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Letter

Reply to comment on, “Compilation of geophysical, geochronological, and geochemical evidence indicates a rapid Mediterranean-derived submergence of the Black Sea's shelf and subsequent substantial salinification in the early Holocene” by A.G. Yanchilina, W.B.F. Ryan, J.F. McManus, P. Dimitrov, D. Dimitrov, K. Slavova, M. Filipova-Marinova [Marine Geology 383 (2017) 14–34]

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ABSTRACT

Soulet (2018) asserts that the calculation of the ^{14}C reservoir age for the geochronology of the Black Sea sediments suffers from a fundamental flaw. He contends that Yanchilina et al. (2017) obtained reservoir ages by first sorting the $\delta^{18}O$ and $\delta^{13}C$ values of the mollusks as a function of their corresponding ^{14}C age before aligning the mollusk isotope curves to those of the nearby Sofular Cave. Sorting by ^{14}C age would lead to an incorrect calendar age for each $\delta^{18}O$ and $\delta^{13}C$ measurement because it does not take into account changing reservoir ages. We reply here that this sorting by ^{14}C age was not the procedure taken. The radiocarbon reservoir ages were derived after tuning the $\delta^{18}O$ and $\delta^{13}C$ composition of the mollusks, sorted by their $\delta^{18}O$, $\delta^{13}C$, radiocarbon age and stratigraphic location in each core, to the $\delta^{18}O$ and $\delta^{13}C$ composition of the U/Th dated Sofular Cave stalagmites as a function of calendar age, shown to reflect Black Sea surface water $\delta^{18}O$ and $\delta^{13}C$ composition.

After the calendar age was derived for each mollusk, it was then converted to a corresponding Northern Hemisphere atmospheric ^{14}C age using Reimer et al. (2009). The ^{14}C reservoir age was subsequently calculated from the difference between the measured ^{14}C age of the mollusks and the calculated Northern Hemisphere atmospheric ^{14}C age of the mollusks, $R(t) = {}^{14}C_{shell}(t) - {}^{14}C_{atm}(t)$ (e.g., Ryan, 2007; Kwiecien et al., 2009; Jull et al., 2013; Philippsen, 2013; Soulet, 2015; Soulet et al., 2016). The Reimer et al. (2009) calibration used in our original study differs < 0.5% from the Reimer et al. (2013) calibration.

1. Introduction

Soulet (2018) states that Yanchilina et al. (2017) used an incorrect procedure in their calculation of Black Sea ^{14}C reservoir ages when tuning the $\delta^{18}O$ and $\delta^{13}C$ compositions of the mollusk specimens to the $\delta^{18}O$ and $\delta^{13}C$ composition of the Sofular Cave. Soulet (2018) further contends that such an inappropriate calculation of the ^{14}C reservoir age casts doubt on the robustness of the conclusions reached by Yanchilina et al. (2017), and questions the validity of the derived calendar age and sedimentation rates obtained from these ages. We aim here to clarify our methodology, confirming the robustness of the original conclusion of ^{14}C reservoir ages and the conclusions drawn in Yanchilina et al. (2017). Throughout this reply, we will adopt Soulet (2018) expression of radiocarbon ages in “^{14}C years B.P.” (B.P. is Before Present), calendar ages in “years B.P.,” and reservoir age offsets in “^{14}C years.”

Additionally, because the original ^{14}C to calendar-age calibration used in Yanchilina et al. (2017) was based on Reimer et al. (2009), we have redone the entire procedure and calculation using the Reimer et al. (2013) calibration between the ^{14}C Northern Hemisphere (N.H.) atmospheric and calendar age, showing each step. We also have added

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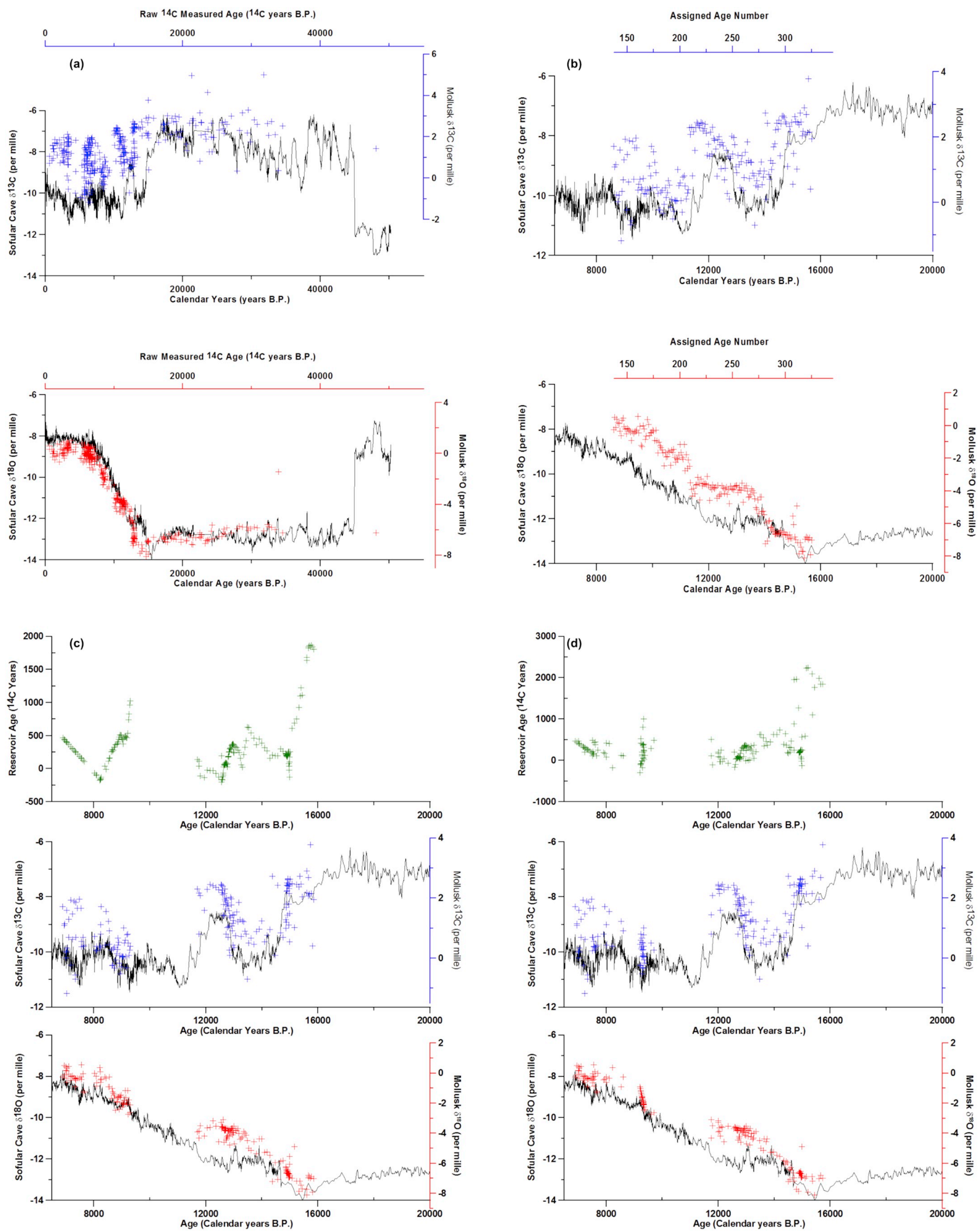

