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DISCUSSION

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Discussion of: Mylroie, J.E., 2018. Superstorms: Comments on Bahamian Fenestrae and Boulder Evidence from the Last Interglacial. *Journal of Coastal Research*, 34(6), 1471–1483.

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INTRODUCTION

Mylroie's (2018) objective was "...to examine the arguments concerning the Cow and Bull [megaboulders on Eleuthera] and the fenestral porosity of the Bahama Archipelago" (The Bahamas and Turks and Caicos Islands, collectively termed "BTC"). Mylroie (2018) sought to debunk several categories of evidence that support superstorms at the close of the last interglacial (*e.g.*, Hansen *et al.*, 2016; Hearty, 1997; Neumann and Hearty, 1996). Our "trilogy," defined in Hearty and Tormey (2017, p. 347), identifies three lines of regional sedimentary features, (1) wave-transported megaboulders, (2) lowland chevron storm ridges, and (3) hillside runup deposits, which collectively provide evidence of frequent, intense storms in the BTC at the end of the last interglacial (marine isotope stage [MIS] 5e).

Based on limited field data from the contested sites, Mylroie's (2018) challenges included: rip-up clasts and fenestral porosity that he attributed to rainfall slurries, use of the term "washovers" (we defined as "runup," not washovers), and evidence of superstorms (his "tempestites"). Mylroie (2018) did not ever mention chevron ridges (Hearty, Neumann, and Kaufman, 1998), a major component of the superstorm trilogy. Eleuthera's megaboulders (Hearty, 1997) and their possible transport mechanisms (*e.g.*, Hearty and Tormey, 2018; Rovere *et al.*, 2017, 2018) also are an important matter under discussion.

Initially, we have some remarks about the body of evidence supporting the superstorm trilogy, the published stratigraphy of Eleuthera, and "controversial AAR results" (where AAR is Amino Acid Racemization Geochrology). Subsequently, we respond to Mylroie's issues related to evidence supporting superstorms, "cliff-top, roll-down," and other challenges.

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REGARDING THE BODY OF EVIDENCE

Over several decades, when combined with the works of Kindler and other colleagues (*e.g.*, Godefroid and Kindler, 2015; Godefroid, Kindler, and Nawratil de Bono, 2010; Kindler *et al.*, 2011; Viret, 2008; see also Table 1 herein), along with numerous other colleagues, we have published over 25 peer-reviewed papers on BTC islands (Table 1), logging over 400 sites, and analyzing well over 2000 petrographic and AAR samples. The research database for BTC is substantial, and we encourage readers to examine our previous relevant contributions (Table 1; see also Hearty and Tormey, 2017, Supplement), which are largely uncited here.

REGARDING NORTH ELEUTHERA STRATIGRAPHY

Mylroie (2018) suggested that Carew and Mylroie (1995, 1997) presented a "model for the Bahamas" (based largely on San Salvador Island) that is said to include Eleuthera. Despite our numerous published modifications (Table 1), their model has remained unchanged for decades. Most relevant here, the entire middle Pleistocene section is schematically represented in their model by one cross-bedded unit (Figure 1A, Owl's Hole Formation). They asserted (Carew and Mylroie, 1995, p. 17) that "we have identified rocks definitely assigned to this unit on Eleuthera...," yet no geologic data were provided. We have documented at least three to four full interglacial sequences (MIS 7–13?) in the middle Pleistocene sequence on Eleuthera, each with numerous facies and pedogenic subdivisions (Figure 1B–E; Tables 1–2). Given this high-resolution stratigraphy, these rocks serve as a premier type section of the middle Pleistocene (Hearty, 1998, ff.). An undifferentiated Owl's Hole Formation does not suffice as representative of middle Pleistocene stratigraphy in BTC.

We have also addressed the morphological evolution of Eleuthera during the last interglacial (Hearty and Tormey, 2017, Supplement), as wave attenuation on variable-morphology coastlines is a key principle of our superstorm model. In Hearty (1998, p. 336), we observed: "Large fractures along the

Table 1. *Summary of peer-reviewed publications of regional scope related to issues raised in Mylroie (2018).*

