Ralska-Jasiewiczowa M., Goslar T., Madeyska T. & Starkel L. (eds), 1998. Lake Gościąż, central Poland. A monographic study. Part 1. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

8. LAKE GOŚCIĄŻ: PALAEOGEOGRAPHY OF THE HOLOCENE

8.1. HOLOCENE SEDIMENTS OF LAKE GOŚCIĄŻ – CHRONOLOGICAL BACKGROUND

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The laminated structure of Lake Gościąż sediments enabled construction of a calendar varve chronology over the whole profile, covering a part of Late-Glacial and the whole Holocene. However, as pointed out earlier (Goslar, Chapter 6.1), the poor quality of laminations in the upper part of the sediment (above 7.34 m) caused serious problems in continuous varve counting, and for that reason the chronology of the lower part of sediment was defined as floating. The absolute calendar age of that chronology, containing 1362±40 varves in the Late-Glacial section and 8300±50 varves in the Holocene section, was estimated only approximately by varve counting in the upper part. It was next determined more exactly (Tab. 8.1) by a series of radiocarbon datings on terrestrial macrofossils (Goslar, Chapter 6.2), and by the correlation of laminae thickness and tree-ring chronologies (Goslar, Chapter 6.3).

It must be stressed that the samples dated by radiocarbon covered almost the whole Holocene section of the floating chronology. For that reason the errors of absolute dates are the same at both ends of the section. The correlation with tree-rings, on the other hand, concerned the sequence in the younger part of the section. Therefore the age of the younger end of floating varve chronology (FVC) is quoted with no error, while the error at YD/PB boundary results from the uncertainty of varve counting over the whole section. The correlation with tree-rings is not clear enough to date the chronology with full confidence. It should rather be interpreted as pointing to the most probable date from the range given by radiocarbon dating. Nevertheless, the time scale chosen for presentation of all data in the following chapter is based on the match to tree-rings.

The visual characteristics of varves change along the whole profile. The boundaries between sections of different lamination coincide generally with the boundaries of Holocene chronozones (Mangerud et al. 1974).

Preboreal and Boreal chronozones (ca. 11,500 – 9000 cal BP)

The boundary between Younger Dryas and Preboreal is distinctly marked in the sediment lithology (Fig. 8.1). At the boundary, the contrast between summer and winter layers changes abruptly. In late Younger Dryas all winter

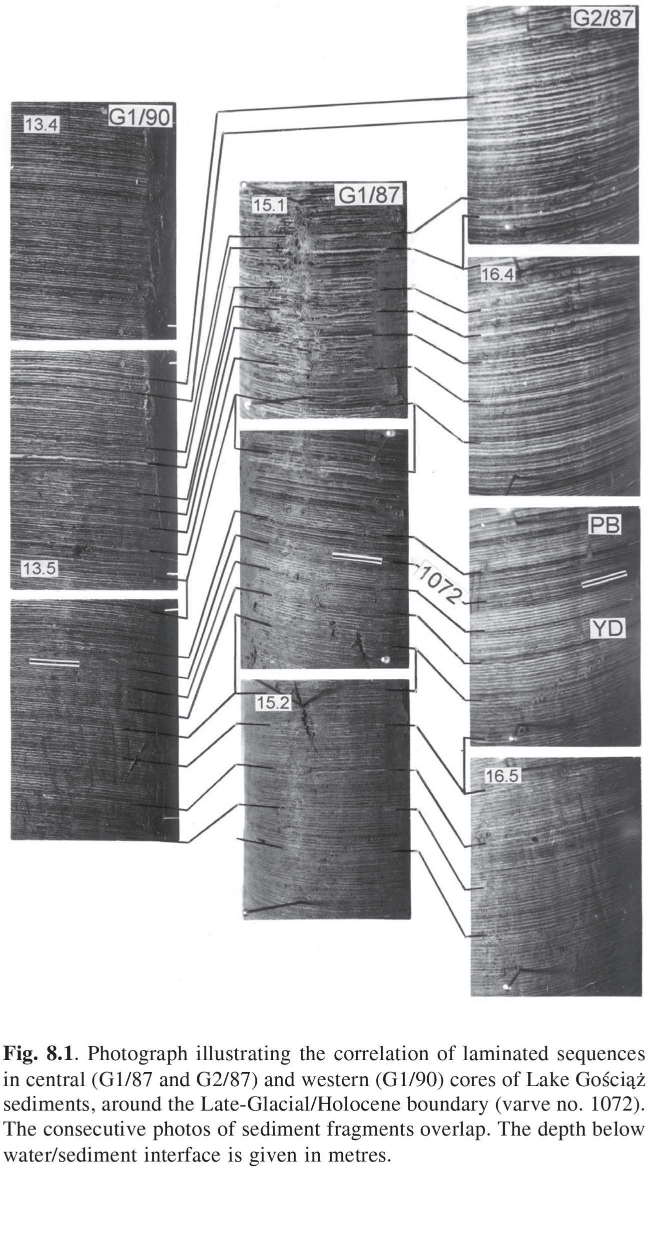

Fig. 8.1. Photograph illustrating the correlation of laminated sequences in central (G1/87 and G2/87) and western (G1/90) cores of Lake Gościąż sediments, around the Late-Glacial/Holocene boundary (varve no. 1072). The consecutive photos of sediment fragments overlap. The depth below water/sediment interface is given in metres.

* The author wishes to thank Dr. J. Merkt (NLfB, Hannover, Germany) for training in varve identification.

Table 8.1. Estimates of calendar age of Holocene section of Lake Gościąż floating varve chronology (FVC).

Information used	Age of younger end of FVC cal BP	Age of YD/PB boundary cal BP
Varve counting above 7.34 m	2900^{+500}_{-200}	$11{,}200^{+500}_{-200}$
AMS radiocarbon dates	3140±120	11,440±120
Correlation with tree-rings	3211	11,511±50

layers are of similar dark yellow colour. In Preboreal the colour of winter layers is more diverse from yellow to dark brown, and the proportion of yellow to dark brown layers occurring in the sediment decreases in time. Unfortunately the chemical composition of sediment at the YD/PB transition was analysed with the resolution of 50 yr, so the direct relationship between short-term changes of colour and composition has not been recognized. The observed change might reflect a drop in the content of mineral matter in sediment and/or an increase of iron. The much lower content of non-carbonate minerals in the Holocene section of sediment is clearly visible on thin sections, and the decrease of accumulation of detrital matter is also confirmed by the content of aluminium (Łącka et al., Chapter 8.2), which at the transition dropped below detection limit. The doubling of iron content within 50 yr at the YD/PB transition was shown by Wicik (1993). This might reflect easier iron outwashing (Engstrom & Wright 1984) from the soils depleted in oxygen due to development of coniferous forests (Mackereth 1966). The year-by-year changes of iron content, however, are difficult to explain by such a mechanism, since the forest evolution had to take a longer time. An alternative explanation of iron content variations is by the changes of its solubility in lacustrine hypolimnion and the sediment itself. Under the extreme deficit of oxygen ferrous sulphide may be formed, which is not dissolved in the sediment (Wetzel 1975). Therefore, the year-by-year rise of the contrast between light and dark layers could be caused by the blooms of plankton productivity, possibly by the well recorded blooms of green algae e.g. *Tetraedron minimum* (Ralska-Jasiewiczowa et al., Chapter 7.4, Goslar et al. 1993). It is worth mentioning that in some lakes a seasonal alternation between ferrous sulphides and ferrous hydroxides in lacustrine deposits, controlled by the seasonal aeration of bottom waters, is a mechanism causing annual lamination of sediments (Dickman 1979, Renberg 1986).

