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Eemian and Vistulian pollen sequence at Kubłowo (Central Poland): implications for the limit of the Last Glacial Maximum

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The Kubłowo site is situated in the southeastern Kujawy region, Central Poland, and slightly to the south of the limit of the Last Glacial Maximum (LGM) in the Vistula Lobe. Late Pleistocene lacustrine and peat deposits found there have been analyzed for their pollen content. The pollen sequence from Kubłowo records the longest continuous succession of vegetation covering the Eemian Interglacial, Early Vistulian and the lower part of the Plenivistulian in Central Poland. In the Early Vistulian two warm (Brörup and Odderade) and two cool (Herning and Rederstall) intervals have been distinguished. The next three climatic oscillations correspond to the Schalkholtz and Ebersdorf stadials and to the Oerel Interstadial. The lack of till or till residua above the Eemian–Vistulian deposits at Kubłowo indicates this area as being beyond the extent of the last Scandinavian ice sheet which confirms the reconstruction of the LGM limit as based on geomorphological evidence.

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INTRODUCTION

Palaeobotanical literature describes numerous sites with the Eemian Interglacial pollen succession. More rare are sites, which in continuous sequence embrace both the Eemian as well as the Vistulian successions. Mamakowa (1989) provides a long list of Eemian and Eemian–Vistulian sites in Poland up to the year 1986. Among them is the Zgierz-Rudunki site (Jastrzębska-Mamełka, 1985) comprising the Eemian Interglacial, Early Vistulian and the lowest Plenivistulian interval. In the 1990's a few new sites were described, i.a. Ruszkówek (Janczyk-Kopikowa, 1997), Mikorzyn (Stankowski *et al.*, 1999) and Machnacz (Kupryjanowicz, 1991), which contain the whole Eemian and part of the Vistulian succession. At the beginning of the 21st century subsequent sites were described which, except for the Eemian and Early Vistulian, comprise a significant part of the Plenivistulian. Most representative are the Kuców site (Balwierz, 2003), Dzierniakowo and Solniki (Kupryjanowicz, 2005, 2008) and the Horoszki Duże site, described in detail (Granoszewski, 2003; Fig. 1). In western Europe the Grand Pile site (Woillard, 1978) represents, up to now, the fullest interglacial-glacial succession. Even though the number of localities embracing in continuous sequence Eemian and Vistulian successions is growing, they are still few in number, and each successive site is significant for understanding the development of vegetation, climate and stratigraphy of the Late Pleistocene.

Numerous sites with organic deposits of Eemian Interglacial age have been detected throughout the area occupied by the Vistula Lobe during the Last Glacial Maximum (LGM) (Fig. 1). The majority of those were found during geological surveying for the *Detailed Geological Map of Poland* (1:50 000 scale) and examined for pollen and lithology.

The Kubłowo site is located in the southeastern Kujawy region (Central Poland), 1 km to the south of the maximum limit of the Vistulian (Weichselian) Glaciation ice sheet (Figs. 1 and 2). A widely accepted reconstruction of the LGM limit during the Late Vistulian main stadial by Kozarski (1986, 1988, 1995) is shown in Figure 1. The maximum extent of the last Scandinavian ice sheet in Poland is diachronous (*cf.* Marks, 2002, 2004; Wysota, 2002). In Western Poland it was connected with the Leszno (Brandenburg) Phase, but in Central and Eastern Poland

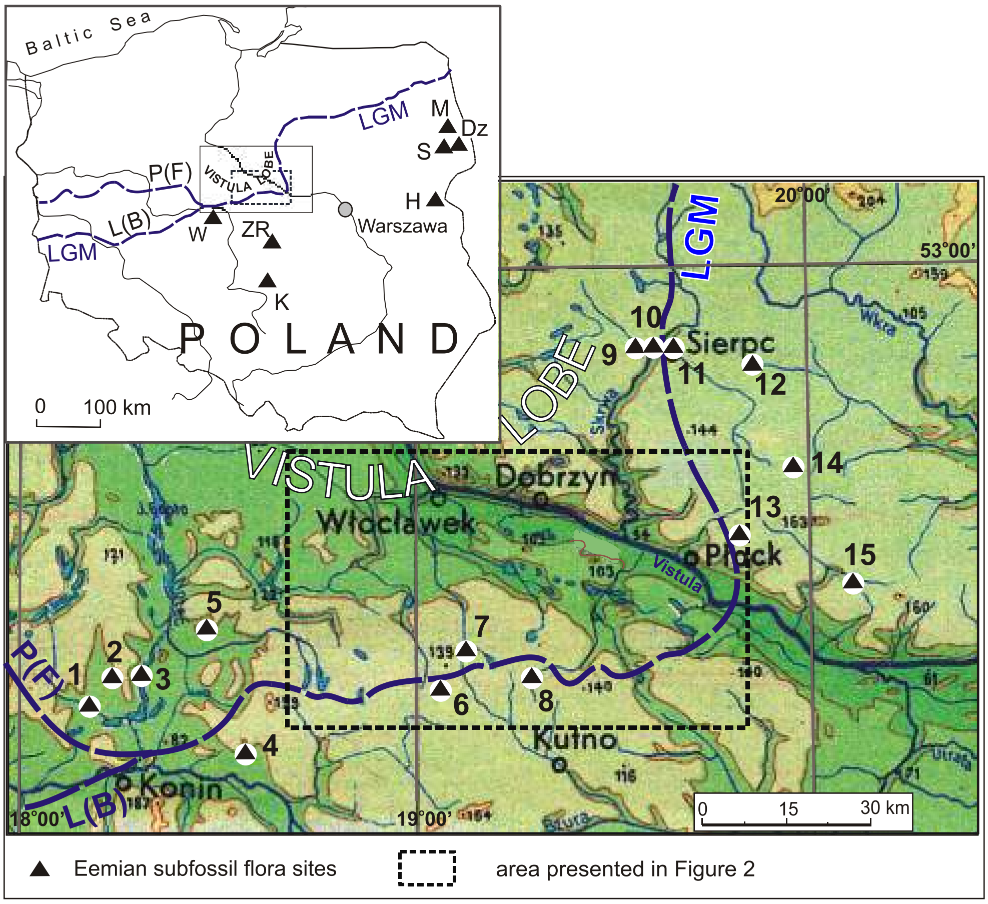

Fig. 1. Location of Eemian subfossil flora sites in Central Poland (after Bruj and Roman, 2007, modified)

Eemian subfossil flora sites: 1 – Kazimierz (Stankowski and Tobolski, 1981); 2 – Jóźwin (Borówko-Dłużakowa, 1979; Tobolski, 1991); 3 – Mikorzyn (Stankowski *et al*., 1999); 4 – Krzyżówki (Noryśkiewicz, 1999; Szałamacha and Skompski, 1999); 5 – Ruszkówek (Kozydra and Skompski, 1995; Janczyk-Kopikowa, 1997); 6 – Kubłowo; 7 – Kaliska (Janczyk-Kopikowa, 1965; Domosławska-Baraniecka, 1965); 8 – Łanięta (Balwierz and Roman, 2002); 9 – Studzieniec (Kotarbiński and Krupiński, 1995); 10 – Babiec Pasieczny (Krupiński, 2005); 11 – Nadolnik (Kotarbiński and Krupiński, 2000); 12 – Rostowa (Krupiński, 2005); 13 – Leszczyno (Krupiński *et al*., 2006); 14 – Sokolniki (Baraniecka and Janczyk-Kopikowa, 1991); 15 – Główczyn (Niklewski, 1968); Dz – Dzierniakowo (Kupryjanowicz, 2005, 2008); H – Horoszki Duże (Granoszewski, 2003); K – Kuców (Balwierz, 2003); M – Machnacz (Kupryjanowicz, 1991); S – Solniki (Kupryjanowicz, 2005, 2008); W – Władysławów (Tobolski, 1986); ZR – Zgierz-Rudunki (Jastrzębska-Mamełka, 1985); LGM – Last Glacial Maximum; P(F) – Poznań (Frankfurt) Phase; L(B) – Leszno (Brandenburg) Phase