Publication (Journal Details in References)	Brief Description	Number of sites	Samples, *N*
Hearty and Kindler, 1993a	"In search of..." a stratigraphic reconnaissance of the geology of the Bahamas. Photos and sketches of 48 sites of rock exposures on 10 major islands.	48	48
Hearty and Kindler, 1993b	"New perspectives..." on a revision of the established stratigraphy and evolution of the Quaternary landscape of San Salvador Island.	50	105
Kindler and Hearty, 1996	Carbonate petrology and stratigraphy of rock units from seven major island groups, showing comparable rock composition and Quaternary sequences from island to island.	61	247
Neumann and Hearty, 1996	First recognition of the dramatic climate and sea-level changes that occurred at the close of the last interglacial (MIS 5e) in the Bahamas, "...between the greenhouse and the icehouse lies a climatic madhouse"! (p. 778)	6 islands	NA
Kindler and Hearty, 1997	Island classification of BTCs (Class I–VII) on the basis of energy, exposure, platform size *vs*. island size, *etc*.	20 islands	NA
Hearty, Neumann, and Kaufman, 1998	Geomorphic, composition and AAR from 35 chevron sites across 800 km of the BTC. 66 WR analyses yield a mean of 0.40 ± 0.03 for MIS 5e oolite.	35	66
Tormey, 1999	Description and statistical facies analyses of five general stratigraphic sections (last interglacial through older Pleistocene) and five runup and chevron exposures on Eleuthera.	10 sites	36
Hearty and Kaufman, 2000	Whole-rock (WR) AAR from 75 sites across six degrees latitude (900 km) of the BTC, with calibration and age model.	75 sites	275
Hearty and Kaufman, 2009	AAR on stratigraphically oriented *Cerion* land snails, calibrated with radiometric dates and age model for the late Quaternary.	6 islands	507
~15 island-specific PR publications on BTC, and other relevant papers on Bermuda	Papers devoted to individual islands dealing with morphostratigraphy, petrology, and AAR: Eleuthera (ELU) (7 papers), San Salvator Island (SSI) (4 papers), others from New Providence Island (NPI), Long Island (LOI), Turks and Caicos Islands (TC), and 25 more papers on Bermuda, another carbonate platform and islands.	15	100s

cliffs suggest...that the bank margin retreats by spalling enormous blocks of limestone..." and that "significant cliff retreat occurred after the emplacement of the last interglacial sequence."

REGARDING THE RELIABILITY OF AMINOSTRATIGRAPHY

No geochronologic method is perfect, and many have criticized AAR as "controversial," perhaps appropriately in some past cases. This subjective view was most recently reiterated in Rovere *et al*. (2017) and Mylroie (2018), yet it is totally unsupported by the facts. Major stratigraphic units (0–VIII) were defined in the BTC by Kindler and Hearty (1996, 1997) on the basis of superposition and petrology (Table 2). In total, 275 whole-rock (WR) samples were collected and analyzed across the BTC. The AAR data demonstrate stratigraphic order in most cases, except in samples from the basal Unit 0, which is correlated with >MIS 13 (~0.5 Ma). Many unreliable Unit 0 values are published again here (Table 3) in order to explain the important age limitations of the AAR method (*e.g*., Hearty and Kaufman, 2000; Hearty and O'Leary, 2008).

From Eleuthera (Table 3), Unit I, correlated with MIS 9/11 (oolitic/peloidal limestone), yields an average ratio of alloisoleucine to isoleucine (A/I) of 0.647 ± 0.061 ($N=13$) from *in situ* rocks. A/I values from the megaboulders average 0.672 ± 0.062 ($N=5$) and clearly correlate with Unit I, except Boulder #4 from Unit 0. The oolite beneath two of the megaboulders (Cow #2 and Hole-in-Rock #4) yielded A/I values of 0.400 ± 0.003 and 0.385 ± 0.004, respectively, which correlate precisely with the Units IV/V island mean of 0.364 ± 0.044. Eleuthera data correlate precisely with the regional (non-random) mean of the MIS 5e oolite A/I ratio of 0.40 ± 0.03 ($N=90$; 75 sites including chevron and runup samples from 13 island groups; Hearty and Kaufman, 2000, their Figure 3).

Thus, in BTC, AAR stratigraphic superposition is maintained in over 85–90% of samples (Tables 1 and 3). In regard to our data, we challenge geochronologists (^{14}C, U/Th, ^{87}Sr/^{86}Sr, optically stimulated luminescence) and AAR critics to stand up to the same rigorous tests of rock-stratigraphic superposition. Given our large database, unbiased scientists should consider this AAR data to be a reliable measure of *relative* stratigraphic age of the deposits, particularly given that over 95% of deposits in BTC do not contain corals.

REGARDING "RAIN-INDUCED FENESTRAE"

"Bubble" fenestrae typically define an intertidal (beach) environment (*e.g*., Dunham, 1970; Shinn, 1983); however, they commonly occur high in MIS 5e chevron and eolian ridges across the BTC (Hearty, Neumann, and Kaufman, 1998; Hearty and Tormey, 2017; Wanless and Dravis, 1989). To explain dune fenestrae, Bain and Kindler (1994) proposed a rainfall origin based on two localities: Annie Bight, Eleuthera (+43 m), and Watling's Castle, San Salvador (+12 m). Tormey (1999, pp. 72–74) contested the rainfall model, showing in detailed outcrop maps (Figure 2; Tormey, 1999, plates 1–5) that fenestral porosity is concentrated in the low-angle backsets and topsets of the eolianites, not in the high-angle foresets or interdune swale. Tormey (1999) further demonstrated that the character and abundance of fenestrae in lowland chevrons

