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The palynological record of the Eemian interglacial and Early Vistulian glaciation in deposits of the Żabieniec Południowy fossil basin (Łódź Plateau, central Poland), and its palaeogeographic significance

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ABSTRACT. The vegetation of the Eemian interglacial and Early Vistulian glaciation was reconstructed on the basis of pollen analysis, biogenic and mineral-biogenic sediments from the Żabieniec Południowy locality. It was revealed that the present-day fossil reservoir was formerly a lake existing continuously from the decline of the Warta stadial (LG MPG) to the end of the Early Vistulian (EV4). The upper Plenivistulian age of top sediments, previously accepted on the basis of the radiocarbon date 24 200 ± 350 yrs BP (uncalibrated), was not confirmed by pollen analysis. In the pollen record from the nearby Żabieniec mire a break in biogenic accumulation corresponding to the Lower and Middle Plenivistulian was discovered. In view of the character of Plenivistulian morphogenesis in that area it appears that the deposits of both basins illustrate the development of one large melt-out depression during the whole postglacial period.

KEYWORDS: pollen analysis, fossil reservoir, Eemian interglacial, Early Vistulian, Plenivistulian, morphogenesis, postglacial period, central Poland

INTRODUCTION

Central Poland has a number of fossil basins recording Eemian floras, which have been well studied there. This is a zone not covered by the Vistulian (= Weichselian) glaciation, where biogenic interglacial deposits occurring *in situ* always have the same stratigraphic position – they are underlain by glacial sediments of the Warta stadial and covered by series of organic and mineral (or both) Vistulian deposits.

The first reports of Eemian fossil lakes in the Polish Lowlands were presented by Kalniet (1955). As new localities were discovered, surveys of them were successively published by Straszewska and Stupnicka (1979), Mamakowa (1989), Klatkowa (1990), Kuszell (1998), Kupryjanowicz (2005, 2008), Bruj and Roman (2007), and others. Today almost 40 of the more than 260 localities in the Polish Lowlands are known from central Poland; in them the pollen profiles document the extent of the Eemian lake district, and its disappearance, in most cases at the end of the early Vistulian (Fig. 1). On the Łódź Plateau, most of the documented interglacial sites are on uplands in the upper sectors of denudation valleys. Only a few are preserved in modern water divides, as is the case with the examined Żabieniec Południowy site. The significance of such sites for palaeogeographic reconstructions in central Poland has long been emphasised (Wieczorkowska 1976, Klatkowa 1989a, b, 1990, 1997).

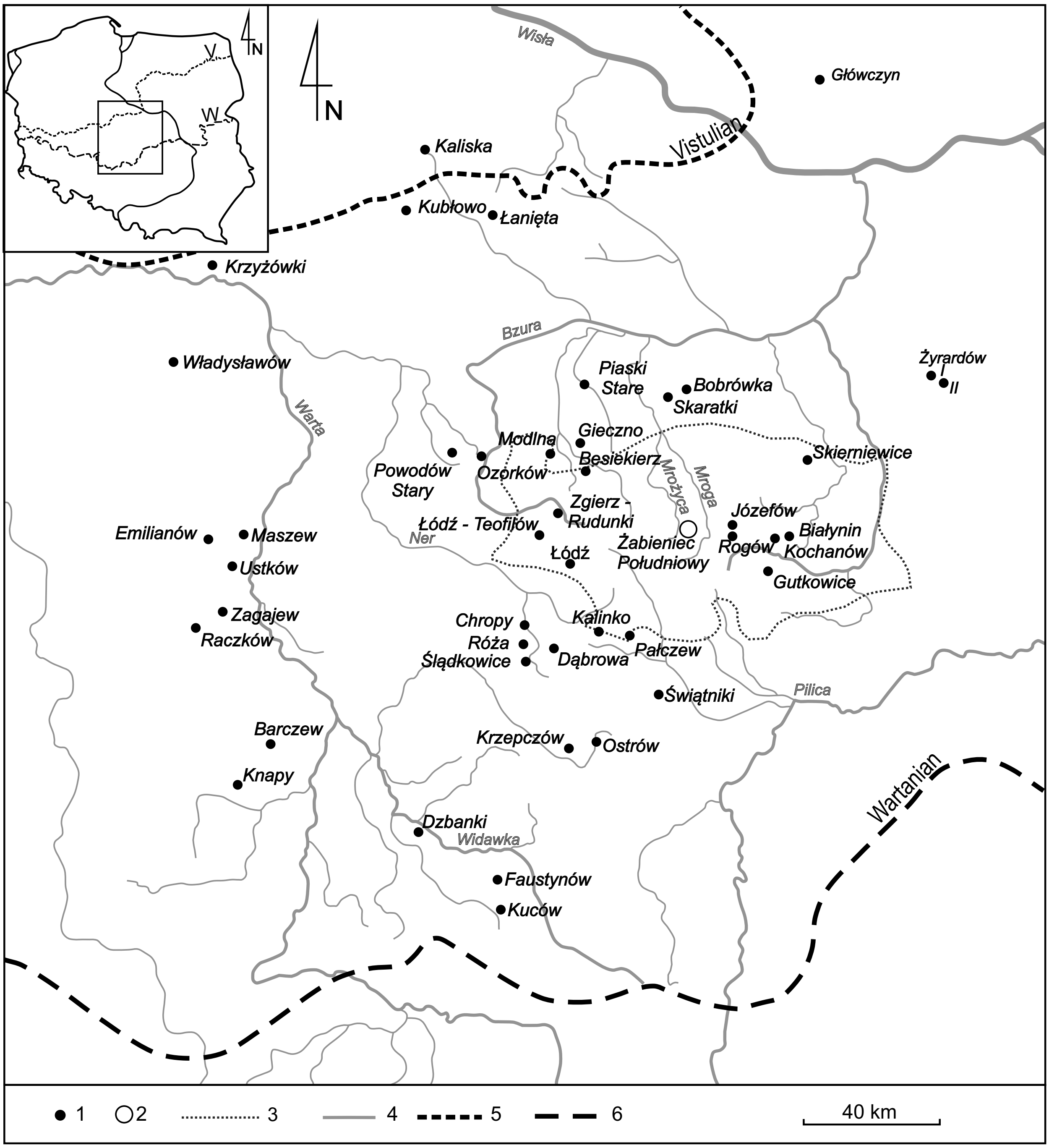


Fig. 1. Locations of the documented Eemian interglacial sites in central Poland

1 – Eemian interglacial sites, **2** – Żabieniec Południowy site, **3** – extent of Łódź Plateau (Gilewska 1986), **4** – rivers, **5** – maximum extension of Vistulian ice-sheet, **6** – maximum extension of Wartanian ice-sheet

The location of Żabieniec Południowy within a watershed offered a rare opportunity to better reconstruct postglacial landscape morphogenesis. Cores taken around the site document their geological structure, the starting point for palaeogeographic analysis (Majecka 2012a). The aim of this study was to reconstruct the changes in vegetation at the Żabieniec Południowy site, based on pollen analysis, and to compare the sections from this site with others from the most valuable localities in the region. This pollen analysis of the Żabieniec Południowy site extends palaeobotanical studies of the Żabieniec mire (Twardy et al. 2010), with the aim of documenting a vegetation succession older than that of the Late Vistulian and Holocene, which Balwierz (2010) described from this mire. Remnants of floras dating from the end of the Warta stadial through the Eemian interglacial to the Vistulian, discovered in pilot boring, were expected to be preserved in biogenic deposits in Żabieniec Południowy. Data from pollen analysis of the Żabieniec mire are not presented in this paper. Only its final results are presented here.

RESEARCH AREA

The Żabieniec Południowy site is located in Łódź Province (51°50′51.76″N, 19°46′54.59″E), ca 25 km north-east of the Łódź city centre, within the buffer zone of Wzniesienia Łódzkie Landscape Park, which includes agrarian and woodland terrain. According to the geomorphological division of Poland (Gilewska 1986) the study area is situated in the central part of the Łódź Plateau, in the watershed of the Mroga river (right bank tributary of Bzura river) and Mrożyca river (left bank tributary of Mroga river). These small lowland rivers drain the Łódź Plateau to the north. The culminations of upland areas between Mroga and Mrożyca belong to a watershed of rank IV.

Żabieniec Południowy is a closed buried reservoir formed due to melting of dead ice blocks during the final phase of the Warta stadial (Nowacki 1990, 1993). It is situated 400 m south of the Żabieniec mire. Both sites lie in a vast (up to 1.5 km diameter at maximum) watershed depression of melt-out origin. The study area is surrounded by glacial forms that developed during the Warta glacial recession. To the north-east the depression is surrounded by morainic hills and crevasse landforms 5–13 m high. To the west the depression is closed by a morainic wave plain of much lower relative elevation (5–9 m) and to the south by fluvioglacial plains filling the depressions in the system of morainic hills (Nowacki 1990, 1993). Several denudation cuts of various age and development stage occurring on the slopes of glacial forms indicate transformation of the original glacial surface (Fig. 2).

Żabieniec Południowy is the largest fossil reservoir within this depression, filled with mineral and biogenic sediments. At present it is a hollow 100 × 40 m in area, elongated W-E and oriented perpendicular to the main morphological axis of the depression. Boring showed that the glacial bottom of the depression lies at 10.8 m depth. The difference in

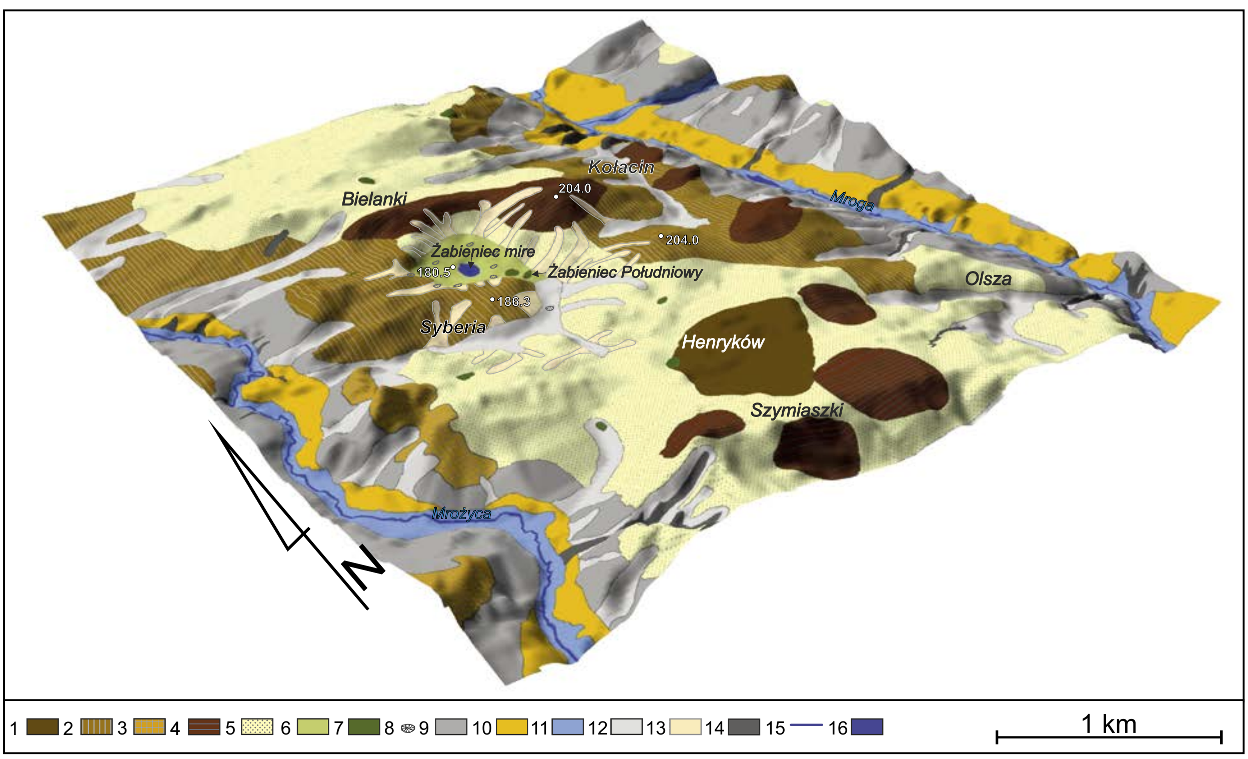
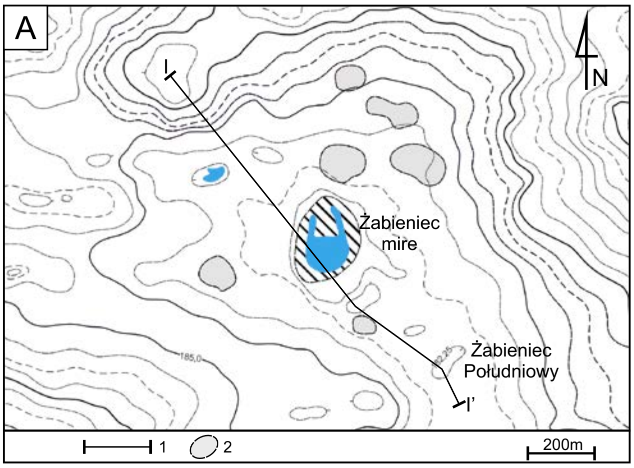


