A 40,000-YEAR VARVE CHRONOLOGY FROM LAKE SUIGETSU, JAPAN: EXTENSION OF THE ^{14}C CALIBRATION CURVE

HIROYUKI KITAGAWA[1] *and JOHANNES VAN DER PLICHT*[2]

ABSTRACT. A sequence of annually laminated sediments is a potential tool for calibrating the radiocarbon time scale beyond the range of the absolute tree-ring calibration (11 ka). We performed accelerator mass spectrometric (AMS) ^{14}C measurements on >250 terrestrial macrofossil samples from a 40,000-yr varve sequence from Lake Suigetsu, Japan. The results yield the first calibration curve for the total range of the ^{14}C dating method.

INTRODUCTION

Lake Suigetsu is located near the coast of the Sea of Japan (35°35′N, 135°53′E). The lake is 10 km around the perimeter and covers 4.3 km^2. It is a typical kettle-type lake, nearly flat at the center, *ca.* 34 m deep. A 75-m-long continuous core (Lab code = SG) and four short piston cores (Lab codes = SG1, -2, -3 and -4) were taken from the center of the lake before 1993 (Kitagawa *et al.* 1995).

The sediments are characterized by dark-colored clay with white layers due to spring season diatom growth. The seasonal changes in the depositions are preserved in the clay as thin, sub-millimeter scale laminations or "varves". Based on observation of varve thickness change, we expect that the annually laminated sediment records the paleoenvironmental changes during the past 100 ka.

This sequence of annually laminated sediments not only forms a unique continuous paleoenvironmental record after the last interglacial but also permits us to reconstruct a complete ^{14}C calibration extending back to at least 40 ka BP, and probably even more by means of combined isotope enrichment and AMS ^{14}C dating (Kitagawa and van der Plicht 1997).

We have performed AMS ^{14}C measurements on >250 terrestrial macrofossil samples of the annual laminated sediments from Lake Suigetsu. Here, we report varve and ^{14}C chronologies of these sediments. The combined varve and ^{14}C chronologies back to 40,000 BP are used to reconstruct a ^{14}C calibration curve for the total range of the ^{14}C dating method.

METHODS

In order to build up a calendar time scale (*i.e.*, varve chronology) for the Suigetsu (SG) core, a total of 85 subsamples were taken in a section of SG extending from 10.42 to 30.45 m below the top sediment, each *ca.* 25 cm in length, including a 1.5 cm overlap with neighboring subsamples. To allow detailed observation of the sediments, the well-cleaned surfaces of sediments were scanned with a digital camera with a resolution of *ca.* 1200 data points per inch. The *ca.* 1500 digital images were processed using an image analyzing program.

Based on a more detailed analysis of the varve sediments, the previous chronology obtained mainly from the short piston cores (Kitagawa *et al.* 1995) is revised for two reasons: 1) a more precise matching of the floating Lake Suigetsu varve chronology to the available dendrochronologies with a high-resolution AMS ^{14}C data set, and 2) an updated varve chronology due to previous miscounting of varve numbers. We had identified the white and diatom-rich layers under a microscope with a UV light source. The white layers typically observed in the Holocene and at limited time intervals in the Glacial are easily identified by this procedure. However, after reassessment of varve counting

[1]International Research Center for Japanese Studies, 3-2 Oeyama Goryo Nishikyo-ku, Kyoto 610-11 Japan
[2]Centre for Isotope Research, University of Groningen, Nijenborgh 4, NL-9747 AG Groningen, The Netherlands

by means of computer image analysis of digital pictures, we found that the much less distinct varves observed in some intervals during the deglaciation and Glacial could be determined only with a relatively large error. In order to reconstruct a more precise and longer varve chronology for the laminated sediments from Lake Suigetsu, we have reassessed the varve chronology in the whole section during the deglaciation as well as the Glacial up to a depth of 30.45 m.

The uncertainty in the varve chronology comes from two sources: core sampling and varve counting. The SG core parts were divided into 90-cm-long sections for sampling from one drilling hole; therefore, there is a potential loss of sediment or varves between samplings. Detailed comparison with short piston cores (SG3 and SG4) for the upper 16 m shows that the sampling does not cause significant loss of varves—typically 0–2 cm to a maximum of 3 cm, corresponding to *ca.* 20–30 yr in the Holocene and *ca.* 50 yr in the Glacial. Since the varve ages from below 18 m (corresponding to *ca.* 20,000 cal BP) were estimated by varve counting of a single core, the ages quoted in this paper should be considered as minimum ages, the error increasing with depth.

Since the detectability of the varve depends on the quality of the lamination, it is not straightforward to estimate the accuracy of the varve counting process. Based on the results of some duplicated countings of selected subsamples and independent counting of different subsamples collected from the same horizon, we estimate that the counting error is < 1.5%, corresponding to 150 yr for 10,000 varve yr.

The sediment from the core top to 19.3 m of SG was split *ca.* every 3 cm (corresponding to 20–50 yr). The macrofossils were washed out from *ca.* 60 cm^3 of sediment. For the deeper part, the relatively large macrofossils were picked up by hand in a dust-free room to reduce contamination from the surroundings. We selected terrestrial-origin macrofossils such as leaves, branches, and insects for AMS ^{14}C measurements.

