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MACROFOSSIL RECONSTRUCTION OF PREBOREAL WETLAND FORMED ON DEAD ICE BLOCK: A CASE STUDY OF THE BORZECHOWO MIRE IN EAST POMERANIA, POLAND

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Abstract

In order to reconstruct environmental changes in the Borzechowo mire, a sediment core was subjected to macrofossil and stratigraphic analyses. The mire is located in the eastern part of the Pomeranian Lakeland (Tuchola Forest, northern Poland). It is a limnogenic mire, formed as a result of terrestrialisation of a water body. The time of basal peat accumulation was estimated by radiocarbon dating as 9860±130 ^{14}C BP (Gd-12393) and by palynological analysis as Preboreal. The analysis of macrofossils shows that in that period, considerable hydrological changes took place in the study area. These hydrological changes were caused by melting of dead ice blocks that was commonplace in the Late Glacial and the Early Holocene.

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Key words: Preboreal, wetland, macrofossils, basal peat, buried dead ice, N Poland

INTRODUCTION

A peat layer found at the base of limnic deposits, overlying mineral bottoms of biogenic sedimentary basins, is generally associated with rapid hydrological changes at the beginning of lake formation. In the early post-glacial landscape of Poland (Liberacki 1958, Kozarski 1963, Stasiak 1963, 1971, Więckowski 1966, 1993, Żurek 1990, Błaszkiewicz, Krzymińska 1992, Nowaczyk 1994a, 1994b, 2006, Wojciechowski 2000, Błaszkiewicz 2003, 2005, 2007), Netherlands (Hoek *et al.* 1999) and North America (Kovanen, Easterbrook 2001), such features were formed as a result of melting of dead-ice blocks buried within glacial deposits. Depending on various conditions, both regional and local, the melting of dead-ice blocks lasted from the beginning of the Late Glacial till the Preboreal period (Błaszkiewicz 2005).

According to the hydrologic and genetic classification by Succow (1988), mires formed on sandy-gravelly deposits and fed by water from melting dead-ice blocks can be defined as paludified. During their formation due to the waning of dead-ice blocks, the overlying deposits collapsed and the telmatic sediments were submerged as a result of subsidence of kettle holes, and subsequently covered with limnic deposits of the emerging lakes.

Literature of the subject reports relatively large number of sites where peat deposits developed above buried dead-ice blocks, but in only a few such sites a macrofossil analysis was conducted (Marek 1994, Wojciechowski 2000, Kowalewski *et al.* 2001, Wright, Stefanova 2004, Drzymulska 2006). Such an analysis is especially important when local environmental conditions are to be defined in a basin where biogenic accumulation takes place. In the case of fossil sediments, macrofossil analysis is vital to distinguish properly between depositional environments, *i.e.* limnic (a layer at the bottom of the lake) and telmatic (starting to accumulate around the lake's perimeter) (Eslick 2001). Since there are doubts concerning proper classification of basal peat, macrofossil analysis seems crucial (Marks 1996, Gałka 2007, Tobolski 2007).

STUDY SITE

The Borzechowo mire is located in the eastern part of the Pomeranian Lakeland (Pojezierze Pomorskie), at the border between the Tuchola Forest (Bory Tucholskie) and the Kociewie Lakeland (Pojezierze Kociewskie), and within the catchment of the Wda River (Fig. 1). The mire occupies the bottom of a subglacial channel formed on the outwash plain at the direct forefield of the glacier in the maximum extent of the Pomeranian phase (Błaszkiewicz 2005).

The mire is an example of a degraded fen. In the 1980s, the area was drained, which influenced significantly the local ecosystem. In terms of hydrology and origin, the Borzechowo mire is limnogenic, *i.e.* formed by the process of terrestrialisation of a water body (Succow 1988).

The lithofacial and chronostratigraphic characteristics of sediments filling the fossil lake basin near Borzechowo were described by Błaszkiewicz (2005). According to that author, the base of the biogenic deposits lies directly on the mineral basal complex. A continuous layer of the Preboreal peat of various thickness (3–10 cm), was found at the depth of 11.42 m. The above layer underlies a thick stratum of calcareous gyttja, which in the top section is covered by peat.

MATERIAL AND METHODS

The sediment core was obtained with the use of 110 cm-long (5 cm diameter) Livingstone corer in Więckowski's modification (Więckowski 1956). The sediment for macrofossil analysis was collected at the central section of the subglacial channel, at the contact zone with the Wda River valley (Fig. 1). In the central section of the channel, for the purpose of this study, we took the complete profile of biogenic sediments, whose total length was 11.42 m. Lithology of the sediments was described following West (1977).

Preparation of samples for macrofossil analysis followed widely accepted methods (Tobolski 2000). Before the analysis the cores were fragmented into 1-cm sections. The bottom deposits, highly decomposed, were boiled in the solution of potassium hydroxide (KOH) for about 10 minutes. Next, the sludge was sieved through mesh sizes of 0.1 mm, 0.25 mm and 0.5 mm. Each sample was used to prepare four microscope slides. Determination of both fossil and subfossil remains was based on the literature (Bertsch 1941, Landwehr 1966, Katz *et al.* 1977, Grosse-Brauckmann 1972, Nilsson 1972, Beijerinck 1976, Daniels, Eddy 1985, Smith 2004, Tobolski 2000, Gałka 2006, Velichkevich, Zastawniak 2006) and the reference collection of the Department of Biogeography and Paleoecology.

The results obtained from the macrofossil study were analysed and presented in the form of macrofossil diagrams plotted by the C2 software (Juggins 2003). The uncountable macrofossils are presented in the diagram on a five-level scale. Countable items, such as seeds and needles, are given in absolute values. The local macrofossil assemblage zones (LMAZ) were delimited.

The digital terrain model for the study area has been generated through the nearest neighbour algorithm from points obtained as a result of vectorisation of contour lines from a topographic map on a scale of 1:10 000 (sheet number and name: 335.113 Borzechowo). The ESRI ArcMap9 software was used.

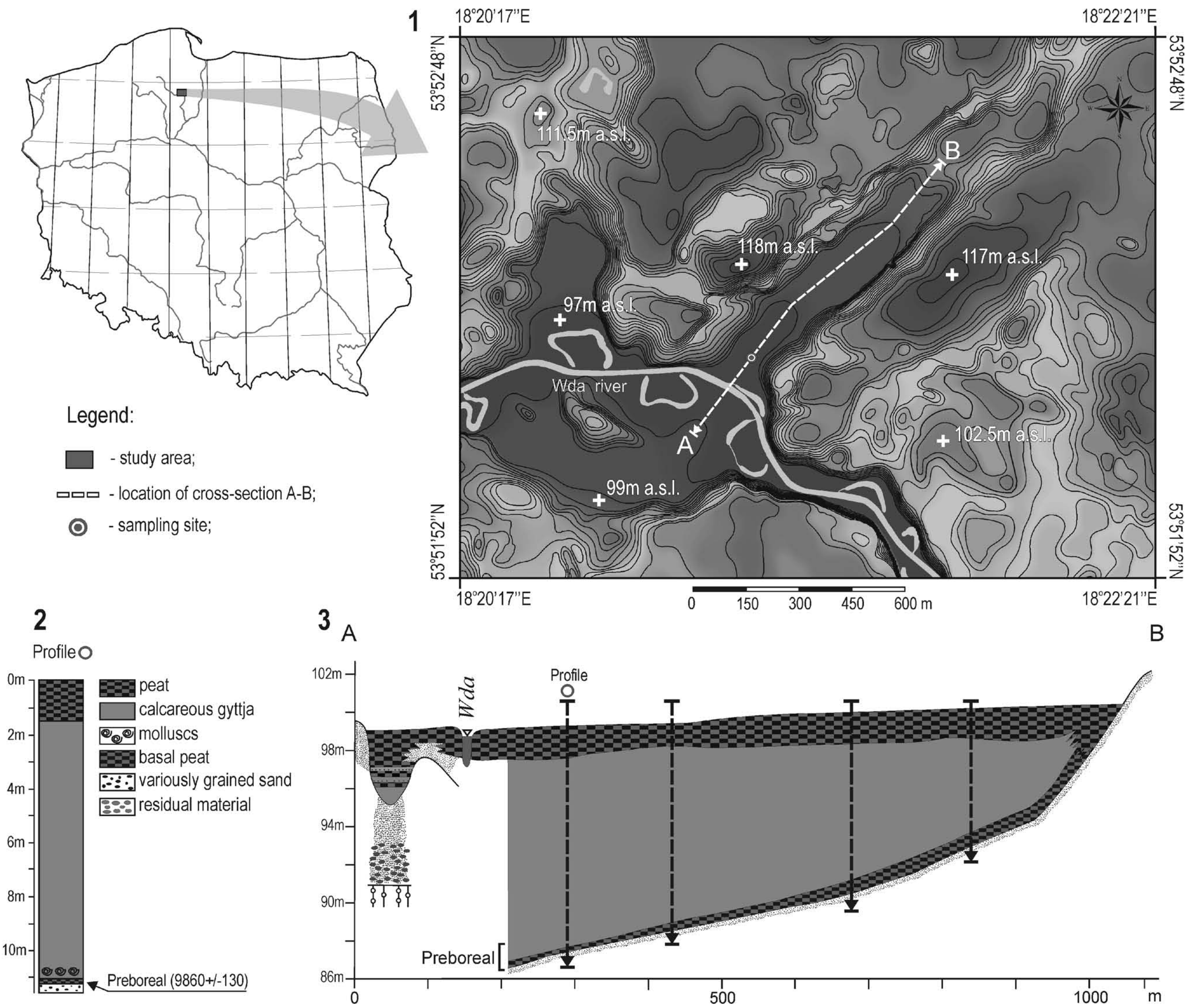

Fig. 1. Location of the study site and the geological cross-section the Borzechowo mire. 1 – digital terrain model (DTM) with location of a core as well as the course of the geological section; 2 – lithology of the profile; 3 – geological section A-B across the Borzechowo mire (after Błaszkiewicz 2005).

RESULTS

Results of the macrofossil analysis are shown in Fig. 2 and Table 1. The diagram in Fig. 2 includes six categories (brown mosses and *Sphagnum* mosses, trees and shrubs, aquatic plants, telmatic vegetation, invertebrates and others). The analysis of biogenic deposits indicates that a 14-cm basal peat, separated by a layer of aeolian sands (4.5 cm) is underlain by sands of various grain sizes (depth 11.42 m). The peat layer is overlain by a greyish-crème calcareous gyttja. The beginning of basal peat accumulation was dated on 9860± 130 years BP (Gd-12393). On the basis of the macrofossil analysis of the core section, two stages of development of the study object can be distinguished: telmatic and limnic.

Telmatic phase

Telmatophytes initiated the development of the mire. They included *Thelypteris palustris* and *Equisetum* sp. According to the ecological indicator values (Zarzycki *et al.* 2002) those species prefer medium shading and fertile (eutrophic) environments with neutral reaction (6≤pH<7) and form dense patches (Kłosowski S., Kłosowski K. 2001). They were accompanied by *Phragmites australis* and *Carex* spp. The existing basin with biogenic sediments was then overgrown by shrubs of *Betula* spp. This point of view is supported by the subfossil findings linked with this species, such as fruit and periderm. *Betula* spp. was accompanied by the dwarf shrub of *Betula nana*, whose fruit was found in the bottom deposits. In the Preboreal period this species was abundant in the vegetation of the Pomeranian region (Latałowa 2003). The other species present in the area included trees: *Populus tremula* and *Pinus sylvestris*. During this phase, fires occurred in the mire area. This is indicated by numerous sharp-edged pieces of charcoal of up to 17 mm in diameter.

Two peaks of charcoal content were recorded: the first one at the depth from 11.38 m to 11.35 m, and the other one at 11.31 m. The fires on that mire, probably including the neighbouring areas, burnt the vegetation. This initiated short-lasting aeolian and denudation processes, leading to the accumulation of a mineral layer. The largest stock of the sandy fraction in the analysed section of the profile is recorded at the depth of 11.31 m. Due to the fire, the pH value in the surface layer increased, while the content of the total nitrate decreased. This brought about a change in both the soil and vegetation cover. The wetland surface lowered down to the water table, resulting in secondary plant succession followed by the paludification process (Kania *et al.* 2006).

The fire caused edaphic changes within the mire substratum, which altered the vegetation. New species appeared, such as *Lycopus europaeus*, *Filipendula ulmaria*, *Calamagrostis* sp., *Scirpus lacustris*, *Eriophorum angustifolium* and *Epipactis* sp. Moreover, the density of emergent vegetation increased – it included *Thelypteris* sp. and *Carex* sp. It must be stressed that the largest stock of seeds of *Lycopus europaeus* is correlated with the waning of charcoal content. This is a result of the fast adaptation of this species – a pioneer of secondary succession (Kania *et al.* 2006). *Lycopus europaeus* tolerates shading in the eutrophic environment with neutral reaction (6≤pH<7) (Zarzycki *et al.* 2002). It is a differential species of the phytosociological class *Phragmitetea* (Podbielkowski, Tomaszewicz 1982). *Filipendula ulmaria*, whose seeds were found at a similar depth, also indicates such edaphic conditions.

Mosses are important bioindicators of the natural environment as well as components of deposits (Dickson 1986, Tobolski 2006, Janssens 1990). Brown mosses are excellent indicators of minerotrophic habitats. *Meesia triquetra* is the dominant brown moss recorded in the analysed deposit. This species is treated as a relic of the rich continental fens (Jannsens 1990, Lamentowicz 2005, Swinehart 1995), in some publications also described as a glacial relic (Tobolski 2003, Gałka 2007). They played an important role in the peat-forming processes at the late Pleistocene and early Holocene (Jasnowski 1957a, 1957b, 1959). In this phase, peat mosses were less abundant than brown mosses.

Testae amoebae are sensitive indicators instantly reacting to changes in the natural environment, such as eutrophication, acidification, drainage or waterlogging (Tolonen 1986, Charman 2002, Lamentowicz 2006, 2007a, 2007b). The appearance of *Centropyxis aculeata* indicates the change of water conditions in the mire. It implies the changing hydrological conditions in the basin of biogenic accumulation, which is proved by the presence of the amoeba *Arcella discoides* (Lamentowicz 2005, 2008). This species prefers wet habitats (Warner 1990a), but it tolerates a wide range of pH (Lamentowicz 2005). Nearly the entire section of the core under question contains head capsules of Chironomidae as well the remains of Cladocera and Oribatida. At the end of

Table 1

Characteristics of the local macrofossil assemblage zones (LMAZ) from the bottom deposits of the Borzechowo mire

Zone	Depth (m)	Characteristics
BorzM1 *Carex-Lycopus*	11.42–11.24	This zone includes mire subfossil plant remains: *Carex* sp., *Phragmites australis*, *Thelypteris* sp., *Equisetum* sp., *Calamagrostis* sp., *Filipendula ulmaria*, *Lycopus europaeus*, *Ranuculus* sp., *Eriophorum angustifolium*, *Pinus sylvestris*, *Betula* sp. and *Calluna vulgaris*. Other findings include moss (*Sphagnum* spp., *Polytrichum commune*, *Messia triquetra*, *Drepanocladus*) and remains of *Pinus sylvestris*, *Populus tremula* and fruits of *Betula* nana. This zone also includes wood, charcoal and sand. In the final section of this zone, water plant remains appear (*Ceratophyllum demersum* and *Nymphaea* sp).
BorzM2 *Nymphaea-Ceratophyllum*	11.24–11.18	A characteristic feature of this zone is the presence of aquatic plants, such as *Ceratophyllum demersum*, *Nymphaea* sp., *Najas marina* and *Chara* sp. Large amounts of Mollusca appear, whose abundance decreases when moving up. Aquatic fauna: *Arcella discoides*, Chironomidae and Cladocera.

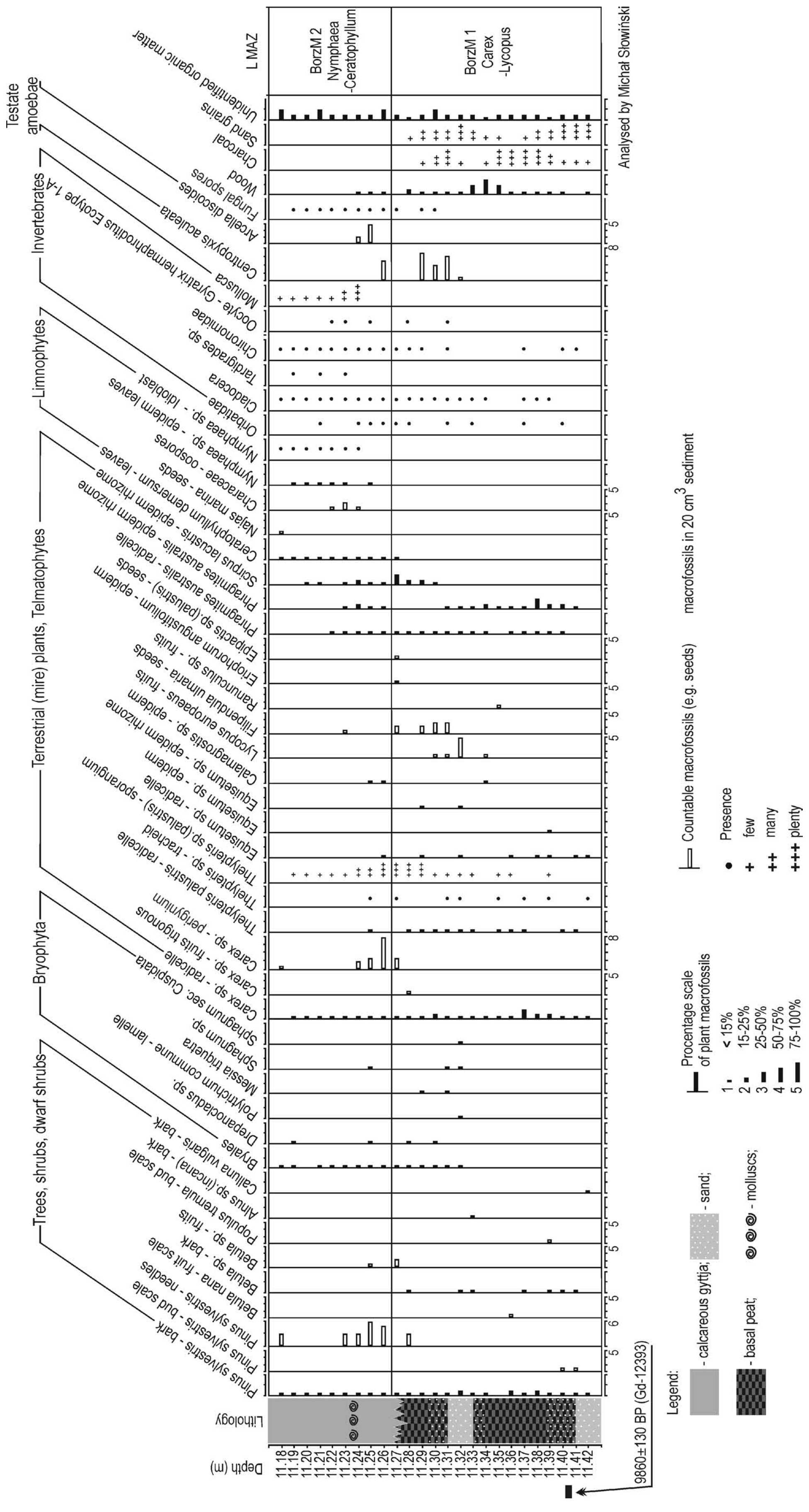

Fig. 2. Plant macrofossil diagram of the basal peat of the Borzechowskie mire.

the telmatic phase, *Thelypteris palustris* and *Scirpus lacustris* increased in abundance. Their maximum is recorded at the depth of 11.26 m. Other plant remains that became more abundant at that time include utricles of *Carex* sp. (*rostrata*?), needles of *Pinus sylvestris*, fruits of *Betula* sp. and epidermis of *Calamagrostis* sp.

Limnic phase

The beginning of this phase indicates a radical transformation of the conditions of biogenic accumulation. The semi-aquatic habitat evolves into an aquatic one. The palynological analysis made by B. Noryśkiewicz (unpublished data) indicates that those changes took place at the turn from the Preboreal to the Boreal periods. The existing then water body was surrounded by pine-birch forests with a quickly spreading hazel.

The limnic phase documents the first stage of lake development. Besides the change of the deposit from a peaty to limnic one (calcareous gyttja), also other changes were recorded, *e.g.* in the subfossil plant remains and the appearance of Mollusca. *Ceratophyllum demersum* was found at the depth 11.27 m. It is a free-floating aquatic plant, which prefers fertile or very fertile small astatic water bodies of neutral or even alkaline reaction (6≤pH>7). *Ceratophyllum demersum* reaches its maximum abundance in shallow water bodies heated intensively in summer. Environmental tolerance enables this species to grow at the depth from 0.5 to 10 metres (Hannon, Gaillard 1997). It creates dense patches (Kłosowski S., Kłosowski K. 2001, Zarzycki *et al.* 2002). The largest amount of Mollusca is found in the third centimetre of the core in the limnic phase, at the depth of 11.24 m. The lake was occupied by species of the genus *Nymphaea* with free-floating leaves. This is proved by its remains, such as the epidermis and idioblasts. Plants of the genus *Nymphaea* prefer meso-eutrophic water bodies, whose reaction ranges from slightly acidic to alkaline (5≤pH>7) (Zarzycki *et al.* 2002). They also tolerate a small depth of water, and rarely live below 3 metres in depth (Hannon, Gaillard 1997). Due to their fast growth and large production of plant biomass, those plants contribute to shallowing and overgrowing of water bodies (Janecki 1999). Nymphaeids were accompanied by *Ceratophyllum demersum*, whose needle-like leaves were found at the top of the analysed section. The presence of oospores indicates that Charales also grew there. Lake conditions are also confirmed by the presence of head capsules of Chironomidae and the decreasing abundance of Oribatida. In this environment, large communities of Cladocera developed. The lake shores were overgrown by sedge communities with brown mosses of the genus *Drepanocladus*, as well as *Thelypteris palustris*, *Phragmites australis* and *Scirpus lacustris*. The top section of the core also included the seeds of *Najas marina*. This macrophyte is an annual plant and forms thick underwater meadows. *Najas marina* prefers shallow meso-eutrophic lakes up to 3 m deep (optimum depth is about 1 m) (Hannon, Gaillard 1997), and alkaline reaction of pH>7 (Zarzycki *et al.* 2002). Such conditions are found in both freshwater and salty water bodies (salinity up to 10‰). *Najas marina* was also recorded in deposits of the Baltic Sea (Bennike *et al.* 2001).

Plant indicators found in the analysed section of the core, such as *Ceratophyllum demersum*, *Lycopus europaeus* and *Scirpus lacustris*, indicate that mean minimum temperature for July at the base of biogenic accumulation ranged between 13°C and 16°C (Isarin, Bohncke 1999, Bos *et al.* 2007). The entire section of the core included an admixture of unidentified organic matter, which is plotted in the diagram as UOM.

