RADIOCARBON, Vol 42, Nr 3, 2000, p 335–348

RADIOCARBON CALIBRATION BY MEANS OF VARVES VERSUS ^{14}C AGES OF TERRESTRIAL MACROFOSSILS FROM LAKE GOŚCIĄŻ AND LAKE PERESPILNO, POLAND

Tomasz Goslar[1] • Maurice Arnold[2] • Nadine Tisnerat-Laborde[3] • Christine Hatté[3] • Martine Paterne[3] • Magdalena Ralska-Jasiewiczowa[4]

ABSTRACT. This paper presents radiocarbon dates of terrestrial macrofossils from Lakes Gościąż and Perespilno, Poland. These data agree very well with most of the German pine calibration curve. In the Late Glacial, they generally agree with the data from Lake Suigetsu, Japan, and indicate constant or even increasing ^{14}C age between 12.9 and 12.7 ka BP, rapid decline of ^{14}C age around 12.6 ka BP, and a long plateau 10,400 ^{14}C BP around 12 ka BP. Correlation with corals and data from the Cariaco basin seems to support the concept of site-speficic, constant values of reservoir correction, in contradiction to those introduced in the INTCAL98 calibration. Around the Allerød/Younger Dryas boundary our data strongly disagree with those from the Cariaco basin, which reflects large discrepancy between calendar chronologies at that period. The older sequence from Lake Perespilno indicates two periods of rapid decline in ^{14}C age, around 14.2 and 13.9 ka BP.

INTRODUCTION

Radiocarbon dating of terrestrial macrofossils from Lake Gościąż (Goslar et al. 1995) demonstrated that annually laminated sediments can be suitable material for ^{14}C calibration. The most severe drawback of such material, the possibility of missing varves in the sequence (cf. Hajdas et al. 1995), has been minimized by varve-to-varve correlation of seven sediment cores from three different lake depths (e.g. Goslar 1998a). The Gościąż data clearly disagreed with those from the German pine chronology (Kromer and Becker 1993), an effect which disappeared (Goslar and Mądry 1998) after the revision of the link between the German pine and oak chronologies (Kromer and Spurk 1998). Beyond the range of long pine chronology, our data roughly agreed with coral ^{14}C calibration (Bard et al. 1998; Burr et al. 1998), but they poorly covered the time scale before 11.6 ka BP and their one-sigma uncertainty was quite large.

Recently, our data set (Tables 1 and 2) has been supplemented with 47 ^{14}C dates from the oldest section of Lake Gościąż (LG) sediments, and 51 dates from the annually laminated sediments of Lake Perespilno (LP) in eastern Poland (Goslar et al. 2000). The new Gościąż samples come from three additional cores, perfectly replicating the LG varve chronology. The chronology of Lake Perespilno sediments (Goslar et al. 1999a) is based on seven cores. However, all of them show a 6–10 cm thick disturbance about 10 cm below the AL/YD boundary. According to ^{14}C dates, this disturbance splits the LP sequence in two separate sections.

Radiocarbon Dating

^{14}C dating was performed on terrestrial macrofossils collected from a few precisely synchronized cores. Only a few well-defined and easy to identify types of macrofossils were used (bud scales, seeds, needles and peridermis fragments of pine, as well as fruit scales and nutlets of birch). We selected only large macrofossils, not destroyed mechanically, and with no traces of decomposition. This lowered the probability of dating reworked material, and material contaminated with foreign

[1]Institute of Physics, Silesian University of Technology, ul. Krzywoustego 2, 44-100 Gliwice, Poland. Email: goslar@zeus.polsl.gliwice.pl.
[2]UMS 2004 (CNRS-CEA), Tandetron Bat. 30, Avenue de la Terrasse, 91198 Gif sur Yvette, France
[3]Laboratoire des Sciences du Climat et de l'Environnement, CNRS-CEA, Avenue de la Terrasse, 91198 Gif sur Yvette, France
[4]W. Szafer Institute of Botany, Polish Academy of Sciences, ul. Lubicz 46, 31-512 Kraków, Poland

carbon. To minimize contamination with modern carbon (e.g. of biological origin), the surface of each macrofossil was thoroughly scraped with a plastic brush before chemical pretreatment. The AMS ^{14}C dating was performed at the Tandetron facility at Gif sur Yvette (Arnold et al. 1989). Usually, two targets were measured, and the results averaged. For all the small samples dated between 1993 and 1998, we used the correction for mass-dependence of background introduced after measurements of "infinitely" old wood samples (Goslar et al. 1993). However, further improvements in the cleaning preparation of samples and glass containers lowered the background in 1999 to about one third of that occurring in 1993. Therefore, although a blank lowering of similar amplitude was also obtained on the C1 marble at the same time by changing sample preparation, it would be possible that the ^{14}C ages of the second set (Tables 1 and 2) are slightly younger than quoted here. This has been checked very recently, by dating Lake Perespilno samples from nearly the same varves as those dated in 1996. Comparison of these dates (Figure 2, Table 2) indicates that the change in the mass-dependence of the background correction was not significant.

Most of the Gościąż dates fit one another quite well (Figures 2, 4). Few ^{14}C dates for the very small samples from the older set appear too young, possibly due to contamination with modern carbon. In the new set, two dates are obviously too old, probably due to redeposition of older material. They occur in the earlier half of Younger Dryas (12.65–12 ka BP), when vegetation cover around the lake was the thinnest (Ralska-Jasiewiczowa 1998), and the sediments contain some amount of material rebedded from the littoral zone (Goslar 1998a). Similar redeposition is revealed by one sample from Lake Perespilno.

Uncertainty of Varve Counting and Absolute Age Determination

The varve chronologies have been constructed using several cores (10 for LG and 7 for LP) varve-to-varve synchronized with one another. Therefore, difficulties with some varves being not clear enough in one core could be overcome by using other cores. The accuracy of the varve chronology is limited by varves that appear unclear in all analyzed cores. The methods of the varve counting method and construction of the LG varve chronology are described in detail elsewhere (Goslar 1998a, 1998b).

The uncertainty in the 2937-varve-long section of the LG sediments between the bottom of lamination and 10,000 cal BP (total 2937 ± 55 varves) is not uniformly distributed in time (Figure 1). Most of the uncertainty appears in the Younger Dryas (YD) part (1140 ± 40 varves), while accuracy of varve counting in the early Holocene is excellent (1496 ± 10 varves). Similarly, worse quality of lamination in the YD part (1125 ± 70 varves) is the reason why the number of varves in the younger section of the LP sediments (2158 ± 100) is less accurate than in the older section (936 ± 35).

The absolute age of the LG varve sequence has been determined (Goslar and Mądry 1998) by wiggle-matching ^{14}C dates from the younger parts of sediments to the revised oak ^{14}C-calibration curve (Kromer and Becker 1998). Since the link between German pine and oak chronologies has been found (Spurk et al. 1998), we now rely also on the match with the pine curve (Figure 2). This suggests an adjustment of the age of LG sediments (Goslar et al. 2000) by 15 yr. However, as the age of German pines is still uncertain (± 20 yr; Kromer and Spurk 1998), taking into account the pine data improved the accuracy of our dating only very slightly. The absolute age of the Lake Gościąż varve chronology is expressed by the age of varve nr. 1072 (11,496 ± 36 cal BP), a midpoint of rapid rise of δ^{18}O at the YD/Holocene boundary (Goslar et al. 1995). It is worth noting that the rise of δ^{18}O in LG perfectly coincides with the increase of tree-ring width of German pines (Spurk et al. 1998), both marking climatic warming at the onset of Holocene (Figure 3).

