Acta Palaeobotanica 48(1): 3–130, 2008

Vegetation and climate of the Eemian and Early Vistulian lakeland in northern Podlasie*

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Received 10 September 2007; accepted for publication 25 April 2008

ABSTRACT. Material for the study comes from 22 palaeolakes and palaeobogs in three macroregions – Białystok Upland, Sokółka Hills and Bielsk Upland – of northern Podlasie (north-eastern Poland). Six hundred and fourteen samples from 28 cores were examined by means of pollen analysis, and 300 samples from two most important profiles – Solniki and Dzierniakowo – using lithological analyses of the sediments were carried out, namely magnetic susceptibility, grain size distribution, concentration of ^{13}C and ^{18}O isotopes, organic carbon and calcium carbonate content. The results of the pollen analysis are presented graphically on diagrams. In each of them biostratigraphical units at the level of local pollen assemblage zones (L PAZ) were distinguished. On that basis it was determined that the studied sediment sequences span the closing phase of the late glacial of Wartanian (Saalian) glaciation, the Eemian interglacial and the early glacial of the Vistulian (Weichselian). Correlation of local pollen zones from all investigated profiles allowed to distinguish 14 regional pollen assemblage zones (R PAZ). They were correlated with pollen zones recognized in other pollen profiles from Poland and Europe, and also with bio- and chronostratigraphical units marked with various methods in Greenland's ice cores and sea sediments. The results of investigation were used to reconstruct vegetation succession and climate changes across the great part of the last interglacial-glacial cycle, from the final stage of the Wartanian glaciation to the end of the Early Vistulian. Two sites – Solniki and Dzierniakowo – play vital role in this reconstruction. Profile from Solniki contains very well developed record of environmental changes during the Eemian interglacial. From the data obtained it occurs that this record registers two intra-Eemian fluctuations of the climate. The first of them fell to the middle part of the hornbeam zone (E_{NP}5 *Carpinus* R PAZ) being probably manifested only by a significant decrease in precipitation with no fluctuations in temperature level. Hiatus, that in the numerous profiles from northern Podlasie contains a younger part of the hornbeam phase of the Eemian interglacial and the entire spruce phase (E_{NP}6 *Picea-Pinus-(Abies)* R PAZ), is probably the effect of that climate change. Additionally, as a result of that change water level in lakes and bogs decreased. It was then followed by a temporal stopping of sediment accumulation in those basins or even through deposit decomposition (through drying) of what was earlier accumulated there. The paper deals also with other hypothetical causes of such abrupt decrease in water level, such as melting of permafrost, lowering of riverine erosion level, or other local conditions. The second climate fluctuation took place in the middle part of the pine phase (subzones b and c of the E_{NP}7 *Pinus* R PAZ). The decrease in forested areas and the increase in open plant communities of a cold step type with domination of the *Artemisia* genus was a result of environment change into a cool continental climate. Profiles from Dzierniakowo and Solniki contain a high-resolution record of the early glacial stage of the Vistulian glaciation. This permitted a detailed reconstruction of environment changes during that period to be done. Cold fluctuation of the climate appeared in the Brørup interstadial *sensu lato*. It seems likely that it represented the cooling that separated the Amersfoord and Brørup *sensu stricto* interstadials.

KEY WORDS: pollen analysis, palaeoecological reconstructions, palaeoclimate, vegetation history, Wartanian, Eemian interglacial, Early Vistulian (Weichselian), Brørup interstadial, Odderade interstadial, Podlasie, Poland

* The palaeobotanical investigations were supported by the Institute of Biology in University of Białystok (project No. BST-109), Ministry of Science and Higher Education (project No. 3 P04C 025 25) and Polish Geological Institute (the Detailed Geological Map of Poland in the scale 1:50 000).

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INTRODUCTION

Rapid changes in climate that were observed at the world's scale during the last decade prompted questions about possible causes. The possibilities of distinguishing between the natural causes and those being influenced by economic development were discussed.

Analysis of the environment of the last interglacial, named in Europe as the Eemian interglacial, plays a crucial part in recognition of climate change that was not related to the human activity. Through numerous comparisons between that interglacial stage and the major part of the Holocene it was indicated that many natural phenomena already took place in both of those periods in similar manner (cf. Iversen 1954, Tobolski 1976). That allows to assume that recognition of climate change in the final part of the Eemian interglacial may enable prediction of other analogous natural changes that most likely occur in the late Holocene in separation from anthropogenic changes.

In the context of contemporary rapid climate change the main task is to answer the question whether there occurred a rapid climate fluctuations during the last interglacial or else if it was as in old and commonly accepted sequence of successive climate changes – with cool beginning of the interglacial, through constant warming culminated with the stage of optimal conditions, and then back again to the beginning of another glaciation – a model that probably better fits any period free from the human presence (Iversen 1954, Tobolski 1976).

The issue of environmental stability during the past interglacials, especially the Eemian one, has been discussed for a long period of time and was many times mentioned in papers from various fields of natural science (Velichko et al. 1982, 2005, Kukla et al. 1997, Saarnisto et al. 1999, Björk et al. 2000, Nitychoruk J. 2000, Guiter et al. 2003, Klotz et al. 2003, 2004, Kühl & Litt 2003, Müller 2005). The discussions got tense when a record of detectable temperature fluctuations from warm to cold conditions during the Eemian interglacial were discovered in ice cores in Greenland. The GRIP ice core contained the evidence of two extreme cold events, both of them lasting over 1000 years (Anklin et al. 1993, Dansgaard et al. 1993, GRIP members 1993). The presence of such fluctuations was confirmed through sets of data from marine cores located in various parts of the world (Cortijo et al. 1994, Seidenkrantz et al. 1995, Stirling et al. 1995, Fronval & Jansen 1996, Maslin et al. 1996, Maslin & Tzedakis 1996, Adkins et al. 1997), by pollen data from a few European sites (de Beaulieu & Reille 1992a, b, Guiot et al. 1993, Field et al. 1994, Thouveny et al. 1994, Cheddadi et al. 1998) and by results from other terrestrial profiles that were studied using different methods (Larsen et al. 1995, Zhisheng & Porter 1997, Ciszek 1999, Karabanov et al. 2000a). Similar results for Europe are derived from the long maar sequences in southern Europe (Tzedakis et al. 1994).

Nonetheless, the majority of terrestrial profiles indicated the successive course of climate changes during the Eemian interglacial (Zagwijn 1961, Mamakowa 1989, Jozuel et al. 1993, Keigwin et al. 1994, McManus et al. 1994, Fauquette et al. 1999). Only few profiles proved that the process might have undergone in a different manner (Müller 1974, de Beaulieu & Reille1989, 1992, Guiot et al. 1993, Field et al. 1994).

During the study held in the last decade, based on the Detailed Geological Map of Poland in the scale 1: 50 000, about 30 new sites of the lacustrine-mire deposits from the Eemian interglacial were discovered in northern Podlasie, north-eastern Poland (Kupryjanowicz 1999a, b, c, 2000a, b, c, d, e, f, 2001a, b, 2002a, b, c, d, e, f, Brud & Kupryjanowicz 2000, 2002, Kupryjanowicz & Drzymulska 2000, 2002, Brud 2001, Kmieciak 2001, 2003, Kurek & Preidl 2001a, b, Boratyn 2003, 2006, Kwiatkowski & Stepaniuk 1999, 2003, Krzywicki 2003, Noryśkiewicz 2005, Bińka 2006b). It served as an opportunity for palaeoecological reconstruction of this region. This area is now situated in a transition zone between oceanic and continental climate, in which way every possible climate change of the European continent should have been reflected in a very short period of time. As an example one may mention the hottest and driest summers in Poland that were noticed here in few previous years. It subsequently led to the decrease in ground water table and even to complete drying out of the Gorbacz lake in 2003. Based on various data (Mamakowa 1989) it may be stated that during the Eemian interglacial this region was also situated in the transition zone being prone to a greater extent, as compared with central Poland, to all even short-term climate changes.

The main aim of the palaeobotanical study was to find out whether during the Eemian interglacial and at the beginning of the following glaciation changes in northern Podlasie environment (especially of the vegetation and climate) followed the scheme of the interglacial (Iversen 1954, Andersen 1964, 1966, Tobolski 1976) and interstadial succession, or the succession was disturbed by some fluctuation. Detailed aims included:

– palynological documentation of the Eemian and the Early Vistulian lakeland in northern Podlasie,

– detailed regional pollen stratigraphy for the Eemian interglacial and the Early Vistulian of northern Podlasie region,

– correlation of the above-mentioned biostratigraphical scheme with units distinguished in Greenland's ice cores, marine sediments and selected pollen profiles from Europe,

– reconstruction of regional changes in vegetation during the last interglacial and at the beginning of the last glacial,

– reconstruction of climate changes during the Eemian and the Early Vistulian,

– reconstruction of development of some selected basins where sedimentation process was recorded, related mainly to the succession of aquatic and reed-swamp plant communities.

Apart from current results in the field of palaeoecological reconstruction that are presented in this paper earlier works of the author coupled with publications of other authors matching this case study were included as well (see Fig. 1 and Tab. 1).

Table 1. Sites of the Eemian interglacial in north-eastern Poland. Site numbers corresponds with that on the map (Fig. 1), in the stratigraphical table (Fig. 53, Tab. 58) and are written in square brackets [ ] in the text

No.	Name	References
1	Żabickie	Krzywicki 2003, Kupryjanowicz 2002g
2	Krasne	Krzywicki 2003, Kupryjanowicz 2002g
3	Grabowo	Krzywicki 2003, Kupryjanowicz 2002g
4	Nowy Dwór – profiles 50, 59 and 62	Noryśkiewicz 2005
5	Miklewszczyzna	Bitner 1957
6	Zacisze	Bitner 1957
7	Ludomirowo	Bitner 1957
8	Starowlany	Kmieciak 2003, Daniluk 2005, and in this paper
9	Chwaszczewo	Kmieciak 2003, Kupryjanowicz 2002b, and in this paper
10	Trzcianka	Kmieciak 2003, Kupryjanowicz 2002d, and in this paper
11	Gilbowszczyzna	Kmieciak 2003, Kupryjanowicz 2002e, and in this paper
12	Poniatowicze – profiles 1 and 2	Boratyn 2003, Kupryjanowicz 2002a, and in this paper
13	Sokółka – profiles 1 and 2	Boratyn 2003, and in this paper
14	Drahle	Boratyn 2003, Kupryjanowicz 2002a, and in this paper
15	Bohoniki	Boratyn 2003, Kupryjanowicz 2002a, and in this paper
16	Podkamionka	Kmieciak 2003, Kupryjanowicz 2002c, and in this paper
17	Machnacz – profiles I and II	Kupryjanowicz 1991, 1994, 1995a, b, c
18	Czarna Wieś	Bitner 1956b
19	Bagno-Kalinówka	Borówko-Dłużakowa & Halicki 1957
20	Harkawicze	Boratyn 2003, and in this paper
21	Kruszyniany	Wiosek 2005, and in this paper
22	Radulin	Kurek & Preidl 2001a, Kupryjanowicz 1999c
23	Pieszczaniki	Kurek & Preidl 2001a, Kupryjanowicz 2000c, and in this paper
24	Dzierniakowo	Kurek & Preidl 2001a, Kuryjanowicz 2000b, 2005a, and in this paper
25	Michałowo	Kurek & Preidl 2001a, Kupryjanowicz & Drzymulska 2000, 2002
26	Hieronimowo	Kupryjanowicz 1999a, Kupryjanowicz et al. 2007, and in this paper
27	Małynka	Kurek & Preidl 2001b, Kupryjanowicz 2000a
28	Solniki	Kurek & Preidl 2001b, Kupryjanowicz 2005a, Kupryjanowicz et al. 2005, and in this paper
29	Klewinowo	Mojski 1974, Borówko-Dłużakowa 1973a, 1974
30	Lesznia-Łuchowa Góra	Kupryjanowicz 2000f, Kmieciak 2001, and in this paper
31	Haćki	Brud & Kupryjanowicz 2002, Kupryjanowicz 2005b
32	Proniewicze PR1/93	Krupiński 1995
33	Proniewicze P-3	Kupryjanowicz 2000g, Kmieciak 2001, and in this paper
34	Otapy – profiles I and II	Bitner 1956a
35	Wólka – profiles 1 and 2	Kupryjanowicz 2002f and in this paper
36	Śliwowo – profiles 1 and 2	Kupryjanowicz 2002f and in this paper
37	Skupowo	Kupryjanowicz 2002e
38	Boćki – profiles 1 and 2	Boratyn 2006, Kupryjanowicz 2005c, and in this paper
39	Choroszczewo	Boratyn 2006, Kupryjanowicz 2005c, and in this paper
40	Milejczyce	Bińka 2006a
41	Zaręby	Bińka 2000
42	Czarna Wielka	Bińka 2000
43	Makarki	Bińka 2005

Table 1. Continued

No.	Name	References
44	Arbasy Duże	Bińka 2005
45	Błoniewo	Borówko-Dłużakowa & Halicki 1957
46	Wyszków	Borówko-Dłużakowa 1973a, 1973b
47	Kutyłowo-Perysie	Winter 1995
48	Mystki	Borówko-Dłużakowa 1971a, 1973a
49	Kowale	Janczyk-Kopikowa 1996
50	Łapy	Janczyk-Kopikowa 1996
51	Podbiele	Krupiński 1996a
52	Czerwin – profiles 1 and 2	Krupiński 1996b, 1996c
53	Stylągi	Krupiński 1996b
54	Konopki Leśne	Borówko-Dłużakowa & Halicki 1957, Borówko-Dłużakowa 1971b
55	Łomża-Łomżyca	Niklewski & Dąbrowski 1974, Straszewska & Goździk 1978, Krupiński 1992
56	Łomża-Łomżyca	Niklewski & Dąbrowski 1974, Straszewska & Goździk 1978, Niklewski & Krupiński 1992
57	Łomżyczka River – 4 profiles	Bińka et al. 2006
58	Kupiski Nowe	Borówko-Dłużakowa 1975, Bałuk 1978
59	Jednaczewo	Bałuk 1973, 1975, Borówko-Dłużakowa 1975
60	Jednaczewo – 2 profiles	Bińka et al. 2006
61	Niewodowo	Musiał et al. 1982, Bińka et al. 1988
62	Kossaki	Winter 2006
63	Rakowo Nowe	Krupiński 2000b
64	Dobrzyjałowo – 2 profiles	Bińka et al. 2006
65	Niebrzydy	Janczyk-Kopikowa 1999
66	Osowiec	Bińka 2006b
67	Sojczyn Grądowy	Bińka 2006b
68	Błotno – profiles S10 and S11	Krupiński 2000a
69	Pyshki	Szafer 1928, Shalaboda & Yakubovskaya 1978, Velichkevich 1982, Shalaboda 2001, Litviniuk et al. 2002a
70	Poniemun-1 = Poniemuń	Szafer 1925, Dyakowska 1936, Środoń 1950, Grichuk 1950
71	Poniemun-2	Kryger et al. 1971
72	Poniemun-3	Rylova &, Khursevich 1978, Karabanov et al. 2000b
73	Poniemun-4	Pavlowskaya et al. 2002
74	Rumlovka = Rumlówka	Środoń 1950, Halicki 1951, Yelovicheva 1978, San'ko et al. 2002a
75	Zhukevichi = Żukiewicze	Środoń 1950, San'ko et al. 2002b
76	Bogatyrevichi-1 = Samostrzelniki = Bohatyrowicze	Trela 1935, Środoń 1950
77	Bogatyrevichi-2	Vozniachuk & Valchik 1978
78	Bogatyrevichi-3	Shalaboda 2001
79	Bogatyrevichi-4	Litviniuk et al. 2002b

RESEARCH AREA

LOCATION

According to regional division of Poland based on palaeobotanical studies, northern Podlasie belongs to the Białystok Upland and Biebrza Basin Region, which is the part of the larger unit – the Masovia-Podlasie Lowlands (Ralska-Jasiewiczowa 1989). In the physical geographical division this area belongs to three mezoregions – predominant part belonging to the Białystok Upland and Bielsk Upland, and the remaining one to the Sokółka Hills (Fig. 1) – being itself a part of the northern Podlasie Lowland macroregion (Kondracki 1994).

GEOLOGY, GEOMORPHOLOGY AND HYDROLOGY

The Pleistocene sediments being placed at northern Podlasie reach from 90 to 180 metres in thickness (Nowicki 1971, Ber 1972, Brud et al. 2002). Six glacial layers are distinguished: Narew, Nida, San, Wilga, Odra and Warta (Mojski 1991, 2005, Lindner & Marks 1995). Holocene formations occupy relatively large areas. They include silts, sands, gravels, gyttjas and peats (Nowicki 1971, Ber 1972).

The relief of the Sokółka Hills is dominated by the extended rolling morainic plateau that was formed during the Mława stadial of the Wartanian glaciation (Boratyn 2003, Kmieciak

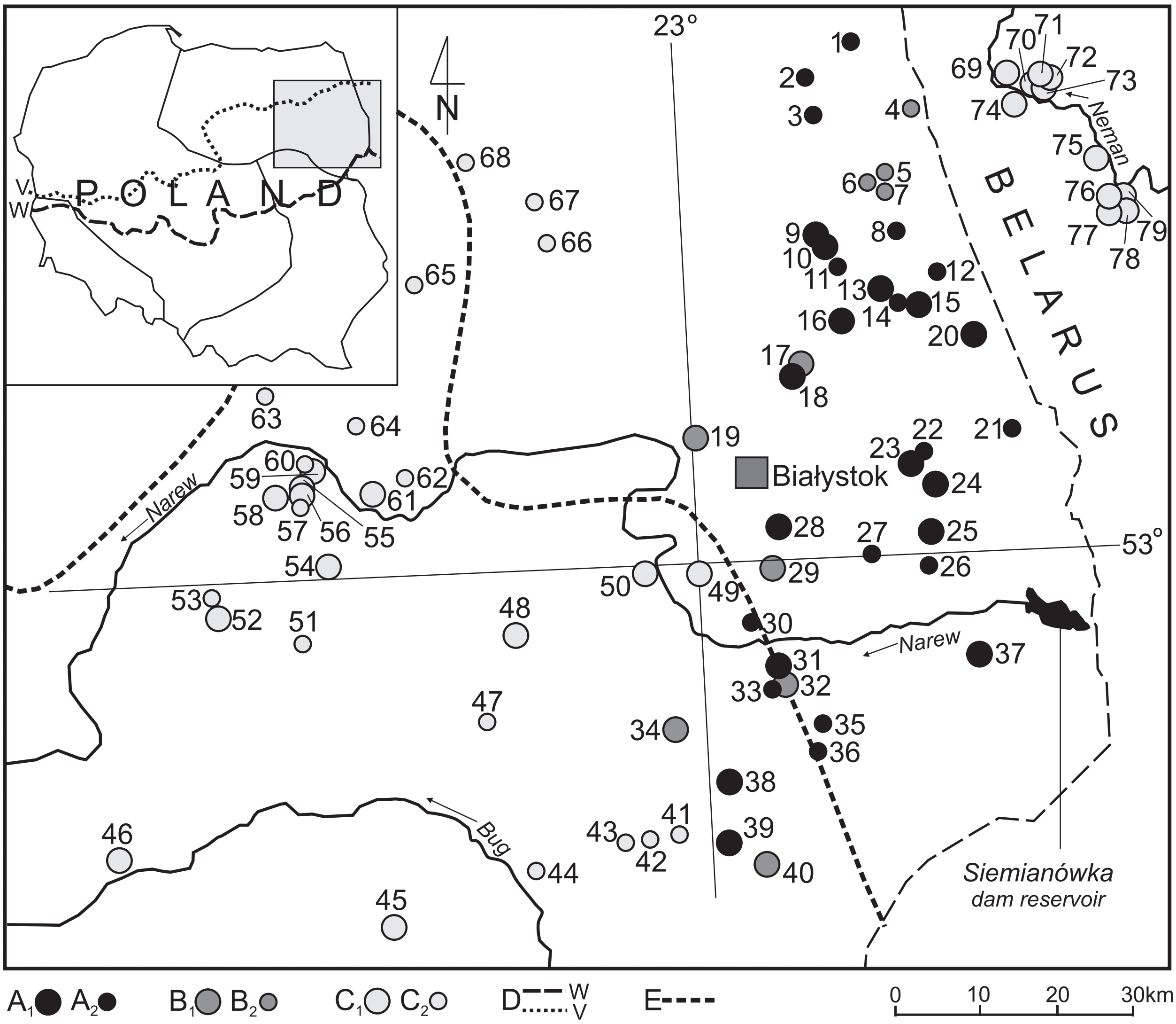

Fig. 1. Sites of Eemian floras in north-eastern Poland. Site numbers on the map are the same as in the Table 1 and in the text: **A** – sites with lake and mire deposits of the Late Wartanian, Eemian interglacial and Early Vistulian in the studied area described in this paper: A_1 – with detailed palynological analysis, A_2 – with expert's report; **B** – sites with lake and mire deposits of the Late Wartanian, Eemian interglacial and Early Vistulian in the studied area described in earlier papers: B_1 – with detailed palynological analysis, B_2 – with expert's report; **C** – sites with lake and mire deposits of the Late Wartanian, Eemian interglacial and Early Vistulian in regions surrounding the study area: C_1 – with detailed palynological analysis, C_2 – with expert's report; **D** – the maximum extents of the last two glaciations (acc. Lindner & Marks 1995): V – Vistulian (= Weichselian), W – Wartanian (= Saalian); **E** – boundary of the Northern Divide in the phytogeographical division of Poland (acc. Szafer 1977a)

2003). Its surface is very diversified. Variously elevated terrain with the highest points reaching above 205 m a.s.l. consists mainly of hills and hummocks of the end moraine, dead ice moraine and narrow banks of crack accumulation. The relief is diversified by frequent melt depressions. At some sites scattered on the moraine plateau surface there are low dune banks and parabolic dunes. Similar forms also appear at the bottom of old lake basins.

The area of the Białystok Upland is splitted by valleys of the rivers Supraśl and Brzostówka into smaller units of microregional rank: the Białystok Forest Zone, the Knyszyn Depression and the Suchowola-Janów Upland (Kondracki 1994). As to topographic features the Białystok Upland is divided by a boundary that runs alongside of a dozen or so kilometres to the north of Białystok. To the south the surface of the land represents features of old-glacial terrain. However areas located to the north from that division are characterized by greater divergence in elevation which is typical for young-glacial areas. Because of those features as early as in the fifties of the previous century Różycki (1972) proposed a hypothesis about the presence of an ice-sheet younger than the Wartanian glaciation but older than the maximum phase of the Vistulian glaciation in this part of northern Podlasie. In previous years this view found further followers (Banaszuk 1980, 1995, 1996, 1998, 2001, 2004a, 2004b, Fedorowicz et al. 1995, Banaszuk & Banaszuk 2004a, 2004b). Their main reasoning was based on the results of the thermoluminescentic dating of ice sediments that occurred in this part of northern Podlasie. According to Banaszuk (2004a) those data form two series – the first of them contains dates from ca. 97–113 ka B.P. and the second from ca. 50–60 ka B.P. – correlated chronologically into two different periods of the Vistulian glaciation. However dates from age interval of 97–113 ka B.P. considering average error of 25.5% (Banaszuk 2004b) may also correspond to the decline of the Wartanian glaciation, which is dated ca. 128 ka B.P. (Mojski 1993, 2005).

The results of the lithostratigraphical investigation of glacial tills from northern Podlasie also suggest the presence of additional glaciation between the Wartanian and the Vistulian. According to Lisicki (2005) it was the Świecie glaciation, which covered area of only northern part of northern Podlasie.

Despite the above-mentioned data, view that the whole region of northern Podlasie lies beyond the range of the Vistulian glaciation is commonly accepted (Musiał 1986, 1992, Lindner & Marks 1995, Ber 2000, Marks 2002). According to the authors mentioned above the presence of lake sediments of the Eemian interglacial being not covered by the glacial till on the Białystok Upland, is one of the arguments put forward, that may confirm that the last glaciation did not cover northern Podlasie. The review of different opinions on the delineation of the southern boundary of that glaciation is published by Krzywicki (2002, 2005).

The Białystok Upland lies in the catchment basin of the Baltic Sea. The natural river system represents a distinctive feature in the local landscape. The main natural watershed is that of the river Narew with its tributaries, which in turn constitutes a tributary of the river Vistula (Schwartz 1989a, 1989b, Łoszewski 1984). Only small eastern part of the region is drained by the river Świsłocz, which sheds its waters into the river Neman (Ziętkowiak 1989). The occurrence of numerous and large mire areas is a characteristic feature of the region. In many places groundwater level is very high and forms springs or bog-springs (Kaniecki 1989). They are concentrated in river valleys of Supraśl, Jaroszówka, Krzemianka, Czarna, Jałówka and Świniobródka (Górniak 1993, Górniak & Jekateryńczuk-Rudczyk 1995a, b). Basins with stagnant water constitute a very rare element of this particular hydrological system. The largests of them are: the Komosa reservoir (14.4 ha), the Gorbacz lake (12.62 ha), the Wiejki lake and dam reservoirs of Siemianówka and Czarna Białostocka. Presently the area of northern Podlasie covered by lakes is less than 2%.

The Bielsk Upland is a gently rolling terrain of the ground moraine, formed by glacial tills and marginal lake deposits, and diversified by the small hills of kames (Brud 2001, Kmieciak 2001). It is less elevated when compared with adjacent mezoregions. When features of the landscape are taken into account the land itself appears to be monotonous. In the southern part it mounts up to about 160.0–177.0 m a.s.l. and in the northern part it descends gently down to the Narew valley. The hydrographical network of the Bielsk Upland is rather sparse with watershed dividing the river Narew and the river Bug catchment areas. Conversely, southwestern part of the region is drained by the river Nurzec, which is the left-bank tributary of the river Bug. The remaining fraction of study area is drained by the river Biała, that flows to the river Narew. Remarkably, large water basins, such as lakes and ponds, are rudimentary or absent, due to the successive land drying in the region. Still in 1950s hundreds of small lakes were present. At the present time even artificial reservoirs stay dried out.

CLIMATE

Northern Podlasie is one of the coldest regions of Poland. The mean annual temperature here stays relatively low reaching on average ca. 7°C, which is 3–4°C below values recorded for western Poland (Kaczorowska 1958, Chrzanowski 1991). The difference between mean temperature of coldest and warmest month is remarkable, 22°C, indicating continental character of the climate in this part of Poland. Noticeably, the mean winter temperature has increased in the last years. At the same time the increase of the minimum annual temperature has been recorded (Górniak 2000). Warming-up of the winter season stays in relation to prevalence of western circulation of air masses.

The mean annual precipitation is 610 mm. Snow remains on the ground for 85–90 days and its coverage is variably deep ranging from 8 to 80 cm. Vegetative season is short beginning in the first decade of April lasting for about 200 days (Sasinowski 1995). Western and south-western (ca. 30%) winds prevail (Górniak 2000).

SOILS

The soils of northern Podlasie are rather poor (Czerwiński 1995). The largest area is covered with brown soils (about 60%), which are divided into two sub-types: typical brown soils and leached brown soils with some variation. Large areas of clays and tills remain covered with lessives soils. In this way they constitute very fertile habitats and most of them are used in agriculture. Rusty soils formed on outwash sands occupy 5% of forest areas, whereas black soils (4%) and marshy soils (5%) found in melt depressions and river valleys, are covered with relatively small forest patches. The last type, peat soils develop on peat bogs.

PLANT COVER

According to geobotanical division of Poland (Szafer 1977a, b) northern Podlasie is located in the Białowieża-Knyszyn Land, a part of Northern Division of the Middle-European Province (Fig. 1).

Area of investigation contains two large forest complexes – the Puszcza Białowieska Forest and the Puszcza Knyszyńska Forest. Forest covers about 70% of the area. Its most characteristic feature is the presence of numerous species and communities distinctive for their northern range distribution. *Picea abies* is a very important component (13.3%) of such stands. It grows in all types of forest associations, whereas *Pinus sylvestris* tends to be the dominant tree species (71.4%) in the Puszcza Knyszyńska Forest.

The transitional character of vegetation represent a distinctive feature of this particular region. It is exemplified by the prevalence of central European and north-east European species and by constituting range limit for numerous plant communities, mainly those of boreal type.

PREVIOUS PALAEOBOTANICAL RESEARCHES IN NORTHERN PODLASIE AND ITS VICINITY

Up to the end of 1980s there have been only as few as 8 palaeobotanical studies on the Eemian vegetation in northern Podlasie region (cf. Mamakowa 1989) – from Otapy and Czarna Wieś (Bitner 1956a, 1956b), Ludomirowo, Zacisze and Miklewszczyzna (Bitner 1957), Bagno-Kalinówka (Borówko-Dłużakowa & Halicki 1957), Mystki (Borówko-Dłużakowa 1971a, 1973a) and Klewinowo (Borówko-Dłużakowa 1973a, 1974). In the nineties next two localities, namely Machnacz (Kupryjanowicz 1991, 1994, 1995a, b, c) and Proniewicze PR./93 (Krupiński 1995) were studied.

In the last decade 26 new sites with palaeolakes and palaeobogs deposits, that are covered with sand-silt layers, have been discovered in the region, what accompanied with works upon the Detailed Geological Map of Poland in the scale 1: 50 000 (Boratyn 2003, Brud 2001, Kmieciak 2001, 2003, Krzywicki 2003, Kurek & Preidl 2001a, b, Kwiatkowski & Stepaniuk 1999, 2003). Additionally, inspectors of the Forest Inspectorate in Krynki have discovered another site at Kruszyniany.

On the basis of preliminary palynological analyses, biogenic sediments from those sites were linked to the Eemian interglacial (Kupryjanowicz 1999a, b, 2000a, b, c, d, e, f, 2001a, b, 2002a, b, c, d, e, f, Noryśkiewicz 2005, Bińka 2006a). So far only two of those sites were studied in a more detailed manner: Michałowo (Kupryjanowicz & Drzymulska 2000, 2002) and Haćki (Brud & Kupryjanowicz 2000, 2002, Kupryjanowicz 2005b).

MATERIAL AND METHODS

BORINGS AND SEDIMENTS DESCRIPTION

Twenty eight profiles from twenty two sites were subject to palaeoecological examination (Figs 1, 2). Twelve profiles were used in detailed pollen analysis, whereas another sixteen were used for additional investigations.

The majority of the borings was made within a framework of the Detailed Geological Map of Poland in the scale 1: 50 000. Four cores – Solniki, Dzierniakowo, Proniewicze P-3 and Pieszczaniki – came from the drillings performed up to the Quaternary sediments (Kurek & Preidl 2001a, b, Kmieciak 2001). Only cores with undamaged sequences of sediments were taken into account. Each of them was 12 cm in diameter.

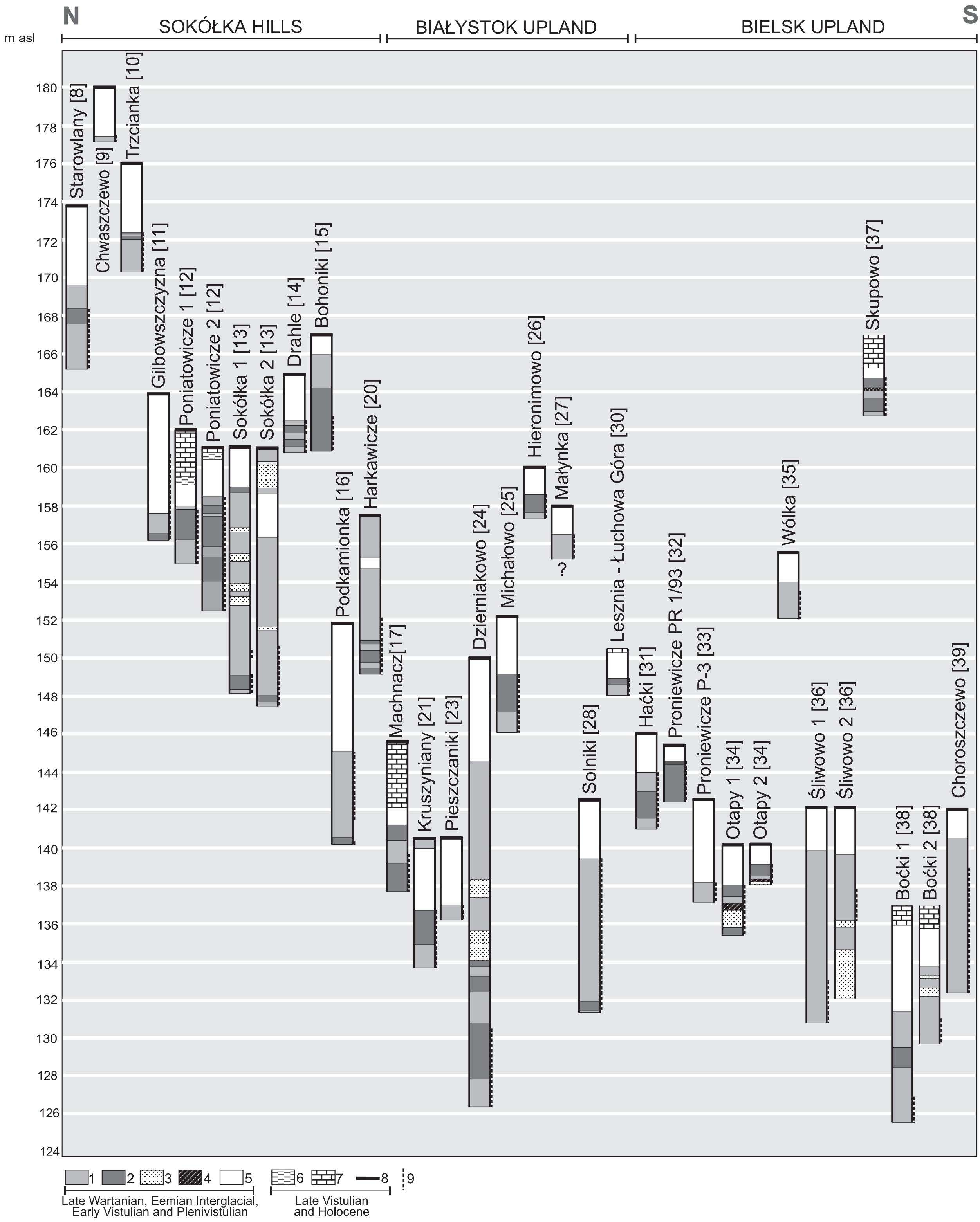

Fig. 2. Absolute altitude of the analysed profiles. **1** – gyttjas and organic clays, **2** – Eemian and Early Vistulian peats, **3** – humus sands, **4** – bituminous shale, **5** – diluvia sediments**, 6** – clays and silts, **7** – Late Vistulian and Holocene peats, **8** – contemporary surface, **9** – sections studied by pollen analysis. Site numbers on the figure are the same as at Figure 1, in Table 1 and in the text

During the fieldwork they were divided into parts of the length of 1.5 meter. Each of the parts was cut lengthwise into two halves. One of them was prepared for palaeoecological investigation being immediately wrapped in aluminium foil and then stored in wooden boxes. Afterwards it was taken to the laboratory of the Department of Botany, University of Białystok.

Another three cores, Boćki 1, Boćki 2 and Choroszczewo (Boratyn 2006), were collected by the GEOPROBE device. One and the half metre sections of the cores were secured into plastic tubes, each 3.5 cm in diameter. The material was hermetically sealed and put into tubes for the transport.

Seventeen borings: Sokółka 1, Sokółka 2, Poniatowicze 1, Poniatowicze 2, Drahle, Bohoniki, Lesznia-Łuchowa Góra, Wólka 1, Wólka 2, Harkawicze, Chwaszczewo, Trzcianka, Gilbowszczyzna, Starowlany, Podkamionka, Śliwowo 1 and Śliwowo 2 were performed using mechanical drill (Boratyn 2003, Kmieciak 2001, 2003) by the Kraków's Geological Company JSC (Przedsiębiorstwo Geologiczne S.A.).

Two corings were made with hand corer – the first one in Kruszyniany by A. Czerwiński and P. Banaszuk and the second one in Skupowo, by W. Kwiatkowski and M. Stepaniuk, all from Białystok Technical University (Kwiatkowski & Stepaniuk 2003). At site the cores were properly cleaned and preliminarily described. Then samples due to the pollen analysis were collected straight from the probe. Each of the samples contained about 50 ml of the material. The samples were taken by the geologists responsible for the borings. Only in case of four borings, i.e. Sokółka 2, Poniatowicze 2, Kruszyniany i Skupowo, the samples were collected by the author herself.

Two profiles were taken from ditch wall of excavation about 3 m deep, while inspecting construction operations of the Jamal gas transportation pipeline. In Hieronimowo 12 monoliths (10 × 10 × 10 cm) and in Małynka 7 samples (each of about 500 ml) were collected (Kurek & Preidl 2001b).

All the samples were hermetically sealed into plastic bags. Brief lithological description of the profiles was completed while working afield. Further and more detailed description was continued in the laboratory. The sediments set for pollen analysis were described on the basis of a system proposed by Troels-Smith (1955). Hence, symbols used in the lithology columns of the pollen diagrams also follow Troels-Smith (1955). A description of its lithology is provided in separate tables.

POLLEN ANALYSIS

Samples, 1 cm^3 in volume, collected for pollen analysis were treated in laboratory conditions. They were taken both from the cores and from relatively large in volume samples collected at sites. The sampling intervals were 3 to 5 cm. The samples were stored in hermetically sealed plastic bags in a refrigerator in temperature of 4°C.

More than 1000 samples were collected. Six hundred and fourteen of them were subject to pollen analysis.

The samples were prepared according to standard procedures. Each sample was treated by Erdtman's acetolysis method (Erdtman 1943, 1960, Faegri & Iversen 1989). Mineral components were removed mainly by hydrofluoric acid (Moore et al. 1991). In case of silt and clay materials a method of gravitational separation of mineral and organic components with the use of a heavy liquid including solutions of potassium iodide and cadmium iodide was employed (Dorogonievskaya et al. 1952). The material was then mounted in glycerine.

Sporomorphs were counted on at least two slides for each sample. Number of pollen grains (AP+NAP) per sample ranging between 500 and 2000 was always counted, in most cases reaching ca. 1000. Sporomorphs were determined using several keys and atlases of pollen and spore determination (Andersen 1979, Beug 1961, 2004, Erdtman 1966, Erdtman et al. 1961, Faegri & Iversen 1989, Moore & Webb 1978, Punt 1976, Punt & Clarke 1980, 1981, 1984, Punt et al. 1988) and with the use of comparative specimens. Determination of fern spores was based on works of Sorsa (1964) and Moe (1974). Genera and species of the family Caryophyllaceae were determined according to Andersen (1961) and Chanda (1962). Species of the genus *Helianthemum* were identified consistently with the description of Wasylikowa (1964), whereas those of the genus *Tilia* according to Pragłowski (1962), Andrew (1971). Classifying to *Tilia platyphyllos* was based on Stockmarr (1974), whereas to *Tilia tomentosa* on Mamakowa (1989),

Some no-pollen microfossils, important for palaeoecological reconstructions, were determined and counted during pollen analysis: Nymphaeaceae idioblasts (127 type – Pals et al. 1980), algae (*Botryococcus braunii*, *Pediastrum* ssp. – Jankovská & Komárek 2000; *Tetraedron minimum*, 371 type – van Geel et al. 1981), fungi (*Tilletia sphagni*, 27 type – van Geel 1978), and Rhizopods (*Amphitrema flavum*, 31A type – van Geel 1978).

For palaeoecological interpretation 590 pollen spectra were used. Three samples were excluded because they included too low a number of sporomorphs or the sporomorphs were very poorly preserved. Twenty one spectra contained no sporomorphs.

The sum of tree, shrub and herb pollen grains, excluding aquatic and swamp plants, spores and no-pollen remnants, was used as the basis for calculating particular percentages. Pollen of thermophilous trees and shrubs, common in the Quaternary and Tertiary were not excluded from the basic sum in the Late Wartanian and the Early Vistulian samples. One may ascertain however that they were quite probably redeposited in many sections of the sites being explored.

The obtained results of investigation were presented in the form of pollen diagrams, constructed according to the suggestions of Berglund & Ralska-Jasiewiczowa (1986). Diagrams were drawn using the POLPAL computer programme (Walanus & Nalepka 1999, 2004, Nalepka & Walanus 2003).

Pollen diagrams were divided into local pollen assemblage zones (L PAZ), being described, defined and named following guidelines of Cushing (1967), West (1970), Birks (1979, 1986), and Janczyk-Kopikowa (1987). Names of the L PAZs indicated basic composition of the pollen spectra. Taxon after which a particular zone was named was not always that the most abundant, though its values usually set a maximum level for higher stratigraphic units. Pollen and spores, for which there was any doubt that they may come from redeposition, were not used to name the pollen assemblages zones.

SUPPLEMENTARY ANALYSES

Several analyses based on sediments from Solniki and Dzierniakwo profiles accompanied those mentioned earlier. These were performed within the framework of research project, No. 3 P04C 025 25 with participation of specialists in the fields listed below. These included chemical analyses by A. Górniak, University of Białystok, measurement of magnetic susceptibility and grain size distribution by D. Ciszek, Wrocław University, analysis of ^{18}O and ^{13}C stable isotopes, by J. Mirosław-Grabowska, Institute of Geological Sciences in Warsaw, analyses of the genus Cladocera, by M. Niska, Pedagogical University in Słupsk and diatoms, by B. Marciniak, Institute of Geological Sciences in Warsaw. Only results of the magnetic susceptibility measurement, grain size distribution, basic chemical analyses of sediments and analysis of stable isotopes were taken into consideration for the purpose of preparing this article. Full compendium of all analyses will be a subject of separate study that is already prepared for publication.

Analysis of sediment granulation was made for 200 samples, 100 from Solniki and 100 from Dzierniakowo. It was carried out by means of laser method.

Organic carbon content was determined using Tiurin's method for mineral sediments, whereas Alten's method was applied in case of organic sediments (Bednarek et al. 2004). As to calcium carbonate content Scheibler's method was used (Bednarek et al. 2004).

Additionally, analysis of magnetic susceptibility was carried out for 300 sediment samples.

Then, carbon and oxygen isotope composition was estimated for the calcareous sediments using the classical phosphoric acid method (McCrea 1950, Craig 1953, Hoefs 1996). Concentration of ^{13}C and ^{18}O isotopes was presented as $^{13}C/^{12}C$ and $^{18}O/^{16}O$ isotope ratios versus the V-PDB standard. The analytical error was ± 0.05‰ for $\delta\ ^{13}C$ and ± 0.1‰ for $\delta\ ^{18}O$.

BACKGROUND TO THE PALAEOECOLOGICAL INTERPRETATIONS

BIAŁYSTOK UPLAND

Solniki

The Solniki [28] site (53°30′N, 23°12′E; 143 m a.s.l.) is located in central part of the Białystok Upland, approximately 18 km south of Białystok and about 4 km south-west of Zabłudów (Figs 1 and 2).

The palaeolake, where coring was carried out, lies some 100 m east of the Solniki to Koźliki road, on the left bank of the river Czarna valley (Fig. 3). The studied sediments fill the subglacial basin, that was formed during the Wartanian glaciation (Kurek & Preidl 2001b). The surface of the basin extends over the area of ca. 700 × 300 m. Nowadays it is used as a wet meadow pasture.

The coring was carried out using a geolo-

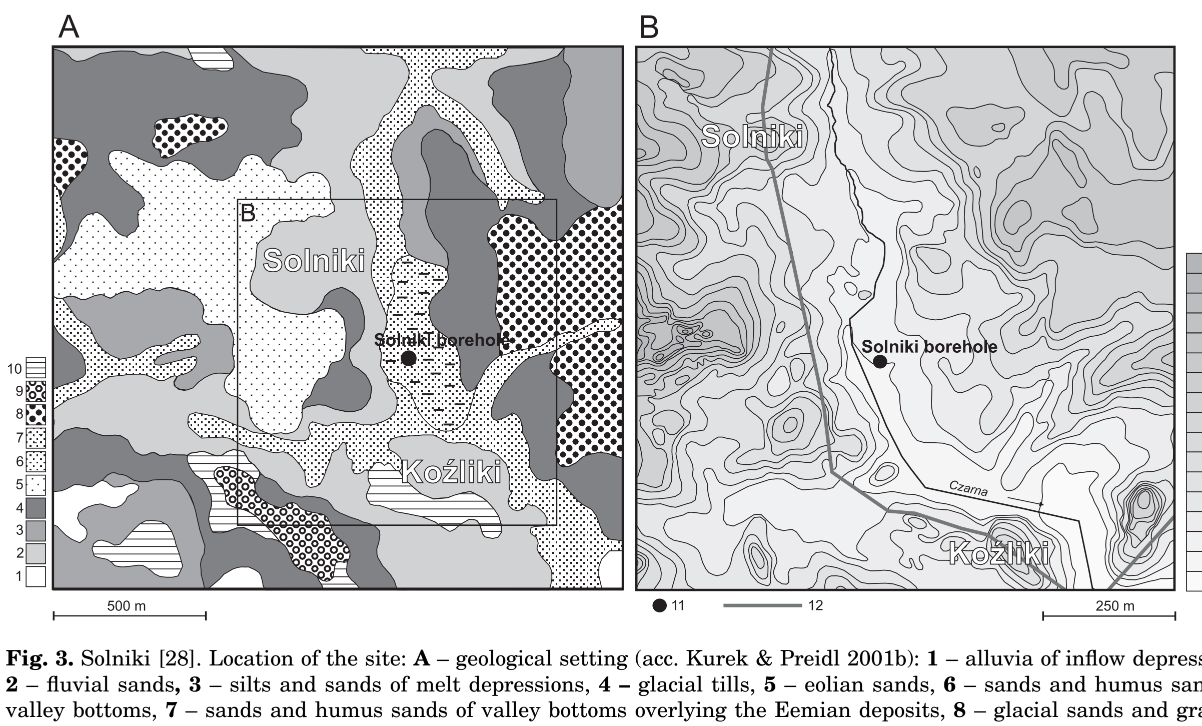

Fig. 3. Solniki [28]. Location of the site: **A** – geological setting (acc. Kurek & Preidl 2001b): **1** – alluvia of inflow depressions, **2** – fluvial sands, **3** – silts and sands of melt depressions, **4 –** glacial tills, **5** – eolian sands, **6** – sands and humus sands of valley bottoms, **7** – sands and humus sands of valley bottoms overlying the Eemian deposits, **8** – glacial sands and gravels, **9** – kame sands and gravels, **10** – kame sands and silts; **B** – topography**: 11** – studied profile, **12** – road

Table 2. Solniki [28]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.40	sandy soil, grey
0.40–2.00	fine and medium sand, yellow
2.00–3.00	silt, slightly sandy, dark grey, compact
3.00–3.90	peaty silt with clay, dark grey; Ag3, As0.5, Th/Tb0.5, Dg+; struc.: homogeneous, with plant detritus; nigr.2+, strf.0, elas.0, sicc.2, lim.sup.0
3.90–5.60	organic silt with sand, slightly clayey, black; Ag3, Ga0.5, Sh0.5, Th/Tb+, Dg+, As+; struc.: very homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.0
5.60–8.20	organic clayey silt, brown-black; Ag3, As1, Sh+, Th/Tb+, Dg+, Ga+; struc.: homogeneous, very compact; nig.2, strf.0, elas.0, sicc.2, lim.sup.0
8.20–10.00	organic clayey silt with small admixture of $CaCO_3$ brown; Ag3, As1, Sh+, Th/Tb+, Dg+, Ga+, Lc+; struc.: homogeneous, very compact; nig.2, strf.0, elas.0, sicc.2, lim. sup.0
10.00–10.60	organic silt, black; Ag3, As+, Th/Tb0.5, Sh0.5, Dg+, Ga+; struc.: very homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.0
10.60–11.00	peat, slightly clayey with traces of sand, black; Tb2, Th1, Sh1, Dg+, Ga+, As/Ag+; struc.: heterogeneous; nig.3, strf.0, elas.1, sicc.2, lim.sup.2
11.00–11.10	organic silt, black; Ag3, As+, Th/Tb0.5, Sh0.5, Dg+; struc.: homogeneous, compact; nig.3, strf.0, elas.0, sicc.2, lim.sup.0

gical corer. It accompanied preparation of the Trześcianka sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Kurek & Preidl 2001b). The cored sequence was 162.50 m long. Lake deposits, over 7.00 m in thickness, were present at a depth of 3.00–11.10 m. The main part of the palaeolake sediments contains organic silts. There is peat layer at a depth of 11.00–10.60 metres below the surface being covered by 3 m deposit of sand. Detailed description of the lacustrine-mire series is showed in Table 2.

More than 180 samples were examined by pollen analysis. Pollen frequency is high or very high in all of them. Pollen percentage diagram (Fig. 4) was divided into 12 local pollen assemblage zones (Tab. 3).

The results of magnetic susceptibility measurement, of the analysis of grain size distribution and of the chemical analysis of sediments are presented in Figure 4.

Lithological variability of the sediments in Solniki makes palaeoenvironmental interpretations of the magnetic susceptibility changes

Table 3. Solniki [28]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
S-1	***Pinus-Betula-Picea***	11.06–10.93	Domination of *Pinus sylvestris* type (84–91%); low values of *Betula alba* type (1.5–6.1%); NAP represented by a very small number of taxa – *Artemisia* pollen is dominant; the presence of pollen of thermophilous deciduous trees (*Quercus*, *Tilia cordata* type, *Ulmus*, *Carpinus betulus*) and *Corylus avellana* (probably redeposited). The upper boundary: the fall of *Pinus sylvestris* type and *Picea abies* type; the increase of *Quercus*, *Ulmus* and *Salix*.
S-2	***Pinus-Salix-Quercus-Ulmus***	10.90–10.77	The rise of *Quercus* and *Ulmus* values (to 23% and 2.6%, respectively); culmination of *Salix* (max. 8%); small increase of *Betula alba* type (max. 13.6%); very high, but continuously decreasing, values of *Pinus sylvestris* type (51.7–87.5%); start of *Fraxinus* continuous curve; the first pollen grain of *Hedera helix*. The upper boundary: the fall in the values of *Pinus sylvestris* type and *Salix* and the increase of *Quercus*, *Ulmus* and *Fraxinus*.
S–3	***Quercus–Ulmus–Fraxinus***	10.75–10.45	The highest values of *Quercus*, *Ulmus*, and *Fraxinus* pollen in the whole profile, with a maximum respectively of 64.6%, 18.7% and 5.5%; continuous presence of *Pinus sylvestris* type, but its values fall consistently to 14%; appearance of *Viscum*, *Taxus baccata* and *Acer*; the proportion of *Corylus avellana* rising to 22.3%; the start of *Alnus* continuous curve. The zone has not upper boundary.
		10.40–10.30	Domination of *Betula alba* type and *Pinus sylvestris* type; sporadic occurrence of pollen of thermophilous deciduous trees (*Quercus*, *Tilia cordata* type, *Ulmus*, *Carpinus betulus*), and *Corylus avellana*; relatively high proportion of NAP; the presence of pollen of *Juniperus* and *Betula nana* type. Pollen spectra probably represent disturbed section of profile.

Table 3. Continued

L PAZ	Name	Depth (m)	Description
S-4	***Corylus-Alnus-Tilia***	10.25–9.85	Domination of *Corylus avellana*, with absolute maximum of 75.3%; the highest values of *Tilia cordata* type in the whole profile (max. 15.1%); somewhat more frequent occurrence of *T. tomentosa*; the culmination of *Alnus* (24%); values of *Ulmus* and *Quercus* lower then in the previous zone – *Quercus* curve fluctuates around 1.5–4.8%, *Ulmus* around 0.6–7.4%; the values of *Fraxinus* below 1 %; the rise of *Carpinus betulus* curve; the occurrence of pollen of *Acer* and *Taxus baccata*, but with very low values; constant presence of *Hedera helix* and *Viscum*; the appearance of *Ilex* in the top part of the zone. The upper boundary: the rise of *Carpinus betulus* pollen values to over 50%; the fall of *Corylus avellana* below 30%.
S-5	***Carpinus-Alnus***	9.80–7.70	Maximum of *Carpinus betulus*; *Alnus* values oscillating around 10%; proportion of *Corylus avellana*, *Quercus*, *Ulmus*, and *Tilia cordata* type lower then in previous zone. The upper boundary: of the increase in pollen values of *Picea abies* type and *Pinus sylvestris* type; decrease in percentages of *Carpinus betulus*. The zone is divided to 5 subzones:
S-5a	*Carpinus-Corylus-Tilia*	9.80–9.45	Values of *Carpinus betulus* oscillating around 50%; depressions of *Corylus avellana* and *Tilia cordata* type.
S-5b	*Corylus-Tilia*	9.40–9.02	The values of *Corylus avellana*, *Ulmus*, and *Tilia cordata* type higher then in other subzones (mean values of this taxa are respectively 25.7%, 6.8% and 2.6%); nearly continuous occurrence of pollen of *Hedera helix* and *Viscum*; the presence of *Tilia platyphyllos* and *Tilia tomentosa* pollen; very different values of *Carpinus betulus* – they fluctuate from 30.2% to 64.8% (mean value is 30.2%).
S-5c	*Carpinus-Corylus*	8.95–8.50	Percentages of *Corylus avellana*, *Ulmus*, and *Tilia cordata* type lower then previously; the slow increase of *Picea abies* type; the values of *Carpinus betulus* more still and higher that S-6b subzone (55.6–72.8%); the presence of of *Viscum* pollen.
S-5d	*Carpinus*	8.45–8.35	Absolute maximum of *Carpinus betulus* (82.4%).
S-5e	*Picea-Quercus*	8.30–7.80	The lowest in whole zone values of *Corylus avellana*, *Ulmus* and *Tilia cordata* type; increase of *Picea abies* type values to over 20% and *Pinus sylvestris* type to over 15%; continuous presence of *Abies alba* pollen; low-percentage culmination of *Quercus* (4%).
S-6	***Picea-Alnus-Carpinus-Pinus***	7.70–7.40	The highest values of *Picea abies* type with maximum of 37.2%; the slow culmination of *Abies alba* (1%); the consistently rising curve of *Pinus sylvestris* type (to 48%); low percentages of *Betula alba* type (to 20%); *Alnus* values about 10%; *Carpinus betulus* proportion falling from 20% to 5%; single grains of *Larix* pollen. The upper boundary: the rise of *Pinus sylvestris* type to over 50%; the fall of *Picea abies* type below 30%.
S-7	***Pinus***	7.35–6.35	Domination of *Pinus sylvestris* type; continuous, but low-percentage curve of *Larix*; still presence of *Picea abies* type pollen; sporadic occurrence of *Abies alba* pollen. The upper boundary: the rise of NAP proportion over 30%. The zone is divided into four subzones:
S-7a	*Picea-Carpinus-Alnus*	7.35–7.10	*Pinus sylvestris* type values by 65% to 84.4%; relatively high proportion of *Picea abies* type, which falls by 20.8 to 6.2%; the presence of pollen of *Carpinus betulus*, *Alnus* and *Quercus*, but with low values.
S-7b	*Betula*	7.05–6.90	Two peaks of *Betula alba* type – higher of they has values of 68.7%; two depressions of *Pinus sylvestris* type with values of 56.4% and 21.6%, which are separated by peak with values of 81.8%; proportion of NAP rising at top part of subzone to about 20%.
S-7c	*Artemisia*-Cyperaceae	6.85–6.70	The culmination of NAP (15–50%) – Cyperaceae (12%), *Artemisia* (10%) and Poaceeae (max. 3%); relatively high values of *Betula alba* type with peak at top part of subzone (41.9%); *Pinus sylvestris* type curve fluctuating around 40.8-53.4%.
S-7d	*Pinus*	6.65–6.35	Maximum of *Pinus sylvestris* type values (91.3%); rather low percentages of *Betula alba* type (7.0–18.6%), similar as at S-6a subzone; low values of NAP at bottom part subzone, at top part they rise to 25%.

Table 3. Continued

L PAZ	Name	Depth (m)	Description
S-8	***Artemisia*-Cyperaceae-Poaceae-*Betula nana***	6.30–5.70	High values of NAP (32–55%) – Cyperaceae (to 35%), *Artemisia* (to 15%), and Poaceae (to 13%); the rise in the pollen values of Chenopodiaceae, Caryophyllaceae undiff., Cichorioideae, *Thalictrum*, and *Anthemis* type; great variety of herbs taxa – more significant in these are *Helianthemum*, *Gypsophila fastigiata* type, *Dianthus* type, and *Aster* type; the increase of values of *Juniperus* and *Betula nana* type; the appearance of *Ephedra fragilis* type; low values of *Pinus sylvestris* type (3.1–49.7%) and *Betula alba* type (8.2–35.4%); the low-percentage culmination of *Salix* (max. 4.5%); the presence of pollen of *Picea abies* type (to 3.9%), *Alnus* (to 6.7%), *Carpinus betulus* (to 2.1%), *Corylus avellana* (to 1.8%), *Ulmus* (below 1%), and *Tilia cordata* type (below 1%) – probably redeposited. The upper boundary: rapidly increase of *Betula alba* type values to 71.1%. Zone S-8 is divided into 4 subzones:
S-8a	*Pinus-Calluna*	6.30–6.00	The highest in the whole profile values of Cyperaceae; more abundant occurrence of *Calluna vulgaris*; the fall of *Pinus sylvestris* type curve from 49.7% to 11.3%.
S-8b	*Juniperus*	5.95–5.90	Absolute maximum of *Juniperus* (20%); depressions of *Pinus sylvestris* type, *Picea abies* type and *Alnus*..
S-8c	*Pinus*	5.85–5.80	The peak of *Pinus sylvestris* type with values of 23.0–24.9%.
S-8d	*Betula-Juniperus-Betula nana*	5.75–5.70	Absolute maxima of *Betula nana* type (6.0%) and Poaceae (13.5%); the rise of pollen values of *Betula alba* type to 35.4%; the lowest in the whole zone values of *Pinus sylvestris* (3.1–3.9%).
S-9	***Betula***	5.65–5.20	Absolute maximum of *Betula alba* type (89.5%); values of *Pinus sylvestris* type fluctuating from 1.4% to 67.7%. The upper boundary: rapid fall in the pollen values of *Betula alba* type and the increase of NAP. Zone S-9 is divided into 2 subzones:
S-9a	NAP	5.65–5.47	Gradual decrease in pollen values of herbs; low proportion of *Pinus sylvestris* type (1.4–3.5%); the presence of pollen of *Juniperus* and *Betula nana* type.
S-9b	*Pinus*	5.45–5.20	Two peaks of *Pinus sylvestris* type, higher with values of 65.3%.
S-10	***Betula-Artemisia***	5.18–4.95	The culmination of NAP (to 32,5%), mainly *Artemisia* and Chenopodiaceae; small increase of *Juniperus* and *Betula nana* type values; high proportion of *Betula sylvestris* type (67.7%). The upper boundary: rapid fall in the pollen values of *Betula alba* type; the increase of *Pinus sylvestris* type. Zone S-10 is divided into 2 subzones:
S-10a	*Artemisia*	5.18–5.05	The increase of herbs pollen values and rapid rise of *Betula alba* type to 71.7%.
S-10b	*Pinus*	5.00–4.95	The peak of *Pinus sylvestris* type (67.7%).
S-11	***Pinus-Betula***	4.90–3.90	Very high values of *Pinus sylvestris type* (10–89.5%) and *Betula alba* type (5.0–73.6%); the presence of *Picea abies* type and *Larix* values to about 4%; low frequency of NAP. The upper boundary: the decrease of *Pinus sylvestris* type values to 55%; the rise of NAP above 30%. The zone is divided into 3 subzones:
S-11a	*Betula-Artemisia*	4.90–4.70	Culmination of *Betula alba* type (ca. 80%); at the lower part peak of NAP (22%).
S-11b	*Pinus-Betula-Larix*	4.65–4.15	Domination of *Pinus sylvestris* type (50–85%); relatively high values of *Betula alba* type (mean 25.1%); more frequent abundance of *Larix* pollen (max. 4.6%).
S-11c	*Pinus*	4.10–3.90	The culmination of *Pinus sylvestris* type pollen (89.5%).
S-12	***Artemisia*-Poaceae**	3.88–3.00	The rise in pollen values of herbs to 63%; the great variety of they taxa; pollen of *Artemisia* (15-32%), Cyperaceae (4–19%), Poaceae (4–8%), Chenopodiaceae (about 2%), and *Thalictrum* is most abundant; the presence of pollen of *Calluna vulgaris* (to 4%) and Ericaceae undiff. (to 2%); shrubs are represented by pollen of *Juniperus* (below 1%) and *Betula nana* type (to 1.5%). No upper boundary. The zone is divided into 4 subzones:
S-12a	*Artemisia-Pinus*	3.88–3.80	The peak of *Artemisia* (to 21%).
S-12b	*Pinus*	3.75–3.65	Culmination of *Pinus sylvestris* type (%); depression of NAP.
S-12c	*Betula nana-Calluna*	3.60–3.20	Values of *Pinus sylvestris* type decreasing from 55% to 30%; still presence of *Salix* and *Betula nana* type;
S-12d	*Pinus-Juniperus*	3.15–3.00	Still presence of *Salix*; *Juniperus* and *Betula nana* type.