DISCUSSION

High resolution analysis of the bottom section of the core enabled reconstruction of the evolution of the mire, which had developed on a buried block of dead ice. According to the macrofossil analysis for the bottom section of the core, the deposit found directly on the mineral base is thought to be fen. It was accumulated in telmatic conditions, which are evidenced by subfossil plant remains. On the basis of the presence and relative abundance of specific plant species, the so-called indicator plants, it was possible to infer the type of fen. It was *Limno-Phragmitioni* (reed peat) (Tobolski 2000, Tołpa *et al.* 1967). In investigations on palaeohydrological changes of wetlands and correlations between that peat and environmental factors, Żurek (1990, 1993) proved that peat was developing on sandy deposits in the Late Glacial period. According to him, this phenomenon is linked with melting out of dead ice blocks and development of peat deposits on top of it. Increasing relative water table finally submerged the peat.

Summarizing all the research, it may be concluded that the 'basal peat' came into being as a result of intensified paludification during an early phase of the dead ice melt-out. Waterlogged basal sedimentary complex, found on top of the melting block, contributed to the development of minerotrophic peat-forming vegetation. Groundwater played a crucial role in the development of the mire. It stimulated sedimentation of biogenic matter directly on sandy-gravely deposits. The rate of peat accumulation depends mostly on climatic and hydrological conditions in the place where biogenic accumulation occurs. Those conditions influence the biogenic decomposition and accumulation. Plant communities that take part in peat sedimentation are also of great significance. However, besides climatic and hydrological conditions they are also dependent on edaphic conditions. The macrofossil analysis, especially of the subfossil artefacts recorded at the bottom of the Borzechowo mire, made it possible to reconstruct palaeohydrological conditions in this locality. The basal deposits that fill up the bed of the subglacial channel indicate two phases of development: telmatic and limnic. Both plant and animal species found in the deposits indicate frequent oscillations of the water table. The telmatic phase indicates a rising water table. At that time a shallow astatic water body existed. This was the effect of systematic melting out of dead ice blocks, which finally caused the deepening of the basin and introduction of new elements in limnic flora. A significant water rise, which brought about a change from a telmatic to a limnic environment, is indicated by the presence of plant macrofossils of *Najas marina*, *Nymphaea* sp. (Hannon, Gaillard 1997), algae *Chara* sp. (Podbielkowski 1978, Pełechaty *et al.* 2007) and animal macrofossils of Tardigrada (Cromer 2008), Cladocera and Chironomidae.

The basal peat was rarely analysed in respect of palaeoecology and macrofossils. A few papers discuss the floristic composition and evolution of wetland development on buried blocks of dead ice (Marek 1994, Wojciechowski 2000, Kowalewski *et al.* 2001, Wright, Stefanova 2004, Drzymulska 2006). Both floristic and faunistic composition of the bottom section of the cores, which included basal peat, indicate palaeohydrological changes in the sedimentary basins. The threshold was the first winter season when the water above the peat bog surface did not freeze to the bottom (Błaszkiewicz 2005). This triggered a sudden disintegration of dead ice, and a quick submerging of the mire. The macrofossil composition indicates quick changes in the water table (Hannon, Gaillard 1997). The origin of the lake basin of the Borzechowo mire correlates with the recorded palaeohydrological changes in the early post-glacial landscape areas in Central Europe. On the basis of the research by Niewiarowski (1990) and Ralska-Jasiewiczowa (1987), Żurek (1990) delimited two periods of low water table. The first one was connected with the final stage of the dead ice melt-out, correlated with the palaeoecological investigations in the bottom deposits of the Borzechowo mire.

The macrofossil analysis is a key element in an unambiguous definition of biogenic sediments and of the character of peat deposits (Tobolski 2000, 2006). Along with other palaeoecological analyses (analyses of pollen, testate amoebae, cladocerans, diatoms, chironomids, *etc.*) it reflects a wider spectrum of environmental changes and enhances possibilities for their more accurate interpretation, as well as the processes that stimulated them.

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