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VEGETATION AND STRATIGRAPHY OF THE MAZOVIAN (HOLSTEINIAN) INTERGLACIAL SECTIONS FROM DOBROPOL AND OTHER NEW SITES IN WESTERN POLESIE REGION, SOUTH-EASTERN POLAND

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Abstract
Geological mapping in eastern Poland resulted in new find of organic deposits near Włodawa. Pollen and plant macrofossils analyses at the Dobropol site proved deposition during the Mazovian (Holsteinian) Interglacial (MIS 11). Pollen spectra indicated strong predominance of *Carpinus* in the optimum phase (pollen period III), suggesting intensive influence of continental climate in this part of Poland. The paleolake Dobropol was shallow, with many species of rushes in a littoral zone. During the Liviecian (MIS 10) and the Krznanian (MIS 8) Glaciations the reservoir was occupied by an ice-dam lake, in which silt and clay deposition prevailed. The Mazovian Interglacial organic deposits were also recorded in immediate surroundings of the study area. Based on geological and paleobotanical examination of the Dobropol site, the ice sheet of the Krznanian Glaciation seemed to have reached at least the southern part of Włodawa. The ice sheet has not covered presumably the whole study area as its advance occurred in several lobes. The surroundings of Włodawa in the West Polesie Region are the third largest Mazovian paleo-lakeland area in Poland, apart from the vicinities of Biała Podlaska and the Łuków Plain.

Key words: Mazovian Interglacial, paleobotanical studies, West Polesie Region, SE Poland.

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INTRODUCTION

The area of Włodawa has been subjected to geological and paleobotanical studies since the first half of the 20th century. The research was performed on outcrops of organic sediments exposed in brick factories at Włodawa, Suszno, Dobropol and Koszary (Fig. 1), the latter in Belarus at present. Organic deposits at Suszno were also exposed at a scarp of the Bug River valley. Organic deposits recorded in the brick factory at Włodawa and Koszary were examined by Lilpop (1925a–c) who, based on a plant macrofossil analysis, concluded the interglacial character of the paleoflora. Detailed paleobotanical (pollen and macrofossil) investigation carried out by Stachurska (1957) suggested the Mazovian Interglacial age of the organic sediments. Silts, peats and shaly peats, drilled at depth of 3–5 m, were overlain by a till, 1.5-m thick, and by sandy-silty deposits. During mapping (Detailed Geological Map of Poland, scale 1:50000, Włodawa sheet) several drillings were done at Włodawa and Suszno (Marszałek, 1997, 2000), however no glacial series were recorded at that time. Expertise paleobotanical analyses of the sections (Obarska, 1996) confirmed the Mazovian Interglacial age of the pollen spectrum.

Organic deposits from Suszno were located at depth of 5–8 m and were overlain by ice-dam lake silts of the Odranian Glaciation and by glaciofluvial sands. Paleobotanical investigation by Stachurska (1961) determined the age of organic deposits for the termination of the Mazovian Interglacial. Trembaczowski (1957, 1960) and Mojski and Trembaczowski (1961) performed a thorough geological survey in this region (Trembaczowski, 1960, 1968; Mojski and Trembaczowski, 1972, 1974) but this region was also examined by many other researchers (Mojski, and Trembaczowski, 1975; Buraczyński *et al.*, 1984; Buraczyński and Wojtanowicz, 1981; Dolecki and Wojtanowicz, 1992). Correlation of ice sheet limits in the borderland of Poland, Belarus and Ukraine by Lindner *et al.* (2005, 2006, 2007) and Marks and Pavlovskaya (2006) provided new data for recognition of the Pleistocene stratigraphy.

The aim of this article is a reconstruction of the paleoenvironment of the Mazovian Interglacial in West Polesie and recognition of surface geological setting of the Dobropol site.

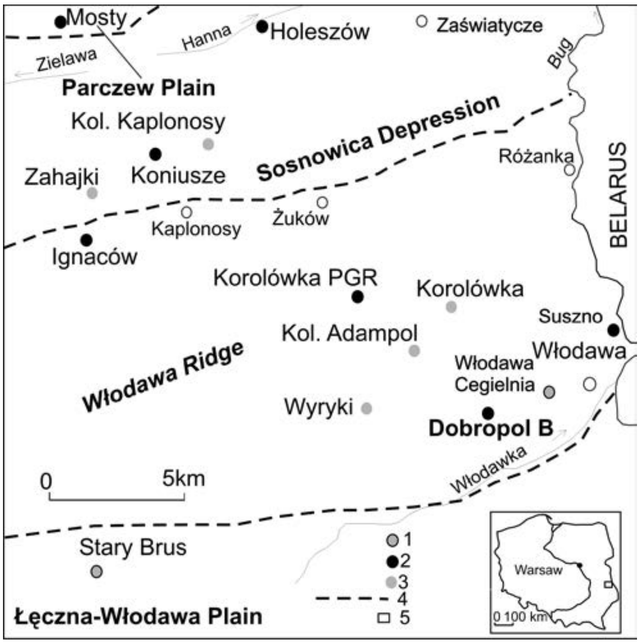


Fig. 1. Location sketch of the West Polesie Region with organic deposits in the Mazovian Interglacial sites. Paleobotanical sites: 1 – archival, 2 – new, 3 – currently examined; 4 – boundaries of physio-geographic regions after Kondracki (2000); 5 – study area.

STUDY AREA

The study area is located within the West Polesie macroregion (Fig. 1; Kondracki, 2000), with its southern part in the Włodawa Ridge mesoregion, northern part in the Sosnowica Depression and the Parczew Plain. The Włodawa Ridge is elevated several tens of metres above the Parczew Plain and is composed mainly of till, flow till and silt of the Krznanian Glaciation (MIS 8; Lindner and Marks, 2012). Surface area of the Sosnowica Depression and Parczew Plain is composed mainly of fluvial sand and silt of the Vistulian Glaciation (MIS 2-5d).

Location and geological description of new sites of the Mazovian Interglacial

The site of Dobropol has been analysed palynologically for the needs of Detailed Geological Map of Poland, 1:50 000 (Kaplonosy sheet (680), by Hrynowiecka (2013). It is located in a former brick factory, in the eastern part of the Włodawa Ridge in an indistinct depression and it has developed most likely from a glacial tunnel valley. The tunnel valley bottom is built of fluvial sands as well as weathered sands and gravels of the Vistulian Glaciation. The surrounding area is composed of glaciofluvial sands and gravels with local flow tills and silts of the Krznanian Glaciation (MIS 8). Geology of the site was investigated already in the first half of the 20th century (Trembaczowski, 1957). The brick factory exposures presented sands with gravels and boulders in the top, 1 m thick, disturbed with solifluction processes, and 2-m thick layer of silts and clays of the Krznanian Glaciation (MIS 8; Lindner and Marks 2012). Drillings performed for the brick factory resulted in a discovery of organic sediments (silt and peat) at depth 8 m, under the Krznanian silt. Paleobotanical analysis of these sediments has not been done, however Trembaczowski (1960) assigned them to the Mazovian Interglacial, based on correlation with the Włodawa and Suszno sections.

The updating of the Kaplonosy sheet of the Detailed Geological Map of Poland (Żarski and Morawski, 2013) involved an initial drilling with the WH probe that performed determination of thickness and age of organic deposits. In a drilling log the pollen spectra at depth 15.3–14.8 m indicated high content of pollen of hornbeam (*Carpinus*), accompanied by fir (*Abies*), abundant alder (*Alnus*), spruce (*Picea*), oak (*Quercus*) and hazel (*Corylus*), with boxwood (*Buxus*) attaining 1% and occurrence of *Celtis* and *Parrotia*. The composition of pollen flora indicated that sediments were deposited during the Mazovian Interglacial.

Subsequently, two cores of Dobropol A and B were acquired for further studies.

The sites Holeszów and Koniusze (Fig. 1; Żarski and Morawski, 2013) were located in a flat and boggy area in the Sosnowica Depression. Peat and silts of the Mazovian Interglacial were covered by 2-m thick layer of sand and silt of the Vistulian Glaciation and underlain by glaciofluvial sand and gravel of the Sanian 2 Glaciation (MIS 12). Erosion in the depression occurred at the termination of the Odranian Glaciation or during the Eemian Interglacial.

