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Eemian and Vistulian pollen records from the Łomża region (NE Poland)

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In the Łomża region, northeastern Poland, many new lacustrine and peat deposits have been found. Pollen analysis of borehole material shows that they accumulated mostly during the Eemian Interglacial. Parts of these sites were active in the Vistulian, probably in its early phases. The sites analysed usually represent small lakes or peat-bogs sediment with accumulating in different time intervals of the Eemian. Only exceptionally they are represented by deep-water facies with a decrease in water level not before the hornbeam zone, as seen at many Eemian sites in Poland. Especially interesting is the occurrence in the pollen spectra of a number of exotic taxa such as *Viburnum lantana*, *Bruckenthalia spiculifolia*, *Falcaria vulgaris*, *Lycopodium lucidulum* t. noted previously in the Eemian Interglacial mainly in the south and in the southeastern Poland, where milder climatic conditions prevailed. The analysed interglacial spectra also show signs of plant — animal interaction. Such signs have been observed in Holocene and Vistulian strata, although in other pollen taxa. Pollen affected by these processes may come to resemble other species and so be misidentified.

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Key words: Eemian, pollen, Łomża region, plant-animal interaction.

INTRODUCTION

The Łomża region, situated in part in an area of fresh morainic landscape (Fig. 1) should be potentially rich in interglacial (Eemian) and glacial peat/lacustrine pollen sequences. Deposits of this ages have already been noted at Konopki Leśne, south of Łomża (Borówko-Dłużakowa, 1957), at Kupiski Nowe (Borówko-Dłużakowa, 1975), at Jednaczewo, west of Łomża (Borówko-Dłużakowa, 1975) and at a few sites in the Łomżyczka valley, formed in an extensive glacitectonic depression, deeply incised into pre-Quaternary strata (Niklewski and Dąbrowski, 1974 unpubl;. Krupiński 1992; Niklewski and Krupiński, 1992; Straszewska, 1992) as well as at Niewodowo, situated in small depressions on a morainic plateau with low water inflow (Musiał *et al*., 1982; Bińka *et al*., 1988). In subsequent investigations for the *Detailed Geological Map of Poland*, a number of new interglacial and glacial lacustrine/marsh deposits have been discovered (Figs. 1and 2).

The aforementioned sites are parts of a large buried lake district, which was present in northeastern Poland during the Eemian. Deposits of this age, often with a Vistulian record, are known, for instance, from a peat-bog at Machnacz (Kupryjanowicz, 1991), from Smolniki (Kupryjanowicz *et al*., 2005), from Haćki (Brud and Kupryjanowicz, 2002) and from Michałowo (Kupryjanowicz and Drzymulska, 2002). The location of Eemian deposits in northeastern Poland is given by Kupryjanowicz *et al*. (2005).

GEOMORPHOLOGY AND GEOLOGY OF THE ŁOMŻA AREA

The Łomża area is located within the Łomża inter-rivers region, which is part of the north Mazovian Lowland. Morphologically differentiated, it includes the Narew River valley and a morainic plateau. The Narew River valley in the vicinity of Łomża has the features of a narrow water-gap. A well-pronounced feature on the morainic plateau, besides end moraines, crevasses (eg. eskers) and dead-ice forms (kames and dead-ice moraines), the Łomżyczka depression was formed above a buried glacial furrow.

The average elevation of the morainic plateau is 135 m a.s.l., but the altitude of the highest forms is about 145 m a.s.l.

