

# A Complete Database of AMS Radiocarbon Estimates from Lake Baikal Sediment Cores with a Lake-Wide Assessment of TOC Age Offsets

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**Abstract.** We present a database of AMS radiocarbon dates from Lake Baikal sediment cores, encompassing 51 cores and 518 dates, providing a complete record from literature spanning 1992 to 2025 (with transcription errors corrected) and including 22 previously unpublished dates from cores CON01-603-5 and CON01-605-5. The most common material used for radiocarbon dating in our dataset is total organic carbon (TOC). Unfortunately, the interpretation of TOC ages in lake sediments is hindered by issues such as the reservoir effect, in situ contamination by old organic carbon, and/or the hardwater effect. These issues may culminate in age estimates thousands of years older than the true depositional age of that sediment, which we term the “age offset”. Linear regression of uncalibrated radiocarbon dates has been used to estimate the age offset in Lake Baikal, with results ranging from 0 to 1.5 <sup>14</sup>C kyr in different cores. Estimates from other methods have returned estimates of approximately 2 <sup>14</sup>C kyr BP. Despite this, most previous studies have not incorporated age offset uncertainty in their age depth modeling, or have included uncertainty of, at most, ± 0.09 <sup>14</sup>C kyr. Furthermore, the varying age offset estimates have been interpreted by some as evidence that different regions of Lake Baikal have different age offsets, with implications as to the cause of the age offsets. We use the database to review the use of linear regression on uncalibrated radiocarbon ages as a method for estimating age offsets of TOC. We apply the linear regression age offset method to all suitable cores in our database, returning 21 estimates of age offset from throughout the lake. Our results provide no statistically significant evidence for a systematic difference in age offset in different regions of Lake Baikal (specifically Academician Ridge and Buguldeika Saddle). Our results return a lake-wide TOC radiocarbon age offset of  $1.62 \pm 0.76$  <sup>14</sup>C kyr, suggesting previous studies in Lake Baikal have significantly underestimated the temporal uncertainty of radiocarbon ages from TOC. Finally, our results are a caution that linear regression-based age offset estimates in lake sediments have a large uncertainty that might only be observable with multiple datasets.

## **1 Introduction**

Lake sediments are natural archives that contain information on environmental histories, spanning every continent, at timescales from the past few decades to tens of millions of years. Spatially, therefore, lakes contain palaeoenvironmental information allowing space-time reconstructions of, for example, human (Dubois et al., 2018) and climate change impacts on the environment (Fritz, 2008). Reconstructing past environments from lake

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Deleted: Abstract. Radiocarbon dates are an essential tool for dating non-varved lake sediments, however their interpretation is hindered by issues such as reservoir age or contamination which culminate in age estimates that can be thousands of years younger or older than the true depositional age of that sediment (we call this an age offset). Often, precise estimators of the radiocarbon age offset are not available, as in the case of Lake Baikal. Linear regression of uncalibrated radiocarbon dates has been used to estimate the age offset, with answers ranging from 0 to 1500 <sup>14</sup>C yr BP. These have been interpreted to suggest that different regions of Lake Baikal have different age offsets, although some dispute this. Other estimators have returned estimates of approximately 2000 <sup>14</sup>C yr BP. Despite this, most previous studies have not included any estimates of uncertainties for these age offsets in their proxy analysis, or have included uncertainty of, at most, ± 90 <sup>14</sup>C yr. Here, we present a complete database of published AMS radiocarbon dates from Lake Baikal sediment cores up to 2023 and, using this, review the use of linear regression on uncalibrated radiocarbon ages as a method for estimating age offsets from the sediments of Lake Baikal. We apply a standardised linear regression age offset method to all cores in our database to better quantify the age offset of Total Organic Carbon (TOC) in the lake's sediments. We conclude that there is no statistically significant evidence from linear regression methods for a large difference in age offset in different regions of Lake Baikal. Our results return a lake-wide age offset estimate of TOC of  $1.56 \pm 0.75$  <sup>14</sup>C kyr BP, suggesting previous studies in Lake Baikal have significantly underestimated the temporal uncertainty of radiocarbon ages. Finally, our results are a caution that linear regression-based age offset estimates in lake sediments have a large uncertainty that might only be observable with multiple datasets.

75 sediments requires appropriate dating techniques and chronology construction. Radiocarbon dating is one of the  
76 most common dating techniques, with an ~50,000-year range of applicability that includes the transition from the  
77 Last Glacial Maximum to the Holocene, one of the most studied periods of paleoclimate. The process of using  
78 radiocarbon dates includes age offset correction (if applicable), calibration, and age-depth modelling – all aspects  
79 that introduce temporal uncertainty, a significant but often ignored limitation to paleoclimate research (Snyder,  
80 2010). Radiocarbon calibration and age-depth modelling techniques are regularly improved and updated (Reimer,  
81 2022), facilitating better understanding of radiocarbon analyses and the opportunity to reduce temporal  
82 uncertainty. However, this can be challenging if the radiocarbon data are not easily findable or accessible. We  
83 present a database of accelerator mass spectrometry (AMS) radiocarbon dates from Lake Baikal sediment cores  
84 to promote 'FAIR' principles (Wilkinson et al., 2016) and facilitate improvement of Lake Baikal paleoclimate  
85 reconstructions. Whilst a number of studies have curated regional radiocarbon datasets to facilitate better age-  
86 depth modelling (Giesecke et al., 2014; Goring et al., 2012; Wang et al., 2019; Zimmerman and Wahl, 2020) to  
87 our knowledge no systematic study has applied such an approach to a single lake before.

88  
89 One challenge to reusing Lake Baikal radiocarbon dates is the presence of a significant age offset, which we  
90 define as a difference between the depositional age of a sample and the analysed age, typically making a  
91 radiocarbon date older than expected. The term "reservoir effect" has been used to describe this phenomenon  
92 (Karabanov et al. 2004) and may be more familiar to readers but we prefer not to use this term as the reservoir  
93 effect is conceptually linked to a specific process, namely the disequilibrium of radiocarbon concentrations  
94 between the atmosphere and the water in which the organic carbon is produced. In the marine setting this is  
95 typically referred to as a result of a slow rate of exchange between deep water and the atmosphere, which may  
96 also occur in lake systems: However, in lacustrine settings it is more common that this disequilibrium is due to  
97 the presence of carbonate bedrock within the watershed which supplies the water with old, radiocarbon-free  
98 dissolved inorganic carbon (DIC), known as the hardwater effect (Phillipsen, 2013). Another potential contributor  
99 to the age offset, which we consider to be different to the reservoir effect, is contamination by both young and old  
100 organic material, due to: deposition and reworking of older sediments (known as the old carbon effect);  
101 bioturbation; root penetration; and infiltration of humic acids (Björck and Wohlfarth, 2002). Contamination that  
102 occurs post-coring, such as in core storage or transport, we do not consider a contributor to age offsets. To  
103 reiterate, the difference between the depositional age and radiocarbon age of a sample (the age offset) may be the  
104 result of a number of processes, potentially including but not limited to the reservoir effect (Colman et al., 1996;  
105 Watanabe et al., 2009a). The use of these terms in the literature is, unfortunately, inconsistent.

106  
107 The majority of the radiocarbon dates from Lake Baikal are of total organic carbon (TOC), also known as bulk  
108 sediment (Strunk et al., 2020). The presence of a significant age offset of TOC radiocarbon dates in Lake Baikal  
109 was highlighted by Colman et al. (1996), who wrote: "One [problem] is the mixture of carbon sources in TOC,  
110 not all of which are syndepositional in age. This problem manifests itself in apparent ages for the surface sediment  
111 that are greater than zero." By applying a linear regression to uncalibrated radiocarbon dates they calculated age  
112 offsets of approximately  $0.47 \pm 0.37$   $^{14}\text{C}$  kyr in Academician Ridge and approximately  $1.22 \pm 0.18$   $^{14}\text{C}$  kyr in  
113 Buguldeika Saddle. The greater age offsets in Buguldeika Saddle were interpreted to be due to reworked sediment  
114 from the Selenga River (which outflows near the Buguldeika Saddle). Subsequent papers have used a similar

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Deleted: We then use the database to perform repeat estimates of the radiocarbon age offset of total organic carbon (TOC) in the lake's sediments, using a linear regression method, to evaluate the most likely TOC age offset, its uncertainty, and whether the age offset differs between the two most studied regions of the lake, Academician's Ridge and Buguldeika Saddle.

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Deleted: We prefer the term age-offset to the more commonly used term reservoir age, as the latter term may be interpreted differently among different groups. For example, marine reservoir ages are conceptually linked to the idea of slow internal mixing of a body of water, leading to aged water masses, and therefore corrections may be based on modelling/evaluating such circulation (Stuiver et al., 1986); In Lake Baikal the ventilation time is known to be less than 25 years (Weiss et al., 1991), which rules out the possibility of a large reservoir age associated with lake mixing processes.

Deleted: The term age-offset encompasses a reservoir age induced by mixing and may also include: a hardwater effect due to the presence of carbonate rocks in the lake; redeposition of older sediment; and systematic contamination; among other things. Our use of the term may closely mirror the term freshwater reservoir effect, as is often used in archaeological studies (Ascough et al., 2011; Phillipsen, 2013; Schulting et al., 2022). When discussing a lake core, the age offset therefore represents the difference between the time since a layer of sediment was deposited in the lake and the radiocarbon age returned from analysing a given sample from that layer of sediment.

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164 linear regression method (Demske et al., 2005; Karabanov et al., 2004), or different methods such as: directly  
165 dating the surface sediment (Murakami et al., 2012); using the Younger Dryas radiocarbon plateau as a tie-point  
166 (Watanabe et al., 2009a); comparing TOC ages to pollen ~~concentrate~~ ages (Nara et al., 2010); using wood  
167 radiocarbon ages (Prokopenko et al., 2007); or equating it to the residence time of the lake (Nara et al., 2023).  
168 The results range from 0.38 <sup>14</sup>C kyr (Nara et al., 2023) to 2.1 ± 0.090 <sup>14</sup>C kyr (Watanabe et al., 2009a).