Table 1 Calendar and ^{14}C ages of terrestrial macrofossils from the laminated sediments of Lake Gościąż. All errors are 1σ. References: 1. Goslar et al. (1995); 2. Goslar et al. (2000); 3. outliers, not included in the discussion.

Cal BP	^{14}C BP	mg C	Ref.
12,927 ± 55	11,310 ± 90	0.65	2
12,907 ± 55	11,120 ± 90	0.97	2
12,877 ± 54	11,250 ± 90	0.86	2
12,847 ± 54	11,150 ± 90	0.94	2
12,827 ± 54	11,130 ± 70	2.69	2
12,807 ± 53	11,140 ± 70	1.38	2
12,787 ± 52	10,990 ± 60	2.58	2
12,767 ± 51	11,140 ± 70	3.03	2
12,747 ± 50	11,190 ± 70	1.59	2
12,727 ± 49	11,280 ± 70	2.34	2
12,718 ± 49	10,920 ± 90	0.56	1
12,707 ± 48	11,170 ± 80	0.92	2
12,687 ± 48	11,180 ± 70	1.65	2
12,668 ± 48	10,890 ± 80	1.68	1
12,667 ± 48	10,990 ± 60	1.84	2
12,637 ± 47	10,770 ± 90	0.63	2
12,597 ± 46	10,780 ± 70	1.22	2
12,573 ± 47	10,440 ± 110	0.84	1, 3
12,567 ± 45	10,930 ± 70	1.71	2
12,527 ± 45	10,890 ± 120	0.51	2
12,467 ± 44	10,950 ± 190	0.16	2
12,427 ± 43	10,620 ± 70	1.66	2
12,387 ± 43	11,070 ± 70	1.44	2, 3
12,337 ± 43	10,560 ± 70	1.33	2
12,307 ± 42	10,640 ± 80	0.83	2
12,277 ± 42	10,550 ± 120	0.54	2
12,247 ± 42	10,390 ± 80	0.81	2
12,227 ± 41	10,530 ± 100	0.38	2
12,194 ± 41	11,230 ± 130	0.39	2, 3
12,188 ± 41	10,300 ± 100	0.56	1
12,183 ± 41	10,200 ± 100	0.51	1
12,178 ± 41	10,030 ± 250	0.17	1
12,169 ± 41	10,450 ± 120	0.76	1
12,167 ± 41	10,450 ± 80	0.62	2
12,135 ± 40	10,860 ± 180	0.20	2
12,107 ± 40	10,400 ± 90	0.65	2
12,087 ± 40	10,410 ± 160	0.85	2
12,057 ± 39	10,660 ± 110	0.44	2
12,027 ± 39	10,710 ± 220	0.15	2
12,012 ± 38	10,330 ± 110	0.34	2
12,007 ± 39	10,440 ± 80	1.44	2
11,987 ± 38	10,650 ± 100	0.52	2
11,963 ± 37	10,420 ± 90	1.19	1
11,957 ± 37	10,550 ± 80	1.16	2
11,948 ± 37	10,170 ± 100	0.96	1
11,927 ± 37	10,410 ± 70	2.00	2
11,907 ± 37	10,560 ± 100	0.52	2
11,887 ± 37	10,470 ± 100	0.69	2
11,884 ± 37	9600 ± 280	0.15	1
11,857 ± 37	10,450 ± 80	0.83	2
11,827 ± 37	10,390 ± 70	2.01	2
11,802 ± 37	10,470 ± 90	0.55	2
11,778 ± 36	9950 ± 120	0.59	1, 3
11,773 ± 36	9440 ± 80	1.00	1, 3
11,768 ± 36	10,340 ± 80	0.93	2
11,763 ± 36	10,510 ± 70	1.18	2
11,747 ± 36	10,310 ± 90	0.57	2
11,732 ± 36	9870 ± 150	0.36	1
11,717 ± 36	10,300 ± 80	0.73	2
11,708 ± 36	9870 ± 330	0.17	1
11,688 ± 36	10,320 ± 80	0.77	2
11,638 ± 36	10,040 ± 240	0.23	1
11,604 ± 36	9830 ± 100	0.52	1
11,538 ± 36	10,360 ± 160	0.33	1
11,524 ± 36	9970 ± 100	1.30	1
11,484 ± 36	10,050 ± 100	2.21	1
11,469 ± 36	9900 ± 90	1.84	1
11,443 ± 36	10,050 ± 90	0.80	1
11,411 ± 36	9750 ± 210	0.23	1
11,393 ± 36	9920 ± 90	0.84	1
11,393 ± 36	10,030 ± 100	0.56	1
11,361 ± 36	10,050 ± 120	0.83	1
11,343 ± 36	10,100 ± 80	2.06	1
11,303 ± 36	9950 ± 90	1.24	1
11,268 ± 36	10,020 ± 100	1.10	1
11,228 ± 36	9680 ± 80	0.86	1
11,183 ± 36	9760 ± 80	0.96	1
11,163 ± 36	9550 ± 120	0.35	1
11,113 ± 36	9700 ± 100	1.01	1
11,113 ± 36	9740 ± 90	1.24	1
11,063 ± 36	9600 ± 90	0.97	1
11,063 ± 36	9650 ± 110	2.60	1
11,021 ± 36	9410 ± 70	1.20	1
11,003 ± 36	9410 ± 120	0.31	1
10,983 ± 36	9600 ± 110	0.40	1
10,953 ± 36	9340 ± 100	0.78	1
10,943 ± 36	9560 ± 90	0.57	1
10,943 ± 36	9770 ± 120	0.66	1
10,913 ± 36	9730 ± 90	2.63	1
10,883 ± 36	9560 ± 90	1.69	1
10,843 ± 36	9670 ± 110	1.46	1
10,833 ± 36	9490 ± 90	0.88	1
10,783 ± 36	9430 ± 100	2.77	1
10,783 ± 36	9400 ± 100	0.77	1
10,743 ± 36	9590 ± 90	1.47	1
10,733 ± 36	9450 ± 90	2.40	1
10,683 ± 36	9420 ± 100	2.09	1
10,653 ± 36	9330 ± 100	1.40	1
10,648 ± 36	9410 ± 80	0.85	1
10,603 ± 36	9360 ± 80	0.69	1
10,598 ± 36	9210 ± 90	1.51	1
10,558 ± 36	9100 ± 110	0.69	1
10,548 ± 36	9280 ± 90	1.93	1
10,513 ± 36	9300 ± 80	1.02	1
10,503 ± 36	9190 ± 110	0.74	1
10,373 ± 36	9340 ± 110	1.24	1
10,328 ± 36	9160 ± 90	2.27	1

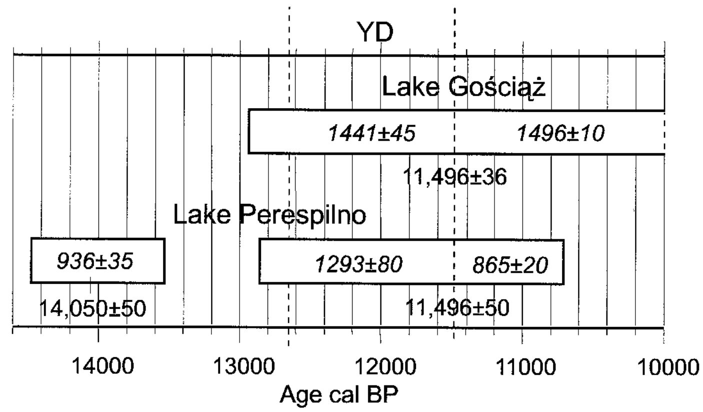

Figure 1 Range of the varve chronologies of Lake Gościąż and Lake Perespilno. Numbers of varves in the Late Glacial and early Holocene parts of sediments have been given within the bars. The numbers below the bars denote calendar ages of characteristic levels (YD/Holocene boundary and varve nr. 415 in the older Perespilno section) of separate sections.