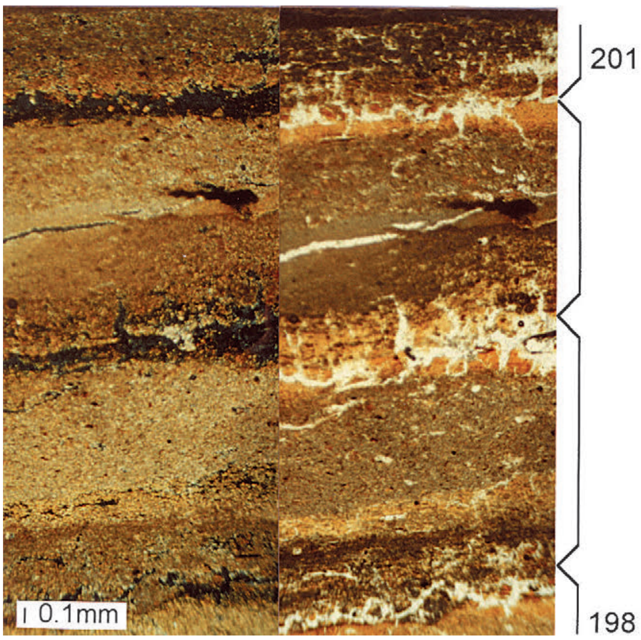

Fig. 8.2. Microphotograph showing the basic structure of lamination typical for the Preboreal and Boreal section of laminated sediment of Lake Gościąż (core G2/87). Left: in polarized light, right: in non-polarized light. 201 and 198 – varve number.

The varve structure in the Preboreal and Boreal sections of sediment (Fig. 8.2) consists of light (white, light yellow) layer rich in calcium carbonate with significant admixture of Mn and Fe carbonates in the oldest part of section and the darker (dark yellow, dark brown) one, with smaller carbonate crystals and higher content of organic matter and of Mn and Fe hydroxides (Łącka et al., Chapter 8.2). The abundance of diatoms is low. Sometimes pale layers rich in silica, as shown by the SEM-EDS analysis (M. Saarnisto, pers. comm.), occur close to the calcite laminae.

The distinct variations in the contrast of light and dark layers enabled easy correlation of individual varves in different cores. The correlation of laminated sections is shown in Fig. 8.3. The YD/PB transition was set at the varve 1072. A massive layer of silt occurs in all cores 1061 varves above this transition. Its thickness is different in different cores (3–8 mm). The composition of the massive layer (Fig. 8.4) does not differ from that of underlying varves containing fine-grained carbonate and decomposed organic matter. The abundance of quartz or any other detrital grains is as low as in underlying varves, the littoral diatoms suggesting redeposition have not been found, and there is no grain-size sorting of carbonates; all these evidences suggest that the massive layer was formed by water currents not strong enough to transport the material from the shore or littoral zone. Surprisingly, synchronous massive layers occur in both lake deeps, situated ca. 300 m apart and separated by an area of relatively shallow water. The disturbance thus covered a relatively large area but obviously did not bring allochthonous material.

Due to the varve correlation it was possible to determine the scale of erosion of underlying sediment by the formation of the massive layer. As shown in Fig. 8.5, the laminated sequence above the massive layer starts with the same calcite layer in all analysed cores, showing that

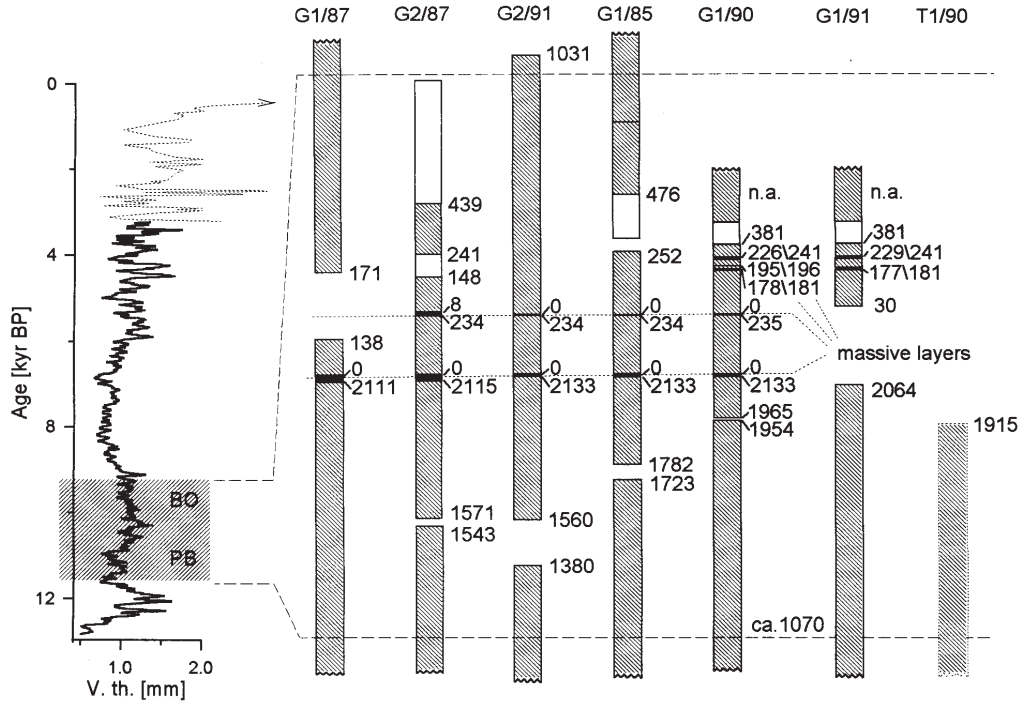

Fig. 8.3. Correlation of laminated sequences of individual cores in the Preboreal and Boreal sections of Lake Gościąż sediments. The cores were collected in 2 m or 1 m segments. Hatched sections – continuous lamination, white – disturbed lamination (not analysed), black – massive layers. Thin lines across the bars show core breaks. The varve numbers of ends of laminated sections are given to the right of cores. The varves were numbered separately in the sequence below, between and above massive layers. n.a.: not analysed. Left-hand side: record of laminae thickness to show the position of considered part in the whole profile.

it was formed by the same event, probably in spring. The underlying varves, on the other hand, are obviously