Fig. 2. Geomorphological diagram of fragment of the Mroga river and Mrożyca river watershed. Numerical model of terrain (Majecka 2012b)

1 – morainic flat plains, **2** – morainic wave plains, **3** – morainic hills, **4** – morainic mounds, **5** – fluvioglacial plains, **6** – melt-out depression, **7** – visible closed depressions, **8** – filled closed depressions, **9** – slopes of river valleys, **10** – upper valley level, **11** – river valley bottoms, **12** – denudation basins and valleys, **13** – younger denudation valleys, **14** – gullies, **15** – rivers, **16** – waters



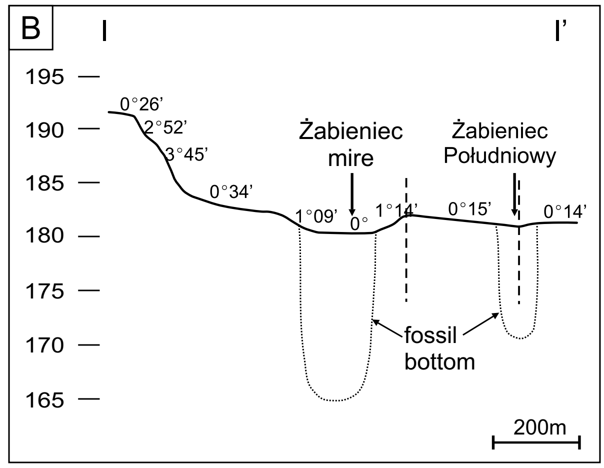


Fig. 3. Hypsometry of the study area

A: hypsometric diagram **1** – line of the hypsometric profile I-I', **2** – fossil closed basins not visible in the relief of the area. **B**: longitudinal hypsometric profile along the axis of the watershed depression

height between the lowest central point of the depression (181.1 m a.s.l.) and its margin (181.30 m a.s.l.) is only 0.20 m. This may indicate originally steep walls of a reservoir which was a kettle hole. At present only barely visible small oval hollows occur on the flat surface of the whole depression. The gentle relief of the area is reflected in slope gradients not exceeding 2° over ca 77% of its surface (Fig. 3). During spring thaws the lowest places are filled with water. The studied depression is undergoing rapid desiccation due to the cutting of a drainage ditch.

MATERIAL AND METHODS

FIELD WORK

The first attempt to collect a continuous sediment core from the Żabieniec Południowy site was undertaken in autumn 2008 by the team from IGiPZ PAN (Institute of Geography and Spatial Organisation, Polish Academy of Sciences) in Toruń, using a Więckowski piston-corer. That attempt failed due to the strong compression of biogenic sediments. A continuous core 10.8 m long was obtained using a stroke system (Powerprobe 9630 PTO); sediments were collected to 1.2 m long pipes. At 10.8 m depth a stone measuring 4.5 × 7.0 cm was driven into the tube, indicating that the lowest section of sediment had been reached, showing the position of the reservoir bottom. The sections of biogenic sediments, mostly peats and gyttja, were strongly compressed and split like shale. Sampling with the stroke system caused significant shortening of core segments as compared to the depths reached (Tab. 1).

The lithology of the core labeled Ż.Pd. was described in the Laboratory of the Institute of Earth Sciences, Łódź University, as were the collected samples. Table 2 presents a detailed lithological description. After the outer surface of each core segment was cleaned, samples ca 2 cm^3 in volume were taken for pollen (1 cm^3) and calcium carbonate content (1 cm^3) analyses. Samples for textural analysis were taken from mineral core sections. Mineral-biogenic and biogenic sections were sampled for analyses of mineral matter content.

LABORATORY TREATMENT

Samples for pollen analysis were taken every 4 cm at 0.0–4.8 m depth and, in view of the considerable compression of sediment, every 3 cm in the 4.8–10.8 m depth interval. Not all samples were suitable for analysis. Samples from the numerous sandy intercalations were not analysed, nor those from the bottom ends of core segments, which were contaminated by silty-sandy deposit coming from the upper layers. The samples were prepared by standard procedures in the laboratories of the W. Szafer Institute of Botany, Polish Academy of Sciences in Kraków, and Adam Mickiewicz University in Poznań. Each sample (1 cm^3 volume) was treated by Erdtman's acetolysis method (Faegri et al. 1989).

Pollen counts were made using a Nikon Eclipse E200 microscope with CFI60 optics. For each taxon the share of pollen as a percentage of the total tree and shrub AP and the herb and dwarf shrub NAP were calculated (Berglund & Ralska-Jasiewiczowa 1986).

Table 1. Length of Ż.Pd core segments

Tube Number	Depth (cm)	Length of core segment (cm)
1	0.0–120	86
2	120–240	85
3	240–360	120
4	360–480	99
5	480–580	70
6	580–680	57
7	680–800	120
8	800–940	104
9	940–1060	93
10	1060–1080	13

Table 2. Lithological description of Żabieniec Południowy Ż.Pd profile

Depth (cm)	Description of sediments
0–20	Humus with admixture of silts, black-grey, slightly wet
15–48	Fine-grained sand, in places silt with humus, black-yellow
48–90	Fine-grained sand with admixture of silts, yellow-rusty
90–140	Various grain-sized sand with admixture of silts, grey, with intercalations of mineral-organic dark grey silts
140–150	Fine-grained sand, light grey
150–216	Mineral-organic silt, black, with fine plant detritus
216–244	Silt, black, without detritus
244–256	Fine-grained sand with addition of middle-grained sand, yellow
256–344	Silt, grey-black, without detritus, sandy
344–360	Fine-grained sand, yellow
360–390	Silt, grey-black, without detritus, sandy
390–394	Middle-grained sand, yellow
394–440	Silt, grey-black, without detritus, sandy
440–483	Silt, dark grey, with fine detritus, compact, smell of H_2S
483–486	Sand grey-yellow
486–508	Silt, dark grey, with fine detritus, compact, smell of H_2S
508–580	Silt, dark grey, sandy, with fine detritus, compact, smell of H_2S
580–600	Peat, brown, compact, with wood detritus, dry
600–743	Lake silt at the border of gyttja, gyttja in places, dark grey
743	Large-size wood detritus
743–750	Lake silt at the border of gyttja, gyttja in places, dark grey
750–794	Mineral-organic silt, laminated, grey, peat intercalations containing small-size brown detritus
794–800	Sand with silt, grey-yellow
800–835	Mineral-organic silt, laminated, grey
835–875	Sand, grey
875–900	Mineral-organic silt, laminated, grey
900–925	Mineral silt, steel-grey, coarse fraction, with precipitated calcium carbonate
925–940	Middle-grained sand, yellow
940–992	Mineral silt, steel-grey, coarse fraction, with precipitated calcium carbonate
992–1025	Middle-grained sand, yellow
1025–1050	Mineral silt, steel-grey, coarse fraction, with precipitated calcium carbonate
1050–1080	Mineral silt, grey, with sand and gravel

Aquatic and reedswamp plants, ferns and algae were excluded from the total. In samples from biogenic sediments with high frequency of pollen, at least 500 AP pollen grains and all NAP grains, and sporomorphs of water and reedswamp plants, ferns, and algae (*Pediastrum*, *Botryococcus*) were counted. Counting was done on two slides (4 cm^2) every second belt. If the required number of 500 AP pollen grains was reached on one slide the second slide was still always surveyed in order to identify more taxa. In samples having low pollen frequency at least 300 AP pollen grains were counted, and in those with very low frequency 300 grains of all sporomorphs. Identification of sporomorphs was based on the reference collection of the W. Szafer Institute of Botany, the Austrian PalDat on-line data base (*Palynological Database*, www.paldat.org), and the available literature (Faegri et al. 1989, Moore et al. 1991, Reille 1992, Ważyńska 1998, Komárek & Jankovská 2001). The identification of taxa was consulted with Dr hab. Dorota Nalepka (W. Szafer Institute of Botany) and with Dr Małgorzata Malkiewicz and Prof. Dr hab. Teresa Kuszell (Department of Palaeobotany, Institute of Geological Sciences, Wrocław University).

Palynological analysis included 43 selected pollen samples of mineral-biogenic and biogenic sediments from core Ż.Pd. from 2.20–7.88 m depth. The results are presented in a percentage pollen diagram (Fig. 4) drawn with the POLPAL program (Nalepka & Walanus 2003). In the diagram the taxa are arranged as follows: trees and shrubs (AP), terrestrial herbaceous plants (NAP), reedswamp and aquatic plants, cryptogams, and algae. The curves of concealed, corroded, degraded and undetermined sporomorphs are added at the end.

DESCRIPTION OF LOCAL POLLEN ASSEMBLAGE ZONES

The pollen diagram (Fig. 4) is divided into 11 local pollen assemblage zones (L PAZ) described in Table 3. Their separation is based on visual analysis of individual pollen curves, compared with diagrams from the nearest sites (Jastrzębska-Mamelka 1985, Sobolewska 1966) and also supported by numerical analysis – ConSLink and PCA cluster analyses (Birks 1979, 1986, Walanus 1995, Walanus & Nalepka 1999, 2007, Nalepka & Walanus 2003, Nalepka 2005). A separate diagram (Fig. 5) presents the results of numerical

Table 3. Description of local pollen assemblage zones (L PAZs) from the Żabieniec Południowy site, Ż.Pd core