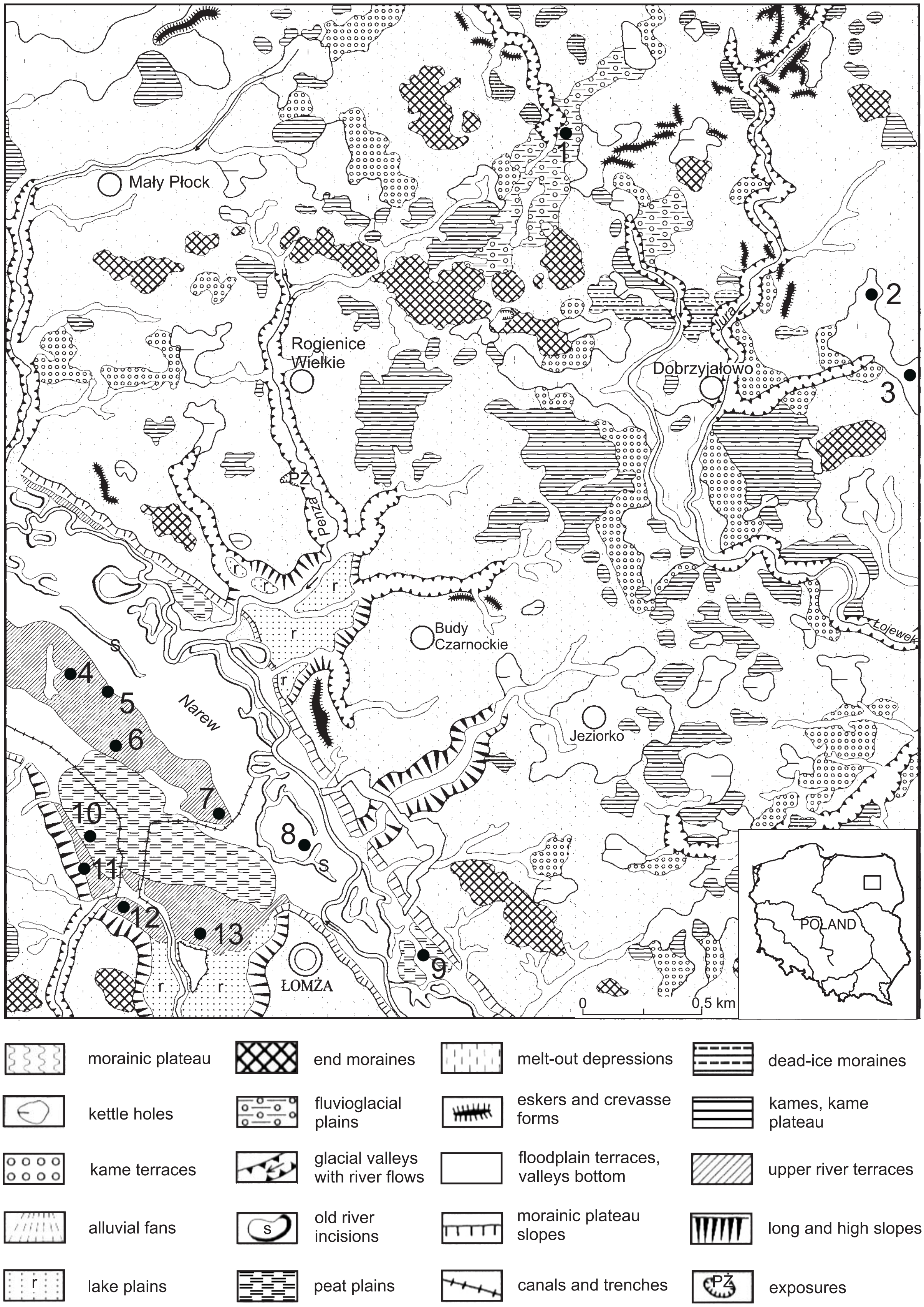

Fig. 1. Geomorphological sketch of the Łomża vicinity and location of sites (1–13) examined by pollen analysis

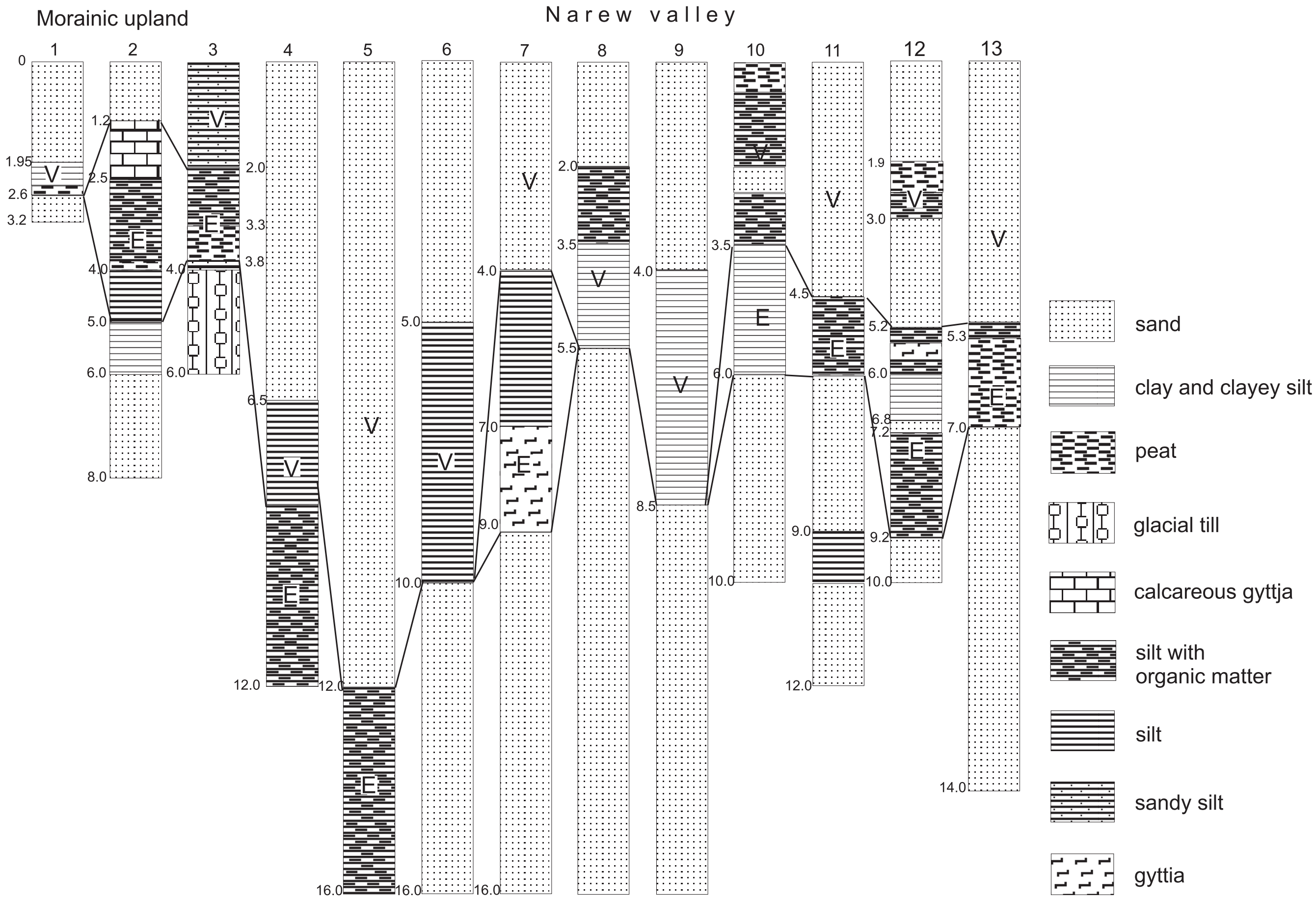

Fig. 2 Correlation of the boreholes analysed

E — Eemian Interglacial, V — Vistulian Glaciation

The Łomżyczka furrow, in which a few sites are situated, is a N–S elongated depression about 7 km in length. Its bottom is located at 105–107 m a.s.l., higher than the bottom of the Narew River. The ancient sediment-filled Łomżyczka furrow was captured by the Narew River during the modelling of the valley. The remodelling and adjustment of the northern part of the Łomżyczka depression by the Narew River took place when a gateway in its valley was formed (Bałuk, 1975, 1991).

