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Late Glacial organic sediments in palaeogeographical reconstructions (cases from the Łódź region)

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Abstract. Late Glacial organic succession is recorded at the Żabieniec and Koźmin Las sites, in the Łódź region. A multiproxy approach provides a palaeogeographical assessment and yields a new insight into the old morainic area of the Polish Lowland. Additionally, the key profile Witów contributes in the reconstruction. It is demonstrated that the Late Glacial organic sediments of the Łódź region contain signs of environmental changes, starting from the first warming just after the Weichselian ice-sheet retreat from the Polish territory. Records at Żabieniec, apart from registering biotic and abiotic conditions which influenced functioning of a peatbog, provides information on the permafrost behaviour throughout the Late Glacial. At Koźmin Las, a unique discovery of the *in situ* riparian forest accompanied by organic sediments led to a high-resolution study of a series of events taking place on the floodplain during the Younger Dryas.

Key words
palaeoenvironment,
geoarchives,
Late Glacial,
Central Poland

Introduction

Recent years have brought a renewed interest in investigations of sediments containing organic remains, especially in the context of data collection for the palaeogeographic reconstruction of the Weichselian–Holocene transition period. Most commonly studied are accumulation basins of biogenic material (mainly lake basins and peatbogs). These objects provide an opportunity for deposition and conservation of geological material, as well as for registration of the complex conditions which influence their functioning. Studying the same object with the potential application of a range of proxy indicators, along with geological, geomorphological and archaeological records, and the geochronological approach, enables one to obtain a multitude of data that can significantly increase understanding of the nature of a palaeosystem. Multiproxy investigations into sediments from profiles of different origin and morphological setting are important for palaeogeographical purposes, because they make possible the reconstruction of ecological conditions and geomorphic processes.

This paper refers to the last few thousand years of the Weichselian, which, in spite of the general trend towards warming, were characterized by alternating warm and cold periods, measured in centuries. According to the Greenland ice-core stratigraphy (Björck et al. 1998; Walker et al. 1999) within the warming of the Greenland Interstadial (GI–1, 14,700–12,650 ice-core yr BP) three subinterstadials and two substadials are represented, while the Greenland Stadial 1 (GS–1, 12,650–11,550 ice-core yr BP) defines an abrupt cool episode. In correlation with the Mangerud's et al. (1974) division, GI–1 is an equivalent of the Bölling-Alleröd chronozone and GS–1 of the Younger Dryas chronozone.

Chronostratigraphy of the Late Glacial in land areas is based on various geoarchives and it may differ in terms of the quantity and timing of the units. For instance, chronologies obtained from annually laminated lacustrine sequences may correspond to the Greenland ice-core records (e.g. Litt et al. 2001), while in regional stratigraphies based on vegetation changes, the Older Dryas cooling was frequently too poorly defined to consider it as a separate unit (e.g. Tobolski 1998).

In the Łódź region, the Late Glacial stratigraphic subdivision is defined on the basis of dune-formation processes (Dylikowa 1967, 1969; Krajewski 1977), palaeosoils (Manikowska 1966, 1985, 1999) and palynological record (Wasylikowa 1964, 1999). It comprises the following sequence: Kamion, Oldest Dryas, Bölling, Older Dryas, Alleröd and Younger Dryas (after Manikowska 1995). Changes in the natural environment appropriate to these units have been confirmed by the results of investigations of biogenic sediments of peatlands of the region (Forysiak 2012).

This paper presents the results of interdisciplinary investigations into a Late Glacial succession from the two best-recognized profiles of the Łódź region: the Żabieniec peatbog and the Koźmin Las site (Fig. 1), both located in the old morainic area of the Warthanian age. In the investigations of these profiles a paleoecological, geochronological and sedimentary approach was used. Literature relevant to these studies is listed in the following text. The main objective of the current study is to review the records preserved in these natural archives and relate them to the palaeogeographical development of the Łódź region (Turkowska 2006; Dzieduszyńska 2013). The authors assume that, as the studied sediments originated at a time of rapid environmental changes, their properties reflect, besides biotic response, highly dynamic morphogenetic processes. By combining the collected data the authors hope to reconstruct, with the greatest possible resolution, the events fashioning the geographic environment of the region. A comparison of previously published material with other environmental records from the region and beyond allowed the data to be interpreted in a broad spatial context.

