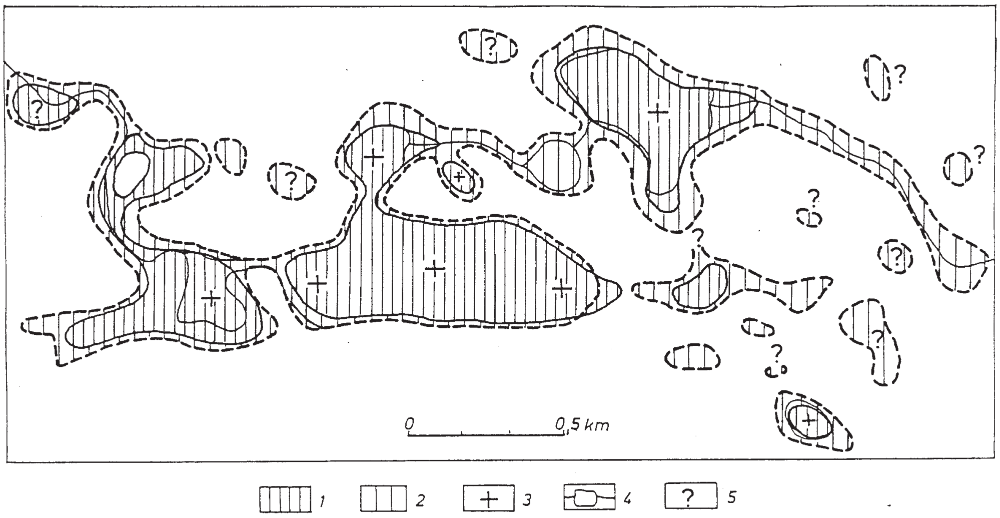

Fig. 7.3. Extent of lakes during various phases of the Late Vistulian. 1 – lakes at the beginning of Allerød, 2 – lake transgression during the late Allerød, 3 – deep dead ice hollows, 4 – present Ruda stream and lakes, 5 – lack of radiocarbon dating of lake formation – the reconstruction is based only on the extent of existing peatbogs.

of ca. 62 ha. The Allerød lake was at least 60% larger. The calculated volume of the present lakes does not exceed 2300 thousands m^3, and reconstructed volume of the late-Allerød lake was close to 8500 thousands m^3. The existence of such a great water volume was possible due to the direct contact of lake water with the ground waters moving freely from the south before the sealing of the lake bottom by the sediments, as well as due to lack of the surficial drainage. During the Younger Dryas the lake level was high but probably unstable and slightly lowering, as may be proved by the change from gyttja to peat in small separated depressions (borings GTO6, GTO3 – see Chapter 5.1). Simultaneously the activity of slope processes increased, facilitated by the seasonal freezing and fluctuations of lake level. The Younger Dryas was a phase of distinct decline in the volume of lakes as a result of intensified slope processes. In the central deep these are documented by a thick sand layer reflecting two subwater laminar flows differing in granulometry (see Chapter 5.1., Fig. 5.3). These flows were facilitated by steep slopes, which still have gradients of 17–27% (9–13°).

7.2. LATE-GLACIAL SEDIMENTS OF LAKE GOŚCIĄŻ – CHRONOLOGICAL BACKGROUND

Tomasz Goslar[*]

Basic varve structures

In a temperate zone the variance in the annual cycle is large enough to affect the growth of organisms as well as the chemical and physical processes that occur around and within the lake. Because of this the composition of matter accumulating at the lake bottom changes seasonally. If no disturbance occurs on the surface of depositing sediment (i.e. through water movements, gas bubbling or bioturbation), the seasonal cycle of accumulation should be reflected in the form of the laminations. The succession of single layers in laminated sediment corresponds then to the succession of processes within and around the lake and therefore should reveal an annual cyclicity. The high diversity of circumstances in which annual laminations may be formed causes the successional seasonal patterns of laminae to differ from lake to lake, and it also may change over time in a single lake. The review made by O'Sullivan (1983), however, led to a conclusion that four groups of basic patterns of annual lamination may be distinguished, and one might expect that any annually laminated lacustrine sediment reveals the cyclicity similar to one of four basic structures.

The sediments of Lake Gościąż reveal quite typical calcareous lamination. In the Allerød section, the varve structure is simple (Fig. 7.4), since it consists only of a calcite-rich light (white, light-yellow) layer and a darker (dark-yellow, light-brown) one with higher content of organic matter. Diatoms are quite rarely visible and occur below the calcite layer.

