result of poor mixing or the Poisson or binomial error in counting, an error getting higher with increasing total influx. It is not to be expected, however, that there is a quasi-periodic pattern in these errors in *Lycopodium* counts. Summarising, there is probably dependence of pollen influxes, but most probably no dependence of the power spectra for influxes of different taxa.

Unfortunately it is not possible to test the influence of over-representation or under-representation of *Lycopodium* on dependence of different taxa in the frequency domain, since it is impossible to separate the role of sample volume and representation in fluctuations of *Lycopodium* counts.

Lack of significance

We would like to make some remarks on the fact that we did not find any globally significant quasi-periodicity in pollen-influx data from the Gościąż sediments. It has to be stressed that both the very long varve chronology and the pollen content of the sediment have been studied and determined very carefully and in great detail. This combination of factors makes the palynology of the varve-dated Gościąż sediments one of the most interesting and reliable palynological data-sets available, particularly for time-series analysis purposes. Before this study several authors have attempted to find patterns in time series of different aspects of the Gościąż sediments (Walanus 1989a, 1989b, Young 1997). Although at selected parts of the varve time-series indications of quasi-periodicities or other patterns exist, in none of the articles the authors would claim to have found significant patterns in the time-series. Also the results of the present study on pollen influxes contain indications for quasi-periodicities, but none of these quasi-periodicities is (globally) significant.

The fact that careful analysis of such precise and reliable data does not result in significant patterns indicates that researchers working with palynological or other soil-related data that have a less precisely known time basis should not expect too significant quasi-periodicities and also should be very careful in interpreting the outcome of any time-series analysis. For even if the results contain seemingly (globally) significant quasi-periodicities, these might be caused by quasi-periodic patterns in the sedimentation rate instead of in pollen, vegetation, or climate, or they might be artifacts of the reconstructed time basis.

Conclusions

In power spectra for pollen influxes in sediment cores of Lake Gościąż, representing the period of ca. 7800–4600 cal BP, only few powers are pseudosignificant, and none is globally significant, taking into account the number of spectra and powers calculated. However, at some periods remarkably many power spectra show a peak. This suggests that there may be quasi-periodic patterns in behaviour of many taxa, for which a common cause may exist. A quasi-periodicity of 400 years appears to occur, which may be explained by fluctuations in water level or water table, probably caused by fluctuations of precipitation or temperature. Also a quasi-periodicity of 800 years appears to be present, for which we suggest fluctuations in summer temperatures or windiness as possible explanations. Indicated quasi-periodicities of 128 and 533 years might be explained by forest clearance and subsequent extensions of grass or heath. Another explanation for the 533-year quasi-periodicity might be a relation with North Atlantic deep-water flux oscillations. We could not relate indicated quasi-periodicities of 200 and 267 years to any anthropogenic or climatic mechanism, whether linked to solar activity or not. Our results indicate that researchers working with palynological or other soil-related data that have a less precisely known time basis than the Gościąż data should not expect too significant quasi-periodicities and also should be very careful in interpreting the outcome of any time-series analysis.

8.8. DISCUSSION OF THE HOLOCENE EVENTS RECORDED IN THE LAKE GOŚCIĄŻ SEDIMENTS

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Just as for the Late-Glacial period (Chapter 7), this chapter summarizes the Lake Gościąż data presented in Chapters 8.1 through 8.7, combined in the form of a table (Tab. 8.9). It illustrates the most distinct events and processes documented by data of different types on the common time scale. The construction of the table is the same as for that shown in Chapter 7.8.

