INTEGRATION OF THE OLD AND NEW LAKE SUIGETSU (JAPAN) TERRESTRIAL RADIOCARBON CALIBRATION DATA SETS

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ABSTRACT. The varved sediment profile of Lake Suigetsu, central Japan, offers an ideal opportunity from which to derive a terrestrial record of atmospheric radiocarbon across the entire range of the 14C dating method. Previous work by Kitagawa and van der Plicht (1998a,b, 2000) provided such a data set; however, problems with the varve-based age scale of their SG93 sediment core precluded the use of this data set for 14C calibration purposes. Lake Suigetsu was re-cored in summer 2006, with the retrieval of overlapping sediment cores from 4 parallel boreholes enabling complete recovery of the sediment profile for the present “Suigetsu Varves 2006” project (Nakagawa et al. 2012). Over 550 14C determinations have been obtained from terrestrial plant macrofossils picked from the latter SG06 composite sediment core, which, coupled with the core’s independent varve chronology, provides the only non-reservoir-corrected 14C calibration data set across the 14C dating range.

Here, physical matching of archive U-channel sediment from SG93 to the continuous SG06 sediment profile is presented. We show the excellent agreement between the respective projects’ 14C data sets, allowing the integration of 243 14C determinations from the original SG93 project into a composite Lake Suigetsu 14C calibration data set comprising 808 individual 14C determinations, spanning the last 52,800 cal yr.

INTRODUCTION

Calibration of radiocarbon data is achieved through comparison of measured 14C determinations with those of samples of known calendar age. Such calibration data sets have been derived from a range of natural paleoenvironmental archives, providing records of atmospheric 14C concentration (Δ14C) through time. For inclusion in the internationally ratified 14C calibration curve (IntCal13, Reimer et al., this issue), such records must also provide a reliable, independent means of deriving calendar age, against which the 14C determinations can be directly compared. For the last 12,550 cal yr, dendro-
chronologically dated tree-ring data are used for this purpose (IntCal09, Reimer et al. 2009). However, this leaves approximately three quarters of the $^{14}C$ timescale to be calibrated via alternative marine records, which incorporate additional uncertainties relating to the temporally and spatially variable “marine reservoir effect” (Suess 1955; Mangerud 1972; Stuiver et al. 1986; Reimer and Reimer 2001). Similarly, speleothem data (demonstrated most extensively by Hoffmann et al. 2010 and Southon et al. 2012) require correction (for the dead carbon fraction [DCF] from geologically old carbonate), which, like the marine correction, incorporates additional uncertainties.

Ideally, the $^{14}C$ calibration curve would be composed of reservoir-free, terrestrial $^{14}C$ data across the entire range of the method. However, archives that provide such a data set are scarce. In 1998, Kitagawa and van der Plicht (1998a,b, 2000) published the first such record, composed of $^{14}C$ measurements of terrestrial macrofossils extracted from the varved sediment profile of Lake Suigetsu, Honshu Island, central Japan ($35^\circ35'N, 135^\circ53'E$). However, problems with the varve-based calendar age scale of their “SG93” sediment core precluded the widespread adoption of this data set for calibration purposes. These problems resulted primarily from gaps between successively drilled sections of the core, but were also due to uncertainties in the varve counting itself (van der Plicht et al. 2004; Staff et al. 2010). Therefore, Lake Suigetsu was re-cored in 2006, with the retrieval of 4 parallel, overlapping sediment cores this time enabling complete recovery of the sedimentary sequence and the subsequent construction of the new “SG06” composite sediment profile (Nakagawa et al. 2012). Over 550 $^{14}C$ determinations have been obtained from terrestrial plant macrofossils picked from SG06, which have been coupled with the core’s improved, independent varve chronology (produced through the integration of 2 complementary counting techniques; Marshall et al. 2012; Schlolaut et al. 2012) to provide what is still the only non-reservoir-corrected $^{14}C$ calibration data set across the entire $^{14}C$ dating range (Bronk Ramsey et al. 2012).

