whole area has been planted with trees until the middle of the sixties, and the lake shore itself by the middle of fifties (1954–56). During forestation, however, the non-forested area of abandoned farms was still used by inhabitants of neighbouring villages who planted cereals and vegetables there.

Only a few elemental disasters from the last two centuries are known to struck the area. In 1921, an especially strong fire destroyed ca. 400 buildings in Kowal and was moved by wind to the next village, ca. 2 km away (Zimecki 1990). The forest fires are not mentioned in written sources. According to Zjawiński (oral inf.) the strongest one happened in summer 1946 and reached the southern shore of Lake Gościąż. The high flood of the Vistula River has been noted in 1867 (Chudzyński 1990b) and 1934. Cholera epidemics in eastern Kujawy were noted especially in the first half of the 19th century: 1831, 1837, 1847, 1848, 1852 (the strongest), and 1894 (Chudzyński 1990a, 1990b). One may expect that they influenced the population growth at that time.

Generally at the beginning of the 19th century the system of three-year crop rotation (winter crop, spring crop, idle land) was applied in the region (Szczepański 1990). In the second half of century, it was being gradually replaced by the system of shift of crops. At that time, fertilizers (superphosphate) were introduced (Chudzyński 1990a). The production of potassium fertilizers in Łowicz started in 1895–1897. Chudzyński (1990b) mentions the strong failures of potato crops in 1847, 1849, and 1850. However, the details of agriculture development in the immediate surroundings of Lake Gościąż are not reconstructed.

9.2.2. Chronological base and reconstruction of yearly cycles in the Lake Gościąż youngest sediments

Tomasz Goslar[*]

Correlation of the cores frozen *in situ*

The long piston cores of sediment from the central deep of Lake Gościąż show no lamination in the fragment above 1.26 m. This is mostly a result of coring, as it is clearly demonstrated by the occurrence of regular laminations above 1.2 m in the cores of sediment frozen *in situ* (Walanus, Chapter 4.1.2 and Goslar, Chapter 8.1). In the years 1989 through 1993, 20 cores were raised in such a way. Usually tube samplers were used, except of the case of cores G31-33f and G42-43f, collected with the wedge-shape sampler (Walanus, Chapter 4.1.2). The individual cores were 0.22–1.60 m long.

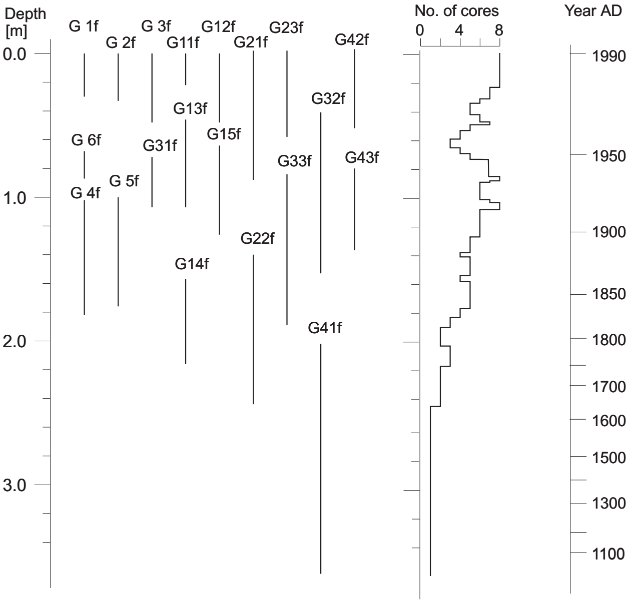

Fig. 9.25. Diagram illustrating the replication of varve chronology in the uppermost sediment from Lake Gościąż, based on the cores frozen *in situ.*

The laminated sequences of all the cores were copied on adhesive tape according to the tape-peel method (Simola 1977, Goslar 1993). The copies are easy to handle and store for a long time, and they were used in precise visual correlation of laminae in individual cores, enabling the construction of continuous, replicated sequence (Fig. 9.25). In that sequence, the characteristic layers are marked in all the cores. The sedimentation rates differ among cores, and the depth scale for the common sequence is an average of all the cores.

Seasonal changes of sediment composition

The seasonal changes of sediment composition along the selected fragments of cores were recognized by microscopic inspection of the tape copies. Each inspected area was ca. 0.5 mm wide, and 200 contiguous areas were analysed per each 10 cm of profile. The main components recognized were chrysophycean cysts, diatoms, carbonate, and organic matter. In each area the chrysophycean cysts and frustules of Centricae (except for *Aulacoseira* sp.) and Pennatae (except for *Fragilaria, Synedra,* and *Asterionella*) diatoms were counted. The frustules of abundant genera of *Aulacoseira, Fragilaria, Synedra*, and *Asterionella* were counted separately. Abundances of calcite and organic matter were expressed as percentages of the microscopic image covered by the carbonate and by organic fragments, and the mean size of calcite grains was determined qualitatively. Additionally, the occurrence of vivianite, pyrite, *Pinus* pollen, and

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[*] The author wishes to thank Dr. J. L. Reyss, Centre des Faibles Radioactivites, Gif-sur-Yvette, France, for providing the unpublished data on ^{137}Cs concentration in the Lake Gościąż sediments. Thanks are also due to Dr. T. Ważny, Academy of Fine Arts, Warsaw, for providing his unpublished data on tree-ring thickness of oak chronologies from Poland. Identification of diatom species dominant in selected laminae was made by Dr. H. Simola, University of Joensuu, Finland.

