RADIOCARBON, Vol 42, Nr 3, 2000, p 370–381

ATMOSPHERIC RADIOCARBON CALIBRATION BEYOND 11,900 CAL BP FROM LAKE SUIGETSU LAMINATED SEDIMENTS

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ABSTRACT. This paper presents an updated atmospheric radiocarbon calibration from annually laminated (varved) sediments from Lake Suigetsu (LS), central Japan. As presented earlier, the LS varved sediments can be used to extend the radiocarbon time scale beyond the tree ring calibration range that reaches 11,900 cal BP. We have increased the density of ^{14}C measurements for terrestrial macrofossils from the same core analyzed previously. The combined data set now consists of 333 measurements, and is compared with other calibration data.

INTRODUCTION

The latest radiocarbon calibration curve (INTCAL98; Stuiver et al. 1998) was produced by combining several data sets of dendrochronologically dated tree rings for the Holocene, and uranium-thorium (U-Th) dated corals and marine sediments for the Glacial. Using the calibration data set and appropriate computer programs, the conversion of radiocarbon- to calibrated ages is now possible for 24,000–0 cal BP (Before Present, 0 cal BP = AD 1950). To generate the atmospheric ^{14}C calibration curve before 11,900 cal BP, however, only a limited number of marine data with an assumed past marine reservoir age has been used.

Atmospheric ^{14}C calibration data with higher resolution for the period before 11,900 cal BP can be obtained from laminated sediments. The terrestrial macrofossils (e.g. leaves, branches, and insects) can be dated "absolutely" by counting varve numbers. They can overcome the uncertain assumptions for past marine reservoir ages, and can produce an atmospheric calibration curve with much higher resolution.

We have measured ^{14}C dates for terrestrial macrofossils from a long sequence of varved sediments from Lake Suigetsu (Kitagawa and van der Plicht 1998a, 1998b). Recently, we increased the density of ^{14}C measurements for terrestrial macrofossils from the same core analyzed previously. Combining the previous and new data sets, we have investigated the fine structure of the atmospheric ^{14}C calibration curve before 11,900 cal BP. The ^{14}C calibration data from the LS varved sediments are presented here and compared with other calibration records.

METHODS

Radiocarbon Dating

^{14}C dating has been performed on terrestrial macrofossils (leaves, branches and insects) from the upper 35-m section of a single 75-m-long core (lab code SG) collected in 1993. All macrofossils used in this study were single pieces retaining its original form, in order to exclude the possibility of reworked material from the surroundings of the lake. To minimize potential contamination, we applied a strong acid-alkali-acid treatment to all the samples.

$^{14}C/^{12}C$ and $^{13}C/^{12}C$ ratios were measured at the Groningen AMS facility (van der Plicht et al. 1995; Wijma and van der Plicht 1997) during 1994–1998. The background was determined by measuring fossil macrofossils collected from deep layers of the same core, with ages in the range 90–100 ka estimated by the tephra chronology of the LS core (Takemura et al. 1994). The average blank correction for the larger samples (>0.7 mg of carbon) is 0.30 ± 0.03 (1σ) percent modern carbon. For smaller samples, we applied a mass-dependent correction based on the results from the ^{14}C-free macrofossils. Duplicate measurements were averaged. The agreement between the previous and new data is excellent. The numbers are listed in Table 1 (see Appendix).

Varve Chronology

The 29,100-yr-long varve chronology in the section 10.42–30.45 m has been constructed using image analysis of around 1500 high resolution digital pictures (Kitagawa and van der Plicht 1998a, 1998b). This was done using the SG core and two short piston cores. The Sakate ash layer (varve nr 9895, corresponding age 18,725 cal BP) was recognized in the deepest part of the short piston cores and 18.67-m deep in the SG cores. The tentative varve chronology produced from the SG core was reassessed based on the observation of the younger sediments above the Sakate ash layer. However, the LS varve chronology of the deeper section below the Sakate ash layer was produced by the varve counting of a single SG core. Beyond 18.8 ka cal BP, the accuracy in the LS varve chronology would become worse, and these ages quoted in this paper should be considered as minimum ages.

Absolute Age Determination and Its Uncertainty

The absolute age of the LS floating varve chronology has been determined by wiggle-matching 22 ^{14}C dates from the younger part of the LS sediment to the revised German oak ^{14}C calibration curve (Spurk et al. 1998; Kromer and Spurk 1998). The previous matching (Kitagawa and van der Plicht 1988a, 1998b) is not revised, even with new data set.

The mean deviation of ^{14}C between our LS data and the revised oak data is 60 ± 130 ^{14}C yr (1σ level). Omitting four outliers (using a 2σ criterion) yields 55 ± 100 ^{14}C yr. Likewise, we compared the LS ^{14}C calibration data with the combined German oak and German pine data (Spurk et al. 1998; Kromer and Spurk 1998). The mean deviation is then 40 ± 170 ^{14}C yr (n=54), and –5 ± 100 ^{14}C yr when nine outliers are omitted. The apparent deviations might be caused by reworked macrofossils in the LS sediments and/or a blank correction problem. But except for a few outliers, the LS calibration data agree very well with the tree-ring curve.

