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# Pollen analysis from fossil podzol soils within a dune at Kaczórki (Middle Roztocze, Poland)

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ABSTRACT: Based on pollen analysis and radiocarbon dating an attempt was made to reconstruct the vegetation cover during the formation of fossil podzol soil in the dune at Kaczórki (Middle Roztocze). Pollen spectrum of the Bfeb horizon indicates the occurrence of forest on the dune since at least the Holocene climatic optimum. At that time, pine forest with an admixture of birch, and a high proportion of heather (*Calluna vulgaris*) grew on the dune, and various forest communities developed in the surrounding areas in a variety of different relief settings. Pedogenesis was interrupted in the 7$^{th}$ century AD. The destruction of forest cover, probably caused by fire, resulted in the activation of aeolian processes and new accumulation of sand deposits occurred on the dune. High entomophilous pollen values of *Tilia*, *Acer*, and *Calluna vulgaris* in soil horizons that are generally not found in lacustrine and peat deposits, probably indicate that the sand deposits and acid environment of podzol soil preserve these pollen well (mineralized grains). High frequencies of *Tilia* and *Acer* pollen probably resulted from the occurrence of forests which resembled modern forest communities of the *Tilio-Acerion* alliance near the examined site.

KEY WORDS: pollen analysis, fossil soil, podzol soil, dune, Holocene, Middle Roztocze, Poland

## INTRODUCTION

Late Vistulian and Holocene fossil soils in dunes are interesting objects of palaeogeographical studies (Tobolski 1975, Manikowska 1985, Miotk-Szpiganowicz & Olszak 1996, Tobolski et al. 1997). Pollen analyses from humus horizons provide possibilities for the reconstruction of vegetation cover development, and also for the reconstruction of some geomorphologic processes. However, palynological examination of the fossil soils presents many problems of methodicalogical nature, as dealt with by many papers (Tobolski 1975, Faegri & Iversen 1989, Nalepka 1999, van Mourik 2003, Latałowa 2004). The question of sporomorphs migration is an important part of these studies.

Pollen grains deposited in lacustrine deposits and peats are an inherent component of the individual deposit; those falling on the soil surface are displaced to its lower horizons. According to Andersen (1986), vertical transport of soil particles by invertebrates, as well as oxidation, are the main processes occurring in present soils. These are reflected in a different degree of sporomorph exine preservation. In fertile humus of the mull type that is enriched in nutrients, intense animal activity is connected with an abundance of earthworm and insects. Lower soil pH in general results in reduced activity of the soil fauna (Dimbleby 1985), and in this regard horizons with acid humus of the moor type are suitable for pollen analysis because invertebrate life is very poor in them. As a consequence mineral material is not mixed, pollen spectra are less disturbed, and the pollen occur in chronological order through the profile.

The results of microstructural analysis concerning the state of pollen preservation

in soils with humus of a mormoder type were published by van Mourik (2003). He distinguished several stages of pollen deposition in soils developing for about 100 years. The first stage is aeolian deposition of pollen on the soil surface. The second stage consists in incorporation of pollen grains into organic aggregates in the upper part of the F horizon. The third stage is associated with microbiological activity within the aggregates in the F, H, and Ah horizons. The fourth stage consists of release of pollen grains from aggregates as a result of microbiological consumption. The mineralization of released pollen grains is the main process occurring in the AE horizon.

The purpose of this paper is to reconstruct the vegetation cover from pollen analysis of fossil podzolic soil occurring in aeolian dunes at Kaczórki (Middle Roztocze), and to obtain information about the time and circumstances in which the examined soil was buried.

## PHYSICO-GEOGRAPHICAL CHARACTERISTICS OF THE STUDY AREA

In the Roztocze region the first dunes started to form about 15–13.5 ka BP, with the Sandomierz Basin the source area for aeolian cover and dune sands (Buraczyński 1993). The distribution of dunes in the Roztocze region is connected with relief. Low, longitudinal dunes occur on hilltops whereas large dune ridges developed in valleys, along leeward slopes. Additionally, small dune hills are found in various morphological positions.

The present investigation was carried out within the dune at Kaczórki (50°34′N, 23°08′E) in the Middle Roztocze (Fig. 1). This dune, composed of aeolian sands from the turn of the Pleistocene and Holocene (Kurkowski 1996), is located in the Wieprz River valley, on the Pleistocene terrace. The relative height of the dune does not exceed 10 m, and its surface is mainly overgrown with pine.

## MATERIAL AND METHODS

The following features of soil samples were determined: grain size by means of the Casagrande aerometric method modified by Prószyński (Lityński et al. 1976), reaction in 1M KCl using the electrometric method, content of organic carbon (C org.) using the method outlined by Tiurin (Lityński et al. 1976), colour in an air-dry state according to Munsell Soil Colour Charts (1994). The age of charcoal from the Ab horizon of the examined fossil soil was determined by radiocarbon dating methods in the $^{14}C$ in the Institute of Physics of Silesian Technical University in Gliwice.