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170 Despite the evident uncertainty in estimating the radiocarbon age offset of Lake Baikal, many papers do not use  
171 uncertain estimates of age offset when constructing their age models (e.g. Murakami et al., 2012; Nara et al., 2010,  
172 2023; Prokopenko et al., 2007) and those that do have very small uncertainty ranges (e.g. ~~± 0.09~~ <sup>14</sup>C kyr; Watanabe  
173 et al., 2009a). One potential reason for this in older papers is that statistical packages to incorporate such offsets  
174 were not available or were not user friendly. This is no longer the case (Sweeney et al., 2018). Bayesian age-depth  
175 modelling software are now more user-friendly and sophisticated (Blaauw and Christen, 2011; Haslett and Parnell,  
176 2008; Bronk Ramsey, 2008 ) and the development of techniques to analyse the resulting temporally uncertain  
177 records has been prolific (i.e. Anchukaitis and Tierney, 2013; Franke and Donner, 2019; Hu et al., 2017;  
178 McClelland et al., 2021; McKay et al., 2021; Rehfeld and Kurths, 2014).

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180 Whilst many papers have estimated the age offset, there remains a very poor understanding of the causes of the  
181 age offset in Lake Baikal. Despite Lake Baikal's immense volume, deep-water renewal or ventilation (the process  
182 whereby surface waters in contact with the atmosphere are exchanged with deep waters) is surprisingly rapid,  
183 ranging between 10-18 years (Hohmann et al., 1998; Weiss et al., 1991). This rapid deep-water ventilation in Lake  
184 Baikal rules out the possibility of aged water masses contributing to the lake's radiocarbon age offset (i.e. ruling  
185 out the reservoir effect). Very few carbonate rocks are present in the Baikal catchment providing no possibility of  
186 a hardwater effect (Prokopenko et al., 2007). Modern <sup>14</sup>C concentrations of dissolved inorganic carbon (DIC) in  
187 both surface and deep waters in the lake corroborate that neither the reservoir or hardwater effect are significant  
188 in the lake (Watanabe et al., 2009a). Contamination by rootlets of subsurface sediments is not expected to be an  
189 issue at the depths from which nearly all the cores that have been dated come from. Although bioturbation does  
190 occur on the surface sediments of the lake, it has little impact on multidecadal trends (e.g. Mackay et al., 2017;  
191 Swann et al., 2020), so also cannot explain a kiloyear-order age offset. Colman et al. (1996) suggested that  
192 reworked carbon from the Selenga Delta may be responsible for the older age offsets at Buguldeika Saddle  
193 however more recent estimates of equally large age offsets at Academician Ridge (Watanabe et al., 2009a) suggest  
194 other mechanisms must also be at play. Furthermore, over 90% of organic carbon in post-glacial Lake Baikal  
195 sediments is autochthonous (mainly from diatoms and picoplankton), and less than 10% is allochthonous (from  
196 catchment sources - Colman et al., 1996; Nagata et al., 1994; Votintsev et al., 1975), so even infinitely old  
197 allochthonous carbon could not, solely, account for the scale of the observed age offsets (see Figure 5 from  
198 Colman et al., 1996).

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200 Using our database, we generate multiple estimates of the radiocarbon age offset of TOC in the lake's sediments  
201 with a linear regression method to better quantify the TOC age offset and its uncertainty in Lake Baikal. We use  
202 a linear regression age offset estimation method because it is the most commonly used in Lake Baikal (Colman et  
203 al., 1996; Demske et al., 2005; Karabanov et al., 2004) and is well-suited to our database. The method has also

219 been used in other locations such as the Tibetan Plateau (see discussions in: Hou et al., 2012; Mischke et al.,  
220 2013). By making multiple estimates on different cores, we can deliver an estimate of age offset with a robustly  
221 calculated uncertainty and evaluate spatial variability of age offset estimates throughout the lake.

## 222 2 Methods

### 223 2.1 Dataset Collection

224 Collation of studies which have published and/or used radiocarbon dates from Lake Baikal sediments was  
225 undertaken initially using Google Scholar with search terms such as "Lake Baikal" and "radiocarbon" alongside  
226 "Palaeoclimate", "Paleoclimate", "Age Depth Modelling", "Holocene", "LGIT". Grey literature, especially reports  
227 published pre-1995 were also consulted, including those in Russian, English and Japanese. Research leads  
228 (identified from corresponding author status in publications) were also contacted. Articles were read and their  
229 citations and references interrogated, leading to ~80 relevant papers being identified. Although our approach did  
230 not set out to be a systematic review, the five basic steps required for a review were followed including (i) careful  
231 framing of the question, (ii) identification of relevant work, (iii) assessment of the quality of identified work, (iv)  
232 summarising the evidence and (v) interpretation of the findings (Khan et al., 2003).

233  
234 Metadata and radiocarbon data were recorded for all cores with radiocarbon data identified from the literature.  
235 Each core was assigned to a region of the lake - as is common in Lake Baikal literature due to the lake's size.  
236 Cores reported with differing names in the literature are reported under a single name.

### 237 2.2 New Radiocarbon Dates

238 The dataset includes 22 previously unpublished TOC radiocarbon dates from cores CON01-603-5 and CON01-  
239 605-5. The samples were pretreated to remove any carbonates by submersion in 0.5M hydrochloric acid at 75 °C  
240 for 1 hr and then rinsed to neutral pH with demineralised water. After drying, the samples were combusted to CO<sub>2</sub>  
241 in quartz tubes and converted to graphite for AMS radiocarbon dating following the protocol described by  
242 Piotrowska (2013). The graphite targets were analysed at Poznan Radiocarbon Laboratory (Goslar et al., 2004).

### 243 2.3 Data Organisation

244 All radiocarbon data are reported as conventional <sup>14</sup>C age alongside its 1σ uncertainty (Stuiver and Polach, 1977).  
245 Following the convention suggested by Millard (2014), we also provide the laboratory codes, δ<sup>13</sup>C values,  
246 indication of how δ<sup>13</sup>C was measured, and carbon content (%), where available. AMS-derived δ<sup>13</sup>C values may  
247 have undergone fractionation during the AMS process hence may not be representative of the true sample value.  
248 We also include the section label and δ<sup>13</sup>C 1σ uncertainty where available.

249  
250 We provide sample depth as a combination of the top, middle, bottom depth and thickness of the sample based on  
251 how the information was presented in the original paper or in our communication with the original author. All  
252 these depths are presented with the core top as the datum. Where cores had depth corrections for estimated loss  
253 of sediment at the top of the core (e.g. Colman et al., 1996; Morley et al., 2005) we provide a corrected middle  
254 depth for each sample. Corrected depths have the lake bottom as their datum. The method for depth correction in

**Deleted:** One hurdle when using Bayesian models, however, is that many users do not know how large the uncertainties they want to incorporate are. This is the problem we faced with radiocarbon age offsets when attempting to construct age-depth models for Lake Baikal, with the literature clearly indicating a large range of estimated age offsets but no advice regarding how to input such information into an age-depth modelling software. The goal of this study is to collect all published AMS radiocarbon data from Lake Baikal and use a single method to estimate age offset for all suitable cores. By making multiple estimates on different cores, we deliver an estimate of age-offset with a calculated uncertainty estimate. We use a linear regression-based technique for our estimates, which has been used by multiple studies of Lake Baikal (Colman et al., 1996; Demske et al., 2005; Karabanov et al., 2004) and on the Tibetan Plateau (see discussion in Hou et al. 2012). Because of data limitations, we only perform this analysis for radiocarbon dates from TOC, but published radiocarbon dates from other sample types are also included in our dataset, which we make public to facilitate future research and so others can perform similar analyses if desired.

A number of studies have curated regional radiocarbon datasets with the aim of developing more robust age-depth models for their respective cores to allow their temporal uncertainty to be integrated into future interpretations of their paleoclimate proxies (Giesecke et al., 2014; Goring et al., 2012; Wang et al., 2019; Zimmerman and Wahl, 2020). As far as we are aware, no systematic study has applied such an approach to a single lake.

Lake Baikal is the oldest, deepest, and most voluminous lake in the world. The lake's surface area covers 23,000 km<sup>2</sup> while its catchment spans over 500,000 km<sup>2</sup>, reaching into northern Mongolia. Sediments from Lake Baikal have been used to reconstruct climate change as far back as the Miocene (Antipin et al., 2001; Williams et al., 2001), although most studies have focussed on the later stages of the Quaternary period (Mackay et al., 2011, 2022; Prokopenko et al., 2001). Of relevance to this study, is the timeframe encompassed by radiocarbon dating, a period of very marked rapid and abrupt climate change, that allows insights to be gained as to how ecosystems respond to global warming at rates observed today. Given the size of Lake Baikal (c. 630 km long) with its complex basin morpho... [1]

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395 any core is explained in the metadata text file attached to the dataset. The original references for each date are  
396 provided. Any differences between the original data and the provided data, for example corrected typos, are  
397 explained as a comment. Any data that did not have age uncertainty values and are therefore unsuitable for re-use  
398 were not included in the dataset but are detailed in a text file for completeness.

400 The metadata text file attached to the dataset also provides metadata for each core, including: the core name; the  
401 general region of the core within the lake (i.e. Buguldeika Saddle or Academician Ridge); latitude and longitude  
402 in degrees; water depth of drilling site; coring method used; length of the core; references for original data; and  
403 comments describing any corrections to the data made by us or providing explanation for depth correction.

405 The selection of what data to provide was driven by our focus on TOC, hence we do not provide information  
406 relevant only to pollen concentrate or lipid fraction dates, such as purity as reported in Piotrowska et al. (2004).  
407 We do not perform calibration on any of the dates, so we do not provide any calibrated date ranges or calibration  
408 information. Furthermore, we do not include an indication of whether an age was rejected by previous authors or  
409 by us in our analysis as rejection can vary across publications. We highlight that all data should be carefully  
410 considered before any reuse.

#### 411 2.4 Age Offset Estimation

412 The most common approach to estimating age offset in Lake Baikal is using linear regression. A linear regression  
413 of the mean of each (uncalibrated) radiocarbon age on sample midpoint depths for each sediment core is made,  
414 with the y-intercept value, which we term the “apparent surface age” (ASA), taken to be the age offset. This  
415 approach assumes the age offset and sedimentation rate are essentially constant over the period included in the  
416 linear regression. Studies using this technique have differed in how many ages they use in the calculation. For  
417 example, Colman et al. (1996) sometimes only used the top two dates of a core and sometimes used all dates  
418 younger than 13 <sup>14</sup>C kyr BP. Karabanov et al. (2004) and Demske et al. (2005) also apply a linear regression  
419 method to calculate age offset in their study but do not describe what subset of ages they used for each regression.

