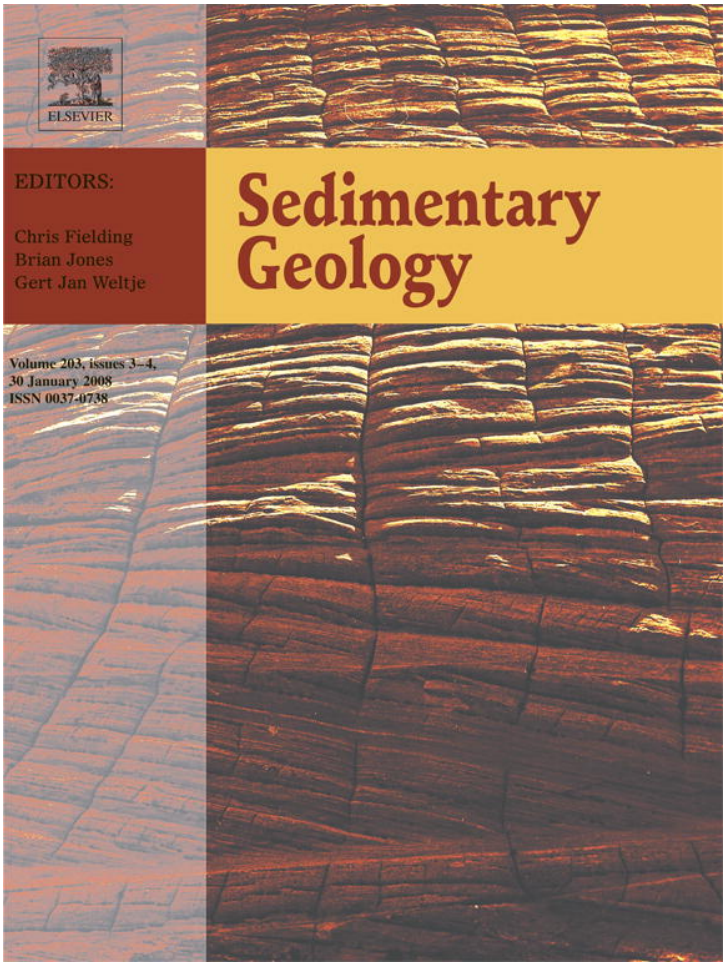

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Discussion

Mega-highstand or megatsunami? Discussion of McMurtry et al. (Elevated marine deposits in Bermuda record a late Quaternary megatsunami: Sed. Geol. 200 (2007) 155–165)

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Abstract

Graded, sorted, rounded, and ponded marine sand and conglomerate deposited in caves and on an erosional terrace at +20 m on Bermuda, previously interpreted as originating in a eustatic highstand of sea level during the middle Pleistocene, were reinterpreted by McMurtry et al. (2007) as the result of a great 20 m megatsunami at sea, propagating out across the North Atlantic from the Canary Islands, cresting, and rolling up and over the Bermuda platform. However, no middle Pleistocene tsunami deposits have been reported elsewhere on Bermuda or anywhere else around the North Atlantic rim. The tsunami origin is unsupportable whereas the available evidence unequivocally establishes a +21 m eustatic sea level during the middle Pleistocene MIS 11 interglacial.

Keywords: Bermuda; Eustatic highstand; Tsunami; MIS 11; U/Th dating

1. Introduction

Land et al. (1967),Vacher (1971),Hearty et al. (1999), and Kindler and Hearty (2000) previously described +20 m highstand deposits in Bermuda and attributed them to a eustatic sea level. These deposits were confirmed to be the result of a sustained highstand correlated with the Lower Town Hill Formation (Vacher et al., 1989) and the marine isotope stage (MIS) 11 highstand (Hearty et al., 1992; Hearty et al., 1999; Hearty et al., 2007a) based on a diverse set of field and laboratory methods.

