development of cavernous sediment in a non-beach environment. J Sedim Petrol 39: 342–344

Strasser A, Davaud E, Jedoui Y (1989) Carbonate cements in Holocene beachrock: example from Bahiret el Biban, southeastern Tunisia. Sedim Geol 62: 89–100

Tebbutt GE, Conley CD, Boyd DW (1965) Lithogenesis of a distinctive carbonate rock fabric. Univ Wyoming Contrib Geol 4: 1–13

Teeter JW (1985) Proceedings of the Second Symposium on the Geology of the Bahamas. Bahamian Field Station, Fort Lauderdale: 296 pp

Teeter JW, Quick TJ (1990) Magnesium-salinity relation in the saline lake ostracode *Cyprideis americana*. Geology 18: 220–222

Titus R (1987) Geomorphology, stratigraphy and the Quaternary history of San Salvador Island, Bahamas. In: Curran HA (ed) Proceedings of the Third Symposium on the Geology of the Bahamas. Bahamian Field Station, Fort Lauderdale: 155–164

Tucker ME, Wright PW (1990) Carbonate Sedimentology. Blackwell, Oxford: 482 pp

Wanless HR (1982) Sea level is rising, so what? J Sedim Petrol 52: 1051–1054

Winter J (1987) Speculations on prehistoric coastal topography of the Bahamas. In: Curran HA (ed) Proceedings of the Third Symposium on the Geology of the Bahamas. Bahamian Field Station, Fort Lauderdale: 205–213