The most complex laminations occur in the Younger Dryas section of sediment. The main varve components (Fig. 7.5 left) are the layers of fine-grained, carbonate-free mineral matter, carbonate grains, and organic matter. In the layer of mineral matter, usually some frustules of centric diatoms (more or less dissolved) are visible. The chrysophycean cysts occur more rarely, and the large quartz grains (Fig. 7.5 right) are rare, too. The calcite (or Ca-rhodochrosite, see Łącka et al., Chapter 7.3) crystals

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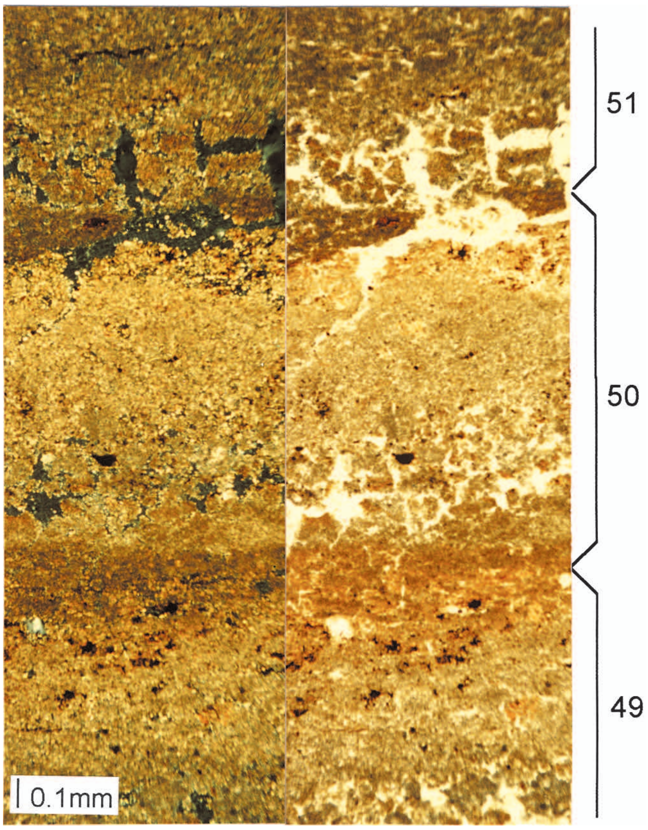

Fig. 7.4. Microphotograph showing the basic structure of laminations in the Late-Glacial part of laminated sediment of Lake Gościąż (core G2/87, varves no. 49–51). Right: in non-polarized light, left: in polarized light.

are blocky polyhedra with the size of up to ten microns. The calcite grains still occur in the layer of organic matter, but they are smaller and less abundant. In the organic layer, fine-grained, yellow aggregates of iron and manganese compounds (see Łącka et al., Chapter 7.3) frequently occur. Above the organic layer diatoms are usually deposited. These partly dissolved diatoms seem to represent a single genus mostly (i.e. *Synedra* sp.). Between the diatoms and non-carbonate mineral matter a thin layer of reddish-brown aggregates is deposited, very similar to the Fe- and Mn- rich layers recognized by Anderson (1993) in post-glacial sediments of Elk Lake. They frequently contain fine (<5 microns), distinct crystals which, according to microscopic analysis, seem to be manganese carbonate (rhodochrosite), formed probably by diagenesis. This is illustrated in Fig. 7.6, where in thicker Mn-rich layers between varves 244/245, 245/246, and 248/249 the carbonate is present, while it is absent from the thinner ones, i.e. 246/247 and 247/248. The occurrence of rhodochrosite in the YD section of sediment has been confirmed by X-ray diffraction (Pawlikowski 1990). In the layers of organic matter and *Synedra* diatoms, pyrite framboids are also observed (Fig. 7.5).

The pattern of lamination described above is very similar to that of annual calcareous lamination found e.g. in Schleinsee (Merkt 1971), Zürichsee (Kelts & Hsü 1978), or Soppensee (Lotter 1989). The occurrence of similar patterns in some sections of sediment from Elk

