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

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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) ¹⁴C 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 ¹⁴C 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 km². 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 ¹⁴C calibration extending back to at least 40 ka BP, and probably even more by means of combined isotope enrichment and AMS ¹⁴C dating (Kitagawa and van der Plicht 1997).

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

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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 cm³ 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 ¹⁴C measurements.

The $^{14}\text{C}/^{12}\text{C}$ and $^{13}\text{C}/^{12}\text{C}$ 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-alkaliacid (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 ¹⁴C 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 ¹⁴C ages at 10.42, 30.45 and 35 m depth are ca. 7800, 35,000 and 42,000 BP, respectively.

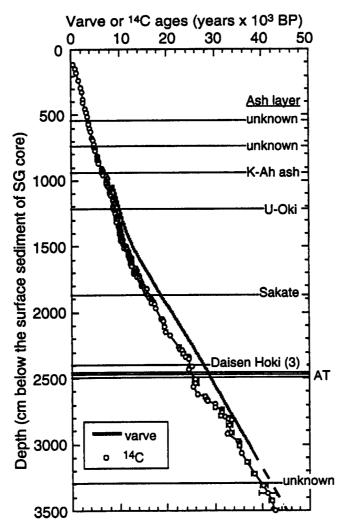


Fig. 1. Varve and radiocarbon chronologies of Lake Suigetsu (SG) core. The ash layers are found in this core section up to 35 m (Takemura et al. 1994).

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 ¹⁴C 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 ¹⁴C 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

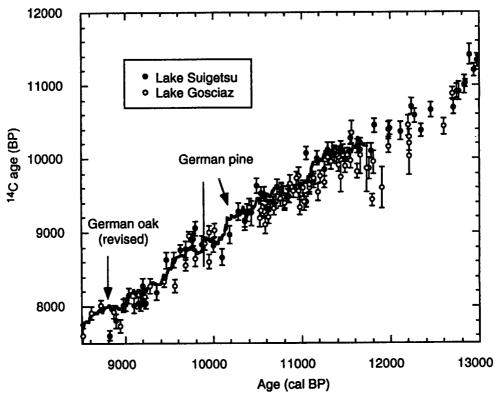


Fig. 2. Matching of the 29,100-yr-long floating varve chronology from Lake Suigetsu to the absolute chronology.

= Lake Suigetsu (Japan); O = 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 ¹⁴C and varve chronologies from Lake Suigetsu are used to calibrate the ¹⁴C time scale beyond the range of the absolute tree-ring calibration. Figure 3 shows an atmospheric ¹⁴C calibration for the complete ¹⁴C 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 ¹⁴C dating of corals (Bard *et al.* 1990, 1993; Edwards *et al.* 1993). Our data confirms the higher ¹⁴C levels for the Glacial period likely induced by a low geomagnetic field intensity (*e.g.*, Laj, Mazaud and Duplessy 1996). The maximum difference between ¹⁴C 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 ¹⁴C 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 ¹⁴C calibration extending into the Glacial is therefore critical for establishing the exact timing of drastic cli-

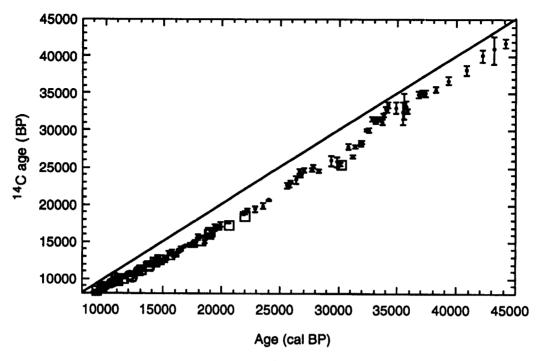


Fig. 3. Atmospheric radiocarbon calibration for the complete ¹⁴C dating range (<45 ka cal BP) reconstructed from annually laminated sediments from Lake Suigetsu (Japan). • with 1- σ bars = Lake Suigetsu. \triangle (Mururoa: Bard et al. 1993), \square (Barbados: Bard et al. 1993), and \bigcirc (Papua New Guinea: Edwards et al 1993) correspond to U-series based ¹⁴C calibration on corals. The numbers of varve and ¹⁴C 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 ¹⁴C changes during the past 45 ka. In order to produce a more complete ¹⁴C calibration curve, we intend to completely reconstruct the continuous varve chronology for this period together with other paleoenvironmental signals recorded in these sediments.