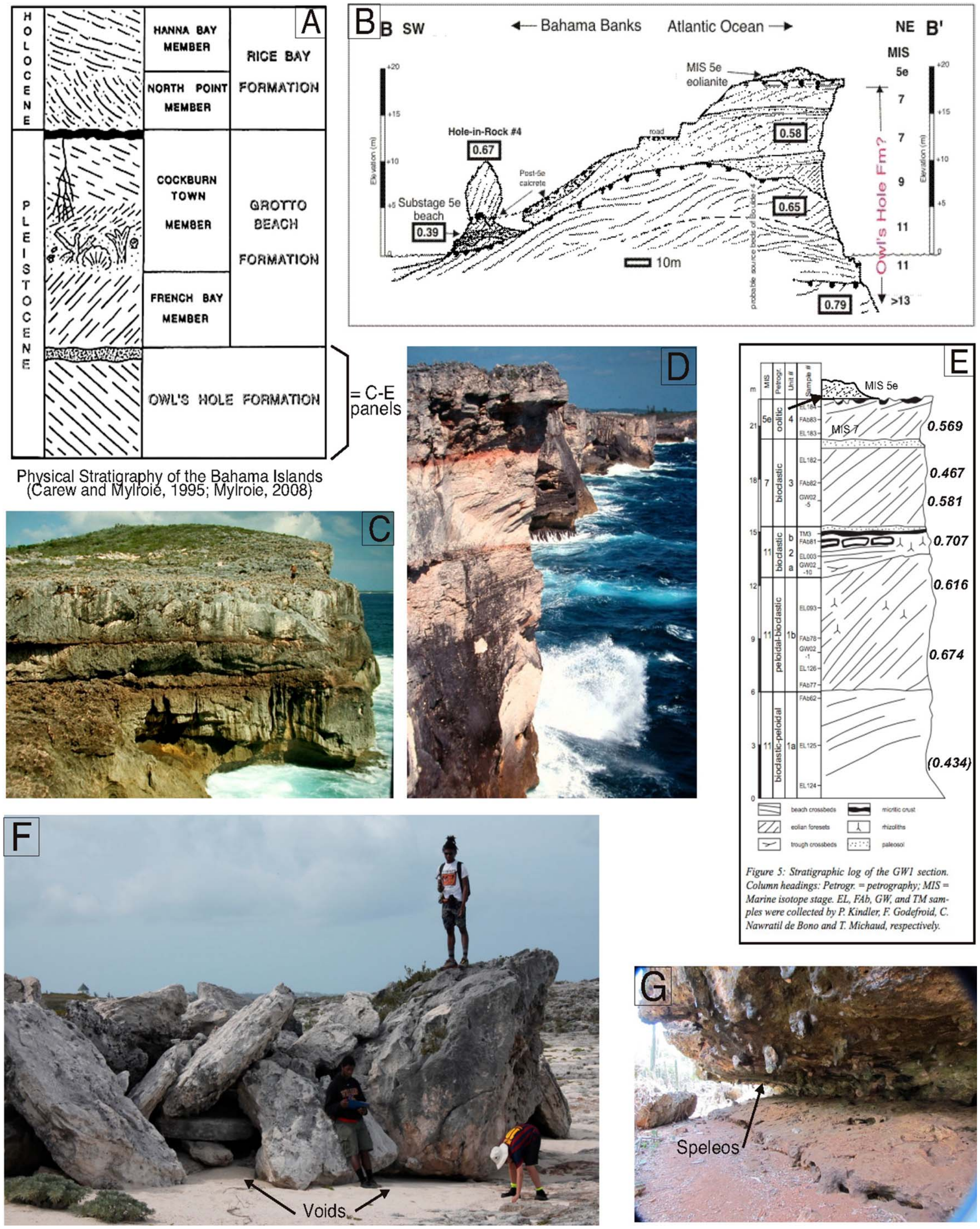

Figure 1. Illustrations of stratigraphic columns and other features related to this reply: (A) The stratigraphic column of Carew and Mylroie (1995) and Mylroie (2008) for comparison with the following. (B–E) Stratigraphic cross sections and photos of predominantly mid-Pleistocene strata just north of Glass Window Bridge (Figure 1B, D; Hearty, 1997, 1998) compared with a schematic section (E) in the same area by Godefroid, Kindler, and Nawratil de Bono (2010). (C) Middle Pleistocene strata (*Geology* cover photo, Hearty *et al.*, 1999, 27[4]) at Goulding Cay Quarry just 1.2 km SE of the boulders. (F) Holocene and recently transported boulders 1 km NW of the megaboulders showing abundant voids beneath them. Cave formation *per se* is not required to explain the voids beneath the megaboulders. (G) Speleothems formed in a laterally extensive MIS 5e wave-cut notch at ∼+15 m on the tectonic island of Curaçao. (Color for this figure is available in the online version of this paper.)