the younger Poznań (Frankfurt) Phase has been found as the most extensive (Fig. 1). There is now a consensus that the last Scandinavian ice sheet only once reached the southeastern Kujawy region (Baraniecka, 1989, 1991, 1993; Roman, 2006, 2007, 2008*b*; Molewski, 2007; Wysota and Molewski, 2007; Wysota *et al*., 2009) and left a separate till, the stratigraphic position of which was well determined as younger than the Eemian Interglacial, referring to the sites of subfossil plants at Kaliska (Domosławska-Baraniecka, 1965; Janczyk-Kopikowa, 1965) and Ruszkówek (Kozydra and Skompski, 1995; Janczyk-Kopikowa, 1997; Fig. 1). This ice sheet advance did not take place before 21 ka BP (Stankowska and Stankowski, 1988; Kozarski, 1986, 1995), and not earlier than 20 300 ka BP (Przegiętka *et al*., 2008). Since the recognition of the last Scandinavian ice sheet in Poland, a lobe of which invaded the Płock Basin (Lencewicz, 1927), a number of papers have been published on its maximum extent in the Vistula Lobe. A review of opinions on this has recently been presented by Wysota and Molewski (Wysota and Molewski, 2007; Wysota *et al*., 2009) and Roman (2006, 2007). The LGM limit in the Vistula Lobe, presented here (Fig. 2) has been reconstructed by means of geomorphological and lithostratigraphical evidence (Skompski, 1969; Baraniecka, 1989, 1991, 1993; Roman, 1999) and recently by sedimentological research and luminescence datings of the Late Vistulian glacial sequence in several key exposures within the marginal zone of the last glacial advance (Roman, 2003, 2007, 2008*a*, *b*). However, the LGM extent has been precisely delineated only in the western part of the area occupied by the Vistula ice lobe, but in the central and eastern part it is still unclear, especially because of doubtful origin of landforms in the

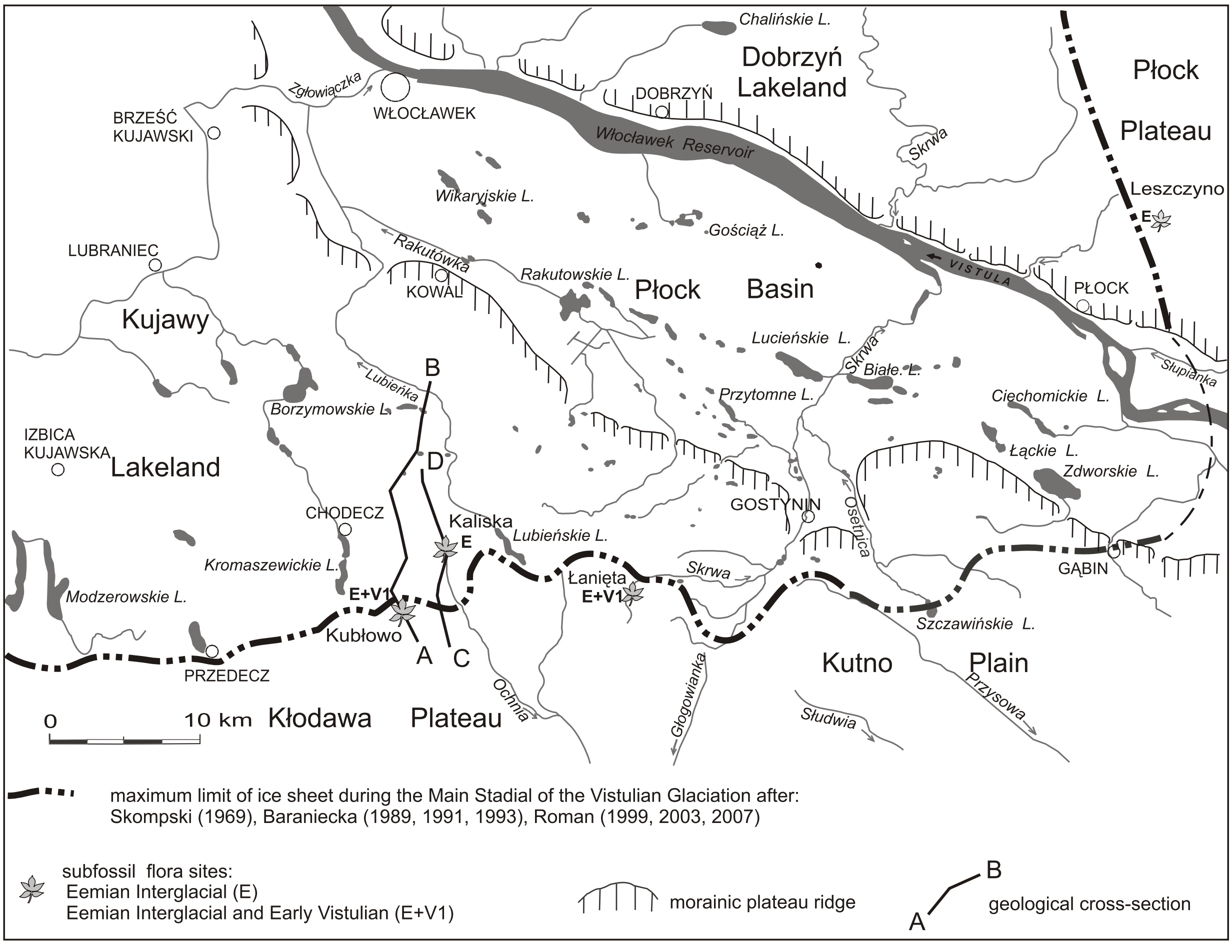

Fig. 2. Location sketch

glaciomarginal zone and a lack of chronostratigraphic data based on radiocarbon or luminescence methods. Whether the Eemian deposits in sites located in the glaciomarginal zone have been till-covered provides sufficient reliable evidence to establish the limit of the Last Glacial Maximum in Central Poland (Baraniecka, 1989; Kotarbiński and Krupiński, 1995; Krupiński *et al*., 2006; Roman, 2008*b*; Fig. 2).

Biogenic deposits underlying the glaciofluvial sands at Narty near Kubłowo (Fig. 2) were recorded by Baraniecka (1993) and determined as probably Eemian based on palynological examination. Subfossil organic deposits at Kubłowo have been found associated with marginal forms of the LGM in the Vistula ice lobe (Roman, 2007, 2008 *a*, *b*; Roman and Balwierz, 2007). The palynological record of the lacustrine and peat deposits from Kubłowo represents a long continuous Eemian–Vistulian sequence, spanning the Eemian Interglacial and the second Plenivistulian cold interval. In this paper the authors present results of palynological studies, with emphasis placed on the post-Eemian phases of the Kubłowo succession. The results are compared with intervals of the same age from adjacent areas.

MATERIAL AND METHODS

To delineate the buried basin at Kubłowo five boreholes were drilled in the axial part of the shallow depression within the outwash plain (Fig. 3). In two (Kubłowo and Narty), subfossil biogenic deposits were found (Fig. 3). At Kubłowo, the drilling reached a depth of 14.5 m. Below 3.5 m of glaciofluvial sands and gravely sands, mineral and organic lacustrine sediments and peat 6.1 m thick were encounterd (Fig. 5). Underneath, at 11.1 m depth, were glaciofluvial sands with then a gray calcareous till from 12.8 m (Figs. 4 and 5). The succession of the Kubłowo core is as follows:

Depth [m]	Lithology
0.0–0.20	sandy soil, dark gray
0.20–1.00	poorly sorted sand with gravel up to 2 cm, yellowish-gray
1.00–1.15	gravel with sand, rusty-grayish
1.15–1.30	fine-grained sand, light gray, –HCl
1.30–1.50	silty sand, light gray, +HCl

Depth [m]	Lithology
1.50–3.10	medium sand, light gray
3.10–3.50	gravely sand, light gray
3.50–3.80	sandy silt, light gray, –HCl
3.80–4.85	laminated silt, with admixtures of fine sand at a depth of 4.20–4.30 m, gray, –HCl
4.85–5.32	laminated silt with plant detritus, gray to dark gray
5.32–5.70	silty gyttja, dark gray, –HCl
5.70–6.00	peat strongly decomposed and compressed, brownish-black
6.00–6.32	silty gyttja, high compressed, brownish-gray, –HCl
6.32–7.10	laminated silt, gray, –HCl
7.10–7.37	silt with laminae of organic matter, dark gray
7.37–7.45	peat, strongly decomposed and compressed, dark brown
7.45–8.00	organic shale, brownish-black
8.00–8.20	silty gyttja, grayish-brown, –HCl
8.20–8.75	peat loamy at the bottom, high compressed, brownish-black
8.75–8.81	loamy peat, dark brown
8.81–9.22	clayey silt, gray, –HCl
9.22–9.40	laminated silt and silty clay, gray to brownish-gray, –HCl
9.40–10.10	gyttja, high compressed, dark gray
10.10–10.35	silt with organic matter, dark gray
10.35–10.50	very fine humic sand, light gray
10.50–11.10	silty sand, light gray, –HCl
11.10–12.80	vari-grained sand with admixture of gravel at the bottom, light gray, +HCl
12.80–14.50	diamicton, gray, ++HCl

Lacustrine and swamp deposits of the Kubłowo profile, between the depths of 3.8 and 11.1 m, were analyzed for their pollen content. 126 samples were collected at intervals of 5 cm, and 71 were selected for pollen analysis. Deposits younger than Eemian were the subject of detailed palynological investigation. Radiocarbon dating of biogenic deposits of the upper part of the Kubłowo core, from depths of 5.45 and 5.80 m, was also carried out (Fig. 5), at the Łódź Archeological and Ethnographical Museum.