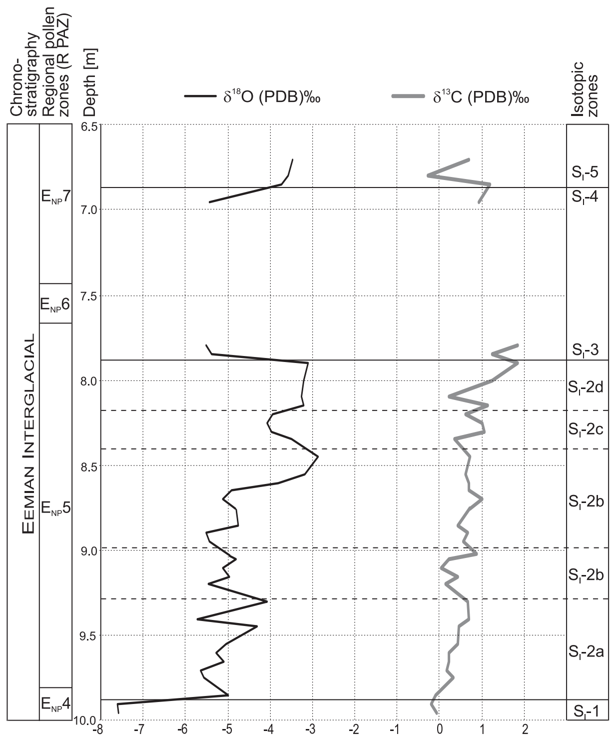

Fig. 5. Solniki [28]. Results of the stable isotope analysis (analysed by J. Mirosław-Grabowska – see Kupryjanowicz et al. 2005)

somewhat difficult. Rapid rise of magnetic susceptibility during the S-3 *Quercus-Ulmus-Fraxinus* local pollen zone and its clear decline lasting from the end of S-5 *Carpinus* L PAZ, through the entire S-6 *Picea-Alnus-Carpinus-Pinus* L PAZ and at the beginning of the S-7 *Pinus* L PAZ is certainly caused by lithological changes. However increase in magnetic susceptibility values at lower part of the S-5b *Corylus-Tilia* pollen subzone within relatively homogenous deposits of the S-5 *Carpinus* zone may indicate some climate fluctuation, probably a cooling or an increase in humidity.

On the ground of the results of stable isotope analysis, five isotopic zones (S_I) were defined and characterized (Fig. 5). Despite lithological variability in lacustrine sediments, especially when considering the presence of organic interlayers, the most detailed picture of environmental changes was obtained only in case of the S-5 *Carpinus* local pollen zone.

Dzierniakowo

The Dzierniakowo [24] site (53°6´N, 23°37´E), is located in the eastern part of the Białystok Upland, about 30 km east of Białystok (Fig. 1).

The boring was carried out at ca. 164 m a.s.l, in a relatively small melt depression, where the river Dzierniakówka starts springs (Figs 6, 7). The surface of the basin spans the area

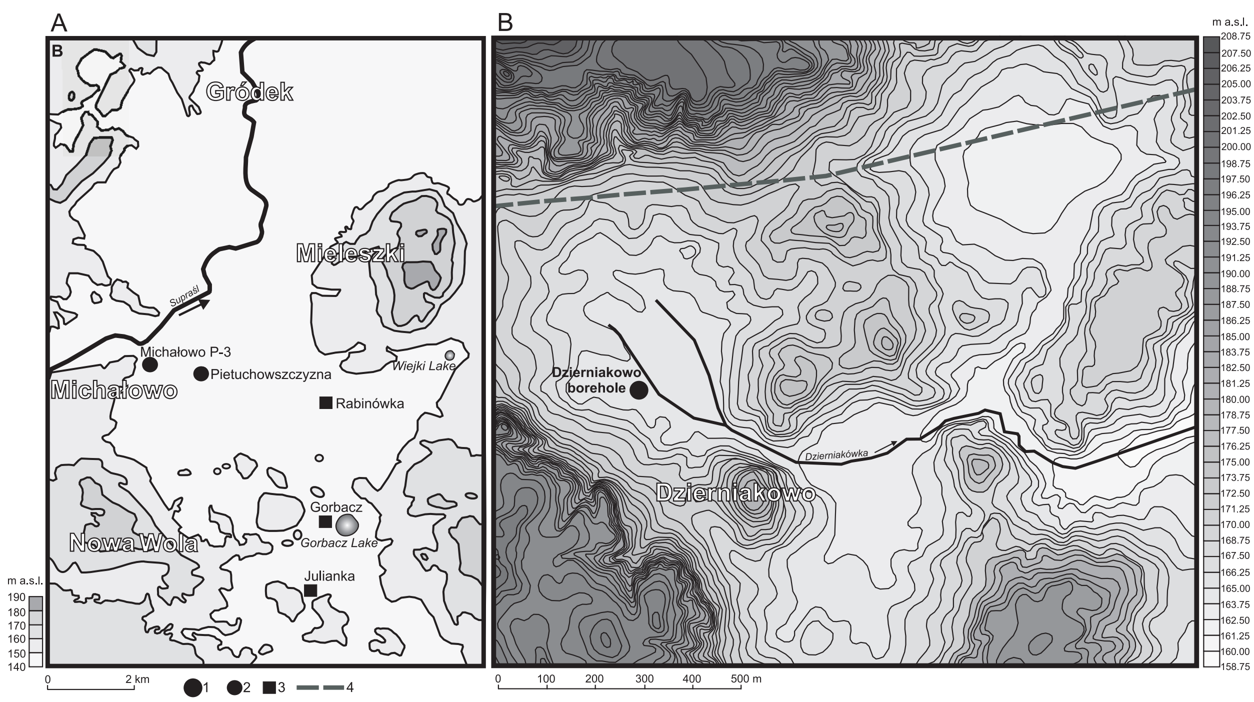

Fig. 6. Dzierniakowo [24]. Location of the site: **A** – hipsometric map of the Niecka Gródecko-Michałowska depression; **B** – more detailed hipsometric map of studied palaeolake region: **1** – studied profile, **2** – other Eemian and Early Vistulian profiles (Michałowo P-3 – Kupryjanowicz & Drzymulska 2002; Pietuchowszczyzna – Prószyńska et al. 1973), **3** – Late Vistulian and Holocene pollen profiles (Rabinówka – Piasecka 1999, Julianka – Szachowicz 2002, Gorbacz – Baszyński et al. 1954, Gierasimow et al. 1957), **4** – railway line

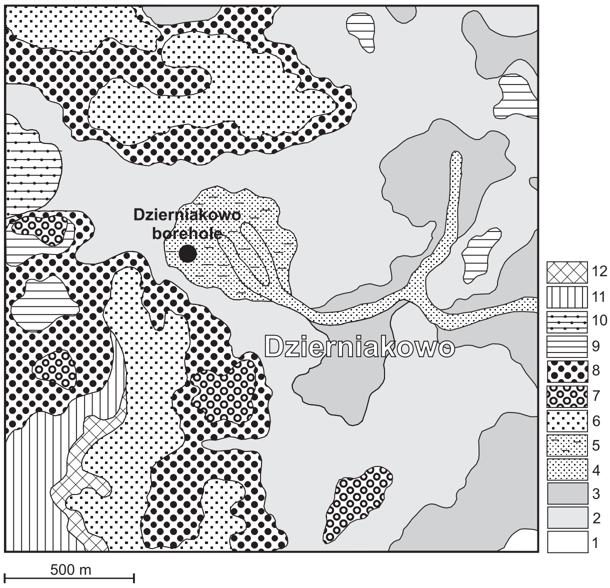

Fig. 7. Dzierniakowo [24]. Geological profile of the site (acc. Kurek & Preidl 2001a): **1** – alluvia of inflow depressions, **2** – fluvial sands and gravels, **3** – melt sands and silts, **4** – humus sands and silts of valley bottoms, **5** – humus sands and silts of valley bottoms overlying the Eemian sediments, **6** – sands and gravels of fissured accumulation, **7** – kame sands and gravels, **8** – glacial sands, gravels and boulders, **9** – kame sands and silts, **10** – alluvia overlying fluvial sands and gravels, **11** – glacial tills, **12** – diluvial sediments

of ca. 300×400 m. From the south, west and the north the examined basin is surrounded by kame hills that reach the height of 210 m a.s.l. To the east of that basin, through the narrow valley of the river Dzierniakówka, it is connected with two other melt depressions and with another broad depression of the Niecka Gródecko-Michałowska (ca. 8–10 km long and 3–12 km wide). It is filled with lake-mire sediments of the Eemian interglacial and the Early Vistulian, covered up by approximately 3 metre layer of sands and thick layers of Late Glacial and Holocene peat. It was well documented by numerous borings from the Niecka Gródecko-Michałowska (Prószyńska et al. 1973, Piasecka 1999, Kupryjanowicz & Drzymulska 2002).

The coring was carried out using a geological corer. It accompanied fieldwork proceeding preparation of the Gródek sheet of the Detailed Geological Map of Poland in scale 1: 50 000 (Kurek & Preidl 2001a). The sequence was about 200 m long. Palaeolake deposits, ca. 19 m in thickness, were present at a depth of 23.72 to 5.00 m. The bottom part of the lake

Table 4. Dzierniakowo [24]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.40	clayey soil
0.40–2.00	fine sand with gravel, light yellow
2.00–4.00	fine sand, light yellow
4.00–5.00	coarse sand, dark yellow
5.00–11.00	sandy silt, dark grey
11.00–12.00	sand with gravel, dark yellow
12.00–13.80	organic silt, slightly clayey, dark grey
13.80–15.80	sand with gravel and głazy, yellow
15.80–19.50	organic silt, dark brown and black
19.50–19.80	organic silt with fragments of sedges leaves and traces of $CaCO_3$, brown; Ag3, As0.5, Th0.5, Dg+, Lc+; struc.: homogeneous; nig.2, strf.0/4, elas.0, sicc.2, lim.sup.0
19.80–20.45	organic silt, compact, with roots of plants, brown and light brown; Ag3.5, As+, Th0.5, Dg+, Sh+; struc.: homogeneous; nig.2, strf.0/4, elas.0, sicc.2, lim.sup.0
20.45–20.50	substantia humosa with silt, black; Sh3.5, Ag0.5, Dg+, As+; struc.: homogeneous; nig.3, strf.0/4, elas.0, sicc.2, lim.sup.0
20.50–20.60	peat, highly decomposed, black; Th1, Tb1, Dg1, Sh1, Ag/As+; struc.: homogeneous; nig.3, strf.0/3, elas.0, sicc.2, lim.sup.0
20.60–20.70	substantia humosa with silt, black; Sh3.5, Ag0.5, Dg+, As+; struc.: homogeneous; nig.3, strf.0/4, elas.0, sicc.2, lim.sup.0
20.70–20.95	peat, highly decomposed, dark brown; Th2, Tb1, Sh1, Ag/As+; struc.: homogeneous; nig.3, strf.0/4, elas.0, sicc.2, lim.sup.0
20.95–21.00	clayey peat, brown; Th2, Tb1, Sh0.5, Ag0.5, As+; struc.: homogeneous; nig.2, strf.0/4, elas.0, sicc.2, lim.sup.0
21.00–21.60	organic silt, brown; Ag2.5, As0.5, Th/Tb0.5, Sh0.5, Dg+; struc.: homogeneous; nig.2, strf.0/4, elas.0, sicc.2, lim.sup.0
21.60–21.87	substantia humosa with silt, black; Sh3.5, Ag0.5, As+, Dg+; struc.: homogeneous; nig.3, strf.0/4, elas.0, sicc.2, lim.sup.0
21.87–21–93	peat, weakly decomposed, brown; Th2, Tb2, Sh+, Ag/As+; struc.: homogeneous; nig.2, strf.0/4, elas.0, sicc.2, lim.sup.0
21.93–22.49	substantia humosa with silt, black; Sh3.5, Ag0.5, As+, Dg+; struc.: homogeneous; nig.3, strf.0/4, elas.0, sicc.2, lim.sup.0

Table 4. Continued

Depth (m)	Sediment description
22.49–22.51	peat, weakly decomposed, brown; Th2, Tb2, Sh+, Ag/As+; struc.: homogeneous; nig.2, strf.0/4, elas.0, sicc.2, lim.sup.0
22.51–22.55	substantia humosa with silt, black; Sh3.5, Ag0.5, As+, Dg+; struc.: homogeneous; nig.3, strf.0/4, elas.0, sicc.2, lim.sup.0
22.55–22.90	organic silt, slightly sandy, brown; Ag2.5, As0.5, Th/Tb0.5, Ga0.5, Sh+, Dg+; struc.: homogeneous; nig.2, strf.0/4, elas.0, sicc.2, lim.sup.0
22.90–23.65	substantia humosa with silt, black; Sh3.5, Ag0.5, As+, Dg+; struc.: homogeneous; nig.3, strf.0/4, elas.0, sicc.2, lim.sup.0
23.65–23.70	substantia humosa with silt and sand, black; Sh3, Ag0.5, Ga0.5, As+, Dg+; struc.: homogeneous; nig.3, strf.0/4, elas.0, sicc.2, lim.sup.0

Table 5. Dzierniakowo [24]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
D-1	***Corylus-Tilia-Alnus***	23.71–23.55	Predomination of *Corylus avellana* (30–62%); high values of *Alnus* and *Tilia cordata* type (ca. 20%); relatively high proportion of *Ulmus* and *Quercus* (to 3% and to 10% respectively); *Carpinus betulus* pollen curve gradually rising from 0.2% to 2.5%); very low percentages of *Pinus sylvestris* type and *Betula alba* type (below 10% and 1% respectively); single pollen grains of *Tilia platyphyllos* and *Tilia tomentosa*. The upper boundary: the increase of *Carpinus betulus* above 20%; the fall of *Corylus avellana* below 30%.
D-2	***Carpinus-Alnus***	23.50–23.25	The increase of *Carpinus betulus* to 68%; the fall of *Corylus avellana* from 20% to 5%; *Alnus* oscillating around 12%, and *Ulmus* around 5%; the decrease of *Tilia cordata* type to 5%; very low proportion of *Pinus sylvestris* type and *Betula alba* type (below 5% and 3% respectively). The zone has not upper boundary – hiatus is present between the uppermost spectrum of this zone (23.25 m) and the lowest spectrum of D-3 zone (23.20 m).
D-2a	*Corylus-Tilia*	23.50	High values of *Tilia cordata* type, similar as in previous zone*;* increase of *Carpinus betulus* up to 30%.
D-2b	*Corylus-Ulmus*	23.45–23.35	Relatively high *Corylus avellana* and *Ulmus* percentages; decreasing proportion of *Tilia cordata* type.
D-2b	*Picea*	23.30–23.25	Start of continuous pollen curve of *Picea abies* type and its rise to 3%.
D-3	***Pinus***	23.20–22.95	Domination of *Pinus sylvestris* type (50–90%); percentages of *Betula alba* type oscillating around 15%. The upper boundary: rise of NAP proportion above 30%; fall of *Pinus sylvestris* type values below 40%.
D-3a	*Picea-Betula*	23.20–23.05	The peak of *Picea abies* type (10%); proportion of *Betula alba* type slightly rising to 9%.
D-3b	NAP-*Betula*	23.03	The peaks of *Betula alba* type (15%), *Artemisia* (6%), Cyperaceae (10%), as well as *Corylus avellana* (4%) and numerous deciduous trees (*Alnus* – 4%, *Carpinus betulus* – 8%, *Picea abies* type – 3%), pollen of which probably occurs at the secondary bed.
D-3d	*Larix*	23.02–22.92	*Larix* culmination (ca. 2%).
D-4	***Artemisia*-Cyperaceae-Chenopodiaceae**	22.90–22.55	NAP predomination; very differentiated values of *Pinus sylvestris* type (10–70%); *Betula alba* type gradually increasing to 20%; relatively high of *Salix* proportion (ca. 2%); pollen of *Corylus avellana*, *Carpinus betulus*, *Tilia cordata* type, *Alnus* and *Picea abies* type probably at the secondary bed. The upper boundary: rapid rise of *Pinus sylvestris* type to 60%; fall of NAP to 2%.
D-4a	Ericaceae	22.90–22.85	Low-percentage culmination of Ericaceae undiff. and *Calluna vulgaris*.
D-4b	*Pinus*	22.80–22.75	The peak of *Pinus sylvestris* type with value of 61%.
D-4c	*Juniperus*-Poaceae-*Betula*	22.70–22.55	Absolute maximum of *Juniperus* (21%); gradually rising values of *Betula alba* type; relatively high proportion of *Betula nana* type.
D-5	***Pinus-Betula***	22.53–22.39	*Pinus sylvestris* type and *Betula alba* type domination – there are two peaks of pine pollen with values of ca. 60% each, and between them the peak *Betula alba* type (max. 82%). NAP proportion below 5%. The upper boundary: rapid fall of *Pinus sylvestris* type to 40%; rise of *Artemisia*.

Table 5. Continued

L PAZ	Name	Depth (m)	Description
D-6	***Artemisia-Betula***	22.36–22.33	The peak of *Artemisia* (15%); values of *Betula alba* type rising to 60%. The upper boundary: fall of *Artemisia*; rise of *Betula alba* type to 75%.
D-7	***Pinus-Betula***	22.31–21.55	*Betula alba* type and *Pinus sylvestris* type domination. The upper boundary: fall of *Pinus sylvestris* type from 85 to 50%; rise of NAP to 40%.
D-7a	*Betula*	22.31	The peak of *Betula alba* type with value of 80%.
D-7b	*Pinus*	22.25–22.00	Proportion of *Betula alba* type oscillating around 40% and *Pinus sylvestris* type around 60%.
D-7c	*Pinus-Picea*	21.95–21.55	Absolute maximum of *Pinus sylvestris* type (90%); regular presence of *Picea abies* type pollen (1-3%).
D-8	***Artemisia-Betula nana***	21.52–20.90	NAP predomination (50–60%), mainly *Artemisia*, Poaceae, Cyperaceae and Chenopodiaceae; relatively high frequencies of *Juniperus* and *Betula nana* type. The upper boundary: rise of *Betula alba* type to 60%; fall of NAP below 50%.
D-9	***Pinus-Betula***	20.82–20.52	*Betula alba* type and *Pinus sylvestris* type domination. The upper boundary: fall of *Pinus sylvestris* type to 60%; rise of NAP to 30%.
D-9a	*Betula*	20.82–20.65	*Betula alba* type culmination (80%); very low proportion of *Pinus sylvestris* (ca. 5%); values of NAP gradually decreasing from 55% to 5%.
D-9b	*Pinus-Larix*	20.60–20.53	*Pinus sylvestris* type domination (ca. 85%); low values of *Betula alba* (ca. 8%); absolute maximum of *Larix* (4%); still presence of *Picea abies* type pollen (ca. 1%).
D-10	***Pinus-Betula*-NAP**	20.48–19.85	*Pinus sylvestris* values gradually decreasing from 60% to 30%; still presence of Ericaceae undiff., *Lycopodium annotinum* and *Botrychium*. The upper boundary: rise of NAP to 70%.
D-11	***Artemisia-Poaceae-Ranunculus***	19.80–19.70	The first culmination of *Ranunculus acris* type; absolute maximum of NAP (80%) – very high values of Poaceae, *Artemisia* and Cyperaceae (max. 30%, 19% and 16% respectively); relatively frequent pollen of *Betula nana* type (to 3%). The zone has not upper boundary.

sediments contained *substantia humosa* with silt. Peat and organic silt appeared at a depth of 22.90 metres below the surface (Tab. 4). The lacustrine-mire series were covered by a layer of ca. 5.00 metres of sand.

Complete pollen record that was contained in the profile from Dzierniakowo site [24] represents the Eemian interglacial, the Early Vistulian and in great part the Plenivistulian (Kupryjanowicz 2005b). Only the results of pollen analysis of the Eemian and the Early Vistulian sediments are presented in this paper. Results of the palynological investigations of the Plenivistulian section of the profile will be a subject of separate study, which is being prepared.

More than 90 samples of the Eemian and the Early Vistulian sediments were subjected to thorough pollen analysis. Pollen frequency is high or very high in all of them. Pollen percentage diagram of the profile (Fig. 8) was divided into 11 local pollen assemblage zones (Tab. 5).

The results of magnetic susceptibility measurement, of the analysis of grain size distribution and the chemical analysis of sediments are presented in Figure 8. Rapid increase in magnetic susceptibility was detected in relation to particular sections, namely within (1) the D-3b *Artemisia* local pollen subzone of the D-3 *Pinus* zone, (2) the D-4 *Artemisia*-Poaceae L PAZ, and (3) at the end of D-5 *Pinus-Betula* L PAZ. Clear declines of MS values (4) starting from the end of the D-8 *Artemisia-Betula nana* L PAZ to the start of the D-9 *Pinus-Betula* L PAZ, and (5) across the D-7 *Pinus-Betula* L PAZ were well documented. The decrease in magnetic susceptibility values at higher parts of the D-10 and in the lower part of the D-11 pollen zone resulted from lithological variability of sediments.

Pieszczaniki

The Pieszczaniki [23] site (53°8′N, 23°34′E; 140 m a.s.l.) is located in the eastern part of the Białystok Upland, approximately 26 km east of Białystok (Figs 1, 2).

The palaeolake where the drilling was

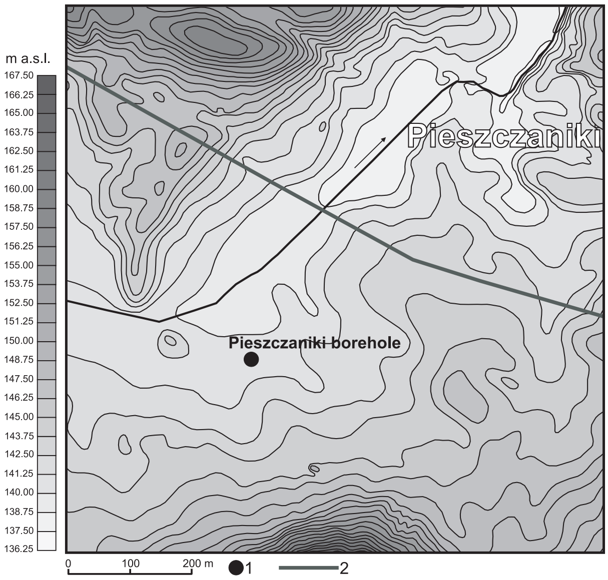

Fig. 9. Pieszczaniki [23]. Location of the site. **1** – studied profile, **2** – road

Table 6. Pieszczaniki [23]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.40	soil
0.40–2.05	clayey sand with gravel and głaziki, light yellow
2.05–3.60	fine sand slightly clayey, brown
3.60–4.60	organic silt, black; Ag3.5, As+, Sh0.5, Th/Tb+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.0
4.60–5.00	sandy silt, dark grey
5.00–5.50	fine and medium sand with gravel, dark grey

Only 6 sediment samples from the Pieszczaniki profile were studied using pollen analysis. Pollen frequency is high in all of them. The pollen percentage diagram (Fig. 10) was divided into 3 local pollen assemblage zones (L PAZ). Their description is showed in Table 7.

Table 7. Pieszczaniki [23]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
Pi-1	***Carpinus-Corylus-Alnus***	4.60–4.40	Very high *Carpinus betulus* values (36.5–55.4%); relatively high proportion of *Corylus avellana* (15.8-17.8%), *Alnus* (8.8–12.7%), and *Tilia cordata* type (2.0–7.9%); low percentages of *Quercus* to 2.0%), *Ulmus* (to 3.1%), and *Picea abies* type (to 4.2%); presence of *Hedera helix* and *Viscum* pollen.
Pi-2	***Pinus-Picea-Carpinus***	4.20–4.10	*Pinus sylvestris* type domination (56.6–59.7%); relatively high proportion of *Picea abies* type (14.9-16.9%) and *Carpinus betulus* (8.7–12.6%); frequency of *Corylus avellana* (1.6–2.6%) and *Alnus* (ca. 3%) lower then previous zone.
Pi-3	***Carpinus-Picea-Corylus***	4.00–3.70	Percentages of *Carpinus betulus* and *Alnus* similar as in the Pi-1 zone; values of *Corylus avellana* (7.6–9.9%) slightly lower then previously, and *Tilia cordata* type (1.9–2.3%) and *Picea abies* type (5.5–7.5%) higher.

carried out lies to the south-west of the Pieszczaniki village (Fig. 9). Its sediments fill melt depression, that was formed during the Wartanian glaciation (Kurek & Preidl 2001b). The surface of the basin extends over the area of ca. 700 × 150 m. The drilling site is in south-western part of the melt basin located approximately 200 m to the south-west off the Białystok-Bobrowniki road, in the middle of the Pieszczaniki village.

As in case of earlier mentioned sites the coring was carried out in accordance with preparation of the Gródek sheet of the Detailed Geological Map of Poland in scale 1: 50 000 (Kurek & Preidl 2001b). The drilled sequence was 128.50 m in length. Lake organogenic deposit, about 1 m in thickness, was drilled from the layer placed at a depth of 4.60–3.60 m below. It contains black organic silt. The lacustrine-mire series are covered by sand layer. Description of the upper part of the coring is showed in Table 6.

Kruszyniany

The Kruszyniany [21] site (53°12′N, 23°49′E; 140 m a.s.l.) lies in eastern part of the Białystok Upland approximately 45 km east of Białystok and about 0.5 km north of the Kruszyniany village (Figs 1, 2, 11). The palaeolake in which drilling was carried out lies about 10 m south off the Łosiniany to Krynki-Kruszyniany road (Fig. 11).

The site lies on the northern edge of the narrow and very long depression (ca. 100–150 by 2500 m) that extends from the river Świsłocz valley to the east to the river Nietupa valley to the west. The site was discovered by forest inspectors from Krynki Inspectorate while digging out artificial water basins. Some of the basins were made in close vicinity of Krynki village. They were usually situated in small shallow depressions. Some organic palaeolake sediments that apparently protruded in two excavation sites were delivered to the

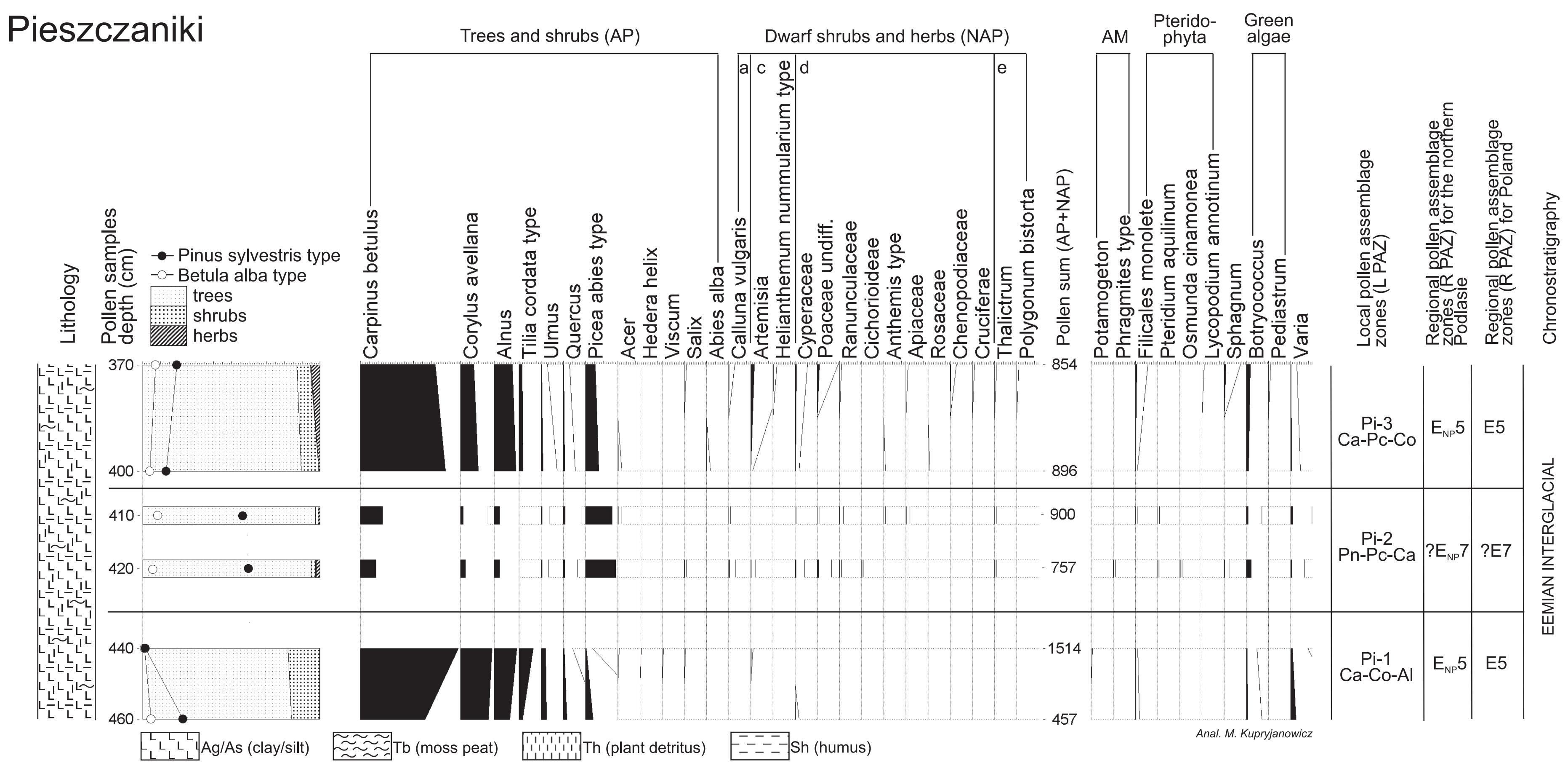

Fig. 10. Pieszczaniki [23]. Percentage pollen diagram; AM – aquatic and mire plants

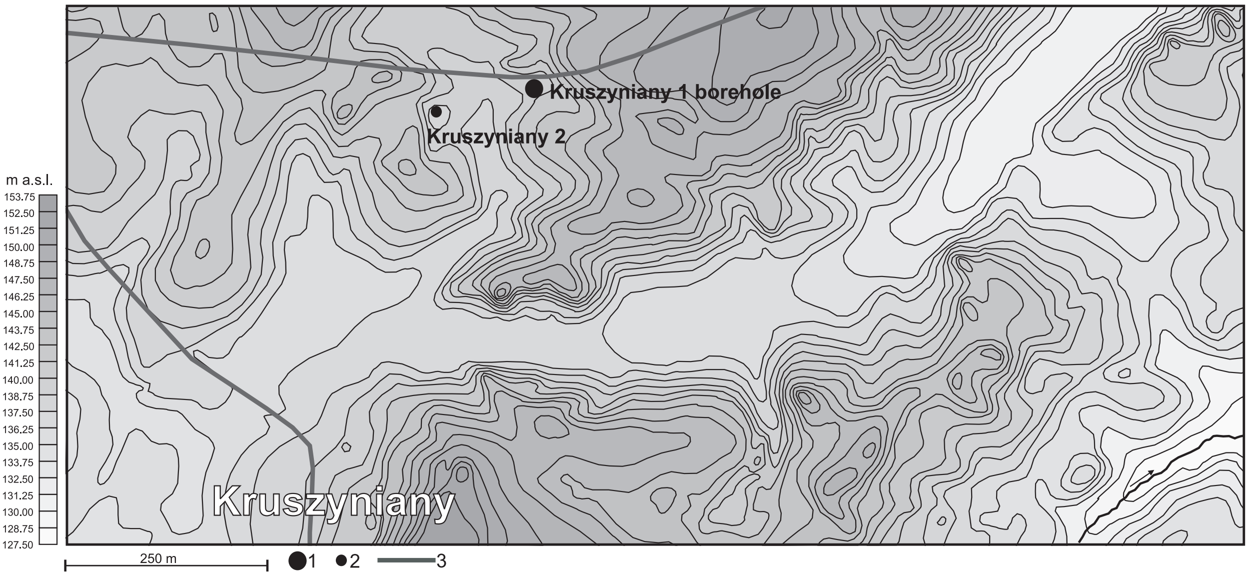

Fig. 11. Kruszyniany [21]. Location of the site. **1** – studied profile, **2** – other Eemian profile, **3** – roads

Biology Institute, the University of Białystok by a forest inspector. Few dozens of kilometres separated the sites from one another (Fig. 11). Preliminary pollen analysis of those collected sediments allowed to relate them with the Eemian interglacial. Boring for the detailed palynological investigation was conducted in the very vicinity of eastern basin by A. Czerwiński and P. Banaszuk, the Białystok Technical University. A location was chosen where the sand layer, almost two metres thick, that covered lake-mire sediments could be removed (Fig. 12). Their sequence was then described on the basis of the profile collected directly from the ditch wall.

Lake-mire deposits, about 3 m in thickness, were drilled to a depth of 3.06–6.05 m. Their main part contains detritus gyttja whereas peat layer appears at a depth of 2.20–2.90 m below the surface. Description of the entire coring is presented in Table 8.

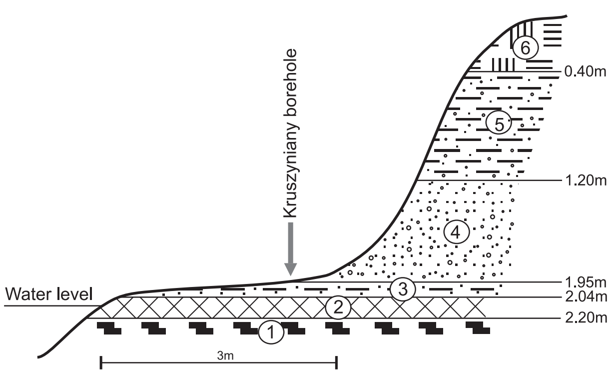

Fig. 12. Kruszyniany [21]. Schematic cross-sketch of the place of boring. Lithology: **1** – moss peat, light brown, **2** – detritus gyttja, very dark brown, **3** – sandy clay, dark yellow, **4** – fine sand with gravel and stones, grey and yellow, **5** – silt with sand, gravel and stones to 5 cm, olive-brown, olive-grey and olive-yellow, **6** – soil

Table 8. Kruszyniany [21]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.40	soil
0.40–1.20	silt with sand, gravel and stones to 5 cm, olive-brown, olive-grey and olive-yellow
1.20–1.95	fine sand with gravel and stones, grey and yellow
1.95–2.04	sandy clay, dark yellow
2.04–2.13	detritus gyttja, slightly clayey, dark brown-black; Ld3.5, Ag0.5, As+, Th/Tb+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
2.13–2.20	coarse detritus gyttja, very dark brown; Ld4, Ag+, As+, Th/Tb+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
2.20–2.90	moss peat, light brown; Tb2.5, Th1.5, Sh+, Ga+; struc.: heterogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
2.90–6.05	detritus gyttja, slightly clayey, brown-black; Ld3.5, Ag0.5, As+, Th/Tb+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1

This palaeobasin had probably a rather small size since no organic sediments were found in another boring located 5 m to the south from the above-described site.

About 50 samples were examined by pollen analysis. In case of 44 samples frequency of pollen is high or very high. In just 3 samples, of the strata at a depth of 1.95, 2.00 and 2.05 m, no sporomorphs were detected. Pollen percentage diagram for the Kruszyniany profile (Fig. 13) was divided into 5 local pollen assemblage zones (Tab. 9).

Table 9. Kruszyniany [21]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
K-1	***Betula-Pinus-(Quercus)***	4.10–3.90	Proportion of *Betula alba* type decreasing from 85.7% to 45.8%; values of *Pinus sylvestris* type rising from 4.6% to 47.2%); still presence of single pollen grains of *Picea abies* type (to 0.9%), *Quercus* (to 0.6%), *Corylus avellana* (to 0.7%), *Alnus* (0.3%), and *Carpinus betulus* (to 0.2%); frequecy of *Salix* pollen falling from 1.8% to 0.1%. The upper boundary: increase of *Betula alba* type proportion.
K-2	***Betula-Pinus-Ulmus***	3.80	Only one spectrum included. Culmination of *Betula alba* type (62.9%); relatively high proportion of *Pinus sylvestris* type (30.0%) and *Ulmus* (3.7%). The upper boundary: rise of *Quercus* above 10%.
K-3	***Quercus***	3.70–3.30	Rise of *Quercus* values to maximum of 24.4%; relatively high proportion of *Ulmus* (0.5–7.6%); decrease of *Betula alba* type values from 29.5 to 4.3%. The upper boundary: increase of *Corylus avellana* above 60%. Two subzones are distinguished:
K-2a	*Pinus*	3.70–3.35	Relatively high proportion of *Pinus sylvestris* type.(above 45%)
K-2b	*Corylus*	3.30	High value of *Corylus avellana* (27.3%).
K-4	***Corylus***	3.09–1.80	Very high proportion of *Corylus avellana* (above 38.8%) with maximum of 69.6%; percentages of *Tilia cordata* type rising to maximum of 34.6%; values of *Alnus* slightly increasing from 3.9% to above 6% with culmination of 15.2% in the middle part of the zone. The upper boundary: increase of *Alnus* above 20% and *Carpinus betulus* above 10%; small decrease of *Tilia cordata* type. Two subzones are distinguished:
K-3a	*Quercus*	3.10–2.50	Relatively high proportion of *Quercus* (6.0–17.0%).
K-3b	*Tilia*	2.40–1.80	Maximum of *Tilia cordata* type (34.6%); rise of *Carpinus betulus* values to 5.0%.
K-5	***Carpinus-Alnus***	1.70–0.40	Very high values of *Carpinus betulus* (above 20%; max. 75.9%) and *Alnus* (generally above 10%; max. 46.9%); gradual fall of *Corylus avellana* (from 36.5% to 3.4%); still relatively high proportion of *Tilia cordata* type (0.3–16.3%) and *Ulmus* (to 9.0%). The upper boundary: increase of *Pinus sylvestris* type above 80%. Two subzones are distinguished:
K-5a	*Corylus*	1.70–0.70	Decreasing, but still relatively high proportion of *Corylus avellana* (20.4–37.1%).
K-5b	*Pinus*	0.65–0.40	Values of *Pinus sylvestris* type rising up to 20.4%.
K-6	***Picea-Pinus-Carpinus***	0.30–0.10	In the samples from a depth of 0.20 and 0.10 m there are peaks of *Picea abies* type (with values of 41.9% and 33.2%), *Carpinus betulus* (26.0% and 28.5%), and *Alnus* (14.8% and 14.5%); in the remaining samples – culminations of *Pinus sylvestris* type (80.2% and 71.9%). No upper boundary.

Hieronimowo

The Hieronimowo [26] site (53°0′N, 23°34′E; 143 m a.s.l.) is located in south-eastern part of the Białystok Upland about 30 km south-east of Białystok (Figs 1, 2).The site to be found at the Narew sheet of the Detailed Geological Map of Poland, in scale 1: 50 000, was discovered by W. Kwiatkowski and M. Stepaniuk, Białystok Technical University, while inspecting construction operations of the Jamal gas transportation pipeline.

In 1999 the profile intended for pollen analysis was collected directly from the ditch wall. The sediments studied are depicted in Figure 14A, whereas their description is to be found in Table 10.

It has turned out that the lake-mire

Table 10. Hieronimowo [26]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.40	soil
0.40–2.00	diluvial deposits, slity-clayey with sand, gravel and stones
2.00–2.28	sandy silt, beige, with traces of fine sand
2.28–2.35	silt, grey, slightly sandy
2.35–2.42	silt, grey, with traces of fine light beige sand
2.42–2.55	organic silt slightly clayey, dark grey, with traces of fine light beige sand; Ag3.5, As0.5, Sh+, Dg+, Dl+, struc.: very homogenous, nig.2, strf.0, elas.0, sicc.2, lim.sup.0
2.55–2.61	fine and medium sand, with admixture of silt and clay, beige and dark beige; Ga3, Ag0.5, As0.5, struc.: heterogenous, nig.2, strf.0/3, elas.0, sicc.2, lim.sup.2

(cont. on page 25)

Table 10. Continued

Depth (m)	Sediment description
2.61–2.63	organic silt, dark grey, slightly sandy; Ag3.5, Ga0.5, Sh+, Dg+, Dl+, struc.: very homogenous, nig.2+, strf.0, elas.0, sicc.2, lim.sup.0
2.63–2.65	fine and medium sand, light beige; Ga4, Ag+, As+, struc.: homogenous, nig.1, strf.0, elas.0, sicc.2, lim.sup.2
2.65–2.70	organic silt, dark brown, with thin layers of fine light beige sand; Ag3, Ga0.5, Sh0.5, Dg+, Dl+, As+, struc.: hetetogenous, nig.3/1, strf.0, elas.0, sicc.2, lim.sup.2
2.70–3.20	fossil fruits, seeds and small fragments of wood, with admixture of fine light grey and rust sand; Dg3, Dl1, Dh+, Ga+, struc.: homogenous, nig.3/1, strf.0, elas.0, sicc.2, lim.sup.2

Table 11. Hieronimowo [26]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Samples	Description
H-1	***Pinus-Quercus-Fraxinus***	1, 2	High values of *Pinus sylvestris* type slightly decreasing from 60.2% to 52.9%); maxima of *Quercus* (23.2%) and *Fraxinus* (6.7%); relatively high proportion of *Corylus avellana* (4.6–9.0%) and *Ulmus* (2.7–3.4%); still presence of single pollen grains of *Picea abies* type and *Alnus*. The upper boundary: increase of *Corylus avellana* proportion to 45.2% and *Ulmus* to 10.4%.
H-2	***Corylus-Tilia-Quercus***	3	Only one spectrum included. Maxima of *Corylus avellana* (45.2%), *Ulmus* (10.4%) and *Tilia cordata* type (13.6%); very high value of *Quercus* (16.7%). The upper boundary: rise of *Carpinus betulus* above 40% and *Alnus* above 20%.
H-3	***Carpinus-Alnus***	4, 5	Very high values of *Carpinus betulus* (max. 40.4%) and *Alnus* (max. 21.0%); relatively high proportin of *Corylus avellana* (ca. 14%) and *Tilia cordata* type (7.6–10.4%). The upper boundary: increase of *Picea abies* type to ca. 30%.
H-4	***Picea-Pinus-Carpinus***	6	Maximum of *Picea abies* type (max. 27.7%); high values of *Pinus sylvestris* type (46.3%) and *Carpinus betulus* (14.8%). The upper boundary: increase of *Pinus sylvestris* type above 80%; fall of *Picea abies* type below 10%.
H-5	***Pinus***	7, 8, 9	Very high frequency of *Pinus sylvestris* type (81.4-86.7%); relatively high values of *Picea abies* type (4.4–7.6%). No upper boundary.

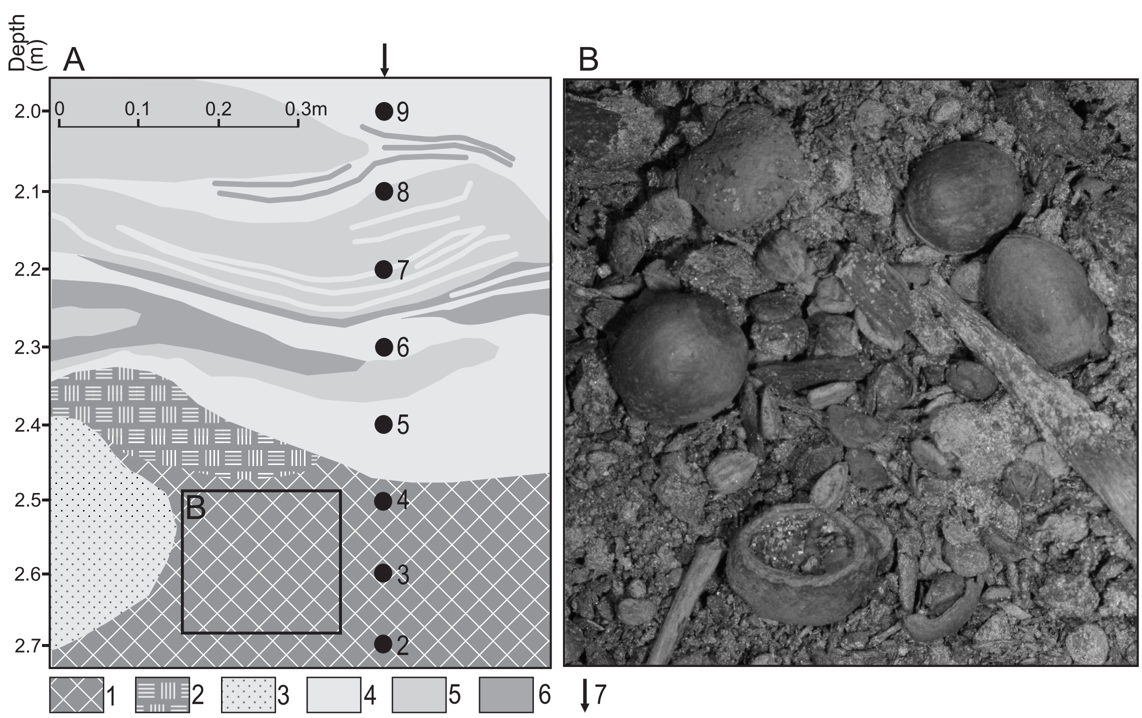

Fig. 14. Hieronimowo [26]. **A** – lower part of sediments of the Eemian palaeolake: **1** – fossil fruits, seeds and woods with small admixture of light grey fine sand and traces of rust sand, **2** – organic silt, dark brown with fossil fruits, seeds and woods, **3** – fine and medium sand, light beige, **4** – silt and clay, light beige, **5** – fine and medium sand, with small admixture of silt and clay, beige and dark beige, **6** – organic silt, dark grey, **7** – location of samples for pollen analysis; **B** – fossil fruits and seeds in sediments of the Eemian palaeolake (Photo J. Kupryjanowicz)

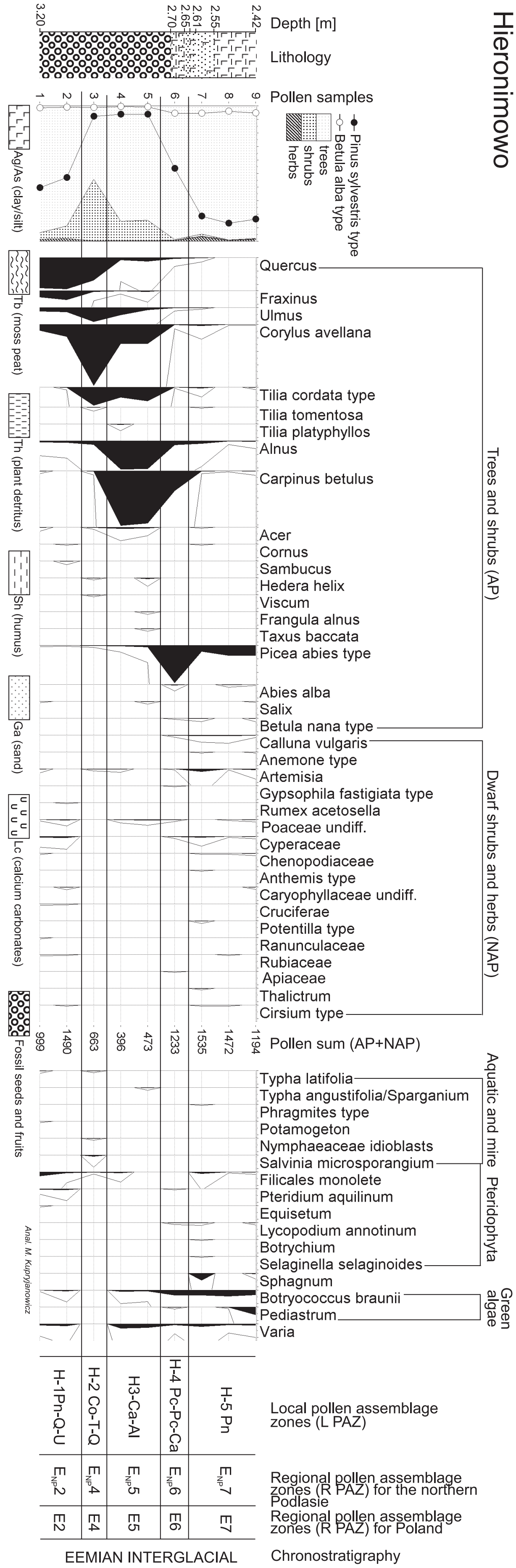

Fig. 15. Hieronimowo [26]. Percentage pollen diagram

sediments from Hieronimowo are very rich in macroscopic plant remains, especially in seeds, fruits of trees and water plants (Fig. 14B). Further analysis of its contents is a subject of another study (Kozub 2006, Staniszewska 2006, Szczurzewska 2006, Kupryjanowicz et al. 2007). A monograph that sums up all the results of these studies is being currently prepared.

Only 9 samples were examined by pollen analysis. Pollen frequency is high or very high in most of them. Only in the samples number 4 and 5 the frequency is low and the condition of sporomorphs preservation is very bad. Pollen percentage diagram from the Hieronimowo profile (Fig. 15) was divided into 5 local pollen assemblage zones (Tab. 11).

Małynka

The Małynka [27] site (53°0′N, 23°34′E; 158 m a.s.l.) is located in south-eastern part of the Białystok Upland, about 30 km south-east of Białystok (Figs 1, 2). The site was discovered during the inspection of construction sites of the Jamal gas transportation pipeline. The site is to be found on the Gródek sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Kurek & Preidl 2001a).

The studied palaeolake lies south of the Małynka village (Fig. 16A). The sediments studied fill the subglacial basin, that was formed during the Wartanian glaciation. The surface of the basin extends over the area of ca. 500×250 m. Nowadays the depression is cut through a small stream, which sheds its waters to the river Małynka, to the east from the Małynka village.

In 1999 the sediments profile for pollen analysis was collected by S. Kurek and M. Preidl right from the ditch wall of the constructed Jamal gas transportation pipeline. Seven samples (each of ca. 0.5 l in volume) were taken from the opposite ditch walls. Their placement is showed in Figure 16B.

Since the ditch has not been properly drained samples could only be taken down to the 2.65 m level below the surface. Sediments of palaeolake appear from the water table of 2.65 m up to the level of 1.30 m below the ground level. They consist of detritus gyttja and silt and are covered by sand layer above. Lithological description of that profile is showed in Table 12.

Table 12. Małynka [27]. Lithology of the profile

Depth (m)	Sediment description
0.00–1.30	fine sand, yellow
1.30–1.70	silt, grey-green; Ag3.5, As0.5, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
1.70–2.35	silt with traces of substantia humosa, grey-blue; Ag3.5, As+, Sh0.5, Ga+; struc.: heterogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
2.35–2.65	detritus gyttja, brown-black; Ld4, Dg+, Ag/As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Only 7 samples were subjected to pollen analysis. In the sample number 1, probed at a depth of 1.70 m no sporomorphs were found. In the remaining six samples the frequency of the pollen is high or very high and the condition of its preservation is very good. Pollen percentage diagram from the Małynka profile (Fig. 17) was divided into 3 local pollen assemblage zones (Tab. 13).

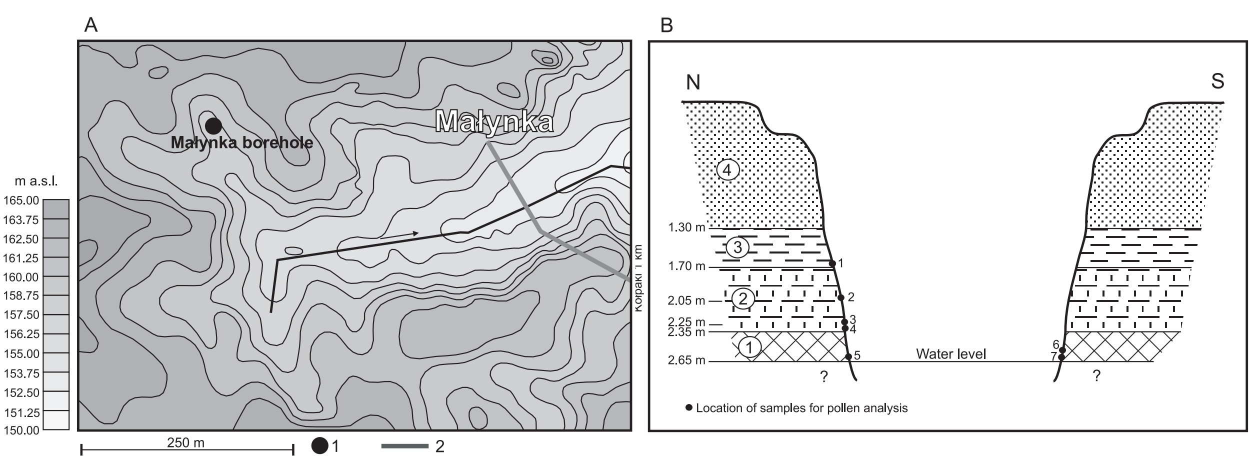

Fig. 16. Małynka [27]. **A** – location of the site: **1** – studied profile, **2** – road. **B** –schematic cross-section through analysed sediments (acc. Kurek & Preidl 2001b); lithology: **1** – detritus gyttja, brown-black, **2** – silt with traces of substantia humosa, grey-blue, **3** – silt, grey-green, **4** – fine sand, yellow

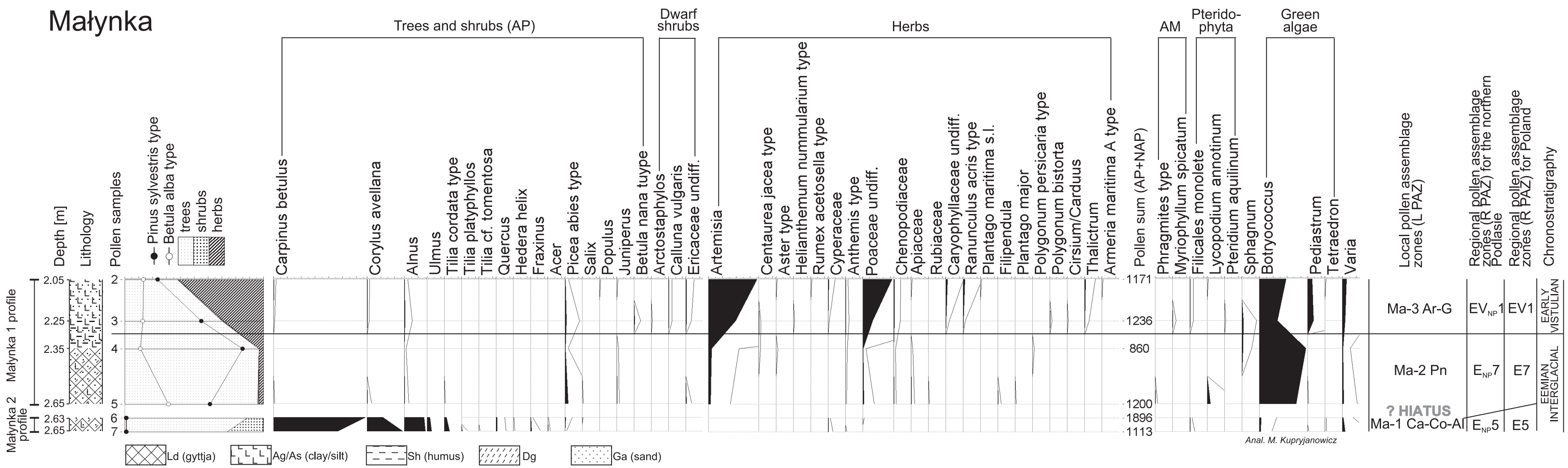

Fig. 17. Małynka [27]. Percentage pollen diagram; **a** – dwarf shrubs, **c** – plants of open, dry to fresh habitats, **d** – ecologically undefined taxa, **e** – plants of open, fresh to wet habitats, **AM** – aquatic and mire plants

Table 13. Małynka [27]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Samples	Description
Ma-1	***Carpinus-Corylus-Alnus***	7, 6	Prewailing of *Carpinus betulus* (46.7–66.4%); high values of *Corylus avellana* (11.6–25.8%) and *Alnus* (14.3–15.4%); relatively high proportion of *Tilia cordata* type (1.5–3.8%) and *Ulmus* (2.1–3.1%); frequency of other trees, including *Pinus sylvestris* type and *Betula alba* type, below 1%. The zone has not the upper boundary.
Ma-2	***Pinus***	5, 4	Domination of *Pinus sylvestris* type (61.5–85.1 %) and *Betula alba* type (11.3–31.4%); single pollen grains of *Picea abies* type and *Alnus*; NAP below 5%. The upper boundary: fall of *Pinus sylvestris* type to ca. 50%; increase of NAP, mainly *Artemisia*.
Ma-3	***Artemisia-*** **Poaceae**	3, 2	Very high values of NAP (32–61%), among which *Artemisia* dominates (19.6–34.9%); proportion of Poaceae undiff. rising from 6.9% to 20.9%. The zone has not the upper boundary.

Lesznia-Łuchowa Góra

The Lesznia-Łuchowa Góra [30] site (52°55′N, 23°5′E; 153 m a.s.l.) is placed in south-western part of the Białystok Upland about 25 km south of Białystok (Figs 1, 2). The Eemian lake silts and peats occur in small depression that lies on the north edge of the Narew valley (Fig. 18). Similar deposits had already been found in that region at the Klewinowo site which is to be found approximately 12 kilometres from the Lesznia-Łuchowa Góra site (Mojski 1974, Borówko-Dłużakowa 1973a, 1974).

The depression studied is located approximately 500 m to the north from the river Narew (Fig. 18). End moraine belts go through that area. These are connected with deglaciation of the Wartanian glaciation (Kmieciak 2001). They culminate with a summit of 168.7 m a.s.l., while denivelation goes down to 15 m a.s.l. Southern hillside gently descends to the Narew valley whereas northern hillside is rather steep. The Narew valley in that area, two metres wide at sites, is bound latitudinally, with its river banks reaching height of 1 to 10 m.

To the north from that site, close to villages: Klewinowo, Rzepniki and Krynickie a cluster of kemes is situated. They are mostly represented by dome-shaped or elongated knolls that reach 5–15 m (Kmieciak 2001). Here and there on top of such kame hills small depressions are scattered which may stay temporarily filled with rain water.

The sampling was carried out by a geological corer as a part of the broader scope of preparing the Plutycze sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Kmieciak 2001). The obtained sequence was 2.5 m long. Lake organogenic deposits, about 1 m in thickness, were taken from a depth of 1.60–2.50 m. The bottom part of the lake sediments contains silt with wood chips. Peat appears at a depth of 1.90 m below the surface. The lacustrine-mire series are covered by 1.40 m of sand and 0.20 m of peat deposit. Description of the profile from Lesznia-Łuchowa Góra is showed in Table 14.