421 We follow Colman et al. (1996) in performing regressions using all dates younger than 13 <sup>14</sup>C kyr BP. The  
422 exclusion of ages older than 13 <sup>14</sup>C kyr BP follows from the change in sediment type at approximately this age,  
423 from organic-poor glacial sediments to organic-rich post-glacial sediments (Carter and Colman, 1994). These  
424 organic-rich sediments have carbon primarily from algae (such as diatoms and picoplankton) whereas the organic-  
425 poor glacial sediments are more heavily influenced by catchment sources of carbon (Vologina and Sturm, 2009).  
426 We also follow Colman et al. (1996) in their creation of composite cores for cores they report from the same  
427 drilling site.

429 For each (composite) core, we perform a simple ordinary least-squares linear regression of mean radiocarbon age  
430 on midpoint depth and use the fitted line to estimate the age at depth = 0, i.e. the ASA (Figure 1). The radiocarbon  
431 profile of each (composite) core was examined beforehand to remove outliers and to check that the ages are  
432 generally ageing with increasing depth and are approximately linear - cores that do not follow this description are  
433 excluded from this analysis. Obvious outliers are also removed, and where the selection of outliers is not clear we

**Deleted:** Regarding data identification, we provide both the laboratory code (a requirement for radiocarbon dates) and the section code when possible. Regarding depth information, data found reported in the literature in the following ways: top depth and bottom depth; middle depth and thickness; only middle depth. To accommodate all this information, we provide the top, middle, bottom depth and thickness of the sample. Where cores had depth corrections (for known losses of top sediment) we provide a corrected depth for each sample. We provide the radiocarbon age as they were reported in the original papers, as conventional <sup>14</sup>C age (Stuiver and Polach, 1977), with the standard 1σ error. We also report δ<sup>13</sup>C values and error when they were provided, specifying the method used for δ<sup>13</sup>C evaluation. Carbon yield values are included when provided. Lastly the original references are provided, and any difference between the original data and the provided data is explained as a comment.

The selection of fields was driven by our focus on TOC. As we do not perform calibration on any of the dates, we do not provide any calibrated date or calibration information. Furthermore, the data format does not include indicati... [3]

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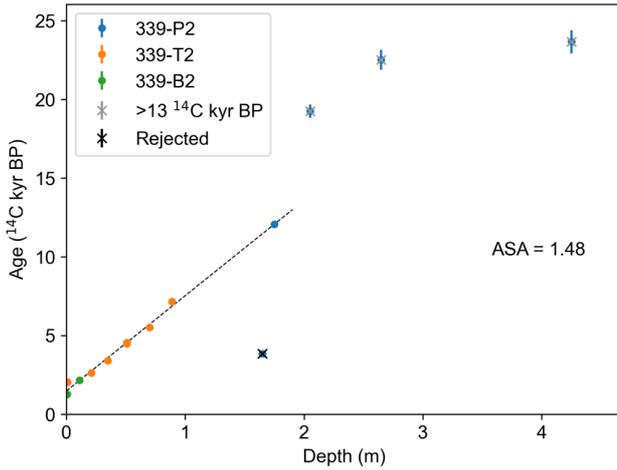
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539 evaluated multiple options and chose one. Analyses were carried out using a reproducible Jupyter Notebook  
 540 workflow: the full notebook and supporting files are publicly archived on Zenodo (Newall, 2025).

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542  
 543 **Figure 1: An example of the creation of composite cores using cores from the same drilling site, following Colman et al. (1996). The radiocarbon ages (all from TOC) from cores 339-B2, 339-T2 and 339-P2 are plotted against depth forming a composite core from Site 339. Circles show the mean radiocarbon age and bars show the analytical 1σ uncertainty. Ages that are rejected or not used in the linear regression are overlain with a black or grey cross respectively. The rejected ages shown here follow the interpretation of Colman et al. (1996), and those older than 13 14C kyr BP are not used in the linear regression. The black dotted line shows the linear regression (only shown up to 13 14C kyr BP). The y-intercept, or ASA, is 1.48 14C kyr BP. In our interpretation of this core, we additionally rejected the 2nd deepest date from 339-P2 (the single blue dot in this figure), because all other ages from this core seem problematic. Both interpretations return an ASA of 1.48 14C kyr BP.**

552 **3 Results**

553 **3.1 Core Data Overview**

554 Our review identified 51 cores that contained AMS 14C dates (Table 1; Figure 2; Figure 3), encompassing 518  
 555 radiocarbon datapoints (Figure 4). The cores are mainly taken from two underwater ridges: the Academician  
 556 Ridge, separating the Northern Basin and Central Basin, and the Buguldeika Saddle, separating the Central Basin  
 557 and the Southern Basin. Bathymetric highs such as these are often chosen as coring sites because they often  
 558 provide continuous and uninterrupted sediment records free from turbidites (Vologina and Sturm, 2009), unlike  
 559 slopes, deep-water basins, or delta fan sites near the mouths of large rivers (Colman et al., 2003).

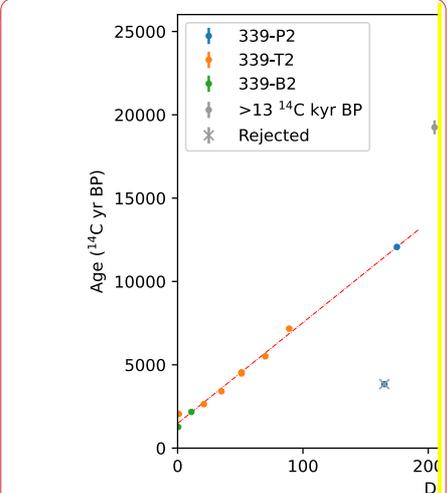
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**Moved up [2]:** The exclusion of ages older than 13 14C kyr the change in sediment type at approximately this age, from diatom-poor glacial sediments to diatom-rich interglacial sediments. By choosing to do linear regression on all ages younger than 13 14C kyr BP, we make the most of the constancy of Lake Baikal's sedimentation rates, whilst reducing the importance of this assumption by cutting off ages that are older than the age for which the major glacial-interglacial shift in sediment composition is observed. Further, this shortens the time over which we must assume a

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**Deleted:** , but doing this also returns an ASA of 1.48 14C kyr BP, so there is no impact of this on the results.

**Deleted:** (Table 1; Figure 2). All data either came from tables in the literature or personal communications from... [7]

**Deleted:** broad regions

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**Deleted:** Some coring has been done in the deeper waters of each of the three basins, however these are few.



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**Figure 2: Map of Lake Baikal showing location of all cores (black crosses). Relevant lake locations and major tributaries are labeled.**

Deleted: Map of all cores in Lake Baikal, showing the groupings by location.

Region	Core Name	Latitude (°)	Longitude (°)	Depth (m)	References
Academician Ridge	18-B1	53.56	108.01	345	Colman et al. (1996)
	18-P2	53.56	108.01	345	Colman et al. (1996); Nakamura et al. (2003)
	307-A3	53.59	108.07	335	Colman et al. (1996)
	331-P1	53.47	107.79	360	Colman et al. (1996)
	331-T1	53.47	107.79	360	Colman et al. (1996)
	333-P2	53.65	108.16	390	Colman et al. (1996)
	333-T2	53.65	108.16	390	Colman et al. (1996)
	340-B1	53.67	108.36	280	Colman et al. (1996)
	340-P1	53.67	108.36	280	Colman et al. (1996)

	340-T1	53.67	108.36	280	Colman et al. (1996)
	BDP96-1	53.70	108.35	335	Nakamura et al. (2003)
	BDP96-2	53.70	108.35	335	Nakamura et al. (2003)
	BDP98-1	53.74	108.41	325	Nakamura et al. (2003)
	VER98-1 St.5GC	53.74	108.41	325	Watanabe et al. (2009a); Watanabe et al. (2009b)
	VER98-1 St.5PC	53.74	108.41	325	Watanabe et al. (2009a)
	VER98-1 St.6GC	53.69	108.35	335	Watanabe et al. (2009a)
	Ver93-2 St.4-PC	53.56	108.02	356	Nakamura et al. (2003)
	Ver94-5 St.16-PC	53.71	108.38	310	Nakamura et al. (2003)
	Ver94-5 St.16-Pilot	53.71	108.38	310	Nakamura et al. (2003)
	Ver94-5 St.19-PC	53.56	108.01	350	Nakamura et al. (2003)
	Ver96-2 St.3-GC	53.7	108.35	320	Nakamura et al. (2003)
	Ver96-2 St.7-PC	53.56	108.1	*	Nakamura et al. (2003)
	Ver96-2 St.7-Pilot	53.56	108.1	*	Nakamura et al. (2003)
	Ver97-1 St.6	53.68	108.33	335	Nakamura et al. (2003); Sakai (2006)
<b>Buguldeika Saddle</b>	305-A5	52.4	106.12	290	Colman et al. (1996)
	316-P3	52.44	106.15	300	Colman et al. (1996)
	316-T3	52.44	106.15	300	Colman et al. (1996)
	339-B2	52.51	106.17	375	Colman et al. (1996)
	339-P2	52.52	106.17	375	Colman et al. (1996)
	339-T2	52.52	106.17	375	Colman et al. (1996)
	BDP93-1	52.52	106.15	354	Colman et al. (1996); Nakamura et al. (2003)
	BDP93-2	52.52	106.15	354	Colman et al. (1996); Nakamura et al. (2003)
	BSS06-G2	52.46	106.13	360	Murakami et al. (2012)