In the Łomża area the Pleistocene is underlain by Miocene and Oligocene deposits (Fig. 3). Their thicknesses and lithology were investigated means of boreholes drilled for the *Review Geological Map of Poland* at a scale of 1:200 000 and, in the last decade, by numerous boreholes drilled for the *Detailed Geological Map of Poland* at 1:50 000 scale, Łomża sheet (Bałuk, 2003, unpubl.).

The Paleogene and Neogene deposits have been partly eroded and their top surfaces show altitude differences of several tens of metres. The differences in altitude define a valley, known also from the adjacent areas, in the sub-Quaternary basement.

The Oligocene deposits are represented by glauconitic fine sands and silts as well as by non-glauconitic grayish-brown clays over 50 metres thick. However, the Miocene, occurring only locally in the Łomża area, is represented by fine sands with a small quantity of the quartz gravels. The thickness of the Miocene deposits exceeds 14 m.

In the Łomża area the maximum thickness of the Pleistocene sediments, comprising glacial and inter-morainic sediments of 7 glaciations and 3 interglacials, is 194.6 m (Bałuk, 2001) (Fig. 3).

The Paleogene (Oligocene) and Neogene (Miocene) deposits are directly overlain by till of the Narevian Glaciation, 20 m thick and partly divided into more than two units.

The Augustovian Interglacial is represented by fluvio-periglacial, partly lake and dammed-lake sediments filling up the buried deep erosional river valleys, that were eroded into tills of the older glaciations.

The Nidanian ice sheet is represented by a continuous till sheed, locally divided into two units.

The Sanian 1 and Sanian 2 glaciations, besides till units, includes inter-morainic deposits of different origin. Fluvio-periglacial and fluvial sediments accumulated during the Ferdynandovian Interglacial (Bałuk, 1975).

During the Mazovian Interglacial the former relief was modelled by erosional processes and formed incisions were filled by lake and fluvial sediments, and then covered by clays of the Ostrołęka dammed-lake series, the principle horizon in

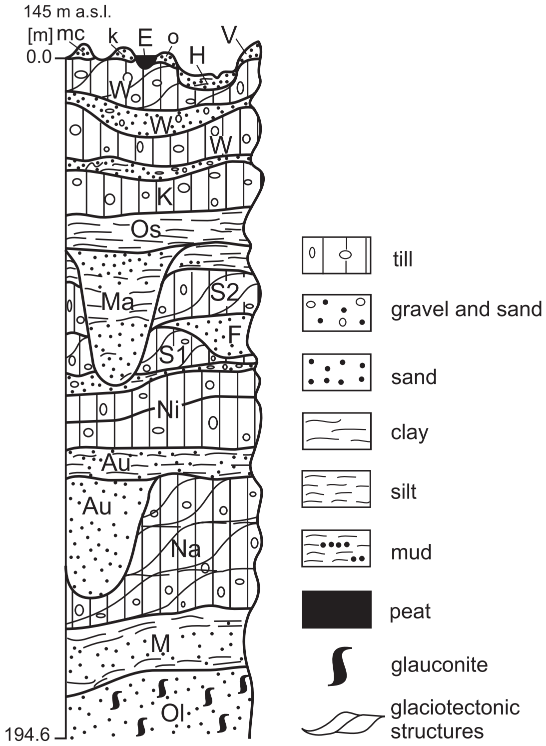

Fig. 3 Synthetic profile of the Quaternary and underlying deposits in the Łomża area

Paleogene: Ol — Oligocene; Neogene: M — Miocene; Pleistocene: Na — Narevian Glaciation, Au — Augustovian Interglacial, Ni — Nidanian Glaciation, S1 — Sanian 1 Glaciation, F — Ferdynandovian Interglacial, S2 — Sanian 2 Glaciation, Ma — Mazovian Interglacial, Os — Ostrołęka clay series, K — Krzna Glaciation, W — Wartanian Glaciation, E — Eemian Interglacial, V — Vistulian Glaciation, H — Holocene; mc — end moraine, o — esker, k — kame

this area. In turn, the Ostrołęka clay deposits are covered by till of Krznanian Glaciation.

Within the glacial deposits of the Wartanian Glaciation two till units representing the lower (Rogowiec) and the middle (Wkra) stadials have been distinguished.

In the area occupied by the present Łomżyczka depression a furrow was formed during the Wkra stadial of the Wartanian Glaciation. The deposits filling the furrow were mostly pelites and pelitic sands of dammed-lake type.

During the Eemian Interglacial, depressions in the morainic plateau, as well as the Łomżyczka furrow, were filled by the organic lacustrine deposits (gyttia and peat) of considerable thickness.

The Narew gate in the Łomża area probably opened during the Vistulian Glaciation (Bałuk, 2001). At that time a fine sand and gravel layer 2–6 metres thick was formed covering the Eemian organic sediments and the entire present-day surface of the Łomżyczka depression. In the gateway part of the Narew River valley an alluvial succession up to 20 m thick accumulated. In the last period of the Vistulian Glaciation, sands accumulated in the Narew gate were affected by periglacial climate conditions and by aeolian processes.

Most recently, in the Holocene, three alluvial sequences, from 2 up to 20 metres thick, consisting of sands and gravels with organic inclusions, accumulated in the Narew valley.

MATERIAL AND METHODS

The Eemian sites discovered in the Łomża vicinity (Fig. 1) during drilling are located in similar geomorphologic situations to these mentioned above: in broad river valleys or on the plateau.

Sites in the valley are situated on the extensive, elongated elevation (about 3 km long) of unknown nature in the middle part of the valley (Jednaczewo 4, 5, 6, 7), where Eemian deposits were discovered and pollen analysed by Borówko-Dłużakowa (1975). The next four sites (10, 11, 12, 13) were found also in the valley incised by the Narew River, close to the estuary of the Łomżyczka River. They lie to the south from the sites described above, at the base of the plateau and about 3–5 km to the north-west from those examined by Straszewska (1974, unpubl.) with pollen analysed by Niklewski and Dąbrowski (1974). Two sites (8, 9) were drilled in the central part of the Narew valley, near Łomża (site 9 located to the south-east of Łomża, outside the sketch on Fig. 1). On the plateau, three sites: 1, 2, 3 are located near Dobrzyjałowo, not far to the NE of Łomża. Geological profiles of the sites studied are shown on Figure 2. At each site samples for pollen analysis were taken using a WH sampler.