Although the varve-based age scale of SG93 has been demonstrated to be compromised, the ~250 $^{14}C$ determinations from the core remain sound. Therefore, if the 2 sediment cores could be reliably linked, a higher-resolution combined $^{14}C$ calibration data set could be provided. Here, a physical comparison between the SG93 and SG06 sediment cores is described, enabling such an integration of the respective $^{14}C$ data sets to be achieved (as has been recently published by Bronk Ramsey et al. 2012).

METHODS

As with the construction of the composite SG06 sediment profile from the 4 contributing, parallel cores (Nakagawa et al. 2012), archive U-channel sediment from most of the SG93 core sections from which $^{14}C$ measurements had been previously obtained (“SG93-11” to “SG93-14” and “SG93-20” to “SG93-36”) were fitted to the SG06 sediment profile through direct matching of distinct marker horizons (tephras, flood layers, turbidite layers, and other distinct sedimentological structures) between the respective cores. Additional robust matching was made for the intervening SG93 core sections (“SG93-15” to “SG93-19”) by microfacies analysis of archive SG93 thin sections using light microscopy. Such thin sections were not available for the other SG93 core sections, however.

The original stratigraphic description of SG93 by H Kitagawa (unpublished) included the depths of distinct marker layers (recorded at 5-mm precision). These layers were, where possible, identified in the archive SG93 sediment and used, along with the visual correlations to SG06 described above, to build a conversion model through which interpolated SG06 composite depth equivalents could be derived for all original SG93 $^{14}C$ samples. Since the depths of the SG93 distinct marker horizons, as well as the depths from which the SG93 $^{14}C$ samples were taken, were recorded close to the time of
the original coring, subsequent expansion/contraction of the archive core material (during the inter-
vening years in storage) is not a problem for the generation of this depth conversion model. Likewise, depth control in SG06 is at 1-mm precision (Nakagawa et al. 2012), as defined by digital phot-
ographs of the freshly exposed core section surface taken immediately after extraction from the 
lake (thereby minimizing subsequent color changes through oxidization and any post-extraction/
storage-related expansion/contraction of the sediment).

RESULTS AND DISCUSSION

Most SG93 core sections could be matched without difficulty to SG06 through purely visual means, 
despite the fact that the SG93 sediment had oxidized and therefore lost much of its visible lamina-
tion. Only a handful of SG93 core sections were more difficult to place. Figure 1 shows 2 examples 
of this physical matching process between the respective SG93 and SG06 sediment cores, using 
both the archive SG93 U-channel material (Figure 1a) and the archive SG93 thin sections 
(Figure 1b). Table 1 gives the equivalent SG06 composite depths thus derived for the top and bottom 
of the 26 individual SG93 core sections.

The span of missing sediment between successive SG93 core sections is obtained through subtract-
ing the equivalent SG06 composite core depth of the bottom of a given SG93 core section from that 
of the top of the underlying section (Table 2). The age span of this gap is given in the varve count 
and 14C model-derived age scale of Bronk Ramsey et al. (2012; see also Staff et al. 2013; given in 
SG062012 yr).

The gaps between core sections are all <20 cm, with the exception of that between sections SG93-
28 and SG93-29, which was a “known problem” to the original authors (Kitagawa and van der Plicht 
1998a,b, 2000), who included 300 yr for the 17 cm of missing sediment estimated. The mean sedi-
ment loss between the 26 SG93 core sections was found to be 8.11 cm (95.4 SG062012 yr), represent-
ing a total loss of 202.8 cm of sediment and approximately 2386 (SG062012 yr). This is slightly 
greater than the “not larger than 2000 varve years” attributed by van der Plicht et al. (2004) to the 
potential cumulative calendar age uncertainties arising from “the possible miscounting of varves 
and/or hiatuses in the varve sequences” (assessed through comparison of the SG93 14C data set with 
those of other long 14C calibration records published at that time). In actuality, it appears that the 
SG93 varve chronology included a slight over-count compared to the combined varve count and 14C 
model-derived SG062012 chronology of Bronk Ramsey et al. (2012); between the top of SG93 core 
section SG93-13 and the bottom of SG93 core section SG93-34, 29,102 SG93 yr were counted, 
compared to 28,625 SG062012 yr (for the retrieved SG93 sediment, i.e. 31,011 total SG062012 yr 
minus the 2386 yr of missing sediment from the inter-core section gaps). This is presumably the 
result of the inclusion of a certain proportion of intra-annual laminations present within the Suigetsu 
record (see Schlolaut et al. 2012), and represents an over-count of 1.67% (cf. the “< 1.5% counting 
error” estimated by Kitagawa and van der Plicht 1998b based upon duplicated counts of selected 
SG93 core sections and parallel subsections from specific core depths).