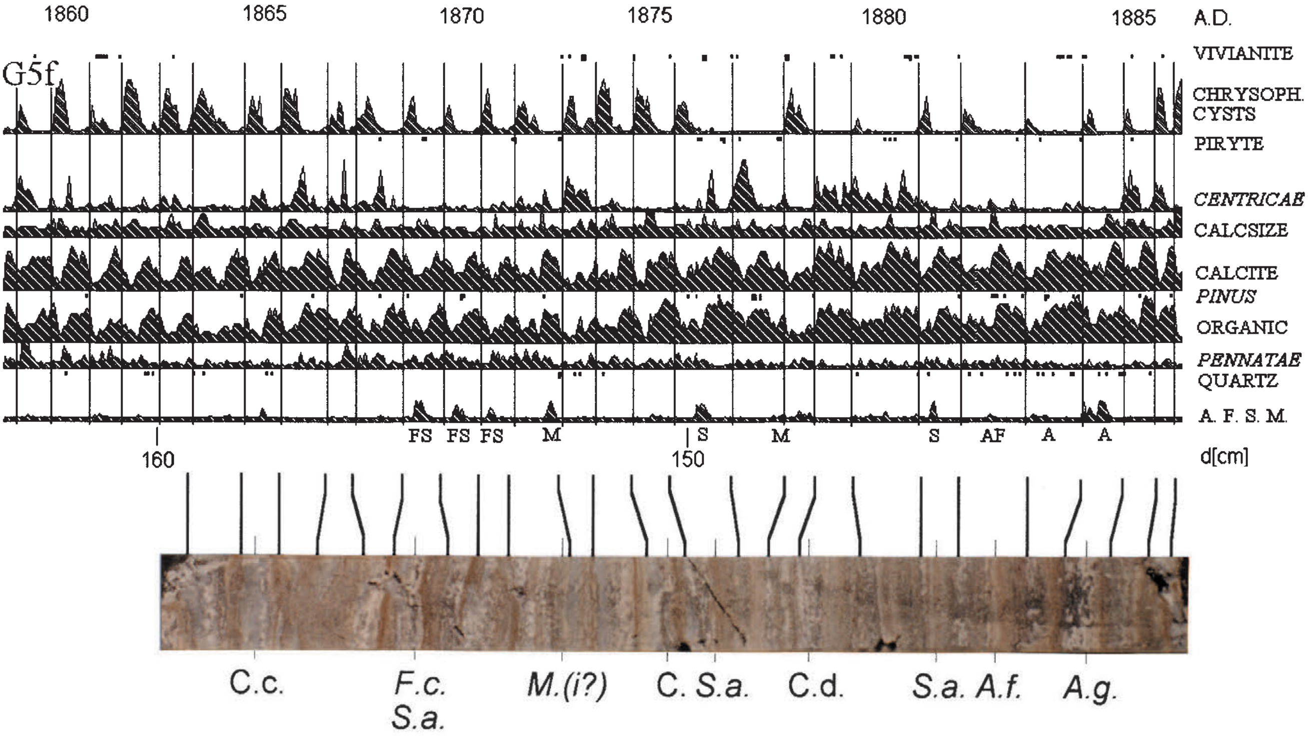


Fig. 9.26. Up: Diagram showing changes of sediment composition in annual cycles, an example from the fragment of core G5f, 140 to 162 cm below the lake bottom. A – *Asterionella*, F – *Fragilaria*, S – *Synedra*, M – *Aulacoseira (Melosira)*. Down: Photograph of considered fragment of the core G5f (replica on an adhesive tape). The dominant components of characteristic laminae are indicated as follow: C.c. – chrysophycean cysts, *F.c. – Fragilaria crotonensis*; *S.a. – Synedra acus*; *M.(i?) – Aulacoseira (Melosira) islandica* ?, C.– calcite, C.d. – centric diatoms, A.f. – *Asterionella formosa*, *A.g. – Asterionella gracillima* (diatom species identified by H. Simola).

quartz was noted. In fragments of the cores G6f and G13f, charcoal fragments were also counted.

A second set of identical tapes was leached for 1 h in hydrofluoric acid, to make easier the identification of organic matter. Comparison of results obtained on both sets of copies show no distinct differences. It also appeared

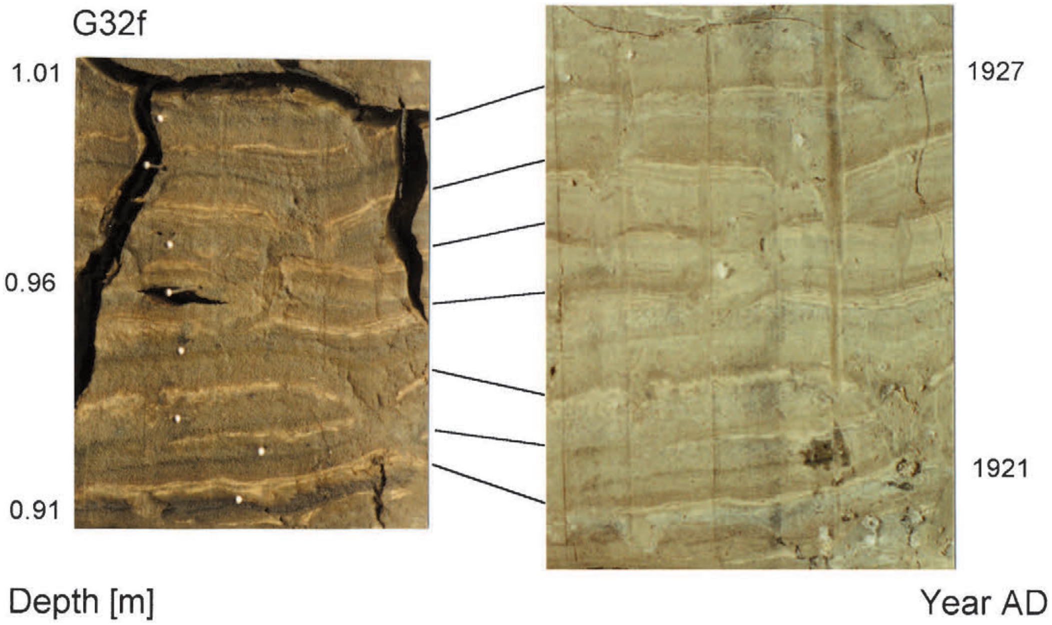


Fig. 9.27. Photographs illustrating the lamination on dried surface of a frozen core (right) and on surface of melted core (left) in the sediment deposited between AD 1920 and AD 1928.

