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The Late Saalian, Eemian and Early Vistulian pollen sequence at Dziewule, eastern Poland

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A relatively undisturbed pollen sequence from the Late Saalian–Eemian–Early Vistulian interval has been discovered in Dziewule in the Podlasie region, eastern Poland. Geological and palynological investigations are used to illustrate the evolution of Eemian climate, which, at this site, shows no large-scale and abrupt oscillations. Almost full interglacial conditions are already present from the early part of the sequence (the end of the boreal *Betula–Pinus* Zone). Thermophilous indicator plants (e.g. *Viburnum lantana, Cornus mas, Cotinus coggygria* — newly found in the Eemian of Poland) show their maximum occurrence in the second half of the *Quercu*s Zone and in the *Corylus* Zone, marking the climatic optimum of the interglacial. We found no signs of substantial climate fluctuations in the *Carpinus* Zone suggested by some authors.

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INTRODUCTION

Eemian deposits typically differ clearly from those of the Holsteinian and the Holocene. Shallow water deposits following initial sedimentation of gyttja are particularly important in Eemian sequences; this is observed in borings as a highly decomposed peat horizon or peaty silt or as minerogenic sediment. Transitional deposits are exceptional. Such a sequence of deposits suggests that abrupt major climatic changes might have taken place in the Eemian Interglacial.

According to some researchers episodes of greater magnitude than those in the Holocene and in the Mazovian may be observed in the Eemian. Field *et al*. (1994) believed that a substantial drop in winter temperatures took place in the Eemian (*Carpinus* Zone). Cheddadi *et al*. (1998) reconstructed a somewhat different record of climatic events. They suggested a decrease in winter temperatures (and in precipitation level), though not as great as that mentioned above. An intra-Eemian cold episode was described by Karabanov *et al*. (2000) from the Lake Baikal.

However, Zagwijn (1996) and Litt *et al*. (1996) do not see any dramatic climatic events in the Eemian. According to their estimations, the rate and amplitude of reconstructed changes, particularly mean temperatures of the coldest and warmest months, do not show any marked oscillations in comparison to other temperate successions.

This divergence in opinion stimulated us to study Eemian deposits in eastern Poland, where they infill numerous interglacial lake basins.

SETTING AND METHODOLOGY

The pollen profile from Dziewule, especially its Late Saalian part and its record of climate evolution, have already been discussed (Bińka and Nitychoruk, 2001). The Dziewule site (Fig.1) is located within a large buried lacustrine terrain consisting of a number of individual shallow lakes and ponds of Eemian age, a characteristic palynology and geology. The lacustrine deposits rest upon a Saalian (Wartanian–Odranian) till and on fluvial deposits at a similar stratigraphic level. The lake deposits in Dziewule underlie glacifluvial sands with gravels of the Warta Glaciation (Fig. 2), which, in the vicinity of the buried basin, build elongated elevations up to 3 m high. These forms resulted from the accumulation of deposits in ice fissures

Fig. 1. Interglacial sites in Poland cited in the paper

1 — Dziewule, 2 — Przywory Duże, 3 — Główczyn, 4 — Łomżyca, 5 — Jóźwin, 6 — Nakło, 7 — Besiekierz, 8 — Świnna Poręba, 9 — Imbramowice, 10 — Gołowierzchy, 11 — Wilczyn, 12— Kaliłów, 13 — Woskrzenice, 14 — Błędowo

within a melting continental glacier. The origin of an interglacial basin has been linked with the melting of blocks of ice, preserved between two rows of sediments accumulated in fissures (Terpiłowski, 2001). During the Vistulian Glaciation, the depression was occupied by extraglacial meltwaters, which deposited fine and medium-grained sands. Peats and peaty alluvial deposits occurring in the lowest parts of the depression were formed during the Holocene.

The Dziewule site was sampled with an Eijkelkamp vibracorer. The cores, 1 m long and about 5 cm in diameter, were cut into 5 cm thick slices and stored in plastic bags. In the laboratory 1 cm^3 samples were treated with cold HF and washed with hot 15% HCl, boiled in 10% KOH and finally treated by the traditional Erdtman's acetolysis. About 1000 pollen grains at a x 400 magnification were counted in each sample (except the bottom ones, where the pollen frequency was lower). Macro-remains were occasionally collected from the upper part of the profile.

The description of the deposits is as follows: 1–185 cm — minerogenic deposits, 185–245 cm — silt with organic matter, 245–275 cm — peat, 275–310 cm — silt with admixture of organic material, 310–560 cm — highly decomposed peat, 560–800 cm — light calcareous gyttja, 800–965 cm — silt with an admixture of organic substance grading upwards into gyttja, 965–1070 cm — light silt, passing upwards into silt with organic matter.

RESULTS

Thirteen Local Pollen Assemblage Zones (L PAZ) are distinguished in the section (Fig. 3). Some pollen taxa mentioned in the description are a result of additional examination of samples and they are not placed in the pollen diagram. The stratigraphy of the Dziewule section is as follows (Figs. 3 and 4).

L PAZ 1 NAP. The initial zone is characterised by a very low concentration of pollen grains, a very high amount of reworked pollen of various ages and very high NAP.

The character of pollen spectra suggests the presence of vegetation resembling that of the "high and middle tundra" in arctic areas farther to the north or on elevated sites, with a discontinuous vegetation cover and soil surface. Grassland with grasses, sedges and goosefoot is a characteristic and widespread feature of late-glacial vegetation. These plants are typically accompanied by herbs such as Compositae (*Antennaria* type and other abundant genera) and *Helianthemum*, though the latter is barely represented at this level. *Juniperus*, *Ephedra distachya* t., *Salix polaris*/*herbacea* t., Ericaceae undiff. (including *Ledum*), occur sporadically. Only *Batrachium* and *Sparganium* grew in shallow lake.

L PAZ 2 *Betula–Salix–Juniperus*. The zone is marked by expansion of shrub communities, high and rich in NAP pollen types and a low, though increasing pollen concentration. A large proportion of reworked pollen indicates still poorly developed soils and movement of the soil particles during daily and yearly temperature cycles (through freezing and thawing). A rich shrub community (dwarf, tall and semi-erect) expanded considerably as a result of climatic amelioration. A wide variety of pollen types indicating such habitats has been noted — *Betula nana* t., *Salix polaris*/*herbacea* t. Spiraeae, *Ledum*, *Juniperus*, Ericaceae undiff., *Ephedra distachya* t., *E. fragilis* t. Non-tree pollen types show increased values or appear regularly e.g. grasses, sedges, *Artemisia*, *Gypsophila fastigiata* t., *Armeria*, *Botrychium*, *Helianthemum*, *Polygonum persicaria*, *P. bistorta* and others. In this pollen zone, *Pediastrum kawraiskyi* and *P. boryanum* grew in shallow water. Other aquatic plants were rarely found, e.g. *Batrachium* t., *Sparganium* t., *P. amphibium*.

L PAZ 3 *Betula–Juniperus*. This pollen zone is characterised by three distinct features:

— a decline in reworked pollen, which indicates better developed soil cover,

— a gradual decrease in NAP and an increase in pollen concentration,

— a small increase in *Hippophaë* and after that a distinct expansion of tree and dwarf birch and *Juniperus*.

The expansion of tree birch and *Hippophaë* marks the first step of the forest succession. The open birch forest was replaced finally by an open pine — spruce forest. As in the previous zone, patches of shrubs e.g. *Betula nana* t., *Hippophaë*, *Salix polaris*/*herbacea* t., cf. Spiraeae, *Juniperus*, *Ephedra fragilis* t., *E. distachya* t., were still abundant. A high NAP suggests partly open vegetation with motherworts, grasses, sedges, *Plantago maritima* t., *P. major*, *Gypsophila fastigiata* t., *Polygonum aviculare* t., *Valeriana officinalis* t., *V. tripteris* t., *Bupleurum*, *Helianthemum*, *Thalictrum flavum* gr., *Botrychium*, *Selaginella selaginoides* as well as numerous taxa of Compositae and Apiaceae.

