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HOLOCENE SEA LEVEL IN THE BAHAMAS

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ABSTRACT

A sea-level curve covering the late Holocene (10,000 years to present) for the Bahamas emerges, based on C-14 dating of basal peat samples from cores recovered from lagoons and tidal flats and on measurements of the rates of coastal erosion. This sea-level curve shows that Bahamian platforms were flooded earlier than predicted, using the Bermuda sea-level curve, and somewhat later than predicted, using the sea-level submergence curve for South Florida.

Using this new sea-level curve, the temporal framework of late Holocene depositional processes can be constrained. The record of lagoon filling is better integrated with the Holocene sea-level rise, and the signal of banktop emergence/submergence in the periplatform record is supported by this new curve. An episode of early Holocene formation of eolian dunes concurs with the concept of a Holocene "high-energy interval." These data enhance our understanding of late Quaternary fluctuations of sea level.

INTRODUCTION

Sea level exerts a profound influence on sedimentary systems for several reasons. Basically, it determines the upper limit of marine processes (erosion and deposition) and the lower limit of subaerial processes (erosion and deposition). Sea level and the rate of sea-level rise control the modern sedimentary sequences of lagoons (Boardman and Neumann, 1976; Bosence et al., 1985; Rasmussen and Neumann, 1987; Andersen and Boardman, 1989; Colby and Boardman, 1989), sand shoals (Hine, 1977; Harris, 1979), reefs (Adey and Burke, 1976; Macintyre and Glynn, 1976; Adey, 1978), tidal flats (Shinn et al., 1969; Shinn, 1986), and eolian dunes (Boardman et al., 1987; Vacher and Hearty, in press). Ancient sequences are also primarily controlled by sea level (Grottzinger, 1986; Pratt and James, 1986; Strasser, 1988; Read, 1988). Sea level is perhaps the most significant single parameter in evaluating the accumulation of carbonates (Schlager, 1981; Schlager and Ginsburg, 1981; Kendall and Schlager, 1981).

There is overall agreement that during the Pleistocene, the volume of water in the ocean has fluctuated in response to glacial advances and retreats, and this has caused worldwide eustatic fluctuations in sea level on the order of 100 to 150 meters (Matthews, 1984). However, this general agreement is moderated by the understanding that a single eustatic sea-level curve is not the panacea for studies of shallow-water processes (Wanless, 1982). Local effects control the vertical stability of the crust and thus control relative sea level. Subsidence (or uplift) can result from loading (or unloading) of water, sediment, and ice (Bloom, 1967; Matthews, 1984) and crustal rebound (Walcott, 1970). Bulges (geoid changes) may propagate through the earth (Walcott, 1970; Mörner, 1980) and cause local changes in relative sea level which are unrelated to any local surficial process.

Evaluation of Holocene carbonate depositional processes in the Bahamas are increasingly asking more detailed questions, and more detailed comparisons are being made. These studies are increasingly more dependent on accurate and specific information on the relative rise of sea level. For example, a large portion of the tidal flats on northwest Andros Island may have been eroded during the past 1000-2000 years because of a small and unknown rise of sea level (Shinn, 1986). The onset of marine conditions in silled lagoons has been shown to be controlled by sea level (Boardman, 1976; Boardman et al., 1986a; Rasmussen and Neumann, 1987; Colby and Boardman, 1989). The exact timing and extent of Holocene flooding of entire platforms is a major point of contention in evaluating the signal of periplatform sedimentation (Droxler et al., 1983; Droxler, 1985, 1986; Boardman and Neumann, 1984, 1985, 1986; Boardman et al., 1986b). The development and evolution of Holocene eolian dunes suggests there was an interval during which sea level had flooded the platforms but was rising too fast to allow dune progradation (Boardman et al., 1987). Studies such as these require an accurate Holocene sea-level curve for the Bahamas.