McMurtry et al.(2007) considered that these elevated marine deposits are "inconsistent with intertidal deposition over an extended period", and they interpreted the origin of marine conglomerates from two "Dead End" caves (sites UGQ4 and UGQ5) in Government Quarry (Fig. 1), Bermuda, as the result of "rapid deposition, perhaps of a high density debris flow" from a "megatsunami", generated by a flank margin collapse of a Canary Island volcano. The extrapolation from mass wasting event to 20-m megatsunami at sea is purely hypothetical and unsupported by any evidence provided.

2. The issues

2.1. Supposed variation in elevation of the deposits between +18 and +28 m

McMurtry et al. emphasize the range of elevations of marine deposits on Bermuda (Fig. 1) are between +18 m and +28 m (Land et al., 1967; Vacher, 1971); although the supposed +28 m site was quarried away over 30 years ago. Hence, their reinterpretation is based on publications, old photographs, one cave site at UGQ5 at +18 m, and archived samples at the Bermuda Museum. From this, McMurtry et al. concluded that the "episodic transport…of sediments…into karst caves…ranging from +18 to +28 m", is better explained by "a wave set that carried sediments from the surrounding reef platform and nearshore waters to elevations of more than 20 m".

The upper +28 m limit was only a field estimate described as being "at *approximately* 28 m above mean sea level" (Land et al. 1967: p. 2003, our emphasis). Land (in litt. to PJH 19 Jan 2007)

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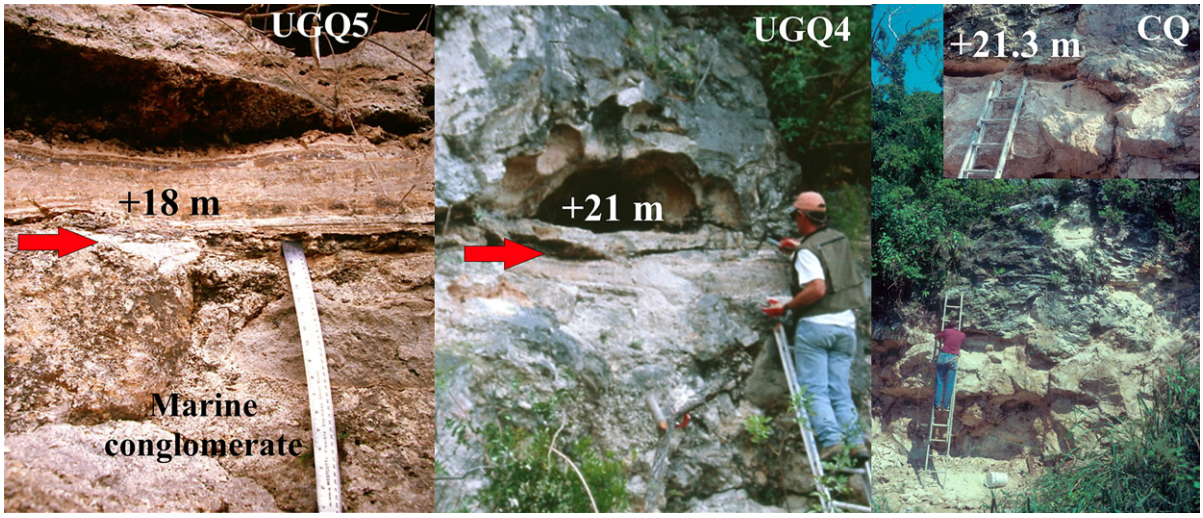

Fig. 1. Photographs of cave UGQ5 and UGQ4 showing the upper flat or "ponded" surface of the marine deposits (arrows). The moderately sorted, graded, and ponded sediments could only be the result of the action of waves and swash during a sustained sea level. Calonectris Quarry (CQ) was surveyed by the Bermuda Ministry of Works in 1984 at 70.00±0.08 feet (+21.3 m).