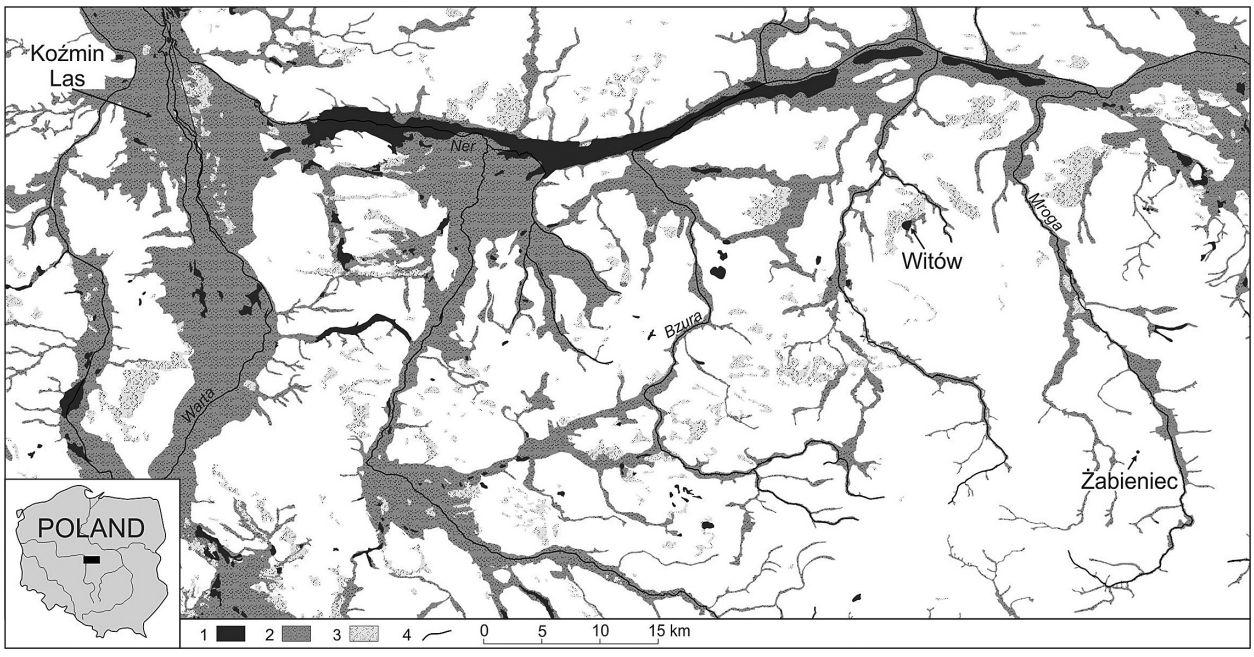

Fig. 1. Location of the studied sites against some geomorpholgical elements: 1 – peatlands, 2 – river valleys, 3 – aeolian forms, 4 – rivers

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Study Area and Profile Locations

The Łódź region (as designated by Turkowska 2006) is situated in the Central Poland Lowland and comprises an old morainic sector between the maximum Weichselian ice-sheet limit to the north and the maximum Warthanian ice-sheet limit to the south. The longitudinal boundaries are delimited by morphological criteria – on the west the region is bounded by the Warta River valley and on the east by the Rawka and Pilica River valleys. The surface relief ranges from pronounced features, with slopes of over 10° steep at elevations of over 200 m a.s.l., to flat surfaces below 100 m a.s.l. Therefore, besides climatic control, the Late Glacial development of the area was also controlled by such local factors as diversified relief and a polygenetic surface formed by ice-sheets and reshaped under the periglacial conditions of the Weichselian.

The Żabieniec study site is situated 25 km east of Łódź (Fig. 1) in an area of moraine plateau. The peatland is located in a 1.5-km-diameter, closed, oval basin on the watershed of the Mrożyca and Mroga rivers. It occupies ca. 2.5 ha and lies at an altitude of 180.5 m a.s.l. The basin originated during the Warthanian ice-sheet melting. The present peatland is situated in the central part of a kettle hole. Peat and lake sediments were formed in the Late Glacial and Holocene, and only in the deepest part of this depression. The geological structure and material for analysis were investigated using probes and a piston corer.