There are many excellent sea-level curves that have been used for studies in the Bahamas. The sea-level curve from Bermuda (Neumann, 1972) is perhaps the most carefully constructed and complete Holocene record of sea-level rise. It is comprised only of dates of peat-on-bedrock and contains 31 sample points from a small area. For this reason, it has been used in several studies in the Bahamas and other areas (Adey and Burke, 1976; Macintyre and Glynn, 1976; Hine, 1977; Boardman and Neumann, 1984; Droxler et al., 1983; Rasmussen and Neumann, 1987). The curve for south Florida (Scholl et al., 1969) is from an area more similar to the Bahamas and is closer to the Bahamas than Bermuda. Because of this, several researchers have used the south Florida curve for Bahamian studies (Harris, 1979). The south Florida curve, however, is based on C-14 dating of several types of sea-level indicators other than samples of peat-on-bedrock and suffers because of the inherent unreliability of using shells as sea-level indicators. Other curves from nearby areas are likewise candidates for use in Bahamian studies (e.g., Fairbridge, 1974; Lighty et al., 1982; Digerfeldt and Hendry, 1987). However, each of these curves must be used with a clear understanding that sea-level fluctuations in the Bahamas are likely to be different, perhaps by a lot. The fact is we don't have a sea-level curve for the Bahamas, and because minor changes in sea level may be critical to processes of deposition, a Bahamian sea-level curve is needed.

METHODS

Sediment cores from shallow-water sediments sometimes contain peat deposits lying directly on top of the Pleistocene bedrock surface. This peat is the last surviving portion of terrestrial or mixed terrestrial/marine material and is usually preserved in shallow depressions ("pocket peat" of Wanless, 1974) or in well-protected, quiet-water environments. Peat is an intertidal deposit which can be dated with C-14 methods. Thus, it is an excellent record of sea level. The C-14 age of ten samples of peat from cores from lagoons on San Salvador, Andros Island, and Bight of Abaco, Little Bahama Bank in the Bahamas have been determined. Only peat directly in contact with the bedrock surface is included in order to limit problems caused by compaction (Bloom, 1964; Kaye and Barghoorn, 1964; Van de Plassche, 1980). To confirm that the peat directly overlies the bedrock, either pieces of rock were recovered or the nose of the aluminum core tubing was bent. In addition, marine shells which directly overly the peat have been dated, where possible, to confirm the timing of initial marine sedimentation. A computer-generated, third-order, best-fit line is drawn through the data points.

RESULTS

The results of C-14 analyses are included in the curve of Bahamian sea level (Figure 1). Evidence of sea-level rise during the last 2000 years is particularly difficult to determine with accuracy because sea-level rise has been slow, and peat has a higher likelihood of being eroded by waves and currents. The sea-level data from studies of erosion of limestone coastlines in the Bahamas (Donn and Boardman, 1988) is used to confirm that sea level has been within 50cm of present for the past 1400 years.

DISCUSSION

The Bahamian sea-level curve is different than other curves of late Holocene sea level (Figure 2). It is higher than the Bermuda curve for all but the last 2000 years which means that depositional events recognized in the Bahamas occur earlier than would be expected or predicted (by up to 1000 years) if the Bermuda curve were used. It is lower than the curve of early Holocene sea level from south Florida which means that Bahamian depositional events occur later than would be predicted, using the south Florida curve.

Lagoon Evolution

The evolution of lagoonal sequences is strongly controlled by sea level and the antecedent topography of the newly-flooded platform. A record of the Holocene rise of sea level is recorded in changing mineralogy and constituent

