Comment on: Comment on "Sea level 400 000 years ago (MIS 11): analogue for present and future sea-level?" by D. Q. Bowen (2010) Can the extrapolation of uplift rates from MIS 5e shorelines to MIS 11 replace direct and tangible evidence of the latter's sea-level history? By P. J. Hearty

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1 Introduction

A difference in opinion exists about sea-level during MIS 11. P.J. Hearty, who has done much impressive work on global shorelines, has long advocated an MIS 11 high sea-level of ~ 20 m (see publications listed in his paper, Hearty, 2010). Others, however, have argued for an MIS 11 sea-level closer to that of the present-day: from benthic oxygen isotope stratigraphy (Waelbroeck, et al., 2002; McManus et al., 2003); uplifted shoreline evidence (Schellman and Radtke, 2004a, 2004b; Murray-Wallace, 2002; Bowen, 2003a, 2010; McMurtry et al., 2010); and the correlation of continuous data sets from major archives with sea-levels over the past 0.5 Ma (Rohling et al., 2009). In a comparison of Holocene and MIS 11 sea-level history Rohling et al., (2010): "strongly supports the MIS-11 sea-level review of Bowen (2009), which also places MIS-11 sea level within uncertainties at the present-day level". Given the orbital similarity between MIS 11 and the present interglacial, and the possibility that the MIS 11 is an analogue for the continuing Holocene, it remains important to discuss this issue for the `long interglacial ahead` (Berger and Loutre, 2002)

The purpose of Bowen (2010) is not to review all the evidence for the MIS 11 sea-level. Only evidence from uplifted locations with acceptable MIS 11 geochronological ages is considered. It is not appropriate in this comment, therefore, to address other issues that "detract strongly from the key substantive points" (referee No. 1 comment on Hearty, 2010). It would also appear that Hearty (2010) has not read the discussion paper nor its referee comments (Bowen, 2009) which plays an essential role in the passage to final publication in *Climate of the Past*.

The quotation cited by Hearty from Bowen (2010) is taken out of context, which is a discussion of the relative means for exploring former sea-levels: either from inferences about ice-volume, and thus sea-level equivalent, drawn from oxygen isotope measurements on benthic foraminifera from deep-sea sediments; or from inferences drawn from the actualities (facts not interpretation) of uplifted geological and geomorphological evidence for former tidewater levels.

2 Uplifted shorelines

Evidence for past interglacial sea-levels could, theoretically, still lie at the sea-level of their day. Or, in the context of a dynamic Earth, may have been uplifted or lowered. It is the uplifted evidence that is addressed in Bowen (2010) with an uplift correction procedure (using average uplift rates), and described as:"a well-established technique in the literature, used many times" (referee No.1 comment in Hearty, 2010). MIS 11.3 (Bassinot et al., 1994) is taken as the target for the highest MIS 11 sea-level, a time when sea-surface temperatures in the Indian Ocean were at their warmest during MIS 11.

Hearty suggests that Oahu, Hawaii, should have been included among the locations listed in (Bowen, 2010). But it is included in the Discussion paper (Bowen, 2009) and Hearty (2002) is cited. It was removed from the final revised paper on the advice of the referee who drew attention to the selective use of U-series ages in Oahu. Referee No. 2 on Hearty`s paper went further: "If Hearty wishes to reject the older U-series ages on Hawaii, then it seems to me that he needs to reject younger U-series ages there, too, along with all U-series ages from other localities as well (including his own from Bermuda)"; and "Based on what others have commented on with Hearty's work from Bermuda, the Bahamas, and Hawaii, it is by no means established (except in Hearty's opinion) that MIS 11 deposits are present on these islands" (referee No. 2 comment on Hearty, 2010). See also Muhs et al., (2004). In their study of `uplifted emerged interglacial highstand reefs` on Oahu, McMurtry et al., (2010) concurred with this view and state there is: "no evidence for a MIS 11 highstand" and little evidence for "past maximum sea levels significantly greater than 2 m above the sea level datum" (McMurtry et al., 2010).

The role of tectonics may have been underestimated in evaluating past interglacial sea-levels. This is illustrated by discoveries that the MIS 7 sea-level lies between 19 and 12 m below present sea-level (Bard et al., 2002; Dutton et al., 2009), a figure in agreement with Waelbroeck, et al., (2002). Its present elevation above present sea-level may, therefore, be an indication of uplift (e.g. Murray-Wallace 2002; Schellmann and Radtke 2004a, 2004 b). Is it, therefore, realistic to exclude possible tectonic shoreline displacement anywhere without careful evaluation? For example, Unit A of the Ironshore Formation (MIS 11) on Grand Cayman is entirely below sea-level (Coyne et al., 2007).