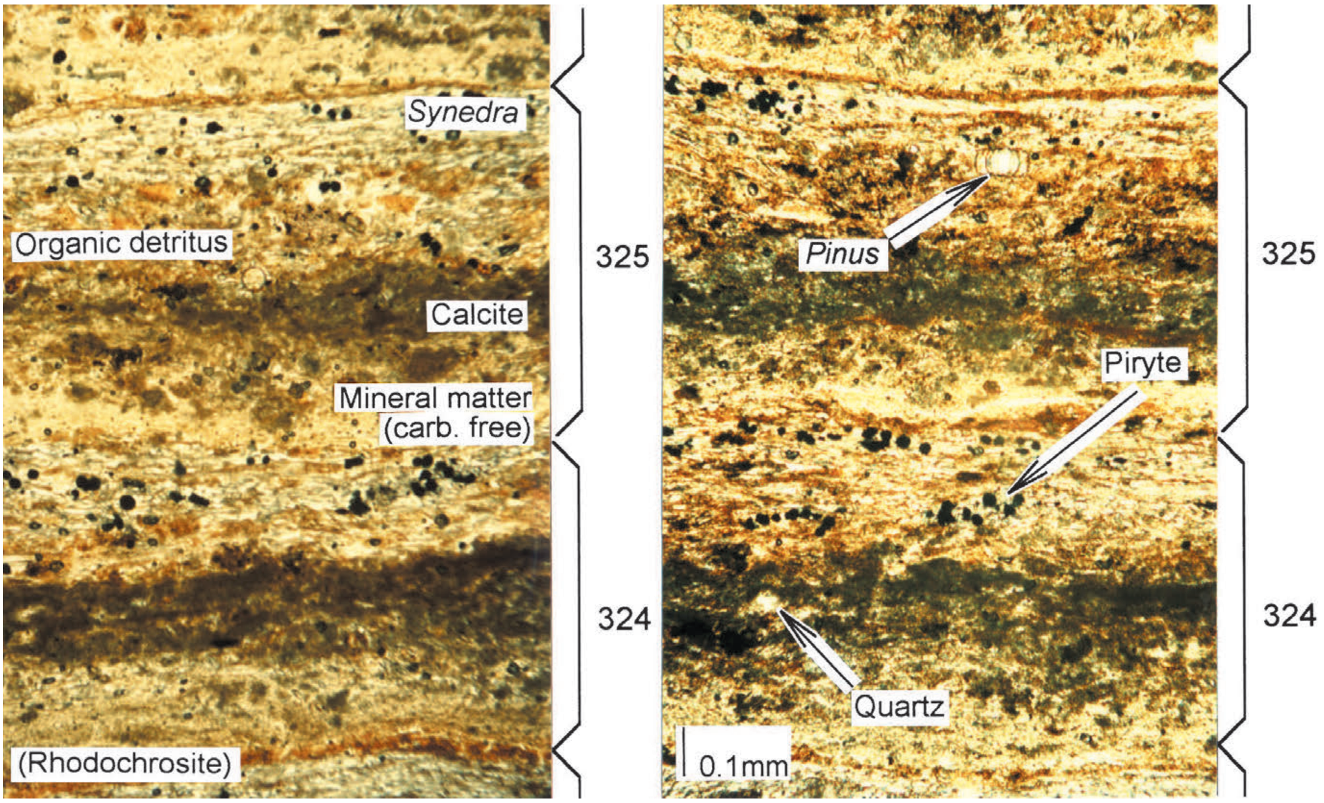

Fig. 7.5. Microphotographs showing the basic structure of laminations in the Late-Glacial part of laminated sediment of Lake Gościąż (core G1/90, varves no. 324 and 325).

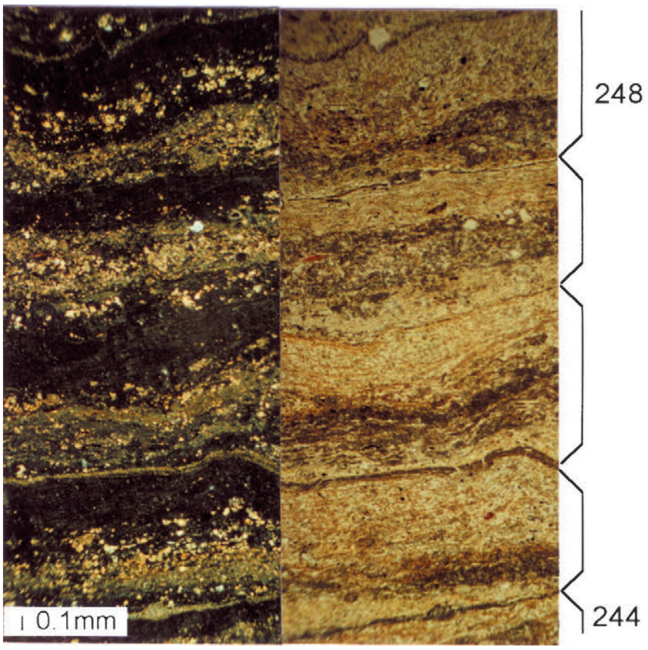

Fig. 7.6. Microphotograph showing the thin layers of carbonate (rhodochrosite?) at the boundaries of annual varves in the Late-Glacial part of laminated sediment of Lake Gościąż (core G1/90, varves no. 244–248). Right: in non-polarized light, left: in polarized light.

