were ascribed to the increased human activity during the time of Roman influences (Ralska-Jasiewiczowa & van Geel, Chapter 9.1.3). They occur in the upper part of sediment, and by varve counting its most probable age was determined to be ca. AD 600. The abrupt termination of this phase of human occupation could be related to the beginning of the Migration Period, commonly dated to ca. AD 375 (Godłowski & Kozłowski 1979), appeared then much older. Due to the dendro-dating of FVC, the chronology of the upper part of sediment has been revised (see Goslar, Chapter 8.1). Accordingly corrected estimate for the age of the above mentioned event – AD 350±70 – corresponds well to archaeological dating (Fig. 6.12).

2. The so-called "*Ulmus* fall", the abrupt distinct decline of *Ulmus* pollen, is well recognized in the Holocene pollen diagrams from Europe (see Troels-Smith 1960; Hirons & Edwards 1986). This phenomenon, dated by radiocarbon in many sites, appears to be rather synchronous, with the majority of dates falling around 5000–5100 ^{14}C BP (Latałowa 1992), which corresponds to a calendar age of 3760–3960 BC. The "*Ulmus* fall" record in the Lake Gościąż sediment was described and interpreted by Ralska-Jasiewiczowa and van Geel 1992 (also Goslar, Chapter 8.1), and according to the dendro-match of FVC it is dated to 3940 BC, in agreement with dating from other sites.

In order to ensure the dendro-match, the sequence of varve thicknesses was compared with 15 local chronologies available in tree-ring laboratories of B. Schmidt and H. H. Leuschner (pers. comm.). The chronologies of Schmidt were: Bronzezeit MWK7, Bronzezeit MWK10, and Neolithic Schleswig-Hollstein containing oaks from the archaeological excavations and bogs in northern Germany, close to the coast of the Baltic Sea; the 12 chronologies of Leuschner contained oaks from the German coast of North Sea, growing on the marine or fluvial deposits at the mouths of Elbe, Weser, and Ems rivers. The comparison with 15 chronologies has not confirmed the correlation described earlier. Though it is possible that the correlation with local chronologies is not viable and appears only after combining them, the described match with dendroscales is not high enough to date the FVC with absolute certainty. The date 3211 cal BP should be rather interpreted as the most probable from the range 3140±120 cal BP given by radiocarbon dating. It has to be mentioned, however, that the dendro-match leads to the date of the Younger Dryas/Preboreal boundary of 11,510±50 cal BP, which agrees very well with the ages obtained in the studies of ice cores GRIP – 11,550±50 cal BP (Johnsen et al. 1992) and GISP2 – 11,640±250 cal BP (Taylor et al. 1993) from Greenland summit. The problems of dating the YD/PB transition are discussed in separate chapter (Goslar et al., Chapter 7.7).

6.5. STATISTICAL ANALYSIS OF THE SEQUENCE OF LAMINAE THICKNESS

Adam Walanus

Laminae thickness

Continuously laminated sediment of Lake Gościąż comprises almost 13,000 varves (Goslar, Chapter 6.1). The thickness of ca. 3000 uppermost varves were not measured because of poor quality of the lamination. For almost 10,000 varves from the lower part of the sediment, the thickness of light (summer) and dark (winter) laminae were measured using the dendrochronological measurement device (Goslar 1987) on photographic negatives twice reduced in size. Such a procedure allowed much easier handling than if containers with the sediment are used, especially if two cores are to be compared. Besides, the sediments are then saved from the heating and drying. Precision of measurement is high enough for laminae 1 mm thick. Some attempt was also made to measure laminae thickness by computer image analysis (Walanus & Goslar 1993).

In the youngest 100 varves, taken by the freezing method (Walanus, Chapter 4.1.2) the layers corresponding to the individual seasons were measured. However, they are much thicker than deeper varves, and not comparable to them because they are not compacted.

Instead of the separate thickness of light and dark laminae, the total (= light+dark) varve thickness is mainly used in the analysis. The information given by two measurements performed on one varve couplet is carried by the ratio of light/total thickness, which seems to have some climatic interpretation (Goslar, Chapter 6.3). The average varve thickness is 1.02 mm, and standard deviation is rather low. As may be seen in Fig. 6.13, only a few varves are thinner than 0.5 mm, and not many are thicker than 1.5 mm. The histogram is asymmetric, as is obvious for the non-negative quantity, which has no upper limit. Logarythmic transformation makes the varve-thickness distribution symmetrical to the Gaussian

