Studia Quaternaria, vol. 19: 19–26.

EEMIAN AND EARLY VISTULIAN VEGETATION AT MICHAŁOWO (NE POLAND)

Mirosława Kupryjanowicz, Danuta Drzymulska

University of Białystok, Institute of Biology, Department of Botany, 15-950 Białystok, Świerkowa 20 B, Poland; e-mail: kuprbot@uwb.edu.pl, drzym@uwb.edu.pl

Abstract

This paper presents the results of palaeobotanical studies (pollen and plant macrofossil analyses) of the sediments from the profile Michałowo P-3 (Gródek-Michałowo Depression, NE Poland). At this profile the second bed of peat under Holocene peat and the layer of silts and sands was discovered. The pollen succession indicates that they were deposited, with some gaps, from the beginning of Eemian Interglacial to Early Vistulian. The local pollen zones, distinguished in the pollen diagram, correlate with the regional pollen stratigraphy of the Eemian Interglacial, but the pollen record of hornbeam (E5 R PAZ) and spruce (E6 R PAZ) regional zones is absent in Michałowo. In the middle part of the Michałowo pine zone (Mi-5 *Pinus* L PAZ), a cool oscillation of climate is marked by an opening of forests and development of herb plant communities.

Key words: Eemian Interglacial, Vistulian, pollen analysis, pollen succession, macrofossil analysis, vegetative plant remains

Manuscript received 06.06.2001, accepted 10.10.2001

INTRODUCTION

At the early seventies in the area of Pietuchowszczyzna peat-bog, located at the territory of the Gródek-Michałowo Depression (NE Poland) at a depth 9.50–15.00 m, a series of organic deposits was discovered (Prószyńska *et al.* 1973). It was covered by a layer of clays and sands (more than 4 m thick) and Holocene peat (more than 5 m thick). The clays and sands were dated by the TL method to the period from the Early to Late Vistulian. It enabled connection of the organic series located underneath with the Eemian Interglacial.

In 1999 the drilling Michałowo P-3, located in the western part of Gródek-Michałowo Depression (Fig. 1), was made by Kurek and Preidl for the Detailed Geological Map of Poland 1:50000, the sheet Gródek. That core was 200 m long and confirmed the presence of the fossil series of organic silt and peat in depth 8.20–4.50 m. The sediments above 8.20 m were expertise studied by pollen analysis. The upper part contained sporadic sporomorphs, so only sediments from below 5.40 m appeared suitable for full palynological analysis.

A main goal of the present research was to determine the age of the deposits and to reconstruct the past vegetation. Very high pollen values of *Alnus* and Cyperaceae, found in several pollen spectra from depths 7.60–5.40 m, made interpretation of the palynological record difficult. The presumption, that it might be connected with the local pollen over-representation of these plants, induced analysis of plant remains in the deposits.

LITHOLOGY

According to Kurek and Preidl (in press) the top part of sediments from Michałowo P-3 borehole is represented by:

0.00–3.80 m – black peat,
3.80–4.00 m – dark grey sand with fragments of organic remains,
4.00–4.50 m – fine grey sand,
4.50–6.00 m – grey silt with organic matter,
6.00–6.25 m – black organic silt,
6.25–8.00 m – black peat,
8.00–8.20 m – organic silt, almost black.

During detailed inspection of the core, and when collecting samples for pollen analysis, numerous small fragments of *Alnus* wood were found at the depths of 6.80–7.10 m and 7.40–7.60 m, and large fragments at 7.10–7.19 m and 7.26–7.40 m.

METHODS

Samples designed for pollen analysis were boiled in 5% KOH. Then, mineral and organic fractions were separated in water solutions of cadmium and potassium iodides (density *ca.* 2.1 g/cm^3) and the organic fraction subjected to Erdtman's acetolysis (Erdtman 1943).

For samples that contained a lot of sporomorphs, most of the pollen spectra were counted to at least 1000 AP grains, except of four samples, with low AP abundance, where the AP count was still above 500.

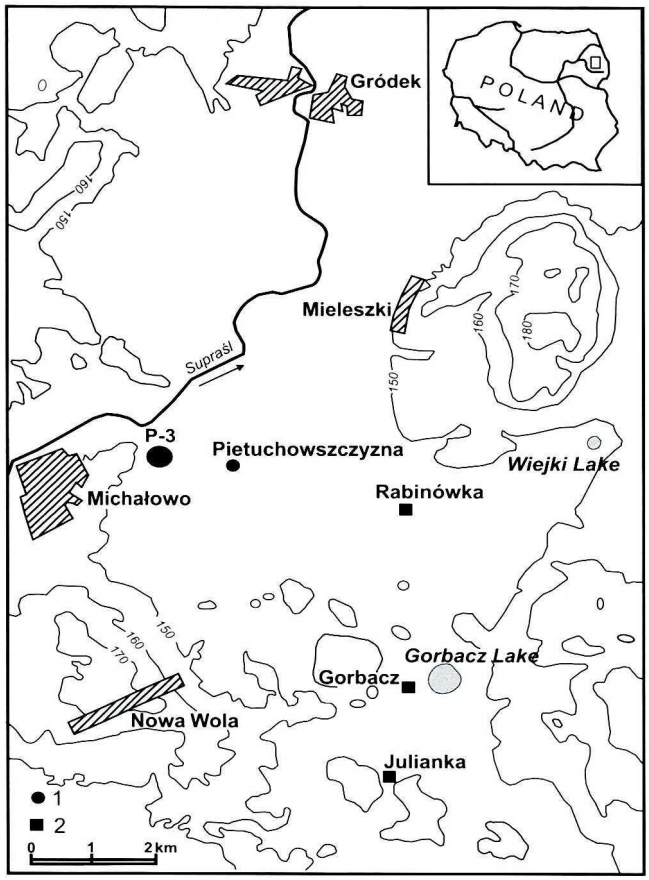

Fig. 1. Sketch map showing the location of the site Michałowo P-3. *1* – section with the Eemian, Vistulian and Holocene sediments that was not analysed palynologically (Prószyńska *et al.* 1973), *2* – palynologically analysed sections of the Late Glacial and Holocene sediments (Kupryjanowicz 1998, Piasecka 1999, Szachowicz 2002).

