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REPLY

Straw Men, Glass Houses, Apples and Oranges: A Response to Carew and Mylroie's Comment on Hearty and Kindler (1993)

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INTRODUCTION

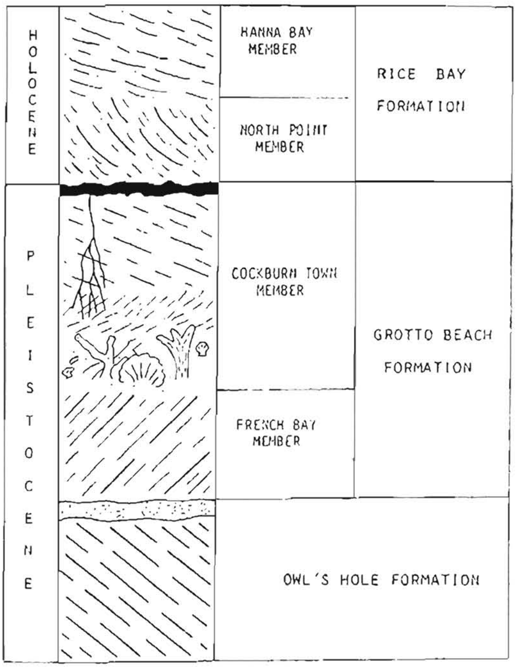
The purpose of the HEARTY and KINDLER (1993a) paper was to provide an overview of the formation of Bahamian Islands, with specific examples from San Salvador Island (SSI). The "perspective" is new because for the past 12 years Bahamian stratigraphy was viewed as tripartite (Holocene, late Pleistocene, middle Pleistocene). Over that period, there was no apparent evolution of the composite section only deletions from it. Table 1 is a comparison between the latest C&M stratigraphic section (CAREW *et al.*, 1992, page 5) and ours from SSI (HEARTY and KINDLER, 1993a). We have significantly altered their proposed tripartite model by adding two new formations, paleosols, protosols, and new members. All newly defined units were based in morphostratigraphy, sedimentology, biostratigraphy, and petrology. The stratigraphic column of San Salvador was confirmed by whole-rock (not *Cerion* land snails) amino acid racemization (AAR) data in Table 3 (HEARTY and KINDLER, 1993a) and Table 1 below, including mean whole-rock A/I ratios from that study. In fact, the succession of all rock units is indeed concordant with whole-rock AAR ratios (Table 3, HEARTY and KINDLER, 1993a), including intra-formational units of Stages 1 and 5e.

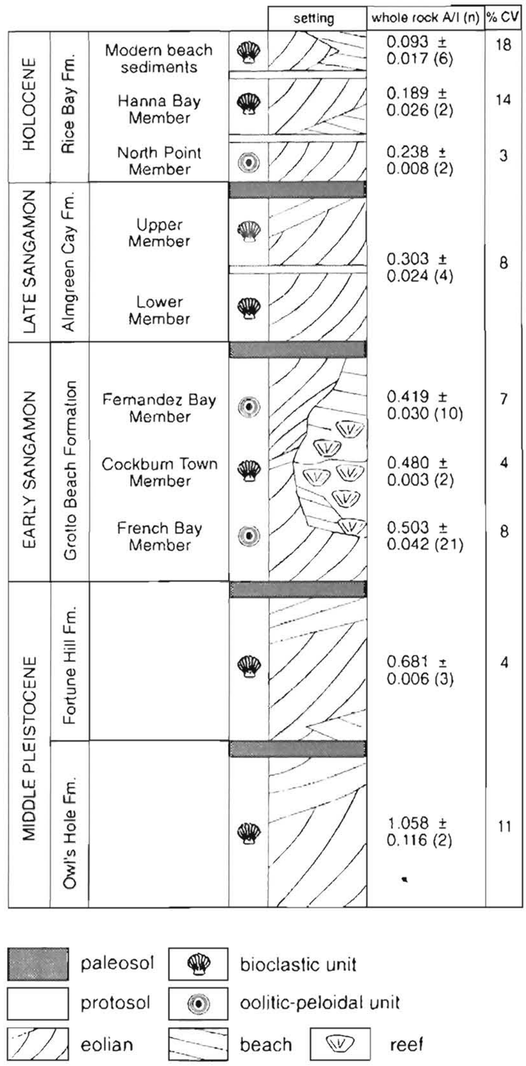
In this response to C&M, we will address the following points: (1) the geochemical reliability of both whole-rock and *Cerion* AAR data—when proficiently applied in a clearly understood geological and diagenetic setting; (2) the difference between "apples" and "oranges" (or whole-rock and *Cerion* land snails); (3) the merits of a "blind" AAR study (MIRECKI *et al.*, 1993); (4) the Almgreen Cay Formation, whole-rock AAR ratios, and insights into coastal processes related thereto; (5) the Dixon Hill fiasco and life in glass houses; (6) a "straw man" at Three Dog; (7) petrology and sea level; (8) miscellaneous topics; and (9) concluding remarks.

