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Chevron Ridges and Runup Deposits in the Bahamas from Storms Late in Oxygen-Isotope Substage 5e

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Landward-pointing V-shaped sand ridges several kilometers long are common along the windward margin of the Bahama Islands. Their axes share a northeast–southwest trend. Internally, the ridges contain low-angle oolitic beds with few erosional truncations. Commonly interbedded are tabular, fenestrae-rich beds such as those formed by the sheet flow of water over dry sand. Defined here as "chevron ridges," these landforms appear to have originated in the rapid remobilization of bank margin ooid bodies by the action of long-period waves from a northeasterly source. Deposits along adjacent coastlines also preserve evidence of the impact of large waves. Reworked eolian sand bodies preserve beach fenestrae and hydraulic scour traces up to +40 m on older ridges. On cliffed coasts, 1000-ton boulders have been thrown well inland, recording the impact of large waves. Amino acid ratios confirm a correlation of the ridges across the archipelago, while stratigraphy, spacing, and cross-cutting relationships indicate emplacement as sea level fell rapidly from the substage 5e maximum at or above +6 m.

Key Words: **sea level, interglaciation, giant boulders, substage 5e, Bahamas.**

INTRODUCTION

The low-lying carbonate platforms of the Bahama Banks are considered to be tectonically stable (Garrett and Gould, 1984; Carew and Mylroie, 1995). As sea level floods the bank top during interglacial high stands, large volumes of sediment accumulate and blanket the platform. Upon this essentially flat-topped, sediment-laden surface, minor or brief changes in sea level can bring about large lateral shifts in coastlines and centers of deposition. Carbonate sediments shift from marine to terrestrial environments as wave and wind activity in the coastal zone moves them landward and to higher elevations to form coastal ridges. Upon subaerial exposure, they are quickly indurated (Halley and

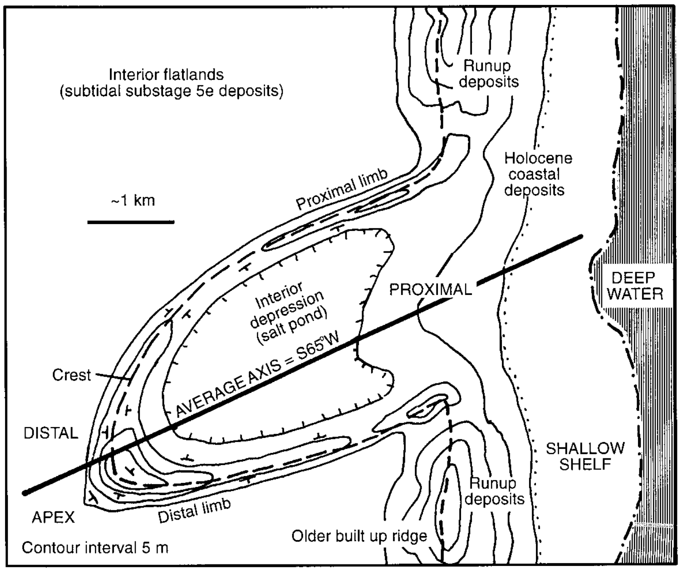

FIG. 1. Schematic map of chevron beach ridge.

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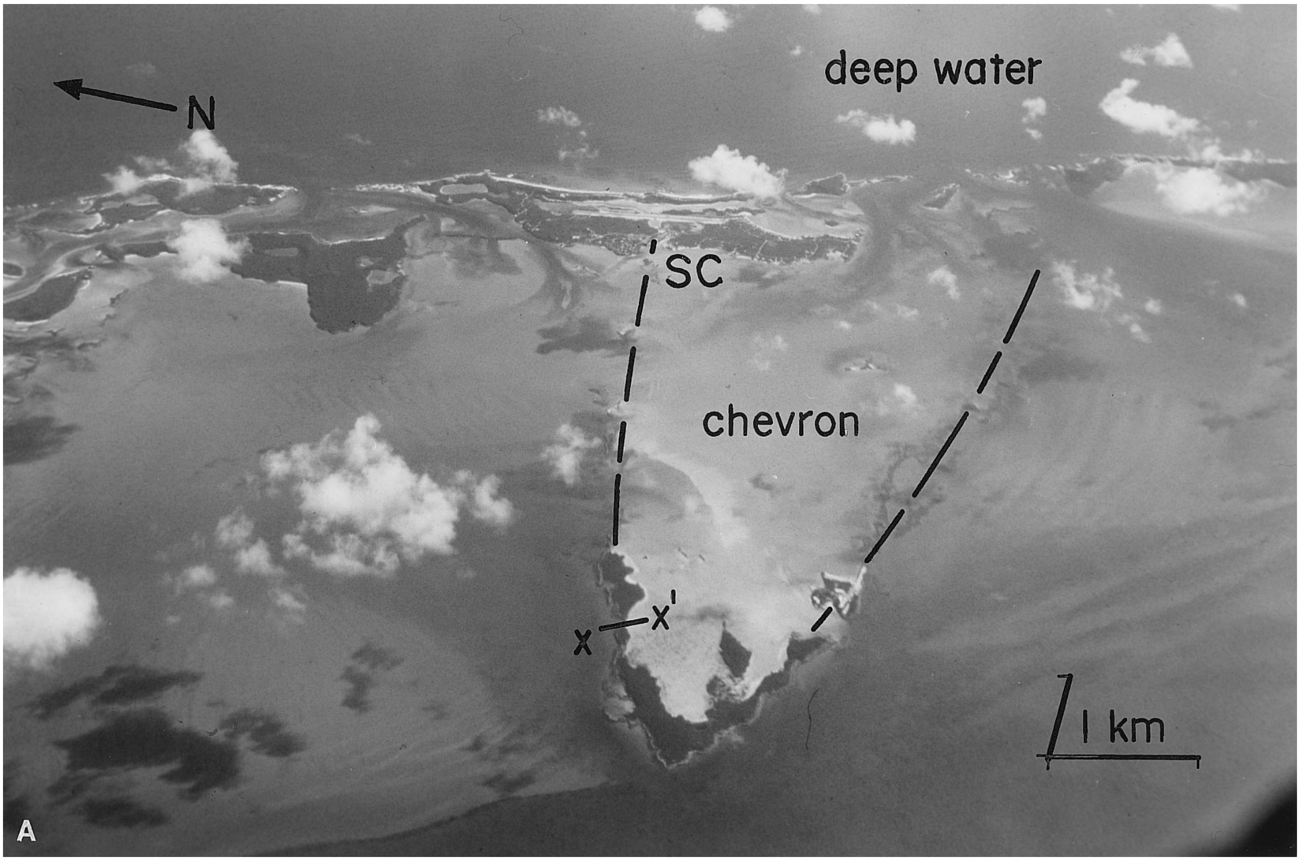

FIG. 2. (A) View to NE of Harvey Cays near Staniel Cay (SC) in the middle Exuma Cays. The chevron in the foreground is 6 km long and 2.2 km wide. (B) A surface profile ("X–X" in photo A) identifies fenestral beds (fp beds) capped by ~1 m of eolianite. The ridge is approximately 6 m high.

Harris, 1979), preserving evidence of both short and long-term eustatic oscillations in the geologic record.

Coastal ridges oriented parallel to the deep water margins thus reflect sea-level events over previous interglacial cycles. Many of these ridges, including some of the largest and most continuous ones, are associated with the last interglacial period (equivalent to oxygen-isotope substage 5e) (Garrett and Gould, 1984; Carew and Mylroie, 1987; Hearty and Kindler, 1993a 1993b 1997).

Here we focus on the final events of substage 5e. After the building of reef crests up to circa +2 m, sea level rose rapidly to at least +6 m toward the end of the interglaciation, cutting coastal notches and flooding interior areas (Neumann and Hearty, 1996). During the fall of sea level from the 5e maximum, large areas of the Bahamas were reshaped by sedimentary processes. As lagoons shallowed and beaches widened, dunes grew so rapidly that standing trees became entombed in sand (Neumann and Hearty, 1996). Along cliffed coasts during the same interval, giant boulders were catapulted landward as far as 0.5 km by the action of large waves (Hearty, 1997). On low-lying areas of the Bahamas, extensive V-shaped storm-beach ridges ("chevrons" in this paper) were emplaced by similar, high-energy events. The origin of these storm ridges, associated run-up features, and boulder deposits, plus the implications for climate history at the close of the last interglaciation, are the subjects of this paper.

