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

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ABSTRACT. Laminated sediments of Gościąż 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 Gościąż Lake corresponds well to the duration derived from ^{230}Th/^{234}U and ^{14}C 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 Δ^{14}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 ^{14}C activity measured in a macrofossil from a varve reflects the atmospheric ^{14}C 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 GOŚCIĄŻ

The laminated sediments of Lake Gościąż, 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-

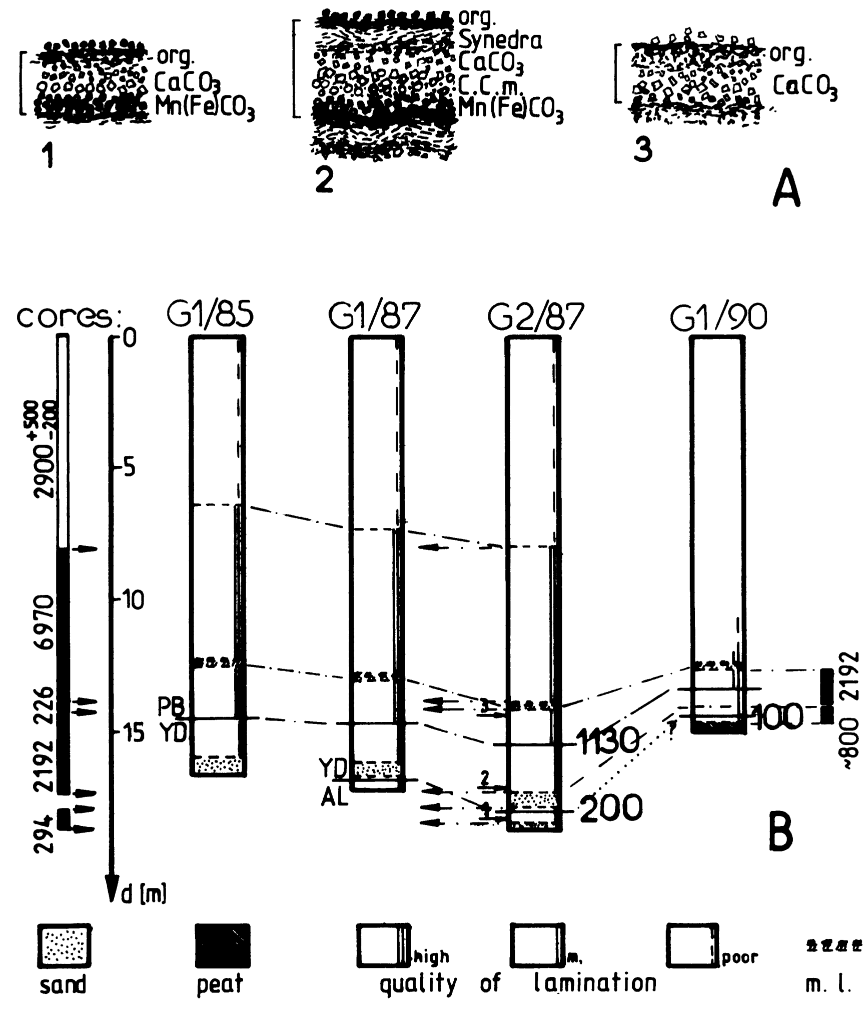

Fig. 1. A. The varve structure in three levels (1, 2 and 3) of Core G2/87; → in B. C.C.m. = *Centricae* diatoms + Chrysophycean cysts + carbonate-free mineral matter; org. = organic detritus. B. The present chronology of laminated sediments of Gościąż Lake. Left side – basic floating varve chronology, with three gaps in levels shown by arrows on Core G2/87. The numbers of couplets in four segments of the basic chronology and the approximate number 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 Gościąż 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 $\delta^{18}O$, by *ca.* 2‰ in *ca.* 100 yr. These changes are associated with an increase in $\delta^{13}C$ 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 $\delta^{18}O$ shows a sharp increase, by *ca.* 1.5‰ in 50 yr, nearly simultaneous with the transition indicated by the pollen spectra. Another increase of $\delta^{18}O$, by *ca.* 0.5‰, occurred *ca.* 300 yr earlier. Shortly after the main change of $\delta^{18}O$, 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. Różański *et al* (1991) discussed the $\delta^{18}O$ 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 $\delta^{18}O$ 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 (Różański *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,