Six samples were delivered by M. Kmieciak, namely two peat samples from a depth of 1.70 and 1.80 m and 4 organic silt samples

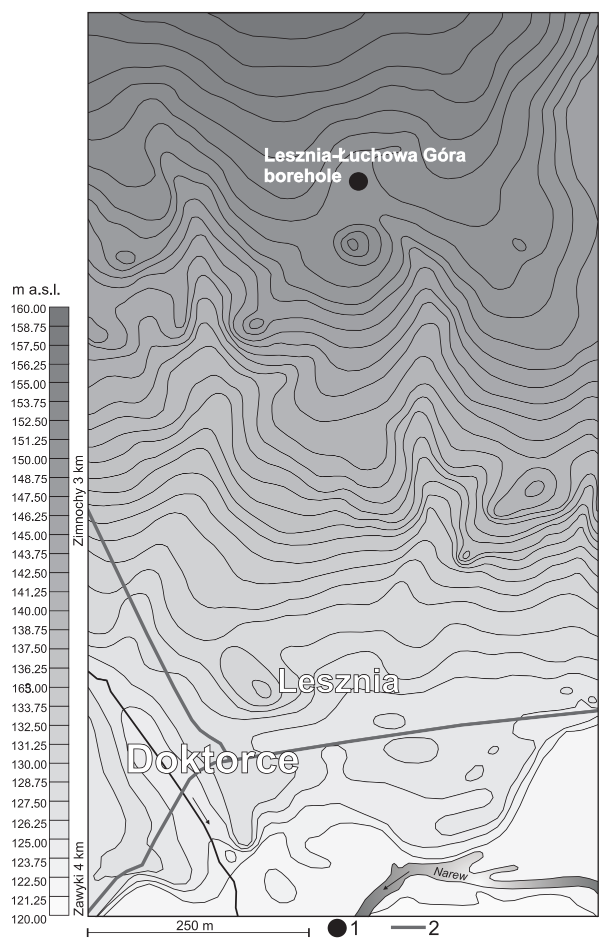

Fig. 18. Lesznia-Łuchowa Góra [30]. Location of the site. **1** – studied profile, **2** – roads

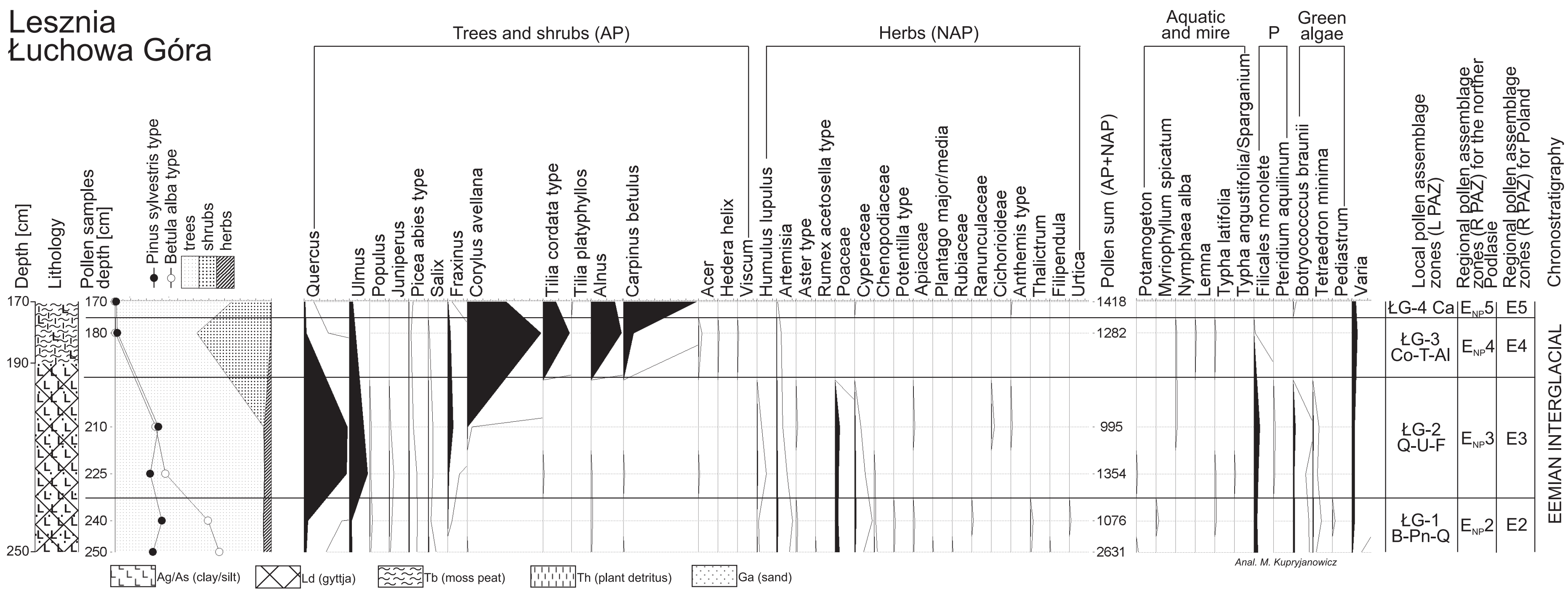

Fig. 19. Lesznia-Łuchowa Góra [30]. Percentage pollen diagram; **P** – Pteridophyta

Table 14. Lesznia-Łuchowa Góra [30]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.20	peat, dark brown
0.20–1.40	fine and medium sand, grey
1.40–1.60	sand with gravel, grey
1.60–1.90	peat, brown and black; Tb3.5, Th0.5, Ag/As+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
1.90–2.50	silt with small fragments of wood, brown and black; Ag3, Dl1, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1

Table 15. Lesznia-Łuchowa Góra [30]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
ŁG-1	***Betula-Pinus-Quercus***	2.50–2.40	Domination of *Betula alba* type (59.6–66.7%) and *Pinus sylvestris* type (24.2–30.1%); relativelly high proportion of *Quercus* (1.4–2.4%) and *Ulmus* (1.4–1.7%); single pollen grains of *Picea abies* type, *Salix* and *Populus*; NAP below 5%. The upper boundary: decrease of *Betula alba* type to ca. 30%, rise of *Quercus* (above 20%) and *Ulmus* (above 10%).
ŁG-2	***Quercus-Ulmus-Fraxinus***	2.25 –2.10	Very high values of *Quercus* (ca. 27%) and *Ulmus* (9.2-11.7%); relatively high frequency of *Fraxinus* (0.7–3.6%); proportion of *Betula alba* type is from 26.0 to 32.3% and *Pinus sylvestris* type from 22.5 to 27.8%; *Picea abies* type, *Salix*, and *Populus* below 1%. The upper boundary: decrease of *Quercus* below 2% and *Ulmus* below 5%, rise of *Corylus avellana* above 40%.
ŁG-3	***Corylus-Tilia-Alnus***	1.80	Domination of *Corylus avellana* (47.3%); very high percentages of *Tilia cordata* type (16.9%) and *Alnus* (19.4%); significant proportion of *Carpinus betulus* (6.4%) and *Ulmus* (3.9%); *Pinus sylvestris* type, *Betula alba* type, *Fraxinus*, and *Quercus* about 1%; single pollen grains of *Viscum* and *Hedera helix*. The upper boundary: increase of *Carpinus betulus* above 45%.
ŁG-4	***Carpinus***	1.70	Prewailing of *Carpinus betulus* (46.7%); high values of *Corylus avellana* (25.0%), *Alnus* (15.4%), and *Tilia cordata* type (8.3%); relatively high proportion of *Ulmus* (2.3%); frequency of other trees, including *Pinus sylvestris* type and *Betula alba* type, below 1%. The zone has not the upper boundary.

from a depth, respectively: 2.10, 2.25, 2.40 and 2.50 m. Pollen frequency is high or very high in all the samples and its condition is very good. Pollen percentage diagram from the Lesznia-Łuchowa Góra profile (Fig. 19) was divided into 4 local pollen assemblage zones (Tab. 15).

SOKÓŁKA HILLS

Sokółka

The Sokółka [13] site (53°25′N, 23°30′E; 161 m a.s.l.) is located in central part of the Sokółka Hills (Figs 1, 2). It lies on the edge of the large depression filled with peat bog that runs from south-eastern part of Sokółka to Drahle village (Fig. 20). The depression constitutes catchment area of the river Sokołda. It is surrounded from all sides by hills of height up to 210 m a.s.l., and at the west end it joins another extensive melt depression, which is also a part of the upper stretch of the river Sokołda valley.

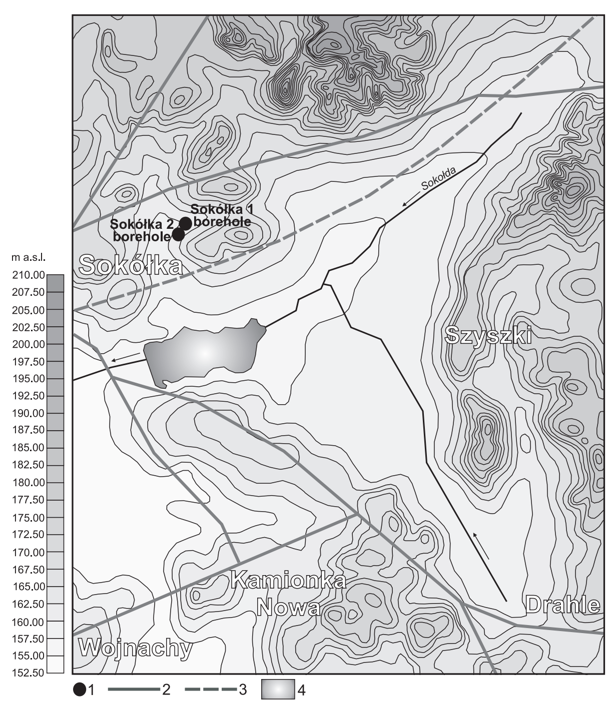

Fig. 20. Sokółka [13]. Location of the site. **1** – studied profiles, **2** – roads, **3** – railway track, **4** – damp reservoir

Two profiles, namely Sokółka 1 and Sokółka 2, were subjected to pollen analysis. Borings were taken few dozen metres away from one another. Fieldwork at these sites, carried out in 2002, accompanied preparation of the Sokółka sheet of Detailed Geological Map of Poland, in scale 1: 50 000 (Boratyn 2003). Both borings were made with mechanical drill by the Kraków's Geological Company JSC (Przedsiębiorstwo Geologiczne S.A). The studied sediments, mainly organic silts, peaty silts and peat layers, occur at a depth of 5.9–16.0 m, under the strata of Holocene peats (0.3 and 0.9 m in thickness), Vistulian organic silts, sands and of sands mixed with gravels (5.1 and 5.9 m). The description of sediments from both analysed cores is showed in Tables 16 and 17.

More than 40 samples collected at Sokółka locality, including 13 samples from Sokółka 1 profile together with 27 collected at Sokółka 2,

Table 16. Sokółka 1 [13]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.20	sandy soil, dark grey
0.20–0.80	fine sand with admixture of medium sand, yellow-grey
0.80–1.60	fine-medium sand, fluvioglacial, beige-grey
1.60–1.80	fine sand, grey-green
1.80–2.00	clayey fine sand, grey
2.00–2.30	peat, highly decomposed, dark brown
2.30–3.60	fine humus sand, dark grey
3.60–4.00	silt, grey-green
4.00–4.10	clayey silt, grey-green
4.10–4.30	fine-medium sand, fluvioglacial, grey-green
4.30–4.70	silt, dark grey
4.70–5.10	peaty silt, grey-brown
5.10–5.30	silt, grey
5.30–5.50	sand with numerous gravel (to 8 mm)
5.50–5.90	silt, dark grey
5.90–7.00	organic silt, from dark grey to black
7.00–7.60	sandy silt, dark grey
7.60–8.10	fine-medium sand, slightly clayey, grey
8.10–8.50	silt with thin traces of brown peat, grey
8.50–8.75	fine-medium sand, dark grey
8.75–9.20	sandy silt with lumps of larger grains, dark grey
9.20–9.70	clayey silt, dark grey
9.70–10.00	silt, slightly sandy, dry, grey
10.00–11.50	clayey silt, plastic, dark grey
11.50–12.30	silt with organic matter, slightly sandy, dark grey; Ag3, As+, Sh0.5, Ga0.5; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
12.30–13.00	silt, dark grey; Ag4, As+, Ga+, Sh+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
13.00–13.80	silty peat, dark brown; Th1, Tb1, Sh1, Ag1, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
13.80–14.10	peaty silt, grey-brown; Ag2, As+, Th0.5, Tb0.5, Sh1, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
14.10–14.50	fine-medium sand, grey
14.50–16.00	fine-medium sand, fluvioglacial, grey

Table 17. Sokółka 2 [13]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.20	slop soil, dark grey
0.20–0.80	sandy-clayey silt, grey-brown
0.80–1.10	fine sand, strongly zaglinione, brown-ginger
1.10–1.50	silty sand with fine gravel (to 3–4 cm), grey-green
1.50–1.80	humus fine sand, silty, dark brown-green and brown
1.80–2.00	humus fine sand, dark brown
2.00–2.50	peaty silt, dark brown
2.50–2.90	fine sand, silty, light grey
2.90–4.00	sand with gravel (3-4 mm), fluvioglacial, light grey
4.00–4.50	coarse sand with fine gravel (to 5 mm), grey
4.50–5.10	fine gravel (1 mm) with coarse and medium sand, grey
5.10–5.80	clayey silt, grey
5.80–6.60	organic silt, clayey, grey-beige
6.60–9.80	organic silt, clayey, dark grey
9.80–10.00	humus fine sand, silty, dark grey
10.00–10.80	clayey silt with gravel and fine-medium sand, dark grey
10.80–11.50	clayey silt, plastic, grey
11.50–11.90	sandy silt with thin layers of sand, dark grey
11.90–13.00	sandy silt, slightly peaty, dry, grey-brown; Ag3, As+, Ga0.5, Th/Tb0.5, Sh+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim. sup.1
13.00–13.40	silt, strongly peaty, dark grey-brown; Ag2, As+, Th1, Tb1, Sh+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim. sup.1
13.40–13.50	organic silt with admixture of sand and fine gravel, dark grey; Ag2, As+, Th/Tb0.5, Sh+, Ga0.5, $Gg_{(min)}$+; struc.: heterogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
13.50–13.80	silty peat, strongly decomposed, dark grey; $Th^3$2, $Tb^3$2, Ag+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
13.80–14.50	peaty silt, dark grey; Ag2.5, As0.5, Th0.5, Tb0.5, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim. sup.1
14.50–14.90	peaty silt, dry, elastic, brown; Ag2.5, As0.5, Th0.5, Tb0.5; struc.: homogeneous; nig.2, strf.0, elas.1, sicc.2, lim.sup.1
14.90–16.00	peaty silt, plastic, with thin layers of dry and elastic silt, brown and yellow-brown; Ag2.5, As0.5, Th0.5, Tb0.5; struc.: heterogeneous; nig.2, strf.0, elas.0/2, sicc.2, lim. sup.1

Table 18. Sokółka 1 [13]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
Sa_1-1	***Corylus***	14.05–13.45	Very high values of *Corylus avellana* (45–55%) and *Quercus* (10–20%); relatively high proportion of *Ulmus* (4–6%); values of *Pinus sylvestris* type about 10%; rather low percentages of *Tilia cordata* type (2–6%) and *Alnus* (4–6%). The upper boundary: decrease of *Corylus avellana* and *Tilia cordata* type; rapid rise of *Carpinus betulus*. Two subzones are distinguished:
Sa-1a	*Quercus*	14.05–13.95	High values of *Quercus* (10–20%).
Sa-1b	*Tilia-Alnus*	13.85–13.45	High proportion of *Alnus* (15–22%), *Tilia cordata* type (max. 15%) and *Ulmus* (ca 5%); low, decreasing values of *Quercus*; very low frequency of *Pinus sylvestris* type and *Betula alba* type; single pollen grains of *Tilia platyphyllos*, *Tilia tomentosa*, *Taxus baccata*, and *Hedera helix*.
Sa_1-2	***Carpinus***	13.35–13.05	Very high values of *Carpinus betulus* (max. 42%); falling proportion of *Corylus avellana*, *Tilia cordata* type, and *Alnus*; rising pollen curve of *Pinus sylvestris* type. Two subzones distinguished. No upper boundary – 75–cm layer of sediments, which not were analysed, occurs above top spectrum. Two subzones are distinguished:
Sa_1-2a	*Corylus*	13.35–13.25	Relatively high proportion of *Corylus avellana*, *Tilia cordata* type, *Alnus*, and *Ulmus*.
Sa_1-2b	*Pinus-Picea*	13.05	Rather high values of *Pinus sylvestris* type, *Picea abies* type and *Betula alba* type.
Sa_1-4	***Pinus-Betula***	12.20–11.65	Predomination of *Pinus sylvestris* type (30–40%) and *Betula alba* type (30–50%); presence of *Salix*, *Betula nana* type, and *Juniperus* pollen; high proportion of NAP (15–25%). No upper boundary – sediments above the top spectrum of this zone were not analysed.

Table 19. Sokółka 2 [13]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
Sa_2-1	***Corylus-Tilia-Alnus***	15.85–15.45	Very high proportion of *Corylus avellana* (48%); rather high values of *Alnus* (16%), *Tilia cordata* type (13%), and *Ulmus* (5%); very low percentages of *Pinus sylvestris* type (ca. 3%) and *Betula alba* type (below 1%); single pollen grains of *Tilia tomentosa*. The upper boundary: rapid rise of *Carpinus betulus* to 40%; fall of *Corylus avellana* and *Tilia cordata* type.
Sa_2-2	***Carpinus-Corylus-Alnus***	15.25–14.50	Very high values of *Carpinus betulus* (ca. 40%); falling proportion of *Corylus avellana*, *Tilia cordata* type, and *Alnus*; still presence of *Picea abies* type (below 1%); single pollen grains of *Viscum*. No upper boundary – hiatus is present above top spectrum of this zone.
Sa_2-3	***Pinus-Betula-*****NAP**	14.30–11.55	Domination of *Pinus sylvestris* type (40–65%) and *Betula alba* type (25–50%); presence of *Salix*, *Juniperus* and *Betula nana* type; NAP proportion from 10 to 16%; high values of *Pediastrum*, mainly *P. kawraiskyi*; still occurrence of *Isoëtes*. No upper boundary – sediments above top spectrum of this zone were not analysed.

were subject to thorough pollen analysis. Frequency of the pollen is high or very high in all samples and the condition of its preservation is very good. According to pollen diagrams local pollen assemblage zones were discerned, three in case of Sokółka 1 profile (Fig. 21, Tab. 18) and five L PAZ for Sokółka 2 profile (Fig. 22, Tab. 19).

Poniatowicze

The Poniatowicze [12] site (53°26′N, 23°39′E) lies in the eastern part of the Sokółka Hills, around 8 km east of Sokółka town (Fig. 1). The site is located at the edge of extensive melt depression at the high of ca. 162.0 m a.s.l (Fig. 2). The river Przerwa flows across that depression (Fig. 23). The area in question is nowadays used as a wet meadow pasture.

Borings for pollen analysis were done in the eastern part of the Poniatowicze village, approximately 50 m to the south off the road, on both sides of a moraine hill at the height exceeding 172 m a.s.l. (Figs 23, 24).

Two profiles from the site, Poniatowicze 1 and Poniatowicze 2, were subjected to pollen analysis. The borings were placed a dozen or

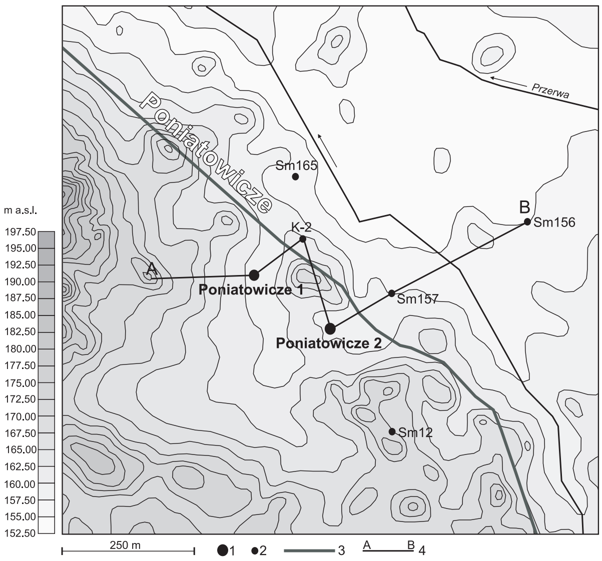

Fig. 23. Poniatowicze [12]. Location of the site. **1** – studied profiles, **2** – other borings in the Poniatowicze region, **3** – road, **4** – geological cross-section showed at Fig. 24

so metres away from one another. They accompanied 2002 fieldwork carried out in relation to preparation of the Sokółka sheet of Detailed Geological Map of Poland, in scale 1: 50 000 (Boratyn 2003). Both borings were made with mechanical probe by the Kraków's Geological Company JSC (Przedsiębiorstwo Geologiczne S.A.).

When analysing Poniatowicze 1 profile grey and dark grey organic silts and peats appear at a depth of 7.0–4.2 m. Then they are covered by 2.5–2.8 metre layer of Holocene peats and by Vistulian sands mixtured with gravels, sands and silts.

In Poniatowicze 2 profile organic deposits are present at a depth of 8.5–4.0 m. They are represented by organic silts with numerous mollusc shells, dark brown organic silts, peaty silts, weakly decomposed moss peats, then strongly decomposed peats and silty peats. These sediments are intersected by glacial tills of the Wartanian glaciation and covered up by Holocene peats, silts and sands. A description of sediments belonging to both analysed cores is presented in Tables 20 and 21.

More than 40 samples collected from Poniatowicze profiles were subject to subsequent pollen analysis, with 12 samples taken at Poniatowicze 1 profile and 29 from Poniatowicze 2. In all samples from Poniatowicze 1 profile frequency of the sporomorphs is high or very high and its preservation is very good or good. No sporomorphs were found in case of 5 samples collected at Poniatowicze 2 (at a depth of respectively 6.95, 6.75, 6.55, 6.35 and 6.15 m). In another 6 samples from the depth of 8.15–7.15 m frequency of the pollen is high or very high and its preservation is very good. In 18 remaining samples (from the depth of 5.95–2.75 m) frequency of the pollen is low

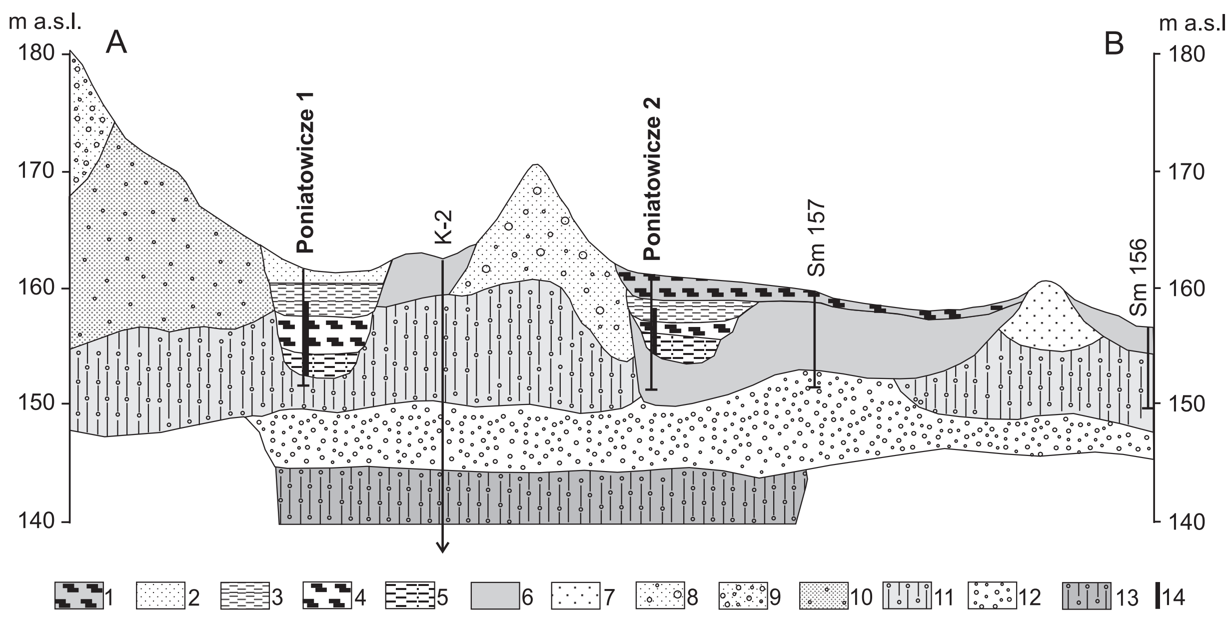

Fig. 24. Poniatowicze [12]. A schematic geological cross-section through the deposits (acc. Boratyn 2003). Holocene: **1** – peat; Vistulian: **2** – deluvial sands, **3** – deluvial and lake sands and silts; Eemian interglacial: **4** – peat, **5** – lake silts and chalk; Wartanian: **6** – melt sands, gravels and silts, **7** – kame sands, gravels and silts, **8** – sands, gravels and boulders of end moraine, **9** – fluvioglacial sands and gravels with boulders, **10** – fluvioglacial sands and gravel, **11** – flow till of the Mława stadial, **12** – fluvioglacial sands and gravels, **13** – flow till of the Wkra stadial; **14** – sections for pollen analysis; Sm 156, Sm 157 and K-2 – other borings in the Poniatowicze region

Table 20. Poniatowicze 1 [12]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.30	peaty soil, black
0.30–0.60	peat, highly decomposed, black
0.60–1.00	peat, weakly decomposed, brown
1.00–1.80	peat, very weakly decomposed, below 1.40 m with visible plant remains, dark brown
1.80 –2.50	peat, highly decomposed, brown
2.50–2.90	peaty silt, brown
2.90–3.50	fine sand with admixture of medium grains and fine gravel (to 3 mm), grey
3.50–4.00	fine sand, slightly clayey, grey
4.00–4.20	organic silt, grey-black
4.20–5.80	peat, highly decomposed, grey-brown and brown; Th2, Tb2, Sh+, Ag/As+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
5.80–6.00	organic silt, grey; Ag3, Th0.5, Tb0.5, Sh+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
6.00–7.00	silt with high content of molluscs shells, grey; Ag3, Lc1, As+, Ga+; struc.: heterogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
7.00–8.50	fine sand, clayey, yellow-grey

or very low and its preservation is poor. Four local pollen assemblage zones were distinguished relying on the pollen diagram of Poniatowicze 1 profile (Fig. 25, Tab. 22) whereas seven L PAZ were delimited as a result of interpreting diagram from the Poniatowicze 2 profile (Fig. 26, Tab. 23).

Table 21. Poniatowicze 2 [12]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.30	peat highly decomposed, black
0.30–0.60	clay, grey
0.60–1.50	fine and medium sand, grey
1.50–1.90	organic clay, grey-brown
1.90–2.50	fine sand, dark grey
2.50–3.00	organic clay, dark brown; Ag3, Th0.5, Tb0.5, Sh+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.00–3.40	peat, highly decomposed, brown; Th2, Tb2, Sh+, Ag/As+, Ga+; struc.: heterogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
3.40–3.60	detritus gyttja, brown-black; Ld4, Ag/As+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
3.60–4.00	clayey peat; brown; Th2, Tb1.5, Sh+, Ag0.5, As+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
4.00–5.20	peat, dark brown; Th2, Tb2, Sh+, Ag/As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
5.20–5.70	organic clay, dark brown and dark grey-brown; Ag3, As+, Th0.5, Tb0.5, Sh+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
5.70–6.40	peat, weakly decomposed, brown; Th2, Tb2, Sh+, Ag/As+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
6.40–7.00	moss peat, brown and light brown; Tb3, Th1, Sh+, Ag/As+, Ga+; struc.: homogeneous; nig.1/2, strf.0, elas.0, sicc.2, lim.sup.1
7.00–8.30	organic clay, dark grey and dark grey-green; Ag3, As+, Th0.5, Tb0.5, Sh+, Ga+; struc.: heterogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
8.30–8.50	organic clay, dark grey, with numerous shells of molluscs
8.50–10.00	sandy-clayey till, with gravel, light grey

Table 22. Poniatowicze 1 [12]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
P_1-1	***Pinus-Betula-Quercus***	6.70–6.40	Predomination of *Pinus sylvestris* type and *Betula alba* type (both ca. 30%); increasing of *Quercus*, *Ulmus* and *Fraxinus*; still presence of *Corylus avellana*, *Tilia cordata* type, and *Alnus* pollen. The upper boundary: fall of *Pinus sylvestris* type and *Betula alba* type; rise of *Quercus* above 20%.
P_1-2	***Quercus-Ulmus-Fraxinus***	6.25–6.00	Peaks of *Quercus* (57%), *Ulmus* (10%) and *Fraxinus* (3%); rising values of *Corylus avellana*; gradual decrease of *Pinus sylvestris* type and *Betula alba* type. The upper boundary: rapid fall of *Quercus*; rise of *Corylus avellana*.
P_1-3	***Corylus-Tilia-Alnus***	5.70–5.50	Very high proportion of *Corylus avellana* (max. 50%), *Alnus* (max. 33%), and *Tilia cordata* type (max. 12%); decreasing values of *Quercus*, *Ulmus*, and *Fraxinus*; beginning of continuous curve of *Picea abies* type. The upper boundary: rapid decrease of *Corylus avellana* and *Alnus*; rise of *Carpinus betulus*.
P_1-4	***Carpinus***	5.30–4.30	Very high values of *Carpinus betulus* (max. 58%); falling proportion of *Corylus avellana*; percentages *Alnus* from 15 to 20%; rising pollen curve of *Picea abies* type. Two subzones are distinguished. No upper boundary.
P_1-4a	*Corylus*	5.30–4.70	Relatively high proportion of *Corylus avellana* (12.5%) and *Alnus* (11.1%).
P_1-4b	*Picea*	4.60–4.30	Rather high values of *Picea abies* type (max. 19.8%) and Cyperaceae (mx.31.9%).

Table 23. Poniatowicze 2 [12]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
P_2-1	***Quercus-Pinus-Corylus-Ulmus***	8.15–8.00	Domination of *Quercus* (49.3–58.0%); relatively high values of *Corylus avellana* (10.2–14.2%) and *Ulmus* (4.8–5.2%); *Pinus sylvestris* type proportion about 24% and *Betula alba* type below 5%; single pollen grains of *Alnus* (1.2%) and *Tilia cordata* type (to 0.4%); relatively high frequency of *Artemisia* (1.4–3.8%). The upper boundary: rise of *Corylus avellana* above 30% and *Tilia cordata* type to 8.0%; fall of *Quercus*, *Pinus sylvestris* type and *Artemisia*.
P_2-2	***Corylus-Quercus-Tilia***	7.75–7.55	Maximum of *Corylus avellana* (50.5%); high proportion of *Tilia cordata* type (8.0–9.2%); values of *Quercus* decreasing from 48.2% to 27.6%; frequency of *Alnus* rising to 6.4%; *Pinus sylvestris* type below 5% and *Betula alba* type below 1.5%; very low proportion of NAP (to 2%). The upper boundary: decrease of *Corylus avellana* to ca. 20%; rise of *Tilia cordata* type above 15%, *Alnus* above 10%, and *Quercus* above 40%; start of continuous curve of *Carpinus betulus*.
P_2.3	***Tilia-Alnus-Corylus***	7.35–7.15	The peak of *Quercus* (43.1%); maximum of *Tilia cordata* type (15.9%); values of *Corylus avellana* from21.0% to 23.9%; rise of *Alnus* frequency to 20.9% and *Carpinus betulus* to 12.5%; very low frequency of *Pinus sylvestris* type (to 3.5%) and *Betula alba* type (to 1.6%) as well as NAP (to 3%. No upper boundary – above spectrum from depth of 7.15 m there is the sediments no content of pollen.
P_2-4	***Picea-Pinus***	5.95–5.75	Domination of *Picea abies* type (27.1–39.9%); high frequency of *Pinus sylvestris* type (51.6–68.8%); very low values of *Betula alba* type (0.9–2.3%). The upper boundary: decrease of *Picea abies* type; rise of *Betula alba* type above 30% and NAP above 20%.
P_2-4	***Pinus-Betula–*** **NAP**	5.05–2.75	Domination of *Pinus sylvestris* type (58.3–92.3%) and *Betula alba* type (8.6–59.9%); proportion of NAP from 6 to 21%. No upper boundary. The zone is divided into 3 subzones:
P_2-4a	*Pinus-Betula*	5.05	Relativelly low values of *Pinus sylvestris* type and *Betula alba* type (45% and 35%, respectively).
P_2-4b	*Betula*	4.75–4.35	The peak of *Betula alba* type (55–60%).
P_2-4c	*Pinus*	3.95–2.75	The rise of *Pinus sylvestris* type from 45% to 75%; the fall of *Betula alba* type from 40% to 17%.

Podkamionka

The Podkamionka [16] site (53°22′N, 23°24′E; 152.0 m a.s.l.) is located in the western part of the Sokółka Hills approximately 10 km north-west of Sokółka town (Figs 1, 2). The coring was carried out with the use of a geological borer as a part of greater project aimed at preparing the Nowa Wola sheet of Detailed Geological Map of Poland, at scale 1: 50 000 (Kmieciak 2003). The sequence obtained was 14.50 m long. Lake deposits, ca. 6 m in thickness, were explored at a depth of 6.40–12.50 m. Their sequence contains silts and organic silts, and are covered by 6.40 m of sand. Detailed description of the coring is presented in Table 24.

Only 17 collected samples were subjected to pollen analysis. Out of that number no sporomorphs was found in 3 samples (pinpointed at a depth of respectively 12.00, 8.20 and 7.40 m). In 14 remaining samples pollen frequency was high or very high and its preservation is very good throughout the profile. Four local pollen assemblage zones were distinguished in the pollen diagram (Fig. 27, Tab. 25).

Table 24. Podkamionka 1 [16]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.30	soil
0.30–6.40	fine and medium sand, brown
6.40–7.00	silt, sandy at the top, dark grey
7.00–8.10	organic silt, black; Ag2, Th1, Tb1, Sh+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim. sup.1
8.10–8.50	silt, plastic, grey; Ag4, As+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
8.50–9.80	peaty silt, black and brown; Ag3, Th0.5, Tb0.5, Sh+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim. sup.1
9.80–11.20	silt, grey and brown; Ag4, As+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
11.20–11.40	organic silt with, brown; Ag3.5, Sh0.5, As+, Ga+; struc.: heterogeneous; nig.2, strf.0, elas.0, cc.2, lim.sup.1
11.40–13.00	silt, grey; Ag4, As+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
13.00–14.50	sandy silt, watered, grey and yellow

Table 25. Podkamionka 1 [16]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
Pa-1	***Pinus-Betula***	12.50–10.20	Domination of *Pinus sylvestris* type (40–65%) and *Betula alba* type (35–45%); still occurrence of *Quercus* (ca. 3%), *Ulmus* (ca. 2%), and *Salix* (below 1%); relatively high proportion of *Alnus* (4%), *Corylus avellana* (2%), and *Tilia cordata* type (1%) – probably redeposited. The upper boundary: rise of *Quercus* and *Ulmus*; decrease of *Pinus sylvestris* and *Betula alba* types.
Pa-2	***Quercus-Ulmus-Fraxinus***	9.70	Peaks of *Quercus* (42%) and *Fraxinus* (3%); very high *Ulmus* value (8%); percentages of *Pinus sylvestris* type and *Betula alba* type clearly lower then previously (20% and 10% respectively); relatively high proportion of *Corylus avellana* (8%); beginning of continuous curves of *Alnus* and *Tilia cordata* type. The upper boundary: rapid fall of *Quercus, Fraxinus, Pinus sylvestris* type and *Betula alba* type; increase of *Corylus avellana* over 60%.
Pa-3	***Corylus-Tilia-Alnus***	9.60–8.30	Maxima of *Corylus avellana* (60%) and *Ulmus* (11%); *Quercus* proportion below 10%; rather low proportion of *Alnus* (4%) and *Tilia cordata* type (3%); single pollen grains of *Tilia tomentosa*; very low percentages of *Pinus sylvestris* type (9%) and *Betula alba* type (4%). The upper boundary: rise of *Tilia cordata* type and *Alnus*; decrease of *Corylus avellana* and *Ulmus*.
Pa-4	***Corylus-Alnus-Tilia***	9.00–8.30	Very high values of *Alnus* (max. 35%) and *Tilia cordata* type (max. 16%); proportion of *Corylus avellana*, *Quercus*, and *Ulmus* lower than previous zone; start of continuous curve of *Carpinus betulus* and *Picea abies* type; presence of *Hedera helix*, *Viscum*, and *Tilia tomentosa*; very low values of *Pinus sylvestris* type (below 10%) and *Betula alba* type (ca. 4%); very high values of Filicales monolete (8–30%). No upper boundary.
	Barren inter-zone	8.20	No pollen.
Pa-4	***Betula-Pinus-*****NAP**	8.00–7.60	Domination of *Pinus sylvestris* type (30–50%) and *Betula alba* type (30–50%); still occurrence of *Alnus* (below 1%), *Picea abies* type (ca. 0.6%); single pollen grains of *Corylus avellana*, *Tilia cordata* type, and *Carpinus betulus* very low values of other trees; high proportion of NAP (ca. 20%), mainly Cyperaceae, Poaceae, *Artemisia*, and *Ranunculus acris* type. No boundaries.

Starowlany

The Starowlany [8] site (53°30′N, 23°23′E; 172 m a.s.l.) occupies central part of the Sokółka Hills, approximately 9 km north of Sokółka town (Figs 1, 2). The palaeolake in which drilling was carried out lies about 50 m to the west of the Starowlany-Popławce road (Fig. 28). The sediments studied fill the southern part of subglacial basin, that was formed during the Wartanian glaciation. The surface of that basin extends over the area of ca. 700 × 400 m. Nowadays it is used as meadow pasture. Boratyn (2003) provides a detailed description of geomorphology of Starowlany site.

The coring was carried out with the use of a geological drill and constituted a part of the framework aimed at preparing the Sokółka sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Boratyn 2003). The sequence obtained was 7 m long. Peaty silts, peats and organic silts are present at the depth of 4.0–6.6 m, under the cover of diluvial deposits of sands, tills and silts. Organic series are covered by clayey silts. Full description of sediments is showed in Table 26.

Twenty five samples collected at Starowlany profile were subjected to further pollen analysis. Frequency of pollen is high or very high in all samples and its preservation is good or very good. Seven local pollen assemblage zones (L PAZ) were distinguished based on the pollen diagram (Fig. 29, Tab. 27).

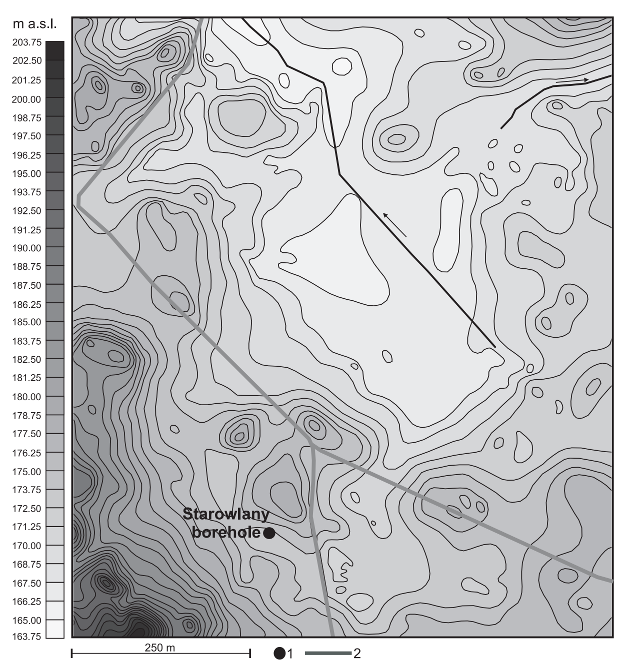

Fig. 28. Starowlany [8]. Location of the site. **1** – studied profile, **2** – roads

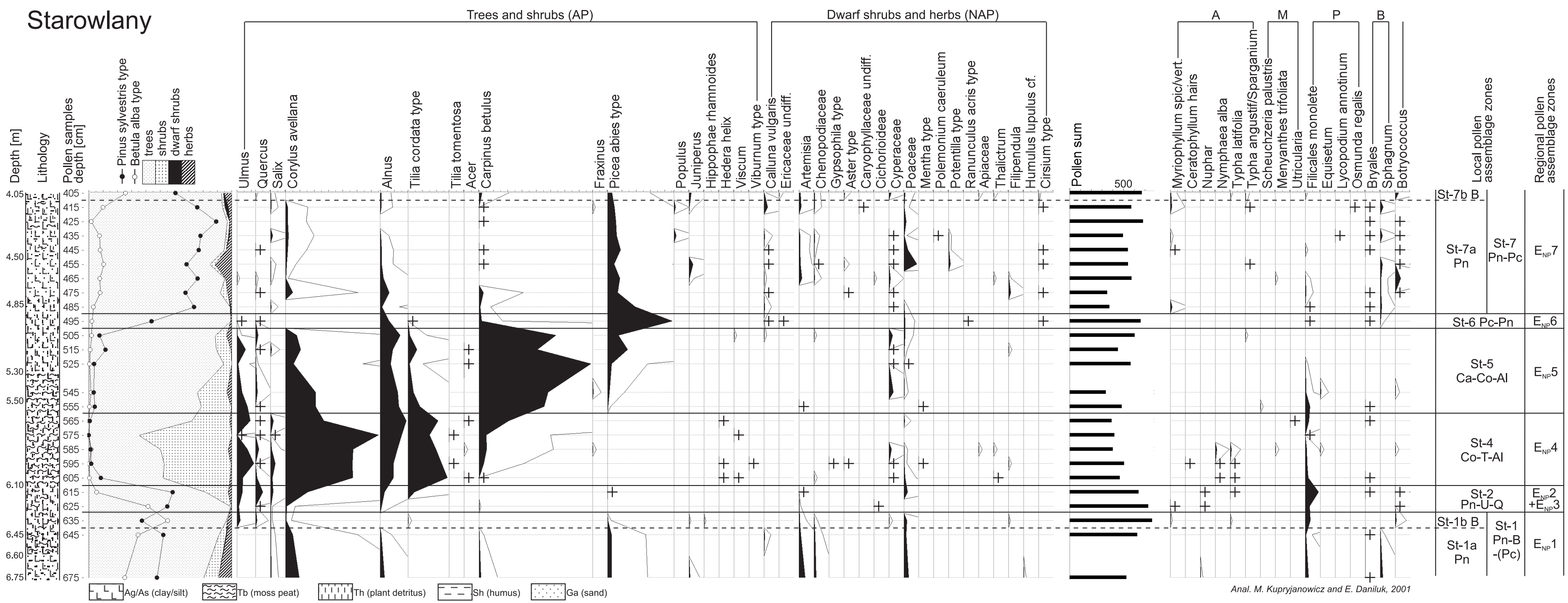

Fig. 29. Starowlany [8]. Percentage pollen diagram; **A** – aquatics, **M** – mire plants, **P –** Pteridophyta, **B –** Bryophyta

Table 26. Starowlany [8]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.80	fine sand, rust
0.80–2.80	till-sandy sediment with gravel, deluvial, horizontally stratified, brown-olive
2.80–3.60	fine and medium sand, dark grey
3.60–4.00	clayey silt, dark grey
4.00–4.50	clayey silt with high content of organic matter, dark brown; Ag3, As0.5, Sh0.5, Th/Tb+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.50–4.85	clayey silt, dark brown; Ag3, As1, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.85–5.30	peaty silt, very dark brown; Ag3.5, Th/Tb0.5, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, icc.2, lim.sup.1
5.30–5.50	peat, weakly decomposed, brown; Tb3, Th1, Ag/As+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, cc.2, lim.sup.1
5.50–6.10	peat, highly decomposed, dark brown; Tb3, Th1, Ag/As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
6.10–6.45	peaty silt, very dark grey; Ag3.5, As+, Th/Tb0.5, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
6.45–6.60	organic silt, clayey, plastic, grey-black; Ag2.5, As0.5, Th/Tb0.5, Sh0.5, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
6.60–7.00	clayey silt, dark grey; Ag3.5, As0.5, Sh+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
7.00–8.50	clayey silt, grey

Table 27. Starowlany [8]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
St-1	***Pinus-Betula-(Picea)***	6.75–6.35	High values of *Pinus sylvestris* type (ca. 40%) and *Betula alba* type (20–30%); still presence of *Picea abies* type. The upper boundary: fall of *Betula alba* type. Two subzones are distinguished:
St-1a	*Pinus*	6.75–6.45	Domination of *Pinus sylvestris* type (ca. 40%); presence of single pollen grains of *Corylus avellana*, *Alnus* and *Carpinus betulus* – probably redeposited.
St-1b	*Betula*	6.35	Maximum of *Betula alba* type (55%); beginning of continuous curves of *Quercus* and *Ulmus*.
St-2	***Pinus-Ulmus-Quercus***	6.25–6.15	High proportion of *Pinus sylvestris* type (55.1–61.7%); maximum of *Quercus* (7%); start of continuous curves of *Corylus avellana*, *Alnus* and *Tilia cordata* type; The upper boundary: rise of *Corylus avellana*, *Tilia cordata* type and *Alnus*; fall of *Pinus sylvestris* type and *Betula alba* type.
St-3	***Corylus-Tilia-Alnus***	6.05–5.65	Very high proportion of *Corylus avellana* (max. 65%) and *Tilia cordata* type (max. 30%); relatively high proportion of *Alnus* (ca. 15%) and *Ulmus* (max. 12%); beginning and gradual rise of continuous curve of *Carpinus betulus* to 5%; the lowest proportion of *Pinus sylvestris* and *Betula alba* types at whole profile. The upper boundary: rapid fall of *Corylus avellana*; increase of *Carpinus betulus*.
St-4	***Carpinus-Corylus-Alnus***	5.55–5.05	Very high proportion of *Carpinus betulus* (max. 55%); decreasing values of *Corylus avellana* (to ca. 15%) and *Tilia cordata* type (to 7%); culmination of *Alnus* (max. 24%); the beginning and rise of continuous curve of *Picea abies* type; increasing percentages of *Pinus sylvestris* type. The upper boundary: fall of *Carpinus betulus* and *Corylus avellana*; increase of *Picea abies* type and *Pinus sylvestris* types.
St-5	***Picea***	4.95	Only one spectrum included. Peak of *Picea abies* type (45%); relatively high values of *Pinus sylvestris* type; low proportion of *Carpinus betulus* (3%) and *Alnus* (ca. 8%). The upper boundary: rise *Pinus sylvestris* type above 50%; fall of *Picea abies* type to ca. 15%.
St-6	***Pinus***	4.85–4.05	Domination of *Pinus sylvestris* type (60–90%); values of *Picea abies* type from 5 to 12%; NAP proportion increasing to 12%; sporadically pollen of *Corylus avellana*, *Alnus* and *Carpinus betulus*. No upper boundary. Two subzones are distinguished:
St-6a	*Pinus*	4.85–4.15	Very high proportion of *Pinus sylvestris* type, with maximum of 90%; values of *Betula alba* type ca. 10%.
St-6b	*Betula*	4.05	Relatively high values of *Betula alba* type (27%).

Bohoniki

The Bohoniki [15] site (53°23′N, 23°36′E; 167 m a.s.l.) is located in central part of the Sokółka Hills around 5 km south-east of Sokółka town (Figs 1, 2). It lies in valley depression of the Bohon mire and it covers the area of ca. 500 × 200 m. Hills reaching up to ca. 200 m a.s.l. surrounds the site in question.

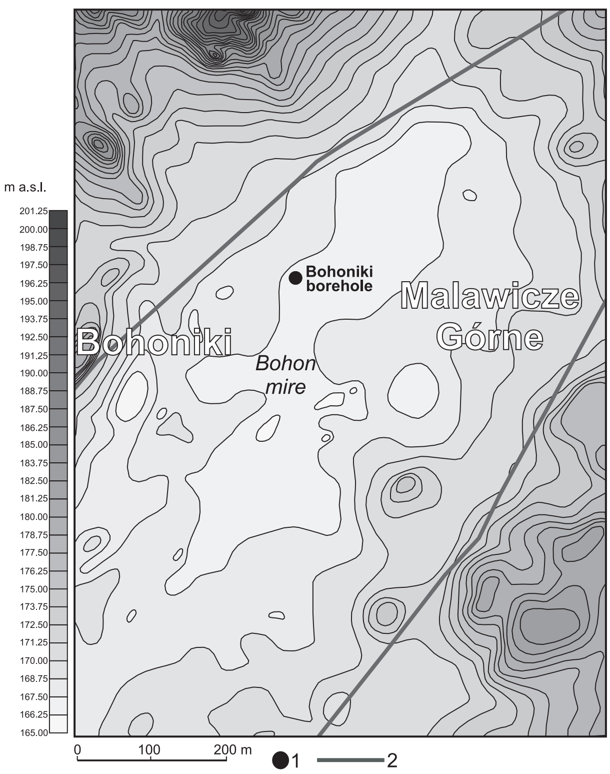

Fig. 30. Bohoniki [15]. Location of the site. **1** – studied profile, **2** – roads

The coring was carried out by means of a mechanical corer. Fieldwork upon this site accompanied preparation of the Sokółka sheet of the Detailed Geological Map of Poland, in scale of 1: 50 000 (Boratyn 2003). The coring was placed approximately 100 m of the Bohoniki-Malawicze road (Fig. 30). The sequence obtained was 4 m long. Organic silts, peats and sandy peats appear at the depth of 2.20–3.55 m under the layer of diluvial sediments – sands and silty slope tills. Their description is showed in Table 28.

Table 28. Bohoniki [15]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.30	sandy soil, grey
0.30–1.00	fine sand, clayey, light grey
1.00–1.80	fine sand, grey
1.80–2.20	till-silt diluvial sediment, light grey with rust streaks
2.20–2.80	clayey silt, grey; Ag3.5, As0.5, Sh+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
2.80–3.00	organic silt, peaty, black; Ag3, As0.5, Th/Tb0.5, Sh+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim. sup.1
3.00–3.10	clayey silt with organic matter, dark brown; Ag3, As1, Th/Tb+, Sh+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.10–3.33	peat, black; Tb2, Th2, Sh+, Ag/As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.33–3.60	sandy peat, black-brown; Tb2, Th1, Sh+, Ga0.5, Ag/As0.5; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim. sup.1
3.60–3.65	varigrained sand, grey
3.65–4.00	silty sand, grey-green

Ten samples collected at Bohoniki profile were subjected to pollen analysis. Frequency of pollen is high or rather high in all samples and its preservation is good or rather good. In respect to the pollen diagram 3 local pollen assemblage zones were distinguished (Fig. 31, Tab. 29).

Table 29. Bohoniki [15]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description of the local pollen assemblage zones
B-1	***Corylus-Tilia-Alnus***	3.60–3.30	Very high proportion of *Corylus avellana* pollen (max. 45%); high proportion of *Tilia cordata* type (10–16%) and *Alnus* (16%). The upper boundary: rapid rise of *Carpinus betulus* values to 40%; fall of *Corylus avellana* and *Tilia cordata* type.
B-2	***Carpinus-Corylus-Alnus***	3.25	Rising proportion of *Carpinus betulus* (to 40%); slight fall of *Corylus avellana*, *Tilia cordata* type and *Alnus* (to 27, 5 and 13%, respectively). No upper boundary – hiatus is probably present above top spectrum.
B-3	***Pinus-Betula*-NAP**	3.10–2.90	Domination of *Pinus sylvestris* type (40–50%) and *Betula alba* type (18–35%); NAP proportion increasing from 6 to 21%. No boundaries.

Drahle

The Drahle [14] site (53°23′N, 23°23′E; ca. 165 m a.s.l.) occupies central part of the Sokółka Hills, approximately 4 km south-east of Sokółka town (Figs 1, 2). It lies on the north side of dry valley that was shaped along the track of past watershed of meltwater (Boratyn 2003). The surface of the basin extends over the area of ca. 700 × 200 m (Fig. 32). It is surrounded from all sides by hills reaching up to ca. 185 m a.s.l. Today the area in question serves as a meadow pasture.

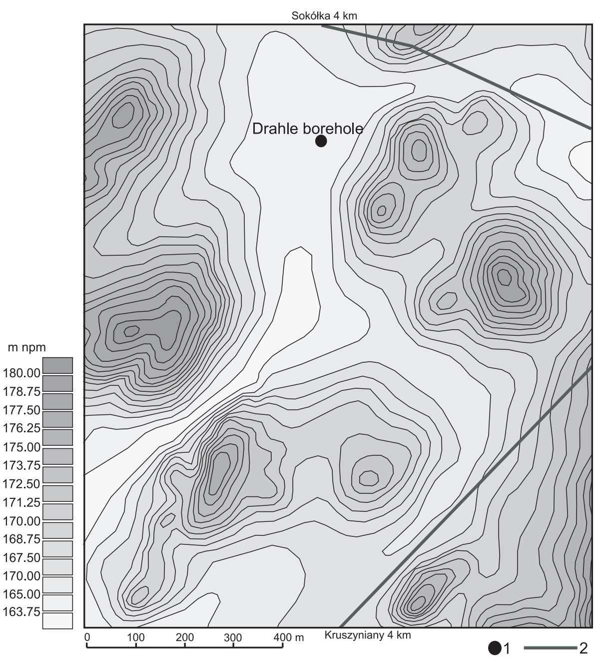

Fig. 32. Drahle [14]. Location of the site. **1** – studied profile, **2** – roads

Table 30. Drahle [14]. Lithology of the profile.

Depth (m)	Sediment description
0.00–0.30	clayey soil, grey
0.30–0.80	clay, grey-beige
0.80–1.00	fine sand, grey
1.00–2.00	silt-sand-clay diluvial sediment, with gravel (to 1 cm), grey and dark grey
2.00–2.10	varigrained sand with fine gravel, brown-grey
2.10–2.30	diluvial till sediment, sandy, grey
2.30–2.50	fine sand, grey
2.50–3.30	clayey silt, grey; Ag3, As1, Sh+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.30–3.40	peaty silt, grey-brown; Ag3, As+, Th/Tb1, Sh+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.40–3.70	sandy peat, brown; Tb1.5, Th1.5, Sh0.5, Ga0.5, Ag/As+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.70–3.85	peaty silt, grey-brown; Ag3, Th/Tb1, Sh+, As+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
3.85–4.00	peat, black-brown; Tb2, Th1.5, Sh0.5, Ga+, Ag/As+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.00–4.10	sandy silt with admixture of peat, dark grey; Ag3, Ga0.5, Th/Tb0.5, Sh+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.10–4.30	fine sand with admixture of larger grain, grey
4.30–5.50	silty fine sand and sandy silt, grey
5.50–7.00	silty fine sand with small admixture of larger grain, grey
7.00–8.50	sand with single grains of gravel (up to 4 mm)

Table 31. Drahle [14]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description of the local pollen assemblage zones
D-1	***Corylus-Quercus***	4.10–4.00	High values of *Corylus avellana* (39.8–45.6%) and *Quercus* (14.0–16.1%); rather high proportion of *Alnus* (6.6–8.5%) and *Tilia cordata* type (to 5.4%). The upper boundary: rise of *Carpinus betulus* above 20%; decrease of *Corylus avellana*, *Quercus* and *Ulmus*.
D-2	***Corylus-Tilia***	3.95	Pollen values of *Corylus avellana* persist high (39.2%); proportion of *Tilia cordata* type higher then previously (10.1%); *Carpinus betulus* curves attains 22.6%. The upper boundary: fall of *Corylus avellana* to ca. 20%; small increase of *Carpinus betulus*.
D-3	***Carpinus-Alnus***	3.85–3.60	*Carpinus betulus* pollen values rising from 27.0% to 57.6%; gradual decrease of *Corylus avellana* to 12.7% and *Tilia cordata* typ to 1.4%. No upper boundary: 40 cm layer of sediments, which not were analysed, is present above top spectrum.
D-4	***Pinus-Betula*-NAP**	3.20–2.70	Domination of *Pinus sylvestris* type (46.8–58.1%); curve of *Betula alba* typ rising from 16.2% to 39.2%; very low values of other trees; rather high proportion of NAP (ca. 10–15%). No boundaries.

The coring was carried out using a geological drill. It was conducted in accordance with preparing the Sokółka sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Boratyn 2003). The coring lies approximately 100 m of the Sokółka-Suchynicze road (Fig. 32). The profile contains peaty silts and peats (4.1–2.7 m). These on the other hand are covered by clays, fine sands, aluvial sandy tills. Underneath clayey sands and sands with gravel grains can be found. Description of sediments is summarized in Table 30.

Only 9 samples collected from the Drahle profile were subjected to pollen analysis. Frequency of pollen is high or very high in all samples and its preservation is good or rather good. In accordance with pollen diagram three local pollen assemblage zones were distinguished (Fig. 33, Tab. 31).

Chwaszczewo

The Chwaszczewo [9] site (53°30′N, 23°21′E; 180.0 m a.s.l.) is located in the western part of the Sokółka Hills approximately 15 km northwest of Sokółka (Figs 1, 2).

The coring was carried out by means of a geological drill. It was conducted in accordance with preparing the Nowowola sheet of the Detailed Geological Map of Poland, in the scale 1: 50 000 (Kmieciak 2003). The sequence obtained was 10 m long. The lake deposits, over 6.5 m in thickness, are placed at a depth of 1.20–8.00 m. Their description is showed in Table 32. The lacustrine series are covered by approximately one metre of diluvial deposits.

Table 32. Chwaszczewo [9]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.90	fine and medium sand, grey, with wood fragments
0.90–1.20	sandy clay, brown, plastic (diluvial deposit)
1.20–1.70	varigrained sand, grey-brown and rust
1.70–2.20	clay, grey and grey-green, compact, with traces of sand
2.20–2.65	organic silt slightly clayey, very dark brown, plastic, with traces of charcoals; Ag3.5, As0.5, Sh+, Th+, Tb+, struc.: very homogenous, nig.3, strf.0, elas.0, sicc.2, lim. sup.0
2.65–7.50	sandy silt with single grains of gravel, grey, plastic, compact
7.50–8.00	varigrained sand, grey
8.00–10.00	sandy till, with gravel, light grey, plastic

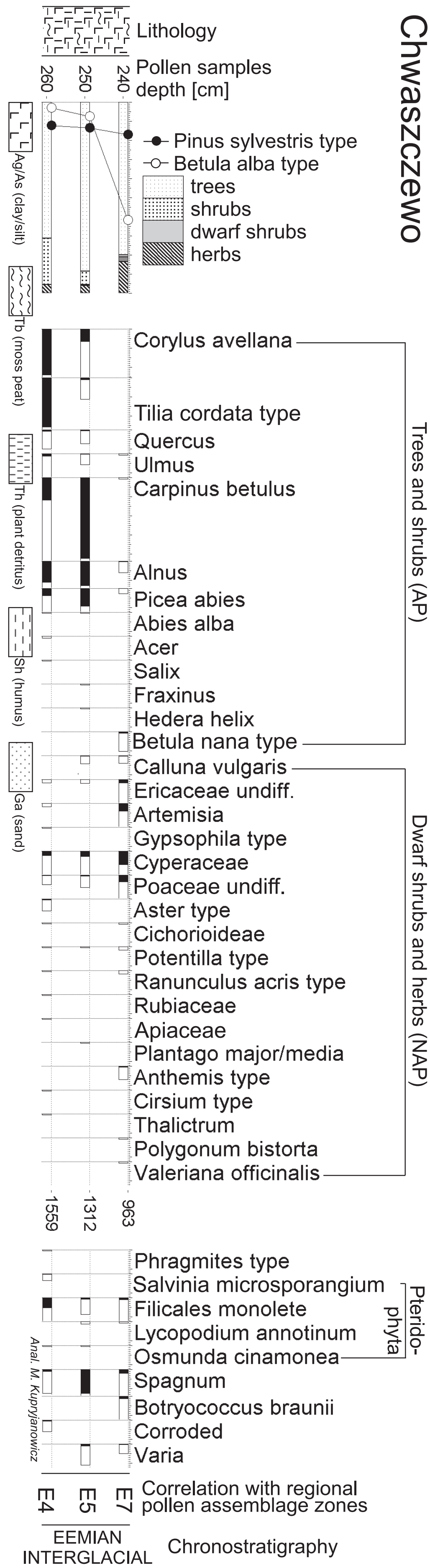

Fig. 34. Chwaszczewo [9]. Percentage pollen histogram

Table 33. Chwaszczewo [9]. Description of pollen spectra

Depth (m)	Description
3.50, 3.00	High values of *Pinus sylvestris* type (39.3–52.5%); percentages of *Betula alba* type decreasing from 7.5% to 3.8%; high proportion of *Carpinus betulus* (15.8–30.0%), *Picea abies* type (5.5–12.9%), *Alnus* (2.9–5.6%), *Corylus avellana* (2.9–3.8%), and *Tilia cordata* type (1.6–2.9%); low values of NAP (below 10%).
2.60	Values of *Tilia cordata* type and *Corylus avellana* very high (26.0% and 24.2% respectively); percentages of *Carpinus betulus* and *Alnus* are of ca. 10%; relatively high *Picea abies* type proportion (3.9%); presence of *Ulmus* (1.5%) and *Quercus* (1.0%); very low values of *Pinus sylvestris* type (12.3%) and *Betula alba* type (2.9%); NAP proportion ca. 5%.
2.50	Maximum of *Carpinus betulus* (42.5%); proportion of *Tilia cordata* type (1.1%) and *Corylus avellana* (6.8%) much lower than previous spectrum; values of other taxa similar as early; presence of Hedera *helix*.
2.40	Domination of *Betula alba* type (61.8%); *Pinus sylvestris* type below 20%; single pollen grains of other trees, such as *Ulmus*, *Carpinus betulus*. and *Picea abies* type; relatively high proportion of NAP (20%); occurrence of *Betula nana* type (1.0%).

Only 3 samples collected were subjected to pollen analysis. Frequency of pollen is high or very high in all samples and its preservation is good or very good. Little number of samples prevented discerning clear local pollen zones out of the pollen diagram (Fig. 34). A short description of pollen spectra is showed in Table 33.

Trzcianka

The Trześcianka [10] site (53°28′N, 23°22′E; 176.0 m a.s.l.) is located in western part of the Sokółka Hills placed around 10 km northwest of Sokółka town (Figs 1, 2). The core was obtained using a geological drill. Fieldwork performed at that site constituted a part of preparation of the Nowowola sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Kmieciak 2003). The lake deposits, 4.60 m in thickness, were present at the depth of 1.20–5.80 m. Their description is presented in Table 34. The lacustrine series are covered by a one metre layer of sand mixed up with gravel and clay.

Table 34. Trzcianka [10]. Lithology of the profile

Depth (m)	Sediment description
0.00–1.20	sand, with clay and gravel, grey-brown
1.20–2.80	sandy silt, plastic, dark grey
2.80–4.00	sandy silt, plastic, brown; Ag3.5, Ga0.5, Sh+, struc.: homogenous, nig.2+, strf.0, elas.0, sicc.2, lim.sup.0
4.00–5.00	silt, grey; Ag4, As+, Ga+, Sh+, struc.: very homogenous, nig.2, strf.0, elas.0, sicc.2, lim.sup.0
5.00–5.80	organic silt, brown; Ag3.5, Sh0.5, Th/Tb+, struc.: homogenous, nig.2+, strf.0, elas.0, sicc.2, lim.sup.0
5.80–7.00	sand, grey
7.00–8.50	till with stones, grey

Only 4 samples collected were suitable for further pollen analysis. Pollen frequency is high or very high in all of them and their preservation is good. Little number of samples prevented discerning clear local pollen zones out of the pollen diagram (Fig. 35). A short description of pollen spectra is showed at Table 35.

Table 35. Trzcianka [10]. Description of pollen spectra

Depth (m)	Description
5.30	Very high proportion of *Carpinus betulus* (60.9%); relatively high values of *Alnus* (13.8%) and *Corylus avellana* (10.8%) as well as *Quercus* (1.8%), *Ulmus* (1.1%), *Tilia cordata* type (0.7%), and *Picea abies* type (1.6%); single pollen grains of *Abies alba*, *Acer*, *Fraxinus*, and *Viscum*; very low percentages of *Pinus sylvestris* type (4.1%) and *Betula alba* type (4.5%).
5.00	Domination of *Pinus sylvestris* type (59.0%); high values of *Betula alba* type (14.2%) and NAP (ca. 15%); relatively high proportion of *Picea abies* type (5.4%), *Alnus* (2.1%), and *Carpinus betulus* (2.1%); presence of *Juniperus* (1.0%) and *Salix* (0.2%); single pollen grains of *Corylus avellana*, *Quercus*, *Tilia cordata* type, and *Tilia tomentosa*.
4.30	Culmination of *Betula alba* type (71.4%); value of *Pinus sylvestris* type is 16.0%; low NAP proportion (ca. 7%); presence of *Betula nana* type (2.8%), *Juniperus* (0.9%), and single pollen grains of *Carpinus betulus*, *Alnus*, and *Picea abies*.
3.50	Very high proportion of NAP (ca. 42%), mainly of *Artemisia* (18.5%), *Ranunculus acris* type (11.5%), Cyperaceae (4.1%), Poaceae (2.6%), Caryophyllaceae (1.4%), and *Helianthemum* (1.0%); high values of *Betula nana* type (11.5%) and *Juniperus* (1.0%); domination of *Betula alba* type (29.3%) and *Pinus sylvestris* type (13.9%) among trees; relatively high percentages of *Picea abies* type (1.2%); sporadic occurrence of *Alnus*, *Carpinus betulus*, *Corylus avellana*, and *Tilia cordata* type.