(caption on next page)

Fig. 1. Steps for tuning the Black Sea Mollusk $\delta^{18}O$ and $\delta^{13}C$ measurements to the Sofular Cave $\delta^{18}O$ and $\delta^{13}C$ record. (a) Black Sea $\delta^{18}O$ and $\delta^{13}C$ mollusk measurements as a function of ^{14}C and Sofular Cave $\delta^{18}O$ and $\delta^{13}C$ measurements as a function of calendar age. The ^{14}C scale is on the top and the calendar age scale is on the bottom. (b) Black Sea $\delta^{18}O$ and $\delta^{13}C$ mollusk measurements as a function of assigned age number and Sofular Cave $\delta^{18}O$ and $\delta^{13}C$ mollusk measurements as a function of calendar age after the first tuning procedure. The assigned age number is on the top and the calendar age is on the bottom. (c) The Black Sea mollusk $\delta^{18}O$ and $\delta^{13}C$ as a function of calendar age after first tuning and the Sofular Cave $\delta^{18}O$ and $\delta^{13}C$ as a function of calendar age. The resulting ^{14}C reservoir age is also calculated (green crosses and is shown in the top panel). (d) The Black Sea mollusk $\delta^{18}O$ and $\delta^{13}C$ as a function of calendar age after second tuning readjustment and the Sofular Cave $\delta^{18}O$ and $\delta^{13}C$ as a function of calendar age. The re-adjusted ^{14}C reservoir age is recalculated (green crosses and is shown in the top panel as is in (c)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

some additional $\delta^{18}O$, $\delta^{13}C$, and ^{14}C measurements from the available data. All of the isotopic measurements are provided in the Supplementary data files 1, 2, 3, and 4. While the overall results remain the same, with the exception of that the timing of a slightly earlier marine transgression we would indeed like to note that we observed some inconsistencies between the data provided in the Supplementary materials in Yanchilina et al. (2017) and the data provided in the supporting files 1-4. Specifically, some of the ^{14}C dates were not interpolated but were actual measurements. We have taken care to provide step by step process of how each and every ^{14}C age was measured and/or calculated by interpolation or extrapolation and the calibration process for the Holocene, deglacial, and preglacial sections of the Black Sea $\delta^{18}O$ and $\delta^{13}C$ mollusk measurements.

2. Interpolation and sorting of $\delta^{18}O$ and $\delta^{13}C$ measurements

A preliminary age model for the measured $\delta^{18}O$ and $\delta^{13}C$ composition of the mollusk was constructed for each sediment core (Supplementary material 1 and 2). For example, for the core 09-SG-13, the top panel in the Supplementary material 2, first page, shows the ^{14}C age of the mollusks. The middle panel shows the $\delta^{13}C$ composition of the mollusk and the bottom panel shows the $\delta^{18}O$ composition of the mollusk. The ^{14}C age that was interpolated is clearly shown with an assumption of linear sedimentation between the two measured ^{14}C ages that bracket the sample. Each of the measurements is listed in the complementary spreadsheet in Supplementary Materials 1 provided under the sheet name, "Cores d^{18}O and d^{13}C". In the original publication, we provided 148 measured ^{14}C dates and 153 interpolated ^{14}C dates. In this reply, we provide 160 measured ^{14}C dates and 230 interpolated ^{14}C dates. Each subsequent page shows the same information for each of the cores used to get the $\delta^{18}O$ and $\delta^{13}C$ measurement as a function of ^{14}C age. The reason that multiple shelf cores were used as opposed to one single core is that there are limited *Dreissena r.* specimens available in those cores retrieved from deeper locations. Furthermore, we need $\delta^{18}O$ and $\delta^{13}C$ measurements from shallow margin cores to tune to the $\delta^{18}O$ and $\delta^{13}C$ measurements of the Sofular Cave (Fleitmann et al., 2009; Badertscher et al., 2011) as the Sofular Cave $\delta^{18}O$ and $\delta^{13}C$ record has been interpreted as reflecting the composition of the Black Sea surface water through time. Care has been taken to sort the $\delta^{18}O$ and $\delta^{13}C$ measurement of each mollusk as a function of its $\delta^{18}O$, $\delta^{13}C$, and ^{14}C age.