L PAZ	Name of L PAZ	Depth (cm)	Description
Ż.Pd-11	*Pinus-Betula*	220–263	*Pinus sylvestris* t. at level of 45–46%, *Betula* up to 27.5–32%. Curve of *Alnus* undiff. increases, that of *Picea abies* oscillates at 1.5–2.5%. *Betula nana* t. pollen occurs (2%); its curve disappears at the top. NAP maximum is 15%, at the top decreases to 9%. ConSLink and PCA analyses show the similarity of pollen spectra from different samples and justify including them in the same L PAZ. The zone is characterised by high taxonomic richness, 18% to 22%.
Ż.Pd-10	*Pinus*	263–273	Zone distinguished on the basis of only one characteristic sample showing a rapid rise of the *Pinus sylvestris* t. curve (up to 75%) synchronous with a fall of *Betula* (down to 13%). The sum of herbs is ca 5%, including mainly Poaceae, Cyperaceae, *Artemisia*, and *Rumex*. *Isöetes* percentages (12%) are the highest in the whole profile. ConSLink indicates similarity to zone L PAZ Ż.Pd-9 and a connection with L PAZ Ż.Pd-11. PCA analysis shows characteristic variability features which confirm the creation of the separate L PAZ.
Ż.Pd-9	*Betula*-NAP	273–318	Lower boundary of this zone marked by a rise of *Betula* (up to 68%) and a decline of *Pinus sylvestris* (to 4%). *Larix* appears (1.6%), *Betula nana* t. and *Salix* undiff. decrease, *Populus* pollen appears. NAP percentages equal ca 25%. Moisture-loving and aquatic plants are recorded. ConSLink analysis shows no close similarity between spectra, only some affinity to L PAZ Ż.Pd-8 is indicated. Low taxonomic richness, varying within 16–22%.
Ż.Pd-8	NAP-*Betula*-*-Betula nana*	318–500	Low sporomorph frequency and increased number of corroded and concealed sporomorphs. Continuous rise of NAP to 68% is correlated with decline of *Pinus sylvestris* t. and smooth *Betula* (8%) curve. At 3.6 m depth the NAP curve rapidly decreases, while higher values are attained by *Pinus sylvestris* t. (36%) and *Betula* (29%). In the upper section of the zone, *Juniperus* (7.5%) and *Betula nana* t. (4%) rapidly increase. Among the NAP, Poaceae, Cyperaceae, and *Artemisia* become dominant. *Myriophyllum spicatum*, *M. verticillatum*, *Sparganium*, *Typha latifolia*, and *Isöetes* were identified. *Sphagnum* and *Pediastrum* curves show the highest values in the whole profile. ConSLink indicates similarity of spectra, allowing them to be included in the same L PAZ, and shows their affinity to the lower zone L PAZ Ż.Pd-7. PCA reveals variable dominance of principal components in total variability. Taxonomic richness is the highest in the whole profile (maximum 32%).
Ż.Pd-7	*Pinus-Picea-* *-Betula*-NAP	500–553	Lower boundary marked by a rapid rise of *Pinus sylvestris* t. percentages (from 2% to 83%). *Betula* curve rises from 2% to 13%. Percentages of *Picea* vary from 1% to 16%, those of *Alnus* undiff. are up to 13% and their higher values are always synchronous with *Pinus sylvestris* t. Trees having higher climatic demands attain the highest percentage values. In the top section of the zone, *Betula nana* t. appears and the NAP curve rises to 20%. Ericaceae show high values (ca 4%), *Salix* undiff. appears. The beginning of a continuous *Sphagnum* curve correlates with high values of *Isöetes* sporomorphs (6%). ConSLink and PCA show the similarity of spectra and their affiliation to one L PAZ, in close correlation with the upper L PAZ Ż.Pd-8. Low taxonomic richness varying between 13 and 22%.
Ż.Pd-6	*Alnus-Picea-* *Abies*	553–570	This zone is represented by one sample. Characteristic are the highest curves of *Alnus* undiff. (23%), *Picea abies* (15.5%), and *Abies alba* (8%), correlated with falling curves of *Carpinus betulus*, *Corylus avellana*, *Ulmus*, and *Taxus baccata*. Single *Quercus* pollen grains are recorded. *Pinus sylvestris* t. and *Betula* play an insignificant role as do the NAP (3%), represented by single grains. ConSLink and PCA indicate similarity to the lower zone L PAZ Ż.Pd-5. Rarefaction analysis shows low taxonomic richness of the spectrum (14%).
Ż.Pd-5	*Carpinus-* *-Corylus-* *-Alnus-Picea*	570–647	The beginning is marked by an increase of the *Carpinus betulus* curve up to 35% and a decrease of the *Corylus avellana* curve to15%. In the upper part of the zone the *Carpinus betulus* curve rises to the maximum value of 54%. *Pinus sylvestris* t. values fall to a minimum and *Betula* appears in small numbers (up to 5%). Pollen grains of *Viscum*, *Hedera helix*, and *Ilex aquifolium* are noted. The NAP values are the lowest in the whole profile (2–3%). ConSLink and PCA show similarity between samples and justify including them in the same L PAZ. Taxonomic richness is low, within 15–18%.
Ż.Pd-4	*Corylus-* *-Quercus-* *-Tilia-Alnus*	647–680	The lower zone boundary is marked by the increase of the *Corylus avellana* curve up to 79%. *Quercus* percentages attain 10% and the values for other trees rise. Minimum values are recorded for *Pinus sylvestris* t. (1.7%) and *Betula* (5%). *Viburnum*, *Hedera helix*, and *Viscum* are present. Percentage values of NAP are very low (to 5%). ConSLink and PCA confirm the similarity of spectra and their affiliation to the same L PAZ. Taxonomic richness as shown by rarefaction analysis is 20% at maximum.
Ż.Pd-3	*Betula-Pinus*	680–684	The zone is represented by one sample only. The *Pinus sylvestris* t. curve decreases down to 30% and the *Betula* curve attains 53%. NAP percentages decrease to 10%. *Salix* undiff. percentages are 0.5% and those of *Betula nana* t. over 3%. ConSLink and PCA indicate the similarity of this spectrum to the spectrum from L PAZ Ż.Pd-2. Rarefaction analysis shows taxa richness diminishing from 20% to 15%.

Table 3. Continued

L PAZ	Name of L PAZ	Depth (cm)	Description
Ż.Pd-2	*Pinus-Betula*	684–740	NAP percentages decrease to 15% synchronously with a slow increase of *Betula* (to 18.5%) and *Pinus sylvestris* t. (to 51%). *Taxus baccata* (1%), *Betula nana* t. (3.4%), *Juniperus communis* (1.3%), and *Salix* undiff (1.5%) are present. ConSLink and PCA confirm the similarity of the pollen spectra and are the basis for including them in the same L PAZ. They also indicate their affinity to L PAZ Ż.Pd-1. Rarefaction analysis shows decreasing taxonomic richness, varying between 18% and 20%.
Ż.Pd-1	NAP	740–788	The zone is represented by only one sample which contains a large proportion of mineral particles. Most of the pollen grains are corroded and degraded. The NAP percentages are high, up to 40%. Cryptogams are represented by *Sphagnum* (1.5%). Neogene pollen and numerous charcoals occur in significant amounts. ConSLink shows the similarity of this spectrum to that from L PAZ Ż.Pd-2 but these two zones are separated by a hiatus recorded in one sterile sample. Low taxa richness at 20% is indicated by rarefaction analysis.

analyses performed with POLPAL (Nalepka & Walanus 2003). This diagram also shows organic matter, $CaCO_3$ concentration, and total sporomorphs counted.

In the diagrams the L PAZs are related to chronostratigraphic divisions accepted by various authors for the Polish Lowlands (Środoń 1967, Jastrzębska-Mamełka 1985, Tobolski 1991, Mojski 2005, Turkowska 2006).

In the discrimination and description of pollen assemblage zones from the bottom section of profile Ż.Pd. (L PAZ Ż.Pd.-1 and Ż.Pd.-2), redeposited Neogene pollen was omitted. The sample from 7.52 m depth (at lithological border) was bare, creating a discontinuity in the plant succession record. The border between the Ż.Pd.-1 and Ż.Pd.-2 pollen zones was drawn conventionally below the bare sample, from 7.28 m depth.

REDEPOSITED MATERIAL

Redeposited Neogene sporomorphs were found in the bottom part of the profile, in mineral-organic silts intercalated by sands and in mineral silt with inserts of sand and gravel. These deposits represented slope sediments of the Warta stadial formed by denudation (slope movement) processes occurring on the former glacial surface (Majecka 2012a, b). The presence of the Neogene sporomorphs can be explained by the fact that positive glacial forms surrounding the melt-out kettle contained buried blocks of Neogene sediments, from which mineral material together with old sporomorphs was eroded and deposited in the depression. Samples from the core bottom (not included in the pollen diagram) contained no Pleistocene plant pollen except for a few *Pinus sylvestris*-type and *Betula* grains. In most cases they were damaged and corroded. This part of the core is not presented in the pollen diagram, and the identified sporomorphs are listed in Table 4. Their identification was based on information in the literature (Ważyńska 1998) and consulted with Prof. Teresa Kuszell and Dr Małgorzata Malkiewicz. Dinoflagellates were the most frequent rebedded fossils. The exotic gymnosperms pollen occurring most abundantly were *Pinus haploxylon*-type, Taxodiaceae (*Taxus*), and *Tsugapollenites* sp. Angiosperms were represented by, for example, numerous grains of *Nyssapollenites* (*Nyssa*), *Pterocaryapollenites*, and *Myricipites* sp. Exotic sporomorphs were also found in the analysed sediments from the Warta decline and in very small numbers in the upper section of L PAZ Ż.Pd-7 and Ż.Pd-8, but due to their very poor preservation they were not determined and were placed in the indeterminate category in the pollen diagram.

Table 4. Exotic sporomorphs identified in the Żabieniec Południowy profile. + sporadic, ++ frequent, +++ very frequent

Number of sample	depth (cm)	*Araliaceoipollenites*	*Celtipollenites* (*Celtis*)	*Cupressacites* (*Cupressus*)	Dinoflagellata	*Engelhardtioipollenites* (*Engelhardtia*)	*Ericipites* sp. (Ericaceae)	*Liquidambarpollenites* (*Liquidambar*)	*Myricipites* sp. (*Myrica*)	*Nyssapollenites* sp. (*Nyssa*)	*Osmundacidites* (*Osmunda*)	*Quercoidites* sp. (*Quercus*)	*Pinus haploxylon*-type	*Pterocaryapollenites* (*Pterocarya*)	*Rhuspollenites* sp.	*Sciadopitys*	*Selaginellisporis*	*Sequoiapollenites* (*Sequoia*)	*Symplocoipollenites*	Taxodiaceae	*Tricolporopollenites edmundi*	*Tricolporopollenites exactus*	*Tricolporopollenites* sp.	*Tsugapollenites* (*Tsuga*)
251	842				++				+	+			+	+		+				+			+	+
264	881			+	+++		+		+	+	+	+	+	+	+	+		+		++	+	+	+	+
277	920				+++				+	+			+	+		+				+			+	+
290	962				+++				+	+			+	+		+				+			+	+
302	998	++	+		+++	++	+	+	+	+++	+		+	+++		+	+	+	+	+		+	+	+

DEVELOPMENT OF VEGETATION AND CLIMATE CHANGES AT THE ŻABIENIEC POŁUDNIOWY SITE

Vegetation history and climatic changes were described on the basis of local pollen assemblage zones (L PAZs) and were compared with the results from other localities of supraregional significance: Zgierz-Rudunki (Jastrzębska-Mamełka 1985) and Józefów (Sobolewska 1966, Dylik 1967). Both sites are in the near vicinity of the present study area and are in similar geomorphological settings. Zgierz-Rudunki lies on the upland between the Bzura and Czarnawka rivers in the upper part of the denudation valley. Józefów lies in an isolated depression in the watershed of the Mroga and Rawka rivers. Other sites from the Polish Lowlands considered in this study include stratotype profiles for Polish Lowlands sites at Imbramowice near Wrocław (Mamakowa 1989) and Horoszki Duże in Podlasie (Granoszewski 2003), as well as sites in the Konin region (Tobolski 1991), Płock Upland (Krupiński 2005), and Wielkopolska Lowland (Kuszell 1997, Malkiewicz 1998). The prevailing climatic conditions were characterised according to Iversen (1954), Mamakowa (1989), Wasylikowa (1964), Kolströp (1980), Granoszewski (2003), Zagwijn (1961, 1989, 1996), and Isarin & Bohncke (1999). The division into four main phases of climatic change and ecological processes for the interglacial cycle in Western Europe follows the classical model proposed by Iversen (1958).