Using the revised core depth/varve age information derived for these SG93 core sections (now lack-
ing the sedimentary gaps that had previously been included, but unrecognized), the SG93 14C data 
are demonstrated to be in excellent agreement with those from the SG06 study (Figure 2). Through 
integrating the 2 cores’ data sets, the 565 14C determinations from the Suigetsu Varves 2006 project 
are bolstered by 243 SG93 14C data points. This significantly enhances the resolution of the com-
bined Lake Suigetsu calibration data set, with 808 individual 14C determinations spanning the last 
52,800 cal yr, as recently published by Bronk Ramsey et al. (2012).
Figure 1a Example matching of an archive SG93 U-channel core section (here, section “SG93-11”) on to the fully continuous SG06 composite core (here, section “B-05”). The online version of this figure is presented in full color.
Integration of Old and New Lake Suigetsu $^{14}$C Data Sets

Figure 1b Example matching of an archive SG93 thin section (here, section “SG93-16-B”) on to the fully continuous SG06 composite core (here, section “B-07”). The thin-section scans of both core sections (SG06 core section B-07, center, and SG93 core section SG93-16-B, right-hand side) are shown in polarized light against the original SG06 core photograph (core section B-07, left-hand side). The online version of this figure is presented in full color.
Table 1 Equivalent SG06 composite depth (August 2009 version; Nakagawa et al. 2012) and varve count and 14C model-derived calendar age scale (given in “SG06\textsubscript{2012} yr BP”; Bronk Ramsey et al. 2012; Staff et al. 2013) for the 26 SG93 core sections (SG93-11 to SG93-36) from which 14C determinations were obtained by Kitagawa and van der Plicht (1998a,b, 2000).