3. Tuning

We did a preliminary sorting of the mollusks' $\delta^{18}O$ and $\delta^{13}C$ composition as a function of their ^{14}C age and stratigraphic location within each core (Supplementary Materials 1, sheet, "Order Cores d18O d13C" and Fig. 1a). The $\delta^{18}O$ and $\delta^{13}C$ composition of the Sofular Cave is shown for comparison.

3.1. Calendar age determination for the deglaciation and pre-connection Holocene

As Yanchilina et al. (2017) point out, the tuning of Black Sea $\delta^{18}O$ and $\delta^{13}C$ measurements to the Sofular Cave $\delta^{18}O$ and $\delta^{13}C$ measurements is only done for the "deglacial" part of the $\delta^{18}O$ and $\delta^{13}C$ measurements. Soulet (2018) correctly observes, as we do, that it is challenging to sort out the $\delta^{18}O$ and $\delta^{13}C$ composition taking into consideration the corresponding ^{14}C age of the mollusks given that the ^{14}C reservoir of the Black Sea water varies through time. In fact, we want point out that there are several occasions where the ^{14}C age either barely changes and/or increases with decreasing age, further complicating the construction of one $\delta^{18}O$ and $\delta^{13}C$ curve for Black Sea surface water.

For the core AKAD09-15 (Supplementary Materials 1 and 2), the measured ^{14}C age of a *Dreissena rostriformis* at 180 cm in the core is 12,950 ^{14}C years B.P. with an error of 55 ^{14}C years whereas the measured ^{14}C age of a *Dreissena rostriformis* at 210 cm is 12,900 ^{14}C years B.P. with an error of 50 ^{14}C years. We know that the actual calendar age is different, for this particular case, based on the markedly different $\delta^{13}C$ composition of the two *Dreissena* specimens. The $\delta^{13}C$ composition of the *Dreissena rostriformis* from 180 cm is 0.85 ± 0.06‰ whereas the $\delta^{13}C$ composition of the *Dreissena rostriformis* from 210 cm is 2.25 ± 0.06‰. This difference in $\delta^{13}C$ is identical to the change in the composition of the Sofular Cave from 14,000 years B.P. to 12,300 years B.P. We would like to point out that, even though determining the correct calendar age for each of the $\delta^{13}C$ and $\delta^{18}O$ compositions of the mollusks is complicated, when comparing the $\delta^{13}C$ and $\delta^{18}O$ compositions of the mollusks relative to the $\delta^{13}C$ and $\delta^{18}O$ composition of the Sofular Cave, there are large similarities and that is what we use to get the best idea of what the calendar age was for each of the $\delta^{13}C$ and $\delta^{18}O$ measurements of the mollusks (Fig. 1).

Using these similarities we align the variations in the $\delta^{18}O$ and $\delta^{13}C$ curves of the mollusks with those of the Sofular Cave (Fig. 1c). The tie points between the curves are shown and numbered (Fig. 2) in Supplementary Materials 1 tab, "Original Deglacial Tuning". The calendar dates in between the tie points are calculated as a function of the assigned age number. Two paired $\delta^{18}O$, $\delta^{13}C$, ^{14}C age measurements were removed from this curve, a measurement from AK93-14 with an age of 10,000 ^{14}C years B.P. and a measurement from AKAD09-29 with an age of 10,800 ^{14}C years B.P. as they did not fit at all well on the curve. This inconsistency is likely a consequence of the likelihood that these mollusks inhabited perched ponds not connected to the Black Sea-Lake and hence their 14C age did not reflect that of the Black Sea surface water at that time. The ^{14}C date for the 10,000 ^{14}C years measurement also has a secondary $\delta^{18}O$ and $\delta^{13}C$ measurement of with a $\delta^{18}O$ composition of −3.28‰ and a $\delta^{13}C$ composition of 2.03‰. The $\delta^{18}O$ and $\delta^{13}C$ composition for the mollusk that has a measured age of 10,800 ^{14}C years looks like it fits best on the Preboreal interval of the curve of the $\delta^{13}C$ change documented in the Sofular Cave record. The 10,800 B.P. ^{14}C age measurement also has a ^{14}C age error of 310 ^{14}C years, hence giving it additional uncertainty of its true ^{14}C age. The data for this procedure is provided in the "Adjusted Deglacial Tuning" tab of the submitted spreadsheet. The ^{14}C reservoir age is calculated after (1) calibrating the assigned calendar age to the N.H. ^{14}C age of the atmosphere using a linear regression between the two and (2) subtracting the calculated N.H. ^{14}C age of the atmosphere from the measured ^{14}C age of the mollusk such that,

$$R(t) = {}^{14}C_{shell}(t) - {}^{14}C_{atm}(t) \quad (1)$$

where R(t) is the ^{14}C reservoir age, $^{14}C_{shell}$ is the measured ^{14}C age for the shell and $^{14}C_{atm}$ is the atmospheric ^{14}C age (Kwiecien et al., 2009; Soulet et al., 2011b; Jull et al., 2013; Philippsen, 2013; Soulet, 2015;

