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New investigations into the Early Vistulian site at Białowice (Zielona Góra area, SW Poland)

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The Białowice site is situated in the north-west of the Nowa Sól Depression which is part of the Central Poland Lowlands. Palynological analysis shows that lake and swamp accumulations took place in the Early Vistulian. Two warm interstadial-rank oscillations (Brörup and Odderade) and a stadial (Rederstall) have been distinguished during the Early Vistulian. The sequence of changes at Białowice is similar to the sequences in profiles from other parts of Poland and Western Europe. Until now, in that region of Poland the vegetation succession of the Brörup and Odderade had remained unknown. The lithology of the profile at Białowice shows rapid changes of sedimentation which have been observed in the younger part of the Brörup and at the Brörup/Rederstall transition. Geological and palynological data suggests that the maximum limit of the Vistulian Glaciation to the south of the Żary Hills.

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INTRODUCTION

The stratigraphy and palaeogeography of Quaternary deposits underlying the Milicz–Głogów Depression were elucidated during mapping of the Krzystkowice sheet of the *Detailed Geological Map of Poland* at 1:50 000 scale, archived together with examination of a borehole log (Bartczak, 1999). This documented a 11.5 m thick sequence of organogenic deposits (peat and silt with plant remains) overlying grey till and covered by a 3 m thick layer of medium-grained sand. The GEOPROBE drilling at the same site yielded a 13.2 m thick interval of lacustrine and swamp deposits which have been the subject of detailed palynological investigations. These deposits represent a continuous and undisturbed sequence spanning the Early Vistulian. The pollen sequence from Białowice is the first sites in SW Poland that shows the Brörup and Odderade interstadials.

It has been established that the full Early Vistulian vegetational succession includes four assemblage zones (EV1–EV4) in Poland (Tobolski, 1991; Granoszewski, 2003; Roman and Balwierz, 2010). Of the four zones, two (EV1 and EV3) represent the vegetation of open areas and correlate to stadials, and two reveal forest vegetation (EV2 and EV4) of interstadial nature. Zones EV1 and EV3 correspond to the Herning and Rederstall stadials, while zones EV2 and EV4 have been correlated with the Brörup and Odderade interstadials in the stratigraphic scheme of Behre and Lade (1986) and Behre (1989).

Of late organic deposits from the Early Vistulian have been frequently found in Poland and the chronostratigraphical position of the older interstadial (EV2) has been discussed (Mamakowa, 1986, 1989; Granoszewski, 2003; Roman and Balwierz, 2010). In Poland, the first warm oscillation was correlated with the Danish Brörup (Andersen, 1961) or with the Dutch Amersfoort and Brörup interstadials succession (Zagwijn, 1961). The biostratigraphy of the Weischelian Glaciation has been thoroughly investigated too in Central Europe by Behre (1989) and by Grüger (1991). These studies involved, *inter alia*, the Early Vistulian. According to Behre (1989) and Grüger (1991) the Dutch Amersfoort–Brörup succession (Zagwijn, 1961) may be correlated with the Danish Brörup (Andersen, 1961), while the Odderade represents the second interstadial.

The Danish Brörup has a well-developed birch zone, whereas the Dutch Brörup shows a particularly high percentage of *Alnus* and *Picea* pollen whereas in Polish sites the older interstadials were characterized by minor occurrences of alder and spruce (Mamakowa, 1989; Stankowski and Nita, 2004; Kuszell *et al*., 2007; Malkiewicz, 2010). The Brörup Interstadial of Denmark is clearly divided into two phases: birch forest at first and then pine forest. These phases are separated by a slight cold oscillation (Andersen, 1961). This oscillation was recognized as a decrease in the proportion of herbaceous plants. The segment from the Amersfoort to Brörup contains the cold oscillation that separated these interstadials as layer of sand (Zagwijn, 1961). However, this layer of sand may be synchronous with deterioration, but does not prove deforestation (Grüger, 1991). This oscillation between the birch and pine phases has been noted only in some sites from Central Poland (Jastrzębska-Mamełka, 1985; Stankowski and Nita, 2004) and mid-eastern Poland (Granoszewski, 2003; Krupiński, 2005; Kupryjanowicz, 2008). Among the remaining sites from Poland correlated with the Brörup Interstadial the palynological investigations give no grounds for the distinction of a climatic oscillation in the older part of Brörup similar to the one found in Holland (Zagwijn, 1961). In most sites in Poland the older warm oscillation (EV2) of the Early Vistulian was correlated with the Brörup Interstadial at its type locality in Denmark (Andersen, 1961) with the cold oscillation separating only birch and pine phases and with a larger role of the herbaceous plants in that interval. There is a lack of distinct evidence of weak cooling in some Polish diagrams (Kozarski *et al*., 1980; Kuszell *et al*., 2007; Malkiewicz, 2010).

Localities with organic deposits and complete Early Vistulian successions have been noted in Western Poland. Despite a large number of sites acknowledged to be Eemian on the basis of palynological investigation, only a few have Early Vistulian with the Brörup and Oderade interstadials (Bruj and Roman, 2007; Malkiewicz, 2010). At the present day sites with a Brörup Interstadial from Western Poland have been recognized at Stare Kurowo (Kozarski *et al*., 1980) and one with containing a section of the Odderade Interstadial at Białowice. Sites with lake and mire deposits of the Eemian–Early Vistulian interval with Brörup and Odderade in Poland have only been documented at Dziadowa Kłoda (Kuszell *et al*., 2007) and Gutów (Malkiewicz, 2010). The other Early Vistulian sites have incomplete lacustrine sequences (Mamakowa, 1986, 1989; Kuszell, 1997; Malkiewicz, 2010). The number of Vistulian sites in Western Poland is low in comparison to other regions (Central and Eastern Poland). An important contribution here is that these sites have been found in an area, where no Vistulian sites have been recorded before.

The subject of this paper is to analyse the development of flora and climate of the Early Vistulian, based on palynological investigation of lacustrine deposits at Białowice. The reconstructed pattern of vegetation and climate has allowed for the recognition of three climatic oscillations corresponding to the Brörup (EV2) and the Odderade interstadials (EV4), and the Rederstall Stadial (EV3).