The Koźmin Las study site is situated in the north-western part of the region (Fig. 1), in the middle section of the Warta River valley. It lies at an altitude of 97.5 m a.s.l., ca. 2 km west of the present-day channel. Geomorphologically it is located on the low terrace of the Younger Dryas age. The terrace stands 1–2 m above the valley floor. The vertical profile of sediments of that terrace is a ca. 0.5 m thick, organic-rich part with a horizon of subfossil wood and an overlying mineral series about 2.0 m thick. The Late Glacial succession was studied in an open test pit of about 120 m^2.

Palaeogeographical reconstructions and stratigraphy of the Late Glacial in the Łódź region are often referred to the record obtained at the Witów site (Wasylikowa 1964, 1999). The Witów key site is located in the Warsaw-Berlin ice-marginal valley (Fig. 1). In the contact zone between the dune slope and the lake basin, profiles of biogenic sediment interlocking with mineral aeolian material have been documented (Wasylikowa 1964, 1999). The closest high resolution record of the Late Glacial is available from Lake Gościąż (Ralska-Jasiewiczowa et al. 1998), with its chronology being successfully correlated with the Greenland ice-core record.

Late glacial records in the selected profiles

Żabieniec site

The Żabieniec site is the only documented example of a biogenic peatbog from the Late Glacial and the Holocene in Central Poland. Sediments of a thickness of over 10 m fill a steep, oval basin (e.g. Forysiak, Twardy 2006; Twardy 2010). Multiproxy investigations were carried out on the sediments from core Z-2 (Forysiak, Twardy 2010). The bottom part of the core, from 16.4 to 14.65 m, consists of sand with a small admixture of dispersed organic matter (Fig. 2). A substantial part of the biogenic sediment is composed of lake and peat series: lacustrine silt containing a few percent of organic material (14.65–12.9 m), detrital-clay gyttja of a significant proportion of organic matter (12.9–8.3 m), detrital gyttja with variable content of plant remains and thin inserts of brown moss peat (8.3–3.8 m), fen peat (3.8–3.2 m), transition peat (3.2–1.2 m), bog peat (1.2–0.65 m), and transition peat (0.65–0 m).

The palaeoecological analyses included: plant macrofossils, pollen, cladocera, chironomid, diatoms, testate amoebae and geochemistry. The results and radiocarbon dates indicate that the stratigraphic boundary between the Weichselian and Holocene is located within lake sediments at a depth of 8.3 m. On the basis of pollen assemblages, the Weichselian part of the core was correlated with 9 local zones (Balwierz 2010), although the analysis was performed with a resolution that was both variable and too low.

The bottom clastic material accumulated in a cold lake basin, as shown by the cold chironomid, cladoceran and diatom taxa (Pawłowski 2010; Żelazna-Wieczorek 2010). Based on the chironomid analysis, a mean July temperature of 9.5–

–13.5°C (Płóciennik 2010) was reconstructed. The pollen spectrum displays a predominance of herbaceous plants, including cold-stenothermic taxa, and rebedded pollen. Radiocarbon dating yielded ages of 18,330 ± 90 ^{14}C BP (Poz-29713) at a depth of 15.3 m and 14,120 ± 70 ^{14}C BP (Poz-23659) at a depth of 12.9 m, so this part of the profile represents the Upper Pleniweichselian.