The samples were treated using standard palynological procedures employed in the analysis of lacustrine sediments — KOH, HF, acetolysis.

For scanning electron microscopy (SEM) acetolyzed pollen grains were rinsed in distilled H_2O and dehydrated.

For transmission electron microscopy (TEM), modern pollen grains of *Tilia tomentosa* were acetolyzed and treated with conventional TEM procedures: FFA-fixed material was post-fixed in OsO_4 and phosphate-buffered $K_3Fe(CN)_6$ and after washing, the pollen sample was dehydrated in DMP. Finally pollen was embedded in Poly Bed 812 low-viscosity resin.

RESULTS

POLLEN ANALYSIS

Eemian. Deposits indicating Eemian conditions were found in boreholes (Figs. 2, 4, 5): 5 (5 samples — Fig. 5), 3 (3 samples), 12 (6 samples — Fig. 5), 13 (2 samples), 7 (3 samples — Fig. 5), 10 (2 samples), 2 (3 samples), 11 (1 sample).

The initial zone *Pinus–Betula R. P.A.Z.* — known from several records in Poland and dominated by birch and pine, was noted in the Łomża vicinity only at two sites (7, 10). The *Quercus–Fraxinus–Ulmus R. P.A.Z.* (also its initial phases) was recorded in four sections (7, 11, 12, 13). An interesting feature of this zone is the occurrence of exotic pollen — *Viburnum lantana* and *Syringa*, despite the northern location of the sites examined. Deposits of this zone, as in most pollen profiles in Poland (Bińka and Nitychoruk, 2001), are represented by deep-water facies with well-preserved pollen. The next zone *Corylus–Quercus–Tilia R. P.A.Z.* — with, characteristic for the Eemian Interglacial, a high content of hazel was documented at five sites (7, 2, 10, 3, 12). At this level also, the exotic pollen types noted in previous zone were found.

The *Carpinus–Corylus–Alnus R. P.A.Z.* was found at three localities (3, 5, 12) and at the two last sites *Picea–Abies–Alnus* and *Pinus R. P.A.Z.* were noted.

These pollen successions undoubtedly represent the Eemian Interglacial.

The frequency of particular main pollen types and the characteristic succession do not differ from these recorded in adjacent Eemian sites (Bińka *et al*., 1988; Niklewski and Krupiński 1992; Krupiński, 1992) and in northeastern Poland and Lithuania (Satkunas *et al*. 2003; Kupryjanowicz *et al*., 2005; Velichko *et al*., 2005). The exotic taxa also demonstrate the interglacial nature of the samples analysed.

Vistulian sequences. Deposits representing the Vistulian vegetational succession were collected from six sites: 4 (6 samples analysed), 6 (3 samples), 1 (4 samples), 9 (4 samples), 8 (1 sample) and at site 12 (6 samples), where the borehole reached the Eemian. Because of the lack of a standard, full Vistulian pollen sequence in the area investigated, the age of deposits was estimated only approximately. Sections 6 and 4, drilled at Jednaczewo, were taken from a depth of 8 to 11.5 m.

They show marked similarity regarding both the character of deposits as well as the pollen spectra. They represent a cold vegetation with a very small content of pollen of trees and shrubs (reworked pollen of thermophilous taxa of little importance), showing that the tree-line was situated in distant areas far to the south. Gramineae and Cyperaceae dominate the pollen spectra. The variety of the herbaceous taxa is poor and the content of *Artemisia* pollen is low.

Arctic-alpine species — *Selaginella selaginoides* together with other plants that appear often in non-interglacial spectra — *Botrychium, Helianthemum* and *Ephedra* — are also present in these plant communities. *Pediastrum* inhabited the lake with low water level.

The low pollen concentration in these samples may not only result from low pollen production but might also reflect a higher sedimentation rate (the influence of subsidence?). Deposits of sections 6 and 4 probably accumulated during the Plenivistulian.

It is interesting to note that below the sediments from these sections, at a depth of several metres, an Eemian succession is found at a nearby site (5). The lithological similarity of all these sections, which are covered with thick layer of sand, suggests the existence of a large depositional basin, formed probably in consequence of land subsidence.

Boreholes 8 and 9 were drilled close to Łomża, in the wide Narew valley. They show a similar pattern of vegetational changes and probably represent the same depositional basin. Deposits of core 9 (5 samples collected from depths of 4–6 m) comprise lake facies with well-preserved pollen. Deposits below 5.5 m depth, almost devoid of pollen, accumulated under the influence of a continental climate, because of the lack of reworked pollen. Spectra from depths of 4, 4.5 and 5 m are dominated by pine and birch pollen (wind-transported from a distance?) as well as by regularly appearing herbs that reflect open boreal vegetation, rather than forest of the initial Holocene or the end of interglacial sedimentation. The sample at 5.5 m represents colder conditions — probably shrub tundra with only small patches of trees (birch) with *Hippophae*, dwarf willows and rich herbaceous vegetation. *Batrachium* type, *Myriophyllum spicatum*, *Oenanthe*, *Typha latifolia* and *Isoetes* dominated taxa-rich water vegetation. We can see in this interval a tendency towards climatic amelioration, as inferred from a higher pollen concentration and a smaller NAP content in the top sample. The low content of reworked pollen (mainly interglacial tree taxa) shows, in part, open conditions, however, a precise age determination is not possible.

Sequence 1 (Fig. 2), found on the plateau, is characterized by a low pollen frequency and shows a tree-less phase with arboreal pollen (pine, birch), probably of long-distance transport, and shrub communities with willows, juniper and Ericaceae (including *Calluna vulgaris*).