Analyses of decomposition degree of peat and macrofossil plant remains were made for 10 selected samples only (see Fig. 3). Decomposition degree of peat was determined by microscopical method, according to Obidowicz (1990). Samples of not scoured peat (about 5 g) were placed on a pan and mixed with water until getting homogenous bulk. Next, two microscopic slides were prepared and humus/peat ratio was determined in ten selected fields of vision, where "peat" denotes the sum of humified and not decayed parts. The decomposition degree is an arithmetical mean of those ten component values.

For analysis of macrofossil plant remains, 50 ml of deposit from each sample was taken. The deposit was boiled in water with an addition of 10% KOH and then rinsed on 0.2 mm sieves. Seeds and fruits were picked out and placed in a glycerine-thymol mixture, and identified under a stereoscopic binocular. Vegetative plant remains were identified with a light microscope. Scoured peat was placed on an object glass in glycerine and covered by a cover glass. For each sample, a proportion of every taxon tissues in the global tissue bulk was estimated in ten selected fields of vision. Only remains with cellular structure were taken into account.

The obtained results are presented in a pollen diagram (Fig. 2) and a diagram of plant macrofossils (Fig. 3). The diagrams were drawn using the POLPAL programme (Walanus, Nalepka 1999). The basic pollen sum consists of tree, shrub and terrestrial herb pollen. The proportion of pollen of aquatic and reedswamp plants, spores of Pteridophyta and *Sphagnum*, and indeterminable sporomorphs, was computed in relation to the basic sum increased by the respective taxon. The pollen diagram has been divided into local pollen assemblage zones – L PAZ. In one zone three subzones of pollen assemblages have been distinguished.

RESULTS

Description of local pollen assemblage zones (L PAZ)

42 samples from depths 8.15–4.70 m and 4 samples from depths 3.80–3.00 m were subjected to pollen analysis. In 13 samples (3.00 m, 3.25 m, 3.50 m, 4.90 m, 5.20 m, 5.70 m, 7.11 m, 7.19 m, 7.25 m, 8.00 m, 8.05 m, 8.10 m and 8.15 m) no sporomorphs were present. In 2 samples (4.90 m and 5.20 m) only single corroded pollen grains of *Pinus*, *Alnus* or *Betula*, or spores of *Selaginella selaginoides* and *Pediastrum* occurred. In some other samples (mostly from the silt) very low abundance of sporomorphs was noted.

Mi-1 *Pinus-Betula-Ulmus L PAZ (depth 7.95 m)*

Pinus (60%) and *Betula* (30%) predominate in this zone. The proportion of *Quercus* (4%) and *Ulmus* (2%) is relatively high. Pollen of other trees, *Fraxinus*, *Alnus*, *Tilia cordata*-type and *Salix*, and *Corylus avellana* appears sporadically. NAP values, represented chiefly by Gramineae undiff. and *Artemisia*, remain below 5%. Pollen of *Typha latifolia*, *Typha angustifolia*/*Sparganium* and *Nymphaea alba* and spores of *Filicales monolete*, *Equisetum* and *Pteridium aquilinum* are present. The upper boundary of the zone is marked by a decrease in the pollen value of *Betula* to 18% and a rise in the frequency of *Quercus* to 14%.

Mi-2 *Quercus-Pinus L PAZ (depth 7.90 m)*

The maximum of *Quercus* (14%), the high values of *Pinus* (58%) and relatively high frequency of *Ulmus* (4%) are characteristic of this zone. Pollen grains of *Hedera helix* and *Viscum* appeared for the first time. The percentages of *Fraxinus*, *Corylus avellana*, *Alnus*, *Tilia cordata*-type and *Salix* are slightly higher than in the preceding zone. Reedswamp plants are represented by *Typha angustifolia*/*Sparganium* only. A weak culmination of *Pteridium aquilinum* and a peak of *Tetraedron* occur. The upper boundary of the zone is placed at the fall of *Quercus* pollen values to 8% and the rapid rise of *Corylus avellana* to 55% and *Alnus* to 12%.

Mi-3 *Corylus L PAZ (depth 7.87–7.65 m)*

Very high pollen values of *Corylus avellana* (55–60%) are characteristic feature. Frequency of *Alnus* increases from 12% to 22% and that of *Tilia cordata*-type from 4% to 10%. Percentage of *Quercus* decreases to 2%. In the central part of the zone *Ulmus* has an absolute maximum (6%). Pollen