recently indicated that he "wouldn't place any confidence on the actual elevations other than the one surveyed by Olson [see below]" and described the marine sediments as "relatively coarse and reasonably well sorted…deposited against an eroded cliff, which doesn't suggest a tsunami deposit." Fred T. Mackenzie confirmed (in litt. to PJH 16 Jan 07) that his sketch and notes reproduced in our Fig. 2 represent the stratigraphy of the deposit and that "approximately 70 feet was my best guess when the (hand) sample was archived." He further described the deposit as "consisting of a basal layer of shell material and erosional debris from the Walsingham…deposited in an erosional nip in the Walsingham cliff, very similar to (that at) Hungry Bay" on the South Shore of Bermuda (our Fig. 3). In any case, the land surface in the vicinity of Government Quarry nowhere extends as high as +28 m, so that number has no validity.

The only benchmark survey of the elevated marine deposits at Government Quarry was made at the request of Olson in 1984 after excavating two small "pockets" of fossiliferous marine sands and other marine deposits from his "Calonectris Quarry" (Olson and Hearty 2003, Olson et al. 2005) (Fig. 1C). Bermuda's Ministry of Works surveyed the horizontal deposit at precisely 70.00±0.08 feet (+21.3 m). This survey of Calonectris Quarry, located within 10 m of "Dead End Cave #1" (UGQ4), provided a datum from which we were able to establish the approximate elevation (±0.5 m) of the deposits by tape and hand level in both Dead End caves (Hearty et al., 1999). The close proximity and similar elevation of the deposits at Calonectris Quarry and UGQ4 hints that these speleogenic features might have been connected underground. Hence, the actual range in elevation of the marine deposits on Bermuda is 4 m between +18 and +22 m. This range corresponds with other described middle Pleistocene shoreline deposits in the Bahamas (Hearty et al., 1999), UK (Bowen, 1999), and the Arctic (Kaufman and Brigham-Grette, 1993). There is probably little significance in McMurtry et al. noting c. +34 m marine deposits in South Carolina, Virginia, and Mallorca because the ages of these deposits were not established and none are considered to have a tsunami origin.

2.2. The sedimentology of the deposits and conflicting interpretations

McMurtry et al. describe the cave deposits as poorly-sorted, fining-upward sand to conglomerate with a greater abundance of marine fossils higher in the section. They further propose that the cave deposit at UGQ5 could not be "a beach deposit" as it contains "no internal stratification (and) no indication of seaward dipping beds", or "foreset bedding that might be expected from dunes or washover deposits." They argue that one massive fining-upward unit in UGQ5, or alternatively, "the presence of two units" (?) were the result of "rapid deposition, perhaps from a high density debris flow". They describe the "grading exhibited by the cave deposits (as) clearly consistent with that expected for a tsunami deposit," yet offer neither citation nor examples of tsunami deposits showing such consistent characteristics.

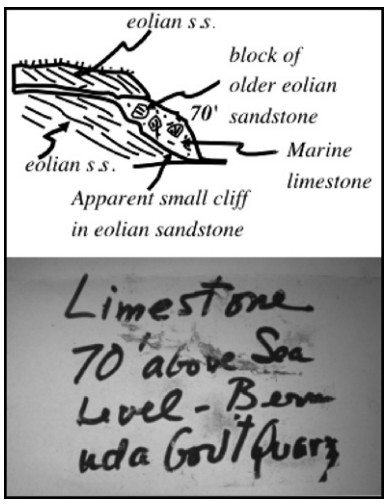

Fig. 2. Hand written sketch and notes by F. T. Mackenzie (accurately reproduced digitally by PJH) accompanying hand sample from "70′ [feet]" in Government Quarry, archived at BAMZ.

Fig. 3. An "erosional nip" (arrow) at Hungry Bay, South Shore, Bermuda formed during a fluctuating sea level during MIS 5e (Hearty et al., 2007b). F.T. Mackenzie indicated that the 70 foot "erosional nip" in Government Quarry was similar to this site.