THE RELIABILITY OF THE WHOLE-ROCK AND *CERION* AAR METHODS

Hearty has examined coastal sites in many regions of the world including the Mediterranean, the southeast U.S. Coastal Plain, Bermuda, and the Bahamas, from which several thousands of geology-based AAR samples have been analyzed (HEARTY, 1986, 1987; HEARTY *et al.*, 1986; HEARTY and AHARON, 1988; HOLLIN and HEARTY, 1990; HEARTY *et al.*, 1992). The potential benefits, problems, and pitfalls of the AAR method are well understood and documented. These extensive AAR investigations have resulted in several guidelines that must be scrupulously adhered to in order to yield consistent ratios (HEARTY, 1986; HEARTY *et al.*, 1986; WEHMILLER *et al.*, 1988; MILLER and BRIGHAM-GRETTE, 1989). Prerequisites to the optimal application of AAR in Bahamian studies include: (1) a *clear* understanding of the geological and diagenetic context from which the samples are extracted; (2) a field assessment of the speed of burial and exhumation of samples; (3) an evaluation of the potential effects of surface heating, pedogenesis, and chemical diagenesis on the samples; and (4) if *Cerion* are used, shell subsamples must be taken from the identical functional portion of every shell. In this case, we refer to the thick apertural lip of adult *Cerion* shells. *Cerion* growth termination (adult) is well marked by an abrupt change to a negative coiling translation, a slight increase in whorl expansion rate, and the secretion of a thickened, definitive apertural lip (GOULD and WOODRUFF, 1986).

Table 1. *A comparison of Carew* et al.*'s (1992, page 5) latest version of the "physical stratigraphy of the surficial rocks of the Bahama Islands" (Table 1A, left), and Hearty and Kindler's (1993a) stratigraphic column of San Salvador Island (Table 1B, right). Not pictured is a comparison of the composite stratigraphies from eight Bahamian islands which show the parallel nature of their depositional histories (Hearty and Kindler, 1993b).*





Mean whole-rock AAR ratios from HEARTY and KINDLER (Table 1) speak for themselves: all stratigraphic units yield unique, and stratigraphically ordered aminozones. Only 5.4% of 56 total samples were out of stratigraphic order. These three samples, all from pre-Sangamonian outcrops, showed low amino acid concentrations. The high-quality results in HEARTY and KINDLER (1993a) are not unique to SSI. In Bermuda (HEARTY *et al.*, 1992), 257 marine shell, land snail (*Poecilozonites* sp. from protosols), and whole-rock samples agreed with previously published stratigraphy (VACHER *et al.*, 1989) in 97% of the cases. Of the three percent (7 samples) showing geochemical "reversals", all were from soils, protosols, or near-surface samples.

In addition to the demonstrable consistency of the whole-rock samples, *Cerion* results are pre-

Table 2A. *Cerion samples collected, prepared and analyzed by PJH at University of Texas at Dallas Organic Geochemistry Laboratory.*

Lab #	Field #	a	b	c	Mean ± 1σ (n =)	% CV
Modern						
UTD20A	NP0	0.033			0.033 (1)	0
Hanna Bay Mb (type locality)						
UTD21A	HB2b	0.080				
UTD21B		0.139			0.110 ± 0.042 (2)	38
North Point Mb (type locality)						
UTD22A	NP2b	0.238				
UTD22B		0.262				
UTD22C		0.246			0.249 ± 0.012 (3)	5
Watlings Quarry, Grotto Beach Fm (French Bay Mb)						
UTD24A	WQ1d	0.700				
UTD24B		0.650				
UTD24C		0.714			0.688 ± 0.034 (3)	5

Table 2B. *Cerion samples collected and prepared by PJH, and analyzed by Dr. Darrell Kaufman, Utah State University, Amino Acid Laboratory.*