In the lake grew e.g. *Batrachium*, *Sparganium*, *Ceratophyllum*, *Myriophyllum spicatum* and *M. vertcillatum* (*Typha latifolia* is also not excluded).

L PAZ 4 *Pinus–Picea*. The zone is characterised by:

— a continuous increase in *Pinus* (largely including the *Pinus cembra* pollen type),

— a constant increase in pollen concentration (though below interglacial values),

— a low and decreasing amount of NAP, smaller than in pollen zone 3, this being also the case for reworked pollen.

A subzone a marks lower *Pinus* values, the occurrence of *Picea* and a higher percentage of NAP and shrub (willow, juniper and dwarf birch). In subzone b *Pinus cembra* is dominant and NAP has lower values.

During this zone a pine forest with an admixture of spruce and later *Populus tremula* expanded gradually with a contemporaneous decrease in the herbaceous plants and shrubs. However, they did not form a closed forest. At Dziewule, *Betula* sec. Albae fruits were found, though the birch curve is very low at that time.

In the lake grew numerous aquatic plants — *Typha latifolia*, *Ceratophyllum*, *M. spicatum*, *Sparganium emersum* t., *Equisetum*, *Rorippa palustris*, *Nuphar* and very abundant *Tetraedron*.

L PAZ 5 *Betula–Pinus*. This zone represents absolute dominance of birch and pine and the first stadium of the interglacial succession representing a fully closed forest.

On the basis of dominant tree pollen types the zone can be subdivided into two subzones: subzone a — *Betula* with a predominance of birch and subzone b — *Pinus–Quercus* with high amounts of pine and the expansion of oak and elm.

This zone is characterised by a consequent decrease in NAP, especially at the onset of the zone. The improvement of climatic conditions must have taken place very quickly judging from the occurrence of *Hedera*, *Cornus sanguinea*, *Viburnum lantana* and *Humulus lupulus*, that is plants with a northern limit not exceeding the temperate zone. The values of hop, a typical plant of initial interglacial zones, in comparison with the Holocene and the Mazovian, are higher.

A decrease in the percentage of *Ceratophyllum*, *Nuphar*, *Batrachium*, *Myriophyllum spicatum* and *Pediastrum* indicates a rise in lake level, although lake shore communities with *Sparganium* and *Typha latifolia* appear to have remained unchanged. *Najas marina* has been found occasionally within the macroremains.

L PAZ 6 *Quercus*. The zone is characterised by a constant rise in the *Quercus* curve and it can be divided into two subzones: subzone a — with a predominance of *Pinus*, and rising *Ulmus, Fraxinus* and *Quercus* values and subzone b — with a decrease in *Betula* and an increase in *Quercus*, which becomes the dominant tree pollen producer of this subzone, with a *Corylus* invasion into forest communities at the end of this subzone.

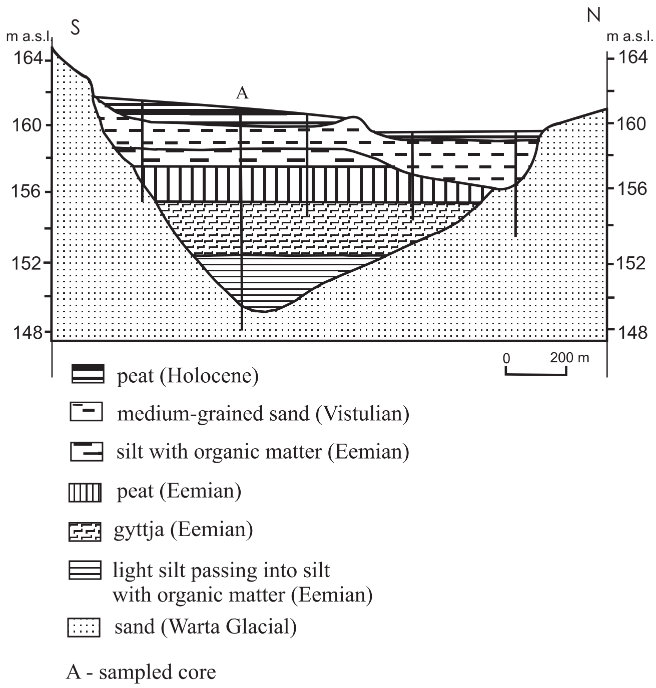


Fig. 2. Geological setting of the organogenic deposits at Dziewule

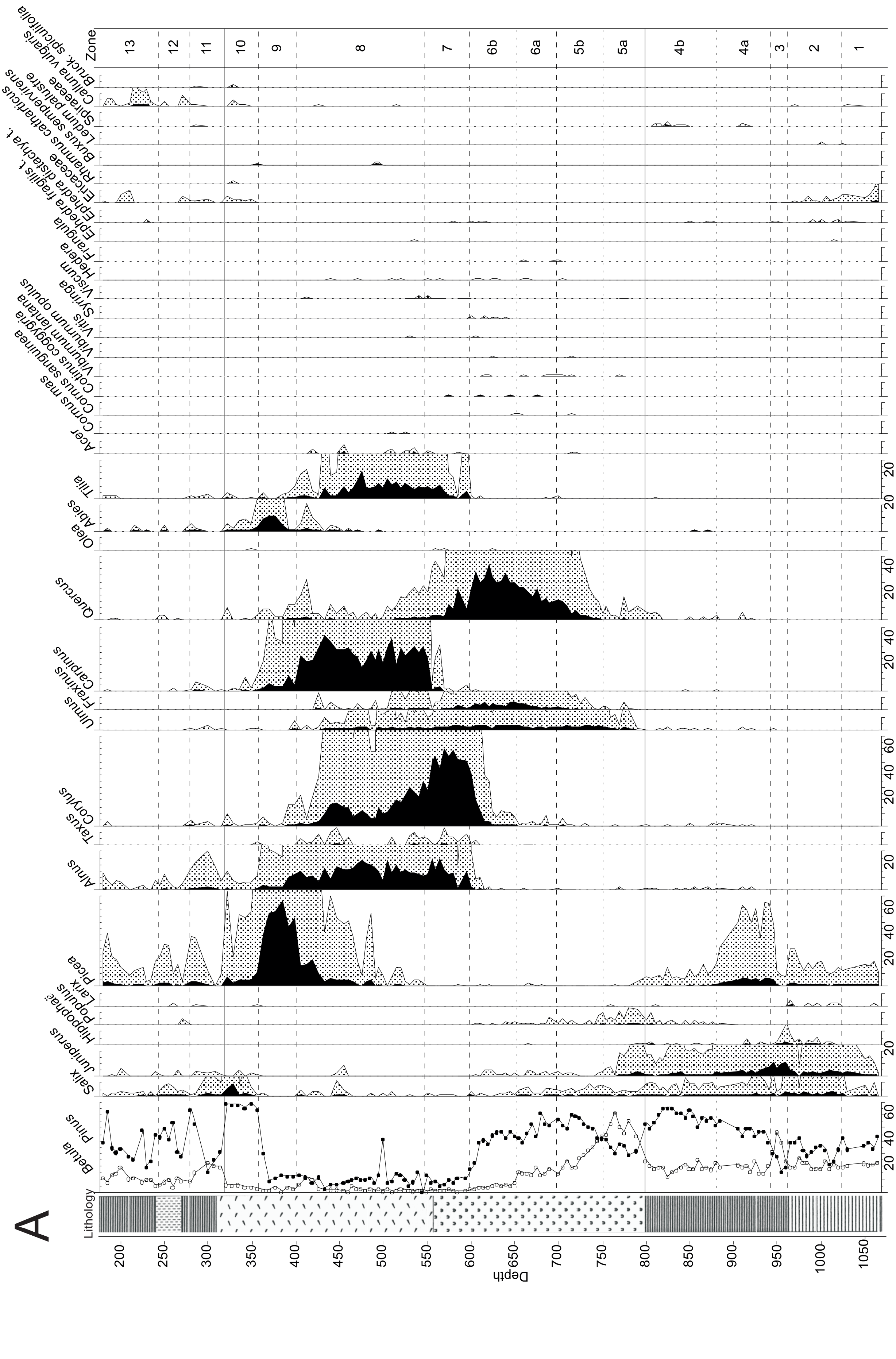
Relatively high values were attained by the indicator plants *Viscum*, *Hedera*, *V. lantana* and *Cotinus* in the early part of the zone, and in subzone b by *Vitis*, *Syringa*, *Cornus mas*. At this time, the *Pinus–Quercus* rich association with somewhat open forest floor with shrubs and herbaceous plants — *Echium*, *Thesium*, *Gypsophila fastigiata* t., *Sedum* and others is very characteristic.