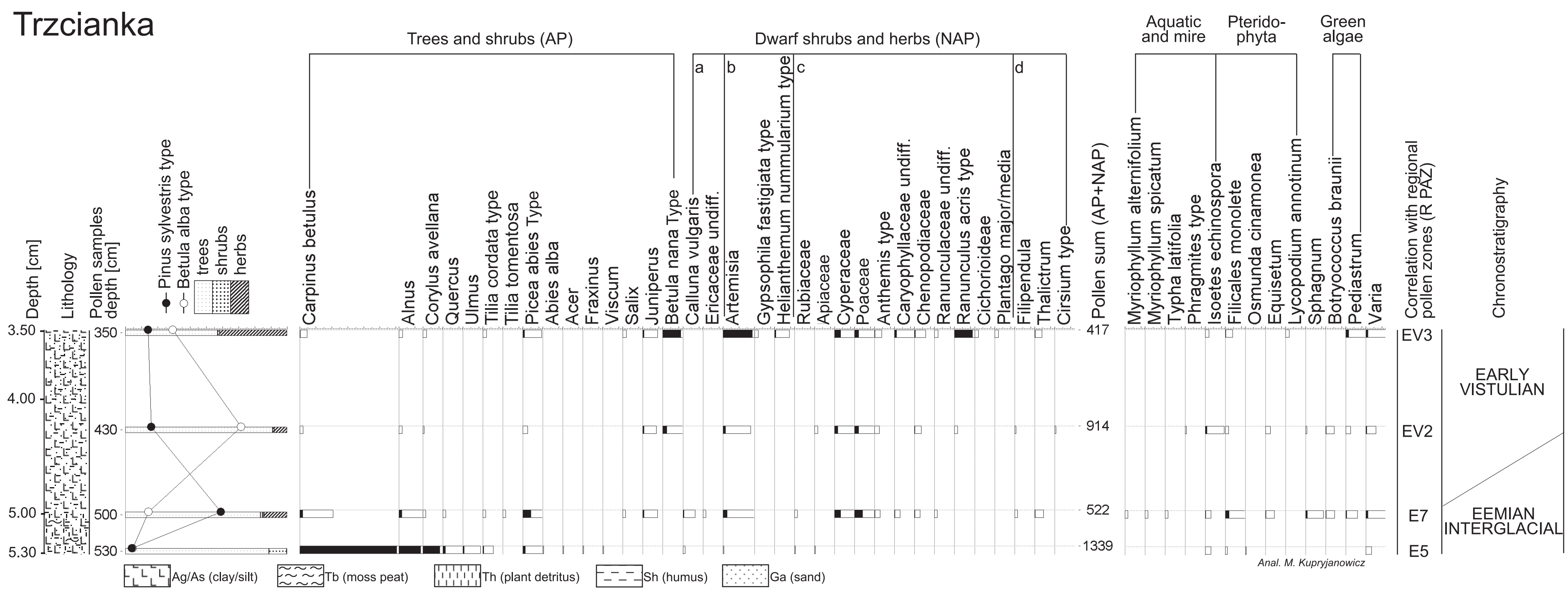

Fig. 35. Trzcianka [10]. Percentage pollen histogram; **a** – dwarf shrubs, **c** – plants of open, dry to fresh habitats, **d** – ecologically undefined taxa, **e** – plants of open, fresh to wet habitats

Gilbowszczyzna

The Gilbowszczyzna [11] site (53°27′N, 23°24′E, 164.0 m a.s.l.) lies in the western part of the Sokółka Hills around 8 km north-west of Sokółka town (Figs 1, 2). The profile was carried out using a geological drill as a part of greater project aimed at preparing the Nowowola sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Kmieciak 2003). Palaeolake deposits, ca. 5 m in thickness, were cored at the depth of 2.50–7.55 m. Their description is presented in Table 36. Lacustrine series are covered by 2.5 metre of fine sand.

Only 5 collected samples were suitable for pollen analysis. Pollen frequency is high or very high in all of them and its preservation is good or rather good. Little number of samples did not allow to properly discern local pollen zones out of the pollen diagram (Fig. 36). A short description of pollen spectra is gathered in Table 37.

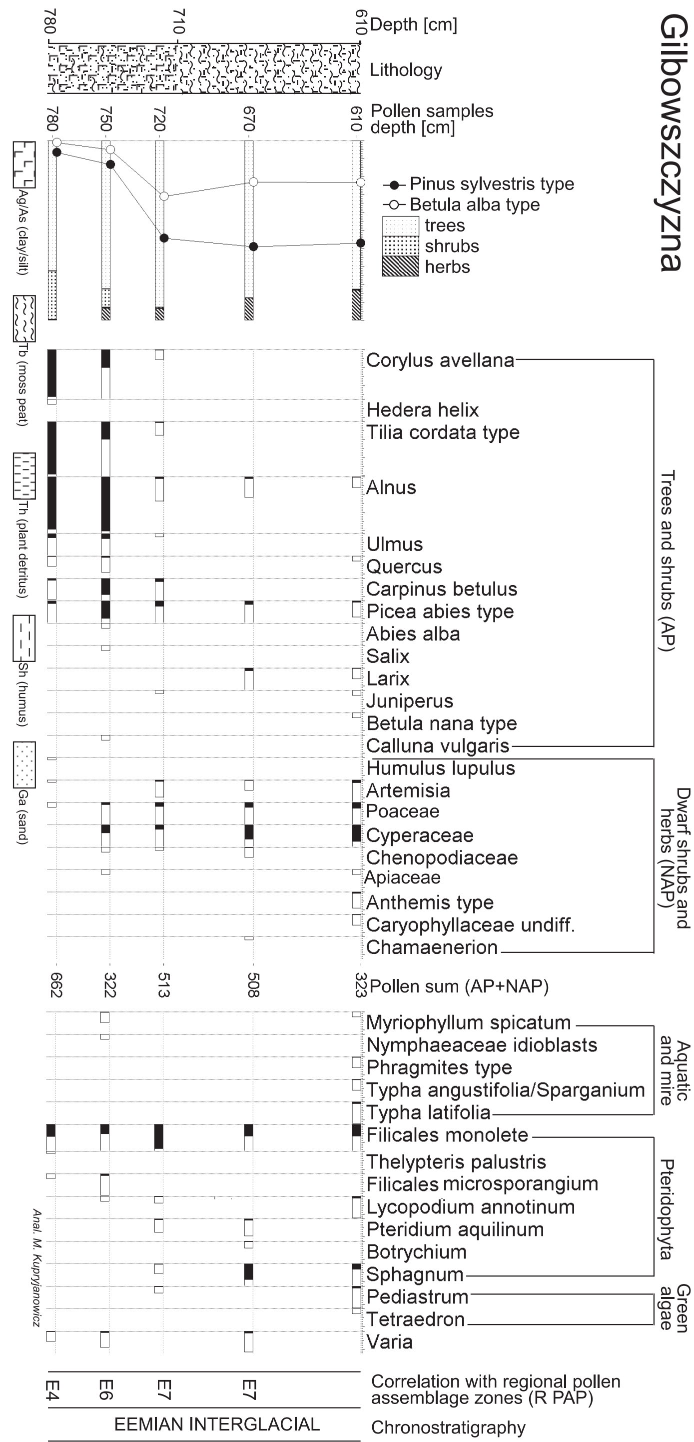

Fig. 36. Gilbowszczyzna [11]. Percentage pollen histogram

Table 36. Gilbowszczyzna [11]. Lithology of the profile

Depth (m)	Sediment description
0.00–2.50	fine sand, brown
2.50–6.00	sandy silt, plastic, grey
6.00–7.10	peat with wood fragments, dark brown; Th2, Tb2, Sh+, Ag/Ag+, Ga+, struc.: homogenous, nig.2+, strf.0, elas.0, sicc.2, lim.sup.0
7.10–7.55	sandy silt, with organic matter, dark grey; Ag3.5, Sh0.5, Th/Tb+, struc.: homogenous, nig.2, strf.0, elas.0, sicc.2, lim.sup.0

Table 37. Gilbowszczyzna [11]. Description of pollen spectra

Depth (m)	Description
7.80	High proportion of *Corylus avellana* (26.6%), *Tilia cordata* type (29.5%) and *Alnus* (29.5%); values of NAP (0.7%) as well as *Pinus sylvestris* type (6.5%) and *Betula alba* type (1.1%) very low; presence of *Ulmus* (2.6%), *Quercus* (0.6%), *Carpinus betulus* (1.2%), *Picea abies* type (1.7%), and *Hedera helix* (0.3%) pollen.
7.50	Domination of *Alnus* (30.4%); values of *Carpinus betulus* (9.3%) and *Picea abies* type (9.9%) slightly higher then previously; proportion of *Corylus avellana* (10.2%) and *Tilia cordata* type (9.9%) above two-time lower then early spectrum; percentages of *Pinus sylvestris* type (13.4%) and *Betula alba* type (5.0%) still relatively low.
7.20, 6.70 and 6.10	Domination of *Pinus sylvestris* type (54.2–59.1%) and *Betula alba* type (23.0–31.0%); NAP proportion increases from 5 to 16%; still presence of *Picea abies* type (0.9–3.3%) and *Alnus* (0.6–1.4%); sporadic occurrence of *Carpinus betulus*, *Ulmus, Quercus,Tilia cordata* type, and *Larix*.

Harkawicze

The Harkawicze [20] site (53°20′N, 23°44′E, 157 m a.s.l.) is to be found in the east-southern part of the Sokółka Hills approximately 16 km south-east of Sokółka town (Figs 1, 2). It lies in central part of a depression with no water outflow (Fig. 37). The surface of the basin extends over the area of ca. 700 × 300 m.

The boring was carried out using a geological drill. It supplemented preparations of the Sokółka sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Boratyn 2003). The sequence in question was approximately 7 m long. Organic silts and peats are placed under the layer of silts and sands at the depth of 3.00–7.15 m. All the above described sediments are placed on the layer of glacial tills

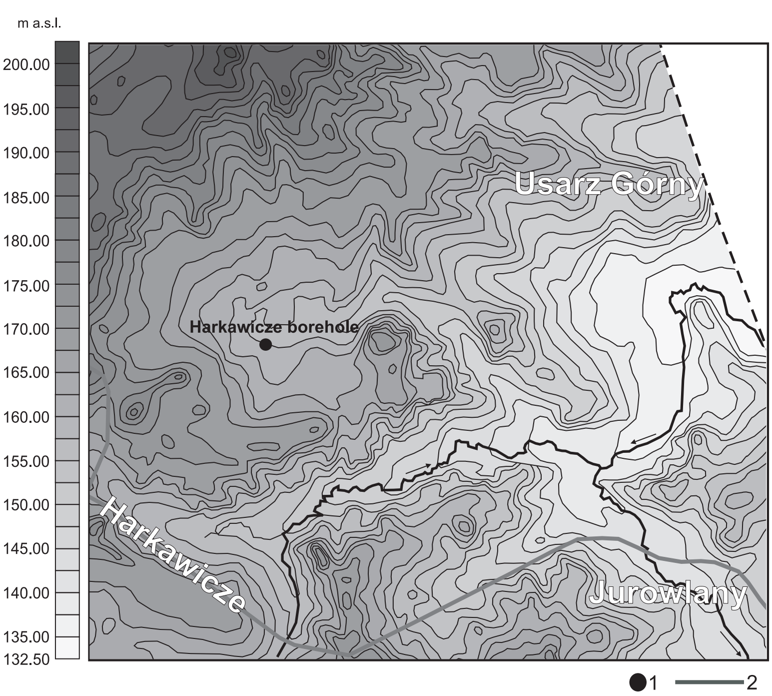

Fig. 37. Harkawicze [20]. Location of the site. **1** – studied profile, **2** – roads

and sands with gravels. A description of the sediments is showed in Table 38.

Only 6 samples collected were suitable for further to pollen analysis. Pollen frequency is high or very high in all of them and its preservation is good. According to the pollen diagram three local pollen zones were distinguished (Fig. 38, Tab. 39).

Table 38. Harkawicze [20]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.20	clayey soil
0.20–0.90	organic silt, dark brown
0.90–1.20	peaty silt, black
1.20–1.80	fine-medium sand with single grains of gravel (to 3 mm) and stones (to 7 mm), slightly silty, yellow-grey
1.80–3.40	calcareous silt, white-grey Ag2, As1, Lc1, Ga+; struc.: homogeneous; nig.1, strf.0, elas.0, sicc.2, lim.sup.1
3.40–3.70	silt, light green; Ag3, As1, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.70–3.90	silt, dark grey with laminas of beige and black silt; Ag3, As1, Sh+, Ga+; struc.: homogeneous; nig.2/3, strf.0, elas.0, sicc.2, lim.sup.1
3.90–4.00	organic silt, dark brown; Ag2.5, Sh1.5, Th/Tb+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.00–4.30	silt with fragments of molluscs shells, dark grey-olive; Ag2.5, As1, Lc0.5, Sh+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.30–5.30	sandy silt, dark grey; Ag3, Ga1, As+, Sh+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
5.30–5.50	sandy silt, olive; Ag3, Ga1, As+, Sh+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
5.50–5.70	peat, dark brown; Tb3.5, Th0.5, Sh+, Ag/As+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
5.70–6.00	peaty silt, dark brown; Ag3, Th0.5, Tb0.5, Sh+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
6.00–6.70	peat, dark brown; Tb3.5, Th0.5, Sh+, Ag/As+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
6.70–7.00	peaty silt, dark grey-brown; Ag3, Th0.5, Tb0.5, Sh+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
7.00–7.30	peat, weakly decomposed, black; Tb3.5, Th0.5, Ag/As+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
7.30–7.60	till, strongly sandy, with gravel (to 4 mm) and stones (to 8 mm), blue-grey
7.60–8.50	fine sand, with single gravels and stones (to 10 mm), blue-grey

Table 39. Harkawicze [20]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description of pollen spectra
H-1	***Corylus-Quercus***	7.15	Very high values of *Corylus avellana* (33%) and *Quercus* (25%); relatively hight proportion of *Pinus sylvestris* type (15%) and *Alnus* (7%) as well as *Ulmus* (4%) and *Tilia cordata* type (2%). The upper boundary: rapid increase of *Corylus avellana* above 50%; fall of *Quercus* and *Pinus sylvestris* type.
H-2	***Corylus-Tilia-Alnus***	6.85–6.35	Domination of *Corylus avellana* (45–65%); high proportion of *Alnus* (16–22%) and *Tilia cordata* type (8–12%); relatively high values of *Ulmus* (6–8%) and *Quercus* (ca. 4%); very low proportion of *Pinus sylvestris* type (1–2%) and *Betula alba* type (below 1%). The upper boundary: rise of *Carpinus betulus* to 30%; decrease of *Corylus avellana* and *Tilia cordata* type.
H-3	***Carpinus-Alnus***	5.85–4.05	Highest values of *Carpinus betulus* (25–55%); gradually decreasing proportion of *Corylus avellana*, *Tilia cordata* type to, *Ulmus* and *Quercus*; percentages of *Alnus* similar as early two samples; rising values of *Picea alba*, *Pinus sylvestris* type and *Betula alba* type. No upper boundary – 1m layer of sediments above the top spectrum was not analysed
H-4	***Pinus-Betula***	3.00	Domination of *Pinus sylvestris* type (82%) and presence of only two other tree pollen taxa – *Betula alba* type (13%) and *Picea abies* (1%). No boundaries.

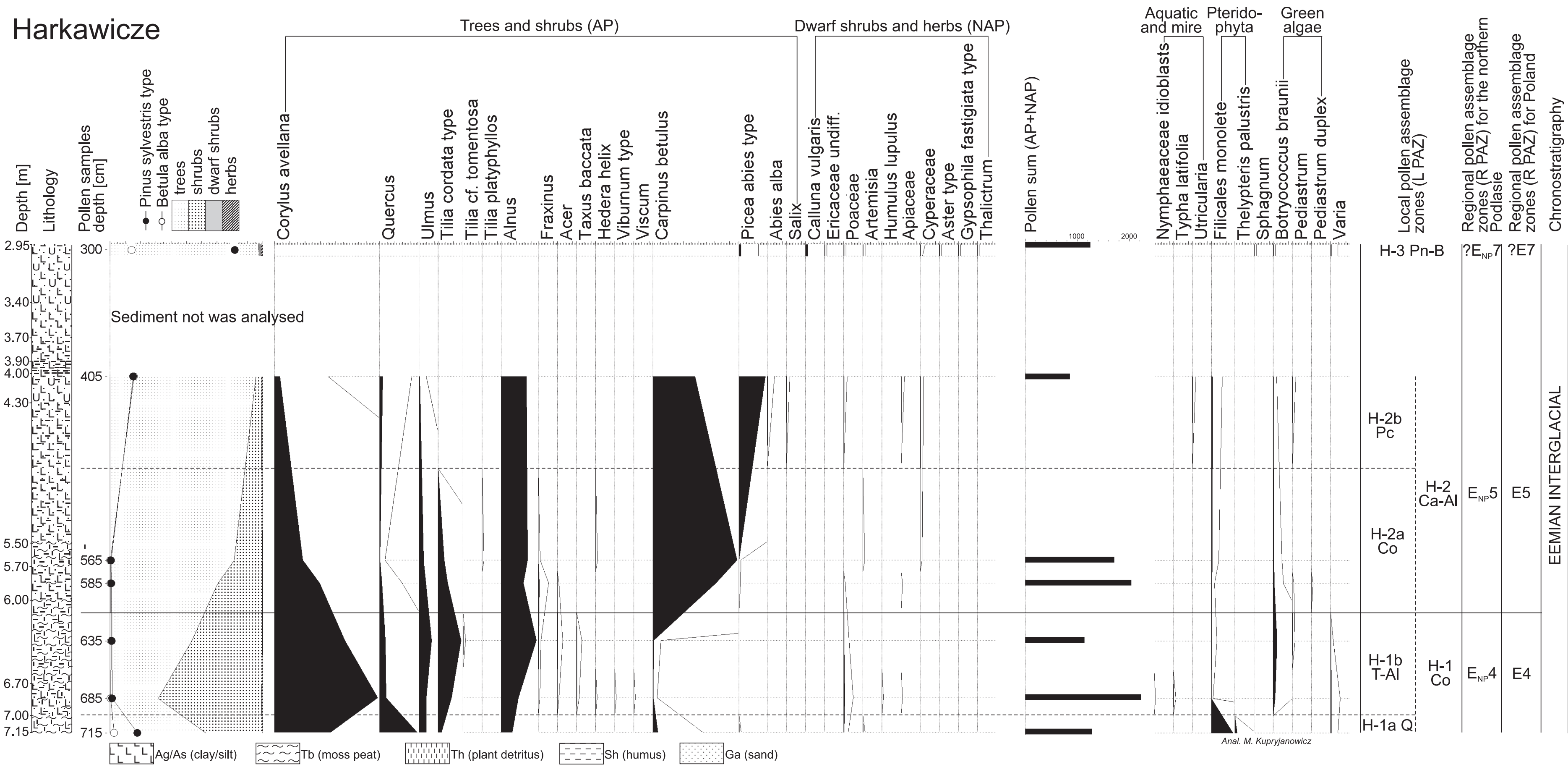

Fig. 38. Harkawicze [20]. Percentage pollen diagram

BIELSK UPLAND

Proniewicze

The Proniewicze P-3 [33] site (52°48′N, 23°12′E; 143.5 m a.s.l.) occupies northern part of the Bielsk Upland being located approximately 5 km north of Bielsk Podlaski (Figs 1, 2). Its location corresponds with ice-melting plain which is to the west from the Proniewicze village (Fig. 39). Vast kame terrace distinguishes north-eastern part of the Bielsk Upland, being placed west of the line delimited by towns of Bielsk Podlaski and Proniewicze-Haćki (Brud 2001, Kmieciak 2001, Brud & Kupryjanowicz 2002, Ber 2005). It is characterized by almost flat floor that reaches the height of 140.0 m a.s.l. (Fig. 39). It consists of silts and silty sands with traces of varved clays and gravels (Brud 2001). There are numerous small melt depressions with biogenic deposits covered by diluvial sediments on the surface of the terrace. At one of the depressions, i.e. Proniewicze P-3, boring was conducted. Its palaeolake deposits were suitable for pollen analysis (Fig. 39).

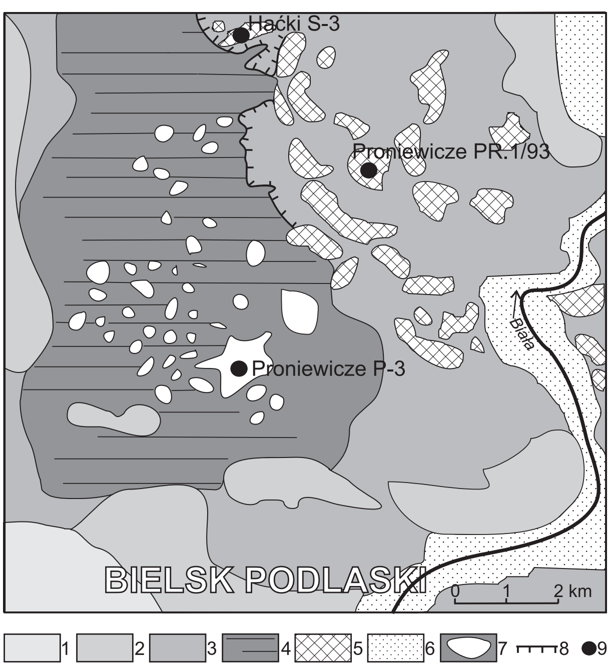

Fig. 39. Simplified geomorphological skech of the Proniewicze region and location of the sites studied by pollen analysis. The Warta glaciation: **1** – end moraine, **2** – tills and fluvioglacial deposits, **3** – ice-marginal deposits, **4** – kame terrace, **5** – limnoglacial kames; the Eemian interglacial, Vistulian and Holocene: **6** – fluvial terraces of the Biała river, **7** – shallow hollows filled with biogenic deposits, **8** – edge of escarpment, **9** – location of borings mentioned in the text (acc. Brud & Kupryjanowicz 2002, modified)

From the east the basin adheres a vast depression (almost 25 km^2) studded with many kames (Mojski & Nowicki 1961, Ber et al. 1964, Brud 2001, Kmieciak 2001). It constitutes end depression shaped by ice masses dated back to the stage of maximum ice cap coverage of the Wkra stadial in the Wartanian glaciation (Ber 2005). It is formed mainly by marginal lake sediments, rarely by diluvial tills, diluvial and mire sediments that appear between various kame forms. Small depressions with organic sediments of the Eemian interglacial (Fig. 39) are situated on flattened ridges of the banks and kame hummocks (Krupiński 1995, Brud & Kupryjanowicz 2002, Kupryjanowicz 2005b). These depressions are probably the remains of dead ice lumps (Ber 2005).

The research area is surrounded by postglacial upland that reaches the height of 166.5 m a.s.l. The landscape is not so diversified and is crossed by rather wide and shallow dry valleys with flat floor (Fig. 39).

The boring was carried out with the use of a geological borer, 12 cm in diameter, by the Geofizyka Toruń Ltd. It was a part of fieldwork set to prepare the Bielsk Podlaski sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Brud 2001). Organic silts appear at the depth of 4.70–5.27 m under the cover of sandy clays. Their description is showed in Table 40.

The pollen percentage diagram was divided into 4 local pollen assemblage zones (Fig. 40, Tab. 41).

Table 40. Proniewicze P-3 [33]. Lithology of the profile

Depth (m)	Sediment description
4.00–4.10	clayey silt, beige
4.10–4.13	fine sand, light beige
4.13–4.30	sandy silt with fine gravel (to 1 cm), beige
4.30–4.68	organic silt, black; Ag2.5, Sh1.5, Th/Tb+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.68–5.00	organic silt with traces of clay and sand, dark grey; Ag2.5, As0.5, Ga0.5, Sh0.5, Th/Tb+, struc.: heterogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
5.00–5.27	organic clayey silt, black; Ag2.5, As1, Sh0.5, Th/Tb+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
5.27–6.00	clayey silt with thin layers of organic matter and with small content of $CaCO_3$ at the top, green

Table 41. Proniewicze P-3 [33]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
Pe-1	***Pinus-Betula-Quercus***	5.25–5.10	Domination of *Pinus sylvestris* type (60.6–71.2%); still presence of *Quercus* (1.5–1.7%) and *Ulmus* (0.5–1.2%); *Betula alba* type from 17.4% to 26.2%; NAP ca. 10% – mainly Poaceae undiff. (6.4–8.2%). The upper boundary: increase of *Quercus* above 25%; start of continuous pollen curve of *Fraxinus*.
Pe-2	***Quercus-Ulmus-Fraxinus***	5.00–4.70	Very high values of *Quercus* (28.1–42.0%); high *Ulmus* proportion (2.4–6.0%); low–percentage, continuous pollen curve of *Fraxinus* (to 1.2%). The zone has not the upper boundary
Pe-3	***Pinus-Betula***	4.69–4.35	Domination of *Pinus sylvestris* type (33.8–38.3%) and *Betula alba* type (34.5–43.4%); single pollen grains of *Picea abies* type (to 0.9%), *Corylus avellana* (to 0.8%), *Alnus* (to 1.0%), and *Salix* (to 0.3%); NAP ca. 15% – mainly Cyperaceae (3.9–15.2%) and *Artemisia* (1.8–5.9%). The zone has not the upper boundary.

Wólka

The Wólka [35] site (52°44′N, 23°17′E; 143 m a.s.l.) is located in central part of the Bielsk Upland around 7 km south-east of Bielsk Podlaski town (Figs 1, 2). It lies slightly to the south from the Wólka village (Fig. 41), in a minute depression, ca. 50 m in diameter, with no water outflow. The depression itself is located on a moraine plateau formed by glacial tills of the Wartanian glaciation.

Two borings analysed were completed by S. Brud with help of a mechanical geological probe. Fieldwork was performed as a part of the broader scope aimed at drawing the Orla sheet of the Detailed Geological Map of Poland, in scale 1: 50 000. The top layer of the sediment is filled with sands, 1.4 m thick. Underneath there appears a layer of clayey and sandy silts. At the bottom of the boring these are replaced by organic silts that reach a depth of 3.3 m. Detailed description of the profile is presented in Tables 42 and 43.

Pollen percentage diagrams of Wólka 1 profile were divided into two local pollen zones (Fig. 42, Tab. 44) whereas those of Wólka 2 profile into four L PAZ (Fig. 43, Tab. 45).

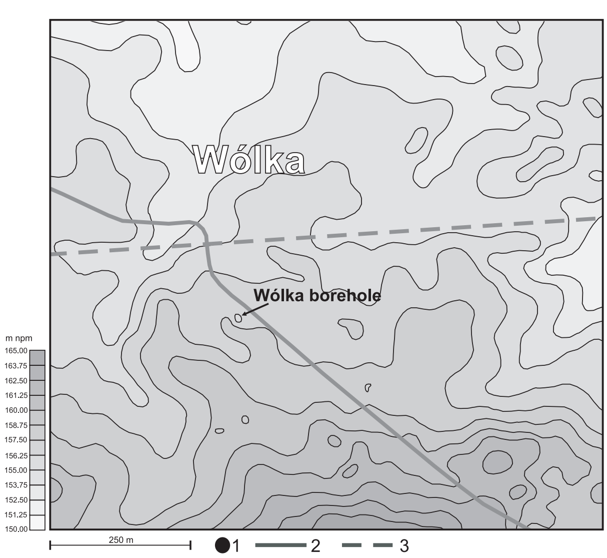

Fig. 41. Wólka [35]. Location of the site. **1** – studied profile, **2** – road, **3** – railway track

Table 42. Wólka 1 [35]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.30	sandy soil, dark grey
0.30–0.70	fine sand, yellow-brown
0.70–1.40	coarse and medium sand, grey
1.40–1.50	organic silt, clayey, dark grey
1.50–2.50	organic silt, clayey, grey-blue; Ag2.5, As1, Sh0.5, Th/Tb+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
2.50–3.30	sandy silt with clay, grey-blue
3.30–6.00	till, clayey, blue-grey

Table 43. Wólka 2 [35]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.30	sandy soil, dark grey
0.30–0.70	fine sand, yellow-brown
0.70–1.40	coarse and medium sand, grey
1.40–1.50	organic silt, clayey, dark grey
1.50–2.50	organic silt, clayey, grey-blue; Ag2.5, As1, Sh0.5, Th/Tb+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
2.50–3.30	sandy silt with clay, grey-blue; Ag2.5, As0.5, Ga0.5, Sh0.5; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.30–6.00	till, clayey, blue-grey

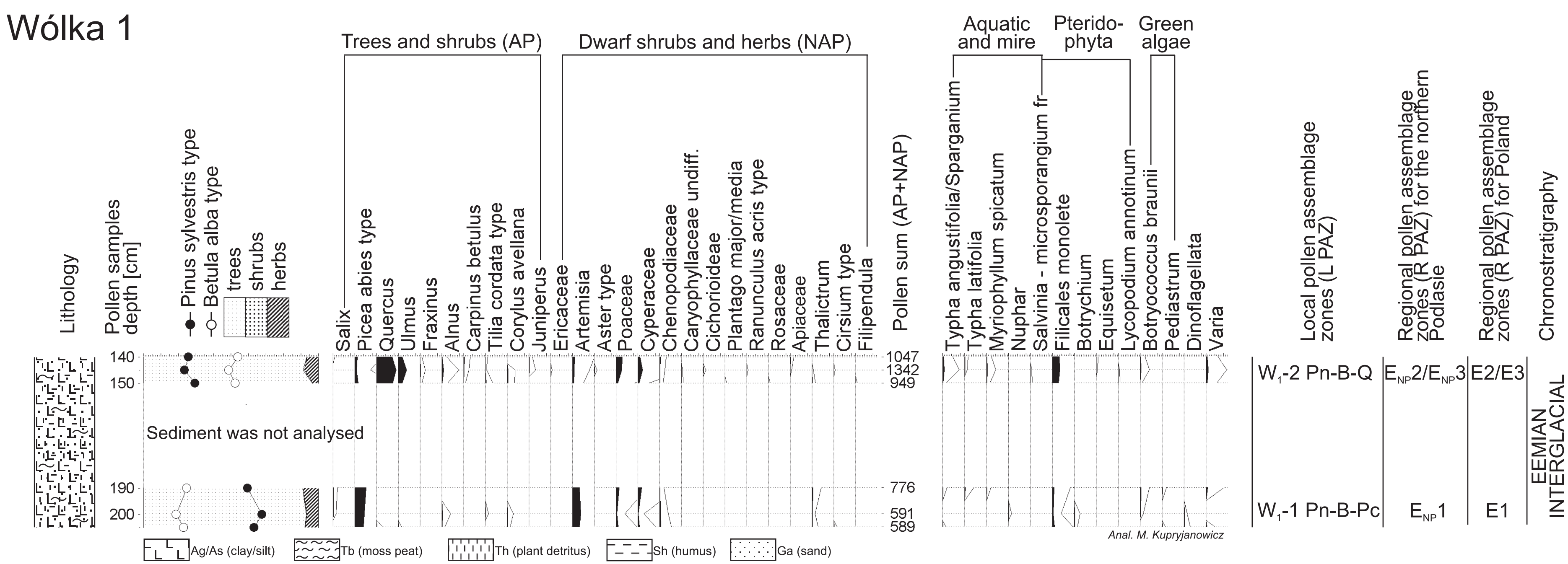

Fig. 42. Wólka 1 [35]. Pollen percentage diagram

Table 44. Wólka 1 [35]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
W_1-1	***Pinus-Betula-Picea***	2.05–1.90	Domination of *Pinus sylvestris* type (59.5–67.9%) and *Betula alba* type (18.8–24.7%); relatively high values of *Picea abies* type (5.1–6.4%); sporadically occurrence of *Salix*, *Quercus*, *Tilia cordata* type, *Corylus avellana*, and *Alnus*; rather low NAP proportion (7–10%) – *Artemisia* to 4.7%, Cyperaceae to 2.3%, and Poaceae to 1.8%. Aquatic plants represented by *Myriophyllum spicatum/verticillatum* and *Nuphar*, reed-swamp by *Typha latifolia* and *Typha angustifolia/Sparganium*, Pteridophyta by Filicales monolete and *Botrychium*, and algae by *Botryococcus braunii* and *Pediastrum*. The zone has not the upper boundary.
W_1-2	***Betula-Pinus-Quercus-Ulmus***	1.50–1.40	Domination of *Betula alba* type (48.8–54.0%); high proportion of *Pinus sylvestris* type (23.6–29.4%), *Quercus* (8.9–11.3%), and *Ulmus* (2.3–4.8%); low values of *Picea abies* type (0.9–2.1%); rare occurrence of other trees (*Alnus*, *Carpinus betulus*, *Fraxinus*, *Tilia cordata* type, and *Salix*), and shrubs (*Corylus avellana* and *Juniperus*); proportion of NAP (7–10%) similar as in previous zone, but values of Poaceae undiff. are slightly higher then previously (1.1–3.4%), and *Artemisia* slightly lower (0.6–1.2%). Fragments of *Salvinia* microsporangia appear. The zone has not the upper boundary.

Table 45. Wólka 2 [35]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
W_2-1	***Pinus-Betula-Picea***	3.30–2.85	Domination of *Pinus sylvestris* type (35–62%); high proportion of *Betula alba* type (26–52%); relatively high frequency of *Picea abies* type (2–5%); sporadic occurrence of pollen of *Salix*, *Quercus*, *Tilia cordata* type, *Corylus avellana*, *Ulmus*, *Fraxinus*, *Carpinus betulus*, and *Alnus* (each taxon below 1%); values of NAP from 3 to 10% – *Artemisia* to 5%, Cyperaceae to 3% and Poaceae to 2%. Swamp plants are represented by *Typha angustifolia/Sparganium*, Pteridophyta by Filicales monolete, and algae by *Pediastrum duplex*. The upper boundary: increase of *Betula alba* type; fall of *Picea abies* type. The zone is divided into 2 subzones:
W_2-1a	*Betula*	3.30–3.15	Values of *Betula alba* type higher then upper subzone.
W_2-1b	*Salix*	3.10–2.85	Maximum of *Pinus sylvestris* type; values of *Salix* slightly higher then lower subzone; peak of *Picea abies* type; depression of *Betula alba* type.
W_2-2	***Betula-Ulmus-Quercus***	2.80–2.70	Domination of *Betula alba* type (ca. 60%) and *Pinus sylvestris* type (ca. 25%); proportion of *Picea abies* type decreasing below 1%; values of *Quercus* systematically rising from 2 to about 10%; *Ulmus* frequency oscillating about 2%; sporadically occurring pollen of other trees (*Alnus*, *Fraxinus* and *Salix*) and shrubs (*Corylus avellana* and *Juniperus*); value of NAP light lower then previous zone (ca. 7%). Water plants are represented by only *Myriophyllum spicatum/verticillatum*. The upper boundary: rise of *Quercus* values; start of *Fraxinus* continuous curve; fall of *Betula alba* type.
W_2-3	***Quercus-Ulmus-Fraxinus***	2.65–2.55	Maximum values of *Quercus* (10–25%); rise of of *Ulmus* proportion to 4%; small culmination of *Fraxinus* pollen; values of *Pinus sylvestris* type similar then previously (ca. 20%); decrease of *Betula alba* type to 40%. The zone has not the upper boundary.
W_2-4	***Betula-Ulmus-Quercus***	2.50–2.45	Composition of pollen spectra similar as in W-2 L PAZ – culmination of *Betula alba* type (60–70%); values of *Quercus* from 2% to about 10%, and *Ulmus* about 2%. The zone has not the upper boundary. It probably represent disturbed sediment
W_2-4	***Carpinus-Picea-Corylus***	2.40–2.05	Relatively high values of *Carpinus betulus* (ca. 10%), *Alnus* (12–22%), *Tilia cordata* type (1–4%), *Corylus avellana* (6–10%), and *Picea abies* type (2–16%); low frequency of *Abies alba* (below 1%) and *Quercus* (2–4%); relatively high proportion of NAP (8–18%), which results mainly from high values of Cyperaceae. No upper boundary.

Śliwowo

The Śliwowo [36] site (52°41′N, 23°16′E; 152.0 m a.s.l.) occupies central part of the Bielsk Upland being placed around 10 km east of Bielsk Podlaski Town (Figs 1, 2). The boring was located in a vast depression. Two borings were carried out by S. Brud with help of a mechanical geological probe. It accompanied fieldwork proceeding preparation of the Orla sheet of the Detailed Geological Map of Poland, in scale 1: 50 000. Series of sandy, clayey and peaty silts are found at the bottom of the Kolonia Śliwowo 1 profile at the depth of 2.6–6.8 m. From that level up to the ground level the sediments gradually change into peaty silts (Tab. 46). As to Kolonia Śliwowo 2 profile, which was located a bit more to the south from the first boring, the profile is represented by peaty silts covered by sandy and clayey silts found at the depth of 3.8–8.8 m (Tab. 47). The sediments described occur underneath Holocene clays and diluvials, on marginal lake silts or directly on tills of the Warta glaciation.

Table 46. Kolonia Śliwowo 1 [36]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.20	soil, grey
0.20–1.20	sand, brown and yellow
1.20–1.70	silty-sandy clay, grey
1.70–2.30	coarse sand, light grey
2.30–2.60	organic clay, dark grey
2.60–4.30	organic clay, peaty, brown; Ag2, As1, Sh0.5, Th/Tb0.5, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.30–5.30	silty clay, grey-green
5.30–5.70	sand, grey-green
5.70–6.80	sandy clay, light grey
6.80–9.40	coarse sand, grey
9.40–11.00	sandy clay, light grey

Table 47. Kolonia Śliwowo 2 [36]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.40	soil, grey
0.40–1.10	fine clayey sand, grey-light yellow
1.10–2.10	tillty sand, medium, dark yellow
2.10–3.80	sandy silt, light grey
3.80–6.60	silty clay, with sand, dark grey
6.60–8.80	organic silt, peaty, brown-black; Ag2.5, Sh1, Th/Tb0.5, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
8.80–11.30	sandy clay, with gravel, grey-green
11.30–12.00	sandy till, with gravel, light grey-green

Table 48. Kolonia Śliwowo 1 [36]. Description of pollen spectra

Depth (m)	Description
8.20	Domination of *Carpinus betulus* (35.0%); high proportion of *Alnus* (20.3%) and *Corylus avellana* (11.3%); relatively low values of *Pinus sylvestris* type (15.0%) and *Betula alba* type (2.7%); frequent pollen of *Picea abies* type (3.8%), *Tilia cordata* type (3.5%), and *Ulmus* (1.7%); single pollen grains of *Acer*, *Fraxinus*, *Fagus*, *Quercus*, and *Salix*; NAP proportion is 6% – Cyperaceae (4.2%) and *Artemisia* (0.7%) dominate; very high values of Filicales monolete (22.1%); presence of *Thelypteris palustris* spores and fragments of Filicales macrosporagia.
7.70	Low frequency of sporomorphs and stan ich zachowania niezbyt dobry; domination of *Pinus sylvestris* type (21.5%), *Carpinus betulus* (22.0%), and *Alnus* (21.5%); relatively high values of *Picea abies* type (11.3%), *Corylus avellana* (11.8%) and *Tilia cordata* type (5.4%); presence of *Betula alba* type (2.2%) as well as *Ulmus* (0.5%) and *Abies alba* (0.5%); very high percentages of Filicales monolete (50.4%); relatively numerous fragments of Filicales macrosporangia (2.7%).
6.70	Domination of *Pinus sylvestris* type (38.0%) and *Picea abies* type (24.5%); increase of *Abies alba* to 0.8%, and *Betula alba* type to 8.8%; values of other trees lower then previous spectra: *Carpinus betulus* – 4.1%, *Alnus* – 7.8%, *Corylus avellana* – 1.0%, *Tilia cordata* type – 0.3%; occurrence of *Juniperus* (0.2%); single pollen grains of *Acer* and *Quercus*; rise of NAP to 14% (Cyperaceae prevails – 10.4%).

Table 49. Kolonia Śliwowo 2 [36]. Description of pollen spectra

Depth (m)	Description
4.20	Domination of *Corylus avellana* (28%); high proportion of *Quercus* (19%); relatively high values of *Tilia cordata* type and *Alnus* (po 9%) as well as *Ulmus* (3%) and *Fraxinus* (1%); rather low percentages of *Pinus sylvestris* type and *Betula alba* type (15% and 4%, respectively); single pollen grains of *Carpinus betulus*, *Picea abies* type, *Acer*, *Hedera helix*, and *Viscum album*; NAP below 5%.
3.50	Very low frequency of sporomorphs; very high values of *Tilia cordata* type(22%), *Carpinus betulus* (20%), *Alnus* (18%), and *Corylus avellana* (14%); *Ulmus* decreases to 1,5%, and *Quercus* below 1%; proportion of *Picea abies* type rises to 4%; low frequency of *Pinus sylvestris* type (11%) and *Betula alba* type (3%); NAP still below 5%; single fragment of *Salvinia* microsporangium.
2.70	Rather low frequency of sporomorphs; domination of *Pinus sylvestris* type (45%), *Picea abies* type (20%) and *Betula alba* type (20%); single pollen grains of *Quercus*, *Corylus avellana*, and *Ulmus*; rise of NAP to 7%.

Only 3 samples from Śliwowo 1 and 3 from Śliwowo 2 profile were suitable for further pollen analysis. Little number of samples prevented discerning clear local pollen zones out of the pollen diagrams (Figs 44, 45). A concise description of pollen spectra is presented in Tables 48 and 49.

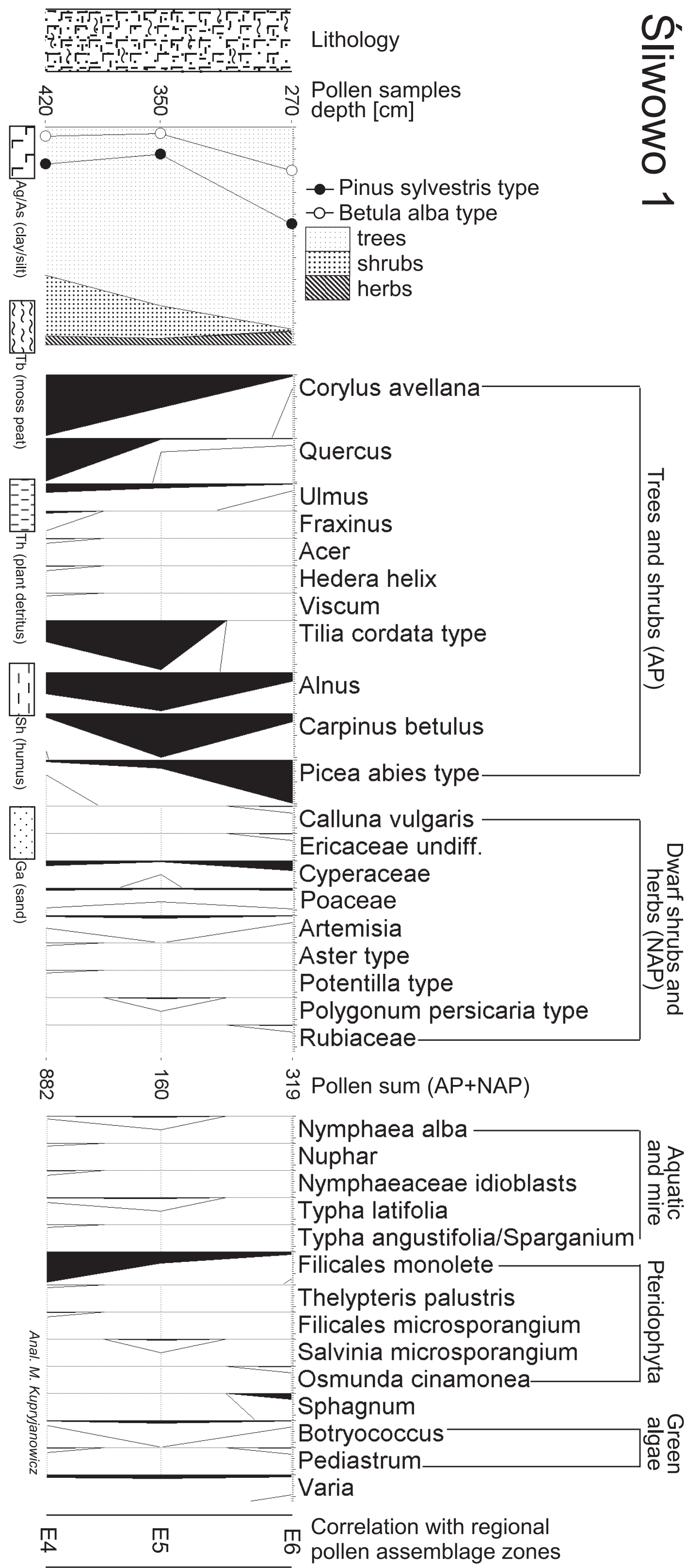

Fig. 44. Kolonia Śliwowo 1 [36]. Pollen percentage diagram

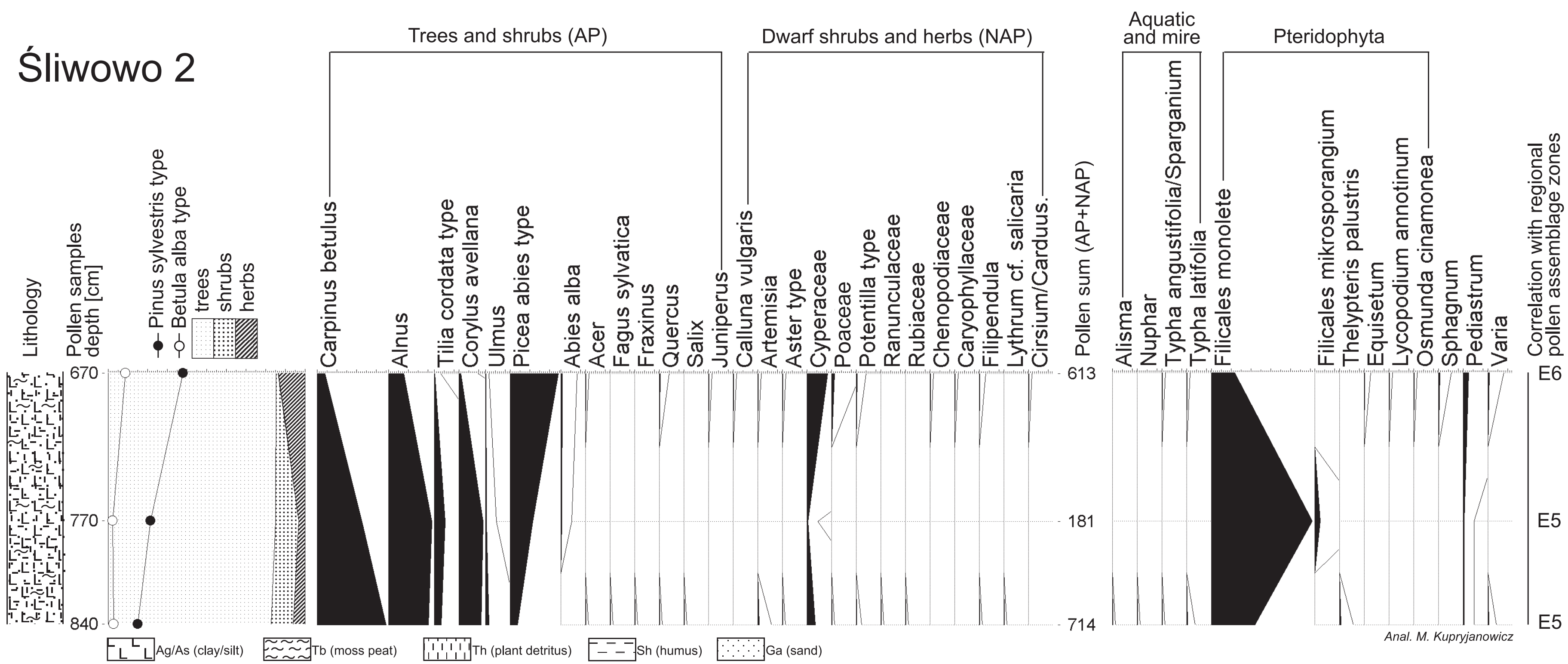

Fig. 45. Kolonia Śliwowo 2 [36]. Pollen percentage diagram

Skupowo

The Skupowo [37] site (52°50′N, 23°42′E; 143 m a.s.l.) lies in the north-eastern part of the Bielsk Upland approximately 35 km north-east of Bielsk Podlaski town and around 12 km south-east of Hajnówka town (Figs 1, 2). Peat-bog where the boring was carried out lies to south-east of the road cross with railway line from Hajnówka to Białystok (Fig. 46). The sediments studied fill the small subglacial basin, that was formed during the Wartanian glaciation. The surface of the basin extends over the area of ca. 150 × 150 m. This particular peat-bog today serves as a rubbish tip of the village.

The boring was carried out by W. Kwiatkowski and M. Stepaniuk with help of a hand geological probe. Fieldwork performed at that site constituted a part of drawing the Białowieża sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Bałuk et al. 2003). Deposits of lake-mire palaeobasin, approximately 2 m thick, were present at the depth of 2.05–3.95 m. Their basal part contains highly decomposed peat. At the depth of 3.10–2.40 m there lies organic silt with a layer of fine sand in the middle section (Tab. 50). These series of palaeobasin deposits are covered by approximately 0.50 m of sand and by 1.45 m layer of organic silt and peat from the late Vistulian and Holocene.

Pollen percentage diagram was divided into 7 local pollen assemblage zones (Fig. 47, Tab. 51).

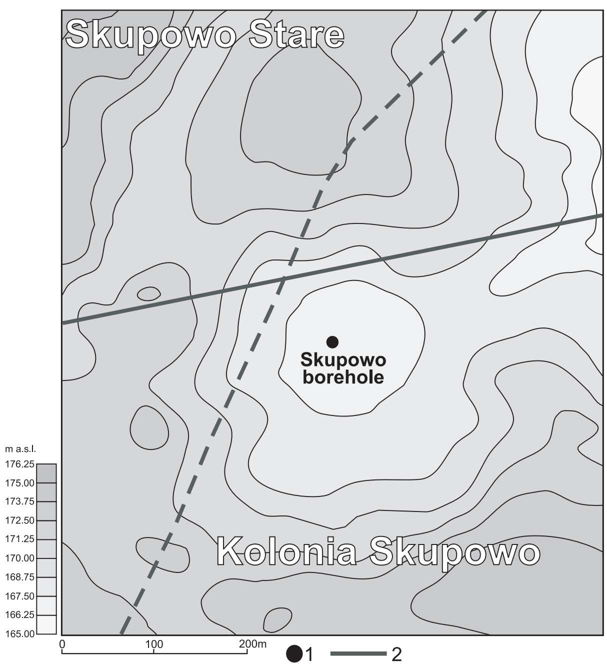

Fig. 46. Skupowo [37]. Location of the site. **1** – studied profile, **2** – road, **3** – railway track

Table 50. Skupowo [37]. Lithology of the profile

Depth (m)	Sediment description
0.00–1.35	peat, weakly decomposed, brown, with sand at the top
1.35–1.60	organic silt, very dark brown
1.60–2.05	varigrained sand, yellow
2.05–2.40	peat, strongly decomposed, black; Th1, Tb1, Sh2, Ag/As+, Ga+, struc.: homogenous, nig.3, strf.0, elas.0, sicc.2, lim.sup.0
2.40–2.52	organic silt, dark brown, with sand; Ag3, As0.5, Sh0.5, Ga+, struc.: very homogenous, nig.2+, strf.0, elas.0, sicc.2, lim.sup.0
2.52–2.82	fine sand, yellow; Ga3.5, Ag/As0.5 struc.: homogenous, nig.3, strf.0, elas.0, sicc.2, lim.sup.0
2.82–3.10	organic silt, dark brown, with sand; Ag3, As0.5, Sh0.5, Ga+, struc.: homogenous, nig.3, strf.0, elas.0, sicc.2, lim.sup.0
3.10–3.55	peat, strongly decomposed, brown; Th1, Tb1, Sh2, Ag/As+, Ga+, struc.: homogenous, nig.2, strf.0, elas.0, sicc.2, lim.sup.0
3.55–3.95	detritus gyttja with traces of sand and silt, dark brown; Ld3.5, Ga0.5, Tb/Th+, Ag/As0.5, struc.: homogenous, nig.2+, strf.0/3, elas.0, sicc.2, lim.sup.0

Table 51. Skupowo [37]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description of pollen spectra
S-1	***Artemisia-Juniperus-Betula nana***	3.90–3.85	Very high NAP proportion (19.5–35.6 %) – *Artemisia*, Cyperaceae, Poaceae undiff., and Chenopodiaceae dominate in this group; relatively high values of *Juniperus* (2.0–5.7%) and *Betula nana* type (0.8–3.0%); still presence of *Salix* pollen; low frequencies of *Pinus sylvestris* type (below 40%) and *Betula alba* type (below 30%). The upper boundary: increase of *Pinus sylvestris* type; fall of NAP as well as *Juniperus* and *Betula nana* type.
S-2	***Pinus-Betula-Picea***	3.80–3.67	Peak of *Pinus sylvestris* type (max. 71.1%); culmination of *Picea abies* type (to 5.1%); depression of *Betula alba* type; NAP proportion decreasing below 10%. The upper boundary: fall of *Pinus sylvestris* type and *Picea abies* type; rise of *Betula alba* type; start of *Quercus* continuous pollen curve.

(cont. on page 57)

Table 51. Continued

L PAZ	Name	Depth (m)	Description of pollen spectra
S-3	***Betula-Quercus-Pinus***	3.63–3.60	Absolute maximum of *Betula alba* type (50.1%); rising values of *Quercus* (to 10.9%) and *Ulmus* (to 3.3%). The upper boundary: fall of *Betula alba* type; increase of *Quercus*.
S-4	***Quercus-Ulmus-Fraxinus***	3.55–3.50	Absolute maximum of *Quercus* (40.9%); relatively high values of *Ulmus* (5.1–6.6%); rising proportion of *Corylus avellana* (to 4.1%); small peak of *Pinus sylvestris* type (50.5%). The upper boundary: rapid increase of *Corylus avellana* above 50%; fall of *Quercus* and *Pinus sylvestris* type.
S-5	***Corylus-Tilia-Alnus***	3.43–3.14	Domination of *Corylus avellana* (42.0–61.2%); high proportion of *Alnus* (4.4–11.2%) and *Tilia cordata* type (3.3–13.0%); presence of single pollen grains of *Tilia tomentosa* and *Taxus baccata*; relatively high values of *Ulmus* (1.5–3.8%) and *Quercus* (2.0–18.9 %); low proportion of *Pinus sylvestris* type (7.1–23.1%) and *Betula alba* type (1.9–7.2%). The zone has not the upper boundary.
S-6	***Pinus-Betula-Juniperus***	3.10–2.43	Domination of *Pinus sylvestris* type (43.5–83.3%); values of *Betula alba* type from 9.4% to 20.8%; relatively high proportion of *Picea abies* type (1.1–4.7%), *Corylus avellana* (to 6.2%), *Carpinus betulus* (to 10.8%) and *Tilia cordata* type (to 1.4%); continuous presence of *Juniperus* (max. 3.8%), *Salix*, *Calluna vulgaris*, Ericaceae undiff., and numerous herbs. The zone has not the upper boundary.
S-7	***Carpinus-Alnus-Picea***	2.40–2.05	Highest in whole profile values of *Carpinus betulus* (23.4–60.9%); high frequencies of *Alnus* (10.3–19.2%) and *Picea abies* type (7.2–18.2%); proportion of *Corylus avellana* below 10%, and *Tilia cordata* type, *Ulmus*, and *Quercus* below 1%; decreasing percentages of *Pinus sylvestris* type(from 35.2% to 8.0%); low percentages of *Betula alba* type (2.2–10.9%). The zone has not the upper boundary.

Boćki

The Boćki [38] site (52°39′N, 23°3′E; 143 m a.s.l.) is located in southern part of the Bielsk Upland around 16 km south-west of Bielsk Podlaski town (Figs 1, 2). The palaeolake where the drilling was carried out lies roughly 100 m east of the road from Boćki to Dubno villages, on the right edge of the river Nurzec valley (Fig. 48). The sediments studied fill the subglacial basin, that was formed during the Warta glaciation (Boratyn 2006). Nowadays it is used as a meadow pasture.

Boćki 1 and Boćki 2 borings were carried out by a Geoprobe borer, 3.5 cm in diameter. They constituted a part of framework aimed at preparing the Boćki sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Boratyn 2006). As to Boćki 1 profile brown peat and organic silts are present at the depth of 10.30–7.0 m (Tab. 52). These sediments lay on silts of the Wartanian glaciation and are then covered by Vistulian silts and sands with organic silts. As to Boćki 2 profile organic silts appear at the depth of 7.2–4.69 m (Tab. 53). The Eemian sediments in that profile lay on till of the Wartanian glaciation.

Only three samples from Boćki 1 and four from Boćki 2 profile were proper for further pollen analysis. Frequency of pollen is high or very high in all samples and its preservation is good or very good. Little number of samples did not allow local pollen zones to be distinguished out of the pollen diagrams (Figs 49, 50). A concise description of pollen spectra is presented in Tables 54 and 55.

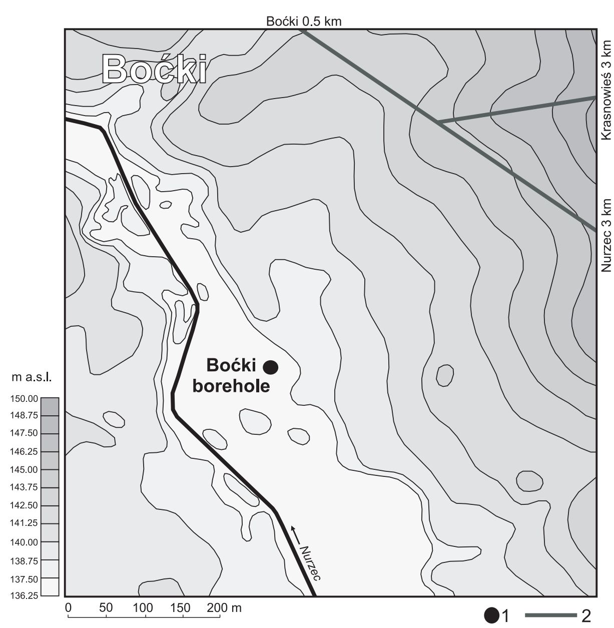

Fig. 48. Boćki [38]. Location of the site. **1** – studied profiles, **2** – roads

Table 52. Boćki 1 [38]. Lithology of the profile

Depth (m)	Sediment description
0.00–1.00	peat, weakly decomposed, brown-black
1.00–2.50	fine-medium sand, grey
2.50–5.50	fine-medium sand, fluvioglacial, grey
5.50–6.00	organic silt, grey
6.00–7.00	clayey silt, dark grey
7.00–7.40	peaty silt, dark brown;
7.40–8.50	peat, highly decomposed, dark brown; Tb2, Th1.5, Sh0.5, Ag/As+; struc.: homogeneous; nig.3, strf.0, elas.0, icc.2, lim.sup.1
8.50–9.00	peaty silt, black-brown; Ag2.5, Sh0.5, Th0.5, Tb0.5, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
9.00–10.00	organic silt, black; Ag2.5, Sh1.5, Th/Tb+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
10.00–10.30	organic silt, dark grey
10.30–11.50	silt, grey

Table 53. Boćki 2 [38]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.30	peat, highly decomposed, slightly sandy, black
0.30–0.47	fine sand, with numerous thin layer of peat, grey-yellow
0.47–1.10	peat, highly decomposed, slightly sandy, black
1.10–1.14	fine sand, grey
1.14–1.20	peat, highly decomposed, slightly sandy, black
1.20–3.14	sand, grey and grey-yellow
3.14–3.60	organic silt with thin layer of fine grey sand at the depth of 3.20–3.22 m, black
3.60–3.73	fine and medium sands, grey-yellow
3.73–4.16	organic silt, black
4.16–4.20	fine sand, dark grey
4.20–4.26	organic silt, dark grey
4.26–4.69	fine and medium sand, grey
4.69–4.87	organic silt, black
4.87–5.15	organic silt, dark brown
5.15–6.00	organic silt, black; Ag2.5, Sh1.5, Th/Tb+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
6.00–6.08	organic silt, dark grey-brown; Ag2.5, As0.5, Sh1, Th/Tb+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
6.08–6.14	sandy silt, grey-green
6.14–6.24	organic silt, dark grey-brown
6.24–6.52	silt with fragments of molluscs shells, slightly sandy, dark grey
6.52–7.20	sandy silt with thin layers of black organic silt, dark grey
7.20–7.96	till, grey
7.96–8.40	fine sand, grey-yellow

Table 54. Boćki 1 [38]. Description of local pollen assemblage zones (L PAZ)

Depth (m)	Description
9.05	Very high *Quercus* values (48.2%); relatively high percentage of *Ulmus* (3.7%) and *Fraxinus* (3.2%); rather low proportion of *Pinus sylvestris* type (26.2%) and *Betula alba* type (12.2%); single pollen grains of *Tilia cordata* type (0.1%), *Alnus* (0.7%), *Carpinus betulus* (0.4%), *Salix* (0.2%), and *Hedera helix* (0.1%); NAP below 5%.
8.65	Domination of *Corylus avellana* (44.9%); high values of *Tilia cordata* type (15.4%) and *Alnus* (16.1%); relatively high proportion of *Quercus* (7.4%) and *Ulmus* (3.2%); rather low percentages of *Pinus sylvestris* type (5.9%) and *Betula alba* type (1.2%); single pollen grains of *Carpinus betulus* (3.3%), *Picea abies* type (0.2%), *Taxus baccata* (1.0%), *Acer* (0.1%), *Tilia tomentosa* (0.1%), and *Fraxinus* (0.4%), as well as *Hedera helix* (0.1%); NAP below 2%.
8.05	Prevailing of *Pinus sylvestris* type (45.5%); high proportion of *Carpinus betulus* (21.3%), *Alnus* (12.6%), and *Picea abies* type (10.7%); *Betula alba* type below 10%; single pollen grains of *Quercus* (0.7%), *Corylus avellana* (0.6%), *Tilia cordata* type (0.1%), and *Ulmus* 0.1%); very low values of NAP (ca. 0.5%).