Samples for pollen analysis were boiled in 10% KOH and then, in order to remove mineral particles, were left in hydrofluoric acid for 48 hours. The material so prepared was macerated by acetolysis following Erdtman (1960). The sediment did not contain carbonates.

The number of sporomorphs counted in particular samples ranged from 500 to 1500. At intervals where the frequency was low, the amount of pollen grains was below 500. The calculation of percentages was based on the total terrestrial pollen sum (AP + NAP): trees and shrubs (AP) and herbaceous plants (NAP). Aquatic and swampy plants, spores of *Sphagnum* and Pteridophyta, along with indeterminable sporomorphs, were excluded from the total sum. The indeterminable sporomorphs consist of corroded pollen grains, unknown, as well as broken or crumpled ones. The share of excluded sporomorphs was calculated in relation to the total sum. The preservation of pollen was good from sediments representing warm periods, and rather poor from sediments representing cooler conditions.

Results of the pollen analysis were plotted using POLPAL for Windows (Walanus and Nalepka, 1999). The pollen diagram presented here is a simplified version, curves of some taxa being omitted, while others are presented together as a single curve.

GEOLOGICAL SETTING

The Kubłowo site is located in the northern part of the Kłodawa Plateau within the area of the Warta Stadial, the final stadial of the Odranian (Late Saalian) Glaciation (formerly Wartanian Glaciation) (*cf*. Lindner and Marks, 1999; Lindner, 2005; Ber *et al*., 2007) and slightly to the south of the limit of the Last Glacial Maximum (Figs. 2 and 3). The Kłodawa Plateau is a monotonous morainic plain at 120–130 m a.s.l., mainly composed of till (Figs. 3 and 4). There are no postglacial lakes but in fossil depressions at e.g. Łanięta (Balwierz and Roman, 2002) and Kubłowo (Fig. 2) biogenic deposits are to be found, which accumulated throughout the Eemian Interglacial and the lower part of the Vistulian, and subsequently were covered by glaciofluvial sediments during the advance of the last ice sheet.

To the north of Kubłowo extends the fresh glacial landscape of the Kujawy Lakeland (Pojezierze Kujawskie) (Figs. 2 and 3), with numerous lakes and kettle-holes along with tunnel valleys. Such a marked change in landscape suggests that the southern limit of the last Scandinavian ice sheet runs in the vicinity of Kubłowo. The last ice sheet maximum limit in the Kujawy Lakeland has been derived from geomorphological evidence such as the distal parts of the glacial troughs and the beginnings of the glaciofluvial fans (Fig. 3). Moreover, the extent has been delineated as based on geological criteria upon the spatial distribution of the till, which constitutes a separate lithostratigraphic horizon (Roman and Lisicki, 2000; Roman, 2003) and at Kaliska it lies above Eemian biogenic deposits (Domosławska-Baraniecka, 1965; Janczyk-Kopikowa, 1965; Baraniecka, 1989, 1993; Fig. 4).

The Kujawy Lakeland morainic plateau is composed of a till and is covered, in places, by thin glaciofluvial sands and gravels (Figs. 3 and 4). Glaciofluvial fans, fixing the ice sheet extent and formed at the mouth of the glacial tunnel valleys, are composed of sands and gravels, with sporadic intercalations of flow till (Fig. 4). They are located at 125–134 m a.s.l. and are the highest, although not distinctive, element of the relief in this area (Fig. 3). Their surface inclines gently southwards into an extensive outwash plain. In the vicinity of Kubłowo a narrow NW–SE depression occurs with a length of *ca*. 1.5 km where, below glaciofluvial sands, lacustrine and swamp deposits have been recognized (Figs. 3 and 4). These sediments fill up a small buried basin that was formed by dead ice at the decline of the Warta Stadial.

The mean thickness of the Quaternary near Kubłowo varies from 30 to 50 m. Neogene clays underlie the Quaternary deposits