The Mosty site was located in a denuded highland with lake sediments at depth 2.5–3.6 m, overlain by ice-dam lake silt of the Krznanian Glaciation (MIS 8) and by weathered sand of the Vistulian Glaciation. Deposits of the Krznanian (Saalian) sequence have been generally eroded.

The Ignaców site was located on northern slopes of the Włodawa Ridge (Fig. 1; Żarski and Morawski, 2013) and Mazovian organic deposits occurred at depth 2–3.5 m. They were covered by weathered sand and gravel of the Vistulian Glaciation and underlain by a till of the Sanian 2 Glaciation (MIS 12). The site was of great significance in recognition of geological setting on northern slopes of the Włodawa Ridge as its tills in the land surface seemed to represent the Sanian 2 and not Krznanian (MIS 8) Glaciation as previously suggested.

The Korolówka site was located in a tunnel valley that provided glaciofluvial waters during the Odranian Glaciation (Fig. 1; Żarski and Morawski, 2013). Organic sediments occurred at depth 4 m. The overlying glaciofluvial sand was connected with ice sheet retreat during the Krznanian Glaciation (MIS 8) and by fluvial sand of the Vistulian Glaciation. In the Korolówka tunnel valley, the organic deposits were recorded in several archival boreholes. Samples for palynological and geological studies of the Mazovian Interglacial organic sediments were collected from new boreholes. The thickness of lacustrine sediments in the sections was reduced by erosion, therefore equal from 1 to 1.5 m.

Genetic and stratigraphic interpretation of the Dobropol A section

Lithology of the log Dobropol A (Fig. 2):

[m]

0.00–0.20 grey-brown silty-sandy humus horizon, without carbonates;

0.20–0.70	pale brown silty sand with grits (0.25–0.5 cm in diameter), without carbonates;
0.70–1.00	brown silty-sandy-clayey till, without carbonates;
1.00–1.60	till, grey with rusty spots; very clayey, at the bottom passing into clay, without carbonates;
1.60–3.00	massive slightly silty clay, pale grey with rusty spots, without carbonates;
3.00–3.20	pale brown clay with indistinct streaks, without carbonates;
3.20–4.00	dark grey massive clay, without carbonates;
4.00–4.10	pale grey massive clay, without carbonates;
4.10–5.64	dark grey fragile, massive clayey silt, without carbonates;
5.64–6.00	grey-brown slightly clayey silt with very fine lamination, without carbonates;
6.00–6.20	grey massive silt, without carbonates;
6.20–8.70	clayey silt, grey with brighter shades, occasional streaks with organic matter, without carbonates;
8.70–8.99	grey-beige massive silt, without carbonates;
8.99–9.01	dark grey fine-grained clayed sand, without carbonates;
9.01–9.30	beige-grey massive clayey silt with single grits, occasional plant macrofossils, without carbonates;
9.30–10.50	dark grey fine- and medium-grained sand, quartz and mica, without carbonates;
10.50–11.90	grey mixed-grained sand with gravel (0.25–0.30 cm in diameter), without carbonates;
11.90–12.00	grey-brown fine- and medium-grained sand, very frequent macrofossils (wood), without carbonates;

A core of the Dobropol A borehole did not contain lake organic deposits. The log started with fluvial sand, 2.7 m thick (depth 12.0–9.3 m), containing gravel, macrofossils and humus interbeds. These sediments corresponded to the Liviecian Glaciation (Lindner and Marks, 2012) when the study area has been presumably occupied by a river that eroded some lake deposits of the Mazovian Interglacial. Fluvial sand was covered by silt, nearly 3 m thick (depth 9.3–6.2 m), locally with streaks of organic matter and also assigned to the Liviecian Glaciation. They were overlain by ice-dam silt and clay, 4.6 m thick (depth 6.2–1.6 m) and correlated with the Krznanian Glaciation (MIS 8). Clay passed gradually into a till, nearly 1 m thick (1.6–0.7 m), with small admixture of gravel. The till has not been recorded in the surroundings of Dobropol, probably due to its erosion. The log ended with 0.7-m thick layer of silty sand with gravel, formed due to weathering of a till. Occurrence of a till was of great significance in identification of the maximum range of the Krznanian ice sheet.

Petrographic analysis of fine gravel (5–10 mm and occasionally, 2–5-mm) was performed at depth of 0.9, 1.4 and 1.5–1.6 m (Kenig, 2013). Scandinavian crystalline rocks, sandstone and quartz occurred in similar contents, limestones both local and Scandinavian were absent. Local quartz occurred at depth 1.5–1.6 m. All quartz grains were well rounded and with mat surface. Lack of limestones and lithology of a till suggested its weathering or flow origin, possibly in an ice-dam lake. Such results of petrographic analysis of a till were completely different than of the same till sampled in an outcrop in the same area (Gałązka (2004, 2006). The petrographic composition of a coarser gravel was predominated by indicator erratic boulders of the Åland Islands (34.7%), Ångermanland (28.6%) and Uppland (16.3%), accompanied by admixture of rocks from Smlland and Dalarna (8.2% each) (Gałązka, 2004). These data provided a basis for determining the theoretical erratic centre, attaining 17.93° (longitude) and 60.53° (latitude). Regional indices were 0.73 (E/W) and 6.5 (N/S). Petrographic indices for the fine gravel fraction of the Dobropol tills attained the following values: O/K – 1.70, K/W – 0.92 and A/B – 1.36, typical for the lithotype Wl, characteristic for tills of the Odranian Glaciation (Lisicki, 2003). In terms of petrography, tills from Dobropol resembled the so-called eastern type, characteristic for the South Polish tills (Gałązka, 2004, 2006).

The till examined by Gałązka (2004) was probably a lodgement till, therefore had different petrographic composition than the weathered or flow till from the Dobropol A section. Stratigraphic setting of this till was above the Mazovian Interglacial deposits. Currently, the outcrop in Dobropol was flooded and it was impossible to re-examine a petrographic composition of the tills. Based on research results, we ould assume a likely maximum extent of the Krznanian Glaciation ice-sheet, at least in the vicinity of Dobropol.

Grain size composition of deposits from Dobropol A was analyzed by laser method (Mycielska-Dowgiałło, 2007). The ice-dam lake series from Dobropol A was quite uniform: with 80% of silt (0.05–0.002 mm), 15–17% of clay (<0.002 mm) and the rest represented by sand (5–2 mm). A deposition was very quiet and occurred in a deep-water reservoir in a periglacial climate. Grain size composition of a till (depth 1.55 m) was similar to that of the underlying clayey silt (Fig. 3).

Sand grain size (> 2–0.05 mm) with admixture of the gravel fraction (5–2 mm) prevailed at depth 0.6, 10.5 and 11 m but there was much silt too (mostly at depth 10.5 m).