Table 55. Boćki 2 [38]. Description of local pollen assemblage zones (L PAZ)

Depth (m)	Description
6.05	Domination of *Pinus sylvestris* type (43.4%) and *Betula alba* type (25.4%); relatively high *Quercus* values (14.6%); single pollen grains of *Ulmus* (1.7%), *Fraxinus* (1.0%), *Corylus avellana* (3.4%), *Tilia cordata* type (0.5%), *Alnus* (0.7%), *Picea abies* type (1.9%), and *Juniperus* (0.2%); NAP proportion ca. 10%.
5.70	Maximum of *Corylus avellana* (49.2%); very high values of *Tilia cordata* type (12.0%) and *Alnus* (19.0%); rather low proportion of *Quercus* (3.7%), *Ulmus* (3.4%), *Fraxinus* (1.5%), and *Carpinus betulus* (4.7%); very low percentages of *Pinus sylvestris* type (4.0%) and *Betula alba* type (0.6%); single pollen grains of *Hedera helix* (0.1%), and *Humulus lupulus* (0.1%); NAP below 2%.
5.40 and 5.25	Prevailing of *Carpinus betulus* (29.3–40.8%) and *Corylus avellana* (27.1–31.1%); high proportion of *Alnus* (18.9–19.8%) and *Tilia cordata* type (6.0–8.8%); single pollen grains of *Quercus* (1.8–2.5%), *Ulmus* (1.2–1.8%), *Fraxinus* (0.3–1.4%), *Acer* (0.1–0.3%), and *Picea abies* type (0.3%); very low values of *Betula alba* type (below 1%), *Pinus sylvestris* type (1.4–3.4%) and NAP (below 1%).

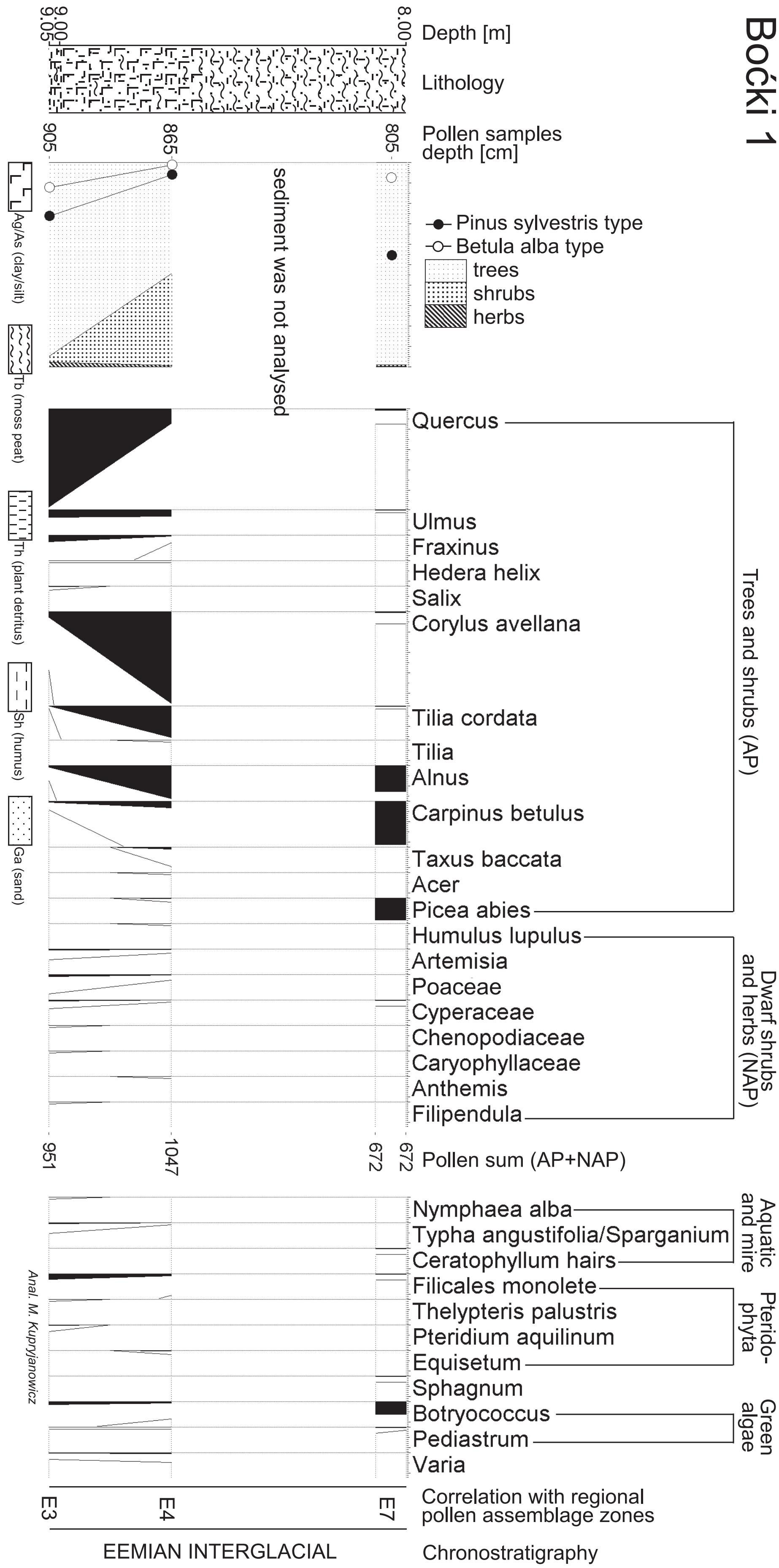

Fig. 49. Boćki 1 [38]. Pollen percentage diagram

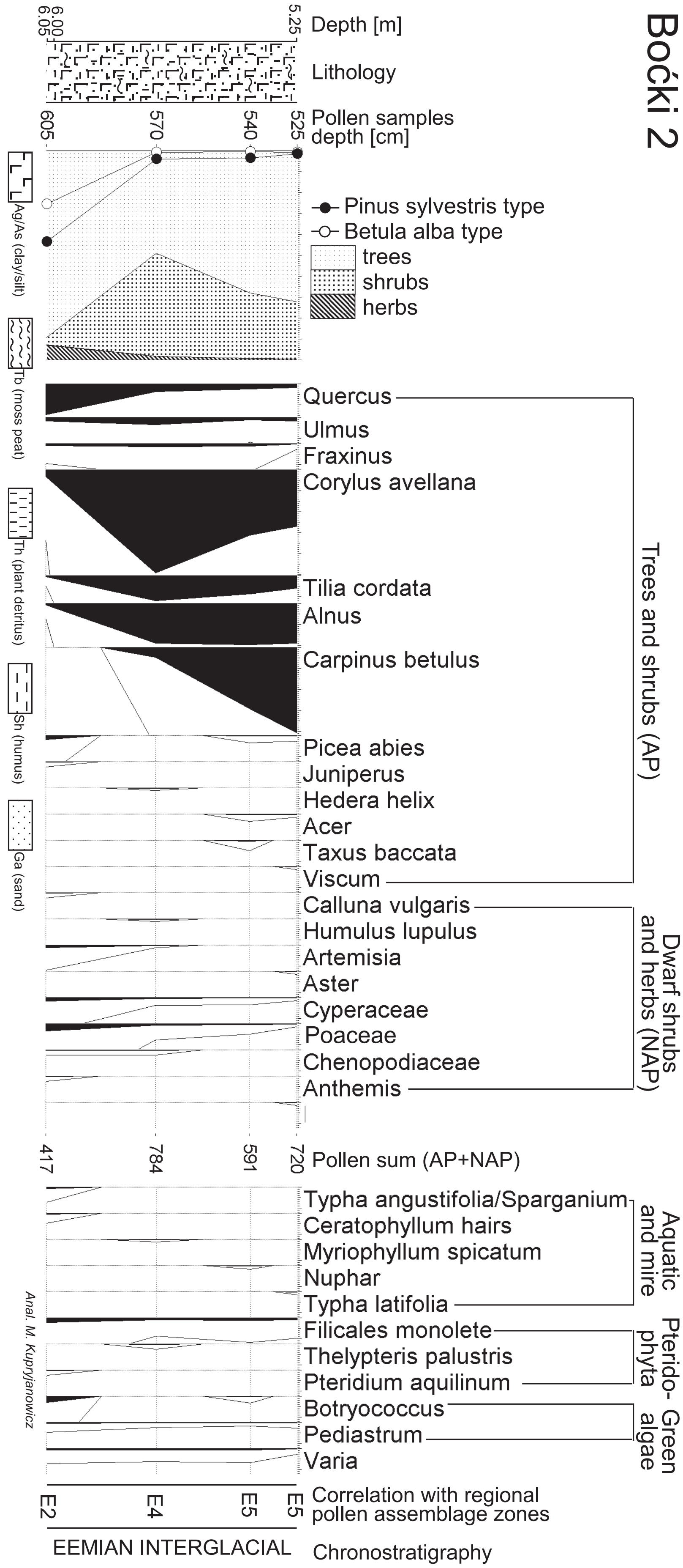

Fig. 50. Boćki 2 [38]. Pollen percentage diagram

Choroszczewo

The Choroszczewo [39] site (52°33′N, 23°2′E; 155.0 m a.s.l.) lies in southern part of the Bielsk Upland, in a borderland with the Drohiczyn Upland, around 25 km south-west of Bielsk Podlaski town and roughly 10 km south of the Boćki site (Figs 1, 2). The locality in question is in the centre of a lake plain behind an extensive kame. The palaeolake where the drilling was carried out lies some 100 m east of the Choroszczewo-Boćki road, on the left bank of the river Nurzec valley (Fig. 51).

The boring was carried out with a Geoprobe borer, 3.5 cm in diameter. Fieldwork was a part of greater project aimed at drawing the Boćki sheet of the Detailed Geological Map of Poland, in scale 1: 50 000 (Boratyn 2006). Directly on the bottom layer of the boring, at the depth of 7.90–6.00 m, organic silts and organic shales were deposited (Tab. 56). Then the Eemian sediment lay on compact plastic silts of the Wartanian glaciation (Boratyn 2006). Clayey silts and organic silts with traces of peats and fine sands (6.0–2.7 m) are present on top of them. Yet another layer to the top, a span of 2.70–1.45 m within the profile, consists of clayey silts, silts, fine sands and varigrained sand with gravels, up to 3.5 cm in diameter.

More than 20 samples were suitable for subsequent pollen analysis. All samples analysed contained sporomorphs. Their frequency was high or very high and their preservation was good or very good. Pollen percentage diagram (Fig. 52) was divided into 8 local pollen assemblage zones (Tab. 57).

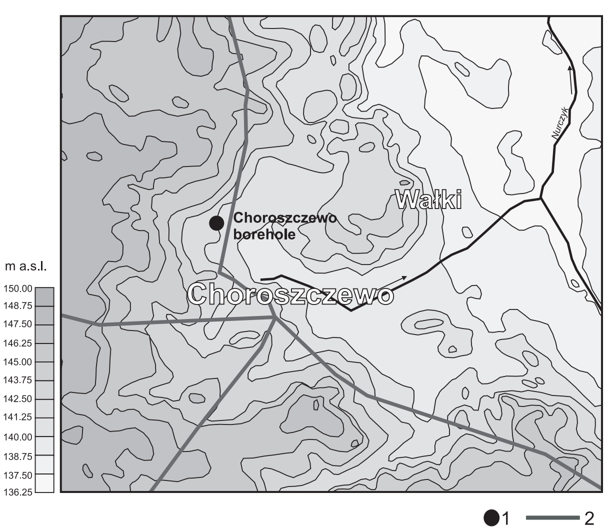

Fig. 51. Choroszczewo [39]. Location of the site. **1** – studied profile, **2** – roads

Table 56. Choroszczewo [39]. Lithology of the profile

Depth (m)	Sediment description
0.00–0.20	soil, sandy, dark grey
0.20–0.60	humus fine sand, grey
0.60–1.10	fine sand, light yellow
1.10–1.20	sand with gravel (to 3.5 cm), grey
1.20–1.40	fine and medium sand with admixture of larger grains (to 3mm), grey-brown
1.40–1.45	fine sand, light grey
1.45–1.60	clayey silt, grey-green at the top and brown at the lower sectio
1.60–1.70	clayey silt with admixture of larger grains (to 2mm)
1.70–2.10	clay, grey-rust
2.10–2.15	clay, stratified horizontally, black and rust
2.15–2.40	organic silt, slightly clayey, dark grey
2.40–2.65	silty clay, grey and grey–ginger
2.65–2.70	fine-medium sand, yellow
2.70–3.75	organic silt, dark grey and grey-brown; Ag2.5, As0.5, Sh1, Th/Tb+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.75–3.80	fine sand, yellow; Ga3, Ag0.5, As0.5; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
3.80–4.20	organic silt, black and grey-brown; Ag2.5, Sh1.5, Th/Tb+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.20–4.70	organic silt, slightly peaty, grey-brown; Ag2.5, Sh1, Th/Tb0.5, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.70–4.85	organic silt, slightly sandy, with thin layers of fine sand, dark grey; Ag2.5, Sh1, Ga0.5, Th/Tb+, As+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
4.85–5.00	fine sand with organic matter, light grey; Ga3.5, Sh0.5, Ag/As+; struc.: homogeneous; nig.1, strf.0, elas.0, sicc.2, lim.sup.1
5.00–5.10	organic silt, slightly sandy, grey-brown; Ag2.5, Sh1, Ga0.5, As+, Th/Tb+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
5.10–5.30	organic silt, peaty, grey; Ag3, Sh0.5, Ga0.5, As+, Th/Tb+,; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
5.30–5.35	peat, weakly decomposed, brown-black; Tb3, Th1, Ag/As+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
5.35–6.00	organic silt, slightly clayey, grey; Ag2.5, As0.5, Sh1, Th/Tb+, Ga+; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1
6.00–6.20	organic silt, dark grey; Ag2.5, Sh1.5, Th/Tb+, As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
6.20–6.90	substantia humosa, with traces of sand and clay, black-brown; Sh4, Th/Tb+, Ag/As+, Ga+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
6.90–7.20	substantia humosa, black and grey-black; Sh4, Th/Tb+, Ag/As+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
7.20–7.90	organic silt, light sandy, black and dark brown; Ag2.5, As0.5, Sh0.5, Ga0.5, Th/Tb+; struc.: homogeneous; nig.3, strf.0, elas.0, sicc.2, lim.sup.1
7.90–9.60	clay, plastic, compact, grey-green; As3, Ag0.5, Ga0.5; struc.: homogeneous; nig.2, strf.0, elas.0, sicc.2, lim.sup.1

Table 57. Choroszczewo [39]. Description of local pollen assemblage zones (L PAZ)

L PAZ	Name	Depth (m)	Description
C-1	***Pinus-Betula-Picea***	8.32–8.14	Absolute domination of *Pinus sylvestris* typ (70%); relatively high values of *Betula alba* type (15%) and *Picea abies* type (5%); presence of single pollen grains of *Alnus*, *Salix*, *Juniperus*, *Ephedra distachya*, and *Hippophaë*; rather low proportion of NAP (11%) – *Artemisia* (5%), Cyperaceae (3%), Poaceae (1%), and Chenopodiaceae (1%) dominate among herbs. The upper boundary: light decrease of *Pinus sylvestris* type; start of *Quercus* continuous curve.
C-2	***Pinus-Betula-Quercus***	7.84	Only one spectrum included. Prevalence of *Pinus sylvestris* type (45%) and *Betula alba* type (30%); relatively high frequency of *Quercus* (5%); appearance of *Ulmus*; still presence of *Picea abies* type (4%), *Salix* (1%), and *Juniperus* (1%); NAP values slightly lower then previous zone (6%). The upper boundary: rise of *Quercus* values above 10%.
C-3	***Quercus-Betula-Pinus-(Ulmus)***	7.74	Maximum of *Quercus* (14%); dominance of *Pinus sylvestris* type (45%) and *Betula alba* type (30%); high frequency and *Ulmus* (4%); sporadic occurrence of *Fraxinus*, *Alnus*, and *Picea abies* type; single pollen grains of *Juniperus* and *Hedera helix*; very low proportion of NAP (2%); water plants are represented by relatively numerous idioblasts of Nymphaeaceae (to 5%) and single cenobia of *Botryococcus braunii*, rush plants by pollen of *Phragmites* type, *Typha angustifolia/Sparganium* and *Typha latifolia*, and Pteridophyta only by spores of Filicales monolete (to 3%). The upper boundary: start of continuous pollen curves of *Corylus avellana* and *Tilia cordata* type; decrease of *Quercus*.
C-4	***Corylus-Tilia-Alnus***	7.62–7.26	Absolute domination of *Corylus avellana* (ca. 40%); very high values of *Tilia cordata* type (15–21%) and *Ulmus* (2–6%); relatively high proportion of *Alnus* (10–18%); *Quercus*, *Fraxinus*, and *Acer* below 2%; the fall of *Pinus sylvestris* type to 12%; the first pollen grains of *Carpinus betulus* and *Viscum*; very low frequency of NAP (below 2%). The upper boundary: rise of *Carpinus betulus* and *Alnus*.
C-5	***Carpinus-Alnus-Corylus***	6.99–6.76	The maximum of *Carpinus betulus* (60%); values of *Alnus* higher then previous zones (ca. 12%); decreasing proportion of *Tilia cordata* type (to 4%), *Ulmus* (to 2%), *Quercus* (to 0.2%), and *Corylus avellana* (to 14%); very low frequency of *Pinus sylvestris* type and *Betula alba* type (0.3% and 1%, respectively); very low values of NAP (0.2%); single pollen grains of *Viscum* and *Hedera helix*. The upper boundary: rise of *Picea abies* type and decrease of *Carpinus betulus*.
C-6	***Picea-Carpinus-Alnus-(Abies)***	6.52	Only one spectrum included. Maximum values of *Picea abies* type (36%) and *Abies alba* (1.5%); still high proportion of *Carpinus betulus* (16%) and *Alnus* (13%); frequency of *Pinus sylvestris* type (15%) and *Betula alba* type (10%) slightly higher then previous zone; low values of *Quercus* (1%), *Corylus avellana* (1%), and *Salix* (0.1%); the first pollen grains of *Calluna vulgaris* (0.2%). Water plants are represented by pollen of *Nymphaea alba* (0.1%), the first spores of *Isoëtes* (0.1%) and cenobia of *Botryococcus braunii* (5%). The upper boundary: increase of *Pinus sylvestris* type above 80%.
C-7	***Pinus***	6.36–6.06	Dominance of *Pinus sylvestris* type (60–80%); proportion of *Betula alba* type oscillating around 10%; relatively high values of *Picea abies* type (3%); low frequency of thermophilous trees: *Carpinus betulus* – 1%, *Alnus* – 1.5%, *Quercus* – 0.2%, *Corylus avellana* – 0.7%; reappearance of *Ephedra distachya* (0.2%), and *Juniperus* (0.2%); values of *Salix* slightly higher then previous zones (1%); also NAP proportion higher then early (%) – mainly pollen of *Artemisia* (6%), *Calluna vulgaris* (2%), Poaceae (1%), Cyperaceae (1%), and Chenopodiaceae (1%); single pollen grains of Ericaceae, *Anthemis* type, Cichoriodeae, *Dianthus* type, and *Filipendula*. *Isoëtes* (5%) dominates among water plants; single cenobia of *Pediastrum integrum* are noted; spores of *Selaginella selaginoides*, *Lycopodium annotinum*, *Equisetum*, *Sphagnum* and Filicales monolete occur sporadically. The upper boundary: decrease *Pinus sylvestris* type to 50%, rise of NAP above 20%.
C-8	***Artemisia-*****Poaceae-*****Salix***	5.93–5.53	Values of *Pinus sylvestris* type decreasing from 50% to 40%; proportion of *Betula alba* type about 15%; relatively high frequency of NAP – domination of Cyperaceae, high percentages of *Artemisia*, Poaceae and Chenopodiaceae. The upper boundary: rapid rise of *Betula alba* type above 50%.
C-9	***Pinus-Betula***	5.33–2.94	Very high values of *Pinus sylvestris* type (to 70%) and *Betula alba* type (to 60%); proportion of NAP oscillating around 15%. No upper boundary. Two subzones are distinguished:
C-9a	*Betula*	5.33–4.87	Domination of *Betula alba* type.
C-9b	*Pinus*	4.08–2.94	Prevailing of *Pinus sylvestris* type.

REGIONAL POLLEN STRATIGRAPHY AND ITS CHRONOSTRATIGRAPHY FOR NORTHERN PODLASIE

GENERAL REMARKS

Local pollen assemblage zones and subzones distinguished for all studied sites from northern Podlasie are gathered in Figure 53. It is clearly visible that the figure indicates that vegetation of the entire area developed in a similar manner. This is confirmed by great similarity of particular local pollen assemblage zones. Therefore such similarity allowed a construction of regional division to be proposed.

Hence, 14 regional pollen assemblage zones are proposed for northern Podlasie region – one placed in the late glacial of the Wartanian glaciation, seven in the Eemian interglacial and another seven in the early glacial of the Vistulian. The scheme presented in Figure 53 is based on subjective comparison of all diagrams from the region of northern Podlasie, that assembled up to 2006.

Regional pollen assemblage zones were described, defined and named after the rules proposed by Cushing (1967), West (1970), Birks (1979) and Janczyk-Kopikowa (1991). The Solniki [28] site described in this article matches the type locality for the majority of those zones.

A concise characteristics of regional pollen zones distinguished for northern Podlasie is presented in Table 58.

LATE GLACIAL OF THE WARTANIAN GLACIATION

The late glacial of the Wartanian is well represented only by one of the profiles from northern Podlasie, namely by the Skupowo [37] site. Comparable pollen records are also present at two other localities: Ludomirowo [7] (Bitner 1957), see Figure 54, and Milejczyce [40] (Bińka 2006a). Therefore one regional pollen assemblage zone was distinguished – LW_{NP} NAP-*Picea* R PAZ relying on the composition of the Late Wartanian pollen spectra found at these three sites (Fig. 54, Tab. 58). The Skupowo [37] site represents a type locality of this zone for northern Podlasie. The zone may be correlated with the LG MPG NAP-*Picea*-*Pinus* regional pollen zone distinguished by Mamakowa (1989) for late glacial of the Middle Polish glaciation in northern Poland. In

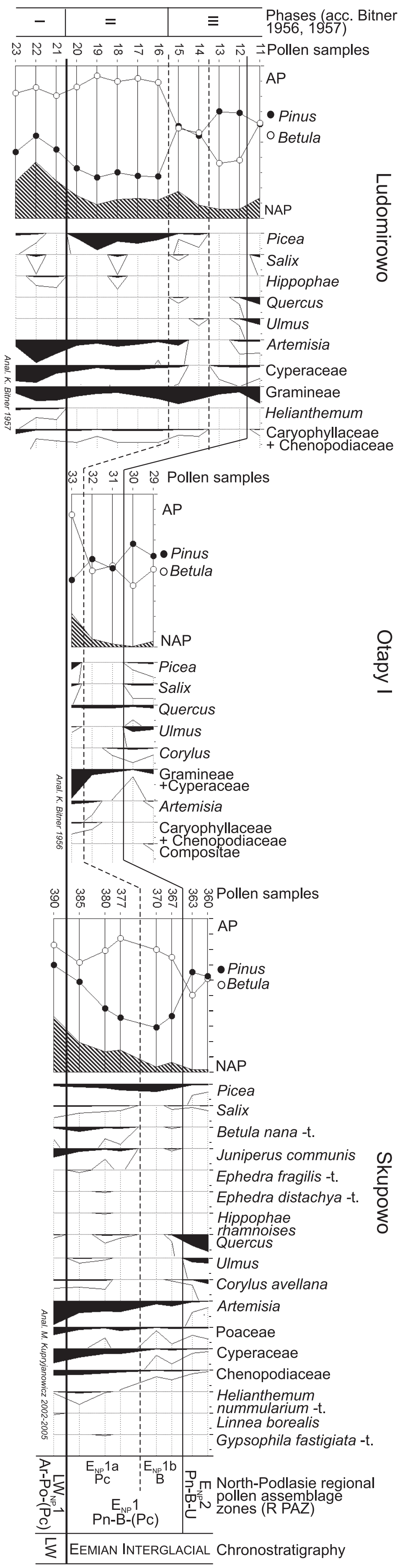

Fig. 54. Boundary between the late glacial of the Warta glaciation and the Eemian interglacial in pollen profiles from three selected sites in the northern Podlasie. Only the lower parts of diagrams are presented. Pollen data from Ludomirowo (a compilation of the data from 12, 12a and 14 profiles – Bitner 1957) and Otapy (Bitner 1956a) are recalculated (total sum = AP + NAP), simplified and modified in relation to the version given by the author. Site numbers as in Figure 1, Table 1 and the text

Table 58. Characteristics of the regional pollen zones (R PAZ) for northern Podlasie. Symbols of R PAZ: LW_{NP} – in the Late Wartanian, E_{NP} – in the Eemian interglacial, EV_{NP} – in the Early Vistulian; for the correlation of local pollen assemblage zones with R PAZ see Fig. 53; * – sites not being present in Fig. 53 (local pollen assemblage zones are not distinguished in original studies).

R PAZ	Name	Type site	Other occurrences	Description of regional pollen assemblage zones (R PAZ)
LW_{NP}1	**NAP-*Juniperus*-*(Picea)***	Skupowo [37]	2 profiles: *Ludomirowo [7] – zone I of Bitner (1957), *Otapy 1 [34] – phase I of Bitner (1956), *Milejczyce [40] Bińka (2006a)	In the type profile NAP proportion ranges from 40% to 12%, in other profiles they remain very similar. Diversity of herbaceous taxa is small; *Artemisia*, Cyperaceae, Poaceae undiff. and Chenopodiaceae dominate in this group. Values of *Juniperus* (up to 7%) and *Betula nana* type (up to 5%) are relatively high. *Salix* pollen is still present, but with values below 1%. *Pinus sylvestris* type is the most abundant pollen type (up to 40%). *Betula alba* type is relatively significant (up to 30%). Pollen of other trees is probably redeposited.
E_{NP}1	***Pinus-Picea-(Betula)***	Solniki [28]	8 profiles: *Ludomirowo [7] – zone II and lower part of zone III of Bitner (1957), Starowlany [8], Kruszyniany [21], Wólka 1 [35], Wólka 2 [35], Skupowo [37], Choroszczewo [39], *Otapy 1 [34] – zone II and lower part of zone III of Bitner (1956)	*Pinus sylvestris* type is the most abundantly represented taxon and prevails throughout the zone. At Solniki its values reach a maximum of 91%; at the other sites they range from 50% (Starowlany) to 75% (Skupowo). At the type locality the presence of *Betula alba* pollen type is marked with very low frequency (max. 6%); in diagrams from other sites in which this zone is distinguished it occurs with values from 10% (Choroszczewo) to 85% (Kruszyniany). Relatively high values of *Picea abies* type are very characteristic for this zone – at Solniki they reach a maximum of ca. 10% while at other sites 1-7%. NAP values remain below 10% in case of all profiles.
E_{NP}2	***Pinus-Quercus-Ulmus-Salix***	Solniki [28]	15 profiles: *Ludomirowo [7] – upper part of zone III of Bitner (1957), Starowlany [8], Podkamionka [16], Poniatowicze 1 [12], Kruszyniany [21], Michałowo [25], Lesznia-Łuchowa Góra [30], Proniewicze PR 1/93 [32], Proniewicze P-3 [33], Wólka 1 [35], Wólka 2 [35], Skupowo [37], *Boćki 2 [38], Choroszczewo [39], *Otapy 1 [34] – upper part of zone III of Bitner (1956)	Pollen of *Pinus sylvestris* type and *Betula alba* type is the most abundant. At Solniki pine reaches values up to ca. 87%, at other sites typically ranging from 30% (Kruszyniany, Proniewicze P-3 and Wólka 1) to 70% (Proniewicze P-3). At the type locality birch remains below 14%. However, in the most of other sites, this zone contains a culmination of *Betula alba* type with maximum pollen values reaching 25% (Poniatowicze 1) and 75% (Lesznia-Łuchowa Góra). *Salix* is the characteristic taxon of the zone at the type locality – it reaches here its interglacial maximum (8%). At other sites *Salix* values remain below 1%. *Quercus* has very different pollen values, from 1% at Podkamionka to 23% at the type locality. *Ulmus* is continuously present, but generally with low percentages, from 1% (Kruszyniany and Wólka 1) to 5% (Choroszczewo and Wólka 2) – at type locality *Ulmus* has values of 2.6%. An exception to that is represented by Poniatowicze 1, where pollen of elm reaches 10%. The proportion of NAP and heliophilous shrubs is very low.
E_{NP}3	***Quercus-Ulmus-Fraxinus***	Solniki [28]	17 profiles: *Ludomirowo [7] – zone IV of Bitner (1957), Poniatowicze 1 [12], Poniatowicze 2 [12], Podkamionka [16], Kruszyniany [21], Michałowo [25], Hieronimowo [26], Lesznia-Łuchowa Góra [30], Proniewicze PR 1/93 [32], Proniewicze P-3 [33], Wólka 2 [35], Skupowo [37], Choroszczewo [39], *Otapy 1 [34], *Otapy 2 [34], *Boćki 1 [38]	Values of *Pinus sylvestris* type are still relatively high, but gradually decrease to ca. 10% at the type locality. The ultimate peaks of *Quercus*, *Fraxinus* and *Ulmus* are characteristic features of this zone. The maximum values of *Quercus* span a wide range of 20-72% (at type locality – ca. 60%). At the type locality *Fraxinus* reaches the maximum of 7% and 2-12% at the remaining sites. *Ulmus* reaches 20% at Solniki and 7-13% at other localities. *Corylus avellana* is already present in all sites, its values rising rapidly in the younger part of the zone. Its very high values are noted at Solniki – 20%. Maximum values of *Alnus* and *Tilia cordata* type remain below 1% in all the profiles. Two subzones were distinguished in the zone:
E_{NP}3a	*Pinus*			*Pinus sylvestris* type values are high (to 55%), often exceeding the *Quercus* values. *Corylus avellana* pollen is sporadic or with low values (to 2%).
E_{NP}3b	*Corylus*			*Corylus avellana* values distinctively rise which stays in line with the accompanying decline in values of *Pinus sylvestris* type. The percentages of *Corylus avellana* usually lie within the range of 5-20% in the youngest part.

$E_{NP}4$	***Corylus-Alnus-Tilia***	Kruszyniany [21]	26 profiles: *Ludomirowo [7] – zone V of Bitner (1957), Starowlany [8], *Chwaszczewo [9], *Gilbowszczyzna [11], Poniatowicze 1 [12], Poniatowicze 2 [12], Sokółka 1 [13], Sokółka 2 [13], Drahle [14], Bohoniki [15], Podkamionka [16], Machnacz [17], Harkawicze [20], Dzierniakowo [24], Michałowo [25], Hieronimowo [26], Lesznia-Łuchowa Góra [30], Haćki [31], Proniewicze PR 1/93 [33], *Otapy 1 [34], *Otapy 2 [34], Skupowo [37], *Śliwowo 1 [36], *Boćki 1 [38], *Boćki 2 [38], Choroszczewo [39]	*Corylus avellana* pollen is dominant throughout the zone. At the type locality it reaches its maximum of ca. 70%, while at other sites it ranges from about 40% (Choroszczewo) to 75% (Solniki). At most sites *Tilia cordata* type reaches its maximum interglacial peak, with maximum values ranging from ca. 12% (Sokółka 2, Poniatowicze 1) to 40% (type locality). *Carpinus betulus* is also an important taxon. At the type locality its pollen values reach 5%, while at other sites even 40% (Solniki). *Alnus* is distinctively represented, but it does not reach its highest pollen values until the younger part of the zone. At the type locality its maximum is 15%, while at other sites maximum values fluctuate from about 5% (Drahle, Choroszczewo) to 22% (Harkawicze). Very high percentages of *Alnus* at Podkamionka (max. 33%) probably result from local over-representation of the pollen content. *Tilia tomentosa, Tilia platyphyllos, Hedera*, *Viscum* and *Ilex* pollen, that denote climate optimum of that period, occur in small values. The NAP values are the lowest in the whole interglacial and do not exceed 3%. Two subzones were distinguished in the zone. The lower subzone represents a minimized variety of the "early lime" acc. to Mamakowa (1989).
$E_{NP}4a$	*Quercus*			*Corylus* and *Quercus* pollen both reach maximum values in the zone. Pollen of *Tilia cordata* type occurs from the beginning of the zone and gradually rises, at the type locality to 10%, at the others up to 3-8%.
$E_{NP}4b$	*Carpinus*			Pollen of *Tilia cordata* type reaches its maximum there. The *Corylus avellana* values are lower than in the lower subzone, 30-60% in the type profile. The *Carpinus betulus* values distinctively increase.
$E_{NP}5$	***Carpinus***	Solniki [28]	27 profiles: Starowlany [8], *Chwaszczewo [9], *Trzcianka [10], Poniatowicze 1 [12], Sokółka 1 [13], Sokółka 2 [13], Drahle [14], Bohoniki [15], Machnacz [17], Harkawicze [20], *Bagno-Kalinówka [19], Kruszyniany [21], Pieszczaniki [23], Dzierniakowo [24], Hieronimowo [26], Małynka [27], *Klewinowo [29], Lesznia-Łuchowa Góra [30], Haćki [31], Proniewicze PR 1/93 [32], *Otapy 1 [34], *Otapy 2 [34], *Śliwowo 1 [36], *Śliwowo 2 [36], Skupowo [37], *Boćki 2 [38], Choroszczewo [39]	*Carpinus betulus* is the distinctive taxon of the zone. At Solniki it dominates reaching a maximum of 82%. Depending on the site maximum values reach the level of 40% (Hieronimowo) up to 75% (Kruszyniany and Starowlany). *Corylus avellana* shows a decreasing trend throughout the entire zone. In case of the type locality it starts from ca. 25% in the lower part of the zone ending up with about 5% in the upper one. At the type locality the maximum of *Alnus* comes up to 15%, at other sites it also does not exceed this value, except for Kruszyniany, Hieronimowo, Harkawicze, Sokółka 2, and Boćki 2 with ca. 20%. *Tilia cordata* type is still relatively frequent especially in the older part of the zone. The proportion of other thermophilous trees and shrubs is lower than in the previous zone. *Picea abies* type and *Abies alba* are significantly represented in the younger part of the zone. Two regional subzones were distinguished in the zone:
$E_{NP}5a$	*Corylus*			Pollen of *Tilia cordata* type, *Corylus avellana* and *Ulmus* is relatively frequent. Pollen of *Picea abies* type and *Abies alba* occurs rather rare.
$E_{NP}5b$	*Picea*			Values of *Picea abies* type gradually rise. *Abies alba* pollen is fairly often noted. *Carpinus betulus* reaches its interglacial maximum. The frequency of *Pinus sylvestris* type and *Betula alba* type increases.
$E_{NP}6$	***Picea-Pinus-(Abies)***	Solniki [28]	12 profiles: Starowlany [8], *Gilbowszczyzna [11], Poniatowicze 2 [12], Machnacz [17], Kruszyniany [21], Hieronimowo [26], Haćki [31], *Otapy 1 [34], Wólka 2 [35], *Śliwowo 1 [36], *Śliwowo 2 [36], Choroszczewo [39]	*Picea abies* type is the most distinctive taxon of the zone. It reaches its interglacial maximum; at the type locality it is ca. 37% while at other sites ranging from 31% (Hieronimowo) to 45% (Starowlany). The maximum values of *Abies alba* reach 1% at the type locality; at other sites their range is similar or even lower. *Carpinus betulus* is still highly represented with maximum values of 20% at Solniki and 2-29% at other localities. Proportion of *Alnus* is still high – with maximum values fluctuating from ca. 3% at Hieronimowo up to 15% at Kruszyniany. At the type locality it reaches 10%. *Pinus sylvestris* type values rise markedly to 48% at Solniki, up to 15-45% at majority of remaining sites. Notably at Poniatowicze 2 it reaches ca. 80%. At Solniki *Betula alba* type has the small peak with values of 15%; at other sites having values of 3-10%. In some profiles *Larix* pollen also appears.

Table 58. Continued

R PAZ	Name	Type site	Other occurrences	Description of regional pollen assemblage zones (R PAZ)
E_{NP}7	***Pinus***	Solniki [28]	29 profiles: Starowlany [8], *Chwaszczewo [9], *Trzcianka [10], *Gilbowszczyzna [11], Poniatowicze 2 [12], Sokółka 1 [13], Sokółka 2 [13], Drahle [14], Bohoniki [15], Podkamionka [16], Machnacz [17], Harkawicze [20], *Bagno-Kalinówka [19], Kruszyniany [21], Pieszczaniki [23], Dzierniakowo [24], Michałowo [25], Hieronimowo [26], Małynka [27], *Klewinowo [29], Haćki [31], Proniewicze PR 1/93 [32], Proniewicze P-3 [33], *Otapy 1 [34], *Otapy 2 [34], Śliwowo 1 [36], Skupowo [37], *Boćki 1 [38], Choroszczewo [39]	The zone is represented in almost all profiles from northern Podlasie. Pollen of *Pinus sylvestris* type is the most abundant. Its maximum values are 91% at Solniki and 75-90% at remaining sites. Four subzones were distinguished in the zone. This subdivision is only reflected in the profile from Solniki; at Machnacz, Michałowo and Dzierniakowo two middle subzones cannot be distinguished.
E_{NP}7a	*Picea*			Values of *Picea abies* type are still high – they gradually decrease from 20% to 6% at the type locality and from 10% to 0.5% at other sites. Pollen of *Carpinus betulus* and *Alnus* is regularly recorded, however with rather low values.
E_{NP}7b	*Betula*			*Betula alba* type reaches its interglacial maximum – 68% at the type locality. NAP values rise to about 20%. *Pinus sylvestris* type decreases down to values of ca. 20%.
E_{NP}7c	NAP			Values of NAP, represented mainly by *Artemisia*, Poaceae undiff. and Cyperaceae, reach their peak (50% at the type locality). Proportion of *Betula alba* type is still high, at Solniki up to ca. 42%.
E_{NP}7d	*Pinus*			*Pinus sylvestris* type has very high peak (ca. 91%). There is a decrease in NAP (ca. 10%) and *Betula alba* type (7-18%).
EV_{NP}1	***Artemisia*-Cyperaceae-Poaceae**	Solniki [28]	9 profiles: Poniatowicze 2 [12], Sokółka 2 [13], Machnacz [17], Dzierniakowo [24], Michałowo [25], Małynka [27], Haćki [31], Proniewicze P-3 [33], Choroszczewo [39]	The proportion of herb pollen is distinctive for this zone. At the type locality it reaches 55%. Remaining sites have their maximum NAP values above 50%. High NAP values are mainly defined by the presence of Poaceae undiff., Cyperaceae, *Artemisia* and Chenopodiaceae. Maximum values of *Artemisia*, the most distinctive taxon of the zone, are fairly high. At the type locality they reach 15% and in most of other sites they remain similar or are considerably higher (up to 18% in Dzierniakowo). The values of other herbaceous taxa also increase and the variety of taxa is very great. The rise of NAP is also accompanied by the increasing pollen values of *Junierus* (to ca. 20%), *Betula nana* type (to ca. 7%) and *Salix* (to ca. 5%). Pollen of thermophilous trees is still present (owing to redeposition). Three subzones were distinguished in the zone:
EV_{NP}1a	*Calluna-Juniperus*			Low-percentage peak of *Calluna vulgaris* (max. 3%), the maximum of *Juniperus* (25%) and values of *Pinus sylvestris* type gradually decreasing from 50% to 5% are the most characteristic features of this subzone.
EV_{NP}1b	*Pinus*			There is no high peak in the *Pinus sylvestris* type; small slumps in NAP and *Juniperus* are described.
EV_{NP}1c	*Juniperus-Artemisia-Betula nana*			Proportion of *Pinus sylvestris* type is very low (below 5%). Values of *Betula alba* type steadily rise to about 40%. *Betula nana* type reaches its maximum with values of 6%.

$EV_{NP}2$	***Betula***	Solniki [28]	5 profiles: *Trzcianka [10], ?Poniatowicze 2 [12], ?Sokółka 2 [13], Machnacz [17], Dzierniakowo [24], Haćki [31]	Very high proportion of *Betula alba* type is the most characteristic feature of the zone. It reaches 89% at the type locality and 78-95% at other sites. Two subzones were distinguished in the zone:
$EV_{NP}2a$	NAP			NAP frequency is relatively high but gradually decreases to 7%.
$EV_{NP}2b$	*Pinus*			*Pinus sylvestris* type proportion rises to 65% at the type locality and to 60-70% at the remaining sites.
$EV_{NP}3$	***Artemisia-Betula*-Poaceae**	Solniki [28]	2 profiles: Machnacz [17], Dzierniakowo [24]	*Artemisia* peaks with values up to 20%. Proportion of *Betula alba* type is 30-65%, and *Pinus sylvestris* type is 40-70%.
$EV_{NP}4$	***Pinus-Betula***	Solniki [28]	4 profiles: Poniatowicze 2 [12], Sokółka 2 [13], Machnacz [17], Dzierniakowo [24]	*Betula alba* type and *Pinus sylvestris* type are characteristic taxa of the zone and their pollen occur in the greatest numbers. *Betula alba* type has maximum values in the lower part of the zone, and *Pinus sylvestris* type in the upper. The values of herbs pollen are low (max. 20% at the lowest part of the zone). Three subzones were distinguished in the zone:
$EV_{NP}4a$	*Betula*			At the type locality *Betula alba* type reaches its peak (80%) at the beginning of the zone. At other sites the maximum values of this taxon range from 75% to 83%.
$EV_{NP}4b$	*Pinus-Betula*			*Pinus sylvestris* type and *Betula alba* type dominate – up to 85% and to 25%, respectively. Pollen of *Larix* and *Picea abies* type is still present.
$EV_{NP}4c$	*Pinus*			At the type locality *Pinus sylvestris* type reaches 89%, at other sites it is quite similar. Values of *Betula alba* type decrease from 25% to 5%. Values of *Picea abies* type fluctuate around 1%, only in Dzierniakowo they reach 5% in some pollen spectra.
$EV_{NP}5$	***Artemisia*-Poaceae**	Solniki [28]	2 profiles: *Trzcianka [10], Machnacz [17], Dzierniakowo [24]	Pollen values of herbs rise up to 63%. Great variety of their taxa is recorded. The most abundant is the pollen of *Artemisia* (15-32%), Cyperaceae (4-19%), Poaceae (4-8%), Chenopodiaceae (about 2%) and *Thalictrum*. Pollen of *Calluna vulgaris* (up to 4%) and Ericaceae undiff. (up to 2%) is still present. Shrubs are represented by pollen of *Juniperus* (below 1%) and *Betula nana* type (to 1.5%). Two subzones were distinguished in the zone:
$EV_{NP}5a$	*Pinus*			Values of *Pinus sylvestris* type are relatively high but gradually decrease below 10%.
$EV_{NP}5b$	*Juniperus-Betula*			
$EV_{NP}6$	***Pinus-Betula***	Dzierniakowo [24]	1 profile: Machnacz [17]	*Betula alba* type and *Pinus sylvestris* type dominate. Two subzones were distinguished in the zone:
$EV_{NP}6a$	*Betula*			*Betula alba* type reaches its peak with values of ca. 80%. Proportion of *Pinus sylvestris* is very low (ca. 5%). Values of NAP gradually decrease from 55% down to 5%.
$EV_{NP}6b$	*Pinus*			*Pinus sylvestris* type dominates (ca. 85%). Values of *Betula alba* (ca. 8%) are low. The maximum of *Larix* (4%) is recorded there. Pollen of *Picea abies* type is still present but with values below 1%. NAP gradually increase to about 45%.

case of northern Podlasie the zone is well represented only by pollen spectra, corresponding to the upper subzone of this zone, that is the *Picea* R PASZ.

Pollen zones with similar pollen records are well known in the literature as the "lower spruce" zone. Its presence is characteristic for north-eastern Poland, Belarus and the Russian Plain (Mamakowa 1989).

THE EEMIAN INTERGLACIAL

Another seven regional pollen zones from northern Podlasie represent the interglacial vegetation succession. Its typical features include: (1) very high pollen values of *Corylus avellana*, (2) the expansion of trees and hazel in particular sequence, i.e. *Betula-Pinus*, *Ulmus*, *Quercus-Fraxinus*, *Corylus*, *Alnus*, *Taxus*, *Tilia*, *Carpinus*, *Picea-Abies*, and *Pinus* and (3) a marked increase in the *Carpinus* pollen presence coupled with high co-occurrence of those of *Corylus* (Fig. 55). That in turn allows unquestionably correlate it with the Eemian interglacial (cf. Mamakowa 1989). Its stratotype site lies close to the Eem river near Amersfoort (Zagwijn 1961).

Cases of the Eemian regional zones described from northern Podlasie are marked with the E_{NP} signature being chronologically numbered.

Northern Podlasie regional pollen zones of the $E_{NP}1$-$E_{NP}7$ match with the E1-E7 zones (Mamakowa 1989) that are assigned to the Eemian interglacial for the entire area of Poland (Fig. 53).

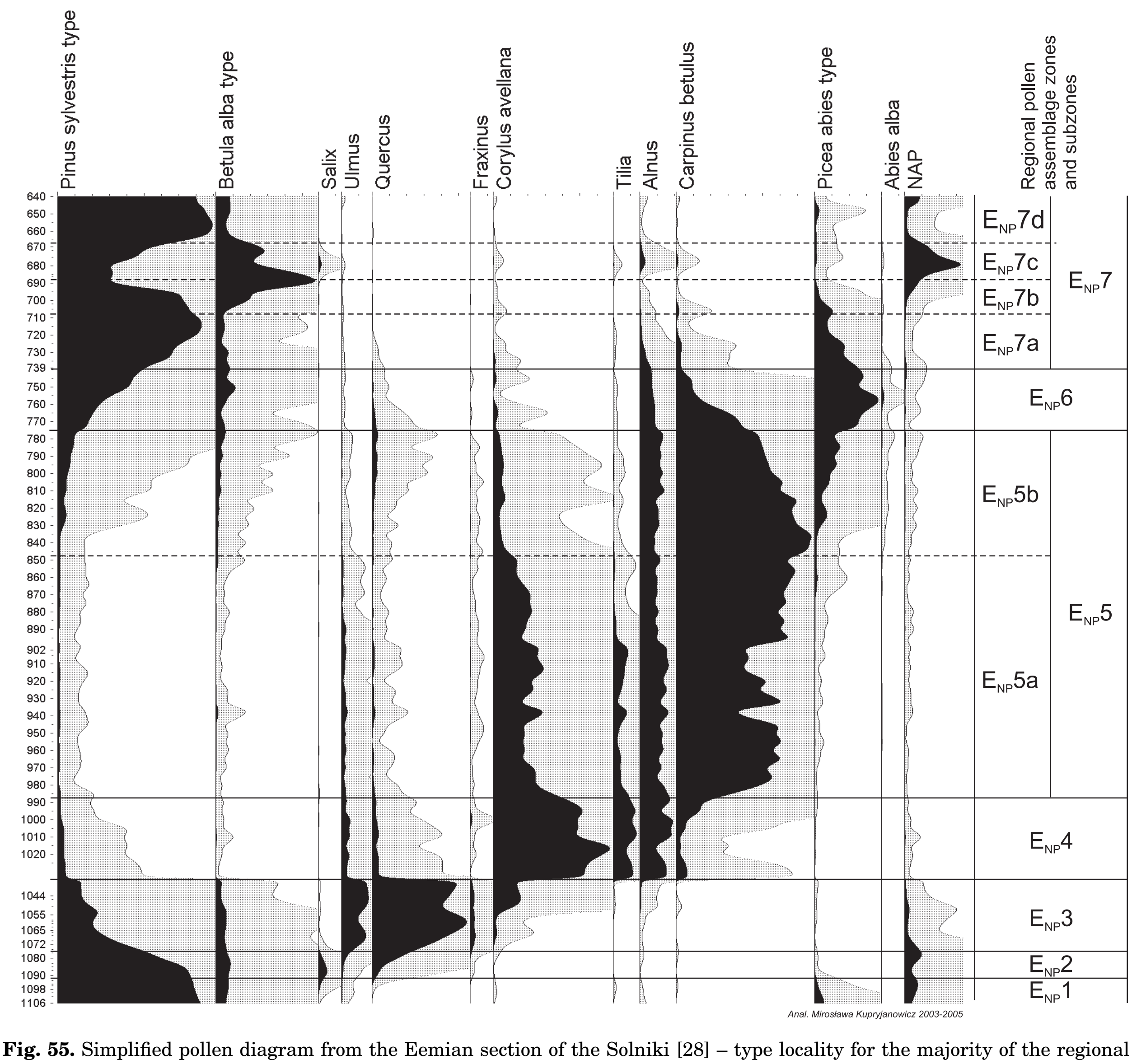

Fig. 55. Simplified pollen diagram from the Eemian section of the Solniki [28] – type locality for the majority of the regional pollen zones (R PAZ) in the northern Podlasie (only curves of main trees and shrubs)

E_{NP}1 *Pinus-Picea-(Betula)* R PAZ

The zone is represented in 6 profiles (Fig. 53, Tab. 58). It is also present at two other sites in northern Podlasie: Ludomirowo [7] (zone II, according to Bitner 1957) and Otapy 1 [34] (Bitner 1956a). As concerns northern Podlasie the type locality for this particular zone is represented by the Solniki [28] site. The zone itself corresponds to the regional E1 *Pinus-Betula* pollen zone distinguished by Mamakowa (1989) in the Eemian pollen succession for the entire area of Poland.

E_{NP}2 *Pinus-Quercus-Ulmus-Salix* R PAZ

The zone is represented in 12 studied profiles (Fig. 53, Tab. 58). It is also known from six other localities in northern Podlasie: Miklewszczyzna [5], Zacisze [6] and Ludomirowo [7] (Bitner 1957), Michałowo [25] (Kupryjanowicz & Drzymulska 2002), Proniewicze PR 1/93 [32] (Krupiński 1995), and Otapy 1 [34] (Bitner 1956a). In northern Podlasie the type locality for this zone is well represented by the Solniki [28] site. The zone may be correlated to the Polish regional E2 pollen zone specified by Mamakowa (1989).

E_{NP}3 *Quercus-Ulmus-Fraxinus* R PAZ

The zone is represented in 11 profiles (Fig. 53, Tab. 58). It is also present in other 9 profiles from northern Podlasie: Nowy Dwór 59 [4] (Noryśkiewicz 2005), Miklewszczyzna [5], Zacisze [6] and Ludomirowo [7] (Bitner 1957), Michałowo [25] (Kupryjanowicz & Drzymulska 2002), Proniewicze PR 1/93 [32] (Krupiński 1995), Otapy 1 [34] and Otapy 2 [34] (Bitner 1956a), and Milejczyce [40] (Bińka 2006a). When considering northern Podlasie the Solniki [28] site represents the type locality for this zone. It is related to the Polish regional E3 zone (Mamakowa 1989)

E_{NP}4 *Corylus-Alnus-Tilia* R PAZ

The zone is represented in 19 studied profiles (Fig. 53, Tab. 58). It is present as well at 10 other sites from northern Podlasie: Nowy Dwór 59 [4] (Noryśkiewicz 2005), Miklewszczyzna [5], Zacisze [6] and Ludomirowo [7] (Bitner 1957), Machnacz [17] (Kupryjanowicz 1991, 1995), Michałowo [25] (Kupryjanowicz & Drzymulska 2002), Proniewicze PR 1/93 [32] (Krupiński 1995), Otapy 1 [34] and Otapy 2 [34] (Bitner 1956a), and Milejczyce [40] (Bińka 2006a). In northern Podlasie the type locality for this zone is at Solniki [28] site.

This particular zone corresponds to the Polish regional E4 *Corylus-Quercus-Tilia* zone. The only difference lies in extremely low proportion of *Taxus baccata* pollen in sediments known from northern Podlasie (up to only 1.3% in Proniewicze PR1/93 [33] profile – Krupiński 1995). Most probably it stays related to the sheer location of the studied area, since this particular region in north-eastern Poland presently lies beyond the contemporary *Taxus* range, and probably this was the case as well through the whole Holocene (Krupiński et al. 2004). *Taxus* pollen was very poorly represented at all the sites representing the Eemian interglacial in the north-eastern part of Poland (Mamakowa 1989). The sites nearest to northern Podlasie, where *Taxus* pollen was represented in values exceeding those presented here, include Niewodowo [58] – up to 2% (Musiał et al.1982) and Łomża-Łomżyca [55] – up to 5.3% (Krupiński 1992). Thus, it is very likely that the area of northern Podlasie was at that time, during the Eemian interglacial, beyond the range of this particular species. Probably for the same reason the profiles from northern Podlasie lacked the pollen of *Ligustrum*.

E_{NP}5 *Carpinus* R PAZ

The zone is represented in 18 profiles, but only in as few as in six of them the pollen record of the lower section is present whereas in one case in its upper part.

The E_{NP}5 *Carpinus* R PAZ occurs also in 12 other profiles from northern Podlasie, namely Nowy Dwór 50 [4] and Nowy Dwór 62 [4] (Noryśkiewicz 2005), Zacisze [6], Ludomirowo [7] (Bitner 1957), Machnacz [17] (Kupryjanowicz 1991, 1995), Bagno-Kalinówka [21] (Borówko-Dłużakowa & Halicki 1957), Klewinowo [29] (Borówko-Dłużakowa 1973a, 1974), Haćki [31] (Brud & Kupryjanowicz 2002, Kupryjanowicz 2005b), Proniewicze PR 1/93 [32] (Krupiński 1995), Otapy 1 [34] and Otapy 2 [34] (Bitner 1956a) and Milejczyce [40] (Bińka 2006a). As it concerns northern Podlasie the type locality for this particular zone is to be found at the Solniki [28] site.

The E_{NP}5 *Carpinus* zone correlates to the Polish regional E5 *Carpinus-Corylus-Alnus* zone, for which case representative site lies at Główczyn (Niklewski 1968). The typical site of the zone is usually divided into two sub-zones.

Therefore in case of northern Podlasie two subzones of the $E_{NP}5$ *Carpinus* regional pollen zone were distinguished as well. The lower one, *Corylus* R PASZ, is characterized by relatively high proportion of *Corylus avellana* pollen whereas the upper one, *Picea* R PASZ, by maximum of *Carpinus betulus* combined with increasing values of *Picea abies* type.

The correlation of local pollen zones known from the analysed profiles with other regional pollen zones indicates that in many profiles the hiatus that contains the younger part of the hornbeam phase and the spruce phase of the Eemian interglacial is present. This phenomenon was noticed for the following profiles:

– Dzierniakowo [24] – between D-2 and D-3 L PAZ (Fig. 8).

– Małynka [27] – between Ma-1 and Ma-2 L PAZ (Fig. 17).

– Sokółka 2 [13] – between the depth of 14.50 m and 14.40 m (Fig. 22). The presence of the hiatus in this profile may be associated with the change from dark brown peaty silt into dark grey silt. Very similar transitional zone is traced in the Sokółka 1[13] profile found there at the depth of 13.00 m (Fig. 21, Tab. 17). It suggests that also in case of that profile the hiatus might occur. Since no sample could be collected at the Sokółka 1 site that would span the interval of 13.05–12.20 confirmation of such hypothesis is out of reach at the moment.

– Podkamionka [16] – in this profile neither the hornbeam phase ($E_{NP}5$ R PAZ), nor the spruce phase ($E_{NP}6$ R PAZ) of the Eemian interglacial are found (Fig. 27). Non-pollen sediment layer, 30 cm thick, starting at the depth of 8.30–8.00 m, placed between the Pa-3 *Corylus-Tilia-Alnus* and Pa-4 *Betula-Pinus*-NAP, probably corresponds chronologically to those phases. Very small thickness of this layer suggests a very low rate of sediment being accumulated at that time or/and a presence of the hiatus itself. The lack of pollen indicates that the sediments formed at that time could simply dried out.

– Bohoniki [15] – the hiatus corresponding to the spruce phase ($E_{NP}6$ R PAZ) and to the younger part of the hornbeam phase ($E_{NP}5$ R PAZ) of the Eemian interglacial seemingly occurs in the profile in question (Fig. 31). A sample from the depth of 3.10 m contains mixed pollen material representing local pollen zones of the B-2 *Carpinus* (equal with older part of the $E_{NP}5$ R PAZ) and B-3 *Pinus-Betula*-NAP (matching the $E_{NP}7$ R PAZ). Such instance however may be the result of natural processes accompanying sedimentation itself or could equally be related to sheer manner of performing the boring.

The occurrence of the hiatus is very frequent in the Eemian profiles representing northern Podlasie. Apart from the profiles mentioned above it is also recorded from other sites presented in this article, i.e. Pieszczaniki [23], Drahle [14], Harkawicze [20], Proniewicze P-3 [33] and from three previously studied localities: Klewinowo [29], Proniewicze PR 1/93 [32] and Otapy 2 [34]. Discussion upon this phenomenon is presented in the last chapter of this paper.

$E_{NP}6$ *Picea-Pinus-(Abies)* R PAZ

The zone is represented in 8 studied profiles (Fig. 53, Tab. 58). It is also present at another 7 sites in northern Podlasie, that is Nowy Dwór 50 [4] and Nowy Dwór 62 [4] (Noryśkiewicz 2005), Ludomirowo [7] (Bitner 1957), Machnacz [17] (Kupryjanowicz 1991, 1995b, c), Haćki [31] (Brud & Kupryjanowicz 2002, Kupryjanowicz 2005b), Otapy 1 [34] (Bitner 1956a) and Milejczyce [40] (Bińka 2006a). The type locality for this particular zone in case of northern Podlasie is the the Solniki [28] site.

The zone corresponds to the Polish regional zone E6 *Picea-Abies-Alnus*, for which the typical site is known from Bedlno (Środoń & Gołąbowa 1956). At its typical site the zone may be divided into two subzones of the E6a *Carpinus* and E6b *Pinus*. Due to small thickness of the sediments representing the $E_{NP}6$ zone assignment of subzones was of no sense though in the pollen diagram the difference between the lower and the higher part of the zone is quite evident. Low percentage of *Abies alba* in profiles known from northern Podlasie stays related to the presence of north-eastern boundary of fir range at the time of the Eemian interglacial.

$E_{NP}7$ *Pinus* R PAZ

The zone is represented in 20 studied profiles (Fig. 53, Tab. 58). It is present as well at 13 other sites cited from northern Podlasie: Nowy Dwór 50 [4] and Nowy Dwór 62 [4] (Noryśkiewicz 2005), Ludomirowo [7] (Bitner 1957), Machnacz [17] (Kupryjanowicz 1991, 1995b, c), Czarna Wieś [18] (Bitner 1956b), Bagno-Kalinówka [21] (Borówko-Dłużakowa & Halicki 1957), Michałowo [25] (Kupryjanowicz & Drzymulska 2002), Klewinowo [29] (Borówko-Dłużakowa 1973a, 1974), Haćki [31] (Brud & Kupryjanowicz 2002, Kupryjanowicz 2005b), Proniewicze PR 1/93 [32] (Krupiński 1995), Otapy 1 [34] and Otapy 2 [34] (Bitner 1956a) and Milejczyce [40] (Bińka 2006a). As it concerns northern Podlasie the type locality for this particular zone is represented by the Solniki [28] site.

In the Pieszczaniki [23] profile the presence of the sediment layer represented by the Pi-2 *Pinus-Picea-Carpinus* local pollen zone is very hard to be explained. If one takes into consideration the composition of the pollen spectra this zone corresponds to the $E_{NP}7$ R PAZ. However, the $E_{NP}7$ R PAZ closes the interglacial pollen succession whereas the Pi-2 L PAZ occurs between the Pi-1 *Carpinus-Corylus-Alnus* and Pi-3 *Carpinus-Picea-Corylus* zones, which represented hornbeam phase of this interglacial ($E_{NP}5$ R PAZ). The lack of deposits containing pollen of *Pinus sylvestris* type above the Pi-3 L PAZ makes the situation impossible to happen, if considering that the core might simply get contaminated during the boring. It therefore allows suspecting that the inversion of the sediments took place owing to the natural course of accumulation process. The similar phenomenon is documented from the Skupowo [37] profile (Fig. 47).