THE AREA OF INVESTIGATIONS

The site studied is located near Białowice, 3.5 km southwest from Nowogród Bobrzański in the Nowa Sól Depression (Fig. 1) which is part of the Milicz–Głogów Depression and belongs to the subprovince of the Central Poland Lowlands (Kondracki, 2000). The Nowa Sól Depression lies between the Zielona Góra Swell in the north and the Dalków Hills and Żary Hills in the south. It is regarded a part of the Baruth–Głogów ice-marginal valley cut across by the Bóbr River valley. Figure 1 shows the general geological setting of the area near Białowice and Nowogród Bobrzański. Two different lithostratigraphic Neogene sequences underlie the Quaternary deposits (Dyjor, 1964, 1969, 1970). The older, Upper Miocene sequence is 30–40 m thick and consists of the heterogeneous Poznań Formation (unit G), shown in Figure 2. This formation contains clays and clayey silts with intercalations of quartz sands. In the area investigated the Poznań clays (unit G) are subhorizontal, dipping slightly northwards with the top at an altitude of 60–70 m a.s.l. near Nowogród Bobrzański in the western part of the Dalków Hills; the deposits are glaciotectonically disturbed (Bartczak, 1999).

The younger Neogene sequence is built of the Pliocene Gozdnica Formation (unit F; Fig. 2). It comprises sands of various grain sizes with minor fine gravels and kaolinitic clays as well as thin lenses of silty-sand and clayey-silt. These, deposits up to 30 m thick, crop out north and south of Białowice (Fig. 1). Their occurrences are separated by a narrow (*ca*. 200 m) depression up to 48 m deep. The depression runs NE–SW and is probably a sub-glacial erosion channel. It is filled by two units of till that correspond to the South Polish Glaciation (Elsterian) (unit E) and Middle Polish Glaciation (Late Saalian), formerly the Wartanian Glaciation (unit C; Lindner and Marks, 1999; Ber *et al*., 2007). They are separated by an layer of sand up to 7 m thick (unit D; Fig. 2). The younger till extends beyond the depression and overlies a part of the Pliocene uplands. The Middle Polish Glaciation till is locally washed out and a basin that formed in the depression is filled with lacustrine and swamp deposits (unit B; Fig. 2). The top of these deposits at Białowice is at an altitude of 91.2 m a.s.l. During the maximum extent of the Leszno (Brandenburg) Phase they were covered by fluvial deposits of the Bóbr River (unit A; Fig. 2).

The Quaternary succession described from this area has been a subject of previous geological and geomorphological studies (Bartkowski, 1961, 1963; Brodzikowski, 1978). The area lies within the limits of the Wartanian Glaciation. However, the extent of the Vistulian Glaciation (Weichselian) in the Western Poland is still being discussed. It is commonly delineated north of the area studied (Gubin Hills and Zielona Góra Swell) while tills of the frontal push moraine along the Nowogród Bobrzański–Jasień line with an adjacent uppermost flood-plain terrace of the Bóbr River are regarded as Wartanian (Brodzikowski, 1978). However, Bartkowski (1961, 1963) in his geomorphological studies shifted the maximum limit to the south of the Żary Hills. Mapping of the Nowa Sól Depression together with palynological analysis of the Białowice deposits show the Vistulian age of the uppermost alluvial horizon above Nowogród Bobrzański in the Bóbr River valley. Consequently, they confirm the maximum limit of the youngest glaciation established by Bartkowski in that area.

The sedimentary sequence in the profile at Białowice which comprises lacustrine and boggy deposits displays some lithological variations (3.6–13.2 m; Table 1). The lower part of the profile comprises medium-grained sands (*ca*. 4 m depth),

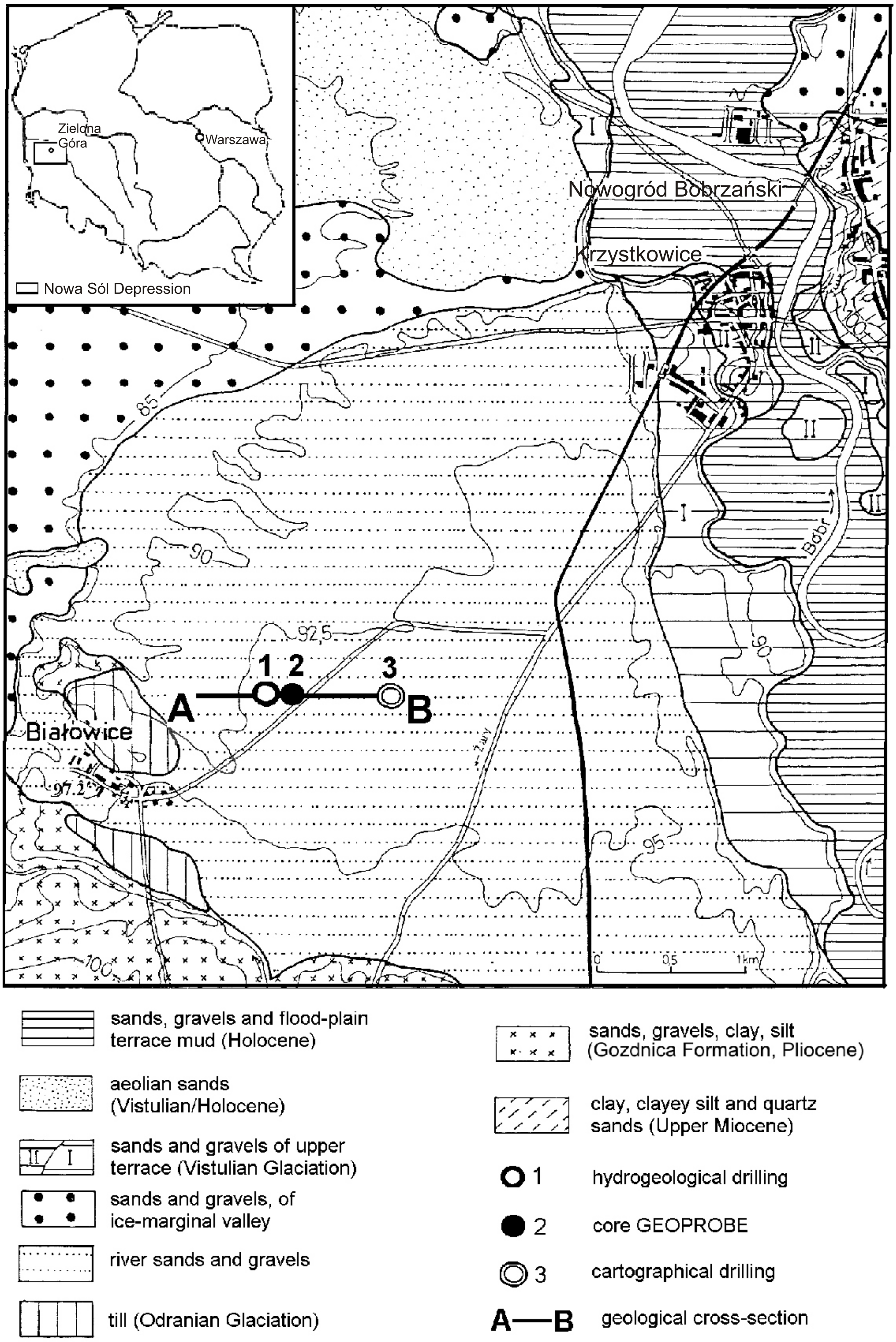

Fig. 1. Geological sketch of the Nowogród Bobrzański area showing the location of the boreholes