Genetic and stratigraphic interpretation of the Dobropol B section

Lithology of the log Dobropol B (Fig. 2):

[m]	
0.00–0.60	brown-reddish earth-brick bank;
0.60–1.00	pale beige silty sand; without carbonates;
1.00–1.60	pale beige fine-grained sand with admixture of silty sand; without carbonates;
1.60–2.40	pale beige well-sorted, fine-grained sand; without carbonates;
2.40–4.50	pale grey fine-grained sand with admixture of silty sand; without carbonates;
4.50–5.90	grey clayey silt; without carbonates;
5.90–7.00	grey watered mixed-grained sand with gravels; without carbonates;
7.00–7.50	dark grey silt; without carbonates;
7.00–7.80	pale grey fine- and medium-grained sand; without carbonates;
7.80–8.22	massive slightly clayey silt; plant macro-fossils at the basal part; without carbonates;

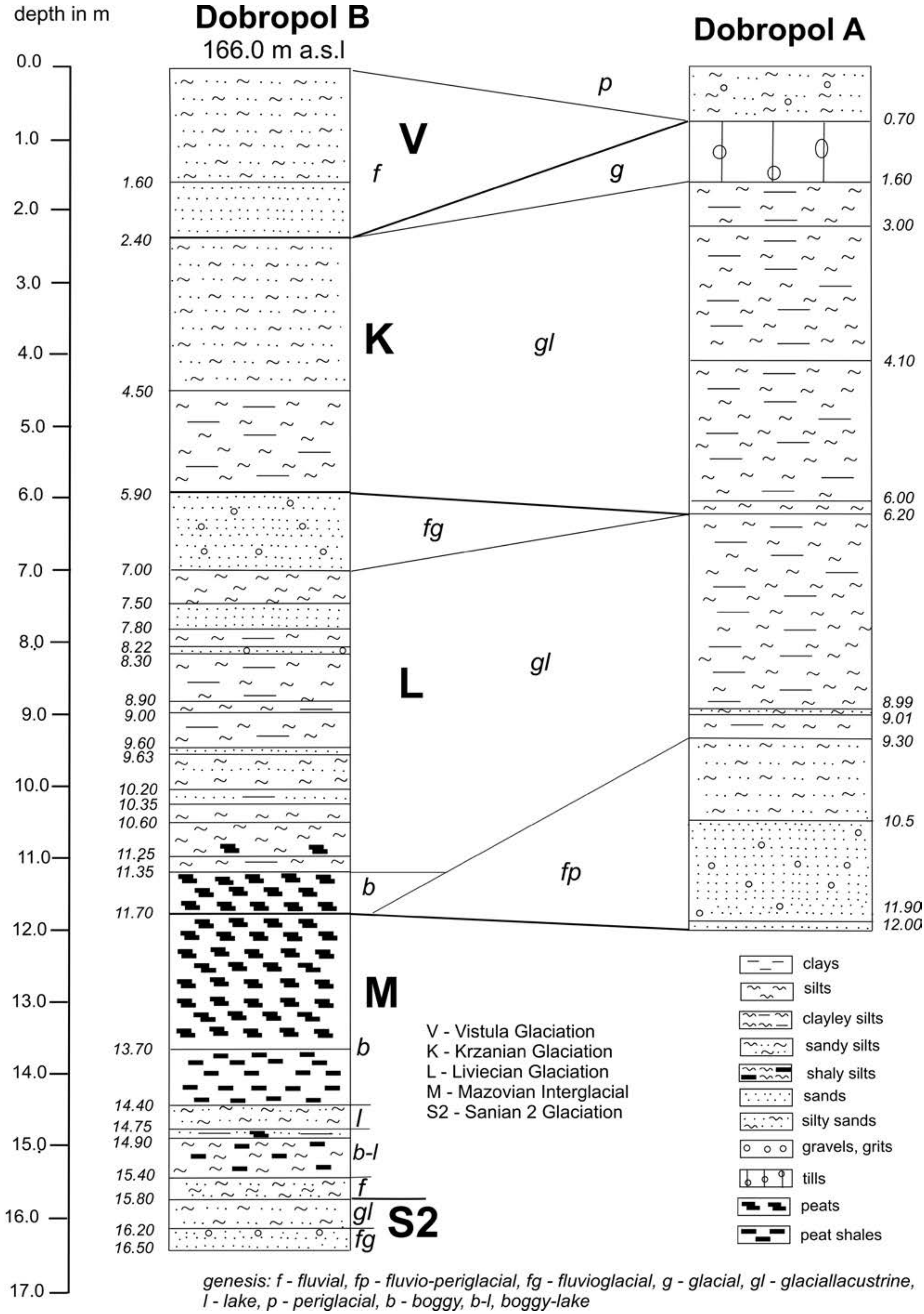


Fig. 2. Dobropol A and Dobropol B sections.

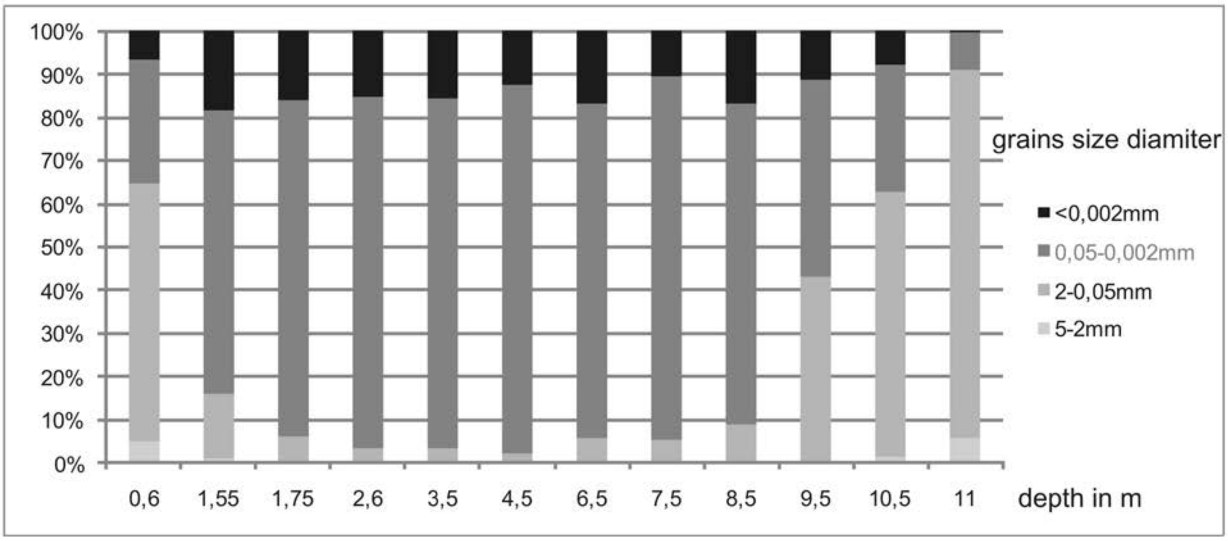


Fig. 3. Grain size distribution in samples from the Dobropol A section.

8.22–8.30	grey mixed-grained sand with single grits (up to 0.5 cm in diameter); without carbonates;
8.30–8.90	grey-beige massive clayey silt; without carbonates;
8.90–9.00	grey-beige massive clayey silt with a slight admixture of sand at the basal part; without carbonates;
9.00–9.60	grey-beige massive slightly clayey silt; without carbonates;
9.60–9.63	pale grey fine- and medium-grained sand; horizontal stratification; without carbonates;
9.63–10.20	grey-brown silt, locally with very fine laminas of fine-grained sand; without carbonates;
10.20–10.35	dark grey fine-grained clayey sand with organic matter; horizontal stratification; without carbonates;
10.35–10.60	dark grey massive clayey silt; without carbonates;
10.60–11.25	dark brown silt with peaty streaks; without carbonates;
11.25–11.35	grey, massive, slightly clayey silt; without carbonates;
11.35–11.70	black peats with a small admixture of sand, clayey at the top, compressed; without carbonates;
11.70–13.70	black peat with a small admixture of sand, clayey at the top, compressed, with abundant plant macrofossils; without carbonates;
13.70–14.40	brown-black very strongly compressed shaly peat; without carbonates;
14.40–14.75	grey sandy silt interbedded with fine-grained sand; horizontal stratification with macrofossils; without carbonates;
14.75–14.90	grey fine-grained clayey sand with laminas of organic matter and peat; horizontal stratification; without carbonates;
14.90–15.40	grey-black shaly silt; without carbonates;
15.40–15.60	grey fine-grained sand with admixture of silty sand; without carbonates;
15.60–15.64	dark grey-olive green silt with organic matter enclosures; without carbonates;
15.64–15.80	grey fine-grained and silty sand; horizontal stratification; interbeddings of humic sand at the basal part; without carbonates;
15.80–16.20	grey-blue fine-grained and silty sand with indistinct lamination; without carbonates;
16.20–16.50	pale grey fine-grained sand with gravels (1–2 cm) of Scandinavian rocks and flints; without carbonates;

In the Dobropol B section the sands and gravels at depth 16.5–15.8 m were assigned to the Sanian 2 Glaciation (MIS 12, Table 1; Lindner and Marks, 2012). These glaciofluvial sediments were covered by a 40-cm thick (15.8–15.4 m) layer of fine-grained silty sands horizontally stratified and with interbeds of sand with organic matter. These sediments, correlated with the Mazovian Interglacial (Table 1) (Nitychoruk *et al.*, 2006), were deposited in a fluvial, low-energy environment. There was a layer of lake organic sediments of the Mazovian Interglacial (MIS 11) at depth 15.4–11.7 m that was examined by paleobotanical analysis (Hrynowiecka, 2013).