Lab #	Field #	a	b	c	Mean ± 1σ (n =)	% CV
Lyford Cay Section, New Providence (French Bay Mb)						
1071A	LC3h	0.745	0.756	0.768	0.756 ± 0.012	
1071B	LC3h	0.739	0.737	0.732	0.736 ± 0.004	
1071C	LC3h	0.763	0.749	0.767	0.760 ± 0.009	
					0.751 ± 0.013 (3)	1.7
1071D	LC3f	0.837	0.833	0.841	0.837 ± 0.004 (1)	
Upper Unit, Hunt's Cave Quarry, New Providence (French Bay Mb)						
1072A	HQ1c	0.777	0.796	0.781	0.785 ± 0.010	
1072B	HQ1c	0.742	0.702	0.720	0.721 ± 0.020	
1072C	HQ1c	0.785	0.747	0.762	0.765 ± 0.019	
1072D	HQ1c	0.753	0.687	0.735	0.722 ± 0.039	
					0.748 ± 0.032 (4)	4

sented in Table 2 to show that they too are reliable indicators of geological age. *Cerion* land snails from San Salvador and New Providence islands were analyzed by PJH at University of Texas–Dallas (UTD), and by Dr. Darrell Kaufman at Utah State University (USU). These data were not yet published, but are offered here to make a point. Samples analyzed at UTD by PJH (Table 2A) include samples from the modern, the Hanna Bay Mb, the mid-Holocene North Point Mb, and the French Bay Mb. All results are in stratigraphic order and have, respectively, % CV's of 0% (1 shell), 38% (2 shells), 5% (3 shells) and 5% (3 shells). % CV's are expected to increase in both very young samples that epimerize very quickly (HEARTY and AHARON, 1988), where 1,000 years may make a considerable difference in ratios and in older samples where diagenetic effects are expected to increase.

Additional *Cerion* shells from equivalent French Bay sites from New Providence Island were collected and subsampled (apertural lip) for AAR by PJH, and analyzed by DK at USU. The results and statistics are presented in Table 2B. Lower case letters (a, b, and c) are reruns of the same dissolved sample. Capital letters associated with lab numbers (*e.g.*, UAL-1071 and 1072 A, B, C and D) are analyses of individual shells. On New Providence Island, samples were collected from two sites 16 km apart (Lyford Cay and Hunt's Cave Quarry, upper unit).

These results demonstrate several important conclusions: (1) consistent *Cerion* ratios are obtained from protosols in the Bahamas when diligent field and shell sampling procedures are maintained; (2) *Cerion*, like whole-rock analyses, yield ratios in stratigraphic order with small % CV's; (3) stratigraphically correlated sites on the same island yield identical *Cerion* ratios: 0.751 ± 0.013 from Lyford Cay, and 0.748 ± 0.032 from upper Hunt's Quarry, and (4) statistically compatible ratios exist between islands, even when analyzed several years apart by different laboratories: 0.751 ± 0.013 and 0.748 ± 0.032 from NPI (USU-1994) vs. 0.688 ± 0.034 from SSI (UTD-1990). Sample 1071D produced a ratio of 0.837 which appears to fall outside the mean of the other three (0.751 ± 0.013) from the same site. Further geological investigation of the Lyford Cay site indicated that two generations of soils were sandwiched between oolitic deposits, and the older soil yielded the appropriately higher ratio. The large coefficients of variance obtained by MIRECKI *et al.* (1993) can be attributed to some or all of the following causes: (1) intrashell variation (HEARTY *et al.*, 1986) particularly in the thin interior (< 0.1 mm) and exterior (0.2–0.4 mm) whorls, protoconch, and/or hollow columella; (2) shell age-mixing by hermit crabs (WALKER and HEARTY, 1993); (3) surface heating by prolonged exposure and geochemical action in shallow soils; and (4) differential rapid epimerization in Holocene samples (HEARTY and AHARON, 1988).

APPLES AND ORANGES

MIRECKI *et al.* (1993) and CAREW and MYLROIE (comment above) presented a self-admitted "blind" AAR study using *Cerion* land snail results. Their purpose was to discredit the whole-rock racemization results in HEARTY and KINDLER (1993a), in which only deeply buried, well preserved whole-rock samples were used. On page 95 of MIRECKI *et al.* (1993) the authors state: "*Cerion* shell A/I values presented here, from many of the same outcrops that have been characterized elsewhere by whole-rock analyses, suggest that the whole-rock results are substantially less reliable than those from *Cerion*."

This statement has neither logic nor scientific merit. How can our whole-rock ratios be evaluated when none have been analyzed by Mirecki and company? The statement that their samples have been extracted "from many of the same outcrops" is completely untrue. Whole-rock samples are never taken from paleosols or protosols, the only abundant source of *Cerion,* because of the enormous potential for geochemical problems in these sedimentary facies.