The $^{14}C/^{12}C$ and $^{13}C/^{12}C$ ratios of terrestrial macrofossils were measured at the Groningen AMS facility (van der Plicht *et al.* 1995; Gottdang, Mous and van der Plicht 1995; Wijma and van der Plicht 1997). An essential procedure is a strict elimination of possible contamination during the sample collection and handling (Wohlfarth *et al.* 1993). The samples are processed using a strong acid-alkali-acid (AAA) treatment (Mook and Streurman 1983) for both samples and reference blank materials. The reference blank consists of >50 ^{14}C-free plant materials collected from the deep layer of the same core (corresponding to an age of *ca.* 90–100 ka). The blank correction is 0.28 ± 0.03 (1 σ) pMC on average for relatively large samples (containing > 0.7 mg carbon), corresponding to 47,000 BP. For smaller samples, the blank level and its scatter increase with decreasing sample size. For age calculation, we include this effect as well as the scatter in 5–6 standards per measurement batch, prepared independently from the HOxII international standard, which is typically 0.5%.

Results

Figure 1 shows the varve and ^{14}C chronologies as a function of depth of the SG core. Until now, the varve numbers have been counted in the 10.42–30.45 m deep section. The Lake Suigetsu floating varve chronology consists of 29,100 varves. As shown in Figure 1, the sedimentation or annual varve thickness is relatively uniform (typically 1.2 mm yr^{-1} during the Holocene and 0.62 mm yr^{-1} during the Glacial). The age below 30.45 m depth is obtained by assuming a constant sedimentation in the Glacial (0.62 mm yr^{-1}). The ^{14}C ages at 10.42, 30.45 and 35 m depth are *ca.* 7800, 35,000 and 42,000 BP, respectively.

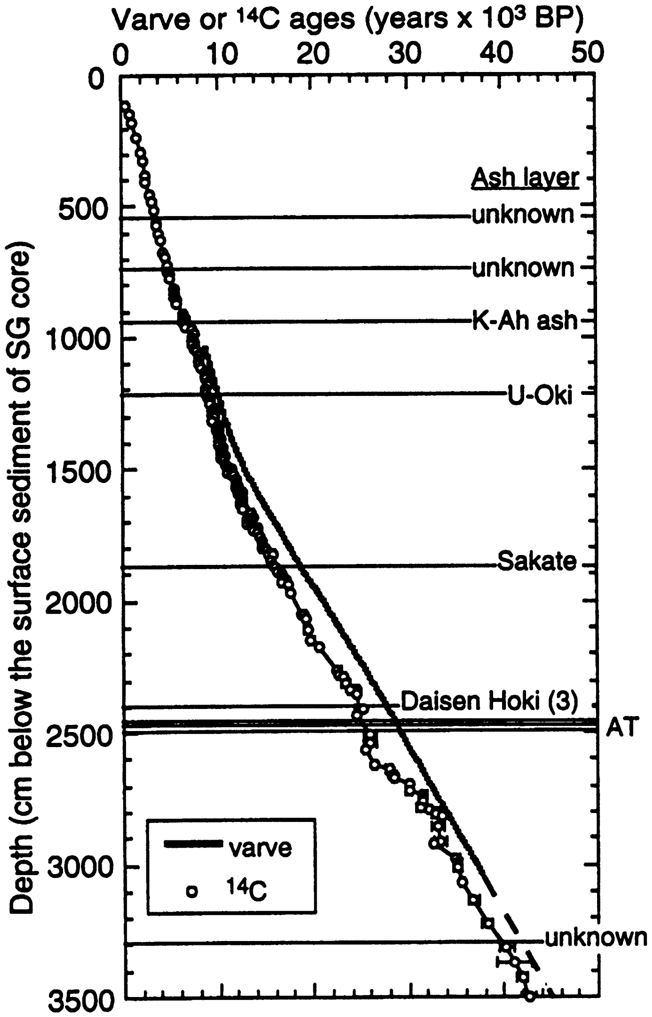

Fig. 1. Varve and radiocarbon chronologies of Lake Suigetsu (SG) core. The ash layers are found in this core section up to 35 m (Takemura *et al.* 1994).

In order to reconstruct the calendar time scale, we compared the Lake Suigetsu chronology with calibration curves obtained from the absolute German oak (shifted by 41 yr at 5241 BC to the older direction, Kromer *et al.* 1996) and the floating German pine (Kromer and Becker 1993) using the least squares minimization. The revised German oak and the floating German pine calibration curves were combined into one calibration curve by moving the age of German pine chronology.

Figure 2 shows the best match between the tree-ring and the Lake Suigetsu chronologies, estimated by minimizing the weighted sum of squared differences between the ^{14}C ages of macrofossils and the tree-ring calibration curve. We found the best match when the German pine chronology is shifted by 160 yr with respect to the pine chronology reported by Kromer and Becker (1993). The features in our data overlapping the tree ring calibration agree very well, even for "wiggles" in the ^{14}C calibration curves. Using this match, we defined the absolute time scale for the Lake Suigetsu varves chronology. The 29,100-yr Lake Suigetsu chronology then covers the absolute age range from 8830