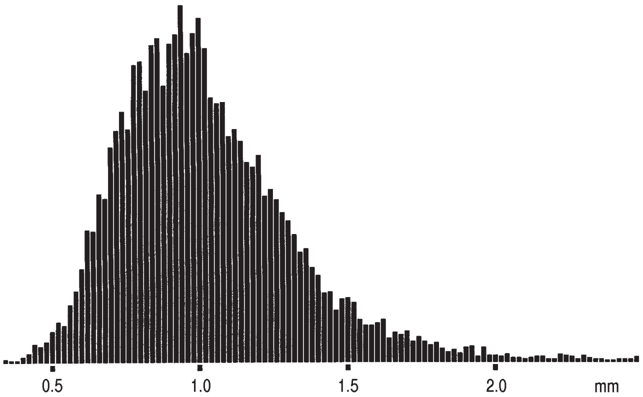

Fig. 6.13. Histogram of varve thickness. Almost 10,000 varves from 12,500 to 3200 cal BP are included.

shape. As usual in the case of histograms built of very large data sets (here 10,000), some differences between adjacent bars are statistically significant. They exist independently of the density of the divisions of the horizontal axis. The only reasonable interpretation is connected with the measuring device, not with the sedimentation processes.

The histogram of thickness ratio (Fig. 6.14) is Gaussian, but not in the sense of statistical agreement, because of the minute scale variations. The light laminae are thinner, in average making 40% of the total varve. The ratio, similarly to varve thickness, has low standard deviation.

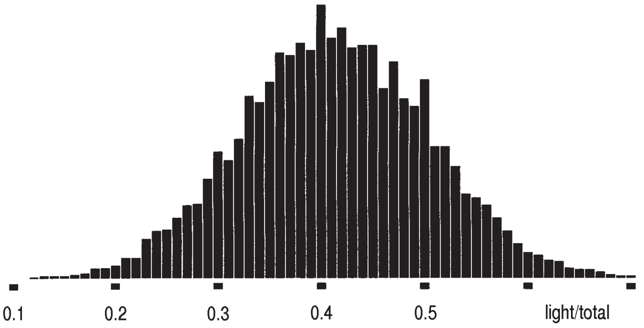

Fig. 6.14. Histogram of the ratio of light laminae thickness to the total varve thickness.

Mechanisms of production of the light and dark laminae are complex. In different climates, factors in the sedimentation process may change their relative intensity. Some factors influence both dark and light laminae, some may influence only the boundary between them, not the total thickness. Inferences about such processes may be drawn from the correlations calculated from the measurements. In Fig. 6.15 the correlation between the light and dark laminae thickness is given. The correlation coefficient is calculated within consecutive intervals 300 yr-long. The most striking is the continuously high correlation in the period 5–3.2 ka BP. Variations of the sedimentation rate (see also Goslar, Chapter 6.3) from year to year are parallel for both seasons. In "good years" thick light and thick dark laminae were produced. Similar, but less distinct, is the situation at the beginning of Younger Dryas. Rather high variation of the correlation coefficient in the middle of the plot may be connected with lamination quality and measurement errors. In the measurements of laminae thickness, an erroneous decision about laminae boundary, for example, makes one lamina thicker and the neighbouring one thinner, which results in a negative or less positive correlation.

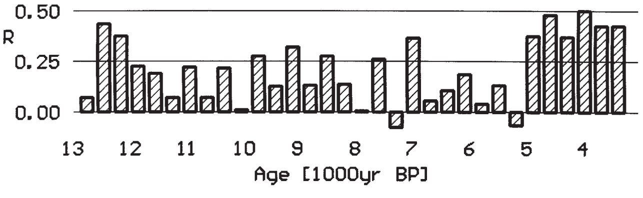

Fig. 6.15. Correlation coefficient between the light and dark laminae thickness calculated in 300 yr intervals. Statistically significant ($\alpha = 0.05$) for one interval is R>0.11.

Question of periodical changes of laminae thickness

The question of existence of periodical component in all the variance of the time series should not be addressed without indication of its possible causes. In large data sets some periodicities may be found in some fragments irrespective of how noisy the data are. It is in the definition of noise that some periods (frequencies) are represented by higher amplitudes than others. In a time series some values are higher or much higher than average. One may attach an interpretation to such peaks. But they also may be treated as "tails" of the normal (Gaussian) distribution, simply as a noise. It is a matter of one's opinion, not of the statistical significance level. Similar situation is in the frequency domain, which is numerically symmetrical to the time domain. But the time domain is much closer to intuition. Statistical assessment of the sig-