The composition of NAP changed throughout this succession. It is restricted to grasses and sedges in the bottom sample, however, in younger ones *Artemisia* and many herb taxa expanded into communities, marking a climatic shift towards a more continental, steppe vegetation and higher summer temperatures.

In all samples analysed *Myriophyllum alternifolium* was noted an oligotrophic element occurring at present sparsely in the "*Lobelia* lakes" of West Pomerania. Another oligotrophic plant — *Isoetës* — was found only in the two bottom samples. The level of oligotrophy seems to be higher in the initial samples of the section.

The age of the section as inferred from the pollen succession is late Vistulian.

An interesting interval of the Vistulian with a high proportion of *Larix* (Fig. 5) was recorded in core 12, registering mostly Eemian vegetation. Higher percentages of this tree can indicate interstadial conditions (Brörup?). However, the low total pollen content probably resulted from a fast accumulation rate in a peat-bog and does not definitely resolve this question.

When we analyse the time span of the Eemian deposits at each site (Fig. 4) and the type of accumulation (Fig. 2) it is clear that the character of the lake described above supports observations from other parts of Poland about a close connection between sedimentation style and the change in some climate pa-

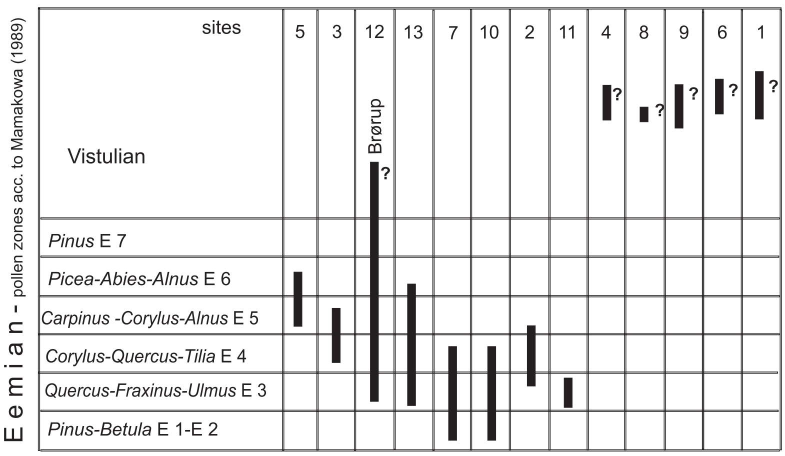

Fig. 4. Zonal correlation of the profiles analysed

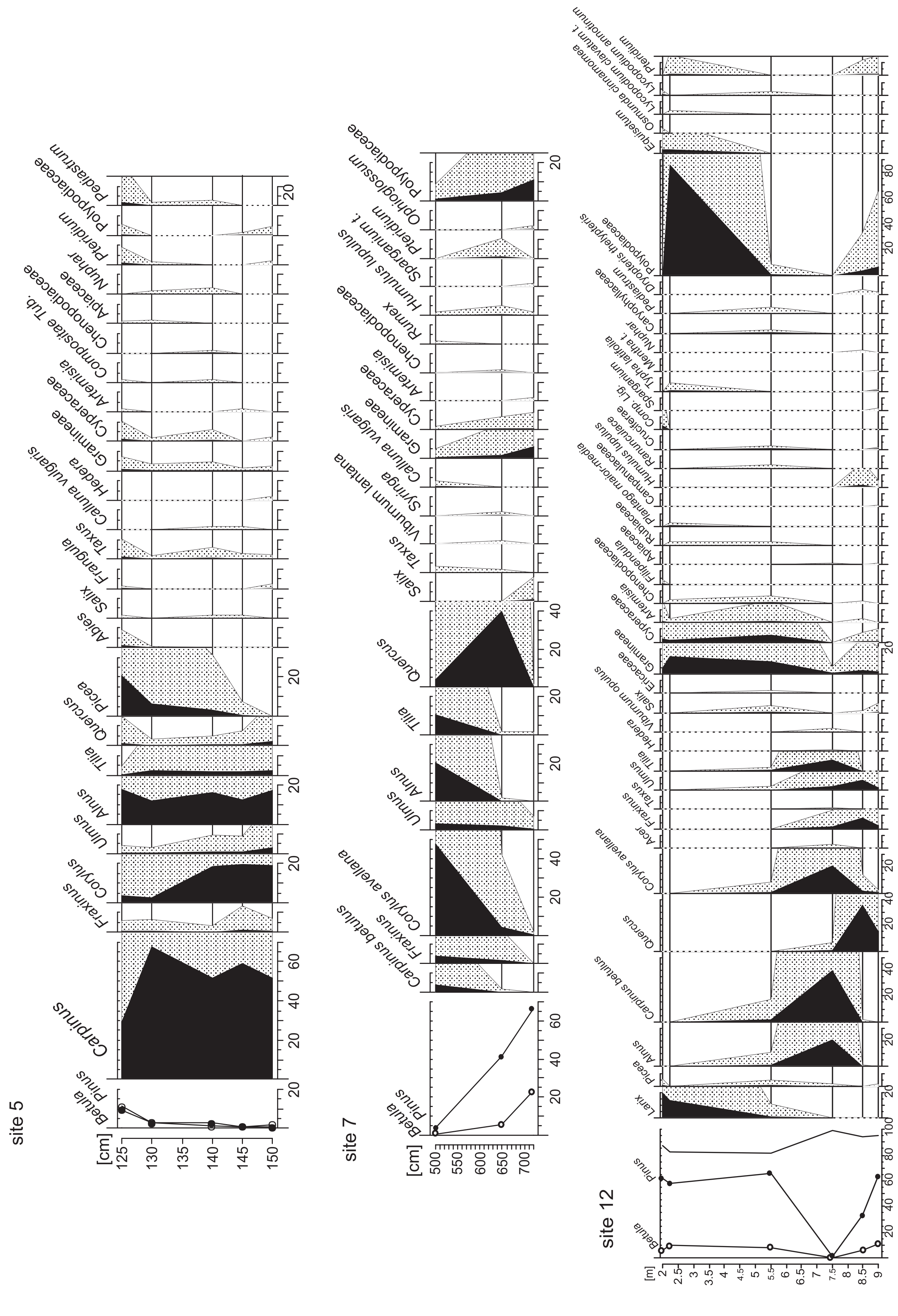

Fig. 5 Pollen diagrams of selected Eemian cores

rameters during the Eemian (Bińka and Nitychoruk, 2003). In Poland, in the first interglacial stages, accumulation in larger lakes is characterized usually by deep-water facies (pollen zones *Pinus–Betula*, *Corylus–Quercus–Tilia*). A marked lowering of water level and partly subaerial sedimentation or even a hiatus is noted not before the *Carpinus–Corylus– Alnus* pollen zone (site 7). This lowering was caused by decrease in precipitation during the hornbeam phase. The drop in water level was certainly accentuated by infilling of the lake basins with sediment, making a minor climatic signal result in a pronounced change in lake sedimentation. Less humid conditions in the hornbeam zone have also been observed in the pollen sequences of western Europe (Cheddadi *et al*., 1998; Björck *et al*., 2000). Numerous small basins, accumulating sediment during favourable hydrological conditions (local or regional in origin) — mostly seasonal pools, small hollows or seasonally activated peat-bogs — with partly subaerial accumulation, infilled with highly humified organic matter or humic mud or silt yielding as a rule poorly preserved pollen (site 2, 3, 13, 10, 11, 12) are the second feature of the Eemian record in Poland (Bińka and Nitychoruk, 2003). Because of their small size they reacted quickly to changes in water level or humidity and these sequences are often interrupted by hiatuses. For this reason the vegetational pattern inferred from pollen data at particular sites is incomplete. These Eemian lakes were of quite different character to those observed in the Holsteinian and the Holocene, where large lakes were infilled with thick sequences of sediments.