In contrast, the deposits filling the Bermuda caves resemble those found along many mixed rocky-sediment limestone coastlines of the world. They were interpreted as "poorly sorted" by McMurtry et al. and "reasonably well sorted" by Land (quoted above) and ourselves. We might perhaps agree they were "moderately sorted", keeping in mind that any level of sorting requires the element of time and oscillatory "swash" effects of waves. "Rapid deposition, perhaps from a high density debris flow" is inconsistent with the physical characteristics of the deposits in coastal caves.

In a tsunami, one would expect widespread distribution of mixed marine sediments and terrestrial "debris" (angular rocks, soil, vegetation, etc.) torn from the shelf and island as well as scouring of existing bedrock, soils, and vegetation on tsunami-facing slopes (including the cave sites), with mixtures of angular marine and terrestrial ripup "debris" being deposited in leeward pockets as flow velocity decreased. Although exposed contacts between the Walsingham, Lower Town Hill, and Upper Town Hill formations have been located, observed, correlated, and mapped across Bermuda (Vacher et al., 1989), and even more closely scrutinized since (Hearty et al., 1992; Hearty and Vacher, 1994; Vacher et al., 1995; Olson and Hearty, 2003), no tsunami deposits have ever been recognized. In extensive cliff, road, quarry and construction exposures across Bermuda, and those within and near Government Quarry, rocks at the contacts of formations (Fig. 4A), and within early Pleistocene dolines and pits (Fig. 4B) in the lee of the postulated waves contain no tsunami debris. Nor has any debris of this type ever been documented around the Atlantic rim. Furthermore, McMurtry et al. provide no photographs, literature citations, geological records, or any other documentation of megatsunami deposits in or outside caves to support their hypothesis.

It is difficult to imagine how a wave 20 m high moving at hundreds of km/h, rolling up, cresting, and almost certainly washing over the entire 1000 km^2 Bermuda platform could create the observed rounded conglomerates and delicate structures. At such speed, water would instantaneously seal and fill the caves, and explosive outward blasts of compressed air, water, and sediment (if present) would presumably result. Such conditions would not result in well-rounded, moderately sorted, and ponded marine sediments (Fig. 1), along with exquisitely preserved delicate vertebrate and invertebrate fossils (Olson and Hearty, 2003; Olson et al., 2005, 2006). We interpret the above features as the result of attenuating wave energy as the cave fills with sediments along a predominantly quiet shoreline.

2.3. Post-depositional cementation: petrography of binding cements in marine sediments

The authors identify three possible phases of cementation of the marine sediments, the first existing only "within clasts", and "probably… marine vadose," the second meteoric phreatic, and the third meteoric vadose. Marine cements occurring only *within* (our emphasis) micro organisms was explained by the original sediment being "laid down in a marine environment, probably on a beach" and was later "eroded and redeposited in the cave at 28 m elevation, where the early cementation was under freshwater phreatic conditions." Thus, to accommodate the megatsunami