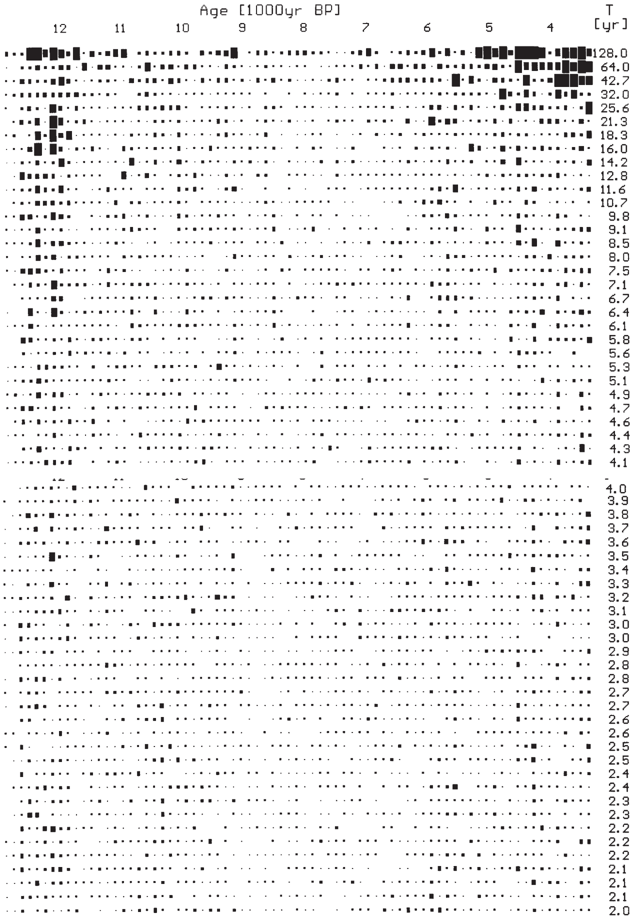

Fig. 6.16. Periodicities in the sequence of varve thickness. The periodical component power is indicated by the area of the black points. The FFT analysis is applied to 128-yr-long non-overlapping subsequences.

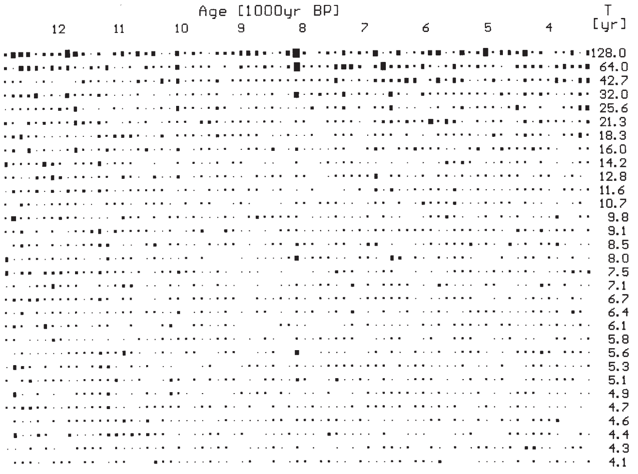

Fig. 6.17. Periodicities in the series of the ratio light/total varve thickness. All the powers for periods shorter than 4.1 yr are small and thus not displayed.

nificance of periodicity when data are generally noisy is not a matter of objective calculation.

A good way to increase significance of the statistical result is to find similar pattern or similar period in independent data sets. Significance levels are multiplied in such a case. For example from $\alpha_1 = 0.05$ and $\alpha_2 = 0.1$ the much lower value (i.e. more significant) $\alpha = \alpha_1 * \alpha_2 = 0.005$ is obtained. That is the reason why the results of searching for a periodical component in laminae thickness are published here, although in the author's opinion the data have (almost) no periodicities. The reason is to enable users of other Holocene or Late-Glacial data to see if some parallelism in periodical components exists. If so, the phase of the wave may be compared. In the most optimistic case the phase synchronization would improve the relative chronology of the two time series. The phases are not given in the figures to save space.

Precision of laminae counting is of order of 1% (Goslar, Chapter 6.3). The resulting precision of the time scale makes searching for the medium size periods (T<200 yr) unreasonable for the whole 10,000 yr series. Searching for the short periods (T>2 yr) in the series longer than about 100 yr is also unreasonable. With such limitations, analyses were made in two stages: the short periods were searched for in 75 non-overlapping sub-sequences 128 yr long, and the long periods were searched for in 7 non-overlapping sub-sequences of 1280 yr. The length of the sub-sequence is chosen for technical reason (128 is a power of 2). Long-period analyses were performed on the 10 yr averages to shorten the length of the time series (there is no loss of information since only long periods are taken into account). The standard Fast Fourier Transformation (FFT) method is applied here.