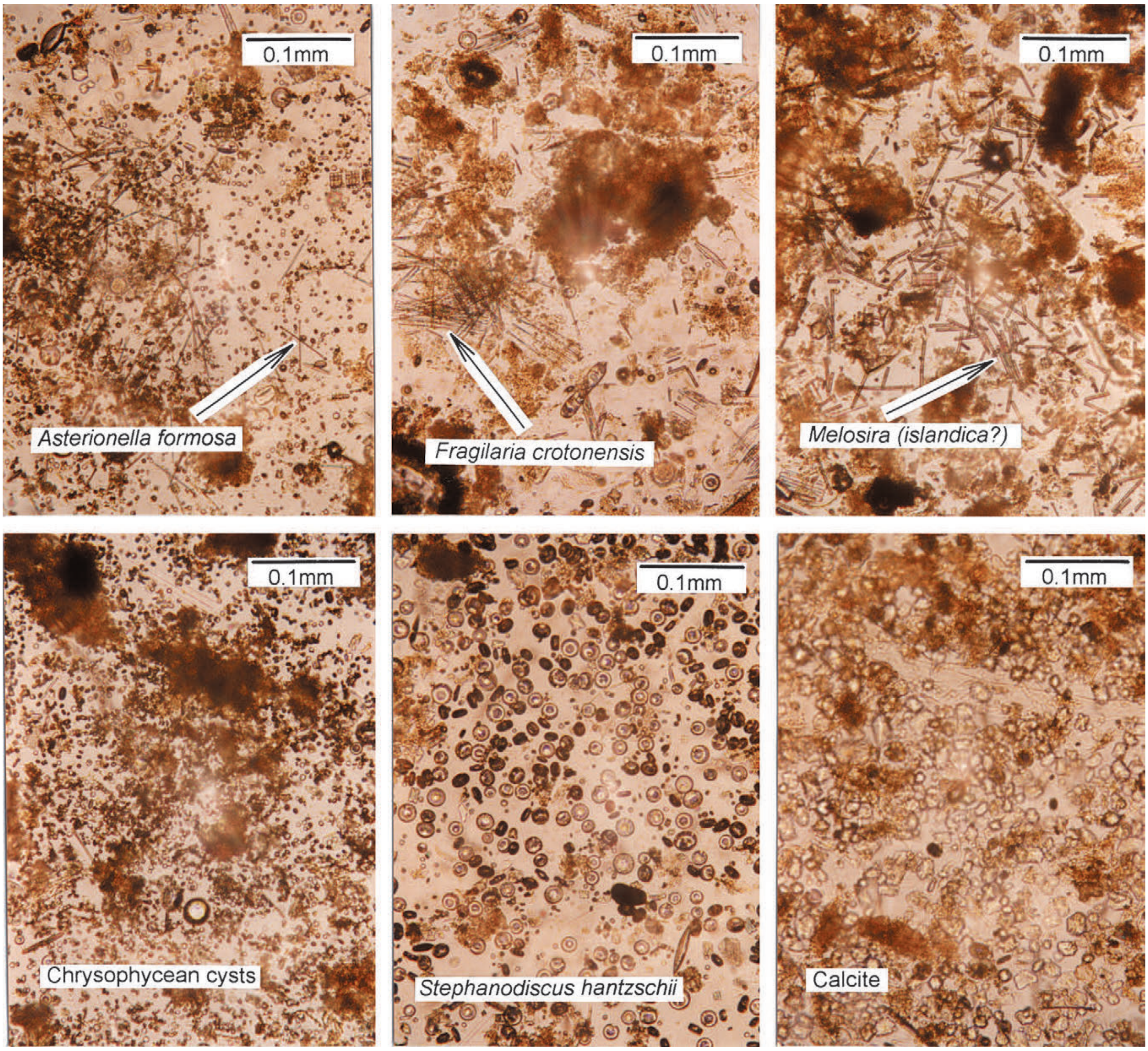


Fig. 9.28. Microphotographs of selected dominant components of the uppermost sediments of Lake Gościąż.

that leaching in HF, which dissolved diatoms and produced white crystals of fluorite in place of the larger calcite grains, made the laminated structure simpler, and hence much easier for varve counting by eye.

The annual cyclicity is most clearly visible in the fragment 140–165 cm (Fig. 9.26). In each cycle (the boundaries are marked by vertical lines) the maximum concentrations of chrysophycean cysts, centric diatoms (mostly *Stephanodiscus hantzschii*, species determination after Simola, pers. comm.), size of calcite grains (up to ca. 20 μm), and concentrations of calcite and of organic matter occur in a succession. It must be mentioned that carbonates in the Lake Gościąż sediment are also abundant in organic layers, but in form of fine grains (<1 μm).

On the melted surface of the core (Fig. 9.27) the layers of diatoms and cysts are grey, yellowish, or greenish, calcite laminae are light cream-coloured, and layers of organic detritus are light brown, dark brown, or almost black, depending on the content of carbonates. After drying, the diatom layers become snow-white (Figs 9.26 and 9.27).

The succession observed in varves of Lake Gościąż sediment is typical of calcareous lamination (Tippett 1964, Kelts & Hsü 1978, O’Sullivan 1983, Saarnisto 1986). The cysts and diatoms were presumably deposited in spring, big crystals of calcite represent summer, and the dominance of organic matter corresponds to the off-season (autumn and winter). Occurrence of spring layers of diatoms and cysts was documented in laminated sediments of many lakes (Geyh et al. 1971, Simola 1977, Saarnisto et al. 1977, Simola & Uimonen-Simola 1983,

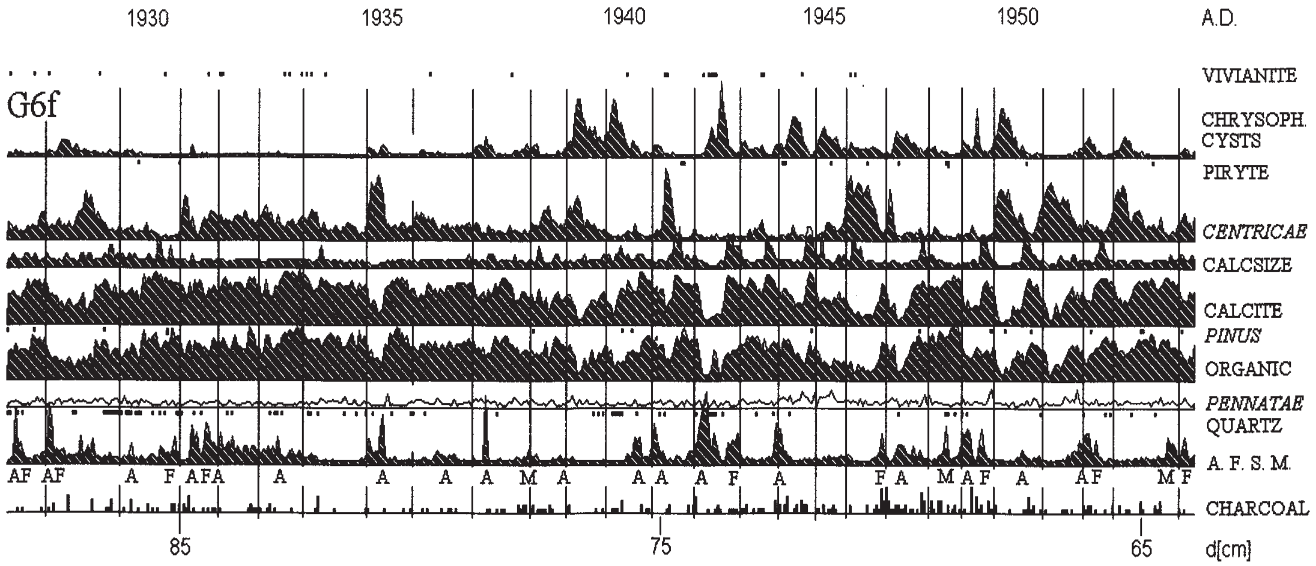


Fig. 9.29. Diagram showing changes of sediment composition in annual cycles, an example from the fragment of core G6f, 64 cm to 89 cm below the lake bottom. A – *Asterionella*, F – *Fragilaria*, S – *Synedra*, M – *Aulacoseira (Melosira)*.

Simola et al. 1990). Observations of seasonal changes of modern phytoplankton in Lake Gościąż (Giziński et al., Chapter 3.5) document blooming of *Stephanodiscus* in spring.

The summer calcite layers were observed in laminated sediments by Merkt (1971) and Lotter (1989). It is commonly accepted that calcite growth in lacustrine environments is caused by supersaturation of CO_3^{2-} ions due to the rise of temperature and/or consumption of dissolved CO_2 by growing phytoplankton (O'Sullivan 1983, Wetzel 1975, p. 170–171). According to Wachniew and Różański (Chapter 3.6) the saturation index in modern Lake Gościąż is permanently high enough to permit precipitation. The mentioned authors observed calcite precipitation between April and October, and, since the accumulation rates of calcite and plankton changed in parallel, it is proposed that the growth of calcite grains in Lake Gościąż is stimulated by seasonal appearance of plankton particles, playing a role of nucleation centers. Analysing the SEM pictures of Holocene sediment, Łącka et al. (Chapter 8.2) pointed to diagenetic reprecipitation of calcite on the surface of other minerals or organic particles. Such an effect might be partly responsible for the occurrence of fine carbonate grains in the off-season layers of young sediment. On the other hand, the almost monospecific composition of layers of big calcite grains (Fig.