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APPENDIX

Varve and ¹⁴C 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	Varve age		Lab code(s)	¹⁴ C age
	(cm)	FVT	cal BP	GrA-	(yr 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

	Depth in SG	Varve age		Lab code(s)	¹⁴ C age
Sample	(cm)	FVT	cal BP	GrA-	(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
SG13D07	1066.4 ± 1.5	200	9028	6232	8035 ± 85
SG13D00	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
SG13C05	1089.1 ± 1.5	368	9196	6236	8035 ± 95
SG13C07	1092.4 ± 1.5	393	9221	2840	8085 ± 85
SG13C07	1097.5 ± 1.3	413	9241	2947, 2948	8050 ± 70
SG13B05	1114.3 ± 2.3	553	9381	2901	8200 ± 105
SG13B03	1114.5 ± 2.5 1128.1 ± 1.5	663	9491	2842	8635 ± 110
SG13A04 SG14D03	1142.0 ± 1.5	750	9578	2843	8635 ± 110
SG14D05 SG14D06	1151.7 ± 1.5	821	9649	3087	8765 ± 80
SG14C01	1159.2 ± 1.5	878	9706	2835	8775 ± 110
SG14C01	1168.8 ± 1.5	950	9778	3085	8900 ± 90
SG14C04 SG14C06	1105.8 ± 1.5 1175.2 ± 1.5	998	9826	3080	9055 ± 90
SG14C00 SG14B02	1173.2 ± 1.5 1184.3 ± 1.5	1067	9895	2844	8845 ± 110
SG14B02 SG14B07	1200.4 ± 1.5	1204	10,032	3082	8830 ± 95
	1200.4 ± 1.5 1213.2 ± 1.5	1298	10,032	2890	8665 ± 110
SG14A04				3079	8970 ± 120
SG15D01	1226.7 ± 1.5 1240.2 ± 1.5	1385 1485	10,213	2971	9280 ± 115
SG15D05			10,313	2845	9150 ± 115
SG15D07	1247.0 ± 1.5	1555	10,383		9270 ± 115
SG15C01	1250.4 ± 1.5	1575	10,403	2921 4595	9270 ± 113 9260 ± 180
SG15C03	1257.2 ± 1.5	1625	10,453 10,513	4585 2915	9635 ± 100
SG15C06	1267.3 ± 1.5	1685			9535 ± 100 9535 ± 80
SG15C08	1274.1 ± 1.5	1735	10,563	3081	
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