The zone may be correlated to the E7 *Pinus* zone. The correlation is partially disturbed by the $E_{NP}7b$ *Betula* and $E_{NP}7c$ NAP subzones described from numerous profiles known from northern Podlasie (Fig. 56). Within the inner layer of the profile the possibility of contamination by adjoining sediments moved along during the boring is rather low. Thus these sediments containing the $E_{NP}P7b$ and $E_{NP}7c$ subzones were likely to occur *in situ* and may therefore indicate cool climatic fluctuations happening during the pine phase. At the Zgierz-Rudunki site (Jastrzębska-Mamełka 1985), that is recognized as typical for the E7 *Pinus* regional zone for central, western and north-eastern Poland, a fluctuation similar in character though less marked was discerned for the earlier part of that phase. Slight variations of similar character are also figured in diagrams representing the following sites: Warszawa-Wola (Borówko-Dłużakowa 1960),

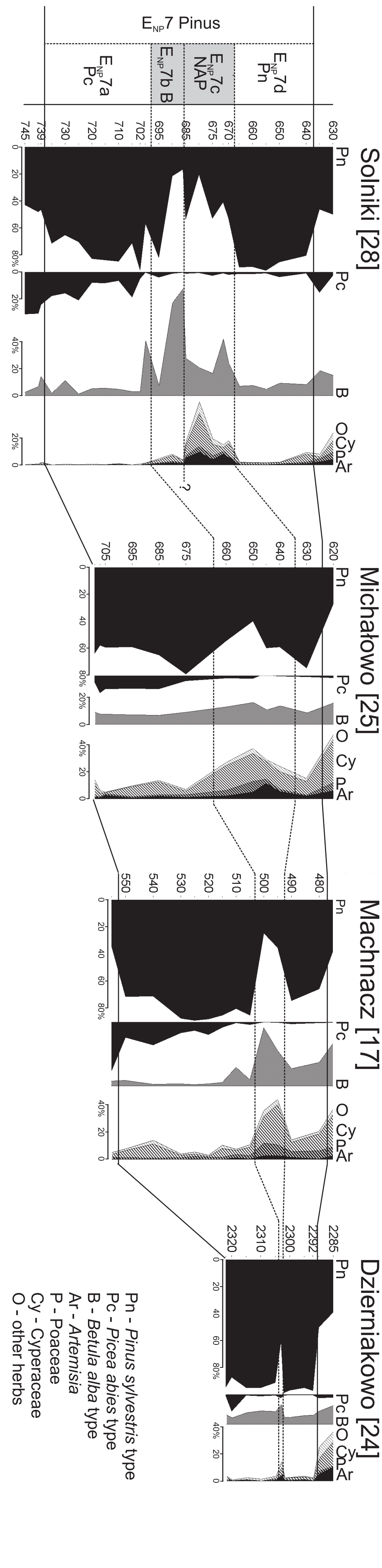

Fig. 56. Comparison of the $E_{NP}7$ *Pinus* R PAZ pollen record from four selected sites in northern Podlasie (only main pollen curves). Site numbers as in Figure 1, Table 1 and the text

Konopki Leśne [54] (Borówko-Dłużakowa 1971a), Nakło (Noryśkiewicz 1978), Józefowo (Sobolewska 1966) and Horoszki Duże (Granoszewski 2003).

The upper boundary of the $E_{NP}7$ *Pinus* zone is accepted as the borderline between the Eemian interglacial and the Early Vistulian, what agrees with the criteria proposed by Andersen (1961), Zagwijn (1961), Behre (1989) and Mamakowa (1989). This boundary was marked out in the profiles known from northern Podlasie at the level where the herb pollen contents increased above 50%. At least in case of some profiles, e.g. Machnacz [17] and Michałowo [25], this increase can be related to much higher values of Cyperaceae and corresponds to the borderline between birch peat and mossy fern peat in the sediment. In relation to the peat layer the proportion of vegetative macroscopic fern debris apparently increases what may suggest that higher values of Cyperaceae in the pollen spectra may be caused by their presence in the peat-bog itself. Although the exclusion of Cyperaceae from the basic sum makes the increase in NAP less definite at the point where the Eemian interglacial and the Vistulian glaciation meet, such omission may be acceptable (Kupryjanowicz 1995, Kupryjanowicz & Drzymulska 2002).

EARLY GLACIAL OF THE VISTULIAN GLACIATION

The Early Vistulian regional pollen zones in northern Podlasie are marked herein with the letters EV_{NP}.

$EV_{NP}1$ *Artemisia*-Cyperaceae-Chenopodiaceae R PAZ

The zone is represented in 9 studied profiles (Fig. 53, Tab. 58). It is also present in four other sites known from northern Podlasie, namely Machnacz [17] (Kuryjanowicz 1991, 1995b, c), Michałowo [25] (Kupryjanowicz & Drzymulska 2002), Haćki [31] (Brud & Kupryjanowicz 2002, Kupryjanowicz 2005b), and Milejczyce [40] (Bińka 2006a). In relation to northern Podlasie the type locality for this zone is represented by the Solniki [28] site.

The $EV_{NP}1$ zone (Fig. 53) corresponds to the Polish regional zone EV1 Poaceae-*Artemisia-Betula nana* (Mamakowa 1989). Lower values of *Artemisia* and Poaceae compared to those in the profile from Zgierz-Rudunki (type site for this zone in Poland) are probably caused by particular local conditions. The zone represents the first post-Eemian cooling of the climate. It may be correlated as well with the Herning stadial distinguished in Germany and the Melisey 1 stadial from the eastern France (Fig. 57). As it concerns North Atlantic cores their equivalent may be that of the C23 cold period.

The $EV_{NP}1b$ *Pinus* regional subzone characteristic of its higher values of *Pinus sylvestris* type is delineated in the middle section of the $EV_{NP}1$ zone. It probably reflects some short-term warm fluctuations within the Herning stadial. Notably, there is no record of this change in any other profile neither from Poland nor from the western or northern Europe. On the other hand it is only quoted from Belarus (San'ko 1987 after Mojski 1993).

$EV_{NP}2$ *Betula*, $EV_{NP}3$ *Artemisia*-Poaceae and $EV_{NP}4$ *Pinus-Betula* R PAZs

All three zones are represented only in 2 studied profiles – Solniki [28] and Dzierniakowo [24] (Fig. 53, Tab. 58). In 4 next profiles, only single pollen spectra reflecting the $EV_{NP}2$ and $EV_{NP}4$ zones occurs. The $EV_{NP}2$ and $EV_{NP}4$ zones are also present in 5 other sites from the Northern Podlasie: Nowy Dwór 50 [4] (Noryśkiewicz 2005), Machnacz [17] (Kupryjanowicz 1991, 1995b, c), Michałowo [25] (Kupryjanowicz & Drzymulska 2002), Haćki [31] (Brud & Kupryjanowicz 2002, Kupryjanowicz 2005b), and Milejczyce [40] (Bińka 2006a). Type locality for these zones in the Northern Podlasie is the Solniki [28] site.

The $EV_{NP}2$, $EV_{NP}3$ and $EV_{NP}4$ R PAZ both represent the Polish EV2 *Betula-Pinus* pollen zone, which is correlated by Mamakowa (1989) with the first interstadial of the Early Vistulian. The above mentioned zones (Fig. 57) correspond to:

German Brørup interstadial = Brørup *sensu lato* = Amersfoort/Brørup (Erd 1973, Menke & Tynni 1984, Behre & Lade 1986):

– Danish Brørup with the stratotype site at Brørup Hotel Bog (Andersen 1961),

– two interstadials – Amersfoort and Brørup *sensu stricto* – and stadial between them in the Netherlands,

– Saint German 1 interstadial in the eastern France (de Beaulieu & Reille 1984, 1992a, b, Reille & de Beaulieu 1990, Reille et al. 1998),

Oxygen isotope stages (acc. Pisias et al. 1984)	Greenland - interstadials (acc. Dansgaard et al. 1993)	North Atlantic - warm (W) and cold (C) periods (acc. McManus et al. 1994)	Poland - R PAZ (acc. Mamakowa 1989)	South Podlasie - R PAZ (acc. Granoszewski 2003)	**Northern Podlasie - R PAZ**	Chronostratigraphy: The Netherlands	Chronostratigraphy: Eastern France	Chronostratigraphy: Northern Germany
5a	21	W21	EV4 Pn-B	from HD-23 to HD-26	**$EV_{NP}6$ Pn-B**	Odderade	Saint Germain 2	Odderade
5b		C21	EV3 G-Ar-Bn	HD-21 HD-22	**$EV_{NP}5$ Ar-P**		Melisey 2	Rederstall stadial
5c	22	W22	EV2 B-Pn (Pn)	from HD-16 to HD-20	**$EV_{NP}4$ Pn-B** (Pn / B)	Brørup (*sensu stricto*)	C — Saint Germain 1	Brørup (*sensu lato*)
		C22	(B)	HD-15 NAP-B	**$EV_{NP}3$ Ar-P**		B	
	23	W23		HD-14 B	**$EV_{NP}2$ B**	Amersfoort	A	
5d		C23	EV1 G-Ar-Bn	HD-13 Po-Cy-J- (Salix polaris t.)	**$EV_{NP}1$ Ar-Cy-Ch**		Melisey 1	Herning stadial

Fig. 57. Correlation of the Early-Vistulian regional pollen zones (R PAZ) from the northern Podlasie and other stratigraphic units of this part of the last glaciation from Europe

– two interstadials – 23 and 22 – and stadial between them in Greenland (Dansgaart et al. 1993),

– two warm periods – W23 and W 22 – and C22 cold period in deep see profiles from the North Atlantic (McManus et al. 1994),

– 5c oxygen isotope stage (Pisias et al. 1984).

One may suppose that regional pollen zones $EV_{NP}2$ and $EV_{NP}3$ as well as the $EV_{NP}4a$ subzone that are correlated with the EV2a pollen zone, represent birch phase of the Brørup *sensu lato* (cf. Mamakowa 1989). Nonetheless, in case of northern Podlasie this period is clearly divided into three parts reflecting:

– the occurrence of high peaks of *Pinus sylvestris* type and *Betula alba* type during the first part of this period ($E_{NP}2$ *Betula* R PAZ) that may indicate the relatively warm period lush with pioneer pine-birch forests,

– the predominance of herbaceous taxa, especially of *Artemisia*, during the second part of this period($E_{NP}3$ *Artemisia*-Poaceae R PAZ) which in turn indicates much drier and colder period than the first or the third one,

– another and rapid increase of *Betula alba* type delimiting the third part of this period ($E_{NP}4a$ *Betula* R PASZ).

The regional $EV_{NP}2$ zone and $EV_{NP}4a$ subzone both represent warm climate fluctuations, whereas the $EV_{NP}3$ a cooler stage between them. Therefore it may be presumed that relatively low values of NAP in the $EV_{NP}3$ R PAZ indicate the presence of forests with open canopy(?) however, not their complete disappearance. That could have been an effect of slight decrease in temperature or in the presence of relatively short cooling period. Similar record of cold period corresponding to the middle part of the birch phase of the Brørup *sensu lato* is also present in some profiles from other parts of Poland, being for example well represented in the diagrams from Horoszki Duże (Granoszewski 2003) and Warszawa-Wola (Borówko-Dłużakowa 1960, with subsequent reinterpretation of Mamakowa 1989).

Short but distinct climate deterioration within the Brørup interstadial *sensu lato* is also known from various European locations, e.g. Amesfoort (Zagwijn 1961), Monticchio (Allen et al. 1999), Bouchet (Reille et al. 2000), Füramoos (Müller et al. 2003). While in the diagrams presented for northern Germany it is not distinguished, in the lower part of the birch phase of the Brørup *sensu lato* a slight cooling is noticeable. It is well reflected by the increase in NAP value (Grüger 1979, 1983, Welten 1982, Menke & Tynni 1984, Behre & Lade 1986).

It is very likely that the $EV_{NP}2$ *Betula* R PAZ represents the Amersfoort interstadial and the part A of the Saint Germain 1 interstadial (Fig. 57). The $EV_{NP}4a$ *Betula* R PASZ refers to the birch phase of the Brørup *sensu stricto* and the part C of the Saint Germain 1. The $EV_{NP}3$ R PAZ reflects the cooling between the Amersfoort and the Brørup interstadials *sensu stricto*. In France it is known as the part B of the Saint Germain 1 interstadial, so-called Montaigu event (Woillard 1978).The Montaigu event within the Saint Germain 1 interstadial, corresponding to the Brørup *sensu lato* or Amersfoort/Brørup, was also traced back in case of Italian sites. Quite probably it correlates to the Monticchio event that spans 101 000 to 100 000 calendar years B.P. (Allen & Huntley 2000).

The $EV_{NP}4b$ *Pinus-Betula* and $EV_{NP}4c$ *Pinus* subzones are correlated with the Polish regional sub-zone of the EV2b and correspond to the pine phase of the Brørup *sensu lato* and Brørup *sensu stricto*. The stratotype site for that part of the early glacial in Europe is located at Brørup Hotel Bog in Denmark (Andersen 1961) and at Zgierz-Rudunki in Poland (Jastrzębska-Mamełka 1985). In relation to both sites the characteristic feature of the pine phase, apart from high values of *Pinus*, is the constant curve of *Larix*. Some profiles representing northern Podlasie contained no pollen of this particular taxon. This may be caused by the character of sediments itself. In the sandy silts that represent the $EV_{NP}4b$ zone in Machnacz [17] and Michałowo [25], large but delicate *Larix* pollen grains might simply got disintegrated.

$EV_{NP}5$ *Artemisia*-Poaceae R PAZ

The zone is represented in 3 studied profiles: Solniki [28], Dzierniakowo [24] and Trzcianka [10] (Fig. 53, Tab. 58). It is also present at Machnacz [17] (Kupryjanowicz 1991, 1995), whereas the type locality for this zone in northern Podlasie is represented by the Solniki [28] site.

The zone represents the next stadial, which in central Europe is named as Rederstall, while in France it is known as Melisey 2 (Fig. 57). It is distinctive with its significant decline in percentage of area covered by forests accompanied by substantial spread of non arborescent plant species. The stadial is also well expressed in slightly increased proportions of sand presence in sediments.

$EV_{NP}6$ *Pinus-Betula* R PAZ

The zone is represented only in one studied profile, Dzierniakowo [24] (Fig. 53, Tab. 58). Another example is quoted for Machnacz [17] location (Kupryjanowicz 1991, 1995).The type locality for this zone is ascribed to the Dzierniakowo [24] site.

The onset of the second interstadial is linked with development of pioneer forests recorded in the $EV_{NP}6$ R PAZ. It is subsequently divided into three parts typical of its:

1) birch woodlands of a boreal character dominated by birch occurring during the first part, i.e. $EV_{NP}6a$ *Betula-Artemisia*-Poaceae R PASZ,

2) pine forests being present during the second part, i.e. $EV_{NP}6b$ *Pinus-Larix* R PASZ,

3) gradual decrease in proportion of *Pinus sylvestris* type and increase in herbaceous taxa presence during the third part, i.e. $E_{NP}6c$ *Pinus-Artemisia*-Poaceae R PASZ, which in turn indicates climate deterioration and following transition to arctic conditions.

The $EV_{NP}6$ *Pinus-Betula* pollen zone is correlated with the Polish EV4 *Pinus-Betula* regional zone (Mamakowa 1989) and represents the Odderade interstadial distinguished in central and northern Europe under the following names: the FW VI recognized from the stratotype site in Odderade (Averdieck 1967), the WF IV from Rederstall (Menke 1976, 1982, Menke & Tynni 1984), the W VI from Kittlitz (Erd 1973), the WF IV from Oerel (Behre & Lade 1986, Behre 1989) and the French Saint Germain 2 interstadial (Fig. 57).

As it concerns profiles from northern Podlasie, which correspond with other sites known from Poland, the record of the Odderade interstadial is not as well developed as the previous one. It is characterized by the actual domination of *Pinus*, relatively high proportion of NAP and only a slight increase in *Betula* presence.

On the basis of the chronology from the Monticchio lake in southern Italy (Allen & Huntley 2000, Allen et al. 2000, Brauer et al. 2000) a definite age of main events accompanying the Early Vistulian in Europe was determined, which includes:

– the transition from the Brørup *sensu lato* (=Amersfoort/Brørup) interstadial into the Rederstall stadial, dated back to 86 600 calendar years B.P.,

– the transition from the Rederstall stadial into the Odderade interstadial, 84 200 calendar years B.P.,

– the transition into the Plenivistulian (equal with the Middle Weichselian glaciation) at the end of the Odderade interstadial, 75 400 calendar years B.P.

The upper boundary of the Odderade analysed from the Oerel profile was dated back using radiocarbon dating method to be 61 000 years B.P. (Behre & van der Plicht 1992).

DEVELOPMENT OF TERRESTRIAL VEGETATION IN NORTHERN PODLASIE

On the basis of pollen analysis presented in the preceding chapter an attempt was made to reconstruct changes in vegetation that occurred in northern Podlasie starting from the end of the late glacial of the Wartanian glaciation through the entire Eemian interglacial up to the end of the early glacial of the Vistulian glaciation. Description of changes is presented in connection with regional pollen assemblage zones.

Granoszewski (2003) recently presented a detailed description of vegetation changes accompanying the Eemian interglacial and the Early Vistulian and Plenivistulian in the region of Horoszki Duże in southern Podlasie. The majority of changes described reflects a very similar course of events to those presented here for northern Podlasie. Because of that the following reconstruction of vegetation contains only approximate description of changes. Only some extraordinary changes or those that were recorded with a high resolution owing to great thickness of studied sediments were described in a more detailed manner.

LATE GLACIAL OF THE WARTANIAN GLACIATION

LW_{NP}1 *Artemisia-Juniperus-Betula nana-(Picea)* R PAZ

The record of changes in vegetation encoded within deposits of palaeolakes and palaeobogs in northern Podlasie allows delimiting the end of the Late Wartanian glaciation. The vegetation at that time comprised the mosaic of various plant communities, of which open herb or shrub plant communities dominated. Shrub tundra played dominating role there. High proportion of *Betula nana* type pollen proved great significance of dwarf birch in such plant formations. The presence of willow shrubs in more fertile habitats is indicated by occurrence of *Salix* pollen. High values of *Juniperus* pollen, characteristic for that zone as well, are presumably caused by the presence of juniper in dry habitats, most probably in open steppe-like grasslands, which at that time developed vigorously thriving under the most favourable conditions. Their occurrence in northern Podlasie is marked by high values of *Artemisia* and Chenopodiaceae, a significant proportion of Poaceae, and the presence of single pollen grains of *Ephedra fragilis* type. Grassland communities prevailing on sandy soils may have served a source of pollen grains of *Helianthemum nummularium* type and *Rumex acetosella* type. Then moist habitats were occupied by segde-moss communities, marked by high pollen values of Cyperaceae. Plant communities occupying yet more wet habitats sustained tall herbs like *Thalictrum*, *Filipendula* and *Linnea borealis*. Apart of that grassland communities of yet another sort served a source of *Anthemis* type, *Ranunculus acris* type and of Rubiaceae pollen.

Regardless of the domination of herbaceous plant communities it is quite possible that patches of peatland, swamp or fen forests were also present. It is reflected in consequent increase in pollen values of the *Pinus sylvestris* type and *Betula alba* type coupled with gradual decrease in pollen values of herbs. It therefore implies the spread of boreal pine-birch forests with simultaneous decline of open habitat plant communities. Constant presence of *Picea abies* type pollen indicates that from the very beginning spruce constituted a crucial component of such forests. Though the determination of spruce pollen down to the species level is impossible, it is somewhat plausible that the pollen of *Picea abies* type being enclosed in the sediments representing the Late Wartanian sections of the profiles from northern Podlasie could be linked to the pollen of *Picea obovata*. It is indicated by the marcroscopic remains of *Picea obovata* that were recorded from several sites in north-eastern Poland, i.e. Ludomirowo [7] (Bitner 1957), Szwajcaria (Borówko-Dłużakowa & Halicki 1957, Borówko-Dłużakowa 1975) as well as from the Neman Valley, including Żukiewicze [75] (Środoń 1950, Litviniuk 1979) and Nieciosy (Bremówna & Sobolewska 1950). Owing to the presence of Siberian spruce forest communities representing the end of Wartanian might remained of contemporary communities of the taiga type.

The occurrence of the spruce at the end of the glaciation, followed by the Eemian interglacial, is a characteristic feature of vegetation succession in northern Podlasie and in the entire north-eastern Poland, which in this respect makes this part of the Country different from other regions (Mamakowa 1989). On the contrary it makes this particular region similar to those of contemporary Belarus and Russia, where at that time spruce built up forests of the boreal type. It is documented by a very high proportion of the *Picea* pollen (up to 80%) at sites in the Moscow region (Gorlova 1975 after Mamakowa 1989). It may indicate that during the Wartanian glaciation central Russia represented a refugium for that tree species. The occurrence of Vistulian refugium of Siberian spruce in that region is well documented by palaeobotanical, as well as through genetic researches (Terhürne-Berson 2005). From that refugium the spruce would periodically spread backwards to the territory of contemporary north-eastern Poland during the Late Vistulian and at the beginning of Holocene (Obidowicz et al. 2004, Latałowa & van der Knaap 2006). It is very likely that the scheme of those events could have been the same, at least to a particular degree, when considering changes between the Wartanian and Eemian as well as those between the Vistulian and Holocene.

The presence of rebedded Tertiary sporomorphs and Dinoflagellata cysts in the $LW_{NP}1$ R PAZ indicates soil erosion processes which in turn implies the ground was not entirely stabilized by plant cover (cf. Mamakowa 1989). Frequently occurring in the sediments pollen of thermophilous trees and shrubs, such as that of *Tilia cordata* type, *Carpinus betulus*, *Alnus* or *Corylus avellana*, can probably be related to redeposition of eroded material, both from the Tertiary and Quaternary.

THE EEMIAN INTERGLACIAL

$E_{NP}1$ *Pinus-Picea-(Betula)* R PAZ

Numerous Eemian palaeolakes documented for northern Podlasie indicate that during the Eemian interglacial a kind of lake district existed in this region. The $E_{NP}1$ zone corresponds to the initial phase of the Eemian succession of vegetation in northern Podlasie. Weakening periglacial processes and further improvement of climatic conditions, allowed forest formations to regain the ground previously occupied by most presumably open communities.

In the older part of the zone, in which the character of vegetation was clearly transitional, herbaceous plant communities and dwarf shrub ones still played a vital role in shaping the landscape (cf. Skupowo [37] profile – Fig. 47). The pollen of *Betula nana* type and that of *Salix* both serve as the evidence for tundra vegetation still being present at that time. The existence of wet meadow communities is documented by pollen of *Thalictrum*, *Filipendula*, *Cirsium* type and Cyperaceae. Then the occurrence of xerothermic grassland communities is exemplified by high percentages of *Artemisia* and single pollen grains of *Helianthemum nummularium* type and *Gypsophila*. These plant communities were probably the source of pollen of Poaceae and Chenopodiaceae, and at least partly of *Juniperus*.

In the younger part of the zone forest plant communities continued its spread. This is indicated by higher AP values in the upper section of the $E_{NP}2$ R PAZ. What regards tree species composition, its diversity was indeed very limited. Predominant proportion of *Pinus sylvestris* type pollen proves the leading role and domination of that particular species in the whole array of habitats. Low pollen proportion of *Betula alba* type in most of the analysed profiles suggests its marginal role in forest structure at that time in northern Podlasie.

According to Mamakowa (1989) the younger part of the Polish E1 R PAZ was marked by the domination of the common birch. Since its lush presence lasted for a rather short period of time, around 100 years according to Müller (1974), it is not always reflected in pollen profiles analysed under standard resolution. Therefore confirmation of that view in case of northern Podlasie is out of reach when solely based on pollen data. Anyhow at no stage of that interglacial zone had the birch the dominant role in stands throughout the entire range of northern Podlasie. Peaks of high or even very high percentages of *Betula alba* type were noticed in case of some profiles, yet they are not synchronized one with another owing to different correlation between local pollen assemblage zones in every single case. Hence:

– only in Ludomirowo [7] (Fig. 54) birch culminates in the youngest part of the $E_{NP}1$ R PAZ (68% according to Bitner (1957), total sum with no *Corylus avellana* and NAP, i.e. 59% having recounted that according to current standards of calculation),

– in Kruszyniany [21] (Fig. 12) two peaks of *Betula alba* type are noted – the first one (85%) occurs in the younger part of the $E_{NP}1$ R PAZ and the second one (65%) in the $E_{NP}2$ R PAZ,

– in the Wólka 2 [35] profile (Fig. 35) *Betula alba* type has two peaks – the first one (55%) in the older part of the $E_{NP}1$ R PAZ, and the second one (65%) in the $E_{NP}2$ R PAZ,

– in Lesznia-Łuchowa Góra [30] (Fig. 30), Podkamionka [16] (Fig. 27), Starowlany [8] (Fig. 29), Skupowo [37] (Figs 47, 54) and Otapy 1 [34] (Fig. 54.) birch culminates in the $E_{NP}2$ R PAZ with values ranging between 50% and 70%,

– in Choroszczewo [39] (Fig. 52) birch reaches a peak of 45% in the $E_{NP}3$ R PAZ.

The above quoted data suggest much localized spread of birch in various parts of the early Eemian interglacial. It seems to be very likely that the presence of the *Betula alba* type pollen, that was recorded in the profiles, reflects its presence in a surroundings of some lakes and of some bogs. That was a result of natural succession sequence in relation to mire/peat bog vegetation. Such interpretation of rapid rise in *Betula alba* type pollen in some profiles starting from the beginning of Holocene is provided by Lang (1952). In a similar way Granoszewski (2003) explains the spreading of birch during the early Eemian in the area of today's Horoszki Duże village. The stands with birch outnumbering pine trees built up communities of the waterlogged birch forests with dominating *Betula pubescens* trees. Its phytocoenoses occupied secluded depressions in the ground moraine.

Culmination of *Picea abies* type pollen, which is characteristic feature of the $E_{NP}1$ zone, depicts the landscape where spruce was an important component of such stands probably occupying moderately moist habitats. Its occurrence at the beginning of the Eemian interglacial is a characteristic feature for the entire north-eastern Poland as well as for western Belarus (Mamakowa 1989). It was probably Siberian spruce that appeared also at the end of the Wartanian. It is documented by the appearance of numerous *Picea obovata* cones at the bottom of interglacial sediments from Rumlówka [74] (Środoń 1950), Nieciosy (Bremówna & Sobolewska 1950) and Janiańce-Maksymańce (Bremówna & Sobolewska 1950). Remains of *Picea excelsa* were not found in any of the profiles. It may therefore suggest that Norway spruce was not a component of the early Eemian forests in this region at that time.

The relatively high proportion of *Salix* and single pollen grains of *Populus* may serve as the evidence of the presence of poplar-willow floodplain forests stretched along river valleys of northern Podlasie. Here and there *Ulmus* trees might have entered these plant communities changing them into the elm riverine forest.

Low proportion of NAP shows how reduced role was played by herbaceous plant communities. Additionally dense forests did not leave much room for open habitat communities, which is well reflected in constant pollen curves of *Artemisia*, Poaceae, Cyperaceae, and Chenopodiaceae as well as by the presence of single pollen grains of other herb taxa, which in turn indicates that open habitat plant communities still existed on verges of dominating forest formations, therefore securing continuality of presence of those light-demanding plants.

$E_{NP}2$ *Pinus-Quercus-Ulmus-Salix* R PAZ

Pine forests were still dominant, but the increase in pollen values of *Quercus* reflects important changes, that were triggered as early as in the beginning of the $E_{NP}2$ zone and which lasted up to the middle part of the $E_{NP}3$ zone. The above mentioned changes are well illustrated by characteristic fluctuations in the presence of the *Pinus sylvestris* type and in *Quercus* curves representing the S-2 and S-3 local pollen zones of the Solniki [28] profile (Fig. 58). Five peaks of *Quercus* that are documented as to northern Podlasie area represent the next stadium of the expansion of this particular tree species. They are in turn separated by four peaks of *Pinus* that show phases of pine regeneration. Every now and again subsequent culminations of *Quercus* presence reach higher and higher values being separated by more

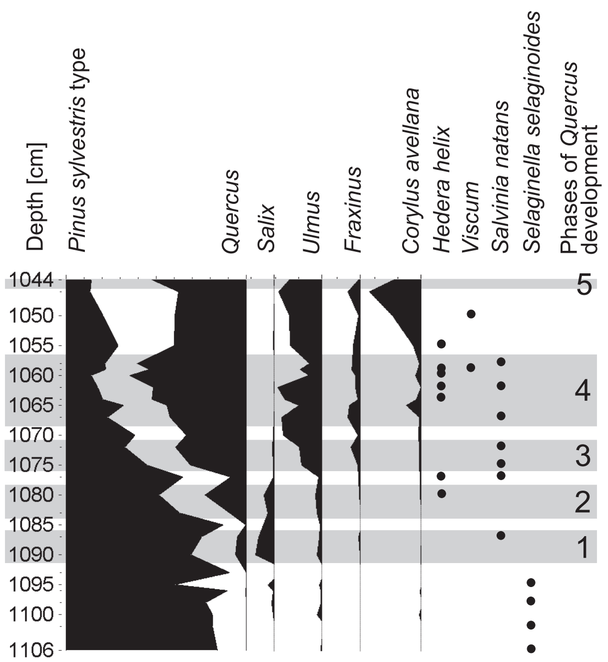

Fig. 58. Solniki [28]. Changes of percentage values of the *Pinus* and *Quercus* pollen, and some other taxa in the $E_{NP}3$ regional pollen zone

and more declining values ascribed to the pollen of *Pinus.* If we accept after Müller (1974) that the period of oak forest domination lasted for about 1 100 years then the average period of each oak expansion should be estimated to span ca. 110–120 years.

The above mentioned pollen records may be interpreted in two separate ways:

– changes in the *Quercus* and *Pinus sylvestris* type values may reflect some short climate fluctuations related to temperature changes or exclusively to those affecting humidity;

– it cannot be excluded that they illustrate changes interrelated with the switch of generations in mature oak-pine forests, for which the climate changes merely set a background. The complete cycle of generation changeover included the phase of oak domination followed by another phase of pine domination. Its approximate duration spanned around 220 years. Similar fluctuations in oak quantity leading to change in generations are nowadays observed in north-eastern Poland in forests with marked oak presence. Depending on forest community those changes may refer to generation changeover from that marked with oak domination to another distinctive for pine or spruce presence in contemporary oak communities of north-eastern Poland (Czerwiński 1973).

According to Granoszewski (2003) oak spread rapidly during the Eemian interglacial forming riverine forests. They thrived on good conditions for its development especially owing to the humid oceanic climate. It is therefore assumed that in a relatively short period of time they occupied extended areas in the whole Europe. Besides, pollen record from Solniki suggests that in northern Podlasie oak could possibly even encroach into much drier habitats, where it won the competition with pine.

Gradual transformation of forests started with the appearance of new tree species. Sediment profiles reflect that in the frequencies of *Ulmus* and *Fraxinus* being much higher. These species in question predominantly invaded fertile habitats of poplar-willow floodplain forests, that were formed during the previous zone. As a result of this expansion, elm-ash riverine forests were formed. This kind of plant community was quite probably similar to the contemporary association of oak hornbeam forest of the *Ficario-Ulmetum campestris* (cf. Matuszkiewicz 2001). Distinctive for their presence were two *Humulus lupulus* and *Quercus*.

High pollen values of *Salix* recorded for the Solniki [28] profile (Fig. 4) may indicate localized expansion of willow-dominated plant communities accompanying waterlogged habitats adjoining lakes and river valleys. These poplar-willow floodplain forests were probably resembling those of the contemporary *Salici-Populetum* association (cf. Matuszkiewicz 2001).

In the $E_{NP}2$ zone a further decline in the presence of open herb and shrub plant communities is observed. The significant rise of NAP curve is provided only for younger part of the zone in pollen profile from Solniki [28] (Fig. 4). It is chiefly connected with the increase in Cyperaceae presence and is related almost exclusively with localized expansion of waterlogged habitats next to this site.

E_{NP}3 *Quercus-Ulmus-Fraxinus* R PAZ

E_{NP}3a *Pinus* subzone

Great increase in pollen values of *Quercus* coupled with simultaneous drop in values of *Pinus sylvestris* type points out an abrupt surge in oak significance in forest assemblages which subsequently resulted in habitats previously occupied by pine being overtaken by this species. That constituted a continuation in changes that were noticed for the previous subzone. It resulted in furthermost oak spreading during the Eemian interglacial. As it concerns pollen records, it usually took place in the middle section of the E_{NP}3 zone however in some regions of northern Podlasie even at the very beginning of this zone (e.g. Proniewicze PR.1/93 [32] – Krupiński 1995).

According to Granoszewski (2003) high proportion of *Quercus* pollen in the oak phase of the Eemian interglacial should mainly be associated with floodplain forests, which was dominant forest community at that time, and perhaps corresponded to the contemporary *Ficario-Ulmetum campestris* or the west European riverine forest of the *Ulmo-Quercetum* type (cf. Ellenberg 1988). Lack of great river valleys in northern Podlasie, especially in the Białystok Upland and Sokółka Hills, probably restrained any expansion of this particular type of forests. Those communities occurred in the above mentioned regions being found exclusively along small watercourses, in gullies with periodically running rainwater, in land dips, on hillsides encircling depressions or on terraces adjoining lakes (cf. Matuszkiewicz 2001). Oak, elm and ash were dominant components of those plant communities. In addition to them also alder, willow and erratically occurring poplar were present. In the shrub layer grew *Sambucus nigra*, *Viburnum*, and *Syringa vulgaris*, whereas creepers were represented by *Humulus lupulus* and *Hedera helix*. The highest values of *Quercus*, *Ulmus*, and *Fraxinus* prove that riverine forest reached the maximum of its Eemian expansion at that time.

Oak-pine forests in type of the contemporary *Querco roboris-Pinetum* association (cf. Matuszkiewicz 2001) most likely existed at locations representing much drier habitats. It seems they occupied sand soils on washed out areas that were most conspicuous in the region. *Pteridium aquilinum*, perhaps together with *Calluna vulgaris* and *Lycopodium annotinum*, were all present in the undergrowth. This type of forest representing the E_{NP}3 zone declined at that time and its subsequent closing stage is well documented from the next zone.

Exceeding values of *Quercus* noted in pollen profiles from Starowlany [8] (Fig. 29, Tab. 27) and Choroszczewo [39] (Fig. 52, Tab. 57), 5% and 15% respectively, are nonetheless much lower than those represented by other profiles recorded from northern Podlasie. As it is well known oak pollen is produced in great quantity and is spread at long distances (Milecka et al. 2004). This overrepresentation in pollen records may spring from such abundance at a particular time (Andersen 1973, Faegri & Iversen 1989).

Whenever a particular pollen record comes from a limited area, that represents a forest marked with low oak presence, being at the same time surrounded by forests distinctive for its oak domination, pollen records will always be contaminated with excessive number of pollen grains coming from those oak abundant forests (cf. Jacobson & Bradshaw 1981). Such limited areas or enclaves can only be reflected in pollen records if they come from the inner sites of approximately 20 m in diameter being placed inside such enclaves. Therefore enclaves from large areas such as those representing palaeolakes in Starowlany [8] (Fig. 28) and Choroszczewo [39] (Fig. 51) cannot possibly be reflected in local pollen records. A conclusion can be drawn that low values of *Quercus* pollen recorded at those sites in relation to the E_{NP}3 R PAZ probably result from hiatus occurrence or too low a resolution of pollen analysis itself, since in the profile from the Starowlany [8] samples were analysed only every 10 cm and as to the Choroszczewo [39] every 10–12 cm.

E_{NP}3b *Corylus* subzone

The appearance of *Corylus avellana* in forests of northern Podlasie in the younger subzone of the E_{NP}3 R PAZ points out the beginning of large-scale and long-term renewal of forest communities that went on throughout the entire next zone.

E_{NP}4 *Corylus-Alnus-Tilia* R PAZ

E_{NP}4a *Quercus* subzone

Very low proportion of herbaceous plants indicates the maximum rate of forest expansion that from the beginning of this period affected the great majority of habitats in northern Podlasie. The most characteristic feature of vegetation succession was the expansion of *Corylus avellana*. As early as at the beginning of this subzone hazel reached its interglacial maximum. This particular species entered elm-oak-ash riverine forests occupying drier sites along river floodplain terraces. Its spreading delimited the first stage of rebuilding of these forest plant communities in the direction of lime-hornbeam associations. However, according to Mamakowa (1989) very high percentages of *Corylus avellana* permit the assumption that it could have grown in apparently single species shrub community that could have resembled this of the contemporary *Peucedano cervariae-Coryletum* association. In northern Podlasie thermophilous hazel shrubs of this type might have occupied calcium carbonate rich sites on the sunlit hillsides of kame hills (cf. Matuszkiewicz 2001).

Other tree species associated with lime-hornbeam forests, namely *Tilia cordata*, *T. platyphyllos*, *T. tomentosa*, and *Carpinus betulus* were also present at that time. Their significance in stand composition gradually increased. The pollen of *Hedera helix* and *Ilex aquifolium* probably originated from the plants growing in these forests at that time.

The regular presence of pollen grains of *Fagus sylvatica* is noted in profiles from Machnacz [17] and Kruszyniany [21]. It is however not accompanied by rebedded sporomorphs. That fact excludes the possibility of redeposition and allows suspecting that beech might have been a component of the forests during the hazel phase in the same areas of northern Podlasie. Occasional occurrence of *Fagus sylvatica* pollen was also noted in some other Eemian profiles from Poland (e.g. Niklewski 1968, Mamakowa 1989, Środoń 1985, 1990, Kuszell 1997, Granoszewski 2003). Środoń (1990) supposed that the species occurred on the second bed of the Eemian deposits and its source may be a redeposited material from the Tertiary or a material dragged with the bore from sediments of the late Holocene. According to Niklewski (1968) and Granoszewski (2003) beech may have been a rare element of the Eemian forests.

In this subzone the elm-oak-ash floodplain forests continued to be a distinctive community on fertile habitats across northern Podlasie. However, at the same time the expansion of alder gradually progressed. It is well documented from pollen diagrams by a gradual increase in percentage values. Alder spread should probably be associated with the most waterlogged sites. It extended onto the areas along the river-banks and lake-shores. It may also have encroached habitats originating from dried-up and overgrown small water-bodies or shallow parts of larger lakes (Jørgensen 1963). The spreading of alder in the floodplain forests caused the gradual alteration of these communities in the direction of such that are reminiscent of contemporary alder carr ones. In northern Podlasie the first phase of this transformation, which falls into the $E_{NP}4a$ subzone, was expressed in the formation of ash-alder riverine forests probably similar in their appearance to the contemporary *Circaeo-Alnetum*. Those changes are confirmed by relatively high values of *Fraxinus* in the most of pollen diagrams. Presently *Circaeo-Alnetum* association also occurs in habitats intermediate between typical floodplain and alder carr ones (Matuszkiewicz 2001).

$E_{NP}4b$ *Carpinus* subzone

The most important feature of vegetation succession in that subzone was the expansion of lime and the beginning of hornbeam spread that led to the formation of mixed broadleaved forests in the type of contemporary lime-hornbeam forest. Hazel was very important element of this community as well. Pollen record from profiles, in which both subzones of the $E_{NP}4$ R PAZ are represented, points out two modes of lime spread in northern Podlasie.

First, according to diagrams from Starowlany [8] (Fig. 29), Otapy 2 [34] (Bitner 1957) and Choroszczewo [39] (Fig. 52) where *Tilia* pollen is reaching high values from the very beginning of the $E_{NP}4$ zone and achieving its peak in the $E_{NP}4a$ subzone before or at the same time as *Corylus*. In Mamakowa's (1989) classification it is named as the "early-lime".

Second, as it concerns diagrams from Ludomirowo [7] (Bitner 1957), Machnacz [17] (Kupryjanowicz 1991, 1994), Kruszyniany [21] (Fig. 12) and Proniewicze PR.1/93 [32] (Krupiński 1995) where pollen of lime occurs in significant numbers (up to 15%) from the maximum of *Corylus*, but its highest proportion being recorded for later stages of the $E_{NP}4b$ subzone.

In the E_{NP}4b subzone lime was at that time the most significant component of forest formations of northern Podlasie. It played dominant role in the formation and dynamics of the multi-species forests and may have also formed communities distinctive for its dominating presence. The genus *Tilia* was represented by three species, i.e. *Tilia cordata*, *T. platyphyllos* and *T. tomentosa*. Noteworthy, the latter one is not considered as native one in the contemporary Polish flora (Szafer et al. 1986). Its presence in forests of northern Podlasie during the middle part of the Eemian interglacial is however well documented not only by pollen records from almost all profiles of this region, but also by virtually countless deposits of nutlets found at the Hieronimowo site (Kupryjanowicz et al. 2007). Facing optimum climatic conditions accompanying the Eemian interglacial *Tilia tomentosa* quite probably constituted a distinctive component of forest formations throughout central Europe (e.g. Kalnina et al. 2007) hence including the area of contemporary Poland as well (Mamakowa 1989, Granoszewski 2003).

The proportion of hornbeam in the stands of mixed broadleaved forests was relatively small. It may have occupied riverine sites and together with elm, oak and ash could have formed transitional communities tending towards lime-hornbeam wood. Ash-alder riverine forests still occurred in northern Podlasie, but their area was probably smaller than in the preceding subzone. While occupying the same habitats they might have gradually transformed themselves into forest communities of alder carr type.

At the same time pine and birch, that occurred as a minute addition to the existing forest associations, played rather insignificant role wherever they were present. Very low percentages and small diversity of herbaceous plants both indicate that the significance of open vegetation was negligible.

E_{NP}5 *Carpinus* R PAZ

E_{NP}5a *Corylus* subzone

The most characteristic feature of vegetation succession during this subzone was the expansion of hornbeam. As early as in the beginning of this period it became the main forest-forming species in northern Podlasie. Together with lime it constituted the starting point of any mixed broadleaved forests, perhaps in the type of the contemporary *Tilio-Carpinetum* association (cf. Matuszkiewicz 2001). In such plant community hornbeam was indeed a dominant component. It formed distinctive tree layer and probably at least partly it eliminated hazel from the shrub and herb layer. Even though edaphic requirements of these two species are quite similar, according to Mamakowa (1989) *Carpinus betulus* might have gained the dominance because it was more shade-tolerant tree species as compared to *Corylus avellana*. Though gradually losing its significance the latter species was still present to the end of this subzone. It might be owing to its ability to form some ecotone plant communities.

The expansion of hornbeam presumably had little effect on alder, which dominated in waterlogged terrain. In less saturated habitats, together with *Fraxinus* it formed ash-alder forests. In habitats with stagnant water it made up communities in the type of contemporary alder carr association of the *Carici elongatae-Alnetum* (cf. Matuszkiewicz 2001).

The subzone witnessed the optimum stage for genera such as *Hedera, Viscum* and *Ilex*. Their presence in pollen records implies warm and mild climate.

Very low pollen values of *Pinus sylvestris* type and *Betula alba* type reveal rather low rank of pine and birch in forest formation at that time. Additionally, a tiny proportion of NAP shows the dominance of dense forests in the landscape of northern Podlasie.

E_{NP}5b *Picea* subzone

The boundary between the E_{NP}5a and E_{NP}5b subzones, marked distinctively by the increase in values of coniferous trees, is likely to reflect deterioration of climate conditions, being probably expressed in becoming much colder and humid. In the next step it might have led to the soil degradation due to its acidification and podsolisation (Iversen 1973). Owing to the fact that hornbeam is less demanding as concerns to sheer soil conditions, when compared with other deciduous trees of that time, these changes would favour its rapid expansion. During the whole interglacial, in the oldest part of the subzone hornbeam reached its greatest significance. Its very high pollen values allow suspecting that at that time it might have formed independent mono-species assemblages with no present time equivalent.

In those communities hornbeam was accompanied only by limited presence of hazel.

After the relatively short period of hornbeam domination its significance began to diminish. This was probably prompted by further worsening of the climate and accompanying soil degradation. Hornbeam was gradually replaced by coniferous species, mainly by spruce. The course of pollen curves of *Carpinus betulus* and *Picea abies* type at this zone suggests apparent competition between these tree species (cf. pollen diagram from Solniki [28], Fig. 4). Quite similar phenomenon was observed in many other Eemian profiles from Poland, e.g. in Góra Kalwaria (Sobolewska 1961), Główczyn (Niklewski 1968), Żyrardów (Krupiński 1978), Jednaczewo (Borówko-Dłużakowa 1975), Niewodowo [61] (Musiał et al. 1982) and Szwajcaria (Borówko-Dłużakowa & Halicki 1957, Borówko-Dłużakowa 1975).

Marked competition between hornbeam and spruce can easily be observed in north-eastern Poland, in contemporary lime-hornbeam forests of the Mazury lake district, which consist mainly of spruce, hornbeam and oak. Czerwiński (1973) distinguishes four successional stages of that particular plant community. Each of those is distinctive for the proportion of tree species composition. While spruce role increased in every stage hornbeam and oak decreased, the latter two being less viable than the previous one. On the other hand, in such forest communities spruce is particularly vulnerable to any catastrophic events (e.g. demographic explosions of insects foraging on wood). In such an instance the increased presence of lime-hornbeam forests should have been the case. Such course of events is commonly regarded as a typical process in any long-life stable phytocenoses (Czerwiński 1973).

As it concerns the composition of pollen spectra forests of the late hornbeam phase of the Eemian interglacial might have resembled those representing contemporary array of the Mazurian lime-hornbeam forests. Thus it cannot be excluded that the process similar to the one described by Czerwiński (1973) took place at that time and that the process itself can be reflected in the diagram with alterable increases of the curves of *Picea abies* type and *Carpinus betulus*.

Very high pollen values of *Alnus* suggest that the area occupied by alder carr forests was not reduced. In the upper part of the previous subzone and the lower part of that subzone, where hornbeam reaches its maximum values, temporary decrease in the percentage of *Alnus* is apparent. However it is probably caused by the statistical effect, expressed by a significant increase in the proportion of *Carpinus betulus* pollen in the AP sum. Alder carrs were nonetheless a very important element of the forest landscape of northern Podlasie. Apart from alder there also grew birches, which reappeared there, the fact reflected by the increase of *Betula alba* type pollen. The appearance of *Osmunda cinnamomea* and Filicales monolete spores points to the presence of conspicuous fern cover.

The low proportion of *Ulmus* and *Fraxinus* pollen indicates a reduction in the extent of elm-ash riverine communities. This together with an increase in the value of *Picea abies* type suggests that in that subzone also elm and ash could have been gradually replaced by spruce. This probably resulted from transformation of the ash-alder into alder-spruce riverine forests.

The increasing proportion of *Pinus* and *Picea abies* type and culmination of *Quercus* pollen (cf. pollen diagram from Solniki [28] – Fig. 4) probably points to the development of mixed coniferous-oak forests. In addition to the dominating spruce or pine and an invariable supplement of oak, some birch could have occurred there as well. Remarkably, *Pteridium aquilinum* and *Calluna vulgaris* occupied the herb layer.

The proportion of *Abies alba* pollen increases while heading towards the top of the zone implying that fir appeared in northern Podlasie. However its role in the formation of plant communities was still insignificant at that time. Fir probably occurred only as an indistinctive addition to mixed forests of various kind.

E_{NP}6 *Picea-Pinus-(Abies)* R PAZ

The zone represents the first stage of detectable cooling accompanied by increased humidity. Deteriorating climate conditions prompted changes in habitat. Processes of acidification, alkalization and podsolization affecting the soil qualities that were initiated in the previous zone were right now much intense (Dzięciołowski & Tobolski 1982). That in turn resulted in rapid vegetation changes reflected in the expansion of coniferous trees, a view backed by pollen curves of *Picea abies* type, *Pinus sylvestris* type and *Abies alba*.

Dramatic increase in the value of spruce indicates its rapid expansion to all possible forest habitats and subsequent changes in their profile. Decreased values of *Carpinus betulus* and *Corylus avellena* suggest further drawback of deciduous species. Habitats with still favourable conditions for lime-hornbeam forests probably harboured their stands for a prolonged time representing anyway its different phytosociological variety. They were likely to resemble the contemporary associations of multi-species mixed forests being found in northern Podlasie, where spruce was dominant and hornbeam and hazel built up shrub and herb layer.

Rise in the *Pinus sylvestris* type curve indicates on the other hand that pine might have competed with hornbeam too and gradually replace it in at least some forest formations. Originally it could overtake habitats marked with poor edaphic conditions (e.g. sandy soils), those with low temperature conditions (e.g. any northern exposures) or those with ongoing soil podsolization affecting widespread areas. Thus lime-hornbeam forests might have been gradually replaced by various kinds of pine, pine-spruce or spruce-pine forests, its set being most probably air humidity dependant.

Slight decrease in the value of *Alnus* may suggest a decline of alder communities. The area of alder carrs was probably reduced mainly due to its replacement by damp birch forests (as indicated by increased values of *Betula alba* type), swampy pine forests (increased values of *Pinus sylvestris* type) or even by swampy spruce forests. The area of ash-alder riverine forests might have decreased as well, which is indicated by very low values of *Fraxinus*. They were probably replaced by alder-spruce riverine forests.

Percentages of *Abies alba* (max. 2%) indicate that the species might have occurred in local spruce-pine forests. Suszka (1983) claims that fir pollen is not capable of being transported at great distances because of its considerable grain weight and fast speed with which it falls. Such reasoning is also supported by Mamakowa (1989). Low percentages of this particular species in the profile from Imbramowice are explained by relatively far distance between the profile and the forest where fir occurred. The pollen grains would probably vanish before even reaching the middle of the lake. Thus, the fir pollen occurring in most of studied profiles from northern Podlasie is likely to have originated from the trees that grew at close range there. Such reasoning follows the opinion of other palaeobotanists who believe that the area of abundant fir occurrence was slightly greater during the Eemian interglacial than during Holocene, with scattered sites reaching as far as to the shores of the Baltic sea and to the North Sea (e.g. Środoń 1983, Terhürne-Berson et al. 2004). The relatively high values of *Abies* in comparison to those from Holocene in nearly all the profiles from north-eastern Poland: Otapy [34] – 4.5% (Bitner 1956b), Horoszki – 3% (Bitner 1954, Granoszewski 2003), Łomża-Łomżyca [55] – 2.5% (Krupiński 1992) and the Niemen valley: Nieciosy – 0.5%, Kmity – 0.5% (Bremówna & Sobolewska 1950), Samostrzelniki – 2% (Środoń 1950) also confirm that northern range boundary of *Abies* was reaching far to the north during the Eemian as compared with the contemporary range of that coniferous species.

A decreasing importance of deciduous tree communities and their replacement by less shady coniferous forest associations favoured the presence of herbaceous plants, which is indeed reflected in higher values of NAP in most of the analysed profiles. Pollen of *Cirsium* type, *Filipendula*, *Valeriana*, *Menyanthes trifoliata*, *Plantago lanceolata*, and spores of *Equisetum* all indicate the existence of herbaceous communities filling damp marshy habitats close to water reservoirs or in forest-free river valleys. The pollen of *Campanula* and *Thalictrum*, and partly that of Poaceae might have originated from those communities. Pollen of *Epilobium angustifolium* and Chenopodiaceae and spores of *Pteridium aquilinum* indicate on the other hand the presence of nitrophilous communities most likely occupying fertile patches of habitats being not covered with forests, which might have resulted from natural fires occurring from time to time.

The presence of single pollen grains of *Ephedra fragilis* type suggests that other light-demanding plants accompanying at least some open-canopy forests could be present at that time wherever climate or edaphic conditions would allow their persistence.

E_{NP}7 *Pinus* R PAZ

The pine zone represents the latest stage of the Eemian succession of vegetation (Fig. 58). The increase in humidity and further cooling of the climate resulted in the change of habitat quality and the character of plant communities as well.

E_{NP}7a *Picea* subzone

Pine became the dominant tree in the landscape. It formed thick boreal forests probably diversified into different types of communities. At that time they occupied nearly all habitats in northern Podlasie. Birch, represented by pollen of *Betula alba* type, larch and poplar were also present there. The expansion of pine forests was prompted by the decline of all other types of forest communities.

Steady and relatively high values of *Picea abies* type pollen indicate that spruce played a major role in forest community formation with two main types being documented: pine-spruce and probably even spruce-pine associations, both resembling contemporary boreal forests, perhaps a sort of the present-day *Sphagno-Piceetum* (cf. Matuszkiewicz 2001).

The area occupied by alder carr communities considerably decreased. They were most likely replaced by marshy pine forests or spruce forests. The expansion of the latter ones is suggested by the steady ascending curve of *Sphagnum* noted in numerous profiles.

E_{NP}-7b *Betula* subzone

The subzone represents the first stage of a short-term climate fluctuation within the pine phase that was marked with series of cold episodes. The record of those fluctuations is encoded in some of the pollen profiles from northern Podlasie. Indeed, it is well developed in the Solniki [28] profile (Fig. 4). Thanks to the high-resolution pollen analysis, a two-step course of that particular fluctuation is clearly visible. Interestingly enough, it is not reflected in the curve based on magnetic susceptibility of sediments (Fig. 4). Conversely, this trend is reflected in changes in Cladocera fauna at that time (Kupryjanowicz et al. 2005).

Similar phenomenon, though less pronounced than that at Solniki [28], is found at sites representing the pine zone of the Eemian interglacial. These include localities of Konopki Leśne [54] and Szwajcaria 1 (Borówko-Dłużakowa & Halicki 1957), Nakło (Noryśkiewicz 1978), Imbramowice (Mamakowa 1989) and Horoszki Duże (Granoszewski 2003).

Noticeable effect of climate cooling with accompanying increase in humidity being itself mirrored in scattered plant cover is well documented within the clay contents of the numerous profiles belonging to this subzone. Such sediments were most probably leached from surrounding hillsides down to any local depression.

The area of the pine forests substantially shrinked with the elapse of time. They were temporarily replaced by birch forests, which is denoted by the peak of *Betula alba* type. According to Granoszewski (2003) at that particular time birch could have locally formed some stands, perhaps in a type of the present-day *Betuletum pubescentis*, occurring in habitats earlier occupied by alder carr communities, where habitat acidification followed owing to the spruce becoming much more abundant. Of other trees, pine and spruce were also found there. In the undergrowth *Calluna vulgaris*, *Pteridium aquilinum*, and *Lycopodium annotinum* might have been there as well. And it appears that pine-spruce forests with larch were still present despite the temporary increase of birch significance.

As a result of changes in climate and soil condition forest formations quite probably gave ground to herbaceous plant communities, appearing especially in places where soil got much drier (e.g. *Artemisia*, Chenopodiaceae) and where it was saturated to a great extent (e.g. *Thalictrum*, *Valeriana*). It is indicated by the ascending curves of NAP.

E_{NP}-7c NAP subzone

Within the pine phase this subzone represents the second stage of the cold episode. Pollen records suggest further drop in temperatures. It led to subsequent decline in areas being covered by birch forests, that were indeed formed during the previous subzone and to the spreading of the open plant communities instead.

Moist habitats were might now occupied by sedge communities (peak of Cyperaceae pollen), as well as by plant communities in shape of today's shrub tundra with *Betula nana* (pollen of *Betula nana* type) and probably with shrub willow species. Most probably *Polygonum bistorta* also grew there. Other marshy areas sustained tall herb communities, a probable source of the pollen record of genera such as *Thalictrum* and *Filipendula*. Conversely, drier habitats harboured steppe grass communities, distinctive for their high proportion of *Artemisia*, Chenopodiaceae, *Gypsophila* type, *Helianthemum nummularium* type, *Linum austriacum*, and shrub species such as *Ephedra distachya* and *Juniperus*. The remaining proportion of the pollen representing unrecognized herbaceous species should be ascribed to the above-mentioned habitats as well.

E_{NP}-7d *Pinus* subzone

After the short cold period the climate once again became a bit warmer. It was accompanied by the return of pine forests to habitats previously occupied by birch and to those lush with open vegetation. Pine forests spread again building up their structure in a different mode to that of the E_{NP}7a zone. Forest associations were sparser, with clearly much lower proportion of spruce, with no fir and thermophilous deciduous trees instead being most probably replaced by birch. Diversity of undergrowth was secured by *Lycopodium annotinum*, *L. complanatum*, and *Botrychium* and most likely by some fern species as well.

As it is assumed, overall tendencies in the sequence of vegetation succession point to the continuous decline of climate conditions. In the Solniki profile [28] this is exemplified by the decrease in organic carbon component and conversely by the increase in the proportion of NAP (Fig. 4). Wet habitats were at that time dominated by damp birch forests and willow thickets. Damp open communities were significantly smaller than those being recognized for the previous subzone. Then on arid sandy soils communities in a type of the steppe developed, which is spurred by the evidence of regular pollen occurrence of taxa such as *Juniperus*, *Gypsophila fastigiata*, Caryophyllaceae undiff., *Aster* type, *Anthemis* type, *Helianthemum nummularium* type, and Rubiaceae.

EARLY GLACIAL OF THE VISTULIAN GLACIATION

The interpretation of diagram components that represented the early glacial of the Vistula glaciation required cautious approach given that the character of the sediments was not that proper for suitable pollen analysis. There was a substantial risk that the studied sediments, which are mainly of the mineral sort, may have contained pollen material located on the secondary bed. Pollen grains in these sediments were found to be partly destroyed, torn apart, crumpled or corroded, non-stainable or hardly so and often impossible to be identified. Overall, pollen frequency was low or very low.

Herning stadial

EV_{NP}1 *Artemisia*-Cyperaceae-Chenopodiaceae R PAZ

This zone represents the first, temporary in its character, post-Eemian cold period in northern Podlasie. The initial part of this stadial is shown by significant increase of magnetic susceptibility of sediments from the Dzierniakowo [24] (Fig. 8) profile. Such a change is interpreted by D. Ciszek (personal communication) as an important climate cooling being probably followed by the increase in humidity. A similar change was also registered in the profile from Solniki [28] (Fig. 4), where high content of clay and sand in profiles serves the evidence of diluvial and/or eolic deposits being present within those sediments.

At that time vegetation of the studied region was predominantly represented by tundra distinctive for its willow clusters possibly enriched with shrub birches as well. Further increase in shares of the herbaceous plant pollen, up to 50%, coupled with greater diversity in herbaceous species composition both provide the evidence for continuous expansion of various open plant communities. A distinct increase in the pollen values of *Artemisia* and Poaceae suggests the rising importance of grass communities, perhaps steppe-like ones. Pollen of *Helianthemum nummularium* type, *Gypsophila fastigiata* type can probably be associated with those communities. Additionally, the occurrence of *Knautia* pollen is to be referred to fresh meadows.

Shrub communities, being distinctive for the occurrence of pollen of *Betula nana* type, *Juniperus*, and *Ephedra fragilis* type, were much more common at that time. Dwarf birch together with shrub willows defined shrub communities of that time. Spores of *Selaginella selaginoides* that were found in those sediments should also be ascribed to the above sketched kind of plant communities.

As it concerns tree species only pine and birch were possibly present at that time, which is exhibited by continuous pollen curves of *Pinus sylvestris* type and *Betula alba* type. They were most presumably forming small patches in otherwise open plant communities. Noteworthy, pollen of *Alnus*, *Carpinus betulus*, *Corylus avellana*, and *Picea abies* type was probably redeposited.

EV_{NP}1a *Calluna*-Ericaceae subzone

The continuous rise in NAP value serves as the evidence of the gradual unhampered spread of open habitats distinct from their herbaceous plant formations. Pine and pine-birch forests were still significant, but their dwindling status was a sign of the past role in plant communities formation.

Right now, open vegetation was delineated by species of the families such as Poaceae, Cyperaceae, Chenopodiaceae and by *Artemisia* all being abundant there. Expansion of peat-bogs was promoted by usually high groundwater table, which in turn is confirmed by relatively high proportion of *Sphagnum*. Representatives of the Ericaceae family especially *Calluna vulgaris* were also supplementing species composition of those peat-bogs. Juniper spread in some regions of northern Podlasie at the end of this subzone (e.g. in Solniki [28] vicinity, Fig. 4).

EV_{NP}1b *Pinus* subzone

The most distinctive change in vegetation in this subzone was a transient spread of pine and larch. It probably occurred due to some short-term climate fluctuations. Such temporary increase in temperatures and humidity is well reflected in the slump of magnetic susceptibility curves representing both the Solniki [28] (Fig. 4) and Dzierniakowo [24] (Fig. 8) profiles. Remarkably, it was not registered in any pollen profiles from other parts of Poland. The same changes in climate accompanying the first stadial of the Early Vistulian were recorded for the territory of today's Belarus (San'ko 1987 after Mojski 1993).

Areas occupied by open plant communities temporarily shrinked, which is manifested through decreased values of herbaceous plant pollen (e.g. clear slumps observed for *Artemisia*, Cyperaceae, Poaceae, Chenopodiaceae, and *Thalictrum*), as well as that of dwarf shrubs (mainly *Calluna vulgaris*) and some other shrubs.

EV_{NP}1c *Juniperus-Artemisia-Betula nana* subzone

Encroachment of open steppe communities into dry sandy habitats constituted the most important stage delineating vegetation succession of this subzone. It is expressed by extreme culminations of *Artemisia* and *Juniperus* pollen as well as by the presence of *Helianthemum nummularium* type and *H. oelandicum* type, *Gypsophila fastigiata* type and that of few other taxa.

Extremely high peak of *Juniperus*, reaching 43%, is registered in one pollen spectrum belonging to a section of the Milejczyce [40] profile, which denotes the Herning stadial (Bińka 2006a). It probably corresponds to the EV_{NP}1c subzone. This particular record indicates that at least in some areas of northern Podlasie shrub communities could have prevailed over typical steppe associations.

Amersfoort interstadial

EV_{NP}2 *Betula* R PAZ

The region of northern Podlasie was occupied by tree birches, which is expressed by rapid rise in values of the *Betula alba* type. It is possible that they formed clusters of the parkland-steppe being scattered in otherwise open vegetation, though the existence of denser birch forests should not be excluded which in turn is suggested by very low NAP proportion. This way or another, the area covered with open communities considerably diminished.