Matrices obtained are given in Figs 6.16–6.18. Amplitude of the given period is indicated by the size of black rectangles. The sub-sequences analysed do not overlap, so a simple assessment of the significance of periodical component amplitude can be based on the statistical independence of data sets. If in one's opinion some point is large enough to be significant, the horizontally neighbouring points should be checked. If they are also reasonably bigger than average, it already may indicate that some oscillating factor influenced the sedimentation at those times. It is essential for the statistical reasoning that neighbouring points are independent. Similar figure, obtained by smoothing, i.e. with overlapping sub-sequences and with "data" points neglected and replaced by isolines (Anderson 1993), may provoke overinterpretation. It is impossible to delimit noise and expected signal unequivocally. The question of statistical significance remains up to the reader's interpretation, when additional knowledge is involved. In the author's opinion, one can never be too sceptical in accepting some structure in the data as meaningful.

The long periods are presented in Fig. 6.18. The youngest and the oldest sub-sequences of varve thickness (left matrix) are more varied than medium ones, especially in low frequencies. That is the possible explanation for continuously high amplitudes in the upper part.

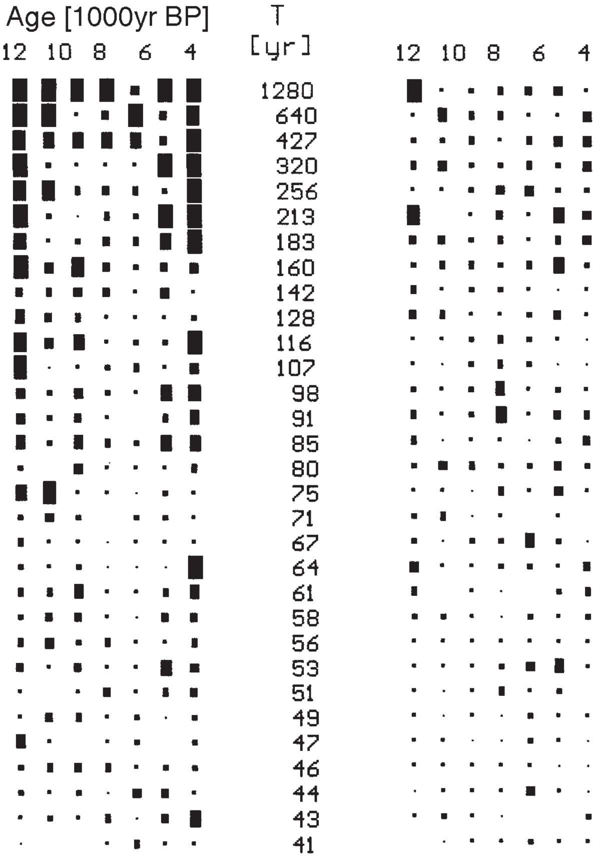

Fig. 6.18. Long period cyclicities in the varve thickness (left) and light/total laminae thickness ratio (right). The periodical component amplitude is indicated by the area of the black points. The FFT analysis has been applied to 1280-yr-long nonoverlapping sub-sequences composed of 10 yr averages of yearly values.

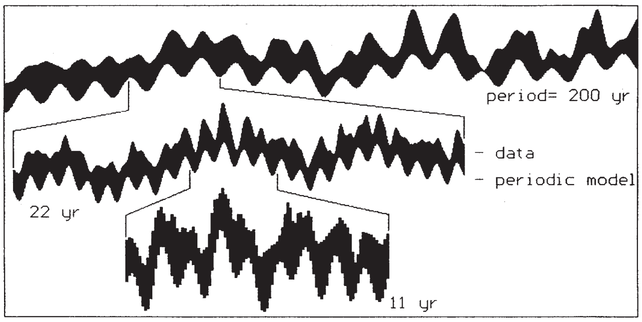

Fig. 6.19. Smoothed series of varve thickness (upper edge of the band) in comparison with the strictly periodic signal (lower edge). The time span of given sequences is respectively: 6727–3212, 6127–5587, and 5937–5832 yr cal BP.

Another presentation of periodicities is shown in Fig. 6.19. Many periods are indicated in literature as observed in nature. 200-yr period is present in $\Delta^{14}C$ signal (Sonett & Finney 1990), and periods of 11 yr and 22 yr are imprints of solar activity onto the atmosphere and, as some authors believe (Mitchell 1979, Schove 1983), on the biosphere. Fig. 6.19 enables easy visual inspection whether the data are periodic or not. Strict periodicity is suggested below the smoothed data sequences for comparison. The magnetic solar activity (22 yr) is precisely correlated with the sunspots (11 yr). May be this fact is visible on the last plot, where 11 yr periodicity seems to be superimposed on the 22 yr period.

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