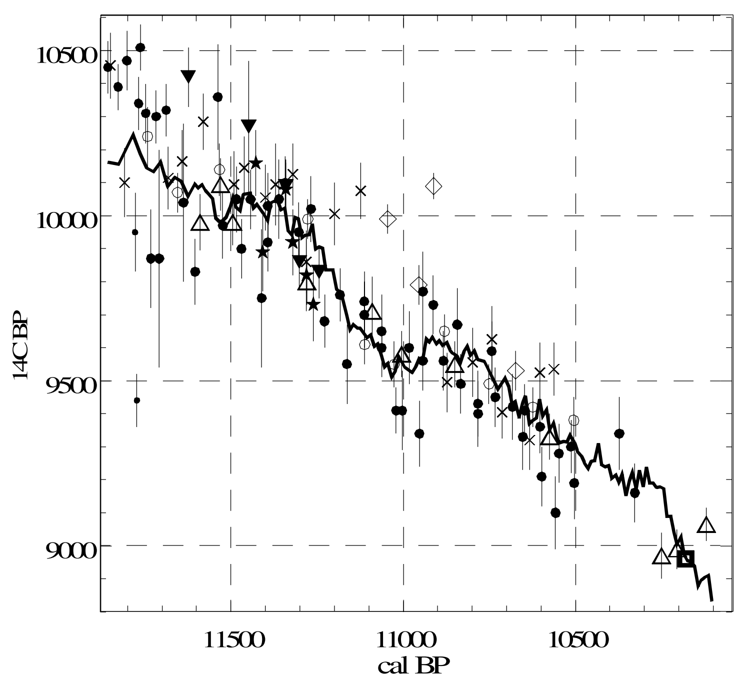

Figure 2 Comparison of ^{14}C ages from Lake Gościąż and Perespilno with the tree-ring ^{14}C calibration and other relevant data. ^{14}C ages are conventional ages in yr BP with statistical errors given at the 1σ level. — = the data from German pines (Kromer and Spurk 1998), ● = data from Lake Gościąż, ▼ = data from Lake Perespilno, ★ = data from Lake Perespilno, obtained in 2000, Δ = data from Barbados, Tahiti and Mururoa (Bard et al. 1998), ◊ = data from New Guinea (Edwards et al. 1993), O = data from Cariaco basin (Hughen et al. 1998), × = data from Lake Suigetsu, Japan (Kitagawa and van der Plicht 1998). ◻ denotes calendar and ^{14}C age of Saksunarvatn ash (Grönvold et al. 1995; Birks et al. 1996). The outlying Gościąż and Perespilno dates (Goslar et al. 2000) have been denoted by smaller symbols.

Table 2 Calendar and ^{14}C ages of terrestrial macrofossils from the laminated sediments of Lake Perespilno. All errors are 1σ. References: 1. Goslar et al. (1999a); 2. Goslar et al. (2000); 3. Outliers, not included in the discussion; 4. Samples used for comparison of mass-dependence of background correction, dated in 1996 (4a) and in 2000 (4b).

Older section				Younger section			
Cal BP	^{14}C BP	mg C	Ref.	Cal BP	^{14}C BP	mg C	Ref.
14,455 ± 53	12,640 ± 110	0.69	2	12,852 ± 85	11,350 ± 200	0.79	2
14,435 ± 52	12,440 ± 130	0.36	2	12,832 ± 85	11,390 ± 100	0.66	2
14,415 ± 52	12,660 ± 130	0.38	2	12,812 ± 84	11,190 ± 70	1.14	1
14,395 ± 51	12,580 ± 120	0.73	2	12,792 ± 84	10,970 ± 100	0.70	2
14,375 ± 51	12,670 ± 110	0.43	2	12,772 ± 83	11,150 ± 80	0.88	2
14,355 ± 51	12,490 ± 110	0.63	2	12,772 ± 83	11,440 ± 130	0.32	2
14,335 ± 50	12,470 ± 70	1.37	1	12,753 ± 83	11,250 ± 70	2.40	1
14,315 ± 50	12,620 ± 110	0.45	2	12,734 ± 83	11,190 ± 100	0.53	2
14,295 ± 50	12,510 ± 90	0.77	1	12,715 ± 82	11,170 ± 90	0.55	2
14,265 ± 50	12,660 ± 130	0.41	2	12,715 ± 82	11,220 ± 100	0.45	2
14,265 ± 50	12,610 ± 110	0.54	2	12,685 ± 82	11,260 ± 100	0.70	2
14,225 ± 50	12,350 ± 110	0.44	2	12,654 ± 82	11,060 ± 90	0.96	1
14,215 ± 50	12,080 ± 90	0.74	2	12,294 ± 75	10,820 ± 70	1.38	1, 3
14,175 ± 50	12,260 ± 120	0.41	2	12,101 ± 45	10,560 ± 70	2.13	1
14,115 ± 50	12,180 ± 120	0.59	2	11,906 ± 45	10,510 ± 70	1.27	1
14,095 ± 50	12,330 ± 80	1.61	1	11,624 ± 45	10,420 ± 90	0.91	1
14,075 ± 50	12,350 ± 140	0.25	2	11,448 ± 45	10,270 ± 200	1.34	1, 4a
14,075 ± 50	12,230 ± 140	0.29	2	11,428 ± 45	10,160 ± 100	0.64	4b
14,055 ± 50	12,050 ± 90	0.79	2	11,408 ± 45	9890 ± 120	0.41	4b
14,035 ± 50	12,120 ± 70	1.53	1	11,341 ± 46	10,090 ± 80	2.09	1, 4a
13,995 ± 50	12,170 ± 100	0.58	2	11,341 ± 46	10,080 ± 80	1.76	4b
13,975 ± 50	12,100 ± 100	0.51	2	11,321 ± 47	9920 ± 100	0.87	4b
13,955 ± 50	12,140 ± 120	0.36	2	11,301 ± 47	9860 ± 80	1.72	1, 4a
13,935 ± 50	12,030 ± 90	0.84	1	11,281 ± 47	9820 ± 110	0.36	4b
13,831 ± 50	11,720 ± 110	0.60	2	11,261 ± 48	9730 ± 11	0.34	4b
13,809 ± 50	11,860 ± 120	0.44	2	11,244 ± 48	9830 ± 80	1.09	1, 4a
13,787 ± 51	12,110 ± 160	0.25	2				
13,765 ± 52	11,710 ± 110	0.43	2				
13,754 ± 52	11,790 ± 200	0.73	1				
13,715 ± 52	11,620 ± 120	0.48	2				
13,685 ± 52	11,780 ± 90	0.73	1				

The younger section of LP sediments has been dated by synchronizing sharp changes of pollen spectra at the YD boundaries with those in the LG sediments (Goslar et al. 1999a). The uncertainty of synchronization, connected with time resolution of pollen data (± 25 yr), makes dating of LP sediments (11,496 ± 50 cal BP) less accurate than of the LG. The absolute age of the older LP section has been determined (Goslar et al. 2000) by wiggle-matching ^{14}C dates to the coral calibration data.