Lake was also reported (Anderson 1993). The deposition of non-carbonate minerals seems connected with the spring floods, and layers of centric diatoms reflect spring diatom blooms. The large calcite grains were presumably precipitated during the late spring and summer, while the layers enriched in organic matter formed during the fall and winter. Such a pattern exists also in the youngest fragment of laminated sediment, where the annual cyclicity was additionally confirmed by the succession of identified diatoms species (Goslar, Chapter 9.2.1). Unfortunately, because annual lamination has not been formed since 1966, the trap observations are not adequate to be applied to the normal regime of past varve formation and thus could not clearly confirm the pattern of annual cyclicity (Giziński et al., Chapter 3.5). Nevertheless, they show that the calcite precipitates seasonally from spring through early fall.

Some complication in the interpretation of varve structure in the YD section arises from the occurrence of *Synedra* and thin Mn-enriched laminae. The monospecific character of diatom layers excludes their formation by redeposition. In sediments of Lake Lovojärvi, Simola et al. (1990) observed the occurrence of *Synedra acus* in spring/summer and *S. ulna* in fall layers, but the diatom species in thin sections of Gościąż sediment were not determined, and the attribution of this layer to any specific season is a problem indeed. If these diatoms were blooming in spring, the occurrence of overlying Mn-rich thin layer is difficult to interpret. If the *Synedra* diatoms were deposited in autumn, the amount of organic matter (connected with Mn-enriched thin layer) deposited after a diatom bloom is surprisingly small. Whatever is the case, the very good regularity of pattern described leaves no doubt that it is annual.

Uncertainty of varve counting

Some laminae in the Late-Glacial section of sediment are difficult to interpret. It is exemplified by the case of varve 241 (Fig. 7.7). Above the thin organic layer at the boundary 240/241, the >1 mm thick layer is formed of pennate diatoms, fine-grained minerals, and large calcite grains. It is overlain by a thin Mn-rich layer (indicated by a question mark), and the structure with “normal” annual succession higher up. The lower part of varve 241 could be regarded as separate varve, because of alternation of carbonate and organic matter. However, the large diversity of diatom species and the high abundance of littoral pennate diatoms suggests that this layer was rather formed by the redeposition of material, perhaps during a spring flood. The occurrence of the carbonate and other minerals in form of dispersed grains seems to confirm such an interpretation. Therefore this layer was counted together with the varve 241. The more difficult case is shown in Fig. 7.8, where in the middle of varve 326 a thin layer similar to those separating the varves 325/326 and 326/327 was formed but with no clear organic layer below and mineral layer above. This short break in cal-

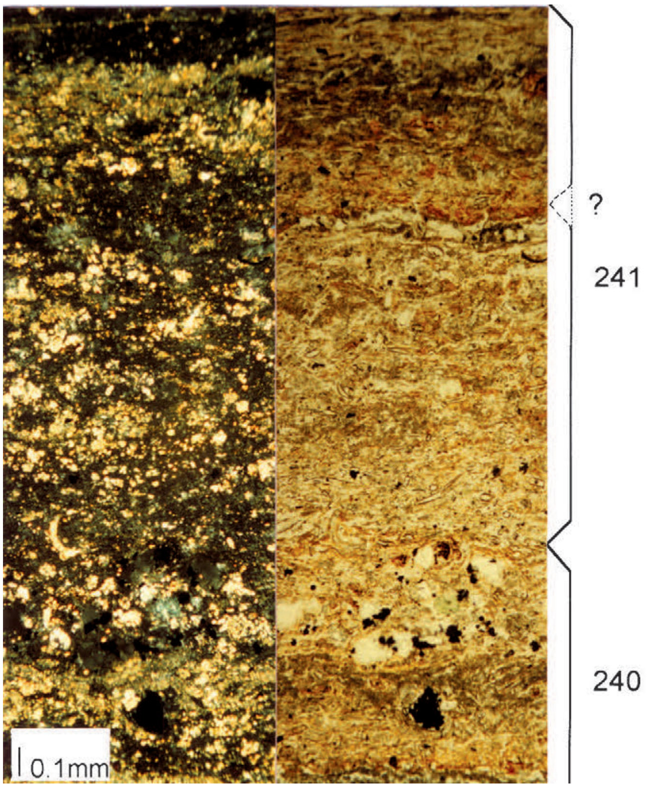

Fig. 7.7. Microphotograph showing the varve (no. 241, core G1/90) with the layer of redeposited sediment. Right: in non-polarized light, left: in polarized light.