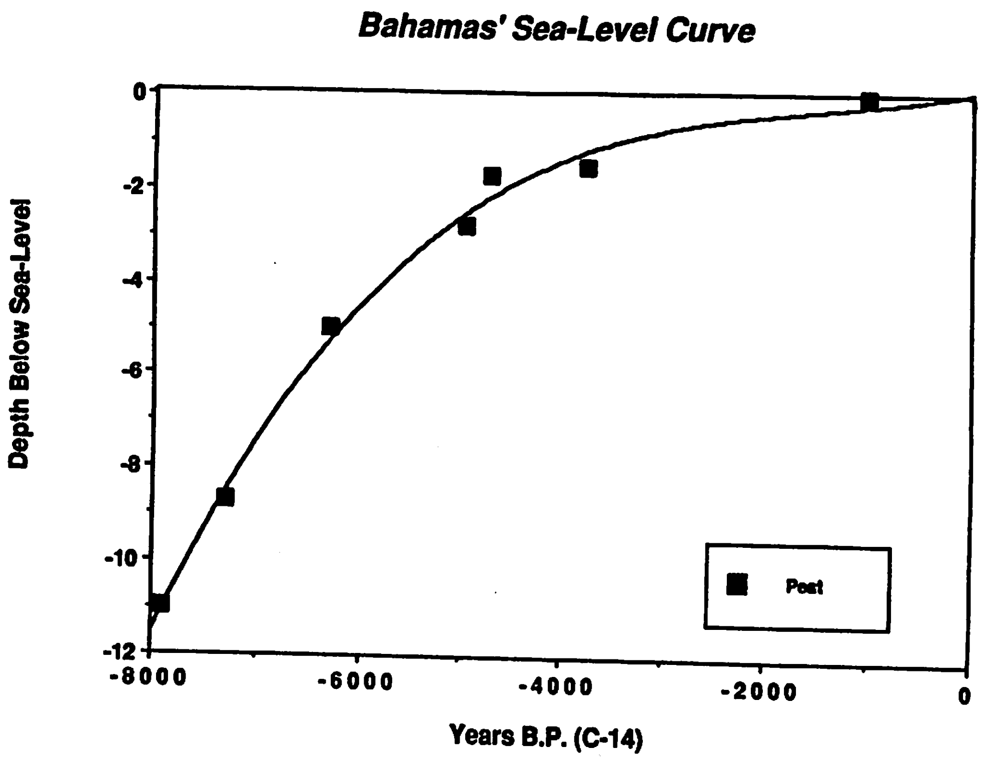

Fig. 1: The Bahamas' sea-level curve is derived from C-14 dates of peat samples recovered from the bedrock interface in sediment cores from San Salvador, Andros Island, and Bight of Abaco.

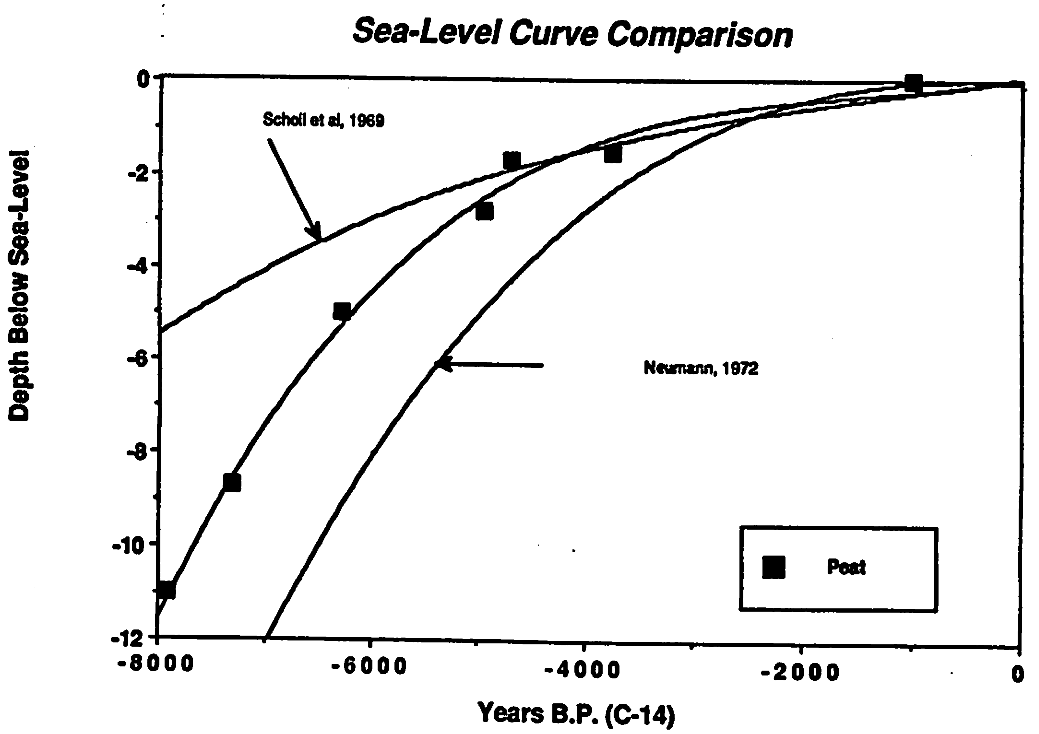

Fig. 2: A comparison of sea-level curves for Bermuda (Neumann, 1972), south Florida (Scholl et al., 1969), and the Bahamas (this paper) shows the increasing difference for dates older than 2,000 years BP.

analysis of the sediment, as well as the geology of the exposure surface. Shallowing-upwards sequences of fine-grained sediment (James, 1984), and the vertical sequences of coarse-grained sediments (Hine, 1977; Harris, 1979) and mud mounds (Bosence et al., 1985) are closely tied to sea level. In some lagoons, the depth of a sill controls the degree of restriction of the lagoon water.