DESCRIPTION OF CHEVRON RIDGES

Chevron ridges are defined as V-shaped, sublinear to parabolic, ribbon-like landforms that extend several kilometers across low-lying island ramps or shelf margins of the eastern, windward Bahamas (Figs. 1, 2A, and 2B). The oolitic sand ridges are generally rounded to asymmetrical in cross-section, with steeper cross beds along the bankward perimeter of the chevron structure. Many individual, low-angle, tabular and cross-set beds exhibit bands of fenestral porosity, or beach fenestrae ("keystone vugs" of Dunham, 1970; "birdseyes" of Shinn, 1983; see discussion in Bain and Kindler, 1994). Beach fenestrae are formed as air bubbles are trapped in fine sand when inundated by sheets of water. The axes of 35 chevron ridges examined in this study point southwest, indicating the

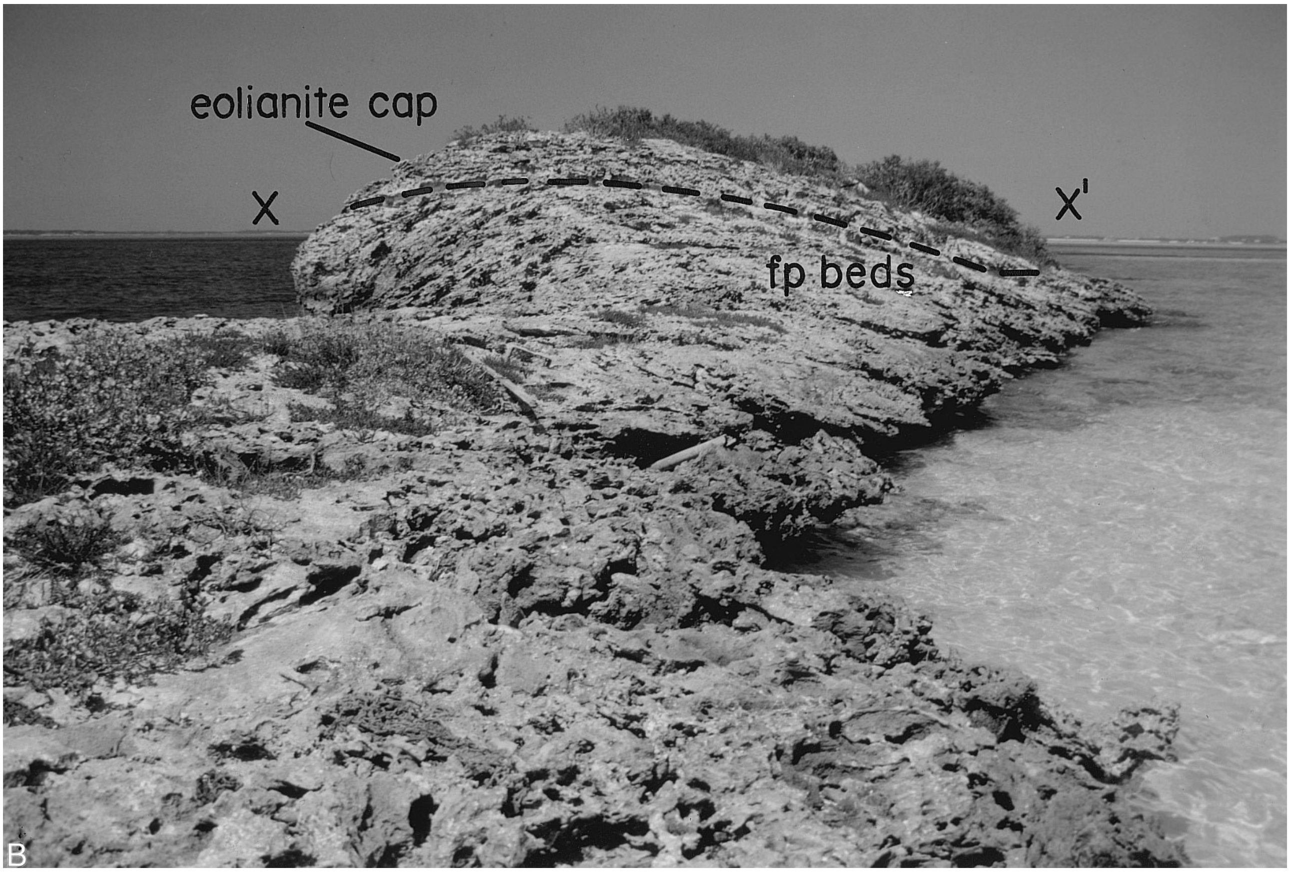

FIG. 2—*Continued*

direction of emplacement (Fig. 3). As with all substage 5e deposits in the Bahamas, the chevrons and their counterparts are oolite that contains minor percentages of skeletal grains, peloids, and aggregates (Kindler and Hearty, 1996).

Chevron ridges are found on broad, low-lying platforms or ramps throughout the Atlantic-facing deep water margins of the Bahamas (Fig. 3) from Abaco to Acklins Islands (~700 km). The main examples used in this study are located in Eleuthera (Fig. 4A; 4B), Long Island (Fig. 4C; 4D), and Exumas (Figs. 2 and 5). The V-shaped limbs of chevrons converge southwestward to a closed bankward or landward apex (Figs. 4 and 5). The axes of the chevron ridges average S65° ± 10°W, generally perpendicular to the shelf margin trend (Figs. 1 and 3).

The chevron landforms average ca. 3 km long with some exceeding 10 km, and width generally measures about a third of the length. The southwest-pointing ridges are generally 20 to 100 m wide and rise 8 to 25 m high above the surrounding plains. Often the highest ridge elevations lie near the distal (landward) apex, with somewhat lower elevations along the proximal (seaward) limbs. Closed topographic depressions are common between chevron limbs, and are often filled by mangrove swamps and/or salt ponds (Fig. 5). In profile, the ridges are generally rounded to asymmetrical in cross section, with somewhat steeper slopes along the outer flank of the limbs and distal margins of the chevrons (Figs. 2B; 6).

Chevron ridges are composed of subparallel, aggrading beds with few interruptions or truncations. Internal sedimentary structures include predominantly thin, low-angle planar cross beds, rich in beach-like fenestral porosity, that are similar to those found in the intertidal zones of most modern beaches of the Bahamas (Bain and Kindler, 1994). Beach fenestrae are abundant in the oolite of the chevrons. Tabular, fenestrae-rich beds 5–10 cm thick alternate with texturally graded and pebble beds with snails and rhizomorphs (Fig. 7A). Low-angle truncations are also observed, but in general the largely planar beds remain subparallel, showing rapid aggradation of the chevron structure. In a regional sense, fenestrae are present in the youngest 5e beds throughout the eastern margin of the Bahamas.

The most important characteristics that distinguish chevron ridges from coastal ridges (Table 1) are their V shape, orientation perpendicular rather than parallel to the coast, and consistent trend of the axes (S65° W) that bears no apparent