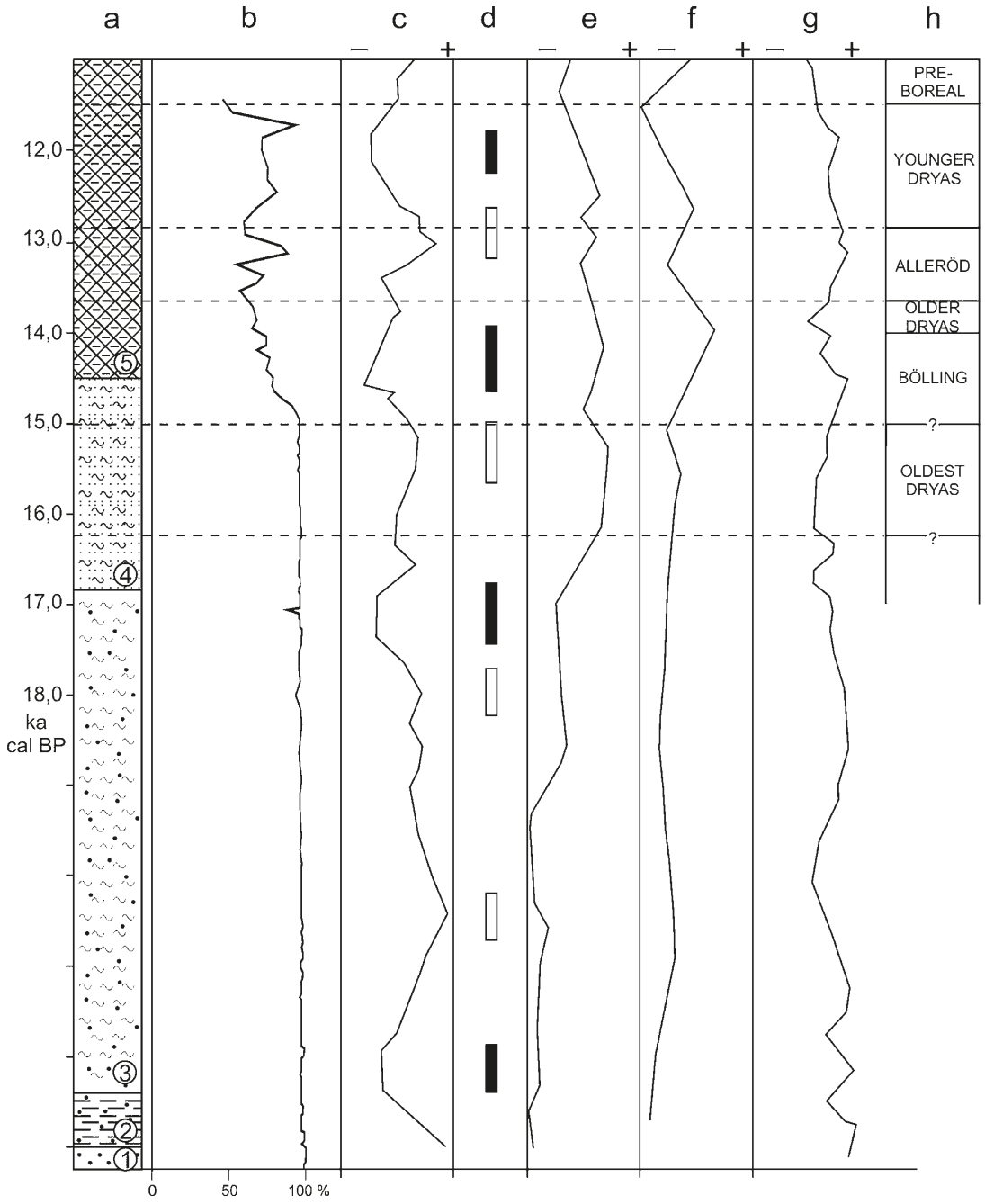

Fig. 2. Some results of analyses of the Żabieniec peatland sediments: a – lithology: 1 – sand with scattered organic material, 2 – fine-grained lacustrine sand with silt, 3 – lacustrine silt with sand, 4 – clay gyttja, 5 – detrital-clay gyttja; b – content of mineral matter; c – tendencies of water level changes (Forysiak et al. 2010; Pawłowski 2010); d – phases of high (white) and low (black) water level; e – reconstruction of tendencies of summer temperatures (Płóciennik 2010); f – tendencies of trophy changes (Forysiak et al. 2010); g – pH (Forysiak et al. 2010; Kloss, Żurek 2010); h – chronozones

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The detrital-clay gyttja is marked by a significant variation in grain size and content of organic matter, which is a reaction to the decreased mechanical denudation of the basin catchment caused by the establishment of vegetation. Local pollen zone *Pinus*-Cyperaceae-*Isoëtes* illustrates warming: AP sum rises up to 75%, pine dominates, values of sedges increase, and *Isoëtes* reaches high values in the middle part. Climatic amelioration is suggested by the presence of warm-stenothermic cladocerans and chironomid fauna, although geochemical investigations indicate persistent, thin vegetation cover.