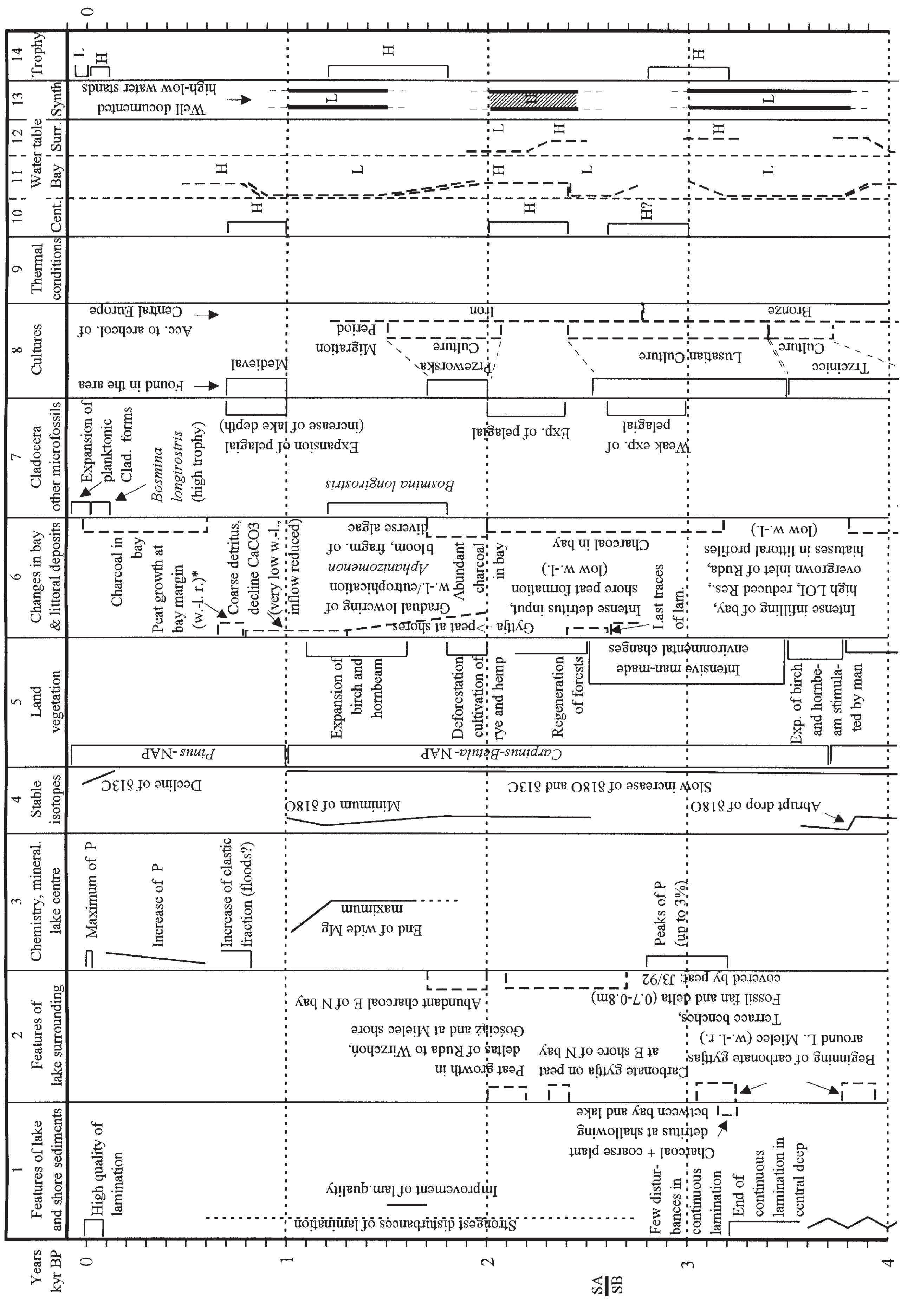
The discussion below is a natural continuation of the Late-Glacial synthesis (Chapter 7.8), which ended at the Younger Dryas/Holocene transition. To cover the whole Holocene, we decided to repeat here the description of that transition, though in somewhat more condensed form.