In the Bahamas, sills have controlled the early deposition of Graham's Harbor, San Salvador (Colby and Boardman, 1988; Colby, 1989), and Bight of Abaco, Little Bahama Bank (Boardman, 1976; Rasmussen and Neumann, 1986). In Bight of Abaco, a prominent sill about 2 meters below present sea level acted as a barrier to water exchange and strongly controlled the early depositional history of the lagoon (Boardman, 1976). A macrofaunal assemblage is found at the base of several cores (to about 9.6 meters below present sea level) which suggests that a restricted environment with widely fluctuating salinity and little *Thalassia* was the earliest "marine" environment. A C-14 date of shells from the base of this core (-9.6 meters) yields 6,600 (plus or minus 100) YBP. Using the Bermuda curve, these shells would have to have been deposited above sea level (by about 1.5 meters) or were exhumed (from where?) and redeposited (Figure 2). Using the Bahamas sea-level curve, the molluscs could have lived in water depths up to 2.5 meters deep within a silled basin (sediment surface at 9.6 meters, sea level at 7 meters, sill depth at 2 meters).

A normal marine macrofaunal assemblage is found at a sediment depth above 130 cm in several cores, and it is suggested that this change of environments of deposition began because the sill was breached and adequate exchange with the ocean was achieved (Boardman, 1976). Using a rate of deposition of 36 cm/1000 years (Boardman, 1976), it is estimated that normal marine conditions began 3,640 years ago. Using the Bermuda sea-level curve, sea level was -2.8 meters or 0.8 meters below the estimated level of the sill. Certainly, the estimate of the sill depth could be in error by this much. However, using the Bahamas sea-level curve, sea level was 1.1 meters below present or 0.9 meters above the estimated level of the sill. This is certainly a reasonable depth and is in agreement with all of the available information.

By using the Bahamas curve rather than a sea-level curve from Bermuda, the data makes better sense. Significant doubt must be cast on the C-14 ages or the measurements of depths if the Bermuda curve is used.

Offbank Transport and the Periplatform Signal

Carbonate production by lagoon organisms is directly controlled by sea level. Lagoon production is only possible after the bank top is flooded, and it seems likely that a certain minimum depth (perhaps 0.5 meters) is necessary for normal production to occur. Lagoons can be "drowned" (Schlager, 1981) if water depths exceed some unknown depth (perhaps deeper than 20 meters). Layers of periplatform sediment which are distinct from planktonic sediments but very similar to shallow, lagoonal sediments (aragonite-rich, high Sr values) have been recorded (Droxler et al., 1983; Boardman and Neumann, 1984; Boardman et al., 1986b). It is thought that the periplatform environment records episodes of lagoon production by recording pulses of lagoon sediment transported off the platform when sea level is high (Kier and Pilkey, 1971; Boardman and Neumann, 1984; Boardman et al., 1986b). Highstand layers (lagoon-derived) are approximately 40cm thick and lowstand layers (planktonic-derived) are about 80cm thick. This interpretation has been challenged on several grounds, one of which is that the C-14 dates of periplatform sediments indicate that the pulse of sediment geochemically similar to lagoonal sediments is deposited prior to the time of bank flooding (Droxler, 1985, 1986). There may be several reasons for this apparent discrepancy, but the most important one may be that these bank-flooding estimates are based on the Bermuda sea-level curve, which would make the flooding events appear to have occurred later than they actually did.

By using the Bahamian curve instead of the Bermuda curve, the initial flooding and rate of flooding of the Bahama Banks (Figure 3) are shown to have occurred earlier than estimated by Droxler (Droxler et al., 1963; Droxler, 1985). Thus, the Holocene flooding history of the Bahamas is in good agreement with the offbank transport model (Boardman and Neumann, 1984; Boardman et al., 1986a,b).