The uncertainty in the absolute age estimation of the LS varve chronology mainly comes from two sources: 1) the varve chronology itself, and 2) the determination of the absolute age by wiggle matching the younger part of the sediment to the tree-ring curve. Since the detectability of the varve depends on the quality of the lamination, it is not straightforward to estimate the uncertainty in the LS varve chronology. Based on duplicate counting of selected sections (about 10% of the 29,100-yr-long varve chronology), we estimate the uncertainty to be less than 1.5%. In order to construct a more precise LS varve chronology, microscopic observation of thin sections will be performed in the near future. Another uncertainty in the LS varve chronology is caused by possibly incomplete sampling. The SG core was sampled for every 90-cm-long section from one drilling hole. The comparison with short piston cores suggests that the sampling does not cause critical loss of varves: typically 0–2 cm to a maximum of 3 cm for every sampling of about 90 cm, corresponding to about 20–30 and 50 yr for the Holocene and the Late Glacial, respectively. However, the sampling loss causes an accumulation error in the LS varve chronology older than about 19,920 cal BP, corresponding to a depth of 19.39 m in the SG core.

RESULTS AND COMPARISON WITH OTHER RECORDS

Deglaciation Period

The updated atmospheric ^{14}C calibration dataset from the LS varved sediments is compared with INTCAL98 (Figure 1). Back to 12.5 ka cal BP, the LS data agree in general with INTCAL98, which is constructed from dendrochronologically dated tree rings, U-Th dated corals (Bard et al. 1998; Burr et al. 1998; Edwards et al. 1993) and marine sediments from the Cariaco basin (Hughen et al. 1998; Stuiver et al. 1998). Our LS calibration dataset also agrees well with new data from varved sediments of Lake Gościąż in Poland (Goslar et al. 2000a, 2000b), where a ^{14}C plateau is observed at 10,400 BP (between 11.8 and 12.2 ka cal BP) and a rapid increase in ^{14}C age to 12.5 ka cal BP.

Before 12.5 ka cal BP, there seems to be a systematic age offset by about 200 ^{14}C yr (Stuiver et al. 1998). It is possible that this is caused by an underestimation of about 200 varves at 12–13 ka cal BP. However, a similar age offset has been observed in Lake Gościąż (Goslar et al. 2000a). We note that at present we have no indication or evidence for missing varves in this time interval.

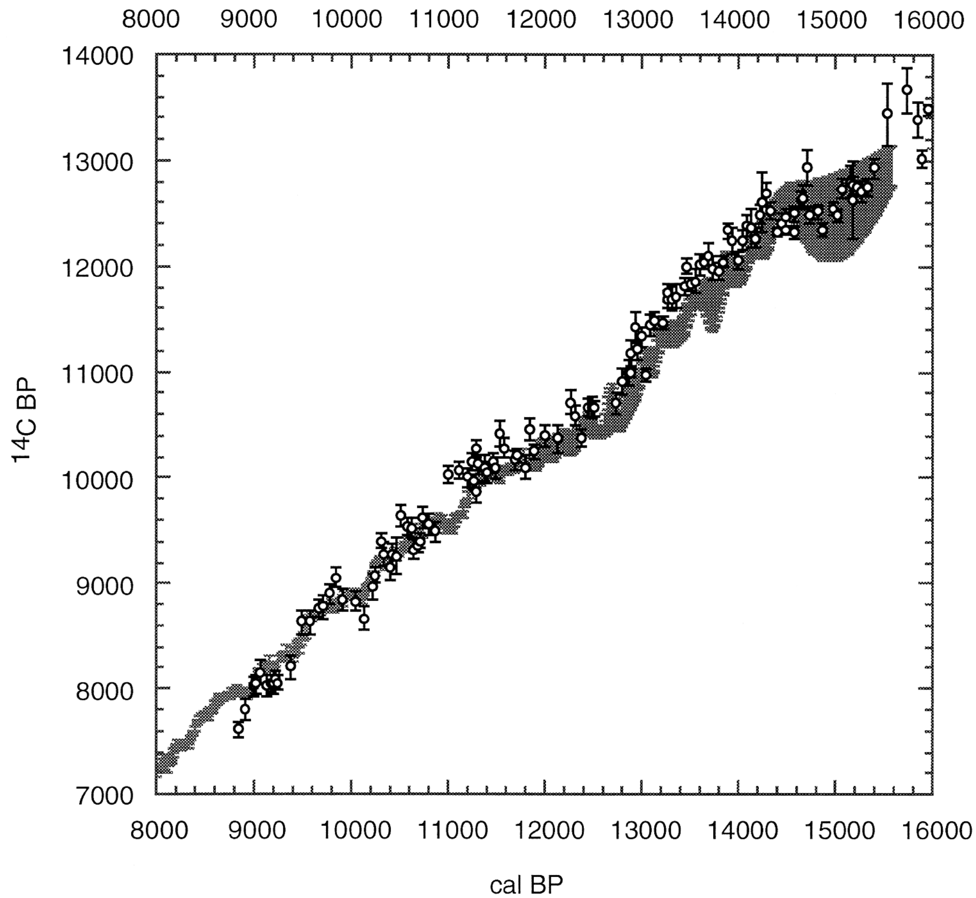

Figure 1 Comparison of atmospheric ^{14}C calibration from the varved sediments of Lake Suigetsu (LS) between 8000 and 16,000 cal BP (open circles with ±1σ error bar) with INTCAL98 calibration curve (shadowed by ±1σ; Stuiver et al. 1998).

Another possible explanation is the uncertainty of the marine reservoir correction (R) applied in INTCAL98. In the marine-derived section of INTCAL98, the following assumptions were made: 1) R remains constant for each individual site, and 2) for the period before 10 ka cal BP, R in the whole tropical surface ocean had a constant value of 500 ^{14}C yr (and 400 ^{14}C yr for samples younger than 10 ka cal BP). If the R values used in INTCAL98 are corrected to the original site-specific reservoir corrections of the corals (300 ^{14}C yr for Tahiti and Mururoa and 400 ^{14}C yr for Barbados; Bard et al. 1998), the systematic age offset decreases to the error range of the LS varve chronology.

