

POSSIBILITIES FOR RECONSTRUCTING RADIOCARBON LEVEL CHANGES DURING THE LATE GLACIAL BY USING A LAMINATED SEQUENCE OF GOŚCIAŻ LAKE

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ABSTRACT. Laminated sediments of Gościąg Lake can be used as an independent source of material for calibrating the radiocarbon time scale. The varve chronology is based on three long cores from the deepest part of the lake, with one additional core from the second deepest part. From pollen and *Cladocera* spectra and stable isotope and chemical content sequences, we have determined the Allerød(AL)/Younger Dryas(YD) and Younger Dryas/Preboreal(PB) boundaries in the three long cores with relatively good accuracy, and have tentatively defined the AL/YD boundary in the fourth core. The Younger Dryas period contains at least 1520 varves, with 980 varves in fragments well replicated in all four cores. The duration of the Younger Dryas as recorded in sediments of Gościąg Lake corresponds well to the duration derived from ²³⁰Th/²³⁴U and ¹⁴C dates on Barbados corals, but disagrees with estimates from Soppensee, Lake Holzmaar and Swedish varves. Two AMS dates of terrestrial macrofossils from the PB and YD periods seem to fit both the data obtained for Swiss lake sediments and Barbados corals.

INTRODUCTION

The extension of the radiocarbon calibration into the Late Glacial is still an open question because of the lack of absolute, reliable dates. Dendrochronologically dated wood would be the best material, but an absolute chronology does not extend this far (Becker, Kromer & Trimborn 1991). Bard *et al.* (1990) used U/Th dates of Barbados corals as an independent time scale to reconstruct the trend of $\Delta^{14}\text{C}$ changes to *ca.* 30,000 cal BP. New results on corals from Mururoa Atoll and replicates of previous measurements (Bard *et al.* 1991) seem to support previous estimates. However, relatively few samples were dated, and some doubts still exist about the reliability of this method for calibration purposes. An alternative approach is to use terrestrial macrofossils from annually laminated lake sediments, which can provide continuous chronologies through several thousands of years. However, long laminated sequences are very scarce, and it is unlikely that a well-replicated master chronology can be constructed. Moreover, we can never be certain that the ¹⁴C activity measured in a macrofossil from a varve reflects the atmospheric ¹⁴C activity at the time the varve was deposited. We cannot rely on any one set of calibration data until close agreement between two independent sources has been achieved.

THE CHRONOLOGY OF LAMINATED SEDIMENTS OF LAKE GOŚCIAŻ

The laminated sediments of Lake Gościąg, central Poland (Ralska-Jasiewiczowa, Wicik & Więckowski 1987) provide a long, almost continuous floating varve chronology, extending from

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ca. 13 to 3 ka cal BP. We constructed the basic chronology, consisting of 9682 couplets in four segments, using three cores from the deepest part of the lake (Goslar, Pazdur & Walanus 1989). The correlation of cores is shown in Figure 1B. The most important break in the chronology is at a sandy layer, ca. 0.5 m thick, overlying a laminated fragment comprising 294 couplets. We must emphasize that, because of the good quality of the lamination, we were able to correlate each layer from one core with corresponding ones from other cores. We have tentatively established the annual pattern of lamination by dating a set of bulk samples (Pazdur *et al.* 1987). The annual pattern was confirmed by a detailed study of seasonalities in diatom, calcite and organic content in two fragments from the top sediments (Goslar (ms.)) and by microscopic inspection of thin sec-