The next cooling, recorded in the pollen level Cyperaceae-Poaceae-*Juniperus-Potamogeton*, is registered in a layer of considerable thickness (12.1––11.05 m). The lake sediments are poor in organic matter (3–5%) and relatively rich in carbonates (14––16%). The pollen diagram displays a distinct increase in sedges and algae *Pediastrum* accompanied by a decrease in trees (up to nearly 50%) and *Sphagnum*. The age-depth model places the end of this phase at ca. 14,560 cal BP (Lamentowicz et al. 2009).

In the overlying gyttja, the content of organic matter increases to 25–26% (Fig. 2). This is the first such significant increase, starting a constant trend, and presumably reflecting a decline in the delivery of mineral material. The geochemical record reflects a distinct increase in the Fe/Mn indicator value as well as the Zn value, which probably coincides with the supply to the lake basin of birch leaves having a particularly strong bioaccumulation ability to zinc (Borówka, Tomkowiak 2010). In the pollen diagram an increase in AP percentages can be seen, which mainly results from the domination of birch pollen, an increase in pine, and relatively low values of pollen from sedges and aquatic taxa.

At a depth of 10.4 m, dated at ca. 13,760 cal BP, summer air temperature inferred from Chironomid assemblages decreases slightly, which is supported by the presence of cold-stenothermic taxa *Micropsectra radialis*-type (Płóciennik 2010). This part of the profile is marked in the pollen diagram by a distinct decrease in the AP sum and an increase in juniper, willow and rebedded pollen (Balwierz 2010). The content of clastic deposit is also higher (Borówka, Tomkowiak 2010).

The subsequent part (10.3–9.6 m), reflecting warming, is also recorded in the detrital-clay gyttja, although the content of organic matter reaches values of 27.7–43.3% and 57–71% of clay particles. Only at a depth between 9.77 and 9.82 m (dated at ca. 12,760–12,840 cal BP) does the organic matter content decline to 16.3 and 11.8% and fine sand appear. At 9.64–9.66 m the first brown peat insert appears. The sedimentation rate in the basin decreased, which is indicative of a generally more compact vegetation cover. In the pollen diagram, pine predominates among the high AP percentages, while birch less so, and again there is more *Isoëtes*, after which, from 10.0 m, arboreal pollen decreases while juniper and willow pollen increases.

The Late Glacial section of the core ends with a ca. 70-cm-thick layer of lake sediments, with the content of mineral matter increasing up to 81.1% at 9.42 m (not more than 93.3% at the top) and a greater quantity of fine sand (Borówka, Brzozowska 2010). The decline of chironomid taxa is significant, while the dominance of cold stenotherms may indicate a drop in water temperature. Chironomid-inferred summer temperature reconstructions based on the Norwegian data-set indicate cooling between 9.4 and 8.8 m (14.5–12°C). In other models the drop in temperature is not marked (Płóciennik 2010). The climatic deterioration is also inferred from palynology.

Koźmin Las site

In the analysed profile the Late Glacial organic material lies between 200 and 250 m below ground level. It is composed of sediments of massive structure: organic mud, at places consisting of strongly decomposed peat, and numerous plant remains, including tree stumps *in situ* and tree trunks which are well-preserved relicts of riparian pine and birch forest. An admixture of laminated inorganic matter appears at the topmost part in the form of thin inserts of fine-grained sands. The organic series is covered by ca. 2-m-thick series of fine-grained layers, reflecting different facies of overbank deposition. Such succession was studied in the test pit and was available for observation along the faces of the nearby, open, brown-coal pits of the Adamów JSC Lignite Mine.

Multiproxy investigations into the organic sediments included the analysis of pollen, macrofossils, diatoms, cladocera and chironomid, as well as

dendrochronological and palaeopedological studies. Same samples for palaeobotanical and palaeozoological analyses were taken at 4-cm intervals, while others were taken at 2-cm intervals for pollen analysis of the lower portion of the deposit. A dendrochronological approach was carried out on over 100 samples of wood. The recognition of the Late Glacial environment at the site was supplemented with analyses of the structural and textural properties of the fluvial sediments. The procedures of these investigations, along with a detailed description of the record, are presented in works by Dzieduszyńska et al. (2014) and Petera-Zganiacz et al. (in press).