<table>
<thead>
<tr>
<th>SG93 core section</th>
<th>Original SG93 depth (cm)</th>
<th>Original SG93 vyr BP</th>
<th>SG06 composite depth (cm)</th>
<th>Revised SG06\textsubscript{2012} yr BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SG93-11</td>
<td>895.0</td>
<td>n/a</td>
<td>945.0</td>
<td>7023 ± 31</td>
</tr>
<tr>
<td></td>
<td>987.0</td>
<td>n/a</td>
<td>1029.6</td>
<td>7950 ± 23</td>
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<tr>
<td>SG93-12</td>
<td>1045.0</td>
<td>n/a</td>
<td>1091.8</td>
<td>8479 ± 23</td>
</tr>
<tr>
<td>SG93-13</td>
<td>1042.0</td>
<td>8828</td>
<td>1095.0</td>
<td>8512 ± 25</td>
</tr>
<tr>
<td>SG93-14</td>
<td>1133.0</td>
<td>9520</td>
<td>1182.2</td>
<td>9347 ± 18</td>
</tr>
<tr>
<td>SG93-15</td>
<td>1225.0</td>
<td>10,213</td>
<td>1280.7</td>
<td>10,172 ± 21</td>
</tr>
<tr>
<td>SG93-16</td>
<td>1317.0</td>
<td>10,880</td>
<td>1374.2</td>
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<tr>
<td>SG93-17</td>
<td>1408.0</td>
<td>11,789</td>
<td>1490.6</td>
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<td>SG93-18</td>
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<td>12,864</td>
<td>1579.0</td>
<td>13,043 ± 33</td>
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<td>SG93-19</td>
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<td>14,267</td>
<td>1672.4</td>
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<td>SG93-20</td>
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<td>15,713</td>
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<td>15,703 ± 55</td>
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<td>SG93-21</td>
<td>1771.0</td>
<td>17,166</td>
<td>1853.5</td>
<td>17,626 ± 56</td>
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<td>SG93-22</td>
<td>1855.0</td>
<td>18,572</td>
<td>1947.3</td>
<td>19,185 ± 52</td>
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<tr>
<td>SG93-23</td>
<td>1939.0</td>
<td>19,992</td>
<td>2036.9</td>
<td>20,800 ± 52</td>
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<tr>
<td>SG93-24</td>
<td>2028.0</td>
<td>21,566</td>
<td>2120.9</td>
<td>22,131 ± 39</td>
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<td>SG93-25</td>
<td>2119.0</td>
<td>23,088</td>
<td>2219.1</td>
<td>23,708 ± 53</td>
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<td>SG93-26</td>
<td>2210.0</td>
<td>24,630</td>
<td>2316.4</td>
<td>25,230 ± 62</td>
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<td>SG93-27</td>
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<td>26,162</td>
<td>2427.2</td>
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<td>SG93-28</td>
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<td>27,601</td>
<td>2526.8</td>
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<td>SG93-29</td>
<td>2477.0</td>
<td>28,938</td>
<td>2609.0</td>
<td>29,903 ± 95</td>
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<td>SG93-30</td>
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<td>30,521</td>
<td>2729.8</td>
<td>31,385 ± 104</td>
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<td>SG93-31</td>
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<td>32,040</td>
<td>2833.3</td>
<td>33,544 ± 104</td>
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<tr>
<td>SG93-32</td>
<td>2770.0</td>
<td>33,470</td>
<td>2918.1</td>
<td>35,286 ± 82</td>
</tr>
</tbody>
</table>
It should be noted that 7 of the original measurements from SG93 were obtained from insect fragments (Kitagawa and van der Plicht 2000). These have been excluded from the composite SG93/SG06 data set presented here (and published by Bronk Ramsey et al. 2012), since the synthesis of $^{14}$C from the atmosphere via the trophic pathway into these organisms is not as direct as is the case with photosynthesizing terrestrial plants—therefore, not representing the contemporaneous $\Delta^{14}$C as reliably as the (relatively short-lived) plant macrofossil samples dated.
Also, while the incorporation of the SG93 $^{14}$C data does improve the resolution of the (pre-Holocene) composite $^{14}$C calibration data set, these data were not included in the Bayesian modeling to anchor the site’s floating varve chronology to the IntCal09 timescale (Staff et al. 2013). The rationale behind this approach was that, while the integration of the $^{14}$C data sets of the 2 projects is deemed robust, the depth control with which $^{14}$C samples were collected from SG93 (i.e. from 3-cm integrated sampling depths for the uppermost 19.3 m of the core, corresponding to 20- to 50-yr temporal resolution; Kitagawa and van der Plicht 1998b), is not as precise as that for the SG06 samples (taken at ~1-mm precision; Staff et al. 2011; Nakagawa et al. 2012). Furthermore, the correlation between SG93 and SG06 has greater uncertainty away from the “key correlation horizons” (which exist at intervals of ~5 to ~30 cm, depending on the stratigraphy of particular core depths and on the differential preservation of the archive SG93 core sections) than does the extremely reliable corre-
lation between the parallel boreholes of SG06 (Nakagawa et al. 2012). Therefore, while the SG93 data contribute additional information for pre-Holocene $^{14}$C calibration, they were not considered appropriate for the high-precision linkage to the decadally resolved IntCal09 tree-ring data set (i.e. the SG93 data were not used for the Bayesian $^{14}$C modeling applied to tie the floating Suigetsu varve chronology to the “absolute” IntCal09 timescale; as described by Staff et al. 2013).

CONCLUSION

Through visual matching of the SG93 and SG06 Lake Suigetsu sediment cores, the $^{14}$C determinations from the respective projects have been combined into a single calibration data set comprising 808 $^{14}$C measurements from terrestrial plant macrofossils over 52,800 cal yr. At present, this Lake Suigetsu record provides the only continuous, non-reservoir-corrected data set of atmospheric $^{14}$C across the entire range of the $^{14}$C dating method, and it contributes a central component of the current version of the international consensus $^{14}$C calibration model, IntCal13 (Reimer et al., this issue).

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REFERENCES


