

Environmental and climate changes reflected in the Domuraty 2 section (NE Poland) based on analysis of plant macroremains

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ABSTRACT. Research in the Domuraty 2 section was focused on a series of lacustrine-river-swamp deposits in which the full spectrum of vegetation and climate changes was recognised in a detailed analysis of plant macroremains and a comparison with the results of pollen analysis. Based on plant macrofossil data, two (Dom II, Dom III) of three palynologically documented warm units were distinguished in the Domuraty succession. The palaeobotanical data from the Domuraty succession document several successive local vegetation changes in both interglacial and glacial periods, which can be related to global climate oscillations. The succession of local vegetation stands and changes in the vegetation, climate, water level, and trophy during the period of the Domuraty succession were analysed and compared with corresponding parameters of the Augustovian and Ferdynandovian interglacials. The taxonomically most diverse unit is Warm unit Dom II, with the highest share of taxa with high thermal requirements, which was compared to the older Augustovian (A II) and younger Ferdynandovian (F II) units. The comparison of the Domuratovian interglacial flora to that of the Korchevian interglacial in Belarus shows high similarity; most of the extinct taxa or taxa unknown in the present-day flora are common to the Korchevian and Domuratovian floras, suggesting similar age for these two communities. However, the Domuratovian flora lacks a few species important to the Korchevian flora, such as *Stratiotes goretzkyi*, *Carex rostrata-pliocenica*, *Brasenia* sp., *Caulinia antiqva*, *Aldrovanda borysthenica*, and *A. zusii*.

KEYWORDS: plant macroremains, climate changes, Middle Pleistocene, MIS 16–18, NE Poland

INTRODUCTION

Biogenic Quaternary strata occurring between glacial till horizons in the Augustów Plain have been studied for many years. Compilation of sheets of the 1:50 000-scale Detailed Geological Map of Poland has resulted in drilling of more than a dozen full cores, piercing through Quaternary deposits down to their basement. In the lowermost parts of the cores, at average depth of 100 m, thick series of lacustrine and swamp deposits were encountered, underlain by basal glacial tills lying directly on the older basement (Ber 1996, 2000, 2006, Ber et al. 1998, Kacprzak & Lisicki 2007). Palynological analyses from these sites (Fig. 1) indicate that they represent the Augustovian succession (Janczyk-Kopikowa 1996, 2009, Winter 2001, 2008, 2009).

Deposits from the Domuraty 2 section were obtained following a second drilling in 2008. A core comprising a series of deposits was obtained, much thicker and of different lithology than the Domuraty section that had been analysed several years earlier during a survey in the area of the Sztabin map sheet for the 1:50 000-scale Detailed Geological Map of Poland as part of the work of the Polish Geological Institute (Kacprzak & Lisicki 2007, Winter & Lisicki 2005, Winter et al. 2008). Pollen and diatom analyses of the sediments from the Domuraty and Domuraty 2 sites indicate that the succession represents a new pollen sequence so far unknown from Poland, with three warm units (Dom I, Dom II, Dom III) differing in the