The chronostratigraphy of the site is based on 25 radiocarbon datings of the samples obtained from the organic material and pieces of tree trunks, as well as on dendrochronological analysis, and was subsequently confirmed by palynology. The radiocarbon ages range from 10,940 ± 50 BP (MKL-1656) to 9,780 ± 150 BP (MKL-1076), therefore covering the period between ca. 13,000 and 11,600 cal BP; in stratigraphic terms it represents the late Alleröd and the Younger Dryas. On the basis of dendrochronological studies it was showed that riparian forest occupied the Warta floodplain between 12,800 and 12,600 cal BP (Dzieduszyńska et al. 2014).

Pollen analysis (by K. Korzeń) was carried out for 17 samples. Within one pollen level, two sublevels were identified. Plant macrofossils (by R. Stachowicz-Rybka) were studied from 13 samples. The obtained palaeogeographic record shows changes starting from the high percentage of pine with an admixture of birch. A subsequent increase in sedges and grasses points to an expansion of non-forest communities. A climatic cooling is drawn from the presence of late glacial species *Selaginella selaginoides* and the remains of *Betula humilis*. The following phase of vegetation changes is connected with the presence of a low peat bog. Pollen of aquatic taxa indicates periodic flooding of the site.

The record of subfossil cladocera (by D. Pawłowski, 13 samples) provided data of two phases of the site development, illustrated by nine species of two families, both mainly littoral. The sequence of events consists of the existence of a shallow pool of stagnant water in the floodplain followed by temporarily dry conditions (loss of remains) and recurrence of a pool, with the sporadic presence of plankton species indicating possible interference of flood waters.

The subfossil chironomid record (by M. Płóciennik, 13 samples) is based on 48 taxa typical for river valley environment, mostly cold-stenothermic taxa of the Late Glacial environment. The occurrence of limnic, telmatic and rheophilic species points to variable hydrological conditions, including shallow stagnant water and periodic inundation of the site. Based on the results of the chironomid analysis, mean summer temperature reconstruction for the Koźmin Las sequence has been calculated at 14 and 15.8°C (by S.J. Brooks).

Diatom species (by M. Lutyńska) in the sediment were identified in order to detect the phases of flooding at the site. The recorded increase of eutrophic diatoms among the recognized species is considered an indication of a dynamic water environment.

Dendrochronological studies (by M. Krąpiec) enabled an average age of trees which grew in the floodplain for about 140 years to be determined (at 50–70 years). Narrow rings and other morphological properties of subfossil trunks (e.g. asymmetrical reactionary wood) reflect unfavourable conditions for the forest community's existence.

Palaeopedological studies of the Koźmin Las organic profile (Jankowski et al. 2014) registered the formation of the peat soil horizon, and afterwards, of the synsedimentary alluvial soil. The former is synchronous with forest development, the latter originating from water-logging of the site.

Contribution of the Record Into Palaeogeography of the Łódź Region

Pre-Oldest Dryas

The bottom sediments, dating from the Pleniweichselian decline, originated in a cold oligotrophic environment. Subfossil assemblages of cladocerans, diatoms and chironomids point to a pool defrosting in summers. The variability of fauna and algae reflects climatic fluctuations. The phases of the basin are clearly indicated, showing colder and warmer conditions, which have tentatively been correlated with the phases of the Weichselian Glaciation (Fo-

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rysiak et al. 2010). More precise correlation is not possible at the current state of studies because the age estimates of the sediments do not provide clear results, while pollen analysis has shown rebedded pollen.

A change in cladoceran, chironomid and diatom subfossils, as well as pollen assemblages (less abundant cold-tolerant species and heliophytes), recorded from a 12.9-m core depth, gives an unambiguous picture of the pre-Oldest Dryas warming. At that time, the accumulation of mineral and organic sediments on the Vistula River floodplain at the Kamion site near Wyszogród was laid down, documented by Manikowska (1985). Hence the proposal to name this period the Kamion Phase, called also Epe after Kolstrup (1980) (cf. Kozarski 1995; Manikowska 1995; Forysiak et al. 2010; Forysiak 2012). This early warming is correlated with the Meiendorf phase, introduced for annually laminated sediments of the Meerfelder Maar (Brauer et al. 2001; Litt et al. 2001).

At around that time, at the Witów site the accumulation of lacustrine sediments took place, while in the middle Warta River valley the Pleniweichselian terrace was cut down (Forysiak 2005, 2012).

The subsequent phases of coolings and warmings are well recorded in the Łodź region in the sediments of aeolian, fluvial, biogenic environment and deposit of denudation processes. The fundamental site for the stratigraphy is Witów (Wasylikowa 1964).

Oldest Dryas

The Oldest Dryas (sensu Iversen 1954), as seen from Witów, was cold, but the initial phase was cool and humid, while the second was even drier (Wasylikowa 1964). The Oldest Dryas was the time of the aeolian cover formation. Therefore, conditions for sand transportation must have been accompanied by sufficient ground moisture for the accumulation. Earlier, in the Upper Pleniweichselian, sand was transported on a large scale, but conditions for the formation of aeolian forms were not fulfilled (Goździk 1995). Palaeoclimatic conclusions inferred from palaeobotanical evidence put forward by Wasylikowa (1964) are corroborated in the Żabieniec record. The chironomid-based summer temperature is about 13.0–14.0°C (Płóciennik 2010). Diatom subfossils indicate mesotrophic and oligotrophic conditions and higher water level, followed by its decreasing concomitant with an increase in lake trophy (Żelazna-Wieczorek 2010). The delivery of fine-grained sand and silt to the lake suggests denudation processes on the adjacent slopes and intensification of aeolian activity (Borówka, Tomkowiak 2010). The $CaCO_3$ content is the highest in the entire core, which results from the start of shallow groundwater circulation within morainic deposits rich in carbonates, surrounding the lake.

Bölling

The Bölling warming is well indicated. At the Żabieniec site a change in the composition of sediments occurred, with a conspicuous decrease in $CaCO_3$ content and a significant increase in organic matter, which is a reaction to vegetation development of the catchment. Pollen analysis indicates high AP values, with *Hippophaë* and a maximum of willow, followed by nearly 50% of birch pollen and a decrease of aquatic taxa and algae. Low water-level is supported by other analyses (Forysiak et al. 2010).

In the Witów record, the Bölling section is identified by loose birch forest with sea buckthorn and aspen, a mean July temperature of about 15°C (Wasylikowa 1964) and humidity presumably similar to the period before. On aeolian covers of the Oldest Dryas, and therefore in poor habitats, a soil horizon developed (Manikowska 1985), which indicates the development of dense vegetation.

Older Dryas

The identification of the role of the Older Dryas in Poland is an issue. Manikowska (1985) estimates its duration at about 400 years, and locates the main Late Glacial dune-forming phase at that time. In the Gościąż record it was a slight cooling phase at ca. 14,000 cal BP, lasting for about 200–300 years (Ralska-Jasiewiczowa et al. 1998; Goslar et al. 1998), which is indicated in the increased dryness and the disappearance of willow-birch communities. At Witów, the birch forest opened up and warm-de-

manding aquatic species did not survive. Drier and colder than the Bölling climatic conditions, summer temperatures of about 10.0–12.0°C are inferred (Wasylikowa 1964). In the Older Dryas the dune at Rąbień formed a barrier across the upper section of the dry denudation valley, creating a small lake (Balwierz 2005). In the Żabieniec profile, in the section dated at 14,000–13,760 cal BP, the mineral fraction increased. Chironomid-based reconstructions of July temperatures indicate a cooling event, supported by the presence of cold stenothermic taxa (Płóciennik 2010). There is no data on record for this period for biogenic sediments accumulated in the fluvial environment.

Alleröd

The Alleröd period is clearly appointed in the history of the Żabieniec bog. Mechanical denudation decreased due to vegetation cover development in the catchment. Estimated summer temperatures based on chironomid assemblage succession show a rise from about 13,760 cal BP up to 15°C (Płóciennik 2010), followed by a drop of about 2°C between 10.0 and 9.8 m (13,130–12,810 cal BP). As the water level fluctuated, it increased initially and then dropped, combined with an increase in lake trophy.