A different type of lake evolution — probably triggered by the neotectonic processes — we can see when the lake basin begins suddenly its existence in the late phases of the interglacial (site 5) with deep-water facies: gyttjas and silts. This pattern contracts with the one, proposed above for the Eemian, where in the *Carpinus–Corylus–Alnus* Zone, shallow-water facies are noted. The advantage of basins of this type, deepened by neotectonic movements, is the deposition of deep-water pollen sequences in the periods of less favorable hydrological conditions — e.g. in the final interglacial phases or in tree-less zones, as was a case at Horoszki (Granoszewski, 2003). Likely examples include the Narew and Łomżyczka valleys close to Łomża, the course of which was surely connected with older tectonic structures (site 5, 4).

REMARKS ON THE SELECTED IDENTIFICATIONS AND ON THE OCCURRENCES OF MORE IMPORTANT POLLEN TAXA

In the sections investigated, situated in the climatic conditions of north-east Poland, interglacial and postinterglacial exotic components of the flora were represented, probably, more sparsely than in the middle and south-east areas of the country.

Nevertheless, in the pollen spectra, *Vitis* (site 5 — 13 m), *Buxus sempervirens* (site 5 — 12.5 m and 13 m), *Viburnum lantana* (Fig. 6O, P), *Ilex, Syringa* (site 7 — 5 and 6.5 m; 5 — 14 m and 14.5 m; 10 — 5 m; 80 — 8.5 m; 2 — 3.5 m), *Osmunda cinnamomea* t., *Lycopodium lucidulum* t. (Fig. 6R), and *Bruckenthalia spiculifolia* were identified. The data set of the fossil sites of the last taxon can be supplemented by the new finding in the Łomża area. Commonly found in the Mazovian and early Saalian floras (Bińka and Nitychoruk, 1995, 1996) they have rarely been noted in the Eemian–Vistulian phases eg. at Dziewule, Podlasie region, and at Świnna Poręba, the Carpathians (Bińka and Grzybowski, 2001; Bińka and Nitychoruk, 2001) as well as at Horoszki (Granoszewski, 2003). It is remarkable, that the occurrence of this plant has been found recently in the Lviv vicinity (Tkačik, 1996). In the pollen zone rich in *Tilia*, pollen grains with *Tilia tomentosa* characteristics were noted rarely. The list of the exotic plants can be complemented by the occurrence of extinct species: *Picea omoricoides*, pollen of which have been confirmed in all Eemian *Picea* phase profiles reinvestigated by us (e.g. Dziewule, Warszawa-Żoliborz, Fryngowo, Nidzica and others). This will be a matter of separate debate.

In one of the profiles analysed (site 7 — 6.5 m) atypical pollen of *Quercus*, equipped with pores instead of colpi, were noted, an enigmatic characteristic found already at Dziewule (Bińka and Nitychoruk, 2003) and at Fryngowo. It seems that these pollen are not teratological forms but they represent a real pollen type occurring in the Eemian of Poland.

The next exotic type, *Lycopodium lucidulum* type (Fig. 6R), with a spore morphology clearly different from *L. selago* (rarely found in colder units of the Pleistocene) — has been noted already in the Eemian Interglacial site at Dziewule as well as in the Holsteinian (Bińka and Nitychoruk, 1995, 1996, 2003).

Viburnum lantana is an interesting indicator plant, pollen of which were noted in the profiles analysed (site 7 — 6.5 and 5 m; 10 — 5 m; 11 — 5.2 m; 12 — 8.5 m; 5 — 13 m (Fig. 6O, P). This species, the nearest modern sites of which are situated in the Ukraine and Slovakia, is undoubtedly a thermophilous element appearing in the interglacial temperate zones of the pollen sequences. To date, however, its characteristic pollen has been found in the Holsteinian and the Eemian of the southern Podlasie region (Bińka and Nitychoruk, 2003) as well as in the Łódz vicinity (Antosiakówna, in: Klatkowa, 1990). The findings near Łomża can show, that the interglacial range of *V. lantana* was greater than its modern distribution, which was undoubtedly caused by warmer climatic conditions in the Eemian.

