Clim. Past Discuss.,
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Climate of the Past Discussions

Interactive comment on "Extreme lowering of deglacial seawater radiocarbon content is recorded by both epifaunal and infaunal benthic foraminifera" *by* Patrick A. Rafter et al.

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Our thanks to Referee 2 for your comments. We adjusted our manuscript to all comments. The comments are listed numerically below, with our actions immediately following.

Comment 1.1. Can the authors elaborate on constructing of age model using wood. What is the criteria for acceptance?

Our test for accepting the 14C age of wood for our age model is that this age had to be older than ALL foraminifera in the same sample depth. This includes planktic 14C

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ages, which were measured for all samples (but are not shown in this manuscript). We adjusted the text of the manuscript to reflect this clarification. While we also recovered wood that passed the "intact bark test" of Zhao and Keigwin (2018) (see Figure 3), we find that our quantitative 14C age test is appropriate.

Comment 1.2. Should clarify the potential errors in assuming quick deposition of wood in sediment. For example, ventilation age estimates (Δ14C) might be older than the Marchitto (2007) and Lindsay (2016) results because of this assumption. Also, potential for "masking" of the wood 14C age difference caused by secular changes in atmospheric 14C during deposition.

We have adjusted the text in the Methods and Results sections to clarify the implications behind our assumption of a "contemporary deposition" of wood alongside our microfossils in Gulf of California sediment.

Here is preliminary adjusted text from the Methods section:

In light of this unusual application of calibrated 14C ages on wood in a marine setting, it is important to understand the potential errors. We assigned all calibrated wood ages a $\pm$100 year uncertainty added in quadrature to the measurement and calibration error to account for possible lag in seafloor deposition. Note that the asymmetry of any errors associated with assuming contemporary growth of wood and foraminifera must be considered: if we underestimate the time from wood growth to sediment deposition, the actual calendar age of the sediment would be younger than the calendar age given in this study; hence foram Δ14C values would be even lower than the large depletions shown here (see equation 1 and Results). For example, it is possible that a longer-than-expected time period between wood growth and sediment deposition could be "masked" by declining atmospheric 14C concentrations (Figure 1), allowing the wood 14C age to pass our test for inclusion in the age model. This error would adjust our benthic foraminifera Δ14C values to lower values than reported below.

Here is the preliminary adjusted text from the Results section:

A wood 14C age-constrained age model has only been applied twice before (Broecker, 2004; Zhao and Keigwin, 2018) and it is worth quantifying the suitability of this approach in our cores. First, we applied a quantitative test: the wood 14C age must be older than all coexisting foraminifera 14C ages. This test included planktic foraminifera measurements that will be discussed in a following manuscript. The difference between benthic foraminifera and wood 14C ages is illustrative of the effectiveness of this test. The difference between the 14C age of benthic foraminifera (P. ariminensis and U. peregrina) and coexisting, wood that passed our test is 2346±1599 years (n=14) and 2309±1063 years (n=14), respectively (Table 2). Only comparing wood with foraminifera abundance maxima gives a 14C age difference of 3353±1957 years (P. ariminensis; maximum of 5815 years, minimum of 1077 years, n=6) and 2697±1117 years (U. peregrina; maximum of 4145 years, minimum of 1480 years, n=6). These values are consistent with bottom water at our core sites that are near or older than the modern, pre-bomb seawater - atmosphere 14C age difference of 1240 years (see above). Given these results, we argue that our test for excluding wood 14C ages is appropriate, but that unlikely circumstances may have existed that could hide the timescale of deposition. In the event of a longer-than-expected time between wood growth and deposition in the sediment, the calendar age would be biased to younger ages, making benthic foraminifera Δ14C values even more depleted than calculated (Figure 5).

Comment 2. “In some places in the paper one might get the impression that the inference that the extreme deglacial radiocarbon anomalies are not species-specific is applicable to everywhere e.g., the paper title”. The rest of this comment is unclear to us, but seems to suggest that a full deglacial record of epifaunal mono-species 14C ages already exists (Thornalley et al. 2011).