The whole series started from the bottom with compressed shaly silt, 0.5 m thick and was typical for and open-water reservoir. Loading by overlying deposits and most likely also by an ice-sheet and water column in the basin, resulted in compression of the sediments. Changing environmental conditions resulted in deposition of 0.5-m thick (up to 14.4 m) fine-grained sands, interbedded with organic matter, peat and sandy silts with abundant plant macrofossils. These sediments were deposited during the pollen period II (Hrynowiecka, 2013) and the basin most likely became shallower, being periodically a flow-through lake.

Specific environmental conditions contributed to deposition of peat, 0.7 m thick (depth 14.4–13.7 m). They were strongly compressed and with shaly structure, therefore indicated post-sedimentary features. Presence of peat suggested intensive development of vegetation in an overgrown basin

Table 1

Chronostratigraphic correlation of Western Europe (Paepe *et al.*, 1996; Nitychoruk *et al.*, 2006), Poland (Mojski; 2005; Ber *et al.*, 2007; Lindner, Marks; 2008), Eastern Europe (Lindner *et al.*, 2004, 2006), and the Alps (Lindner, 1991; Mojski; 1993) and marine isotope stages (MIS)

Stratigraphy		Central Europe (Poland)	Western Europe (Germany)		The Alps		Eastern Europe		MIS
							Belarus	Ukraine	
Quaternary	Holocene	Holocene							1
	Late Pleistocene	Vistulian	Weichselian		Würm		Poozerian	Valday	2–4
		Eemian	Eemian		Riss/Würm		Muravian	Pryluky (Horokhiv)	5
	Middle Pleistocene	Odranian	Saalian	Drenthe+Warthe	Riss	Riss II	Dnieperian II (Pripyatian)	Dnieper 2 (Tyasmyn)	6
		Lublinian		Schöningen		R I/R II	Shklovian	Kaydaky	7
		Krznanian		?		Riss I	?	Dnieper 1	8
		Zbojnian		Reinsdorf		Pre-R/R I	Smolenskian	Potagaylivka	9
		Liviecian		Fuhne		Pre-Riss	Cooling	Orel	10
		Mazovian	Holsteinian		Mindel/Riss		Alexandrian	Zavadivka (LIkhvin)	11
		Sanian 2	Elsterian		Mindel		Berezinian	Tiligul (Krukieniche)	12
		Ferdynandovian	Cromerian		Günz/Mindel		Belovezhian	Lubny	13–15
		Sanian 1			Günz		Servetskian	Sula	16
		Małopolanian					Korchevian	Martonosha	17–19
	Early Pleistocene	Nidanian					Narevian	Pryazovsk	20
		Augustovian			Donau/Günz		Rogachevian	Shirokino	21–27

(without open water) and high humidity, presumably due to increased rainfall. The peat was deposited during the pollen period III (climatic optimum) of the Mazovian Interglacial. A subsequent environmental change resulted in deposition of compressed peat, 2 m thick (depth 13.7–11.7 m), with small admixture of sand and abundant plant macrofossils. Admixture of sand could indicate more scarce vegetation and supply of mineral material from immediate surroundings of the basin. Deposition of the above-mentioned sediments occurred during the pollen period IV of the Mazovian Interglacial. The Mazovian Interglacial/early glacial boundary was determined on the basis of palynological examination at depth 11.7 m, within a sandy peat. A lack of any erosive boundary indicated continuous peat deposition, therefore suggested that cooling was associated with the Liviecian Glaciation (MIS 10). During this glaciation, the ice-sheet did not reach the study area (Żarski, 1994) and peats, 35 cm thick, developed during the anaglacial phase. The following cooling resulted in gradual disappearance of vegetation and in deposition of grey massive silts, 1 m thick (depth 11.35–10.35 m), interbedded with organic matter and peat. The silts were overlain by grey clayey silts, 3.35 m thick (depth 10.35–7.0 m), locally with enclosures of fine-grained sand. This ice-dam lake sediment was deposited in a very cool climate. The Zbójnian Interglacial (MIS 9, according to Lindner *et al.*, 2005, 2006, 2007) was not reflected by a warming in this section. The silt was overlain by glaciofluvial vari-grained sand with gravel, 1.1 m thick (depth 7.0 – 5.9 m), indicating filling of the basin with sediments. The sands were deposited most likely during ice-sheet retreat during the Liviecian Glaciation but their deposition during advance of the Krznanian ice sheet cannot be excluded (MIS 8, according to Lindner and Marks 2012). The sand with gravel was overlain by ice-dam lake sediments, 3.5 m thick (depth 5.9–2.4 m), assigned to the Krznanian Glaciation and comprising from the base the clayey silt, 1.4 m thick and fine-grained and silty sand. The sedimentary sequence terminated with 1.8 m thick fluvial fine-grained and silty sand of the Vistulian Glaciation (MIS 2-5d), with a brick bed in the topmost part.

PALEOBOTANICAL ANALYSIS

Paleobotanical investigation included pollen and macrofossil analysis. Pollen analysis was performed for 59 samples from the site Dobropol B, three samples from Holeszów, three samples from Ignaców, two samples from Koniusze and three samples from Mosty. The material was subjected to typical laboratory preparation applied for Pleistocene sediments. Each sample, 1 cm^3 in volume, was subjected to the acetolysis of Erdtman (1960), using HF and a *Lycopodium* tablet (in order to determine frequency of sporomorphs), sieved on a 5 µm sieve. The pollen grains were eventually counted in two slides.

Plant macrofossil analysis was carried out for 9 samples in the Dobropol B section (depth: 11.57, 12.41, 12.95, 12.97, 13.15, 13.41, 13.65, 15.17 and 15.29 m) and macerated in 10% KOH and detergents. Sediment samples, volume of 150 ml each, were soaked in water for ca. 24h and boiled with addition of KOH. After the sediment was boiled to a pulp, it was wet-sieved on a 0.2 mm sieve. Material that remained on the sieve was sorted out under a binocular magnifying glass. All plant remains suitable for identification were isolated and placed in a mixture of glycerine, water and ethyl alcohol in the ratio of 1:1:1, with addition of thymol. Since its examination, the material has been kept in separate small "boxes" (Stachowicz-Rybka, 2011). Isolated plant remains, as far as it was possible and if the material was preserved in a sufficiently good condition, were determined to the rank of species.

The results were presented in a simplified pollen diagram (Fig. 4A) and in histograms (Figs. 4B, 5) plotted with the POLPAL software (Nalepka and Walanus, 2003; Figs. 4A, B; 5).

In all samples from the Dobropol B sections, the sporomorphs were frequent and very well preserved. Counting was carried out up to over 500 pollen grains and for all spores of lower plants. In total, 76 sporomorph taxa were identified (full description in Hrynowiecka, 2013). The palynostratigraphic distinction of pollen periods was based on the proposal of Szafer (1953).