The local culmination of *Hedera* can be observed in subzone b, which gives evidence of more oceanic climate conditions with higher winter temperatures.

Only a small fluctuation in the composition of aquatics is observed in the lake. *Myriophyllum spicatum* occurs at higher frequencies than in the previous zone.

L PAZ 7 *Corylus*. This zone is dominated by *Corylus avellana*. The lower boundary of the zone marks a rapid decrease in *Pinus*. *Tilia* and *Alnus* first form a low continuous curve. The thermophilous and photophilous shrub communities with *Syringa*, *Viburnum lantana*, *V. opulus*, *Cotinus* and herbs are limited to small patches in comparison with the previous zone. A relatively high amount of *Hedera* and *Viscum* is noted particularly in the second half of the zone. Other indicator elements — *Olea* (of distant origin?) and *Ilex aquifolium* — occur sporadically.

Throughout zones 5 and 6 the lake shore was occupied by various plants characteristic of a littoral zone with low water level e.g. *Typha latifolia*, *Dryopteris thelypteris*, *Sparganium*, as well as rooted aquatic plants and open water plants in deeper places, such as *Myriophyllum spicatum*, *Nymphaea*, *Nuphar*, *Ceratophyllum* and *Lemna*. In the *Corylus* Zone these plants and *Pediastrum* disappear, whereas *Najas marina* was the most common aquatic plant in the lake at that time. This may indicate a rise in water level. *Najas marina* may grow in up to 3 m deep water.


A
Lithology
Depth
Zone
Betula
Pinus
Salix
Juniperus
Hippophaë
Populus
Larix
Picea
Alnus
Taxus
Corylus
Ulmus
Fraxinus
Carpinus
Quercus
Olea
Abies
Tilia
Acer
Cornus mas
Cornus sanguinea
Cotinus coggygria
Viburnum lantana
Viburnum opulus
Vitis
Syringa
Viscum
Hedera
Frangula
Ephedra fragilis t.
Ephedra distachya t.
Ericaceae
Rhamnus catharticus
Buxus sempervirens
Sedum
Ledum palustre
Spiraeeae
Calluna vulgaris
Bruck. spicifolia

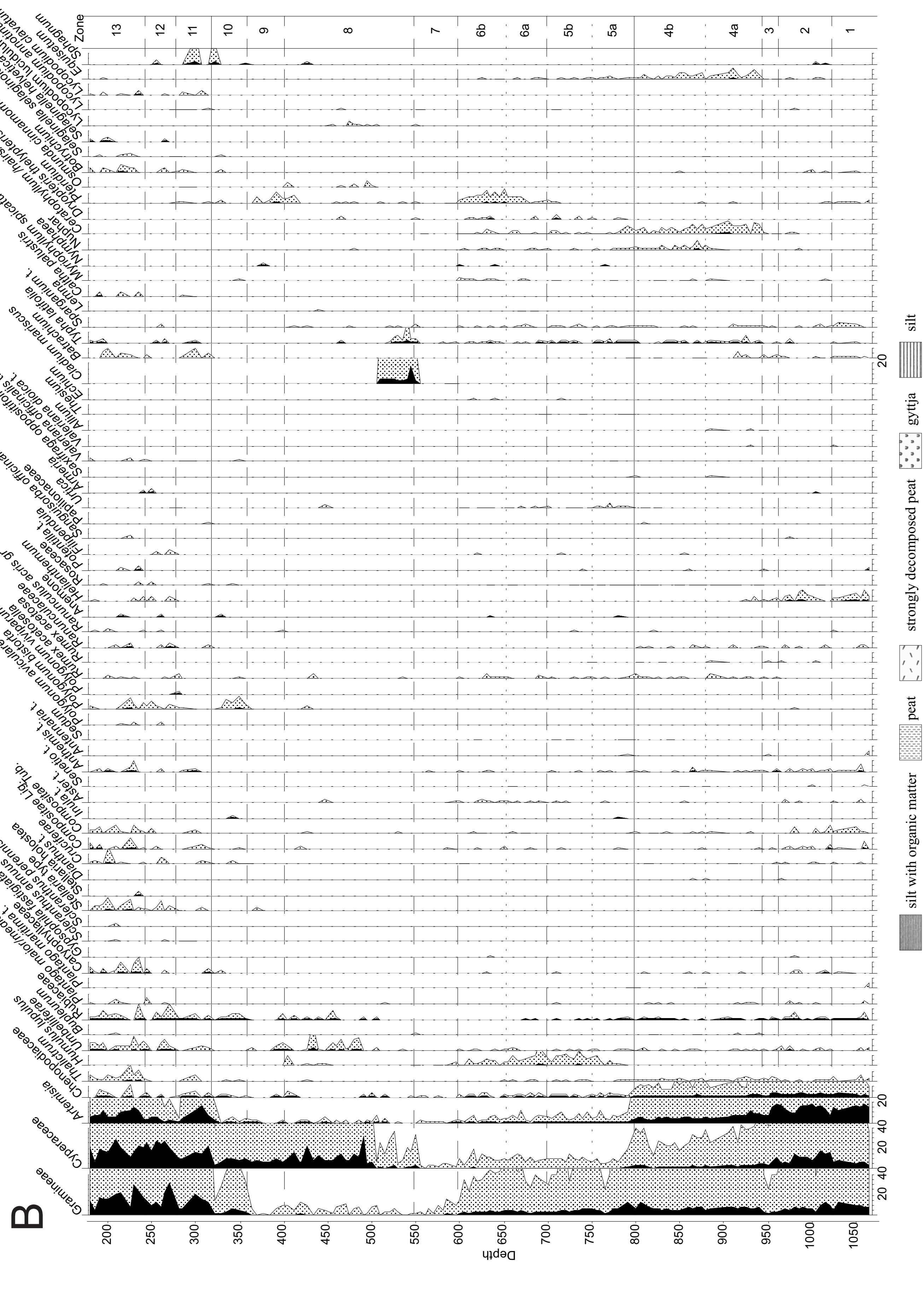


Fig. 3. Dziewule site — percentage pollen diagram
A — arboreal pollen (AP), B — non-arboreal pollen (NAP)