THE MERITS OF A "BLIND" AAR STUDY

As mentioned above, MIRECKI *et al.* (1993) and CAREW and MYLROIE (comment above) participated in an AAR study of *Cerion* land snails in San Salvador Island. In the MIRECKI, CAREW and MYLROIE study, "*Cerion* shells were recovered from a variety of fossil and modern sites, including many that had previously been analyzed by another amino acid geochemist (CAREW and others, 1984; CAREW and MYLROIE, 1987), and some from rocks which have recently been studied using whole-rock amino acid geochemistry . . .". Standard cleaning, leaching, preparation, and analytical procedures are mentioned and their results are presented. There is no mention, however, of the geological setting, the nature of the enclosing soil deposits, or the shell thickness, color, preservation, thickness, morphology, or subsampling procedures. In fact, nowhere in the "blind" study do the authors show any indication that they are aware of the pitfalls of random sampling of land snails in soils for AAR. *Cerion*-bearing protosols, particularly those of the early Sangamonian, may be thin (< 30 cm), chemically weathered (by fresh water, aluminum and iron oxides, and organic acids), and subject to surface heating over several thousands of years. They do not show any awareness of, or mention of the use of juveniles, protoconch, thin portions of mollusk shells, or lichen/algae encrusted shells that may contain vastly different amino acid compositions than the thick, apertural lip of mature adult *Cerion*, which is the only portion of *Cerion* sampled for Hearty analyses in Table 2 above. A comparison of %CV's from their data and ours reveals one fact: haphazardly applied AAR methods yield poor results.

Previous publications of the commenting authors and related references are precisely the types of AAR studies that have, in the past, cast a shadow of doubt on the tremendous utility of the AAR method—a utility that is manifest in the proper application of the method in a clear geological and diagenetic context. Our colleagues apparently think that shells can be randomly plucked from an exposed, thin, heated, and leached soil, ground up, dissolved and analyzed to yield flawless results. When they fail to obtain such quality data (as in Table 2), they incorrectly and illogically conclude that all similar studies, whether properly applied or not, whether *Cerion* or whole-rock, should be called into question. A "blind" AAR investigation like that in CAREW *et al.* (1984) and MIRECKI *et al.* (1993), in the absence of a published track record of AAR applications, and a clear understanding of the geological and geochemical setting of the sample site, is exactly that—a "blind" study.

THE ALMGREEN CAY FORMATION

Article 24 of the North American Stratigraphic Code (1983) states, "A formation is a body of rock identified by lithic characteristics and stratigraphic position. It is prevailingly but not necessarily tabular and is mappable at the earth's surface or traceable in the subsurface."

The name Almgreen Cay Formation was adopted (HEARTY and KINDLER, 1993a) in order to describe a sequence of large dune ridges lying on the eastern margin of San Salvador Island (see map Phase III, page 581, HEARTY and KINDLER, 1993a), and throughout the Bahamas on high-energy shelf margins (HEARTY and KINDLER, 1993b). In contrast to the nearly purely oolitic marine and dune facies of the Grotto Beach Formation, these deposits are exclusively eolian (apparently lacking marine deposits), nearly purely skeletal in composition, and produce radically different *Cerion* landsnail morphologies (SCHEL-

LENBERG and HEARTY, 1991; HEARTY *et al.*, 1993). These deposits lie in a morphostratigraphic position younger than the Sangamonian oolites. Dune sets are retrogressive, *i.e.*, stratigraphically higher sets overtop lower dune sets in a landward direction. They are bracketed at the base by an unconformable contact (dune foresets on coral reef) with deposits of early Sangamonian (CAREW and MYLROIE, 1985), and at the top by a crust and a glacial-age terra rossa soil. The formation is interrupted midway by a mature *Cerion*-bearing protosol with pisolites (BEIER, 1987).

Whole-rock AAR analyses were made subsequent to field studies of the Almgreen Cay and correlative deposit "The Bluff", which lies 5 km south. Identical, but stratigraphically reversed ratios were obtained from lower and upper units, respectively, from Almgreen Cay (Figure 1A; 0.284/0.312) and The Bluff (Figure 1B; 0.283/0.333). These results support the following interpretations: (1) the possibility that two sites separated by 5 km could yield identical AAR whole-rock ratios in corresponding lower and upper units defies any coincidence or random number generation by AAR; and (2) the average ratio for the formation is 0.303 ± 0.024 (n = 4), a ratio which lies between the Holocene values of 0.189 (Hanna Bay) and 0.238 (North Point), and early Sangamonian values averaging 0.480. Based on a parabolic whole-rock racemization model from Bermuda (HEARTY *et al.*, 1992), the Almgreen Cay mean represents an age between 60,000 and 80,000 years ago.

In addition to the above AAR characteristics of the Almgreen Cay Fm, there is a beauty in a method that reveals geological processes that are not immediately apparent in the field. Coastal dunes are, by their nature, a product of redeposition. Carbonate sediments must first be manufactured and deposited on the shelf (Deposits 1, 2, and 3 of decreasing age) (Figure 1C). With changes in oceanic energy brought about by sea-level change or stormy periods, the sediments are transported to land by water, and further into dunes by wind. When the subtidal deposits are transported to land, in what order must they be redeposited? The older shelf sediments cannot be transported to land first because they are buried by younger sediments. The order of redeposition must be (Figure 1D): unit 3 (the youngest), then 2, then 1 (the oldest on top). This simple sedimentary process constitutes a reversal of stratigraphic age, and is an explanation of the small, but revealing inversion of AAR ratios at Almgreen Cay and The Bluff.