Results of pollen analysis carried out for the Dobropol B section indicated the Mazovian Interglacial age of sediments. In two basal samples (depth 15.40–15.30 m; Fig. 4A), representing the protocratic pollen period I, the highest values were attained by pollen of *Betula alba* (max. 74%). Other tree taxa, apart from *Pinus sylvestris* (34%), were absent or recorded only in trace amount. Samples of sediments (15.10–15.20 m; Fig. 4A) corresponding to the mesocratic pollen period II were dominated by pollen of *Alnus glutinosa* (31%). *Picea abies* (10%), *Taxus baccata* (10%) and *Pinus sylvestris* (39%) were abundant as well. *Betula alba* was no more an important component (17%). The mesocratic pollen period III (13.50–15.00 m) was characterised by noticeable dominance of *Carpinus* pollen (10–43%), high proportions of *Abies* (2–10%), *Quercus* (3–10%) and *Corylus* (4–12%), lower content of *Alnus glutinosa* (16–24%) and *Pinus sylvestris* (12–42%) and infrequent occurrence of *Picea abies* (9–1%) and *Taxus baccata* (~1–3.5%). Appearance of *Pterocarya fraxinifolia* (<1–3.6%), *Buxus sempervirens* (~1%), *Juglans* and *Carya* (see full pollen diagram in Hrynowiecka, 2013) was observed as well. Among aquatic plants, *Nymphaea alba* and *Nuphar lutea* were very numerous. Samples from overlying sediments (depth 11.70–13.40 m), corresponding to the telocratic pollen period IV, indicated a remarkable increase in pollen content of *Pinus sylvestris* (45–87%) and a slight rise in *Betula alba* (3–18%, max. 45%). Other tree taxa were absent or recorded as single grains. Topmost samples (depth 8.50–11.60 m) were characterised by decreased content of *Pinus sylvestris* (down to 7%), slight increase of *Betula alba* (up to 26%; 4% in the upper part) and disappearance of other trees. Pollen values of grasses (up to 36%), sedges (up to 23%), mugworts (22%) and other herbaceous plants and dwarf shrubs, such as *Betula nana* (up to 7%) and *Salix herbacea* (up to 2.5%), increased greatly (Hrynowiecka-Czmielewska, 2010).

Results of palynological examination of other sites in the study area

According to results of palynological analyses performed for sediments from the sites at Holeszów, Ignaców, Koniusze and Mosty, a deposition occurred during the Mazovian Interglacial, particularly in its final part. In spite of a small content of examined samples, features of pollen spectra enabled correlations with regional pollen assemblage zones (RPAZ) defined for the Mazovian Interglacial in eastern Poland (Winter, 2008a, 2013).

In the Holeszów material (Fig. 5A), features displayed by the spectrum of the oldest sample, with values of *Abies* amounting to 2%, of *Picea* to 3.9% and including *Azolla filiculoides* microsporangia, indicated that deposition might have occurred within the close of the Mazovian Interglacial that is the zone R PAZ VIII *Pinus-Picea* or even R PAZ Ma IX *Pinus-Betula*. Samples from the overlying sediments were indicated by increased content of pollen of herbaceous plants, providing evidence for a strong cooling (Winter, 2013).

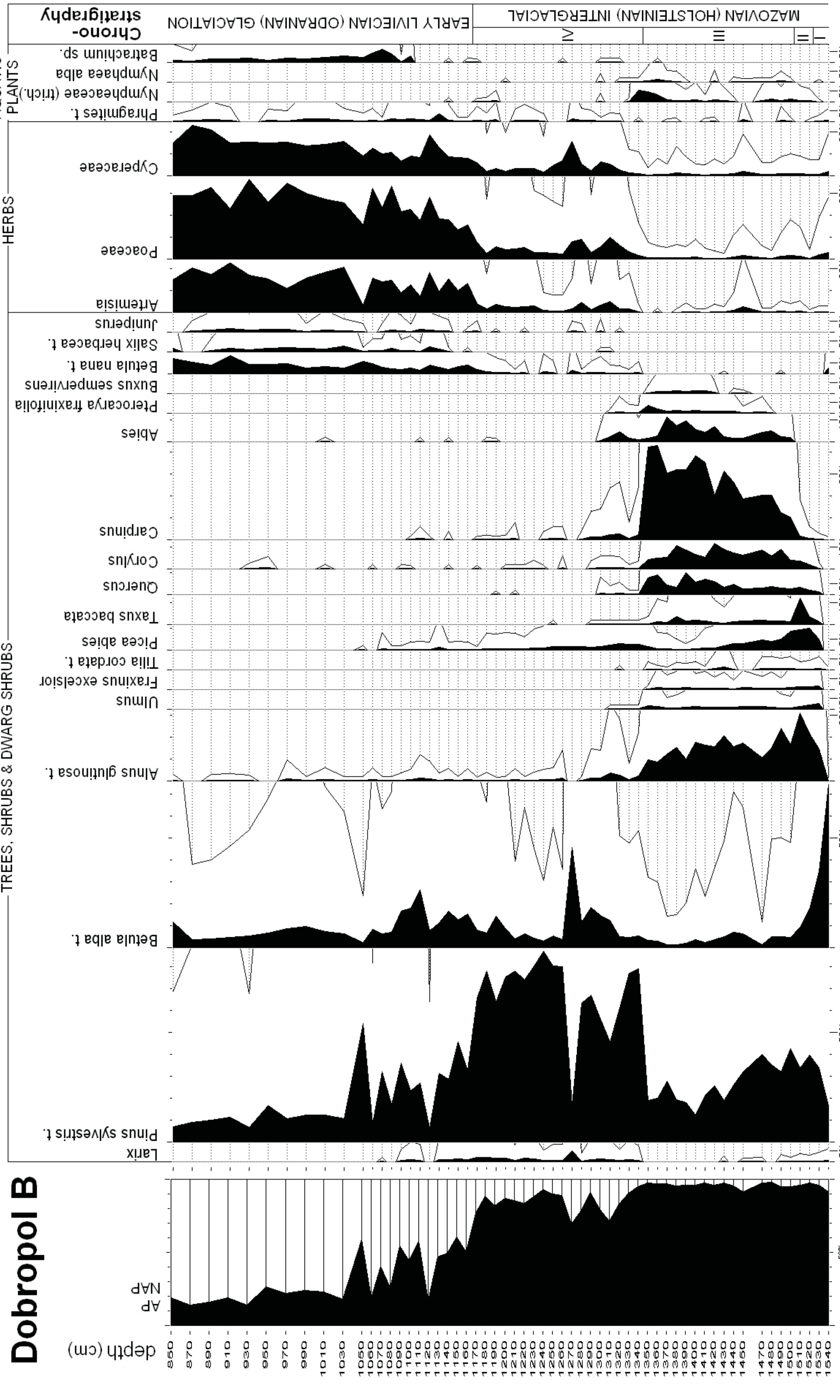
At the Ignaców site (Fig. 5B), sample from the depth 3.4 m indicated spectrum with high pollen values of *Abies*, great contribution of *Carpinus* and *Pterocarya* and presence of taxa such as *Buxus* and *Hedera*. These characteristic features suggested the age of the Mazovian Interglacial and the R PAZ Ma VII *Picea-Pterocarya*. Samples from the depth 3.25 and 2.8 m, typified by dominance of *Pinus* pollen, however accompanied by *Picea*, bore a record of the close of the interglacial. The spectra could be correlated with R PAZ Ma VIII *Pinus-Picea*.

At the Koniusze site (Fig. 5C), the section (depth 3.0 m) and its spectra provided an unequivocal estimation of deposition time during the Mazovian Interglacial and close to R PAZ Ma VII *Picea-Pterocarya*. High amount of NAP pollen found in the sample collected at the depth 1.93 m were likely to represent already the early glacial.

The Mosty site (Fig. 5D), indicated by high frequency of pine pollen and the occurrence of *Picea* and *Abies* pollen, followed by an increase in the content of NAP, demonstrated a close of a warm succession. Such palynological description of the terminating succession was likely to indicate the Mazovian Interglacial, particularly when considering the appearance of microsporangia of the *Azolla* aquatic fern, recorded in the Mazovian (Krupiński, 1995; Pidek, 2003), Augustovian and Domuraty (Winter, 2008b, 2009; Winter *et al.*, 2008) interglacials but absent at the close of the Eemian Interglacial. However sediments of older interglacials have not been found in the investigated area. Samples from Mosty most likely originated from the close of the Mazovian Interglacial and corresponded to R PAZ Ma IX *Pinus-Betula*.