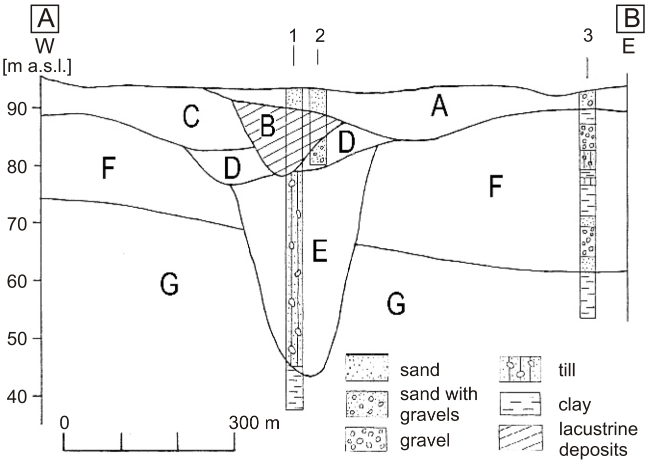

Fig. 2. Geological cross-section A–B of the Białowice area

A – Holocene, B – Early Vistulian, C – Middle Polish Glaciation (Saalian), D – South Polish Glaciation/Middle Polish Glaciation, E – South Polish Glaciation (Elsterian), F – Pliocene (Gozdnica Formation), G – upper Miocene (Poznań Formation); for location and other explanations see Figure 1

Table 1

Lithological succession of the deposits cored at Białowice

Depth [m]	Lithology
0.0–3.8	fine-grained sand, with laminated silt
3.8–6.2	varied-grained sand or medium sand
6.2–6.3	silty sand
6.3–6.7	organic silt
6.7–7.1	silt, with traces of sand
7.1–7.2	gyttja
7.2–7.9	lack of core (sand)
7.9–8.0	silt, with traces of peat
8.0–8.9	peat, dark-brown
8.9–9.0	silty peat
9.0–9.3	brown silty sand
9.3–9.6	brown sand
9.6–10.8	lack of core (sand)
10.8–13.2	medium sands with traces of organic matter

overlain by peat, gyttja, sand and organic or mineral silt. This succession is covered by *ca.* 4 m of sand. Such a sequence probably accumulated with a small and relatively shallow sedimentary basin characterized by unstable conditions.

MATERIAL AND METHOD

Deposits from Białowice from the depth interval 3.6–13.2 m have been subjected to palynological analysis (Table 1). This profile comprises lacustrine and swamp deposits about 9 m thick. The core obtained was placed in PVC tubes and wrapped in plastic foil. 77 samples were taken from the Białowice profile, although only 44 samples (depth 6.3–7.2 m and 7.9–9.3 m) contained sufficient pollen for interpretation. In the depth range of 7.2–7.9 m there was lack of core (sand).

The material for pollen analysis was prepared in two ways. Peat and organic silts were boiled in 10% KOH, whereas mineral samples were treated with HF. Standard Erdtman's acetolysis was applied. The pollen spectra were counted on at least two slides and in the samples with a low sporomorph frequency were identified in four slides. In each sample from 500 to 1300 pollen grains were determined. The frequency of sporomorphs was highest in peat layers and organic silts. Only *in situ* pollen was found in the material analysed.

The results of pollen analysis from lacustrine and swamp deposits of the Białowice profile between the depths of 6.3 and 9.3 m are shown in a pollen diagram (Fig. 3). The diagram has been subdivided into five local pollen assemblage zones (L PAZ), and marked with the first letter of the locality name B1 to B5.

VEGETATION SUCCESSION

Five local pollen assemblage zones L PAZ (B1–B5) representing three different units were distinguished in the Białowice pollen diagram and can be ascribed to a phase of the Early Vistulian from EV2 to EV4 (Fig. 3). Description of each zone is given in Table 2.

Zone B1 is dominated by boreal forest with pine or pine and birch. The small but persistent values of *Alnus* and *Picea* indicate their important role in wetter habitats around Białowice. In the forest undergrowth, there occur *Juniperus, Larix, Ephedra* with a greater variety of pollen of Ericaceae. *Corylus, Quercus* and *Tilia* pollen occur sporadically in the pollen diagram. This may have come from the lower part of the Sudetes Mountain and from their foreland, and their pollen may have been derived by long distance transport. In zone B1 there is sand in the silt layer (depth 9.0–9.3 m), which may be the result of runoff into the lake (Fig. 3). Initially, in the older part of this zone the non-forest vegetation plays an important role. This is indicated by a considerable content of herbaceous plants, reaching 34.2%. Cyperaceae, Poaceae, Chenopodiaceae and *Helianthemum* pollen was probably derived from steppe communities. At the end of the B1 zone a relatively small area was occupied by open vegetation and the forest area significantly increased. The formation of dense forests in this zone suggest moderately cold climatic conditions, yet much milder at that time. The mean temperature of the warmest month probably did not fall below 10°C and the occurrence of *Pinus* may suggest even a value of 12°C (Granoszewski, 2003). At the end of the B1 zone the accumulation type changed from lacustrine to swamp-like. Aquatic and swamp plants are absent. It seems likely that water levels decreased.