Although there are still uncertainties in the absolute age axis of our ^{14}C calibration as well as in the ^{14}C age axis of INTCAL98 before 12 ka cal BP, our data show periods of a rather constant ^{14}C age (plateaux) at 11.6, 12.1, and 12.5 ka BP. This is consistent with the data from Lake Gościąż (Goslar et al. 2000a).

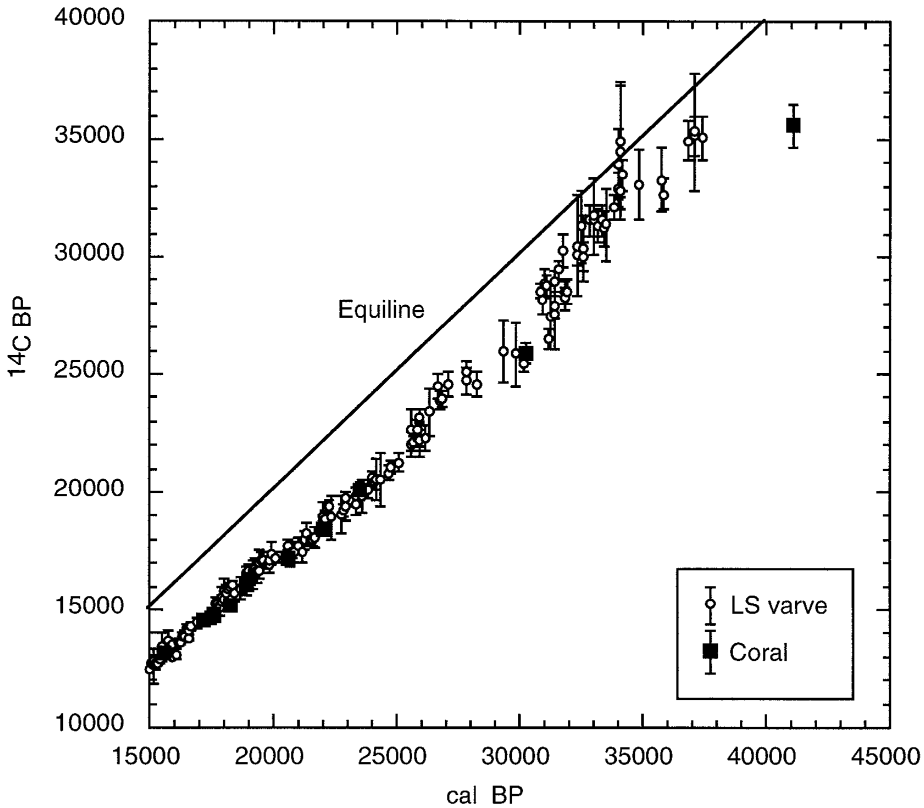

Figure 2 Radiocarbon calibration data from the varved sediments of Lake Suigetsu and U-Th dated corals (Bard et al. 1998) between 15,000 and 41,000 cal BP. Note that the error bars are ±2σ.

Full Glacial Period

The older part of the LS ^{14}C calibration dataset is compared with calibration data obtained from corals (Figure 2). Between 15,000 and around 24,000 cal BP, the long-term trend of the LS calibration agrees in general with the extended atmospheric calibration curve (INTCAL98) obtained from the U-Th dated corals (Bard et al. 1998), confirming the long-term increasing difference between ^{14}C and calendar ages. This trend agrees with the available calibration data obtained by cross-calibration of stable isotope ratios (^{18}O from planktonic foraminifera) in North Atlantic cores with the Greenland GISP2 ice core (Voelker et al. 1998), U-Th age based calibration of South African stalagmites (Vogel and Kronfeld 1997) and Lake Lisan sediments in the northern Jordan Valley (Schramm et al. 2000; Stein et al. 2000).

Before 24 ka cal BP, Bard et al.(1988) report two additional calibration datapoints at 30 and 41 ka cal BP, suggesting that the age difference between ^{14}C and calibrated timescales increase to 3000–4000 and 4000–6000 ^{14}C yr, respectively. This large difference is confirmed by ^{14}C calibration data, obtained from U-Th dated sediments of Lake Lisan (Schramn et al. 2000). However, our data for Lake Suigetsu show a very different trend, suggesting a decrease of the ^{14}C/calendar age difference between 30 and 35 ka cal BP. The precise calendar age determination for the LS varved sediment becomes more difficult with increased age because we reconstructed the LS varve chronology from one single core. Furthermore, possible contamination becomes more critical for older and smaller samples. The older part of the LS ^{14}C calibration curve remains still tentative, and additional work is needed to confirm the ^{14}C calibration in this age range.

Fine Structure of the Glacial Calibration

The time resolution of the LS calibration dataset for the Glacial period permits the investigation of fine structure in the atmospheric ^{14}C calibration curve. This curve can be strongly influenced by changes in ^{14}C production as well as by rearrangements in equilibrium between major C reservoirs (atmosphere, ocean and biosphere). For example, our data documents three periods of rather constant ^{14}C age at 12.5, 17.2, and possibly 25 ka BP, recognized at 14.3–15.0, 20.0–22, and 28–30 ka cal BP, respectively. Stuiver et al. (1998) suggest possible ^{14}C age plateaux during the Glacial, related to paleo-oceanic changes. Further discussions of the possible century- and millennium-scale fluctuations recognized in our Lake Suigetsu calibration data will be reported elsewhere.