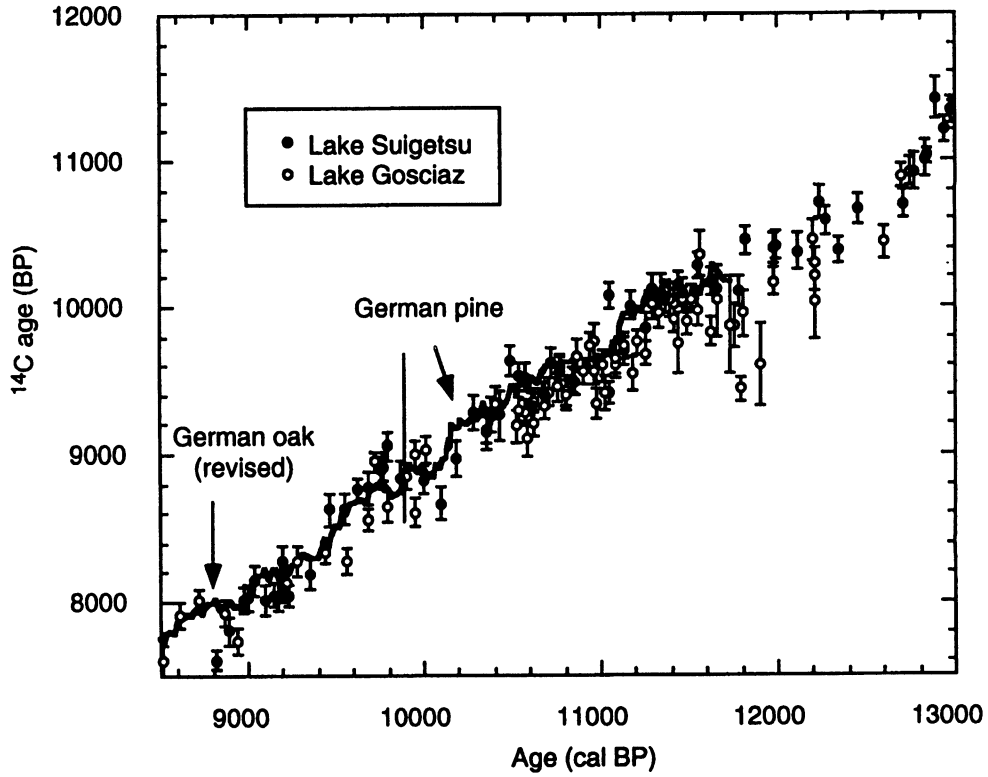

Fig. 2. Matching of the 29,100-yr-long floating varve chronology from Lake Suigetsu to the absolute chronology. ● = Lake Suigetsu (Japan); ○ = Lake Gościąż (Poland) (Goslar *et al.* 1995, ms.). Continuous lines show the German oak and pine chronologies fixed by comparison with the varve chronology of Lake Suigetsu.

to 37,930 cal BP. Our varve chronology also confirms the revised floating German pine chronology, which was recently shifted by 160 yr to the older direction (Björck *et al.* 1996; Kromer *et al.* 1996).

The combined ^{14}C and varve chronologies from Lake Suigetsu are used to calibrate the ^{14}C time scale beyond the range of the absolute tree-ring calibration. Figure 3 shows an atmospheric ^{14}C calibration for the complete ^{14}C dating range (<45 ka) reconstructed from annually laminated sediments from Lake Suigetsu. The numbers are given in the Appendix. Beyond the-tree ring calibration range, our calibration agrees well with the European sediments (Goslar *et al.* 1995, Goslar, Arnold and Tisnerat-Laborde ms.) and generally with marine calibrations obtained by combined U/Th and ^{14}C dating of corals (Bard *et al.* 1990, 1993; Edwards *et al.* 1993). Our data confirms the higher ^{14}C levels for the Glacial period likely induced by a low geomagnetic field intensity (*e.g.*, Laj, Mazaud and Duplessy 1996). The maximum difference between ^{14}C and calendar ages during the past 45 ka is *ca.* 5000 yr around 30,000 cal BP. Similar data are obtained by Voelker *et al.* (1998).

Conclusion

The atmospheric ^{14}C concentration is sensitive to parameters such as geomagnetic field strength and solar fluctuations (also through magnetic effects) as well as rearrangements in equilibrium between the major carbon reservoirs (atmosphere, ocean and biosphere). High-resolution ^{14}C calibration extending into the Glacial is therefore critical for establishing the exact timing of drastic cli-

https://doi.org/10.1017/S0033822200018385 Published online by Cambridge University Press