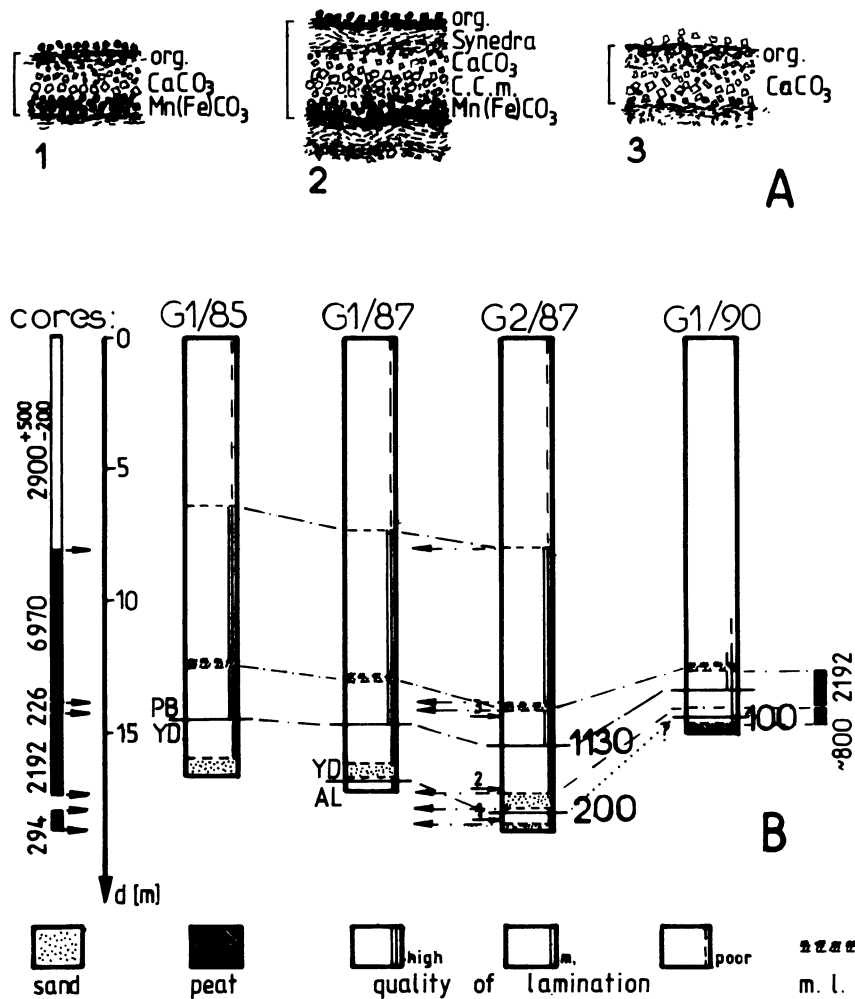


Fig. 1. A. The varve structure in three levels (1, 2 and 3) of Core G2/87; → in B. C.C.m. = *Centricae* diatoms + Chrysophycean cysts + carbonate-free mineral matter; org. = organic detritus. B. The present chronology of laminated sediments of Gościąż Lake. Left side - basic floating varve chronology, with three gaps in levels shown by arrows on Core G2/87. The numbers of couplets in the uppermost part of the sediment are given. Right side - chronology of the lowermost part of Core G1/90. The AL/YD and YD/PB boundaries in all cores and corresponding couplet numbers are denoted; m.l. = massive layers.

tions from three levels of significantly different varve structures. Figure 1A shows the varve structure at these levels. Lamination is, however, much less distinct between 2 and 8 m, and the number of varves in this part of the profile can be determined only with a relatively large error.

As several proxy climatic and ecological indicators are available from the same material, the laminated lake sediments offer a unique possibility for multiparameter reconstruction of the dynamics of environmental events. One of the most intriguing is climatic cooling from *ca.* 10.8 to 10 ka BP; *e.g.*, the Younger Dryas. The AL/YD and YD/PB transitions in the sediment of Lake Gościąg have been recognized in pollen and *Cladocera* spectra, as well as in stable isotope and chemical content sequences.

THE AL/YD AND YD/PB TRANSITIONS

The AL/YD transition in pollen spectra is characterized by a strong decline of *Betula* tree pollen-type curve, a decrease in *Populus* and *Filipendula* frequencies and a somewhat synchronous rise of *Juniperus*, *Cyperaceae*, *Gramineae*, *Artemisia* and *Chenopodiaceae*. All these changes together indicate the reduction of birchwoods and progressive development of open shrub-herb communities. The decline of *Betula* is synchronous with a decline of $\delta^{18}\text{O}$, by *ca.* 2‰ in *ca.* 100 yr. These changes are associated with an increase in $\delta^{13}\text{C}$ by *ca.* 4‰ and a decrease in carbonate content.

The YD/Holocene transition in the pollen diagram appears as a sharp boundary between Couplets 1080 and 1130, preceded, however, by a zone corresponding to nearly 300 yr, which could be called a “descending part of the Younger Dryas.” This zone is characterized by increased, though oscillating, *Betula* pollen values, including *Betula nana* type, consistently declining *Juniperus*, *Salix polaris* type and *Chenopodiaceae* pollen curves, followed by some decrease in *Artemisia* values, as well. The boundary itself is indicated by a definite reduction in *Juniperus*, *Salix polaris* type, *Artemisia*, and *Chenopodiaceae* pollen percentages, a distinct rise of *Populus tremula* type, *Filipendula* and *Urtica* pollen and the appearance of *Ulmus* pollen, forming a continuous curve in *ca.* 100 yr. The $\delta^{18}\text{O}$ shows a sharp increase, by *ca.* 1.5‰ in 50 yr, nearly simultaneous with the transition indicated by the pollen spectra. Another increase of $\delta^{18}\text{O}$, by *ca.* 0.5‰, occurred *ca.* 300 yr earlier. Shortly after the main change of $\delta^{18}\text{O}$, we observed a sharp increase in Fe content. The cooling between the two transitions is also confirmed by *Cladocera* assemblages.