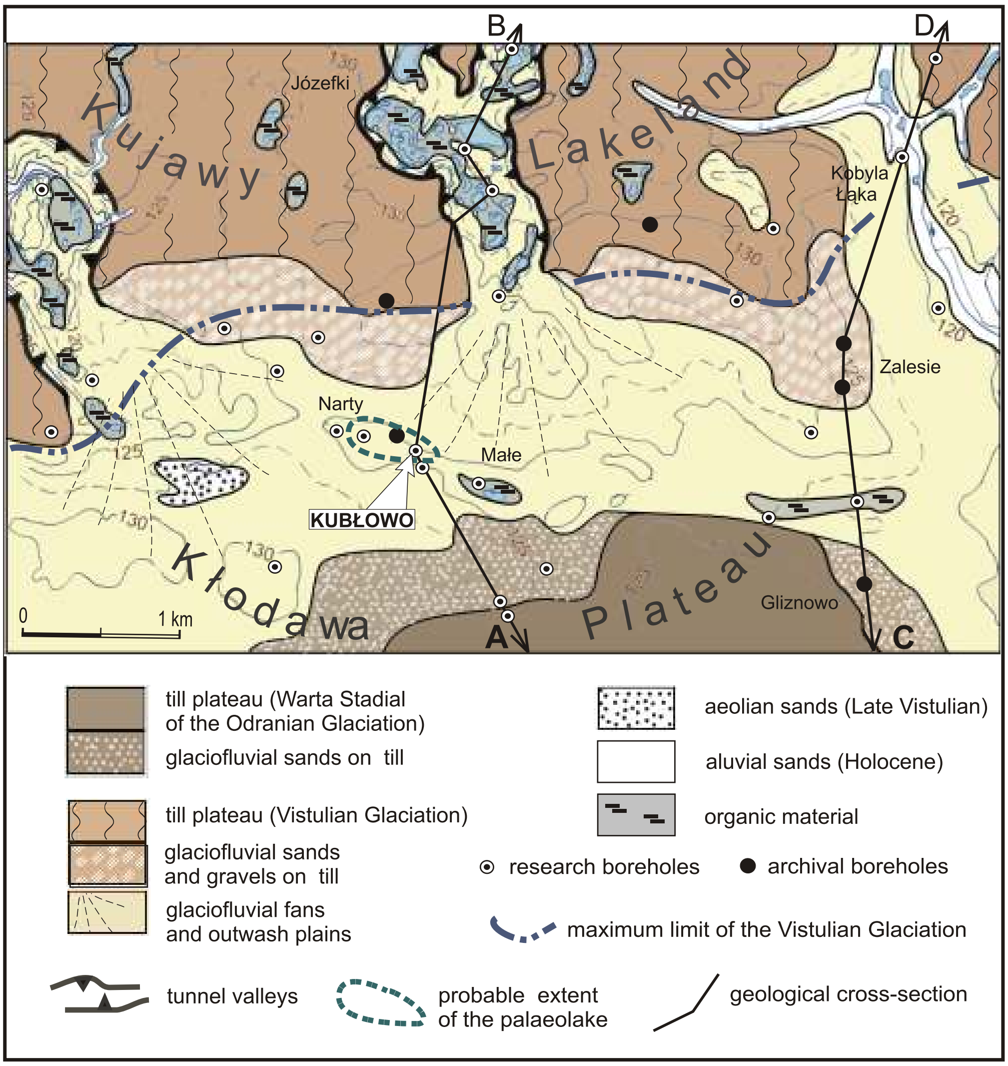

Fig. 3. Geology and geomorphology of the Kubłowo vicinity

at 80–90 m a.s.l. (Fig. 4). The Pleistocene appears mainly as glacial and glaciofluvial deposits and infrequently as fluvial deposits, while sporadical organic lacustrine deposits and peat are to be found. Four till units have been distinguished (Fig. 4) and correlated, from bottom to top, with the South Polish Glaciation (Elsterian) – one till, the Middle Polish Glaciations (Saalian) – two tills: Krznanian and Odranian with Warta Stadial, and with the Vistulian (Weichselian) Glaciation – one till. The Mazovian Interglacial (Holsteinian) is represented by sand-gravelly river deposits with thin mud interlayers occasionally containing dispersed organic matter. River deposits are commonly overlaid by glaciolacustrine silts and clays, that form a significant correlation horizon in the Kłodawa Plateau region (Baraniecka, 1979, 1993). The Pleistocene stratigraphy of the region is mainly based on lithostratigraphic criteria. Only the stratigraphic position of the uppermost till has been well determined as younger than the Eemian Interglacial, based on the site with subfossil plants at Kaliska (Domosławska-Baraniecka, 1965; Janczyk-Kopikowa, 1965). The till represents the Main Stadial of the Vistulian Glaciation (*ca*. 20–18 ka BP).

RESULTS

POLLEN ANALYSIS AND BIOSTRATIGRAPHY

The results of pollen analysis from Kubłowo are shown in a pollen diagram (Fig. 6). In this, 18 local pollen assemblage zones (L PAZ) were distinguished according to criteria submitted by Janczyk-Kopikowa (1987). The features of each L PAZ are presented in Table 1. The pollen sequence from Kubłowo records an interglacial succession and a number of stadial/interstadial-rank phases of vegetation development. The correlation of local pollen assemblage zones (L PAZ) from Kubłowo with regional pollen assemblage zones (R PAZ) distinguished by Tobolski (1991) for the Konin region, by Krupiński (2005) for the Płock Plateau, by Mamakowa (1986, 1988, 1989) for Poland and also with the chronostratigraphy (Menke and Tynni, 1984; Behre and Lade, 1986; Behre, 1989) is shown in Table 2.

Local pollen assemblage zones K1 to K7 record the interglacial vegetation succession concurrent with regional pollen as-

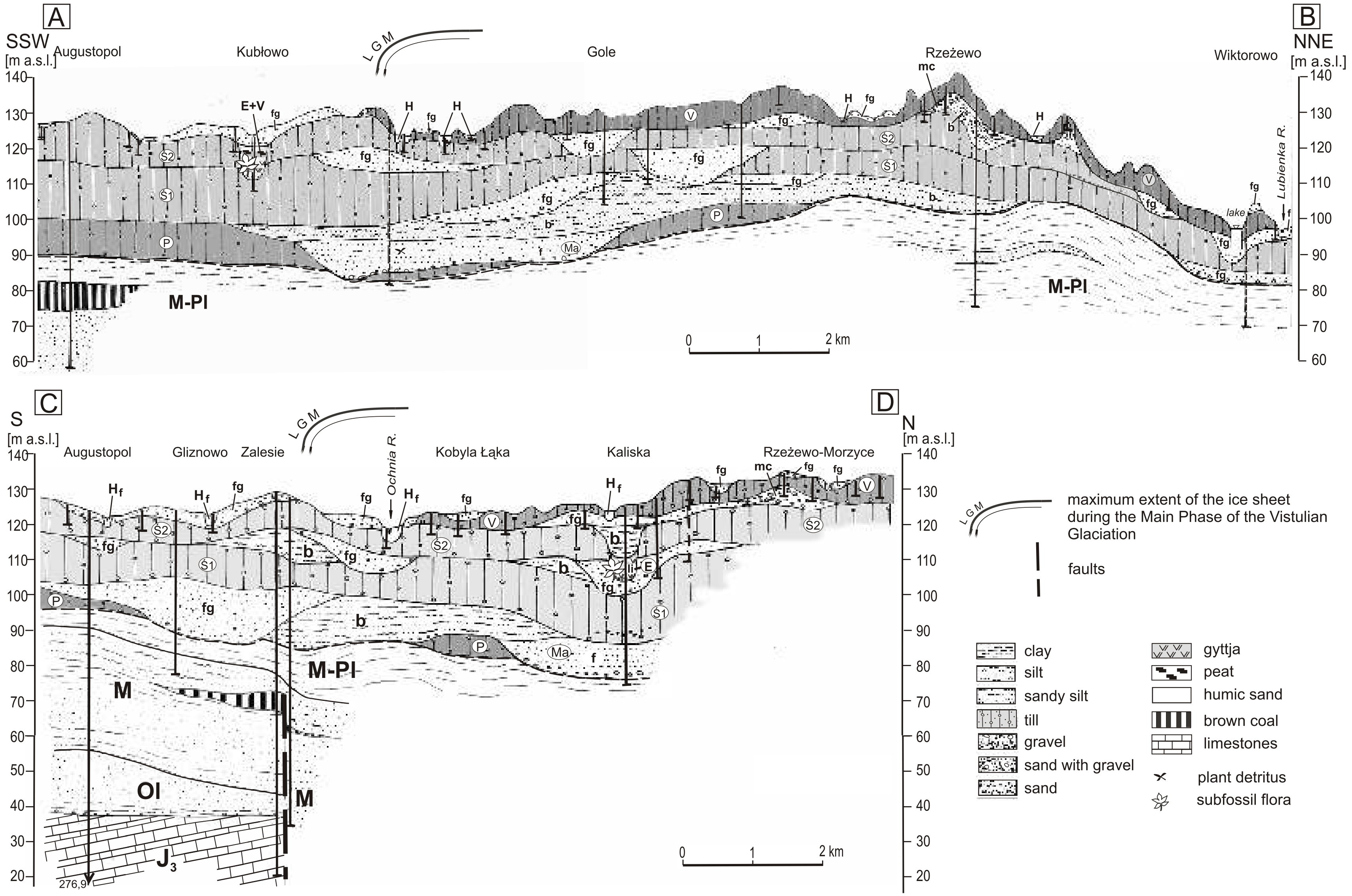

Fig. 4. Geological cross-sections: A–B and C–D

J_3 – Upper Jurassic; Ol – Oligocene; M – Miocene; M-Pl – Late Miocene and Pliocene; P – South Polish Glaciations (Elsterian); Ma – Mazovian Interglacial (Holsteinian); Ś – Middle Polish Glaciations (Saalian): Ś1 – Krznanian, Ś2 – Odranian; E – Eemian Interglacial; V – Vistulian Glaciation (Weichselian); H – Holocene; f – fluvial, b – glaciolacustrine, mc – end moraine, fg – glaciofluvial, li – lake and bog