CONCLUSION

The long sequence of varved sediments from Lake Suigetsu (Japan) permits an unique opportunity to establish a high-resolution atmospheric ^{14}C calibration curve back to 45,000 years or more. In general, varve-counting dating is only possible if the record is truly continuous; i.e. there is no hiatus or the hiatus is exactly known in time. Indeed the varve chronologies from Sweden (Wohlfarth 1996), Holzmaar in Germany (Hajdas et al. 1995), and Soppensee in Switzerland (Hajdas et al. 1993) have been shifted by several hundred years toward an older age. For Lake Suigetsu, independent checks of varve-^{14}C calibration still need to confirm our ^{14}C calibration curve, in particular beyond 24,000 cal BP. Nevertheless, some fine structure during the glacial has been partly revealed.

ACKNOWLEDGMENTS

All the ^{14}C AMS measurements were performed during 1995–1998 at Groningen AMS Facility (the Netherlands). We thank Stef Wijma for precise AMS ^{14}C measurements.

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APPENDIX

Table 1 Varve and ^{14}C chronologies of varved sediments from Lake Suigetsu. In the first column, I shows already reported data (Kitagawa and van der Plicht 1998a, 1998b); II and III show the new data measured in March, 1998 and August, 1998, respectively. Duplicate measurements are averaged.

		Depth (cm)		Varve age (cal BP)		^{14}C age	Lab code
ID	Sample	Upper	Lower	Upper	Lower	(BP ±1σ)	GrA-
I	SG13D01	1042.0	1045.3	8828	8862	7610 ± 70	6234
I	SG13D04	1051.8	1055.0	8907	8931	7810 ± 100	2849
I	SG13D07	1061.5	1064.8	8984	9013	8020 ± 90	6233
I	SG13D08	1064.8	1068.0	9013	9050	8040 ± 90	6232
I	SG13D09	1069.1	1073.4	9050	9078	8150 ± 110	2839
I	SG13C03	1077.8	1081.0	9118	9138	8020 ± 100	2914
I	SG13C05	1084.3	1087.5	9158	9183	8050 ± 80	6235
I	SG13C06	1087.5	1090.8	9183	9207	8040 ± 100	6236
I	SG13C07	1090.8	1094.0	9207	9224	8090 ± 90	2840
I	SG13C09	1095.6	1098.3	9243	9263	8050 ± 70	2947; 2948
I	SG13B05	1113.5	1118.4	9373	9402	8200 ± 110	2901
I	SG13A04	1126.5	1129.8	9481	9501	8640 ± 110	2842
I	SG14D03	1139.5	1142.7	9575	9600	8640 ± 110	2843
I	SG14D06	1149.2	1152.5	9646	9671	8770 ± 80	3087
I	SG14C01	1156.8	1160.1	9705	9727	8780 ± 110	2835
I	SG14C04	1166.6	1169.8	9769	9800	8900 ± 90	3085
I	SG14C06	1173.0	1176.3	9825	9848	9060 ± 90	3080
I	SG14B02	1182.2	1185.5	9892	9918	8850 ± 110	2844
I	SG14B07	1198.5	1201.7	10,030	10,055	8830 ± 100	3082
I	SG14A04	1211.5	1214.7	10,127	10,146	8670 ± 110	2890
I	SG15D01	1225.0	1228.4	10,213	10,239	8970 ± 120	3079
II	SG15D02	1228.4	1231.8	10,239	10,261	9070 ± 70	8184
III	SGD-012	1237.4	1238.6	10,307	10,316	9400 ± 70	10,243
I	SG15D05	1238.5	1241.9	10,316	10,350	9280 ± 120	2971
I	SG15D07	1245.3	1248.7	10,377	10,403	9150 ± 120	2845
I	SG15C01	1248.7	1252.1	10,403	10,425	9270 ± 120	2921
I	SG15C03	1255.5	1258.9	10,450	10,470	9260 ± 180	4585
I	SG15C06	1265.6	1269.0	10,510	10,532	9640 ± 100	2915
I	SG15C08	1272.4	1275.8	10,556	10,580	9540 ± 80	3081
I	SG15B02	1279.2	1282.6	10,603	10,626	9530 ± 90	2847
I	SG15B03	1282.6	1286.0	10,626	10,655	9320 ± 90	2944
II	SG15B05	1289.3	1292.7	10,680	10,706	9360 ± 60	8183
I	SG15B06	1292.7	1296.1	10,706	10,732	9410 ± 80	2913
I	SG15B07	1296.1	1299.5	10,732	10,758	9630 ± 100	2912
I	SG15A01	1303.5	1306.8	10,785	10,809	9560 ± 110	3083
I	SG15A04	1313.6	1317.0	10,857	10,880	9500 ± 90	2907
III	SGD-089	1326.2	1327.4	10,995	11,009	10,030 ± 80	10,260
I	SG16D06	1334.8	1338.6	11,102	11,144	10,080 ± 90	3086
I	SG16C01	1342.5	1345.9	11,180	11,215	10,010 ± 100	2904
III	SGD-109	1348.9	1350.0	11,243	11,253	10,150 ± 80	10,240
II	SG16C03	1349.2	1352.5	11,246	11,278	9960 ± 80	8182
I	SG16C04	1352.5	1355.8	11,278	11,303	9860 ± 100	2905
I	SG16C04	1352.5	1355.8	11,278	11,303	9860 ± 100	2905
III	SGD-114	1354.5	1355.7	11,293	11,301	10,280 ± 90	10,233