Eolian Dune Formation

The Bahamian sea-level curve is necessary to our proper understanding of the formation of early Holocene, transgressive sand dune forma

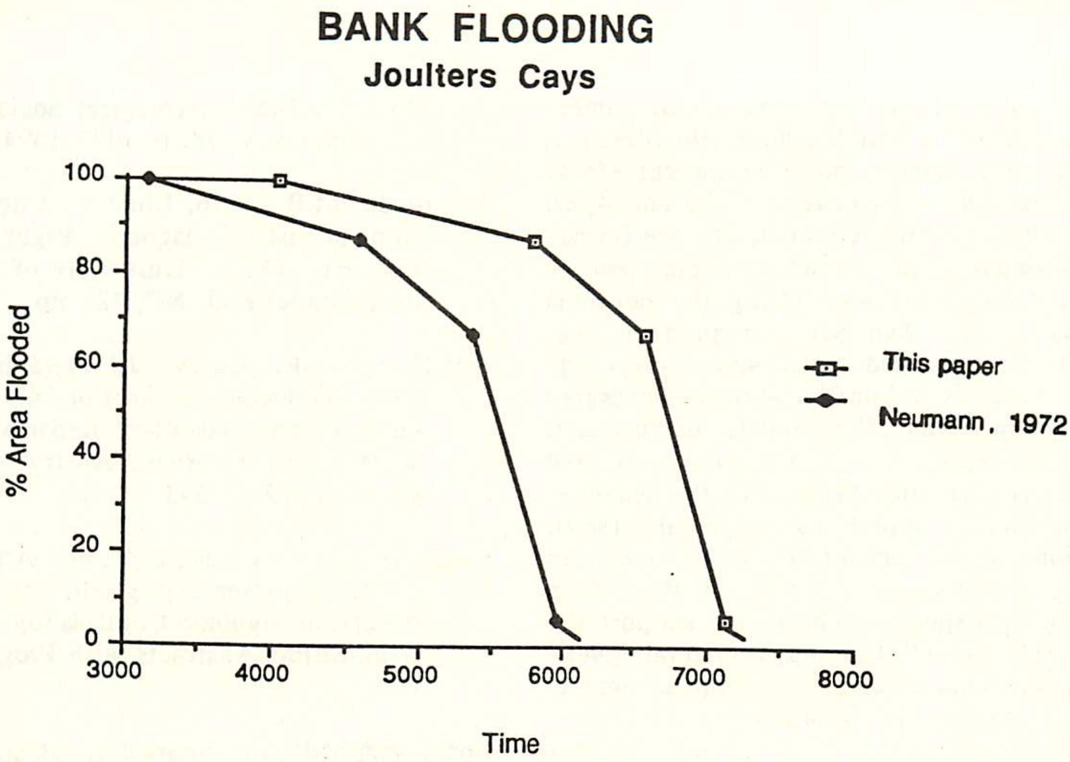

Fig. 3: Using the Bahamas curve (this paper) to determine the flooding history of Great Bahama Bank at the Joulters Cay area, it is seen that flooding is expected much earlier than predicted using the Bermuda curve (Neumann, 1972).