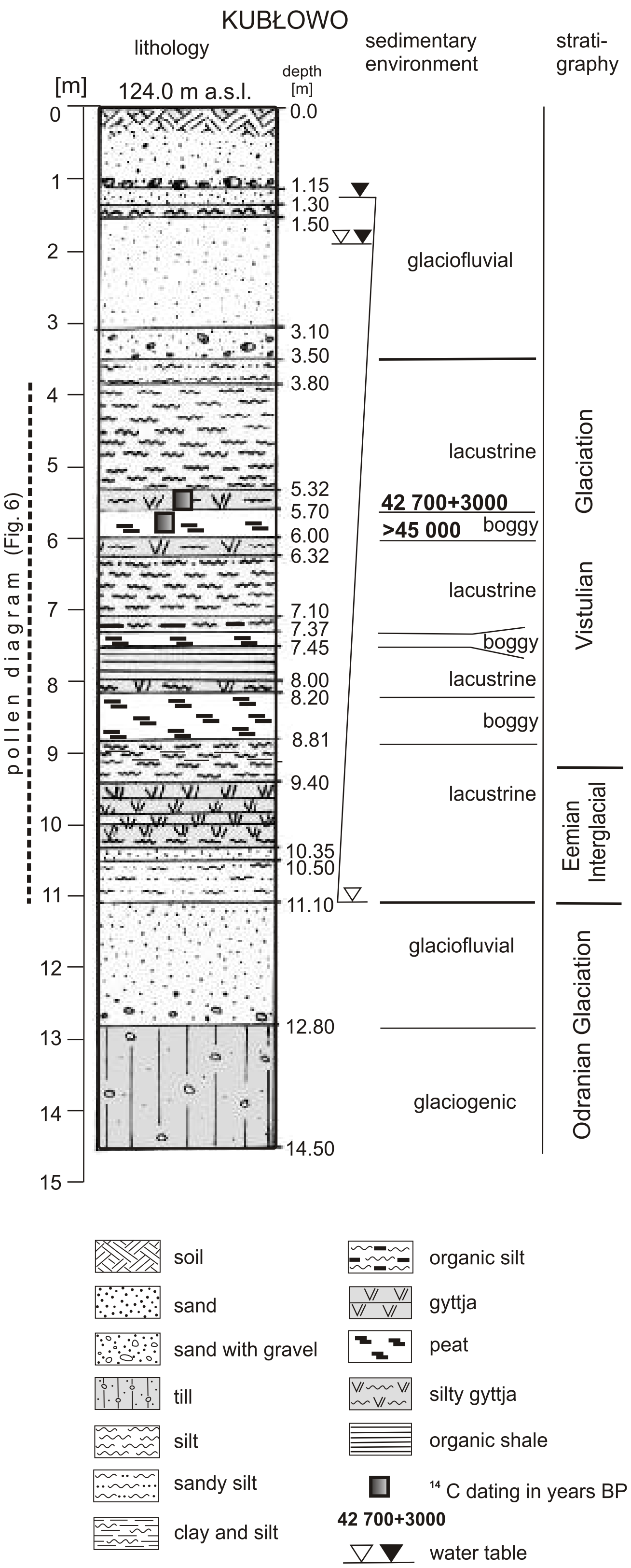

Fig. 5. Lithological profile of the Kubłowo borehole

semblage zones of the Eemian Interglacial defined for Poland by Mamakowa (1986, 1989). Thus other pollen zones, K8 to K18 L PAZ, lying above the Eemian, may be correlated with the Vistulian. Pollen spectra of the K9–K10 and K12–K15 pollen zones record two warm climatic oscillations correlated respectively with the Brörup and Odderade interstadials (Behre and Lade, 1986; Behre, 1989). The pollen zone K14 (*Pinus–Betula* L PAZ), related to the upper part of the Odderade Interstadial, has been radiocarbon dated (Figs. 5 and 6). The age of loamy gyttja from 5.45 m depth is determined as 42 700 ±3 000 ^{14}C BP and the age of peat, from 5.80 m, as older than 45 000 ^{14}C BP (Fig. 5). However, at the Oerel site, the top of the Odderade deposit has been dated as 60 800 + 2 300/–1 800 ^{14}C BP (Behre and Plicht, 1992). The first date from Kubłowo is thus "rejuvenated" as compared to the one from Oerel. The second date is reliable, although scarcely significant. Pollen zones K8 and K11, representing cool oscillations, have been correlated with the Herning and Redestall stadials (Behre and Lade, 1986; Behre, 1989). The interstadials and stadials, mentioned above, have been related to the Early Vistulian. The three uppermost pollen zones, K16, K17 and K18, have been included in the Plenivistulian (Table 2).

Differences between the K17 *Pinus*–Poaceae L PAZ and the K16 Poaceae–*Artemisia–Pinus* L PAZ are not very distinct but are clear. They depend on a higher AP share than in the adjacent pollen levels, mostly *Pinus*, and also on a less diversified assortment of herbaceous taxa than in the K16 zone. Pollen zones K16 and K17 represent non-forest vegetation intervals. The northern forest limit was shifted far to the south of Kubłowo. However, the increase in AP in the K17 zone may indicate that the boundary shifted back to the north, which possibly shows an amelioration in climate (Balwierz, 2003; Granoszewski, 2003). This feature was essential to distinguish the K17 L PAZ and to correlate it with the Oerel Interstadial. Consequently, the lower K16 L PAZ has been correlated with the Schalkholz Stadial, and the K18 L PAZ, lying above, with the Ebersdorf Stadial (Behre and Lade, 1986; Behre, 1989; Table 2).

VEGETATION HISTORY

EEMIAN INTERGLACIAL

The Eemian Interglacial deposits at Kubłowo are 175 cm thick, of which only 55 cm come from the climate optimum. The deposits are thus strongly compressed. With a 10 cm sample resolution for that part of the profile, some phases appear only in one sample which the consecutive ones overlap, rendering reconstruction of Eemian vegetation history around Kubłowo rather general. Consequently, and as the Eemian Interglacial vegetation of Poland is well known, this paper concentrates on Vistulian vegetation for which the number of sites is much smaller. The development of vegetation in the Eemian Interglacial in the vicinity of Kubłowo was similar to that in adjacent areas i.e. the Płock Plateau (Krupiński, 2005), the Konin area (Tobolski, 1991; Stankowski *et al.*, 1999) and also around other sites near Kubłowo (Janczyk-Kopikowa, 1965, 1997; Niklewski, 1968; Kotarbiński and Krupiński, 1995; Balwierz and Roman, 2002) shown in Figure 1.