Table 2. *Stratigraphic units defined by Kindler and Hearty (1996, 1997).*

Stratigraphy of Bahamian islands (modified from Kindler and Hearty, 1996)

Name (Unit of Kindler and Hearty, 1996)/Descriptive notes
Stage-1 bioclastic calcarenite (Unit VIII). Multiple generations of beach and eol. deposits. Usually rests on Pleist. limestones; locally overlies stage-1 oolite. Eol. ridges (>40 m elev. on Lee Stocking I.) capped by sandy brown soil and thick vegetation. Grains preponderantly bioclasts; some peloids and ooids, probably reworked. A/I[1] ~0.09.
Stage-1 oolite (Unit VII). Small unit, along island strandlines; partly submerged, low-elev. eolianite remnants. Predominantly superficial ooids and peloids. DG[2], I–II. Youthful morphology of landforms. A/I[1], ~0.1.
Substage-5a bioclastic calcarenites (Unit VI). Well-preserved eol. ridges on windward islands bordering shelf margin. Except for some basal samples that may contain reworked ooids, grains are pristine bioclasts, largely made of coral and red algae. Barely altered; DG[2], II; Mg-calcite retained in some samples; sparry cement rare. A/I[1], 0.29–0.31.
Early and late substage-5e oolites (Units IV and V). Occur throughout Bahamas, including the highest hill (63 m, Cat I.). Include two sets of fossil shoreline deposits, both with various features indicating reef, shoreface, foreshore and backshore (incl. eolian and washover) environments. Grains preponderantly thickly coated, tangential ooids and peloids, still aragonite; bioclasts rare, esp. in older unit. DG[2], III–IV. Associated karst features include vert. dissolution pits, but not the horiz. conduits and phreatic caves common in stage 9/11 limestones. A/I[1], 0.35–0.43.
Stage-7 bioclastic calcarenites (Units II and III). Seen in vert. superposition between 5e and 9/11 and older units in Eleuthera, where it consists of two bioclastic deposits separated by a sandy, orange protosol. Consists of altered bioclastic frags, mostly benthic forams and red algal debris. DG[2], IV; meteoric cements <10%; metastable minerals present in some samples; micrite envelopes rarely filled. A/I[1], 0.53–0.58.
Stage-9/11 oolitic-peloidal limestones (included in Unit I). Usually occur inside islands or at base of retreating seacliffs. On Eleuthera, constitute bulk of some high cliffs. Incl. two similar units showing marine and eolian facies, separated from each other by terra rossa or deeply karsted surface. Separated from younger rocks by mature paleosol. Oolitic-peloidal grainstones; typically <15% bioclasts. DG[2], IV; constituents commonly leached; several generations of meteoric and marine cements; some remaining aragonite. A/I[1], 0.64–0.68.
Stage-13(?) bioclastic calcarenites (not identified; Unit 0). Recently identified on n. Eleuthera where it occurs at base of seacliffs composed of stage-9/11 limestones. Consists of altered bioclastic fragments, mostly benthic forams and algal debris. Highly altered; DG[2], V; little primary porosity; several generations of meteoric cement; spar-filled micrite envelopes; no metastable minerals remain. Occurs below dark red, clay-rich soil.

1. Whole-rock AAR ratios, from Table 2 in Kindler and Hearty (1996).
2. Diagenetic grade, concept developed by Land et al. (1967).

(Hearty and Tormey, 2017, their Figure 10AB) were noticeably different from those of high-elevation eolianites (Hearty and Tormey, 2017, Figure 10C), a critical distinction that Mylroie (2018) apparently missed.

Kindler and Strasser (2000) argued that associated eolian bedding structures support a strictly eolian origin for supratidal fenestrae. Hearty, Tormey, and Neumann (2002) countered that a mix of wave and eolian structures is typical of supratidal environments, particularly during and after storms, and that MIS 5e chevrons contain both waterlain fenestral bedding and eolian structures (Hearty, Neumann, and Kaufman, 1998; Tormey, 1999).

Mylroie (2018) stated, "There is no convincing evidence presented by Hearty and Tormey (2017) to disprove the rainfall slurry." We ask, how does one provide evidence to disprove something that is virtually unknown in the geologic record? Proponents of the rainfall slurry model are encouraged to publish in reputable journals independent stratigraphic descriptions, and supporting first-hand documentation (in a rainstorm) of this elusive process. If seasonal rainfall creates fenestrae in dunes, it should be universally observed in carbonate eolianites of all ages.

REGARDING THE CLOSE INSPECTION OF OUTCROPS

Outcrop maps precisely locating sedimentary structures (*e.g.*, fenestrae, rip-up clasts, scour, protosols, roots) in MIS 5e chevrons and eolianites have been produced from several islands (*e.g.*, Hearty, Neumann, and Kaufman, 1998; Tormey, 1999; Tormey and Donovan, 2015). Tormey (1999) also

Table 3. *Summary of whole-rock A/I values from MIS 5e, 7, 9/11, and >13 rocks (post-5e data not included; stratigraphy trumps AAR) from Eleuthera Island. Aggregate mean values are provided for stratigraphic units. The basal units from The Cliffs, Boiling Hole, and Goulding Cay Quarry are stratigraphically the oldest unit in Eleuthera. The amino acid concentration from this Unit 0 (Kindler and Hearty, 1996) is generally too low (reflecting great age, diagenesis, and recrystallization) to yield reliable A/I values. Samples in bold indicate samples beneath the megaboulders (MIS 5e), or from the megaboulders themselves (MIS 9/11 or >13). Samples were prepared by P.J. Hearty and analyzed at the Amino Acid Geochronology* Laboratory *in Flagstaff, Arizona (D. Kaufman, Director).*