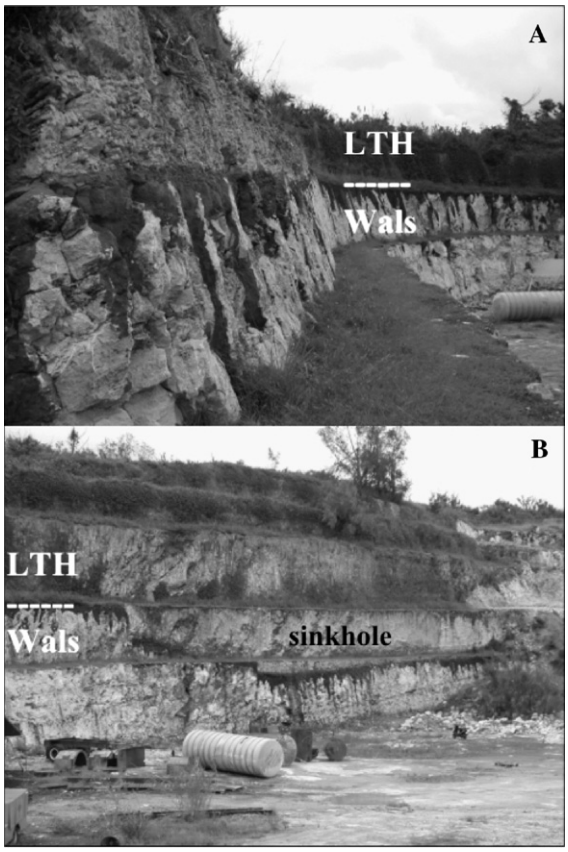

Fig. 4. (A). The Walsingham-Lower Town Hill (Wals-LTH) contact in Wilkinson Quarry, located ~2.5 km NW of GQ. (B). Collapse sinkhole in the early Pleistocene Walsingham Fm, filled with Lower Town Hill eolianite sediments. Had a megatsunami struck Bermuda around the time of Lower Town Hill deposition, depressions such as these would be most likely filled with clastic marine and terrestrial ripup debris. Despite detailed mapping of all of Bermuda, no such deposits have ever been found.

hypothesis, the sediments were cemented previously along a distant beach of unknown elevation, from which they were subsequently eroded, transported, and deposited into two caves and a nip high on the island (and nowhere else), where second and third generation cements were formed.

For cementation to occur under "freshwater phreatic conditions" more than a few tsunami-scaled hours would be required, as would a Ghyben-Herzberg freshwater lens, which cannot be maintained on a limestone island perforated with vertical and horizontal solution caverns and conduits unless supported by sea level near the same elevation. Therefore McMurtry et al.'s own data controvert their interpretation.

We also dispute McMurtry et al.'s dismissive views regarding isopachous rim cements. Although we presented an excellent example in the photomicrograph in Fig. 3 of Hearty et al. (1999), and three more unambiguous examples of rim cements in Figs. 6, 9, and 10 of Kindler and Hearty (2000), several wider frames are offered here of isopachous rims (indicating prolonged submergence in marine water) and pendant cements (indicating sustained intertidal conditions) from correlated +20 m marine sediments from Bermuda, Bahamas, and Hawaii (Fig. 5).

2.4. The significance of fossil microfauna and macrofauna

McMurtry et al.'s analysis of the microfauna provides some new information about the elevated marine deposits in Government Quarry. They identify biofacies originating from lagoon to back reef environments, which they interpret as having been transported by tsunami from these environments to the caves above +18 m.

The relevance of this new biofacies information as proof of a tsunami is not immediately apparent, as sediments from various environments are known to mix along coastlines from storms, tides, and longshore drift. Sediments reaching the shoreline at +20 m at UGQ should *necessarily* contain contrasting microfaunal and textural properties that reflect shifting sedimentary environments and evolving ecological conditions as the site matures and sea level stabilizes. McMurtry et al.'s microfaunal studies thus demonstrate normal sedimentary processes along the coastline.

The basal sediments in Calonectris Quarry, including those in a vertical pipe, consist of rounded cobbles, angular pieces of calcrete, worn marine invertebrate remains, and other marine derived rubble often with adhering patches of calcareous sand with isopachous cements. These are succeeded by very fine, limey lagoonal silts riddled with worm burrows, and finally by pure beach sand containing a variety of terrestrial and marine vertebrates and invertebrates (Olson and Hearty, 2003; Olson et al., 2005; Grady and Olson, 2006; Olson et al., 2006). Many of these are very delicate and well preserved, e.g. thin skulls and long, slender bones of birds. From the number of individuals and diversity of species, and from the growth stages of one of the seabirds, these fossils had to have been deposited over a period of years and at different times of the year. There is no possibility of this incomparable record of a +21 m sea stand being the result of a several hour-long tsunami event (Olson and Hearty, Calonectris Quarry, in manuscript).