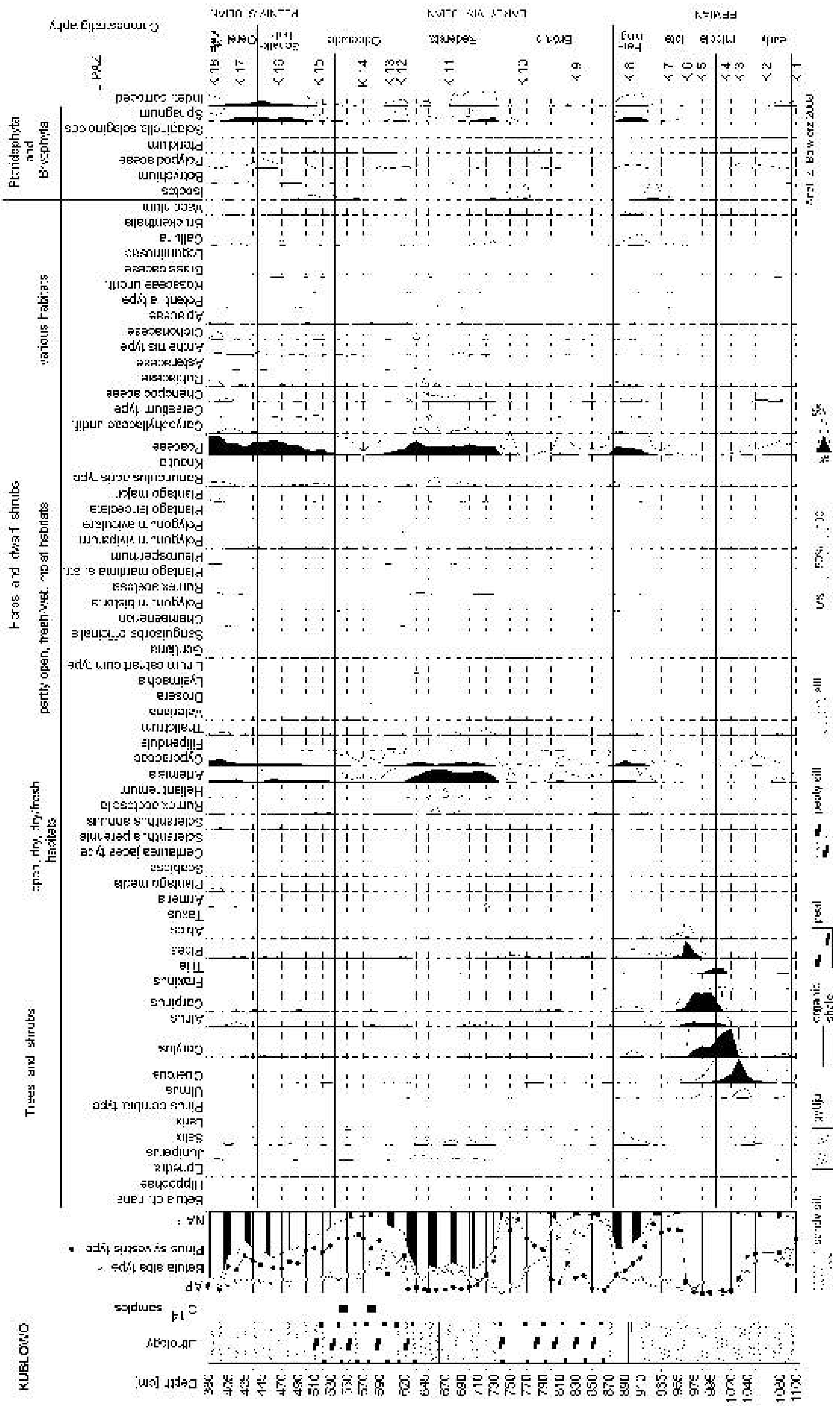

Fig. 6. Kublowo pollen diagram

Table 1

Description of the local pollen assemblage zones from Kubłowo

Local pollen assemblage zones (L PAZ)		Depth [cm]	Description of local pollen assemblage zones (L PAZ)
K18	Poaceae–*Artemisia*–Cyperaceae	380–395	Values of AP are the lowest (15.1%) in the whole profile. Dominates Poaceae (49.3%), Cyperaceae, and *Artemisia*. Herbs attain great variety, among others *Armeria*, *Helianthemum*, *Pleurospermum*, *Sanguisorba officinalis*, *Plantago major*, *P. media*, *Rumex acetosa*, *R. acetosella*, *Ranunculus acris* t., Caryophyllaceae, Rubiaceae and Cichorioideae.
K17	*Pinus*–Poaceae	405–435	AP increase to 65.3%, mainly *Pinus* (46.2%) and Poaceae falls. More abundant pollen of *Artemisia*, Cyperaceae and *Sphagnum*. Pollen of *Salix* and *Juniperus* as well as *Botrychium* spores are present.
K16	Poaceae–*Artemisia*–*Pinus*	445–490	Alternating percentages of AP from 44.2 to 58.2%. Values of *Betula* pollen is lower than *Pinus* and more stable. Present are *Botrychium* spores. Increase of *Sphagnum* spores value. A rise of AP, and mainly *Pinus*, marks the upper limit of the zone.
K15	*Pinus*–Poaceae–*Artemisia*	500–530	The curve of *Pinus* falls. The share of *Betula* is slightly below 20%. Variety of herbaceous plants taxa grows. The upper limit of the zone is pointed by a decline of AP, and an abrupt increase of Poaceae pollen.
K14	*Pinus*–*Betula*	540–590	The AP value reaches 94.9%, and *Pinus* dominates again (72.5%). The upper boundary of the zone is denoted by a drop in AP and an increase in *Artemisia* and Poaceae.
K13	*Betula*–*Pinus*	600	The AP share slightly rises (83.5%), but *Betula* pollen dominates (57.3%). The rise of *Pinus* marks the boundary of the next zone.
K12	*Pinus*–*Betula*	620	AP climbs to 75.6%. *Pinus* prevails (46.7%). Curves of *Artemisia* and Poaceae descend. Diversity of herbs also falls. The limit of the next zone is marked by an increase in *Betula*.
K11	*Artemisia*–Poaceae–*Juniperus*	625–730	Only in 2 samples AP value is higher than 50%, in others it remains lower than 40%. The curve of *Betula*, after a distinct fall in the earlier level, increases to about 20%. *Pinus* value is less than 10%. Pollen of *Juniperus* and *Salix* occurs. Domination of NAP, an increasing in *Artemisia* (max. 33.6%), Poaceae (20.8–34.6%) and Cyperaceae. High variety of herbaceous taxa (*Helianthemum*, *Rumex acetosella*, *R. acetosa*, *Pleurospermum*, *Polygonum viviparum*, *Sanguisorba officinalis*, *Plantago maritima* s. str., *Linum catharticum* t., *Ranunculus acris* t., Caryophyllaceae, Chenopodiaceae). The upper limit of the zone is marked by a growth in AP.
K10	*Pinus*	740–790	AP value persists very high (max. 99.5%), but with *Pinus* dominant. Only some pollen grains of *Larix* and *Juniperus* are present. Upper part of the zone shows a rapid fall of AP curve accompanied with a growth of *Artemisia* value. Sharp decrease of AP curve constitutes the boundary with the next zone.
K9	*Betula*	800–870	High values of AP (97%), and *Betula* dominates. A small but distinct decrease of AP is visible in the upper part of the zone accompanied by a growth of *Artemisia* and *Juniperus* pollen share. The top of the zone is marked by a drop of the *Betula* pollen and increase in *Pinus.*
K8	Poaceae–*Artemisia*–*Juniperus*–*Salix*	880–915	The AP curve declines to 53.5%, particularly in *Pinus* (23.5 %). *Betula* pollen values persist on the same level. The share of Poaceae rises to 24.4%. Pollen of *Salix*, *Juniperus* and *Artemisia* (8.4%) is present. Herbs attain greater variety, *i.al.* Cyperaceae, *Calluna*, Chenopodiaceae, Rubiaceae, Caryophyllaceae, *Thalictrum*, *Rumex acetosella*, *Helianthemum*, *Sanguisorba officinalis.* The value of *Sphagnum* reaches 12.5%.
K7	*Pinus*–*Picea*	925–960	Sharp rise of *Pinus* (77.1%) and slight of *Betula* (18.6%). The curve of *Quercus*, *Corylus*, *Alnus*, *Carpinus* and *Abies* disappears and *Picea* drops noticeably. The continuous curve of Poaceae and *Artemisia* appears for a second time which together with a significant decrease of AP value points the upper limit of the zone.
K6	*Picea*–*Abies*–*Carpinus*	965	The share of *Picea* and *Abies* reach 43.9% and 4.9% respectively. The curve of *Pinus* ascends to 14.8%. The boundary with next zone is marked by a decrease of *Picea* and progressive increase in *Pinus.*
K5	*Carpinus*–*Alnus*–*Corylus*–*Tilia*	975–995	The curve of *Carpinus* reaches 47.4%. *Corylus* and *Alnus* curves descend and *Tilia* disappears. The upper limit of the zone is denoted by a decrease of *Carpinus,* an appearance and increasing amount of *Picea* pollen and also appearance of a continuous curve of *Abies*.
K4	*Corylus*–*Tilia*–*Alnus*	1010–1020	The level of AP exceeds 99.1%. The *Corylus* curve rises and reaches its maximum value of 68.9%. A continuous curve of *Alnus* and *Tilia* appears, and *Tilia* shows its maximum value (14.9%). A fall of *Corylus* pollen together with a increase in *Carpinus* features the upper zone boundary.
K3	*Quercus*	1030	The AP curve reaches 93.4%. Maximum value of *Quercus* is 59.4% whereas share of *Pinus* and *Betula* pollen is very low. The top of the zone is marked by the *Quercus* curve decline and an increase in *Corylus.*
K2	*Pinus*–*Betula*–*Quercus*	1040–1090	AP value persists high. The curves of *Pinus* and *Betula* remain the same. *Artemisia* and *Juniperus* disappear and *Quercus* pollen emerges. The continuous curve of *Ulmus* appears and attains the maximum value of 2.7%. The upper limit of the zone is indicated by a rise in *Quercus* and a drop in *Pinus* and *Betula.*
K1	*Pinus*–*Artemisia*–*Juniperus*	1100	AP over 90% and *Pinus* pollen dominates (66.9%). *Betula* reaches 22.4%. Poaceae, Cyperaceae, *Artemisia* and *Juniperus* pollen is present. The upper boundary of the zone is marked by an decrease in *Pinus* and a rise in *Betula*.