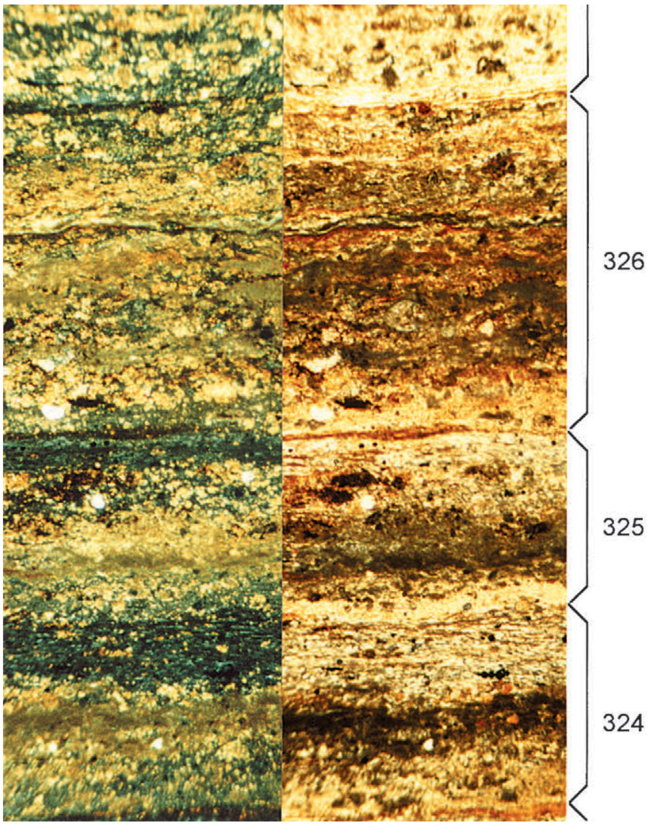

Fig. 7.8. Microphotograph of the complex (no. 326) which might be interpreted as a single varve or two varves. Right: in non-polarized light, left: in polarized light.

cite deposition could reflect either a very mild winter or the short-lasting, abrupt cooling during the summer. Because of no clear arguments for either or both interpretations, this uncertainty is included in the error of varve counting.

Correlation of laminated cores

The correlation of laminated cores in the Late-Glacial part of sediment is shown in Fig. 7.9. The cores were raised in 1 m or 2 m segments and the gaps between core segments were the main reason of discontinuities in single-core varved sequences. Besides the gaps, the discontinuities were associated with breaks in the cores (e.g. in the upper segment of core G1/85), disturbances of the lamination (mostly at the ends of segments), and the non-laminated sand layer. This layer, ca. 0.6 m thick, was found 20 cm above the bottom of the laminated sequence in cores from the lake centre (G1/87 and G2/87; see Goslar, Chapter 6.1). It does not occur in the western deep (cores G1/90 and G1/91) and northern bay (T1/90), so the correlation of sequences of seven cores enabled the construction of continuous chronology. The numbers of varves deposited below the sand layer are negative, and the numbers of younger varves are positive.

The sand layer is a critical level in the continuous chronology. The most dramatic climatic changes at the onset and termination of Younger Dryas (YD) are re-