Forests of the following zone, B2, were dominated by pine with a smaller contribution of birch. *Picea* and *Alnus* played a considerable part in the formation of forest communities and should probably be associated with the most waterlogged sites. Spruce could have been abundant also in the pine forest, particularly on wetlands. *Salix* was present in wetter habitats in the region of Białowice. In those communities, *Larix* and *Juniperus* appear only sporadically. The area around Białowice was completely covered by forest during this zone (B2). This is supported by the low percentages of the herbaceous pollen (Fig. 3). The clear decrease in the proportion of Cyperaceae and the almost complete disappearance of Poaceae pollen suggest a decrease in the area of open herbaceous vegetation. The pres-

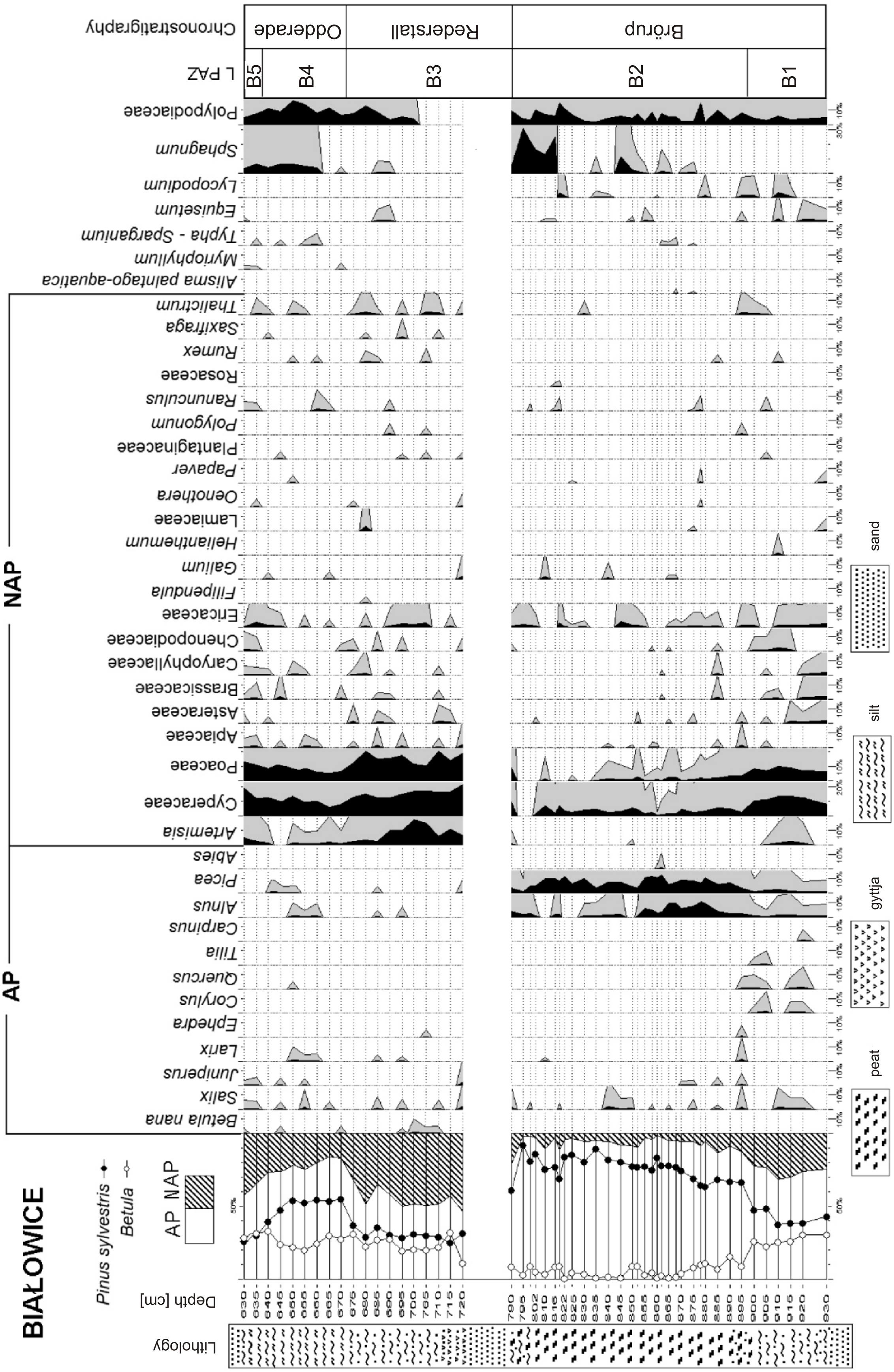

Fig. 3. Pollen diagram from Białowice

Table 2

Description of the local pollen assemblage zones from Białowice

Local pollen assemblage zones L PAZ	Depth [m]	Description of L PAZ
B5 *Betula*-NAP	6.3–6.37	The zone spans two samples. The highest proportions among AP (max. 57.2%) being those of *Betula* and *Pinus*. Its share of oscillate around 26%. Pollen of *Betula nana*, *Salix* and *Juniperus* occur. In NAP the highest values are those of Cyperaceae (up to 19.2%), Poaceae (13.4%) *Artemisia* (5.1%) and Ericaceae (2.1%).
B4 *Pinus-Betula*	6.37–6.72	The zone spans six samples. AP values increase to 81.8%; the pollen *Pinus* (53.8%) and *Betula* (31.6%) dominates. Pollen of *Alnus* and *Picea* are rarely found. Pollen of *Salix*, *Juniperus*, *Larix* and *Betula nana* are noted. Curves of Cyperaceae, Poaceae, *Artemisia* and Chenopodiaceae descend.
B3 Poaceae-*Artemisia*	6.72–7.2	The zone spans eleven samples. The values of AP oscillate from 33.2 to 42.6%. The NAP curve reaches 53.8%. Value for *Betula* is lower than for *Pinus*. *Betula nana* pollen occurs for the first time. *Salix*, *Juniperus* and *Larix* are present. Taxonomic diversity increases among herbaceous plants. The highest pollen values are those of Cyperaceae (22.7%), Poaceae (21.2%) and *Artemisia* (18.1%).
B2 *Pinus-Alnus-Picea*	7.9–8.97	The zone spans twenty samples. AP values persists very high (97.3%), but with *Pinus* dominant (90.2%). The share of *Betula* is slightly below 10%. The maximum proportion of *Picea* and *Alnus* is 10.1% and 14.2% in respectively. The percentages of *Salix* are below 1.5%. Pollen of *Juniperus* and *Larix* occurs sporadically. Curve of Poaceae and Cyperaceae descend. *Artemisia* was found only in two samples. In the upper part of the zone spores *Sphagnum* reach around 30%. Pollen of thermophilous trees was noted.
B1 *Pinus-Betula*-NAP	8.97–9.3	The zone spans five samples. The values of AP fluctuate between 65.8 and 73.6%. *Pinus* and *Betula* dominate in this zone. *Alnus* (1.7%) and *Picea* (2.2%) have continuous curves. There are single pollen grains of *Salix*, *Larix* and *Ephedra*. Pollen of *Corylus*, *Quercus* and *Tilia* are rarely found. Among NAP the highest proportion being those of Cyperaceae (13.2%), Poaceae (10.1%), Chenopodiaceae and Ericaceae. Pollen of *Helianthemum* is present.

ence of spruce, which requires enough moisture in the air and soil, in forest communities suggests a temperate and humid climate (Obmiński, 1977). The character of the vegetation in zone B2 indicates a boreal climate with a mean temperature in July at about 15°C (Tobolski, 1991), however, the expansion of alder and spruce probably point to warmth. In this zone indications of an oceanic climate are more abundant Ericaceae pollen and a very high proportion of *Sphagnum* spores (Tobolski, 1986). In the upper part of the zone (depth 7.9–8.0 m) a change took place in composition of the sediment from peat to lake deposits (silty peat, with traces of sand). A marked decrease in the proportion of *Sphagnum* spores from 30% to 7% indicates a change towards wetter conditions at the time (Granoszewski, 2003). The participation of aquatic plants is very low, comprising individual pollen grains of *Myriophyllum* and *Typha latifolium* only in the older part of the zone.