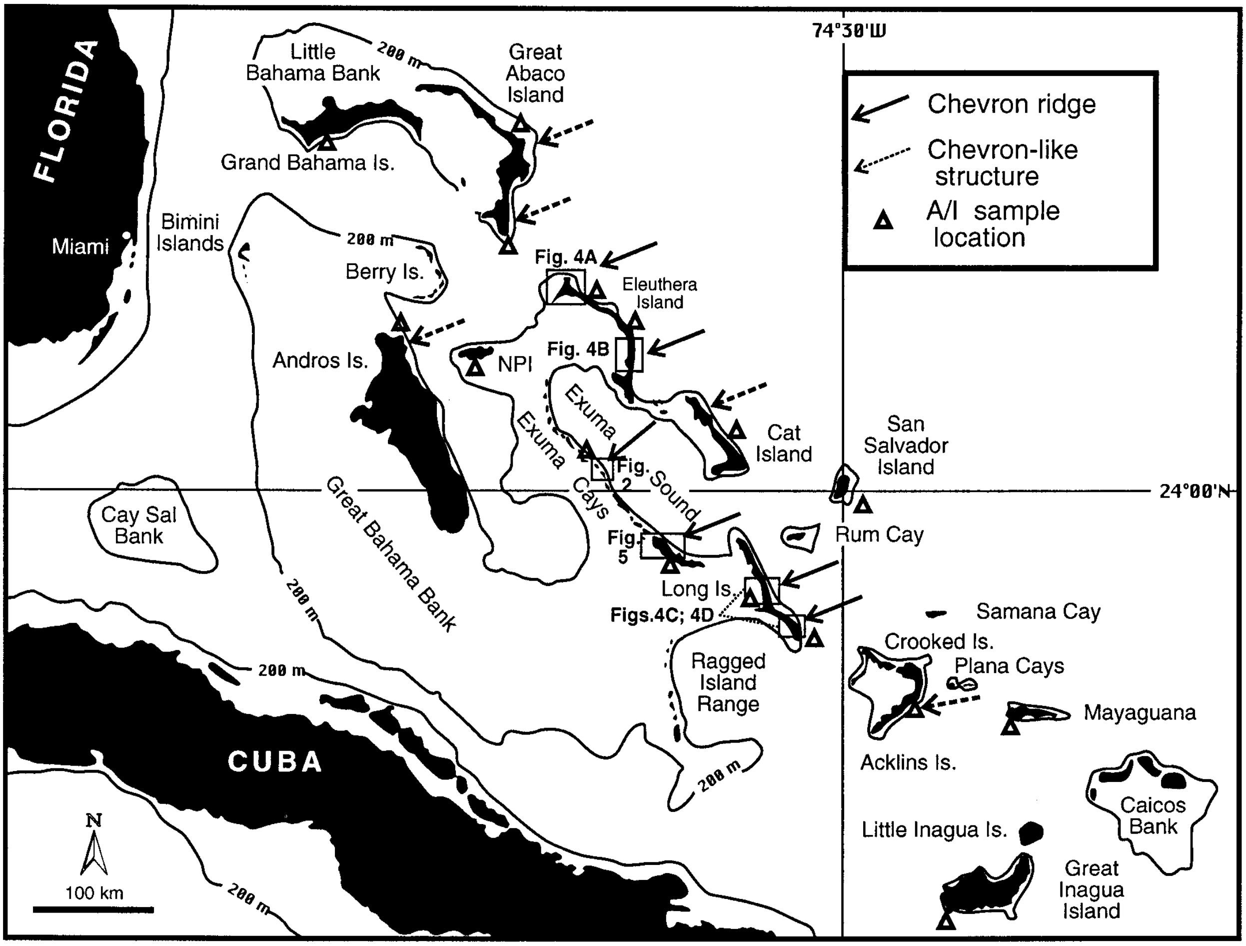

FIG. 3. Map showing location and approximate orientation (arrows) of chevron landforms and amino acid samples (Table 2).

relationship to the changing orientation of the coastline. Although similar to parabolic dunes in gross morphology, several features in chevrons demonstrate that chevrons are deposited by water rather than by wind. These distinctions include (Table 1) the presence of beach fenestrae, graded bedding, and the absence of the compact bedding and bedforms typical of the migratory parabolic dunes. Indeed, there are no known examples of true migratory carbonate dunes in the Bahamas despite abundant sand supply and strong prevailing winds. As described below, runup deposits and giant boulders provide supporting evidence of the occurrence of large waves during the last interglaciation on pre-existing, older coastlines *adjacent to* the lowland areas where chevron ridges are found.

RUNUP DEPOSITS ON RIDGES ADJACENT TO CHEVRONS

Chevrons ridges are not found behind built-up shore-parallel ridges. Instead, the youngest deposits on these ridges consist of thick (1–5 m) fenestrae-filled seaward-dipping tabular beds of substage 5e age (Figs. 6 and 7) that rise to over +25 m, well above the sea level stand maxima of the last interglaciation (Neumann and Moore, 1975; Chen *et al.*, 1991; Neumann and Hearty, 1996). These beds are also frequently found above +25 m more than a kilometer from the coast on the leeward flanks of substage 5e ridges. Scour structures, lenses of pebbles, plant morphs, and land snails are interbedded with fenestral beds (Fig. 7B). Scour structures (Fig. 8) are observed in substage 5e oolite above +20 m; they show backfilling toward the crest of the hill and are capped by fenestrae-rich planar beds ("fp" in Fig. 8B) that dip seaward and pinch out against topographic irregularities in the older eolianite (Fig. 7B). This unit contains ripup clasts up to 10 cm long and truncates eolian sets below.

Beach fenestrae at high elevations are considered to result from runup of very large waves (Wanless and Dravis, 1989). If so, they should resemble "intertidal fenestrae" that form when

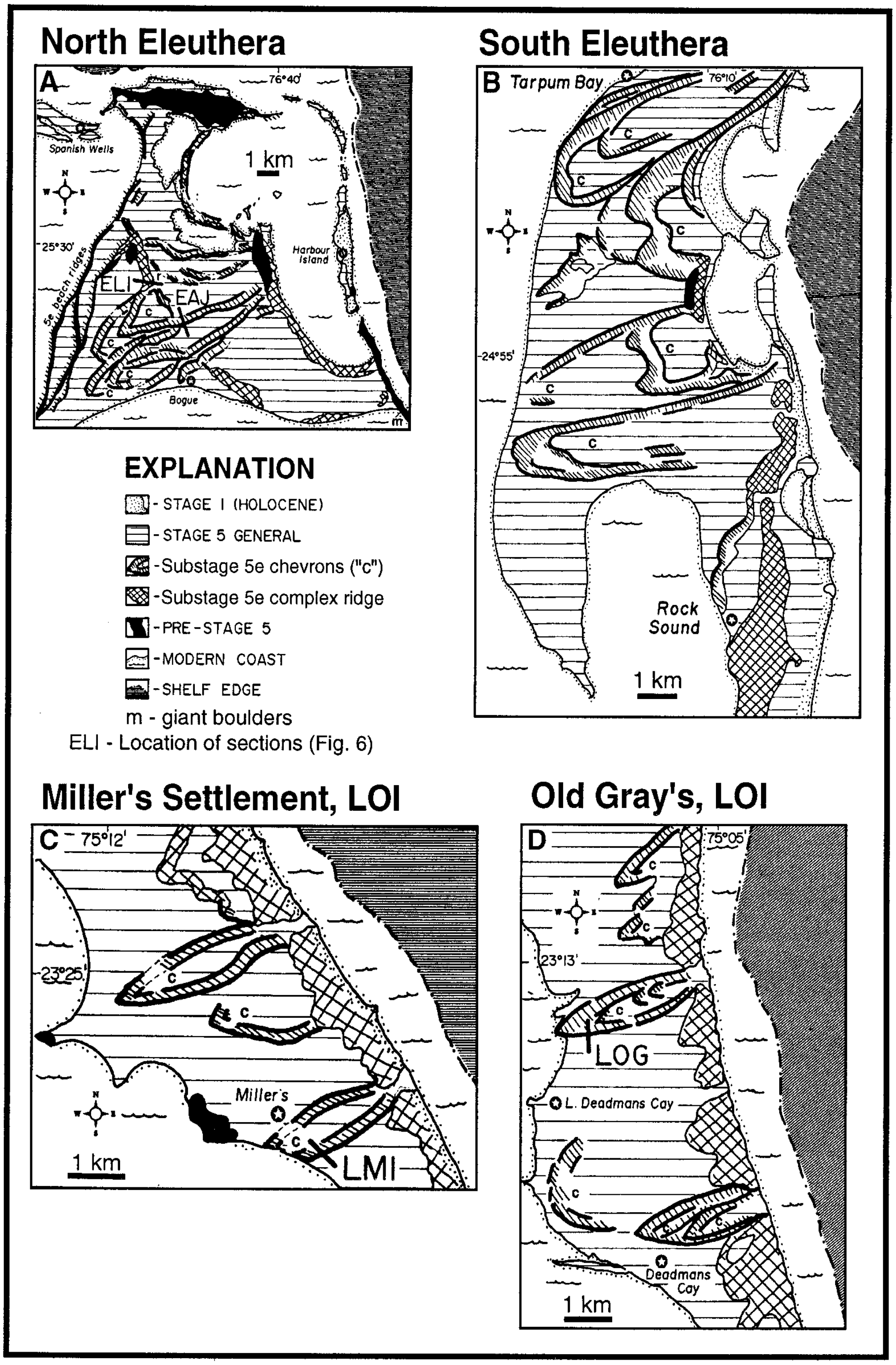

FIG. 4. Sketch maps of typical areas having chevron ridges (simplified from Bahamas Department of Lands and Surveys Topographic Maps, original scale 1:25,000).

air is trapped in dry sand by the sheet-like inundation. The runup fenestrae fit most of the criteria outlined by Bain and Kindler (1994) for intertidal fenestrae including: (1) dip of the beds in a seaward direction; (2) alternating fine and coarse laminations; (3) flattening of the fenestrae oriented parallel to bedding (Fig. 7A); and (4) abundant and traceable fenestrae in this unit. On a regional scale, beach fenestrae are widespread at high elevations in the youngest substage 5e unit across the eastern Bahamas, but are lacking in ridges of other ages.