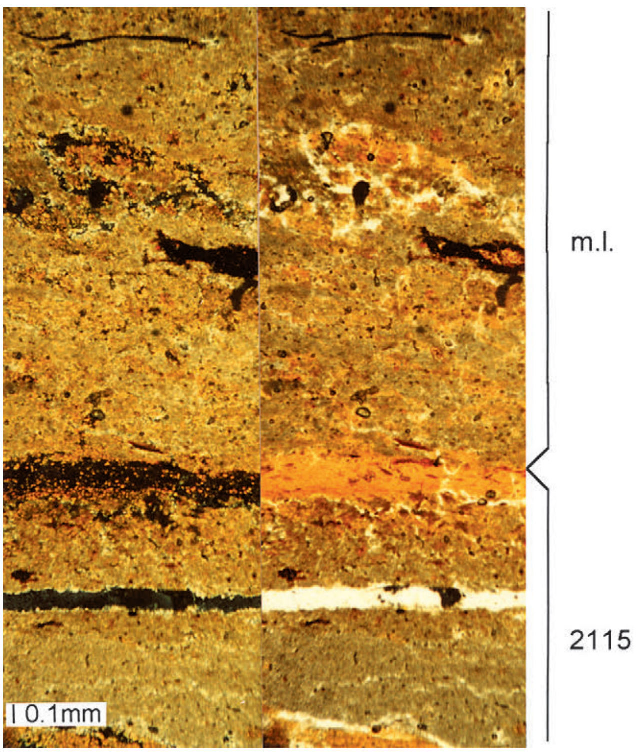

Fig. 8.4. Microphotograph showing the structure of lower part of massive layer (m.l.) in core G2/87. Left: in polarized light, right: in non-polarized light. 2115 – varve number.

eroded. The correlation shows that in core G2/87 18 varves more than in G1/90 were lost. In core G1/87 more varves than in G2/87 were preserved, but their structure was slightly disturbed. The erosion is also visible in other cores, though the lamination reaches there to the same varve as in core G1/90 (Fig. 8.3). A similar situation concerns the next massive layer, occurring 235 varves above.

Because the massive layers occurred in all cores, the absolute numbers of eroded varves could not be determined. One could only expect that the absolute numbers should not be much higher than the differences between them. Luckily, the number of eroded varves could be determined directly for the massive layers placed higher up in the cores from the western deep, in the section where the lamination in central deep was continuous (Fig. 8.3). It is clear that in the core G1/90 the layers 4, 2, and 6 mm thick, caused the erosion of 2, 0, and 14 varves, respectively. The similar numbers of varves were eroded in core G1/91. One can therefore assume that by the formation of two massive layers breaking varve chronology, only a few varves were lost from the continuous sequence.

In the cores from the western deep and northern bay, the continuous lamination ends definitively in the PB/BO section. The serious disturbances above varve 1915 in the core from northern bay (T1/90) break continuous lamination into fragments too short to be correlative with that from other cores. The continuous lamination in the cores

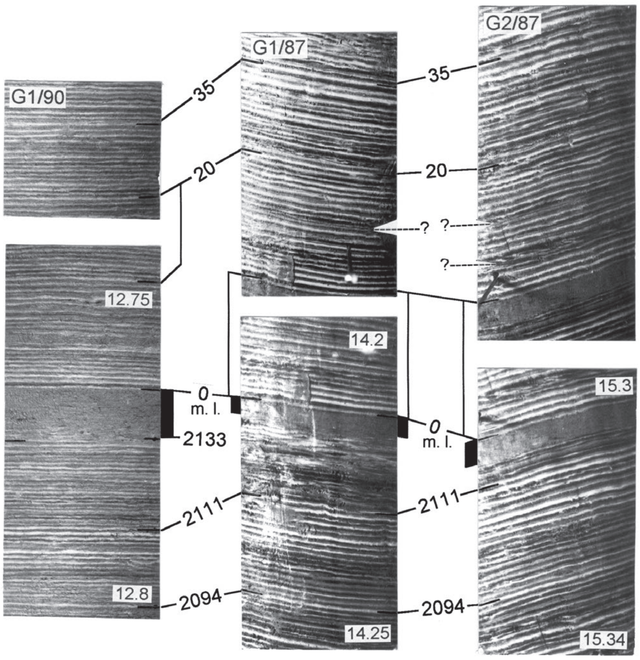

Fig. 8.5. Photograph showing the correlation of laminated sequences in cores G1/90, G1/87 and G2/87 around lower massive layer (m.l.). The numbers of marked varves are given between cores, the doubtful varves are indicated by question mark. The depth below water/sediment interface is given in metres. The unclear separation of varves no. 5 and 6 in core G2/87 (indicated by question mark), was overcome due to their good preservation in other cores. The complex no. 11, where the two carbonate-rich laminae are separated by the very thin dark layer, was counted as a single varve, but because of unclear interpretation in all cores, it was included in the overall error of chronology.

from the western deep disappears ca. 840 years later. The gradual deterioration of lamination seems to be partly connected with the shallowing of the lake, due either to the increasing oxygenation of bottom waters and subsequent growth of benthic fauna or to the enhanced penetration of the hypolimnion by wind-driven water currents. The second mechanism seems to explain the fact that the youngest three massive layers occurred in the western deep but not in the central deep. The continuous lamination in the central deep reaches much higher, i.e. to 3211 cal BP. It is interesting to compare the absolute water depths by which the continuous lamination disappeared in three parts of the lake. They may be calculated under the assumption of small changes of water level through the Holocene (Pazdur et al. 1994, Starkel et al., Chapter 8.5), by adding the present depth of water to the depth within the sediment itself. The depths of disappearance of continuous lamination calculated in such a way are ca. 29 m, ca. 24 m, and ca. 14 m, in the central deep, western deep, and northern bay, respectively. One must remember that the real absolute depths are smaller, since the calculation does not take into account the effect of sediment compaction. Nevertheless, they reasonably reflect the relationship among depths at several localities. The fact that the lamination in northern bay could be preserved in distinctly shallower water than in central and western deeps may be partly explained by the lake morphometry. Both deeps are situated on the lake axis (of 1 km length), along the direction of prevailing winds, while the northern bay is much more effectively sheltered from wind stress. Also the susceptibility of both deeps on the wind-driven water movements may be different, since the western deep is situated 200 m and the central one ca. 500 m from the forested lake shore, which is the natural shield against the wind.

As illustrated in Fig. 8.5, due to the correlation between cores, the unclear varves in a single core were elucidated. The unclear varves occurring in all analysed cores were included in the overall error of the chronology.

Atlantic chronozone (ca. 9000 – 6000 cal BP)

The varves in this section are thinnest, the light-dark contrast is weaker than in PB and BO parts and does not change over the whole section. The lower contrast could be connected with the decline of iron content. The high content of gypsum in the light layer (Łącka et al., Chapter 8.2) is probably responsible for the high ratio of light to (light+dark) laminae thickness in this section (Goslar, Chapter 6.3).