2.5. Past and recent U/Th dating and the timing of deposition

McMurtry et al. provided four new ICPMS ages, with their age from UGQ4 being 312±30 ka, in contrast to our 420±30 ka from the same hand sample (Hearty et al., 1999). Their new flowstone sample produced an age of 360±40 ka, while a bulk sediment age of 476±50 ka reflects the average age of formation of the sediment. McMurtry et al. argue on the basis of the combined flowstone ages (theirs and ours; $N=3$) ranging from 312 to 420 ka that this interval equates with "known" giant debris avalanches in the Canary Islands between 320 and 650 ka

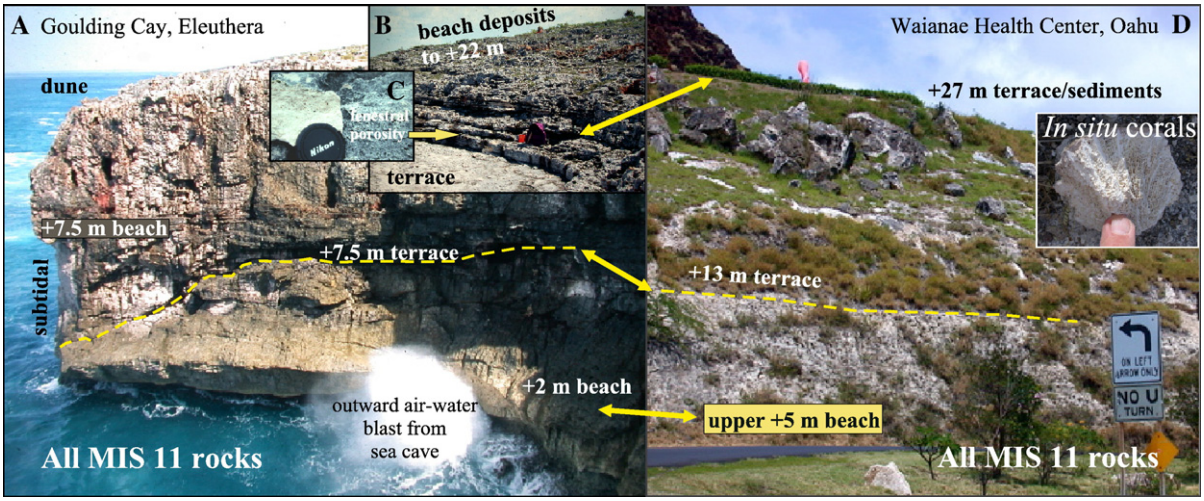

Fig. 5. Vertical stratigraphic sequence at Goulding Cay, Eleuthera, showing the "stepping up" of sea level from +2 m to +7.5 m. The eroded terrace surface at +7.5 m is extends over 40 m horizontally, and required several thousands of years to form. (B). The highest sea-level step at Eleuthera showing an narrow terrace eroded in the lower dune, mantled with beach sediments filled with fenestral porosity (C) up to +22 m. Isopachous fibrous "rim" cements (Fig. 6) document early diagenesis in a marine environment at all sites. (D) Corrected for tectonics, a stratigraphic sequence in western Oahu exposes almost an identical "stepping up" sequence of sea levels as in Eleuthera. A broad, eroded terrace surface at +13 m at Oahu corresponds with the +7.5 m level at Eleuthera. When corrected for uplift, the highest level on Oahu at +28±2 m correlates with the +20 m level in stable locations and contains coral heads in growth position (inset).

Table 1
U/Th dating results on flowstone samples from UGQ4 and UGQ5. The error is 2σ

Sample Number	^{238}U (ppb)	^{232}Th (ppt)	d^{234}U* (measured)	^{230}Th/^{238}U (activity)	^{230}Th Age (ka) (uncorrected)	^{230}Th Age (ka) (corrected)	d^{234}U$_{Initial}$** (corrected)
UGQ5B	26.82±0.03	263±6	2.0±4.7	0.9670±0.0047	364±24	364±24	5.6±13.1
UGQ4e	38.32±0.03	47±5	−16.0±2.7	0.9541±0.0047	405±28	405±28	−50.4±9.5
UGQ5e	109.3±0.1	5222±17	21.0±1.2	1.0049±0.0030	411±15	409±15	66.8±4.8