EV_{NP}2a NAP subzone

In the older subzone vegetation profile may be labelled as a typically transitional one. Gradual changes in the landscape promoted open birch forests, which obviously meant a further reduction in ratio of the area being occupied by herbaceous plant communities in the previous zone. Relatively large areas of dry habitats remained covered by steppe communities with domination of *Artemisia*, Chenopodiaceae, *Anthemis* type, and *Aster* type, whereas wet habitats were still occupied by grass communities similar to contemporary damp meadows, a tendency being reflected in high values of Cyperaceae and Poaceae and by regular occurrence of the pollen of *Cirsium* type, *Thalictrum*, and *Filipendula*.

EV_{NP}2b *Pinus* subzone

Birch forests thrived within this subzone with tree birches reaching their maximum level of expansion. The proportion of steppe, grass and tundra communities decreased. The diagrams show two high peaks of *Pinus sylvestris* type values, that confirm pine was temporarily an essential component of birch forests or even formed separate assemblages.

Cold fluctuation (Montaignu event)

EV_{NP}3 *Artemisia*-Poaceae R PAZ

The zone corresponds to a period of cooling representing middle phase of the Brørup interstadial *sensu lato*. In northern Podlasie this cooling was reflected by spread of the area covered with cold steppe communities lush with *Artemisia*, Chenopodiaceae, *Anthemis* type, Caryophyllaceae undiff., and some grasses.

Dramatic decrease in the pollen value of trees indicates a substantial reduction in the areas being covered with forests. Simultaneous fall in the proportion of *Sphagnum*, *Pteridium aquilinum*, Filicales monolete, *Calluna vulgaris* and Ericaceae undiff. suggests further degradation of various types of forests, both dry and damp ones. Such a reduction in tree's presence is inasmuch indicated by their low percentages as it is marked by distinct culmination of *Selaginella selaginoides*, a heliophyte indicating that open areas should have been widely accessible at that time. The open areas were occupied by herbaceous plant communities, whereas damp places harboured plant communities distinct for the spread of Cyperaceae, Poaceae, *Thalictrum*, and *Valeriana*.

Continuous forest decline and spreading of herbaceous plant communities both indicate a considerable deterioration of climate conditions in the lower part of the subzone. Heading towards the end of this subzone the proportion of pine steadily increased, which may point to a gradual improvement of climate.

A similar picture of changes in vegetation in that part of the Vistulian was reflected in many other pollen diagrams from Poland (Jastrzębska-Mamełka 1985, Mamakowa 1989, Granoszewki 2003), Germany (Erd 1973, Behre 1989, Hahne et al. 1994, Müller et al. 2003), France (Reille et al. 1992), and Sweden (Robertsson 1988).

Brørup interstadial *sensu stricto*

EV_{NP}4 *Pinus-Betula* R PAZ

After the cool episode there was an improvement in climate conditions, which made spreading of forests possible again. At that time dominant community in northern Podlasie was boreal forest resembling today's taiga. Vegetation succession of the Brørup interstadial *sensu stricto* can be divided into three parts. At first, birch forests spread (subzone EV_{NP}4a), then they transformed into pine-birch communities (subzone EV_{NP}4b), to turn in the end into pine communities with the participation of larch and spruce (subzone EV_{NP}4c).

EV_{NP}4a *Betula* subzone

Rapid increase in the proportion of *Betula alba* type indicates that forests were restored quite quickly during this subzone. Birch forests dominated the landscape. Steppe open communities with Caryophyllaceae undiff., *Artemisia* and Chenopodiaceae probably still occurred in dry places, particularly throughout the older part of this subzone. Wetter habitats fostered plant communities with sedges (Cyperaceae pollen) and tall herbs (pollen of *Thalictrum*, *Filipendula*, and *Cirsium* type).

EV_{NP}4b *Pinus-Betula* subzone

In the middle part of the Brørup interstadial *sensu stricto*, after the most prosperous time for birch presence, forest communities transformed into pine-birch assemblages, a tendency being accentuated by Scots pine dominance. Pollen record in the diagram from Solniki [28] (Fig. 4) shows few fluctuations in the rate of *Betula alba* type and *Pinus sylvestris* type. High peaks in grain size distribution suggest possible interrelation with changes in humidity or precipitation. Nonetheless, the course of magnetic susceptibility curve does not confirm their occurrence.

Larch and spruce reappeared in northern Podlasie becoming relatively important elements of pine-birch forests in this region. *Pteridium aquilinum*, *Lycopodium annotinum* and *Calluna vulgaris* were present in the undergrowth of these communities, whereas *Juniperus* shaped their understorey.

A very high proportion of trees and shrubs (ca. 95–98%) would support both forests with remarkable closeness of canopy, as well as non-forest communities, occupying quite limited areas at that time. Open communities occurred probably only in the wettest habitats (pollen of *Filipendula*, *Polygonum persicaria* type, *Polygonum bistorta*), and the driest ones (pollen of *Artemisia* and *Rumex acetosella* type), but their role in this subzone was much more reduced than in the preceding one.

EV_{NP}4c *Pinus* subzone

The expansion of pine took place in this particular subzone being accompanied by simultaneous decrease in birch presence. The Solniki [28] profile (Fig. 4) reflects these changes through the rise of organic carbon content in the sediments and the fall of magnetic susceptibility that marks warming of the climate. The lower quantity of the coarse mineral grains indicates the decrease in the rate of material dislocation being caused by rainwater.

On the prevailing area of northern Podlasie various types of pine forests emerged. Stable but low percentage curves of *Picea abies* type and *Larix* type suggest the presence of spruce and larch in those forests. As it concerns the dry variety of forests the undergrowth was composed of *Calluna vulgaris* and *Pteridium aquilinum*. Though more humid forest varieties still secured spruce presence, most probably it occurred only in small numbers. Their undergrowth was probably a source of the pollen of Ericaceae undiff. and the spores belonging to Filicales monolete, *Botrychium*, *Lycopodium annotinum*, and *Sphagnum*. Then in turn, waterlogged habitats were occupied by marshy varieties of pine forests with *Sphagnum* dominating in the herb-moss ground layer.

The role of open plant communities was still insignificant and limited mainly to arid habitats, being then represented by *Artemisia*, *Helianthemum oelandicum* type, *Aster* type, and to well saturated ones, whenever development of trees was hindered. Then plant assemblages with *Thalictrum*, *Filipendula*, *Polygonum persicaria*, and *Cirsium*/*Carduus* developed.

Rederstall stadial

EV_{NP}5 *Artemisia*-Poaceae R PAZ

Cold continental climate of the Rederstall stadial led to the spreading of cold steppe communities, that at that time reached the maximum of their development when taking into account the entire Early Vistulian. With little exception steppe formations dominated the landscape, which is expressed by extremely high pollen values of *Artemisia*, the most important component of such plant communities. In addition a very high proportion was noted for Poaceae undiff., Chenopodiaceae, *Aster* type, *Dianthus* type, *Helianthemum nummularium* type, *Gypsophila fastigiata* type, *Papaver rhoeas* type, and *Rumex acetosella* type as well as for *Juniperus* and *Ephedra fragilis* type.

Dwarf birch (pollen of *Betula nana* type) and shrub willow (*Salix* pollen) formed dwarf shrub tundra. It was also represented by ericaceous plant species, chiefly by *Calluna vulgaris*, and other herbaceous plants such as *Dryas*, *Dianthus* type, *Campanula*, and *Thalictrum.* It is however quite possible that some other members of Cyperaceae family were also present in tundra communities.

Wetter habitats were occupied by tall herb and moist meadow plant communities with *Thalictrum*, *Cirsium* type, *Filipendula*, *Valeriana*, *Polygonum bistorta*, *Pleurospermum austriacum*, and some other accompanying species representing the Poaceae family. It is likely that *Selaginella selaginoides* also occurred in such plant communities.

Forest communities declined, which is reflected in the low proportion of AP. Nevertheless, single tree stands or their clusters probably still persisted.

Odderade interstadial

EV_{NP}6 *Pinus-Betula* R PAZ

The zone is characterized by a marked spreading of trees, which mirrors considerable improvement of climate conditions, expressed mainly in detectable rise of temperatures. The vegetation succession of the Odderade interstadial can be divided into three major parts. First stage is marked by the spread of birch forests (subzone EV_{NP}6a), then their subsequent transformation into dense pine communities (subzone EV_{NP}6b), followed by their turning into open pine communities, where herb vegetation was of much greater importance (subzone EV_{NP}6c).

EV_{NP}6a *Betula-Artemisia*-Poaceae subzone

An increase above 50% in the proportion of AP, based on the Dzierniakowo pollen diagram [24] – Fig. 8, suggests fresh spread of forest communities. Tree birches dominated, whereas the role of pine was insignificant. Seeing that its pollen value did not exceed 5% there, it may be assumed it almost completely vanished in northern Podlasie of that period. As it concerns open communities formed in the previous zone though they remained, they underwent a noticeable decline. Such course of events is assumed in relation to the consequent decrease in the rate of *Artemisia*, implying a reduction of the areas occupied by steppe open communities.

EV_{NP}6b *Pinus-Larix* subzone

Pine forests followed pioneer birch associations. They spread rapidly at the beginning of the subzone and then reached the interstadial maximum of their expansion. This period constituted the climate optimum of the Odderade. Boreal pine forests, which dominated at that time, were apparently very dense (NAP proportion below 5%) and included a small fraction of spruce and larch, being represented by pollen of *Picea abies* type and that of *Larix*. In addition, *Calluna vulgaris*, *Pteridium aquilinum*, and *Lycopodium annotinum* grew in their undergrowth. After a probably short phase characterized by the lack of any noticeable changes, pine forests began to recede, which on the other hand was coupled with open vegetation starting to spread again.

EV_{NP}6c *Pinus-Artemisia*-Poaceae subzone

Changes in vegetation composition imply alteration of the climate heading towards a continental set of features. Peat bogs with *Sphagnum* started to play a crucial role, which in turn can indicate the return of permafrost (cf. Granoszewski 2003). Pine forests became less dense and the area occupied by open plant communities extended considerably, especially when taking into account shrub tundra (higher values of *Betula nana* type and *Salix*). Wet meadow communities thrived again, with buttercups (*Ranunculus acris* type pollen) being the most characteristic feature of such plant communities. Steppe-like assemblages distinctive for their unrestrained domination of *Artemisia* gained gradually their ground.

The youngest part of subzone, close to the end Plenivistulain faced a succession of changes leading towards domination of open vegetation associated with almost complete disappearance of forest formations.

CHANGES OF THE CLIMATE

GENERAL REMARKS

A study reflecting the course of natural changes in climate during past warm periods, yet undisturbed at that stage by human presence, may somewhat help to understand current changes in the environment. The Eemian interglacial serves as an ideal object of comparison with Holocene since it represents a complete period of warm climate preceding it most closely. As it concerns terrestrial habitats, fossil plants remains are one of the most significant sources of information about past climate changes. Since there is more palynological data than macrofossil ones that span Pleistocene, analyses of pollen data are used much more frequently and on much broader scale. Two decades ago a distinctive method was proposed, which is called "the modern analogue technique" (cf. Guiot et al. 1989, Guiot 1990, Field et al. 1994, Cheddadi et al. 1998).

Pollen records in profiles representing northern Podlasie served as the base for the reconstruction of climate changes throughout the Eemian interglacial and the early glacial of the Vistulian glaciation in north-eastern Poland (Fig. 59). For the purpose of such reconstruction a now classic method of "plant indicators of climate change" (Iversen 1944, 1954, 1964, Troels-Smith 1960, Grichuk 1969, 1984) in Zagwijn's version (1994, 1996) was applied.

Accordingly, only some vascular plant representatives can serve as the appropriate source of reliable information about mean summer and winter temperatures and annual precipitation. These include:

– *Ilex* and *Hedera*, indicating mean January temperatures above respectively 0°C and –2°C and mean July temperatures above respectively +15 and +16°C (Iversen (1944);

– *Taxus baccata*, sinse it represents similar pattern of distribution to that of *Hedera helix*, therefore comparable values can be inferred (Iversen 1944);

– *Tilia platyphyllos*, with its northern range limit lying close to the +17°C isotherm of July;

– *Tilia tomentosa*, with mean January temperatures ranging between slightly over 0°C and about –5°C, average July temperatures above +21°C and annual precipitation

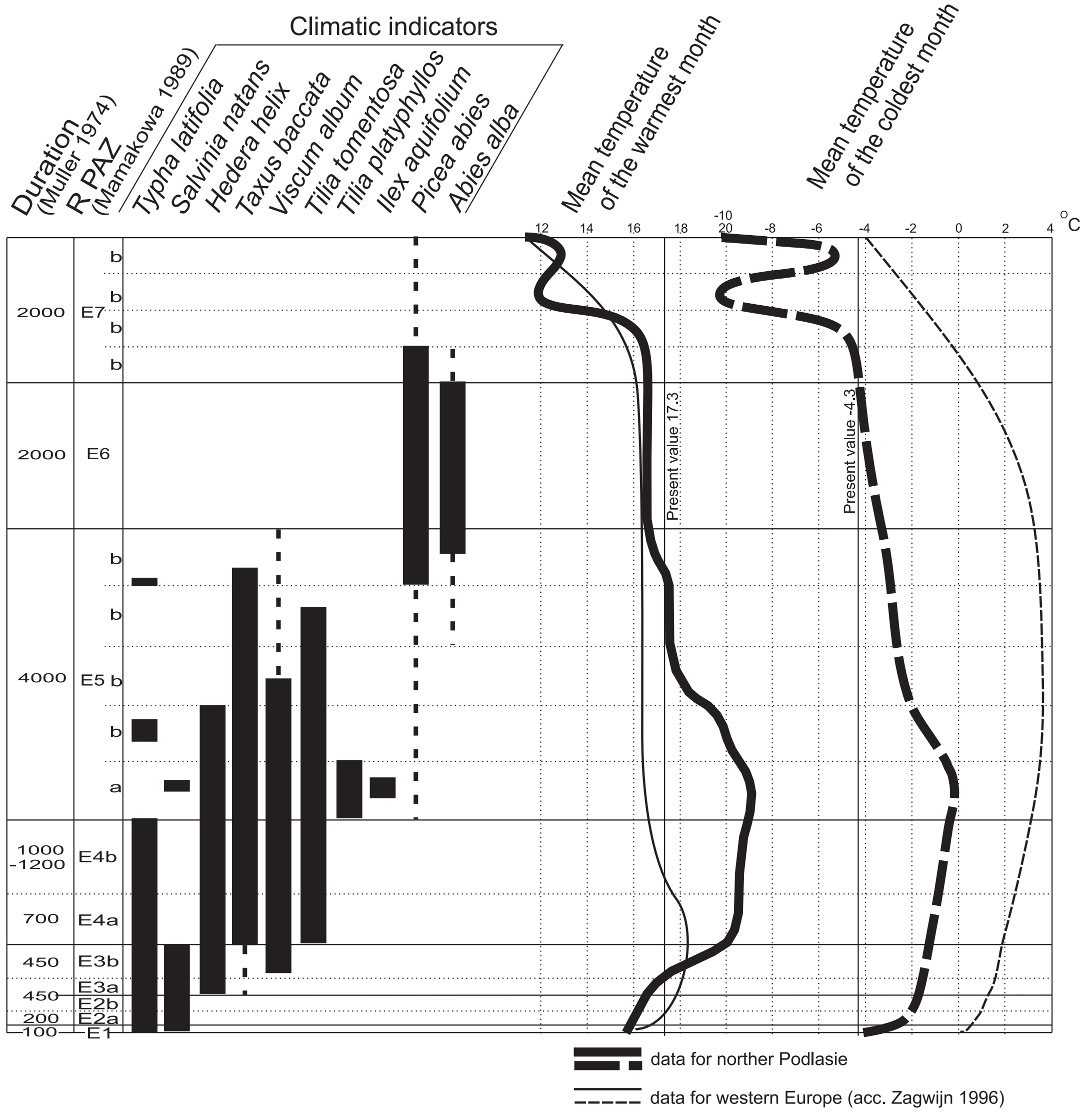

Fig. 59. Reconstructed climatic curves for the Eemian interglacial in northern Podlasie. R PAZ – regional pollen assemblage zones; the time scale is based on the Bispingen varve counts (acc. Müller et al. 1974)

of about 400 mm or more (Mamakowa 1997, Frenzel 1991, Granoszewski 2003).

The analysis is also based on widely recognized correlation between the northern and upper forest range limit and both the +10°C July isotherm and –5°C January isotherm (Zagwijn 1994, 1996).

LATE GLACIAL OF THE WARTANIAN GLACIATION

Domination of plants denoting open vegetation together with large proportion of heliophytes (*Artemisia*, *Helianthemum nummularium* type, Chenopodiaceae) imply cold climate conditions and suggest that northern forest boundary was situated to the south from northern Podlasie. Accordingly it indicates that in this particular region the mean temperature of the warmest month was below +10°C and that of the coldest month did not exceed –5°C (cf. Zagwijn 1996). Quite in contrast, high values of *Juniperus* pollen indicate that the lowest mean temperature of July was slightly exceeding +10°C. If we then consider the presence of *Picea abies* type pollen the mean January temperature may be expected to be much lower. As it concerns northern Podlasie during the late Wartanian the pollen of this type quite probably was predominantly represented by *Picea obovata*. Dahl (1998) assigns Siberian spruce to the Siberian boreal sub-element of the contemporary European flora and sets –10°C as the limiting isotherm for the coldest month at the highest points of the landscape. The values of mean summer and winter temperatures suggest the mean annual amplitude of temperatures at that time to be about 20°C and indicate a strongly continental character of the climate. The high proportion of *Artemisia* and the presence of *Ephedra fragilis* type both confirm this feature of the climate.

THE EEMIAN INTERGLACIAL

Changes in climate of northern Podlasie

The reconstructed climate changes were presented with reference to regional pollen assemblage zones and subzones delimited for northern Podlasie (Fig. 59).

E_{NP}1 ***Pinus-Picea-(Betula)*** **R PAZ**

High pollen values of trees and shrubs (AP), showing the spread of boreal forests, indicate that both the summer and the winter mean temperatures were higher than at the end of the Wartanian glaciation and probably exceeded +10°C in July and –5°C in January (Zagwijn 1996). On the other hand the presence of *Picea abies* type pollen, reaching the first interglacial culmination in this particular zone, quite probably denoting the expansion of *Picea obovata*, serves as the evidence for the mean temperature of the coldest month staying below –10°C. This top line was calculated by Dahl (1998) as the limiting one for the contemporary range of Siberian spruce at the highest points in the landscape. On the whole, we cannot rule out that at the beginning of the Eemian interglacial this species was only present at lower, mostly cold, locations.

Seeing that very high values of *Pinus sylvestris* type reflect the domination of pine forests, it may be concluded that the mean July temperature increased in comparison to the previous period exceeding +12°C (Zagwijn 1989). The presence of herbaceous plants on its own suggests that this temperature could even reach higher values. This, in particular, is indicated by the presence of *Typha latifolia*, which at present inhabits areas where the mean July temperature stays above +14°C (Kolstrup 1980, Paus 1992, Harmata 1995). The same applies to the occurrence of *Myriophyllum spicatum* or *M. verticillatum*. Then again, relatively high values of *Selaginella selaginoides* confirm that the mean temperature of the warmest month did not exceed either +17°C (cf. Tobolski 1991) or +20°C (Mamakowa 1997, Granoszewski 2003).

The presence of heliophyte steppe-like communities, showed by high values of *Artemisia*, may point to continental features of the climate.

E_{NP}2 ***Pinus-Quercus-Ulmus*** **R PAZ**

The mean temperature of the warmest month can be estimated on a basis of the occurrence of *Typha latifolia* to reach between +14°C and +15°C. Still, the constant presence of *Ulmus* implies that it could be somewhat higher. Nowadays, *Ulmus scabra* does not grow in areas where the mean July temperature drops below +16°C, whilst the other two species of elm have even higher thermal requirements (Granoszewski 2003).

The increase in warmth and humidity of the climate is revealed by the presence of *Hedera helix*. It may suggest that as early as in this part of the interglacial summer temperatures were moderately high and the temperature of the coldest month did not fall below –2°C (Iversen 1944, Zagwijn 1994). The abundance of *Salvinia natans* spores in sediments leads to very similar conclusion.

E_{NP}3 ***Quercus-Ulmus-Fraxinus*** **R PAZ**

The strong expansion of elm, ash and oak confirms an increasing oceanic character of the climate (Granoszewski 2003). The initial phase of hazel spread may also prove further increase in oceanic character of the climate. According to Mamakowa (1989) such climate changes, expressed in pollen profiles representing the entire Poland, were probably connected with the transgression of the Tychnowy Eemian Sea.

The presence of *Hedera* suggests that the mean January temperature was above –2°C. In the younger part of the zone *Viscum album* appeared for the first time in northern Podlasie. When analysing their climate-induced range it may be deduced that the mean July temperature most certainly remained at the level of at least +16°C.

E_{NP}4 ***Corylus-Alnus-Tilia*** **R PAZ**

According to many palaeobotanists (e.g. Frenzel 1991) the beginning of the hazel phase coincides with the outset of the climatic optimum of the Eemian interglacial. Pollen records from northern Podlasie profiles provide numerous data confirming that in north-eastern Poland at that time a very warm and oceanic climate prevailed. As early as in the older part of the $E_{NP}4$ zone *Tilia platyphyllos* and *T. tomentosa* appeared for the first time. It is well documented by the accumulation of their pollen in numerous profiles, as well as by great numbers of nutlets that were found at the Hieronimowo [26] site (Kupryjanowicz et al. 2007). According to Frenzel (1991) during the Eemian interglacial, the northern range limits of those species lay much further to the north-east. The presence of pollen and nutlets of *T. tomentosa* at the Satiki site in western Latvia (Kalnina et al. 2007) represents another well-known evidence of that fact. The existence of *T. tomentosa* at that time, a typical sub-Mediterranean Balkan species (Walter & Straka 1970), in the hazel phase of the Eemian interglacial of northern Podlasie allows the assumption that the mean July temperature did not fall below +21°C (cf. Frenzel 1967) being about 4°C higher than the present mean temperature in that region, which according to Górniak (2000) remains at the level of +17.3°C. The presence of *Hedera helix* shows the mean January temperature to be above –2°C.

All that reasoning implies that a very mild and warm climate with moderate rainfall prevailed in northern Podlasie across the $E_{NP}4$ zone.

$E_{NP}5$ *Carpinus* R PAZ

The hornbeam zone was the second part of the climatic optimum of the Eemian interglacial (Mamakowa 1989, Frenzel 1991, Litt et al. 1996). The presence of *Tilia tomentosa* and *T. platyphyllos* pollen, as well as of its nutlets in case of the Hieronimowo [24] site (Kupryjanowicz et al. 2007), allows the assumption that the minimum temperature of the warmest month was the same as in the previous zone.

The appearance of *Ilex aquifolium*, another climate change indicator species, in the $E_{NP}5a$ subzone suggests that the mean temperature of the coldest month increased above 0°C at that time (cf. Iversen 1944, Zagwijn 1996). Very high winter and summer temperatures reflect a climate being very warm and humid, strongly oceanic in its character, not only in comparison with the present climate in northern Podlasie, but even when compared with the older part of the climate optimum representing the Eemian interglacial. According to Granoszewski (2003) the best climate conditions fall into that part of the last interglacial also in case of southern Podlasie.

Accompanying feature to the rise of winter temperatures was the increase in precipitation enhancing oceanic character of the climate. *Ilex aquifolium* on its own indicates the minimum value of the annual rainfall to be 500 mm (Mamakowa 1997, Granoszewski 2003). An increase of the annual rainfall up to that particular level is also confirmed by the rising proportion of *Picea abies* type pollen and by the constant presence of *Abies alba* pollen. At present the Białowieża region, where their remaining stands are still present, receives the annual precipitation of about 650 mm (Górniak 2000). Presumably that value may be proposed as the range limit of fir occurrence on lowlands.

Rapid expansion of hornbeam during the $E_{NP}5a$ subzone may suggest that with the rise of winter temperatures summer temperatures also increased or that at least the summer lasted much longer. According to Faliński and Pawlaczyk (1993) generative reproduction, constituting a major expansion mode that enabled the very encroachment into new areas for that species, strongly depended on late spring and summer temperatures. At present in western Europe high seed crop of hornbeam is positively correlated with years characterized by especially long and warm summers. Therefore it is probable that this particular correlation defines species western range limit (Christy 1924, after Huntley & Birks 1983). Also during Holocene, the hornbeam expansion on the Polish Lowlands accompanied climate changes that were expressed in the increase of summer temperatures (e.g. Makohonienko 2000). However, conversely to the Eemian interglacial, during Holocene precipitation decrease fell into that period (Ralska-Jasiewiczowa & Starkel 1988).

In the middle part of the hornbeam phase of the Eemian interglacial represented by the $E_{NP}5b$ subzone, the mean temperatures of the warmest month were comparable with those representing the previous subzone and probably still exceeded +21°C, which is indicated by the presence of *Tilia tomentosa*. At the same time the mean January temperature slightly decreased remaining below 0°C, which in turn is marked by the regression of *Ilex aquifolium* from the area covering today's northern Podlasie. Additionally, the presence of *Taxus* *baccata* shows that the mean temperature of the coldest month was not lower than –2°C (Iversen 1944).

In the E_{NP}5c subzone two tendencies are distinctive, the first, a gradual increase in *Picea abies* type and the second, a nearly constant presence of *Abies alba*. The expansion of Norway spruce may suggest that the mean January temperature reached values spanning –12°C to +7°C according to Mamakowa (1997), or below –3°C according to Firbas (1949) or below –2°C according to Dahl (1998). The mean January temperatures for *Abies alba* range from –5°C to +7°C (Mamakowa 1997, Granoszewski 2003). All those data allow suggesting that during the E_{NP}5c subzone the mean temperature of coldest month was approximately from –5°C to –2°C. The mean July temperature, based on the extinction of *Tilia tomentosa* in this region, was lower than in the previous part of the hornbeam phase. However the presence of *T. platyphyllos* proves that it was still higher than +17.5°C. The reconstructed mean temperature values both for summer and winter months are in accordance with the requirements of *Viscum album* (Iversen 1944, Zagwijn 1994), which was continuously present in this subzone.

E_{NP}6 *Picea-Pinus-(Abies)* R PAZ

The most important changes in the vegetation, such as the recession of thermophilous trees and shrubs as well as simultaneous expansion of spruce, fir, pine and birch, all reflect the decrease in thermal conditions. The mean January temperature, being based upon rather rare occurrence of *Abies alba*, was at that time about –5°C (cf. Mamakowa 1997, Granoszewski 2003). In comparison to such winter temperatures, the mean July temperature reached at least +17°C, even at the end of this zone, the fact being confirmed by the presence of *Viscum album* (cf. Iversen 1944).

As it concerns thermal changes precipitation increased, the minimum annual rainfall for *Picea abies* and *Abies alba* being about 200 mm higher than the minimum requirements for the *Carpinus betulus* presence (Granoszewski 2003).

E_{NP}7 *Pinus* R PAZ

The E_{NP}7a subzone represents a period marked with domination of pine forests. Spruce was gradually losing its position as the dominant forest component, that it still exerted at the beginning of this phase. Thermophilous trees that lingered so far, such as *Carpinus*, *Tilia cordata*, and *Alnus*, disappeared almost entirely. Therefore we assume that a continental in its character climate succeeded. At that time the mean July temperature was not lower than +12°C (Zagwijn 1989), though if the presence of *Larix* and *Tilia cordata* type was taken into account, the mean July temperature should have been slightly higher. At present, *T. cordata* tolerates the mean temperatures for the summer months exceeding +13°C (Hintikka 1963, after Zagwijn 1996) and the mean July temperature for *Larix decidua* is +17°C (Mamakowa 1997, Granoszewski 2003). The mean January temperature decreased below –5°C, being marked by the disappearance of *Abies alba*.

In the subzone E_{NP}7b, the established *Pinus* forest was now invaded by *Betula*. Yet neither in pollen spectra nor in lithology reflecting that part of the profile evidence was found that would prove the encroachment of *Betula* as being correlated with any other phenomena of the local character (e.g. secondary succession to areas destroyed by fire, development of local communities with birch growing around lakes or in bogs). Because of that fact the cooling of the climate seems to be the most probable reason staying behind the above mentioned changes.

It is presumed the mean July temperature probably decreased down to about +12°C (cf. Zagwijn 1989). Nowadays, the same temperature value is recorded for northern Europe, close to forest range limit, where boreal birch forests are the dominant community.

In the subzone E_{NP}7c a rise of NAP proportion, exceeding 20%, is noticed. It signifies a substantial reduction in areas being covered with boreal forests accompanied by simultaneous spread of herbaceous plant communities, mainly in the steppe-like type. Those changes point to relatively dry continental climate. At present, a similar scenario undergoes in northern Scandinavia, where birch-pine forests get replaced by herbaceous vegetation in response to much harsh winter conditions, being expressed mainly in temperatures dropping below –10°C (Cheddadi et al. 1998). As it concerns the E_{NP}7c subzone the mean July temperature probably also decreased. It is worth being mentioned that the contemporary northern forest range limit is expressed by herb values of at least 50%. This line coincides with the +10°C July isotherm (Zagwijn 1989). In case of northern Podlasie the proportion of herbs did not reach that high values. Thus it suggests that the mean July and January temperatures were slightly higher than the baseline values.

In the E_{NP}7d subzone, a new phase of *Pinus* forest expansion at the cost of the decline in *Betula* and herb presence undoubtedly reflects a bit more milder and temperate climate. The mean July temperature once again had to be higher than +12°C. On the contrary, the mean January temperature is much more difficult to be reconstructed. Still, coinciding northern forest range limit and the isotherm of –5°C may indicate that the temperature had to be higher than this particular value.

Synthesis of climatic data from northern Podlasie

On a basis of the preceding data a concise synthesis of the climate history representing the Eemian interglacial in northern Podlasie is presented herein (Fig. 59).

– At the very beginning of the Eemian interglacial the mean July temperatures rose rapidly to values of about +14°C reaching the maximum value of at least +21°C during the *Corylus* zone, less than 1200 years after the beginning of the interglacial. Later, in the youngest part of the *Carpinus* zone the mean summer temperatures slightly dropped to values slightly exceeding +17.5°C and then in the *Picea* zone to above +17°C, whereas at older part of the *Pinus* zone down to about +13°C.

– At the beginning of the interglacial the mean January temperature was above –10°C. It rose rapidly to over –2°C in the E_{NP}2 zone and reached the highest values of 0°C in the oldest part of the *Carpinus* zone. Later, in the middle part of the *Carpinus* zone, winter temperatures dropped once again, and reached roughly the present values of –5°C to –3°C. Then, at the beginning of the *Pinus* zone the mean temperature of the coldest month decreased below –5°C.

– The thermal optimum of the Eemian interglacial in northern Podlasie was reached during the older part of the *Carpinus* zone, characterized by the highest mean January and July temperatures, 0°C and +21°C respectively, and the smallest amplitude between them for the whole interglacial.

– There is no data to be found in the material from northern Podlasie, that might point to any great drop in winter or summer temperatures in the hornbeam phase.

– At the end of the interglacial, in the middle part of the *Pinus* zone, the short-term cold fluctuation took place, with the mean summer temperatures staying slightly below +10°C and the mean temperatures of winter below –12°C.

Discussion – Was the climate of the Eemian interglacial stable?

As a result of numerous thorough pollen analyses the succession of the Eemian vegetation in Europe is very well documented (Zagwijn 1961, Mamakowa 1989, Fauquette et al. 1999, Müller 2000, Turner 2000, Beets et al. 2006, and the others). As it regards climate conditions, what is based on the pollen data representing the Eemian interglacial, it can be stated that it was a stable period. For example, no abrupt climate fluctuation during the Eemian interglacial was documented for north-western Germany (Caspers & Freund 1997, 2001, Caspers et al. 2002).

Climate studies based on the data from marine cores (Keigwin et al. 1994, McManus et al. 1994) as well as those from the first Greenland's ice core (Jozuel et al. 1993) illustrate the climate of the last interglacial as a stable one.

Conversely, in the last decade of the previous century, such climate stability has been questioned as a result of the broad scope project of GRIP (European Greenland Ice Core Project). New ice cores showed that during the Eemian interglacial strong temperature fluctuations from warm to cold conditions took place. Data contains the evidence of two extreme cold events both of them lasting for over 1000 years (Dansgaard et al. 1993, GRIP members 1993).

Whatever the result, such a discrepancy between the new GRIP cores and the previous results upon the Eemian climate do inspire scientists to carry out new researches. The ice core oxygen isotopic and electrical conductivity records in the next core – GISP2 (Greenland Ice Sheet Project) – suggest that the instability of oxygen isotopic temperature, being vaguely signalled in the previous core, could have been caused by ice-flow deformations (Boulton 1993, Grootes et al. 1993, Taylor et al. 1993, Alley et al. 1995, Chappellaz et al. 1998).

At the same time the pollen record from Grand Pile triggered the discussion on whether it is accurate to accept such scenario of climate variation as reflected by the GRIP records (Thouveny et al. 1994). Similar cold fluctuations within the Eemian interglacial were also distinguished in case of a few other European pollen sequences (de Beaulieu & Reille1989, 1992a, b, Guiot et al. 1993, Müller 1974, Field et al. 1994, Cheddadi et al. 1998) and in many other profiles, though studied with the use of different methods, that represent various regions of the world (Cortijo et al. 1994, Larsen et al. 1995, Seidenkrantz et al. 1995, Stirling et al. 1995, Fronval & Jensen 1996, Maslin et al. 1996, Maslin & Tzedakis 1996, Adkins et al. 1997, Zhisheng & Porter 1997, Ciszek 1999, Karabanov et al. 2000a and the others).

The results of high resolution climate reconstruction represented by seven records from France and Poland, document rapid and significant drop in temperatures within the Eemian interglacial (Cheddadi et al. 1998). It occurred between 4000 and 5000 years after the beginning of the interglacial itself and was related to a spread of the *Carpinus* forests. What has to be born in mind though is the fact that the correlation of the pollen data with the GRIP records is rather weak.

According to Ciszek (1999) the results of magnetic susceptibility from five Polish pollen profiles (Imbramowice, Lechitów, Ruszkówek, Obrzynowo and Lipcze) also allow accepting the hypothesis about the presence of a few clear climate fluctuations during the last interglacial. For the most part, these are reptresented by Polish regional zones of the E2 and E5 as well as by a transition between the E6 and E7 zones. In the hornbeam phase (E5) two separate coolings took place. According to Ciszek (1999) they correspond to the 5e2 i 5e4 substadials in the Greenland isotopic curve.

The records both from the Nordic Sea and from western Ireland show a cooling of the North Atlantic in the middle part of the Eemian interglacial, somewhere between 122 and 125 ka (Cortijo et al. 1994, Larsen et al. 1995, Fronval & Jensen 1996). Records from north-western European shelf sediments that were collected to the south from the previous sites, suggest a similar picture of cold intervals during the Eemian interglacial (Seidenkrantz et al. 1995). In this way, the mid-Eemian cooling, which lasted for about 400 years, was documented (Adkins et al. 1997). It was associated with an abrupt reorganization in the North Atlantic deep-water circulation. The short mid-Eemian cooling that was correlated with changes in the North Atlantic circulation, was also found in the record of biogenic silica and siliceous microfossil abundance from the bottom sediments of Lake Baikal, which is located in the mid-continental Siberia (Karabanov et al. 2000a). The presence of the mid-Eemian cooling signalled in the sedimentary record of Lake Baikal suggests the strong climatic connections between the North Atlantic and the continental northern Asia. Evidence of a single sudden cooling during the Eemian interglacial is also present in record from loess sediments in central China (Zhisheng & Porter 1997).

Also a detailed study of Ocean Drilling Project site 658 in the subtropical eastern Atlantic found that the Eemian interglacial included a short cold event. It was shown in the benthonic oxygen isotope record at about 122 ka (Maslin et al. 1996, Maslin & Tzedakis 1996).

Further evidence of the existence of the intra-Eemian cooling comes indirectly from coral reef records. New data from western Australia and a review of other high precision U-series coral data indicate that during the last interglacial the main global episode of coral reef building was confined to just a few thousand years between 127 to 122 ka (Stirling et al. 1995). This period of reef building seems to have ended at the same time as the beginning of the intra-Eemian cold event at about 122 ka (Adams et al. 1999).

While considering all the above stated facts the questions concerning climate stability in the Eemian interglacial and the sheer quantity of the climate cold fluctuations during this interglacial still remain open. Therefore obtaining new data sets is of crucial importance. In line with such a necessity the case study representing northern Podlasie meets requirement of such specified palynological investigation. The result presented here show undeniably that in this region of Poland no extreme climatic events, such as strong decrease in winter and summer temperatures, occurred across the *Carpinus* zone. Granoszewski (2003) and Bińka & Nitychoruk (2003) both made similar conclusions with regard to southern Podlasie.

The lack of distinct cooling in the middle part of the Eemian interglacial differentiates north-eastern and eastern Poland from south-western part of the Country. The mean temperature curves from northern Podlasie (Fig. 59) were compared to the thermal curves from Imbramowice, lying in south-western Poland, that were drawn relying on the results of using modern pollen analogue technique (Cheddadi et al. 1998). This comparison shows crucial differences between these two regions. As concerns the Imbramowice site it reflects in the middle part of the *Carpinus* zone a slump in the mean January temperature of about 9°C, from ca. +4°C to ca. –5°C. At the same time in northern Podlasie the decrease in the mean temperature of the coldest month was vaguely detectable dropping from over 0°C to over –2°C. That does not however indicate a catastrophic character of such a change. Minor decreases in temperatures at that time were registered also in southern Podlasie. According to Granoszewski (2003) in the Horoszki Duże region the mean July temperature fell from +21°C to +18°C, and the mean January temperature was still above 0°C as in the *Corylus* zone.

In Imbramowice no cold fluctuation was registered in the pine phase E7, whereas such fluctuation is very clear in a few profiles from northern Podlasie (Michałowo [25], Dzierniakowo [24] and Machnacz [17] – see Fig. 56). In those profiles, sediment sections of the *Pinus* zone are made up of homogeneous undisturbed lacustrine deposits. Therefore, the described cold fluctuations cannot result from sediment redeposition.

Cold climate fluctuation during the E7 zone is indicated, though less clearly than in northern Podlasie, also in case of Horoszki Duże in southern Podlasie (Granoszewski 2003) and in a few additional sites representing other regions in Poland, e.g. Konopki Leśne and Szwajcaria 1 (Borówko-Dłużakowa & Halicki 1957), Warszawa-Wola (Borówko-Dłużakowa 1960), Józefów (Sobolewska 1966), Nakło (Noryśkiewicz 1978), Zgierz-Rudunki (Jastrzębska-Mamełka 1985), and Imbramowice (Mamakowa 1989).

Notably, cold event in the E7 zone was not distinguished by Bińka and Nitychoruk (2003) in the Dziewule profile in southern Podlasie. The authors correlate the upper local pollen zones of this profile with the Herning stadial (11 *Betula*-NAP), Brørup interstadial (12 *Pinus*) and Rederstall stadial (13 NAP). Nevertheless, pollen record representing those zones, what the authors themselves admit, is not clearly developed. Then, the pollen record from the Dziewule site was correlated with one of northern Podlasie sites representing the Eemian *Pinus* zone and also with the Horoszki Duże site (Granoszewski 2003). It seems very likely that 11–12 local zones from Dziewule correspond to the middle and younger part of the Eemian *Pinus* regional zone. Eleven *Betula*-NAP L PAZs may represent the cooling within this zone. However, only 13 NAP L PAZs may be connected with the first stadial (Herning) of the Early Vistulian.

De Beaulieu and Reille (1989) has already described a similar cold fluctuation in the late part of the Eemian interglacial in Les Echets. It is reflected there as a temporary reduction of *Abies* accompanied by the spread of *Pinus*. The authors correlate it with similar fluctuations recorded in Sulzberg-Baden (Welten 1981), Gondiswill (Wegmüller 1986), La Grande Pile (Woillard 1978), Brørup (Andersen 1961) and Odderade (Averdieck 1967).

The fact that this fluctuation is not recorded in numerous other profiles, both from Poland and from Europe, may be caused by different reasons. In case when the thickness of sediments, where the final part of the Eemian interglacial is recorded in, is low, the oscillation may not be noticed with the standard distance between pollen samples, i.e. when being taken every 5–10 cm. It is also possible, according to de Beaulieu and Reille (1989), that this short and low amplitude oscillation induced notable vegetation changes only next to ecotones zones.

A correlation of the intra-Eemian climatic fluctuations contained both in the records from European terrestrial sites and of cold events reflected in Greenland's ice or deep marine cores is indeed weak. Great majority of cases lack exact age determination of these fluctuations, which in turn disallows any further data analysis. In case of the profiles that were not subjected to the appropriate pollen analysis and exact dating there is no certainty whether they really contain a record of the entire interglacial or not. Consequently, there lies sheer inability to define precisely where exactly a particular change within any part of the interglacial took place.

Taking into consideration all that, it cannot be excluded that at least some cold events from deep marine cores, that are usually placed within the middle part of the Eemian interglacial, are quite possibly reflected within the final part of the interglacial. If yes, they could be correlated with the cooling recorded in the *Pinus* phase of the Eemian vegetation succession.

Another reason causing such difficulties springs from one method being used at a time, which leads to incorrect or uncertain interpretation being ascribed to a particular profile. A very good example of such a situation is represented by the Solniki [28] profile (Fig. 4), where a record from magnetic susceptibility (MS) curve shows a clear peak in the lower part of the *Carpinus* zone. Hence, according to Ciszek (Ciszek 1999, Kupryjanowicz et al. 2005) it may be interpreted as an important cooling related to the decline in areas covered with forests, a viewpoint that exemplifies a standard interpretation of such type data. Then again the same MS curve can indicate an increase in the rate of material dislocation being caused by rainwater. The second explanation seems to be more likely when taking into account the pollen record itself, since no significant decrease in temperature in this part of the Eemian interglacial was reflected in this content.

EARLY VISTULIAN

Changes in climate of northern Podlasie

The disappearance of coniferous forests and the domination of open vegetation both indicate that in the Herning stadial northern forest range limit was situated to the south of northern Podlasie. That suggests that the mean temperature of the warmest month was below +10°C and the mean temperature of the coldest month remained below –5°C. At present these values determine northern and upper forest limit (Zagwijn 1996). The high proportion of *Artemisia* and the presence of *Ephedra fragilis* type would register a continental character of the climate. In the middle part of the stadial, the short-term change of the climate is indicated by a temporary increase in the pollen values of *Pinus sylvestris* type. This fluctuation may correspond to a slight increase in temperatures.

The improvement in climate condition in the Amersfoort interstadial is indicated by the spread of birch forest communities. The presence of tree birches implies the mean July temperature reached +12°C to +13°C. The presence of *Typha latifolia* may suggest that this temperature was indeed one degree higher. The mean temperature of the coldest month increased above –5°C at that time.

During the cold fluctuation between Amersfoort and Brørup interstadial *sensu stricto* the birch forest was replaced by herbaceous vegetation in response to more rigorous winter conditions, where the mean January temperature dropped below –5°C and the mean temperature of the warmest month decreased once again below +10°C. The presence of heliophyte communities in steppe-like type, which is denoted by high values of *Artemisia*, would point to the climate of a more continental type.

In the older birch part of the Brørup interstadial the mean July temperature probably increased to about +12°C, which is documented by the spread of birch forests (cf. Zagwijn 1989). Additionally, the reappearance of *Typha latifolia* suggests that this temperature might however exceed even +14°C.

The younger pine part of the Brørup interstadial was characterized by the expansion of boreal pine-birch formation then being followed by pine associations. The mean temperatures of the warmest month at that time might have been higher than in the birch phase, reaching even +17°C. This is showed by the presence of *Larix,* quite presumably of *Larix decidua* (Mamakowa 1997, Granoszewski 2003). The mean temperature of the coldest month ranged between –5°C and –2°C, which is indicated by simultaneous occurrence of pollen representing *Picea alba* type and *Larix*. When taking into account the presence of *Larix decidua* there the mean January temperature reached a span of –5°C to +7°C (Mamakowa 1997, Granoszewski 2003), whereas if considering the presence of *Picea abies* it stayed below –2°C (Dahl 1998).

The Rederstall stadial was associated with a substantial decrease in areas being covered with forest associations which in turn was followed by a major spread of open steppe vegetation. Northern forest range limit was located to the south of northern Podlasie. The mean January temperature decreased again below –10°C, whereas the mean July temperature stayed below –5°C. Additionally, the presence of *Dryas* pollen strongly points to subarctic climate.

In the older part of the Odderade interstadial the mean July temperature probably increased slightly to about +12°C. It was reflected by the return of birch forests (cf. Zagwijn 1989). The spread of pine, spruce and larch in the middle part of the interstadial reflects continued increase of the mean July temperatures to above +13°C. However, if the larch at that time was indeed represented by *Larix decidua*, the increase might have been even higher reaching about +17°C (Mamakowa 1997, Granoszewski 2003). The mean temperature of the coldest month ranged between –5°C to –3°C, which is reflected by simultaneous presence of larch and spruce. The middle part of the Odderade interstadial constituted its thermal optimum. Then afterwards the summer and winter temperatures once again began to gradually decrease.

Global changes of the climate after the end of the Eemian interglacial

In accordance with marine records, the Eemian interglacial ended up with a rapid cooling event about 110 000 years ago (Imbrie et al. 1984, Martinson et al. 1987, Turner 2002). This fact is also registered in ice cores and pollen records being disseminated across Eurasia. Adkins et al. (1997) suggest that the final cooling lasted less than 400 years. After the end of the Eemian interglacial numerous sudden changes and short-term warm and cold alternations have been noticed. Most or even all of them occurred on a global scale. The most extreme points in these fluctuations were represented by warm interstadials and cold stadials, being named as "Heinrich events" (Heinrich 1988). Ice core and ocean data suggest that interstadials began and ended rapidly, though it is suggested that the abrupt change in climate at the beginning of an interstadial was generally followed by a more gradual decline. It involved a stepwise series of smaller cooling events and often a fairly large terminal cooling event, that restored the conditions to the colder glacial state (Rasmussen et al. 1997). The warming in each interstadial may have lasted from a few centuries to nearly two thousand years (Mayewski et al. 1997).

Relying on European and North American pollen records many of Heinrich events have also been interpreted as particularly cold and arid intervals (Grimm et al. 1993 Satkūnas & Grigienė 1997a, b, Satkūnas et al. 1998, 2003). Though there are some researches published, vegetation changes of the Early Vistulian and Plenivistulian are not so well studied as those of the Eemian interglacial (Mamakowa 1989). That in turn results from a very little number of sites with organic sediments being found that would properly represent this particular period. In Poland as well as in other parts of Europe only the Early Vistulian is adequately described. The pollen record of that period is usually placed in continuous sequences above the strata representing the Eemian vegetation succession. Notably, in the profiles from some European sites the pollen record of different interstadials or interphases is presented without a proper interrelation with the Eemian pollen records. In such case the age of a particular interstadial and interphase has been dated by a radiocarbon method (Balwierz 1995).

In central and eastern Europe there is only one pollen sequence represented by the Horoszki Duże site (Granoszewski 2003) that contains almost complete record of the Early Vistulian and the Plenivistulian. Quite the opposite, sites of that type are more frequent in southern part of the continent (Follieri et al. 1998, Allen et al. 2000).

Rapid warm fluctuations of the climate nick-named as "Dansgaard-Oeschger" events (DO), that occurred during the last glaciations are clearly reflected in Greenland's ice cores (Dansgaard et al. 1993, Grootes et al. 1993) and in marine sediments representing both high and low latitudes (Bond et al. 1993, McManus et al. 1994, Schulz et al. 1998). The environmental impact of the DO fluctuations on the expanses representing intermediate latitudes such as those of central Europe is still not so well documented.

As it concerns wide range of terrestrial palaeoclimate proxies, pollen record appears to be the most reliable source of information. Long and continuous pollen records are predominantly found in the Mediterranean region (Tzedakis et al. 1997, 2001, Allen et al. 1999). Conditions for the preservation of long pollen records in central and northern Europe were less favourable because of the periglacial processes that led to erosion and unconformities (Tzedakis et al. 1997). Hence, the long and continuous pollen records are in short supply in case of northern Poland and changes in vegetation in central Europe during the last glaciation are therefore still poorly understood (Behre 1989, Grüger 1989, Mamakowa 1989). As a consequence, the response of central European vegetation to short-term warming episodes such as Dansgaard-Oeschger interstadials remains still unclear.

DEVELOPMENT OF MIRE AND AQUATIC VEGETATION IN NORTHERN PODLASIE – SELECTED ASPECTS

SUCCESSION OF WATER VEGETATION IN THE SOLNIKI PALAEOLAKE

Based on the Solniki [28] pollen diagram (Fig. 60), changes in frequency and percentage values of mire, water plants, and non-pollen microscopic remains enabled zone delimitation. These special pollen zones are marked by the alfa-numerical symbol starting with "S_W" in order to make a distinction between main zonation in the diagram. The succession of water and mire plants at the Solniki [28] basin [28] was therefore presented using the above described scheme.

The Eemian interglacial

Stage 1 (S_W-1 Filicales L PAZ, depth of 11.06–10.93 m – Fig. 60) – a development of water-mire vegetation in the Solniki [28] basin falls to the beginning of the Eemian interglacial that corresponds to the regional pollen zone of the E_{NP}1 *Pinus-Picea-(Betula)*. The sheer character of the sediments accumulated there confirms the studied basin was a lake at that time. The most characteristic feature of pollen record of this stage is a very high proportion of Filicales monolete (25–50%). To some extent this taxon might have been represented by *Thelypteris palustris*, which is suggested by the presence of single spores belonging to this particular fern species. *Thelypteris palustris* together with *Phragmites* (*Phragmites* type pollen) might have formed rush communities in the type of the contemporary *Thelypteridi-Phragmitetum* (cf. Tomaszewicz 1977, Kłosowscy 2001). They probably intertwined with other types of rushes, which presence is signalized by pollen grains of *Typha latifolia*, some Cyperaceae and by *Equisetum* spores, putitatively that of *Equisetum limosum*. Single pollen grains of *Menyanthes trifoliata* and spores of Bryales and *Sphagnum* suggest the presence of plant communities which might have formed floating islands at least partially covering water table. In the lower S_W-1a subzone *Myriophyllum spicatum* reached its interglacial maximum of 2%. Its presence reflects relatively deep water of the lake (up to 6 m) and richness of calcium carbonate (cf. Podbielkowski & Tomaszewicz 1982).

Stage 2 (S_W-2 Filicales-Cyperaceae L PAZ, depth of 10.90–10.83 m – Fig. 60) – a development of lake plants representing the older and middle part of regional pollen zone of the E_{NP}2 *Pinus-Quercus-Ulmus-Salix*. Very low frequencies of aquatic and mire plants remains are distinguishing feature of the zone. Only spores of Filicales monolete and pollen of Cyperaceae occur regularly.

Stage 3 (S_W-3 *Equisetum*-Cyperaceae-*Salvinia-Typha* L PAZ, depth of 10.80–10.72 m – Fig. 60) – covers a span of the younger part of the E_{NP}2 *Pinus-Quercus-Ulmus-Salix* R PAZ and the older part of the E_{NP}3 *Quercus-Ulmus-Fraxinus* R PAZ. The regular occurrence of microsporangium fragments belonging to *Salvinia* and peaks of Cyperaceae, *Nymphaea alba*, *Typha latifolia* and *Equisetum* are characteristic features of the zone. Pollen of *Nuphar*, *Lemna* and *Potamogeton*, and Nymphaeaceae idioblasts appeared there for the first time. Development of plant communities with *Salvinia* and *Nymphaea alba* probably resulted from gradual warming of the climate. Rise in the proportion of *Equisetum*, quite probably that of *E. limosum*, as well as of Cyperaceae and *Typha latifolia*, and the appearance of *Typha angustifolia*/*Sparganium* pollen may suggest the spread of the littoral zone having its result in more intensive development of swampy communities. Change in sediment properties from that represented by silt to that of the peat suggests that the basin was much more shallow at that time.

A change took place that is placed in the lithological profile at the bottom part of the S_W-2 zone. Silt was gradually replaced by peat. Most probably it was formed in shallow waters. It is also possible that it represented a kind of seasonally flooded basin. Both cases may be confirmed by the presence of algae representing *Botryococcus* and *Pediastrum* genera. The appearance of *Salvinia natans* macrosporangia serves as the evidence of its rampant proliferation in lake waters. In much shallower parts of the basin there occurred communities being assembled with *Nuphar*, *Nymphaea alba*, and *Potamogeton*. Rush zone with *Typha latifolia*, *Phragmites*, and *Menyanthes trifoliata* was also well developed on the margins of the basin. Additionally, at the end of the zone *Equisetum* spores reached very high values, which may indicate its occurrence in those communities.

Stage 4 (S_W-4 *Ceratophyllum-Botryococcus* L PAZ, depth of 10.70–10.44 m – Fig. 60) – corresponds to the middle part of the E_{NP}3 *Quercus-Ulmus-Fraxinus* regional pollen zone. Percentage values of *Ceratophyllum* hairs are the highest within the entire profile, which on its own may illustrate greater depth of the lake. Silt accumulation is once again found at a bottom of the basin (see Fig. 60). Pollen of *Typha angustifolia*/*Sparganium*, *Typha latifolia*, and *Myriophyllum spicatum*/*verticillatum* as well as Nymphaeaceae idioblasts occur quite frequently there. Their presence indicates that in this lake there were both deep water habitats with submerged plants and patches of shallow water covered with nymphoides and rushes. Additionally, the frequency of *Botryococcus braunii* cenobia is higher than in the previous zones.

Stage 5 (S_W-5 *Botryococcus-Pediastrum*-Filicales L PAZ, depth of 10.25–7.02 m – Fig. 60) – a long lasting stage, from the E_{NP}4 *Corylus-Alnus-Tilia* R PAZ to the older part of the E_{NP}7 *Pinus* R PAZ. Very low frequencies of aquatic and mire plants remains are a distinguishing feature of the zone. Only cenobia of *Botryococcus braunii*, *Tetraedron minimum*, and a few species of *Pediastrum* (*P. duplex, P. integrum, P. kawraiskyi*) as well as spores of Filicales monolete regularly occur. Sporomorphs of all other plants belonging to that group sporadically appear. Very low proportion of *Pediastrum* reflects very deep water of the lake basin. Organic silts and calcareous-organic gyttja were deposited in the lake at that time, which serves as the evidence of favourable edaphic conditions.

The occurrence of single *Amphitrema flavum* remains in the middle part of that stage provides reliable information about conditions within the basin. Van Geel (1978) suggests that *A. flavum* increased in numbers along with rising humidity but it did not adapt to large bodies of open water and eutrophic conditions. On this basis the middle part of the stage 4 representing local succession at the Solniki profile may be related to the temporary lake shallowing and to the transition towards oligotrophic conditions. Then again, pollen record does not reflect any changes neither in the lake water level, nor in its edaphic properties. On the other hand, diatom results, Cladocera analyses, magnetic susceptibility data and ^{18}O and ^{13}C stable isotopes (Kupryjanowicz et al. 2005) all reflect a significant increase in water level going on at the beginning of that stage with subsequent rapid lowering in water level at Solniki in the middle part of the E_{NP}5 regional pollen zone.

This stage was marked with unbalanced conditions. In the substages 5b and 5d the basin might have had eutrophic character expressed by increase in the frequency of Cladocera individuals of *Chydorus sphaericus*, *Leydigia leydigi*, and *Bosmina longirostris*. During the substage S_W-5c an anaerobic zone was probably present in the lake, which is indicated by oxygen isotope curve. Record denoting significant deepening of the basin is registered at the depth of 7.65–7.40 m and 7.10–6.95 m. It is reflected by great increase in the frequency of deep-water Cladocera forms. Noteworthy, none of these changes is reflected in the composition of macrophytes. At that time clayey silts and shales accumulated at the bottom of the lake.

Stage 6 (S_W-6 *Sphagnum*-Cyperaceae L PAZ, depth of 7.00–6.70 m – Fig. 60) – represents the middle part of the E_{NP}7 *Pinus* R PAZ. Characteristic traits of this stage are temporary cooling of the climate and the spread of open steppe-like vegetation. At that time *Sphagnum* reaches the first peak whereas Cyperaceae its second within the profile. Low-percentage culmination of Filicales monolete is noticed, with *Osmunda cinnamomea* spores being sporadically present. Pollen of *Phragmites* type and *Typha angustifolia*/*Sparganium* occurs more frequently than in the previous zone and shallowing of the lake is signalled in pollen record. Spores of *Isoëtes* appear for the first time. Their presence suggests the transition of lake's edaphic conditions towards oligotrophic ones. In the middle part of the stage changes affected lithological properties of the profile, with peat being gradually replaced by silt.

Stage 7 (S_W-7 *Botryococcus-Myriophyllum* L PAZ, depth of 6.65–6.35 m – Fig. 60) – falls on the youngest part of the pine phase of the Eemian interglacial (E_{NP}7d R PASZ). Cenobia of *Botryococcus braunii*, spores of *Sphagnum* and pollen of Cyperaceae regularly occur,

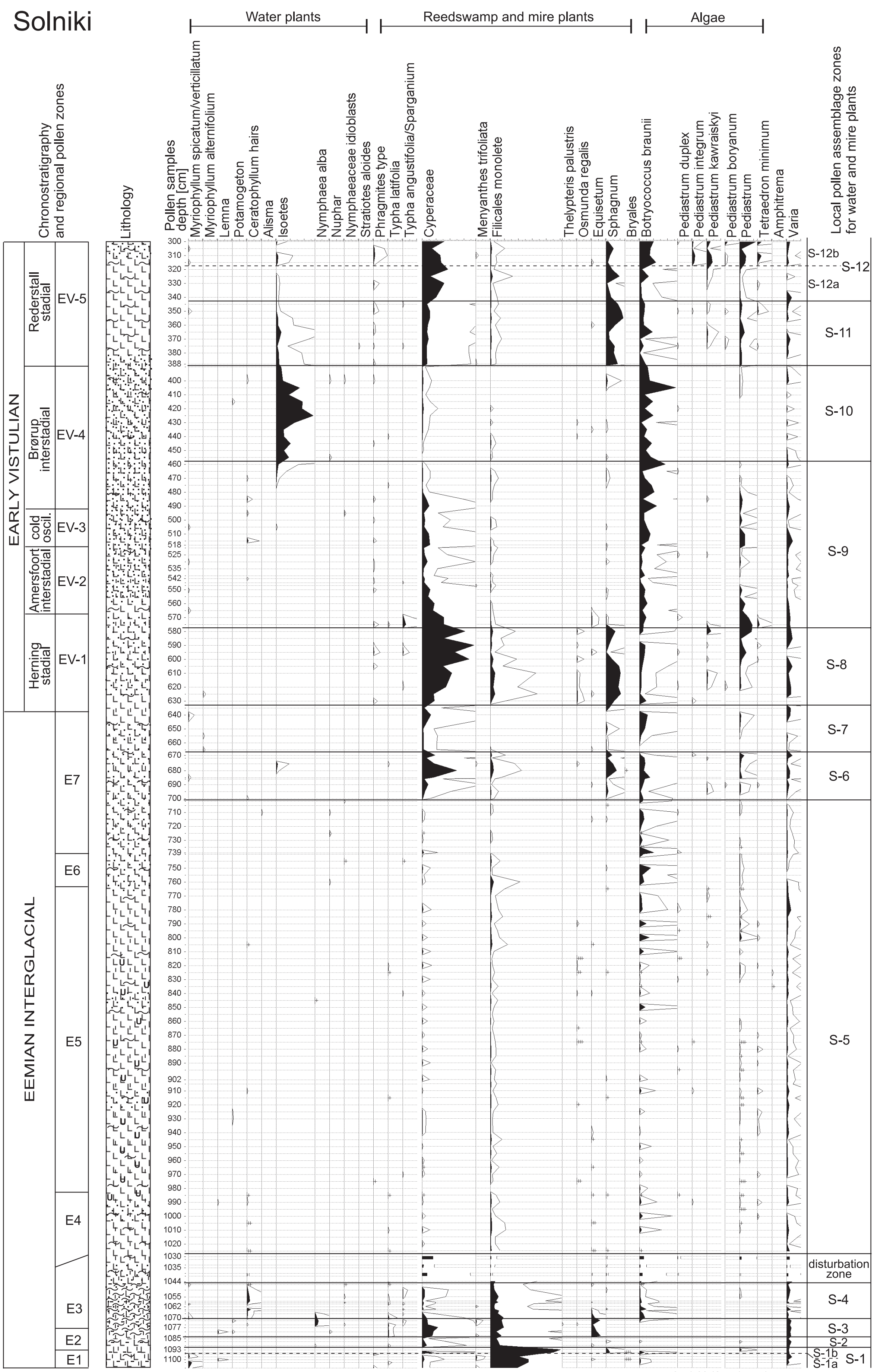

Fig. 60. Solniki [28]. Special percentage pollen diagram illustrating development of aquatic and mire vegetation; for description of lithology see Fig. 4

whereas sporomorphs of all other water and swamp plants sporadically appear. The presence of *Myriophyllum alternifolium* pollen may be the evidence of dystrophic conditions prevailing in the lake. Such a conclusion is also supported by the fall in organic matter (see Fig. 4) below 1% in the sediment at the end of the stage (cf. Granoszewski 2003).

Early Vistulian

Stage 8 (S_W-8 Cyperaceae-*Sphagnum-Osmunda* L PAZ, depth of 6.30–5.80 m – Fig. 60) – corresponds to the first cooling of the Early Vistulian, named as Herning stadial ($EV_{NP}1$ *Artemisia*-Cyperaceae-Chenopodiaceae R PAZ). The zone is characterized by high peaks of Cyperaceae, *Sphagnum* and Filicales monolete. The increase in Cyperaceae pollen and *Sphagnum* spores coupled with more frequent occurrence of rush sporomorphs (*Typha angustifolia/Sparganium*, *Phragmites* type, *Equisetum*) indicate a transient shallowing of the basin. It might have been caused by dry climate conditions dominating throughout that period.