The abrupt character of both transitions is well documented in the diagram of principal components (Fig. 2A). Figure 2B shows the factors contributing to the first three components. Rózański *et al.* (1991) discussed the $\delta^{18}\text{O}$ sequence in detail; diagrams and discussion of other data will be published elsewhere.

It seems most reasonable to place the AL/YD and YD/PB boundaries in the middle of the sharp rise and decline of the $\delta^{18}\text{O}$ curve; *i.e.*, at Couplet 200 below the sandy layer, and at Couplet 1130 above the sandy layer, respectively (*cf.* Fig. 1A). On the basis of this definition and data from Cores G1/85, G1/87 and G2/87, we were able to estimate the duration of the Younger Dryas period as no shorter than *ca.* 1250 yr (Rózański *et al.* 1991).

The laminated sequence of Core G1/90, taken from the second deepest part of the lake, has been accurately correlated with the laminated sequences occurring above the sandy layer in Cores G1/85, G1/87 and G2/87. Below this level, the lowermost segment of Core G1/90 is also laminated, with *ca.* 800 couplets identified in preliminary counting. However, its correlation with the corresponding laminated sequences in cores G1/87 and G2/87, where the AL/YD transition is observed, is not possible. Preliminary pollen analysis seems to suggest that the transition occurs below Couplet 200,