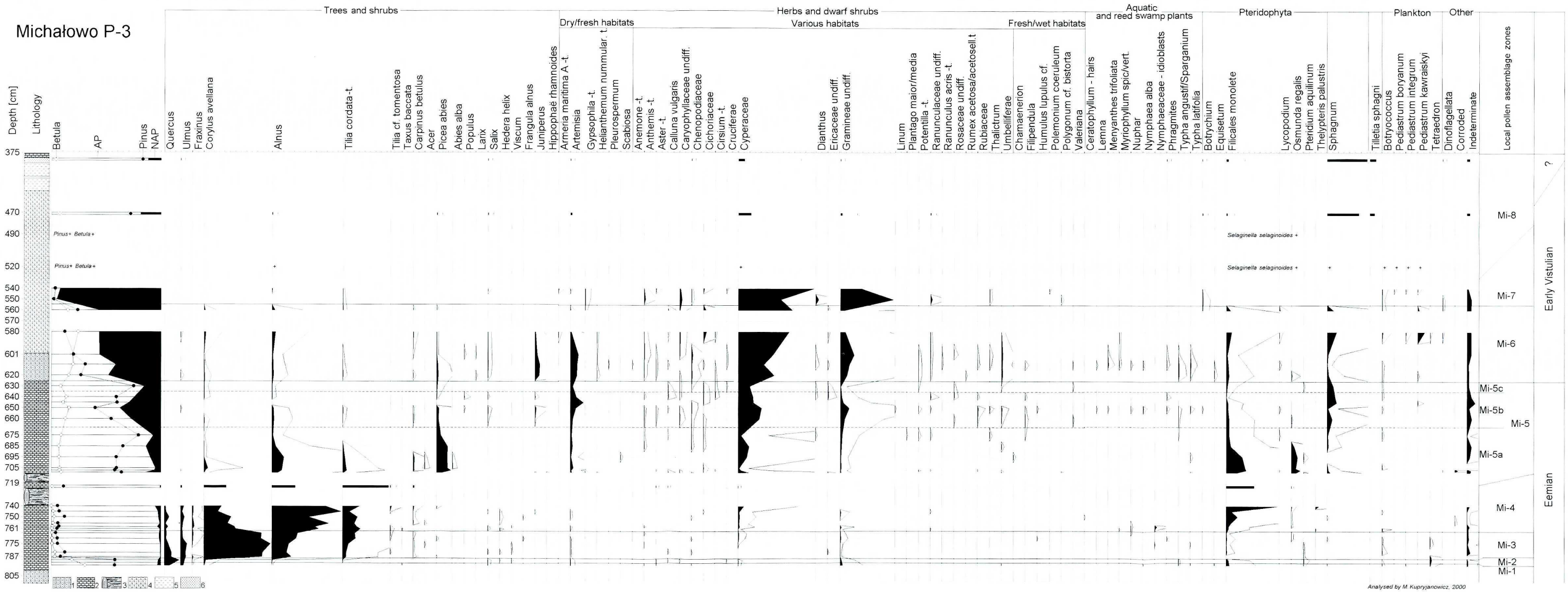

Fig. 2. Percentage pollen diagram from Michałowo. Lithology: *1* – organic silt, *2* – peat, *3* – wood, *4* – silt with organic matter, *5* – silt, *6* – sand.

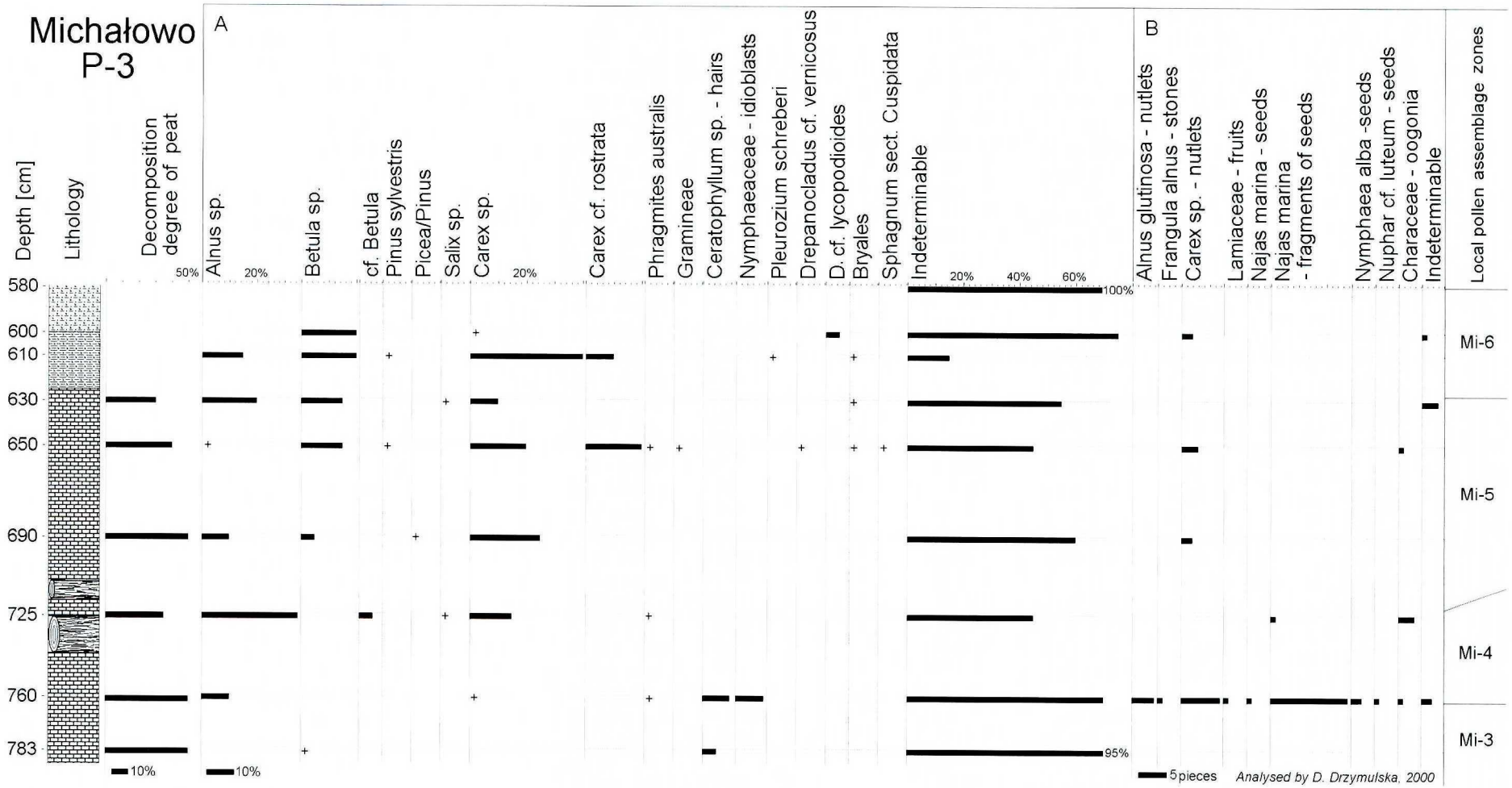

Fig. 3. Diagram of vegetative (**A**) and generative (**B**) plant remains from Michałowo (lithology as in Fig. 2).

grains of *Carpinus betulus* and *Picea abies* appear for the first time, but their values are below 0.5%. *Hedera helix* and *Viscum* pollen is present. The values of NAP are below 3%. Pollen of *Phragmites* and *Typha latifolia* and Nymphaceae idioblats occur sporadically. *Osmunda* spores appear for the first time. The upper boundary of the zone is placed at the fall of *Corylus avellana* pollen values to about 30% and the rise of *Alnus* to about 40%.