In this section the correlation of laminae in different cores is most difficult. First, the application of a characteristic pattern of colours of consecutive dark layers, making the correlation in the former section quite easy, is impossible here. Second, the pattern of thickness of consecutive laminae is difficult to use, since both the light

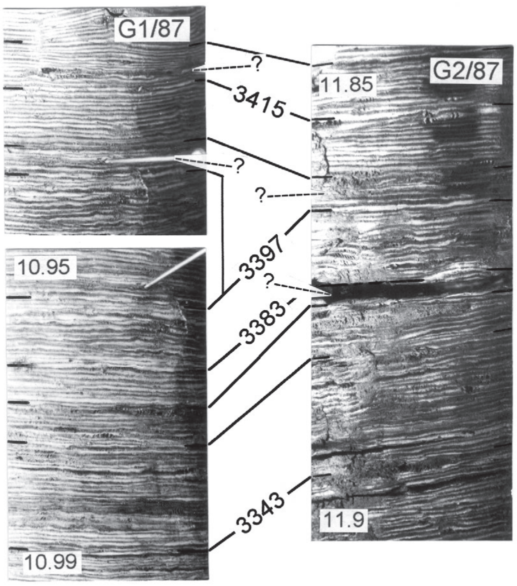

Fig. 8.6. Photograph showing the correlation of laminated sequences in cores G1/87 and G2/87 in the Atlantic section of Lake Gościąż sediments. The numbers of marked varves are given between cores, the doubtful varves are indicated by question mark. The depth below water/sediment interface is given in metres. The break of core G2/87 below varve 3383, and a disturbance between varves 3417/3418 in core G1/87 were overcome on the second core. The disturbance and unclear separation of two calcite laminae around varves 3399 and 3400 in both (and other) cores was included in the uncertainty of varve chronology.

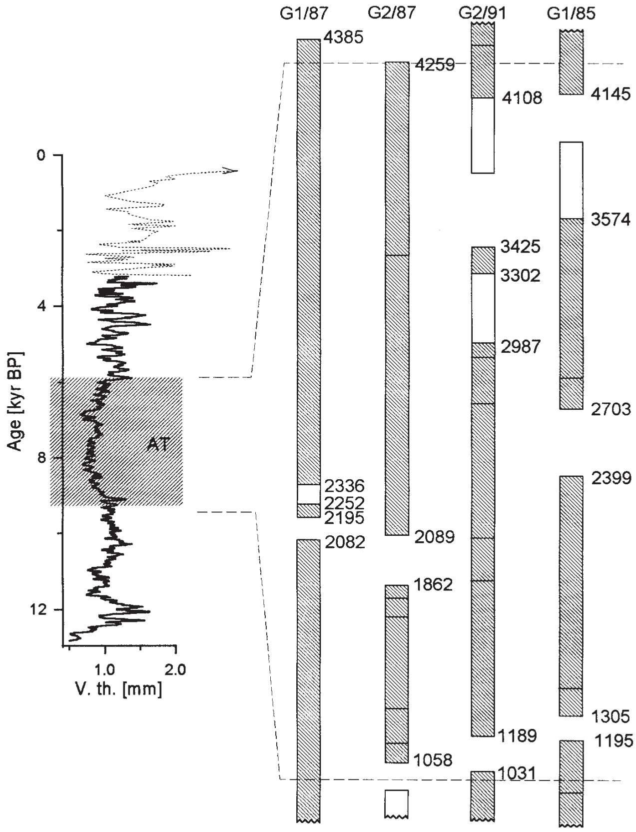

Fig. 8.7. Correlation of laminated sequences of individual cores in the Atlantic section of Lake Gościąż sediments. For further explanations see Fig. 8.3.

and dark layers are slightly wavy, and the thickness is not strictly determined. Therefore, to prove the correlation at any point it was necessary to compare sequences of a few tens of varves, counted with an absolute certainty. It was generally possible, since luckily the doubtful varves did not occur too frequently. The example of correlation and connected problems is shown in Fig. 8.6.

The continuous varve chronology in the Atlantic section is built using four cores from the central deep only, and it is replicated in at least two cores (Fig. 8.7). In individual cores, fragments of disturbed lamination occur mostly near the ends of 2 m segments and, in all probability, they were produced during field work. The critical point of chronology was the gap between varves no. 2082 and 2089 in G1/87 and G2/87, attributed to 7 varves due to a correlation with continuous sequences of G1/85, and confirmed by the core G2/91. It is worth mentioning that the obvious strategy in pulling out the basic twin cores G1/87 and G2/87 was to obtain long overlaps between 2 m segments of cores. This was controlled by depth within the sediment. However, because of different sedimentation rate the gaps between lower segments of both profiles appeared at nearly the same varves. Such an effect would be much more difficult to discover in non-laminated sediment.

Floating varve chronology in Subboreal chronozone (ca. 6000–3211 cal BP)

At the boundary between Atlantic and Subboreal chronozones, a distinct change of varve thickness occurred (Fig. 8.8). It was connected with the increase of thickness of dark layers (almost doubled within 100 yr), caused by the increased content of non-carbonate mineral fraction, reflecting the higher accumulation of allochthonous matter (Goslar, Chapter 6.3). The rise of varve thickness is synchronous with the fall of *Ulmus* pollen (Ralska-Jasiewiczowa & van Geel 1992, and Chapter 8.3). The declining percentages of elm pollen, accompanied by the short-lasting increase of pollen influx of major trees (including the elm itself), was interpreted as reflecting the temporal opening the forest canopy due to the gradual extinction of elms. Therefore it seems possible that the erosion was increased at that time due to the forest opening (Ralska-Jasiewiczowa & van Geel 1992). Unfortunately the detailed mineralogical and chemical data from that period are not available.

In the whole Subboreal section, however, the average accumulation of non-carbonate minerals was not higher than that in previous sections. The calcite content is the

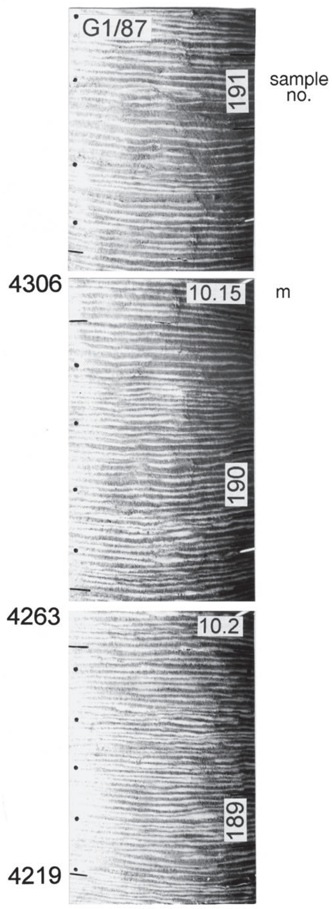

Fig. 8.8. Photograph showing the increase of deposition rate of the Lake Gościąż sediments (core G1/87) around the elm decline (starting above the sample 190). The numbers of varves are given to the left of core. The depth below water/sediment interface is given in metres.