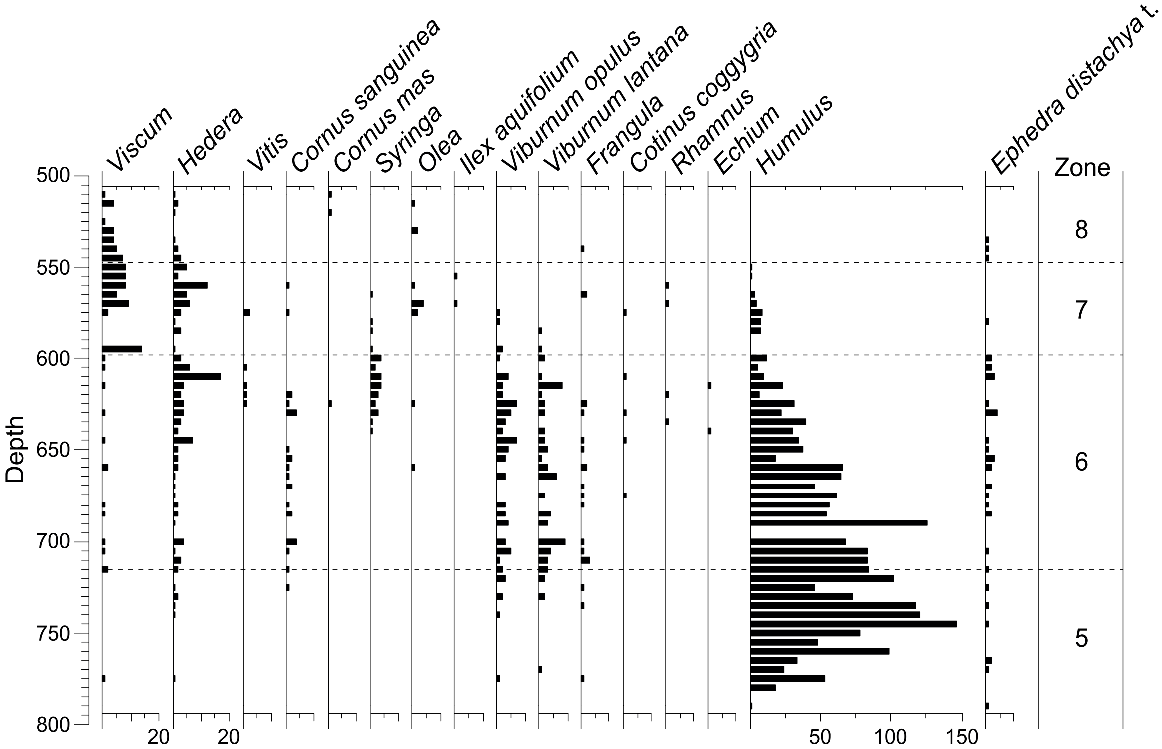


Fig. 4. Special pollen diagram from the part of the Dziewule section showing the total number of pollen grains of selected plants found in three slides

Watermilfoil is believed to build monospecific communities and this may also have caused the elimination of other taxa.

L PAZ 8 *Carpinus*. This pollen zone, dominated by hornbeam with an admixture of *Tilia*, *Alnus* and *Corylus*, marks the end of a deep lake basin. Thermophilous plants (except *Viscum*) are poorly represented in this zone.

The sediments are composed largely of highly decomposed organic deposits with damaged and corroded pollen grains. At the onset of the zone the lake rapidly became shallower. This is marked by an expansion of lakeshore vegetation — *Typha latifolia*, *Cladium mariscus* (abundant fruits), *Sparganium* and a lack of plants from deeper parts of the littoral zone. Later, plants from terrestrial environments or wet habitats — hornbeam nuts, *Rubus*, *Typha*, *Carex* and *Sparganium* minimum-prevail amongst the macro-remains. Only one fruit of *Potamogeton* and several Characeae oogonia were found in this level. These findings argue for a sporadically higher water level. Pollen of *Cornus mas*, *Olea* and *Vitis* represent the thermophilous plants at this level.

L PAZ 9 *Picea–Abies*. This zone starts with a distinct and abrupt decrease in *Carpinus*, *Corylus* and *Tilia*, followed by an increase in *Picea* and *Abies*. The late occurrence of fir is particularly interesting. The maximum abundance of fir in the Eemian is very short and late. It seems that, apart from the rate of migration, the unfavorable moisture conditions in the *Carpinus* Zone of the Eemian are responsible for this late *Abies* phase

At the site studied, highly decomposed peat with sedge nuts, remains of Hepaticeae thalli and sporadic *Comarum*, *Lycopus* and *M. spicatum* accumulated at the end of the zone, thus marking a rise of water level. Leaves and fruits of *Betula nana*, probably relict in origin, were also found.

L PAZ 10 *Pinus.* Practically all of the thermophilous trees declined in this zone. Pollen of *Pinus* with a small admixture of *Picea* prevail in the spectrum, indicating thus boreal conditions. However, numerous macro-remains of *Betula nana* (fruit scales, leaves, fruits) are found in sedge peat. Rare *M. spicatum*, *Batrachium*, *Sparganium minimum*, *Potamogeton praelongus* and Characeae were also noted. This zone represents the last interglacial unit.

L PAZ 11 *Betula*–NAP. This zone is the first post-Eemian non-tree stadial. It is characterised by a drastic decrease in the amount of *Pinus*, a small rise in *Betula* (including the *Betula nana* type) with a contemporary rise in NAP (mostly *Artemisia,* Gramineae and Cyperaceae). A characteristic change also takes place in the type of sediment. Peat was replaced by partly organic silt and pure silt. This change is a typical and frequently observed sign of post-interglacial conditions. It is remarkable that, in this zone, the macro-remains of *Betula nana*, abundant in the last interglacial phase, declined in the first Vistulian stadial. This is probably a result of a change in the type of sediment only.

It seems that in this zone a rise in lake level took place. Sporadically noted macrofossils represent water and wet habitats — *Potamogeton praelongus* (at the onset of the zone), *Batrachium*, *Comarum palustre* and *Typha*.

L PAZ 12 *Pinus*. The zone is marked by a renewed increase in *Pinus* and a decrease in *Betula* and NAP (especially of *Artemisia*, which played an important role in the previous zone).

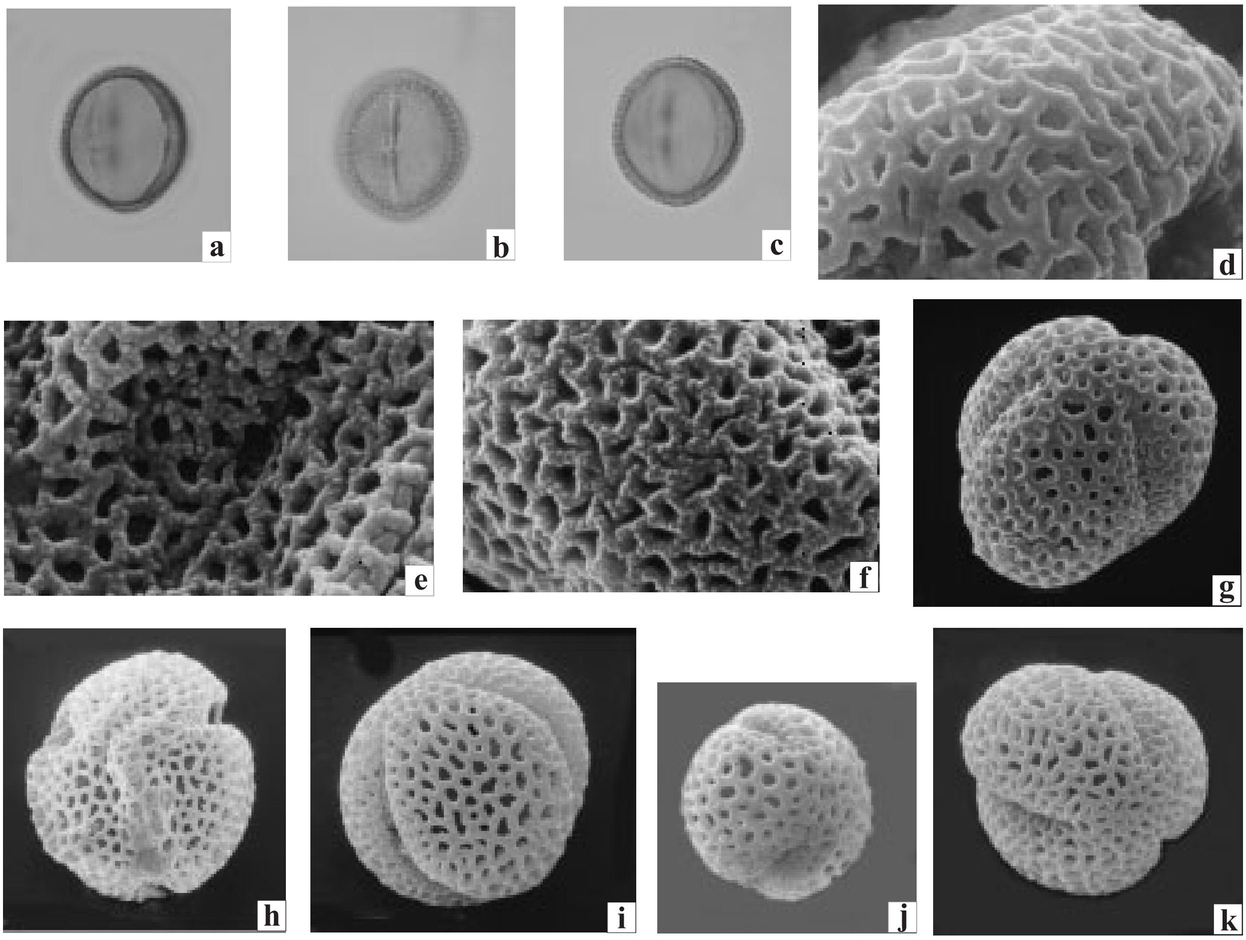


Fig. 5. Pollen grains of selected taxa from the Eemian at Dziewule against the Ferdynandovian, Mazovian and Brörup ones in Poland