Stage 9 (S_W-9 Cyperaceae-*Botryococcus-Pediastrum* L PAZ, depth of 5.75–4.60 m – Fig. 60) – may be correlated with the Amersfoort interstadial ($EV_{NP}2$ *Betula* R PAZ), birch phase of the Brørup interstadial *sensu stricto* ($EV_{NP}4a$ *Betula* R PASZ) or the cooling between them ($EV_{NP}3$ *Artemisia*-Poaceae R PAZ). Very low frequencies of aquatic and mire plants are a distinguishing feature of this stage. Only cenobia of *Botryococcus braunii* and *Pediastrum*, pollen of Cyperaceae and spores of Filicales monolete together with *Sphagnum* regularly occur. The presence of *Myriophyllum spicatum* indicates relatively deep waters, reaching a depth of up to 6 m (cf. Podbielkowski & Tomaszewicz 1982). Additionally, composition of the Cladocera fauna also stands for high water level (Kupryjanowicz et al. 2005). On the other hand, the cooling between the Amersfoort and Brørup *sensu stricto* interstadials does not face with species composition of water vegetation at that time, which is hinted by the decrease in carbon content ^{13}C/ stable isotope content (see Fig. 4).

Stage 10 (S_W-10 *Isoëtes-Botryococcus* L PAZ, depth of 4.55–3.90 m – Fig. 60) – corresponds to the pine phase of the Brørup interstadial *sensu stricto* ($EV_{NP}4$ *Pinus-Betula* R PAZ – subzones $EV_{NP}4b$ *Pinus-Betula* and $EV_{NP}4c$ *Pinus*). Here, values of *Isoëtes* microspores reach their maximum constituting the most characteristic feature of the pollen record in this stage. The presence of *Isoëtes* is the evidence of meso- to oligotrophic conditions prevailing in the lake as well as of the water depth reaching up to 10 m. Presently, *Isoëtes lacustris* together with *Lobelia dortmanna*, *Litorella uniflora*, and *Myriophyllum alternifolium* are the components of macrophyte flora in the *Lobelia* lakes, that are unique for their distinct physical and chemical water properties (Kraska & Piotrowicz 1994, Kraska et al. 1994, Milecka 2005). As it concerns stage 10, the occurrence of *Isoëtes* and a strong limitation in the presence of macrophyte communities may serve as the evidence of limited edaphic water conditions in that lake and of much colder climate at that time. A marked presence of *Botryococcus braunii* may probably indicate specific lake conditions. It is likely that this particular species dominated in rather extreme environments preventing massive proliferation of other coccal green algae, like those of the genus *Pediastrum* (cf. Jankovská & Komárek 2000). At that time the lake water was very cold, clear and oligotrophic. On the contrary, a significant increase in the quantity of eutrophic Cladocera species (Kupryjanowicz et al. 2005) suggests an increasing eutrophication of the lake and its gradual shallowing. Changes in the Cladocera species may suggest that in the final phase Solniki [28] lake was eutrophic.

Stage 11 (S_W-11 *Sphagnum-Isoëtes*-Cyperaceae L PAZ, depth of 3.88–3.45 m – Fig. 60) – is correlated with the older part of the Rederstall stadial ($EV_{NP}5$ *Artemisia*-Poaceae R PAZ, subzone $EV_{NP}5a$ *Pinus*). *Sphagnum* values reach their peak and percentages of Cyperaceae are relatively high. Microspores of *Isoëtes* are still present but have lower values as compared to the previous stage. The composition of the Cladocera fauna, being predominantly shaped by the presence of *Acroperus harpae* and *Chydorus sphaericus*, reflect low water temperature during this stage (Kupryjanowicz et al. 2005). Additionally, the occurrence of *Alona quadrangularis* may indicate a decrease in pH value of the water (cf. Krause-Dellin & Steinberg 1986).

Stage 12 (S_W-12 Cyperaceae-*Sphagnum-Isoëtes* L PAZ, depth of 3.40–3.00 m – Fig. 60) – corresponds to the younger part of the Rederstall stadial ($EV_{NP}5$ *Artemisia*-Poaceae R PAZ, subzone $EV_{NP}5b$ *Juniperus-Betula*). This time Cyperaceae achieve yet another peak. *Sphagnum* and *Isoëtes* are still present. The proportion of *Pediastrum*, *Botryococcus braunii* and *Tetraedron minimum* rises in the upper S_W-12b subzone. Their spread may point to the process of lake shallowing and subsequent filling up and overgrowing by lake verge plant communities. The abundant occurrence of *Pediastrum* may indicate meso- or even eutrophic conditions prevailing in the lake at that time (cf. Podbielkowski & Tomaszewicz 1982). On the other hand, the increase in *Pediastrum kawraiskyi* and *P. integrum* as well as sporadic occurrence of *P. duplex* signify cold and oligotrophic water of the lake (cf. Jankovská & Komárek 2000).

SOME REMARKS ON THE OCCURRENCE OF THE *LOBELIA* LAKES DURING THE EEMIAN INTERGLACIAL AND THE EARLY VISTULIAN

The occurrence of *Isoëtes* microspores was expressed in few profiles from northern Podlasie. Apart from the Solniki [28] site, those microspores are also present in the profiles from Dzierniakowo [28] (Fig. 8), Sokółka 2 [13] (Fig. 20), Bohoniki [15] (Fig. 29), Drahle [14] (Fig. 31), Trzcianka [10] (Fig. 33) and Choroszczewo [39] (Fig. 49). As to sediments from all remaining sites the occurrence of any other components of the *Lobelia*-lake vegetation was not confirmed.

As it concerns the Solniki [28] profile (Fig. 60) in two pollen spectra representing the middle part of the $E_{NP}7$ *Pinus* R PAZ *Isoëtes* microspores appear for the first time at the end of the Eemian interglacial. Apart of that, the main period of the *Isoëtes* occurrence falls on the Early Vistulian. *Isoëtes* reaches its maximum values in the pine phase of the Brørup interstadial *sensu stricto* ($EV_{NP}4$ *Pinus-Betula* R PAZ). Its relatively high proportion remains during the whole Rederstall stadial ($EV_{NP}5$ *Artemisia*-Poaceae R PAZ).

In the Dzierniakowo [24] profile, *Isoëtes* microspores appeared two times (cf. Fig. 7). Their first distinct presence being denoted by high values is documented from the younger part of the pine phase of the Brørup interstadial *sensu stricto* ($EV_{NP}4$ R PAZ, subzone $EV_{NP}4b$ *Pinus-Betula*) to the middle part of the Rederstall stadial ($EV_{NP}5$ *Artemisia*-Poaceae R PAZ). The second time they are recorded in is during the younger part of the Odderade interstadial ($EV_{NP}6$ *Pinus-Betula* R PAZ, subzone $EV_{NP}6a$ *Betula-Artemisia-Pinus*).

In the Sokółka 2 [13] profile (Fig. 20), single microspores of *Isoëtes* are noted as early as in the younger part of the *Corylus-Alnus-Tilia* pollen zone ($E_{NP}4$ R PAZ) and then in the *Pinus* zone ($E_{NP}7$ R PAZ). Still, they are not as that frequent as in the pine phase of the Brørup interstadial *sensu stricto* (subzone $EV_{NP}4b$ *Pinus-Betula* and $EV_{NP}4c$ *Pinus* of $EV_{NP}4$ *Pinus-Betula* R PAZ).

In the Bohoniki [15] profile (Fig. 29) very high values of *Isoëtes* microspores (to ca. 23%) are solely linked with the pine zone of the Eemian interglacial ($E_{NP}7$ *Pinus* R PAZ).

In the Drahle [14] profile (Fig. 31) single microspores of *Isoëtes* are noted throughout the entire pollen profile, from the *Corylus-Alnus-Tilia* zone ($E_{NP}4$ R PAZ), through the *Carpinus* zone ($E_{NP}5$ R PAZ) to the *Pinus* zone ($E_{NP}7$ R PAZ). The record of the *Picea* phase is altogether absent in the profile.

In the Choroszczewo [39] profile (Fig. 49), *Isoëtes* microspores appeared for the first time in the *Picea-Pinus-(Abies)* pollen zone of the Eemian interglacial ($E_{NP}6$ R PAZ). At that time, they reach very low values and only occur in a single pollen spectrum. After that, they are recorded in the *Pinus* zone ($E_{NP}7$ R PAZ) and during the Early Vistulian of the pine phase in the Brørup interstadial ($EV_{NP}4$ *Pinus-Betula* R PAZ, subzones $EV_{NP}4b$ *Pinus-Betula* and $EV_{NP}4c$ *Pinus*), when they reach their ultimate peak.

Data comparison in relation to the presence of *Isoëtes* microspores in the Eemian/Early-Vistulian lakes in northern Podlasie (Fig. 61) allows stating that from the onset of the climatic optimum in the Eemian interglacial *Isoëtes,* though sporadically, already occurred there. Indeed, in the warm and typically eutrophic waters of that period it did not find favourable conditions for its development. Probably because of that it did not spread on a large scale neither during the hazel phase ($E_{NP}4$ R PAZ) nor during the hornbeam ($E_{NP}5$ R PAZ) or the spruce ($E_{NP}6$ R PAZ) phase. Not until the end of the interglacial, during the pine phase ($E_{NP}7$ R PAZ) did the first significant spread of *Isoëtes* take place. Quite probably it was caused by the climate cooling and changes in edaphic properties of lake waters to that reflecting oligotrophy. In northern Podlasie plant communities with *Isoëtes* probably

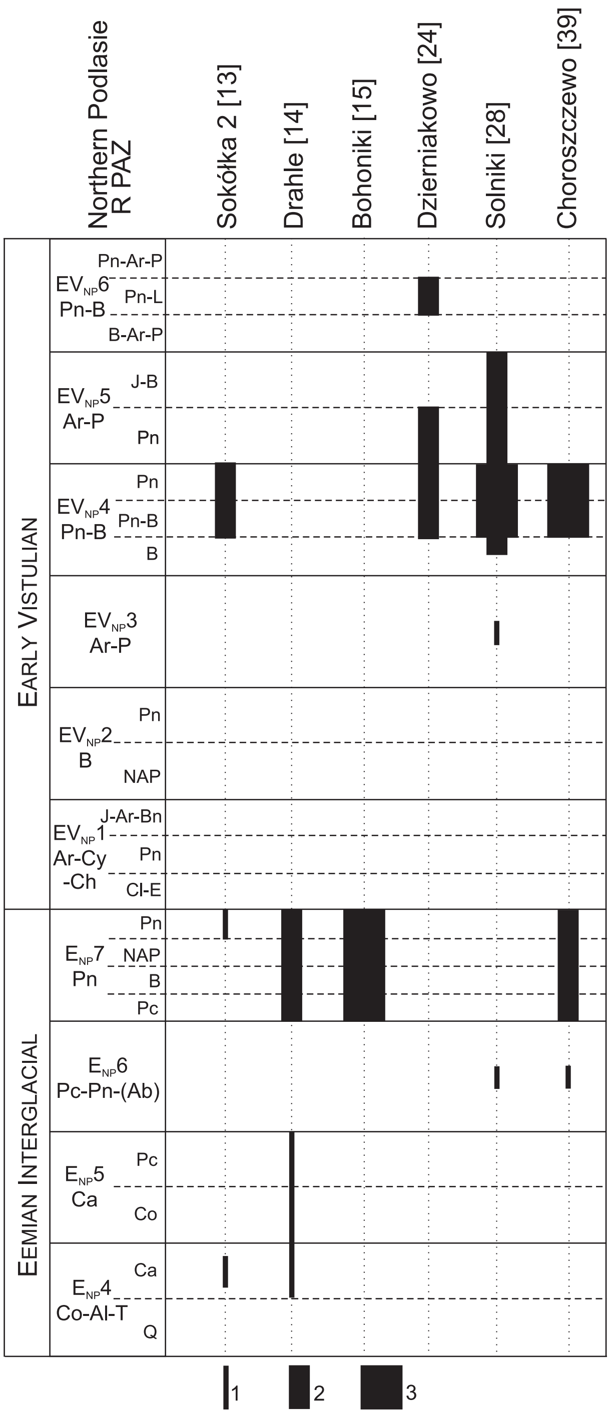

Fig. 61. The occurrence of *Isoëtes* spores in Eemian and Early Vistulian pollen profiles from northern Podlasie: **1** – sporadic appearances, **2** – continuous presence, but with low values (to 1%), **3** – high values (above 1%). Site numbers as in Figure 1, Table 1 and the text

remained till the end of the interglacial. They might have been limited or even completely disappeared as early as in the first Early Vistulian cooling (Rederstall stadial). As to that time the microspores are present at no site within the area of northern Podlasie.

Not until the warmest pine phase of the Brørup interstadial (subzone $EV_{NP}4b$ and $EV_{NP}4c$ of $EV_{NP}4$ R PAZ) did the reappearance of *Isoëtes* take place and only then did they reach the maximum of their expansion when the last glacial/interglacial cycle lasted.

When coming to the conclusion, it should be emphasized that in northern Podlasie during the Eemian and the Early Vistulian, the presence of the *Lobelia* lake vegetation was closely connected with boreal climate prevailing at that time. During the Eemian interglacial as well as during the Early Vistulian, when the boreal pine forests spread, this type of water plant communities developed under favourable conditions. Both of the periods were relatively cold and humid. Even today the *Lobelia* lakes are usually accompanied by vast stretches of pine forests with their extent being delimited by the influence of boreal climate in northern Europe (Milecka 2005).

During pine phases of the Eemian interglacial and the Early Vistulian not all the lakes in northern Podlasie represented those with *Lobelia* plant assemblages. Therefore it may be suggested that local conditions indeed played crucial role in the development of this type of lakes. Relying on the lithology of the analysed profiles it may be stated that almost all of the lakes studied, except for the basins in Drahle [14] and Bohoniki [15], were relatively deep basins. They lasted till the end of the Early Vistulian, whereas at least three of them, in Dzierniakowo [24], Sokółka [13] and Choroszczewo [39], existed much longer, even through the major part of the Plenivistulian.

WATER LEVEL FLUCTUATION IN LAKES DURING THE EEMIAN INTERGLACIAL

RECORD OF WATER LEVEL CHANGES IN NORTHERN PODLASIE

Methodical remarks

The analysed profiles of lacustrine-mire sediments were used to reconstruct fluctuations of water level in the Eemian lakes of northern Podlasie. The record interpretation of those profiles is generally based on the assumptions presented by Ralska-Jasiewiczowa and Starkel (1988) about the Late Vistulian and Holocene deposits.

A starting point for setting analysis was to apply the simplest model reflecting deposit sequence that would allow constructing a successional series of the organogenic deposits, whenever stable water level and undisturbed natural conditions were documented. An example order of successional layers in case of eutrophic to mesotrophic environment would begin with mineral bed, then gyttja sediments gradually turning into swamp deposit, being then followed by fen peat and forested fen deposits at the top. Any modification or redeposition should reflect any unusual fluctuations in water level (Fig. 62). In order to set a particular reconstruction of changes in lake or mire water level, following data were gathered: facial changes, changes in physical and chemical features of deposits, presence of indicator plant taxa and changes in local plant communities.

Thirty two profiles representing northern Podlasie with more or less complete pollen record have been considered in the investigation. These included sites studied by the author as well as by other scientists. Lithological profiles from all discussed sites were compared on the basis of chronostratigraphical division of the late Pleistocene and regional palynostratigraphy for the late glacial of the Wartanian glaciation, the Eemian interglacial and early glacial of the Vistulian glaciation in northern Podlasie (Fig. 63). Duration of the Eemian regional pollen zones was in accordance with the time scale given by Müller et al. (1974) on the base of annually laminated sediments from Bispingen (Fig. 64).

Description of changes

The analysed sites show an essential difference as to the beginning of sediment accumulation. They mainly resulted from specific localized conditions and thickness of overlying till at a particular locality.

$LW_{NP}1$ *Artemisia-Juniperus-Picea* R PAZ

Only in one profile from northern Podlasie, i.e. Skupowo [37] (Fig. 47), sediments from the late glacial of the Wartanian glaciation were found. The absence of deep-water plants indicates, that studied basin was very shallow lake at that time (Fig. 64). It is possible as well that it could seasonally dry out. It was probably situated above the block of dead-ice that emerged at the bottom of these depressions.

$E_{NP}1$ *Pinus-Picea-(Betula)* R PAZ

At the beginning of the Eemian interglacial, during the first regional pollen zone, lacustrine accumulation have started in some of the basins (case of 6 profiles: Starowlany [8], Kruszyniany [21], Solniki [28], Otapy 1 [34] (Bitner 1956), Wólka 2 [35] and Choroszczewo [39]). Significant climate warming was followed by gradual ice-melting. This phenomenon along with the deepening processes led to the gradual rise of water level, which resulted in further lake formation. Different types of clays, silts and gyttjas accumulated there. On the basis of sediment character and pollen occurrence of plants requiring moderately deep water basins (e.g. in Starowlany [8]: *Myriophyllum spicatum/*

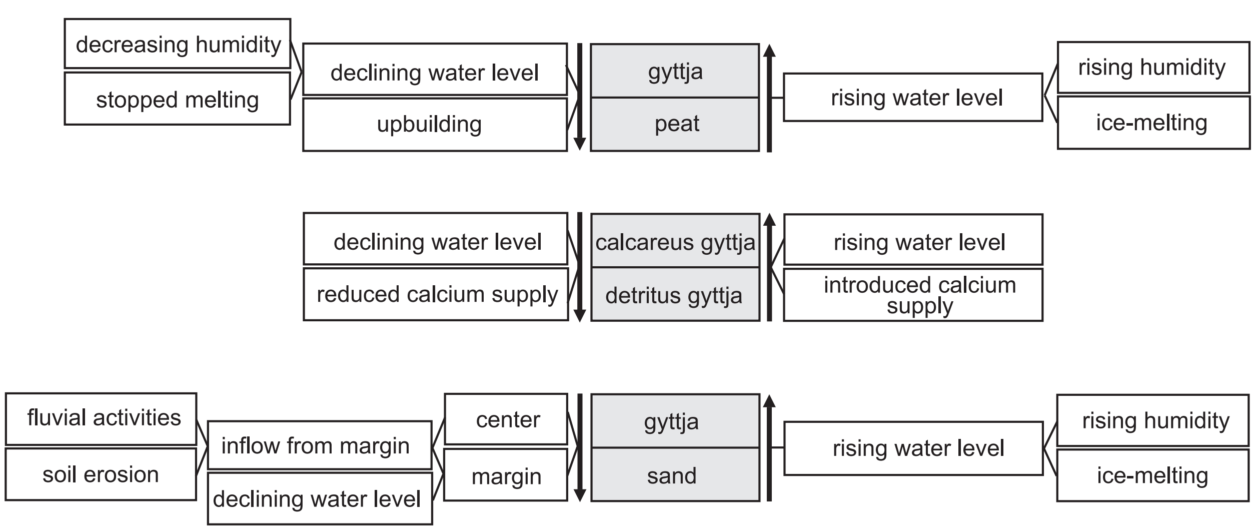

Fig. 62. Possibilities of different palaeohydrological interpretation of vertical deposit sequences in the lake and mire environments (acc. Ralska-Jasiewiczowa & Starkel 1988, simplified)

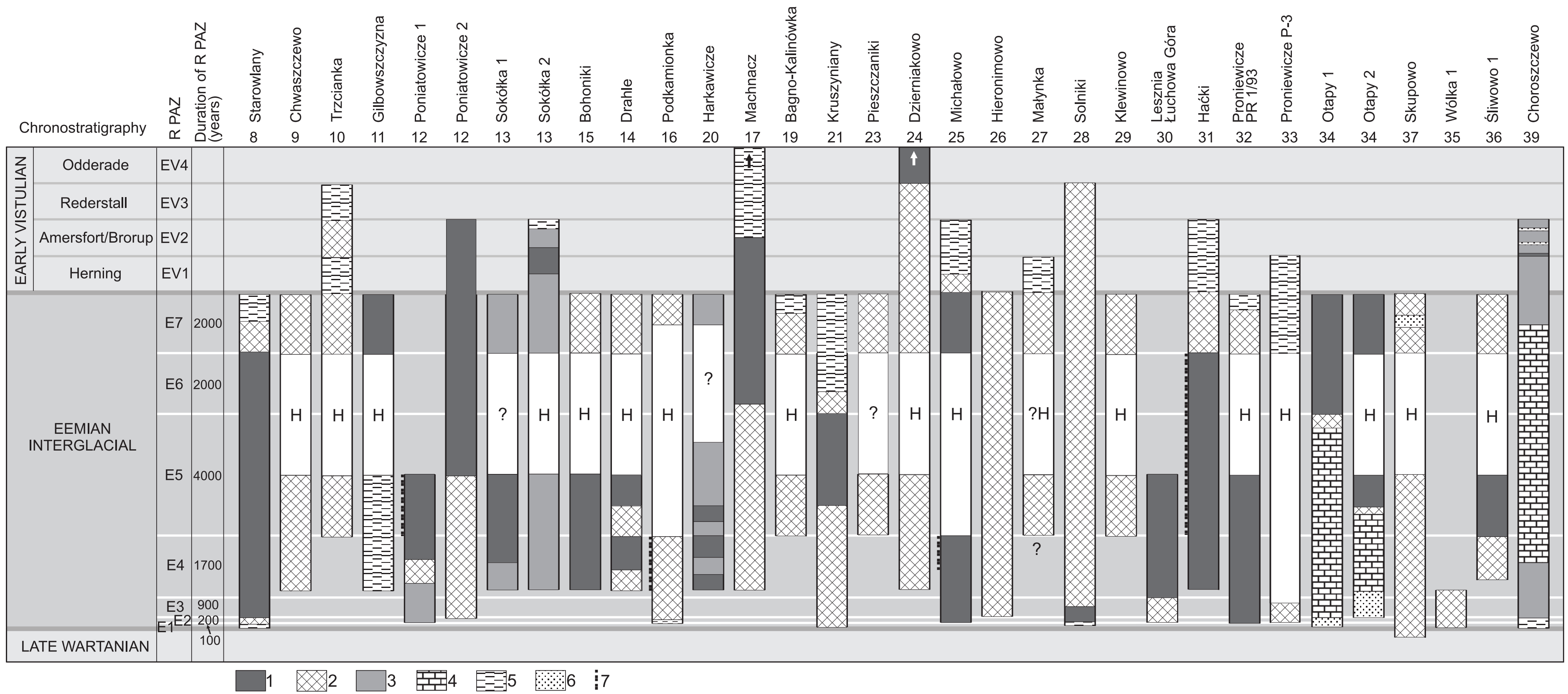

Fig. 63. Comparison of lithological profiles from northern Podlasie mentioned in this paper. Duration of regional pollen zones for the Eemian interglacial is based on the Bispingen varve counts (acc. Müller et al. 1974). The lithology of profiles is generalized: **1** – peat, **2** – detritus gyttja and organic silt, **3** – calcareous gyttja and lacustrine chalk, **4** – bituminous shales, **5** – silts and clays, **6** – sands, **7** – sections with destructed sporomorphs. **H** – hiatus, **?** – lack of pollen data. Site numbers as in Figure 1, Table 1 and the text

verticillatum, *Nuphar*, *Typha latifolia)* it may be concluded that from the very beginning of that stage these basins were much deeper than earlier records suggested (Fig. 64).

Changes in composition of water vegetation in the lake Skupowo [37], that was formed in the previous zones (e.g. the appearance of *Myriophyllum spicatum* pollen) reflect slight deepening of this basin.

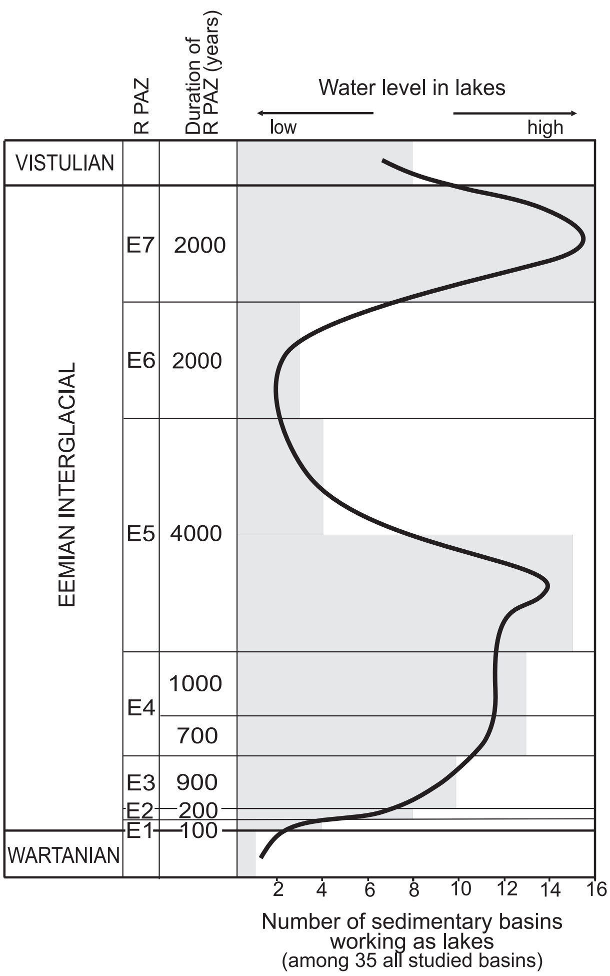

Fig. 64. Changes of the water level in the Eemian lakes of northern Podlasie. The time scale is based on the Bispingen varve counts (acc. Müller 1974)

$E_{NP}2$ ***Pinus-Quercus-Ulmus-Salix*** **R PAZ**

As to next few sites, lake sediment accumulation started during the second regional pollen zone (7 profiles: Poniatowicze 1 [12], Podkamionka [16], Michałowo [25], Hieronimowo [26], Lesznia-Łuchowa Góra [30], Proniewicze PR 1/93 [32] and Proniewicze P-3 [33]). It was probably caused by intensified melt processes that resulted from the continuous improvement of climate, especially as a direct result of temperature increase (see Fig. 59). The deepening of lakes progressed. Nevertheless one cannot reject the rise of ground water level as being also caused by the increase in precipitation reflecting much more humid oceanic climate. Vegetation composition of most of the basins that were formed in the previous zones, confirms that with the elapse of time lake water basins were gradually getting deeper.

Quite the opposite to the general tendency presented above, in some instances disturbances were described, being mainly expressed in some transient decreases in water level.

– At Solniki [28], during the $E_{NP}2$ zone and in the oldest part of the $E_{NP}3$ zone, organic silt accumulation was temporarily stopped, which is expressed by the appearance of peat layer denoting phase of lake shallowing (Fig. 4, Tab. 2).

– At Choroszczewo [39], in the upper part of the $E_{NP}2$ zone, in organic silt, which was accumulating there from the beginning of the zone, a substantial portion of sand appeared (Fig. 52, Tab. 56). It may reflect lowering of water level in this particular basin. At Choroszczewo [39] low water level probably lasted till the end of the $E_{NP}3$ zone, which is suggested by the lack of typical to that period sediments or by their very low thickness, not exceeding 12 cm.

– At Starowlany [8], similar scheme of events appears within the profile. Sediments of the $E_{NP}3$ zone are altogether absent. Pollen spectrum at the depth of 6.15 m probably contains mixed pollen material of both of two succeeding zones (Fig. 29, Tab. 26). This section of the profile contains a thin layer of peaty silt mixed with great portion of sand dividing peaty silt of the $E_{NP}2$ zone from peat of the $E_{NP}3$ zone.

$E_{NP}3$ ***Quercus-Ulmus-Fraxinus*** **R PAZ**

It appears that during that zone the process of new lake formation was temporarily hindered. Climate conditions were very similar to those from the previous period, therefore melt processes were not promoted at that time. Water depth in lake basins probably did not change and was similar to that from the previous period. As early as in the $E_{NP}2$ zone and throughout the whole $E_{NP}3$ zone a stabilization between melt processes, precipitation and evaporation maintained.

Relatively stable level of lake water in the $E_{NP}3$ zone is documented by a continuous presence of *Myriophyllum spicatum/verticillatum* in the profiles from Kruszyniany [21] and Lesznia-Łuchowa Góra [30], where the $E_{NP}3$ zone is represented by a substantial thickness of the sediment.

There is also data that indicates that at the same time water level could rise at least in case of some basins. For example, the Otapy lake [34] extended its coverage as a result of inundation of surrounding areas. Otapy 2 [34] boring reflects that trend, since it was earlier situated at the distance of 150 m of the lake shore, a span of land between two borings made in this area (Bitner 1956a). From the end of the Wartanian glaciation and onwards the lake formed close to Otapy 1 [34] profile constantly deepened. It was mainly due to melting processes going on at that time. The increase in water level between the $E_{NP}2$ and $E_{NP}3$ zone was especially great resulting in the increase of even 3.5 m. It is documented by sediment occurrence of the $E_{NP}3$ zone in the Otapy 2 [34] profile being 0.5 m higher than in case of the Otapy 1 [34] profile. Secondarily, it is proven by the presence of *Najas major* seeds at the bottom of those deposits (Bitner 1956). As it concerns its contemporary requirements, this particular species needs basins of ca. 3.0 m depth for its proper development (Podbielkowski & Tomaszewicz 1982). The main reason staying behind of the lake deepening was the increase in water level. In the marginal part of the depression, where the Otapy 2 [34] boring is located, the melting processes themselves probably played a secondary role.

Similar situation is also noted with regard to the Poniatowicze [12] site. In the area close to the Poniatowicze 1 [12] boring the lake appeared during the $E_{NP}2$ zone. Sediments of this phase and those belonging to the $E_{NP}3$ phase lie at the depth of 6.70–6.00 m within that profile (Fig. 25). Then as it concerns the Poniatowicze 2 [12] boring vicinity, lake sediment accumulation started slightly later, that is during the $E_{NP}3$ zone. Noteworthy, sediments denoting this particular phase do occur almost 1.5 m lower (at the depth of 8.15–8.00 m – Fig. 26) than in case of the Poniatowicze 1 [12] profile. It may be argued that where the Poniatowicze 2 [12] boring was carried out at that time a massive dead-ice block was present having its influence on local water balance. Not until did the $E_{NP}3$ R PAZ start the melting process continued. To cup it all, one has to consider that the cause staying behind these changes might have rather been linked with for example an increase in precipitation at that time.

$E_{NP}4$ *Corylus-Alnus-Tilia* R PAZ

In case of the majority of localities, lakes were formed only during the hazel phase of the Eemian interglacial. These include the following 11 profiles: Chwaszczewo [9], Gilbowszczyzna [11], Sokółka1 [13], Sokółka 2 [13], Bohoniki [15], Drahle [14], Harkawicze [20], Machnacz [17], Dzierniakowo [24], Haćki [31] and Śliwowo 1 [36]. The process of new lake formation, or that denoting their extension, shall mainly be linked to the climate warming, especially during summer months close to the end of the $E_{NP}4$ zone. A substantial rise in humidity was indeed of great significance. According to Mamakowa (1989) it was correlated with the transgression of the Eemian Tychnowy sea, which was the greatest sea transgression in the whole Quaternary within the area of today's Poland. Both above stated factors significantly prompted deepening of melted depressions. It cannot be excluded that during the hazel phase the process of the dead-ice melting finally ended. Since that zone the precipitation has started to be a major modifying factor that influenced particular lake's depth. Other important factors included accumulation of bottom sediments and local conditions of the terrain.

In the majority of basins water level was relatively high and invariable throughout the entire hazel phase of the interglacial. It is reflected in pollen profiles by almost continuous presence of deep-water plants (e.g. *Myriophyllum spicatum*, *Potamogeton*, *Ceratophyllum*). In spite of overall water level invariability, some of the basins began to shallow. This process was probably connected with natural sequence of events occurring in those water bodies. During the $E_{NP}4$ zone in Michałowo [25] (Kupryjanowicz & Drzymulska 2002) and Podkamionka [16] lakes become filled up with sediments and got overgrown with communities in the older carr type. It is well documented by a very high proportion of *Alnus* and Cyperaceae pollen, spores of Filicales monolete, by the occurrence of *Osmunda cinnamomea* spores, *Alnus* wood and by the accumulation of black strongly decomposed peat.

$E_{NP}5$ *Carpinus* and $E_{NP}6$ *Picea-Pinus-(Abies)* R PAZs

The next stage of deepening and/or extension of existing lakes as well as formation of new ones shaped the older part of the *Carpinus* zone. Water basins at Trzcianka [10], Bagno-Kalinówka [19], Pieszczaniki [23], Małynka [27] and Klewinowo [29] appeared at that time. Probably the most rapid and essential rise in lake water level took place in this particular period (Fig. 64). In the Solniki profile it is expressed by great though temporary increase of magnetic susceptibility (Fig. 4), clear changes in stable isotope values (Fig. 5), and that of Cladocera and diatom composition (Kupryjanowicz et al. 2005). In the Otapy 1 [34] profile the maximum occurrence of *Najas major* seeds (Bitner 1956a) coincides with this part of the hornbeam phase. It may therefore indicate the greatest depth of the basin there for the entire interglacial. In the Drahle [14] profile a frequency of *Nymphaea alba* and *Typha latifolia* decreased, whereas at the same time a proportion of *Isoëtes* increased. Spores of the former taxon also appeared in Bohoniki [15]. The spread of *Isoëtes* may be interpreted there as signalling deepening of both basins. At present, *I. lacustris* and *I. echinospora* inhabit rather deep waters, with the former appearing at the depth of 2.0–4.0 m, as Szmeja (2001) states. According to Birks (2000) quillwort becomes a dominant species only at the depth below 3.0 m. Podbielkowski & Tomaszewicz (1982) add that it may even grow down to the depth of 10 m. The probable reasons staying behind changes in water level are discussed within the next part of this chapter.

As to great majority of sites, the younger part of the $E_{NP}5$ zone and the entire $E_{NP}6$ zone have not been recorded there (Fig. 63). Sediments representing that age are usually altogether absent. Rarely do they occur and if yes they are extremely poorly represented in its pollen record (cf. Poniatowicze 2 [12], Haćki [31]). Perhaps this phenomenon reflects a drastic decrease in water level (Fig. 64), which resulted in extremely low accumulation ratio of lake and bog sediments or even in the accumulation being stopped altogether in case of some basins. As it is suggested by high values of Cyperaceae pollen, the Poniatowicze 1 [12] basin at that time was covered with a lowland bog lush with sedges (Fig. 25). On a basis of a low pollen frequency in the peats and of its very bad preservation it is concluded that water level in this bog was constantly or at least temporarily low. Similar situation is also reflected in sediments representing the Haćki [31] lake (Kupryjanowicz 2005b).

Only in some basins, i.e.Starowlany [8], Machnacz [17], Kruszyniany [21], Hieronimowo [26], Solniki [28], Otapy [34], Choroszczewo [39], lake or bog accumulation spanned the entire $E_{NP}5$ and $E_{NP}6$ zones. Depth of the Eemian sediments indicates that apart from the Solniki [28] lake these basins were neither deeper nor larger when compared with the others. However, even in these basins the record of their shallowing is reflected, especially in relation to the younger part of the hornbeam zone. At Solniki [28] this change is indicated by the higher frequency of *Osmunda cinnamomea* spores and by the appearance of single remains of *Amphitrema flavum*. It is also confirmed by the increase in shallow-water species represented by the genus Cladocera (Kupryjanowicz et al. 2005). At Otapy [34] constant accumulation was the case only in relation to the environs of the Otapy 1 [34] boring (putative central part of the basin). The significant decrease in water level is documented there through the transition from gyttja to peat and by the change in water plant composition. At that time *Najas major* disappeared whereas shallow-water plants (e.g. *Najas flexilis*, *Nymphaea alba*) and mire plants (e.g. *Calla palustris*, *Menyanthes trifoliata*) occurred (Bitner 1956a). The biogenic accumulation in the region of Otapy 2 [34] profile was completely stopped at that time.

$E_{NP}7$ *Pinus* R PAZ

During the zone, the water level raised again and sedimentation of lake organic silt started again in 17 sites (Starowlany [8], Chwaszczewo [9], Trzcianka [10], Sokółka 1 [13], Sokółka 2 [13], Bohoniki [15], Drahle [14], Podkamionka [16], Harkawicze [20], Bagno-Kalinówka [19], Dzierniakowo [24], Małynka [27], Klewinowo [29], Proniewicze PR 1/93 [32], Proniewicze P-3 [33], Skupowo [37] and Śliwowo 1 [36]). As to next three sites (Gilbowszczyzna [11], Michałowo [25] and Otapy [34]) the accumulation of peat started once again, which in turn serves as the evidence of the rise in water level. It was probably due to the increase in precipitation being accompanied by the decrease in evaporation related on the other hand to the great slump in winter and summer temperatures (see Fig. 59).

Many of the Eemian lakes and bogs were still present till the Early Vistulian (e.g. Trzcianka [10], Sokółka 2 [13], Machnacz [17], Dzierniakowo [24], Michałowo [25], Hieronimowo [26], Małynka [27], Solniki [28], Haćki [31], Proniewicze P-3 [33] and Choroszczewo [39]).

REGISTRATION OF WATER LEVEL DECREASE DURING THE *CARPINUS* ZONE IN POLAND AND CENTRAL EUROPE

The immediate drop in water level during the *Carpinus* zone of the Eemian interglacial affected many lakes and bogs from different regions of today's Poland. In profiles it is manifested in various ways, most often by:

– hiatus presence that spans the entire zone or at least its younger part (e.g. Szwajcaria 2 profile – Borówko-Dłużakowa & Halicki 1957, profile G28a at Główczyn – Niklewski 1968, Besiekierz – Janczyk-Kopikowa 1991, Józwin – Tobolski 1991, Rogowiec – Balwierz 1992, Bieganin – Malkiewicz 2003, Nadolnik – Krupiński 2005),

– significant decrease in sedimentation rate (e.g. Dąbrówki – Krupiński 2005, Leszczyno – Krupiński et al. 2006),

– high degree of organic sediment decomposition with damaged and corroded pollen grains (e.g. Szwajcaria 1 – Borówko-Dłużakowa & Halicki 1957, Dziewule – Bińka & Nitychoruk 2003, Kontrowers – Kupryjanowicz et al. 2003, Śniedzanowo SN.1/99 – Krupiński 2005),

– final stages of lake sediment accumulation (e.g. Kopaszewko and Zbytki 1 – Kuszell 1994a, b, 1997, Łączka Łk.1/97 and Łączka Łk.2/97 – Bruj & Krupiński 2000, Sławoszewek – Stankowski & Nita 2004, Lubowidz – Krupiński 2005, Wola Okrzejska 49B – Żarski et al. 2005, Porzewnica – Bruj & Krupiński 2006, Zieluń – Kotarbiński & Krupiński 2000).

In other regions of Poland similarly to northern Podlasie sites with the record of hydrological disturbances within the hornbeam zone, are located near the sites with a complete record of the Eemian vegetation succession. Płock Upland may serve as a good example of such co-occurrence. In this particular region localities reflecting the decrease in water level in the younger part of the *Carpinus* zone (i.e. Dąbrówki, Śniedzanowo, Nadolnik, Lubowidz) are located close to the Studzieniec site representing a complete Eemian sequence. The *Carpinus* zone sediments there are up to 2.0 m thick (Krupiński 2005).

Shallow-water or mire deposits that replaced initial sedimentation of gyttja are particularly important also in case of some Eemian sequences from other parts of central Europe. This particular process is observed in profiles in a remarkable form of layers with highly decomposed peat, peaty silt or minerogenic sediment, which are the most clearly defined stratigraphical unit in the Eemian interglacial for the entire central Europe (Bińka & Nitychoruk 2003).

The record of water lowering during the *Carpinus* phase of the Eemian interglacial is frequently present at sites located along the Neman valley in Belarus. In Zhukevichi [75] (Żukiewicze, in Polish) the biogenic accumulation ended at that particular time (Środoń 1950, San'ko et al. 2002b). In Poniemun (Poniemuń, in Polish) in some parts of the basin (Poniemun-1 [70] profile, putative marginal zone of the lake) the accumulation ended in the *Carpinus* zone (Dyakowska 1936), whilst in other parts (Poniemun-4 [73] profile, probably a central part of the basin) it continued till the Early Vistulian (Pavlowskaya et al. 2002). When taking into account that in the same basin at location in Rumlovka [74] (=Rumlówka, in Polish) lake sediment accumulation started during the *Carpinus* zone (San'ko et al. 2002a) it maybe stated that such an increase in water level occurred in a distinctive moment of this zone.

In Pyshki [69] site the lake basin was entirely filled up with sediments before the end of the E4 *Corylus* zone. This closing stage of the lake presence was preceded by a significant increase in Polypodiaceae (=Filicales monolete) rate mirrored within the pollen profile as well as through the change of gyttja into sandy peat. It may prove a preceding shallowing of the lake basin and its subsequent transformation into a bog (Litviniuk et al. 2002a). At the same time there appear profiles of lake-mire deposits that contain the whole interglacial reflecting no particular decrease in water level, a case of the following localities: Nieciosy, Janiańce-Maksymańce, Kapitaniszki, Małe Dugnie, Kmity (Bremówna & Sobolewska 1950).

When heading westwards in Poland records of the intra-Eemian decline in water level occur much rarer. One of just few examples is represented by the Kiestagebau Hinterste Mühle site in northern Germany. During the E5 pollen zone at that site the lacustrine sediment deposition was rapidly replaced with peat layer. That in turn implies that the balance between evaporation and precipitation was altered (Strahl 2000).

PROBABLE REASONS OF INTRA-EEMIAN DECLINE IN WATER LEVEL

In Central Europe, an extent of area from western Belarus to western Poland, sites that contain a record of decrease in water level during the *Carpinus* zone of the Eemian interglacial commonly occur. The sheer scale of this phenomenon implies that the driving force behind it was operating at least at regional scale. Apart of that one has to reconsider the role being played by local conditions in water level maintaining at least in case of some lakes of that time, which is indeed reflected in simultaneous presence of basins with complete sediment sequences.

Changes in climate

Possibly regional in its scale driving force that triggered the process of water level lowering in the middle part of the Eemian interglacial might have been represented by an abrupt change in climate conditions. It could have been reflected in a decrease in precipitation or quite conversely by great increase in mean July temperatures combined with evaporation enhancement.

From climate reconstruction of northern Podlasie, that was presented in the previous chapter, it is clear that the older part of the hornbeam phase constituted thermal optimum of the interglacial, with the highest mean summer and winter temperatures. Pollen records from that region reflect no evident slump in precipitation. On the other hand Cheddadi et al. (1998), in their reconstruction of precipitation for selected sites of the Eemian interglacial in France and Poland, showed that precipitation from the very beginning of the *Carpinus* zone dropped by about 200–300 mm/yr.

It would be somewhat controversial if such changes resulted from the fall in water level. According to Bińka and Nitychoruk (2003) large majority of interglacial basins, measuring from tens to at most several hundred meters in diameter, were very susceptible to climatic change. Studying the Eemian sites in central (Klatkowa 1990) and eastern Poland (Bińka & Nitychoruk 2003) enabled drawing a conclusion that a large proportion of depositional basins covered small areas. Based on depression size, where particular deposits of the Eemian lakes of northern Podlasie were discovered, it may be concluded that they were much differentiated in size – starting with these representing a small diameter of dozen or so metres, e.g. Skupowo [37], Wólka [35]), through the medium ones covering the area of few hectares, like in Dzierniakowo [24], Machnacz [17] (Kupryjanowicz 1991, 1994), to the very large ones spanning several square kilometres, a case of Michałowo [25] lake (Kupryjanowicz & Drzymulska 2002). None correlation between the decrease in water level and the size of the basin was proved. In one of the largest basins (Michałowo [25]), the change in water level was very explicit (Kupryjanowicz & Drzymulska 2002).

Melting of deep permafrost

The probable reason that stayed behind water level lowering during the hornbeam phase of the Eemian interglacial was final permafrost melting. It is quite doubtful whether permafrost could have lingered for at least 5 thousand years, a span of time separating the middle part of the *Carpinus* zone from the end of the Wartanian glaciation. It appears that permafrost being present in northern Podlasie during the Wartanian glaciation could have reached great depths in some places therefore securing a prolonged ice-melting quite probably much exceeding the end of the glaciation itself.

According to Safanda et al. (2004) in the Suwałki region during Vistulian permafrost reached a depth of nearly 600 m. The reason lying behind permafrost formation and its subsequent preservation was the simultaneous occurrence of low heat flow and very porous highly water-saturated sedimentary overburden. This overburden served as an insulation lying on top of the ice strata slowing the pace of permafrost decomposition, that was otherwise fastened when the climate got warmer. Some authors like Szewczyk (2005) even suggest that there could have been some localized ice patches lingering much longer than the rest of ice masses, even till the present time. Relying on analyses of heat flow variation, scientists have quite recently discovered that thermal disturbances related to Pleistocene-Holocene climate changes are recorded in boreholes practically throughout the entire area of Poland.

It cannot be excluded that equally thick layer of permafrost was formed in areas covered with the Warta glaciation, including northern Podlasie as well. It is possible that sandy deposits prevailing in that region served as a good insulation for deep permafrost lying beneath which in turn retarded its melting. Much denser forest cover, that was formed at the very beginning of the interglacial, also helped to shield large expanses of permafrost. Investigation carried out in Alaska indicates that the contemporary permafrost defrosts much deeper in areas with open vegetation. Conversely, it remains constant if the overlying forest formation stays unchanged (Gedney 1983).

Lowering of riverine base level of erosion

The Solniki profile reflects that, after the period of exceptionally high water level during the *Carpinus* pollen zone, there occurred a slump in water level. The former stage might have resulted from abundant precipitation. A record of increased humidity and heavy rainfall during the hornbeam phase of the Eemian interglacial is also reflected in the profile from Imbramowice (Mamakowa 1989). In such sediments it is mirrored in a form of layer with outwash sand and in changes in aquatic vegetation composition that indirectly indicate a rise in lake's water level. According to Mamakowa (1989) changes in sediments registered in Grodzisk Mazowiecki (profile 10/69 – Janczyk-Kopikowa 1973), Grudziądz-Mniszek (Drozdowski & Tobolski 1972, Makowska 1979b), Główczyn (Niklewski 1968), Żyrardów (profile 4/69 – Krupiński 1978), Kalisz (Tołpa 1952) and Rusinów (Heck 1929 and Stark et al. 1932 after Mamakowa 1989) may also be interpreted in similar way. Changes recorded in those profiles hint at climate deterioration occurring as early as in the younger part of the *Carpinus* zone. They are mirrored in the increase in coarser sand fractions in the sediments, which indirectly indicates a spell of intense rains and floods during the period otherwise distinctive for ultimate lake shallowing. The shift in balance between precipitation and evaporation resulted in the rise of water level.

Very abundant precipitation in the older part of the hornbeam phase probably triggered a string of events, with the first direct result faced in the rise of water level in rivers and the ultimate one reflected in lowering of water level in lakes.

Local conditions

The existence of stratigraphic hiatuses, similar to those from the *Carpinus* zone of the Eemian interglacial, seems to be a widespread phenomenon also in case of the middle Holocene of central Europe. In many profiles the middle Holocene layers are absent or their small representation result from some delay in peat accumulation. Middle Holocene hiatuses are observed in profiles from different altitudes, climate zones and vegetation, staying under various hydrological, geomorphological and sedimentary regimes. Environmental variability of sites where the hiatuses are found suggests that the reasons for their presence cannot be uniformed and that no standardized and generally valid explanation of the phenomenon does exist.

According to Rybníček and Rybníčková (1987) there are two main lines of explanation for hiatus presence: (1) the sediment either did not accumulate at all or only did in a form of a thin layer, (2) the sediment did accumulate but it later disappeared, either completely or partly (Fig. 65). In the first case climatic and hydrologic barriers could be considered as a reasonable cause for the limited peat growth and limnic sedimentation. The barriers are caused by extreme either dry or wet conditions. A state of drought can logically be accepted when considering glacial periods in central Europe, or generally in relation to arid conditions, either today or in the distant past, but it is vaguely plausible in temperate zones during interglacial periods. At that time indeed a moderately warm and moist climate prevailed. The same applies to the above mentioned slow peat growth accompanying extremely humid climate or extremely wet local conditions typically experienced in central Europe at that time.

Another approach is based on the assumption that the sediment did actually accumulate though disappearing in later stages. Water erosion or abrasion could have served a suitable reason for secondary redeposition of the material. It equally applies to lakes being influenced by vertical or horizontal water movement.

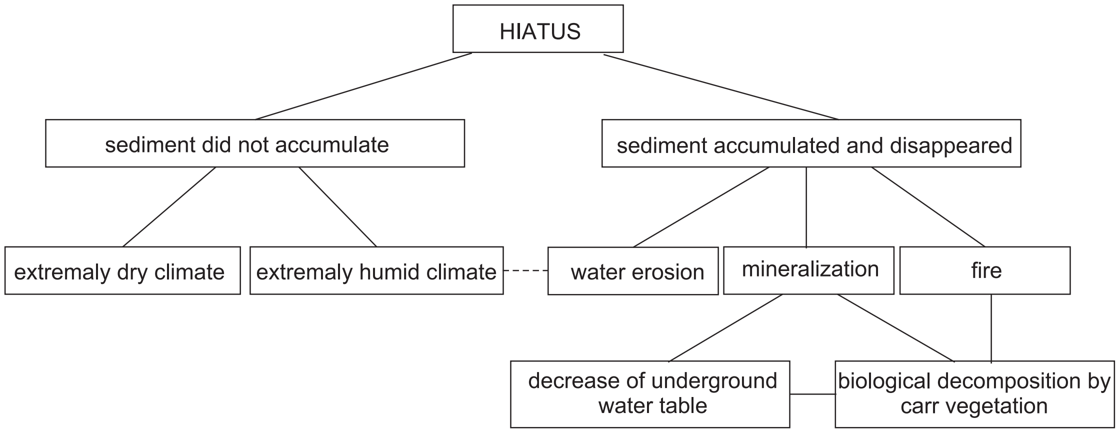

Fig. 65. Scheme of the possible explanations of hiatuses in mire profiles (acc. Rybníček & Rybníčková 1987)

Rybníček and Rybníčková (1987) conclude that in case of mires the hiatus could have been brought about by a mineralization of peat layers during some developmental stages. That in turn may be linked with utter or at least partial lowering of the groundwater table. In such cases water level dropped as a result of a local decrease in rainwater retaining capacity of the soil, or in relation to changes either in spring water supply or in water shed properties in a particular section of river catchment encompassing today's study sites. Another explanation could be that relative lowering of water level was simply an effect of greater elevation of mire surface itself. The above described changes having its direct result in enhanced gas exchange within rhizosphere layer could have accelerated ensuing encroachment of tree formations in the type of carr communities distinctive for the presence of *Alnus*, *Picea*, *Betula* and *Salix*. While utilising water supplies and evaporating them in the process of transpiration, forest assemblages at least to some extent canalized water flow preventing its stagnation which could otherwise block proper development of the rhizosphere. Under such water and air regime decomposition processes should indeed have been accelerated and continued until mire surface got lowered once again, or otherwise water level mounted prompting renewed accumulation of the peat layers on top of the already decomposed strata. The above described scheme of events could just operate on a local scale. Whether did it apply to processes at a greater scale remains an open question.

Rybníček and Rybníčková (1987) put forward a viewpoint that the absence of the middle Holocene or other layers should not be regarded as a direct result of global or regional changes in climate or hydrology of a certain area but as another phenomenon in general.

FINAL CONCLUSIONS AND SUMMARY

Regional palynostratigraphy representing a considerable part of the late Pleistocene spanning the late glacial of the Wartanian (=Saalian) glaciation, the Eemian interglacial and the early glacial of Vistulian glaciation was assembled for the area of northern Podlasie. When being compared with similar study presented by Mamakowa (1989) differences clearly appear as to the interpretation of data collected. These are listed below (see Fig. 53).

1) A section distinctive for its peak of *Picea abies* type pollen and moderately low values of herb plants was classified as denoting an interglacial within the $E_{NP}1$ *Pinus-Picea-*(*Betula*) R PAZ. It was recognized as such in respect to typical forest character of vegetation recorded for the section, while Mamakowa places the entire phase of so-called "lower spruce" within the Late Wartanian.

2) The $E_{NP}7$ *Pinus* zone was splitted into 3 subzones; the middle subzone ($E_{NP}7b$) reflects records a short-term cold climate fluctuations, hardly ever being distinguished in previous palaeobotanical studies representing Polish lowlands.

3) Three regional pollen zones were distinguished that represent the Brørup interstadial *sensu lato* (a period of the Vistulian here represented by the Solniki [28] and Dzierniakowo [24] profiles). In Polish palynostratigraphy by

Mamakowa (1989) they correspond to the single zone of the EV2 *Pinus-Betula*. The lower zone ($EV_{NP}2$ R PAZ) probably correlates to the Danish Amersfoort interstadial, while the upper one ($EV_{NP}4$ R PAZ) to the Brørup interstadial *sensu stricto*. Then the middle zone ($EV_{NP}3$ R PAZ) denotes a clear cooling separating these two interstadials. Whether such cold fluctuation better fits an interstadial or interphase rank was not yet settled.

An attempt to assemble a reconstruction of the Late-Wartanian, Eemian and Early-Vistulian changes in vegetation of northern Podlasie brings a new array of data that broaden our contemporary knowledge on this issue in this region. Generally speaking it should be highlighted that: the Late Wartanian vegetation ($LW_{NP}1$ R PAZ) gathered a whole gamut of plant assemblages reflecting diversified habitats, quite probably mosaic in their character. In dry habitats a cold steppe with domination of *Artemisia* with scattered juniper clusters prevailed. Wetter places were covered with tundra communities studded with dwarf willow and birch thickets. Though spruce was still a remarkable feature in the landscape, it was much rarer. It may be assumed that this genus was probably represented exclusively by *Picea obovata* species.

As to the Eemian plant succession in that region features of the greatest importance were as follow:

1) a relatively marked presence of spruce (probably *Picea obovata*) in pioneer pine-birch forests, that developed here at the very beginning of the interglacial ($E_{NP}1$ R PAZ);

2) the regular occurrence of white lime (*Tilia tomentosa*) in the middle part of the interglacial (from the beginning of the $E_{NP}4$ R PAZ to the middle part of the $E_{NP}5$ R PAZ);

3) minor role of fir during the spruce phase ($E_{NP}6$ R PAZ);

4) wide opening of forest canopy and temporary development of vegetation in the type of cold steppe in the middle part of the pine phase ($E_{NP}7c$ R PASZ).

During the interstadial correlated to the Amersfoort interstadial ($EV_{NP}2$ R PAZ) there spread relatively dense boreal birch forests with pine participation.

The cooling between Amersfoort and Brørup interstadials *sensu stricto* ($EV_{NP}3$ R PAZ) had its result in limitation of areas covered with forests and in development of steppe communities with domination of *Artemisia*.

The interstadial vegetation succession in the period correlated with the Brørup interstadial *sensu stricto* was divided into four stages:

1) at the beginning of the interstadial ($EV_{NP}3$ R PAZ) there developed birch forests with a limited participation of pine. Apart of that, open plant communities in the type of tundra and cold steppe still occupied large areas;

2) in the second part of the interstadial (EV_{NP} R PAZ) dense pine-birch forests dominated;

3) in the third part ($EV_{NP}4$ R PAZ), representing climate optimum of the entire interstadial, there spread almost entirely single-species pine forests with a very limited participation of spruce and larch. They resembled contemporary communities of the Siberian taiga;

4) in the youngest part of the interstadial ($EV_{NP}5$ R PAZ) area occupied by pine forests reduced in favour of open plant communities that spread very rapidly.

In the succession of vegetation during the Odderade interstadial three stages were distinguished:

1) development of open birch forests taking place in the first stage ($EV_{NP}6a$ R PASZ);

2) tree stocking in forest communities and their transformation into boreal pine forests with a small participation of *Larix* ($EV_{NP}6b$ R PASZ), which marks the second stage;

3) gradual opening of the forest canopy and gradual reappearance of open plant communities of cold steppe type denoting the third stage ($EV_{NP}6c$ R PASZ).

The reconstruction of temperature changes during the Eemian interglacial (Fig. 59) based on the method of "lant indicators of climate change"allows drawing the following conclusions:

1) from the very beginning of the interglacial winter temperatures were relatively high. In the $E_{NP}1$ R PAZ they reached values which are nowadays noted in this region and in the $E_{NP}2$ R PAZ its mean value roughly exceeded +2°C. Summer temperatures increased more steadily and in the $E_{NP}1$ R PAZ, its mean value(?) reached ca. 14°C. Then at the end of the $E_{NP}4$ R PAZ or at the beginning of the $E_{NP}4$

R PAZ they levelled with the presently noted values. It therefore allows concluding that only at the very beginning of the interglacial (in $E_{NP}1$ R PAZ) the climate was continental. Afterwards through a long period of time, that spanned the oak ($E_{NP}3$ R PAZ), hazel ($E_{NP}4$ R PAZ) and hornbeam ($E_{NP}5$ R PAZ) phases, it remained clearly oceanic;

2) the mean July temperatures reached their maximum of above +21°C in the hazel phase of the interglacial ($E_{NP}4$ R PAZ) and remained at that level till the middle part of the hornbeam phase ($E_{NP}5b$ R PASZ). Then they slightly decreased to above +17.5°C in the younger part of the *Carpinus* zone ($E_{NP}5c$ R PASZ) and *Picea* zone ($E_{NP}6$ R PAZ);

3) the maximum mean January temperatures of up 0°C dropped in the older part of the *Carpinus* zone ($E_{NP}5a$ subzone). Shortly afterwards, in the middle part of this zone ($E_{NP}5b$ R PASZ) mean winter temperature dropped to above –2°C. In spite of that oceanic conditions with relatively high winter temperatures still remained unchanged;

4) in the middle part of the interglacial no substantial climate fluctuation was recorded, neither as to July nor to January temperatures;

5) major and probably relatively rapid short-term slump in temperatures to about –10°C in winter and +12°C in summer occurred in the middle part of the *Pinus* zone ($E_{NP}7b$ and $E_{NP}7c$ subzones). It triggered the shifting from temperate to cold glacial conditions. A similar decrease in temperatures marked also the very end of the interglacial;

6) rapid decrease both in winter and summer temperatures, down to the values that restrained forest presence, occurred in the middle part of the *Pinus* zone. The very end of the interglacial was characterized by clear improvement of the climate that happened shortly before the recurring of the great climatic deterioration of the regional pollen zone $EV_{NP}1$, which is correlated with the first stadial of the Vistulian glaciation.

Pollen analysis and changes observed in the lithology of the studied profiles enabled reconstruction of the evolution of investigated basins.

1) the beginning of lake sediment accumulation in northern Podlasie did not occur in a synchronised manner during the last interglacial. It stretched through a long period starting from the late Wartanian (LW_{NP} R PAZ) to the older part of the *Carpinus* regional pollen zone ($E_{NP}5a$ R PAZ). That probably resulted from the gradual deepening of basins, which was caused by dead-ice block melting and by the increase in groundwater table what expressed humid climate conditions of the pre-optimal part of the Eemian interglacial;

2) a very characteristic feature of the Eemian interglacial in northern Podlasie was the significant decrease in water level during the younger part of the *Carpinus* zone ($E_{NP}5$ R PAZ) and *Picea* zone ($E_{NP}6$ R PAZ). This might have resulted from climate changes and from the fact that small lakes, which probably dominated at that time, were much susceptible to such changes than the larger ones;

3) the renewed rise in water level in northern-Podlasie lakes is recorded in the *Pinus* zone ($E_{NP}7$ R PAZ). From that moment lakes of the region have individually developed. Most of them disappeared at the end of the Eemian interglacial. That mainly resulted from sediment allocation in basins. Pollen record from the remaining basins did not indicate water level lowering at that time. On the contrary, it suggests the increase in water level. A few lakes was still present during the Early Vistulian, with two of them, Dzierniakowo [24] and Machnacz [17], still being there across great part of the Plenivistulian;

4) the results allow implying that during the periods with cool and humid boreal climate such as the pine phase of the Eemian interglacial and the pine phases of the Brørup and Odderade interstadials a few lakes in northern Podlasie were transformed into *Lobelia*-lakes. This phenomenon was mainly conditioned by the climate, though local conditions also played an important role, an instance being especially reflected in case of deep basins.

In none of the analysed profiles the glacial till was registered above the Eemian and Early Vistulian lake-mire deposits. They are always covered by sand or sand-silt series, above which in a few profiles the late-Vistulian and/or Holocene organic sediments occur.

ACKNOWLEDGEMENTS

I would like to express my warmest thanks to everyone who helped me in preparation of this article. I am grateful to (in alphabetical order): Dr. Piotr Banaszuk, MSc. Józef Boratyn, Dr. Stanisław Brud, Professor Andrzej Czerwiński, MSc. Mariusz Kmiecik, MSc. Stefan Kurek, Dr. Włodzimierz Kwiatkowski, MSc. MSc. Maria Preidl and Mirosław Stepaniuk for collecting material to palaeobotanical analyses. For many scientific discussions I would like to thank Professor Kazimiera Mamakowa, Dr. Dr. Dariusz Ciszek, Barbara Marciniak, Joanna Mirosław-Grabowska, Monika Niska, Renata Stachowicz-Rybka, and Hanna Winter. For discussions on the scientific as well as editorial subjects I would like to thank Dr. Dorota Nalepka. I am also thankful to MSc. Daniela Czerniawska for a complete sample preparation for pollen analysis. I am extremely grateful to the reviewers, Professor Magdalena Ralska-Jasiewiczowa and Dr.Wojciech Granoszewski for valuable comments upon the manuscript. I would like to express my warmest thanks to Dr. Arthur Gumieniak (W. Szafer Institute of Botany) for linguistic verification of the English text.

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