Because we interpret wave runup to have reworked well-

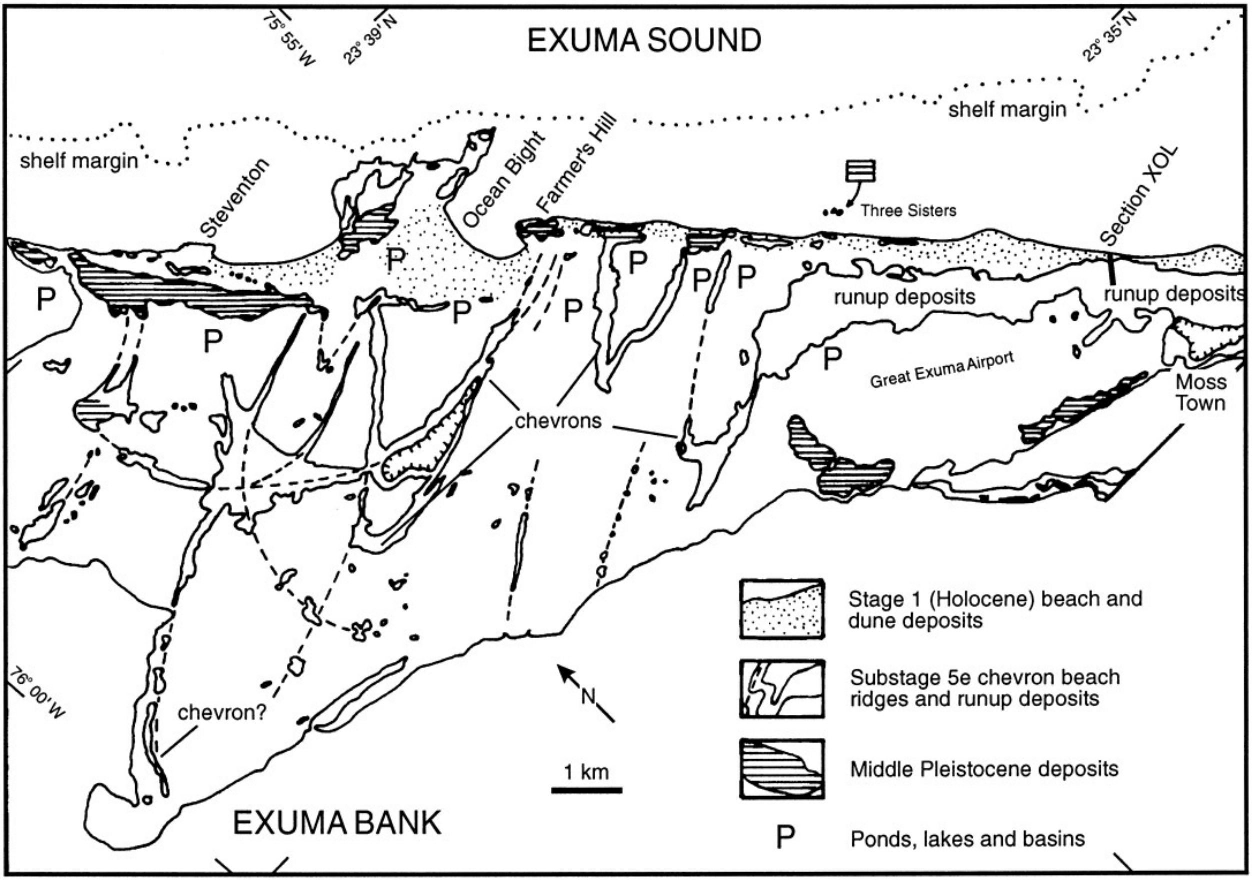

FIG. 5. The Steventon–Farmers Hill area of Great Exuma Island showing chevron ridges highlighted by the 20-ft (6.1 m) contour (redrawn from original scale 1:25,000 topographic maps, Bahamas Department of Lands and Surveys Sheets 13 and 14, Exumas).

sorted eolian sediment, we expect some features characteristic of dunes to be associated with the runup deposits including fine-grained, well-sorted sand and terrestrial mollusks (*Cerion sp.*). In the Bahamas, Bain and Kindler (1994) attribute fenestrae at high elevations in late substage 5e "eolianites" to torrential rains. However, they did not consider the alternate possibility of their genesis by wave runup, nor explain the absence of fenestrae in dunes formed during other interglaciations.

RUNUP EVIDENCE FROM THE NORTHERN SHORE OF BERMUDA

Seaward-dipping planar beds rising to ca. +20 m at Blackwatch Pass, Bermuda have been the subject of divergent interpretations (Land et al., 1967; Harmon et al., 1983; Vacher and Rowe 1997). These beds (Fig. 9A) are present along several kilometers of the north coast, and stand in marked contrast to sedimentary structures in older substage 5e eolianites that underlie them. Beds in the youngest unit are graded, contain numerous shell fragments up to 1 cm long, and are filled with abundant, angular beach fenestrae in platy grains and thick, air-filled laminations (Fig. 9B). Ripup clasts are observed at the base of the beds (Fig. 9B). From the nearly identical sedimentary structures, facies relationships, and stratigraphic settings present in the Bahamas and on the north shore of Bermuda, it is apparent that these latest substage 5e beds share a common timing and genesis.

GIANT BOULDERS

Published accounts of the mechanisms of transport of giant boulders in north Eleuthera (Hearty, 1997) are critical to this discussion of chevron ridges because they document the occurrence of large waves about the same time, and in the immediate vicinity (<10 km), of the chevron and runup deposits. Giant waves are the only obvious mechanism powerful enough to transport the boulders, the largest of which weighs over 2000 tons. The maximum age of emplacement is established from the regressive substage