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	VER93-2 St.24GC	52.52	106.15	355	Karabanov et al. (2004); Tarasov et al. (2007)
	VER99G12	52.53	106.15	350	Watanabe et al. (2007); Watanabe et al. (2009b); Nara et al. (2010)
<b>Barguzin Bay</b>	BarguzinBa y18	53.42	108.82	41	Fedotov et al. (2023)
<b>Central Basin</b>	308-A3	53.42	108.32	1700	Colman et al. (1996)
<b>Continent Ridge</b>	CON01- 603-5	53.95	108.91	386	Piotrowska et al. (2004);
<b>Maloe More</b>	287-K2	53.42	107.78	300	Colman et al. (1996)
	342-B1	53.4	107.59	240	Colman et al. (1996)
	342-P1	53.4	107.59	240	Colman et al. (1996)
	342-T1	53.4	107.59	240	Colman et al. (1996)
<b>Northern Basin</b>	323-PC1	55.54	109.52	710	Ogura (1992); Nakamura et al. (2003);
	Ver94-5 St.22-GC	55.32	109.54	825	Nakamura et al. (2003)
<b>Posolskoe Bank</b>	CON01- 606-3	52.08	105.87	130	Piotrowska et al. (2004)
	Ver.99 G-6	52.09	105.84	200	Tani et al. (2002)
<b>Southern Basin</b>	BAIK13-1C	51.77	104.42	1360	Swann et al. (2020)
	BAIK13-4F	51.69	104.3	1360	Swann et al. (2020)
	BDP97-1	51.85	105.55	1450	Nakamura et al. (2003)
<b>Vydrino Shoulder</b>	CON01- 605-3	51.59	104.85	675	Demske et al. (2005)
	CON01- 605-5	51.58	104.85	665	Piotrowska et al. (2004); Demske et al. (2005)

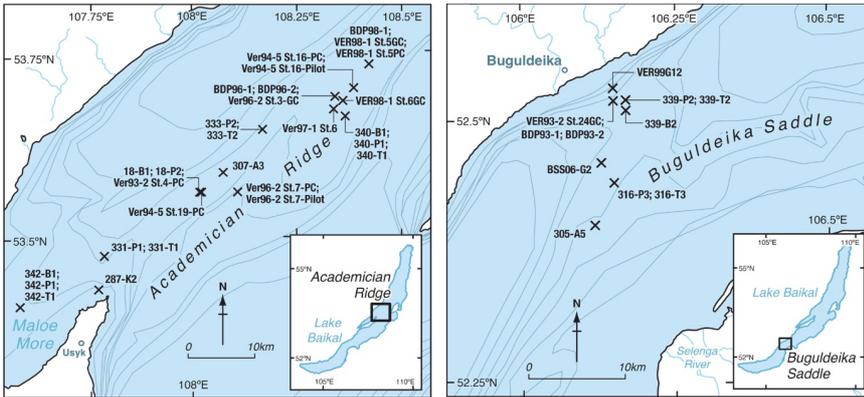
634 **Table 1: A list of all cores for which radiocarbon data were found. Each core was categorized by its general location,**  
635 **and the longitude, latitude and depth are provided. The references for the original radiocarbon data (or important**  
636 **metadata) are provided. Boxes with asterisks denote information that was not found.**

637 The location data provided for core CON01-603-5 by Piotrowska et al. (2004) and for core 287-K2 by Colman et  
638 al. (1996), placed the cores outside the boundaries of the lake. The location of 287-K2 was corrected by sight to  
639 match the locations provided on the map figures of Colman et al. (1996) and the location of CON01-603-5 was  
640 revised to fit that of Demske et al. (2005). Numerous slightly differing location data for BDP96-1 and BDP96-2  
641 were found (Kashiwaya et al., 2001; Nakamura et al., 2003; Sakai et al., 2000), being 20 km apart at most. We  
642 use the value from Nakamura et al. (2003). Note, latitude/longitude data for core Ver97-1 St.6 was only found to  
643 the precision of degree minutes, not degree seconds (Sakai, 2006).  
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647 To aid the reader in finding the locations of cores in the densely cored regions, we provide higher resolution maps  
 648 of Academician Ridge and Buguldeika Saddle (Figure 3).

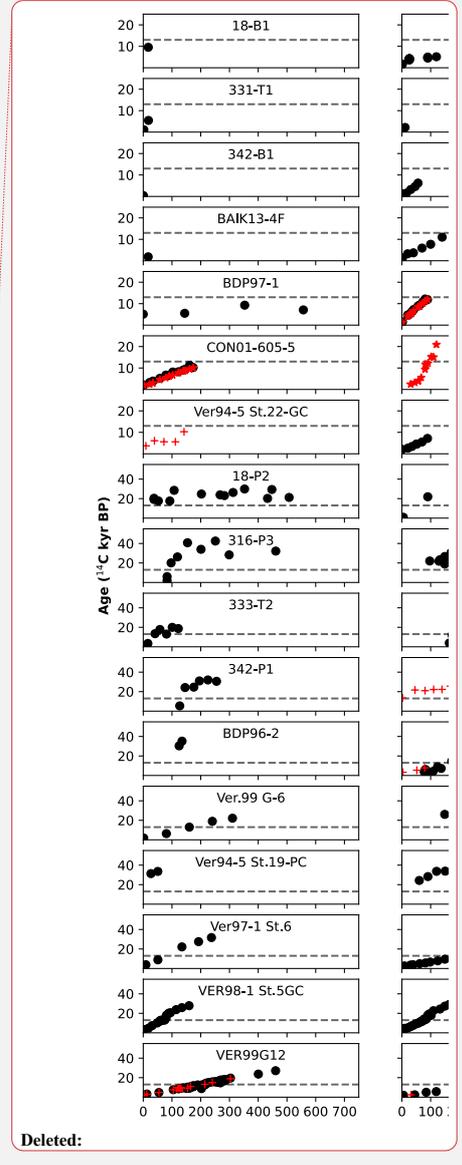
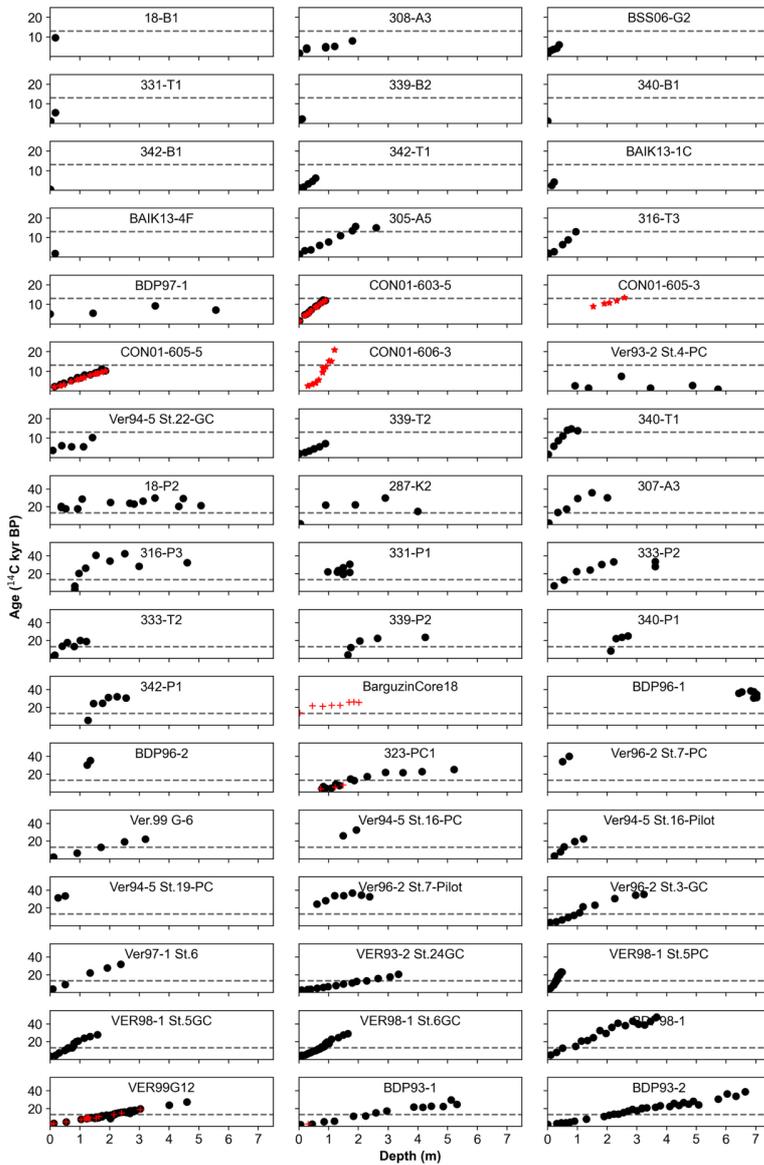


649  
 650 **Figure 3: Detailed maps of the core locations in Academician Ridge (left) and Buguldeika Saddle (right). Black crosses**  
 651 **denote core locations, some crosses represent multiple cores.**

652 **3.2 Radiocarbon Ages Overview**

653 The cores in the database have between 1 and 71 radiocarbon dates (Figure 4). The vast majority of radiocarbon  
 654 dates (438 dates) in the dataset are from TOC (a.k.a. decalcified bulk sediment). The dates from core  
 655 BarguzinCore18 (8 dates) were described as being from “bulk silty clay” - no acidification/decalcification step is  
 656 mentioned, hence we are unable to confirm that they are TOC dates (they may contain inorganic carbon). Pollen  
 657 concentrates have also been dated (42 dates). However, they are not nearly as widely exploited due to their more  
 658 intensive preparatory workload. It is notable that the pollen concentrate dates still seem to suffer from age offsets,  
 659 as they show non-zero surface ages after regression (Demske et al., 2005). A few other materials have been dated  
 660 but only in very low numbers. These include total lipids (9 dates), picked organic matter (POM; 7 dates), fine  
 661 organic matter (FOM; 5 dates); lipid fraction (2 dates); and wood (2 dates). Note that POM and FOM relate to  
 662 two different forms of organic matter, described by Colman et al. (1996). It was concluded that they were not  
 663 statistically different to the TOC ages they reported.

- Deleted:** Many cores have been analysed for radiocarbon ages in Lake Baikal, few have had many dates evaluated. The cores' radiocarbon profiles are illustrated in Figure 4. The cores in the database have a mean of 10 dates per core, but one core, VER99G12, has over 70 dates.
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680 Figure 4: Radiocarbon data from all 51 cores in this database, with mean uncalibrated radiocarbon age in  $^{14}\text{C}$  kyr BP  
 681 on y axis and depth in m plotted on x axis. TOC ages are shown as black dots, pollen ages as red stars, and all other  
 682 materials (lipids, diatom/pelitic silt, wood) are shown as red crosses. The top seven rows have smaller y axis limits to  
 683 better show shorter cores. All x axes are the same. Horizontal dashed lines are plotted at 13  $^{14}\text{C}$  kyr BP to highlight the  
 684 cut-off for our linear regression method.