a–**d** — *F. ornus* — Dziewule (Eemian), *Carpinus* Zone, equatorial view: **a** — cross-section, **b** — colpus view, **c** — the columellae x 500, **d** — ornamentation, microreticulum with fine ridges x 10000; **e**–**f** — *F. excelsior* — Dziewule (Eemian), *Quercus* Zone: **e** — x 10000; Woskrzenice site (Mazovian), *Carpinus* Zone: **f** — x 10000, ornamentation, muri beset with granules; **g**–**k** — *Syringa* sp. ornamentation — Dziewule (Eemian), polar view: **k** — x 2500; Woskrzenice site (Mazovian), *Carpinus* Zone, polar view: **h**, **j** — x 2500; Gołowierzchy site (Ferdynandovian), *Quercus*/*Ulmus* level: **g** — x 2500; Świnna Poręba (Brörup), Carpathians, mesocolpium area: **i** — x 2500 (Bińka and Grzybowski, 2001)

The high proportion of Gramineae and Cyperaceae may be regarded as a purely local effect, as deduced from macrofossils.

Local plants recorded in weakly decomposed peat: *Rumex acetosella*, *Polygonum aviculare*, *Betula nana*, *Arctostaphylos uva-ursi*, *Menyanthes trifoliata*, *Comarum palustre*, *Ranunculus sceleratus*, numerous *Carex*, *Batrachium*, *Typha*, *Potamogeton pusillus*, Characeae and *Zannichellia palustris*, show varied terrestrial and lake habitats.

L PAZ 13 NAP. A return to treeless conditions can be observed in this interval at Dziewule. This zone is characterised by a decrease in *Pinus* with an associated rise in the percentages of *Artemisia* and most herb pollen types. Macroremains of *Thalictrum alpinum*, *Armeria*, *Potentilla anserina*, *Rumex acetosella*, *Galium*, *Ranunculus* and various pollen types of herbs were recognised in the samples.

The lake and its littoral zone were occupied by a wide variety of water plants: *Batrachium, Potamogeton pusillus, Najas marina, M. spicatum,* Characeae, *Menyanthes trifoliata, Eleocharis, Typha latifolia, Ranunculus sceleratus, Lysimachia thyrsiflora* and *Comarum palustre*.

NOTES ON THE SELECTED IDENTIFICATIONS

Cf. *Quercus* — untypical pollen grains with verucate sculpture probably representing *Quercus* (Fig. 6 a–d) have been found in the Dziewule section as well as in the adjacent Przywory Duże (Fig. 1). They have a well-defined endoaperture (pore) and they differ from the typical forms by the absence of colpi. Pores are developed as a small, abrupt more or less circular lowering of the exine. It is clearly thinner in the porus area and weaker verrucae than those at the mesoporium cover it. The annulus and costae are absent.

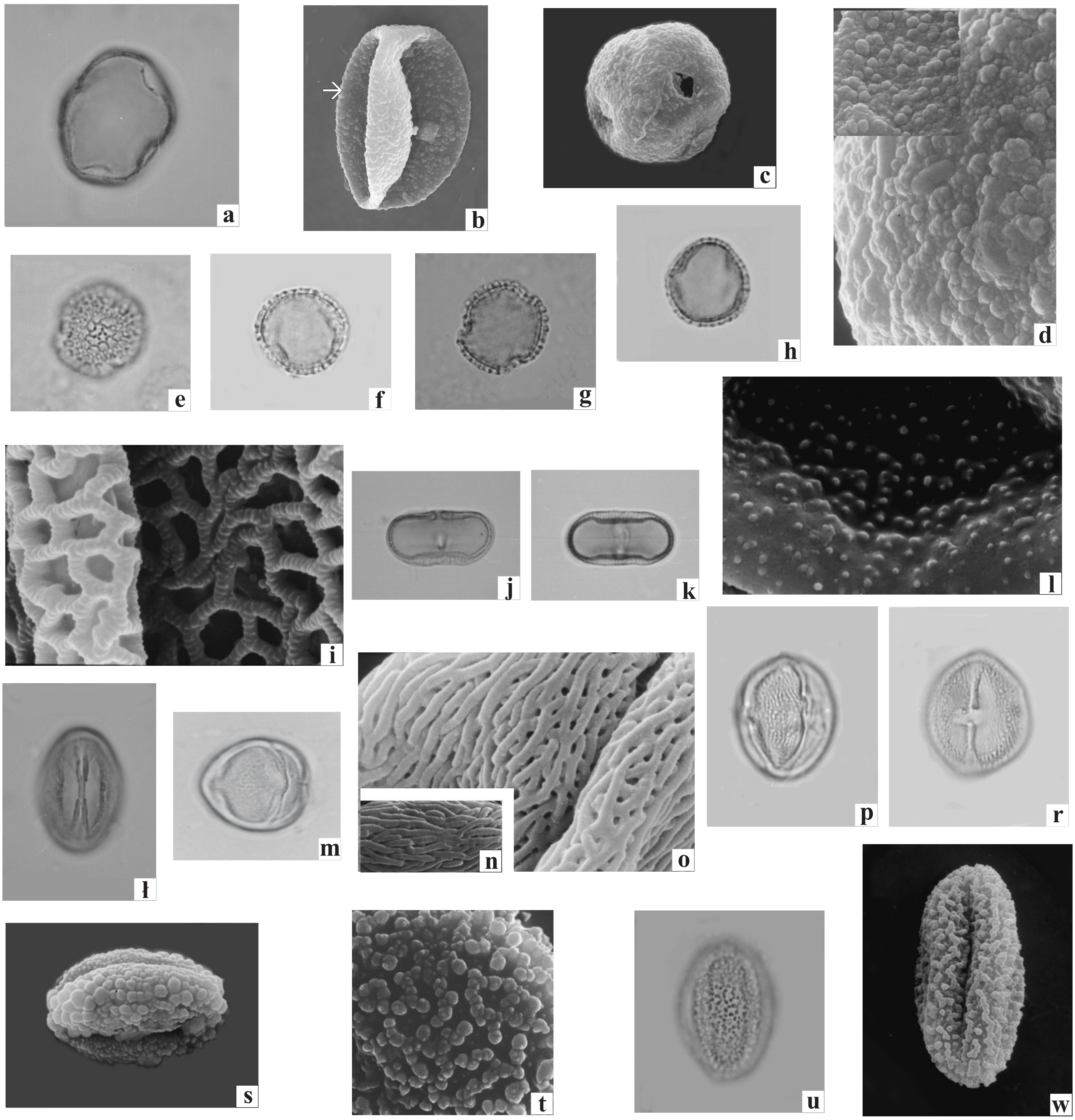


Fig. 6. Pollen grains of selected taxa from the Eemian at Dziewule against the Ferdynandovian, Mazovian and Brörup ones in Poland