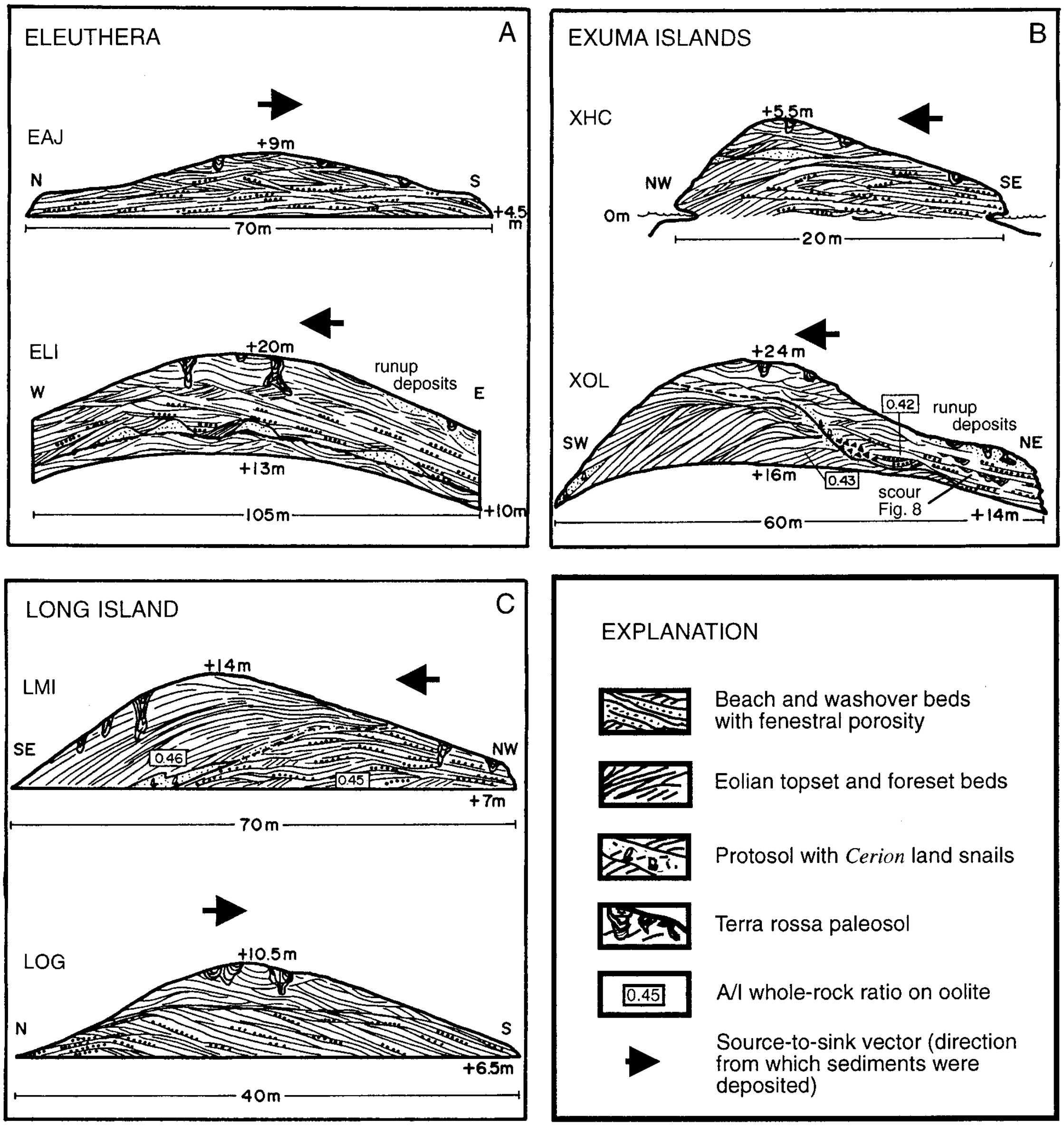

FIG. 6. Cross-sections drawn from photos and field sketches showing morphology and internal structure of chevron ridges in Eleuthera (A), Exumas (B), and Long Island (C). Figure 6B shows the location of the photo and sketch of scour structures in Fig. 8. A/I ratios and approximate locations of whole-rock A/I samples are identified in boxes.

5e marine and eolian deposits upon which the boulders rest. The minimum age is constrained by onlapping terra rossa paleosols (Muhs et al. 1990), which began to form with cessation of coastal deposition (i.e., sea-level regression), probably at the beginning of substage 5d. Finally, it is reasonable to assume that the boulders were emplaced during the late substage 5e highstand, while sea level remained relatively high, because even larger waves would have been required at times of lower sea level during substages 5c and 5a in order to lift the boulders over the cliffs (Hearty, 1997).

AMINOSTRATIGRAPHY OF CHEVRONS, RUNUP, AND BOULDER DEPOSITS

A regional geochronological study of the youngest substage 5e unit associated with chevron ridges was made across the Bahamas from Abaco to Great Inagua. Whole-rock limestone samples, including chevron fenestral beds, runup deposits on high ridges, sub-boulder marine and eolian deposits, and eolianite capping the chevrons were analyzed by amino acid racemization (AAR) techniques. Background and methods are available in Hearty *et al.* (1992). A/I ratios (or

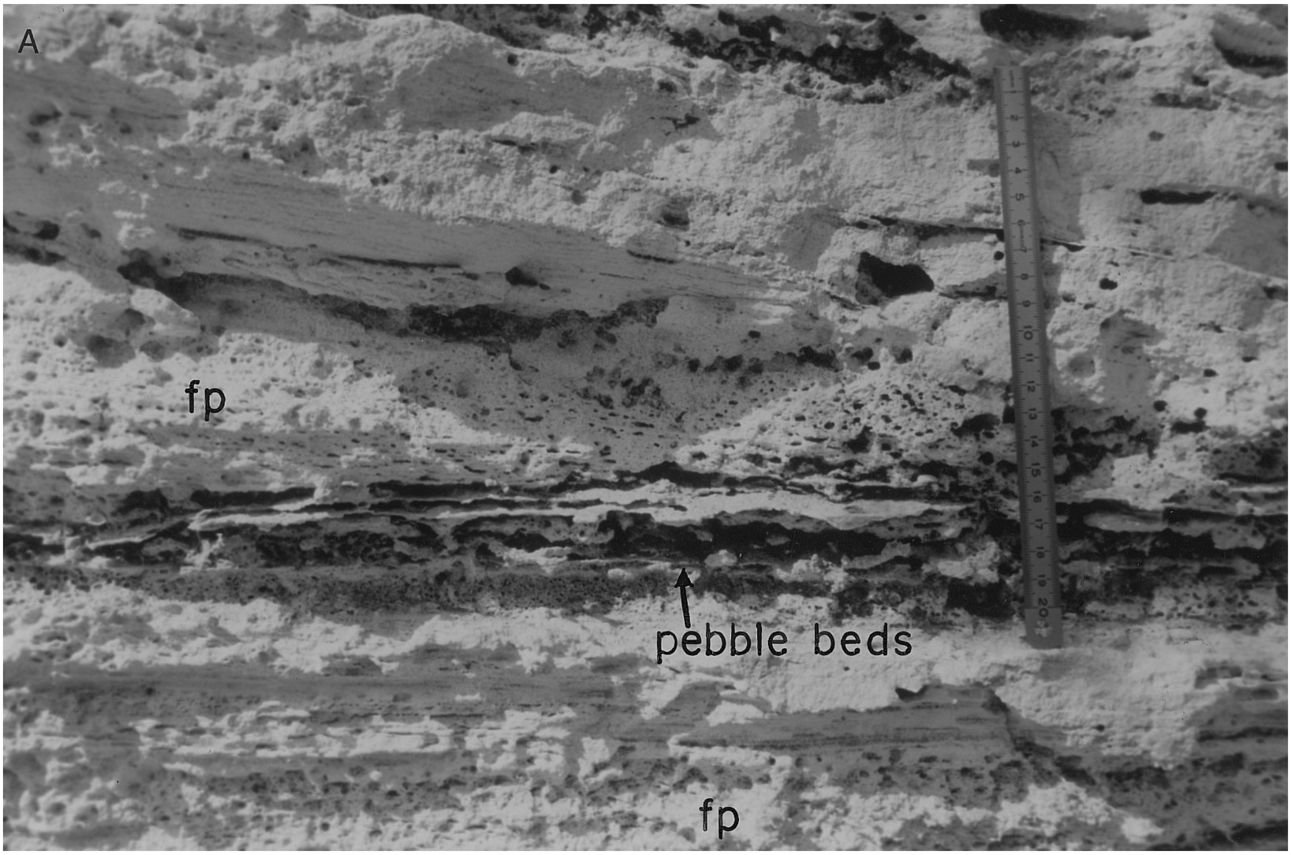

FIG. 7. (A) Lenses of fenestral porosity (fp) at +25 m on Licrish Hill ("ELI", Figure 4A) interbedded with pebbles, horizontally oriented rhizomorphs, and land snails. Scale is 20 cm long. (B) Pinch-out of runup fenestral beds ("fp beds") against older eolianite and an obstacle (plant cast?) at +23 m at Old Land ("XOL" in Figure 5) road in Great Exuma. Note the fenestral beds in the lee of the obstacle. Scale is 1 m long.

D-alloisoleucine/L-isoleucine) were determined on oolite samples stratigraphically correlated to substage 5e (Hearty and Kindler, 1993a 1997; Kindler and Hearty, 1996 1997). Mitterer (1968) showed that ooids and aragonite muds contain concentrations of amino acids similar to those in mollusks and bioclastic limestones.

The whole-rock AAR data demonstrate a regionally consistent trend (0.40 ± 0.03, 66 samples) among 13 islands across 700 km of the archipelago (Table 2; Hearty and Kindler, 1997; Hearty, 1998). This regional trend suggests that (1) variations in sample composition are compensated by "averaging" of the ratios of various allochems, with no ultimate effect on the A/I ratio; or (2) local and regional variations in sample composition are too small to affect significantly the A/I ratios (Kindler and Hearty, 1996). The reaction in whole-rock samples follows well-established kinetic guidelines by yielding higher ratios at warmer, lower-latitude sites (Table 2).

On New Providence Island, ratios from lower and upper substage 5e oolites at Lyford Cay, of 0.38 and 0.36, respectively (Hearty and Kindler, 1997), encompass five whole-rock U-series ages averaging 123,000 ± 5000 yr (Muhs *et al.* 1990), confirming the correlation with substage 5e. Uranium-series dates of corals from the Bahamas (Neumann and Moore, 1975; Carew *et al.*, 1987; Chen *et al.*, 1991) constrain the age of the deposits between about 140,000 and 118,000 yr.