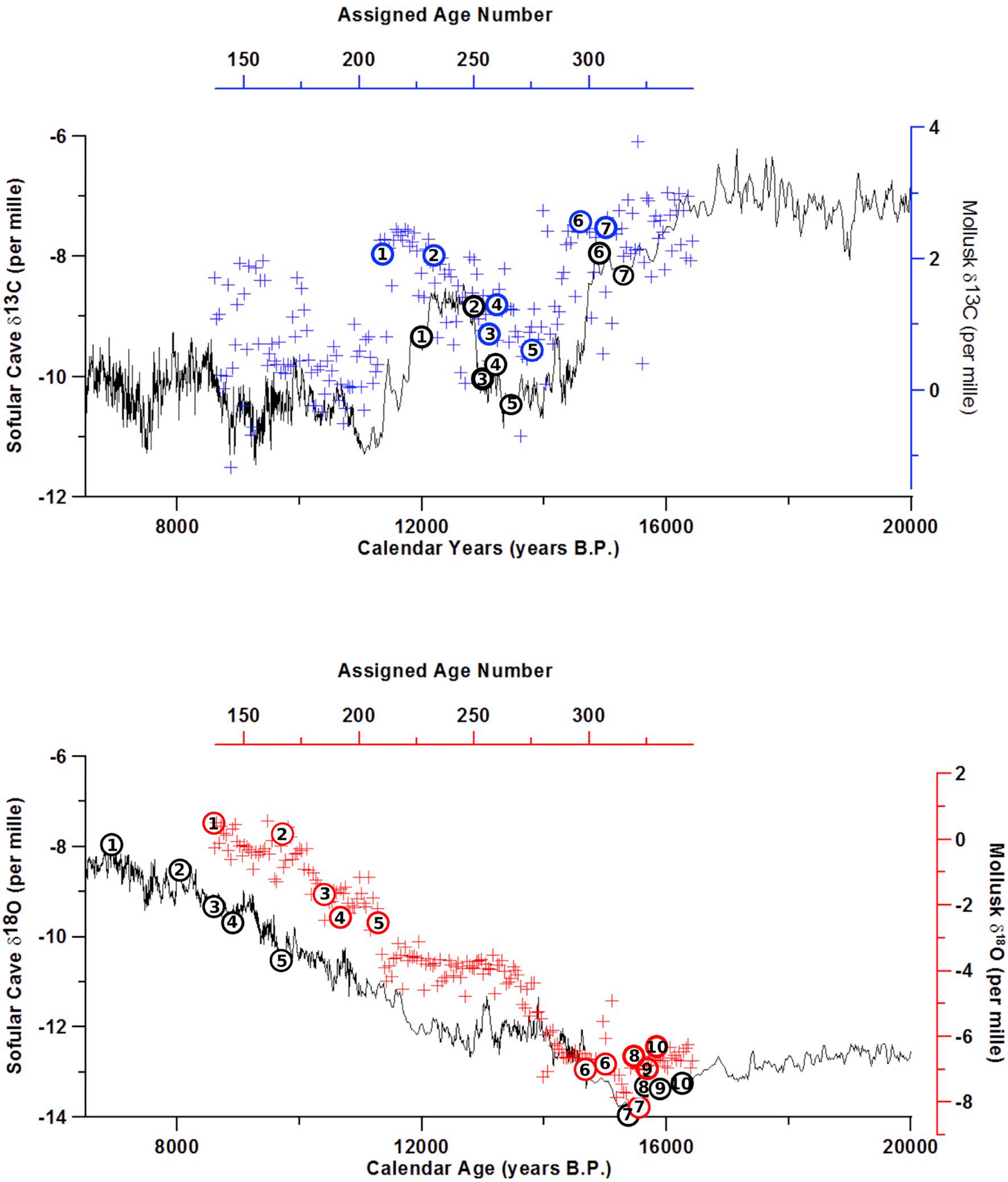

Fig. 2. Shows each of the tuning points initially used to tune the Black Sea mollusk $\delta^{18}O$ and $\delta^{13}C$ record to the Sofular Cave $\delta^{18}O$ and $\delta^{13}C$.

Soulet et al., 2016). This is exactly the method Soulet (2018) indicates as the appropriate one to calculate ^{14}C reservoir ages. The linear regressions used are shown to the right of the data in the "Adjusted Deglacial Tuning" for reproducibility.

To further improve the tuning, we match the $\delta^{18}O$ and $\delta^{13}C$ composition of each mollusk to the Sofular Cave record and make the related adjustments (Supplementary Materials 3 and 4) to the calendar ages. We take into consideration the resulting ^{14}C reservoir age for each $\delta^{18}O$ and $\delta^{13}C$ measurement such that it is not negative, although some negative reservoir ages do result, possibly because of the intrinsic error associated with the ^{14}C dating of the mollusks. We resort the measurements as a function of the calendar age only and not the original ^{14}C age (Fig. 1d). The data are provided in the "Adjusted Deglacial Tuning 2" in Supplementary Materials 1 For the period between 9350 and 8220 years B.P., we decided to interpolate the calendar age between 9350, 9200, and 8220 years B.P. as a function of the $\delta^{18}O$ change to get the final corresponding N.H. Atmospheric ^{14}C ages as the change in the $\delta^{18}O$ composition is larger than the error associated with the $\delta^{18}O$ change.

Reanalyzing our results, we confirm that the ^{14}C reservoir ages increases almost immediately after the connection to the modern measured ^{14}C reservoir age of 460 ^{14}C years. This is observed by noting that the curve in the mollusk $\delta^{18}O$ measurements corresponds to the curve in the Sofular Cave $\delta^{18}O$ measurements (i.e., tuning points 1 and 2 in Fig. 2). This observation has led us to adjust our ^{14}C reservoir applied for calibrating ^{14}C ages to calendar ages in the post-connection Holocene, discussed in Section 3.2 below.