We are unaware of another study that produces a full record of epifaunal mono-species 14C measurements. Accordingly, we argue the title is appropriate for this study. Addressing the last part of the comment above, the Thornalley et al. 2011 paper has a

section titled,

“Table S1. Benthic 14C dates. Mixed benthic foraminifera were picked from the >212mm fraction and were centred on local abundance maxima. Where samples from several adjacent 1 cm were combined, the assigned age is the weighted mean age of the sample period based on the mass of material from each 1 cm interval. Cibicidoides d13C from ref. S5.”

In the case where the reviewer mistook the Thornalley et al. 2011 for Thornalley et al. 2015 (yet another Science paper), the appropriate quote from that study is:

“Mixed benthic ventilation ages. It was not always possible to obtain single genera benthic foraminifera ventilation ages, and therefore, to obtain a more complete deglacial record of ventilation changes, we had to use measurement made on mixed benthics.”

Unless we have misunderstood the comment (our apologies if we have), the text above clearly states that mixed benthic species had to be used to obtain a full deglacial benthic foraminifera 14C record from either Thornalley paper.

With regards to a new title for our study, we have a new title based on comments from Reviewer #1 (to highlight the rare use of wood to constrain our age model), which we think this is an appropriate addition to an already overlong title. The new title is:

“Extreme lowering of deglacial seawater radiocarbon recorded by both epifaunal and infaunal benthic foraminifera in a wood-dated sediment core”.

We do not find this title to be inaccurate or misleading.

Comment 3. What do the authors think about interspecies benthic 14C age differences in their records? Could stable isotope measurements help to explain these differences?

Our 14C measurements of four benthic foraminifera species are the first of their kind and we hope that our comparisons of the species’ values both on and off abundance maxima are helpful for future applications of this widespread technique for reconstruct-

ing seawater 14C.

We understand the enthusiasm to further explore the difference between species 14C. New stable isotope measurements would be useful in this regard, but we find this important subject is outside of the scope of this study and rightly deserves a stand-alone study. Because these comments are public, we would like to advertise that we are looking for collaborators to further investigate the inter-species relationships with new stable isotope measurements and modeling.

Comment 4.1. The 'W' shape in the Marchitto (2007) study should not be dismissed so readily.

This echoes a similar comment from Tom Marchitto himself (Reviewer #1) and we have adjusted our text as such (underlined text):

It is possible that this and other some smaller-scale features of a mixed benthic Δ14C record reflect the bias of a particular species and/or the influence of bioturbation in our lower sedimentation rate sites.

Comment 4.2 The higher values of the 'W' shape in Marchitto et al. (2007) are based on 1 mixed, 2 Uvigerina spp., and 1 Bolivina spp. dates. Therefore, the explanation proffered in our manuscript (potential inclusion of T. bradyi) is not the case.

Unless our datasets are different, we politely disagree that the 'W' shape only contains 1 mixed species 14C date. The attached figure shows that the highest points of the 'W' shape are 7/9 mixed benthic measurements, including 2 of the 3 middle-high point, Bolivina spp. measurements make up the other 2 measurements. The bottom part of the 'W' and much of the lower values for the rest of the record are Uvigerina species. Therefore, we stand by our language that the 'W' shape is "not obviously reproduced by any of the 4 mono-species benthic foraminifera Δ14C."

Comment 5.1 Compare Undercurrent and Gulf benthic foram d18O.

This comparison would be between P. ariminensis (epifaunal) and Uvigerina spp. (in-

faunal), which comes with some caveats. The argument against including this additional data is that it clutters the figure, but we are willing to add this to our figure if the Editor feels it adds to the study.

Comment 5.2 Synchronize Pacific Margin site results (Marchitto and Lindsay studies) and calculate Undercurrent ventilation ages.

This is another good suggestion for future work and are open to collaborations on this and other subjects.

Minor Comments: 1. size fraction for abundance? This was also commented on by Reviewer 1 and added to the manuscript. It was >150 um.