Table 2

Correlation of local pollen zones (L PAZ) from Kubłowo with regional pollen zones (R PAZ) distinguished for the Konin region (Tobolski, 1991), for the Płock Plateau (Krupiński, 2005), and for Poland (Mamakowa, 1986, 1988, 1989) and also with the chronostratigraphy (Menke and Tynni, 1984; Behre and Lade, 1986; Behre, 1989)

<table>
<tr><th>Depth [cm]</th><th>L PAZ at Kubłowo</th><th>Płock Plateau R PAZ (Krupiński, 2005)</th><th>Konin region R PAZ (Tobolski, 1991)</th><th>Poland R PAZ (Mamakowa, 1986, 1988, 1989)</th><th colspan="3">Chronostratigraphy (Menke and Tynni, 1984; Behre and Lade, 1986; Behre, 1989)</th></tr>
<tr><td>380–395</td><td>K18 Poaceae–*Artemisia*–Cyperaceae</td><td rowspan="4">–</td><td>NAP II</td><td rowspan="5">–</td><td>WP III Ebersdorf Stadial</td><td rowspan="5">Plenivistulian</td><td rowspan="15">Vistulian</td></tr>
<tr><td rowspan="3">405–435</td><td rowspan="3">K17 *Pinus*–Poaceae</td><td>*Betula nana–Empetrum*</td><td rowspan="3">WP II Oerel Interstadial</td></tr>
<tr><td>*Betula alba–Artemisia*</td></tr>
<tr><td>*Betula nana*–NAP</td></tr>
<tr><td>445-490</td><td>K16 Poaceae–*Artemisia–Pinus*</td><td>NAP–(*Artemisia–Pinus*)</td><td>*Salix–Equisetum*</td><td>WP I Schalkholz Stadial</td></tr>
<tr><td>500–530</td><td>K15 *Pinus*–Poaceae–*Artemisia*</td><td rowspan="4">*Pinus*</td><td rowspan="2">*Pinus*</td><td rowspan="4">EV4 *Pinus–Betula*</td><td rowspan="4">WE IV Odderade Interstadial</td><td rowspan="10">Early Vistulian</td></tr>
<tr><td>540–590</td><td>K14 *Pinus–Betula*</td></tr>
<tr><td>600</td><td>K13 *Betula–Pinus*</td><td rowspan="2">*Pinus–Betula*</td></tr>
<tr><td>620</td><td>K12 *Pinus–Betula*</td></tr>
<tr><td>625–730</td><td>K11 *Artemisia*–Poaceae–*Juniperus*</td><td>NAP–*Artemisia*–(*Larix*)</td><td>NAP I</td><td>EV3 Gramineae–*Artemisia–Betula nana*</td><td>WE III Rederstall Stadial</td></tr>
<tr><td rowspan="2">740–790</td><td rowspan="2">K10 *Pinus*</td><td rowspan="2">*Pinus–Betula–(Larix–Artemisia)*</td><td>*Pinus*</td><td rowspan="4">EV2 *Betula–Pinus*</td><td rowspan="4">WE II Brörup Interstadial</td></tr>
<tr><td>*Betula*–NAP</td></tr>
<tr><td rowspan="2">800–870</td><td rowspan="2">K9 *Betula*</td><td rowspan="2">*Betula–(Pinus)*</td><td>*Betula–Larix*</td></tr>
<tr><td>NAP–*Betula*</td></tr>
<tr><td>880–915</td><td>K8 Poaceae–*Artemisia–Juniperus–Salix*</td><td>NAP–*Artemisia*</td><td>*Artemisia*–NAP</td><td>EV1 Gramineae–*Artemisia–Betula nana*</td><td>WE I Herning Stadial</td></tr>
<tr><td>925–960</td><td>K7 *Pinus–Picea*</td><td>*Pinus*</td><td>*Pinus*</td><td>*Pinus*</td><td colspan="2" rowspan="2">Late</td><td rowspan="7">Eemian Interglacial</td></tr>
<tr><td>965</td><td>K6 *Picea–Abies–Carpinus*</td><td>*Picea*</td><td>*Picea–Abies*</td><td>*Picea–Abies–Alnus*</td></tr>
<tr><td>975–995</td><td>K5 *Carpinus–Alnus–Corylus–Tilia*</td><td>*Carpinus*</td><td>*Carpinus*</td><td>*Carpinus–Corylus–Alnus*</td><td colspan="2" rowspan="3">Middle</td></tr>
<tr><td>1010–1020</td><td>K4 *Corylus–Tilia–Alnus*</td><td>*Corylus*</td><td>*Corylus*</td><td>*Corylus*</td></tr>
<tr><td>1030</td><td>K3 *Quercus*</td><td>*Quercus*</td><td>*Quercus*</td><td>*Quercus*</td></tr>
<tr><td>1040–1090</td><td>K2 *Pinus–Betula–Quercus*</td><td>*Pinus*</td><td>*Pinus–Betula*</td><td>*Pinus–Betula*</td><td colspan="2" rowspan="2">Early</td></tr>
<tr><td>1100</td><td>K1 *Pinus–Artemisia–Juniperus*</td><td>*Betula*</td><td>–</td><td>–</td></tr>
</table>

Sedimentation of the organic deposits at Kubłowo commenced when in the neighborhood there were open pine forests with a distinct share of birch (K1 L PAZ), scarce unforested terrains being grassy with heliophytes, junipers (*Juniperus*), sea-buckthorn (*Hippophaë*) and sage-brush (*Artemisia*) prevailing. Amelioration of the climate led to a visible reduction in heliothytes, replaced by dense birch-pine forests (K2 L PAZ). The interglacial climatic optimum begins with oak forests and some elm and ash (K3 L PAZ). Those forests were subsequently replaced by multispecies deciduous ones with hazel and lime dominant (K4 L PAZ). In humid habitats, perhaps near water bodies, alder has been found. With time, hornbeams began to spread. Hornbeam forest developed, in which initially were also oaks and lime. Hazel may have grown in the underbrush. With time the number of various tree species declined and hornbeam became dominant (K5 L PAZ). The decline of the climatic optimum was marked by the pre-eminence of hornbeam forest. The gradual cooling of the climate led to a recession of thermophilous trees and the appearance of spruce and fir (K6 L PAZ). Yew also grew in that phase, having sporadically appeared earlier in the hazel phase. Although the amount of yew pollen in the Kubłowo spectra is insignificant it may have been present in the tree-stand. It is equally scarce at Łanięta (Balwierz and Roman, 2002; Figs. 1 and 2). The Studzieniec site on the Płock Plateau shows the amount of the yew pollen at 9% (Krupiński, 2005) while at other sites in the area it is only 1–4%. The spreading of pine trees with some spruce and initially also fir (K7 L PAZ) marks the decline of the Eemian Interglacial.

VISTULIAN

The effect of climate change at the onset of the Vistulian was the withdrawing of the forest from the area investigated as open vegetation communities spread (K8 LPAZ). At the beginning of the first post-Eemian stadial (K8 LPAZ), pine was still present whereas in its younger part it probably disappeared (Fig. 6). Shrub communities grew, mainly juniper and willow. Most prevalent, however, were meadow-type grassland communities. Meadow communities were mostly at moist and fresh sites with *Sanquisorba officinalis, Polygonum bistorta, Rumex acetosa, Ranunculus acris* t., and *Plantago major* accompanying various grass species. At wet sites were present Cyperaceae, *Filipendula* and *Thalictrum*. Dry sites were populated by numerous sage-brushes, rock-roses and sorrels (*Rumex acetosella*). In open settlements and leached soils heathers developed. *Ephedra fragilis* pollen show that the vegetation communities were of an open type.

The Brörup Interstadial (K9–K10 L PAZ) at Kubłowo was tripartite (Fig. 6). In its older stadium birch was dominant (K9 L PAZ). Expansion of birch had already begun before the end of the first Early Vistulian stadial and resulted in a significant reduction of herbaceous communities. The share of pine pollen is low, which may be indicative of the absence of the pine at that time around Kubłowo. It is, however, possible that initially birch outcompeted pine, the latter only appearing at few sites, hence its insignificant share in the pollen spectra despite its presence in the tree stands. Its short-lived expansion took place at the end of the birch phase. At that time pine was also common in Central Poland (Krupiński, 2005) and Eastern Poland as shown by macrofossil remains (Granoszewski, 2003). The end of the birch phase was a cool climatic event expressed by the growth of herbaceous communities, mainly Poaceae, Cyperaceae, *Artemisia*, *Rumex acetosella* and shrubs with *Juniperus* (Fig. 6). Then, following a short cooler episode, birch forest regained significance although in the younger part of the interstadial it became restricted. Dense pine forests spread with larch and spruce (K10 L PAZ). At the end of the pine phase we observe a subsequent cool event within the Brörup. It is characterized, similarly to the former one, of a larger growth of herbaceous communities including heliophytic sage-brush, followed by a short-term return of pine forests. The pine phase terminated rapidly and a subsequent stadial of the Early Vistulian began.