Pollen analysis was carried out on samples from three horizons (Ab, Eesb, and Bfeb) from the fossil podzol soil. Each 100 g of sediment, after removing sand by decantation, was treated with HF acid, and prepared by Erdtman's acetolysis method (Faegri & Iversen 1989, Wasylikowa 1973). Pollen grains were examined under a light microscope with the magnification of 400×. The magnification of 1000× using immersion oil was applied in more difficult cases. About 600–800 grains of tree pollen were determined. Only sporomorphs with strongly damaged sculpture (which made determination impossible) were classified as corroded grains. The percentages of individual taxa were calculated in relation to the sum of AP+NAP, but without limnophyta and telmatophyta. The results of pollen analysis are presented in the form of histogram and cyclograms for the main tree taxa.

High pollen values of *Tilia* and *Acer* in all analysed spectra raised doubts. In order to exclude accidental error, the analysis was repeated for the rest of the material, and additional samples were taken from other places of the same soil horizons. All additional samples also contained high frequencies of *Tilia* and *Acer* showing that their pollen was not accidentally over-represented, e.g. due to the occurrence of the whole anther.

## RESULT OF ANALYSES

### DESCRIPTION OF FOSSIL SOIL

The investigated fossil soil profile was situated in the wall of a sand pit located in the central part of the dune, 4.80–6.20 m below ground surface (Fig. 2). The examined soil is a typical podzol soil according to the Systematics of Polish Soils (Trzciński 1989), and has the following features:

| | | |
|---|---|---|
| 4.80–4.90 m | Ab | Loose sand: 92.4% of the fraction 1.0–0.1 mm, 4.6% of the fraction 0.1–0.02 mm, 3.0% of the fraction <0.02 mm; grey colour (2.5 Y 6/1); distinct, clear irregular boundary; $pH_{KCl}$ = 4.0; C org. content – 0.52%; charcoal dated at 1380±110 years BP (Gd-15161). |
| 4.90–5.08 m | Eesb | Loose sand: 92.6% of the fraction 1.0–0.1 mm, 4.4% of the fraction 0.1–0.02 mm, 3.0% of the fraction <0.02 mm; light-grey colour (10 YR 7/2); sharp, abrupt irregular boundary; $pH_{KCl}$ = 3.9; C org. content – 0.29%. |
| 5.08–5.20 m | Bfeb | Loose sand: 90.3% of the fraction 1.0–0.1 mm, 9.7% of the fraction 0.1–0.02 mm, 0.0% of the fraction <0.02 mm; yellowish-brown colour (10 YR 6/8); gradual boundary; $pH_{KCl}$ = 4.6; C org. content – 0.24 %. |