In the uppermost limit of zone B2 vegetation was dominated by herbaceous plants, mainly Cyperaceae, Poaceae and *Artemisia* and was subjected to a cold climate which did not restrict development of compact forest communities. A decrease in temperature and humidity caused the gradually retreat of alder and spruce and spread herb communities. At the time a change in accumulation took place, from silt to sand (depth 7.2–7.9 m) that separates zones B2 and B3. A similar situation is known also in other regions of Poland (Stankowski and Nita, 2004; Kuszell *et al*., 2007) as well as in Western Europe (Behre and Lade, 1986; Behre, 1989; Grüger, 1991).

In the lake basin above the sand deposits is gyttja only 0.1 m thick which underlies silt (B3). The pollen spectra from organic deposits adjoining the lower and upper sandy levels show a clear similarity. A different vegetation cover characterizes zone B3 (Fig. 3). The amount of tree and shrub pollen decreased significantly suggesting that progressive deforestation took place. In the initial part of the zone the birch was important in the tree community, as indicated by significant quantities of *Betula* pollen in only one sample. After the maximum spread of *Betula*, *Pinus* was undoubtedly the most important tree in the landscape. At the same time the birch forest was succeeded by pine forests with a small admixture of larch. Towards the end of this zone forest communities were replaced by more diverse herbaceous plants. Vegetation specific to open habitats expanded as indicated by the spread of herbaceous plants that reach a maximum proportion of 52.3%. The areas were covered by herbaceous and shrub communities with a contribution of heliophytic taxa. Increasing contents of *Artemisia*, Cyperaceae and Poaceae suggest a development of grasslands. This is reflected in the pollen spectra in the depth interval from 6.95 to 7.1 m, in which the proportion of *Artemisia* reaches 18.1%. The high content of this taxon indicates the presence of steppe-type vegetation whereas pollen of *Salix* and Chenopodiaceae, *Saxifraga, Thalictrum* and a more stable occurrence of the Ericaceae suggests a shrub-tundra ecosystem. *Betula nana* is a notable element of the communities of this zone. A marked decrease in proportion of *Sphagnum* spores suggests a change towards wetter conditions (Mamakowa, 1989; Granoszewski, 2003). Progressively more continental climatic conditions undoubtedly suppressed the development of forests (Kolstrup, 1980). The type of vegetation in this zone indicates that the maximum mean temperature of the warmest month must have been little more than 10 to 11°C, as also inferred from deposits in Eastern Germany (Aalbersberg and Litt, 1998).

In zone B4 a decline of the open communities took place. A characteristic feature of vegetation at this time is a significant increase in the proportion of the pine in the communities of the region of Białowice. Pine-forest dominated in the landscape, being locally associated with birch and spruce (Fig. 3). *Betula nana* is sporadically present in the zone. Of other trees, *Alnus* together with *Salix* occurred in more boggy habitats. The area of shrub tundra decreased, as suggested by the low pollen proportion of herbaceous plants. Poaceae and Cyperaceae occur in low quantities, and *Artemisia*, Chenopodiaceae and Ericaceae are sporadic. The character of vegetation suggests that in zone B4 a relatively smaller area was occupied by forest communities than during zone B2. At the same time, the proportion of mineral matter in sediments was less and organic silts were deposited in the lake. Littoral and aquatic vegetation was noted sporadically at the time (Fig. 3). Subsequent improving climatic conditions and expansion of pine forests significantly restricted the effectiveness of these processes and led to organic silt deposition in the lacustrine basin (depth 6.3–6.7 m). Presumably, the mean temperature of the warmest month in the zone was not lower than about 10°C and the presence of *Pinus* may even suggest temperatures reaching up to 12°C (Granoszewski, 2003).

Zone B5, represented by two samples only, is characterized by the spread of diverse open communities. The low pollen proportion of *Pinus* and *Betula* probably indicates that pine and birch may have occurred in the patches of boreal forest or forest tundra. A high content (up to 44.5%) of herbaceous plants suggests that the communities of the shrub-tundra type prevailed in severe temperature conditions. Grass-sedge communities with a distinct share of the families Asteraceae, Caryophyllaceae, Chenopodiaceae, Brassicaceae and *Thalictrum* as well as the genus *Helianthemum* dominated at that time. The presence of *Juniperus* and Chenopodiaceae is of particular diagnostic value in the interpretation of steppe-tundra (Granoszewski, 2003). The tundra ecosystem was represented by boreal-arctic dwarf willow (*Betula nana*), whose presence confirms a temperate-cold climate with a weakly pronounced continental character (Tobolski, 1991; Bińka and Nitychoruk, 1996).

CORRELATION OF THE LOCAL POLLEN ZONES FROM BIAŁOWICE WITH REGIONAL POLLEN ZONES OF THE VISTULIAN GLACIATION

The local pollen assemblage zones (L PAZ), distinguished on the Białowice diagram, were correlated with the regional pollen zones (R PAZ) of the oldest sections of the Vistulian Glaciation (Early Vistulian) in accordance with the biostratigraphic subdivision of Poland by Mamakowa (1988, 1989) as well as the subdivision of Western Europe (Behre and Lade, 1986; Behre, 1989; Table 3). Zones B1 and B2 (L PAZ) correlate with the Brörup Interstadial, corresponding to regional pollen zone EV2 (R PAZ), while zone B3 represents the Rederstall Stadial (EV3) and zones B4 and B5 correspond to the Odderade Interstadial (EV4).

Though a number of Early Vistulian sites have been documented in Poland, few of them record a diagnostic succession in the Brörup and Odderade interstadials. They were described in detail by Janczyk-Kopikowa (1969) and more recently by Balwierz (2003), Granoszewski (2003) and Malkiewicz (2010). The new sedimentary sequence deserves special attention as, until now, the site at Dziadowa Kłoda (Kuszell *et al*., 2007) was the only occurrence of the Brörup Interstadial known from SW Poland (Fig. 4).