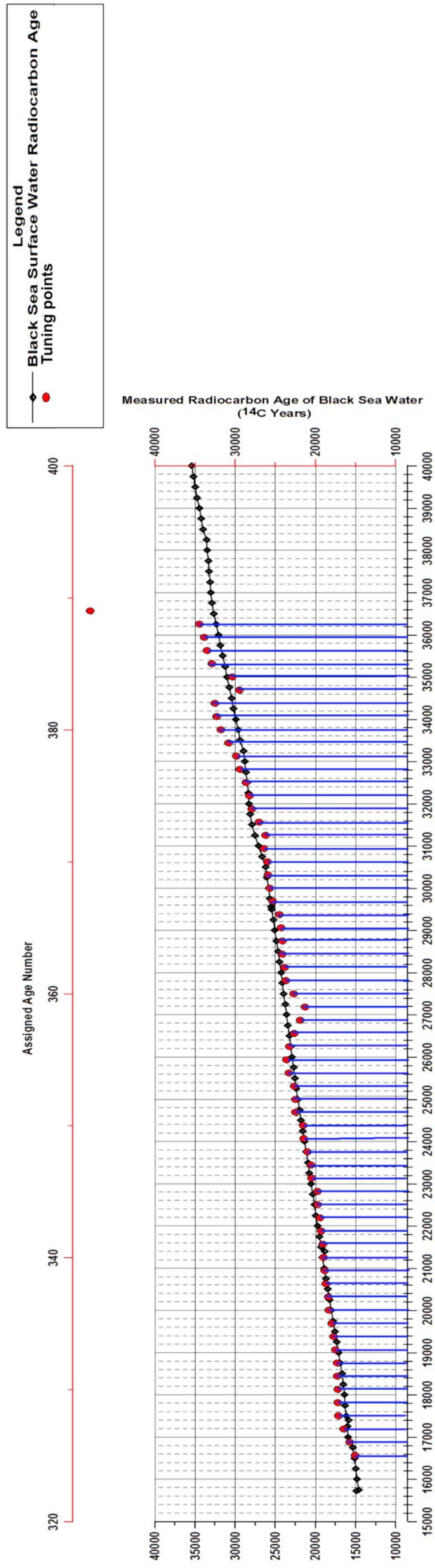

Fig. 3. Calibrating Black Sea mollusk $\delta^{18}O$ and $\delta^{13}C$ measurements to calendar age for the pre-deglaciation period. The modeled ^{14}C age of Black Sea water is illustrated as black diamonds with the corresponding scale on the left. The measured ^{14}C age of Black Sea water is illustrated as red circles with the corresponding scale on the right. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.2. Calendar age determination for the Holocene

We further note that we applied different calibration methodologies for periods that do not include the deglacial period (< 9300 years B.P. and > 18,000 years B.P.) as explicitly stated in Yanchilina et al. (2017). In other words, Yanchilina et al. (2017) exclusively tune the $\delta^{18}O$ and $\delta^{13}C$ composition of the mollusks to the $\delta^{18}O$ and $\delta^{13}C$ composition of the Sofular Cave stalagmites for the deglacial period between 18,000 years B.P. and 9300 years B.P. For the period older than 18,000 years B.P. and younger than 9300 years B.P., Yanchilina et al. (2017) state, "For the Holocene period post connection, the ^{14}C reservoir adopted in this paper is set to rise progressively to that of the modern surface ^{14}C reservoir of the Black Sea of 460 ^{14}C years (Jones and Gagnon, 1994)." Furthermore, "The ^{14}C ages from mollusks retrieved from Sakarya coastal plain, perched ponds, and paleo-river beds are given a zero ^{14}C reservoir correction with the understanding that since these specimens previously inhabited an environment predominantly fed by river-water with permanent exposure to the atmosphere, this water is assumed to have equilibrated to the atmospheric ^{14}C age."

As noted previously, after tuning the $\delta^{18}O$ and $\delta^{13}C$ composition of the mollusks to that of the Sofular Cave, we noticed striking similarity between the $\delta^{18}O$ change in the mollusk record and that of the Sofular Cave record between 6890 years B.P. and 8000 years B.P. that allowed us to derive an increase in the ^{14}C reservoir age of the Black Sea surface water to 467 ^{14}C years. Hence, instead as was done in Yanchilina et al. (2017), we apply a reservoir age of 460 ^{14}C years after the calendar date of 6890 years B.P. After this date, the variability of $\delta^{18}O$ and $\delta^{13}C$ records is reduced and it becomes even more challenging to align the mollusk $\delta^{18}O$ and $\delta^{13}C$ record to the Sofular Cave $\delta^{18}O$ and $\delta^{13}C$ record. The application of this reservoir age and its calibration to calendar age are provided in the "Holocene Tuning" tab of the tuning spreadsheet. This is an imperfect method as, after we included some additional measurements, we noted that as during the deglacial period, there are periods when the radiocarbon increases with decreasing age (2305 to 2583 years B.P., 2920 to 3281 years B.P., and 5227 to 5290 years B.P.). While this is a very interesting observation that merits further investigation, we decided to leave this discussion for another manuscript that will specifically look at the ^{14}C reservoir evolution of the Black Sea surface water. Instead, we decided that the most appropriate resolution is to interpolate between bracketing calendar ages for each of these three periods.

3.3. Calendar age determination for the prior deglacial

For the glacial period prior to 18,000 years B.P., our adopted ^{14}C reservoir ages are set approximately between those of Soulet et al. (2011a) and Nowaczyk et al. (2012) as a compromise between modest differences. These calculations are shown in the tab entitled, "Pre-deglacial tuning" of the Supplementary Materials 1 data provided.

For the glacial period prior to 18,000 years B.P., our adopted ^{14}C reservoir ages are set approximately between those of Soulet et al. (2011a) and Nowaczyk et al. (2012) as a compromise between modest differences. These calculations are shown in the tab entitled, "Pre-deglacial tuning" of the Supplementary Materials 1 data provided.

We note, that similar to the observations made after retuning with more data and using the Reimer et al. (2013) vs. the Reimer et al. (2009) calibrations between the ^{14}C N.H. atmospheric age and the calendar age, we instead made two changes in the calibration of the measured (and interpolated) ^{14}C ages to calendar ages. First, we decided to apply a predetermined ^{14}C reservoir age for a period beginning at 14,870 years B.P. as opposed to 18,000 years B.P. as it does not appear there are any reasonable tie points before this date, contrary to what was observed earlier. Second, after recalculating the resulting ^{14}C reservoir measurements from the results of Nowaczyk et al. (2012) using the Reimer et al. (2013) calibration, we calculate that for the period earlier than 32,500 years B.P., we obtain negative ^{14}C reservoir changes. Instead of applying a ^{14}C reservoir age of ~300 ^{14}C years, we decided that a zero ^{14}C reservoir age for this period is more appropriate.