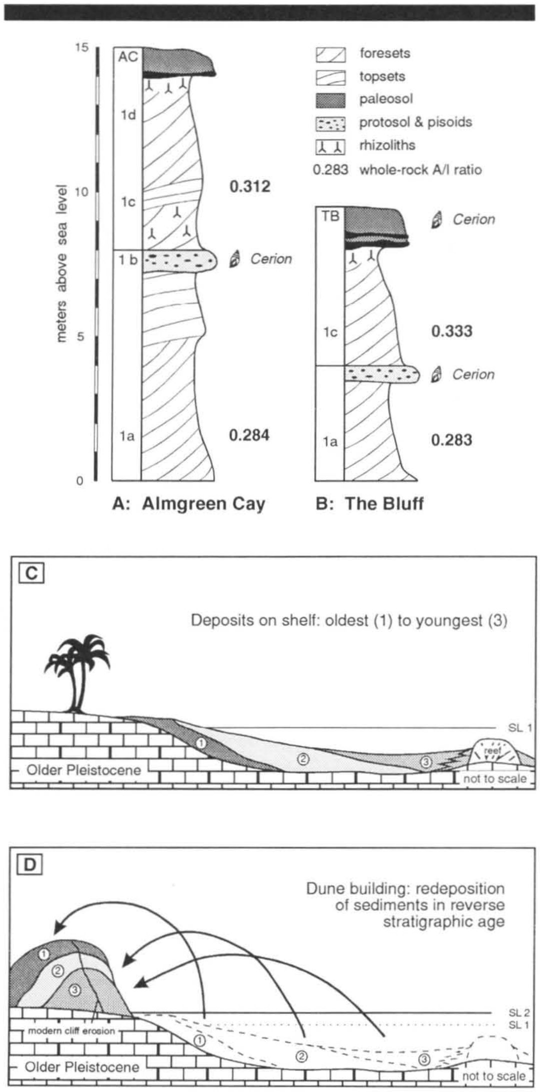


Figure 1. Stratigraphy, whole-rock amino acid ratios, and processes related to the development of the Almgreen Cay Fm. Figure 1A and B are stratigraphic sketches of Almgreen Cay and The Bluff with whole-rock AAR ratios, while Figures 1C and 1D explain the processes resulting in the inverted stratigraphic order of the whole-rock ratios.

The Almgreen Cay deposits are considered to be a regressive phase of the early Sangamonian Grotto Beach Formation (CAREW and MYLROIE, 1985) despite a long list of unique geological characteristics contrary to this explanation. If the

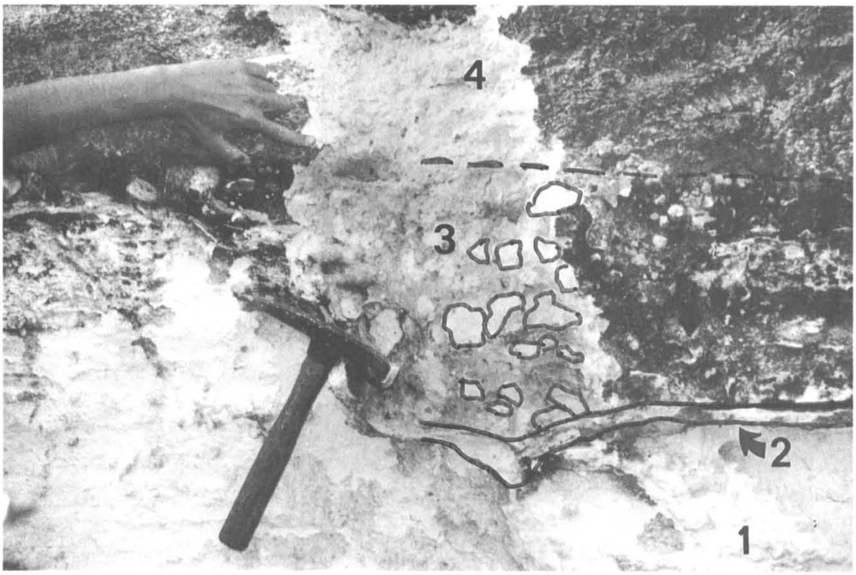


Figure 2. A photograph, from an exposure in a roadcut near Rainbow Cay, Eleuthera showing a well-developed brecciated red paleosol (3) and a 1-cm calcrete (2) lying between the lower equivalent of the early Sangamonian French Bay Mb (1) and the late Sangamonian equivalent of the Almgreen Cay Fm (4). The time required for the development of this paleosol and crust excludes the regressive or "waning phase" explanation of the Almgreen Cay rocks.