What are the implications of this for Bermuda? At Grape Bay, the marine MIS 7 Belmont Formation, 198 to 200 ka, (Muhs et al., 2002), lies above sea-level where it is overlain by the MIS 5.5 Rocky Bay Formation, 113 to 125 ka, (Muhs et al., 2002) (see also the alpha spectrometric ages of Land et al., 1967 and Harmon et al., 1983). At Watch Hill, (Fig. 3 in Meischner et al., 1995), MIS 7 marine deposits lie at 7.5 m above sea-level. MIS 7 deposits of the Belmont Formation also lie above sea-level at Rocky Bay (Land et al., 1967; Vacher and

Harmon, 1988). These data may well indicate long-term uplift of Bermuda, something that is not precluded by consideration of the history of the Bermuda Rise (Vogt and Jung, 2005).

With the emergence of the plate-tectonic paradigm Pleistocene sea-level investigations changed and an appreciation of shoreline displacement was heightened (Bowen, 1978). Previously, Zeuner (1959) had envisaged a secular fall in sea-level throughout the Pleistocene, then Fairbridge (1961) superimposed glacio-eustatic fluctuations on that model and correlated them with the oxygen isotope stratigraphy of Emiliani (1955, 1957) and solar radiation variability calculations of van Woerkon (1957). Zeuner and Fairbridge both maintained that \`last interglacial\` sea-level was more or less at the same elevation everywhere: what was to be called the \`6 m *de facto* sea-level\` (Murray-Wallace and Belperio, 1991) that is still routinely adopted by some.

In a probabilistic assessment of sea-level during MIS 5e (5.5) Kopp et al., (2009) proposed that sea-level was at least 6.6 m and possibly 9.4 m above present. This contrasts, for example, with shoreline elevations in the Cape Verde Islands of 2 m (Zazo et al., in press); and 2 m from the Canary Islands (Zazo et al., 2002, 2003). In their review, Kopp et al., (2009) adopt the *de facto* figure of 6 m for MIS 5.5 for the Bristol Channel (Allen, 2002), the second highest tidal range in the world after the Bay of Fundy. Whereas elsewhere on that coastline MIS 5.5 marine deposits commonly occur at 10 m (Bowen et al., 1985), sometimes higher (George, 1932), and where possible uplift has occurred (Bowen, 2005). Much the same considerations, of elevation or lowering, attend the resolution of the MIS 5.1 sea-level in Bermuda and Virginia (Bowen, 2009, 2010), as well as, for example, in Mallorca (Dorale et al., 2010) and Croatia (Surić et al., 2009). Regional sea-level is controlled by glacio-hydrostatic changes that involve ocean basins and coastlines as well as by ice-volume. A universal \`eustatic\` signal for the MIS 5.5 sea-level event may prove to be just as illusory as a Holocene sea-level signal once was.

Given uncertainty in the timing and duration of MIS 5.5 on land (Winograd et al., 1992), and a not dissimilar sea-level response (Muhs et al., 2002), it is desirable to use local data for estimating uplift correction rates. But with a range of elevations for sea-level at different times (Table 3 in Bowen, 2010). Hearty dismissed this as "a fog of numbers" (Hearty, 2010). But according to a referee of Bowen\`s (2009) discussion paper it is "the strength of the paper".

3 Sussex: a clarification and amplification

It has been suggested (referee No. 1 comment on Hearty, 2010) that there is agreement between Bowen and Hearty on a high MIS 11 sea-level in Sussex. But the papers by Bowen in 1999 and 2003b were written four years before Bowen (2003a), by which time it was evident that a maximum elevation for the MIS 5.5 sea-level in Sussex, for uplift rate calculation, was not known. Since then the lithostratigraphy of the Sussex coastal plain has been greatly clarified by Bates et al., (in press), and although some MIS 5.5 sediments have been identified, the highest elevation of that sea-level event remains unknown (Bates, personal communication, 2010). It should also be noted that some maintain that the ~40 m terrace in question is MIS 13 in age (Roberts et al., 1994).

4 Some concluding remarks

It is reassuring that the interpretation of benthic oxygen isotope stratigraphy, uplifted shoreline features and correlation of continuous data sets from major archives yield much the same conclusions about the MIS 11 sea-level being close to its present level. Routine evaluation of tectonic factors in the evidence for Middle Pleistocene changes in sea-level may hold a key to further understanding.

Given the rigorous editorial checks at EGU it is surprising to note the text omissions found by Hearty. Some of the references, however, are in the discussion paper (Bowen, 2009). An erratum is now available.

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