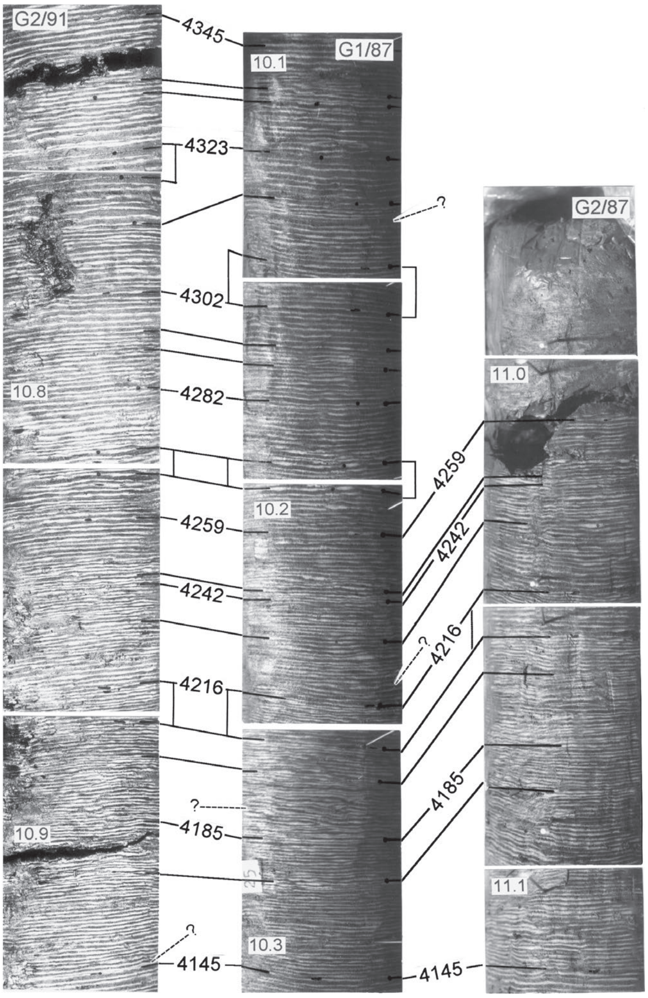

Fig. 8.9. Photograph showing the correlation of laminated sequences in cores G2/91, G1/87, and G2/87 in the Subboreal section of the continuous varve chronology of Lake Gościąż sediments. The numbers of marked varves are given between cores. Indicated by question mark are doubtful varves: apparently double varve no. 4145 in core G2/91, the light layers no. 4191 and 4220 in G1/87, disappearing in the right and left edges of the core, respectively, and varve no. 4311 in G1/87, with a very thin layer of calcite. The depth below water/sediment interface is given in metres.

highest, and its annual accumulation is significantly correlated with that of organic matter (Goslar, Chapter 6.3). The colours of individual laminae are not much differentiated, but the distinct differences in thickness of consecutive varves make the cross-correlation of cores easier than in the Atlantic (Fig. 8.9). The uncertain varves in single cores occur quite rarely, and they could be overcome with the help of other cores.

The varve chronology in Subboreal chronozone is replicated in at least two cores, except for a break between varves 6885 and 6911 near the younger end of chronology (Fig. 8.10). The disturbances of continuous sequences in individual cores are mostly connected with the core breaks near the ends of core segments, produced during field work. The critical point was the short overlap between 2 m segments of cores G1/87 and G2/87 (varves no. 4382– 4385). In the first attempt, this fragment was erroneously correlated with the core G1/85 and the overlap regarded as 36 varves (Goslar et al. 1989). The error was discovered when the next core G2/91 was analysed. Due to the small number of uncertainties in individual cores, it was possible to construct a sequence of 2636 varves (between varves no. 4043 and 6677), where the uncertainties of single years occurred only between varves no. 5415– 5416, 5750– 5751, and 6308– 6309. Two uncertainties allowed an addition of a single year, and one allowed a subtraction of a single year. The minimal error of the very long sequence (i.e. +2,-1 years) enabled a realistic comparison of the varve thickness with the dendrochronologically dated tree-rings (Goslar, Chapter 6.4). Above varve no. 6749, the continuous sequences in individual cores are broken by sectors of disturbed lamination. These disturbances, occurring more and more frequently upwards, are with no doubt natural. The disturbance above varve no. 7000, occurring in all the cores, makes the end of the continuous floating varve chronology at the depth of 7.34 m.

Correlation of laminated sequences above 7.34 m

The varve chronology of the upper 7.34 m of sediment was constructed from cores G1/87, G2/87, and G1/85. In the lower section of this part of the profile, the continuous sequences of well preserved varves are often interrupted by fragments of bent and dispersed laminae. Some

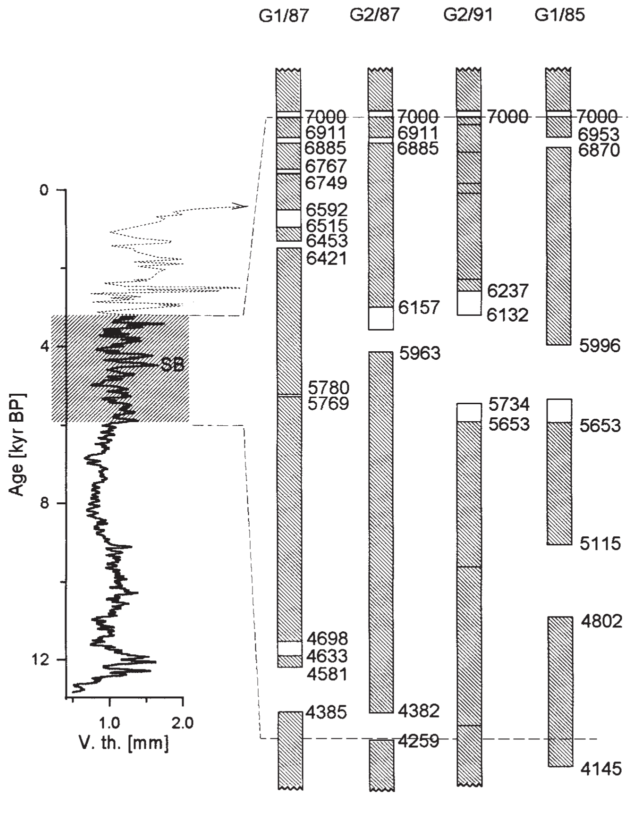

Fig. 8.10. Correlation of laminated sequences of individual cores in the Subboreal section of continuous varve chronology of Lake Gościąż sediments. For further explanations see Fig. 8.3.

disturbances are clearly caused by gas bubbles evolving from the sediment (Fig. 8.11). In many sections above 6.55 m, some agglomerations of calcite grains are visible which, however, do not form continuous layers. Because of many disturbances, the varve-by-varve correlation of cores was not possible. However, in the part between 7.34 m and 1.26 m, ca. 130 individual characteristic varves (see Fig. 8.11) common to all cores, have been found. The correlation of 2 m (or 1 m) segments of cores is shown in Fig. 8.12.

Between 2.0 and 1.5 m the relatively well preserved varves form an almost continuous sequence. Above 1.26 m, however, the laminae are completely invisible. This is caused by gases (hydrosulphide, methane?) coming from decomposing young sediment. When the cores were raised from the lake bottom, the gases, because of decompression, formed bubbles, destroying the structure of uncompacted sediment. The destruction of lamination as a result of coring is clearly confirmed by the occurrence of regular laminations above 1.2 m in the cores of sediment frozen in situ. The replication of well preserved varves in many cores frozen in situ enabled the construction of chronology in the youngest part of the sediment covering 19th and 20th centuries (Goslar, Chapter 9.2.2). The correlation between frozen and long 'piston' cores (Fig. 8.13) made it possible to fix the upper end of the laminated sequence in long cores on the time scale.