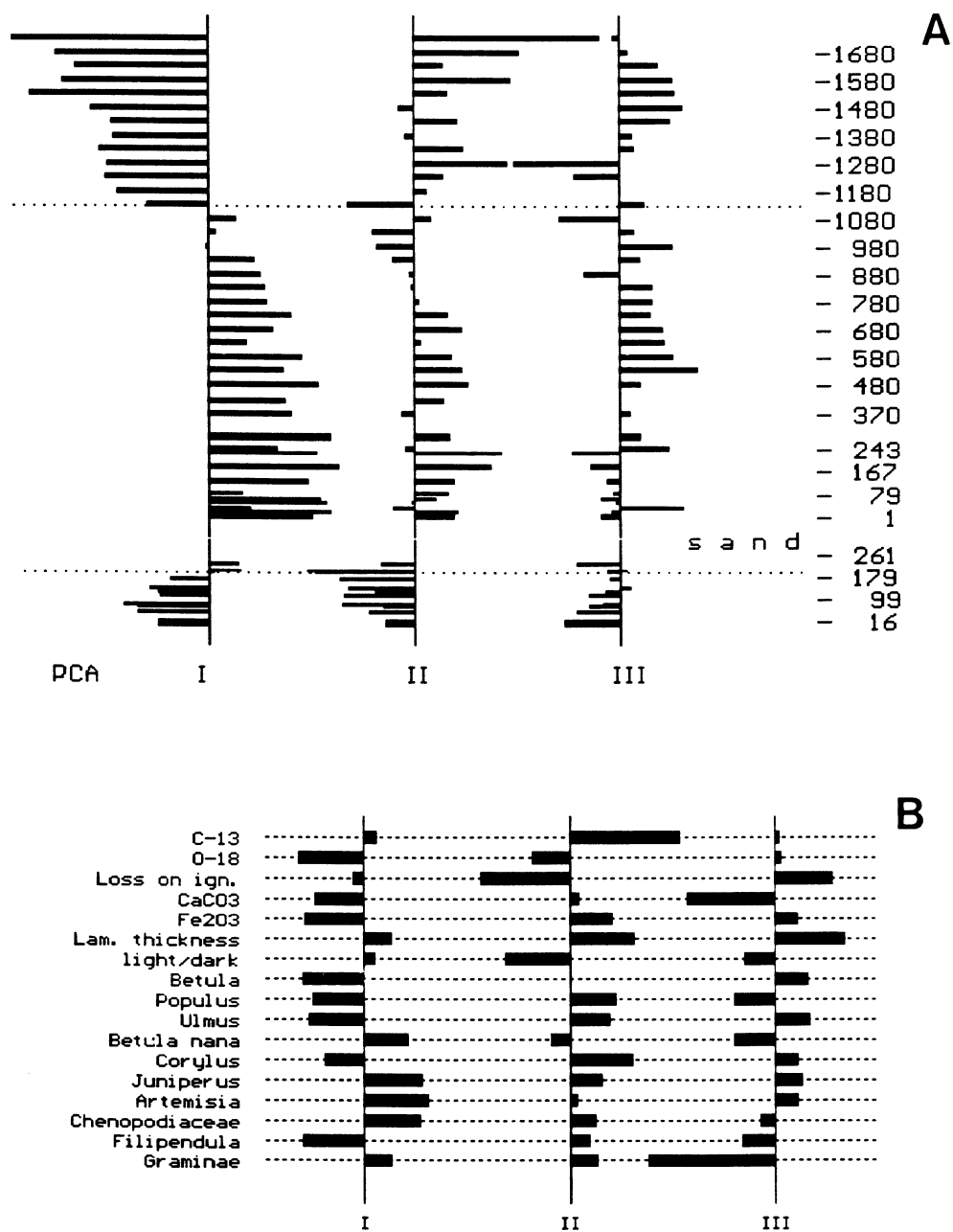


Fig. 2. A. The principal components (PCA I, II and III) of 17 records: pollen, isotope, chemical and varve thickness from the lowermost part of the long cores from Gościqż Lake. Right side – couplet number according to the basic chronology (cf. Fig. 1B). The AL/YD and YD/PB boundaries are denoted. B. The contributions (negative or positive) of 17 records to the first three principal components. All records were normalized to the same mean and standard deviation.

supported by the $\delta^{18}\text{O}$ results, which show a drop between Couplets 50 and 150. The AL/YD boundary was tentatively placed at Couplet 100 (*cf.* Fig. 1B). The resulting total number of couplets deposited during the Younger Dryas appears to be substantially higher than that reported previously (Róžański *et al.* 1991) and disagrees with estimates based on varve counts from Soppensee (*ca.* 800: Lotter *et al.* 1991), from Lake Holzmaar (*ca.* 400: Zolitschka, Haverkamp & Negendank 1991) and from the Swedish varve chronology (Bjørck *et al.* 1991).

The first possible source of such a discrepancy could lie in the fact that not all couplets in the basic chronology represent annual varves. This cannot be excluded, because the annual pattern of the YD sequence has been established only on a single thin section (2 in Fig. 1A), *ca.* 8 cm long, whereas the lamination in this sequence is irregular, and in many fragments, poorly visible. We made two counts of the varves in the YD sequence: for the unoxidized surface, and using specially prepared thin sections. We used an unoxidized surface to improve the visibility of lamination, and the thin-section method for a detailed examination of the microscopic structure of the single couplet. Only the well-developed varves were counted, *i.e.*, those comprising a clear sequence of carbonate-free mineral matter, calcite and organic layers. This counting yielded 980 varves in the segment of the YD replicated in all four cores, and 1520 varves in the whole YD sequence. The number of varves estimated from the unoxidized surface was close to that obtained on thin sections in the well-replicated segment, whereas the difference was found as high as 20% in the lowermost sequence.

Another source of discrepancy between Gościąg Lake and other varve sequences may be associated with the possibility of missing and/or doubled sediment fragments along the profile. However, the replication of four cores taken from different parts of the lake precludes such a possibility in the younger part of the YD sequence comprising 980 varves. In the lowermost part, we found no evidence for significant slumpings, thus, the occurrence of doubled varves seems rather improbable.

The AL/YD boundary in Core G1/90 is not yet precisely defined. Also, the compatibility of definitions of AL/YD and YD/PB boundaries is still an open question. However, this seems to be insufficient explanation for the discrepancies between different estimates of the duration of the Younger Dryas.

THE POSSIBLE TREND OF RADIOCARBON VARIATION

Two AMS dates ($10,080 \pm 120$ BP and $10,450 \pm 120$ BP) were obtained by E. Bard and M. Arnold on macrofossils extracted from 10-year segments of Core G1/87. The samples are separated by 750 varve years. The younger one was collected from the segment corresponding to Varve 100 above the YD/PB boundary, the older one from Varve 650 below this boundary. Conventional ^{14}C ages of these samples differ by *ca.* 400 years, corresponding to a decline of $\Delta^{14}\text{C}$ by *ca.* 45‰. The absolute age of these samples cannot be estimated with high accuracy by varve counting because of lamination disturbances between 2 and 8 m of the sediment column. We expect that accurate dating of macrofossils extracted from segments of laminated sediments corresponding to the 9th and 8th millennia BP, and matching the floating varve chronology to the radiocarbon calibration curve, will yield absolute ages of these samples.