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ID	Sample	Depth (cm)		Varve age (cal BP)		^{14}C age	Lab code
		Upper	Lower	Upper	Lower	(BP ±1σ)	GrA-
I	SG16C05	1355.8	1359.7	11,303	11,336	10,130 ± 100	2911
I	SG16B01	1362.5	1365.8	11,358	11,384	10,100 ± 130	2961
I	SG16B02	1365.8	1369.2	11,384	11,414	10,060 ± 100	2838
I	SG16B04	1372.5	1375.8	11,447	11,474	10,150 ± 100	2917
I	SG16B05	1375.8	1379.1	11,474	11,506	10,100 ± 100	2916
III	SGD-138	1382.8	1383.3	11,539	11,545	10,410 ± 120	10,234
I	SG16A02	1385.3	1388.6	11,562	11,596	10,290 ± 90	3078
I	SG16A05	1395.2	1398.6	11,664	11,699	10,170 ± 100	2902
I	SG16A06	1398.6	1401.9	11,699	11,733	10,120 ± 100	2909
II	SG16A06	1398.6	1401.9	11,699	11,733	10,270 ± 70	8181
I	SG17D01	1408.0	1411.1	11,789	11,827	10,100 ± 110	2969
I	SG17D02	1411.1	1414.1	11,827	11,870	10,460 ± 100	2836
II	SG17D03	1414.1	1417.2	11,870	11,905	10,250 ± 80	1736
I	SG17D06	1423.3	1426.3	11,986	1,2023	10,400 ± 110	2970
I	SG17D10	1435.5	1438.0	12,129	12,157	10,370 ± 130	2981
I	SG17C03	1444.1	1447.2	12,240	12,282	10,710 ± 110	2837
I	SG17C04	1447.2	1450.2	12,282	12,322	10,590 ± 100	2913
I	SG17B01	1453.3	1456.3	12,352	12,383	10,380 ± 90	2906
II	SG17B03	1459.4	1462.4	12,421	12,461	10,670 ± 80	8179
I	SG17B04	1462.4	1465.5	12,461	12,500	10,670 ± 100	2848
II	SG17B05	1465.5	1468.5	12,500	12,537	10,660 ± 70	8178
I	SG17A02	1482.2	1485.3	12,718	12,754	10,700 ± 100	2908
I	SG17A04	1488.3	1491.4	12,782	12,805	10,920 ± 130	2920
I	SG17A07	1496.5	1498.0	12,851	12,864	11,000 ± 130	3077
I,II	SG18E01	1498.0	1501.0	12,864	12,910	10,990 ± 40	4532; 8177
III	SGD-248	1499.6	1500.6	12,887	12,905	11,180 ± 130	10,268
I	SG18E02	1501.0	1504.0	12,910	12,947	11,420 ± 150	5634
I	SG18E03	1504.0	1507.0	12,947	12,987	11,210 ± 90	5635
I	SG18E04	1507.0	1509.9	12,987	13,028	11,340 ± 90	5637
I	SG18E05	1509.9	1512.9	13,028	13,067	10,980 ± 60	4533
I	SG18E06	1512.9	1515.9	13,067	13,112	11,440 ± 110	5638
I	SG18E07	1515.9	1518.9	13,112	13,151	11,480 ± 90	5639
I	SG18D01	1521.4	1524.4	13,188	13,236	11,460 ± 60	4534
I	SG18D02	1524.4	1527.3	13,236	13,284	11,690 ± 90	5640
III	SGD-274	1525.8	1526.9	13,255	13,276	11,760 ± 80	10,232
II	SG18D03	1527.3	1530.3	13,284	13,338	11,700 ± 120	8190
II	SG18D04	1530.3	1533.3	13,338	13,394	11,720 ± 110	8139
III	SGD-284	1536.0	1537.0	13,435	13,454	11,810 ± 80	10,238
II	SG18D06	1536.3	1539.3	13,441	13,492	12,000 ± 80	1719
I	SG18C01	1539.3	1542.3	13,492	13,537	11,830 ± 70	5641
II	SG18C02	1542.3	1544.2	13,537	13,573	11,860 ± 110	8176
II	SG18C03	1544.2	1547.2	13,573	13,621	12,010 ± 100	8151
I,II	SG18C04	1547.2	1550.2	13,621	13,672	12,030 ± 60	4535
II	SG18C05	1550.2	1553.2	13,672	13,717	12,100 ± 130	8194
I	SG18B01	1553.2	1556.7	13,717	13,767	11,980 ± 110	5653
II	SG18B02	1556.7	1559.7	13,767	13,814	11,960 ± 80	8175