Between 14,870 and 29,560 years B.P., we average the ^{14}C reservoir applied between the calculations of Soulet et al. (2011a) and ^{14}C reservoir calculations resulting from the work Nowaczyk et al. (2012). Between 29,560 and 32,500 years B.P. we interpolate between the last positive calculated ^{14}C reservoir age and where it is calculated to become negative (i.e., 32,500 years B.P.). The ^{14}C reservoir age used from the calculations of Soulet et al. (2011a) was from the most positive points on the curve. We justified this as those ^{14}C reservoir ages calculated from the measurements of Nowaczyk et al. (2012) do not show such large variability as do those calculated by Soulet et al. (2011a).

As the ^{14}C reservoir age for a certain calendar date cannot be applied to the measured ^{14}C age because the ^{14}C reservoir age is different for each different calendar date, we first calculated the N.H. Atmospheric ^{14}C age for each of the calendar dates using a linear regression. We then applied the ^{14}C reservoir to this age to estimate what should the ^{14}C age of the Black Sea surface water during this period. We then compare the results with that of what was measured to get a calendar date for each of the $\delta^{18}O$ and $\delta^{13}C$ measurements (Fig. 3). This was not the methodology used initially as the applied ^{14}C reservoir age was subtracted directly from the measured ^{14}C age. Although this has little influence on the results, as our paper is not about the variability of the $\delta^{18}O$ and $\delta^{13}C$ composition of the Black Sea during the glacial period, this method is nevertheless more appropriate.

One of the ^{14}C age measurements of the age of 48,100 ^{14}C years is likely ^{14}C dead, it is a measurement for a brown *Dreissena* specimen found in the core catcher of core AKAD09-27. We believe it is most appropriate that this measurement not used.

3.4. Calibration between N.H. atmospheric ^{14}C age and calendar age

Soulet (2018) shows in Figs. 1 and 2 that there is some disagreement between the reservoir offsets calculated using ResAge software and those calculated by Yanchilina et al. (2017). We believe that the reason for this observation is because the reservoir age offsets in Yanchilina et al. (2017) were calculated first, after which they were used to calculate the corresponding atmospheric ^{14}C age and calibrated using a linear regression to a corresponding calendar age.

Soulet (2018) further comments on the subject of the calculation of sedimentation rates, an important piece of information for interpolating those $\delta^{18}O$ and $\delta^{13}C$ measurements that do not have corresponding ^{14}C dates. While we agree that we do interpolate between bracketing ^{14}C ages to get interpolated ^{14}C ages, we afterwards tune the $\delta^{18}O$ and $\delta^{13}C$ measurement to that of the Sofular Cave. The calendar age of the $\delta^{18}O$ and $\delta^{13}C$ measurements is at the end of the tuning process, independent of the sedimentation rate. While it is risky to interpolate ^{14}C ages as the ^{14}C age of the Black Sea Lake water is shown to have varied with calendar age, we made an assumption that the ^{14}C age between individual ^{14}C age measurements would not change significantly.

The results that are calculated using either the Reimer et al. (2009) or the Reimer et al. (2013) calibration between radiocarbon and calendar age are nearly identical and thus do not challenge the original conclusions (Fig. 4). The data for Fig. 4 is presented in a table as Supplementary Materials 5. The largest disagreement between the two calibrations are for the last glacial period and older (Supplementary Materials 6), not for the deglaciation and the Holocene, when they are within the error of ^{14}C dating for these periods.

Yanchilina et al. (2017) do note that ^{14}C reservoir ages are the product of the calibration rather than a starting point, "The age model for assembling all of the isotope measurements in chronological order is created by deriving ^{14}C reservoir ages for the late Pleistocene and Holocene stages of the Black Sea history, and then using the ^{14}C reservoir ages to convert the measured ^{14}C dates into calendar ages," utilizing an alignment to the nearby Sofular Cave. The approach of deriving a chronology and reservoir effects by alignment of a ^{14}C-dated Black Sea geochemical dataset to a reliable calendar-age-dated climate reference record, was previously utilized by Ryan (2007), using the oxygen isotopic record from the NGRIP Greenland ice core. Our application of this approach was applied exclusively to the early Holocene (i.e., > 9300 years B.P.) and not the entire Holocene. We also acknowledge that we originally used Reimer et al. (2009) calibration and not Reimer et al. (2013) calibration as noted in the manuscript. The difference between the two calibrations is < 3% for the deglacial period (i.e., 18,000 to 9300 years B.P.) and is < 0.02% for the period immediately before our calculation of the timing for the entry of the marine water into the Black Sea (i.e., 10,000 to 9300 years B.P.) (Supplementary Materials 6). In absolute years (also provided in Supplementary Materials 6), the difference is largest between 25,000 and 40,000 years with maximum of 1200 years but for the period during which we contest the Black Sea connected to the global ocean (10,000 years B.P. to 5000 years B.P.), the difference in absolute years is maximum of 7 years.