Figure 3 shows the tentative position of both dates on BP vs. cal BP scales, compared to the results obtained on terrestrial macrofossils from Swiss lake sediments (Zbinden *et al.* 1989), and on Barbados corals (Bard *et al.* 1990, 1991). The YD/PB boundaries in varve sediments of Gościąg Lake and Soppensee have been fixed at 10,280 cal BP (Becker & Kromer 1986). The dates from Gościąg Lake seem to fit the Swiss curve and, when fixed at 10,280 cal BP, the results obtained on corals. The duration of the Younger Dryas itself can also indicate the possible trend of the

calibration curve. The AL/YD boundary is represented in Figure 3 with the radiocarbon age of 10.8–11 ka BP and calibrated age *ca.* 1.5 ka older than the age of the YD/PB boundary. This point seems to match very well the results obtained on Barbados corals and does not fit the Swiss data.

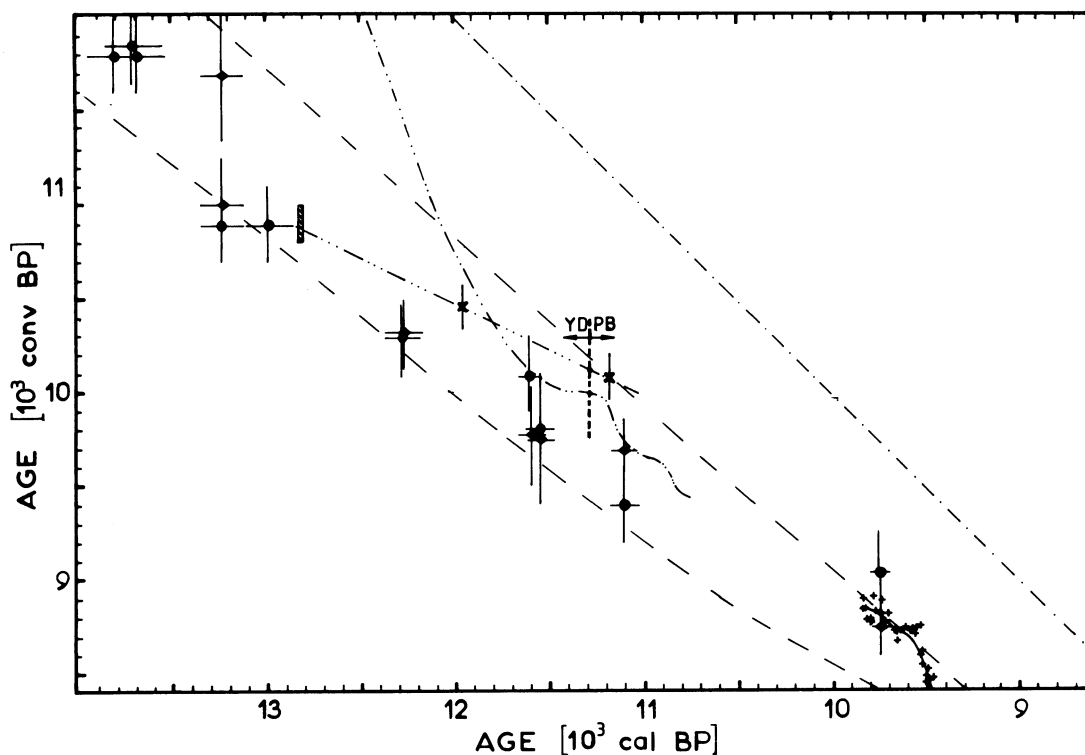


Fig. 3. Possible trends of ¹⁴C calibration in the Late Glacial. +, — = the older end of the calibration curve, based on the German oak chronology. • and ♦ = ²³⁰Th/²³⁴U (cal BP scale) vs. ¹⁴C dates of Barbados corals. ×, ■, — · — · = two AMS dates and AL/YD boundary in sediments of Gościąż Lake. — · — · = smoothed curve obtained from ¹⁴C dates of terrestrial macrofossils from Swiss lakes. The YD/PB boundaries in both Lake Gościąż and Soppensee chronologies were fixed at 11,280 cal BP. — — — = possible trends of calibration curve derived from model calculations (Stuiver *et al.* 1991), assuming the changes of geomagnetic dipole moment (from two independent reconstructions) as the only cause of ¹⁴C variations. — · — · = ¹⁴C age = true age.