Almgreen Cay deposits are regressive from the +6 m sea level associated with the Grotto Beach Fm, where are the marine deposits? And how could a regressive sequence have younger dune sets overtopping older sets in a landward direction? How do our colleagues explain the transition from pure oolitic to pure skeletal petrology, and the radically different *Cerion* morphologies in these two units?

Further evidence of a significant age difference between the Almgreen Cay and Grotto Beach Fms is available on Eleuthera Island where, at Boiling Hole and near Rainbow Cay, the Grotto Beach oolite is directly overlain by the skeletal Almgreen Cay eolianite. However, in this more landward setting, the two units are separated by a 30 cm thick, brecciated red paleosol and a 0.5 to 1.0 cm calcrete crust (Figure 2) (Hearty and Kindler, 1993b). Such soils and calcretes obviously require tens of thousands of years to form, a duration supported by AAR ratios in SSI. Parallel chronological and geological relationships have been demonstrated in Southampton (5a) and Rocky Bay (5e) Fms in Bermuda (Vacher and Hearty, 1989; Hearty *et al.*, 1992).

GRAPESTONES AND GLASS HOUSES

A chronology of events regarding San Salvador geology may shed some light on the ephemeral opinions of our colleagues over the past decade. Of particular interest are those related to their perception of glacio-eustasy, the age of Dixon Hill and Lighthouse Cave, and C&M's "use (we think misuse) of a variety of geological techniques coupled with intensive field work".

1982 (Proceedings volume). Titus (1982) proposes a three-part stratigraphy, suggesting that deposits older than the Grotto Beach may be present. Carew (1982, p. 12) determined "that the rocks exposed on San Salvador range in age from modern beach rock to approximately 140,000 years . . ." based on AAR ratios from *Cerion*. Carew *et al.* (1982) only state that sea level was higher than −0.5 m between 35,000 and 47,000 years and that Lighthouse Cave must be "older than 47,000 years", or has a "minimum age of 125,000 years".

1983 (Field Guide to Geology of SSI). Carew (1983) proposes periods of eolian depositional at 10,000, 20,000 and 75,000, and 100,000 ± 25,000 years ago based on AAR data from *Cerion*. Most of these deposits are now mapped as early Sangamonian (HEARTY and KINDLER, 1993a), and we have known for decades (BRETZ, 1960; LAND *et al.*, 1967) that eolianites are non-migratory and clearly interglacial shoreline facies.

1984 (Proceedings volume). Dixon Hill rocks are named (TITUS, 1984) and "dated" at 70,000 years old using "solely" *Cerion* AAR ratios from within Lighthouse Cave (CAREW *et al.*, 1984). The cave is a product of intense chemical activity and dissolution in the mixing zone between fresh and salt water (MYLROIE and CAREW, 1988). A high sea level (+1 m) at *ca.* 50,000 years was proposed based on U-series dates on one stalagmite found submerged (−0.5 m) in the cave. A sea level mechanism was thus provided to explain the expedient formation of the largest cave on San Salvador Island in a scant 30,000 years (in the midst of a glacial interval). This speleothem discovery was a means to reconcile this amazing karst development by: (1) substantial rainfall and accumulated fresh water lens, and (2) a sea level close to present sea level to perch the fresh water lens (CAREW, 1983). The existence of the proposed 49,000 year old sea level depends exclusively on the *in situ* marine origin of encrustations in the stalagmite. Photos and our observations of the speleothem show that the serpulids grow in a crack that cross-cuts time lines (in CAREW, 1983, p. 167). Could not the growth the marine encrustations have occurred in a "fresh" crack in the stalagmite during Recent inundation?

1987 (Proceedings volume). CAREW and MYLROIE (1987) propose sea level highstand(s) continuous at 150,000 to 100,000 years ago, *or* discontinuous at 140,000, 125,000, 105,000 years, and at 49,000 years ago, based on U-series and AAR. In the same paper, reversed paleomagnetic data yield "the oldest surface rocks yet discovered in the Bahamas." This latter statement has apparently been recanted; in the comment above they say "paleomagnetic information indicates that surficial rocks in the Bahamas are younger than the last paleomagnetic reversal".

1991 (Abstract, GSA Regional Meeting, Baltimore). CAREW and MYLROIE (1991) propose a stratigraphic and depositional model for the Bahamas. No mention is made of pre-Brunhes rocks, Dixon Hill, Lighthouse Cave or their previous interpretations of these deposits.