WARTA STADIAL

Cryocratic phase

Ż.Pd-1 NAP L PAZ; Ż.Pd-2 *Pinus-Betula* L PAZ

The floristic composition of the Ż.Pd-1 NAP L PAZ indicates dominance of park tundra communities and patches of pine-birch woods, with representatives of Ericaceae undiff. in the undergrowth (Fig. 4). Herbaceous vegetation was dominated by grasses. The percentages of pine (*Pinus sylvestris*-type) pollen are high, reaching 46%. The presence of Neogene and indeterminate sporomorphs indicates that the ground was not stabilised by plant cover and that intensive erosion processes took place in the catchment area. The large number of exotic sporomorphs and their taxonomic diversity suggest that the core was collected from the deepest part of the basin, where redeposited sediments were the main component of allochthonous gyttja. The considerable amount of calcium carbonate, up to 7%, leached out from deposits of young-glacial forms, and the low percentage of organic matter, below 5%, also indicate depauperate plant cover. Redeposition is also confirmed by the occurrence of numerous pieces of charcoal and pollen of thermophilous (e.g. *Alnus*, *Populus*) and exotic (*Pinus haploxylon*-type) trees. For these reasons the pollen spectrum from zone Ż.Pd-1 NAP does not properly reflect the vegetation type and climatic conditions, and may only suggest the dominance of intensive erosion processes in cold climatic conditions. The decline of the NAP curve and the rise of trees, mainly pine and birch, indicate progressive climate warming. The pollen spectrum from zone Ż.Pd-2 *Pinus-Betula* indicates a smaller role for communities of open habitats with grasses and light-demanding plants including *Artemisia*, Chenopodiaceae, and *Helianthemum*, accompanied by *Rumex*, Asteraceae, and Saxifragaceae. Shrub communities were dominated by light-demanding *Juniperus communis*. The occurrence of juniper suggests a warmest-month mean temperature of ca 8°C (Isarin & Bochncke 1999), and according to Iversen (1954) even exceeding 10°C (Mamakowa 1989, Wasylikowa 1964, Granoszewski 2003). *Thalictrum* and *Urtica dioica* occurred in shaded places; *Betula nana*-type, *Salix*, and *Alnus* developed in moist habitats. The occurrence of dwarf birch indicates weakly marked continentality. A high share of pine in forest communities indicates July temperatures above 12°C (Mamakowa 1989). In the top section of zone Ż.Pd-2 the pine percentages decrease in favour of birch. The occurrence of redeposited pollen of *Ilex aquifolium* and trees having higher temperature demands (*Quercus*, *Corylus avellana*, *Picea abies*, *Abies alba*) as well as the presence of calcium carbonate (up to 5%) in the sediment indicate that the ground was not completely stabilised by plant cover yet. Organic matter content systematically increases up to ca 25%.

The observed poor development of aquatic vegetation in the reservoir probably was due to inflow of cold water from the catchment area

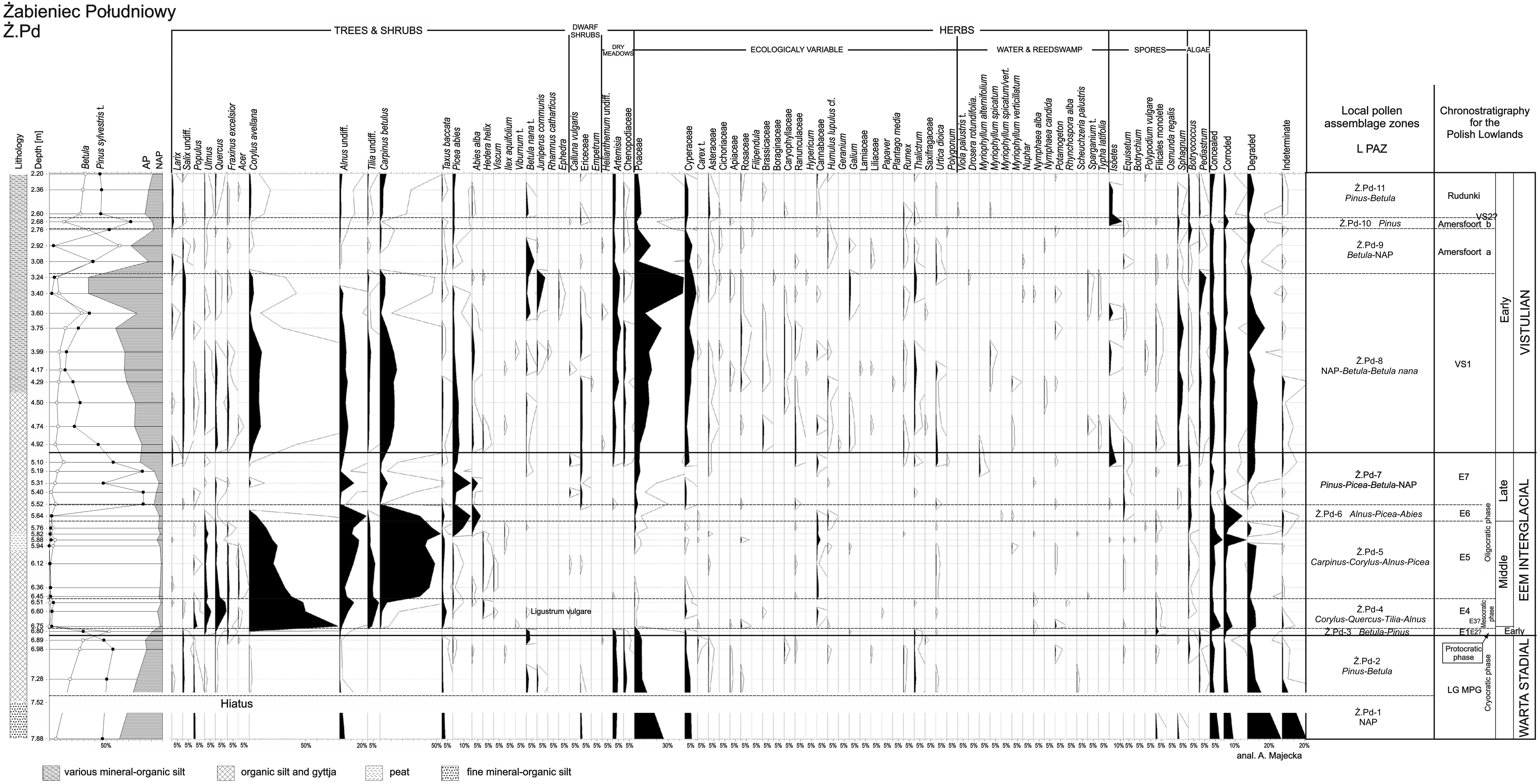


Fig. 4. Percentage pollen diagram of the Żabieniec Południowy profile (Ż.Pd)

and to water movement (Mamakowa 1989). Aquatics are represented by algae from the genera *Botryococcus* and *Pediastrum*, which increase their percentages in parallel with the decrease in organic matter content (10% on average). *Scheuchzeria palustris* was growing within the area of floating mats of mosses, and the near-shore vegetation included Cyperaceae and *Equisetum*. The finding of *Sphagnum* in the older section of the Warta stadial decline may suggest short periods of lake terrestrialisation and peat accumulation, which are indicated by the presence of peat insertions in the deposit.

The history of vegetation at the transition from the Warta stadial of the Odra glaciation to the Eemian interglacial was documented in several profiles from central Poland and Podlasie, for example in Zgierz-Rudunki (Jastrzębska-Mamełka 1985), Imbramowice (Mamakowa 1989), Szwajcaria near Suwałki (Borówko-Dłużakowa & Halicki 1957), Warszawa-Wawrzyszew (Krupiński & Morawski 1993) and a few sites in the Płock Upland (Krupiński 2005). The results show great variation of vegetation successions in different parts of the country at that time. At all sites the transition from the Warta to the Eemian succession is not reflected in the change of lake sediments or in sedimentation breaks (Mojski 2005), as is the case in the profile from Żabieniec Południowy.

EEMIAN INTERGLACIAL

Protocratic phase

Ż.Pd-3 *Betula-Pinus* L PAZ

The beginning of the protocratic phase (Ż.Pd-3 *Betula-Pinus* L PAZ) was characterised by the development of boreal forests. The brief dominance of *Betula* in the woods was accompanied by the decline of *Pinus sylvestris*-type and the appearance of small numbers of trees having higher warmth demands (Fig. 4). The decrease of calcium carbonate content in the sediments (Fig. 5) indicates soil stabilisation due to better-developed plant cover in the whole catchment basin. Moisture increase is indicated by the appearance of *Ulmus*, which grew in carr communities together with *Alnus*, *Quercus*, and *Fraxinus excelsior*. *Betula nana*-type and *Salix* also were abundant. Communities of dry open sites with grasses (Poaceae) and light-demanding plants declined.

Water plants were represented only by *Nymphaea alba*, which can grow in water not more than 3 m deep (Podbielkowski & Tomaszewicz 1996). The overgrowing of the reservoir is indicated by the decrease of the algae curves and the rise of organic matter content to up to ca 30%. The presence of *Nymphaea alba* also indicates ca 13–14°C mean July temperature (Kolströp 1980, Mamakowa 1989).

The profile from Żabieniec Południowy yielded no record of the interglacial plant succession from the end of the protocratic and the beginning of mesocratic phases corresponding to the biostratigraphic regional pollen assemblage zones (R PAZs) E2 *Pinus-Betula-Ulmus* and E3 *Quercus-Fraxinus-Ulmus* (Mamakowa 1988, 1989). Hiatuses in the Eemian succession have also been found at other sites, for example at Jóźwin/82, Kazimierz, and Władysławów in the Konin region (Tobolski 1991). At the first two sites there is no R PAZ E2, and the third one has two hiatuses: R PAZ E3, with a characteristic oak maximum, is only fragmentarily recorded, while zones E6 and E7 are completely missing (Tobolski 1986, 1991). The oak phase was not distinguished in the profile from Lubowidz in the Płock Upland either (Krupiński 2005).

Mesocratic phase

Ż.Pd-4 *Corylus-Quercus-Tilia-Alnus* L PAZ

The pollen spectra from L PAZ Ż.Pd-4 *Corylus-Quercus-Tilia-Alnus* indicate the spread of thermophilous deciduous forests typical for a climatic optimum. *Corylus avellana* rapidly expanded and became dominant. Its pollen curve reached 79%, the percentages of *Pinus sylvestris*-type and *Betula* fell to minima, and *Quercus*, *Tilia*, *Ulmus*, and *Populus* reached their maximum values.

A characteristic feature of the diagram is the early appearance of hornbeam when hazel still dominated and lime values were high (7.5%). A similar picture can be seen in corresponding spectra of some other profiles from, for example, Lechitów and Zbytki in the Wielkopolska Lowland (Malkiewicz 1998, Kuszell 1997) and Rogaczewo and Zofiówka in the Silesian Lowland (Kuszell 1997). The considerable share of *Taxus baccata*, over 4%, documents its