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REFERENCES

- Bard, E., Hamelin, B., Arnold, M. and Buigues, D. 1991 $^{230}\text{Th}/^{234}\text{U}$ and ^{14}C ages obtained by mass spectrometry on corals from Mururoa Atoll, French Polynesia. Abstract. *Radiocarbon* 33(2): 173.
- 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(6274): 405–410.
- Becker, B. and Kromer, B. 1986 Extension of the Holocene dendrochronology by the Preboreal pine series, 8800 to 10,100 BP. In Stuiver, M. and Kra, R. S., eds., Proceedings of the 12th International ^{14}C Conference. *Radiocarbon* 28(2B): 961–967.
- Becker, B., Kromer, B. and Trimborn, P. 1991 Absolute minimum age of the Late Glacial-Holocene transition by radiocarbon calibration and stable isotope analyses of a 1477-year German pine dendrochronology. Abstract. *Radiocarbon* 33(2): 174–175.
- Björck, S., Cato, I., Brunnberg, L. and Strömberg, B. 1992 The clay-varve based Swedish time scale and its relation to the Late Weichselian radiocarbon chronology. In Bard, E. and Broecker, W. S., eds., *The Last Deglaciation: Absolute and Radiocarbon Chronologies*. NATO ASI Series I-2. Berlin/Heidelberg, Springer-Verlag: 25–44.
- Goslar, T. (ms.) Annual rhythm in the uppermost part of laminated sediments of Lake Gościąg, central Poland. In preparation.
- Goslar, T., Pazdur, M. F. and Walanus, A. 1989 Chronology of lower part of annually laminated sediments of the Gościąg Lake. *Zeszyty Naukowe Politechniki Śląskiej seria Mat-Fiz 1 57*, *Geochronometria* No. 5: 11–20.
- Lotter, A. F., Amman, B., Beer, J., Hajdas, I. and Sturm, M. 1992 A step towards an absolute timescale for the Late Glacial: Annually laminated sediments from Soppensee (Switzerland). In Bard, E. and Broecker, W. S., eds., *The Last Deglaciation: Absolute and Radiocarbon Chronologies*. NATO ASI Series I-2. Berlin/Heidelberg, Springer-Verlag: 45–68.
- Pazdur, A., Pazdur, M. F., Wicik, B. and Więckowski, K. 1987 Radiocarbon chronology of annually laminated sediments from the Gościąg Lake. *Bulletin of the Polish Academy of Sciences, Earth Sciences* 1(35): 139–145.
- Ralska-Jasiewiczowa, M., Wicik, B. and Więckowski, K. 1987 Lake Gościąg – a site of annually laminated sediments covering 12,000 years. *Bulletin of the Polish Academy of Sciences, Earth Sciences* 1(35): 127–137.
- Róžański, K., Goslar, T., Duliński, M., Kuc, T., Pazdur, M. F. and Walanus, A. 1992 The Late Glacial-Holocene transition in laminated sediments of the Lake Gościąg (central Poland). In Bard, E. and Broecker, W. S., eds., *The Last Deglaciation: Absolute and Radiocarbon Chronologies*. NATO ASI Series I-2. Berlin/Heidelberg, Springer-Verlag: 25–44.
- Stuiver, M., Braziunas, T. F., Becker, B. and Kromer, B. 1991 Climatic, solar, oceanic, and geomagnetic influences on Late-Glacial and Holocene atmospheric $^{14}\text{C}/^{12}\text{C}$ change. *Quaternary Research* 35: 1–24.
- Zbinden, H., Andrée, M., Oeschger, H., Amman, B., Lotter, A., Bonani, G. and Wölfli, W. 1989 Atmospheric radiocarbon at the end of the Last Glacial: An estimate based on AMS radiocarbon dates on terrestrial macrofossils from lake sediments. In Long, A. and Kra, R. S., eds., Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 795–804.
- Zolitschka, B., Haverkamp, B. and Negendank, J. F. W. 1992 Younger Dryas oscillation – varve dated palynological, paleomagnetic and microstratigraphic records from Lake Holzmaar, Germany. In Bard, E. and Broecker, W. S., eds., *The Last Deglaciation: Absolute and Radiocarbon Chronologies*. NATO ASI Series I-2. Berlin/Heidelberg, Springer-Verlag: