on exchange with the ocean. Generally, the smaller the atmospheric CO_2 inventory and its exchange with the deep sea are, the higher is the specific ^{14}C activity in atmosphere.

The large increase of atmospheric CO_2 from ca. 200 to 280 ppm between 17 and 10 kyr BP is well documented (Barnola et al. 1987, Neftel et al. 1988, Staffelbach et al. 1991), though the mechanisms of this increase are not completely known (Leuenberger et al. 1992, Marino et al. 1992). The model calculations show that change of CO_2 from 200 to 280 ppm might decrease steady state $\Delta^{14}C$ by 25–75‰ (Lal & Revelle 1984, Keir 1983, Siegenthaler et al. 1980), so the 20‰ decrease between mean pre-YD and Holocene $\Delta^{14}C$ residuals could be explained by the change of CO_2 concentration. On the other hand, the changes of CO_2 during the short periods of $\Delta^{14}C$ variations at the boundaries of YD and about 9.5 kyr BP were presumably too small to alter $\Delta^{14}C$ more than by 10‰. Another factor influencing atmospheric $\Delta^{14}C$ is the rapidity of carbon exchange between atmosphere and ocean surface. It is generally accepted that the winds were stronger in glacial time (Petit 1981), raising the exchange by even 50% (Bard 1988), and due to this effect one could expect the lowering of $\Delta^{14}C$ by 20‰ (Siegenthaler et al. 1980). This mechanism would cause the lowering of $\Delta^{14}C$ during cold periods, and therefore it cannot explain observed $\Delta^{14}C$ variations.

The other possible mechanism is the exchange with the deep ocean. It is especially important, since a significant part of total exchange is through the formation of North Atlantic Deep Water (NADW), which is a driving force of thermohaline circulation heating the North Atlantic region (Manabe & Stauffer 1988). As was hypothesized by Broecker & Denton (1989), switching NADW formation on and off would be a plausible mechanism of abrupt climatic changes. According to box or box-diffusion models, the instant drop of exchange with the deep ocean by a factor of two would raise $\Delta^{14}C$ by 100‰ within a few hundred of years (Siegenthaler & Beer 1988). This, however, should be accompanied by an increase of radiocarbon age of deep water by more than 1000 yr. The growing evidence from radiocarbon dating of contemporaneous planktonic and benthic foraminifera (Andree et al. 1986, Shackleton et al. 1988, Broecker et al. 1988, 1990) says that such an increase did not occur. Therefore the Late-Glacial/early-Holocene decline of $\Delta^{14}C$ by 150‰ cannot be explained by changes of deep-sea ventilation alone. Fortunately most of this decline could be explained by the GDM-induced changes of radiocarbon production and changes of CO_2 concentration. The residual variations, the 40‰ increase of $\Delta^{14}C$ at the onset of YD and its 30‰ decline at the beginning of the Holocene, would require the changes of deep-sea ventilation less than 20%. The corresponding ^{14}C age difference between benthic and planktonic foraminifera would then change at the beginning and termination of YD by only 250–300 yr. The difference of ventilation index between Glacial Maximum and Holocene by 75–325 yr seems well documented (Broecker et al. 1990), but the data available now are too scarce to support or to rule out the postulated short-term $\Delta^{14}C$ variations during YD and early Holocene. The $\Delta^{14}C$ record from YD, if interpreted in terms of ventilation rate, suggests the lowest oceanic circulation in the earlier part of Younger Dryas. This seems to be consistent with the amelioration of climate in the second half of YD, reconstructed in the Lake Gościąż sediment (Goslar et al. 1993) and other regions in Europe (Björck & Digerfeldt 1984, Pennington 1977, Lowe & Walker 1980, De Groot et al. 1989).

The direct reconstructions of NADW formation during YD and early Holocene do not give clear results. Many palaeooceanographic reconstructions, based on faunal, chemical and isotopic data (Boyle & Keigwin 1987, Boyle 1988, Keigwin et al. 1991, Keigwin & Lehman 1994) suggest that the NADW formation was significantly reduced during both YD and Last Glacial Maximum (LGM). Other studies (Jansen & Veum 1990, Charles & Fairbanks 1992) suggest that to some extent the formation of NADW was continued throughout the YD. These discrepancies may be reconciled if only the deeper part of NADW circulation was weakened while the upper belt persisted, though at different depths during LGM and YD (Lehman & Keigwin 1992). The reconstruction of distribution of different ocean-water masses in the past is then a very complicated task and is beyond the scope of the present work. Obviously the radiocarbon concentration in the atmosphere is not sensitive to the details of oceanic circulation but rather integrates the effects of vertical mixing over the whole ocean.

7.8. DISCUSSION OF THE LATE-GLACIAL RECORDED IN THE LAKE GOŚCIĄŻ SEDIMENTS

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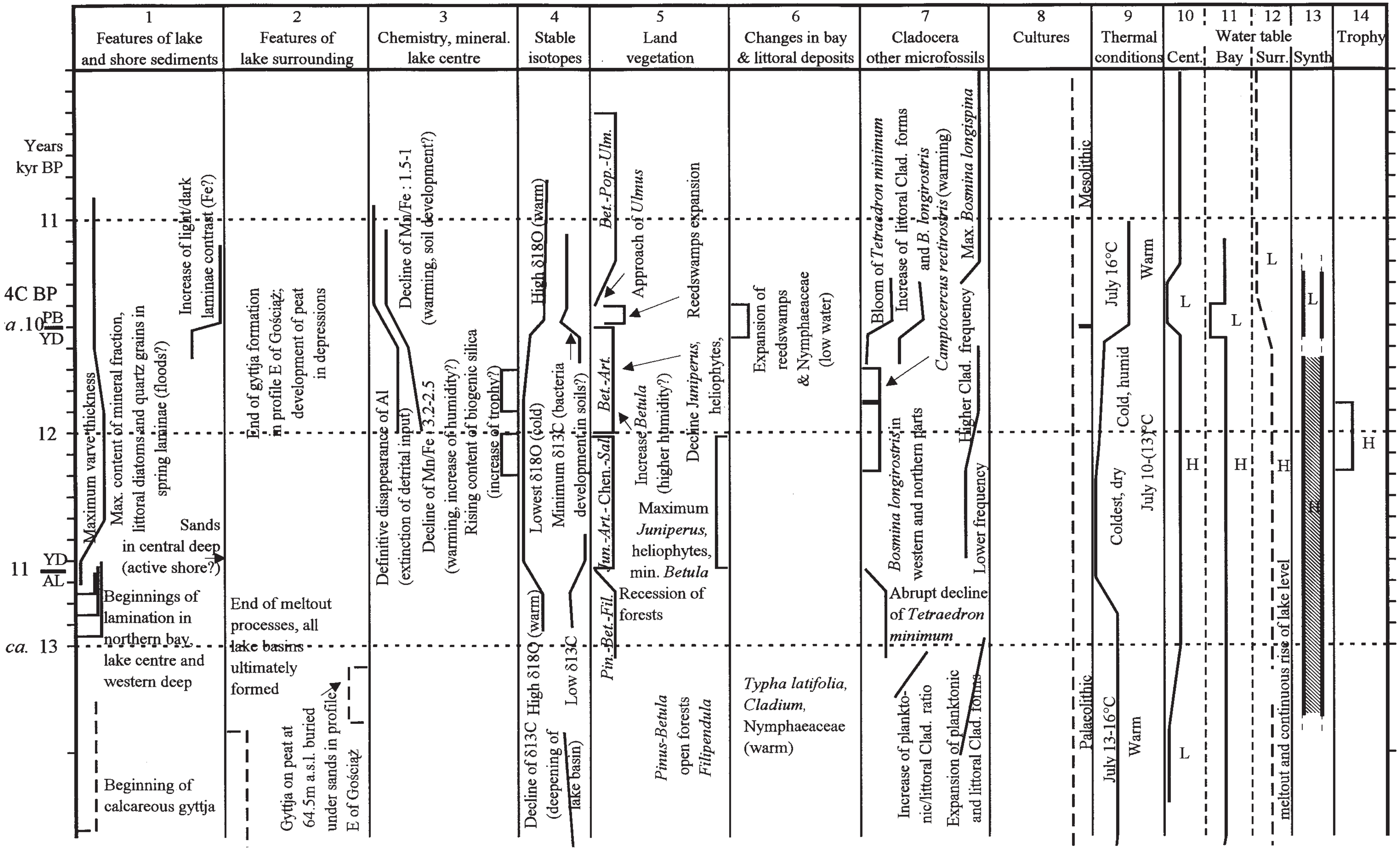
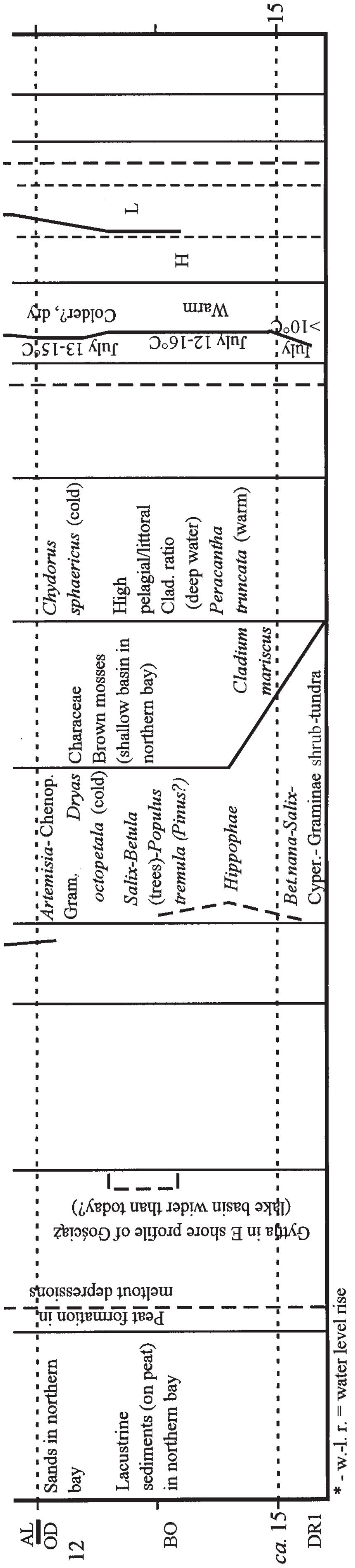
The extended studies on sediments of Lake Gościąż and its environmental setting aimed to reconstruct the history of the lake and surrounding area during the last 15 kyr. They brought a large set of data concerning changes of different environmental components, which, for the Late-Glacial period, were described in individual Chapters 7.1–7.7. However, the components of environmental system respond jointly to external forcing as well as interact with one another, so they cannot be treated separately. In this chapter we attempt to confront the more significant data from individual chapters (Tab. 7.7) and discuss them together. For reasons outlined in the In-

Table 7.7. List of more important information derived from individual studies on Lake Gościąż setting and sediments – Late-Glacial part.





troduction (Chapter 1) we decided not to refer our synthesis to the relevant regional or global elaborations, but we focused rather on the evolution of the Lake Gościąż system alone, on the local scale. This chapter thus will serve as a background for further research and more general discussion, which we are going to publish in a further part of the Lake Gościąż Monograph.

The events and processes documented by data of different types are presented on the common time scale. This scale, in calendar years BP, is divided into chronozones, their boundaries being set by calibration of radiocarbon ages originally proposed by Mangerud et al. (1974). The data coming from annually laminated sediments are marked in Table 7.7 by solid lines. The information from the non-laminated sediment and from the lake's surroundings as based on the time scale derived from calibrated radiocarbon datings is marked by dashed lines. The varve chronology of Lake Gościąż covers the range from ca. 12,900 yr BP till now. The available data on radiocarbon calibration for ages before 12,900 yr BP are rather inaccurate, and there the calculated calendar time scale should be treated as approximate.

The different types of data are ordered in columns. The first two columns (nos. 1 and 2) summarize lithological features of sediments in Lake Gościąż and its surroundings. Columns nos. 3 and 4 illustrate the most important observations on chemical, mineralogic, and stable-isotopic composition of laminated sediments from the lake centre. Column no. 5, in its section above 13 kyr BP, summarizes results of palynological studies coming from cores representing the lake centre and the northern bay, before 13 kyr BP, the pollen data from the northern bay alone. Column no. 6 contains data summarized from several cores on the transect between the northern bay and the kettle hole to the east, which is the zone especially sensitive to changes of water table. Data on lacustrine ecosystems presented in column no. 7 include information on Cladocera and on other microfossils from the central cores, completed in the oldest section by the data from the northern bay.

The 8th column is meant to present information on cultural history of the area. It is not relevant in the Late-Glacial table, but it is placed here to maintain the same column numbering in both Late-Glacial and Holocene lists of data. The columns no. 9 through 14 summarize conclusions about the changes of thermal conditions, water table, and lake trophy. The oscillations of water table (columns 10, 11, and 12) are detected from three independent sets of data. The periods of high and low water level indicated in column no. 10 are deduced from the Cladocera assemblages, which are sensitive to changes in the volumetric ratio between littoral and pelagial zones. The data in column no. 11 are derived directly from formationio of the surroundings of the northern bay or deduced from changes of littoral vegetation along the northern bay-kettle hole transect. Column no. 12 presents occurrence of peat and lacustrine sediments in cores retrieved from the Lake Gościąż surroundings. The conclusions on water-level changes are synthesized in column no. 13. In column no. 14 the periods of high lake trophy suggested by changes in lake ecosystems (mostly Cladocera) are indicated.

Pre – Younger Dryas chronozones (ca. 15,000–12,650 cal BP)

The history of the Na Jazach lake system starts after the retreat of the Vistulian ice-sheet, which probably formed the original depressions and buried there large masses of dead ice. As the vegetation started to develop between ca. 16 and 13.5 kyr BP (13,900–11,500 ^{14}C BP), the organic peat-like deposits formed in wet hollows also on top of buried ice. These deposits gradually collapsed in the course of ice meltout, and now in some places they underlie the sediments of lacustrine origin. Pollen spectra of the oldest, pre-Bølling deposits indicate that the area was covered by open shrub-herb vegetation with the dominance of *Betula nana*-*Salix* and Cyperaceae-Gramineae communities, reflecting rather cold climate with July temperatures of ca. 10^{o}C. The onset of the warmer Bølling period was marked by development of *Hippophaë-Salix* thickets, followed by appearance of tree stands composed of *Betula*, *Populus tremula*, and *Salix* spp. The warming is also evidenced by presence of *Cladium mariscus* and of the thermophilous Cladocera species *Peracantha truncata*.

The oldest lacustrine sediments of Bølling age, were found in the northern bay. The high abundance of moss vegetative remains indicates that the bay was rather shallow at that time. Surprisingly, this contradicts what could be derived from the high ratio of pelagic to littoral Cladocera. The deposition of gyttja at the eastern shore of Lake Gościąż suggests that the main lake basin might already have been formed or at least have extended its eastern part more to the east than today. Unfortunately, the cores from the lake centre do not contain sediments old enough to confirm this hypothesis. On the other hand, the development of the western part of the lake commenced only a few hundred years later, during the Allerød.

The short-lasting deterioration of climate between the Bølling and Allerød periods (around 14 kyr BP), probably involving mostly the increase of dryness (van Geel & Kolstrup 1978), is marked by the reduction of *Salix*-*Betula* stands, spread of *Artemisia*-Chenopodiaceae-Gramineae communities, and occurrence of *Dryas octopetala*. The cold-tolerant *Chydorus sphaericus* appears in the lake. The opening of forests probably facilitated the deposition of sands in the northern bay. Similar activation of shore-slumping processes occurred also after the next recession of forests, at the early phase of Younger Dryas.

The land vegetation of the Allerød period (ca. 13.5–12.65 kyr BP) was dominated by the *Pinus*-*Betula* forests. The composition of telmatophyte/limnophyte communities suggests relatively warm climate (13–16^{o}C in July). The lake depth gradually increased, partly due to the collapse of its bottom, and partly because of the rise of water level, as indicated by gyttja found in the eastern shore well above the present lake-level. The western basin of the lake was formed then, its deepening process reflected by monotonic decrease of δ^{13}C. In the late Allerød all separate lake depressions became connected in one lake system. The ultimate end of meltout processes enabled the formation of laminated sediments, which commenced almost simultaneously (between 12,950 and 12,750 cal BP) in all basins of Lake Gościąż. During the rise of water level in the Allerød active landslides and slumps were formed. They are recorded in the steep eastern shore of lake, where gyttja and peat layers are buried under sandy deposits. Younger organic lenses from late Boreal and early Subboreal indicate that this scarp was reactivated during several humid phases of the Holocene.

Younger Dryas chronozone (12,650–11,510 cal BP)

The climatic change at the transition between Allerød and Younger Dryas (YD) was clearly evidenced in all types of records available. The abrupt decline of δ^{18}O, completed within 150 yr, indicates the decrease of air and water temperature by a few degrees. The age of 12,650 cal BP in the middle of this decline, has been accepted for the AL/YD boundary. The cooling is also documented by rapid reduction of the green alga *Tetraedron minimum* and Cladocera frequencies in the lake and by the development of heliophyte xeric herb vegetation with *Juniperus* shrubs, coincidently with a substantial recession of woods. The recession of forests triggered probably the slumping processes at the beginning of Younger Dryas, facilitating enhanced erosion through the whole YD (maximum sedimentation rate of allochthonous minerals) and intensified spring floods (abundant littoral diatoms (Marciniak, Chapter 7.5.1) and quartz grains in the spring laminae). During the older part of YD (up to ca. 12 kyr BP) the climate was probably the coldest and driest. The decline of xeric herb vegetation with *Juniperus* and some regeneration of birch during the middle YD suggests some rise of humidity around 12 kyr BP. In the later part of YD the climate warmed gradually, as suggested by the rise of δ^{18}O. It is confirmed by increase of Cladocera frequency followed by appearance of *Camptocercus rectirostris*, and on land by progressive reduction of open herb-shrub communities by spreading *Betula*. The warming and increase of humidity were probably responsible for the observed decline of Fe/Mn ratio in the lake sediments. At the same time an increase of lake trophy is also detected (*Bosmina longirostris*). High trophy and constantly high input of detrital minerals led to the maximum content of biogenic silica in the sediments. Through the whole YD the water level was high, and the basins of all lakes connected now by the Ruda stream (i.e. Wierzchoń, Brzózka, Gościąż and Mielec) were probably joined together in one great lake.

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

The most essential environmental changes occurred at the transition between Younger Dryas and Holocene (dated to 11,510 cal BP). According to the $\delta^{18}O$ curve, the rise of annual mean temperature by more than 5°C was completed within 70 years. Abrupt increase of summer water temperature is confirmed by the bloom of *Tetraedron minimum*. In terrestrial vegetation the beginning of the Holocene is marked by reduction of heliophyte herb/shrub vegetation and the spread of *Populus* and tall herbs with *Filipendula*, followed by expansion of *Betula* woods. The warming and expansion of forests enhanced microbial activity in soils and led to their oxygen depletion (indicated by temporary drop of $\delta^{13}C$ values and rapid decline of Fe/Mn ratio in the sediments). Development of forests inhibited also input of detrital material to the lake (decrease of varve thickness and definitive disappearance of aluminium from the sediments). Enhanced evaporation and evapotranspiration due to increase of temperature and development of more abundant vegetation cover, coincident perhaps with increase of soil permeability (shorter season of frozen ground), resulted in temporary shallowing of the lake. It is documented by the development of littoral Cladocera species and short-lasting expansion of reedswamps and Nymphaeaceae, especially in the northern bay. The general lowering of water table was evidenced by the end of gyttja formation as well as peat development in depressions around the lake.