Mi-4 *Alnus-Corylus-Tilia L PAZ (depth 7.61–7.22 m)*

Alnus pollen prevails (max. 63%). The proportions of *Corylus avellana* and *Tilia cordata*-type are still rather high (up to 20% and 15%, respectively). In the lower part of the zone *Fraxinus* has the highest values, of about 2%. Percentages of other trees (*Quercus*, *Ulmus*, *Carpinus betulus*, *Picea abies*, *Salix*) are relatively low. *Hedera helix* and *Viscum* pollen is present. NAP values slightly increase, represented mainly by Cyperaceae (up to 5%). The absolute maxima of *Filicales monolete* (45%) and *Thelypteris palustris* (3%) occur.

In samples from 7.25 m and 7.19 m, from the thin peat layer located between large wood fragments, sporomorphs were absent. Only in the sample from 7.22 m a pollen was abundant, but extremely destroyed. Exceptionally high proportion of *Tilia cordata*-type pollen in this sample is connected with selective pollen preservation *i.e.* stronger degradation of *Corylus* and *Alnus* pollen than that of *Tilia*. Nevertheless, pollen spectrum of this sample is similar to the other spectra from the Mi-4 zone. The zone Mi-4 has no upper boundary. Above the sample 7.22 m a large fragment of *Alnus* wood occurs and the sediment above belongs to the next zone, Mi-5.

Mi-5 *Pinus L PAZ (depth 7.09–6.30 m)*

In this zone, *Pinus* pollen is dominant. The zone has been divided into three subzones:

– subzone Mi-5a *Picea-Alnus* (depth 7.09–6.75 m) is characterised by a rise of *Pinus* to 80% and relatively high values of *Picea* (max. 12%) and *Alnus* (max. 10%). The proportion of NAP remains below 15%. Percentages of *Filicales monolete* are still high, up to 20%. There is a clear culmination of *Osmunda;*

– subzone Mi-5b NAP-*Juniperus-Betula* (depth 6.60–6.40 m) shows peaks of NAP (40%) and *Juniperus* (about 1%), absolute maximum of *Artemisia* (12%) and a small rise of *Betula* (to 20%). A depression of *Pinus* curve (min. 40%) occurs;

– subzone Mi-5c *Pinus*-NAP (depth 6.30 m) represents the second peak of *Pinus* (70%). The proportion of NAP decreases to about 15%.

The upper boundary of the Mi-5 L PAZ is defined by the fall of *Pinus* pollen values to about 27% and the rise of NAP to about 50%.

Mi-6 *Gramineae-Artemisia-Juniperus L PAZ (depth 6.20–5.60 m)*

The proportion of NAP is very high (45–60%). There are peaks of Gramineae undiff. (20%), *Artemisia* (10%), Chenopodiacae (2%) and Umbelliferae (2%). *Juniperus* culminates (6%). The *Pinus* values remain below 30% and *Betula* below 25%. There is a barren layer in the top part of this zone represented by the sample at 5.70 m. The upper boundary of the zone is marked by a rise of NAP and a drop in the *Betula* and *Pinus* pollen values below 5%.

Mi-7 *Gramineae-Cyperaceae L PAZ (depth 5.50–5.40 m)*

NAP predominates (90–95%). There are absolute maxima of Gramineae undiff. and Cyperaceae (50% and 70%, respectively). The values of *Dianthus*, *Gypsophila*-type and Caryophyllaceae undiff. are higher than in the other zones. Pollen grains of *Armeria maritima* A-type are present. The zone has no upper boundary. The top of the zone is in direct contact with the bottom of a barren layer (samples 5.20 and 4.90 m).

Mi-8 *Pinus-Cyperaceae L PAZ (depth 4.70 m)*

This zone is represented by a single sample. *Pinus* pollen (72%) predominates. The value of *Betula* is below 10%. Pollen grains of other trees (*Alnus*, *Picea* and *Salix*) occur sporadically. Herb plants (NAP = 18%) are represented mainly by Cyperaceae (12%), Gramineae undiff. (2%) and *Artemisia* (2%). The proportion of *Sphagnum* is high (25%). Spores of *Tilletia sphagni* appear for the first time. The zone has neither upper nor lower boundary, because the top and the bottom of the zone are in contact with the barren layers. Above the upper barren layer of silt a bed of clay and sand occurs and above it a new peat series extends up to the surface of the present peat-bog.

Pollen spectrum from the depth 3.75 m is similar to that one from 4.70 m. *Pinus* (93%) is a dominant taxon. *Betula* has 5% and NAP 13%. The proportion of *Sphagnum* is still high (25%). Spores of *Tilletia sphagni* are present.

Description of plant macrofossils

Peat samples from the depths 7.25 m, 6.90 m, 6.50 m, 6.30 m, 6.10 m and 6.00 m showed medium and high decomposition degree (30–60%). Medium-decomposed peat is characterised by visible structural changes in tissues. The tissues are often broken up and much humus appears. In highly-decomposed peat these features dominate and then recognition of vegetative remains can be difficult or even impossible (Obidowicz 1990). Therefore indeterminable remains had very high participation in these samples (even 75%).

Betula sp. tissues were present in each sample analysed (5–20%), but in the sample from 7.25 m they were identified as cf. *Betula*. Vegetative remains of *Alnus* sp. are highly represented (35%) in the sample 7.25 m. The fragments of *Alnus* sp. woods are numerous in the whole profile, except of the samples from 6.00 m, where no such tissues were found, and 6.50 m, where they appeared sporadically.

