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COMMENT

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This article is a comment on *Abdul et al.* [2016] doi:10.1002/2015PA002847.

Key Points:

- MWP-1B at approximately 11.3 kyr B.P. may partly be an artifact of Barbados tectonics linked to the proximity of an active subduction zone
- Fossil samples of *Acropora palmata* may not be reliable sea level markers during rapid and large sea level rises
- Glacio-hydro-isostatic adjustments may have also contributed to the observed discrepancy between the Barbados and Tahiti deglacial records

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Comment on "Younger Dryas sea level and meltwater pulse 1B recorded in Barbados reefal crest coral *Acropora palmata*" by N. A. Abdul et al.

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Abstract Based on new U-Th ages of corals drilled offshore Barbados, Abdul et al. (2016) have confirmed the existence of the abrupt stratigraphic feature called meltwater pulse 1B (MWP-1B), which they interpret as being due to a very large and global sea level step change dated at about 11.3 kyr before present (approximately 15 m and equivalent to twice the amount of water stored in the present Greenland ice sheet). This contrasts with the Tahiti record, in which MWP-1B is essentially absent or very small, as Carlson and Clark (2012) and Lambeck et al. (2014) also conclude in their recent reviews of deglacial sea levels at the global scale. However, the evidence provided by Abdul et al. and their main conclusions are not convincing as they are affected by the following three main problems, which may explain the apparent discrepancies: Problem #1/Barbados is located in a subduction zone, which was also active throughout the Late Glacial period. Furthermore, the Barbados cores studied by Abdul et al. were drilled on both sides of the extension of a tectonic feature identified at the southern tip of Barbados (South Point) as underlined by several studies of the Barbados stratigraphy. Problem #2/Fossil samples of *Acropora palmata* may not be reliable sea level markers during rapid and large sea level rises. Indeed, the asexual reproduction strategy of this species may not be optimal to keep up when the water depth is increasing very rapidly. This may in part explain why the living depth of *A. palmata* at Barbados was significantly greater than 5 m during some periods of the last deglaciation, notably between 14.5 and 14 kyr B.P. and possibly between 14 and 11.5 kyr B.P. Problem #3/The slow glacio-isostatic adjustment and the rapid responses due to gravitational changes of ice and water masses complicate the interpretation of individual relative sea level (RSL) records at specific locations. Therefore, the Barbados and Tahiti record cannot be compared directly in terms of absolute sea level values as done by Abdul et al. In addition, different glaciohydroisostatic adjustments at the two sites may also have contributed to the observed discrepancy between their deglacial RSL records.

1. Is MWP-1B a Real Event or an Artifact of Local Barbados Tectonics?

As shown by Bard et al. [2010], the Barbados cores are located on both sides of the extension of a tectonic feature [Taylor and Mann, 1991; Speed et al., 2012] that may have been reactivated during the Late Glacial period (see also Schellmann and Radtke [2004] for a review on the Barbados stratigraphy, Radtke and Schellmann [2005] on the marine isotope stage 5e terrace and tectonics on the south coast of Barbados, and Radtke and Schellmann [2006] on testing the assumption of constant uplift at Barbados).

The new cores used by Abdul et al. are close to the former ones, and the problem of MWP-1B being linked to the merging of records from two groups of drill cores located around South Point in two different tectonic compartments still persists (i.e., close to cores RGF12 and RGF7, respectively; see map Figure S2 by Bard et al. [2010]). Figure 1 compares the Tahiti coral record [Bard et al., 1996, 2010] with that of Barbados corals in shallow and middepth cores [Abdul et al., 2016]. Also shown is an updated version for Barbados which employs the greater uplift rate proposed by Carlson and Clark [2012]. It was deduced by these authors from the depth discrepancies between deeper cores (RGF9 and RGF15) spanning the early part of the last deglaciation cores, which are located on each side of the assumed tectonic structure (this determination is thus independent from the data on shallow and middepth cores spanning MWP-1B).