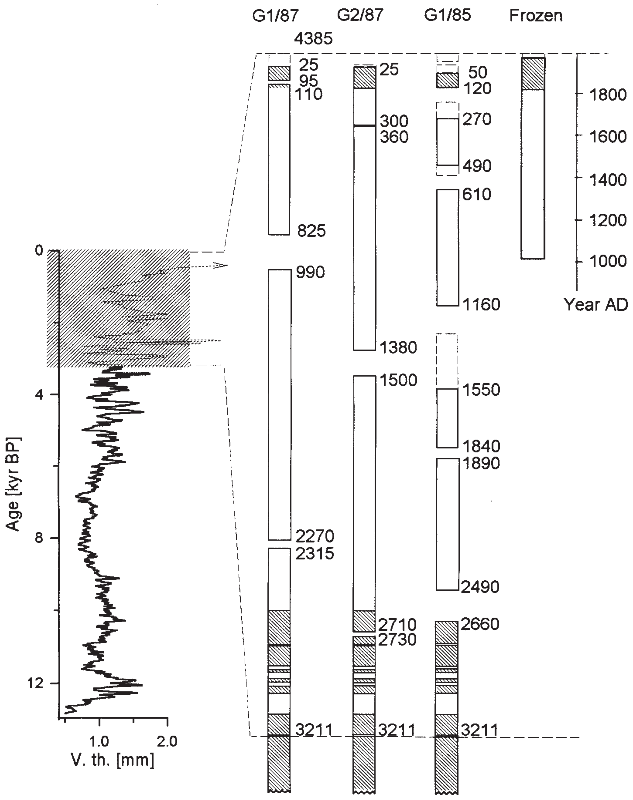

Fig. 8.12. Correlation of laminated sequences of individual cores in the upper part of Lake Gościąż sediments. The cores were pulled out in 2 m or 1 m segments. The sections with continuous laminations are hatched. The ages (in years cal BP) of ends of laminated sections are given to the right of cores. The last bar to the right represents chronology of uppermost sediment, pulled out frozen in situ (Goslar, Chapter 9.2.2). Right-hand side: scale of years AD. Left-hand side: record of laminae thickness to show the position of considered part in the whole profile.

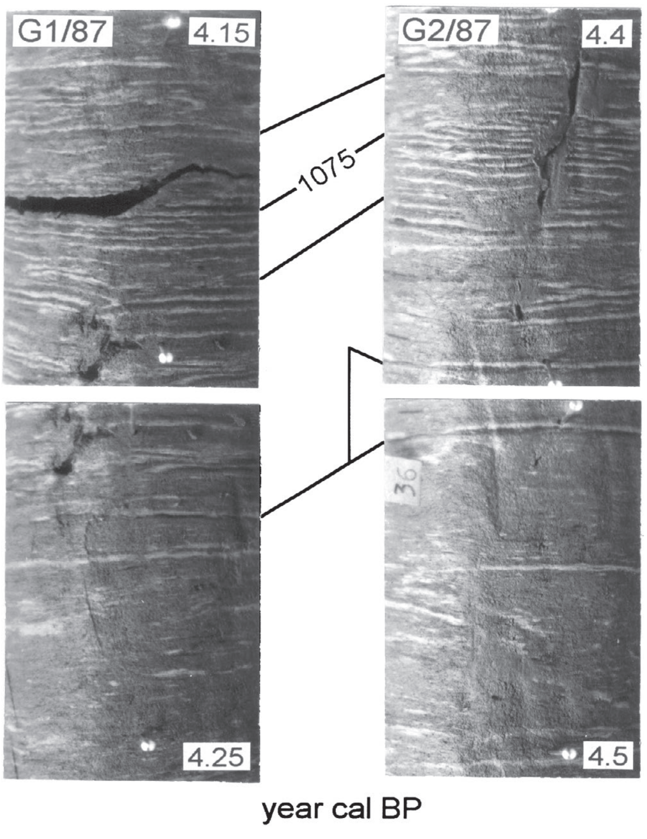

Fig. 8.11. Photograph showing the correlation of laminae in the upper part of Lake Gościąż sediments (around 1075 cal BP). The depths below water/sediment interface are given in metres.

Varve counting in construction of chronology above 7.34 m

The structure of well preserved varves, consisting of a light layer of calcium carbonate (often accompanied by light layer of centric diatoms) and a dark layer rich in organic matter is clear enough to enable reliable varve counting. The main problem in counting, however, is the poor preservation of many varves. Above 7.34 m, the light layers are often dispersed and hardly visible, and in many sections on the core surface only individual agglomerates of carbonate occur, which do not form any continuous layers and are difficult to be ascribed to consecutive laminae. In order to improve the distinction of varves the method of X-ray radiography is usually applied (Koivisto & Saarnisto 1978, Mehl & Merkt 1992). The X-ray radiographs of the fragments 1.00– 1.75 m of core G1/87 and 3.0– 7.0 m of core G2/87 were prepared in the Univ. of Oulu (M. Saarnisto, pers. comm.) and of the fragment 6.05– 7.05 m of core G1/87 in the Institute of Physics in Gliwice (H. Orwat, pers. comm.). In both

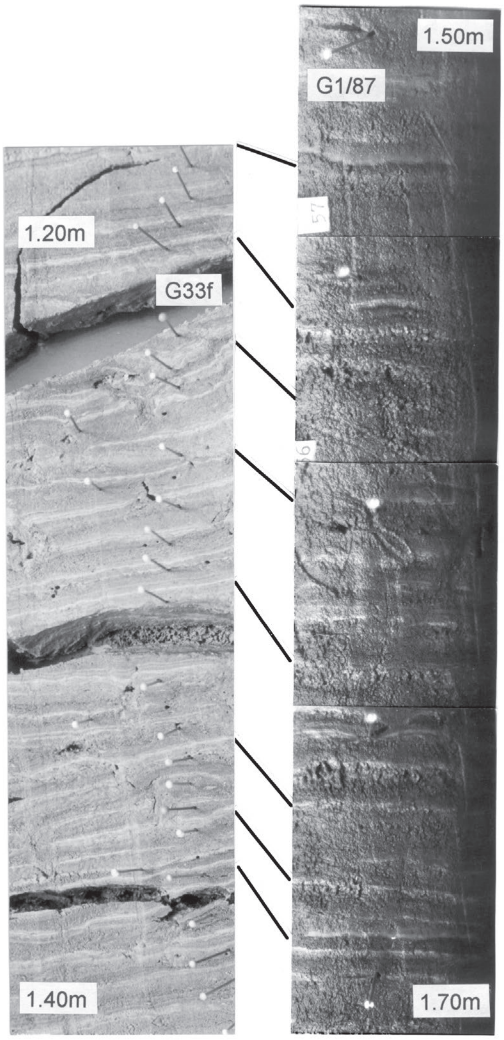

Fig. 8.13. Photograph showing the correlation of cores pulled out from Lake Gościąż sediments with the conventional piston corer (G1/87) and frozen in situ (G33f). The depths below water/sediment interface are given in metres.