RESULTS AND COMPARISON WITH OTHER CALIBRATION DATA

Holocene Section (10,000–11,500 cal BP)

In the Holocene section, our data agree very well with the tree-ring calibration, and confirm the plateaux of the calibration curve at 10,000 and 9500 BP (Figure 2). The mean uncertainty of the ^{14}C age of the LG macrofossils can be assessed from the mean-square deviation of ^{14}C dates from the tree-ring ^{14}C-calibration curve, which between 11.65 and 10.3 ka BP is 1.32 times the standard error (i.e. 130 yr on average). Systematic bias of the LG dates can be determined as a mean deviation from the calibration curve at the 10,000 and 9500 BP plateaux. These deviations (–25 yr for 11.65–11.3 ka BP and −10 yr for 11.1–10.8 ka BP) show that the systematic error of the LG dates is negligible.

In general, agreement between calibration data from different archives (tree rings—Kromer and Spurk 1998; Barbados corals—Bard et al. 1998; New Guinea corals—Edwards et al. 1993; sediments from Cariaco Basin, Atlantic—Hughen et al. 1998; and sediments from Lake Suigetsu, Japan —Kitagawa and van der Plicht 1998) is reasonable (except for two New Guinea dates around 11 ka BP, and one date from Suigetsu at around 11.1 ka BP), and the calibration curve in this section seems well established.

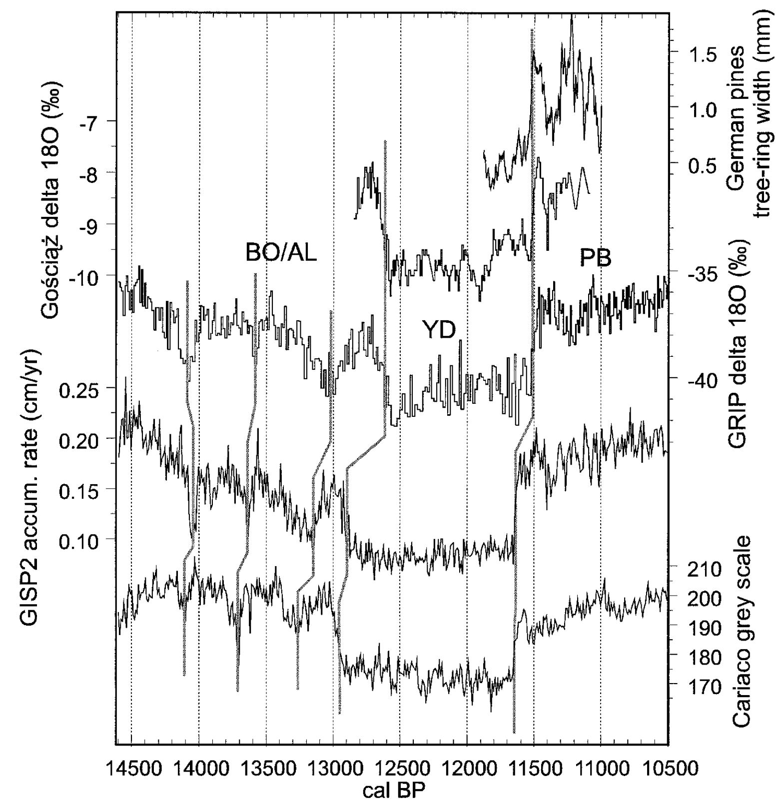

Figure 3 Comparison of calendar time scales of the records discussed in the text. The climatic events during the Late Glacial, common to all the records (e.g. boundaries of YD) have been marked by vertical lines.

Late-Glacial Section of Lake Gościąż and Younger Lake Perespilno Sequence (11,500–13,000 cal BP)

In this section, the Gościąż and Perespilno dates indicate constant or even increasing ^{14}C age between 12.9 and 12.7 ka BP, rapid decline of ^{14}C age after the beginning of Younger Dryas (at 12.65 ka BP), and around 12 ka BP a long plateau at around 10,400 BP.

Comparison with Tree-Ring Calibration

Before 11,650 cal BP, the LG data offset the pine curve significantly, much beyond the uncertainty of ^{14}C age. This might be due to some varves missing from the LG sequence, which seems difficult to accept as the LG chronology is replicated in several cores from three separate lake basins (e.g. Goslar 1998a). An alternative explanation is perhaps inadequate cross-correlation of the pine tree-ring sequences in the period, where few trunks are available, the tree-rings are very thin, and frequently missing (Spurk et al. 1998).

Comparison with Lake Suigetsu Data

The LG and LP dates agree with those obtained on sediments from Lake Suigetsu (LS), Japan (Kitagawa and van der Plicht 1998). Most LS data (except one date at around 11.8 ka BP) fit the plateau at 10,400 BP, documented by our data between 12.2 and 11.8 ka BP (Figure 4), and show a similar slope of the calibration curve between 12.5 and 12.2 ka BP. Also before 12.5 ka BP, only one LS date (at around12.75 ka BP) is distinctly younger than those from LG and LP, and the group of LS dates between 12.9 and 13.2 ka BP continues the trend indicated by the LG and LP data. The deviation between the LS and LG/LP (Table 3) dates is insignificant during the millennium 12.5–11.5 ka BP, while before 12.5 ka BP, the LG/LP ^{14}C dates appear too old by about 150 years. However, both data sets may be reconciled within error limits of varve chronologies, e.g. shift of the LG/LP curve by 50 calendar years cancels that deviation almost completely (cf. Table 3). Another reason for the deviation could be systematic error of ^{14}C dates, because of admixture of rebedded macrofossils in the LG/LP samples, and partly because of problems (uncertainties?) with the background correction (cf. "Radiocarbon Dating" section). The systematic bias, however, seems constrained by the comparison of Cariaco and LG/LP dates, which agree quite well when synchronized (cf. further paragraph).

Table 3 Comparison between the Gościąż/Perespilno and other calibration data in the section 11,500–13,000 cal BP. The numbers give mean deviations of ^{14}C dates of given data set from the spline curve fitted to the LG/LP data (Goslar et al. 2000). Numbers of samples from each set and period have been denoted in parentheses. The values obtained when one date from LS (with LS-LG/LP = –460 yr) is omitted, are given in italics. All uncertainties are 1σ. Cor. = corals.

Period (ka BP)	LS-LG/LP	LS-LG/LP[a]	Cor.-LG/LP	Cor.-LG/LP[a]	CB-LG/LP	CB[b]-LG/LP
Original values of reservoir correction[c]						
11.5–12.0	−50 ± 75 (6)	14 ± 74 (6)	−100 ± 89 (3)	−64 ± 96 (3)	−147 ± 90 (4)	−114 ± 51 (5)
12.0–12.5	−38 ± 67 (6)	17 ± 72 (6)	−176 ± 100 (4)	−161 ± 96 (4)	−193 ± 64 (4)	−44 ± 33 (4)
12.5–13.0	−179 ± 71 (6) *−134 ± 63 (5)*	−132 ± 66 (6) *−97 ± 65 (5)*	−164 ± 52 (8)	−117 ± 64 (8)	−454 ± 70 (5)	−37 ± 56 (8)
INTCAL98 value of reservoir correction[d]						
11.5–12.0	−50 ± 75 (6)	14 ± 74 (6)	−241 ± 125 (3)	−205 ± 137 (3)	−241 ± 98 (3)	−194 ± 51 (5)
12.0–12.5	−38 ± 67 (6)	17 ± 72 (6)	−201 ± 113 (4)	−186 ± 104 (4)	−260 ± 39 (5)	−124 ± 33 (4)
12.5–13.0	−179 ± 71 (6) *−134 ± 63 (5)*	−132 ± 66 (6) *−97 ± 65 (5)*	−323 ± 58 (8)	−276 ± 64 (8)	−524 ± 64 (5)	−117 ± 56 (8)

[a]LG/LP curve shifted by 50 yr towards the older age

[b]CB and LG/LP chronologies synchronized at the AL/YD and YD/PB boundaries

[c]Reservoir correction of marine ^{14}C dates as in original publications (300 yr for Tahiti and Mururoa, 400 yr for Barbados, 420 yr for Cariaco, 500 yr for New Guinea)

[d]Reservoir correction according to the INTCAL98 calibration (Stuiver et al. 1998)

Comparison with Corals from Barbados, Tahiti, Mururoa and New Guinea

The quality of agreement with coral ^{14}C-calibration data depends on the "reservoir age" correction of coral ^{14}C dates. Bard et al. (1998) used different corrections for corals from different sites (300 yr for Tahiti and Mururoa, and 400 yr for Barbados). A constant correction (400 yr) was also applied by Edwards et al. (1993) for the corals from New Guinea. On the other hand, in the INTCAL98 paper (Stuiver et al. 1998), the same coral data were used with the correction uniform over the whole tropical ocean, but variable in time (500 yr for samples older than 10,000 cal BP vs. 400 yr for younger samples).