In addition, *Acropora palmata* samples from below an unconformity at the base of shallow Barbados cores indicate a sea level position at about –60 m around 60 kyr before present (B.P.), after correction for the Barbados uplift rate assumed to be constant by Abdul et al. However, several independent sea level

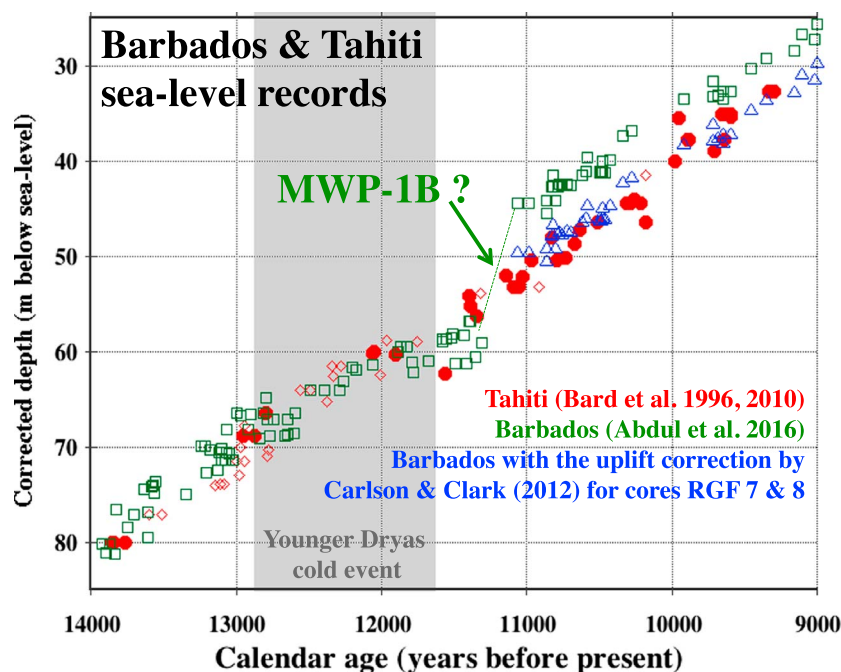


Figure 1. Comparison between Barbados [Abdul et al., 2016] and Tahiti [Bard et al., 1996, 2010] coral records. Ages of corals are based on U-Th dating and are provided in years before present (i.e., 1950). Analytical errors are smaller than symbols. The green dashed line corresponds to the hypothetical sea level step referred to as MWP-1B. The grey zone corresponds to the Younger Dryas event as defined from climatic boundaries well dated in the Greenland NorthGRIP ice core: 12.85 and 11.65 kyr B.P. for the YD start and end, respectively [Rasmussen et al., 2006]. The green squares stand for *Acropora palmata* samples from Barbados published by Abdul et al. [2016] by assuming a constant tectonic uplift of 0.34 mm/yr. The blue triangles correspond to the samples from Barbados cores RGF 7 and 8 corrected for a larger uplift rate (0.8 mm/yr) as proposed by Carlson and Clark [2012]. This value is based on the comparison of deep cores predating the MWP-1B time interval: RGF9 located to the northwest of the fault and core RGF15 to the southeast of the fault (this determination is thus completely independent from the shallow and middepth cores used to study the YD and MWP-1B chronozones). The red symbols stand for Tahiti coral samples [Bard et al., 1996, 2010] corrected for the regular subsidence of the island (0.25 mm/yr). The large filled circles correspond to the shallow branching corals such as *Acropora* and *Pocillopora*, whereas the small open diamonds stand for the corals less restricted in water depth such as *Porites* and *Favidae*. As explained by Bard et al. [2010], the deepest part of Tahiti core P8 is excluded because this core was drilled on the outer part of the barrier reef, with a deviation of 33° toward the sea, and it is logical to observe a small (<6 m) but systematic shift at greater depth as predicted by numerical modeling of reef growth [Bard et al., 1996] (their Figure 3 and further tests with the same model). The main advantage of the Tahiti coral record is that it is based on four drill cores encompassing the time window, which includes the controversial MWP-1B without any gap. As stated in section C, the Barbados and Tahiti data represent relative sea level (RSL), which cannot be directly compared quantitatively in terms of absolute sea level without corrections of glacio-hydro-isostatic adjustment effects. This figure is thus provided for the sake of simplicity and to match those published by Abdul et al. [2016].

reconstructions [Siddall et al., 2003; Cutler et al., 2003; Lisiecki and Raymo, 2005; Bintanja et al., 2005; Elderfield et al., 2012; Spratt and Lisiecki, 2016] exhibit much deeper levels around –80 or –90 m during the same period, which is indeed compatible with a higher uplift rate for Barbados. In any case, it may be oversimplifying to compare global sea level data (i.e., marine $\delta^{18}\text{O}$ stacks with some admitted uncertainties) with the local relative sea level curve from Barbados (see section C concerning the local glacio-isostatic adjustment).