The differentiation/separation between the interstadials (EV2, EV4) and stadial (EV3) on the Białowice diagram was based on the composition and succession of vegetation communities, reflecting clearly different climatic conditions. The results of pollen analysis allowed for the reconstruction of vegetation changes due to the transition from an interstadial density of forest communities of boreal climate (EV2) to the stadial subarctic ecosystem of the park tundra type (EV3) and again a succession of an interstadial character (EV4).

The Brörup Interstadial (B1 and B2) is characterized by a distinct supremacy of dense pine-dominated forests with a relatively high proportion of spruce and alder (B2). The vegetation composition of the interstadial (EV2) at Białowice does not differ from those of other sites of that age in Poland (Kozarski *et al*., 1980; Tobolski, 1991; Stankowski and Nita, 2004; Kuszell *et al*., 2007). The main difference lies in the lack of pollen spectra in the lower part the interstadial (B1) with a smaller proportion of *Betula*. Successions at the beginning of the interstadial expressed by consecutive proportion maxima of *Betula* and *Pinus* pollen are known from the some diagrams of the Brörup Interstadial from Poland (Mamakowa, 1989; Tobolski, 1991; Kuszell *et al*., 2007; Malkiewicz 2010; Roman and Balwierz, 2010). Birch-dominated communities at the beginning of the Brörup Interstadial have also been identified at sites in Germany and Netherlands (Behre, 1989; Grüger, 1991; Litt, 1994; Aalbersberg and Litt, 1998). In some sites in Poland the domination of birch forest communities was only a poorly marked episode. The short occurrence of these forest communities was identified on the diagram of Kuców (Balwierz, 2003) and in the section at Stare Kurowo (Kozarski *et al*., 1980), documenting the classical undisputed interstadial vegetation (Fig. 4). At the present stage of investigations it is difficult to comment on the birch proportion variations, especially given that sites with a documented Brörup Interstadial in Poland are scarce (Malkiewicz, 2010), comparing to those of the Eemian Interglacial (Bruj and Roman, 2007; Roman and Balwierz, 2010). The variation in the Białowice section could be result of the local overrepresentation of *Pinus* or the result of too low a number of samples collected relative to the thickness of the deposits. It also cannot be ruled out that the sedimentary variations were caused by erosional activity of a river feeding the sedi-

Table 3

Correlation of local pollen zones (L PAZ) from Białowice with regional pollen zones (R PAZ) distinguished for Poland (Mamakowa, 1989) and the chronostratigraphy for NE Europe (Menke and Tynni, 1984; Behre and Lade, 1986)

Local pollen zones (L PAZ) Białowice	Plant cover	Regional pollen zones (R PAZ) Mamakowa (1989)	Chronostratigraphy (Menke and Tynni, 1984; Behre and Lade, 1986)	
B5	steppe with shrubs pine-birch forest	EV4	Odderade Interstadial WE IV	Early Vistulian
B4				
B3	steppe with shrubs	EV3	Rederstall Stadial WE III	
B2	pine fores with alder and spruce pine-birch forest	EV2	Brörup Interstadial WE II	
B1				
	steppe with shrubs	EV1	Herning Stadial WE I	

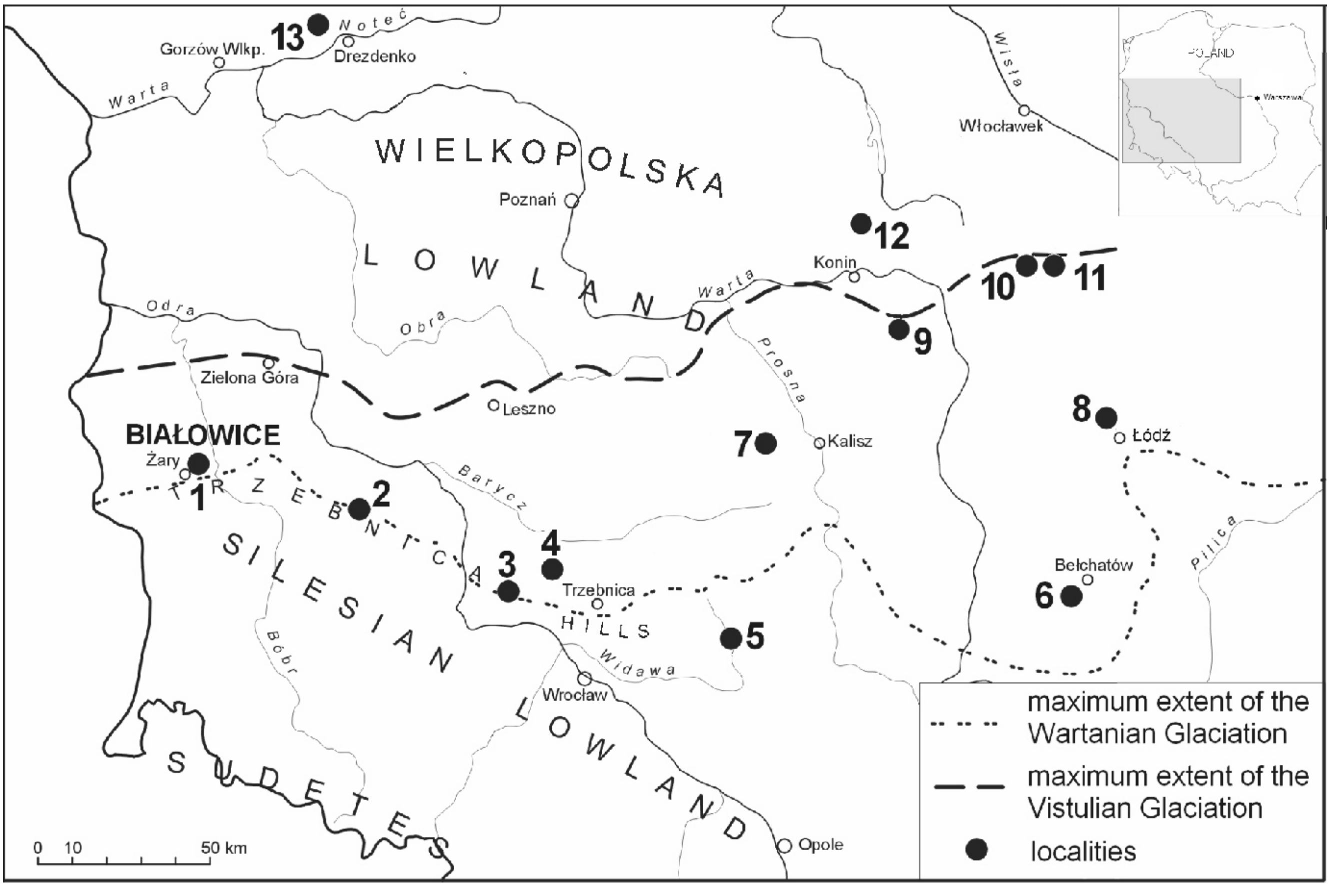

Fig. 4. Localities of the Eemian Interglacial with Early Vistulian and Brörup Interstadial