Results of macrofossil analysis

Samples collected at the base included infrequent macrofossils (Fig. 4B), mainly seeds of aquatic plants: *Najas flexilis* and *Najas marina*. Seeds of *Nuphar* sp. and oospores of *Chara* were found as well. Among swamp plants, single fruits of *Scirpus kreczetowiczii* and *Carex* sp. were recorded. Terrestrial plants were represented by fruits of *Urtica dioica* and *Potentilla reptans* and among trees by seeds and seed scales of Pinaceae, fruits and fruit scales of *Betula* and a fruit of *Alnus glutinosa*. Five consecutive samples (from the depth 12.95, 12.97, 13.15, 13.41 and 13.65 m) were very rich in macrofossils, both considering their quantitative and qualitative composition. Aquatic plants were represented by seeds of *Najas flexilis*, spines of *Stratiotes aloides*, endocarps of Potamogeton, seeds of *Brasenia borysthenica*, *Aldrovanda dokturovskyi*, *Nymphaea alba* and *Nuphar luteum*, megaspores of *Salvinia natans* and other taxa. Swamp plants were preserved mostly as fruits of *Carex caespitosa*, *C. vesicaria*, *C. rostrata*, *C. nigra*, *C. lasiocarpa* and *C. gracilis*, seeds of *Aracites interglacialis*, fruits of *Eleocharis praemaximowiczii*, seeds of *Menyanthes trifoliata* (inhabiting the peat


Dobropol B
depth (cm)
AP
NAP
Chrono-
stratigraphy
EARLY LIVIECIAN (ODRANIAN) GLACIATION
MAZOVIAN (HOLSTEINIAN) INTERGLACIAL
AQUATIC PLANTS
Batrachium sp.
Nymphaea alba
Nymphaeaceae (trich.)
Phragmites t.
HERBS
Cyperaceae
Poaceae
Artemisia
TREES, SHRUBS & DWARG SHRUBS
Juniperus
Salix herbacea t.
Betula nana t.
Buxus sempervirens
Pterocarya fraxinifolia
Abies
Carpinus
Corylus
Quercus
Taxus baccata
Picea abies
Tilia cordata t.
Fraxinus excelsior
Ulmus
Alnus glutinosa t.
Betula alba t.
Pinus sylvestris t.
Larix

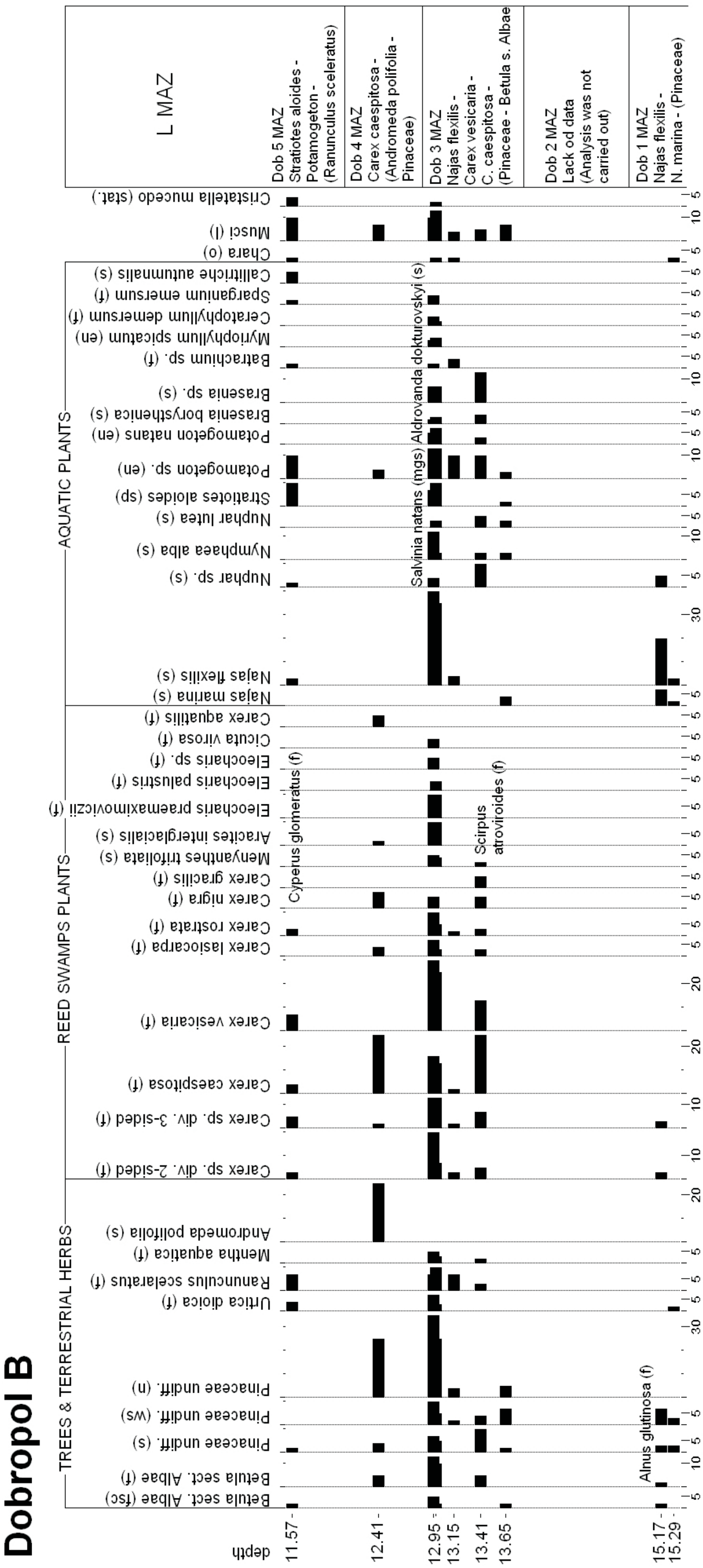


Fig. 4. A. Simplified percentage pollen diagram and of selected taxa from the Dobropol B section. **B.** Simplified plant macrofossil histogram of selected taxa from the Dobropol B sections. en – endocarps, f – fruits, mgs – megaspores, s – seeds, sc – sclerotia, stat. – statoblasts of Bryozoa, t – tegmens.

bog) and remains of other taxa. The shore of the basin was overgrown by communities with *Ranunculus sceleratus*, *Mentha aquatica* and *Urtica dioica* (fruits). Forest around the basin was composed mainly of Pinaceae (seeds, seed scales and needles) and *Betula* (fruits and fruit scales). The sample from the overlying sediment (12.41 m) was noticeably less abundant in plant macrofossils. Seeds of *Andromeda polifolia*, found in the peat bog and fruits of *Carex caespitosa* and *C. nigra* are relatively frequent. Nearly all aquatic plants disappeared, while numerous needles of Pinaceae and single fruits of *Betula* were identified among terrestrial trees. The topmost sample (depth 11.57 m) comprised only small amounts of terrestrial and swamp plant macrofossils that is spines of *Stratiotes aloides*, endocarps of Potamogeton, seeds of *Callitriche autumnalis*, fruits of *Batrachium* and other taxa.

DISCUSSION

Paleorelief reconstruction based on studies in Dobropol A and B sections

During ice sheet retreat of the Sanian 2 Glaciation, a nearly meridonally oriented glacial tunnel valley was formed at Dobropol. At the beginning of the Mazovian Interglacial, it was transformed by a river, what resulted in deposition of sand interbedded with peat and organic matter. A very slow river flow could be eventually stopped as the climate warmed, enabling development of a lake with deposition of silt (pollen period II). Further climate warming, vegetation development and increasing humidity supported peat-forming processes in the basin (pollen period III). In the post-optimum climate cooling, the peat was supplied with mineral material (pollen period IV). As an effect of a very strong cooling during the Liviecian Glaciation and gradual disappearance of vegetation, open water occurred in the basin and silt was deposited. Simultaneously, the Mazovian Interglacial sediments were washed out by a river that temporarily flowed across the eastern side of the basin. The river flow has been stopped finally or changed its direction and again the Dobropol basin was an ice-dam lake. During the ice sheet retreat of the Liviecian Glaciation or during ice sheet advance during the Krznanian Glaciation, the western part of the basin included a channel in which glaciofluvial sand and gravel were deposited. After the river flow at Dobropol had stopped, an ice-dam lake developed in front of the Krznanian ice sheet. Clayey silt and clay deposited in the eastern, much deeper part of the basin (Dobropol A), while in the western, shallower part, located at a distance of ca. 30 m (Dobropol B), deposition of sandy silt took place. Subsequently, the Dobropol area was most likely covered by an ice sheet of the Krznanian Glaciation, as indicated by presence of a till (Gałązka, 2004, 2006). Petrographic composition of this till was characteristic for the lithotype W1 of the Odranian Glaciation (Lisicki, 2003). It cannot be excluded that the till from Dobropol A was a flow till, likely to be represented by discontinuous tills and solifluction structures observed by Trembaczowski (1957) in the outcrop. During the Vistulian, a river discharge eroded most likely the till in the western part of Dobropol and it supplied with sand deposition.