Falcaria vulgaris is another rarely noted pollen type found in the spectra (site 13, Fig. 6M, N). It has already been noted in Eemian interglacial deposits, however in the southern Podlasie region, within the area of its natural modern distribution (Bińka and Nitychoruk, 2003). A northern late glacial and Holocene extension of this species, outside the modern range, was noted at the Błędowo site, Mazovia region (Bińka, 2003*a*). More recently, lateglacial pollen of *Falcaria* were reported as far as the Suwałki region, Northern Poland (Bińka and Żurek, in prep.).

The present finding in Eemian deposits situated far to the north confirms the greater range of *Falcaria vulgaris* in the Eemian then at present.

Falcaria vulgaris preferring a high content of calcium carbonate in the soil cover, had a larger past distribution that may be ascribed to fresh moraine landscapes in the late glacial. With leaching of calcium from the soils during this interglacial and during the Holocene the occurrence of *Falcaria* was limited quickly to rare localities. It is also possible that the decrease of sites was caused by intensive consumption by prehistoric man

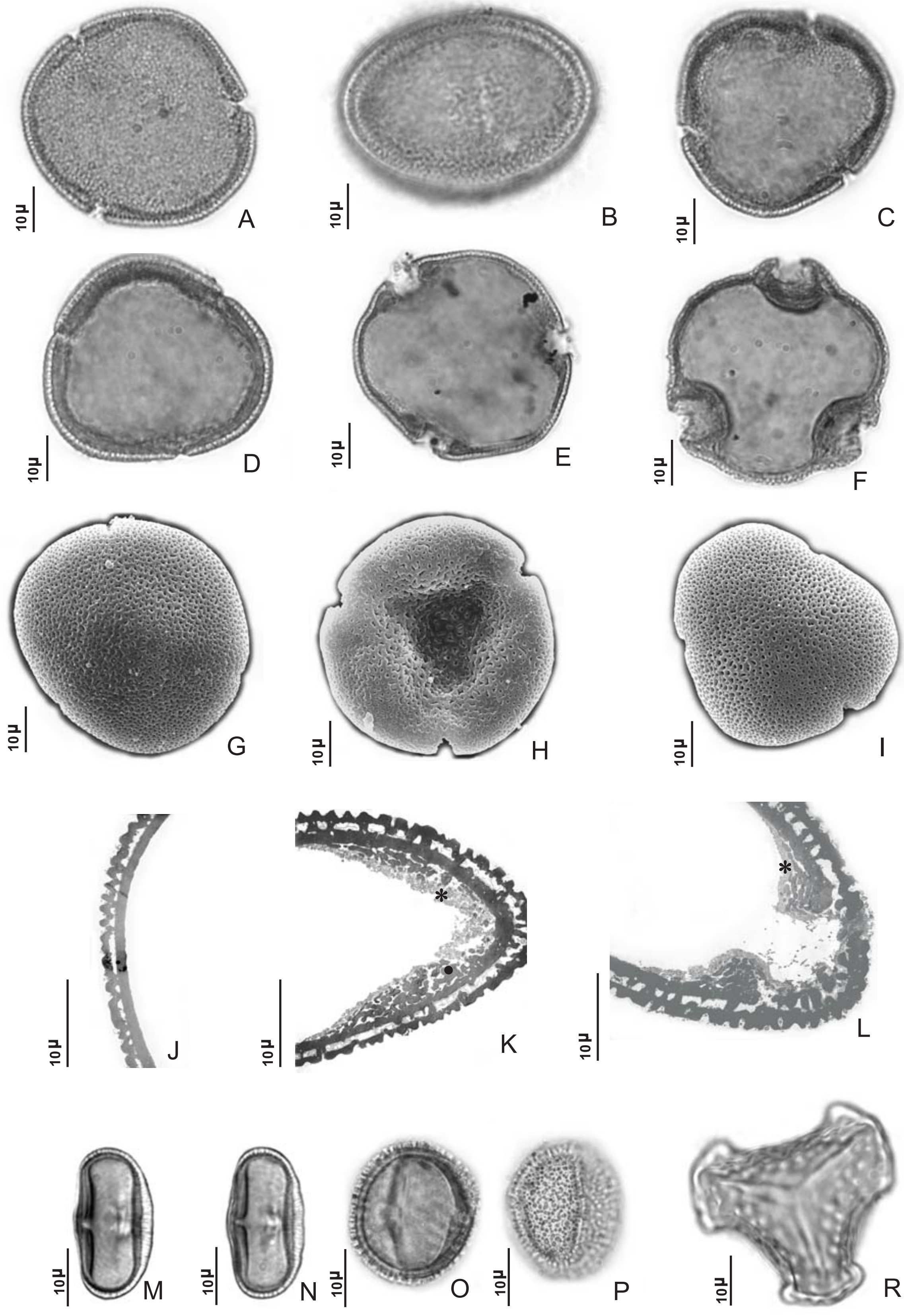

Fig. 6. Table of selected pollen taxa

A–**D** — fossil Tilia pollen (costae pori removed) site 6: D — exine in the polar — mesocolpial areas; A, C, D polar view, B colpus view; **E**–**F** — fossil Tilia pollen with possible effects of pseudogermination processes; **G** — modern Tilia tomentosa pollen versus fossil pollen of Tilia with removed costae (H–I); **J**–**L** — pollen wall of modern Tilia tomentosa grains; **K**–**L** — various cross-sections through the apertural area. Note: loosely arranged exine forming costae pori (black point) underlain by layer of unidentified substance (asterisk); **M**–**N** — pollen of Falcaria vulgaris, site 18; **O**–**P** — pollen of Viburnum lantana, site 5; **R** — Lycopodium lucidulum type, site 6 (*op. cit*.). Its modern distribution pattern hence a relic of a much wider ancient range.