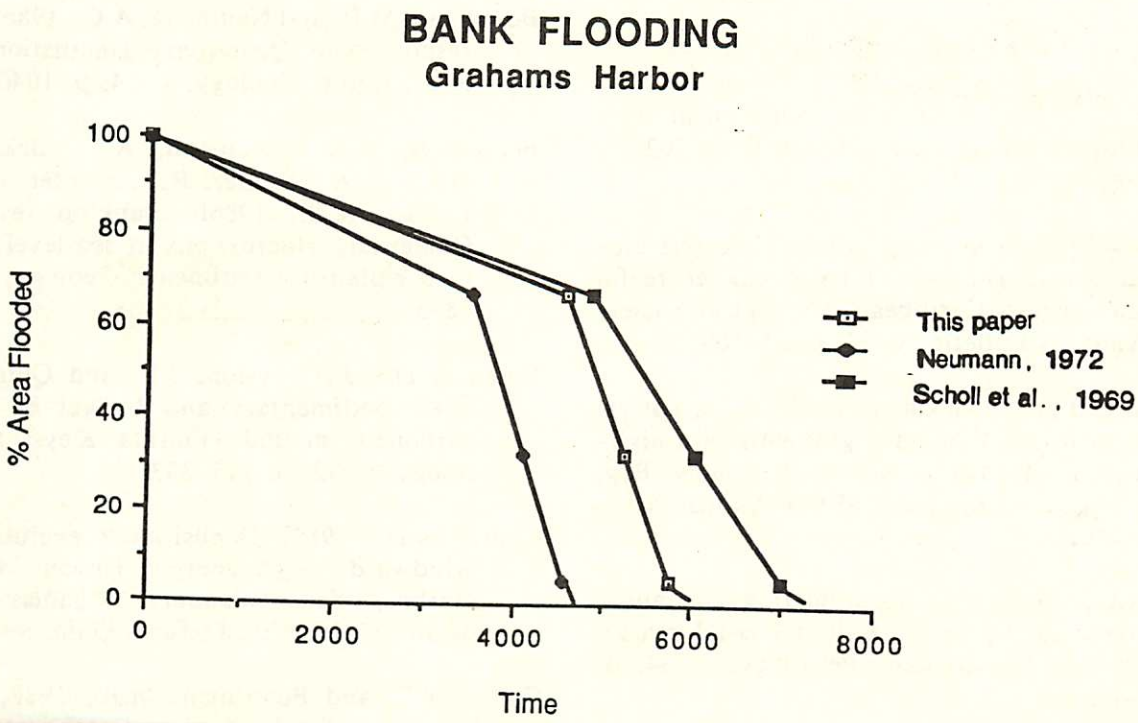

Fig. 4: The history of bank flooding of Graham's Harbor, San Salvador, is clearly dependent on the selection of a sea- level curve. Using the Bahamas curve (this paper), it is now recognized that over half of Graham's Harbor was flooded by 5,000 years BP versus 0% predicted if the Bermuda curve (Neumann, 1972) is used.

tion. C-14 dating of bioclastic sand from numerous coastal dunes of San Salvador (Boardman et al., 1987) clearly suggest that a major episode of dune building occurred between 6,000 and 4,000 years ago. Dunes require sediment, and the formation of sediment requires that the platform be flooded by 6,000 years ago. Using the Bermuda sea-level curve, the San Salvador platform was not significantly flooded until 4,000 years ago (Figure 4), which is in conflict with the measured ages of the dune sand. This conflict of timing is resolved if the Bahamian sea-level curve is used to evaluate the flooding history. If the sea-level curve from Florida applies (Scholl et al., 1969), large portions of the platforms would have been flooded earlier and older dates of the eolian dunes would be expected. These data support the general concept of a "high-energy interval" (Neumann, personal communication) for sand accumulation in many parts of the Bahamas.

CONCLUSIONS

The sea-level curve prepared from C-14 dating of peat samples from Bahamian sediment cores is significantly different from the sea-level curves from Bermuda and South Florida. Using the Bahamian curve for studies in the Bahamas is essential to the proper evaluation of late Holocene depositional events in the Bahamas.

REFERENCES CITED

Adey, W.H., 1978, Coral reef morphogenesis: a multidimensional model: Science, v. 202, p. 831-837.

Adey, W.H. and Burke, R.B., 1976, Holocene bioherms (algal ridges and bank barrier reefs) of the eastern Caribbean: Geological Society of America Bulletin, v. 87, p. 95-109.

Andersen, C.B. and Boardman, M.R., 1988, Lateral and vertical sedimentary gradients in a high-energy carbonate environment, Snow Bay, San Salvador, Bahamas: SEPM Annual Midyear Meeting, v. 5, p. 4.

Bloom, A.L., 1964, Peat accumulation and autocompaction in a Connecticut coastal marsh: Journal of Sedimentary Petrology, v. 34, p. 599-603.

Bloom, A.L., 1967, Pleistocene shoreline: a new test of isostasy: Geological Society of America Bulletin, v. 78, p. 1477-1494.

Boardman, M.R., 1976, Lime mud deposition in a tropical island lagoon, Bight of Abaco, Bahamas: Thesis, University of North Carolina, Chapel Hill, NC, 121 pp.