a–**d** — *Quercus* sp., porate pollen, Dziewule (Eemian), *Quercus* level: **a** — x 500, **b**, **c** — pores x 2500, **d** — ornamentation, verrucae x 10000; **e**–**i** — *Olea* sp., Dziewule (Eemian), *Quercus* level: **e**–**g** — x 500, **i** — ornamentation, distinct transversal ridges x 10000; Woskrzenice site (Mazovian), *Carpinus* Zone: **h** — x 500; **k**–**j** — *Falcaria vulgaris* Dziewule (Eemian), Quercus zone: **k** — side view: x 500, **j** — colpus view; **l**–**ł** — *C. mas*, Dziewule (Eemian), *Quercus* level, ornamentation, scabrae **l** — x 10000, **ł** — a distinct, "H" endoaperture x 500; **m** — *C. mas*, Błędowo side view x 500 (LM); **n**–**r** — *C. coggygria* — recent specimen, Lvov vicinity, ornamentation, striae pattern, **n** — x 4000, Dziewule (Eemian), *Quercus* level, striae pattern: **o** — x 5000, **p** — mesocolpium area, striae, colpus view, broad pores: **r** — x 500, **s** — *Ilex aquifolium*, Dziewule (Eemian), *Carpinus* Zone, equatorial view, ring of less distinct clavae around the equator x 2500; **t**–**w** — *V. lantana* — Dziewule (Eemian), *Quercu*s Zone, pilate ornamentation: **t**, **w** — x 2500; **u** — mesocolpium area x 500

Viburnum lantana — pollen with a typical pilate pattern (Fig. 6 t–w) have been very rarely noted in Eemian records from Poland (Antosiakówna, in Klatkowa, 1990) as well as in Germany at Zeifen (Jung *et al*., 1972). In Dziewule and the other Eemian sites in the Podlasie region this type co-occurs with that of the second species — *Viburnum opulus*. The special pollen diagram for the middle part of Eemian Interglacial (Fig. 4) shows the proportion of *V. lantana* and *V. opulus*, which do not reveal any clear variation in their curves. In the pollen diagram the first species appears later than *V. opulus* and it declines earlier than it. A different scenario is seen in reanalysed Mazovian (Holstenian) material from the Woskrzenice site (Bińka and Nitychoruk, 1995). The pattern of *Viburnum* frequencies shows that *V. opulus* is restricted to the *Picea–Alnus* Zone and the end of the intra-interglacial *Pinus* phase. *V. lantana*, by contrast, occurs exclusively in the climatic optimum, in the *Carpinus–Abies* Zone. Suitable native habitats for *V. lantana* are open oak and pine forests on fertile, often calcareous soils, today seen in warm marginal areas of forests of western and southern Europe (Rothmaler, 1988).

Cotinus coggygria — 7 grains of *C. coggygria* (Fig. 6n–r) were noted in the *Quercus* and *Corylus* zones. Similar pollen grains were found in the nearby Mazovian (Holstenian) sites at Kaliłów (Bińka and Nitychoruk, 1996, reanalysed) and Woskrzenice. They differ clearly from other members of the family Anacardiaceae present in modern European flora. *C. coggygria* is reported from Slovakia (Bertova, 1984), where it occurs in similar plant communities such as *V. lantana* — Quercion pubescenti-petraeae, Erico-Pinion, Prunetalia.

Cornus mas — only 4 pollen grains with characteristic endoaperture and sculpture elements (Fig. 6l–m) were found in the *Quercus* and *Capinus* zones. This plant, reaching as far north as Slovakia in its present-day distribution pattern, like the two species noted above, must also be regarded as a thermophilous element in a temperate interglacial succession. Pollen of *Cornus mas* were noted in the *Carpinus* Zone in reanalysed Mazovian Interglacial (Holstenian) deposits at Woskrzenice and in the Holocene from Błędowo (Fig. 6m).

Olea — pollen grains of *Olea* with a clear reticulum pattern and distinct transversal ridges (Fig. 6e–i) are generally known from the *Corylus* Zone and rarely from the oak phase. At the nearby Przywory site they occur in the *Carpinus* Zone. They were recognised also in Mazovian (Holstenian) deposits in Podlasie (at Woskrzenice, Kaliłów and Wilczyn — Bińka *et al*. 1997, reanalysed) in the *Carpinus–Abies* Zone.

It seems that the Eemian range of *Olea* as well as other previously mentioned thermophilic elements must, in this interglacial, have extended farther north than today. The extrazonal single locality of *Olea* might have been close to the Dziewule site.

Fraxinus ornus — rare *F. ornus* were noted both in the Mazovian (Holstenian) and in the Eemian, mainly in the *Carpinus* Zone (Fig. 5a–d). Similarly to *Cotinus* and *V. lantana*, this species has a southern type of distribution with the nearest localities in Slovakia. Other SEM photographs of *Fraxinus* pollen from Eemian and Mazovian (Holstenian) deposits in Podlasie show that almost all represent the *F. excelsior* type (Fig. 5e–f) (Punt *et al*., 1991).

Syringa — identification of *Syringa* and *Ligustrum* pollen in LM usually causes problems. Such features as the length of the colpus or columellae and poorly visible endopori (Punt *et al*., 1991) do not always allow a univocal recognition because of the considerable morphological variability of interglacial pollen grains, especially the shape of the reticulum and columellae. Three pollen types can be distinguished in the Mazovian Interglacial (Holstenian) in the study area — *Syringa* sp., *Ligustrum* type and *Ligustrina amurense* (Bińka and Nitychoruk, 1995). By contrast, as suggested by SEM, *Syringa* is the only pollen type found at Dziewule. SEM of *Syringa* pollen from other Quaternary stratigraphic units in Poland (Ferdynandovian–Gołowierzchy; Mazovian–Wilczyn, Woskrzenice; Brörup–Świnna Poręba (Bińka and Grzybowski, 2001) (Fig. 5g–k) show a diverse character of the reticulum. The pollen examined are not similar either to modern grains of *Ligustrum vulgare* (lack of granules in lumina), nor to *Syringa vulgaris* in the reticulum character. Some specimens from the Ferdynandovian and Mazovian show a very solid semitectum with small lumina and broad muri. The lumina of Eemian, Brörup and some Mazovian specimens, diverse in character, are somewhat larger and the muri seem to be narrower.

DISCUSSION

In spite of regional differences there is a clear match with pollen zones recognised from sequences in West Europe (Menke and Tynni, 1984; Behre, 1989; Litt *et al*., 1996; Zagwijn, 1996) and those from Poland (Mamakowa, 1989; Tobolski, 1991). The principal features of these sequences include an undisturbed Late Saalian succession, an Early Eemian *Quercus* phase, a noticeable *Corylus* Zone and a short *Picea–Abies* Zone at the end of interglacial. The Vistulian part of profile (pollen zones 11–13) is not clearly developed and it covers the Herning Stadial (L PAZ *Betula* — NAP 11), the Brörup Interstadial (L PAZ *Pinus* 12) and probably the Rederstall Stadial (L PAZ NAP 13). All these intervals allow the section from Dziewule to be correlated with Oxygen Isotope Stages 6–5b of the oceanic stratigraphy.

Detailed climate reconstruction based on individual plant taxa is considered by palynologists as the most important source of information. However, climatic inferences from the appearance of particular trees and indicator plants in the case of interglacial deposits must be treated with caution. Considering their appearance in successive interglacial periods (e.g. Mazovian, Eemian and Holocene) in the limited area, we can see that pollen of particular indicator plants declined gradually in younger deposits. The best example is *Vitis*. It appears very abundantly in the Mazovian, is less abundant in the Eemian and very rare in the Holocene (Latałowa, 1976; Bińka *et al*., 1991; Ralska-Jasiewiczowa *et al*., 1998). Similarly, *Buxus* noted as a continuous curve in the Mazovian appeared sporadically in the Eemian. It seems that the consequent limitation in plant distribution hold *Hedera*, *Ilex* and *Viscum*, also occurring in Poland. Both in the Eemian and in the Mazovian, these plants ranged commonly beyond their present-day limits. In the Holocene, the Carpathians barrier was also not to be crossed by plants present in older deposits such as *V. lantana*, *Tilia tomentosa*, *C. coggygria*.