TIMING OF CHEVRON FORMATION DURING THE REGRESSION FROM THE SUBSTAGE 5e HIGHSTAND

That sea level was in its final regression from the substage 5e highstand can be established from geologic evidence. First, it is apparent from the "nesting" of several chevron ridges in a seaward direction (Figs. 4 and 5) to the shelf margin that sea level was falling. That retreat was fairly rapid is implied by the stranding of each chevron as a distinct depositional landform, not reworked or rewashed by the sea. Second, the chevron and runup deposits occupy the youngest stratigraphic position in the substage 5e complex. Third, facies sequences associated with this interval are characterized by a shallowing-upward transition from intertidal, to eolian, to pedogenic phases. If the chevron ridges were deposited earlier in the interglaciation, it would be expected that in at least some coastal areas they would have been buried by younger sediments. Furthermore, one of the several giant boulders in north Eleuthera overlies a

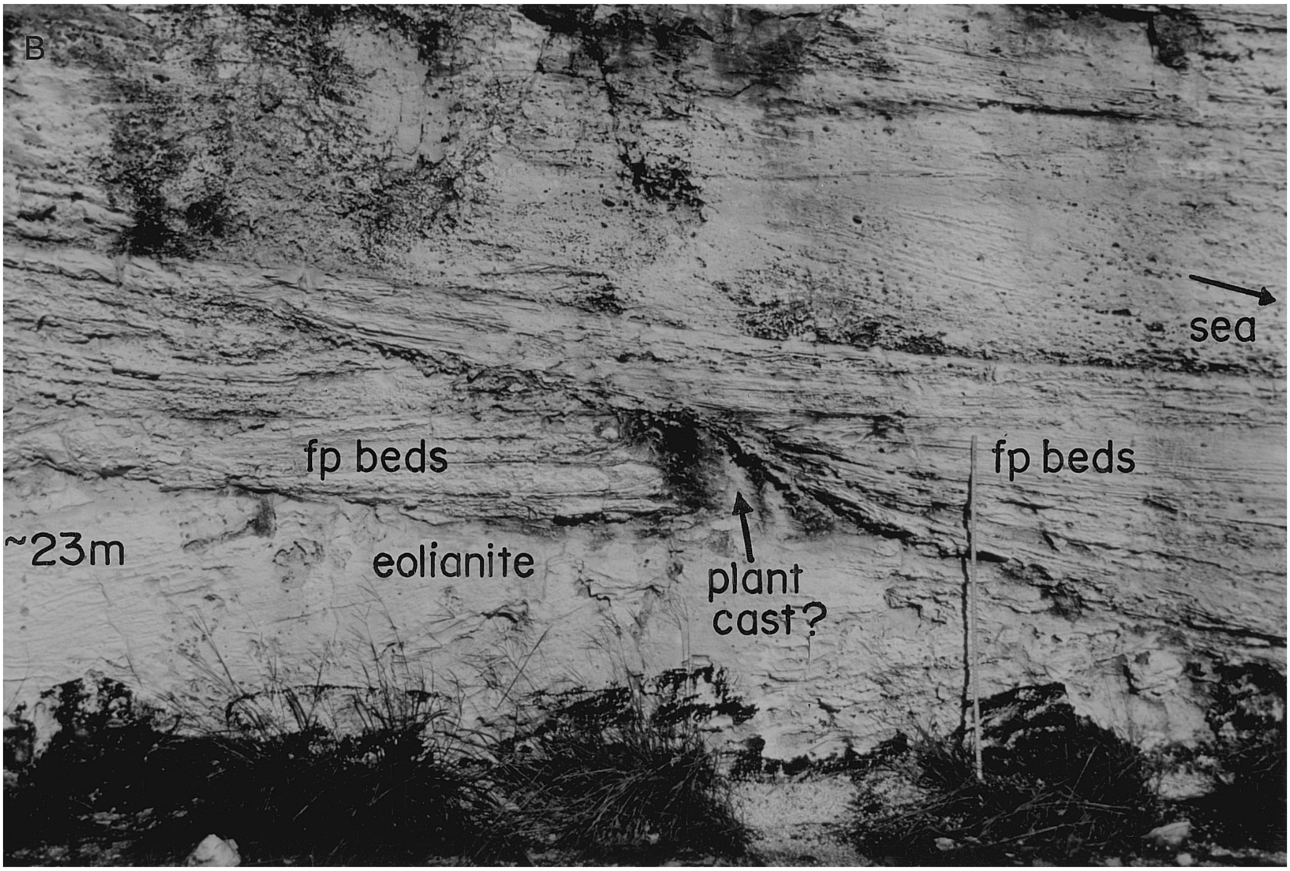

FIG. 7—*Continued*

substage 5e shallowing-upward sequence (subtidal, beach, protosol) at +2 m and is seaward of a notch at +2.5 m. The boulder, which lies in the same peritidal zone, is not notched, and lacks evidence of subsequent marine inundation of substage 5e deposits following the emplacement of the boulder.

WAVE ORIGIN OF CHEVRON RIDGES

The shape, orientation, sedimentary structures, size, and cross-cutting history of the chevrons is best explained by the work of many waves acting over a short time interval, during which a ridge was produced as an isolated depositional landform within the general framework of a rapidly falling sea level. The structure and orientation of the ridges point to well-organized sets of large waves from a northeasterly source. Wave-generated features can be traced continuously across flatlands where chevron ridges occur, to built-up ridges with wave runup features (Fig. 5), and to giant boulders on cliffed coastlines (Fig. 4A).

The formation of chevrons and related features must have taken place bankward of differing marginal environments, yet clasts from reefs or beachrock are not common in the chevrons. This suggests that the volume of sediment composing them came from a source such as the well-winnowed ooid sands of flood tidal deltas (FTDs). Possibly the substage 5e FTDs were remobilized and redeposited as chevrons at the close of the interval. The absence of large clasts is not surprising, because the FTDs, as we observe them today, are blanketed by fine, oolitic sediments. Furthermore, the growth of reefs likely would not be favored under the adverse conditions created by a thick blanket of mobile ooids in a tidal pass.

On coastlines with older built-up ridges, there is evidence of wave runup to elevations as high as +40 m. In these deposits, thin lenses of land-snail shells and rhizomorphs are observed between layers of beach fenestrae in fine, well-sorted sand (Fig. 7A). From this, we infer that partially vegetated dunes composed of “presorted” eolian sand were remobilized and reworked by the action of large waves. On rocky or cliffed coastlines, crashing waves would detach and deposit storm breccia and giant boulders (Hearty, 1997). Although these features share the same geologic interval of late substage 5e, it is not certain whether they formed simultaneously or nearly sequentially.

Figure 10 is a hypothetical reconstruction illustrating the

TABLE 1
Common Characteristics of Chevron Ridges in Comparison with Beach Ridges and Parabolic Dunes

	Chevron ridge	High-energy beach ridge	Parabolic dune
Gross morphology	V-shaped sand ridge extending several km landward (bankward), *perpendicular* to shelf margin, 100–200 m wide, 8–25 m high, with greatest elevation at apex. Clearly defined shape and consistent orientation of axes. Modifies older headlands.	Undulating ridge or ridges oriented *parallel* to deep margin. Ridge buildup occurs within 100's m of coast. Catenary between older headlands.	U-shaped sand ridge extensive in siliciclastic environments (not present on Holocene coasts in Bahamas) Orientation dependent on wind direction. Often braided patterns of coalescent blowouts. Limited sand supply. Migratory. Does not modify older headlands.
Sedimentary bedforms and geometry	Subparallel, aggradational bedding filled *with beach fenestrae.* Few minor cross beds with fenestrae. Asymmetrical profile (steeper outer face) to rounded profile. Absent or thin eolian cap. On platform of subtidal beds.	Shore-parallel wedge of sub-, inter-, and supratidal beds that thicken landward into the dune. Steep, extensive foresets on lee side. Common cross-bedding and reactivation surfaces.	Entirely cross-cutting eolian bedforms (steep convex foresets on lee side; scoop-shaped on windward). *No fenestrae.*
Facies assemblage	Thick, laminated, fenestrae-filled beds. Interbedded lenses of coarser material.	Shallowing and fining upward from subtidal to dune. Basal conglomerate.	Compact, well-sorted fine sand. No fenestrae.

attack of large waves on coastlines with low tidal passes, older built-up ridges, and cliffed coastlines. As waves surge through a tidal pass, they would scour the basin landward of the gap (explaining the presence of ponds and depressions within the central basin of the chevrons). Wave energy would attenuate in all directions as it is spent on the shallow shelf, stimulating deposition and creating the chevron landforms. Runup and boulders would be deposited along adjacent built-up and cliffed coastlines.