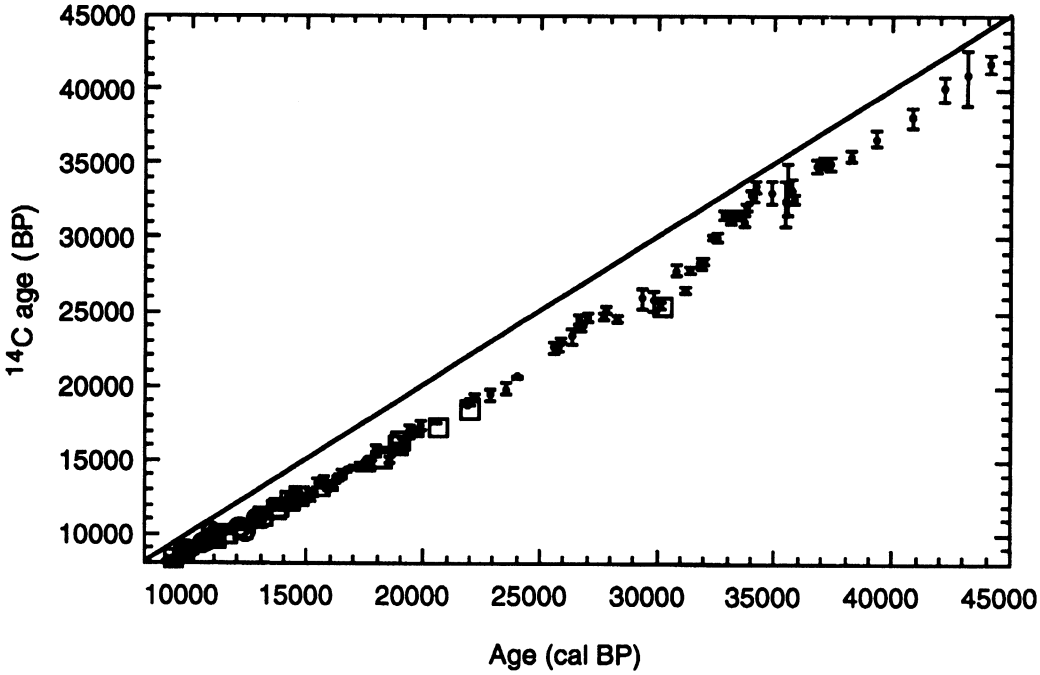

Fig. 3. Atmospheric radiocarbon calibration for the complete ^{14}C dating range (<45 ka cal BP) reconstructed from annually laminated sediments from Lake Suigetsu (Japan). ● with 1-σ bars = Lake Suigetsu. △ (Mururoa: Bard *et al.* 1993), □ (Barbados: Bard *et al.* 1993), and ○ (Papua New Guinea: Edwards *et al* 1993) correspond to U-series based ^{14}C calibration on corals. The numbers of varve and ^{14}C ages of Lake Suigetsu are listed in the Appendix.

matic changes, as well as for better understanding of geophysical changes in the Earth's system. A detailed discussion of our results from this point of view will be published elsewhere (Kitagawa and van der Plicht 1998).

The long sequence of annually laminated sediments from Lake Suigetsu provides a very exciting record of atmospheric ^{14}C changes during the past 45 ka. In order to produce a more complete ^{14}C calibration curve, we intend to completely reconstruct the continuous varve chronology for this period together with other paleoenvironmental signals recorded in these sediments.

Acknowledgments

The unpublished data on Lake Gościąż varve chronology were kindly provided by Tomasz Goslar of the Institute of Physics, Silesian Technical University, Gliwice, Poland. This work was sponsored partly by the Grant-Aid for Scientific Research from the Ministry of Education, Science and Culture (no. 04212116) and by the Toyota Foundation (96-A-232).

References

Bard, E., Arnold, M., Fairbanks, R. G. and Hamelin, B. 1993 ^{230}Th-^{234}U and ^{14}C ages obtained by mass spectrometry on corals. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 191–199.

Bard, E., Hamelin, B., Fairbanks, R. G. and Zindler, A. 1990 Calibration of the ^{14}C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados Corals. *Nature* 345: 405–410.

Björck, S., Kromer, B., Johnsen, S., Bennike, O., Hammarlund, D., Lemdahl, G., Possnert, G., Rasmussen, T. L., Wohlfarth, B., Hammer, C. U. and Spurk, M. 1996 Synchronised terrestrial-atmospheric deglacial records around the North Atlantic. *Science* 274: 1155–1160.

Edwards, R. L., Beck, J. W., Burr, G. S., Donahue, D. L., Chappell, J. M. A., Bloom, A. L., Druffel, E. R. M. and Taylor, F. W. 1993 A large drop in atmospheric ^{14}C/^{12}C and reduced melting in Younger Dryas, documented with ^{230}Th ages of corals. *Science* 260: 962–967.

Goslar, T., Arnold, M., Bard, E., Kuc, T., Pazdur, M. F., Ralska-Jasiewiczowa, M., Rózanski, K., Tisnerat, N., Walanus, A., Wicik, B. and Wieckowski, K. 1995 High concentration of atmospheric ^{14}C during the Younger Dryas cold episode. *Nature* 377: 414–417.

Goslar, T., Arnold, M. and Tisnerat-Laborde, N. (ms.) An updated synchronization of the Lake Gościąż varve chronology with the German pine and oak chronologies. In preparation.

Gottdang, A., Mous, D. J. W. and van der Plicht, J. 1995 The HVEE ^{14}C system at Groningen. *In* Cook, G. T., Harkness, D. D., Miller, B. F. and Scott, E. M., eds., Proceedings of the 15th International ^{14}C Conference. *Radiocarbon* 37(2): 649–656.

Kitagawa, H., Fukusawa, H., Nakamura, T., Okamura, M., Takemura, K., Hayashida, A. and Yasuda, Y. 1995 AMS ^{14}C dating of varved sediments from Lake Suigetsu, central Japan and atmospheric ^{14}C change during the late Pleistocene. *In* Cook, G. T., Harkness, D. D., Miller, B. F. and Scott, E. M., eds., Proceedings of the 15th International ^{14}C Conference. *Radiocarbon* 37(2): 371–378.

Kitagawa, H. and van der Plicht, J. 1997 Enrichment of sub-milligram size carbon samples. *Nuclear Instruments and Methods in Physics Research* B123: 218–220.

____1998 Atmospheric radiocarbon for the complete ^{14}C dating range: Late glacial fluctuations and cosmogenic isotope production. *Science* 279: 1187–1190.

Kromer, B., Ambers, J., Baillie, M. G. L., Damon, P. E., Hesshaimer, V., Hofmann, J., Joris, O., Levin, I., Manning, W., McCormac, F. G., van der Plicht, J., Spurk, M., Stuiver, M. and Weninger, B. 1996 Report: Summary of the workshop "Aspects of high-precision radiocarbon calibration". *Radiocarbon* 38(3): 607–610.

Kromer, B. and Becker, B. 1993 German oak and pine ^{14}C calibration, 7200–9439 BC. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 125–135.

Laj, C., Mazaud, A. and Duplessy, J.-C. 1996 Geomagnetic intensity and ^{14}C abundance in the atmosphere and ocean during the past 50 kyr. *Geophysical Research Letters* 23(16): 2045–2048.