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

	Depth in SG	Varve age		Lab code(s)	¹⁴ C age
Sample	(cm)	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	$13,440 \pm 300$
SG20D01	1684.7 ± 1.5	6966	15,794	4550	$13,665 \pm 215$
SG20D03	1691.0 ± 1.5	7066	15,894	5649	13,385 ± 165
SG20D04	1694.1 ± 1.5	7116	15,944	4551	$13,015 \pm 80$
SG20D05	1697.3 ± 1.5	7176	16,004	5650	$13,475 \pm 100$
SG20C01	1706.7 ± 1.5	7326	16,154	5636	$13,105 \pm 110$
SG20C03	1712.9 ± 1.5	7416	16,244	4552	$13,572 \pm 60$
SG20C05	1719.2 ± 1.5	7526	16,354	5651	$13,885 \pm 80$
SG20C06	1722.4 ± 1.5	7586	16,414	4553	13,855 ± 125
SG20B01	1729.2 ± 1.5	7706	16,534	6203	$14,205 \pm 170$
SG20B02	1732.3 ± 1.5	7746	16,574	4554	$13,815 \pm 70$
SG20B04	1738.6 ± 1.5	7856	16,684	5652	$14,295 \pm 85$
SG20A03	1757.4 ± 1.5	8136	16,964	4555	$14,440 \pm 95$
SG21D04	1778.6 ± 1.5	8466	17,294	4556	$14,695 \pm 60$
SG21D07	1787.7 ± 1.5	8616	17,444	4557	$14,595 \pm 90$
SG21C02	1795.8 ± 1.5	8736	17,564	4558	$14,630 \pm 60$
SG21C02	1801.9 ± 1.5	8841	17,669	4559	$14,860 \pm 195$
SG21C07	1811.0 ± 1.5	8991	17,819	4556	$15,125 \pm 185$
SG21B03	1820.1 ± 1.5	9131	17,959	4561	$15,755 \pm 270$
SG21B03	1823.1 ± 1.5	9181	18,009	5658	$15,480 \pm 140$
SG21B03	1826.2 ± 1.5	9232	18,060	5668	$15,730 \pm 145$
SG21A05	1847.9 ± 2.0	9616	18,444	4562	$15,695 \pm 180$
SG22D03	1864.1 ± 2.0	9886	18,714	4564	$15,915 \pm 230$
SG22D06	1874.0 ± 1.3	10,011	18,839	4565	$15,990 \pm 180$
SG22C06	1891.9 ± 2.5	10,296	19,124	4566	$16,280 \pm 195$
SG22B02	1901.0 ± 1.5	10,466	19,294	5669	$16,750 \pm 220$
SG22B04	1907.1 ± 1.5	10,571	19,399	5668	16,700 ± 178
SG22B05	1910.7 ± 2.0	10,636	19,464	4567	$17,065 \pm 240$
SG22A01	1919.3 ± 1.5	10,791	19,619	4586	$17,135 \pm 170$
SG22A04	1928.4 ± 1.5	10,971	19,799	4569	$16,950 \pm 185$
SG22A05	1931.4 ± 1.5	11,023	19,851	4570	$16,760 \pm 185$
SG22A06	1934.4 ± 1.5	11,081	19,909	5660	$17,380 \pm 240$
SG23-4	1968.7 ± 0.5	11,716	20,544	6193	$17,745 \pm 140$
SG24-5	2051.1 ± 0.5	13,117	21,945	6192	$18,810 \pm 110$
SG24-4	2054.3 ± 0.5	13,172	22,000	6191	$18,975 \pm 290$
SG24-3	2065.4 ± 0.5	13,372	22,200	6190	$19,370 \pm 135$
SG24-1	2106.9 ± 0.5	14,032	22,860	6189	$19,425 \pm 305$
SG25-2	2149.5 ± 0.5	14,752	23,580	6188	$19,830 \pm 365$
SG25-1	2175.5 ± 0.5 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	16,752	25,785	6185	22,630 ± 220
SG26-1	2276.4 ± 0.5 2286.1 ± 0.5	17,067	25,785	6184	$23,170 \pm 150$
SG27-7	2312.2 ± 0.5	17,492	26,320	6183	$23,400 \pm 500$
SG27-5	2312.2 ± 0.3 2334.7 ± 0.5	17,492	26,680	6182	24,495 ± 270
SG27-4	2337.1 ± 0.5	17,902	26,730	6181	$23,890 \pm 210$
SG27-3	2340.4 ± 0.5	17,902	26,785	6180	$23,890 \pm 210$ $23,970 \pm 170$
SG27-2	2340.4 ± 0.5 2356.2 ± 0.5	18,206	27,034	6179	$23,970 \pm 170$ $24,595 \pm 265$

	Depth in SG	Varve age		Lab code(s)	¹⁴ C age
Sample	(cm)	FVT	cal BP	GrA-	(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	$25,980 \pm 670$
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	$26,460 \pm 215$
SG30-4	2636.4 ± 0.5	22,572	31,400	6169	$27,880 \pm 235$
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	$28,220 \pm 245$
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	$30,080 \pm 200$
SG31-6	2716.5 ± 0.5	23,757	32,585	5617	$30,010 \pm 310$
SG31-5	2733.1 ± 0.5	23,997	32,825	5616	$31,545 \pm 340$
SG31-4	2740.0 ± 0.5	24,122	32,950	5615	$31,545 \pm 335$
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	$31,547 \pm 330$
SG31-7	2784.8 ± 0.5	24,877	33,705	5625	$31,190 \pm 360$
SG32-6	2792.2 ± 0.5	25,007	33,835	5624, 6199	$32,140 \pm 260$
SG32-5	2800.7 ± 0.5	25,137	33,965	5623	$32,875 \pm 370$
SG32-4	2807.0 ± 0.5	25,242	34,070	5622	$32,825 \pm 380$
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	$33,070 \pm 730$
SG33-4	2913.8 ± 0.5	26,882	35,710	5626	$33,270 \pm 680$
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	$35,070 \pm 460$
SG35-1	3067.0 ± 0.5		38,285	4515, 4516	$35,560 \pm 340$
SG35-2	3132.8 ± 0.5		39,350	4517	$36,755 \pm 550$
SG36-1	3224.9 ± 0.5		40,840	4518	$38,205 \pm 650$
SG37-1	3311.5 ± 0.5		42,241	4545	$40,210 \pm 820$
SG38-1	3367.2 ± 0.5		43,143	4546	$41,100 \pm 1800$
SG39-1	3428.3 ± 0.5		44,131	4525, 4526,	$41,890 \pm 570$
			•	4527	
SG39-3	3496.8 ± 0.5		45,240	4528, 4529	42,640 ± 780