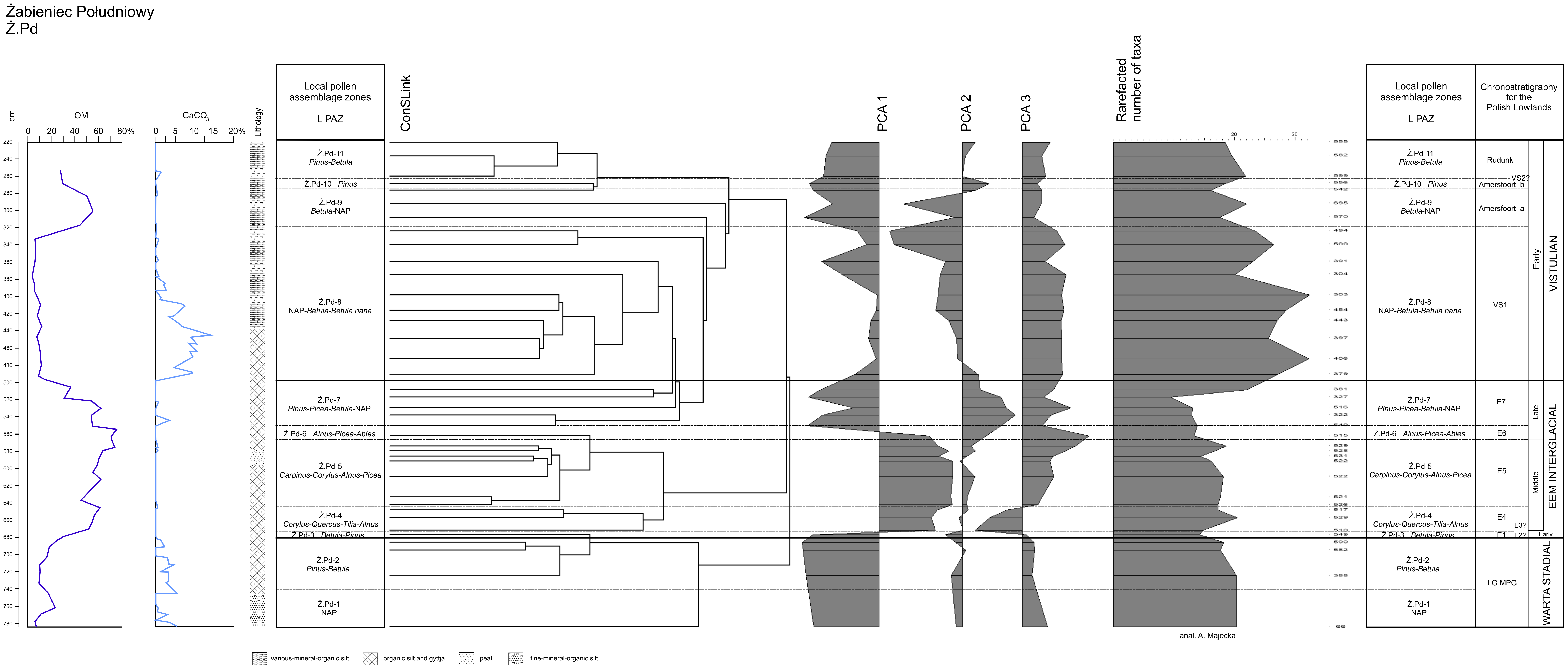


Fig. 5. Content of organic matter (OM) and sodium carbonate ($CaCO_3$) and numerical analysis diagrams of the Żabieniec Południowy profile (Ż.Pd)

significant forest-forming role in the Eemian interglacial in central Poland. Relatively high percentages of this taxon were also found in profiles from Imbramowice (Mamakowa 1989), Wołów and Zofiówka (Kuszell 1997). At the end of the climatic optimum, *Picea abies* and *Abies alba* appeared in dense mixed deciduous forest phytocenoses. *Ligustrum vulgare* grew among shrubs, and the occurrence of the thermophilous climber *Hedera helix* suggests mean July temperature above 13°C and January temperatures not below −1.5°C (Mamakowa 1989). Wet places were covered by alder carrs with *Alnus*, *Salix*, and *Viburnum*, which were best developed in the final phase of this period.

The depauperate herbaceous vegetation of moist and shaded places was represented mainly by Cannabaceae, Rosaceae, Brassicaceae, *Humulus lupulus*, and *Urtica dioica*. The vegetation overgrowing the lake shore contained *Rhynchospora alba*, the main component of dystrophic pioneer communities growing on humus-rich sandy soils or on peat substrate in raised bogs (Matuszkiewicz 2006).

Oligocratic phase

Ż.Pd-5 *Carpinus-Corylus-Alnus-Picea* L PAZ; Ż.Pd-6 *Alnus-Picea-Abies* L PAZ; Ż.Pd-7 *Pinus-Picea-Betula*-NAP L PAZ

The Ż.Pd.-5 *Carpinus-Corylus-Alnus-Picea* zone marks the beginning of the oligocratic phase of the Eemian interglacial. The increase of climatic oceanity is manifested in increasing cooling and higher humidity. Warmest-month mean temperature was above 17°C, and coldest-month mean temperature ca −0.5°C (Iversen 1954). At the beginning, forests were formed mainly by *Carpinus betulus*, with *Corylus avellana* in the undergrowth. Hornbeam percentages rose to maximum at 54%, synchronously with the fall of the hazel curve. Hornbeam dominance is particularly pronounced in the profiles from other sites such as Józefów (Sobolewska 1966), Horoszki Duże (Granoszewski 2003) or Główczyn near Wyszogród (Niklewski 1968). At Żabieniec Południowy it was not so abundant. Besides this species, *Tilia*, *Ulmus*, *Fraxinus excelsior*, and *Quercus* appeared in oak-hornbeam forests. Herb communities had a large share of abundantly occurring Cannabaceae, including sporadic *Humulus lupulus*, and *Urtica dioica*. Dwarf shrubs of Ericaceae and *Calluna vulgaris* appeared in the middle level of this zone. A general feature of the vegetation of this zone is that the herbaceous flora has the lowest share in the whole profile. Grass (Poaceae) pollen is completely absent from some spectra.

The progressive rise of *Picea abies* and *Abies alba* corresponds with the decrease of *Carpinus betulus*, *Corylus avellana*, and other trees having higher climatic requirements. Increased humidity led to the spread of moist and wet habitats favouring the expansion of alder carrs with *Alnus*, *Ulmus*, and *Fraxinus excelsior*. Due to higher humidity the lake depth increased; among the aquatics, *Myriophyllum verticillatum* and *Potamogeton* appeared. A brief change of water trophy is indicated by the appearance of *Isöetes*, which grows in oligotrophic water bodies (Podbielkowski & Tomaszewicz 1996).

The next zone, Ż.Pd-6 *Alnus-Picea-Abies*, starts with the spread of rich alder communities overgrowing numerous wet habitats, and the expansion of coniferous-deciduous forests of mixed pine-spruce type. Aquatic plants growing in the lake included *Myriophyllum verticillatum*, *M. spicatum/verticilatum*, and *Potamogeton*; the shore zone vegetation was formed by Cyperaceae, among which *Carex*-type appeared. The highest organic matter content of the whole interglacial, up to almost 80%, was recorded in this stage. However, *Sphagnum* spores, which could evidence lake terrestrialisation and local peat accumulation, were not found.

The Ż.Pd-7 *Pinus-Picea-Betula*-NAP zone corresponds to the telocratic phase. The climate of this period was moderately humid, had a short vegetation period, and was transitional from temperate to boreal climate. Mean temperature was ca 14°C in July, and −4°C to −5°C in January (Iversen 1954). In the younger part of the telocratic phase, trees able to thrive in harsher climate appeared. Pine forests dominated by *Pinus sylvestris*-type with a small share of birch *Betula* expanded rapidly, and representatives of Ericaceae occurred in the herb layer. It is thought that the warmest-month mean temperature was then ca 12°C and that the climate was continental boreal-subarctic (Mamakowa 1989, Krupiński 2005). Temporary milder climate is indicated by the appearance of *Picea abies*, *Abies alba, Carpinus betulus*, *Corylus avellana*, and *Quercus*.

Alder carrs dominated in wet places. *Salix* and *Larix* appeared at the end of the Eemian interglacial. The presence of redeposited material that includes Neogene sporomorphs and taxa having higher climatic requirements is connected with heavy rains typical for the interglacial decline and with transport of mineral material washed out from the catchment area (Mamakowa 1989). The presence of *Picea abies*, *Abies alba*, and *Larix* indicates that minimum annual precipitation was 500 mm (Granoszewski 2003).

During the final phase of the Eemian interglacial the landscape was slowly becoming less densely wooded. Thinning of the forests favoured the spread of steppe with grasses (Poaceae) and heliophilous plants including *Artemisia*, Chenopodiaceae, Asteraceae, and *Rumex*.

The lake again became shallower. *Sphagnum* occupied the zone of telmatic vegetation. Aquatic vegetation was represented by *Myriophyllum alternifolium*, which nowadays grows in shallow mesotrophic waters down to ca 0.2–1.0 m depth (Podbielkowski & Tomaszewicz 1996), and algae from the genus *Botryococcus*. At the end of the Eemian the reservoir became oligotrophic, as indicated by the occurrence of numerous spores of *Isöetes*, a taxon characteristic for the boreal zone (Milecka 2005).

EARLY VISTULIAN

Ż.Pd-8 NAP-*Betula-Betula nana* L PAZ

In Żabieniec Południowy the beginning of the Vistulian is not reflected in any change of biogenic sediments. The change from lake to terrestrial accumulation, seen in the presence of mineral-biogenic silts, took place in the middle of zone Ż.Pd-8 NAP-*Betula-Betula nana*. This zone is correlated with R PAZ EV1 (Mamakowa 1989) and with the cooling of Vistulian 1 (VS1) (Lindner 2005, Mojski 2005) and Herning (e.g. Litt 1990). The beginning of the Vistulian was characterised by temperate climate with increasing continentality, indicated by the continuous and rising *Betula nana* curve. NAP percentages systematically increased. This was the first woodless stage of the Early Vistulian. The landscape was dominated by park tundra communities with patches of birch-pine and pine forests composed of rare *Picea abies*, *Abies alba*, and *Larix* trees, and dwarf shrubs in the herb layer. Pine and birch pollen also have considerable shares in material from the Zgierz-Rudunki site (Jastrzębska-Mamełka 1985). According to Jastrzębska-Mamełka the pollen of these taxa must have originated in part from long-distance transport. Spruce and pine were progressively declining. The presence of *Larix* may suggest that mild climate prevailed at the transition from the interglacial to the Early Vistulian. According to Mamakowa, *Larix decidua* requires minimum July temperature no lower than 17°C for its growth (Granoszewski 2003). This climatic interpretation cannot be applied to Żabieniec Południowy because the species of larch was not determined.

The vegetation of open sites was dominated by grasses (Poaceae) and communities of dry-habitat heliophytes composed of *Artemisia*, Chenopodiaceae, and sporadically occurring *Helianthemum*. Wide variation of the herb communities is indicated by the presence of Asteraceae, Rosaceae, Brassicaceae, Caryophyllaceae, *Rumex*, *Thalictrum*, and *Galium*. Alder carr communities composed mainly of *Alnus*, *Salix*, and *Ulmus*, with some *Quercus* and *Fraxinus excelsior*, still occupied wet habitats. *Humulus lupulus*, found in the older section of this zone, indicates that July temperature was at least 15°C (Iversen 1954).

Both the mineral-biogenic deposits and biogenic lake silts contain admixtures of mineral particles washed by renewed erosion-denudation from lake slopes, which were less and less stabilised by vegetation. These processes may also explain the origin of pollen of *Hedera helix* and *Ilex aquifolium*, and pollen of more thermophilous trees. Intensification of denudation processes is confirmed by the increase of calcium carbonate content simultaneously with the decline of organic matter content.

In the upper section of Ż.Pd-8 L PAZ, dominance of herbaceous vegetation is recorded, reflecting the spread of steppe communities in open areas. High percentages of Poaceae, *Artemisia*, Cyperaceae, and Chenopodiaceae, the occurrence of *Betula nana* and the appearance of *Ephedra* unequivocally indicate continentality of climate. *Juniperus communis* was an important component of plant communities, suggesting mean July temperature from 8°C to above 10°C (Iversen 1954, Mamakowa 1989, Isarin & Bochncke 1999). Subarctic climate prevailed (Tobolski 1991). The vegetation changes observed in the younger part of the Early Vistulian were caused by rapid cooling.

Continental climate with low precipitation influenced conditions in the lake. The water level decreased and colonies of algae from the genus *Pediastrum*, an indicator of stagnant waters (Tobolski 2000), spread in the lake together with *Myriophyllum spicatum*, *M. verticillatum*, *Potamogeton*, *Nuphar*, and *Nymphea alba*. The appearance of *Sphagnum* may indicate short phases of lake shore terrestrialisation and the formation of raised bog (Tobolski 2000) on which *Drosera rotundifolia* could grow, but peat was not recorded in this core section. The occurrence of *Isöetes* was noted between the phases in which peat-forming vegetation appeared.