The same reservations can be also applied to some interglacial trees — *Picea*, *Abies*, *Carpinus* and *Taxus*, which had a much wider distribution and may have been better adapted to warm periods than their recent representatives. This was also suggested by West (1961), who proposed somewhat different climatic demands in the case of *Corylus* in successive interglacials, and by Andersen (1966) regarding interglacial populations of *Picea abies*.

The presence of numerous exotic taxa in interglacial floras of Central Europe — *Pterocarya*, *Parrotia*, some species of *Acer* and *Crataegus*, *Hydrocotyle* as well as abundant macrofossils of *Euryale*, presently occurring in distant, limited areas (Mania and Mai, 1969; Mai, 1990; Bińka and Nitychoruk, 1995), also testify to the considerable restriction of present-day ranges in comparison with Pleistocene ones, and, as a consequence, the limitation of climatic demands during successive interglacials. It seems also that this is responsible for cases when the ranges of oceanic and continental plants (in present-day understanding) more often bordered each other, occupying wider areas in interglacials than nowadays. An example of such broader coexistence of different floristic elements may be the *Quercus* Zone in the Eemian, from which numerous oceanic and continental plants have been noted.

The Late Saalian sequence recorded at Dziewule does not confirm observations from some European pollen records, which noted a two-step deglaciation at that time with a short intervening period of a Younger Dryas style (Jung *et al*., 1972; Wegmüller, 1992; Seidenkrantz *et al*., 1996; Drescher-Schneider and Papesch, 1998). The improvement of climatic conditions is gradual without any reestablishment of colder phases (Bińka and Nitychoruk, 2001).

The initial pollen zone of the interglacial, the birch pine interval, is characterised by a rapid change in climate. In the Dziewule section a pronounced hop phase took place. Its native distribution today is limited to the temperate zone. This suggests that in a boreal climate *Humulus lupulus* migrated ahead of its temperate tree rivals. Thus the temperature conditions seem to be better than can be deduced from the forest components of that time. Zagwijn (1996) assumes a mean temperature of the warmest month of around 17°C at that time for the Netherlands.

The subzone 5b of pine-elm phase, especially its second half, marks a radical amelioration of climate. Pollen of *Hedera*, *V. lantana*, *V. opulus*, *Viscum* and *Cornus sanguinea* appeared regularly for the first time.

It is commonly assumed (Zagwijn, 1996; Litt *et al*., 1996) that the initial pollen zones of the Eemian — *Quercus* and *Corylus* — are characterised by the highest mean July temperatures of the entire interglacial. This is suggested by the occurrence of thermophilous plants such as e.g. *Dulichium spathaceum*, *Brasenia schreberi*, *Acer tataricum*, *Trapa*, *Aldrovanda vesiculosa* and *Cyperus glomeratus* (l.c.). According to Aalbersberg and Litt (1998) as well as Litt *et al*. (1996), as deduced from the macrofossils of *Acer tataricum* and *Cyperus glomeratus*, the mean July temperatures in this interval reached up to 20°C in the subcontinental type climate of Poland and in southeastern Germany. Their maximum was attained in the E4b level (in Zagwijn's stratigraphic scheme — Zagwijn, 1996) of the Eemian.

Zagwijn (1996) assumes that the maximum of July temperatures in the Netherlands took place in the E3b–E4a pollen zones under fairly low winter temperatures and low precipitation. Aalbersberg and Litt (1998) and Zagwijn suggest winter temperatures at a level around — 2°C. Tobolski (1991) estimated the highest mean July temperatures of 20–21°C in the *Corylus* Zone of Central Poland, where numerous macrofossils of *Dulichium spathaceum*, *Brasenia schreberi*, *Aldrovanda vesiculosa* and *Cyperus glomeratus* have been found.

At Dziewule, the *Quercus* Zone (especially its second half) and *Corylus* Zone evidently contain a significant amount of thermophilous elements. *Vitis*, *Viburnum lantana*, *Viscum*, *Olea* (far transported?), *Cotinus coggygria*, *Cornus mas*, *Syringa* and probably *Fraxinus ornus* are noteworthy. A very significant change took place at the transition from the *Quercus* to the *Corylus* Zone (Figs. 3 and 4). Thermophilous shrubs with *Cornus mas, C. sanguinea*, *Viburnum opulus*, *V. lantana* and *Syringa* disappeared or were restricted, whereas *Viscum* reached higher values, which, as mentioned above, is reported most often from the *Corylus* Zone of the Eemian in Poland. It seems that its broader expansion in this zone may be a sign of rising winter temperatures, as can be also deduced from pollen grains of *Ilex* recorded in the deposits. It is problematic, however, why its occurrence in the previous zone, also with favourable winter temperatures and good light conditions, is so barely marked.

The climate of the *Quercus*/*Corylus* zones as proposed by researchers was characterised by high temperatures in January and July, higher than presently in this area. According to Mai (1992) and Aalsbersberg and Litt (1998) some plants found in the *Quercus*/*Corylus* Zone e.g. *Acer tataricum*, *Carex secalina* and *Viola rupestris* indicate the subcontinental — suboceanic features of climate in this interval. Undoubtedly varied floristic elements are reported in these intervals from Central Europe. At Dziewule, on the one hand, *Pinus* and Ephedraceae with their continental distribution pattern still show a high proportion. *Vitis*, *Cornus mas*, *Cotinus* and *Falcaria* — have rather subcontinental impress on communities in the *Quercus* Zone. On the other hand, oceanic elements such as *Viburnum lantana*, *Hedera* and *Viscum* occur in this zone, which indicate milder winter conditions.

At the onset of the *Carpinus* phase, an instantaneous drop of the water level took place, as can be observed at many Eemian sites in Poland (e.g. Dziewule, Jóźwin — Tobolski, 1991; Główczyn — Niklewski, 1968; Besiekierz — Janczyk-Kopikowa, 1991 and several sites in eastern Poland) as well as in Europe. Lacustrine sedimentation is replaced by a episodic peat deposition or stratigraphical hiatuses are observed in the profiles, suggesting that the balance between evaporation and precipitation changed. This view is irreconcilable with Zagwijn's (1996) and Aalsbersberg and Litt's (1998) estimations. Zagwijn suggests that a decrease in mean summer temperatures (July temperatures around 17°C) and an increase in winter temperatures of up to 2 or 3°C occurred under increasing precipitation. This scenario of temperature changes and probably precipitation is in accordance with Aalbersberg and Litt (1998) who suggest that the mean temperatures of the coldest month (MTCO) would rise (maximum amount of pollen grains of *Ilex* throughout the interglacial) and those of July would decrease in the *Carpinus* pollen zone. Finally, Cheddadii *et al*. (1998) assumed that, at the beginning of the hornbeam zone, a dramatic change in winter temperature took place. A decrease in precipitation, although less pronounced, is also reported.

The presence of *Ilex* since the beginning of the *Corylus* phase with the culminating point in the *Carpinus* Zone and the similar composition of *Hedera* pollen show an increase in winter temperatures in Central Europe. It is, however, worth noting that *Vitis*, *Fraxinus ornus*, *Cornus mas*, *Buxus* and *Olea* are noted from this interval in the pollen diagram from Dziewule. This suggests a possibility of still rather high summer temperatures. At Grabschütz (Mai, 1990), thermophilous plants: *Aldrovanda*, *Caldesia*, *Dulichium* and *Brasenia* are also reported the in the *Carpinus* Zone, which supports this conclusion. By comparison, the *Abies–Carpinus* Zone marks the maximum July temperature in the Mazovian of Central Europe. This is emphasised by a significant amount of thermophilous flora in this zone. Some interpretation problems arise when these facts are confronted with Zagwijn's (1996) estimations. If a stability of precipitation is accepted (or its increase as proposed by Zagwijn) in relation to the previous zone, then the mean July temperature would not have dropped in the light of the data discussed above. Taking into account the commonly observed decline of lake levels at that time, the temperature should be at least at the same level or higher. This could well explain the oscillations of water level at the Dziewule. Finally it is suggested that the July temperature of the *Carpinus* Zone is similar to that of the *Quercus* and *Corylus* zones and simultaneously the amount of precipitation decreased in comparison with the previous intervals, or the July temperatures were higher under a constant precipitation level. This is necessary to explain the occurrence of shallow water sediments in this zone. The MTCO is considered the same or higher than in the *Corylus* Zone as shown by Zagwijn (1996) and Aalbersberg and Litt (1998).