Boardman, M.R., Carew, J.L. and Mylroie, J.E., 1987, Holocene deposition of transgressive sand on San Salvador, Bahamas: Geological Society of America, Abstracts with Programs, v. 19, p. 593.

Boardman, M.R., Evans, L.A., and Andersen, C.B., 1986a, Sedimentary gradients of Holocene Bahamian lagoons: Controls by sills and sea level: SEPM Abstracts with Program, v. 3, p. 11.

Boardman, M.R. and Neumann, A.C., 1984, Sources of periplatform sediment to Northwest Providence Channel, Bahamas: Journal of Sedimentary Petrology, v. 54, p. 1110-1123.

Boardman, M.R. and Neumann, A.C., 1985, Sources of periplatform carbonates: Northwest Providence Channel, Bahamas, Reply: Journal of Sedimentary Petrology, v. 55, p. 929-931.

Boardman, M.R. and Neumann, A.C., 1986, Banktop responses to Quaternary fluctuations in sea level, Reply: Geology, v. 14, p. 1040-1041.

Boardman, M.R., Neumann, A.C., Baker, P.A., Dulin, L.A., Kenter, R.J., Hunter, G.E., and Kiefer, K.B., 1986b, Banktop response to Quaternary fluctuations in sea level recorded in periplatform sediments: Geology, v. 14, p. 28-31.

Bosence, D.W.J., Royston, J.R. and Quine, M.L., 1985, Sedimentary and budget of a recent carbonate mound, Florida Keys: Sedimentology, v. 32, p. 317-343.

Colby, N.D., 1989, Depositional evolution of a windward, high-energy lagoon, Graham's Harbor, San Salvador, Bahamas: Thesis, Miami University, Oxford, Ohio, 99 pp.

Colby, N.D. and Boardman, M.R., 1988, Vertical sequence of a high-energy carbonate lagoon: Graham's Harbor, San Salvador, Bahamas:

SEPM Annual Midyear Meeting, v. 5, p. 11-12.

Digerfeldt, G. and Hendry, M.D., 1987, An 8000 year Holocene sea-level record from Jamaica: implications for interpretation of Caribbean reef and coastal history: Coral Reefs, v. 5, p. 165-170.

Donn, T.F. and Boardman, M.R., 1988, Bioerosion of rocky carbonate coastlines on Andros Island, Bahamas: Journal of Coastal Research, 4, p 381-394.

Droxler, A.W., 1985, Last deglaciation in the Bahamian basins and the adjacent Atlantic Ocean - A dissolution record from variations of aragonite content, in E.T. Sundquist and W.S. Broecker, eds., The Carbonate Cycles and Atomspheric CO_2 - Natural Variations, Archean to Present, American Geophysical Union Monograph, 32, p. 195-207.

Droxler, A.W., 1986, Comment on "Banktop responses to Quaternary fluctuations in sea level recorded in periplatform sediments": Geology, v. 14, p 1039-1040.

Droxler, A.W., Schlager, W. and Whallon, C.C., 1983, Quaternary aragonite cycles and oxygen-isotope record in Bahamian carbonate ooze: Geology, v. 11, p. 235-239.

Fairbridge, R.W., 1974, The Holocene sea-level record in South Florida, in P.J. Gleason, ed., Environments of South Florida, Past and Present. Miami Geological Society Memoir, 2, p. 223-232.

Grottzinger, J.P., 1986, Cyclicity and paleoenvironmental dynamics, Rocknest platform, northwest Canada: Geological Society of America Bulletin, v. 97, p. 1208- 1231.

Harris, P.M., 1979, Facies anatomy and diagenesis of a Bahamian ooid shoal: University of Miami, Comparative Sedimentology Laboratory, Sedimenta, 7, 163 pp.

Hine, A.C., 1977, Lily Bank, Bahamas; case history of an active oolite sand shoal: Journal of Sedimentary Petrology, v. 47, p. 1554-1581.

James, N.P., 1984, Shallowing-upward sequences in carbonates, in R. Walker, ed., Facies Models, Geoscience Canada Reprint Series, v. 1, p. 213-228.