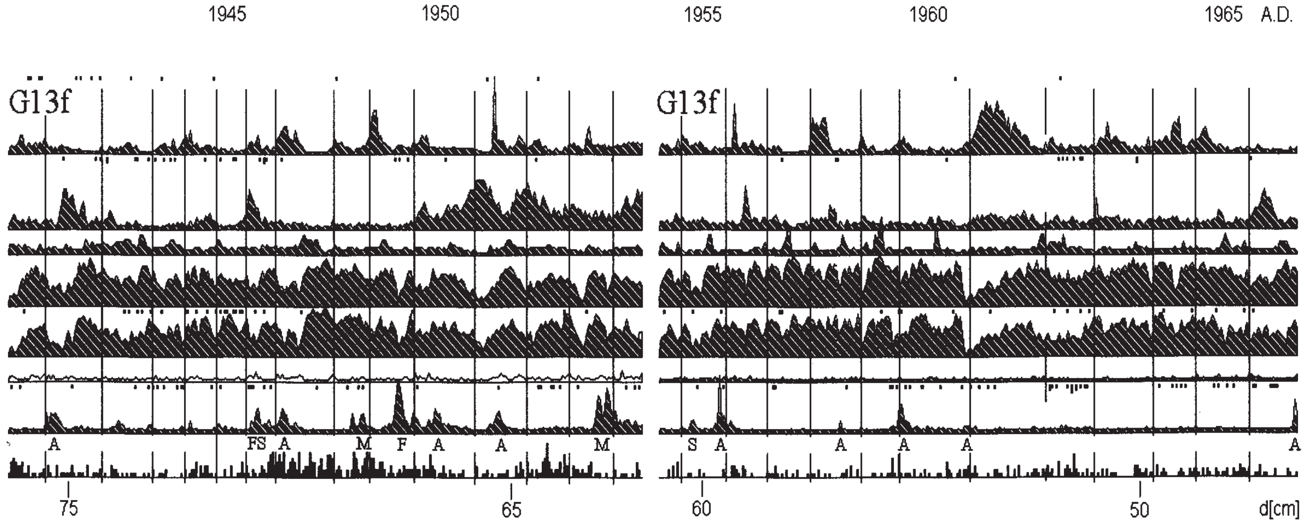


Fig. 9.30. Diagram showing changes of sediment composition in annual cycles, an example from the fragment of core G13f, 46 cm to 76 cm below the lake bottom. A – *Asterionella*, F – *Fragilaria*, S – *Synedra*, M – *Aulacoseira (Melosira)*.

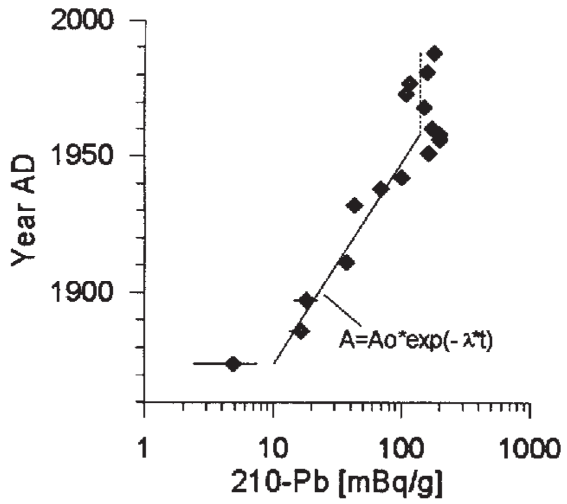


Fig. 9.31. Plot of specific activity of ^{210}Pb in the uppermost sediments of Lake Gościąż (after Wachniew 1993) on the time scale provided by varve chronology.

9.28) does not suggest precipitation depending on other particles. Giziński et al. (Chapter 3.5) have documented a significant role of resuspention in modern sedimentation in the central deep of Lake Gościąż, suggesting that some laminae could be formed by redeposited sediment. However, the upper 50 cm (last 30 yr) of the Lake Gościąż sediment is not laminated (see Goslar, Chapter 9.2.3), and modern observations may be inadequate analogues for the past. Unfortunately, neither Wachniew nor Giziński et al. analysed the grain size of calcite deposited in traps.

Besides the basic annual pattern, some varves reveal extra laminae of diatoms. One can see, (Figs 9.26, 9.28, 9.29, and 9.30) that *Asterionella* (mainly *A. formosa* (Fig. 9.28) and *A. formosa* var. *gracillima*)) occurs mostly in spring, *Fragilaria* (*F. crotonensis*, Fig. 9.28) and *Synedra* (mostly *S. acus*) appear usually in summer, whereas *Aulacoseira* (= *Melosira*, mostly *A. islandica?*, Fig. 9.28) reveals blooms in the autumn season. Similar seasonality in occurrences of *Asterionella formosa* and *Synedra acus* was observed in sediments of Lake Lovojärvi (Simola 1977, Simola et al. 1990). The species of *Aulacoseira* (*A. italica* and *A. granulata*) observed in Lovojärvi revealed maxima later than other diatoms. Also, Wetzel (1975, p. 285) has shown a delay between maxima of *Asterionella* sp. and *Fragilaria* sp. The seasonal pattern in occurrence of observed diatoms seems to confirm the annual character of lamination.

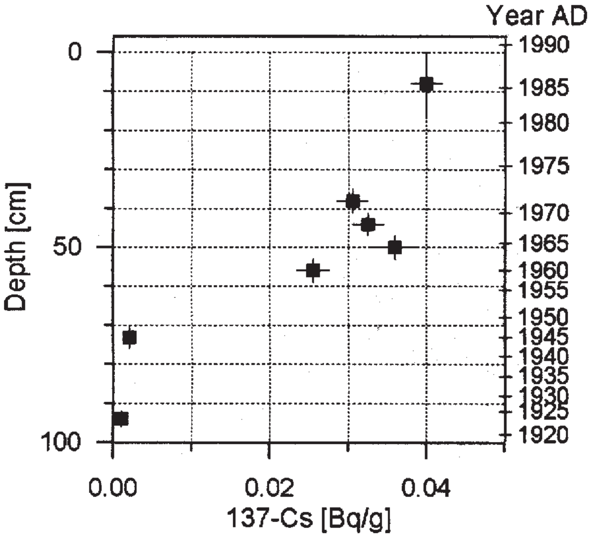


Fig. 9.32. Plot of specific activity of ^{137}Cs (after J. L. Reyss, unpubl.) in the uppermost sediments of Lake Gościąż. The time scale is provided by varve chronology.