An important feature of the pollen spectra from this zone is the appearance of *Sparganium* and *Typha latifolia* at the time of maximum climatic cooling. According to Iversen (1954), both taxa are characteristic of mild temperature, with a warmest-month mean of up to 13–14°C (Wasylikowa 1964, Kolströp 1980). Their presence supports the hypothesis that the reaction of aquatic plants to temperature decrease is slower than the reaction of terrestrial vegetation (Szafer 1954).

AMERSFOORT INTERSTADIAL

Ż.Pd-9 *Betula*-NAP L PAZ; Ż.Pd-10 *Pinus* L PAZ

The first forest stage of the early Vistulian is connected with the first interstadial warming, correlated with R PAZ EV2 *Betula-Pinus* (Mamakowa 1989). In the profile from Żabieniec Południowy it is represented by two zones, L PAZ Ż.Pd-9 *Betula*-NAP and Ż.Pd-10 *Pinus*, corresponding to the Amersfoort (Środoń 1967) or Amersfoort-Brörup and Brörup (Van der Hammen & Wijmstra 1971, Zagwijn 1961, 1989, 1996) interstadial distinguished in the Netherlands and Germany. The first locality in central Poland from which this oldest interstadial of the last glaciation was recorded was Józefów on the Łódź Plateau (Dylik 1967, 1968). The regional name Józefów interstadial was used for this period (Mojski 2005) and two cycles of vegetation development were distinguished in it. In the older part of the interstadial, the climate warmed, enabling vegetation to spread. The Ż.Pd-9 zone in Żabieniec Południowy shows expansion of birch forests and decline of NAP. The reduction or even disappearance of *Juniperus communis* from the forests indicates warming. Krupiński (2005) suggested that warmest-month mean temperature was 16°C in that period. According to Klatkowa (1996) the mean July temperature during the warmest part of the older section of the Amersfoort in central Poland rose to ca 10°C. Boreal climate prevailed, markedly continental as indicated by high (up to maximum) percentages of *Betula nana*. The expansion of birch woods was connected with sandy substrate and the development of podzolic soils, fossil localities of which were identified in central Poland by Manikowska (1966, 1999).

Depauperate communities of herbaceous plants were formed by Poaceae, Cyperaceae, and *Artemisia*, with rare taxa of Chenopodiacee, Asteraceae, and *Thalictrum*. *Filipendula*, which is typical for initial stages of warm climatic periods, appeared, as well as *Carex* and *Rumex*, which include some species that indicate warmest-month mean temperature of ca 15°C (Granoszewski 2003).

From the Eemian interglacial, accumulation of sediments in the Żabieniec Południowy basin continued without interruption; organic matter content again increased to 60%. There was also a lake in the Zgierz-Rudunki basin at that time. The Ż.Pd-9 *Betula*-NAP L PAZ from Żabieniec Południowy is correlated with the ZRII-11 *Betula-Pinus-Larix* L PAZ from Zgierz-Rudunki (Jastrzębska-Mamełka 1985). The pollen record from the latter site indicates a rise of water level in an oligotrophic lake dominated by *Isöetes*. This plant was not recovered from the Żabieniec Południowy sediments, possibly suggesting a low water level not typical for that period. Nymphaceae and *Potamogeton* were the only representatives of depauperate aquatic vegetation. The occurrence of *Sphagnum* and a distinct decrease of *Pediastrum* are evidence of a shrinking lake surface or even its temporary disappearance (Krupiński 2005).

Although the Ż.Pd-10 *Pinus* L PAZ is distinguished on the basis of only one sample, the characteristic increase of pine forest replacing birch forests (L PAZ Ż.Pd-9) corresponds to the younger cycle of the Amersfoort (Środoń 1967) or Józefów (Dylik 1967) interstadial, and biostratigraphically to R PAZ EV2b *Betula-Pinus* (Mamakowa 1989). The climate of this period was distinctly cooler and drier than the older phase. Transformation of forest communities took place. Pine forests expanded, with frequently occurring *Larix* and *Picea abies* and small shares of *Taxus baccata*; shrubs of *Calluna vulgaris* and Ericaceae grew in the herb layer. *Juniperus communis* disappeared from the forests. The dominance of pine forests caused a further reduction of herbaceous vegetation, which was represented by communities of dry grassland with grasses (Poaceae), *Artemisia*, Chenopodiaceae, Asteraceae, and *Rumex*. According to Krupiński (2005) the warmest-month mean temperature did not exceed 14–15°C.

The disappearance of aquatic vegetation suggests a decrease of lake area during the younger part of the interstadial. *Sphagnum* occurs in small quantities. Organic matter content distinctly decreases (down to ca 30%). Only *Isöetes* becomes very abundant, reaching its maximum percentages; it was not recorded in the corresponding pollen spectrum from Zgierz-Rudunki (Jastrzębska-Mamełka 1985). This suggests that oligotrophic habitat conditions prevailed at the studied site and that the lake vegetation consisted of underwater meadows formed only by *Isöetes*.

In general the characteristic feature of the Amersfoort interstadial in the profile from Żabieniec Południowy is its bipartition: initial domination of birch forests with larch (L PAZ Ż.Pd-9), later superseded by pine forests with larch and spruce (L PAZ Ż.Pd-10). The pollen spectra, however, give no indication that the boreal climate in the older part of the interstadial was distinctly wetter and in its younger part more continental, as is the case for many other sites (Jastrzębska-Mamełka 1985, Krupiński 2005). This disparity might be explained by specific microclimatic conditions prevailing in the area of the studied basin.

The material from the Żabieniec Południowy locality yielded no organic sediments or structures reflecting climatic-floristic changes during this part of the Early Vistulian, which is correlated with the biostratigraphic zone R PAZ EV3 Gramineae-*Artemisia-Betula nana* (Mamakowa 1989), the cooling of the Vistulian 2 (VS2) stadial (Lindner 2005, Mojski 2005), and the Rederstall horizon in Germany (Litt 1990). At that time the progressively increasing cooling precipitated the development of steppe vegetation, and the interstadial pine forests were replaced by park tundra with patches of pine-birch forests (Jastrzębska-Mamełka 1985). Deposits of that age were not identified at some other sites in central Poland, such as Świątniki (Turkowska 1988, 2006). Their absence is taken as evidence that soil processes terminated and that Eemian-Early Vistulian pedogenesis came to an end before the lower Plenivistulian, as suggested by Manikowska (1999). In Żabieniec Południowy the sedimentation break is temporary and may be the result of renewed denudation on the slopes of the catchment basin and redeposition of biogenic sediments from higher slopes of the basin to its central bottom part.

RUDUNKI INTERSTADIAL

Ż.Pd-11 *Pinus-Betula* L PAZ

The second forest phase of the Early Vistulian is the last stage of vegetational and climatic changes recorded from the Żabieniec Południowy site. This stage corresponds to R PAZ EV4 *Pinus-Betula* (Mamakowa 1989), the younger Rudunki interstadial ZRII-14 *Pinus-Betula* (Jastrzębska-Mamełka 1985) and the Oderade warming described from the Netherlands and Germany (e.g. van der Hammen & Wijmstra 1971, Zagwijn 1996).

During the Rudunki interstadial the landscape was dominated by open pine-birch forests with *Larix* as an important component and some Ericaceae in the herb layer. Milder climate is indicated by the appearance of *Corylus avellana*, *Carpinus betulus*, *Quercus*, and *Tilia*. Alder carrs spread in wet habitats. Continentality of climate is suggested by the presence of *Betula nana* t. Herbaceous vegetation was poorly developed (10–15% in diagram, Fig. 4). Dry grasslands were formed by grasses (Poaceae), *Artemisia*, Chenopodiaceae, Asteraceae, and *Rumex*; Cannabaceae, *Urtica dioica*, and *Thalictrum* appeared in shaded moist habitats.

Vegetation of a distinctly shallower lake included *Pediastrum*, *Potamogeton*, *Myriophyllum spicatum*, and *Isöetes*. The presence of *M. spicatum* may indicate that moderate temperature prevailed. According to Kolströp (1980), mean July temperature was ca 10–13°C. *Sphagnum* percentages decreased, and *Viola palustris* occurred among the mire plants.

DISCUSSION

Distinguishing zones in the Żabieniec Południowy profile was problematic. In a few cases it was based on only one sample. For this reason it seemed useful to compare the proposed stratigraphy of the Żabieniec Południowy basin deposits with the stratigraphy of other selected localities. The aim was to determine whether the deposits from the Żabieniec Południowy basin and the Żabieniec mire represent the most complete profile of biogenic sediments in central Poland, covering the vegetation succession of the whole postglacial stage.

STRATIGRAPHY OF THE ŻABIENIEC POŁUDNIOWY BASIN DEPOSITS COMPARED WITH OTHER SELECTED LOCALITIES

The local pollen assemblage zones distinguished in the profile of the Żabieniec Południowy deposits correspond to L PAZs described from the most important sites, Zgierz-Rudunki and Józefów (Tab. 5), with the biostratigraphic division proposed for Polish Lowlands by Mamakowa (1989), and with the chronological divisions of Lowland Poland (Środoń 1967, Jastrzębska-Mamełka 1985, Tobolski 1991, Mojski 2005, Turkowska 2006) and Western Europe (Zagwijn 1961, 1989, 1996, Van der Hammen & Wijmstra 1971, Litt 1990).

The decline of the Warta stadial, corresponding to the terminal phase of the 6^{th} OIS (Shackelton & Opdyke 1973), was recognised in the Ż.Pd-1 NAP and Ż.Pd-2 *Pinus-Betula* L PAZs. The reconstructed vegetation very much resembled that of ZRII 1 and ZRII 2 L PAZs from the Zgierz-Rudunki (Jastrzębska-Mamełka 1985). Only shrubs were missing in the Ż.Pd-1 zone. At both sites the pollen spectra from these zones represent herbaceous plants and pine-birch forests. In the profile from Józefów (Sobolewska 1966, Dylik 1967), sediments corresponding to this zone were missing. L PAZ Ż.Pd-1 NAP and Ż.Pd-2 *Pinus-Betula* correspond to biostratigraphic zones R PAZ LG MPG (Mamakowa 1989) and Saalian a and Saalian b (Środoń 1967).

The Eemian interglacial corresponds to the 5^{th} e OIS (Shackelton & Opdyke 1973). Ż.Pd-3 *Betula-Pinus* L PAZ from Żabieniec Południowy is similar to ZRII 3 *Betula-Pinus* L PAZ in Zgierz-Rudunki and R PAZ E1 (Mamakowa 1989). The pollen succession of zone "d" in the profile from Józefów is a stratigraphic counterpart to R PAZ E1 and E2. Vegetation successions corresponding to R PAZs E2 and E3 were not recorded in the profile from Żabieniec Południowy. According to Tobolski (2000) the sedimentation breaks could be connected with marginal zones of water basins. Steep slopes of melt-out kettles filled with Eemian reservoirs were exposed to slope movement processes (soil flow); in addition, waves could erode slope sediments and deposit them on the lake bottom during episodes of low water level. Under this scenario it seems possible that the lower section of the Ż.Pd. core comes from the slope of the melt-out kettle, and that the deepest part of the reservoir, where the core was taken, was located near its shore and not in the centre.

In Zgierz-Rudunki, L PAZ ZRII 4 (with dominance of pine-birch forests) and L PAZ ZRII 5 (with the *Quercus* maximum) correspond to regional pollen assemblage zones E2 and E3. The difference between ZRII 5 and zone "e" in Józefów can be seen in the *Quercus* curve, which shows a low maximum in zone "e" and a much higher one (over 70%) in L PAZ ZRII 5 at Zgierz-Rudunki.