Mook, W. G. and Streurman, H. J. 1983 Physical and chemical aspects of radiocarbon dating. *In* Mook, W. G. and Waterbolk, H. T., eds., *Proceedings of the 1st International Symposium, ^{14}C and Archaeology.* PACT 8. Strasbourg: Conseil de l'Europe, Assemblée parlementaire: 31–55.

Takemura, K., Kitagawa, H., Hayashida, A. and Yasuda, Y. 1994 Sedimentary facies and chronology of core samples from Lake Mikata, Lake Suigetsu and Kurota Lowland, central Japan – sedimentary environment in Mikata Lowland since the last interglacial time. *Journal of Geography* 103(3): 233–242.

van der Plicht, J., Aerts, A., Wijma, S. and Zondervan, A. 1995 First Results from the Groningen AMS facility. *In* Cook, G. T., Harkness, D. D., Miller, B. F. and Scott, E. M., eds., Proceedings of the 15th International ^{14}C Conference. *Radiocarbon* 37(2): 657–661.

Voelker, A., Sarnthein, H., Grootes, P., Erlenkeuser, H., Laj, C., Mazaud, A., Nadeau, M.-J., and Schleicher, M. 1998 Correlation of marine ^{14}C ages from the Nordic Seas with the GISP2 isotope record: Implications for ^{14}C calibration beyond 25 ka BP. *Radiocarbon*, this issue.

Wijma, S. and van der Plicht, J. 1997 The Groningen AMS tandetron. *Nuclear Instruments and Methods in Physics Research* B123: 218–220.

Wohlfarth, B., Björck, S., Possnert, G., Lemdahl, G., Brunnberg, L., Ising, L., Olsson, S. and Svensson, N.-O. 1993 AMS dating Swedish varved clays of the last glacial/interglacial transition and the potential difficulties of calibrating Late Weichselian 'absolute' chronologies. *Boreas* 22: 113–128.

Appendix

Varve and ^{14}C chronologies of the annually laminated sediments from the Lake Suigetsu, Japan. The numbers in the FVT column represent relative varve numbers from the beginning of the presently floating varve chronology (1042.0 cm below the top sediment). The varve age below 3045.0 cm is estimated by assuming a constant sedimentation (0.62 mm yr^{-1}).

Sample	Depth in SG (cm)	Varve age		Lab code(s) GrA-	^{14}C age (yr BP)
		FVT	cal BP		
SG02C04	111.7 ± 1.5			4571	525 ± 60
SG02A02	146.4 ± 1.5			4572	940 ± 65
SG03E05	177.1 ± 2.0			4573	1045 ± 60
SG03A03	240.4 ± 1.5			4574	1575 ± 60
SG04D05	291.7 ± 1.5			4575	2140 ± 90
SG04A01	328.4 ± 1.5			4576	2285 ± 65
SG05D07	382.7 ± 1.5			4577	2470 ± 60
SG05C01	385.5 ± 1.5			4578	2450 ± 65
SG05B05	410.6 ± 1.5			4579	2590 ± 65
SG06E05	452.9 ± 2.2			4580	3040 ± 60
SG06C03	479.8 ± 1.5			4581	3115 ± 60
SG06B07	515.4 ± 1.5			4582	3420 ± 60
SG07E08	562.7 ± 2.0			1899	3680 ± 60
SG07E08	569.2 ± 1.5			1897	3705 ± 60
SG07B05	604.9 ± 1.5			1900	3870 ± 60
SG08C02	626.6 ± 1.5			1953	4120 ± 60
SG08C10	652.1 ± 1.5			7746	4416 ± 40
SG08B08	677.5 ± 1.5			1939	4460 ± 60
SG08A03	692.5 ± 1.5			1894	4525 ± 60
SG09D04	728.4 ± 1.5			2493	4725 ± 60
SG09C01	748.1 ± 1.5			2498	4875 ± 60
SG09C05	760.0 ± 1.5			4583	5095 ± 125
SG09B01	775.8 ± 1.5			4584	5040 ± 70
SG10C05	817.0 ± 1.5			2499	5460 ± 60
SG10C09	829.4 ± 1.5			2496	5420 ± 65
SG10B03	844.9 ± 1.5			2495	5435 ± 65
SG10B05	851.1 ± 1.5			2500	5800 ± 85
SG10B07	857.3 ± 1.5			2494	5775 ± 70
SG10B11	869.7 ± 1.5			2491	5850 ± 70
SG10A02	875.9 ± 1.5			7744	5960 ± 60
SG10A05	885.2 ± 1.5			7742	5890 ± 60
SG10A08	894.0 ± 1.5			7745	6250 ± 90
SG11D02	912.8 ± 1.5			2963	6390 ± 200
SG11D03	915.8 ± 1.5			7738	6220 ± 70
SG11D04	919.0 ± 1.5			2964	6455 ± 110
SG11B03	925.2 ± 1.5			2965	6445 ± 100
SG11B03	931.9 ± 2.0			2966	6675 ± 150
SG11D10	937.8 ± 1.3			2967	6585 ± 150
SG11C01	940.7 ± 1.5			7741	6410 ± 80
SG11C02	943.8 ± 1.5			2982	6520 ± 115
SG11C03	946.9 ± 1.5			7734	6500 ± 70
SG11C04	950.0 ± 1.5			2977	6590 ± 95