2. Is *A. palmata* a Better Sea Level Proxy Than Coralgal Assemblages From Pacific Reefs?

The Tahiti sea level record updated with offshore drill cores [Deschamps et al., 2012] demonstrated that the age of MWP-1A is older by about 500 years than was previously thought based on the Barbados record. This implies that the series of *A. palmata* samples dated between 14.5 and 14 kyr B.P. in core RGF9 [Peltier and Fairbanks, 2006] must have lived at depths of 10 to 15 m and that this species did not keep up with the pace of the deglaciation (see Weaver et al. [2003] and Deschamps et al. [2012] for a reinterpretation of the Barbados sea level record).

The main error made by Abdul et al. is to assume that the spatial zonation of coral species observed in modern reefs (i.e., during a period of stable sea level for several millennia) is strictly applicable to a period of substantial and rapid sea level changes during which different species of corals and other builders were competing to keep up with sea level rise.

In particular, the so-called Elkhorn coral (*A. palmata*) was indeed the dominant coral species in Caribbean reefal crest environments, before recent disturbances. The monospecific reefal flats formed by this coral are linked to its particular adaptation to colonize horizontally shallow environments, which explains its morphology (fast growing branches) and reproductive strategy (asexual rather than sexual). Besides this favored habitat, isolated *A. palmata* colonies can live at depths greater than 5 m, commonly at 10–15 m [Goreau and Wells, 1967; Hubbard, 2009] and down to a recorded maximum of 24 m [Zimmer et al., 2006].

In the Pacific Ocean, notably in the French Polynesian islands, *Acroporid* species reproduce mainly through sexual recruitment with release of gametes during mass spawning events [Wallace, 1985; Carroll et al., 2006], a behavior which is complemented by asexual fragmentation for many species. By contrast, the main reproduction mode of *A. palmata* is by means of colony fragmentation, allowing this coral to repopulate areas disturbed by strong waves affecting the reefal flat and by episodic hurricanes and tropical storms [Bak and Engel, 1979; Highsmith, 1982; Rogers et al., 1984; Lirman and Fong, 1997; Lirman, 2000].

This asexual propagation actually benefits from storms [Fong and Lirman, 1995; Lirman, 2000, 2003] and avoids the high mortality rates of larvae, but the cost is a reduction of the genetic diversity and population connectivity. Low genotypic diversity due to clonal growth of *A. palmata* reduces its resilience to environmental changes [Baums et al., 2005, 2006; Japaud et al., 2015].

The survivorship of *A. palmata* fragments is also affected by the type of substratum [Lirman and Fong, 1997; Lirman, 2000]: the lowest mortality is observed for those propagules which fall down onto older *A. palmata* colonies, which explain the formation of monospecific reefal crests. By contrast, the mortality of *A. palmata* fragments is much greater on substratums such as sands or bare rocks not previously occupied by colonies of the same species.

Consequently, modern *A. palmata* characteristics (shallow bathymetry and high linear growth rate of its branches) may not be reliable indicators of its capacity to track extreme sea level changes during the last deglaciation. Indeed, asexual reproduction may not be optimal to keep up when the water depth is increasing very rapidly since most coral fragments fall downslope and not upslope, since wave energy decreases rapidly with depth, and also because the shallowest substratum was previously above sea level, and thus unoccupied by *A. palmata* colonies.

These reasons may in part explain why the living depth of *A. palmata* was significantly greater than 5 m during some periods of the last deglaciation, notably between 14.5 and 14 kyr B.P. [Deschamps et al., 2012] and possibly between 14 and 11.5 kyr B.P. This paleowater depth problem may also contribute to the depth discrepancies observed between *A. palmata* samples from deep Barbados cores (RGF9 and RGF15) as underlined by Carlson and Clark [2012]. Indeed, finding fragments of fossil *A. palmata* in cores of a few centimeters of diameter does not allow to discriminate between an extended shallow monospecific reefal flat and the presence of isolated colonies living at depths greater than 5 m, which may be a common behavior of this coral during periods of rapid sea level rise.

Abdul et al. argue that fossil *A. palmata* which lived in the reefal crest can be identified by the presence of secondary calcification filling the corallites, which strengthens the branches of the colony. However, the authors cite a paper [Gladfelter, 1982] which is precisely focused on a different coral species (*Acropora cervicornis*), whereas no information indicates that it is possible to distinguish colonies that lived at shallow and deeper depths based on the extent of secondary calcification.