Lab #	Field #	Locality	Unit†	Pet. ‡	Age§	A/I¦¦	SD	Excl.¶
1275A	EHA1a	Hatchet Bay East	IV/V	Sk/Oo	5e	0.406	± 0.007	
1275B	EHA1a	Hatchet Bay East	IV/V	Sk/Oo	5e	0.388	± 0.008	
1094B	ETP1c	Two Pines	IV/V	Oo	5e	0.370	± 0.001	
1104C	ETP1c	Two Pines	IV/V	Oo	5e	0.356	± 0.008	
1094A	ETP1a	Two Pines	IV/V	Oo	5e	0.301	± 0.014	
1104B	ETP1a	Two Pines	IV/V	Oo	5e	0.339	± 0.008	
1467A	ERC2a	Rainbow Cay	IV/V	Oo	5e	0.369	± 0.006	
1567A	EWP2i	Whale Point	IV/V	Oo	5e	0.395	± 0.002	
1094D	ESV1c	Savannah Sound	IV/V	Oo	5e	0.345	± 0.005	
1094C	ESV1a	Savannah Sound	IV/V	Oo	5e	0.403	± 0.004	
1563A	EBH1d	Boiling Hole	IV/V	Oo	5e	0.407	± 0.003	
1564A	ECH2i	Cotton Hole	IV/V	Oo	5e	0.372	± 0.010	
1814A	**EMB2o**	**Beneath Cow and Bull**	IV/V	**Oo**	**5e**	**0.400**	± **0.003**	
1812A	**EMB4e**	**Beneath Hole in Rock**	IV/V	**Oo**	**5e**	**0.385**	± **0.004**	
2531	EAJ1a	Airport Junction	IV/V	Oo	5e	0.238	± 0.020	RU
2532	ELI1a	Licrish Hill	IV/V	Oo	5e	0.319	± 0.008	RU
2533	EEB1a	Eastern Bluff	IV/V	Oo	5e	0.387	± 0.014	
2534	ESP2a	Sweeting's Pond	IV/V	Oo	5e	0.381	± 0.001	
MIS 5e aggregate mean = 0.364 ± 0.044 (N = 18)								
1388D	EGW1h	Glass Window	III	Sk	7	0.569	± 0.022	
1388C	EGW1f	Glass Window	III	Sk	7	0.581	± 0.023	
1101A	ETC2a	The Cliffs	III/0	Sk	7/13	0.576	± 0.008	
1101B	ETC2c	The Cliffs	III/0	Sk	7/13	0.352	± 0.004	RC
1568AB	ETC1e	The Cliffs	III/0	Sk	7/13	0.339	± 0.018	RC
MIS 7 and/or >13 = not calculated								
1565AB	ECH1c	Cotton Hole #1	I	Oo	9/11	0.510	± 0.045	RC
1388B	EGW1d	Glass Window	I	Oo	9/11	0.616	± 0.021	
1566A	ECH1a	Cotton Hole #1	I	Oo/pel	9/11	0.651	± 0.019	
1387B	EGC1d	Goulding Cay Quarry	I	Oo	9/11	0.632	± 0.013	
1682A	EGC6f	Goulding Cay Quarry	I	Oo	9/11	0.716	± 0.023	
1389A/1561A	EGC3f	Goulding Cay Quarry	I	Oo	9/11	0.712	± 0.177	
1392A	EGC2c	Goulding Cay Quarry	I	Oo	9/11	0.561	± 0.026	
1675A	EGC2c	Goulding Cay Quarry	I	Oo	9/11	0.708	± 0.000	
1676A	EGC2d	Goulding Cay Quarry	I	Oo	9/11	0.625	± 0.010	
1677A	EGC3d	Goulding Cay Quarry	I	Oo	9/11	0.670	± 0.023	
1679A	EGC5eII	Goulding Cay Quarry	I	Oo	9/11	0.631	± 0.007	
1387A	EGC1c	Goulding Cay Quarry	I	Oo	9/11	0.678	± 0.024	
1816A	ECC1a	Cupids Cay	I	Oo	9/11	0.699	± 0.001	
MIS 9/11 aggregate mean = 0.647 ± 0.061 (N = 13)								
1673A	EBH3aa	Boiling Hole	0	Sk	>13	0.283	± 0.000	RC
1392B	EGC2a	Goulding Cay Quarry	0	Sk	>13	0.789	± 0.036	
1680A	EGC6c	Goulding Cay Quarry	0	Sk	>13	0.401	± 0.082	RC
1681A	EGC6a	Goulding Cay Quarry	0	Sk	>13	0.300	± 0.021	RC
1674A	EGC2a	Goulding Cay Quarry	0	Sk	>13	0.391	± 0.006	RC
1388A	EGW1c	Glass Window	0	Sk	>13	0.434	± 0.013	RC
MIS >13 (0.5 Ma) = very low concentrations/values; due to age; not calculated#								
Whole-Rock A/I of Megaboulders								
1815A	**EMB1**	**Bull #1**	**I**	**Oo/pel**	**9/11**	**0.604**	± **0.008**	
1809A	**EMB2g**	**Cow #2**	**I**	**Oo/pel**	**9/11**	**0.734**	± **0.019**	
1811A	EMB3	Maverick #3	I	Oo/pel	9/11	0.667	± 0.016	
1813A	EMB5	Twin Sisters #5	I	Oo/pel	9/11	0.619	± 0.013	
1810A	**EMB4g**	**Hole-in-Rock #4**	**0**	**Sk**	**>13?**	**0.737**	± **0.025**	
Megaboulder aggregate mean = 0.672 ± 0.062 (N = 5)								