The variation of reservoir correction (R) has been derived from comparison of coral and tree-ring ^{14}C ages (Stuiver et al. 1998). Indeed, R—when averaged for all the sites—seems higher before than after 10,000 cal BP (Table 4). However, reservoir ages differ significantly between sites (except for the millennium 8–9 ka BP), which disagrees with the assumption of uniform R. The site-specific data show also that there is no reason to suspect that the reservoir ages in Barbados and Tahiti varied in the period considered. With the INTCAL98 value of R, all ^{14}C ages from Barbados and Tahiti between 12 and 10 ka BP (11 points; cf. Figures 3 and 5 in Stuiver et al. 1998) appear younger than those of tree rings, which is an indication of a systematic error in the reservoir correction.

Table 4 Mean reservoir ages of corals from Barbados and Tahiti (Bard et al. 1998) and New Guinea (Edwards et al. 1993) derived from comparison with the tree-ring ^{14}C calibration. Numbers of samples from each site and period are in parentheses. The values obtained when one outlying date from New Guinea (R = 900 ± 60 yr) is omitted, are given in italics. All uncertainties are 2σ.

Period (ka BP)	Barbados	Tahiti	New Guinea	Whole
8–9	360 ± 160 (1)	370 ± 200 (1)	360 ± 130 (2)	360 ± 90 (4)
9–10	430 ± 100 (2)	220 ± 70 (4)	500 ± 45 (3)	420 ± 35 (9)
10–11	—	290 ± 60 (5)	700 ± 50 (4)	530 ± 40 (9)
			520 ± 70 (3)	*380 ± 45 (8)*
11–12	400 ± 100 (3)	230 ± 90 (3)	790 ± 170 (1)	360 ± 60 (7)
Whole 8–12	400 ± 65 (6)	260 ± 40 (13)	580 ± 30 (10)	450 ± 25 (29)
			500 ± 40 (9)	*400 ± 25 (28)*

The LG and LP data do not differ much from those from the Barbados, Mururoa, and Tahiti corals when the original reservoir correction (Bard et al. 1998) is applied (Figure 4 and Table 3a), but deviate clearly from the coral data with R=500 yr (Figure 5 and Table 3b). This would support a site-specific, constant R, at least for the period after 13,000 cal BP. This converges with the earlier suggestion of low R (325 instead of 500 yr), derived from comparison between corals and Lake Suigetsu (Stuiver et al. 1998).

Further support for the original reservoir correction is given by dating of the Vedde ash layer, which has been identified in the GRIP core at 11,980 cal BP (Grönvold et al. 1995). This layer has been independently dated by ^{14}C to 10,330 ± 30 BP (based on 11 AMS ^{14}C ages from Bard et al. 1996 and Birks et al. 1996), which agrees with the coral date from Tahiti (at 11,930 cal BP) only when R=300 yr is applied (Figures 4 and 5).

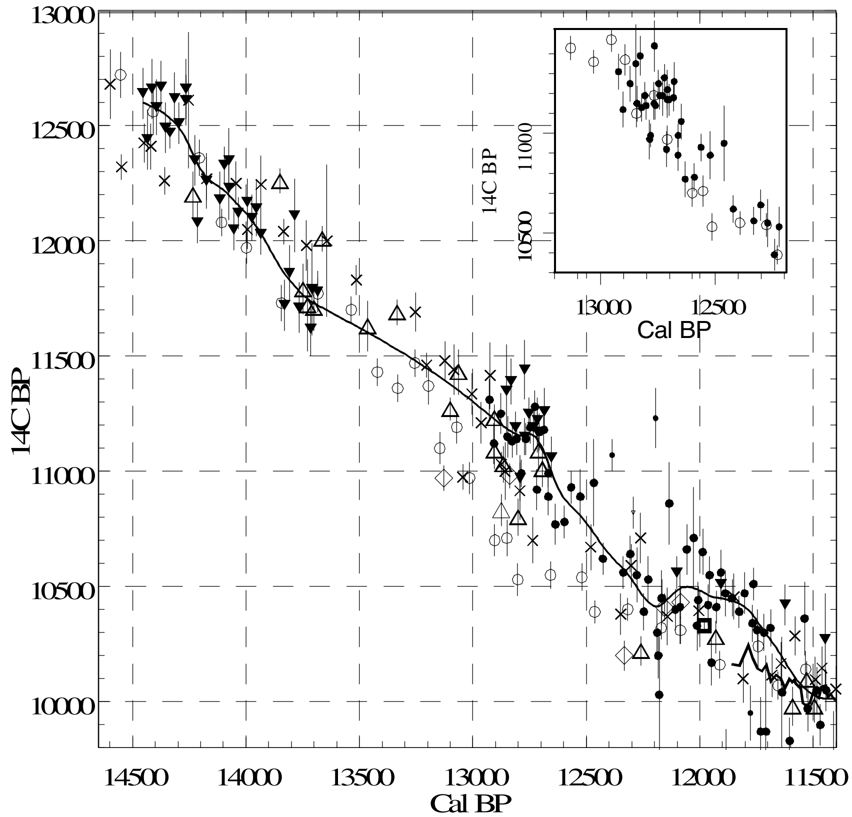

Figure 4 Comparison of ^{14}C ages from Lake Gościąż and Perespilno with the ^{14}C calibration data in the Late Glacial. For oceanic samples (corals and Cariaco basin sediments), values of reservoir correction published originally (i.e. by Bard et al. 1998, Edwards et al. 1993 and Hughen et al. 1998) were used. □ denotes calendar and ^{14}C age of Vedde Ash (Grönvold et al. 1995; Birks et al. 1996), other symbols are as in Figure 2. Thin smooth line represents the spline function fitted to the LG and LP data (Goslar et al. 2000). The inset figure illustrates good correspondence of the ^{14}C dates from Gościąż and Perespilno with Cariaco basin, when the Cariaco Allerød/YD transition (cf. Figure 3) is synchronized with that recorded in the LG sediments.

Comparison with Data from the Cariaco Basin

Independent of the value of reservoir correction (Figures 4 and 5), ^{14}C dates from the Cariaco basin (Hughen et al. 1998; Stuiver et al. 1998) in the period between 13 and 12.5 ka BP are significantly younger than the LG and LP dates. As indicated elsewhere (Goslar et al. 2000) this disagreement reflects the large difference between absolute ages of the AL/YD boundary in both archives (Figure 3) and disappears when the Cariaco and LG/LP chronologies are synchronized at the AL/YD transition (inset to Figure 4).