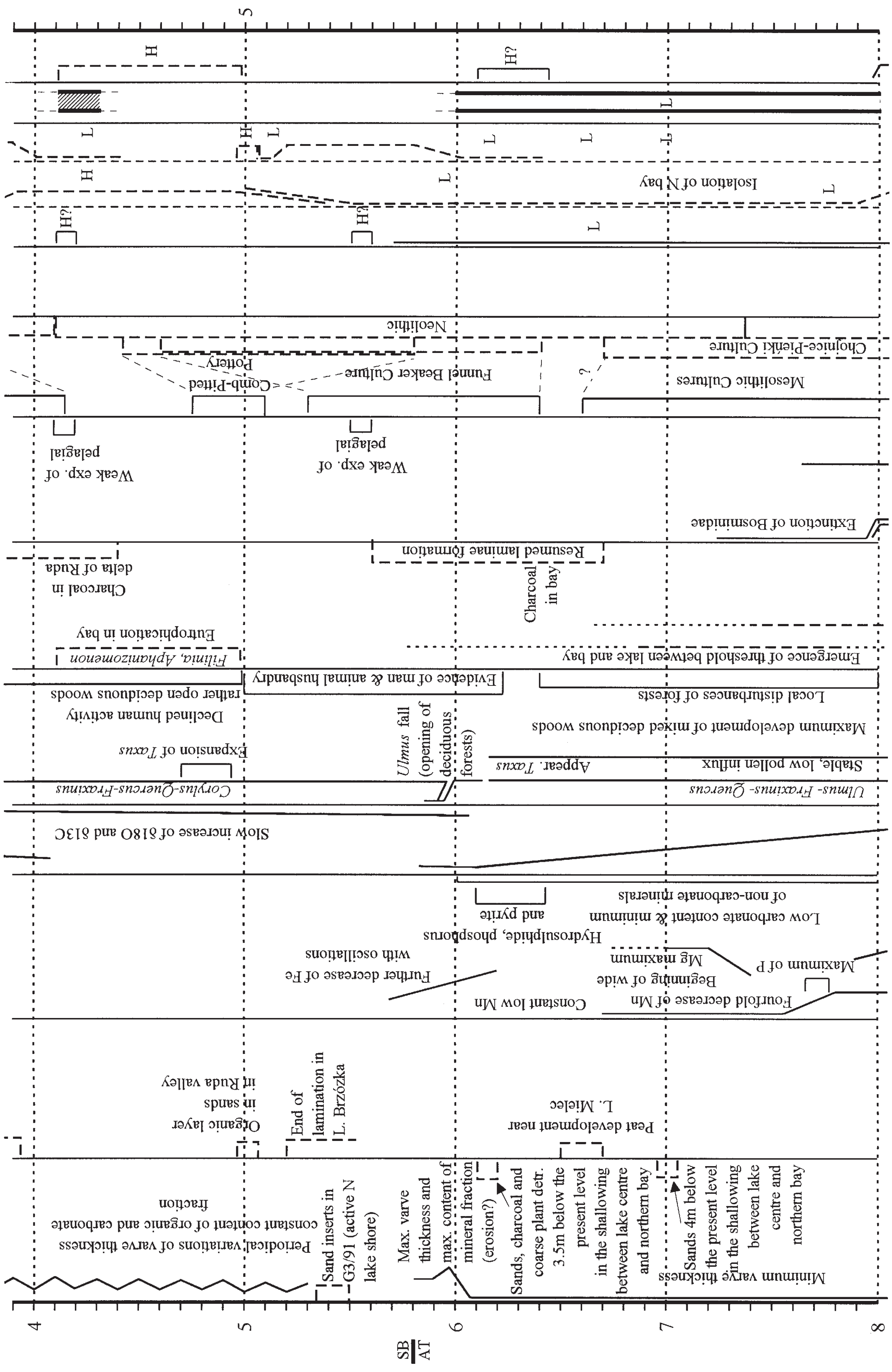
In this table, however, some included data come from the Demske's Ph. D. thesis (1995) which will be published in the second part of Lake Gościąż Monograph. We decided to do so, because these data seemed to be essential for understanding the complete basic image of environmental changes.

Younger Dryas/Holocene transition (11,510 cal BP)

The Younger Dryas/Holocene transition was marked by the rapid rise of the δ^{18}O curve and blooms of *Te-*

Table. 8.9. List of more important information derived from individual studies on Lake Gościąż setting and sediments – the Holocene.