https://doi.org/10.1017/S0033822200030319

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ID	Sample	Depth (cm) Upper	Depth (cm) Lower	Varve age (cal BP) Upper	Varve age (cal BP) Lower	^{14}C age (BP ±1σ)	Lab code GrA-
I	SG18B03	1559.7	1562.6	13,814	13,865	12,040 ± 60	4536
II	SG18B04	1562.6	1565.6	13,865	13,914	12,330 ± 70	8147
I	SG18B05	1565.6	1568.6	13,914	13,967	12,250 ± 130	6206
I	SG18B06	1568.6	1572.1	13,967	14,023	12,050 ± 90	4537
I	SG18A01	1572.1	1575.1	14,023	14,067	12,250 ± 100	5642
II	SG18A02	1575.1	1578.1	14,067	14,116	12,380 ± 100	8189
II	SG18A03	1578.1	1581.0	14,116	14,159	12,360 ± 190	8191
I	SG18A04	1581.0	1584.0	14,159	14,198	12,270 ± 100	6202
II	SG18A05	1584.0	1587.0	14,198	14,238	12,490 ± 90	8148
I	SG18A06	1587.0	1589.0	14,238	14,267	12,610 ± 300	5654
II	SG19D01	1589.0	1592.1	14,267	14,316	12,680 ± 120	8150
II	SG19D02	1592.1	1595.3	14,316	14,366	12,520 ± 80	8143
I,II	SG19D03	1595.3	1598.4	14,366	14,421	12,320 ± 50	4539; 8185
I	SG19D04	1598.4	1601.6	14,421	14,467	12,410 ± 100	6204
III	SGD-350	1602.4	1603.4	14,480	14,497	12,460 ± 90	10,231
I,II	SG19D05	1601.6	1604.7	14,467	14,514	12,350 ± 50	5643; 8188
I	SG19D08	1601.6	1604.7	14,467	14,514	12,500 ± 70	5644; 8160
I,II	SG19D07	1607.8	1611.0	14,558	14,607	12,320 ± 60	4540
III	SGD-360	1612.7	1613.8	14,633	14,648	12,630 ± 90	10,239
II	SG19C01	1614.1	1617.2	14,651	14,702	12,660 ± 110	8156
III	SGD-364	1616.8	1617.9	14,695	14,713	12,940 ± 160	10,235
II	SG19C02	1617.2	1620.4	14,702	14,748	12,480 ± 90	8159
I	SG19C04	1623.5	1626.7	14,787	14,838	12,520 ± 70	5645
I	SG19C05	1626.7	1629.8	14,838	14,879	12,350 ± 60	4541
II	SG19C08	1636.1	1638.2	14,961	14,992	12,550 ± 60	8173
I	SG19B01	1638.2	1641.3	14,992	15,044	12,490 ± 60	4542
II	SG19B02	1641.3	1644.4	15,044	15,093	12,740 ± 100	8135
III	SGD-394	1647.8	1648.8	15,151	15,169	12,800 ± 150	10,242
I	SG19B04	1647.6	1650.7	15,148	15,202	12,630 ± 370	5646
III	SGD-395	1648.8	1649.8	15,169	15,187	12,770 ± 90	10,237
I	SG19B05	1650.7	1653.9	15,202	15,251	12,750 ± 80	4543
I	SG19B06	1653.9	1657.0	15,251	15,306	12,710 ± 110	6205
II	SG19B07	1657.0	1660.1	1,5306	15,370	12,750 ± 80	8140
II	SG19A01	1660.1	1663.3	15,370	15,427	12,930 ± 90	8136
I	SG19A03	1667.4	1670.6	15,501	15,555	13,440 ± 300	5648
I	SG20D01	1680.0	1683.3	15,713	15,764	13,670 ± 220	4550
I	SG20D03	1686.5	1689.8	15,815	15,867	13,390 ± 170	5649
I	SG20D04	1689.8	1693.0	15,867	15,926	13,020 ± 80	4551
I,II	SG20D05	1693.0	1696.3	15,926	15,982	13,480 ± 60	5650; 8130
I	SG20C03	1693.0	1696.3	15,926	15,982	13,630 ± 50	4552; 8128
II	SG20C01	1702.8	1706.0	16,096	16,137	13,110 ± 110	5636
I,II	SG20C02	1706.0	1709.3	16,137	16,183	13,610 ± 70	8134
I	SG20C05	1715.8	1719.0	16,298	16,351	13,890 ± 80	5651
I	SG20C06	1719.0	1722.3	16,351	16,408	13,860 ± 130	4553
I,II	SG20B01	1726.0	1729.3	16,474	16,528	14,220 ± 80	6203; 8142
I	SG20B02	1729.3	1732.5	16,528	16,577	13,820 ± 70	4554

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		Depth (cm)		Varve age (cal BP)		^{14}C age	Lab code
ID	Sample	Upper	Lower	Upper	Lower	(BP ±1σ)	GrA-
II	SG20B03	1732.5	1735.8	16,577	16,633	14,160 ± 120	8133
I	SG20B04	1735.8	1739.0	16,633	16,688	14,300 ± 90	5652
I	SG20A03	1755.3	1758.5	16,928	16,982	14,440 ± 100	4555
II	SG20A05	1761.8	1765.0	17,028	17,072	14,580 ± 90	8132
I	SG21D04	1779.8	1782.7	17,318	17,366	14,700 ± 60	4556
II	SG21D06	1785.7	1788.6	17,417	17,463	14,740 ± 80	8193
I	SG21D07	1788.6	1791.5	17,463	17,503	14,600 ± 90	4557
II	SG21D08	1791.5	1793.5	17,503	17,536	14,630 ± 110	8113
I	SG21C02	1796.4	1799.3	17,582	17,631	14,630 ± 60	4558
I	SG21C03	1799.3	1802.3	17,631	17,683	14,860 ± 200	4559
II	SG21C04	1802.3	1805.2	17,683	17,727	15,240 ± 150	8116
II	SG21C05	1805.2	1808.1	17,727	17,773	15,280 ± 80	8111
II	SG21C06	1808.1	1811.0	17,773	17,820	15,200 ± 90	8120
I	SG21C07	1811.0	1814.0	17,820	17,863	15,130 ± 190	4556
II	SG21B01	1814.0	1816.9	17,863	17,911	15,390 ± 120	8119
II	SG21B02	1816.9	1819.8	17,911	17,955	15,540 ± 210	8112
I	SG21B03	1819.8	1822.8	17,955	18,006	15,760 ± 270	4561
I	SG21B04	1822.8	1825.7	18,006	18,059	15,480 ± 140	5658
I	SG21B05	1825.7	1828.6	18,059	18,109	15,730 ± 150	5668
II	SG21B06	1828.6	1831.6	18,109	18,159	15,860 ± 80	8114
II	SG21A02	1837.4	1840.3	18,265	18,311	15,990 ± 80	8186
II	SG21A03	1840.3	1843.3	18,311	18,367	16,040 ± 80	8192
I	SG21A05	1846.2	1850.1	18,419	18,485	15,700 ± 180	4562
I	SG22D03	1862.1	1866.1	18,688	18,729	15,920 ± 230	4564
I	SG22D06	1872.7	1875.2	18,823	18,851	15,990 ± 180	4565
II	SG22C02	1877.3	1880.3	18,880	18,929	16,350 ± 90	8124
II	SG22C03	1880.3	1883.3	18,929	18,979	16,570 ± 130	8118
II	SG22C04	1883.3	1886.4	18,979	19,036	16,700 ± 130	8123
I	SG22C06	1889.4	1894.5	19,083	19,179	16,280 ± 200	4566
II	SG22C07	1894.5	1896.5	19,179	19,212	16,680 ± 210	8122
I	SG22B02	1899.5	1902.6	19,266	19,320	16,750 ± 220	5669
II	SG22B03	1902.6	1905.6	19,320	19,374	16,640 ± 260	8115
I	SG22B04	1905.6	1908.6	19,374	19,422	16,700 ± 180	5668
I	SG22B05	1908.6	1912.7	19,422	19,498	17,070 ± 240	4567
II	SG22B06	1912.7	1915.7	19,498	19,554	17,110 ± 170	8127
I	SG22A01	1917.7	1920.8	19,589	19,646	17,140 ± 170	4586
II	SG22A03	1924.8	1926.9	19,725	19,766	16,950 ± 80	8155
I	SG22A04	1926.9	1929.9	19,766	19,825	16,950 ± 190	4569
I,I	SG22A05	1929.9	1932.9	19,825	19,883	17,140 ± 90	4570; 8187
I	SG22A06	1932.9	1936.0	19,883	19,939	17,380 ± 240	5660
III	SG23D02	1943.2	1946.3	20,084	20,142	17,220 ± 120	10,245
I	SG23-4	1968.9	1969.8	20,588	20,606	17,750 ± 140	6193
III	SG23C04	1971.5	1974.6	20,636	20,684	17,200 ± 180	10,246
III	SG23C05	1974.6	1977.7	20,684	20,744	17,470 ± 130	10,247
III	SG23C07	1980.9	1984.0	20,794	20,850	17,450 ± 210	10,269