Sample	Depth in SG (cm)	Varve age FVT	Varve age cal BP	Lab code(s) GrA-	^{14}C age (yr BP)
SG11C06	956.4 ± 1.8			2989	6635 ± 110
SG11B01	959.8 ± 1.5			7733	6780 ± 90
SG11B02	962.9 ± 1.5			2978	6670 ± 85
SG11B03	966.0 ± 1.5			7732	6770 ± 70
SG11B04	969.1 ± 1.5			7730	6930 ± 70
SG11B05	972.2 ± 1.5			2981	7330 ± 200
SG11B06	976.1 ± 2.3			7743	6990 ± 60
SG11A01	979.1 ± 1.5			7731	6850 ± 70
SG11A03	986.1 ± 1.5			7737	7030 ± 70
SG11A06	995.4 ± 1.5			7736	6920 ± 70
SG12C01	988.6 ± 1.5			2930	7530 ± 100
SG12C05	1001.0 ± 1.5			2846	7445 ± 100
SG12B07	1009.3 ± 1.5			6231	7315 ± 85
SG12B04	1021.7 ± 1.5			2888, 2889	7500 ± 60
SG12B06	1025.3 ± 2.0			2946	7480 ± 100
SG12A01	1028.9 ± 1.5			6230	7325 ± 110
SG13D01	1043.6 ± 1.5	13	8841	6234	7610 ± 70
SG13D04	1053.4 ± 1.5	91	8919	2849	7805 ± 100
SG13D07	1063.1 ± 1.5	172	9000	6233	8020 ± 90
SG13D08	1066.4 ± 1.5	200	9028	6232	8035 ± 85
SG13D09	1070.2 ± 2.0	231	9059	2839	8150 ± 105
SG13C03	1079.4 ± 1.5	301	9129	2914	8020 ± 105
SG13C05	1085.9 ± 1.5	343	9171	6235	8050 ± 80
SG13C06	1089.1 ± 1.5	368	9196	6236	8035 ± 95
SG13C07	1092.4 ± 1.5	393	9221	2840	8085 ± 85
SG13C09	1097.5 ± 1.3	413	9241	2947, 2948	8050 ± 70
SG13B05	1114.3 ± 2.3	553	9381	2901	8200 ± 105
SG13A04	1128.1 ± 1.5	663	9491	2842	8635 ± 110
SG14D03	1142.0 ± 1.5	750	9578	2843	8635 ± 110
SG14D06	1151.7 ± 1.5	821	9649	3087	8765 ± 80
SG14C01	1159.2 ± 1.5	878	9706	2835	8775 ± 110
SG14C04	1168.8 ± 1.5	950	9778	3085	8900 ± 90
SG14C06	1175.2 ± 1.5	998	9826	3080	9055 ± 90
SG14B02	1184.3 ± 1.5	1067	9895	2844	8845 ± 110
SG14B07	1200.4 ± 1.5	1204	10,032	3082	8830 ± 95
SG14A04	1213.2 ± 1.5	1298	10,126	2890	8665 ± 110
SG15D01	1226.7 ± 1.5	1385	10,213	3079	8970 ± 120
SG15D05	1240.2 ± 1.5	1485	10,313	2971	9280 ± 115
SG15D07	1247.0 ± 1.5	1555	10,383	2845	9150 ± 115
SG15C01	1250.4 ± 1.5	1575	10,403	2921	9270 ± 115
SG15C03	1257.2 ± 1.5	1625	10,453	4585	9260 ± 180
SG15C06	1267.3 ± 1.5	1685	10,513	2915	9635 ± 100
SG15C08	1274.1 ± 1.5	1735	10,563	3081	9535 ± 80
SG15B02	1280.9 ± 1.5	1775	10,603	2847	9525 ± 90
SG15B03	1284.3 ± 1.5	1805	10,633	2944	9320 ± 90
SG15B06	1294.4 ± 1.5	1885	10,713	2913	9405 ± 80
SG15B07	1297.8 ± 1.5	1915	10,743	2912	9625 ± 100
SG15A01	1305.1 ± 1.5	1970	10,798	3083	9555 ± 105
SG15A04	1315.3 ± 1.5	2045	10,873	2907	9495 ± 90

https://doi.org/10.1017/S0033822200018385 Published online by Cambridge University Press