SIGNS OF PLANT — ANIMAL INTERACTION

At Imbramowice, Mamakowa (1989) found, in Eemian deposits, pollen grains identified by her as *Tilia tomentosa*. This indicator plant is an exotic element inhabiting mainly southern Europe. Macrofossils of this species have been noted in Poland (Granoszewski, 2003). Therefore we should find its pollen in Eemian spectra. Pollen grains of *T. tomentosa* differ from the two species — *T. cordata* and *T. platyphyllos*, native to Poland, primarily in less prominent, thinner and broader costae pori (Beug, 2004). However, as can be seen on microphotographs (Mamakowa, 1989), illustrated pollen grains of *Tilia* do not show any costae pori (a structure present in pollen of the whole genus). For this reason it is not possible, in our opinion, to identify these fossil grains to species level. Thus, the illustrated pollen probably do not represent *Tilia tomentosa*.

In the material analysed we found similar pollen of *Tilia.* In our view, plant-animal interaction is the main factor responsible for a partial lack of exine.

In Holocene deposits, especially in its younger phases, where human impact on the environment is clearly visible, we can observe in the pollen spectra signs of exine degradation or its partial removal. Before final deposition in the bottom sediment, they usually were consumed by insects — pollen eaters and these in turn were caught by insectivorous birds and bats or other insects. Their faeces are finally deposited in the lake sediments.

This transportation typically results in substantial changes to pollen exines such as degradation of end- and ectexine, destruction and removal of endexines and signs of pseudogermination (Bińka, 2003*a*, *b*). These changes take place during initial digestion in insect intestines and further in the alimentary canals of their consumers — vertebrates — and finally in the depositional environment, where exines are attacked by bacteria or together with faeces are again consumed by fish or by small bottom animals (Bińka, 2005).

Signs of consumption are visible in a few pollen taxa e.g. — Apiaceae, *Centaurea cyanus*, *C. rhenana* and *Polygonum aviculare*, pollen of which are noted in Holocene sediments.

In older Pleistocene deposits only the last species has hitherto been found so altered, in deposits of treeless Vistulian phases. Thus, it is interesting that, mostly in the warm linden — hazel pollen zone of the Eemian (site 2 — 6.3 m, 3.5 m, 12 — 7.5 m, 5 — 14.5 m, 10 — 5 m and 7 — 5 m), grains of *Tilia* lacking the very characteristic costae pori of the exine were noted (Fig. 6A–C, F). This part of exine (usually formed by endexine), as clear from earlier discussion (Bińka, 2003*a*, *b*) is the area most subject to attack by digestive enzymes. And as is more important, prominent costae (or their lack) formed by endexine are more easily recognizable in LM observations then the layer of endexine situated in the mesocolpium or in the polar area. Certain problems arise in the case of *Tilia* pollen. Acetolyzed modern pollen of *Tilia tomentosa* analysed by transmission electron microscopy showed a lack of the endexine layer in the polar/mesocolpium areas. Near the pori, thick costae are visible. They are formed by very loosely arranged exine — "cerebroid" type (Fig. 6J–L), underlain in this area only by an unidentified residual substance. This loosely bound structure can obviously facilitate rapid degradation during the processes described above. However, it is hard to find any boundaries in exine between end — and ectexine, normally clearly visible on TEM photographs. The whole material forming the exine is uniformly coloured. Thus it is possible that only ectexine is present. The similar structure of exine, as described above in *Tilia tomentosa*, can be seen on TEM microphotographs of pollen of the common European species, *Tilia platyphyllos* (Chambers and Godwin, 1961; Hesse, 1993). In this case exine also seems to be uncoloured and boundaries cannot be seen in this layer.

Scanning electron microphotographs of fossil *Tilia* pollen without costae pori did not reveal signs of ectexine degradation as shown in the case of *C. cyanus* (Bińka, 2003*b*). Only on one specimen were degradation processes visible as a general weakness of exine (Fig. 6F).

Pollen without costae are not numerous in spectra, though occur regularly in a few profiles. The state of preservation of all examined pollen types forming the spectra — as is important in such considerations — was very good. Examined sediments with atypical grains of *Tilia* were deposited in a moderately deep lake with *Nuphar* and *Ceratophyllum*. Any stratigraphical hiatuses would have been observed.

In the material analysed there were also noted pollen of *Tilia*, which can be interpreted as an effect of pseudogermination processes — i.e. initial stages of germination with associated swelling of exine covering pores, rather then its disruption (Fig. 6D, E). In fossil grains described earlier (Bińka, 2003*a*) this results in the origin of star-shaped structures developed due to impairment of the costae layer or the partial perforation of a pore. Such perforated apertures were observed in the samples analysed.

The factors leading to exine destruction in this genus seem to have been complex. Despite numerous pollen counting, such grains were not found in Holocene deposits nor in those of the Mazovian Interglacial.

CONCLUSIONS

1. Palynologically examined Eemian and Vistulian deposits show similar evolution of vegetation to the pollen sequences in northeastern Poland.

2. The sites analysed are consistent with observations from other parts of Poland in that most Eemian basins, depending on local or regional hydrological conditions, are usually represented by small lakes, often with low water level and partly subaerial sedimentation, registering only fragments of the pollen succession. Deeper lakes, however, in the hornbeam phase, under the influence of a less humid climate, accumulated shallow-water facies or show a lack of deposits in this zone.

3. Exotic pollen types, being some kind of bioindicators, are rarely identified in the pollen diagrams of the European Lowland. Apart from commonly identified types such as *Viscum*, *Hedera*, *Buxus* and *Vitis*, we found evidence of such species as *Viburnum lantana*, *Cornus mas*, *Rhus cotinus* (Bińka and Nitychoruk, 2003), plants with a more southerly distribution to-

day. Unfortunately, the range of their interglacial occurrence is only partly known, because of their identification to genus level.

4. Plant–animal interaction, usually visible in pollen grains as a degradation of costae, may cause superficial resemblance of these grains to the other important species and this can be a cause of incorrect identification. An example of this process is fossil pollen of *Tilia* with partially removed exine, that is very similar to modern pollen of *Tilia tomentosa.*

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