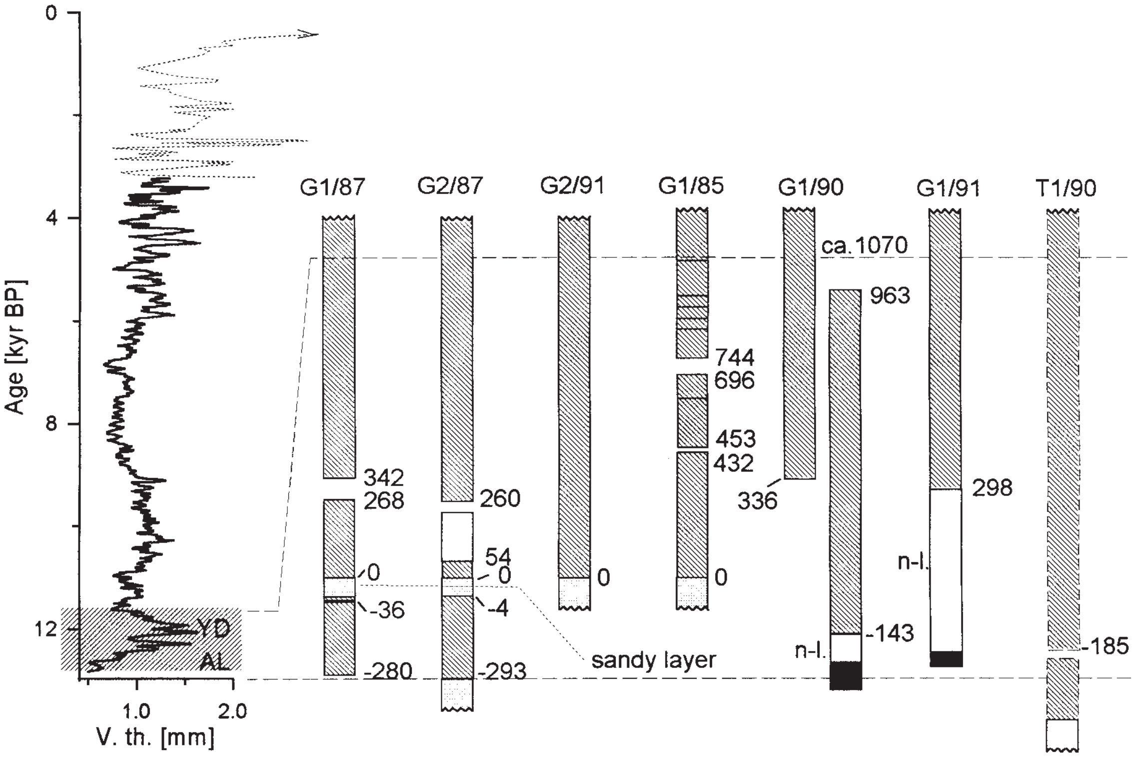

Fig. 7.9. Diagram showing the correlation of laminated sequences of individual cores in the Late-Glacial section of sediment. The cores were pulled out in 2 m or 1 m segments. Hatched sections – continuous lamination, dotted – sand or sandy layer, white – non-laminated lacustrine gyttja, black – layer of humus. The varve numbers on ends on laminated sequences are given to the right of the cores. Left-hand side: record of laminae thickness to show the position of part considered in the whole profile.

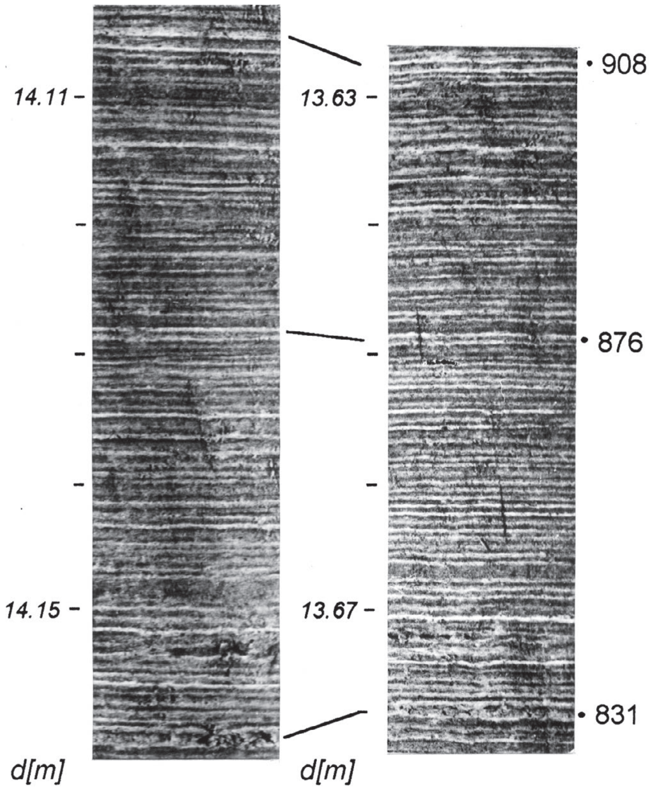

Fig. 7.10. Photograph illustrating the correlation of laminated sequences in two overlapping segments of core G1/90. Varve numbers are given to the right of segments, depth scale (according to the field notation) is given to the left.