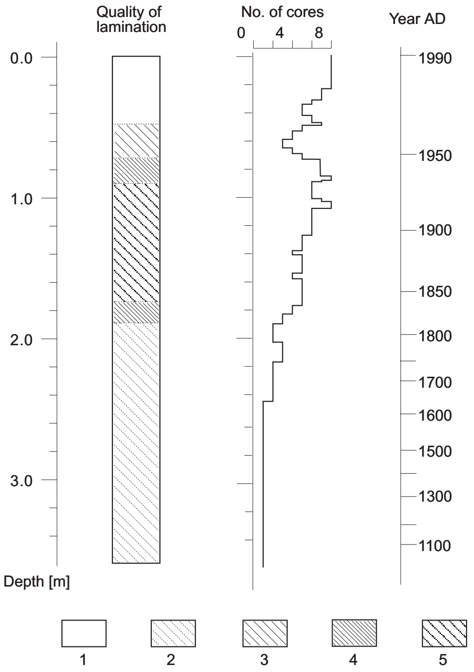


Fig. 9.33. Diagram illustrating quality of lamination in cores frozen *in situ* from the uppermost sediments of Lake Gościąż. 1 – only a few (highly dispersed) layers visible, counting varves impossible; 2 – laminae irregular, wiggly, and in some short fragments invisible, quality of lamination usually worse than in corresponding fragments of cores taken by piston corer (see Goslar, Chapter 8.1); accuracy of varve counting in order of a few per cent; 3 – laminae poorly visible by eye, varve counting possible under microscope; 4 – distinct, wiggly laminae, easy to count by eye; 5 – distinct, regular laminae.

The grains of vivianite ($Fe_3(PO_4)_2$) were usually observed in the second part of the annual cycle (autumn, winter?), especially in core G5f (Fig. 9.26, see also Fig. 9.34), in agreement with the findings from Lovojärvi (Saarnisto et al. 1977, Simola 1977). On the other hand, no seasonality has been observed in the occurrence of other Pennatae diatoms, quartz, pyrite, and *Pinus* pollen grains.

The annual character of lamination has been independently confirmed by the analyses of ^{210}Pb (Wachniew