†*Petrostratigraphic units defined by Kindler and Hearty (1996, 1997) and Table 2 herein.*

‡*Petrologic composition (determined by hand lens and thin section): Oo = oolitic sand; Sk = skeletal; Pel = peloidal.*

§*Age = correlation with marine oxygen isotope stages based on field relationships, petrology, soils,* etc. *(see text for discussions and references).*

¦¦*A/I = mean A/I ratio ± 1 SD calculated from at least three injections of single sample.*

¶*Exclusions of sample data from calculation of group mean A/I values were based on the following criteria: RC = rejected on the basis of very low concentration of amino acids; RU = rejected for unknown reasons and/or conspicuously out of stratigraphic order.*

#*Carbonates ≥0.5 Ma (>MIS 13 or older) are expected to be diagenetically altered and recrystallized* (e.g., Land, Mackenzie, and Gould, 1967) *and depleted in amino acids.*

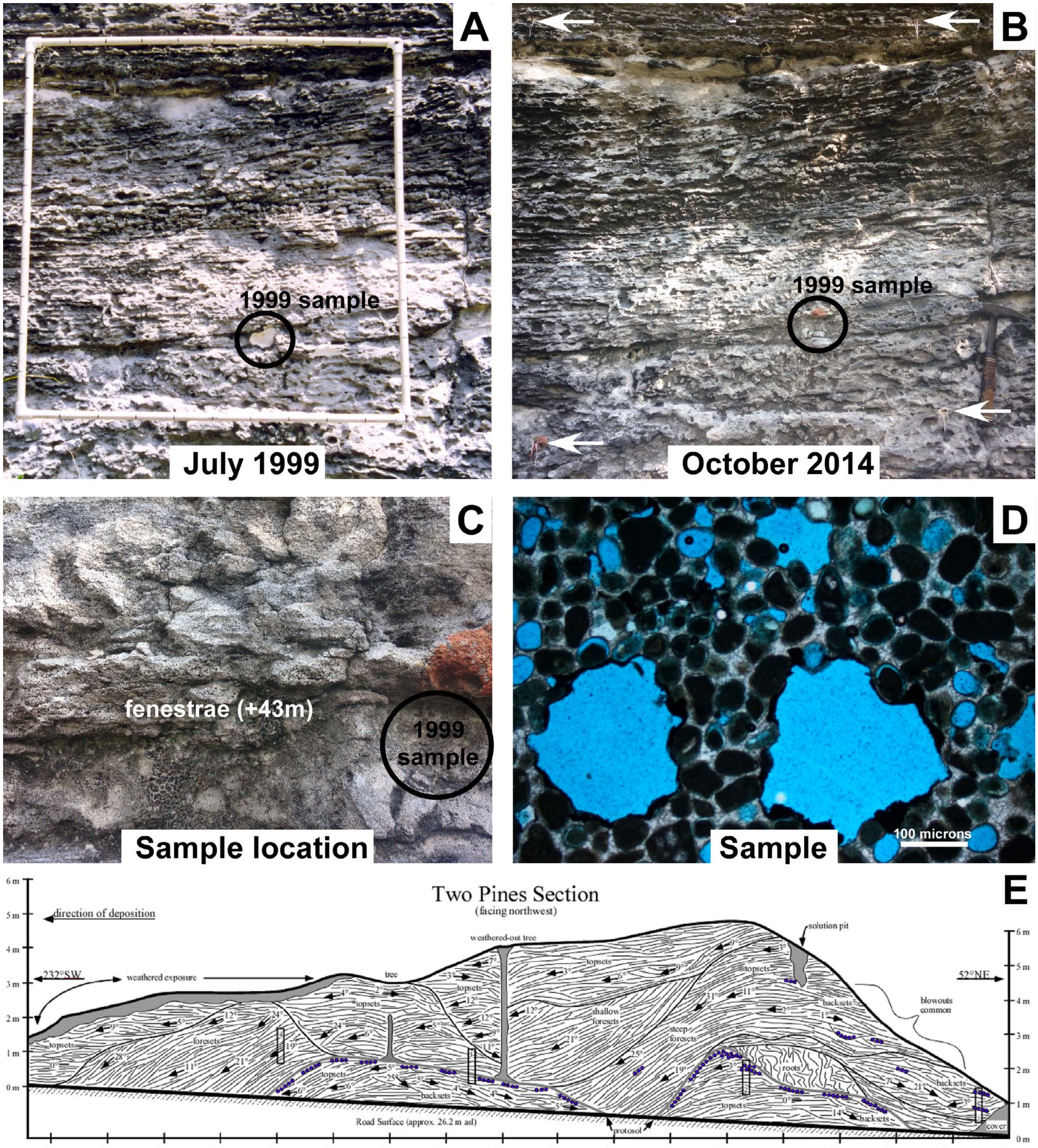

Figure 2. (A–D) A single 1 m^2 of outcrop at Annie Bight, Eleuthera (+43 m), described and sampled by Tormey (1999). The location is 49.7 m from NE end of the road cut, in the south highwall, 1.3 m above the road. Tormey (1999) reported six distinct fenestral beds in this 1 m^2, up to 3 cm thick. The 1 m^2 was photographed (A) in July 1999, and again (B) in October 2014. The nails, string (white arrows), and paint marking the 1 m^2 PVC frame in 1999 were still present at all the sites in 2014. (C) The sampled fenestral horizon can be traced laterally for 6 m, with a tabular dip of $<2°$ seaward to the NE. (D) Thin section confirms equant fenestrae. (E) Detailed outcrop map of the road cut at Two Pines, Eleuthera (+26 m). Note the fenestral horizon (dots) beneath the recognized protosol, as well as fenestral horizons above. (Color for this figure is available in the online version of this paper.)

collected comprehensive statistical data on primary structures (*e.g.*, abundance and orientation of laminae and fenestral beds in a 1 m^2 polyvinyl chloride frame; repeated 36 times) at 10 localities on Eleuthera (Figure 2A–D).

Mylroie (2018, his Figure 2) asserted that we misinterpreted clasts within a protosol at Two Pines, Eleuthera, as "storm surge rip-ups" (Mylroie, 2016), and "the result of washover scour" (Mylroie, 2018). This assertion is simply not true. Tormey (1999, pp. 38–40) thoroughly described this "protosol" (as defined by Vacher and Hearty, 1989) at Two Pines. There is no association of the protosol with runup; rather the latter features occur lower in the section (Figure 2E). Mylroie (in Kindler et al., 2010, p. 29) also reported the "occurrence of fenestral porosity in the lower unit suggest[ing] the possibility of marine washover[sic]" at Two Pines.