689 Several errors were found in Table 2 of Colman et al. (1996) providing depth values off by a factor of 10. These  
 690 were cross-checked by contacting S. M. Colman and are reported correctly here. These errors were simply  
 691 transcription errors, so no results are affected. Lab IDs and sample top/bottom depths for core BSS06 G-2 were  
 692 added to this dataset by personal communication with Murakami. Finally, some lab codes that were wrongly  
 693 transcribed in Nara et al. (2023) are corrected. Thirteen dates were reported with ‘lower-bound’ or negative  
 694 radiocarbon ages (>43240 or -1300 respectively). These are reported in Newall et al. (2025) in a separate file  
 695 for completeness, but we suggest not using them.

Deleted: TOC radiocarbon ages for cores CON01-603-5 and CON01-605-5 are published here for the first time. Extra TOC ages for core VER98-1 St.6GC are also published here for the first time, supplementing the data published by Watanabe et al. (2009a).

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### 696 3.4 Age Offset Estimates from Linear Regression

697 Of the 51 cores with radiocarbon data reported in this compilation, 26 are used to calculate age offsets. In total,  
 698 21 ASA estimates are made, using 140 TOC ages. To recap, the ASA is the y-intercept of the linear regression on  
 699 TOC ages younger than 13 <sup>14</sup>C kyr BP and represents an estimate of the age offset. The results for each core,  
 700 grouped and summarised by their location are provided below.

#### 701 3.4.1 Academician Ridge

Core/Site	# of ages	ASA ( <sup>14</sup> C kyr BP)
Ver94-5 St.16	2	-2.49*
333 (2)	4	0.08
331 (1)	2	0.55
340 (2)	5	1.28
Ver96-2 St.3-GC	5	1.94
VER98-1 St.6GC	16	2.17
VER98-1 St.5 (1)	9	2.54
Ver97-1 St.6	2	2.77
BDP98-1	3	2.86
Mean		1.77
Range		2.78

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711 **Table 2: The ASAs (<sup>14</sup>C kyr BP) for each core/site at Academician Ridge. Where cores were analysed as a composite,**  
 712 **the number of cores from which data was used in the linear regression is denoted in parentheses. Cores with anomalous**  
 713 **ASAs are marked with \*.**

714 The ASA of 9 sites, using 11 cores, were returned from Academician Ridge (Table 2). Core Ver94-5 St.16 returned  
 715 a negative age offset estimate and we consider it an outlier, leaving 8 accepted ASAs. Cores 18-P2 and 18-B1  
 716 were left out as the former was non-linear and the latter only had one age. Core 340-P1 was left out because its  
 717 only age younger than 13 <sup>14</sup>C kyr BP was a large reversal from the older ages of 340-T1 and was clearly erroneous.  
 718 Core 307-A3 was left out because it only had one age younger than 13 <sup>14</sup>C kyr BP. Cores 331-P1, Ver94-5 St.19-  
 719 PC, Ver96-2 St.7-Pilot, Ver96-2 St.7PC, BDP96-1, and BDP96-2 were left out because they had no ages younger  
 720 than 13 <sup>14</sup>C kyr BP. Core Ver98-1 St.5PC seems to have suffered from partial compression (clear from comparison  
 721 to Ver98-1 St.5GC; Watanabe et al., 2009a) so was left out.

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Deleted: Lastly, core Ver94-5 St.22-GC didn't have any ages from TOC.

740 **3.4.2 Buguldeika Saddle**

Core/Site	# of ages	ASA ( <sup>14</sup> C kyr BP)
316 (1)	6	0.92
BDP93 (1)	9	1.26
305-A5	6	1.34
<u>339 (2)</u>	<u>8</u>	<u>1.48</u>
BSS06-G2	5	1.50
▲		
VER93-2 St.24GC	11	1.75
VER99G12	11	1.99
Mean		1.46
Standard Deviation		0.32

749 **Table 3: The ASAs** (14C kyr BP) for each core/site at Buguldeika Saddle. Where cores were analysed as a composite, the number of cores from which data was used in the linear regression is denoted in parentheses.

752 The ASA of 7 sites, using 8 cores, were returned from Buguldeika Saddle (Table 3). Core 339-P2 was left out due to its non-linearity (Figure 1). Core 316-P3 was also left out due to its non-linearity. BDP93-1 was also left out, due to its suspected contamination by modern carbon (Colman et al., 1996). Including data from BDP93-1 would have changed the BDP93 ASA to 1.15 <sup>14</sup>C kyr BP.

756 **3.4.3 Other Locations**

Location	Core/Site	# of ages	ASA ( <sup>14</sup> C kyr BP)
Maloe More	342 (3)	7	0.50
Posolskoe Bank	Ver.99 G-6	2	1.19
Central Basin	<u>308-A3</u>	<u>4</u>	<u>1.42</u>
Vydrino Shoulder	CON01-605-5	12	1.62
Continent Ridge	CON01-603-5	10	1.89
Northern Basin	VER94-5	3	2.80
	St.22-GC		
Southern Basin	BDP97-1	4	5.06*
	BAIK13-1C	2	-0.45*
Mean			1.61
Standard Deviation			0.76

757 **Table 4: The ASAs** (<sup>14</sup>C kyr BP) for each core/site in other regions. Where cores were analysed as a composite, the number of cores from which data was used in the linear regression is denoted in parentheses. Cores with anomalous ASAs are marked with \*.

760 The ASA of 8 sites, using 10 cores, was returned from other locations in the lake (i.e. not Academician Ridge or Buguldeika Saddle). The ASA of 1 site, using 3 cores, was returned from Maloe More. Core Ver.99 G-6 has a 10cm depth correction applied (Tani et al., 2002) after comparison with a corresponding multiple core M-6. Both

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Deleted: , similar to the estimate of 1.16 <sup>14</sup>C kyr BP by Colman et al. (1996), yet still different due to the inclusion of ages published by Nakamura et al. (2003).

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Deleted: No mean or range is provided here because they are each from different regions and so are not directly comparable as their own subset.

Deleted: The ASA of 1 site, using 3 cores, was returned from Maloe More. Continent Ridge, Vydrino Shoulder and Posolskoe Bank also had one estimate of ASA each, all from one core only.

783 CON01-603-5 and CON01-605-5 were suggested by Demske et al. (2005) to have had sediment missing from the  
 784 core tops. Morley et al. (2005) calculated a depth correction for CON01-605-5 of 12.5cm based on correlation of  
 785 diatom species profiles, which we apply to this data. However, no such depth correction for CON01-603-5 has  
 786 been provided, so its ASA may be an overestimate. We did not calculate an ASA for core BarguzinBay18 for two  
 787 reasons. First, we could not confirm that dates from core BarguzinBay18 were TOC dates, and second, it has no  
 788 ages younger than 13 <sup>14</sup>C kyr BP. The top 3cm of core sediment returned a radiocarbon age > 13 <sup>14</sup>C kyr BP,  
 789 suggesting there has been erosion at this location, likely due to its shallow setting or proximity to the mouth of  
 790 the Barguzin river, further rendering the core unsuitable for the linear regression method.

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 Deleted: All cores from the deep basins did not have ASAs. These deep basins are known for common turbidites which might significantly affect the age offset of the data and make for non-continuous sedimentation rates or disturbed sediment profiles, which would affect the method used here

791 **3.4.4 Synthesis**

Deleted: . Core BarguzinBay18 has no ages younger than 13 <sup>14</sup>C kyr BP, so no ASA was calculated for that core (furthermore, the top 3cm of sediment returned a radiocarbon age > 13 <sup>14</sup>C kyr BP, suggesting there has been erosion at this location, likely due to its shallow setting, rendering the site unsuitable for the linear regression method).<sup>¶</sup>

792

	No. of ASAs	No. of ages	Mean	Standard Deviation	Min	Max
<u>Academician Ridge</u>	<u>8</u>	<u>46</u>	<u>1.77</u>	<u>1.04</u>	<u>0.08</u>	<u>2.86</u>
<u>Buguldeika Saddle</u>	<u>7</u>	<u>56</u>	<u>1.47</u>	<u>0.37</u>	<u>0.92</u>	<u>2.34</u>
<u>Other Locations</u>	<u>6</u>	<u>38</u>	<u>1.57</u>	<u>0.77</u>	<u>0.5</u>	<u>2.80</u>
<u>All</u>	<u>21</u>	<u>140</u>	<u>1.62</u>	<u>0.76</u>	<u>0.08</u>	<u>2.86</u>

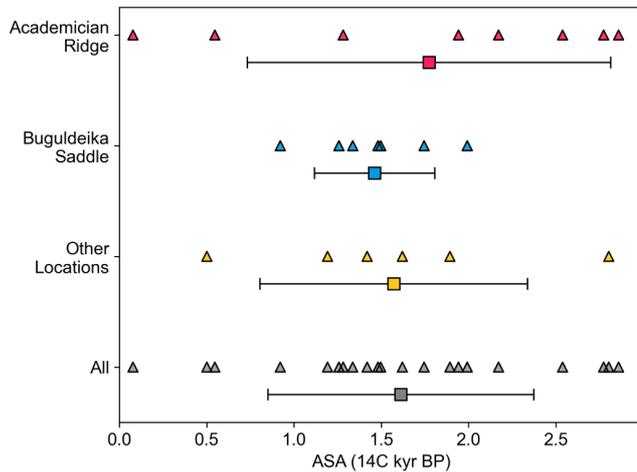
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Deleted: The mean ASA estimate for the whole lake, using our linear regression of ages younger than 13 <sup>14</sup>C kyr BP, is 1.56 <sup>14</sup>C kyr BP (Table 5). The median estimate is similar, at 1.48 <sup>14</sup>C kyr BP. The minimum and maximum ASA estimates are 0.08 and 2.86 <sup>14</sup>C kyr BP respectively, providing a very large range. The means for Buguldeika Saddle and Academician Ridge are similar to the mean of the entire lake, and their ranges overlap completely. The individual estimates from the other regions are all within the range of Academician Ridge (Table 5).<sup>¶</sup>

793 Table 5: Summary statistics of all ASA (<sup>14</sup>C kyr BP) estimates, when looking at different subsets, one of which being  
 794 the entire lake.