Environmental changes recorded in plant macrofossils from Dobropol were similar to those observed in other Mazovian Interglacial sections (e.g. Stachurska, 1957; Hrynowiecka and Obidowicz, 2011; Hrynowiecka and Szymczyk, 2011). The strongest evidence for the Mazovian age of the sediments was provided by seeds of *Aracites interglacialis*, recorded exclusively in the Mazovian Interglacial (Velichkevich and Mamakowa, 1993). Out of the Mazovian sections from the Włodawa Ridge, the Dobropol B section was among the drill cores that have been most thoroughly paleobotanically investigated.

Interpretation of results of paleobotanical studies

The results of the study were compared to the palynostratigraphic scheme of the regional pollen assemblage zones (Winter, 2008a). Sedimentation in the basin was initiated in the period predominated by *Betula* (Ma I *Betula-Pinus*) with a small admixture of *Pinus sylvestris*, frequency of which indicated rather long-distance transport. Afterwards, humid and water-logged areas were dominated by riparian forest with *Alnus glutinosa*, *Ulmus*, *Fraxinus excelsior*, *Sambucus nigra* and *Hedera helix*. These and slightly drier habitats also supported development of communities with *Picea abies* and *Taxus baccata* (Ma III *Picea-Alnus*, Ma IV *Taxus-Picea-Alnus*). Areas of greater aridity were overgrown by *Pinus sylvestris* and gradually colonised by *Quercus*, *Corylus* and *Carpinus*, forming oak-hornbeam forests. As a result of successive environmental changes, *Carpinus* became dominant. This fertile, relatively humid forest created also the habitat of *Abies*, *Quercus* and *Corylus* (Ma VI *Abies-Carpinus*). Drier and insolated habitats were covered by *Buxus sempervirens*, while humid ones – by *Alnus glutinosa*, *Pterocarya fraxinifolia* and *Frangula alnus*. The continuing cooling and climate continentalization resulted in disappearance of thermophilous trees and dominance of boreal forest with *Pinus sylvestris* and *Betula* (Ma IX *Pinus-Betula*). Subsequently, both *Pinus sylvestris* and *Betula* were replaced by herbaceous plants, mainly Poaceae, Cyperaceae and *Artemisia*, forming steppe-like communities. *Betula nana* and numerous mosses, inhabiting patches of dwarf shrub tundra, appeared as well.

Palaeobotanical investigations indicated predominance of birch forest during the pollen period II (samples at depth 15.17 and 15.29 m; Fig. 4A, B). The basin was relatively deep, as indicated by numerous macrofossils of *Najas flexilis* and *Najas marina*, however with local shallowings, as suggested by presence of *Nuphar* and *Scirpus kreczetowiczii*. The shores were covered by humid riparian forest with *Urtica dioica* and *Alnus glutinosa*. During the pollen period III the edges of the reservoir were overgrown by wetland forest with *Alnus glutinosa*, *Ulmus*, *Fraxinus excelsior*, *Sambucus nigra* and *Hedera helix, Pterocarya fraxinifolia* and *Frangula.* The landscape was predominated by oak-hornbeam forest with *Carpinus*, *Quercus*, *Corylus* and *Pinus sylvestris*. Drier and insolated habitats were covered by *Buxus sempervirens*. Also communities with *Abies alba*, *Taxus baccata* and *Picea* were important. The reservoir was probably relatively shallow, as indicated by a number of trichosclereids of Nympheaceae (the samples bearing a re-

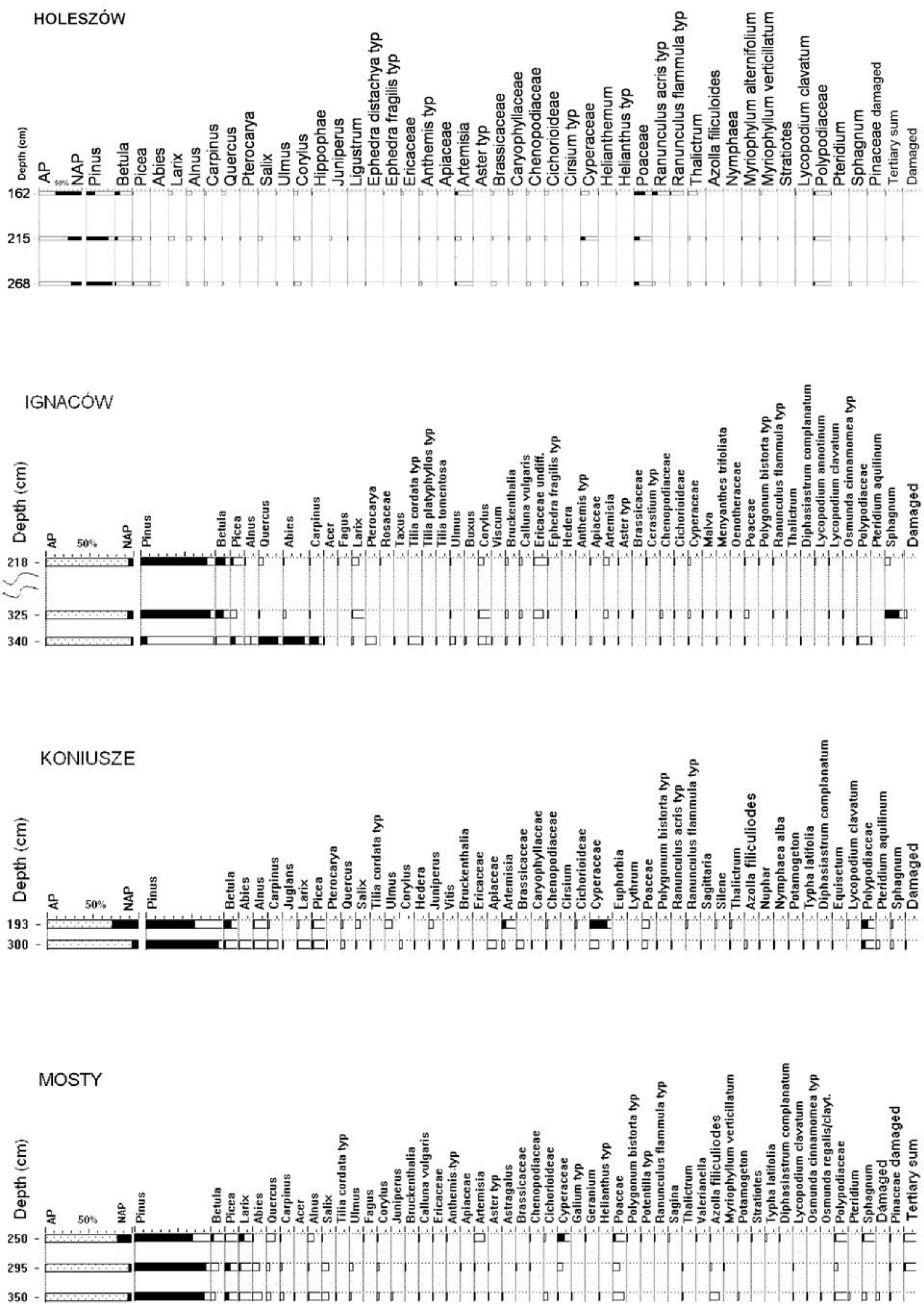


Fig. 5. Pollen histogras. **A**. Holeszów section; **B**. Ignaców section; **C**. Koniusze section; **D**. Mosty section.