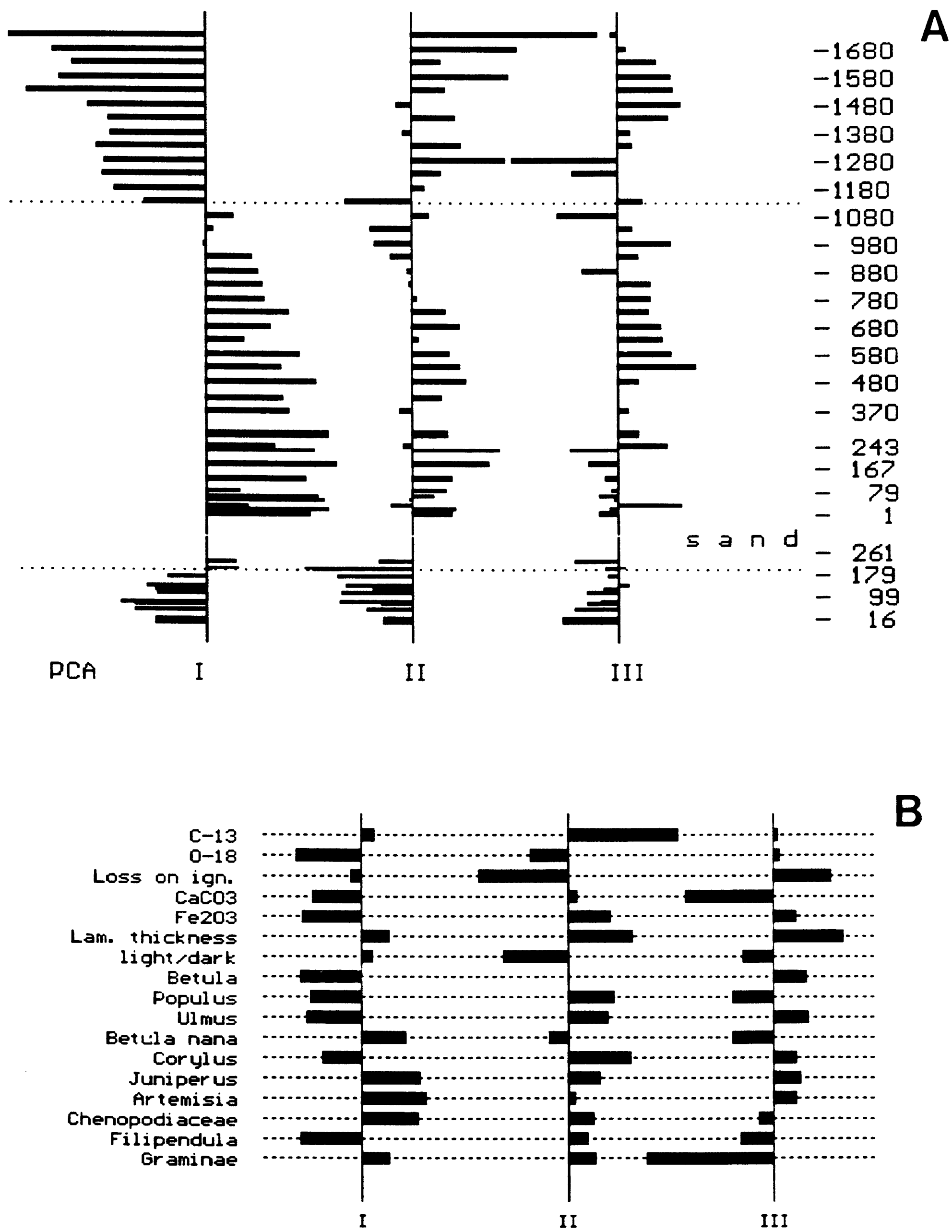

Fig. 2. A. The principal components (PCA I, II and III) of 17 records: pollen, isotope, chemical and varve thickness from the lowermost part of the long cores from Gościąż Lake. Right side – couplet number according to the basic chronology (*cf.* Fig. 1B). The AL/YD and YD/PB boundaries are denoted. 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 $\delta^{18}O$ 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 (Różański *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 Gościąż 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 ± 120 BP and 10,450 ± 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 $\Delta^{14}C$ 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 