Vegetative tissues of *Carex* sp. are frequent between 7.25 and 6.10 m, and most numerously represented in the sample from 6.10 m, attaining 40%. Additionally, 10% of tissues in this sample were identified as *Carex* cf. *rostrata*, but no *Carex* sp. fruits were found there. The *Carex* sp. fruits ap-

pear in the samples from 6.90 m (two nutlets), 6.50 m (three nutlets) and 6.00 m (two nutlets, one of them incomplete).

In the sample from 7.83 m hairs of *Ceratophyllum* sp. appeared (5%). Numerous seeds and fruits of different taxa (*Nuphar* cf. *luteum*, *Nymphaea alba*, *Najas marina*, *Carex* sp., *Alnus glutinosa*) and *Characeae* oogonia occurred at 7.60 m. In the sample from 7.60 m *Ceratophyllum* sp. hairs and Nympheaceae idioblasts were also present (both constituting 10% of vegetative remains).

At the depth 6.00 m leaves of *Drepanocladus* cf. *lycopodioides* occur, reaching 5%. In other samples, abundance of mosses is low. *Pleurozium schreberi* appeared vestigially in the sample from 6.10 m, and *Drepanocladus* cf. *vernicosus* at 6.50 m. Leaves of *Sphagnum* (section *Cuspidata*) occurred only at 6.50 m.

Oogonia of Characeae were found at 6.50 m and 7.25 m (one piece and three pieces, respectively). At 7.25 m a fragment of *Najas marina* seed occurred. The sample from 5.80 m contained only indeterminable fragments of tissues. Fruits and seeds were not found.

AGE OF SEDIMENTS

The results of pollen analysis indicate that the lowest part of the analysed profile – from the bottom up to 6.30 m – shows the pattern of interglacial succession. This is not a complete succession. However, its characteristic features such as very high *Corylus avellana* pollen values (with a maximum of 60%) and the order of expansion of trees and hazel (*i.e. Betula-Pinus*, *Ulmus*, *Quercus*, *Corylus*, *Alnus-Tilia*) suggest correlation of the pollen succession from Michałowo with the scheme of Eemian Interglacial succession in Poland (Mamakowa 1989, Janczyk-Kopikowa 1991).

The local pollen assemblage zones (L PAZ) from Michałowo correlate well with the regional pollen zones of the Eemian, established by Mamakowa (1989).

The local PAZ Mi-1 *Pinus-Betula-Ulmus* corresponds to the regional zone E2 *Pinus-Betula-Ulmus*. One difference is that in the diagram from Imbramowice – the type locality for this zone – *Ulmus* reaches its maximum and *Quercus* values are relatively low, but there are many localities in Poland where the absolute *Ulmus* culmination takes place later, just as in Michałowo, and *Quercus* has values about 5% already in this zone (Mamakowa 1989).

The local PAZ Mi-2 *Quercus-Pinus* corresponds in general to the regional zone E3 *Quercus-Fraxinus-Ulmus*, but it is characterised by high *Pinus* pollen values and a rather low maximum of *Quercus*. For this reason it should be correlated with the lower *Pinus* subzone of the E3 R PAZ. It is quite probable that this zone is incomplete in the Michałowo profile.

The local PAZ Mi-3 *Corylus*, with characteristic very high hazel content, corresponds directly to the regional zone E4 *Corylus-Quercus-Tilia*.

Correlation of the local pollen zone Mi-4 *Alnus-Corylus-Tilia* with the regional pollen stratigraphy is very difficult. In the samples of this zone, the frequency of *Corylus* pollen reaches only about 30%, and *Alnus* is very high, up to 60%. High pollen values of *Tilia*, *Ulmus*, *Quercus*, *Fraxinus* and sporadic occurrence of *Carpinus betulus* might argue for correlation with the E4 *Corylus-Quercus-Tilia* regional zone. In all probability the very high *Alnus* pollen values are connected with its local over-representation. This feature is noted in some other Polish profiles (Mamakowa 1989), and even higher local over-representation of *Alnus* pollen is recorded in the hazel phase in profile 1 from Szwajcaria (Borówko-Dłużakowa, Halicki 1957; Mamakowa 1989). The single sample with the very high *Tilia cordata*-type value (from 7.22 m) belongs most probably to the regional E4 zone too.

Pollen record corresponding to the regional zones E5 *Carpinus-Corylus-Alnus* and E6 *Picea-Abies-Alnus* is absent in the Michałowo profile. These zones might be represented here by sediment layer with large fragment of alder wood, found at the depth 7.10–7.19 m. Evident disproportion between very small thickness of this layer and long duration of hornbeam and spruce phases (*ca.* 4000 yr and *ca.* 2000 yr respectively, according to Müller 1974) suggests the presence of hiatus in this part of profile. The sedimentation gaps or sediment disturbances during the hornbeam and/or spruce zones are also noted in some Eemian profiles from other sites in north-eastern and eastern Poland, such as Otapy (Bitner 1956a), Bagno-Kalinówka (Bitner 1956b), Klewinowo (Borówko-Dłużakowa 1974), Proniewicze PR 1/93 (Krupiński 1995), Hańcki (Brud, Kupryjanowicz 2002) or Bohoniki, Drahle, Chwaszczewo, Trzcianka, Gilbowszczyzna, Podkamionka, Dzierniakowo (Kupryjanowicz in prep.) and Kontrowers (Kupryjanowicz, Żarski, Drzymulska in prep.). This problem will be discused in further paper.

The local PAZ Mi-5 *Pinus* corresponds directly to the regional zone E7 *Pinus*, closing the Eemian succession of vegetation. The rise of *Artemisia* proportion to 12% and NAP to 35% in the subzone Mi-5b reflects opening of forests in the middle part of the pine phase, caused perhaps by climate cooling. Similar oscillation was registered in pollen diagrams from the other sites located in north-eastern Poland, such as Machnacz (Kupryjanowicz 1991) or currently analysed Solniki and Dzierniakowo (Kupryjanowicz in prep.). Detailed analysis of this problem will be the subject of separate paper.