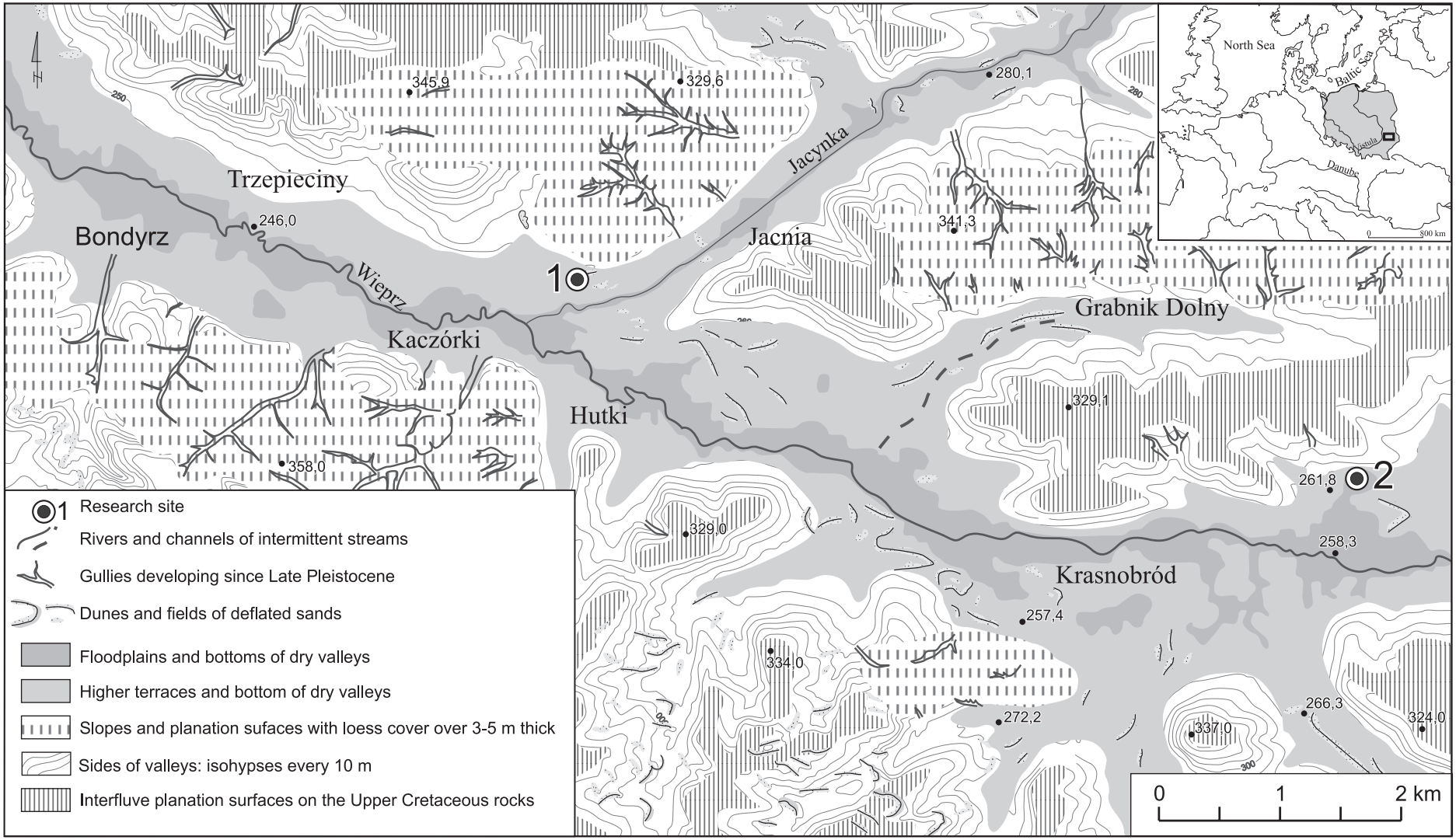



**Fig. 1**. Location of the investigated sites at Kaczórki (site **1**) and Krasnobród (site **2**) against a background showing the main features of topographic relief (after H. Maruszczak 1996)

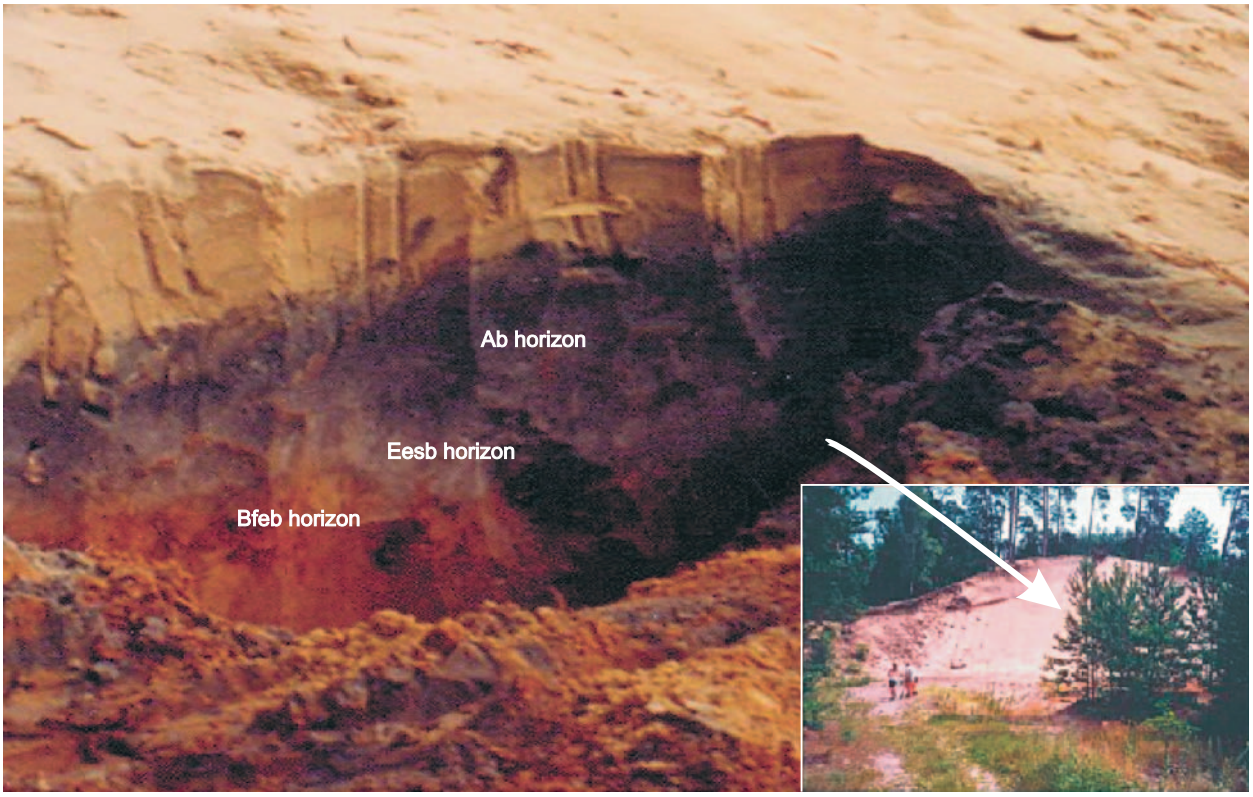



**Fig. 2**. Fossil podzoil soil in the dune at Kaczórki. Phot. J. Chodorowski

| | | |
|---|---|---|
| 5.20–5.35 m | BfebC1 | Loose sand: 92.7% of the fraction 1.0–0.1 mm, 7.3% of the fraction 0.1–0.02 mm, 0.0% of the fraction <0.02 mm; yellow colour (2.5 Y 7/8); gradual boundary; $pH_{KCl}$ = 4.7; C org. content – 0.13 %. |
| 5.35–5.60 m | C1 | Loose sand: 89.4% of the fraction 1.0–0.1 mm, 10.6% of the fraction 0.1–0.02 mm, 0.0% of the fraction <0.02 mm; light-yellow colour (2.5 Y 7/4); $pH_{KCl}$ = 4.7. |
| 5.60–6.20 m | C2 | Loose sand: 94.3% of the fraction 1.0–0.1 mm, 5.7% of the fraction 0.1–0.02 mm, 0.0% of the fraction <0.02 mm; light-yellow colour (2.5 Y 8/4); $pH_{KCl}$ = 4.7. |

The examined podzol soil was formed from loose sands, in which the content of sand fraction (1.0–0.1 mm) ranges from 89.4% to 94.3%. This soil is very acid in its upper genetic horizons, but reactions change into medium-acidic with increasing depth. The highest content of organic carbon (0.52%) is in the Ab horizon, and it decreases with the depth.

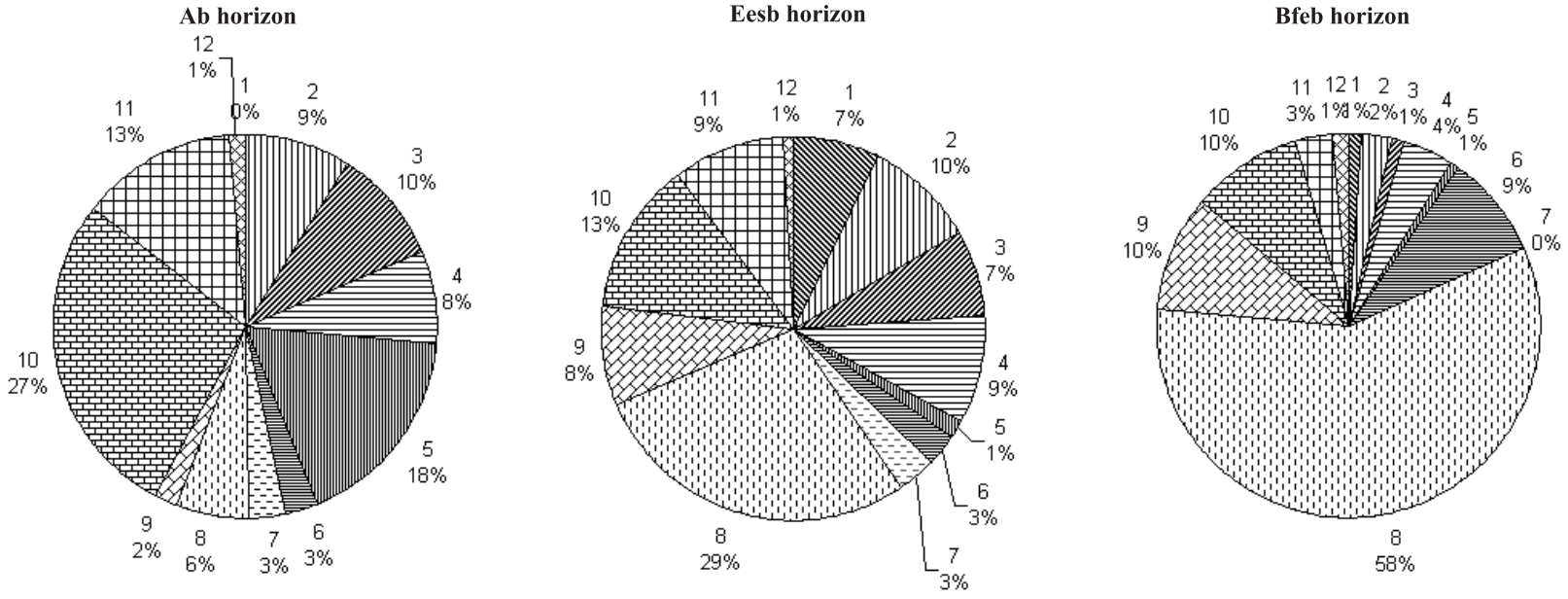
## RESULTS OF POLLEN ANALYSIS – DESCRIPTION OF POLLEN SPECTRA

The results of pollen analysis are presented in Figures 3 and 4. Pollen spectra reveal considerable quantitative differentiation in individual horizons indicating a transformation of plant communities during pedogenesis. Predominant taxa are connected with three types of habitats: 1) wet (*Alnus*), 2) fertile and moderately wet (*Carpinus betulus*, *Tilia*, *Fagus sylvatica*, *Acer*, *Quercus*, *Corylus avellana*), and 3) dry and sandy (*Pinus*, *Calluna vulgaris*).

The Bfeb horizon (the sample taken from the depth of 5.10–5.20 cm) is characterized by high pollen values of *Tilia* (64.5%) and *Calluna vulgaris* (10.7%). The frequency of *Pinus* is 9.5%, of *Carpinus* about 5%, of *Acer* 1.3%, those of *Fagus* do not exceed 1%, and typically comprise 0.3% of corroded grains. Most of grains are mineralized.

In the Eesb horizon (the sample taken from the depth of 4.90–5.00 cm) the pollen value of *Calluna vulgaris* is still high (13.2%). The frequency of *Carpinus* (over 9%), *Acer* (7.5%), and *Fagus* (1.4%) rise. Percentages of *Tilia* are <50% of those from the previous spectrum, and do not exceed 30%. The values of *Pinus* decrease, and those of *Betula* and NAP increase. Pollen grains of cereals (*Triticum* type), and *Plantago lanceolata* are also present. Corroded grains account for 1.2%.

In the Ab horizon (the sample taken from




**1** – *Acer*, **2** – *Alnus*, **3** – *Betula*, **4** – *Carpinus betulus*, **5** – *Fagus sylvatica*, **6** – *Pinus*, **7** – *Quercus,* **8** – *Tilia*, **9** – *Corylus avellana*, **10** – *Calluna vulgaris,* **11** – NAP, **12** – other trees

**Fig. 4**. Percentages of the selected taxa in the genetic horizons of podzol soil

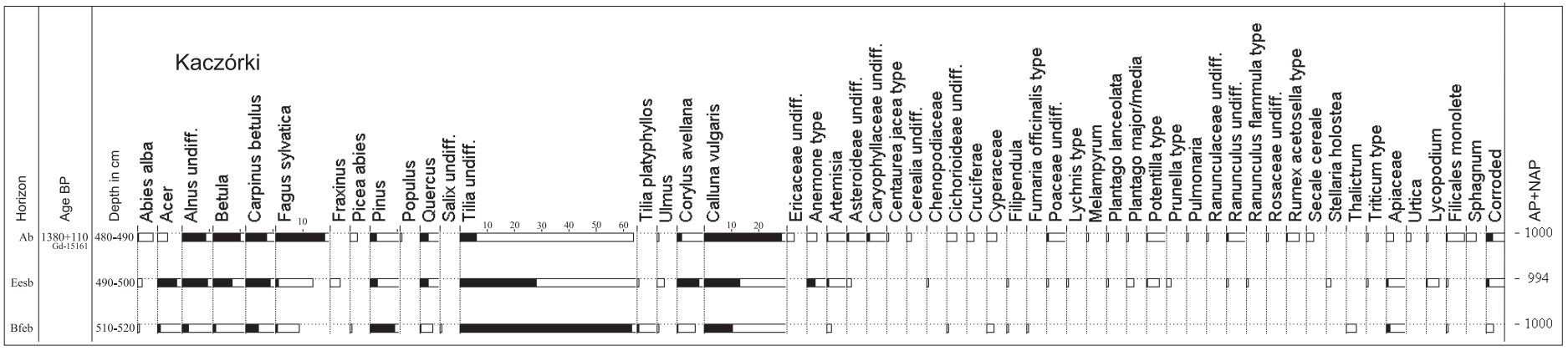



**Fig. 3**. Percentage pollen diagram of podzol soil at Kaczórki

the depth of 4.80–4.90 cm) the percentages of *Calluna vulgaris* are still the highest (29.0%). From among tree taxa the highest frequencies are those of *Fagus* (18%), *Alnus* (9.1%), and *Carpinus* (8.0%). The NAP values rise. Pollen grains of cereals, in it of *Secale cereale*, are present. Corroded grains make 2.5%.

The composition of the spectra is characterized by high pollen values of lime that has occurred in the Roztocze Region since about 8500 years BP (Bałaga 1998) reaching the maximum proportion in forests during the Atlantic period. This indicates that pedogenesis started on the dune not later than in the middle Holocene, and was interrupted in the younger Holocene when hornbeam-beech forests intensively developed. Radiocarbon dating of charcoals from the Ab horizon of the examined soil yielded age estimate of 1370±100 years BP indicating that forest cover was probably destroyed in the 7th century AD (Walanus & Goslar 2004). The results of pollen analysis of the Ab horizon were compared with the pollen diagram obtained for the nearby mire at Krasnobród (situated about 7 km westwards). This comparison reveals that the soil was still developing in the period of the "Migration of People". The pollen data from the mire evidence the regeneration of forest communities, mostly hornbeam-beech ones, at that time (Bałaga 1998). The percentages of the selected tree taxa in the part of the Krasnobród profile correlated with that period are presented in the Figure 5 and Table 1.

The pollen values of *Pinus*, *Betula*, and *Quercus* in the soil profile are lower than in the peat profile. This fact could have resulted both from the conditions of pollen deposition and differentiation of local habitats. Pollen spectra of soil represent rather local vegetation.

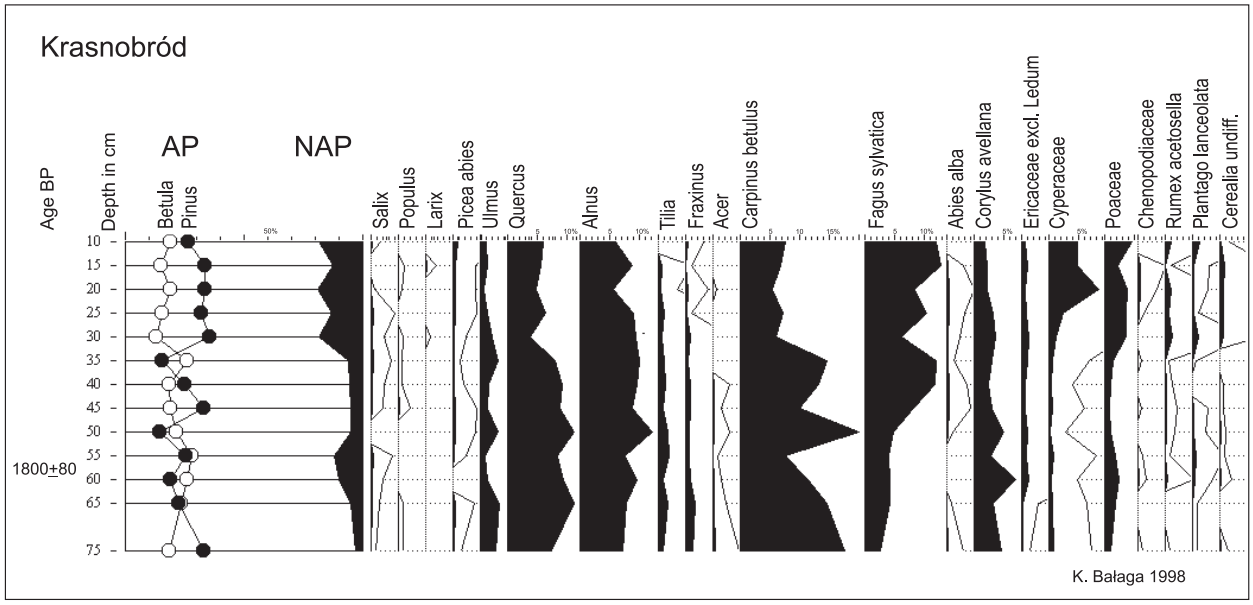



**Fig. 5**. A fragment of the pollen diagram of the Krasnobród profile (Bałaga 1998)

**Table 1**. The percentages of selected tree taxa (with *Corylus*) in the part of the Krasnobród profile correlated with the period 1500–1050 years BP (interpolated ages). Gray line indicates the radiocarbon age of pollen spectrum, which is the most similar to the radiocarbon age of the soil

| Depth cm | Age BP | *Acer* | *Alnus* | *Betula* | *Carpinus* | *Fagus* | *Quercus* | *Tilia* | *Ulmus* | *Pinus* | *Corylus* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 | 1050 | – | 10.1 | 26.0 | 14.5 | 12.0 | 8.0 | 0.1 | 3.0 | 15.4 | 3.0 |
| 40 | 1200 | 0.3 | 9.6 | 18.7 | 13.2 | 11.9 | 9.2 | 1.1 | 1.4 | 25.2 | 2.3 |
| 45 | 1350 | 0.1 | 8.7 | 18.8 | 10.1 | 8.3 | 8.7 | 0.7 | 1.2 | 33.1 | 3.1 |
| 50 | 1500 | 0.3 | 12.3 | 12.1 | 20.0 | 4.8 | 11.3 | 1.7 | 3.1 | 14.1 | 5.0 |
| Average | | 0.23 | 10.17 | 18.9 | 14.45 | 9.52 | 9.3 | 0.9 | 2.17 | 21.95 | 3.35 |

RECONSTRUCTION OF VEGETATION COVER

The character of pollen spectrum of the Bfeb horizon indicates that in the middle Holocene the dune was occupied by open pine forest with an admixture of birch, and abundant *Calluna vulgaris* as an undergrowth. Diversified relief in the dune surroundings favoured the development of various forest communities. In close proximity to the dune, in the valleys of the Wieprz River and the tributary Jacynka stream, alder carrs, in which alder was the main component, dominated. The low pollen values of *Fraxinus* and *Ulmus* indicate that riverine forests with elm and ash, usually preferring less wet habitats, occupied probably very small areas. Elevations with moderately wet soils were occupied by deciduous forests with lime, oak, and elm. The occurrence of hornbeam and beech pollen can be related to the Subboreal forest communities because these species encroached on the Roztocze territory about 3500 years BP (Bałaga 1998). The highest values of lime in the pollen spectrum resulted probably from the abundance of this tree in forest communities near the studied site during the Atlantic period. Its pollen grains are resistant to destruction, and can be washed down into the Bfeb horizon.

The increasing pollen values of *Carpinus* and *Fagus* in the Eesb horizon evidence the higher proportions of hornbeam and beech in forest communities surrounding the dune, connected with the Subboreal and then Subatlantic period when these species became more abundant in forests of the Central Roztocze (Bałaga 1998). Single pollen grain of *Stelaria holostea*, a species characteristic of *Carpinion betuli* alliance, can indicate significance of dry-ground associations in the formation of forest communities in the studied area. Their expansion was probably favoured by the Neolithic economy. Pollen grains of cereals (*Triticum* type) and *Plantago lanceolata* in this horizon indicate the occurrence of man but the dune itself was probably out of its economic activities.

The rising pollen values of NAP in the Ab horizon, the occurrence of cereals (*Secale cereale*, *Triticum* type), and *Calluna vulgaris* indicate the transformation of vegetation cover, which resulted from the progressive deforestation of not only fertile habitats but also sandy ones (such as on the described dune). However, considerable changes in vegetation cover occurred on more fertile soils. The changes in forest composition were conducive for beech growth (its pollen values increase over ten times). The Ab horizon can be correlated with the pollen zone in the Krasnobród diagram (Bałaga 1998), which is characterized by the highest pollen percentages of beech (the period of "Migration of People").

## DISCUSSION

The highest number of taxa (41) is determined in the Ab horizon, in which the content of C org. is the highest (0.52%). In this horizon the number of difficult to identify corroded pollen grains is also the highest. It can be assumed after van Mourik (2003) that pollen grains in this horizon were incorporated into organic aggregates, which were next subjected to microbiological activity. The number of determined taxa decreases in the Eesb and Bfeb horizons (analogically to the content of humus: 0.29 and 0.24, respectively), which was presumably caused by the destruction of thin-walled pollen grains. The highest number of mineralized grains is found in the Bfeb horizon, in which the content of silt (0.1–0.01 mm) is two times higher than in two overlying horizons. Thick-walled, resistant to destruction pollen grains of *Tilia* predominate in this horizon. *Acer* and *Calluna vulgaris* also occur but their curves reveal a reverse tendency than that of *Tilia*. Among the trees, only the curve of *Pinus* is similar but its pollen values are considerably lower, albeit pine undoubtedly grew on the dune. The grain size of the examined soil, and especially the content of the fraction $< 0.02$ mm, does not evidence the migration of fines down the soil profile. Accordingly, the problem of pollen migration down the profile is difficult to resolve. However, a substantial preservation of the pollen allows us to reconstruct the vegetation history; it predominantly applies to the species, whose pollen is preferentially preserved in the examined soil.

Lime (*Tilia cordata*, *T. platyphyllos*) produces rather large number of pollen grains (Dyakowska 1959) but due to its entomophily, weigh and size of its pollen, this genus is weakly represented in "pollen rain". Weak dispersion of lime pollen results in its under-

representation in pollen diagrams (Andersen 1970, Środoń 1991). It is generally assumed that lime is more frequent in forest communities than it appears from pollen analysis. On the other hand, pollen grains of lime are resistant to destruction, and even when damaged they can often be identified. This fact could result in over-representation of this taxon, especially in dry, weakly oxidized deposits.

The pollen values of lime in the examined soil profile progressively increase with depth probably indicate that its pollen was displaced into lower horizons. This phenomenon can also be responsible for over-representation of this taxon. The high pollen frequency of lime and similar distribution (a rise in its percentages with depth) was also found in fossil soil in the Błędowo Desert (Okuniewska-Nowaczyk 2005).

Small-leaf lime is a species characteristic of *Carpinion betuli* alliance (Matuszkiewicz 2002). It occurs mostly in subcontinental oak-hornbeam forests (*Tilio-Carpinetum*), and also in lowland communities of *Acer platanoides* and *Tilia cordata* (Matuszkiewicz 2002). It can be also found in beech, oak, mixed coniferous, and riverine forests. On the other hand, *Tilia platyphyllos* is species characteristic of *Tilio platyphylli-Acerion pseudoplatani* alliance, i.e. humid slope forests with maple-tree, sycamore, and lime.