Localities discussed in the paper: 1 – Białowice, 2 – Zofiówka (Kuszell, 1997), 3 – Wołów (Kuszell, 1980), 4 – Raki (Dyjor and Kuszell, 1975; Kuszell, 1980), 5 – Dziadowa Kłoda (Kuszell *et al*., 2007), 6 – Kuców (Balwierz, 2003), 7 – Gutów (Malkiewicz, 2010), 8 – Zgierz-Rudunki (Jastrzębska-Mamełka, 1985), 9 – Władysławów (Tobolski, 1991), 10 – Kubłowo (Roman and Balwierz, 2010), 11 – Łanięta (Balwierz and Roman, 2002), 12 – Mikorzyn (Stankowski and Nita, 2004), 13 – Stare Kurowo (Kozarski *et al*., 1980)

mentary basin and giving rise to an increased amount of sand at the beginning of the Brörup Interstadial. However, according to Mamakowa (1989) the sites in which the EV2 – *Betula-Pinus* zone is well-developed are grouped in middle Poland, from the Łódź Upland to the eastern edge of the south-Podlasie Lowland. Its maximum southwestern range is reliably indicated by Raki near Żmigród (Kuszell, 1980).

The local pollen zone B2 is the warmest interval of the section representing the boreal type of climate. The expansion of pine forest accompanied by relatively high proportion of alder and spruce took place at that time. This type of vegetation is similar to that from the other profiles from Poland e.g., Stare Kurowo (Kozarski *et al*., 1980), Dziadowa Kłoda (Kuszell *et al*., 2007) and Gutów (Malkiewicz, 2010), however, the proportion of alder and spruce in those sites is relatively smaller. The Brörup at Białowice is not typical of the Early Vistulian in Poland. It is probable that this is an interstadial with a specific floristic character and it is warmer than the other Polish sites. The development of similar forest with an admixture of alder and spruce of this age was registered in Western Europe (Behre, 1974; Behre and Lade, 1986; Litt, 1994). In NW Germany *Alnus* pollen generally does not exceed 10%, but at Amersfoort it even exceeds 60% in the Brörup (Zagwijn, 1961). On the basis of the several sites in northern Germany, Grüger (1991) writes "...much higher *Alnus* and *Picea* values are recorded for the Brörup". At Białowice their development was undoubtedly influenced by the milder climatic conditions. The higher pollen values of the trees at Białowice may indicate a more oceanic character of the boreal climate and a temperature probably a little higher in SW Poland at the time. According to Litt (1994) the July mean temperature might have been 13–15°C, as Behre (1974) has claimed, or even higher with a maximum of 16°C.

At the boundary between zones B2 and B3 (Rederstall Stadial), a change in deposition from organic to sandy sediments took place (Fig. 3). The changes in accumulation indicate a deterioration of climatic conditions. This climate must have resulted in increased fluvial transport and intensified erosion and accumulation (Mamakowa and Środoń, 1977; Klatkowa, 1990).

Zone B3 representing the Rederstall Stadial (EV3), documents a different vegetational situation with shrub-tundra and herb communities, but most probably single stands of pine and birch were present in the area. During this period plant communities probably included Poaceae, Cyperaceae, Chenopodiaceae and a very high proportion of *Artemisia* of steppe type (Tobolski, 1991). It may be supposed that these communities doubtless reflect the deterioration and continental character of the climate.

A similar situation is also observed at from Dziadowa Kłoda (Kuszell *et al*., 2007) and other sites in Central Poland (Jastrzębska-Mamełka, 1985; Tobolski, 1986; Balwierz, 2003; Malkiewicz, 2010; Roman and Balwierz, 2010).

Zones B4 and B5 represent the Odderade Interstadial (EV4) that indicates somewhat cooler conditions than the Brörup. This is suggests by the sporadic occurrence of *Alnus* and *Picea*, as well as a higher pollen proportion and taxonomic diversity increases among herbaceous plants. The relatively high values of *Pinus* and *Betula* probably indicate that pine-birch forest become more significant in the B4 zone, though in the older part of this zone there was marked though brief decrease in the proportion of birch. It may be supposed that in the Odderade communities approximated to forest-tundra and shrub-tundra only in small patches in comparison to the Rederstall Stadial. In the interstadial optimum, climatic conditions were much milder at that time, enabling the development of dense forests. The climate in SW Poland was similar to that in Central Poland and northwestern Europe (Erd, 1973; Menke and Tynni, 1984; Behre and Lade, 1986), though was probably slightly milder and more humid in SW Poland at that time.

The general trend of climatic changes is also observed in the Middle and Upper Vistulian in southwestern Poland (Krzyszkowski and Kuszell, 2007). Climatic conditions during the Early Vistulian interstadials were slightly milder in SW Poland than in central and above all in Eastern Poland (Granoszewski, 2003).

At the end of the Odderade (B5) climatic conditions became severe and more continental, an event expressed by growth of herbaceous communities and very low pollen proportions of *Pinus* and *Betula*. (Fig. 3). It is possible that this zone represents the beginning of Plenivistulian.

EVOLUTION OF THE SEDIMENTARY BASIN

The deposit character and style of sedimentation allow reconstruction of the main stages in the evolution of the palaeobasin at Białowice. The present geological analysis and the lithologies seen in archive sections suggest the relatively small area and depth of the lake. This is shown by two distinctly different lithological sections obtained from closely spaced sites (Fig. 2). Lacustrine and swamp deposits were observed only in the borehole located in the GEOPROBE site.

Palynological investigations showed the diversity of palaeoflora documented mostly by terrestrial vegetation because the lake at Białowice was exceptionally poor in aquatic and swamp communities (Fig. 3). Presumably the water contained little organic content and few mineral salts. The occasional presence of aquatic and swamp plants may suggest that the sediments accumulated in the deeper parts of the lake, out of the littoral zone (Tobolski, 2000).