Gościąż Lake and Soppensee have been fixed at 10,280 cal BP (Becker & Kromer 1986). The dates from Gościąż 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.

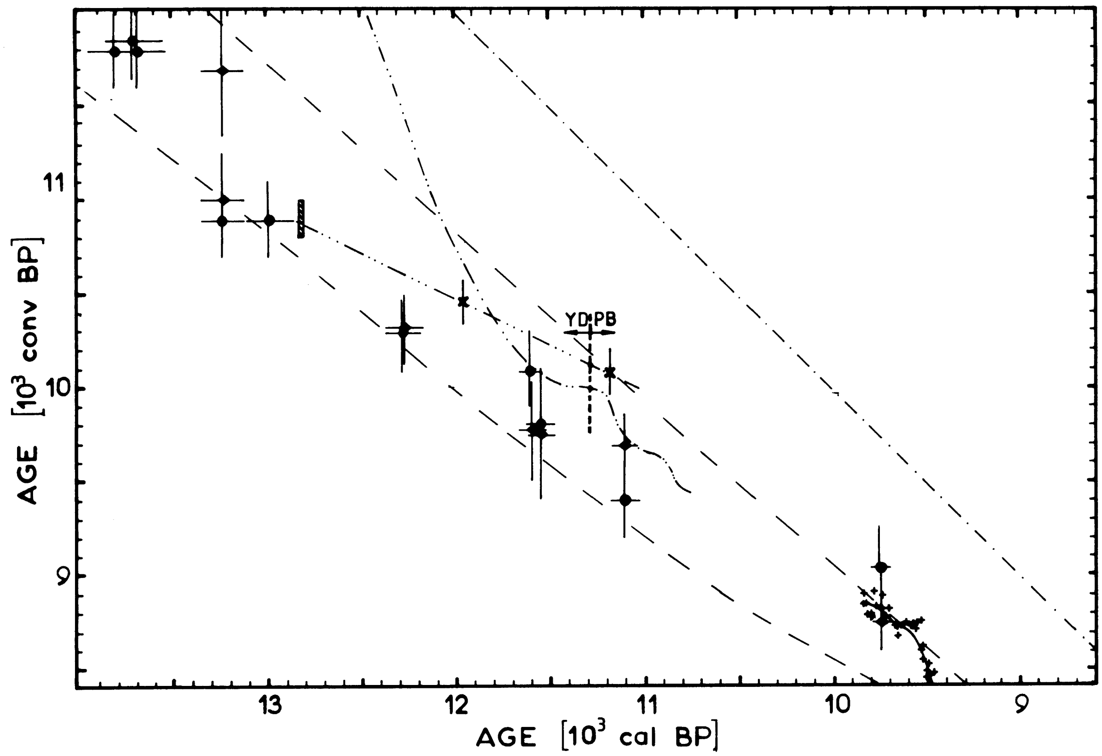

Fig. 3. Possible trends of ^{14}C calibration in the Late Glacial. +, — = the older end of the calibration curve, based on the German oak chronology. • and ♦ = $^{230}Th/^{234}U$ (cal BP scale) *vs.* ^{14}C dates of Barbados corals. ×, ▌, —··— = two AMS dates and AL/YD boundary in sediments of Gościąż Lake. —··— = smoothed curve obtained from ^{14}C 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 ^{14}C variations. — · — = ^{14}C age = true age.

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