THE PROBLEM OF EEMIAN CLIMATE FLUCTUATIONS

Recently, suggestions were made that the Eemian Interglacial in Europe and in adjacent areas was interrupted by a ,"severe cooling event" (Field *et al*., 1994 and also Karabanov *et al*., 2000). Based in part on numerous cold oscillations recorded in the Greenland ice core (GRIP Members, 1993), the credibility of which is nowadays questioned (Grootes *et al*., 1993), the findings from continental sites in Europe were reinterpreted.

According to Fied *et al*. (1994), the climate, as reconstructed from a laminated lake sequence at Bispingen, suggests a considerable instability of climate. The authors suggested a distinct MTCO decrease (from plus 5°C to min. 5°C at the start of the *Carpinus* Zone with a major oscillation at its end) with MTCO temperatures about min. 20°C as in Central Siberia today. In their reconstruction of MTCO and precipitation for selected sites of the Eemian in France and Poland, Cheddadi *et al*. (1998) showed also that the MTCO from the very beginning of the *Carpinus* Zone dropped by about 6–10°C. The same applies to precipitation, a decrease of which coincides with the MTCO decrease. The magnitude of the precipitation decrease is suggested at about 200 to 300 mm/yr. However, some pollen diagrams analysed, Główczyn and Imbramowice, like most European diagrams (including Dziewule), are less reliable in the *Carpinus* Zone, because they are recorded in peat deposits and thus should be considered with caution. This may cause some disturbance in the shape of pollen curves and thus in the finally reconstructed pattern. Only deepwater sediments are a very reliable source of reconstruction when the course of pollen curves is analysed.

The severe drop in winter temperatures in the *Carpinus* Zone reconstructed by Cheddadi *et al*. (1998) and Field *et al*. (1994) has no support both in the Dziewule section, taking into consideration the indicator plants, and the course of tree curves in pollen sequences which have a reliable deepwater record such as Nakło (Noryśkiewicz, 1978) and Łomżyca (Krupiński, 1992). Based on interglacial sites at Grabschütz, Gröbern and Neumark, Litt *et al*. (1996) in their multiproxy study also suggested a lack of such drastic events in the Eemian. The Eemian sites from northern Europe also do not confirm a drastic drop of winter temperatures, a continuous sequence without any sudden climatic events being recorded from northern Finland (Saarnisto *et al*., 1999).

As shown above, there is possibility of an increase (or the same as in the *Corylus* Zone) rather than a decrease in the MTCO in the *Carpinus* Zone. The only event in the Eemian of Central Europe, which is recognised as significant, is the commonly noted drop in water level in the *Carpinus* Zone. This might result from an increase in mean July temperatures (the level of precipitation remaining the same) and as a consequence of an increase in evaporation levels, or the July temperatures remaining unchanged with a simultaneous decrease in precipitation. This would be in agreement with the observations of the Eemian transgression in Europe, where, as shown by Zagwijn (1996), the maximum Eemian transgression is correlated with the *Carpinus* phase. Such a scheme of climatic change is partly suggested by Cheddadi *et al*. (1998). According to them, a small decrease in precipitation level might have taken place in this pollen zone, which resulted in the changes of sedimentation character or significant drop in water level. However, it is not clear whether the decline of the lakes in the *Carpinus* Zone is indeed an effect of a drastic climatic event.

When the changes of the Eemian lake basins are taken into consideration, substantial differences in sedimentary records, which distinguish them from Mazovian and Holocene ones, cannot be overlooked. As deduced from the Mazovian (Nitychoruk, 1994) and Holocene lake records (reference sites of IGCP 158b sub-project), despite a different course of the major climatic changes in these intervals, the lake basins are generally similarly developed. The deposits usually start with late-glacial mineral deposits, followed by long sequences of different types of interglacial gyttjas, which were sediments of deep basins developing in dead ice hollows. In such lakes the identification of the hydrological changes, strongly marked only in littoral areas, is difficult. In this respect, most of the Mazovian and Holocene sections contain relatively continuous deposits without any marked hiatuses, especially until the middle parts of the sequences. Examples of such stratigraphical hiatuses may be often noted as a lack of the intra-interglacial *Pinus* Zone or as numerous gaps after the *Carpinus–Abies* Zone in the Mazovian Interglacial. The latter took place, however, at a time when the lake basins had largely been infilled with deposits throughout the interglacial. The importance of such facts is surely rather minor, even though this event is commonly observed.

A quite different pattern arises from analysis of the numerous Eemian lakes reported in Poland. The observations of dozens of Eemian sites in Central Poland (Klatkowa, 1990) have enabled the relatively precise conclusion that a large proportion of depositional basins occupy small areas, unlike the modern lakes in Poland, and this leads to the suggestion that the Late Saalian deglaciation of the discussed area proceeded in the abundant presence of disintegrated dead ice blocks.

In origin, generally they represent meltwater lakes. Similar investigations of Eemian lakes in the Podlasie region, eastern Poland, confirm these observations. A large majority of interglacial basins ranging in size from tens to a maximum of several hundred of metres in diameter are very susceptible to climate changes.

Contrary to Klatkowa's opinion about the Eemian deposits of Central Poland, it is suggested that most of the Eemian basins in Poland were rather infilled with shallow water or terrestrial deposits. The consequence of the small size of the Eemian lakes is their high susceptibility to climate change.

Late Saalian and Early Eemian sedimentation until the *Corylus* Zone recorded in rare deepwater lakes, as a rule resembled those of the Mazovian and Holocene with gyttjas. At the end of this zone, a decrease in lake level took place at most sites. Lacustrine deposits were replaced by peat or shallow water minerogenic sediments, which show many hiatuses. As mentioned above, reliable continuous sequences representing the second half of the Eemian are very rare in Poland. This situation lasted till the end of the *Carpinus* phase and after that sedimentation in the lakes usually appeared again. In the intervening period, different types of peat, often with a high degree of humification, accumulated. This is the most clearly defined stratigraphical layer in the Eemian of Central Europe.

It seems, however, that the climate changes which resulted in the lake level oscillation, did not have a catastrophic character and despite their regular appearance in Eemian records, this phase can be regarded as a climatic oscillation of lower rank. This is confirmed by a rather consequent course of pollen curves without any major oscillations in the *Carpinus* Zone in deepwater lakes of the Eemian. This decrease of water levels is well marked in most deposits, primarily because of the small size of depositional basins, which are more sensitive than bigger ones.

GENERAL CONCLUSIONS

1. A characteristic feature of the Eemian Interglacial is a commonly observed decrease in water level in the *Carpinus* Zone. Contrary to some opinion, this event recorded in the numerous Eemian lakes is only an effect of decrease in the precipitation level under similar mean July temperatures. This might result from the fact that small lakes and ponds are very susceptible to changes of climate parameters than larger ones. Thus even a small climatic oscillation might have caused coupled results. No substantial climatic events (such as a strong decrease in winter temperatures) inferred in some works (Field *et al*., 1994, Karabanov *et al*., 2000) are recorded in the *Carpinus* Zone.

2. The Eemian succession is marked by a very early expansion of thermophilous plants (end of the initial *Betula–Pinus* Zone) with a maximum in the second half of the *Quercus* Zone, the *Corylus* Zone, as well as in the hornbeam phase. Especially important are species rarely noted in pollen sequences: *V. lantana*, *C. mas*, *C. coggygria* and *Olea*.

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