The palaeobasin at Białowice was formed in a depression within a river valley (old-river beds). At the initial stages sedimentation took place in unstable hydrogeological and climatic conditions due to the earliest periglacial cooling of the youngest glaciation. The Early Vistulian profile overlies sandy deposits (Fig. 2). The sedimentary sequence (depth 9.3–13.2 m) at the site investigated starts with a 4 m thick layer of clastic deposits preserved as medium and coarse sands (Table 1). These deposits contain a few poorly preserved sporomorphs. Most probably they represent an initial stage of the lake development, with periodic rise of a lake water level in the cool and humid climate. Scarcer vegetation seems to have enhanced the processes of denudation, transport and deposition of mineral particles at the beginning of the Vistulian Glaciation. In the profiles on the Silesian Lowland (Kuszell, 1980, 1997; Mamakowa, 1989) similar changes of sedimentation took place in lakes at that time. Consequently the lake at Białowice filled with water-transported sands that underlie the biogenic deposits. The humid climate increased the transportation potential of rivers and increased both erosion and accumulation rates (Mamakowa and Środoń, 1977). Sedimentation of the organic deposits drilled at Białowice started as early as the Brörup Interstadial (B1). A gradual improvement of climatic conditions and the appearance of pine-birch forests significantly restricted the effectiveness of these processes and led to mud-dominated deposition in the lacustrine basin (depth 9.0–9.3 m). From the lithological section it may be inferred that further evolution of the lake at Białowice brought about its diminishing and shallowing in the older part of Brörup. The change of hydrological conditions and lake dimensions had a crucial influence on the course of biogenic sedimentation (Tobolski, 2000). These processes resulted in peat-bog formation seen in the depth interval 8.0–9.0 m (B2). The change in accumulation is reflected in aquatic and swamp plants with a scant participation of *Myriophyllum* and *Typha latifolium* in the older part of the zone only. The peat bog was flooded and, eventually, peat accumulation terminated at the end of the zone (Fig. 3). Later a decrease in temperature must have resulted in increased fluvial transport and intensified erosion and accumulation. The peat-bog was inundated and mineral sediments were washed in. Reestablishment of the lake and lacustrine-type deposition was recorded by the final stage of the B2 zone. This is suggested by the silt with a trace of peat from the depth of 7.9–8.0 m. After this short episode there was again increase in the water level in the basin during the Rederstall Stadial (B3). At the time, a change also took place in the composition of the sediment, from silt to a layer of sand (7.2–7.9 m) that separates the zones B2 and B3 (Fig. 3). A similar situation is known also in other regions of Poland (Stankowski and Nita, 2004; Kuszell *et al*., 2007) as well as in NW Europe (Behre and Lade, 1986; Behre, 1989; Grüger, 1991).

During the B3 zone the change in hydrological conditions either caused deepening of the lake or blocked the outflow. The changes in accumulation and plant succession seem to reflect cooling in the Rederstall Stadial (EV3). Initially, gyttja was deposited (7.1–7.2 m) then, in the late stadial the water level went up and the gyttja sedimentation changed to that of a silt with traces of sand (6.7–7.1 m). The climatic deterioration must have resulted in increased fluvial transport and intensified erosion in the younger part of zone EV3. There was no littoral and aquatic vegetation at that time.

The Odderade Interstadial (EV4) at Białowice is recorded by organic deposits in the profile. This warming is marked by the accumulation of organic silt (6.4–6.7 m). The beginning of the organic accumulation, occurring in zone EV4, might indicate a process of stabilization of boreal climatic conditions, which restrict erosional processes. The participation of aquatic plants is very low, comprising individual pollen grains of *Typha latifolia* and *Myriophyllum*.

Later, at the end of the Odderade Interstadial (EV4), decreases in temperature and humidity took place. In the basin sandy silt was then deposited (6.3–6.4 m). The presence of silt with varying proportions of sand indicates occasional more severe climatic conditions. The higher content of mineral fraction observed in the upper part of zone B5 may indicate that sand was transported into the lake by streams during heavy rainfall or by rivers under more severe and unstable climatic conditions. These processes led to the formation of about 6 m of water-deposited sand above B5 (depth 0.3–6.3 m).

CONCLUSIONS

This new sedimentary sequence deserves special attention as, until now, in that region of Western Poland the vegetational succession of the Early Vistulian has remained unknown. The Early Vistulian has been recognized in the SW Poland within the Białowice for the first time.

1. Five local pollen zones (B1–B5) the Early Vistulian were recognized at Białowice. The Herning Stadial (EV1) has not been recognized at Białowice. But, in this section two Early Vistulian interstadials (EV2 and EV4) have been distinguished corresponding to the Brörup (EV2) and Odderade (EV4). These interstadial units are separated by layers of sand, correlated with the Rederstall cold period (EV3).

2. The preserved flora from Białowice includes a vegetation succession of the Early Vistulian only. Two intervals of more or less boreal conditions and moderately cold climate with a distinct fluctuation showing a deterioration of climate have been distinguished. The earliest plant communities of the youngest glaciation (Herning Stadial), typical to the sub-arctic climate were not preserved.

3. The type of vegetation represented in the Białowice section does not differ significantly from the Brörup Interstadial (EV2) succession known from Central Poland and has also similarities to that in the Polish-German part of the Middle-European Lowland, which was covered by pine-dominated forests during the climatic optimum. The pollen values of alder and spruce noted from Białowice are higher than those from other sites of Eastern and Central Poland. This may be result of more humid and milder climatic conditions in the Brörup Interstadial in this part of the country. The Brörup in Białowice is not typical of the Early Vistulian in Poland. It is probable that this is an interstadial of specific floral characteristics, representing warmer conditions than the other Polish sites. The vegetation succession is similar to the sequence at the Danish Brörup site as well as in Germany. This is also seen in the increases of *Alnus* and *Picea* pollen.

4. The Odderade Interstadial (EV4) is characterized by distinct diagnostic features expressed by the continuous dominance of pine with simultaneously a considerably proportion of herbaceous plants and the scant occurrence of other trees, with a small rise at the level of the Rederstall/Odderade boundary. In the older part of the younger interstadial an expansion of *Betula* took place but it was very short. The Odderade Interstadial was slightly colder and a relatively smaller area was occupied by the dense coniferous forest than during Brörup time; however, at Białowice, forested conditions were recorded for both interstadials.

5. The sedimentary sequence at Białowice displays some lithological variations. Oscillations of the water level in the lake were fairly frequent, as reflected by changes in the deposits. This indicates that the lake was unstable, a feature characteristic of small and relatively shallow sedimentary basins.

6. Changes in the composition of the sediments in the lake basin are observed in the Rederstall Stadial. The geological research and palynological analysis support a maximum limit of the Vistulian Glaciation to the South of the Żary Hills.

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