Sample	Depth in SG (cm)	Varve age FVT	Varve age cal BP	Lab code(s) GrA-	^{14}C age (yr BP)
SG16D06	1336.7 ± 2.0	2296	11,124	3086	10,075 ± 85
SG16C01	1344.2 ± 1.5	2371	11,199	2904	10,005 ± 95
SG16C04	1254.2 ± 1.5	2453	11,281	2905	9860 ± 95
SG16C05	1357.8 ± 1.8	2492	11,320	2911	10,125 ± 95
SG16B01	1364.2 ± 1.5	2543	11,371	2961	10,095 ± 125
SG16B02	1367.5 ± 1.5	2572	11,400	2838	10,055 ± 100
SG16B04	1374.2 ± 1.5	2633	11,461	2917	10,145 ± 95
SG16B05	1377.5 ± 1.5	2663	11,491	2916	10,095 ± 100
SG16A02	1386.9 ± 1.5	2752	11,580	3078	10,285 ± 85
SG16A05	1393.6 ± 1.5	2814	11,642	2902	10,165 ± 95
SG16A06	1396.9 ± 1.5	2854	11,682	2909	10,115 ± 95
SG17D01	1410.5 ± 1.5	2981	11,809	2969	10,100 ± 105
SG17D02	1413.5 ± 1.5	3022	11,850	2836	10,455 ± 100
SG17D06	1425.6 ± 1.5	3177	12,005	2970	10,395 ± 105
SG17D10	1437.4 ± 1.3	3315	12,143	2981	10,370 ± 125
SG17C03	1446.2 ± 1.5	3433	12,261	2837	10,710 ± 110
SG17C04	1449.2 ± 1.5	3474	12,302	2913	10,590 ± 95
SG17B01	1455.3 ± 1.5	3540	12,368	2906	10,380 ± 90
SG17B04	1464.3 ± 1.5	3652	12,480	2848	10,670 ± 100
SG17A02	1483.9 ± 1.5	3908	12,736	2908	10,700 ± 100
SG17A04	1490.0 ± 1.5	3965	12,793	2920	10,915 ± 125
SG17A07	1497.2 ± 0.8	4030	12,858	3077	11,000 ± 125
SG18E01	1499.0 ± 1.5	4046	12,874	4532	11,030 ± 55
SG18E02	1502.0 ± 1.5	4096	12,924	5634	11,415 ± 145
SG18E03	1505.0 ± 1.5	4136	12,964	5635	11,210 ± 90
SG18E04	1508.0 ± 1.5	4176	13,004	5637	11,335 ± 90
SG18E05	1511.0 ± 1.5	4216	13,044	4533	10,975 ± 55
SG18E06	1514.0 ± 1.5	4256	13,084	5638	11,440 ± 110
SG18E07	1517.0 ± 1.5	4296	13,124	5639	11,480 ± 85
SG18D01	1522.5 ± 1.5	4376	13,204	4534	11,460 ± 55
SG18D02	1525.5 ± 1.5	4426	13,254	5640	11,690 ± 85
SG18C01	1540.5 ± 1.5	4686	13,514	5641	11,830 ± 65
SG18C04	1548.5 ± 1.5	4816	13,644	4535	12,000 ± 330
SG18B01	1554.8 ± 1.8	4906	13,734	5653	11,980 ± 110
SG18B03	1561.0 ± 1.5	5006	13,834	4536	12,040 ± 55
SG18B05	1567.0 ± 1.5	5106	13,934	6206	12,245 ± 125
SG18B06	1570.3 ± 1.8	5166	13,994	4537	12,050 ± 85
SG18A01	1573.5 ± 1.5	5216	14,044	5642	12,250 ± 95
SG18A04	1582.5 ± 1.5	5346	14,174	6202	12,270 ± 95
SG18A06	1588.0 ± 1.5	5426	14,254	5654	12,610 ± 295
SG19D03	1594.8 ± 1.5	5531	14,359	4539	12,260 ± 60
SG19D04	1598.0 ± 1.5	5591	14,419	6204	12,410 ± 100
SG19D05	1601.3 ± 1.5	5621	14,449	5643	12,425 ± 85
SG19D07	1607.7 ± 1.5	5721	14,549	4540	12,320 ± 55
SG19D08	1610.9 ± 1.5	5771	14,599	5644	12,680 ± 150
SG19C04	1623.8 ± 1.5	5961	14,789	5645	12,520 ± 70
SG19C05	1627.0 ± 1.5	6031	14,859	4541	12,345 ± 55
SG19B01	1638.8 ± 1.5	6171	14,999	4542	12,490 ± 55
SG19B04	1648.4 ± 1.5	6331	15,159	5646	12,625 ± 370

https://doi.org/10.1017/S0033822200018385 Published online by Cambridge University Press

Sample	Depth in SG (cm)	Varve age		Lab code(s)	^{14}C age
		FVT	cal BP	GrA-	(yr BP)
SG19B05	1651.6 ± 1.5	6389	15,217	4543	12,745 ± 75
SG19B06	1654.8 ± 1.5	6441	15,269	6205	12,705 ± 105
SG19A03	1668.8 ± 1.5	6681	15,509	5648	13,440 ± 300
SG20D01	1684.7 ± 1.5	6966	15,794	4550	13,665 ± 215
SG20D03	1691.0 ± 1.5	7066	15,894	5649	13,385 ± 165
SG20D04	1694.1 ± 1.5	7116	15,944	4551	13,015 ± 80
SG20D05	1697.3 ± 1.5	7176	16,004	5650	13,475 ± 100
SG20C01	1706.7 ± 1.5	7326	16,154	5636	13,105 ± 110
SG20C03	1712.9 ± 1.5	7416	16,244	4552	13,572 ± 60
SG20C05	1719.2 ± 1.5	7526	16,354	5651	13,885 ± 80
SG20C06	1722.4 ± 1.5	7586	16,414	4553	13,855 ± 125
SG20B01	1729.2 ± 1.5	7706	16,534	6203	14,205 ± 170
SG20B02	1732.3 ± 1.5	7746	16,574	4554	13,815 ± 70
SG20B04	1738.6 ± 1.5	7856	16,684	5652	14,295 ± 85
SG20A03	1757.4 ± 1.5	8136	16,964	4555	14,440 ± 95
SG21D04	1778.6 ± 1.5	8466	17,294	4556	14,695 ± 60
SG21D07	1787.7 ± 1.5	8616	17,444	4557	14,595 ± 90
SG21C02	1795.8 ± 1.5	8736	17,564	4558	14,630 ± 60
SG21C02	1801.9 ± 1.5	8841	17,669	4559	14,860 ± 195
SG21C07	1811.0 ± 1.5	8991	17,819	4556	15,125 ± 185
SG21B03	1820.1 ± 1.5	9131	17,959	4561	15,755 ± 270
SG21B03	1823.1 ± 1.5	9181	18,009	5658	15,480 ± 140
SG21B03	1826.2 ± 1.5	9232	18,060	5668	15,730 ± 145
SG21A05	1847.9 ± 2.0	9616	18,444	4562	15,695 ± 180
SG22D03	1864.1 ± 2.0	9886	18,714	4564	15,915 ± 230
SG22D06	1874.0 ± 1.3	10,011	18,839	4565	15,990 ± 180
SG22C06	1891.9 ± 2.5	10,296	19,124	4566	16,280 ± 195
SG22B02	1901.0 ± 1.5	10,466	19,294	5669	16,750 ± 220
SG22B04	1907.1 ± 1.5	10,571	19,399	5668	16,700 ± 178
SG22B05	1910.7 ± 2.0	10,636	19,464	4567	17,065 ± 240
SG22A01	1919.3 ± 1.5	10,791	19,619	4586	17,135 ± 170
SG22A04	1928.4 ± 1.5	10,971	19,799	4569	16,950 ± 185
SG22A05	1931.4 ± 1.5	11,023	19,851	4570	16,760 ± 185
SG22A06	1934.4 ± 1.5	11,081	19,909	5660	17,380 ± 240
SG23-4	1968.7 ± 0.5	11,716	20,544	6193	17,745 ± 140
SG24-5	2051.1 ± 0.5	13,117	21,945	6192	18,810 ± 110
SG24-4	2054.3 ± 0.5	13,172	22,000	6191	18,975 ± 290
SG24-3	2065.4 ± 0.5	13,372	22,200	6190	19,370 ± 135
SG24-1	2106.9 ± 0.5	14,032	22,860	6189	19,425 ± 305
SG25-2	2149.5 ± 0.5	14,752	23,580	6188	19,830 ± 365
SG25-1	2175.5 ± 0.5	15,182	24,010	6187	20,630 ± 130
SG26-3	2264.0 ± 2.0	16,732	25,560	6186	22,600 ± 440
SG26-2	2278.4 ± 0.5	16,957	25,785	6185	22,630 ± 220
SG26-1	2286.1 ± 0.5	17,067	25,895	6184	23,170 ± 150
SG27-7	2312.2 ± 0.5	17,492	26,320	6183	23,400 ± 500
SG27-5	2334.7 ± 0.5	17,852	26,680	6182	24,495 ± 270
SG27-4	2337.1 ± 0.5	17,902	26,730	6181	23,890 ± 210
SG27-3	2340.4 ± 0.5	17,957	26,785	6180	23,970 ± 170
SG27-2	2356.2 ± 0.5	18,206	27,034	6179	24,595 ± 265