4
5
6
7
8
SB
AT
H
H?
L
H?
Isolation of N bay
Neolithic
Chojnice-Pieńki Culture
Mesolithic Cultures
Funnel Beaker Culture
Comb-Pitted
Pottery
?
Weak exp. of
pelagial
Extinction of Bosminidae
Resumed laminae formation
Charcoal in
delta of Ruda
Charcoal
in bay
Eutrophication in bay
Filinia, Aphanizomenon
Emergence of threshold between lake and bay
Evidence of man & animal husbandry
Local disturbances of forests
Declined human activity
rather open deciduous woods
Maximum development of mixed deciduous woods
Expansion of Taxus
Ulmus fall
(opening of
deciduous
forests)
Appear. Taxus
Stable, low pollen influx
Corylus-Quercus-Fraxinus
Ulmus- Fraxinus- Quercus
Slow increase of δ18O and δ13C
Low carbonate content & minimum
of non-carbonate minerals
Hydrosulphide, phosphorus
and pyrite
Further decrease of Fe
with oscillations
Beginning of wide
Mg maximum
Maximum of P
Constant low Mn
Fourfold decrease of Mn
Organic layer
in sands
in Ruda valley
End of
lamination in
L. Brzózka
Peat development near
L. Mielec
Periodical variations of varve thickness
constant content of organic and carbonate
fraction
Sand inserts in
G3/91 (active N
lake shore)
Max. varve
thickness and
max. content of
mineral fraction
(erosion?)
Sands, charcoal and
coarse plant detr.
3.5m below the
present level
in the shallowing
between lake centre
and northern bay
Sands 4m below
the present level
in the shallowing
between lake
centre and
northern bay
Minimum varve thickness