The top part of the biogenic series (6.20–4.70 m) above Mi-5 L PAZ represents Vistulian. The local pollen zones Mi-6 Gramineae-*Artemisia-Juniperus* and Mi-7 Gramineae-Cyperaceae are likely to correspond with the first post-eemian cold oscillation of the stadial rank (Herning).

The local PAZ Mi-8 *Pinus*-Cyperaceae occurring above the barren layer can be correlated with any warm oscillation of the Early Vistulian. However, single pollen spectrum with no connection with the underlying zone Mi-7, does not allow for more precise correlation of this zone. The very high *Pinus* pollen value excludes its reference to the Plenivistulian.

Basing on geological reasons the sands and clays from 4.2–4.0 m have been associated with the maximum of the Vistulian Glaciation (Kurek and Preidl in press). The sample from the bed of the peat, which has grown continuously till today (depth 3.75 m), represents the pollen record of pine forest with small admixture of birch. It would be thus justified to associate it with the Late Vistulian or Early Holocene. However, there are no sporomorphs in sediments above this sample, and determination of age basing exclusively on pollen

analysis is impossible. So, ^{14}C dating of this material is necessary.

DEVELOPMENT OF VEGETATION

On the basis of analyses described above an attempt was made to reconstruct the changes of vegetation.

Zone Mi-1 *Pinus-Betula-Quercus-Ulmus*. Predomination of AP indicates that forest communities prevailed. However, diversity of tree and shrub taxa was very poor. The high proportion of *Pinus* pollen evidences a leading role of pine in the forest communities and its domination in various habitats. The rather high pollen value of *Betula* points to its significant role in the forests of that time. The relatively high percentages of *Quercus* reflect most probably its presence in the pine communities developed on richer soils. *Ulmus* pollen may have originated from various forests. Its occurrence together with *Fraxinus* pollen may indicate, for example, development of the elm-ash riverine forest type. Spores of *Filicales monolete* might come, at least in part, from these forests.

The sedimentation basin was a lake at that time. Reed-swamp communities with *Typha latifolia* and *Typha angustifolia*/*Sparganium* and aquatic communities with *Nymphaea alba* occurred in its inshore zone. *Botryococcus*, *Pediastrum integrum* and *Tetraedron* represented algae.

The zone Mi-2 *Quercus-Pinus* was a period of maximum expansion of oak. On more fertile soils it formed oak-pine mixed forests, perhaps similar to the modern association *Pino-Quercetum* (cf. Matuszkiewicz 2001). The appearance of *Pteridium aquilinum* spores is probably connected with the herb layer of these forests. The role of *Betula* and *Ulmus* still was very important. The moist eutrophic habitats were probably supporting riverine elm-ash communities. Alder might occur in these forests only sporadically (low percentages of *Alnus* pollen). The warming of climate is revealed by the appearance of *Hedera helix* and *Viscum* (cf. Iversen 1944). The aquatic vegetation was similar to that in the previous zone.

Zone Mi-3 *Corylus*. The low proportion of NAP indicates very high density of forest communities. The forest probably surrounded the lake in Michałowo pretty closely. Its most characteristic feature was the absolute domination of *Corylus*. The relatively high values of *Quercus* and *Ulmus* and the presence of *Fraxinus* pollen highlight still considerable role of mixed oak forests and riverine forest communities. Some of the *Corylus* pollen undoubtedly originates from the hazel understorey of these forests. However, the very high pollen values of hazel, typical for the climatic optimum of the Eemian, must have had also some other sources (Mamakowa 1989). Presumably, these were communities of termophilous thickets or even hazel woods. Starting from the beginning of this zone, the oak and riverine forests were enriched with new components, which is evidenced by the almost continuous presence of *Carpinus betulus* and relatively frequent pollen of *Tilia cordata*-type. A distinct change in forests was caused by the expansion of *Alnus*. The rise of the *Alnus* pollen values indicates development of alder-dominated communities in the close surrounding of the lake. The role of pine and birch in these stands was insignificant. This period was the climatic optimum of the interglacial. The high temperature at that time is also evidenced by the presence of *Tilia* cf. *tomentosa* (cf. Frenzel 1967), and *Hedera helix* and *Viscum* (cf. Iversen 1944).

Zone Mi-4 *Alnus-Corylus-Tilia*. The expansion of lime in forest communities began before the end of the previous zone. However, it haven't reached its maximum until the younger phase of the zone Mi-4. In addition to the already existing communities, formation of species-rich deciduous and mixed forests began at that time, presumably with a high proportion of lime, hazel, and already invaded hornbeam.

The exceptionally high peaks of the *Alnus* pollen values were undoubtedly connected with a local over-representation. Both palynological records and botanical composition of deposits suggest that the lake was shallowed at that time. First of all, communities of shallow-water developed rapidly. It is shown by culmination of the *Nuphar* pollen frequency and presence of *Najas marina*, *Nuphar* cf. *luteum* and *Nymphaea alba* seeds and numerous Nymphaeaceae idioblasts and *Ceratophyllum* sp. hairs at the bottom part of the zone Mi-4. Next, the dried up marginal parts of the lake became overgrown with alder forest. It is indicated by the absence of pollen of aquatic plants, presence of *Alnus* bark and wood, increase of *Alnus* pollen values, appearance of *Thelypteris palustris* spores with the simultaneous sudden rise of *Filicales monolete* and occurrence of *Osmunda* spores, which in such a type of communities had optimal living conditions (Matuszkiewicz 2001). The selective pollen degradation in sample from the depth 7.22 m is just connected with drying up of the peat.