Chronologies of the LG and the Cariaco basin (CB) sediments are supported by those of the GRIP (Johnsen et al. 1992) and GISP2 (Alley et al. 1993, 1997) ice cores (Figure 2), respectively, which show distinct time lags between several events, too. Probably, some of the considered chronologies (either GRIP/LG or GISP2/CB) need an adjustment.

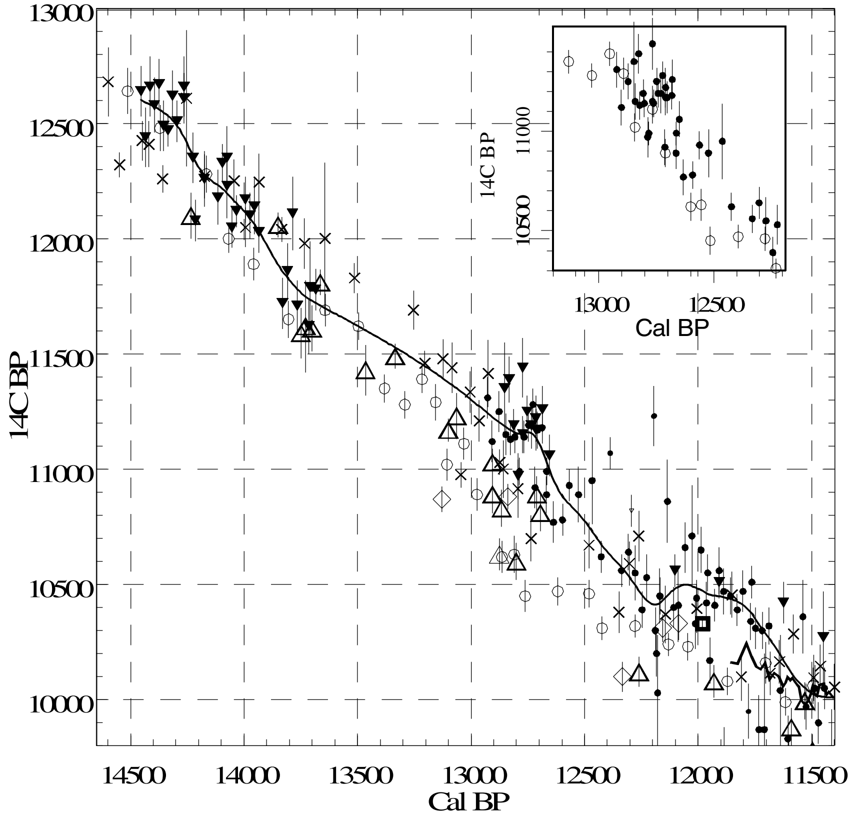

Figure 5 Comparison of ^{14}C ages from Lake Gościąż and Perespilno with the ^{14}C calibration data in the Late Glacial. For oceanic samples (corals and Cariaco basin sediments), the INTCAL98 version of reservoir correction (Stuiver et al. 1998) was used. Symbols are as in Figure 2. The inset figure illustrates correspondence of the ^{14}C dates from Gościąż and Perespilno with Cariaco basin, when the Cariaco Allerød/YD transition (cf. Figure 3) is synchronized with that recorded in the LG sediments.

The YD/Holocene boundaries in GRIP and Gościąż are synchronous with that found in German pines, while those in Cariaco and GISP2 are about 100 years older. The discrepancy between GISP2 and tree-ring chronologies is supported by the GISP2 ^{10}Be record (Finkel and Nishiizumi 1997) between 8 and 5 ka BP, which lags the dendro-dated record of atmospheric ^{14}C by about 100 years, too. As noted by Bard et al. (1998), the GRIP timescale is also confirmed through the Saksunarvatn ash layer, which has been identified in the GRIP core and dated to 10,180 (Grönvold et al. 1995). This layer has been independently dated by ^{14}C to 8960 ± 70 BP (based on three AMS ^{14}C ages from Birks et al. 1996), which perfectly fits the pine calibration curve (Figure 2).

In the Late Glacial, reliability of the GRIP and LG time scales is supported by the data from Lake Perespilno and German Maar lakes (Brauer et al. 1999 and this issue), all revealing significantly shorter duration of the Younger Dryas period (about 1150 years) than in the GISP2 and CB archives (about 1300 years). Moreover, ^{14}C dates of the oldest samples from LG agree with most of the dates from Lake Suigetsu (Figure 4, Table 3), while in the same period, and also in the preceding millennium, all the Cariaco dates are much younger than those of LS. On the other hand, comparison with the coral data is not too conclusive, as the deviations between LG/LP and coral and CB data distinctly depend on the model of reservoir age correction (cf. Tables 3a, 3b).

The arguments above seem to suggest that the GISP2 and CB time scales might be not adequate. This would imply that the maximum of atmospheric ^{14}C concentration at the beginning of Younger Dryas was smaller than previously believed (e.g. Goslar et al. 1999b; Hughen et al. 1998; Broecker 1997), and as argued by Goslar et al. (2000), it is explicable without ocean circulation changes. However, the reasons that could produce a too-long CB chronology, are difficult to imagine.

Synchronization of the CB and LG/LP records at the AL/YD transition completely cancels the discrepancy between ^{14}C dates from these archives, when the original value of reservoir correction for the CB (R=420 yr; Hughen et al. 1998) is applied (inset to Figure 4; Table 3a). With R=500 yr (Stuiver et al. 1998) the agreement is worse (inset to Figure 5; Table 3b), but still much better than without synchronization. This constrains the marine reservoir correction in the range between 500 yr (INTCAL98 value) and 400 yr (if the LG/LP ^{14}C ages are free of systematic bias), and the systematic bias of the LG/LP ^{14}C dates between 0 (no rebedded macrofossils) and about 100 years (if the INTCAL98 value of R is correct). It is worth noting that this finding is independent of whichever calendar (either the CB or LG/LP) is incorrect.

Comparison with Vanuatu Corals

The Lake Gościąż data document rather constant ^{14}C ages between 11.7 and 12.2 ka BP, which disagrees with data from Vanuatu corals (Figure 6). Surprisingly, variations of atmospheric ^{14}C suggested by the data from Vanuatu, are comparable or even stronger than that documented at the beginning of YD. The Vanuatu sequence is broken by three hiatuses, when the coral died off for some period. It is remarkable that ^{14}C declined rapidly in periods of coral growth, and in all four sections it was minimum just prior to the end of the growth period. It is improbable that the alternation of coral growth and die-off was in phase with ^{14}C variations by chance. One possible link between those two signals would be large changes of vertical oceanic circulation, but such changes are visible neither in paleoceanographic nor in paleoclimatic data. An alternative possibility is that the Vanuatu data are affected by changes of apparent ^{14}C age. As stated by Burr et al. (1998), the hiatuses could be an effect of emergence, which would raise the ^{14}C content of the coral due to recrystallization. However, no evidence of recrystallization was found (Burr et al. 1998).

The Vanuatu and LG data could be also reconciled if >300 varves were missing from the LG sequence at around 11.65 ka BP. However, adding 300 yr would make the Gościąż YD section 1450 yr long, in disagreement with what is known from any other archives. At any rate, an independent calibration data set with time resolution comparable to those from Vanuatu and LG is needed to resolve the problem.

Older Lake Perespilno Sequence (>13,500 cal BP)

The older LP section has been dated (Goslar et al. 2000) by the wiggle-match of ^{14}C dates to coral calibration data (Bard et al. 1998). The small uncertainty for that date (varve nr. 415 at 14,050 ± 50 cal BP) may be surprising, regarding that only a few coral dates in the period of overlap are available. However, the absolute age of LP section is tightly constrained by matching both ends of 12,150 BP plateau in the middle part of that section, with two coral points at around 13.8 and 14.2 ka BP (Figure 4).