Kaye, C.S. and Barghoorn, E.S., 1964, Late Quaternary sea-level change and crustal rise at Boston, Massachusetts, with notes on the autocompaction of peat: Geological Society of America Bulletin, v. 75, p. 63-80.

Kendall, G.St.C. and Schlager, W., 1981, Carbonates and relative sea level: Marine Geology, v. 44, p. 181-212.

Kier, J.S. and Pilkey, O.H., 1971, The influence of sea-level changes on sediment carbonate mineralogy, Tongue of the Ocean, Bahamas: Marine Geology, v. 11, p. 189-200.

Lighty, R.G., Macintyre, I.G. and Stuckenrath, R., 1982, *Acropora palmata* reef framework: a reliable indicator of sea level in the western Atlantic for the past 10,000 years: Coral Reefs, v. 1, p. 125-130.

Macintyre, I.G. and Glynn, P.W., 1976, Evolution of modern Caribbean fringing reef, Galeta Point, Panama: American Association of Petroleum Geology Bulletin, v. 60, p. 1054-1072.

Matthews, R.K., 1984, Dynamic Stratigraphy, Prentice Hall, Inc., Engelwood Cliffs, NJ, 489 pp.

Mörner, N.-A., 1980, Eustasy and geoid changes as a function of core/mantle changes, in N.-A. Mörner, ed., Earth Rheology, Isostasy, and Eustasy, Wiley, Chichester, p. 535-553.

Neumann, A.C., 1972, Quaternary sea level history of Bermuda and the Bahamas: AMQUA Abstract, p. 41-44.

Pitman III, W.C., 1978, Relationship between eustacy and stratigraphic sequences of passive margins: Geological Society of America Bulletin, v. 89, p. 1389-1403.

Pratt, B.R. and James, N.D., 1986, The St. George Group (Lower Ordovician) of western Newfoundland: tidal flat island model for carbonate sedimentation in shallow epeiric seas: Sedimentology, v. 33, p. 313-343.

Rasmussen, K.A. and Neumann, A.C., 1987, Holocene overprints of Pleistocene paleokarst: Bight of Abaco, Bahamas, in N.P. James and P.W. Choquette, eds., Paleokarst, Springer-Verlag, New York, p. 132-148.

Read, J.F., 1988, Carbonate cycles, sea level curves, and computer modelling: SEPM Annual Midyear Meeting, v. 5, p. 44.

Schlager, W., 1981, The paradox of drowned reefs and carbonate platforms: Geological Society of America Bulletin.

Schlager, W. and Ginsburg, R.N., 1981, Bahama carbonate platforms - The deep and the past: Marine Geology, v. 44, p. 1-24.

Scholl, D.W., Craighead, F.C. and Stuiver, M., 1969, Florida submergence curve revised: its relation to coastal sedimentation rates. Science, v. 163, p. 562-564.

Shinn, E.A., 1986, Modern carbonate tidal flats: their diagnostic features: Colorado School of Mines Quarterly, v. 81, p. 7-35.

Shinn, E.A., Lloyd, R.M. and Ginsburg, R.N., 1969, Anatomy of a modern carbonate tidal flat, Andros Island, Bahamas: Journal of Sedimentary Petrology, v. 39, p. 1202-1228.

Strasser, A., 1988, Shallowing-upwards sequences in Purbeckian peritidal carbonates (lowermost Cretaceous, Swiss and French Jura Mountains): Sedimentology, v. 35, p. 369- 383.

Vacher, H.L. and Hearty, P., in press, History of stage-5 sea level in Bermuda: review with new evidence of a brief rise to present sea level during substage 5a: Quarternary Science Reviews.

Van de Plassche, O., 1980, Compaction and other sources of error in obtaining sea-level data: some results and consequences: Eiszeitalter Ggw, v. 30, p. 171-181.

Walcott, R.I., 1970, Flexural rigidity, thickness, and viscosity of the lithosphere: Journal of Geophysical Research, v. 75, p. 3941-3954.

Wanless, H.R., 1974, Mangrove sedimentation in geologic perspective, in P.J. Gleason, ed., Environments of South Florida, Past and Present, Miami Geological Society Memoir, 2, p. 190-200.

Wanless, H.R., 1982, Editorial: Sea level is rising- So what?: Journal of Sedimentary Petrology, v. 52, p. 1051- 1054.