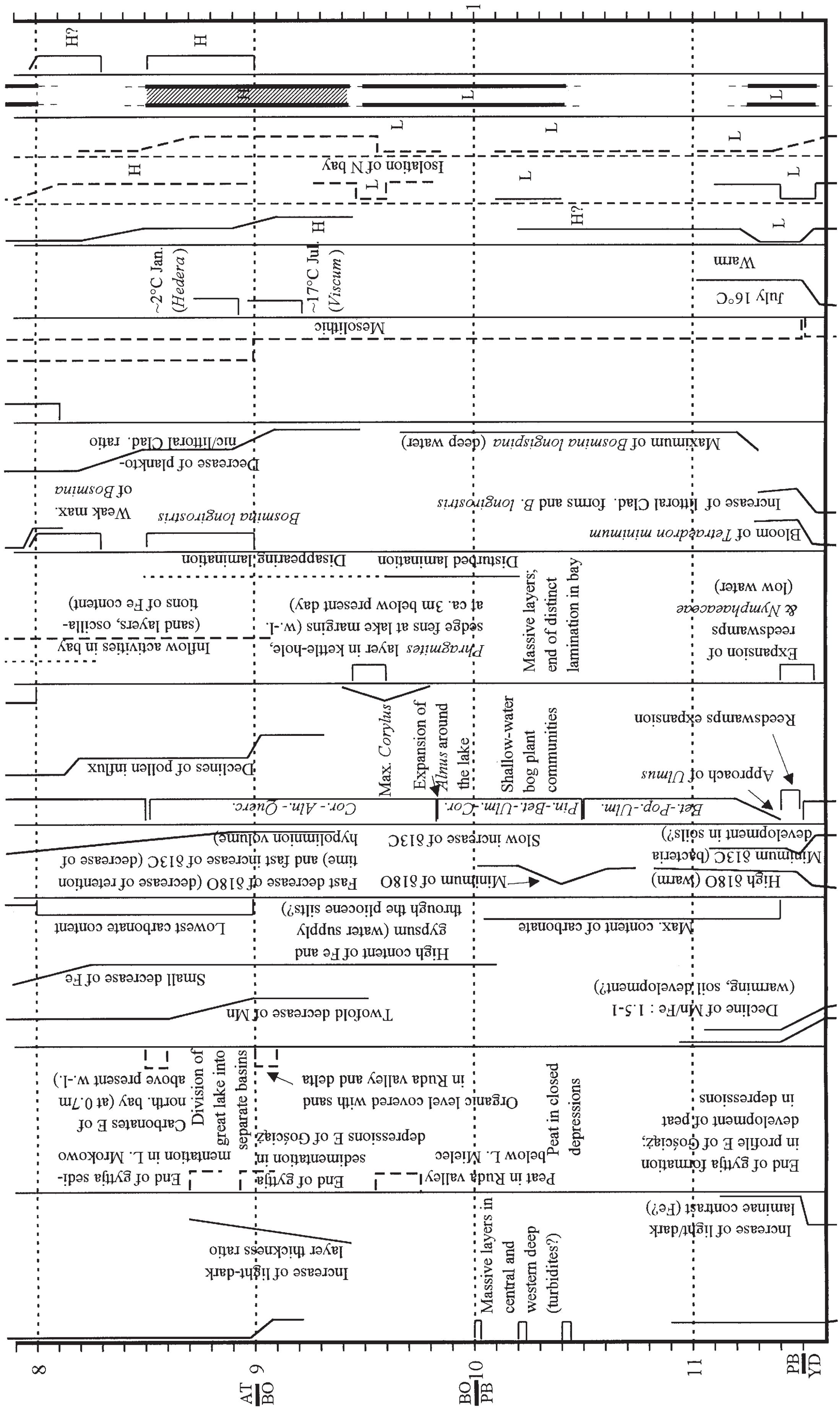


Table 8.9. Continued.

traedron minimum, indicating rise of mean annual temperature by more than 5°C within 70 years. In land vegetation, it is characterized by a reduction of xeric grasslands with *Juniperus* shrubs and *Artemisia*, and spread of *Populus* and tall herbs of humid habitats with *Filipendula, Urtica*, etc. followed by expansion of *Betula* and first appearance of *Ulmus* trees. The warming and expansion of forests led to development of oxygen-poor soils (indicated by the rapid decline of Fe/Mn ratio and temporary drop of the $\delta^{13}C$ values in the sediments), which inhibited input of detrital material to the lake (drop of varve thickness and definitive disappearance of aluminium from the sediments). Enhanced evaporation and evapotranspiration, coincident perhaps with increase of soil permeability, resulted in shallowing of lake water. This shallowing was rather temporary, as documented by the population growth of littoral Cladocera species followed by development of *Bosmina longispina*, as well as a short-lasting expansion of reedswamps and Nymphaeaceae, in the shallower parts of lake. The absolute water level was lowered, as indicated by the end of gyttja formation and peat development in depressions around the lake.

Preboreal chronozone (11.5–10.0 kyr BP)

The climatic warming (and perhaps also increase of precipitation) at the onset of Holocene probably triggered enhanced flow of groundwater rich in carbonate ions through the lake, which led to the maximum carbonate content in the sediments. The inflow of highly mineralized groundwater strengthened thermal stratification of lake water, which might have caused, together with increase of biological productivity, an extreme oxygen deficit in the hypolimnion and maximum content of iron in the sediments (high contrast of light and dark laminae). The water table, however, was initially low, and closed depressions became filled by peat deposits. In this chronozone, two stages of forest development can be distinguished: the older stage (11.5–10.5 kyr BP) was characterized by expansion of *Betula*, *Populus*, and later also the appearance of *Ulmus*. Its pollen, reflecting approach of elm trees, was recorded slightly earlier in the lake centre by the regional pollen rain than in northern bay, where mostly pollen of local vegetation was deposited. During the younger stage (10.5–10.0 kyr BP), *Pinus* became dominant and *Corylus* appeared. The approach of *Corylus* was also detected earlier in the lake centre (ca. 10.6 kyr BP) than in the northern bay (10.45–10.3 kyr BP). The high abundance of limno- and telmatophytes after 10.5 kyr BP indicates decrease of water depth, which disabled further formation of regular laminae in the northern bay (Demske 1995). In the central and western deeps of the lake the continuous laminated sequences were disturbed several times by deposition of massive layers. Some lowering of $\delta^{18}O$ of sediment carbonates at that time might have been related to the decrease of water residence time in the lake. In the course of filling the lake basins with sediments, the ratio of hypolimnion/epilimnion volumes gradually decreased. This process was responsible for the increasing trend of $\delta^{13}C$ in sediment carbonates through the whole Holocene.

Boreal chronozone (10.0–9.0 kyr BP)

In the early Boreal, after ca. 9850 cal BP, deciduous forests of different types began to develop. This period is characterized by maximum pollen influx, as the still easy penetration of light through the open canopies stimulated intense flowering. The progressive warming is evidenced by the appearance of *Viscum* (mean July temperatures >17°C) at ca. 9200 cal BP. The very fast expansion of *Alnus* around the lake might have contributed substantially to the distinct lowering of water level. As indicated by the formation of sedge fens at the lake margin (Demske 1995), it might have been lowered by about 3 m. Due to that lowering, the deposition of gyttja in Ruda valley below Lake Mielec was interrupted by peat growth. Ca. 100–200 years later the high water level was restored, as documented by renewed gyttja formation below and around Lake Mielec. Some organic lenses in the eastern lake shore date from the late Boreal. The sand deposits in Ruda valley, contributing to the formation of its delta to Lake Gościąż, date also from this time.