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 No. of ASAs ... [9]

795 Our results have a mean and standard deviation of 1.62 ± 0.76 <sup>14</sup>C kyr BP (Table 5; Figure 5). The median  
 796 estimate is similar to the mean, at 1.48 <sup>14</sup>C kyr BP and a Shapiro-Wilk test returns a p-value of 0.70, suggesting  
 797 it would be reasonable to consider the results normally distributed. The means for Buguldeika Saddle,  
 798 Academician Ridge, and for all other locations are similar to the mean of the entire lake (Figure 5). The  
 799 minimum and maximum ASA estimates are 0.08 and 2.86 <sup>14</sup>C kyr BP respectively, both from Academician  
 800 Ridge, providing a very large range. The Buguldeika Saddle region provides a much less variable set of ASA  
 801 estimates than Academician Ridge.



831

832 **Figure 5: Individual ASA estimates (triangles) grouped as being either from Academician Ridge,**  
 833 **Buguldeika Saddle, or other locations. The mean of each location is denoted as a square and the standard**  
 834 **deviation is illustrated with symmetrical error bars. Estimates from all locations are then considered as a**  
 835 **single group (“All”, in grey), showing the mean and standard deviation.**

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836 **4 Discussion**

837 **4.1 Data Compilation**

838 Whilst radiocarbon specific data compilation papers have been published for Lake Baikal before (Colman et al.,  
 839 1996; Nakamura et al., 2003) this paper represents the first complete collection of all AMS radiocarbon data from  
 840 sediment cores published before 2025 for Lake Baikal. Whilst most of the data we present is not of our own  
 841 analysis, the paper represents a large step towards making all the data more accessible for future reuse. Having  
 842 all data in one compilation, with transcription errors fixed, extra metadata, and some data made accessible for the  
 843 first time will reduce the time needed to find/verify data of interest. We hope it may encourage those interested to  
 844 utilise more data than they would have previously or to work on compiling databases of other proxies from the  
 845 lake. Within the radiocarbon realm there is still room for growth, as radiocarbon dates from surface sediment  
 846 samplers, sediment traps, suspended sediment and DIC are not included here but are present in the literature and  
 847 regularly invoked when discussing the age offset (discussed in detail below; Colman et al. 1996; Prokopenko et  
 848 al. 2007; Watanabe et al. 2009a). We stuck to data from sediment cores as opposed to from other sources in this  
 849 paper due to the significantly better reporting of sediment core data.

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850 **4.1.1 Poor Representation in Data Repositories**

851 Archiving of radiocarbon data (and proxy data in general) from Lake Baikal into international data repositories  
 852 has been poor; compiling data using typical data repositories (Neotoma, Pangaea, NOAA) provided data from  
 853 only three cores (searches done as of 1<sup>st</sup> July 2025): Neotoma contained 1 dataset for core CON01-603-5, but

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861 under a slightly different core name (CON16035); Pangaea contained datasets for CON01-603-5, CON01-605-5  
862 and CON01-606-3, although data for core CON01-606-3 was reported twice with differing reporting standards;  
863 NOAA held no radiocarbon datasets from Lake Baikal. Furthermore, interrogating the case of CON01-605-5 from  
864 Pangaea, this dataset is actually a composite core consisting of dates taken from neighbouring cores CON01-605-  
865 5 and CON01-605-3. Whilst composite cores are certainly useful when presenting and analysing data for study,  
866 we only report datasets that are delineated by core (and we deconstruct composite cores into their original cores),  
867 as this helps highlight the origin of the data.

Deleted: Incorrect core names – or inconsistent naming across publications, as was observed for a few cores in this study - means that simple data searches across multiple data repositories might report more data/cores than actually exist (i.e. CON16035 and CON01-603-5 might be reported as two different cores).

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868  
869 The lack of this representation in recognised data repositories means these data are not contributing to influential  
870 large scale data compilation or assimilation projects (Erb et al., 2022; Kaufman et al., 2020). Whilst reporting  
871 their radiocarbon data alone will not allow their inclusion in such studies, this study may act to spur proxy  
872 compilation work for Lake Baikal or the Baikal region.

#### 873 4.1.2 Naming/Data Inconsistencies

874 Horiuchi et al. (2000) report radiocarbon data from a gravity core ‘VER94/st.16’ which were identical to data  
875 reported by Nakamura et al. (2003) from core Ver94-5 St.16-Pilot and a sediment sampler - we report the data  
876 under Ver94-5 St.16-Pilot and do not report the date from the sediment sampler (which has laboratory code  
877 NUTA-4152). This inconsistency in core naming, and the reporting of a date from a sediment sampler as if it was  
878 from a core, makes proper reuse of data more difficult. Inconsistency in the spellings of different locations within  
879 the lake, such as five different spellings for Posolskoe Bank, may also make searching for relevant literature  
880 difficult. However, different spellings are to be expected across such a broad range of research, perhaps for cultural  
881 or linguistic reasons. We chose the more common spellings in the radiocarbon literature (such as “Northern Basin”  
882 instead of “North Basin” and “Posolskoe Bank” instead of “Posolsky Bank”). There were also inconsistencies in  
883 the data reported for a single core between different papers: For example, subsequent papers describing  
884 radiocarbon data for cores Ver93-2 St.24GC and VER99G12 sometimes left out some radiocarbon dates from  
885 previous papers without explanation. Lastly, there were some radiocarbon data with identical laboratory codes  
886 (which are supposed to be unique) but different data.

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Deleted: The core naming inconsistency highlighted above was not unique. Multiple cores had different names across publications, which makes searching for them in the literature more challenging.

#### 888 4.1.3 Data Reporting Conventions

889 Despite longstanding published conventions for reporting radiocarbon ages (Stuiver and Polach, 1977) and recent  
890 calls for better adherence to these conventions (Millard, 2014) many of the papers that have reported radiocarbon  
891 in Lake Baikal do not follow the conventions. All followed the most important convention of reporting  
892 conventional radiocarbon ages. However, two papers did not provide the laboratory codes (Murakami et al., 2012;  
893 Swann et al., 2020) and 7 papers did not provide any quality control measurements such as  $\delta^{13}\text{C}$  in their  
894 radiocarbon data tables (Fedotov et al., 2023; Murakami et al., 2012; Nara et al., 2023; Swann et al., 2020;  
895 Watanabe et al., 2007, 2009a, b). We were able to gather much missing information by contacting the authors,  
896 but not all authors were within contact. We reaffirm the need for better adherence to radiocarbon age reporting  
897 conventions.

Deleted: . Some publications, when using data previously reported, seemed to reject ages without mentioning them whatsoever. This practice can be confusing for those interested in reusing the data and may lead to poor reuse.

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918 Another proposal by Millard (2014) is that the pretreatment method should be described or referenced. Description  
919 regarding preparation of samples for dating TOC was generally very concise. All papers, with the exception of  
920 Fedotov et al. (2023), describe an acidification step similar to the steps we describe in section 2.2. Only Colman  
921 et al. (1996) describes any sieving procedure, but this is likely because they analysed samples of both picked  
922 organic matter (POM) and fine organic matter (FOM) to evaluate whether these fractions of organic matter may  
923 have provided better results than TOC. They found no consistent relationship between the POM, FOM, and TOC  
924 ages, which may be why future studies did not mention (and therefore, we assume, did not perform) any sieving  
925 or filtering. No papers reported any treatment with alkaline solution to remove base-soluble organic carbon (humic  
926 acids).

927  
928 No convention has been agreed upon regarding how to report sample depth information from sediment cores. In  
929 the papers reporting radiocarbon data in Lake Baikal, sample depth information was reported in the following  
930 three ways: (1) reporting the top and bottom depth of the core sample; (2) reporting the middle depth and thickness  
931 of the core sample; (3) reporting just the middle depth of the sample. Khider et al. (2019) record a community  
932 belief that sample thickness should be an essential property to report and note a community preference for top and  
933 bottom depth to be reported. Lacourse and Gajewski (2020) stress the importance of this metric after analysing a  
934 set of publications from 2018 and 2019 in *Quaternary Research* and *Journal of Quaternary Science*, finding that  
935 75% of 34 papers they analysed failed to report sample thickness. Only 56% of radiocarbon dates in this  
936 compilation contain thickness data. We reaffirm the need for better reporting of sample thickness, either by  
937 reporting top and bottom depth of the core sample or reporting the middle depth and thickness.

#### 938 **4.2 Age Offset Estimates**

939 The application of a single age offset estimation method to a number of cores within a single lake, or a single  
940 region of a lake has been done before by Colman et al. (1996;  $n=10$  age offset estimates) and Watanabe et al.  
941 (2009a;  $n=3$  age offset estimates) however this study represents the largest number of cores analysed with the  
942 same method ( $n=21$  age offset estimates). The method used in this paper is similar to that of Colman et al. (1996).  
943 The method of Watanabe et al. (2009a), by contrast, aligns positive anomalies in linear sedimentation rate to the  
944 radiocarbon plateau of the Younger Dryas. We first discuss other results on the age offset for Lake Baikal, then  
945 compare them to our own. The papers discussed below are not an exhaustive list of papers that utilise an age offset  
946 estimate but focus on those that make some justification for their choice.

##### 947 **4.2.1 Previous Age Offset Estimates**

948 Colman et al. (1996) use linear regression methods to estimate the age offset for cores in Lake Baikal, using either  
949 the topmost two ages in a core or all ages younger than 13  $^{14}\text{C}$  kyr BP. The cores they analyse come from either  
950 the Academician Ridge or Buguldeika Saddle regions. They report that the age offsets from these two regions are  
951 distinct from each other ( $0.47 \pm 0.37$   $^{14}\text{C}$  kyr BP at Academician Ridge and  $1.22 \pm 0.18$   $^{14}\text{C}$  kyr BP at Buguldeika  
952 Saddle). They hypothesise that the older age offset in Buguldeika Saddle may be due to an influx of older  
953 terrestrial sediment from the Selenga River, with its outflow very near the Buguldeika Saddle, supported by a  
954 radiocarbon age of  $2.68 \pm 0.03$   $^{14}\text{C}$  kyr BP from suspended sediment of the Selenga River. However, they

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Deleted: What is starkly absent from all the reporting standards previously published are guidelines/recommendations on how to report the depth information regarding the position of the dated material from an archive. This is likely because different archives will have different ways of reporting position. This is vital information for constructing age-depth models (Heegaard et al., 2005), and even just in palaeolimnology there are a number of ways publications will report such data. These are: (1) reporting the top and bottom depth of the core sample; (2) reporting the middle depth and thickness of the core sample; (3) reporting just the middle depth of the sample. The last of these does not provide important thickness data. Our data format accommodates any of these reporting styles – the NOAA standard, which only accepts top and bottom depth data, not middle depth data, does not. The importance of the thickness data relates to what Heegaard et al. (2005) call the between-object error. Whilst many age-depth models do not utilise such data, their ability to help better represent uncertainty means they should be considered important data regardless. 56% of radiocarbon analyses in this compilation report thickness data. Lacourse and Gajewski (2020) stress the importance of this metric after analysing a set of publications from 2018 and 2019 in *Quaternary Research* and *Journal of Quaternary Science*, finding that 75% of 34 papers they analysed failed to report sample thickness.