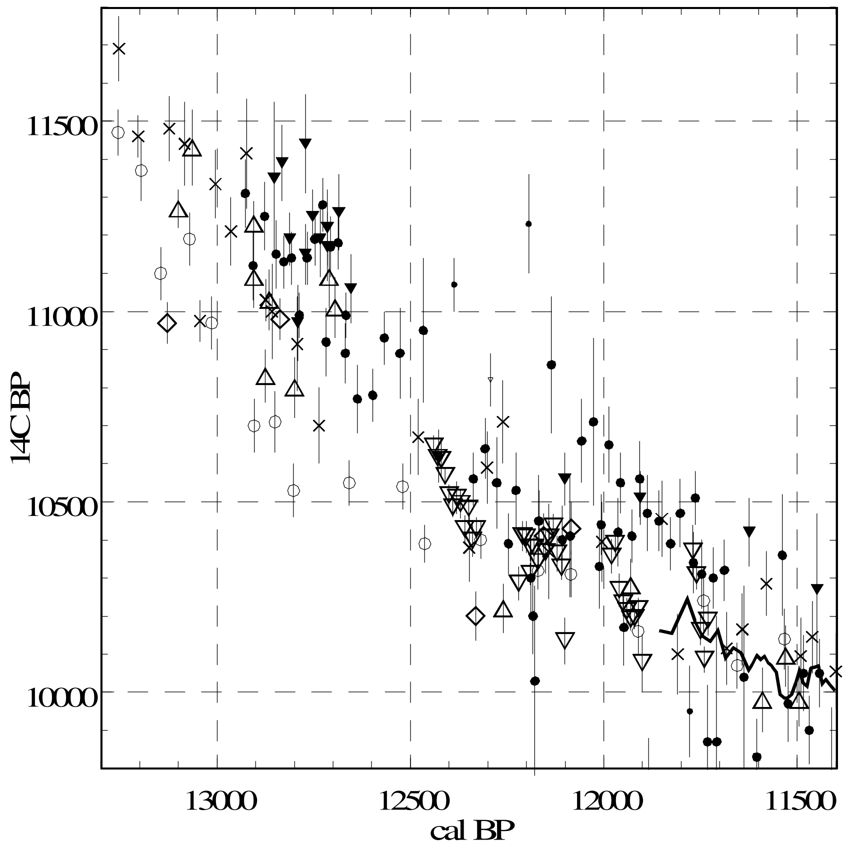

Figure 6 Comparison of ^{14}C ages from Lake Gościąż and Perespilno with the ^{14}C calibration data from Vanuatu corals. ∇ = data from Vanuatu (Burr et al. 1998), other symbols as in Figure 2.

An additional uncertainty of that match is introduced by the not exactly known reservoir age of the corals. Indeed, the match to the coral data with R=500 yr (Stuiver et al. 1998) makes the age of LP younger by 95 yr, but as argued above the R=500 yr model seems problematic.

An independent check of the LP dating is possible through the match to the Lake Suigetsu data, which makes the LP 55 years younger, and to the Cariaco Basin dates, which makes it 65 or 60 yr (depending on whether the R=420 or R=500 yr model is used) older than 14,050 cal BP. Both matches appear more precise than those with corals, since more data points were involved in the match. On the other hand, accuracy of absolute dating through those matches is limited by uncertainty of calendar age of the LS and CB samples. The uncertainty of chronology of the CB sediments around the AL/YD boundary was discussed in the former chapter. This had been connected with large discrepancy between the CB/GISP2 and LG/GRIP chronologies around 12.8 ka BP (Figure 3). Around 14 ka BP, all chronologies converge, making the CB time scale quite confident in that period. For all the reasons above we maintain the original date of the LP sequence.

The general slope of ^{14}C-calibration curve documented by our data seems a bit higher than that reflected with the Suigetsu set, but it agrees very well with that shown by the Cariaco points. Moreover, our data reveal three periods of rather constant ^{14}C age at 12,500, 12,100–12,200, and

11,700 BP, separated by rapid declines of ^{14}C age around 14.2 and 13.9 ka BP. This has not been shown by previous reconstructions, as they covered the relevant time span too sparsely.

CONCLUSION

Except for a few outliers, the ^{14}C dates of terrestrial macofossils from Lakes Gościąż and Perespilno constitute a self-consistent set of ^{14}C calibration data, which covers the time span 12,900–10,300 cal BP and 14,450–13,700 cal BP, respectively. These data agree very well with the German pine calibration curve, and other calibration data in the Holocene section.

In the Late Glacial, the scatter of calibration data from different archives is distinct. In the period 13,000–11,500 cal BP our data agree with those from Lake Suigetsu, and indicate a constant or even increasing ^{14}C age between 12.9 and 12.7 ka BP, a rapid decline of ^{14}C age after the beginning of Younger Dryas, and a long plateau 10,400 BP around 12 ka BP. Correlation with corals seems to support the values of the reservoir correction used originally by Bard et al. (1998) and Edwards et al. (1993), in contradiction to those introduced in the INTCAL98 calibration (Stuiver et al. 1998). Around the Allerød/Younger Dryas boundary our data disagree with ^{14}C dates from Cariaco basin, which beyond any doubt reflects large discrepancy between calendar chronologies of GRIP/Gościąż/Perespilno and GISP2/Cariaco archives at that period. We argue the Gościąż chronology to be correct, though the deviation of the Cariaco time scale is not easy to imagine. Unlike the corals from Vanuatu, our data do not reveal large fluctuations of ^{14}C age between 12.4 and 11.7 ka BP, which could reflect variations of apparent age of Vanuatu corals. There is no fundamental argument to choose any set of ^{14}C calibration data for that period.

The older sequence from Lake Perespilno confirms the general slope of the ^{14}C-calibration curve between 14.5 and 13.7 ka BP, documented by the data from Suigetsu and Cariaco, and indicates a rapid decline of ^{14}C age around 14.2 and 13.9 ka BP.

ACKNOWLEDGMENTS

The authors wish to thank R Alley for sharing the data on the GISP2 accumulation rate, K Hughen for the ^{14}C calibration data and the grey-scale record of the Cariaco sediments, S Johnsen and C Hammer for the data on the GRIP time scale, and M Spurk for the data on the German pine tree-ring thickness. The work of TG has been sponsored by the Polish Committee for Scientific Research, through the grant 6 P04E 046 16, and AMS ^{14}C dating by the French Centre National de la Recherche Scientifique et Commissariat de l'Energie Atomique. TG wishes to thank K Więckowski (retired), A Walanus, A Rakowski, J Pawlyta (Silesian University Techn., Gliwice), and K Bałaga (M Curie-Skłodowska University, Lublin, Poland), for their kind help in raising the sediment cores. The terrestrial macrofossils have been separated with the help of D Moszyńska-Moskwa, Z Tomczyńska, M Zurzycka (Szafer Inst. Bot., Kraków) and J Czernik (Silesian University Techn., Gliwice). Some macrofossils have been identified by D Demske (currently at Freie University Berlin).

REFERENCES

Alley RB, Meese DA, Shuman CA, Gow AJ, Taylor KC, Grootes PM, White JWC, Ram M, Waddington ED, Mayewski PA, Zielinski GA. 1993. Abrupt increase in Greenland snow accumulation at the end of the Younger Dryas event. *Nature* 362:527–9.