The record of vegetation development corresponding to hornbeam (E5 *Carpinus-Corylus-Alnus* R PAZ) and spruce (E6 *Picea-Abies-Alnus* R PAZ) phases of Eemian Interglacial is absent in the Michałowo profile (see section "Age of sediments").

Zone Mi-5 *Pinus*. Changes in vegetation are expressed by an expansion of pine forests, probably with an admixture of birch, and by simultaneous regression of other forest communities.

Subzone Mi-5a *Picea-Alnus*. In spite of their downward trend the pollen values of *Picea* suggest that the spruce was abundant in the Gródek-Michałowo Depression. Its role in the expanding pine forests might have been prominent, especially in bog pinewoods (cf. Matuszkiewicz 2001). The presence of *Sphagnum* spores may indicate development of such forest type during this zone. The regression of alder communities is indicated by decrease of the *Alnus* pollen values. The marginal zone of the lake was still occupied by the alder forest. The appearance of wood and bark of *Betula* and *Picea*/*Pinus* and spores of *Sphagnum* in the deposit suggests, however, some change in this community. Perhaps it was connected with a rise of the habitat acidity.

Subzone Mi-5b NAP-*Juniperus-Betula*. The rise in pollen values of *Artemisia* and Chenopodiaceae, accompanied by the peak of *Juniperus* pollen, indicates some opening of forests and expansion of steppe-like and grassland communities. They were undoubtedly the major source of the Gramineae undiff. and Cyperaceae pollen. The role of wet and/or swamp meadows is evidenced by a rise of the values of Cyperaceae and by presence of *Filipendula*, *Valeriana*, *Tha-*

lictrum and *Cirsium*-type pollen. The values of *Pinus* pollen, within the range of 35–55%, imply occurrence of open pine-woods or stands of pine. Development of steppe-like communities and appearance of boreal species *Pediastrum kawraiskyi* (cf. Jankovská, Komárek 2000) indicate some cooling and increased continentality of climate. In the middle part of the subzone Mi-5, a rise of water level probably occurred. It likely resulted from cooling and/or increasing humidity of climate. The alder forests were flooded then, that is documented by re-appearance of the pollen of aquatic (*Nymphaea alba*) and reedswamp (*Typha latifolia*, *Typha angustifolia*/*Sparganium*, *Phragmites*) plants.

Subzone Mi-5c *Pinus*-NAP. In this subzone, the area of herb communities decreased, the pine forests expanded and the water level fell down again. The drying up marginal parts of the lake became overgrown with alder forest (indicated by an absence of aquatic plant pollen, and the presence of the *Alnus* bark and wood).

Zone Mi-6 Gramineae-*Artemisia-Juniperus*. A continuous rise of the NAP values throughout the zone Mi-6 provides evidence of the progressive spread of open habitats occupied by herbaceous plants. A distinct increase of the pollen values of Gramineae undiff. and *Artemisia* suggests growing importance of grass communities, perhaps steppe-like in nature. Pollen of *Helianthemum nummularium*-type is probably associated with these communities. The sporadic presence of *Armeria maritima* A-type pollen may indicate the existence of halophilous communities. Shrub communities in dry sandy habitats are emphasised by the occurrence of *Juniperus* pollen. In moist habitats *Salix* occurred more abundantly than in the previous zone. The high proportion of Cyperaceae pollen documents development of wet communities with sedges. However, the presence of vegetative remains of *Carex* sp. and *C.* cf. *rostrata* in the deposit suggests local over-representation of Cyperaceae pollen.

From the beginning of this zone the water level rose significantly, that was expressed by the change of deposit type from peat to organic silt. Initially, the inshore zone of the lake has become occupied by aquatic (the peak of *Nymphaea alba*) and reedswamp vegetation (the peaks of *Phragmites*, *Typha latifolia* and *Typha angustifolia*/*Sparganium*). Next, this vegetation gradually disappeared, probably as a result of the still rising water level or/and cooling of climate, and in the cool and clear water of meso- to oligotrophic lake, *Botryococcus* and *Pediastrum* (chiefly *P. kawraiskyi*) were developing at the first stadial of the Early Vistulian (cf. Jankovská, Komárek 2000).

Zone Mi-7 Gramineae-Cyperaceae. Exceptionally high pollen values of NAP (above 90%) imply completely open vegetation in this period. The grass and sedge communities were dominant, perhaps in all habitats. Very low proportion of *Pinus*, *Betula* and other tree pollen suggests the absence of trees in the surroundings of Michałowo.

The sample from depth 4.70 m, representing the zone Mi-8 *Pinus*-Cyperaceae shows the dominance of pine forests, perhaps with small admixture of birch and not very large areas occupied by open vegetation, chiefly of meadow type with sedges and grasses and steep-like with *Artemisia*. The high proportion of *Sphagnum* and the presence of spores of *Tilletia sphagni*, the fungus connected with *Sphagnum* (Van Geel 1978), document development of peat-bog at that time. The sample from depth 3.75 m has very similar pollen composition and reflects the same character of vegetation, but it was formed in quite different period.

CONCLUSIONS

The lower part of the analysed profile, from the bottom up to the depth of 6.30 m, represents Eemian Interglacial. It includes the interval from the pine-birch-elm phase (Mi-1 L PAZ) to the hazel phase (Mi-3 and Mi-4 L PAZ) and, after a gap, also the pine phase (Mi-5 L PAZ) of this interglacial. Palynological record documents opening of forests in the middle part of the Mi-5 zone, caused perhaps by climatic cooling. In the profile from Michałowo there is no sediments from the Eemian pine-birch (E1 R PAZ), hornbeam (E5 R PAZ) and spruce (E6 R PAZ) regional pollen assemblage zones.

The part of the profile between 6.20 m and 4.70 m corresponds to the Early Vistulian and documents existence of arctic open vegetation (Mi-6 and Mi-7 L PAZ) and boreal pine forests (Mi-8 L PAZ) at that time.