cord of the pollen period III are still under analysis). In the first half of the pollen period IV (depth 12.95, 12.97, 13.15, 13.41 and 13.65 m), with prevailing boreal pine forest, the basin became shallower. Communities with *Carex vesicaria*, *C. caespitosa* and *Aracites interglacialis* (characteristic species of the Mazovian Interglacial) developed intensely. The shores were covered by a peat bog with *Menyanthes trifoliata* and, most likely, *Betula humilis*. However, there was still a deep-water in the basin, inhabited by *Najas flexilis*, *Stratiotes aloides*, Potamogeton, thermophilous *Brasenia borysthenica* and other numerous aquatic plants. Dominance of *Pinus* in the landscape was confirmed by abundant Pinaceae remains. Surroundings of the lake were also overgrown by *Betula*, *Ranunculus sceleratus* and *Mentha aquatica*. The close of the pollen period IV (depth 12.41m) was still predominated by a boreal pine forest, however with a notably lower content of *Betula*. Among terrestrial plants, *Andromeda polifonia* indicated still intense development of a peat bog. The belt of swamp was noticeably diminished, as well as aquatic plants that most likely disappeared as the basin became much shallower. Pine forest encroached onto the peat bog. At the onset of the early Liviecian Glaciation (MIS-10; depth 11.57 m), terrestrial plants were infrequent in the area. Possibly, swamps disappeared as well and the water level could have risen again. The occurrence of aquatic plants, such as *Stratiotes aloides*, Potamogeton, *Callitriche autumnalis*, *Batrachium* and other taxa, supported this assumption.

Results of palaeobotanical analyses for the Dobropol section in comparison with adjacent sites with the Mazovian Interglacial sediments

The Mazovian succession of the Dobropol site was compared with the Brus section, located ca. 15 km to the southwest (Pidek, 2003; Hrynowiecka *et al.*, 2013; Fig. 1) and bearing a record of complete successions of part of the late Sanian 2 Glaciation, entire Mazovian Interglacial and early and pleni-Liviecian Glaciation. Two other sections at Włodawa (Stachurska, 1957) and Suszno (Stachurska, 1961) did not include a complete Mazovian succession, however their location justified correlation with the Dobropol section (Fig. 1). All three sites were also subjected to plant macrofossil analysis.

Two sections from Włodawa, studied by Stachurska (1957), represented a close of the pollen period II, entire pollen period III and the beginning of the pollen period IV of the Mazovian Interglacial. They were characterized by low contents of *Picea*, *Carpinus* and *Abies* and relatively high amount of *Pinus sylvestris*. High content of pollen of *Pterocarya stenoptera*, *P. fraxinifolia* (Stachurska, 1955) and *Buxus sempervirens*, as well as appearance of *Juglans* and *Carya* were particularly significant. Among aquatic plants, seeds of *Brasenia purpurea*, *Najas flexilis*, *Aldrovanda vesiculosa* and *Dulichium spathacetum* (*arundinaceum*) were common.

Stachurska (1961) examined also the Suszno section located on the Bug River, several kilometers to the north of Włodawa. The section covered a close of the pollen period IV. Although the area was affected by moderate climate and predominated by a boreal pine forest, trees such as *Pterocarya* (probably *P. stenoptera* and *P. fraxinifolia*), accompanied by *Carya*, *Juglans* and *Keteleeria*, and shrubs *Ilex*, *Vitis silvestris* and *Keteleeria* were found as well. Plant macrofossils were still represented by remains of aquatic plants only, indicating predominantly a cool climate.

The Brus site (Fig. 1; Pidek, 2003) with its complete record of the Mazovian succession, differed only slightly from the Dobropol succession. Both sites indicated very high frequencies of *Betula* in the pollen period I. Sediments representing the pollen period II were noticeably thicker at Brus, allowing for a more detailed study of the proceeding changes. In this period, *Picea* and *Taxus* attained greater pollen values at Brus, while at Dobropol, like at Włodawa, there were higher amounts of *Pinus sylvestris* and *Alnus*. More significant difference was recorded for the optimum (pollen period III). The Brus pollen diagram was characterized by a relatively low content of *Carpinus* (with only one peak) and high content of *Abies* (ca. 40% and more than two peaks), and by occurrence of pollen and megaspores of *Pterocarya fraxinifolia*, *Buxus sempervirens*, *Azolla filiculoides* and *Parrotia*. The Dobropol succession was dominated by *Carpinus*, frequency of which exceeded 40%. The proportion of *Abies* accounted for 10%, which was comparable with *Quercus* and *Corylus*. For the pollen period IV, the sites differed primarily in a thickness of sediments, however they still indicated a very similar outline of the early Liviecian Glaciation. The Dobropol succession had typical features described by Krupiński (1995) and Winter (2008a).

CONCLUSIONS

Geological and paleobotanical investigations enabled characterization of a lake district that existed during the Mazovian Interglacial in the area of Włodawa, West Polesie Region. New sites of the Mazovian Interglacial were located on northern slopes of the Włodawa Ridge and within the Sosnowica Depression. Examination of sediments from the Dobropol sections provided the basis for paleorelief and palaeoenvironment reconstruction since the end of the Sanian 2 Glaciation, through the Mazovian Interglacial, until the anaglacial phase of the Liviecian Glaciation.

Environmental changes recorded in sediments from Dobropol resembled those already observed in other Mazovian sections. Sedimentation in the basin was initiated in a period of dominance of *Betula* with a small admixture of *Pinus sylvestris*. Subsequently, humid areas were covered mainly by a riparian forest with *Alnus glutinosa*, *Ulmus*, *Fraxinus excelsior*, *Sambucus nigra* and *Hedera helix*. These were also the sites with communities of *Picea abies* and *Taxus baccata*. Drier areas, supporting *Pinus sylvestris*, were gradually colonized by *Quercus*, *Corylus* and *Carpinus*, forming an oak-hornbeam forest. Successive environmental changes enabled *Carpinus* to become dominant. *Abies*, *Quercus* and *Corylus* were frequent as well. More insolated habitats were overgrown by *Buxus sempervirens*, while humid ones – by *Alnus glutinosa*, *Pterocarya fraxinifolia* and *Frangula alnus*. Gradual cooling and climate continentalization resulted in withdrawal of thermophilous trees and dominance of a boreal forest with *Pinus sylvestris* and *Betula*. However, both taxa eventually disappeared due to further cooling. Herbaceous vegetation, particularly Poaceae, Cyperaceae and *Ar-*

temisia, forming steppe-like communities, became most important in the landscape. *Betula nana* and numerous mosses, growing in patches of dwarf shrub tundra, appeared as well.

Results of plant macrofossil analysis indicated that the basin was relatively deep at the beginning of the Mazovian Interglacial, with only local shallows. The shores were inhabited by a humid riparian forest. At the close of the interglacial, the basin became shallower and its shores were covered by a peat bog. However, a renewed rise in the water level supposedly occurred at the onset of the early Liviecian Glaciation.

At Dobropol, organic sediments of the Mazovian Interglacial were underlain by glaciofluvial sediments of the Sanian 2 Glaciation and were covered by basin deposits of the Liviecian and Krznanian glaciations, in turn overlain by a till. Based on geological and palaeobotanical investigation of the Dobropol site, it may be hypothesized that the Krznanian Glaciation ice-sheet (MIS 8) reached at least the southern area of Włodawa. The ice sheet advance occurred probably in ice streams and the ice did not cover the whole study area (Ignaców site in Fig. 5B).

At other sites, the Mazovian organic deposits were reduced and therefore only fragments of the Mazovian succession were examined. The sediments occurred near the land surface and were covered by a thin layer of the Vistulian Glaciation fluvial and overflow deposits only. Full reconstruction of the Mazovian paleo-environment in the West Polesie Region will be provided after examination of other neighboring sites with organic deposits (Holeszów, Ignaców, Koniusze, Mosty). It will have great importance for clarification of the maximum range of the Krznanian Glaciation ice sheet in this area.

The surroundings of Włodawa in the West Polesie Region constitute the third largest area, apart from the vicinity of Biała Podlaska and the Łuków Plain, bearing a record of a Mazovian paleo-lakeland (Żarski *et al.*, 2005).

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