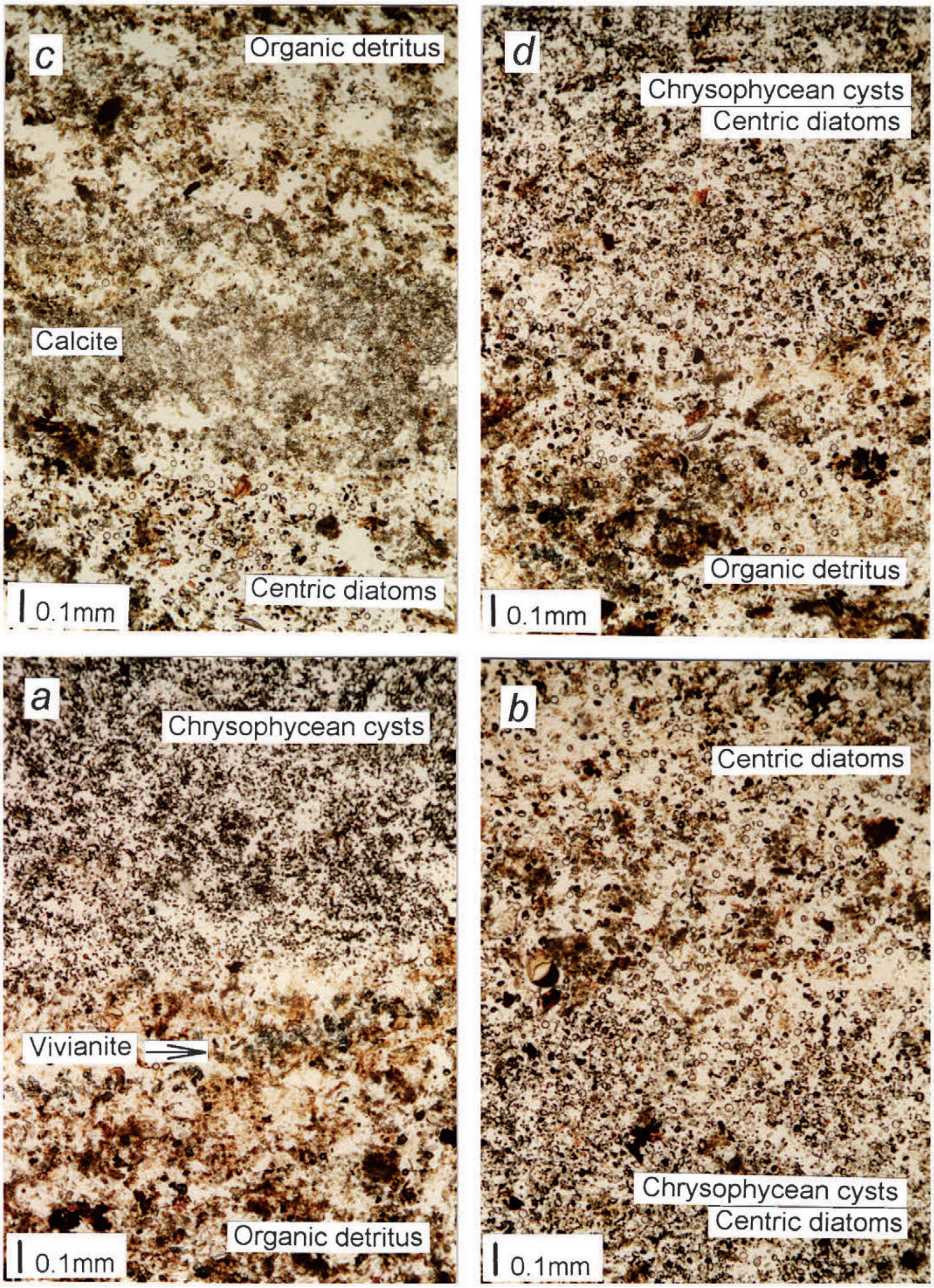


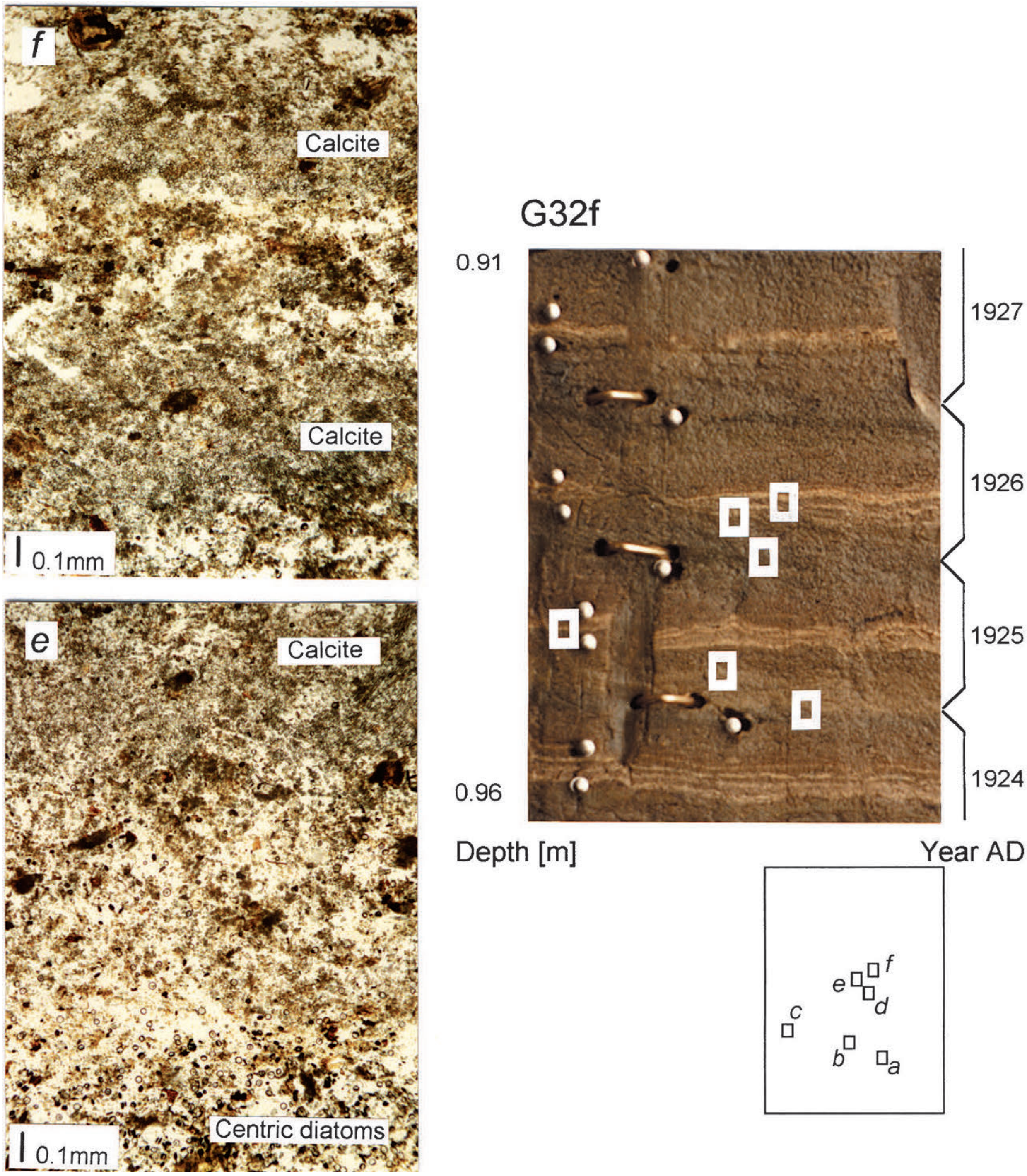
Fig. 9.34. Microphotographs illustrating boundaries between laminae of different dominant components in the varved sediment of Lake Gościąż.

1993). The specific activity of excess lead-210 in Gościąż sediment below ca. 50 cm, shows a reasonable dependence on time if the time scale is provided by varve counting (Fig. 9.31). The non-monotonic ^{210}Pb-depth relationship in the section above 50 cm, where the lamination was not preserved, may be partly explained by resuspension and mixing of sediment and partly by an increased molecular mobility of lead in the youngest part of profile (Wachniew 1993, Goslar, Chapter 9.2.3).

An interesting feature is the two- or three-year periods of higher concentration of *Stephanodiscus*, recurring each ca. 6 years, especially visible in the fragment 140–165 cm (Fig. 9.26) and less clear between 85 and 60 cm (Figs 9.29 and 9.30). Examples of such a cyclicity in other laminated sediments are not known to the author.

Varve chronology of the youngest sediment

Correlation of laminated sequences of individual cores frozen *in situ* enabled the construction of a continuous



The enlarged fragments of varves deposited in AD 1925 and AD 1926 (right) are denoted by letters *a* through *f*.

varve chronology. Unfortunately, varve counting was not possible in the uppermost 47 cm of sediment, where only a few single laminae are visible. Therefore the age of chronology was determined using other markers. They are peaks of concentration of ^{137}Cs and of charcoal.

The analysis of ^{137}Cs is widely used for dating the youngest sediments (Walling & He 1993). The basis for using ^{137}Cs in this context is that radiocaesium is rapidly and strongly bound to fine particulates and that its distribution in the sediment profile directly reflects the chronology of sediment deposition. The significant total annual fallout of radiocaesium since the middle of the 1950s is related to the tests of nuclear weapon and shows maxima in 1959 and between 1962 and 1964, and a drop to very low values after 1965 (Cambray et al. 1982). Because bomb-radiocaesium was injected into stratosphere, its worldwide distribution is rather uniform. A second substantial fallout took place in 1986, after the Chernobyl accident (Higgitt et al. 1992), but it was spread over a limited area. The profile of ^{137}Cs concentration in the

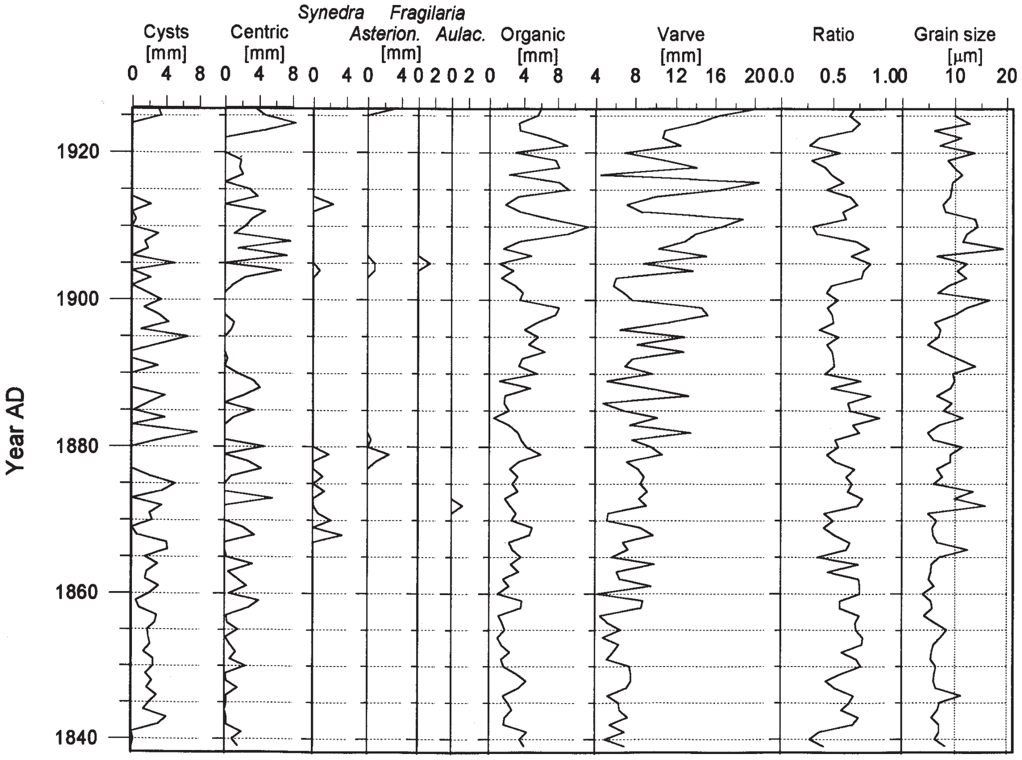


Fig. 9.35. Diagram showing thickness of layers of different dominant components. Varve = whole varve thickness. Ratio = ratio of thickness of diatom+calcite (light) layer to whole varve (light+dark), and mean grain size in calcite layers, in the fragment of Lake Gościąż sediment deposited between AD 1839 and AD 1926. *Asterion. – Asterionella*, *Aulac. – Aulacoseira (Melosira).*