cases, the X-rayed samples were in the form of slices of sediment ca. 5 mm thick cut along the profile, and to obtain the high black-white image contrast low-energy radiation was applied. An example of a radiograph in comparison to a conventional photograph of the core surface is shown in Fig. 8.14. In this case the application of X-rays did not improve the visibility of varves in the problematic sections. The radiographs revealed zig-zag dark lines, usually a few mm long and a few tenths of mm thick, oriented vertically. A microscopic inspection revealed that they are formed by clusters of spherical aggregates of pyrite filling the "channels" in the matrix of sediment. The channels were probably formed by small bubbles of gas liberated from the decomposed organic matter. The wiggles would then correspond to passages of a bubble through the sediment layers of different permeability. The pyrite was probably formed afterwards due to the flow of sulphur and iron-rich solutions through the channels. In the majority of channels, two wiggles per one varve occur. The channels are often distinct in sections with lamination unclear or invisible on radiographs, for example in section 2800–2809 cal BP the counting of wiggles on the radiograph suggests 9 varves, in agreement with what is visible on the core surface. Some channels are also distinct in sections where the varves are unclear as well on the core surface as on radiographs. They suggest that the sedimentation rates in fragments 2750–2760 cal BP and 2869–2878 cal BP were similar to those in adjacent, regularly laminated sections.

Just as for the lower part of the sediments, the varves above 7.34 m were counted between marked levels separately in all cores. Because of poor quality of lamination the strategy of construction of varve chronology was different from that in the lower part of the sediments. Generally it was not expected that exactly the same number of varves would be counted, and the countings in different cores were regarded totally independent. Where possible, the varves were also counted on X-ray radio-

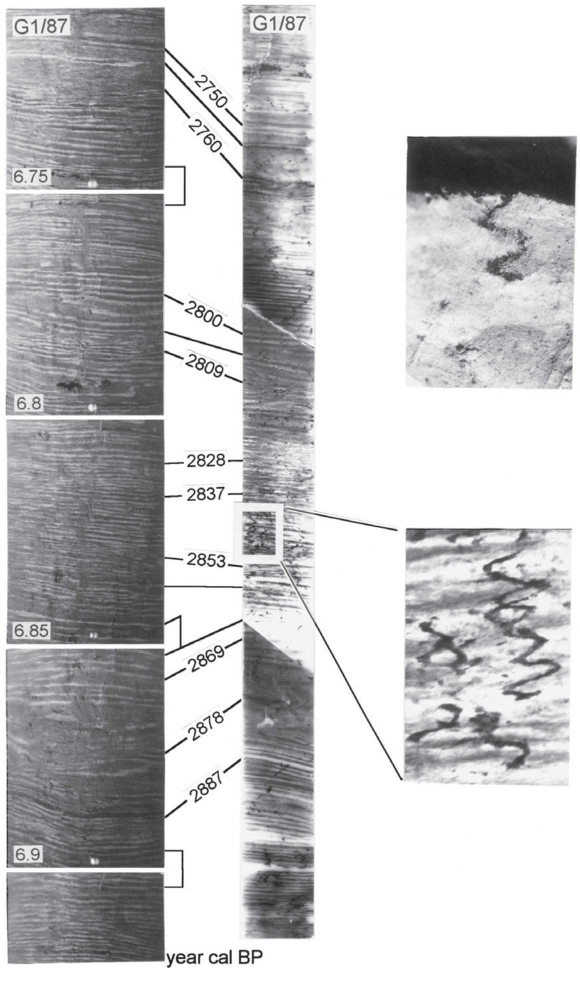

Fig. 8.14. Photograph illustrating the correlation of conventional photographs and X-ray radiographs of the upper part of laminated core from Lake Gościąż. The approximate age (in years cal BP) of marked varves is denoted between photographs. The depths below water/sediment interface are given in metres. In right-hand side the magnified views of pyrite-filled channel are shown: lower picture – X-ray radiograph; upper picture – conventional photograph of dried core surface, scrapped to uncover the channel.

graphs. For each given pair of markers the varve numbers obtained for a different archive (photographs of 3 cores and X-ray radiographs of fragments of 2 cores) were compared, and the error of chronology was estimated from the spread of single counting results. Quite often, the distinctness of varves differed significantly between cores, and when estimating the most probable number of varves for each pair of markers these differences were taken into account. In sections of invisible lamination (e.g. in the fragment 4.2–4.25 m in G1/87; see Fig. 8.11), the agglomerates of calcite forming traces of separate layers were counted. Usually, the deposition rates suggested by "trace counting" in these fragments were higher than in adjacent, well laminated sections. The most probable number of varves for the whole part of profile above 7.34 m was estimated in such a way to 2900. This number may be overestimated by even 200, if the counted traces of layers are not true varves. On the other hand, it may be too low by ca. 500, if, as suggested by zig-zag features, the deposition rate in all disturbed sections was similar to that in laminated fragments. Therefore, basing on the varve counting alone the age of level 7.34 m was estimated at 2900^{+500}_{-200} cal BP.

The record of lamination quality of the sediments above 7.34 m

The varying frequency of disturbances along the upper part of the Lake Gościąż sediments may be expressed in terms of quality of lamination (Fig. 8.15). Only in a few fragments between ca. 3200 cal BP and 2600 cal BP and in a short fragment about AD 1900 the quality of lamination is comparable to that occurring below 7.34 m. It seems that the lamination quality is correlative with intensity of human occupation in the lake surroundings, reconstructed by pollen analyses (Ralska-Jasiewiczowa & van Geel, Chapter 9.1.3). The drop of lamination quality about 2600 cal BP is synchronous with an abrupt decrease of *Rumex acetosella* and *Plantago lanceolata* percentages, marking the decline of period of intense human impact in the Late Bronze Age. Some improvement of quality between 1800– 1500 cal BP corresponds to the maxima of taxa showing human activity in the Roman Age. The renewed intensification of human impact in Early Medieval time is correlative with small improvement of quality after 1100 cal BP, and distinct one after ca. 850 cal BP. The period of most intense agricultural activity in the end of 19th and beginning of 20th century (Ralska-Jasiewiczowa & van Geel, Chapter 9.1.3) coincides with the highest regularity of lamination in modern time. All these correlations seem to argue that the regularity of lamination in the last three millennia is positively related to human activity. The anthropogenic influence on lamination quality has been concluded in a few studies of varved sediments. The mechanism usually