4. Implications

Soulet (2018) correctly notes how complicated it is to give a corresponding calendar age to a $\delta^{18}O$ and $\delta^{13}C$ measurement that was ^{14}C dated. Soulet (2018) notes that "the critical issue with this approach is that sorting the mollusk shells according to their ^{14}C age does not ensure that they are in calendar chronological order because of one key reason: the unconstrained reservoir age offset evolution. For instance, a 10,000 calendar years B.P. old mollusk shell with a reservoir age offset of 1000 ^{14}C years has a ^{14}C age of 9880 ^{14}C years B.P. [according to Eq. (2): $^{14}C_{shell}(t) = R(t) + Intcal13(t)$]. Similarly, a 10,500 calendar years B.P. old mollusk shell with a reservoir age offset of 500 ^{14}C years has a ^{14}C age of 9780 ^{14}C years B.P. So in the ^{14}C age timescale, the 10,500 years old shell appears younger than the 10,000 years old shell. Thus, according to Yanchilina et al. (2017), the mollusk shells would have been sorted the wrong way around. Now let's assume that the oldest shell (10,500 years B.P.) had a $\delta^{18}O$ value of -2, and the youngest shell (10,000 years B.P.) a $\delta^{18}O$ value of 0, showing an increase in $\delta^{18}O$. Thus sorting the geochemical data according to the ^{14}C age of the shells impacts the shape of the $\delta^{18}O$ and $\delta^{13}C$ records the authors reconstructed."

This possibility is not in dispute. However, Yanchilina et al. (2017) did not follow this approach as described above. One of the best demonstrations is core AKAD09-15 (Supplementary Materials 1, 2, 3, and 4). While the measured ^{14}C age of the mollusks barely decreases, there is a large change in the $\delta^{18}O$ and $\delta^{13}C$ composition of the mollusks. This interval in the core takes place between 180 and 375 cm. We know that these changes in the $\delta^{13}C$ composition of the mollusks happened during the transition from cold/meltwater event in the Black Sea, to Bølling/Allerød, to Younger Dryas, specifically from studying the $\delta^{13}C$ composition of the Sofular Cave during this period. This shift from high $\delta^{13}C$ to low $\delta^{13}C$ and back to high $\delta^{13}C$ did not happen during any other period except perhaps, pre-Eemian, the last time the Black Sea reconnected with the Mediterranean, an event during which all ^{14}C age measurements of the mollusks would have been ^{14}C dead. Those mollusks with the $\delta^{13}C$ composition of 2‰ and ^{14}C age of ~13,000 ^{14}C years lived during the post meltwater event, those mollusks with the $\delta^{13}C$ composition of 0‰ and ^{14}C age of 13,000 ^{14}C years lived during the Bølling/Allerød warming, and those mollusks with the $\delta^{13}C$ composition of 2‰ and ^{14}C age of 10,500 ^{14}C years lived during the Younger Dryas. Hence, although yes, we did preliminarily sort the mollusks taking their ^{14}C age into consideration (i.e., a mollusk of 25,000 ^{14}C years could not have lived during the Holocene unless there is indication of a 20,000 ^{14}C reservoir age of which there is not), the final tuning looked at the $\delta^{18}O$ and $\delta^{13}C$ measurement of the shell individually and was tuned to the $\delta^{18}O$ and $\delta^{13}C$ composition of the Sofular Cave with the largest care and attention.

We next illustrate differences between the ^{14}C reservoir age calculated in Yanchilina et al. (2017) and the ^{14}C reservoir age re-calculated in the response manuscript (Fig. 5): (1) The ^{14}C age decreases

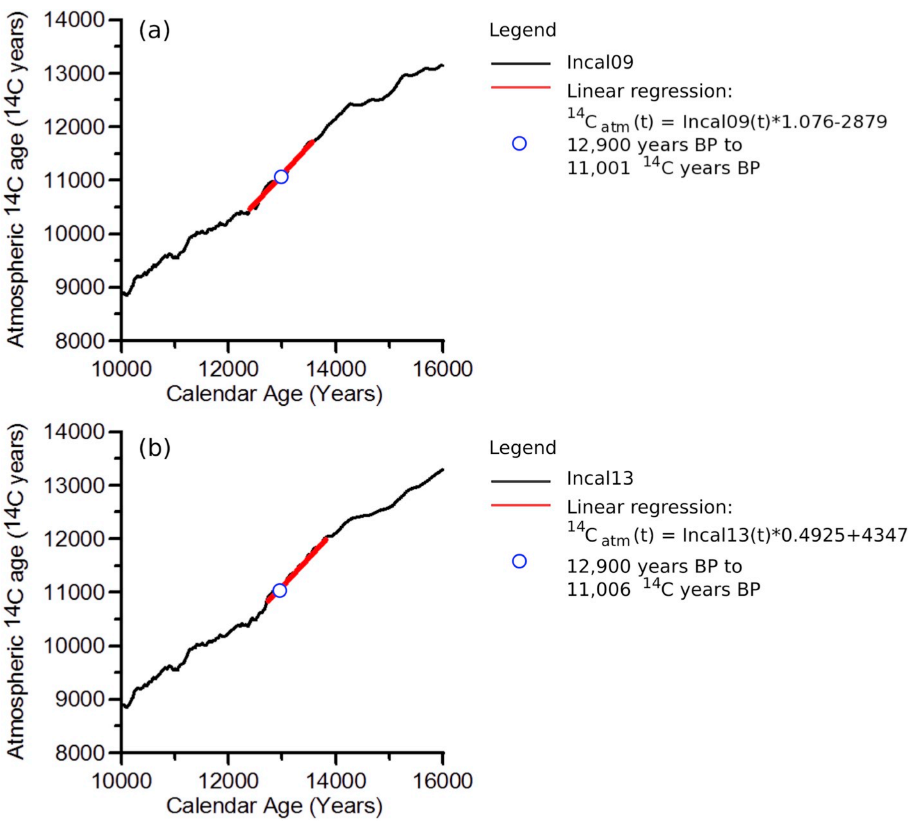

Fig. 4. (a) Illustrates the two calibrations between calendar age and Northern Hemisphere ^{14}C age. The black contour refers to the Reimer et al. (2009) calibration and the blue contour to the Reimer et al. (2013) calibration. (b) Illustrates the percent difference between the Reimer et al. (2009) and Reimer et al. (2013) relative to Reimer et al. (2009) calibration. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

substantially during the meltwater input, (2) the ^{14}C age rises during Bølling/Allerød, (3) the ^{14}C age decreases during Younger Dryas and is low, (4) the ^{14}C age must have been high during the Preboreal warming to account for the decrease in ^{14}C age of the mollusks according to their δ^{18}O and δ^{13}C composition upon the connection with the Mediterranean Sea. Our timing of the initiation of the post-glacial meltwater event that resulted in delivery of red silt and clay is 1000 years younger than observed by Soulet et al. (2011a) and our calculated duration of the event is 400 years shorter.