The second Early Vistulian Stadial (K11 LPAZ) was a forestless interval (Fig. 6). A very low share of pine pollen suggests that the tree was absent at that time around Kubłowo. The boundary between the Brörup and the Rederstall Stadial is quite sharp, suggestive of a hiatus. Thus it is possible that at the beginning of the stadial there were patches of pine forest likewise at Łanięta (Balwierz and Roman, 2002), Mikorzyn (Stankowski *et al*., 1999) and the Płock Plateau (Krupiński, 2005). This also refers to birch, of which macro remains along with those of larch and spruce have been found at Horoszki (Granoszewski, 2003). At mid-stadial, however, heliophytic communities and mainly grasses and sage-brushes were dominant at that time, and much more numerous than in the Herning Stadial. There were also more taxa characteristic of open dry and dry/fresh sites (*Armeria, Plantago media, Centaurea jacea* t., *Helianthemum, Rumex acetosella*), fresh/moist and wet (*Thalictrum, Filipendula, Sanguisorba officinalis, Plantago maritima* s. str., *Polygonum viviparum, Plantago major, Ranunculus acris* t.) and also herbaceous plants at various habitats. *Betula nana* grew in peat bogs. Juniper and willow were also common and birch spread significantly at the end of the stadial.

The Odderade Interstadial (K12 –K15 L PAZ) is marked by a short spread of pine (K12 L PAZ) which is followed by a short dominance of birch (K13 LPAZ; Fig. 6). The pine (K14–K15 L PAZ) returned later to the investigated area. A constant appearance of heliophytic plants indicates that forest communities of the Odderade were not very dense. There were olso open site communities. These were most numerous at the onset and towards the end of the interstadial. Birch was predominant at the beginning of the interstadial and later its share decreased. A clearly birch-type character of the interstadial was also found at Mikorzyn (Stankowski *et al*., 1999), Horoszki (Granoszewski, 2003) and Dzierniakowo (Kupryjanowicz, 2008). No birch phase, however, has been found on the Płock Plateau (Krupiński, 2005).

The Schalkholz Stadial (K16 L PAZ) around Kubłowo was a forestless period (Fig. 6). The forest limits receded southwards. In the area investigated, however, there may have been small tree stands or isolated trees. Herbs and mainly grasses were predominant. *Artemisia* pollen is here much lower than in the Rederstall Stadial, possibly showing either a lesser influence of the continental climate or a higher groundwater level and more widespread moist and wet locations possibly indicating grassland communities.

The Oerel Interstadial (K17 L PAZ) has been delimited based on the AP curve growth and mainly that of *Pinus* (Fig. 6). Amelioration of the climate may have shifted the northern limit of the forest and/or a greater release of pollen. Hence a higher *Pinus* pollen share (Fig. 6), although the landscape around Kubłowo may have remained forestless. Herbaceous communities still dominanted in the area

An Ebersdorf Stadial (K18 L PAZ) fragment in the diagram features the highest herbaceous plant pollen in the entire profile, where it amounts to 84.9% (Fig. 6). Thus, in the area investigated, no trees were present. A high percentage of Poaceae pollen indicates a dominance of fresh/moist grassland settlements including *Thalictrum*, *Sanguisorba officinalis*, *Rumex acetosa*, *Pleurospermum*, *Plantago major* and *Ranunculus acris* t. Dry/fresh habitats were populated by *Artemisia*, *Rumex acetosella*, *Scleranthus annuus*, *Helianthemum*, *Plantago media* and *Juniperus*. Moreover plants of the Caryophyllaceae, Chenopodiaceae, Rubiaceae, Cichorioideae, Asteroideae and Apiaceae have been found. The prevalence of Poaceae and Cyperaceae over pollen grains of plants characteristic of dry habitats indicates the dominance of most grassy tundra communities over steppe forms. The presence of species characteristic of fresh/moist as well as dry settings suggests that at that time tundra and steppe communities could cohabit.

DISCUSSION

A great number of palynologically well-documented Eemian sites in Poland, described up to the year 1986 (Mamakowa, 1989), later (Tobolski, 1991), and recently (Krupiński, 2005; Kupryjanowicz, 2008) allowed precise documentation of the succession of vegetation of that interval. In the light of this knowledge an age determination of the bottom part of the deposit at the Kubłowo site as Eemian, in spite of its strong compaction, is beyond discussion. A low share of *Pinus* and *Betula* pollen grains at the Kubłowo site shows an absence of those trees in the area investigated in the younger part of the first post-Eemian stadial (Fig. 6) but at other sites (Granoszewski, 2003) birch-tree macro remains have been found, which indicated their presence at that time; however, there were no pine macro remains. Nita (Stankowski *et al*., 1999) does not exclude the withdrawal of the trees from the Mikorzyno area, Krupiński (2005), by contrast, suggested individual occurrence of pine, birch and spruce on the Płock Plateau.

The next issue is the presence of the cool climatic oscillation that took place at the end of the Brörup Interstadial birch phase. This oscillation is distinctly featured in the Kubłowo diagram (Fig. 6) and also appeared in the diagram from Łanięta (Balwierz and Roman, 2002), Władysławów (Tobolski, 1986), Mikorzyn (Stankowski *et al*., 1999), Horoszki (Granoszewski, 2003), Solniki and Dzierniakowo (Kupryjanowicz, 2008). However, that oscillation has not been marked in the diagrams from the Płock Plateau (Krupiński, 2005). The older, birch part of the interstadial is correlated by Kupryjanowicz (2008) with the Amersfoort Interstadial, and the younger, the pine part, with the Brörup *sensu stricto*. According to Granoszewski (2003) the older part of the interstadial at the Horoszki site corresponds with the Amersfoort Interstadial (Zagwijn, 1961), and the younger one with the Brörup Interstadial *sensu* Andersen (1961). Other authors (Stankowski *et al*., 1999; Balwierz, 2003) correlate both the older as well as the younger part of the interstadial with the Brörup (Behre and Lade, 1986; Behre, 1989). On account of the distinct cool oscillation between the birch and the pine phases at Kubłowo one should determine that interstadial as the Brörup *sensu lato*. In the pine phase decline of the Brörup Interstadial at Klubowo there is still one cool oscillation, expressed by an increase of the share of the open communities (Fig. 6). This oscillation has been marked also at the Mikorzyn site (Stankowski *et al*., 1999); however, there is no oscillation at Horoszki (Granoszewski, 2003) or at, Dzierniakowo and Solniki (Kupryjanowicz, 2008).

The distinction two stadials and one interstadial in the Plenivistulian in the diagram from Kubłowo (Fig. 6) is debateable. That distinction in the continuous pollen diagrams is difficult, especially with no independent dating. It has been noted earlier, and no stadials and interstadials were distinguished (Balwierz, 2003) or interpretation was ambiguous (Granoszewski, 2003). A low AP share shows, that the Plenivistulian in Central Poland was a woodless period. Slight fluctuations of the AP curve, almost all of *Pinus* and *Betula*, can only show movement of the forest boundary in the southern part of Poland. Therefore the tree pollen grains found in Plenivistulian deposits in Central Poland probably originated from long-distance aeolian transport and redeposition (Balwierz, 2007).

Changes in the herbaceous plant communities registered in the pollen diagrams may have depended more on habitat changes, mainly on changing ground humidity, and might have resulted from other local causes or be synchronous with changes in climate. The continuous pollen diagrams from the Dzierniakowo section (Kupryjanowicz, 2005) may plausibly be helpful for distinguishing the stadials and interstadials in Plenivistulian.

CONCLUSIONS

The Kubłowo profile comprises one of the longest Upper Pleistocene interglacial-glacial successions in Poland. Lacustrine and peat sedimentation at Kubłowo began at the onset of the Eemian Interglacial and lasted continuously throughout that interglacial, the Early Vistulian and part of the Plenivistulian.

Two stadials and two interstadials have been distinguished in the Early Vistulian. In the Brörup Interstadial, towards the close of the birch phase, a cooling event has been recorded. Two stadials and one interstadial have been found in the Plenivistulian. The warm and cool units in the Vistulian were correlated with the divisions established for Western Europe (Menke and Tynni, 1984; Behre and Lade, 1986; Behre, 1989).

The different climatic conditions shown in the pollen record are clearly visible as reflected in lithology changes which indicates an organic to mineral transition observed at the boundaries between the Eemian Interglacial and the Vistulian, and also between interstadials and stadials within the Vistulian. The lack of till or till residua overlying the Eemian deposits at Kubłowo indicates the area as being beyond the reach of the last Scandinavian ice sheet, which confirms the reconstruction of the LGM ice sheet limit as based on geomorphological evidence. Analysis of the spatial distribution of till-covered and till-free Eemian sites appears useful for regional delimitation of the LGM extent around the Vistula ice lobe.

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