7.9. A COMPARATIVE STUDY ON THE LATE-GLACIAL/EARLY HOLOCENE CLIMATIC CHANGES RECORDED IN LAMINATED SEDIMENTS OF LAKE PERESPILNO – INTRODUCTORY DATA

Krystyna Bałaga, Tomasz Goslar & Tadeusz Kuc

Characteristics of the region

Lake Perespilno (other name: Pereszpa) is one of 67 lakes of the Polesie Lubelskie region within the Łęczna-Włodawa Lake District. This complex of lakes is situated ca. 300 km to the south of the extent of the Vistulian Glaciation (Fig. 7.52). The region is characterized by great variation of climatic parameters. Continentality of climate is well expressed by a high annual amplitude of air temperatures, reaching 22–23°C. The mean annual temperatures range between 7° and 8°C. The mean annual rainfall does not exceed 600 mm (Zinkiewicz & Zinkiewicz 1975, Michna & Paczos 1978).

The study area of the Łęczna-Włodawa Lake District is characterized by relief less than a dozen metres. It lies in the depression between Włodawa Hump in the north and Uhrusk Elevation in the south. Low relief and very small slopes impede the surface runoff and cause the formation of extensive wet and swampy areas. Lakes and mires are the most common elements of the landscape in this region.

The sub-Quaternary surface relief had great significance both for the water conditions and the origin of lake complex. The sub-Quaternary bedrock consists of marl and chalk with a relief of 30–50 m. Chalk and marl are very susceptible to karst processes in rock outcrops as well as on surfaces covered by the Quaternary deposits. These deposits (up to several dozen metres thick) consist of clays, sands, fluvioglacial gravels of older glaciations, and of lacustrine silt (Maruszczak 1966a). The role of karst and thermokarst processes in the origin of the lakes is still under debate (Wilgat 1954, 1991, 1994, Maruszczak 1966b, Buraczyński & Wojtanowicz 1974, 1983, Wojtanowicz 1994).

Description of the lake

Lake Perespilno is located in the western part of the Łęczna-Włodawa Lake District in the area of the Sobibór Landscape Park and is one of three lakes situated within a swampy plain in relief not exceeding several metres (Fig. 7.52). The plain is covered by fine river sands and locally small dunes. Fluvioglacial deposits building strongly denuded hills are exposed in places (Zgorzelski 1987). Marls and chalk occur probably at a depth of about 20 m (Projekt, unpubl.). Apart from lakes the depressions are filled by peat or peat underlain by gyttja several metres thick.

Lake Perespilno (165 m a.s.l.) is 24.3 ha in area and consists of two depressions. The deeper depression in the northern part (6.2 m water depth) is separated from the shallower one (4.5 m in depth) by a distinct shallows of 2.7 m. Pine forest grows on the high, sandy shores, especially on the east side of the lake. On the west side only remnants of forest remained as shrubs and single old trees. Alderwood communities are situated mainly on the SE and N sides. In some places the lake shores are swampy and overgrown by reedswamp vegetation. Carpets of floating plants also occur, mainly with *Nymphaea alba* (Fijałkowski 1960).

Description of laminated sediment sequence

Coring was carried out by K. Więckowski in March 1991. Two cores 16.7 m long were taken from organogenic deposits in the north part of the lake 6.0 m deep. Sand occurred in the bottom of cores at a depth of 22.7 m