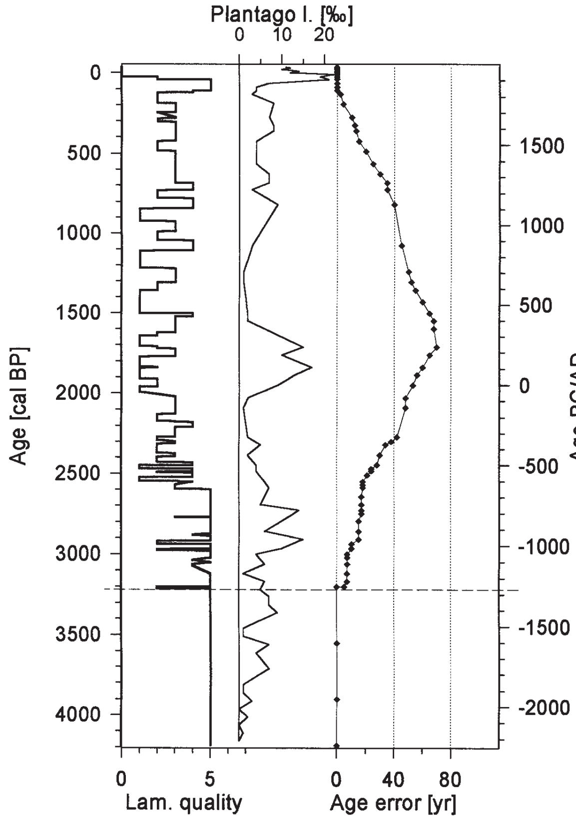

Fig. 8.15. Record of quality of lamination and error of age in the upper part of varve chronology of Lake Gościąż sediments, in comparison to intensity of human occupation (see Ralska-Jasiewiczowa & van Geel, Chapter 9.1.3), represented by percentage of *Plantago lanceolata*. The quality of lamination is expressed in scale 0–5 in a following convention: 5 – continuous regular lamination; 4 – continuous laminated fragments with short disturbed fragments (of single varves) in between; 3 – alternation of regularly laminated and disturbed fragments of comparable thickness; 2 – single varves occurring among traces of laminae; 1 – traces of laminae; 0 – no visible lamination.

involved is lake eutrophication driven by increasing input of nutrients, which, because of intensified decay of dead organic matter, results in growing oxygen deficit and a lake's meromixis. Huttunen and Tolonen (1980) concluded that the meromixis of Lake Lovojärvi in Finland was triggered by the eutrophication driven by man after AD 300. In recent years some shift to oligotrophy accompanied by disappearance of lamination in that lake is observed. A similar correspondence between lake trophy and meromixis was observed in Lake Hannisenlampi (Vuorinen 1978) and Laukanlampi (Battarbee 1981). It seems reasonable that the observed relationship between human occupation and quality of lamination in the Lake Gościąż sediments was caused by a similar mechanism, though such direct indicators, as fossil akinetes of *Aphanizomenon* and *Anabaena* (Van Geel et al. 1994), demonstrate strong eutrophication of the lake during last 4000 BP, mostly after ca. AD 1000. If the apparent human influence on the lake meromixis is real, the termination of continuous lamination at 7.34 m was not caused by man, whose appearance should rather bear better preservation of varves, but it was natural effect of lake shallowing.

Chronology of laminated sediments above 7.34 m

The chronology of the sediment above 7.34 m, though based on varve counting, is significantly affected by the knowledge of calendar age of its older end, determined to 3211 cal BP (Goslar, Chapter 6.4). This age agrees, within limit of error, with the estimate based on varve counting. Fixing of both ends of the laminated sequence 3200 varves long, however, distinctly changes the estimate of age error within this sequence.

If the chronology is not fixed at its lower end, the error of age determined by counting varves from the top of sequence has a cumulative character and is distinctly asymmetric. This error, however, implements a general uncertainty of interpretation of disturbed sections. For example, the maximum positive error in the whole part of profile (+500 varves) corresponds to the maximum underestimation of varve number in all disturbed sections. If the chronology is fixed at both ends, the error of age depends on counting the varves both from the top and from the bottom. The change of age at any level requires thus the opposite corrections of varve counting below and above that level. Separately, both corrections may be allowed by the uncertainty of varve counting. However, the opposite simultaneous corrections in two fragments are less probable, since all disturbed sections were similar, and the varves were counted everywhere in the same manner. Therefore the error of chronology fixed at both ends is more symmetric and distinctly lower than the error of varve counting alone. Obviously, the age near one end of chronology is little dependent on varve counting from the second end. Both the error of varve counting and the error of age are dependent on quality of lamination, varying along the profile. The analytical calculation of age error in these circumstances is a very difficult problem, and it was estimated relying rather on the author's intuition than on strict calculations (Fig. 8.15). One may note that the error rises towards the middle of considered part of profile. The rate of rise at particular level is dependent on quality of lamination.

8.2. MINERALOGY AND GEOCHEMISTRY OF THE LAKE GOŚCIĄŻ HOLOCENE SEDIMENTS

Bożena Łącka, Ewa Starnawska, Michał Kuźniarski & Leszek Chróst

The mineral and chemical analysis of the Holocene deposits from the central part of Lake Gościąż was carried out on 52 samples representing six selected parts of the G1/87 sediment core. These parts of the Holocene profile correspond to the sedimentation during following intervals of calendar age: (1) 11,458 – 11,408; (2) 10,708 – 10,446; (3) 8596 – 8296; (4) 6534 – 6084; (5) 4061 – 3461; (6) 820 – -35 years BP, i.e. AD 1130 – 1985 (for chronological background see Goslar Chapter 8.1).

Mineral components of bulk and homogenized samples encompassing 10 varves were identified by XRD and DTA methods (Chapter 4.5). XRD identification of minor mineral components in the Holocene deposits was difficult due to the occurrence of amorphous and poorly crystallized hydroxides of Mn and Fe or/and the transformation products of the metastable authigenic minerals, and the high content of $CaCO_3$, up to 75%. Nevertheless, the variations in the content of the major authigenic minerals as well as terrigenous detritus allow us to state that these selected parts of the Holocene sediments represent six complexes with different mineral composition:

(1) 11,458 – 11,408 cal BP. The main mineral constituents of the lowest part of Holocene sediments are Mn, Ca, and Fe carbonates and Mn hydroxides. Within the carbonate group, Ca-rhodochrosite predominates over calcite, siderite, and kutnahorite. These sediments, like the Younger Dryas deposits, may be regarded as Mn ores.

(2) 10,708 to 10,446 cal BP. Within the sediments formed during this time interval, the increase of calcite content was observed. This mineral becomes more abundant than Mn and Fe carbonates. Mn mineral phases other than carbonate displayed on the diffraction patterns are pyrolusite and todorokite.

(3) 8596 to 8296 cal BP. Mn and Fe carbonates decrease to the trace level. The main mineral components recorded in the diffraction patterns are calcite and gypsum. In this sequence of sediments vivianite appears to be another mineral phase of iron. Because of the high content of calcite the sediments from the third complex can be classified as carbonate gyttja.

Gypsum was recorded in the diffraction patterns of all samples investigated from Younger Dryas to recent, but within the carbonate gyttja that formed during the interval from 8596 to 6084 cal BP (complexes nos. 3 and 4) gypsum may be considered as one of the major mineral components of gyttja. The combined EDS and SEM analyses indicate that gypsum occurs more frequently within the light varve laminae. The morphology of gypsum crystals points to its late diagenetic origin.

(4) 6534 to 6084 cal BP. Sediments show the mineral composition similar to that of the underlying carbonate gyttja. The only exception is the occurrence of pyrite. In this part of the core two Fe-containing minerals, vivianite and pyrite, were X-ray detected.

(5) 4061 to 3461 cal BP. The mineral composition of the sediments is similar to that of the sediment complex no. 4. There occur two Fe-containing mineral phases, sulfides and phosphates. Pyrite and vivianite were undoubtedly identified by means of X-ray diffraction. The