As noted previously, after closer examination of the Sofular Cave δ^{18}O and δ^{13}C composition and that of the Black Sea Mollusk δ^{18}O and δ^{13}C composition, it appears that the connection of the Mediterranean with the Black Sea occurred 50–100 years slightly earlier, around 9350 years B.P. Taking this observation into consideration, the main conclusions from the study do not change. Those δ^{18}O and δ^{13}C measurements that lie all around −2‰ are tuned to calendar ages between 9330 and 9375 years B.P., suggesting that the water that entered from the Mediterranean raised the lake-sea level of the Black Sea-Lake to depths above 50 mbsl. The subsequent salinification took a few hundred years based on the evolution of the δ^{18}O and δ^{13}C isotope curves. The δ^{18}O and δ^{13}C composition of the mollusks living between 9375 and 6890 years B.P. is a function of the evolving δ^{18}O and δ^{13}C composition of the water. The ^{14}C reservoir age decreased at first upon the ingress of water but was later followed by a subsequent increase. In this supporting manuscript we observe that the ^{14}C reservoir age increased to a value of 467 ^{14}C years, not observed from the original tuning described in Yanchilina et al. (2017). The transition must have taken < 40 years. It is interesting to note that a specimen of *Dreissena rostriformis*, generally considered to live in freshwater was extracted at a present water depth of 49 m in core AK93-3-2. This specimen has a ^{14}C age of 8330 ^{14}C years B.P. indicating that it lived after the connection with the Mediterranean, but its anomalous δ^{18}O measurement of −2.46‰ is only found in mollusks that lived prior to connection. Its more negative δ^{18}O composition can be readily explained by its location at 49 mbsl that puts this location in close proximity to coastal rivers following the connection with the Mediterranean.

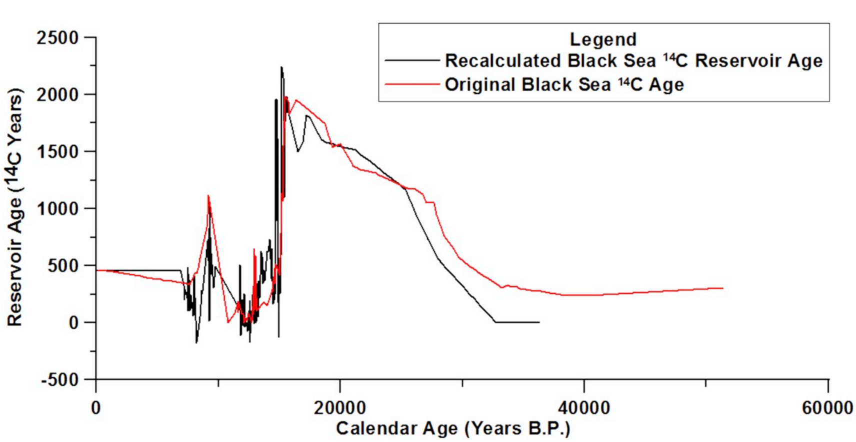

Fig. 5. Illustrates the ^{14}C reservoir applied in Yanchilina et al. (2017) (red contour) and the ^{14}C reservoir applied if using the Reimer et al. (2013) calibration as opposed to the Reimer et al. (2009) calibration and repeating the calibration steps with some adjustments in Yanchilina et al. (2017) (black contour). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5. Conclusions

We would like to thank Soulet (2018) for submitting a comment on the Yanchilina et al. (2017) age model and resulting conclusions. In response, we here show that we sorted the mollusks according to their stratigraphic location in the core and their $\delta^{18}O$, $\delta^{13}C$, and ^{14}C measurements as a preliminary step in the tuning process. For the final tuning, we use the $\delta^{18}O$ and $\delta^{13}C$ composition of the mollusk (Fig. 1d). This allowed us to calculate the corresponding atmospheric ^{14}C age and ^{14}C reservoir age for each of the $\delta^{18}O$ and $\delta^{13}C$ measurements. We acknowledge that we initially used the calibration between atmospheric radiocarbon ages and calendar ages from Reimer et al. (2009) instead of Reimer et al. (2013), and demonstrate that there is minimal difference for these two calibrations for the deglaciation period. We include a specific example crucial to determining the entry of the marine water into the Black Sea-Lake in the early Holocene. We appreciate this opportunity to clarify the methodology used to derive the age model, calculation of the atmospheric radiocarbon ages and reservoir ages in Yanchilina et al. (2017), and to reassess and refine the interpretations therein. The primary conclusions drawn from the original calculations remain robust. The sudden submergence of the Black Sea shelf and subsequent rapid salinification of its water at 9350 calendar years B.P. was a consequence of the inflow of Mediterranean water. The only potential significant difference that emerges is that, upon closer examination, the reconnection of the Black Sea to the global ocean may have occurred slightly earlier, than initially reconstructed, as it appears that the shift to an approximately $-2‰$ $\delta^{18}O$ composition of the mollusk that was shown to have been living in water with a saltwater signal from the complementary $^{87}Sr/^{86}Sr$ measurements may more appropriately lie at 9350–9375 years B.P. rather than 9300 years B.P.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.margeo.2018.11.006.

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