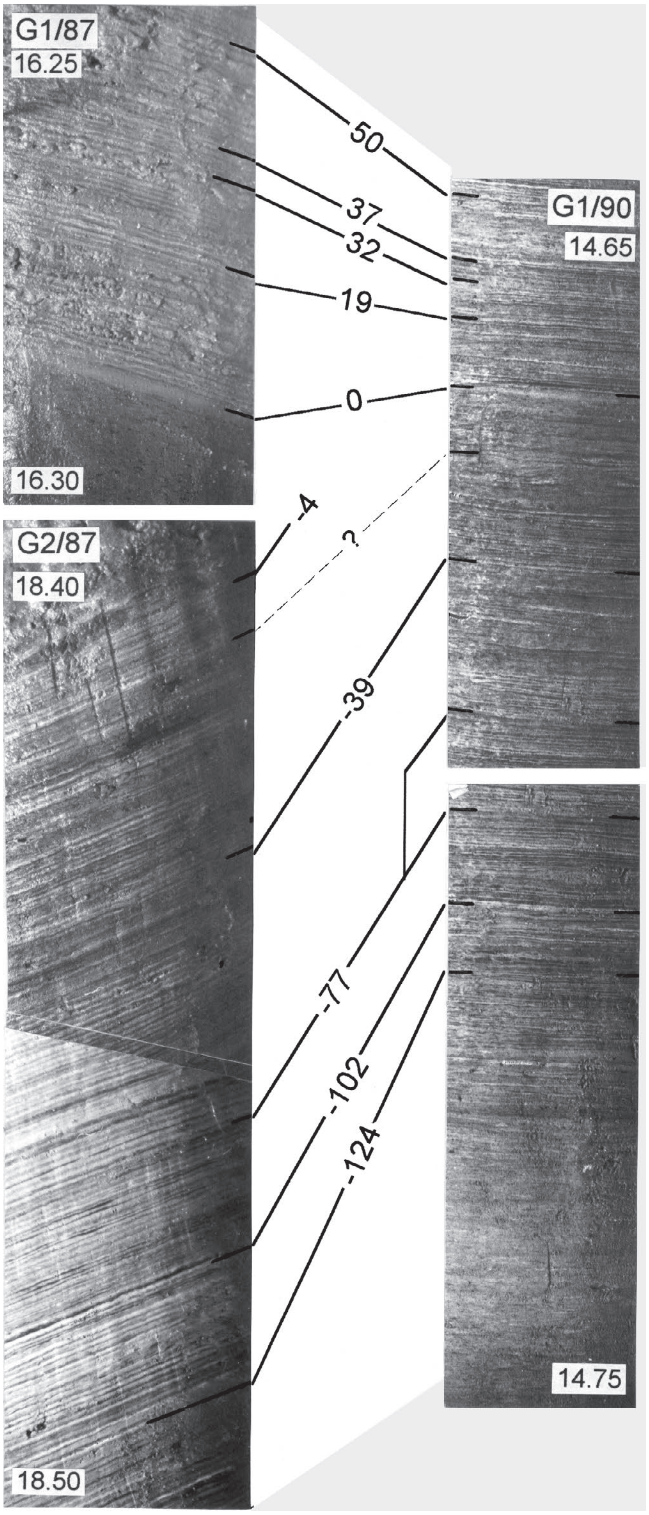

Fig. 7.11. Photograph illustrating the correlation of western profile (G1/90) with the laminated sequences below and above the sandy layer in the central profile (cores G1/87 and G2/87). The depth scale of individual cores is shown on the photos, the numbers of correlative varves are given in the middle. The Allerød/Younger Dryas transition is placed about the varve -70. The two photographs of core G1/90 overlap.

corded in the central cores (G1/87 and G2/87) below and above the sand, respectively. The unknown duration of event (events?) of sand deposition and the unknown number of varves possibly eroded by this event made the direct determination of the duration of Younger Dryas impossible in the first stage of investigation (Różański et al. 1992). In core G1/90 from the western deep the laminated sequence was undisturbed over the whole YD. This core was pulled out in 1 m segments. At the first attempt the upper Late-Glacial segment of G1/90 (from the varve 336 up) and the bottom section of the lower segment (up to varve no. -4) were properly correlated with the cores from central deep (Goslar et al. 1993). However, the upper part of lower segment of G1/90 was erroneously correlated with the central cores. When the correlation was sought for, it was assumed that the segments of G1/90 obviously do not overlap, so the upper end of lower segment was thus correlated with varve 295, and the break corresponding to the sandy layer was determined to 536 years. This led to an estimate of the duration of Younger Dryas as 1640 yr (Ralska-Jasiewiczowa et al. 1992, Goslar et al. 1993). The new cores T1/90 from the northern bay and G1/91 from the western deep revealed, however, that the two segments of G1/90 do overlap (Goslar 1993). It is clearly confirmed by direct comparison of segments (Fig. 7.10). It should be stressed that all other cores (but not G1/90) were collected in winter, from the ice surface, and the consecutive core segments were taken from the same borehole in sediment. The G1/90 core was taken in summer from a raft. The shifting of the raft during the penetration of hard sediment caused the consecutive segments to be taken from slightly different locations, and a mistake in the control of the coring depth could be the reason for the overlap (Więckowski, oral inf.).

The photograph in Fig. 7.11 illustrates the correlation of laminated sequences in western deep with those below and above the sand layer in the central deep. In spite of the distinct difference in sedimentation rates, the correlation above the sandy layer is quite clear. Below it the similarity of the varved sequences is weaker, and with no support from additional data the correlation could not be defended. The close similarity of δ^{13}C and δ^{18}O curves in fragments of both cores (Goslar et al. 1993, see Kuc et al., Chapter 7.6) and of AL/YD transitions reflected in pollen spectra (Ralska-Jasiewiczowa et al., Chapter 7.4), however, strongly confirms the proposed correlation. According to the present status of correlation, the sandy layer corresponds to the period of only 4^{+6}_{-2} yr. The quoted error reflects an uncertainty in counting the doubtful varves (similar to those described in Chapter 7.1) in the section of G1/90 corresponding to sand layer.