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991 recognise that where allochthonous carbon is ~10%, as in Academician Ridge, even infinitely old terrigenous  
992 sediment could not cause some of the age offsets they observe.

Deleted: Many papers use these results, however, most use the value of 1.16 <sup>14</sup>C kyr BP, as returned from analysis on BDP93, instead of using the summary statistics reported (Colman et al., 1999; Tarasov et al., 2007).

994 Karabanov et al. (2004), use a regression methodology to estimate an age offset of 1588 years from core VER93-  
995 2 st.24GC in the Buguldeika Saddle, however do not describe whether all their dates are used for regression. This  
996 result was not reproducible by us using any subset of their ages. Tarasov et al. (2007), examining the same core,  
997 chose instead to use an age offset estimate from Colman et al. (1996). However, instead of using the average  
998 Buguldeika Saddle estimate of 1.22 ± 0.18 <sup>14</sup>C kyr, they use 1.16 <sup>14</sup>C kyr based on the linear regression of the  
999 BDP93 cores' radiocarbon data.

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1000  
1001 Demske et al. (2005) estimate the age offset of pollen concentrate ages (not the TOC age offset) by performing  
1002 linear regressions on three cores, however the number of ages used for each regression is not described. For core  
1003 CON01-603-5 (Continent Ridge) they use a value of 0.930 <sup>14</sup>C kyr, which we could reproduce using the shallowest  
1004 three ages in the core. For core CON01-606-3 (Possolskoe Bank) they report a value of 0.675 <sup>14</sup>C kyr and for the  
1005 composite core consisting of cores CON01-605-3 and CON01-605-5 (Vydrino Shoulder) they report a value of  
1006 0.96 <sup>14</sup>C kyr. We could not reproduce either of those values using any combination of their data with a simple  
1007 ordinary least squares linear regression. Note these results are from pollen concentrates, which likely have a  
1008 different age offset to TOC. The non-zero nature of these offsets however highlights that pollen concentrate ages  
1009 in Lake Baikal still suffer from an age offset similar to what has been determined by other studies (Kilian et al.,  
1010 2002; Neulieb et al., 2013; Schiller et al., 2021), possibly through contamination or redeposition.

Deleted: . It is possible this is because they report their ages as the 'analytical age' which might suggest they are reported without the correction for isotopic fractionation however, correction for isotopic fractionation is mentioned in their methodology and δ<sup>13</sup>C data is provided. Many of their dates are reused by Tarasov et al. (2007) in the same form reported by Karabanov et al. (2004). We therefore interpret this to mean that the data reported by Karabanov et al. (2004) do not need further isotopic correction.

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Deleted: Lake Baikal TOC age correction "should not exceed 500yr", and argue against the previously proposed age offset estimates of greater than 1000 <sup>14</sup>C yr.

1011  
1012 Prokopenko et al. (2007) argue that a "true reservoir effect for a lake cannot be core- or site-specific" and reject  
1013 age offset estimates determined from linear regression-based approaches due to their resulting in "core-specific  
1014 reservoir corrections... from the same site". However, the different estimates from nearby cores can be simply  
1015 reconciled by recognising that the estimation method used has uncertainty, like all estimation methods. Further,  
1016 they propose that Lake Baikal TOC age corrections "should not exceed 500yr". However, this proposal is based  
1017 on 3 ages from surface sediments or modern sediment traps, which may underestimate the age estimates due to  
1018 bomb carbon (Colman et al. 1996) and their justifications show misunderstandings that both wood samples and  
1019 pollen concentrates are free themselves from age offsets (which they are not). For example, Prokopenko et al.  
1020 (2007) suggest a "critical cross-check" for the TOC age offset is available in the radiocarbon ages of the twin  
1021 BDP-93 cores, referencing a wood and a TOC age that are from similar depths in different cores. The wood age  
1022 is approximately 500 years younger than the slightly deeper TOC age, so imposing an offset of over 500y on the  
1023 TOC age creates a stratigraphic reversal, the deeper age now being younger. This supposed contradiction,  
1024 however, doesn't account for the fact that wood ages are also known to have age offsets (Hatté and Jull, 2013).  
1025 For example, Oswald et al. (2005) compare the ages of different macrofossil types in Arctic lakes and find that  
1026 "wood and charcoal are generally older than other macrofossils of the same sample depth with age differences  
1027 ranging from tens to thousands of years", which they attribute to the decay-resistance and/or the in-built age of  
1028 woody macrofossils. Similarly, Prokopenko et al. (2007) discuss a lamina enriched in the diatom *Synedra acus*  
1029 and compare the age of this lamina in CON01-603-5, interpolated from pollen concentrate ages, to the TOC ages  
1030 of similar lamina in three other cores. They suggest the difference in radiocarbon age of only ~0.3 <sup>14</sup>C kyr is

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064 consistent with a 500-yr adjustment to bulk TOC ages. Again, this doesn't account for the fact that pollen  
065 concentrate ages can exhibit age offsets (Kilian et al., 2002; Neulieb et al., 2013; Schiller et al., 2021). These two  
066 instances of mistaking dates of terrestrial material as being free of age offsets highlight here the utility in using  
067 the term age offset, instead of reservoir age: The fact that terrestrial material is free of a reservoir age does not  
068 mean it is free of an age offset.

070 Watanabe et al. (2009a) present radiocarbon dates from three cores in Academician Ridge, each showing a region  
071 of paired positive and negative linear sedimentation rate (LSR) anomalies. These events all show anomalously  
072 low apparent sedimentation rate and then anomalously high apparent sedimentation rate before returning to  
073 'normal' sedimentation rates at 12.1 <sup>14</sup>C kyr BP or 12.2 kyr BP. Several explanations for these LSR anomalies  
074 are ruled out before settling on the possibility that they represent the radiocarbon plateau of the Younger Dryas  
075 (YD). Using a calendar age of 11.6 cal kyr BP for the end of the YD, they de-calibrate this to 10.1 <sup>14</sup>C ka BP and  
076 calculate a  $2.1 \pm 0.09$  <sup>14</sup>C kyr correction to match their LSR anomaly dates to the end of the YD. The uncertainty  
077 of their estimate does not include the uncertainty of the de-calibration, however.

079 Nara et al. (2010) apply an age offset of  $0.5$  <sup>14</sup>C kyr to both TOC dates and pollen concentrate dates from core  
080 VER99G12. They mention the modern sediment trap radiocarbon age of  $0.61 \pm 0.04$  reported by Colman et al.  
081 (1996) and that Boës et al. (2005) found a lag of ~500 yr between the GISP2  $\delta^{18}O$  and a record of grayscale  
082 fluctuation from core CON01-603-5 attached to a pollen concentrate radiocarbon chronology (no age offset  
083 correction is mentioned for the pollen concentrate radiocarbon chronology). Recognising the offset predicted by  
084 Watanabe et al. (2009a) of  $2.1 \pm 0.09$  <sup>14</sup>C yr at Academician Ridge, they suggest that this lower offset at  
085 Buguldeika Saddle may be due to a large input of modern organic material from the Selenga River. Coincidentally,  
086 this is the mirror image of the reasoning Colman et al. (1996) who suggested the Selenga may have provided older  
087 carbon material.

089 Murakami et al. (2012) use an age offset value of  $1.418$  <sup>14</sup>C kyr. This is inferred from a radiocarbon date from  
090 depth 0-1cm in their core BSS06-G2, reported with an age  $1.418 \pm 0.036$  <sup>14</sup>C yr BP, assuming that this sediment  
091 should be approximately modern.

093 Nara et al. (2023) correct for a reservoir effect of  $0.38$  <sup>14</sup>C kyr in core VER99G12, due to the 380 yr water  
094 residence time of the lake measured by Shimaraev et al. (1993). There is no reason the residence time of water  
095 should impact the reservoir age, however, especially given the lake's rapid ventilation rates (Weiss et al., 1991).

#### 096 4.2.2 Our Age Offset Results

097 We return  $2.1$  age offset estimates from cores across the whole lake (Figure 5; Table 5). The range of accepted  
098 estimates ( $0.08 - 2.86$ ) is greater than the range of estimates in the previous literature. The range and standard  
099 deviation of estimates from Buguldeika Saddle ( $n=7$ ), are much lower than the Academician Ridge ( $n=8$ ). The  
100 lower spread of estimates in Buguldeika Saddle is likely related to higher sedimentation rates, approximately 5  
101 times that of the Academician Ridge (Colman et al., 2003), for two reasons: Regarding the estimation method,  
102 the y-intercept of a linear regression is more susceptible to error in the y-direction when the slope is lower;

Deleted: Their reasoning represents the most involved discussion of the age offset for Lake Baikal, so we take time here to examine their different claims. Their reasoning begins with a suggestion that linear regression-based approaches to estimating the TOC age offset have produced contradicting results for nearby cores, such as the 1160 <sup>14</sup>C yr estimate for BDP-93 (Colman et al., 1996) and the 1588 <sup>14</sup>C yr estimate for VER93-2 St.24GC (Karabanov et al., 2004), both from the Buguldeika Saddle. They use the argument that a "true reservoir effect for a lake cannot be core- or site-specific" to refute these two estimates and their methodologies. Tangentially, we highlight that reservoir effects could indeed be site-specific, as they are in the ocean, highlighting that Lake Baikal is the largest lake by volume in the world with three large basins. Although, when correcting radiocarbon ages before calibration, it is their age offset, not solely their reservoir effect, that must be accounted for, and this can clearly have site-specific component in theory, for example if the regions receive different influx, as the Buguldeika Saddle and Academician Ridge areas do. Noting that the two cores highlighted above are both in the same region, we agree that they should both have the same age offset, however instead of disregarding the differing results of Colman et al. (1996) and Karabanov et al. (2004) a (... [10])

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244 Regarding sediment processes, in slower accumulating sediments dates may be affected by post-depositional  
245 processes, such as bioturbation of the surface sediments, for longer.