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ID	Sample	Depth (cm)		Varve age (cal BP)		^{14}C age	Lab code
		Upper	Lower	Upper	Lower	(BP ±1σ)	GrA-
III	SG23B04	1993.4	1996.6	21,015	21,070	17,750 ± 160	10,249
III	SG23B06	1999.7	2002.9	21,123	21,173	17,430 ± 200	10,248
III	SG23A01	2006.0	2009.2	21,219	21,274	17,960 ± 200	10,270
III	SG23A03	2012.3	2015.4	21,332	21,379	18,240 ± 230	10,250
III	SG23A07	2024.9	2028.0	21,518	21,566	17,960 ± 130	10,252
III	SG24E01	2028.0	2031.0	21,566	21,622	17,970 ± 130	10,253
III	SG24E02	2031.0	2034.0	21,622	21,675	18,090 ± 230	10,254
I	SG24-5	2050.5	2051.6	21,961	21,979	18,810 ± 110	6192
III	SG24D03	2051.1	2054.1	21,972	22,027	18,770 ± 130	10,255
I	SG24-4	2053.8	2054.8	22,021	22,037	18,980 ± 290	6191
III	SG24D04	2054.1	2057.2	22,027	22,080	18,780 ± 200	10,383
III	SG24D05	2057.2	2060.2	22,080	22,136	18,830 ± 150	10,256
I	SG24-3	2064.9	2065.9	22,211	22,224	19,370 ± 140	6190
III	SG24C02	2068.7	2071.7	22,273	22,325	18,930 ± 450	10,258
III	SG24B05	2094.9	2097.9	22,696	22,742	19,030 ± 390	10,262
III	SG24B08	2103.9	2105.9	22,840	22,877	19,190 ± 130	10,263
I	SG24-1	2106.4	2107.4	22,884	22,901	19,430 ± 310	6189
III	SG24A01	2105.9	2108.9	22,877	22,924	19,760 ± 140	10,261
III	SG25E05	2131.1	2134.1	23,280	23,331	19,810 ± 200	10,264
III	SG25E06	2134.1	2137.1	23,331	23,386	19,460 ± 200	10,265
III	SG25D01	2140.2	2143.2	23,441	23,494	20,040 ± 210	10,266
I	SG25-2	2149.0	2150.1	23,600	23,618	19,830 ± 370	6188
III	SG25C02	2163.3	2166.3	23,833	23,885	20,110 ± 200	19,401
I	SG25-1	2175.0	2176.0	24,030	24,046	20,630 ± 130	6187
III	SG25C06	2175.3	2178.4	24,036	24,090	20,430 ± 150	10,361
III	SG25C08	2181.4	2183.4	24,144	24,182	20,500 ± 450	10,362
III	SG25B03	2189.4	2192.4	24,301	24,347	20,540 ± 560	10,367
III	SG26D01	2210.0	2213.0	24,630	24,692	20,830 ± 150	10,360
III	SG26D03	2216.1	2219.1	24,750	24,813	21,060 ± 150	10,368
III	SG26C01	2234.3	2237.4	25,104	25,151	21,270 ± 200	10,404
III	SG26B03	2263.7	2266.7	25,581	25,627	22,060 ± 260	10,369
I	SG26-3	2264.8	2266.9	25,600	25,629	22,600 ± 440	6186
III	SG26B05	2269.8	2272.8	25,679	25,733	22,080 ± 160	10,370
I	SG26-2	2277.9	2278.9	25,803	25,818	22,630 ± 220	6185
III	SG26A01	2278.9	2281.9	25,819	25,859	22,280 ± 160	10,371
III	SG26A02	2281.9	2285.0	25,859	25,906	22,280 ± 170	10,372
I	SG26-1	2285.6	2286.6	25,915	25,932	23,170 ± 150	6184
III	SG26A03	2285.0	2288.0	25,906	25,954	22,230 ± 390	10,373
III	SG26A07	2297.2	2301.0	26,100	26,162	22,300 ± 260	10,375
I	SG27-7	2311.3	2312.3	26,336	26,351	23,400 ± 500	6183
I	SG27-5	2333.9	2334.9	26,696	26,714	24,500 ± 270	6182
I	SG27-4	2336.2	2337.3	26,742	26,757	23,890 ± 210	6181
I	SG27-3	2339.5	2340.6	26,790	26,819	23,970 ± 170	6180
I	SG27-2	2355.5	2356.5	27,047	27,061	24,600 ± 270	6179
I	SG28-4	2406.2	2407.2	27,803	27,821	24,700 ± 270	6178
I	SG28-3	2408.7	2409.7	27,847	27,862	25,130 ± 190	6177