Alley RB, Shuman CA, Meese DA, Gow AJ, Taylor KC, Cuffey KM, Fitzpatrick JJ, Grootes PM, Zielinski GA, Ram M, Spinelli G, Elder B. 1997. Visual-stratigraphic dating of the GISP2 ice core: basis, reproducibility, and application. *Journal of Geophysical Research* C102:26,367–81.

Arnold M, Bard E, Maurice P, Valladas H, Duplessy JC. 1989. C-14 dating with the Gif-sur-Yvette Tandetron accelerator: status report and study of isotopic fractionations in the sputter ion source. *Radiocarbon* 31(2):191–9.

Bard E, Arnold M, Mangerud J, Paterne M, Labeyrie L, Duprat J, Melieres MA, Sonstegaard E, Duplessy JC. 1994. The North Atlantic atmosphere-sea surface ^{14}C gradient during the Younger Dryas climatic event. *Earth and Planetary Science Letters* 126:275–87.

Bard E, Arnold M, Hamelin B, Tisnerat-Laborde N, Cabioch G. 1998. Radiocarbon calibration by means of mass spectrometric $^{230}Th/^{234}U$ and ^{14}C ages of corals: an updated database including samples from Barbados, Mururoa and Tahiti. *Radiocarbon* 40(3):1085–92.

Birks HH, Gulliksen S, Haflidason H, Mangerud J, Possnert G. 1996. New radiocarbon dates for the Vedde Ash and Saksunarvatn Ash from Western Norway. *Quaternary Research* 45:119–27.

Brauer A, Endres CH, Günter C, Litt T, Stebich M, Negendank JFW. 1999. High resolution sediment and vegetation responses to Younger Dryas climate change in varved lake sediments from Meerfelder Maar, Germany. *Quaternary Science Reviews* 18:321–9.

Broecker WS. 1997. Thermohaline circulation, the Achilles Heel of our climate system: will man-made CO_2 upset the current balance? *Science* 278:1582–8.

Burr GS, Warren Beck J, Taylor FW, Recy J, Edwards RL, Cabioch G, Correge T, Donahue D, O'Malley JM. 1998. A high-resolution radiocarbon calibration between 11,700 and 12,400 calendar years BP derived from ^{230}Th ages of corals from Espiritu Santo Island, Vanuatu. *Radiocarbon* 40(3):1093–1106.

Edwards RL, Warren Beck J, Burr GS, Donahue DJ, Chappell JMA, Bloom AL, Druffel ERM, Taylor FW. 1993. A large drop in atmospheric $^{14}C/^{12}C$ and reduced melting in the Younger Dryas, documented with ^{230}Th ages of corals. *Science* 260:962–8.

Finkel RC, Nishiizumi K. 1997. Beryllium 10 concentrations in the Greenland Ice Sheet Project 2 ice core from 3-40 ka. *Journal of Geophysical Research* 102: 26,699–706.

Goslar T, Kuc T, Ralska-Jasiewiczowa M, Różański, K, Arnold M, Bard E, van Geel B, Pazdur MF, Szeroczyńska K, Wicik B, Więckowski K, Walanus A. 1993. High-resolution lacustrine record of the Late Glacial/ Holocene transition in Central Europe. *Quaternary Science Reviews* 12:287–94.

Goslar T, Arnold M, Bard E, Kuc T, Pazdur MF, Ralska-Jasiewiczowa M, Tisnerat N, Różański K, Walanus A, Wicik B, Więckowski K. 1995. High concentration of atmospheric ^{14}C during the Younger Dryas cold episode. *Nature* 377:414–7.

Goslar T. 1998a. Late-glacial sediments of Lake Gościąż chronological background. In: Ralska-Jasiewiczowa M, Goslar T, Madeyska T, Starkel L, editors. *Lake Gościąż, central Poland. A monographic study, part 1*: 119–24. Kraków: Szafer Institute of Botany.

Goslar T. 1998b. Floating varve chronology of Lake Gościąż. In: Ralska-Jasiewiczowa M, Goslar T, Madeyska T, Starkel L, editors. *Lake Gościąż, central Poland. A monographic study. Part 1*: 97–9. Kraków: Szafer Institute of Botany.

Goslar T, Bałaga K, Arnold M, Tisnerat N, Starnawska E, Kuźniarski M, Chróst L, Walanus A, Więckowski K. 1999a. Climate-related variations in the composition of the Late Glacial and early Holocene sediments of Lake Perespilno (eastern Poland). *Quaternary Science Reviews* 18:899–911.

Goslar T, Wohlfarth B, Björck S, Possnert G, Björck J. 1999b. Variations of atmospheric ^{14}C concentrations over the Alleröd-Younger Dryas transition. *Climate Dynamics* 15:29–42.

Goslar T, Arnold M, Tisnerat-Laborde N, Czernik J, Więckowski K. 2000. Variations of Younger Dryas atmospheric radiocarbon explicable without ocean circulation changes. *Nature* 403:877–80.

Goslar T, Mądry W. 1998. Using the Bayesian method to study the precision of dating by the "wiggle-matching" procedure. *Radiocarbon* 40(1):551–60.

Grönvold K, Oskarsson N, Johnsen SJ, Clausen HH, Hammer CU, Bond G, Bard E. 1995. Ash layers from Iceland in the Greenland GRIP ice core correlated with oceanic and land sediments. *Earth and Planetary Science Letters* 135:149–55.

Hughen KA, Overpeck JT, Peterson LC, Trumbore S. 1996. Rapid climate changes in the tropical Atlantic region during the last deglaciation. *Nature* 380:51–4.

Hughen KA, Overpeck JT, Lehman SJ, Kashgarian M, Southon J, Peterson LC, Alley R, Sigman D. 1998. Deglacial changes in ocean circulation from an extended radiocarbon calibration. *Nature* 391:65–8.

Johnsen SJ, Clausen HB, Dansgaard W, Fuhrer K, Gundestrup N, Hammer CU, Iversen P, Jouzel J, Stauffer B, Steffensen JP. 1992. Irregular glacial interstadials recorded in a new Greenland ice core. *Nature* 359:311–3.

Kitagawa H, van der Plicht J. 1998. Atmospheric radiocarbon calibration to 45,000 yr B.P.: Late Glacial fluctuations and cosmogenic isotope production. *Science* 279:1187–90.

Kromer B, Becker B. 1993. German oak and pine ^{14}C calibration, 7200-9439 BC. *Radiocarbon* 35(1):125–35.

Kromer B, Spurk M. 1998. Revision and tentative extension of the tree-ring based ^{14}C calibration, 9200-11,855 cal BP. *Radiocarbon* 40(3):1117–26.

Ralska-Jasiewiczowa M, Demske D, van Geel B. 1998. Late-glacial vegetation history recorded in the Lake Gościąż sediments. In: Ralska-Jasiewiczowa M, Goslar T, Madeyska T, Starkel L, editors. *Lake Gosćiąż, central Poland. A monographic study, part 1.* Kraków: Szafer Institute of Botany. p 128–43.

Spurk M, Friedrich M, Hofmann J, Remmele S, Frenzel B, Leuschner HH, Kromer B. 1998. Revisions and extension of the Hohenheim oak and pine chronologies: new evidence about the timing of the Younger Dryas/ Preboreal transition. *Radiocarbon* 40(3):1107–16.

Stuiver M, Reimer PJ, Bard E, Warren Beck J, Burr GS, Hughen KA, Kromer B, McCormac G, van der Plicht J, Spurk M. 1998. INTCAL98 Radiocarbon age calibration, 24,000-0 cal BP. *Radiocarbon* 40(3):1041–83.