Atlantic chronozone (9.0–5.8 kyr BP)

Around the Boreal/Atlantic transition winter seasons became milder, as documented by the appearance of *Hedera* pollen at ca. 8950 cal BP (January temperatures >2°C). The significant changes in hydrology of the area occurred then also. Development of peats in the Ruda valley marks the ultimate division of one big lake into separate basins (Lake Wierzchoń, Brzózka, Gościąż, and Mielec). This was partly caused by a general rapid drop of water table, ending the gyttja sedimentation in depression to the east of Lake Gościąż and in Lake Mrokowo. The inflow of carbonate-bearing groundwater to Lake Gościąż was significantly reduced, as reflected in lowering of carbonate content in the sediments to its minimum value. Nearly simultaneously with the lowering of water level the first decline of pollen influx is observed. It resulted from increasing density of forest canopies, reducing tree flowering, and probably also from the lowering of water level itself. The diminution of the water body (decreasing ratio of planktonic/littoral Cladocera), the closing of deciduous forests, and increase of temperature were probably the reasons for increase of lake trophy, as documented by growing populations of *Bosmina longirostris*. Short-lasting period of higher water level in the middle of the 9th millennium BP (documented by carbonate concretions found east of the northern bay) coincided with the temporal decrease of *Bosmina* abundance. In spite of a lower content of carbonate ions, intense biological productivity in spring and summer stimulated precipitation of large calcite grains and formation of relatively wide light laminae. However, the absolute sedimentation rate in the central deep was low, since it collected material from smaller lake area.

Between 8400 and 8000 cal BP further lowering of water table occurred. This process initiated a period of minimum water level 2000 yrs long, when the threshold emerged isolating the northern bay from the main basin of Lake Gościąż (Demske 1995). Deposition of sands and coarse plant detritus at the threshold, found at depths of 4 m and 3.5 m below the present lake level (ca. 7 and 6.2 kyr BP), indicates temporal activation of shore processes. Lowering of water level terminated formation of gyttja near Lake Mielec (6.7–6.5 kyr BP), and peat deposits started to develop there.

The whole Atlantic period was a time of maximum development of mixed deciduous woods (with dominance of *Ulmus*, *Fraxinus*, and *Quercus*) on more fertile and humid soils. The mixed pine forests were dominant on poor sandy soils. Pollen influx, after a second drop at ca. 8200 cal BP, remained low and stable. Sedimentation rate between 8000 and 5950 cal BP was as low as at 9–8 kyr BP, but the carbonate content increased at the cost of minimum input of non-carbonate minerals. Formation of rather dense forests was presumably responsible for the low input of detrital matter, decrease of iron, and later further decrease of manganese content in the sediments. These decreases might be also an effect of general depletion of soils in Mn (and Fe) due to long-lasting intense leaching of manganese (and iron) from minerals fertilizing the soils in the early Holocene. The rise of magnesium concentration, observed between 7400 and 7200 cal BP, remains unexplained.

Essential rearrangement of the water-supply regime just at the Boreal/Atlantic transition is confirmed by the abrupt change of the long-term $\delta^{13}C$ and $\delta^{18}O$ trends. The stable-isotope data suggest rapid decrease of mean residence time of water in the lake and of the hypolimnion/epilimnion volume ratio. However, the implied shallowing would be rather gradual through the whole Atlantic, not reflecting any hydrological changes documented by other indicators.

The first traces of human presence appeared in the Lake Gościąż region between 8.0 and 6.6 kyr BP. The structure of forests was then locally influenced by Mesolithic tribes. The grouping of their sites was found near northern bay (Chapter 9.1.1). From 6400 cal BP on, the Neolithic populations started to settle the region, represented first by the Funnel Beaker Culture. The oldest level of abundant charcoal deposited in bay sediments corresponds just to that settlement (Demske 1995). The next charcoal levels further up in the profile correspond also to subsequent phases of intensified human activity. Around 6.4–6.1 kyr BP the lake trophy increased, as documented by the high content of phosphorus, hydrosulphide and pyrite in sediments. However, evidence is insufficient to attribute those changes to human activity. Whether just eutrophication was responsible for the restoration of laminae formation in the northern bay remains also unknown.