Lake Gościąż sediments (J. L. Reyss, pers. comm., Fig. 9.32), shows a single broad bomb maximum around 50 cm, and also a high value in the uppermost sample, probably related to Chernobyl accident.

The wide bomb-caesium maximum in Lake Gościąż may only partly reflect integration of ^{137}Cs signal in thick samples. Unclear separation of bomb ^{137}Cs peaks and lack of substantial reduction towards the surface is common in lacustrine sediments (Walling & He 1993). Explanations involve molecular diffusion (Davis et al. 1984), resuspension and focusing of deposited sediment (Brunskill et al. 1984), or the influence of delayed inputs of radiocaesium from the drainage basin of the lake (Miller & Heit 1986). The small area of Gościąż drainage basin suggests that the majority of the radiocaesium in Lake Gościąż descended from direct atmospheric fallout, and that the delayed input from the surrounding soils is negligible. This seems additionally confirmed by the small content of allochthonous matter in the sediment. A contribution of soil inwash may also be estimated from the total inventory of ^{137}Cs in the Gościąż sediment. Because of scarcity of data points and the not precisely determined dry-sediment density (0.1–0.15 g/cm^3), it may be only roughly estimated to 150–400 mBq/cm^2. Comparison of that estimate to total atmospheric fallout of 285 mBq/cm^2 recorded in two British lakes (Walling & He 1993), where no influence of Chernobyl was noted, and to 800 mBq/cm^2 recorded in soils from Polish Carpathians (Froehlich et al. 1993), where ca. 50% of total fallout was that of Chernobyl, supports hypothesis that the input of radiocaesium from the drainage basin is small. The most probable explanation for the smooth ^{137}Cs profile is thus the resuspension and focusing of deposited sediment. The effects of resuspension could be especially strong after the middle of the 1960s, when the lamination disappeared. Resuspension in the recent Lake Gościąż sediments was investigated by Giziński et al. (Chapter 3.5).

About 20 cm below the peak of ^{137}Cs, a maximum of charcoal concentration was documented in two cores (Figs 9.29 and 9.30). This was attributed to the strongest known forest fire, in spring 1946, which reached the southern shore of Lake Gościąż (Goslar, Chapter 9.2.1). It must be stressed that the dating of the varve sequence by caesium peak and by charcoal maximum support each other. According to Clark (1988a, 1988b), local forest fires are well documented in lacustrine sediments by charcoal fragments bigger than 50 µm, while the small fragments (5–20 µm) may be transported over long distances. The charcoal maximum in the Lake Gościąż cores is shown by large (up to 150 µm) as well as small fragments (above 15 µm). The broad charcoal maximum extends over three years. It remains unknown, if single fire could raise charcoal concentration in the sediment through a few years; nevertheless Clark (1988b) mentions such a possibility.

Relying on the charcoal marker, the level of 71 cm was dated to 1946. Accordingly, the youngest clear varve (47 cm) was dated in 1966, and mean accumulation rate in the last 30 yr was estimated to ca. 1.6 cm/yr. The direct comparison of cores raised in May 1990 and March 1991 indicated an increment of ca. 2 cm, in rough agreement with estimated mean deposition rate, especially if the effects of sediment compaction are taken into account.

The chronology of sediment above and below 71 cm was constructed by counting varves in correlated frozen cores. In most of the cores, the varves were identified by eye, relying on the pattern of seasonal cyclicity recognized in fragments of cores G5f, G6f, and G13f. In fragment 175–92 cm, varve identification was supported by a qualitative microscopic analysis of dominant sediment components in a single core. The quality of lamination in frozen cores varies with depth (Fig. 9.33). Below ca. 190 cm, the laminae are bent, in some fragments the light layers are hardly visible, and in some sections on the core surface only individual agglomerates of carbonate occur, which do not form any continuous layers. In this fragment the use of the freezing technique did not improve preservation of varves in comparison with conventional coring, and the error of chronology is the same as discussed in Chapter 8.2. The regular laminae occurred between 190 and 47 cm, but between 75 and 47 cm they were hard to interpret when not analysed under the microscope.

The record of laminae thickness

Between 1.75 and 0.92 m the sediment composition was analysed qualitatively under microscope. The sections with several dominant components were distinguished. The components were chrysophycean cysts, centric diatoms, calcite grains, organic matter, and other diatoms and vivianite crystals. In some varves a significant amount of organic matter was observed through the whole varve. Besides the basic laminae of large coarse calcite, the large grains were also dispersed in many layers of centric diatoms. They were presumably rebedded from another parts of the lake during spring. The boundaries between sections with different dominants were illustrated in Fig. 9.34. Thickness of each section was measured with an accuracy of 0.1 mm. Moreover, the size of 20 typical grains was measured in each calcite layer. The thickness of separate sections of each varve is plotted in Fig. 9.35. For individual components, only the sections with distinct dominance of a single component were displayed. The analysed sequence spans between AD 1839 and 1926.

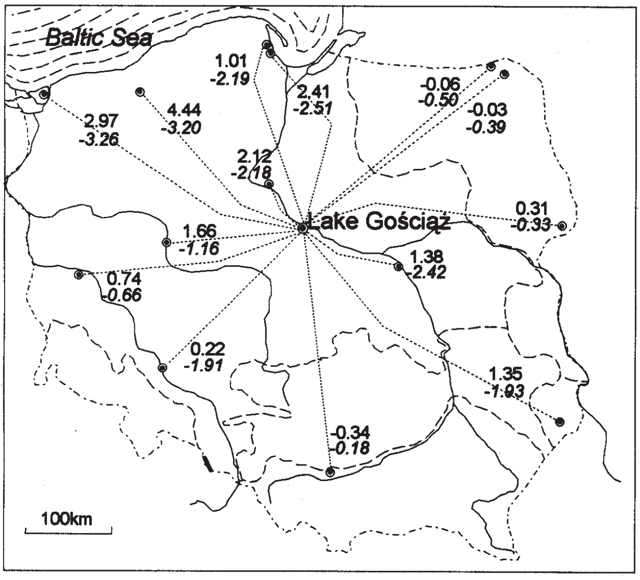


Fig. 9.36. Map illustrating the correlation between sequence of laminae thickness from the Lake Gościąż sediment and tree-ring thicknesses of oak chronologies from several localities in Poland. The correlation is expressed in terms of t-values (see text). Upper numbers: t-values for the ratio of light to light+dark laminae thickness, lower numbers: t-values for the whole varve thickness. The boundaries between main geographical regions in Poland (Kondracki 1978) are denoted by dashed lines.