1991 (Spring): Draft of Hearty and Kindler SSI manuscript sent to C&M for review. No review offered to date.

1991 (GSA San Diego). HEARTY and KINDLER (1991) present new stratigraphy and initial findings from San Salvador Island placing the former Dixon Hill rocks in the middle Pleistocene, and renaming the unit the Fortune Hill Formation. The "Dixon Hill Formation" was eliminated from the stratigraphy (by us) because of the enormous confusion generated by our predecessors associated with Dixon Hill. The Almgreen Cay Fm was also added to the stratigraphic column.

1992. In their comments above, C&M state that they, "stopped using the Dixon Hill Member in publications after 1989, and in 1992 (CAREW and MYLROIE, 1992b) *formally readjusted* (H&K emphasis) (their) stratigraphy to reflect (their) earlier interpretation for Dixon Hill". There are several problems associated with this statement: (1) to our knowledge, there is no published "earlier interpretation" of Dixon Hill. The first mention of Dixon Hill refers to a 70,000 to 85,000 year age (1984 above); (2) the authors cite no references at all in their bibliography (above) on this topic between 1989 and 1991. We note that STOWERS *et al.* (1989) refer to the Dixon Hill Mb at 70,000 years; (3) the "formal readjustment" of their stratigraphy took place on Page 5 of a Field Guide (*on New Providence Island* ?!) (CAREW *et al.*, 1992) to the 6th Symposium on the Geology of the Bahamas, in which the authors state: (slightly paraphrased) "This member (the Dixon Hill) thought to represent an eolianite deposited during oxygen isotope substage 5a about 85,000 years ago, based solely on amino acid racemization data . . ., has been eliminated from the stratigraphy (CAREW and MYLROIE, 1991a)".

1993 (Spring). HEARTY and KINDLER (1993a) published in JCR.

In the above comment, implications are being made that we have presented insupportable information regarding the Dixon Hill. To the contrary we cite, in addition to AAR ratios, six geological reasons why the Dixon Hill cannot be younger than the early Sangamonian (Page 585 of HEARTY and KINDLER, 1993a).

STRAW MAN AT THE THREE DOG SITE

Two generations of rocks outcrop at the Three Dog Site. The older generation consists of highly indurated conglomeratic storm deposits and capping eolianites that form a small rocky headland a couple meters above sea level. The younger generation of deposits, which has produced abundant Lucayan artifacts, forms a catenary embayment to the south of the point, anchored on the older generation of rocks. The relative ages of the two deposits were based on this anchor-catenary relationship.

Since both generations of deposits expressed evidence of a sea level near to present and the younger clearly was of Lucayan age (< 2,000 years old), it was determined that the older deposit must predate the younger by a significant amount of time. Due to several criteria, the least of which was a scatter of late Sangamon and Holocene AAR whole-rock ratios (as expected from such shallow, exposed sampling), we interpreted the conglomerate to be late Sangamonian (late Stage 5) and presented our initial findings in an abstract at the 1991 GSA San Diego meeting.

Subsequent to that, 1992 (6th Symposium on the Geology of the Bahamas) our colleagues presented their ^{14}C dates from the site. It came as no surprise to us that there were Holocene deposits at the site. We willingly revised our thinking in light of their data. Our preliminary findings were presented in an abstract intended to provide an outlet for new research discoveries.

At this one site we had identified two generations of deposits, the younger of which was clearly Holocene while the older was either Holocene or latest Sangamonian. The scatter of AAR data supported deposition during the same interval, and the AAR data were in stratigraphic order in an island-wide context. We had narrowed the age down to one of two possible, consecutive depositional phases. The ^{14}C dates support the younger option. However, it is implied that, because the age of this ONE of our 50-some sample sites was narrowed to one of two consecutive depositional phases, somehow our whole study is flawed. This position simply does not have a sound basis in scientific fact.

If our scientific approach were seriously flawed, then certainly at least one of the seven reviewers (including CAREW and MYLROIE) would have raised the red flag previous to publication.