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ID	Sample	Depth (cm)		Varve age (cal BP)		^{14}C age	Lab code
		Upper	Lower	Upper	Lower	(BP ±1σ)	GrA-
I	SG28-2	2433.0	2434.0	28,275	28,290	24,550 ± 270	6176
I	SG29-3	2508.6	2509.6	29,353	29,374	25,980 ± 670	6173
I	SG29-2	2537.7	2538.7	29,860	29,876	25,840 ± 670	6172
I	SG29-1	2560.5	2561.6	30,166	30,177	25,450 ± 190	6171
III	SG30D06	2600.9	2604.5	30,780	30,852	28,530 ± 150	10,381
III	SG30C01	2604.5	2607.6	30,852	30,905	28,140 ± 290	10,378
III	SG30C03	2610.7	2613.8	30,964	31,016	28,860 ± 290	10,380
III	SG30C04	2613.8	2616.8	31,016	31,081	28,770 ± 230	10,376
I	SG30-5	2622.9	2623.9	31,192	31,209	26,460 ± 220	6168
III	SG30C07	2623.0	2626.1	31,194	31,250	27,420 ± 670	10,395
III	SG30C10	2632.3	2635.3	31,355	31,411	27,520 ± 720	10,388
III	SG30B01	2635.3	2637.4	31,411	31,444	28,960 ± 230	10,389
I	SG30-4	2635.9	2636.9	31,421	31,438	27,880 ± 240	6169
III	SG30B05	2646.6	2649.2	31,578	31,617	29,450 ± 190	10,391
III	SG30A04	2658.5	2661.6	31,759	31,809	30,270 ± 330	10,390
I	SG30R-1	2661.0	2662.1	31,801	31,816	28,500 ± 250	6174
I	SG30-3	2662.9	2664.0	31,829	31,845	28,220 ± 250	6170
I	SG30-1	2671.2	2672.3	31,939	31,955	28,500 ± 260	6167
III	SG31-7	2697.8	2698.9	32,320	32,337	30,080 ± 200	5618
I	SG31D08	2698.8	2695.5	32,336	32,389	30,470 ± 060	10,415
III	SG31C02	2709.2	2712.5	32,505	32,559	31,310 ± 770	10,416
I	SG31-6	2716.0	2717.1	32,606	32,620	30,010 ± 310	5617
III	SG31C04	2715.8	2719.1	32,603	32,652	30,360 ± 700	10,417
I	SG31-5	2732.0	2733.1	32,834	32,850	31,550 ± 340	5616
I	SG31-4	2739.5	2740.6	32,969	32,989	31,550 ± 340	5615
III	SG31B05	2741.0	2744.3	32,995	33,047	31,750 ± 810	10,419
I	SG31-1	2751.3	2752.4	33,162	33,176	31,350 ± 360	5613
I	SG31-3	2760.9	2762.0	33,317	33,336	31,550 ± 330	5614
I	SG31-7	2764.1	2765.2	33,371	33,388	31,190 ± 360	5625
III	SG32F03	2770.0	2773.2	33,470	33,526	31,380 ± 760	10,422
I	SG32-6	2791.7	2792.7	33,853	33,871	32,140 ± 260	5624
III	SG32D02	2797.8	2801.0	33,943	33,996	33,980 ± 740	10,426
I	SG32-5	2800.1	2801.2	33,980	33,998	32,880 ± 370	5623
III	SG32C01	2804.2	2807.4	34,053	34,100	34,940 ± 180	10,429
I	SG32-4	2806.5	2807.5	34,086	34,101	32,830 ± 380	5622
III	SG32C02	2807.4	2810.7	34,100	34,144	34,500 ± 470	10,430
I	SG32-2	2812.8	2813.9	34,177	34,194	33,480 ± 350	5620
I	SG32-1	2855.1	2856.2	34,841	34,858	33,070 ± 730	5619
I	SG33-4	2913.3	2914.4	35,733	35,749	33,270 ± 680	5626
I	SG33-3	2920.1	2921.2	35,848	35,865	32,640 ± 330	5627
I	SG34-2	2976.0	2977.2	36,798	36,813	34,950 ± 420	5631
I	SG34-4	2993.7	2994.9	37,088	37,107	35,140 ± 420	5632
III	SG34B06	2994.3	2997.8	37,096	37,155	35,320 ± 250	10,434
I	SG34-3	3012.6	3013.7	37,392	37,417	35,070 ± 460	5633

https://doi.org/10.1017/S0033822200030319