Subboreal chronozone (5.8–2.6 kyr BP)

The Atlantic/Subboreal chronozone transition is marked by the abrupt extinction of *Ulmus* trees (ca. 5900 cal BP). Simultaneous temporary rise of pollen influx evidences intensified flowering of other trees caused by distinct thinning of forest canopy. Short-lasting opening of forests triggered also the increased supply of allochthonous matter to the lake. The distribution pattern of anthropogenic pollen indicators suggests that the *Ulmus* fall though caused by factors other than man, stimulated the intensification of settlement processes by forest opening.

The Subboreal and Subatlantic chronozones are distinguished by increasing activity of man and his influence on the environment. The further development of Neolithic settlements involved, besides the Funnel Beaker Culture, also the Comb-Pitted Pottery and Epibeaker Cultures and lasted till ca. 4.8 kyr BP. The transformations of forest structure, visible from ca. 6100 cal BP and accelerated 150 years later due to the *Ulmus* fall, led to the formation of rather open woods, with the high abundance of *Corylus* and intensively flowering *Quercus*, and diverse facies of shrubs and xerothermic herbs. Such a structure was rather stable till ca. 3700 cal BP. The local spread of *Taxus* after ca. 5000 cal BP might have proceeded on abandoned pastures. During the phase of the Comb-Pitted Pottery Culture, when the dwelling place was situated close to the lake, the lake trophy increased, as documented by the appearance of *Filinia* and *Aphanizomenon* around 5000 cal BP. The period of enhanced trophy lasted long after the decline of Neolithic settlement.

Around 4100 cal BP, the tribes of Bronze Age cultures appeared. The pollen record of the Trzciniec Culture activities is initially rather weak, but the spread of *Betula* after 3800 cal BP might have been stimulated by this culture. *Carpinus* expanded at the same time. Simultaneous strong reduction of *Corylus* and decrease of *Quercus* evidences the final change in composition of deciduous woods. From this time through the following 2800 years, *Carpinus* is their most essential component, with *Betula* forming the pioneer stage of wood development on lands left after deforestation and economic practices. Around ca. 3400 cal BP the hornbeam forests were for the first time destroyed by the tribes of Lusatian Culture. According to archaeological data, the main concentration of settlements of this culture existed ca. 7 km west of Lake Gościąż. The Lusatian tribes were active in the area till ca. 2500 cal BP. Their activity could be responsible for lake eutrophication, as indicated by maxima of phosphorus content in sediments between 3.2–2.8 kyr BP.

The water level during Subboreal appears more variable and seems to be less precisely reconstructed than in former periods. The Cladocera record suggests three short phases of high lake level: 5.6–5.5 kyr BP, 4.2–4.1 kyr BP, and 3.0–2.7 kyr BP. The high (and perhaps unstable) water table in the 6th millennium is also indicated by the sands deposited north of the lake at ca. 5.5 kyr BP and in Ruda valley at ca. 5.0 kyr BP. End of laminae formation in Lake Brzózka at ca. 5.2 kyr BP may result from the lowering of water-level or from the general shallowing of lake basins gradually filled by sediments. The vegetation in the transect between northern bay and kettle hole (Demske 1995) suggests increase of water level between ca. 5.5 and 5 kyr BP and high water stand through the whole following millennium. The lenses of organic material in the eastern lake shore indicate reactivation of this scarp then, just as during several earlier humid phases of the Holocene. During the next millennium (4–3 kyr BP) the intense infilling of northern bay, overgrowth of Ruda inlet, and hiatuses in littoral profiles document a long period of low water, though the deposition of carbonate gyttja around Lake Mielec suggests short-lasting rises of water level at its beginning and end (dated to 4–3.8 and 3.3–3.1 kyr BP). The decrease of water level (and hence of retention time in the lake) about 3800 cal BP is also suggested by the drop of $\delta^{18}O$ of sediment carbonates.