$\lambda_{230}=9.1577\times10^{-6}$ y^{-1}, $\lambda_{234}=2.8263\times10^{-6}$ y^{-1}, $\lambda_{238}=1.55125\times10^{-10}$ y^{-1}.
*$\delta^{234}U=([^{234}U/^{238}U]_{activity}-1)\times1000$. ** $\delta^{234}U_{initial}$ was calculated based on ^{230}Th age (T), i.e., $\delta^{234}U_{initial}=\delta^{234}U_{measured}\times e^{\lambda234\times T}$. Corrected ^{230}Th ages assume the initial ^{230}Th/^{232}Th atomic ratio of $4.4\pm2.2\times10^{-6}$. Those are the values for a material at secular equilibrium, with the crustal ^{232}Th/^{238}U value of 3.8. The errors are arbitrarily assumed to be 50%.

ago and their assumed link with turbidites in the Madeira abyssal plain. But no one knows more precisely (±100 ka) when the older collapse events occurred, or whether they happened in minutes or hours (possible tsunami); days, weeks, or years (no tsunami).

Another critically important consideration of the tsunami hypothesis is the eustatic position of sea level. The lower the position of sea level, the greater wave height and force would be required to reach the caves at +20 m, so chances of impact on the island surface would be maximized during an interglacial highstand. Depositional potential is greatly diminished as sea level falls, and virtually nullified when the level drops below the platform margin (c.−20 m). Highstands at or above present constitute only a fraction the interglacial-glacial record, thus creating only two narrow windows of optimal depositional opportunity within the time frame of the ages obtained for the deposits: one at the beginning of MIS 9 c. 330 ka (supported by one date); the other at the end of MIS 11 around 390–400 ka (supported by five dates). Further, *if* volcaniclastic turbidites are somehow linked with flank margin collapse, as suggested by Masson (1996), the fact there are no turbidites recorded at any time in the Madeira abyssal plain between MIS 11 and 7 would suggest there was no flank margin collapse during this interval; hence, no tsunami. Age determinations of purely hypothetical events are inherently problematic.

Herewith we provide three additional TIMS analyses from the flowstone-beach contact yielding U/Th ages of 364±24, 405±28, and 409±15 ka (Table 1). The weighted mean of our four flowstone ages is 399±11 ka. Adding the two new ICPMS ages of McMurtry et al. (312±30; 360±30 ka) slightly reduces the weighted mean to 389±26 ka, with only the younger age of 312 ka being a significant departure. The maximum constraining age of the marine sediments falls between 477±50 ka and 525±50 ka (Hearty et al., 1999). The weighted mean of 399±11 ka (N=4) (or 389±26 ka; N=5) corresponds precisely with MIS 11, known to be one of the longest and warmest interglaciations of the past million years; thereby providing a direct explanation for the elevated marine deposits.

3. Summary and conclusions

The "reinterpretation" of the well-documented eustatic shoreline deposits in Government Quarry, Bermuda, as megatsunami deposits is built on a tenuous chain of assumptions, speculation and conjecture. No comparative sedimentology is provided from known megatsunami deposits and only one vague reference is made to possible characteristics of tsunami deposits in an abstract (Moore et al., 2006). There is no independent evidence that a flank margin collapse *caused a tsunami* anywhere, or at any time in the Atlantic. Also, there is no precedent for a megatsunami creating rounded, graded, sorted, and ponded sediments, especially in caves, over several hours, and within a 4-m topographic range. Delicate bones and fossil traces could not survive the extreme grinding energy of