WAVE-GENERATING MECHANISMS

Several mechanisms could generate the large waves capable of producing the chevron ridges and related deposits. First, powerful storms of local origin could strike the bank margin directly; however, because of the implied great size of the waves (Hearty, 1997) and the common SW–NE orientation of the chevrons, it is more likely that they originated from a distant source that would propagate large, well-organized, unidirectional waves through dispersion. The unexpected occurrence of sets of large waves, even on fair-weather days, is documented in the Bahamas (e.g., October 30–31, 1991), where they are referred to as "rages" by the local population. Second, wholesale failure of a large section of the bank edge is evident based on the steep and scalloped nature of the margin (Mullins and Hine, 1989) in north Eleuthera. Possibly the shelf margin collapsed toward the end of substage 5e, thus increasing the exposure of the coast to the huge waves that transported the megaboulders. A shallow seaward shelf (that must have served as an ooid source for the voluminous dunes and ridges of late substage 5e) is now missing. Tsunamis generated by this collapse could possibly have generated large waves, such as those described in the Hawaiian Islands (Moore and Moore, 1984; Lipman *et al.,* 1988), but no mechanism is known to explain how they could strike the remainder of the east coast of the Bahamas while being propagated eastward. Third, tsunamis produced by rare and random external occurrences such as a submarine earthquake or a meteorite or comet impact in the Atlantic are more remote possibilities.

Whereas large single waves or wave sets could explain the runup and the giant boulders of northern Eleuthera, it is more probable that all of these features are related to the same cause or set of associated causes. We consider extreme storms and attendant waves as the probable agents that formed these features, because of the northeastern orientation of the chevrons, the continuous and multiple bedding sets they contain, and the nature of the megaboulder deposition.

LARGE NORTHEASTERN STORMS AT THE CLOSE OF SUBSTAGE 5e?

Adkins *et al.* (1997) identified a "rapid shift in oceanic conditions in the western North Atlantic" about 118,000 yr ago. They attribute the shift to an increase in southern source waters, a marked reorganization of the oceanic circulation patterns, and the initiation of a "climatic deterioration" over a ~400-yr period. This major oceanographic shift appears to

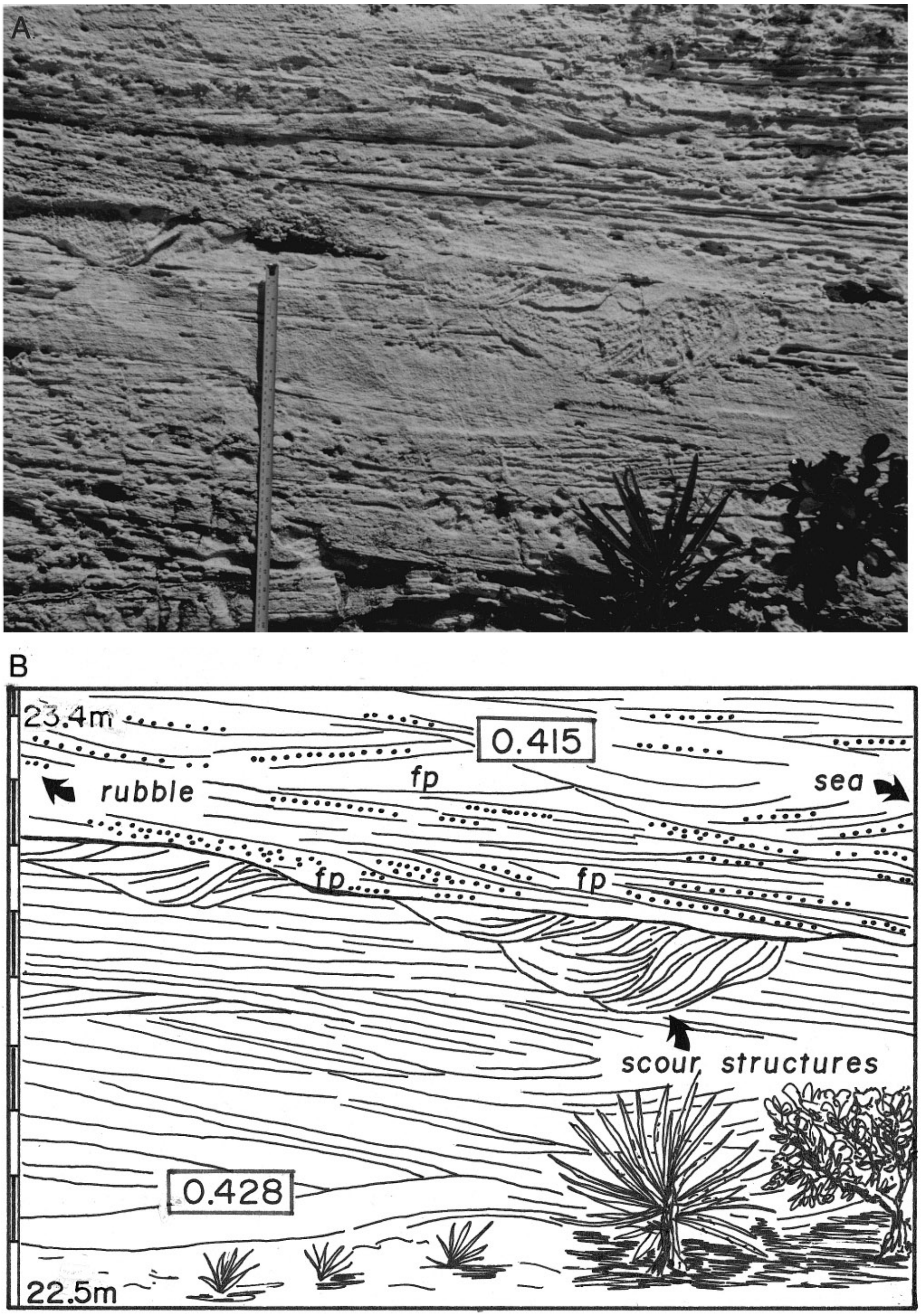

FIG. 8. Photo (A) and explanatory sketch (B) of wave runup deposits at the Old Land section (“XOL”, Figure 5) on older eolianite. Scour structures and fenestral beds (“fp” in sketch) lie at approximately +23 m. A/I ratios are identified in boxes.

coincide with the occurrence of major storms originating from the same region.

The abrupt fall of sea level from the high stand at the close of substage 5e reflects the rapid expansion of high latitude snow cover and the following rapid growth of the ice sheets (Andrews and Mahaffy, 1976; Neumann and Hearty, 1996). Steeper pressure, temperature, and moisture gradients adjacent to warm tropical waters could presumably spawn larger and more frequent cyclonic storms in the North Atlantic than those seen today.