Palaeobotanical age determination of the sample from 3.75 m including pollen record of the pine forest period appeared impossible. It would be justified to associate it with the Late Vistulian or Early Holocene. In the top peat layers, above 3.75 m, no sporomorphs were present.

Acknowledgements

We wish to express our heartfelt to Mr. J. Kurek and Mrs. Z. Preidl, who provided the deposits from Michałowo for our study. We also thank very much to Mrs. D. Czerniawska for some laboratory work.

REFERENCES

Bitner K. 1956a. Interglacial flora in Otapy/District Białystok (original: Flora interglacjalna w Otapach). *Biuletyn Instytutu Geologicznego* 100, 61–142 (in Polish with English summary).

Bitner K. 1956b. Three new localities of Pleistocene flora (original: Nowe stanowiska trzech plejstoceńskich flor kopalnych). *Biuletyn Instytutu Geologicznego* 100, 247–262 (in Polish with English summary).

Borówko-Dłużakowa Z. 1974. Eemian flora at Klewinowo in the Podlasie Lowlands (original: Eemska flora z Klewinowa na Nizinie Podlaskiej). *Biuletyn Instytutu Geologicznego* 269, 11–22 (in Polish with English summary).

Borówko-Dłużakowa Z., Halicki B. 1957. Interglacial sections of the Suwałki region and the adjacent territory. *Acta Geologica Poloniae* 7, 361–401 (in Polish with English summary).

Brud S., Kupryjanowicz M. 2002. Eemian Interglacial deposits at Haćki near Biels Podlaski: implications for the limit of the last glaciation in northeastenr Poland. *Geological Quarterly* 46, 75–80.

Erdtman G. 1943. An Introduction to Pollen Analysis. Mass. Verdoorn.

Frenzel B. 1967. Die Klimaschwankungen des Eiszeitalters. Braunschweig.

Iversen J. 1944. *Viscum*, *Hedera* and *Ilex* as climate indicators. A contribution to the study of the Post-Glacial temperature climate. *Geologisk Förenings Förhandlingar* 66, 463–483.

Janczyk-Kopikowa Z. 1991. Problems of the palynostratigraphy of the Pleistocene in Poland and the palynological analysis of in-

terglacial deposits from Besiekierz (Central Poland). *Annales Universitatis Mariae Curie-Sklodowska*, Sect. B 46, Suppl. I, 1–26 (in Polish with English summary).

Jankovská V., Komárek J. 2000. Indicative value of *Pediastrum* and other coccal green algae in palaeoecology. *Folia Geobotanica* 35, 59–82.

Krupiński K. 1995. Pollen analysis of Eemian Interglacial sediments from Proniewicze in the Podlasie (original: Analiza pyłkowa osadów interglacjału eemskiego z Proniewicz na Podlasiu). *Przegląd Geologiczny* 43, 581–585 (in Polish).

Kupryjanowicz M. 1991. Eemian, Early and Late Vistulian, and Holocene vegetation in the region of Machnacz peat-bog near Bialystok (NE Poland) – preliminary results. *Acta Palaeobotanica* 31, 215–225.

Kupryjanowicz M. 1998. Results of palynological expertise of Imszar peat-bog sediments (original: Wyniki ekspertyzy palinologicznej osadów torfowiska Imszar). University in Białystok, Institute of Biology. Manuscript (in Polish).

Kurek S., Preidl M. (in press) Explanations for the sheet Gródek (341) of Detailed Geological Map of Poland 1: 50 000 (original: Objaśnienia do arkusza Gródek (341) Szczegółowej Geologicznej Mapy Polski 1:50000) (in Polish).

Mamakowa K. 1989. Late Middle Polish Glaciation, Eemian and Early Vistulian vegetation at Imbramowice near Wroclaw and the pollen stratigraphy of this part of the Pleistocene in Poland. *Acta Palaeobotanica* 29, 11–176.

Matuszkiewicz W. 2001. Guide to determining of plant communities of Poland (original: Przewodnik do oznaczania zbiorowisk roślinnych Polski). PWN, Warszawa, 536p (in Polish).

Müller H. 1974. Pollenanalytische Untersuchungen und Jahresschichtenzählung an der eem-zeitlichen Kieselgur von Bispingen/Luhe. *Geologisches Jahrbuch* A-21, 149–169.

Obidowicz A. 1990. Eine Pollenanalytische und Moorkundliche Studie zur Vegetationsgeschichte des Podhale-Gebietes (West-Karpaten). *Acta Palaeobotanica* 30, 147–219.

Piasecka K. 1999. Holocene changes of vegetation in the region of Rabinówka peat-bog (Gródek-Michałowo Depression) (original: Holoceńskie zmiany roślinności w rejonie torfowiska Rabinówka (Niecka Gródecko-Michałowska). University in Białystok, Institute of Biology. Manuscript (in Polish).

Prószyńska W., Prószyński M., Szymaniak M., Wicik B. 1973. Early Pleistocene sediments of melt-out depressions in SE part of Białostocka Upland (original: Młodoplejstoceńskie osady wytopisk SE części Wysoczyzny Białostockiej). Uniwersytet Warszawski, Zakład Geografii Fizycznej, Ogólnej i Regionalnej. Manuscript (in Polish).

Szachowicz M. 2002. Holocene changes of vegetation in the region of Julianka peat-bog, at peripheries of Gródek-Michałowo Depression (original: Holoceńskie zmiany roślinności w rejonie torfowiska Julianka na obrzeżu Niecki Gródecko-Michałowskiej). University in Białystok, Institute of Biology. Manuscript (in Polish).

Walanus A., Nalepka D. 1999. Polpal Program for counting pollen grains, diagrams plotting and numerical analysis. *Acta Palaeobotanica, Suppl.* 2, 659–661.

Van Geel B. 1978. A palaeoecological study of Holocene peat bog sections in Germany and The Netherlands, based on the analysis of pollen, spores and macro-and microscopic remains of fungi, algae, cormophytes and animals. *Review of Palaeobotany and Palynology* 25, 1–12.