From ca. 5950 cal BP on, the mean sedimentation rate was high and revealed periodicity of ca. 200 years. Amplitude of these periodical variations was high, but the relative contents of organic matter, carbonates, and other minerals remained fairly constant. It is not known whether these variations resulted from changes of lake volume (and of the “funnel effect”) or from changes of biological productivity in the lake. After ca. 3400 cal BP the first disturbances of laminae started to appear in the central deep, bringing the first serious break in the continuity of laminated sequence at 3210 cal BP. This perturbation could be provoked by the activities of Lusatian population (fishing?) but could also be the well known effect of hypolimnion oxidation in the shallowing lake basin, partly counterbalanced by the human-induced eutrophication. The second mechanism might explain why the heaviest disturbances of lamination occurred only after the decline of Lusatian Culture and lowering of lake trophy. At the same time the last traces of laminae disappeared in the northern bay (Demske 1995).

Subatlantic chronozone (after 2.6 kyr BP)

As consistently shown by data from the bay (shore peat formation) and from the lake centre (decrease of pelagic Cladocera) the water table at the beginning of Subboreal (2.6–2.4 kyr BP) was rather low. The retreat of the Lusatian settlement at the onset of the Subatlantic chronozone, which enabled expansion of birch and regeneration of hornbeam forests between 2.5–2.0 kyr BP, was coincident with the rise of water table. This rise is documented well by the sedimentation of carbonate gyttja on the eastern shore of northern bay (Demske 1995) and by the expansion of planktonic Cladocera in the lake. The fossil fan and delta formed at the inlet of Ruda to the bay, and terrace benches formed in many places of the lake shore 0.7–1 m above the present water surface. This was consistently the highest water level of transfluent Lake Gościąż during the whole Holocene. Unfortunately their calibrated radiocarbon age is inaccurate due to large irregularities of ^{14}C calibration curve for that period.

In the period of Roman influences, the human impact intensified again. The populations of the Przeworska culture (ca. 2000–1700 cal BP) deforested large areas for agricultural purposes and introduced *Secale cereale* and *Cannabis sativa* into common cultivation. The abundant deposition of charcoal in the sediments of northern bay and to east of it (Demske 1995) was probably connected with their activities. The covering of gyttja by peats at the shores of the bay around 2000 cal BP suggests gradual lowering of water level, which could initiate formation of peats in deltas of Ruda to lakes Wierzchoń and Gościąż and at the shore of Lake Mielec, although according to radiocarbon dates those peats are 100–200 years older. The decreasing frequencies of pelagial Cladocera are also noted at that time. The gradual decline of water level led to very low water stands after ca. AD 700, as documented by appearance of coarse detritus in bay sediments. It is consistent with the extremely low values of $\delta^{18}O$ in authigenic carbonates.

The settlement of Przeworska Culture and probably also the diminution of lake volume stimulated gradual lake eutrophication, as suggested by increasing diversity of algae, blooms of *Aphanizomenon*, and development of *Bosmina longirostris*. Just as in the 5th millennium BP, the phase of increased trophy lasted a few hundred years after the fall of settlement. The high trophy favoured anoxic conditions in the hypolimnion, and probably due to that the formation of non-disturbed varves was temporarily restored in the lake centre (300–500 cal BP).

Reduction of human populations during the Migration period (AD 400–1000) enabled again the expansion of post-farming *Betula* copses and *Carpinus* woods. The new intensification of human settlement accompanied the formation of the Polish state in the 10th century. This led to the gradual extinction of deciduous forest stands, the pine and mixed pine woods remaining the only meaningful forest communities. Such forest structure survived till modern time.

After AD 1000 the last distinct rise of water level is recorded by the expansion of pelagial Cladocera and, further on, peat growth at the shores of the northern bay (Demske 1995). This probably intensified the input of clastic material to the lake, noted after AD 1100. Development of human economy in historical times was also responsible for the increases of iron (primitive smelting factories), and phosphorus (eutrophication stimulated by agriculture) in lake sediments. The distinct lake eutrophication and restored formation of regular laminae in the 19th and 20th centuries, followed by the lowering of trophy after the 2nd World War, are strictly connected with the history of settlement in the area as known from archival sources. These questions are discussed in detail in Chapter 9.2.

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