Pollen grains of *Acer* are most frequent in the Eesb horizon. *Acer* (*A. platanoides*, *A. pseudoplatanus*, and *A. campestre*) is also weakly represented in "pollen rain". Its pollen occurs sporadically, and its values usually do not exceed 1% of AP+NAP. The low frequency of *Acer* can be also connected with low pollen production resulting from entomophily of this genus as well as the weight of its pollen grains. Its pollen grains are fairly thick and as resistant to decay as those of lime. Despite the low values of *Acer* in pollen diagrams, it is considered to be an important component of forests in Holocene. Similarly as in the case of lime, the high pollen values of *Acer* were found in fossil soil in the Błędowo Desert (Okuniewska-Nowaczyk 2005).

Individual species of *Acer* genus occur in different forest communities, such as beech wood, dry-ground forests, and riverine forests. *Acer pseudoplatanus* is characteristic species of the *Tilio-Acerion* alliance (Matuszkiewicz 2002). *Acer platanoides* is one of characteristic components of thermophilous shrub communities of the *Rhamno-Prunetea* class, and also deciduous forests of the *Querco-Fagetea* class, and especially *Galio-Carpinetum* (Matuszkiewicz 2002).

In our times the proportions of *Tilia cordata*, *Acer pseudoplatanus*, *A. platanoides* in forests of the Central Roztocze are low, and that of *Tilia platyphyllos* is very low. *Tilia platyphyllos* and *Acer pseudoplatanus* reach their limits in this region (Izdebski et al. 1992).

During its Holocene history in the Central Roztocze, lime reached the development optimum in the Atlantic period as evidenced by its high pollen values (6.2%) in the Krasnobród diagram. The values of *Acer* in pollen diagrams from the Central Roztocze do not exceed 1%, and its highest recorded frequencies correspond to the end of the Atlantic period in the Krasnobród profile, and to the Subboreal period in the Krasnobród and Tarnawatka profiles (Bałaga 1998).

The high pollen values of *Tilia* and *Acer* in the obtained spectra were probably connected with high proportions of these trees in forest communities near the studied site. Can we conclude that lime-sycamore forests, in our times classified to *Tilio-Acerion*, existed probably in the dune surroundings at that time? In modern forests of the Roztocze the increased proportions of maple-tree and sycamore are found in the patches of slope beech wood (*Fagetum carpaticum*) occurring in forest ravines. Similarly, *Tilio-Carpinetum* forests in the *stachyetosum silvaticeae* and *caricetosum pilosae* varieties, occupying lower parts of forest ravines, are characterized by the increased proportions of lime (Izdebski et al. 1992). Differentiated relief of the studied region and so varied habitats favoured the abundance of lime (*Tilia cordata*, *T. platyphyllos*) as well as different species of *Acer* in forest communities. Therefore, it can be supposed that nowadays-deforested slopes of elevations, which are situated near the dune, were once covered by forest. Those communities, locally with high proportions of lime, maple-tree, and sycamore, probably resembled modern slope forest communities of *Tilio-Acerion* alliance. Erosion processes, also those caused by human activities, e.g. of Early Neolithic people (Gurba 1960), could have created favourable conditions for the development of such communities. On the other hand, wide

ecological tolerance of the above-mentioned taxa allowed them to enter different forest communities as components.

## CONCLUSIONS

1. Results of pollen analysis and radiocarbon dating indicate that the fossil podzol soils developed on the dune until about the 7$^{th}$ century AD. The dune was occupied by pine forest with an abundant heather undergrowth, and different forest communities developed in its surroundings.

2. The high pollen values of plants from fertile habitats indicate that dry-ground forests with hornbeam, beech, and oak were predominant. Hypsometrically differentiated surroundings of the dune favoured the development of these communities. Alder carrs with *Alnus* occurred in the valleys. The low frequency of *Ulmus* and *Fraxinus* pollen probably evidence small, even local occurrence of riverine communities with elm and ash.

3. High frequency of *Tilia* and *Acer* pollen probably resulted from the occurrence of forests which resembled modern forest communities of *Tilio-Acerion* alliance near the examined site.

4. With the intensification of human economic activities during the early Middle Ages, the forests on the dune and in its surroundings were destroyed. Consequently, aeolian processes were initiated, and sandy deposits started to accumulate again.

5. Pollen grains of entomophilous species (*Tilia*, *Acer*, *Calluna vulgaris*) are very well preserved in this sandy podzol soil with acid reaction. The high values of *Tilia* in the Bfeb horizon is probably due to the displacement of its pollen grains, which are accumulated in lower horizons of the fossil soil. The curve of *Pinus* has similar tendency but its pollen values are considerably lower though pine undoubtedly grew on the dune. Grain size of the examined soil, and especially the content of the fraction < 0.02mm, does not evidence the migration of fines down the soil profile. Therefore, the problem of pollen migration down the profile is difficult to resolve.

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