Geochronology Discuss.,
https://doi.org/10.5194/gchron-2019-10-RC2, 2020

Interactive comment on "Re-evaluating ^{14}C dating accuracy in deep-sea sediment archives" *by* Bryan C. Lougheed et al.

Anonymous Referee #2

Received and published: 20 January 2020

Lougheed et al. address the influence of bioturbation in ocean sediments on the accuracy of sediment ages determined by 14C dating. Accurate ages are relevant for global correlation of sediment records and thus for a better understanding of the interactions of oceanography, climate, and the carbon cycle in the past and future. As such the subject of the paper is highly relevant. The modelling approach using the established SEAMUS model is clearly described and the many processes that can influence the 14C concentration of a sample of foraminifera picked from a discrete sediment layer are indicated.

The paper focuses on the calculation of the age spectrum of foraminifera in a discrete sediment section resulting from bioturbation and demonstrates that the average age of the individual foraminifera generally will differ from the age derived from a measure-

ment of their combined 14C content. In practical sediment dating, the aim is, generally, to establish the time of deposition of the particular sediment section by determining the 14C content of planktic foraminifera deposited coevally. Thus the demonstration that bioturbation may significantly affect the 14C content of planktic foraminifera in a sediment section (5.0 Conclusion) does not directly contribute to a better age determination of ocean sediments (6.0 Outlook).

Of practical use would be modelling of the difference between the average planktic 14C content and the planktic 14C at time of deposition of a section. Comparing this difference with the uncertainties of the 14C measurement and the estimation of the original planktic 14C content, would show where bioturbation influence may be negligible, where a correction should be attempted, and the added age uncertainty due to bioturbation. It should be noted that the model results presented have been obtained under very idealized conditions, as clearly stated in the model assumptions. To demonstrate the value of SEAMUS in the real world it would be good to see results for common sized mono-specific foram samples (0.1 to 1.0 mg C, $\sim$30 to 300 shells) selected from a sediment section and modelled with sedimentation rates and species abundance as well as local surface reservoir age varying over time according to a realistic local scenario. The uncertainty of the measured age, depending on sample 14C concentration, background, and surface reservoir age uncertainty, may vary from 0.2% for very young to several % for old (>30 ka) samples.

A critical issue to be addressed for the use of single forams, that now may become possible as mentioned in Outlook, is the variability in the isotopic signal of individual coeval foraminifera. During the lifetime of a single foram the 14C concentration of the water surrounding the foram may vary due to varying ocean-atmosphere exchange, turbulent mixing with deeper layers, planktic bloom, and change in depth of the foram as it ages. The natural spread in 14C concentration, δ13C, and δ18O in a population of contemporaneous foraminifera needs to be determined and compared with the magnitude of the paleoclimatic signals expected to see what Information may be obtained.

To a lesser degree this individual variability also needs to be considered in deciding to what extent a finite number of shells is representative for conditions at the ocean surface. 300 foraminifera may be representative, for a sample of 30 shells it may be an uncertainty factor.

In conclusion, I agree with the authors that bioturbation needs to be considered when interpreting 14C ages obtained on planktic foraminifera samples but I find the present paper too far removed from reality to be published in Geochronology. In its present form it seems more appropriate for a modelling-oriented journal.

I would like to encourage the authors to invest a bit more time in this interesting work by running their model under (more) realistic conditions, as mentioned above, and comparing the results for the 14C age that will be measured with the quantity sought in sediment dating, i.e. the time of deposition of the sediment section and the bulk of the foraminifera in it. Such a paper would be highly suitable for Geochronology and the 14C dating of deep-sea sediment archives.

Specific comments:

Line 44: True difference in age is not the only possible cause of 14C age heterogeneity. Other causes as listed in lines 83-87 also come into play.

Line 77: "14C history of the Earth" is too general. It is better to separate the atmospheric 14C history, which is largely global, from the oceanic 14C history, which is strongly local.

Line 90: The discussion does not differentiate between the probability distribution of the measured 14C concentration and that of the related 14C age although the latter follows nonlinearly, via e-log, from the first, which for old samples has significant consequences . Line 118: 10 4 specimens represents ideal conditions compared with 30 to 300 foraminifera selected from the population of the 1-cm section.

Line 121: the primary parameter is F14C, an apparent 14C age follows from it. Al-

though Marine20 is quite different from Marine13 beyond 14 ka, this is for the discussion of the technique, at present, not important.

Line 130: There seems to be confusion on the meaning of blank value. 14C convention is that only definitive 14C values (measured minus background) that exceed twice their uncertainty should be given. This does not mean that foraminifera older than this limiting age/concentration have all the same 14C concentration. They don't; their 14C content keeps decreasing but we can no longer reliably measure it. Thus assigning a constant 14C concentration to all older forams reduces the calculated effect of upward mixing of old forams in deep core sections.

Line 155: Near the blank value the age uncertainty will be asymmetric and generally significantly larger than 200 years because not only the uncertainty in the measured 14C but also that of the blank to be subtracted has to be considered.

Line 209: Note that one is usually seeking the time of deposition of the section and thus the 14C age of the foraminifera raining down at time of deposition. The bias of measured age relative to this will be towards older.

Line 245: Is the second decimal in 95.45 % relevant? Usually only one is given.

Line 287: Are the artefactually young 14C ages the result of assigning a constant "blank" 14C concentration to older foraminifera (see line 130 above)? Modelling could be changed.

Line 297: 1% contribution of 14C free carbon is equivalent with 1 % decay, meaning 80 years too old. In the age range mentioned here, this is well below the measurement uncertainty (i.e. fortunately negligible).

Line 355: The statement that considering bioturbation could improve dating accuracy certainly is true. More realistic modelling is, however, needed to demonstrate the potential of SEAMUS to produce significant improvements.

The authors should check for text duplications.

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