246  
247 The mean and standard deviation of the estimates from each site are  $1.77 \pm 1.04$   $^{14}\text{C}$  kyr for Academician Ridge  
248 and  $1.47 \pm 0.37$   $^{14}\text{C}$  kyr for Buguldeika Saddle. To test whether we can argue the Academician Ridge or Buguldeika  
249 Saddle have different age offsets we use a Welch's T-Test. This returns a p-value of 0.44, so we cannot reject the  
250 null-hypothesis that these regions have statistically indistinguishable age offsets. Estimates from other regions of  
251 the lake are all within the range of estimates from Academician Ridge, providing no clear evidence that the age  
252 offset of the lake differs between different regions of the lake.

253  
254 However, the absence of statistically significant spatial variation in age offset does not imply that spatial  
255 variability does not exist. This may contribute to the spread in ASA estimates, alongside other sources of  
256 variability such as: temporal variability of sedimentation rate; temporal variability of age offset; and variable loss  
257 of top sediment during coring. Temporal variability of sedimentation rate or age offset will increase scatter in the  
258 results but are not expected to introduce a systematic bias. In contrast, variable loss of top sediment during coring  
259 would introduce scatter and impart a bias towards older ASAs. This bias would be greater where sedimentation  
260 rates are lower, which may partially explain why the Academician Ridge ASAs have a greater mean than the  
261 Buguldeika Saddle estimates. Additionally, while all samples in our analysis appear to have undergone broadly  
262 comparable pretreatment (i.e., an acidification/decalcification step applied to bulk sediment), we cannot rule out  
263 the possibility that differences in laboratory pretreatment protocols contributed to some of the observed variability  
264 in age offset estimates.

265  
266 Grouping the cores by location helps control for spatial variability in age offset, however even within our regional  
267 groupings the Academician Ridge cores are spread over ~35km and the Buguldeika Saddle cores over ~15km  
268 (Figure 3). We highlight a cluster of cores/sites within the Buguldeika Saddle area (BDP93, 339, VER93-2  
269 St.24GC, and VER99G12) that are within 2km of each other (Figure 3) and can, with high confidence, be expected  
270 to have experienced the same sediment input. These returned ASA estimates of 1.26, 1.48, 1.75 and 1.99  $^{14}\text{C}$  kyr  
271 BP respectively, with a mean and standard deviation of  $1.62 \pm 0.28$   $^{14}\text{C}$  kyr BP. This demonstrates that factors  
272 other than spatial variability account for a standard deviation of at least 0.28  $^{14}\text{C}$  kyr in Buguldeika Saddle.

273  
274 Other methods of estimating age offset, such as taking a surface sample or comparing to some perceived known  
275 date (i.e. Watanabe et al., 2009a), may seem to have lower uncertainty, however this uncertainty is likely less well  
276 constrained and may be just as large. We argue, therefore, that any estimate of age offset should, for Lake Baikal,  
277 incorporate a 1sigma uncertainty of at least 0.28  $^{14}\text{C}$  kyr - a more conservative approach would be to use the  
278 standard deviation of all estimates in the lake, leading to a 1sigma uncertainty of 0.76  $^{14}\text{C}$  kyr. Considering that  
279 most previous studies incorporated no uncertainty in their age offset estimates, or at the most an uncertainty of  
280 0.09  $^{14}\text{C}$  kyr, it is clear that previous work using radiocarbon will have significantly underestimated their temporal  
281 uncertainty. Temporal changes in carbon dynamics may lead to temporal changes in the age offset. For example,  
282 given the change in carbon content in Lake Baikal sediments at 13  $^{14}\text{C}$  kyr BP, it is reasonable that the age offset

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- Deleted: Given the uncertainty around measuring age offsets, it is not surprising that we cannot statistically argue this. The result has interesting implications for considering the source of the age offset, however. A region-specific age offset may be explained by some source of old carbon entering the system and having a local effect, for example through the Selenga River as was proposed by Colman et al. (1996). However, considering the Academician Ridge is approximately 200km from the Selenga Delta, it is unlikely that particles of old sediment would influence Buguldeika Saddle and Academician Ridge in a similar manner. Uncovering the source of this age offset still poses a challenge.
- Deleted: Given that we cannot argue that there is a systematic age offset impacted by lake location, we suggest that the best estimate of age offset in the lake will be the mean and standard deviation of all estimates throughout the lake, which is  $1.56 \pm 0.75$   $^{14}\text{C}$  kyr BP. A more precise estimate might be reasoned for using only the data from Buguldeika Saddle, which provides an estimate of  $1.51 \pm 0.45$   $^{14}\text{C}$  kyr BP. This might be justified by reasoning that Buguldeika Saddle, with its high sedimentation rate, provides the best estimates. However, we believe that more data is needed from that region of the lake to solidify those results. Further, we do consider whether the large uncertainty in our estimate is due to the use of sediments that are geographically distant, for even within our regional groupings of Academician Ridge and Buguldeika Saddle, some cores are over 10km apart.
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- Deleted: 4 core sites each provided an ASA, and are within 2km of each other, and yet the
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- Deleted: (Carter and Colman, 1994)

349 of TOC may be significantly different when comparing post-glacial and glacial sediments, imparting further  
350 uncertainty on the age offset for older ages.

351

352 The indistinguishable mean age offsets at Academician Ridge and Buguldeika Saddle have interesting  
353 implications regarding the sources of the age offsets. A region-specific age offset may be explained by some  
354 source of older terrestrial carbon entering the system and having a local effect, for example through the Selenga  
355 River as was proposed by Colman et al. (1996). However, it is not obvious that this mechanism could explain the  
356 lake-wide age offsets that our results suggest.

357

358 More generally, our results highlight that the method of using a linear regression to estimate the age offset can  
359 have uncertainties of multiple hundreds of years. Linear regression is likely to provide a more accurate answer  
360 where sedimentation rates are high, but it should not be used where turbidites or variable sedimentation break the  
361 assumption of constant sedimentation that is required for the technique. Ideally, when used in previously unstudied  
362 lake systems, multiple cores should be taken/used to evaluate the uncertainty in the estimate. A further implication  
363 of our result is that many previous studies are likely to have significantly underestimated the uncertainty in their  
364 estimates of age offset. Future work to improve the linear regression method would be welcome. For example,  
365 we followed Colman et al. (1996) in using simple ordinary least squares linear regression, however given the  
366 provided uncertainties in radiocarbon ages we could have used a weighted least squares linear regression  
367 technique. Furthermore, when multiple subsets of ages could be used in the regression for each core, we made a  
368 subjective choice regarding which seemed the best - protocol as to how to propagate the uncertainty related to  
369 making those subjective choices would be welcome. The promise of reliable radiocarbon dating free of age offsets  
1370 through a new technique preparing pollen concentrates by Omori et al. (2023) is particularly exciting in light of  
1371 our results.

## 1372 5 Data Availability

1373 The data can be accessed at <https://doi.org/10.1594/PANGAEA.973799> (Newall et al., 2025).

## 374 6 Interactive Coding Environment

375 A fully interactive computing environment (ICE) accompanying this study is archived in Zenodo and can be  
376 accessed at <https://doi.org/10.5281/zenodo.17636062> (Newall, 2025). The ICE provides a Jupyter Notebook  
377 (notebooks/ASAanalysis.ipynb) containing age offset analyses and creation on non-map figures used in this paper.  
378 This allows readers to reproduce all scientific results presented here and to interact directly with figures, plots,  
379 and analytical steps. The ICE is containerized using Binder web services, enabling the notebook to be executed  
380 online in a browser without local installation. The environment can be accessed via its DOI on Zenodo, and  
381 executed through the Binder launch link provided in both the Zenodo record and the associated GitHub repository  
382 ([https://github.com/samrnewall/baikal\\_essd\\_ice](https://github.com/samrnewall/baikal_essd_ice)). To access the analyses within the ICE navigate to  
383 [notebooks/ASAanalysis.ipynb](https://github.com/samrnewall/baikal_essd_ice).

1384

**Deleted:** Lastly, we have highlighted that the method of using a linear regression to estimate the age offset has uncertainties of hundreds of years. Linear regression is likely to provide a more accurate answer where sedimentation rates are high, but it should not be used where turbidites or variable sedimentation break the assumption of constant sedimentation that is required for the technique. Ideally, multiple cores should be taken/used when using this technique to estimate age offset. This should not discourage investigators from using a linear regression method to estimate age offsets (when appropriate), however. Other methods, such as taking a surface sample or comparing to some perceived known date, may seem to have lower uncertainty, however this uncertainty is likely less well constrained and may be just as large. A further implication of our result is that many previous studies are likely to have significantly underestimated the uncertainty in their estimates of age offset.

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404 **7. Conclusions**

405 In this study, we have (i) created a complete database of all AMS radiocarbon dates from Lake Baikal sediment  
406 cores published up to 2025, standardising the reporting, updating missing or incorrect metadata, and adding some  
407 previously unpublished dates, (ii) produced a new estimate of age offset for TOC in Lake Baikal sediments of  
408  $1.62 \pm 0.76$  <sup>14</sup>C kyr BP, and (iii) did not find evidence to suggest that different regions of Lake Baikal have a  
409 statistically different age offset, as previous studies have suggested. The primary implication of our results is that  
410 previous Lake Baikal studies have significantly underestimated the temporal uncertainty from radiocarbon results.  
411 More generally, our study has shown that a linear regression method for estimating age offsets has a large inherent  
412 uncertainty that has likely been underestimated when used in other lakes/previous studies. Other techniques for  
413 estimating age offset should be examined in a similar manner to evaluate their uncertainties. We hope that this  
414 study facilitates further research in Lake Baikal by improving access to, and understanding of, previous  
415 radiocarbon work that has taken place, and spurs on further work to understand the uncertainties in estimating  
416 radiocarbon age offsets.

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417 **8. Author Contribution**

418 Conceptualisation: SN and AM  
419 Data Curation: SN  
420 Formal Analysis: SN  
421 Investigation: SN and NP  
422 Methodology: SN  
423 Project Administration: SN and AM  
424 Software: SN  
425 Supervision: AM  
426 Visualisation: SN  
427 Writing: original draft preparation: SN  
428 Writing: Review and Editing: SN, AM, NP, and MB

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429 **9. Competing Interests**

430 The authors declare that they have no conflict of interest.

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431 **10. Acknowledgements**

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