We have documented rip-up and scour at multiple localities (Hearty and Tormey, 2017, Figures 11–12), in some cases with scour structures indicating *uphill flow* at +23 m (Hearty, Neumann, and Kaufman, 1998, Figures 7–8). Despite this, Mylroie (2016) stated: "...the dunes at all elevations show no evidence of scour." As Tormey (1999) demonstrated, finding the evidence requires close, detailed inspection of each outcrop. Rather than dismissing the evidence as "myth" (Mylroie, 2016), might it be that some are not looking closely enough?

REGARDING THE MEGABOULDERS

Boulder names, numbers, and descriptions (Bull #1, Cow #2, Maverick #3 [mid island], Hole in Rock #4] 0.3 km, Soundside shore], and Twin Sisters #5 [0.5 km in Exuma Sound]) have been published in Hearty and Kaufman (2000, Appendix A) and Hearty and Tormey (2017, Supplement, p. 7). Since 1997, we have described the "local phenomena" surrounding the megaboulders, including the unique, deep horseshoe bathymetry and paleogeomorphology. Mylroie (2018, p. ##) stated, "the boulders were far bigger when they were emplaced...," and we agree, having noted in previous publications the: "...high erosion and dissolution rates on the exposed surfaces" (Hearty, 1997, p. 332), and "increased density by cementation, and decreased volume by dissolution of the rocks...over the past 120 kyr" (Hearty and Tormey, 2017, p. 354).

REGARDING A SUBBOULDER PALEOSOL

There is no *terra rossa* soil between the megaboulders and underlying MIS 5e oolite. Hearty (1997, p. 332) stated: "The pedogenic calcrete encircles the base of the boulders, marking the previous level of the land surface, and is not developed on the strata beneath them" (Hearty, 1997, Figure 7C, p. 334).

The voids beneath the boulders contain speleothems, which necessarily must have formed after the boulders were deposited. Accordingly, U/Th ages confirm younger, post–MIS 5e ages. The earliest flowstone (2–3 mm) that developed on the MIS 5e oolite beneath the largest boulder Bull #1 produced a U/Th age of 109 kyr. A 46-mm-thick flowstone beneath boulder Hole-in-Rock #4 produced U/Th ages 90–64 kyr (Hearty and Tormey, 2017, Figure 8). Viret (2008) analyzed two additional samples from one stalactite formed on the base of Boulder #2, which yielded ages of 82 and 56 kyr, respectively.

REGARDING SUBBOULDER "CAVES" AND SPELEOTHEMS

Mylroie (2018) faulted us for not addressing a "cave issue," maintaining that caves were formed at the base of the boulders by a "freshwater body...at least 2 m thick." We disagree with both the cave formation and groundwater model. Many Holocene megaclasts have voids beneath them (Figure 1F). Irregular surfaces may have formed before the rocks were transported. Other possible mechanisms are fracturing during transport, post-transport mechanical erosion of the softer sediments beneath them, and/or dissolutional processes, including the focus of rain and seawater by the flagging of tall boulder structures.