At Witów the Alleröd is subdivided into two parts: the birch phase, when there were birch and pine-birch forests, and a younger phase, warmer and slightly wetter, dominated by pine communities (Wasylikowa 1964).

In the Alleröd, the middle Warta was probably a meandering river, which is supported by a biogenic infilling of the palaeochannel (Majecka et al. 2014). The floodplain was covered by a pine forest whose final stage of development was registered at Koźmin Las.

Younger Dryas

The rapid climatic changes at the onset of the Younger Dryas are reflected in poor conditions of existence and degradation of the forest at Koźmin, resulting from environmental events influencing the floodplain formation of the Warta River. Evidence from Witów suggests that the first part of the Younger Dryas was the coldest and driest, recorded by high percentages of NAP dominated by heliophytes, with a drop of summer temperatures down to even 12–13°C. Increasing humidity in the second part of the period is seen in a reduced significance of dry habitat plants. Geomorphological studies from Central Poland indicate that the Younger Dryas was environmentally unstable with efficient morphological processes (Dzieduszyńska 2011).

At Koźmin Las, although the summer temperatures of 10–12°C required for pine forests (Iversen 1954) were probably exceeded, the local conditions did not allow the continued existence of the forest throughout the Younger Dryas cooling. The course of climatic deterioration, as seen from the Koźmin Las site, is known from a series of short terrestrial events interrupted firstly by periodical flood episodes, followed by permanent inundation of the floodplain (see Dzieduszyńska et al. 2014; Petera-Zganiacz et al. in press). The lithological description of the profile, the accurately dated sediments and exhaustive conclusions from palaeoecological proxies seem enough to allow detailed reconstructions, despite the lack of laminated sediments. Additionally, the inferred events could be directly compared to changes observed in the high-resolution record of Lake Gościąż (Ralska-Jasiewiczowa et al. 1998) and follows Starkel's (2011) opinion on the phase of increased fluvial activity in Poland at the Younger Dryas/Preboreal transition.

Comprehensive studies from the Koźmin Las profile hint at permafrost reactivation in response to severe Younger Dryas conditions. Even though no ice wedge casts have been found, phenomena such as periodic water-logging of the site, flat-bottomed involutions at the base of the organic series (see Dzieduszyńska, Petera-Zganiacz 2012) and poor living conditions for the trees growing on the presumably boggy surface of the active layer may indicate frozen ground. Such prerequisites are promising, although more work is needed to investigate this possibility.

Final Remarks

1. The well-preserved succession of the Late Glacial organic sediments from the Łódź region, exem-

plified at the Żabieniec site, contains a record of environmental evolution from the first warming after the Weichselian ice-sheet retreat from the Polish territory onwards; results obtained from multiproxy investigations leave no doubt as to the existence in the Late Glacial history of the region of all stratigraphic units known from European terrestrial records.

2. The Żabieniec record provides arguments to engage in a discussion of the course of the degradation of permafrost as a rapid phenomenon starting in the Oldest Dryas and ending in the Alleröd.
3. The organic sediments from the Koźmin Las site are valuable for palaeogeographical reconstructions because of their stratigraphic position; a multiproxy approach allowed the dynamics of changes and floodplain evolution in response to the Younger Dryas conditions to be investigated.
4. Following the Witów profile, the reconstruction of changes in humidity is possible; this is supported by the profile of the interfluve location (Żabieniec) and the river valley (Koźmin Las).
5. The clear stratigraphic context of the Koźmin Las profile shows that it is still promising and requires further investigation, which should be aimed at detecting the possibility of permafrost reactivation with the onset of the Younger Dryas.
6. Subfossil chironomid assemblages provide a significant contribution into the palaeoclimatic record; studies on the mean summer temperatures in this field of research are rare in Poland.
7. The record obtained from the multiproxy studies extends and complements the recognition of the palaeogeographical development of the Łódź region during the Late Glacial, known from previous geomorphological investigations of fluvial tendencies (e.g. Turkowska 1995), aeolian environment (Dylikowa 1967, 1969; Krajewski 1977; Manikowska 1985, 1995) and pedogenetic processes (Manikowska 1985).

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