The Ż.Pd-4 L PAZ in Żabieniec Południowy corresponds to the climatic optimum of the Eemian interglacial. This phase is visible in spectra from all selected localities. The composition of forest communities from the optimum of the Eemian interglacial has great significance for stratigraphic and biostratigraphic interpretation of this period (Krupiński 2005). Hazel became very abundant through almost all of Europe and constituted the main forest component. Its occurrence in quantities not recorded in any other part of the Pleistocene and Holocene is an indicator phenomenon for Eemian vegetation. Hazel occurs in great quantities at all sites mentioned above. High hazel percentages, up to 79% in the Ż.Pd-4 L PAZ, indicate that the study area was within the range of this species migrating from Southern Europe (Mojski 2005). The shares of hazel at Eemian sites decrease towards the north (Krupiński 2005). In the corresponding zone "f" in Józefów there are also high shares of *Carpinus betulus* recorded, unlike at Żabieniec Południowy and Zgierz-Rudunki where its maxima occur in zones Ż.Pd-5 and ZRII-7 respectively. Subzones ZRII-7a and ZRII-7b described from Zgierz-Rudunki were not distinguished in the regional

Table 5. Stratigraphy of deposits from Żabieniec Południowy Ż.Pd core in relation to profiles from comparable localities, and corresponding biostratigraphic and chronostratigraphic divisions

LOCAL POLLEN ASSEMBLAGE ZONES (L PAZ)			BIOSTRATIGRAPHY	CHRONOSTRATIGRAPHY				OIS
Żabieniec Południowy	Zgierz-Rudunki (Jastrzębska-Mamełka 1985)	Józefów (Sobolewska 1966, Dylik 1967)	Regional pollen assemblage zones (Mamakowa 1988, 1989)	Lowland Poland (e.g. Jastrzębska-Mamełka 1985, Turkowska 2006)	Western Europe (Zagwijn 1996b)			
	ZRII 15 NAP-*Betula* cf. *nana*		EV5	VS3	Schalkholz	Plenivistulian	VISTULIAN	4
Ż.Pd-11 *Pinus-Betula*	ZRII 14 *Pinus-Betula*		EV4	Rudunki	Odderade	Early Vistulian		5a
?	ZRII 13 b NAP-shrubs		EV3	VS2	Rederstall			5b
	ZRII 13 a NAP-*Pinus-Betula*							
Ż.Pd-10 *Pinus*	ZRII 12 *Pinus-Larix-Picea*	Amersfoort b *Pinus-Picea*	EV2b	Amersfoort/Józefów interstadial b	Brörup			5c
Ż.Pd-9 *Betula*-NAP	ZRII 11 *Betula-Pinus-Larix*	Amersfoort a *Betula*	EV2a	Amersfoort/Józefów interstadial a				
Ż.Pd-8 NAP-*Betula-Betula nana*	ZRII 10 NAP-*Juniperus*	i	EV1	VS1	Herning			5d
Ż.Pd-7 *Pinus-Picea-Betula*-NAP	ZRII 9 b *Betula-Pinus-Picea*-NAP		E7	E7		Late	EEM INTERGLACIAL	5e
	ZRII 9 a *Pinus-Picea-Betula*	gh						
Ż.Pd-6 *Alnus-Picea-Abies*	ZRII 8 *Picea-Abies-Carpinus-Alnus*		E6	E6				
Ż.Pd-5 *Carpinus-Corylus-Alnus-Picea*	ZRII 7 b *Carpinus-Picea*		E5	E5		Middle		
	ZRII 7 a *Carpinus-Tilia-Corylus-Alnus*							
Ż.Pd-4 *Corylus-Quercus-Tilia-Alnus*	ZRII 6 *Corylus-Tilia-Acer*	f	E4	E4				
?	ZRII 5 *Quercus-Corylus*	e	E3	E3				
	ZRII 4 *Pinus-Betula*	d	E2	E2		Early		
Ż.Pd-3 *Betula-Pinus*	ZRII 3 *Betula-Pinus*		E1	E1				
Ż.Pd-2 *Pinus-Betula*	ZRII 2 *Pinus-Betula*		LG MPG	Saalian b		Warta decline	WARTA STADIAL	6
Ż.Pd-1 NAP	ZRII 1 NAP-shrubs			Saalian a				

biostratigraphic division (Mamakowa 1989), nor in the profile from Żabieniec Południowy. However, the increased shares of *Carpinus betulus* and *Picea abies* recorded at the top of L PAZ Ż.Pd-5 in Żabieniec Południowy may correspond to the hornbeam forests from subzone ZRII-7b *Carpinus-Picea* in Zgierz-Rudunki (Jastrzębska-Mamełka 1985).

The floristic features of the Ż.Pd-6 *Alnus-Picea-Abies* L PAZ support the hypothesis that *Abies alba* had a larger range during the Eemian interglacial than at present (Środoń 1983, Zagwijn 1961, 1989, 1996, Mamakowa 1989, Krupiński 2005). In Żabieniec Południowy a higher share of *Alnus* than *Picea abies* is a local feature of this zone.

This zone is similar to zone L PAZ ZRII 8 in Zgierz-Rudunki and R PAZ E6 (Mamakowa 1989). In the Józefów diagram the synchronous occurrence of *Carpinus betulus*, *Picea abies*, and *Abies alba* probably was the reason for treating the sections corresponding to R PAZ E5 and E6 as one zone, "gh" (Tab. 5). The top part of this zone corresponds to the beginning of R PAZ E7, which marks the end of the oligoctaric phase of the Eemian interglacial (Mamakowa 1989). Subzone ZRII 9b from Zgierz-Rudunki corresponds to zone "i" in Józefów. Its stratigraphic position has often been the subject of discussion. According to Zagwijn (1961) it represents the border between the Eemian interglacial and Vistulian glaciation. On the basis of palynological indications showing woody character of the vegetation, Środoń (1967) considered zone "i" to be the final stage of the interglacial succession. Data from investigations of the Imbramowice site near Wrocław prompted Mamakowa to identify it as the first stage of the Early Vistulian succession, corresponding to R PAZ EV1.

The first Early Vistulian cooling (VS1) falls in the 5th d OIS (Shackelton & Opdyke 1973). In the corresponding Ż.Pd-8 L PAZ in Żabieniec Południowy the *Juniperus communis* curve is discontinuous, unlike the synchronous zone L PAZ ZRII 10 in Zgierz-Rudunki. On the other hand, the high percentages for thermophilous trees noted in zone Ż.Pd-8 are not recorded in the profiles from Zgierz-Rudunki (Jastrzębska-Mamełka 1985) and Józefów (Sobolewska 1966), possibly suggesting that the pollen of these trees occurs on a secondary bed. A distinct feature of zone ZRII 10 from Zgierz-Rudunki is the rapid dominance of herbaceous vegetation, while in zone Ż.Pd-8 from Żabieniec Południowy it increases slowly. These zones should be linked with R PAZ EVI distinguished by Mamakowa (1988).

The first Early Vistulian interstadial, Amersfoort, corresponds to the 5th c OIS (Shackelton & Opdyke 1973). The bipartition typical for this interstadial is a characteristic feature of all described localities. In Józefów the profile ends with biogenic sediments recording the Józefów interstadial (Amersfoort).

The second cooling of the Early Vistulian (VS2), correlated with the 5th b OIS (Shackelton & Opdyke 1973), was recorded only in the profile from Zgierz-Rudunki. The second interstadial warming of the Early Vistulian, called the Rudunki (Jastrzębska-Mamełka 1985) and Odderade interstadial (Van der Hammen & Wijmstra 1971, Zagwijn 1996b) falls in the 5th a OIS (Shackelton & Opdyke 1973). Its counterparts are the Ż.Pd-11 L PAZ from Żabieniec Południowy and the ZRII 14 L PAZ from Zgierz-Rudunki, correlated with R PAZ EV5. The succession from the beginning of the lower Plenivistulian, recognised as the ZRII 15 L PAZ only in Zgierz-Rudunki, was not recorded in the sediments from Żabieniec Południowy. This horizon, corresponding to the 4th OIS (Shackelton & Opdyke 1973), conforms to the third cooling of the Vistulian VS3 (Lindner 2005), the Świecie stadial (Mojski 2005), and the Schalkholz stadial in Western Europe (Litt 1990).

PALAEOGEOGRAPHICAL SIGNIFICANCE OF SEDIMENTS FROM THE ŻABIENIEC POŁUDNIOWY SITE, ASSESSED IN TERMS OF PALYNOLOGICAL DATA FROM THE ŻABIENIEC MIRE

The Żabieniec Południowy basin and the Żabieniec mire are situated within the watershed of a single closed depression of melt-out origin (Nowacki 1990, 1993). The palynological investigations of both sites yielded unequivocal evidence that they existed and that they were filled at different times. The Żabieniec Południowy closed basin is of Warta-Eemian-Early Vistulian age. Eemian basins are among the most frequent basins documented from central Poland. On the Łódź Plateau the localities include Skierniewice (Borówko-Dłużakowa 1973), Pałczew (Wieczorkowska 1975), and Modlna (Klatkowa 1990, Klatkowa & Balwierz 1990). Examples of sites of Eemian-Early

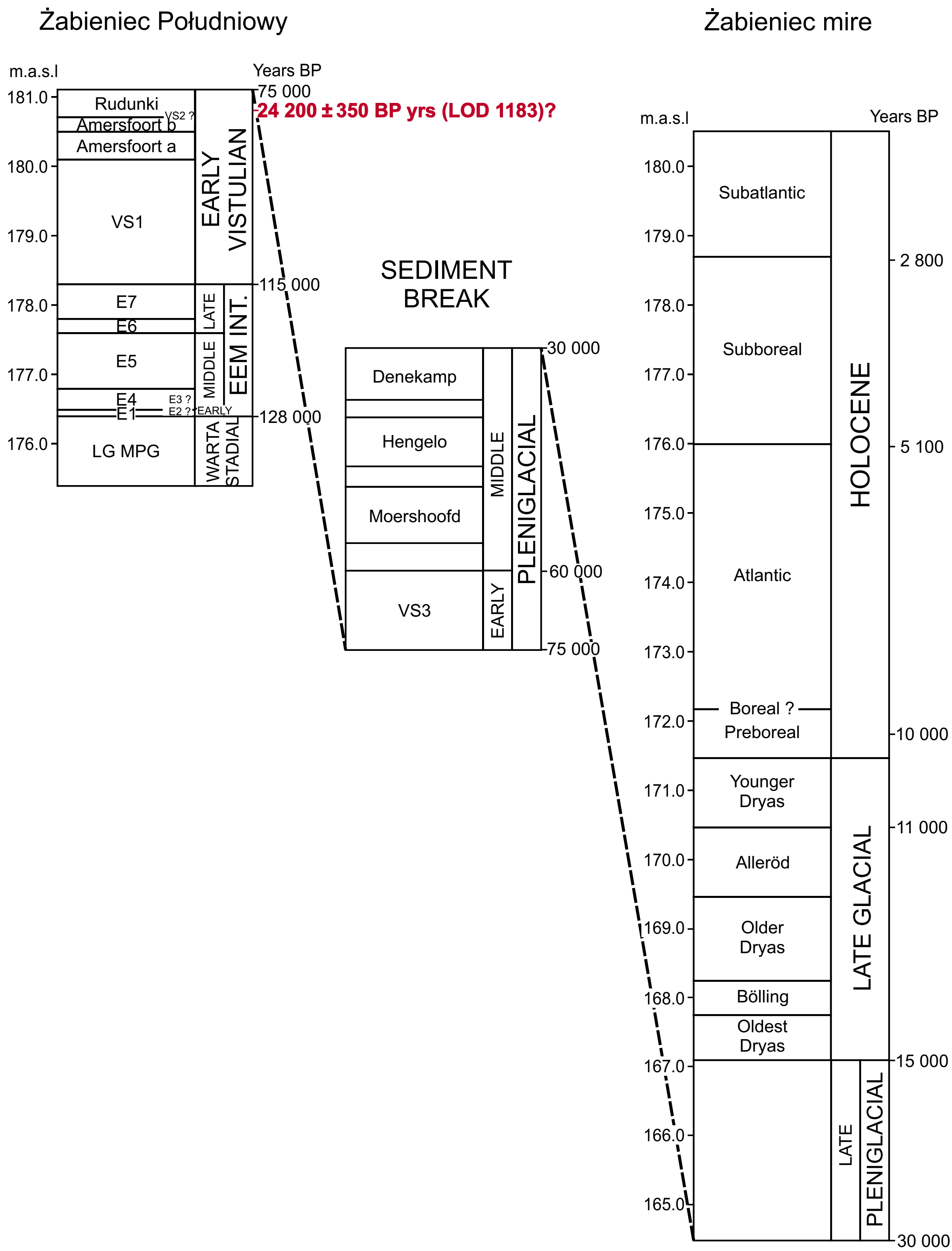


Fig. 6. Stratigraphy of deposits from the Żabieniec Południowy basin and Żabieniec mire (Balwierz 2010)