The varve thickness shows a general increase towards the top of the sediment. Besides the trend, abrupt increases of sedimentation rate took place in 1864, 1882, 1893, and 1904. The increase of deposition rate is accompanied by a decline of chrysophycean cysts, which, according to Smol (1985), probably reflects lake eutrophication. First increase occurred together with the blooms of *Synedra*, *Asterionella*, *Fragilaria*, and *Aulacoseira* (*Melosira*) diatoms. It has been suggested that an Araphidinae-to-Centriceae ratio of 2 indicates eutrophication (Stockner 1971). This suggestion was confirmed by extensive investigations of Lake Ahvenainen (Tolonen 1978), where the highest level of eutrophication corresponded to the maximum occurrence of Araphidinae diatoms. In Lake Gościąż the Araphidinae diatoms were developing in the early stage of eutrophication, and after 1928 until 1960 (Figs 9.29 and 9.30). Also between 1860 and 1870, the regularity of very distinct dominance of a single component in each layer, was broken. The regular dominance of cysts in the beginning of the annual cycle ended between AD 1876 and 1877. The distinct change of sediment composition in the seventies of the 19th century is documented better by the quantitative analyses (Figs 9.26, 9.29, and 9.30). The appearance of vivianite from 1873 on (Fig. 9.26) is followed by an increase of varve thickness and distinct decrease of chrysophycean cysts after 1877. All observed changes could then indicate eutrophication of Lake Gościąż between 1873 and 1878. An increase of lake productivity corresponds also to the distinct change of radiocarbon concentration in the carbonate fraction between 160 and 150 cm to 150 and 140 cm (Goslar et al. 1992). In all probability, eutrophi-

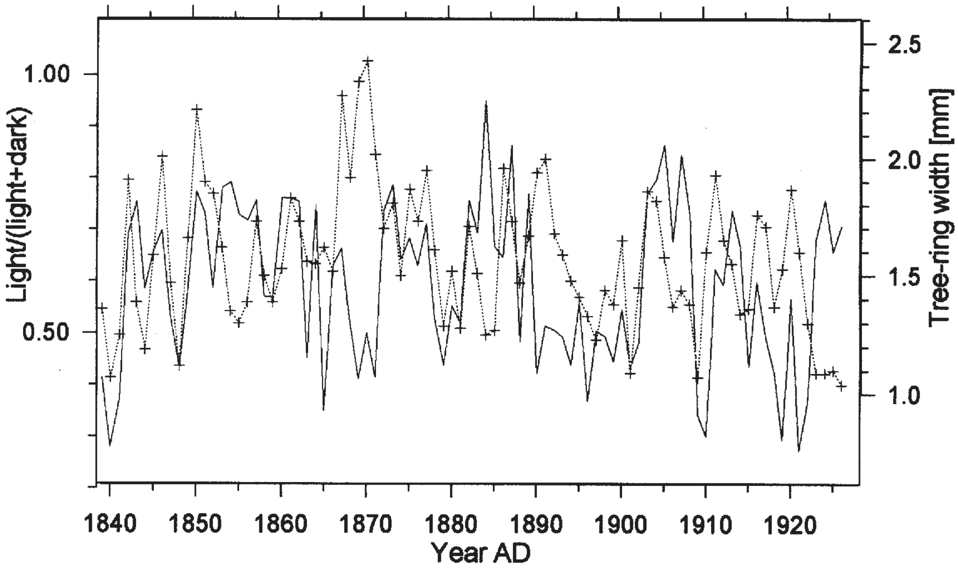


Fig. 9.37. Plot of ratio of light/(light+dark) laminae thickness from Lake Gościąż (thick line), in comparison with tree-ring widths of oaks from Koszalin (thin line) (t = 4.44).

cation was connected with the settlement of village Dąb Borowy (Goslar, Chapter 9.2.1) in the near vicinity of the lake.

Some decrease of trophy is indicated at the depth of 76 cm (Figs 9.29 and 9.30) by a rise of Chrysophyceae concentration and decline of varve thickness, followed by an almost total extinction of vivianite in AD 1946. It might reflect the reduction of agricultural activity after farms were abandoned near the lake.

Short-term variations of laminae thickness were compared with those of tree-rings. For each varve, the sequences of thickness of light layer (i.e. that containing cysts, centric diatoms, and coarse calcite), dark layers (i.e. that of organic matter, deposited after calcite layer), light+dark, and the ratio of light/(light+dark) layers were compared with the sequences of tree-ring widths from 14 local oak chronologies from different regions of Poland (Ważny 1990, and pers. comm.). The correlation is reasonably dependent on geographical location of oaks (Fig. 9.36), showing the highest similarity of Gościąż sequences with those of oaks from the regions situated along the NW-SE transect of Poland. The best case of correlation is illustrated in Fig. 9.37. The documented positive correlations between tree-ring width and light/(light+dark) ratio as well as negative correlation between tree-ring width and organic varve thickness were the basis for searching for the correlation between the varve sequence from the Subboreal chronozone and the German oak chronologies (Goslar, Chapter 6.3). The mechanism linking tree-ring thickness and varve thickness parameters has not been resolved. According to Ważny (1990), the oaks in sequences from northern, western and eastern Poland respond positively to summer precipitation. The dependence of oak growth on temperature is less clear, e.g. the oaks from northern Poland show significant positive response to the temperature of May, while those from eastern Poland seem to respond negatively to the temperature of June. The record of varve thickness was also compared with the instrumental records of monthly air temperature and the sum of precipitation, but no significant correlation was found.

9.2.3. Anthropogenic changes in the chemical composition of the Lake Gościąż sediments

Tomasz Goslar

The seasonal variations of sediment composition, described in the previous section, were used to study the annual cycle and to construct the calendar chronology of sediments. Climatic and anthropogenic environmental variations are recorded in the sediment on a longer time basis. The composition of sediment may then reflect the human- and climate-driven changes of conditions in the lake catchment as well as in the lake itself. Here the time relationship between known anthropogenic events or climatic variations and the changes of chemical composition of sediment are presented.

In this study, the contents of organic matter, calcium carbonate, 14 elements, and accumulation rate were analysed.

For single varves between AD 1821 and 1955, the content of organic matter and carbonate was determined by the loss of sample mass during heating for 3h in 550°C (LOI = loss on ignition) and 900°C, respectively. The initial mass of dry sample was determined after heating in 130°C. In calculations it was assumed that all carbonate is that of calcium. The previous analyses, made on