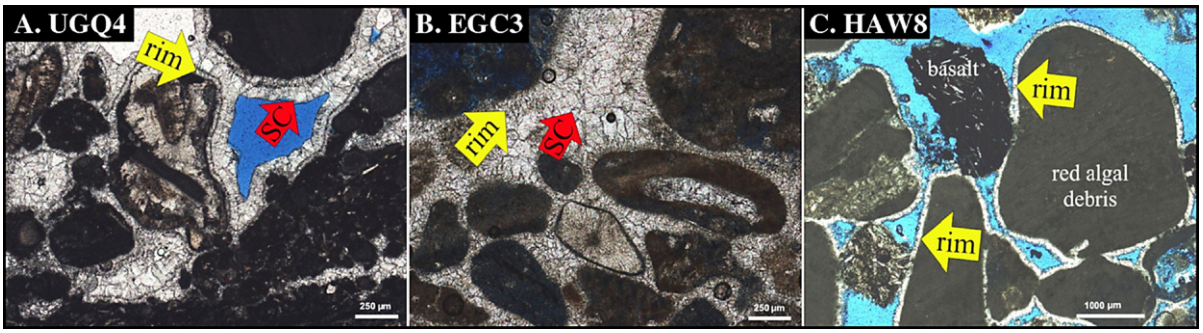

Fig. 6. Cements in +20 m (Bermuda and Bahamas) and +30 m (Hawaiian Islands) shore deposits: (A). Bermuda cave UGQ4 filled with marine sands cemented initially by isopachous (rim) cements indicating early diagenesis in a marine environment, and subsequent diagenesis under vadose conditions indicated by sparry calcite (SC). (B). Eleuthera, Bahamas, +20 m marine limestone showing delicate textures of early and late generations of rim and sparry calcite cements. (C). Kaena Point, west Oahu (HAW8) at +26 to +30 m (calculated uplift at 2 m/100 k/yr) with isopachous rim and lacking later generation of sparry calcite, possibly due to very arid, rain shadow conditions on leeward Oahu.

megatsunami transport. The "inheritance" of an early generation of "internal" marine cements transported from far away beach rocks is purely conjectural. Tsunami deposits of middle Pleistocene age cannot be confirmed anywhere on Bermuda and have not been suggested or confirmed anywhere on the margins of the Atlantic Ocean. Such catastrophic hypotheses may have arisen from an Indo-Pacific bias where tsunamis have been experienced in recorded human history, although even there, authenticated geological signatures of tsunamis are still poorly documented.

Bermuda is one of the best-studied carbonate islands in the world geologically. Several preeminent carbonate geologists (i.e., Land et al., 1967; Vacher et al., 1989) previously interpreted the marine conglomerate in Government Quarry as indicating a eustatic sea level. We rigorously demonstrated a shoreline origin in an interdisciplinary fashion (Hearty et al., 1999; Kindler and Hearty, 2000). A middle Pleistocene eustatic shoreline at +20 m is characterized by sea caves, terraces, and erosional nips; rounded, graded, and sorted sediments; biogenic structures and beach fenestrae; marine and freshwater isopachous "rim" cements, and the preservation of extremely delicate marine and terrestrial fossils and their traces. Our flowstone ages of 399 ± 11 ka point to one of the most important interglacials in the past million years.

McMurtry et al. do not recognize the stratigraphic complexity of the Lower Town Hill formation in Bermuda, and its association with *long-term* interglacial sea-level fluctuations. They disregard deposits of similar age and identical elevations in Eleuthera, Bahamas, published in the same report as the Bermuda deposits (Hearty et al., 1999). In addition to the full complement of diagnostic sea-level indicators, two earlier sea-level stillstands of similar age leading up to the +20 m maximum are recorded in the same cliff section of Eleuthera (Fig. 6A–C). A morphostratigraphic sequence in western Oahu (Fig. 6D) reveals the same "stepping up" sequence during MIS 11 to +20 m when corrected for uplift (Hearty 2002; Hearty et al., 2007b; and Fig. 6). Deposits of similar age, elevation, and complexity have also been described in the northeastern Atlantic (Bowen, 1999) and the western Arctic Ocean (Kaufman and Brigham-Grette, 1993). Our interdisciplinary scientific findings are parsimonious: a sustained global sea-level highstand at +20 m during MIS 11 explains all of our field and analytical observations.

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