Vistulian age are Józefów (Sobolewska 1966, Dylik 1967), Żyrardów (Krupiński 1978), and Kuców (Goździk & Balwierz 1994). Those of Wartanian-Eemian age include Grodzisk Mazowiecki (Nowak 1973, Janczyk-Kopikowa 1973) and Śládkowice (Klatkowa & Jastrzębska-Mamełka 1990). Examples of basins of Wartanian-Eemian-Early Vistulian age, the rarest, are Zgierz-Rudunki (Jastrzębska-Mamełka 1985) and Świątniki (Turkowska 1988). Biogenic sediments from the lower Vistulian were also documented at a few sites, for example at Zgierz-Rudunki (Jastrzębska-Mamełka 1985). So far no continuous succession from the Warta decline to the Holocene has been found at any of the studied sites. The proximity of the Żabieniec Południowy basin and the Żabieniec mire to each other suggests that these basins may have developed one after the other and thus could provide the most complete profile of biogenic sediments in central Poland, covering the vegetation succession of the whole postglacial period. This possibility was supported by the radiocarbon date 24 200±350 yrs BP uncalibrated (LOD 1183) obtained from the uppermost biogenic sediments at Żabieniec Południowy, suggesting that their accumulation took place in the upper Plenivistulian (Twardy et al. 2010). This date was not confirmed by pollen analysis, however.

The sediment stratigraphy of the Żabieniec Południowy and the Żabieniec basins shows discontinuity and the absence of records of the lower and middle Plenivistulian (Fig. 6). This hiatus begins with the end of the period of Eemian-Early Vistulian pedogenesis according to Manikowska (1999). Plenivistulian deposits were found only in the form of mineral series overlying fossil basin fills and evidencing their final disappearance at the end of the Early Vistulian. A few causes of such a situation might be cited, including distinct cooling during the anaglacial phase of the Świecie transgression (Mojski 2005), which hampered vegetation development and soil processes, as well as the increased activity of slope processes which resulted in complete filling of the Żabieniec Południowy reservoir.

Pollen analysis dated the uppermost mineral-biogenic sediments of the fossil basin to the end of the Early Vistulian, ca 75 000 years BP, which disagrees with the radiocarbon date given above (Twardy et al. 2010). The Ustków site on the Turek Upland presents a similar situation. There the age estimated from three radiocarbon dates for the topmost deposits suggested their origin from the upper Plenivistulian (Klatkowa & Załoba 1991), while pollen analysis indicated Early Vistulian age, the Redelstall stadial (Kołaczek et al. 2012). Pollen analyses from both sites indicates that the vegetation successions covered a shorter time span and that the radiocarbon dates are much too young. This discrepancy may be the effect of penetration of deposits lying nearer to the surface by roots of plants growing on the spot. The profile from Żabieniec Południowy is another example of the importance of using various methods to verify age based on ^{14}C dates.

The middle Plenivistulian, also called the interpleniglacial period, corresponds to the 3rd OIS (Shackelton & Opdyke 1973). It is often a source of controversy when palaeogeomorphological and palaeobotanical analyses are applied to younger interstadials – Moershoofd, Hengelo, and Denekamp – previously identified on the basis of ^{14}C dating. These interstadials were named after localities in the Dinkel valley at the border between the Netherlands and Germany, where Western Europe's best-documented deposits of that age are located (Kolströp & Wijmstra 1977, Ran & Van Huissteden 1990).

In the Dinkel valley the Moershoofd younger interstadial is characterised by communities of shrub tundra and tundra, the highest precipitation in the whole middle Plenivistulian, and annual temperatures not exceeding −1°C (Ran & Van Huissteden 1990). Humid climate prevailed during the Hengelo interstadial in the Netherlands, and mean annual temperatures were between 0°C and −4.5°C (Ran & Van Huissteden 1990, Kasse et al. 1995). The vegetation of both the Hengelo and the younger Denekamp interstadials was formed by communities of shrub tundra (Ran & Van Huissteden 1990). Sites with fossil soils and biogenic sediments containing middle Plenivistulian floras are very rare in Poland. A stratigraphic hiatus covering the older part of the middle Plenivistulian has been found in deposits of the north-western part of the Uniejów basin (Petera 2002). Organic deposits of that age were not found in the valleys or in fossil closed basins on the Łódź Plateau. Their stratigraphic counterparts were widespread mineral sandy-silty series.

The most often recorded warming oscillation of the middle Plenivistulian is correlated with the Denekamp interstadial. Together with the Moershoofd interstadial it was recorded in a fossil river valley in the KWB Bełchatów brown coal strip mine exposure (Krzyszkowski et al. 1993, Manikowska 1996, Goździk & Zieliński 1996). Other localities of the Denekamp in Poland include Kalinko (Manikowska 1993), the Moszczenica river valley (Kamiński 1993), Kuców (Goździk & Balwierz 1994, Balwierz 1995, 2007), and Kępno in the Prosna river valley (Rotnicki & Tobolski 1969). Radiocarbon dating of sediments in the Uniejów basin dates them to the younger part of the middle Plenivistulian (Petera 2002). There are great discrepancies in assessments of temperature conditions for the Denekamp interstadial. Mean annual temperatures not exceeding 0°C were suggested for the Netherlands (Ran & Van Huissteden 1990), and ca −5°C for the Prosna river catchment (Rotnicki 1996). A warmest-month mean temperature of 10°C (Mycielska-Dowgiałło 1978, Kolströp 1980, Klatkowa 1996) would indicate relatively good conditions for the development of tundra vegetation. Mean annual temperature between 1.5 and −4.5°C favours the development of permafrost and periglacial structures (Romanovsky 1985, Ran & Van Huissteden 1990, Kolströp 1980, Klatkowa 1996, Balwierz & Goździk 1999, Manikowska 1999). Cold stadial periods were characterised by annual temperatures of ca −6°C and the continuous spread of herbaceous vegetation (Ran & Van Huissteden 1990, Balwierz 1995, Manikowska 1999).

Radiocarbon dating of interstadial deposits indicates their continuity from the Moershoofd to Denekamp interstadials (Behre 1989). Their occurrence in lowland river valleys, for example the Dinkel river valley (Ran & Van Huissteden 1990, Kasse & Bohncke & Vandenberghe 1995) and Warta river valley (Petera 2002), and their total absence in areas having diversified topography, such as on the Łódź Plateau, indicate specific conditions for the formation of organic and soil horizons in the valleys. The formation of biogenic sediments should be connected with the sedimentary environment of old river-beds and flood basins and locally favourable moisture and microclimate (Balwierz 1995, Manikowska 1996). According to Turkowska (2006), this type of sediment to which interstadial rank was wrongly attributed and was in fact formed synchronously, associated with the development of a meandering river, and represents one climatic oscillation.

No traces of middle Plenivistulian vegetation were documented in the Żabieniec Południowy fossil basin. The varied topography of the watershed slopes, the occurrence of ground ice, and high precipitation intensified denudation processes, among which downwash was the most effective (Dylik 1972). Due to denudation the upper parts of slopes were eroded and sandy-silty deposits were accumulated at their base.

Upper Plenivistulian sediments were recorded at the bottom of the profile from the Żabieniec mire, below 13.35 m depth (Balwierz 2010). This period corresponds to the main stadial of the Vistulian ice-sheet advance (Lindner 2005, Mojski 2005), connected with the most pronounced climatic cooling during the Vistulian and with the 2nd oxygen phase (Shackelton & Opdyke 1973). As climatic conditions deteriorated and cooling and dryness increased, the vegetation cover on the Łódź Plateau became island-like "puzzle vegetation" (Balwierz 2010 after Kolströp). Slope and aeolian processes predominated within the melt-out depression. Reconstructing the vegetation of this cool period from mineral sediments or sediments containing a high proportion of mineral particles is difficult and may raise doubts. The lack of comparable localities from central Poland is another reason why stratigraphic correlation of the distinguished pollen assemblage zones was not attempted from the Żabieniec mire profile (Balwierz 2010).

CONCLUSIONS

– Pollen analysis of the Żabieniec Południowy fossil basin distinguished 11 local pollen assemblage zones corresponding to the period from the decline of Warta stadial through the Eemian interglacial to the Early Vistulian Rudunki interstadial. Vegetation development and climatic conditions were reconstructed and compared with the most important localities from the Łódź Plateau.

– The decline of the Warta stadial begins with dominance of park tundra communities and scattered patches of pine-birch forest which progressively displace communities of open habitats. The significant share of redeposited pollen is evidence of soil instability and intensive erosional processes within the basin catchment, caused by lack of plant cover. Therefore the pollen spectrum does not properly reflect the composition of the plant communities, nor climatic conditions.

– The vegetation succession of the Eemian interglacial recorded in the sediments is described by five local pollen assemblage zones which correspond to R PAZ E1, E4, E5, E6, and E7 (Mamakowa 1988, 1989). The absence of zones corresponding to R PAZ E2 and E3 is explained by erosion of deposits on steep slopes of the melt-out kettle.

– The pollen spectrum from the climatic optimum is distinguished by very high percentages (up to 79%) of *Corylus avellana*, high *Tilia* (7.5%), and the early appearance of *Carpinus betulus*.

– The Early Vistulian is represented by the first forestless stadial, VS1, with dominance of park tundra landscape and next by the first forest stage corresponding to the Amersfoort interstadial. It is characterised by a typical bipartition with initial dominance of birch forests with *Larix*, progressively replaced by pine forests with *Larix* and later with *Picea abies*.

– The prevailing highly oligotrophic conditions in the Żabieniec Południowy basin during the younger part of the Amersfoort interstadial are evidenced by high percentages of *Isöetes* (10%), not recorded in neighbouring localities.

– The sedimentation hiatus documented in Żabieniec Południowy and correlated with R PAZ EV3 is incidental and may result from redeposition of sediments due to increased slope denudation in the catchment area of the basin.

– The Vistulian succession ends with the second forest stage of open birch-pine forests, correlated with the Rudunki interstadial.

– The Żabieniec Południowy basin was a shallow eutrophic lake, with short oligotrophic phases at the decline of the Eemian interglacial and in the Early Vistulian separated by terrestrialisation phases indicated by the presence of *Sphagnum*.

– The pollen analysis did not confirm the age of the top section of biogenic sediments in Żabieniec Południowy based on radiocarbon date 24 200±350 yrs BP uncalibrated (LOD 1183), which suggested that they accumulated in the upper Plenivistulian. The pollen spectra from that sediment section documented a vegetation succession of the Rudunki interstadial, Early Vistulian.

– Pollen analysis documented a discontinuity in the record of floras from the lower and middle Plenivistulian between biogenic sediments in the Żabieniec Południowy basin and Żabieniec mire. Plenivistulian deposits were represented only by sandy-silty series overlying the biogenic fill of the fossil reservoir. They provide evidence of its definite disappearance at the end of the Early Vistulian.

– The Wartanian-Eemian-Early Vistulian succession documented in the Żabieniec Południowy basin supplements the sequence of Vistulian-Holocene deposits from the Żabieniec mire. Despite the sedimentation break caused by morphogenesis processes during the lower and middle Plenivistulian, the deposits from both basins illustrate the development of one large melt-out area during the whole postglacial period. Evidence of the complete evolution of the melt-out depression rests not solely on the discovered deposits but also on their absence.

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