The continuous lamination through the whole YD is also revealed in the core T1/90. The bottommost lamination in this core is probably older than in any other cores. Unfortunately, the oldest short laminated fragment (205 varves) was found in separate 1 m segment and was not correlative with the continuous chronology.

7.3. MINERALOGY AND GEOCHEMISTRY OF THE YOUNGER DRYAS SEDIMENTS FROM LAKE GOŚCIĄŻ

Bożena Łącka, Ewa Starnawska & Michał Kuźniarski

The mineral composition of bulk homogenized Late-Glacial samples each encompassing 6 varves, is dominated by carbonates and poorly crystallized or amorphous hydroxides and oxyhydroxides of Mn. Minor admixtures of gypsum and clastic minerals were detected by XRD in every sample. The clastic mineral fraction consists of quartz, feldspars and layer silicates (mica, chlorite, and mixed-layer species). Because of the high background on the diffractograms caused by considerable high concentration and poor crystallinity of Mn phases, the precise identification of Mn minerals as well as mixed-layer silicates was impossible. Only two Mn hydroxides, pyrolusite and todorokite, were detectable by XRD.

The carbonate fraction within the uppermost part of the Late-Glacial deposits consists of at least two mineral phases: the minor component is calcite, and the other one is mostly carbonate that displays the presence of d_{104} = 2.88–2.89 Å reflection in the powder-diffraction patterns. This d_{104} value is one for dolomite. However, it is also characteristic for Ca-rhodochrosite and for carbonates with chemical composition fitting to the ternary system $CaCO_3$ – $MnCO_3$ – $FeCO_3$ (Capobianco & Navrotsky 1987, Peacor & Essene 1987). EDS analyses of the intergrowing carbonate grains within single varves report presence of Mn, Ca, and frequently – Fe. None of analysed grains contained Mg. Moreover, DTA and TG curves of homogenized samples did not show any dolomite endothermal effect at 850°C. Thus in the case investigated the value d_{104} = 2.88–2.89 Å indicates Ca-rhodochrosite with about 20 mole per cent of $CaCO_3$ or carbonate close to the ankerite composition $(Ca, Fe, Mn)(CO_3)_2$. It is the main carbonate within Late-Glacial deposits.

The other minor carbonate phases display in diffraction patterns d_{104} values of about 2.96 and 2.80 Å, corresponding to Ca-kutnahorite (Bini & Manchetti 1985, Cancian & Princivalle 1991) and siderite, respectively. Occurrence of these two Ca- and Mn- bearing carbonates and in one sample also rhodochrosite, may arise from the metastability of the carbonate system within the deposits.

In the diffraction patterns of raw powdered and homogenized samples only the mineral phases described above were recorded. However, Pawlikowski (1990) reported the presence of manganese sulphides – alabandite and hauerite – within the deposits underlying the Younger Dryas sequence.

The results of chemical analyses of bulk homogenized samples encompassing 6 varves are plotted versus calendar years BP (Fig. 7.12). Usually diagrams of element concentration show the general pattern of changes of sedimentation and diagenesis conditions. In continental environments both of them are strongly influenced by climate variations.

The Younger Dryas deposits in Lake Gościąż are distinguishable by their high concentration of Mn (Fig. 7.12). The uppermost sediments of the core investigated from the central part of Lake Gościąż contain up to 12 weight per cent of Mn. The Mn content of the underlying deposit is even higher, up to 20 weight per cent (Pawlikowski 1990) – as high as in the Mn-ores.

The Fe content (Fig. 7.12, about 4–5 weight per cent) is lower than Mn concentration, and the value of the Mn/Fe ratio (2.5–3.5) exceeds by two orders of magnitude the mean Mn/Fe ratio for shales (Perelmann 1977). The processes controlling the mobility and distribution of Mn and Fe in sedimentary environments depend on the factors causing the decrease of redox potential and/or the increase of acidity (Balistrieri et al. 1992, 1994, Søresen & Jørgensen 1987, Young & Harrey 1992). Because Mn solubility exceeds that of Fe, for any given Eh and pH value, the separation of these elements occurs during soil formation processes, lacustrine deposition, or diagenesis of lacustrine sediments (Borchert 1970, Crerar et al. 1971/72). Soil-formation processes due to mineralization of organic matter create acidic-reducing conditions with-