Speleothems beneath the boulders also are not necessarily diagnostic of "caves" (Figure 1G). On Cayman Brac, Jones (2010, p. 15) described the formation of speleothems in MIS 5e wave-cut notches, stating, "Speleothems...are typically associated with mineral precipitation in the dark, enclosed environments of caves. Such precipitates, however, are not confined to caves because they can grow wherever water drips from bedrock into an open cavity or from an overhanging ledge." U/Th dating showed the speleothem growth coincided with the MIS 5a to 4 and MIS 2 to 1 transitions, long after the notch was cut during MIS 5e. (Jones, Zheng and Li, 2018).

REGARDING KARST TOWERS

Mylroie (2018) stated, "The tower karst model was presented as a possible alternative to a bank margin collapse, tsunami, or storm origin for the boulders...but the tower karst model has not been disproved" and he asks "...where are all the other [transported mega-] boulders?" Our initial reaction: Where are all the other karst towers or "*karrentisch*?"

The formation of tower karst as modeled by Mylroie (2008, 2018) requires a specific series of major erosional and dissolutional events to fortuitously occur in a complex paleotopographic setting of high-relief dune and swale, all traces of which apparently have completely disappeared, leaving only the megaboulders. The implication is that this process, along with 2 m of fresh groundwater, occurred at each of the seven megaboulders in their own unique settings and topography, and nowhere else in BTC. The tower karst hypothesis could be easily tested by stratigraphy and petrography, but it is already disproven by the published stratigraphy of the cliffs strata (Figure 1B–D). Finally, the karst tower idea is directly contradicted by both of Mylroie's (2018) alternatives of roll down and margin failure.

REGARDING ROLLING AND SLIDING OF MEGABOULDERS

As in Table 1, Hearty and Tormey (2017, 2018) have repeatedly maintained that the boulder site cliff stratigraphy does not accommodate the "cliff-top, roll-down" hypothesis of Rovere *et al*. (2017, 2018). Despite this, Mylroie (2018, p. xx) persisted: "Wave energy need not be enough to lift blocks up and over a sea cliff, but only enough to fracture the cliff edge such that the boulders roll or slide downslope landward onto the younger, on-lapping eolianites to create both the age inversion and dip of beds reported by Hearty and Tormey (2017)."

Mylroie's (2018) model (his Figure 6) from The Cliffs (22 km SE) is misleading. In reality, the average seaward slope of the outcropping middle Pleistocene cliffs around Cow and Bull is considerably less (see Figures 1B–D), making it just as likely that the paleocoast sloped *downward* hundreds to ~1000 m further seaward.

We challenge the "cliff-top, roll-down" hypotheses for the following reasons:

(1) Mylroie (2018) and Rovere *et al*. (2017, 2018) avoided the fact that some of the boulders are far from the present Atlantic coastline. Twin Sisters #5 boulder is deposited on the sound side, 0.5 km west of Cow and Bull. How much further did they roll down, or up, on a wider, low-profile paleocoastline 120 ka ago…greater than 1 km?

(2) Regardless of greater distance or slope of the paleocoastline, far more energy would be required than the 10 m/s velocity estimated by Rovere *et al*. (2017) to transport the Cow and Bull boulders from the present coastal cliff. Without knowing the stratigraphy and source of the megaboulders (Table 1; Figure 1; Hearty and Tormey, 2018), the calculation of hydrodynamic forces of boulder transport is a stab in the dark.

(3) "With the exception of the exposed cliff faces (probable source of the [mega]boulders), most of the study area is mantled by at least two sequences of younger rocks that are less diagenetically altered than the [mega]boulders." (Hearty, 1997, p. 330, Figures 4–5).

(4) No "supersized" boulders are found near modern sea level, nor are chevron and runup deposits observed in Holocene dunes. All the physical elements of the late Pleistocene at the megaboulder site (exposed cliff strata, deep horseshoe-shaped bathymetry, and a powerful ocean) are still present, "locked and loaded." If current storms were capable of moving rocks the size of the megaboulders, they would have done so over the last several millennia since sea level approached the present datum.

REGARDING A CATASTROPHIC END OF MIS 5e

Our superstorm trilogy provides a snapshot of the past impacts of climate change in the Atlantic Ocean at the close of MIS 5e. Our hypotheses are supported by dozens of sites and hundreds of analyses in multiple disciplines, published in numerous peer-reviewed papers (Table 1). Our trilogy demonstrates the differential effects of large waves crashing onto the coastal geomorphology of the BTC. Giant waves are not likely attributed to local hurricane events, but more likely super versions of the "Perfect Storm" (late October 1991) in the North Atlantic Ocean. We recognize there may be alternative hypotheses, but at this time, the lion's share of field evidence points to superstorms impacting coastlines across the BTC at the end of MIS 5e.

Our current climate is being dramatically altered by the extraordinary events of the Anthropocene: We can observe and document rapidly rising CO_2 levels, global air and ocean temperatures, and acidification of the oceans; disappearing Arctic summer sea ice; increasing frequency of extreme weather events; and rising sea levels. Extreme caution is advised as our studies of past natural cycles indicate ominous signs of potential severe effects of climate change in the future.

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