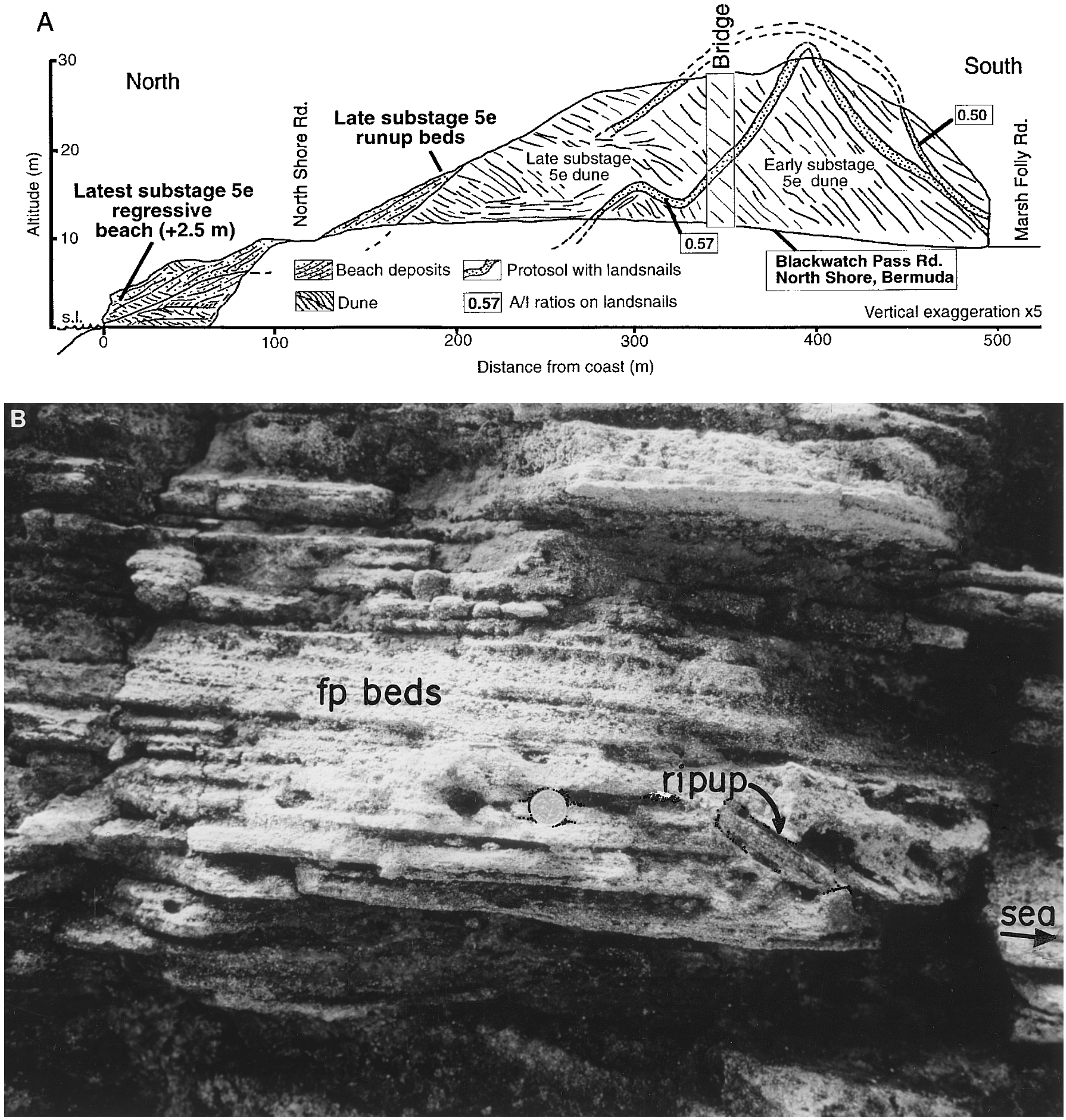

FIG. 9. Blackwatch Pass roadcut section (Fig. 9A) along the northern shore of Bermuda showing two large eolian build-ups (early and late substage 5e dunes) succeeded by a beach unit unconformably above those older dunes. Beach fenestrae (fp beds) are observed throughout the unit, while imbricated, seaward-dipping ripup clasts (Fig. 9B) occur at the base of the unit. Coin is 2 cm in diameter. These youngest beds contain runup deposits (latest substage 5e) up to +20 m. Sketch in Fig. 9A modified from an original drawing by Hearty in Vacher *et al.* (1995).

In the Bahamas, the SW–NE orientation of the chevron ridges and runup deposits, and the restricted wave access to the megaboulder deposits of northern Eleuthera (Hearty, 1997) favor formation from long-period waves generated from a distant northeastern source. The orientation of these features at the Bahamas and Bermuda points to a very large and extremely energetic and weather systems in the North Atlantic Ocean at this critical time of abrupt climate change. A comparison of the size of wave-deposited boulders between the late Pleistocene and Holocene along the northern Eleuthera coastline supports this hypothesis, with the size of the Pleistocene boulders averaging an order of magnitude greater than the size of their Holocene counterparts (Hearty, 1997).

CONCLUSIONS

(1) Chevron ridges were emplaced perpendicular to the eastern margin of the Bahamas during high-energy oceanic events and climatic fluctuations at the end of substage 5e. They are unlike any beach ridges, strand plains, or flood tidal deltas observed today. Although they resemble parabolic dunes in a general morphological sense, beach fenestrae and water-made structures are ubiquitous in the chevrons and confirm their origin by waves. Emplacement of the chevrons is also coincident with the deposition of thousand-ton megaboulders on and over 20-m-high cliffs in northern Eleuthera and wave runup between +20 and +40 m on older ridges in the region. The characteristics shared by these deposits, including A/I ratios, are strong evidence that they were formed concurrently by the same mechanism.

(2) There are global indications of abrupt climate shifts at the end of substage 5e. The rapid expansion of polar ice and concomitant compression of midlatitude atmospheric cells may have greatly amplified storms in the North Atlantic. Among the many implications of these findings, the most significant is that present global warming and climate change could hasten an apparently abrupt and extreme destabilization which, from geologic evidence, characterized the transition from last interglaciation to glacial conditions of the globe.

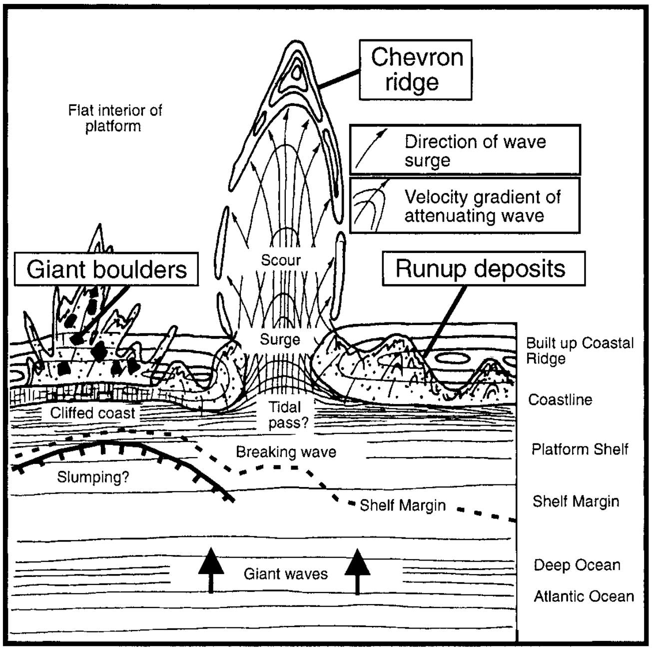

FIG. 10. Map showing hypothetical origin of chevron ridges landward of former tidal passes, runup deposits on older built up ridges, and giant boulders landward of high cliffs, respectively, upon impact by giant waves from a northeasterly source.

TABLE 2

Whole-Rock Amino Acid Ratios (D-Alloisoleucine/L-Isoleucine) from the Youngest Isotope Substage 5e Oolites, Associated with Chevron Ridges and Runup Deposits

Island group Bahamas[a]	W-R A/I Ratio—Latest 5e unit[b]	North latitude
Abaco Island	0.36 ± 0.02 (2)	26 °45′
Grand Bahama	0.36 (1)	26 °40′
Eleuthera	0.37 ± 0.02 (7)	25 °15′
North Andros	0.39 ± 0.02 (2)	25 °10′
New Providence	0.34 ± 0.01 (3)[c]	25 °05′
Cat	0.37 ± 0.03 (4)	24 °30′
San Salvador	0.41 ± 0.04 (19)[d]	24 °00′
Exuma Cays	0.40 ± 0.03 (18)	23.5 to 24.5°
Great Exuma	0.42 ± 0.01 (2)	23 °36′
Long	0.43 ± 0.03 (2)	23 °25′
Acklins	0.44 ± 0.06 (4)	22 °30′
Mayaguana	0.45 (1)	22 °20′
Inagua	0.47 (1)	20 °55′
13-ISLAND MEAN	0.40 ± 0.03 (*N*=66)	

[a] The 13 islands are arranged according to latitude. The sample set spans over 800 km distance, 6° of latitude, and 3°C mean annual temperature of the sites.

[b] The mean, one standard deviation, and number of samples analyzed (brackets) is presented for each island group.

[c] Equated with 117,000 yr U date on oolite (Muhs *et al.*, 1990).

[d] Correlated with ~123,000-yr coral dates from Chen *et al.* (1991). Samples were collected by Hearty and analyzed by Kaufman during his tenure at Utah State University.

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