2. Unclear why variable depths of planktic foraminifera calcification is an example of an "assumption about the reliability of the foraminifera archive" (our words). Studies often use modern observations to establish calcification depths. We have changed our text to read, "For example, an important assumption when using planktic foraminifera is that the depth of calcification does not vary based on modern observations"

3. Specify units for carbon. This was also noted by prior reviewer. Has been changed.

4. Change core to sediment cores Done.

5. Change kyr to yr. Done.

6. Holocene 14C ages are tuned to modernâĂŤuse modern. Similar comment to Reviewer 1. Changed text to this: The shallowest and therefore most recent benthic foraminifera Δ14C are roughly equal to modern DIC Δ14C measurements at the depth of the cores of -173‰ (Key et al., 2004).

7. Detail the previously stated tests for removing authigenic carbonates. This has been changed in the text. Thank you.

8. Figure 5E. Add symbols to signify species. Done.

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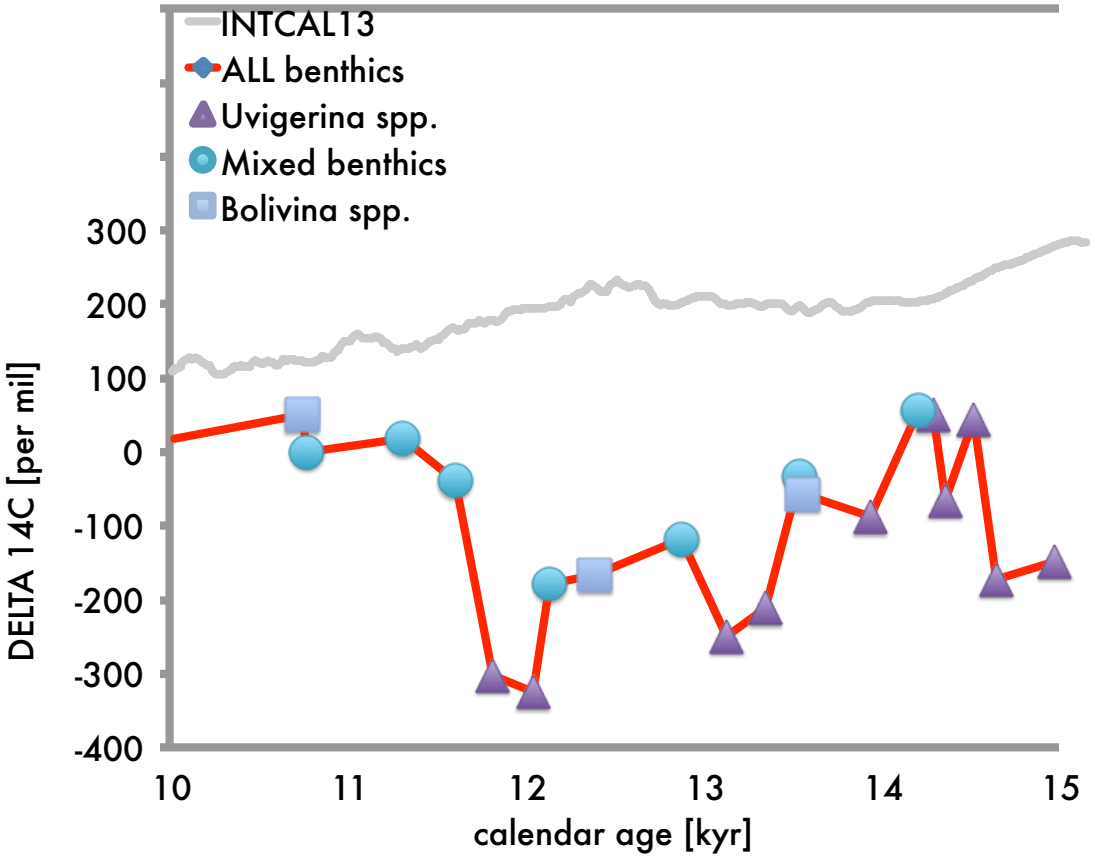

Fig. 1. Atmosphere and benthic foraminifera D14C (mixed, Uvi spp., and Bolivina spp.) from Marchitto et al. (2007) and Lindsay et al., (2016)