In their section 4.2, Abdul et al. make confusing statements about the coralgal assemblages observed in Pacific reefs. This term should be used to refer to the mix of corals and coralline algae [see Camoin et al., 2012, and references therein], excluding the microbialites, which grew several centuries later than the coralgal framework as demonstrated by Seard et al. [2011]. Hence, Abdul et al. are simply incorrect when they state in their section 4.2 that in the Pacific “The microbial communities... capable of thriving at depths from the surface to 25 m, ... potentially buffer against ‘reefal drowning’ during periods of accelerated sea level rise.” Obviously, microbial communities could not influence events that predated their own development by several centuries.

3. Does the Barbados Coral Record Track Global or Regional Sea Level?

Abdul et al. have largely overlooked the geophysical response of the Earth to deglaciation events: the slow glacio-isostatic adjustment (GIA) and the rapid responses due to gravitational changes of ice and water masses. These effects seriously complicate the interpretation of individual relative sea level records at specific locations (including Barbados), which cannot be compared directly in terms of absolute sea level values as Abdul et al. have done (i.e., their Figures 2 and S2 and related discussion). The Barbados case is further complicated by the proximity of a subduction zone and of the South American continent. This led *Austermann et al.* [2013] to develop a three-dimensional mantle viscoelastic model to study postglacial sea level change at Barbados.

In their discussion of the sources of ice contributing to MWP events, Abdul et al. neglected to take into account regional effects due to the rapid gravitational rearrangements which have been underlined in a series of geophysical modeling papers, notably *Clark et al.* [2002] and *Liu et al.* [2016], who specifically studied the amplitude of deglacial MWPs. Depending on the source—or the combination of sources—contributing to an MWP, one cannot expect the same sea level jump everywhere. Suggesting the opposite, as Abdul et al. do, is oversimplifying.

Indeed, based on the work done by *Clark et al.* [2002], *Bard et al.* [2010] hypothesized that part of “the apparent discrepancy between the Barbados and Tahiti records over the MWP-1B period around 11,300 cal year B.P. may be reconciled by assuming that the ice was released exclusively from the Pacific sector of the Antarctic ice sheet.” If Abdul et al. are correct about a northern source for MWP-1B, the GIA modeling results by *Clark et al.* [2002] clearly indicate that the jump at Tahiti would be much larger than the jump at Barbados and not smaller (see also the GIA modeling results provided in Figure S11 by *Deschamps et al.* [2012]).

Even if a major ice contribution from West Antarctica may be a way to partly reconcile the Barbados and Tahiti records, this solution contradicts a major conclusion drawn by Abdul et al., who propose that MWP-1B was only linked to the melting of Northern Hemisphere ice sheets (Laurentide and Fennoscandian ice sheets). This conclusion also conflicts with the most recent reconstructions of the retreat of these two ice sheets (see *Tarasov et al.* [2012] and *Gowan et al.* [2016] for the Laurentide ice sheet and *Stroeven et al.* [2016] and *Cuzzone et al.* [2016] for the Fennoscandian ice sheet), which document no significant melting acceleration after the Younger Dryas event as proposed by *Abdul et al.* [2016].

The possibility of different GIA responses at Barbados and Tahiti is not exclusive of the problems related to the local Barbados tectonic context and to the paleobathymetry of *A. palmata* that are underlined in sections 1 and 2 of this comment, respectively. Indeed, all three problems could have contributed to produce the discrepant records on the two islands.

In summary, the balance of evidence clearly points to an unsolved problem associated with the stratigraphic feature called MWP-1B that may not be a genuine, abrupt step in global sea level (at least not on the order of 15 m).

One way to further understand the issue at Barbados would be to collect and study additional deeper cores in the vicinity of RGF7 and/or shallower cores in the vicinity of RGF12 in order to demonstrate that MWP-1B is not a tectonic artifact.

There is also a need for further research on living *A. palmata* to observe and understand the behavior of this Caribbean coral species in response to rapid sea level rise, while competing with other reefal builders.

The controversy around the existence of MWP-1B also justifies the necessity for new drilling efforts to obtain cores spanning the entire Holocene coral reefal sequence from other islands in the Atlantic and Pacific Oceans—or even from Indian Ocean islands, which would have the advantage of being located roughly halfway between the two other oceans. This may be the ultimate solution to fully document and better understand the final disintegration of glacial ice sheets.

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