Sample	Depth in SG (cm)	Varve age FVT	Varve age cal BP	Lab code(s) GrA-	^{14}C age (yr BP)
SG28-4	2405.8 ± 0.5	18,902	27,730	6178	24,700 ± 270
SG28-3	2408.4 ± 0.5	18,982	27,810	6177	25,130 ± 185
SG28-2	2433.0 ± 0.5	19,422	28,250	6176	24,545 ± 270
SG29-3	2508.2 ± 0.5	20,487	29,315	6173	25,980 ± 670
SG29-2	2537.6 ± 0.5	21,002	29,830	6172	25,840 ± 670
SG29-1	2560.8 ± 0.5	21,312	30,140	6171	25,445 ± 190
SG30-5	2623.4 ± 0.5	22,342	31,170	6168	26,460 ± 215
SG30-4	2636.4 ± 0.5	22,572	31,400	6169	27,880 ± 235
SG30R-1	2665.5 ± 0.5	23,012	31,840	6174	28,495 ± 250
SG30-3	2665.5 ± 0.5	23,012	31,840	6170	28,220 ± 245
SG30-1	2671.8 ± 0.5	23,092	31,920	6167	28,495 ± 255
SG31-7	2698.3 ± 0.5	23,472	32,300	5618, 6200	30,080 ± 200
SG31-6	2716.5 ± 0.5	23,757	32,585	5617	30,010 ± 310
SG31-5	2733.1 ± 0.5	23,997	32,825	5616	31,545 ± 340
SG31-4	2740.0 ± 0.5	24,122	32,950	5615	31,545 ± 335
SG31-1	2751.8 ± 0.5	24,312	33,140	5613	31,345 ± 355
SG31-3	2761.4 ± 0.5	24,472	33,300	5614	31,547 ± 330
SG31-7	2784.8 ± 0.5	24,877	33,705	5625	31,190 ± 360
SG32-6	2792.2 ± 0.5	25,007	33,835	5624, 6199	32,140 ± 260
SG32-5	2800.7 ± 0.5	25,137	33,965	5623	32,875 ± 370
SG32-4	2807.0 ± 0.5	25,242	34,070	5622	32,825 ± 380
SG32-2	2813.4 ± 0.5	25,332	34,160	5620	33,475 ± 345
SG32-1	2855.7 ± 0.5	25,997	34,825	5619	33,070 ± 730
SG33-4	2913.8 ± 0.5	26,882	35,710	5626	33,270 ± 680
SG33-3	2920.6 ± 0.5	26,997	35,825	5627	32,640 ± 330
SG34-2	2976.3 ± 0.5	27,942	36,770	5631	34,950 ± 415
SG34-4	2993.8 ± 0.5	28,232	37,060	5632	35,140 ± 415
SG34-3	3012.4 ± 0.5	28,532	37,360	5633	35,070 ± 460
SG35-1	3067.0 ± 0.5		38,285	4515, 4516	35,560 ± 340
SG35-2	3132.8 ± 0.5		39,350	4517	36,755 ± 550
SG36-1	3224.9 ± 0.5		40,840	4518	38,205 ± 650
SG37-1	3311.5 ± 0.5		42,241	4545	40,210 ± 820
SG38-1	3367.2 ± 0.5		43,143	4546	41,100 ± 1800
SG39-1	3428.3 ± 0.5		44,131	4525, 4526, 4527	41,890 ± 570
SG39-3	3496.8 ± 0.5		45,240	4528, 4529	42,640 ± 780