PETROLOGY *VERSUS* SEA LEVEL

C&M's comment about petrology shows best how their perspective is confused and inconsistent. At the beginning of the section they acknowledge, "allochems found in eolianites produced during the various glacio-eustatic sea-level highstands fall in general patterns". However, they conclude, "it should be recognized that sediment composition is site specific, and not simply related to the time of deposition". Let us make a few things clear about the petrology of Bahamian rock units. C&M have not demonstrated their proficient use of petrology. Suffice it to say, they once stated that the middle Holocene North Point member, "revealed a preponderance of skeletal material" (HUTTO and CAREW, 1984, p. 201). Observers can easily recognize that this unit essentially contains ooids and peloids (*e.g.* WHITE and WHITE, 1990). They go on to say, "compositional similarities between eolian ridges cannot be used as evidence for coeval formations" (HUTTO and CAREW, 1984, p. 201). Therefore, to now pretend that they emphasized petrologic similarities and differences before we did is wholly unsupported by fact. We agree that there is a variety of allochems in the Bahamas today: bioclastic particles along the margins, ooids in the vicinity of tidal channels, peloids toward the bank interior (PURDY, 1963; SCHLAGER and GINSBURG, 1981), but when considering lithified deposits both within and among islands, one rapidly realizes that petrologic similarities are greater than the differences, as we pointed out (KINDLER and HEARTY, 1992, 1993). When used in conjunction with other tools, such as morphostratigraphy, aminostratigraphy and sedimentology, petrology is a perfectly reliable tool for identifying stratigraphic units in the Bahamas. For Carew and Mylroie to attempt to make sweeping generalizations about Bahamian stratigraphy without having observed that most islands have similar petrographic sequences (HEARTY and KINDLER, 1993b) seriously jeopardizes their qualifications as "modelers" of Bahamian island stratigraphy.

MISCELLANY

About Karst Processes. We never claimed to be karst specialists, and we are very respectful of C&M's 16 years experience in Bahamian caves and pits. However, we maintain that the degree of cave development provides useful indications of age. In the Bahamas, phreatic caves never occur within Holocene and Sangamonian rocks. Only pre-Sangamonian deposits present extensive cave development. If this is not an age indicator, what is it? Recently, one of C&M's graduate students (SCHWABE *et al.*, 1993) confirmed our opinion by demonstrating that, in most caves, caves occur within the bioclastic eolianites of the pre-Sangamonian Owl's Hole Formation.

About Figure 3 (in Hearty and Kindler, 1993a). One can agree with C&M that our Figure 3 is difficult to understand. It represents several complex processes. But what is even more difficult to understand is their interpretation of this figure. Part A, for example, depicts a fully flooded platform. We refer to this phase as an early transgression as opposed to subsequent ones. We could have used the term "antecedent", which is not really more understandable. We consider Figure 3 as a theoretical model accounting for the complex morphostratigraphic relationships that may occur between deposits formed during successive highstands of various amplitudes in a limited area. Thus, contrary to C&M's opinion, Figure 3 is not a reconstruction of the geologic conditions which prevailed on Bahamian platforms during the Quaternary. This argument being biased, we shall not discuss this point any longer.

CONCLUSIONS

We do not agree that our data support the stratigraphy and depositional model of CAREW and MYLROIE (1985; in press). C&M propose a three-unit stratigraphy including a pre-Sangamonian unit (Owl's Hole Fm), a Sangamonian unit (the Grotto Beach Fm), and a Holocene unit (the Rice Bay Fm). This succession was incomplete and presented major flaws, *i.e.*, the attribution of the Dixon Hill rocks to the late Sangamonian and the oversight of the Almgreen Cay Formation. We have placed Dixon Hill rocks in their correct stratigraphic pre-Sangamonian position and regrouped them under the label of Fortune Hill Fm. We have created the Almgreen Cay Fm (as a correlative of the Southampton Fm of Bermuda, VACHER *et al.*, 1989; VACHER and HEARTY, 1989) to represent late Sangamonian rocks that were previously attributed to the early Sangamonian Cockburn Town member (CAREW and MYLROIE, 1985, p. 18). We present a five-unit stratigraphy (2 pre-Sangamonian, 2 Sangamonian, and 1 Holocene) that is clearly different from the model presented by C&M (Table 1) and that certainly does not support it. Furthermore, our stratigraphic scheme is open-ended. It is open to the likelihood that additional middle Pleistocene units exist (HEARTY and KINDLER, 1993b), and the possibility that early Pleistocene will be discovered in the future, as we investigate more islands and our ability to identify these deposits improves. We also summarily reject the statement that our stratigraphic refinements rest solely on amino acid racemization analyses. We have clearly stated, "Single methodological approaches are inadequate to resolve the complex history of San Salvador" (HEARTY and KINDLER, 1993a, p. 577). We have also used a variety of geological techniques including morphostratigraphy, sedimentology, petrology, biostratigraphy, and AAR where applicable in the characterization of all geological units.

We also feel obligated to point out that nearly all of C&M's publications are buried in obscure and uncirculated guidebooks, proceedings volumes, and abstracts that defy discovery, critical review and recognition by outside researchers.

Nevertheless, we would like to acknowledge that their work provided an essential stepping stone in our interpretation of the geology of San Salvador Island, and such will be the fate of our work in future years by subsequent researchers. *Sic transit gloria mundi* . . . and so goes science.

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