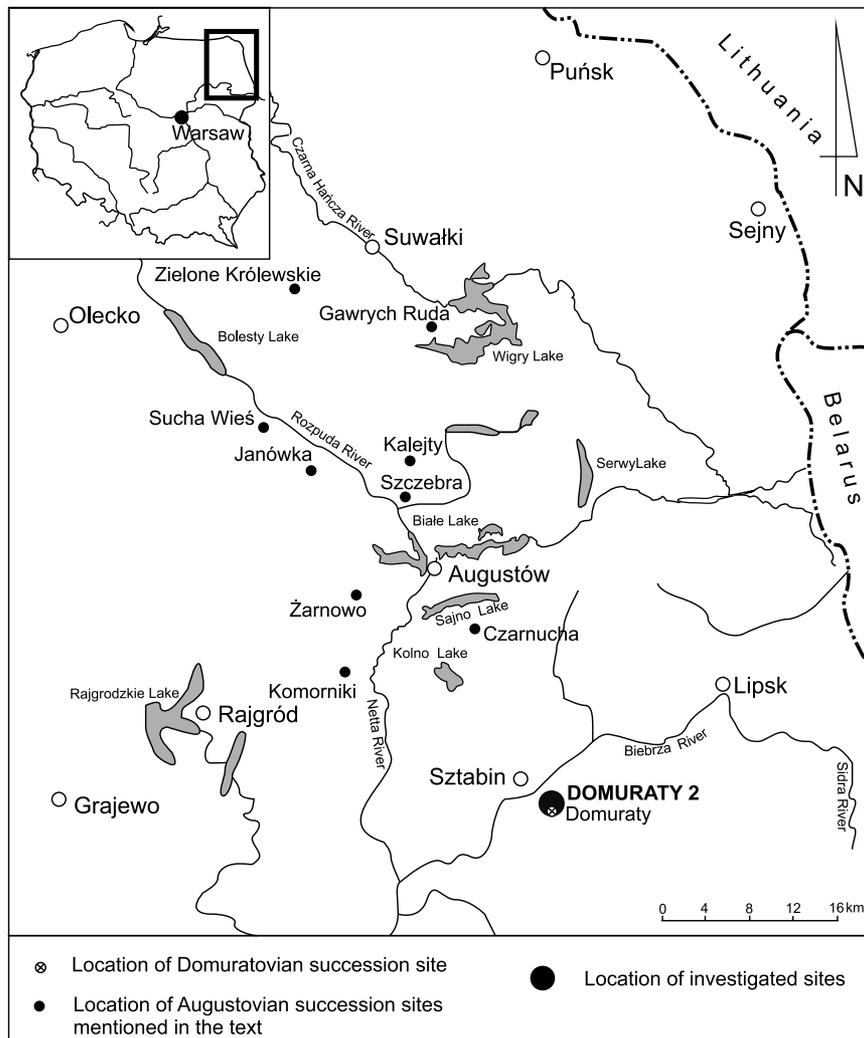


Fig. 1. Location of the investigated sites

development of forest vegetation and separated by cold periods with vegetation of open landscape, and in one of them also taiga-type forest vegetation (Winter et al. 2008, Winter et al. in press). The tripartite character of the Domuraty succession, containing three separate interglacial successions recorded in sediments between horizons of glacial till, is a phenomenon previously unknown from Central Europe. At present a similar succession comparable with the Domuraty complex has not been recognised.

The Domuraty succession is located between the Nidanian and Sanian 2 glaciations, although in stratigraphic schemes this position is occupied by the Małopolanian interglacial (Lindner 1992). However, there is no complete pollen succession documenting the Małopolanian interglacial. The terminal part of a succession assigned to the Małopolanian succession is registered at the Łowisko site (Stuchlik & Wójcik 2001). The Domuraty succession is related to climate changes taking

place in MIS 17, with a threefold increase of $\sigma^{18}\text{O}$ values and double drop of $\sigma^{18}\text{O}$ values, visible in many deep ocean cores (Bassinot et al. 1994, Lisiecki & Raymo 2005). Palaeomagnetic data indicate that the succession mainly contains normal-polarity remnant magnetisation, indicating deposition in the Brunhes interval. Based on palynological and palaeomagnetic data it can be assumed that the Domuraty 2 succession records a series of climate events of global significance related to the early Middle Pleistocene Transition (Winter et al. in press).

In Western Europe, a succession with development similar to Domuraty was distinguished at the Göttingen site (Grüger 1996), with high similarity in the pattern of isotope curves, similar taxonomic composition, and the multiple occurrence of warm units separated by cold units (Winter et al. 2008). However, in view of the new pollen data from Domuraty 2, the contemporaneity of the two sequences is excluded. Moreover, the Domuraty succession can hardly

be correlated with an interval encompassing the termination of the Early and Middle Pleistocene. Likewise, correlation with the interglacials of the Cromerian complex (Zagwijn 1996) is not possible.

In Eastern Europe the oldest warm unit distinguished in Belarus is the Korchevian interglacial (Yakubowskaya et al. 2014, Mamakowa & Rylowa 2007, Velichkevich et al. 1997). The pollen floras from the Korchevian (Yelovicheva 2001) and Smolarka sections (Rylowa 1985, Velichkevich et al. 1997) assigned to the Korchevian interglacial show high similarity with the flora from Domuraty, and the correlation of the Korchevian interglacial with the Małopolsanian interglacial (Lindner & Yelovicheva 2001) also may suggest the position of the Domuraty succession in the Małopolsanian interglacial.

Repeated drilling of deposits of the Domuraty 2 section have enabled further detailed palynological and palaeomagnetic studies, and plant macroremains analyses, the main focus of this paper.

STUDY AREA AND SEDIMENT DESCRIPTION

The Domuraty 2 drilling (Nieżnany Bór PGI 1) was done in Domuraty village (Suchowola municipality). The Domuraty 2 site (23°07'30"W, 53°40'15"N; 121.0 m a.s.l.) is close to the southern margin of the Biebrza ice-marginal valley (Fig. 1), on a flat moraine plateau. The base of the Quaternary deposits was

Depth (m)	Lithology
90.30–92.65	silt, in places clayey, with plant detritus, 92.3–91.55 m having detritus of malacofauna
92.65–94.45	clay and silty clay towards base
94.45–99.00	silt, in places sandy
99.00–107.20	sand, in places with humus
107.20–111.40	clayey silt with streaks of humus and accumulation of plant macroremains, with interbedding of fine-grained fluvial sand
111.40–114.90	clayey silt with interbedding of peat and malacofauna accumulations, of lacustrine-swamp origin
114.90–117.20	sandy silt, silty sand and clayey silt, locally with peat interbedding
117.20–119.42	sand with humus
119.42–119.77	brown silt with plant detritus, peaty at base
119.77–120.20	peat and coarse detritic gyttia, strongly compressed
120.20–124.00	fine-grained and very fine-grained sand, with interbedding of peat and sandy silt
124.00–128.90	clayey silt, in places occur brownish red horizons

drilled at 222.8 m depth; Pleistocene deposits overlie Upper Cretaceous strata. Directly on the Cretaceous deposits is a series of grey-brown glacial tills 85.5 m thick, assigned to the oldest Narevian glaciation (MIS 22). Above lie fluvioglacial fine-grained sands 8.4 m thick, covered by ice-dammed laminated clay silts 4.9 m thick. These deposits probably are related to the Nidanian glaciation (MIS 18). Above is a complex of lacustrine-river-swamp deposits 30.9 m thick. The analysed series is covered by grey sandy-clay glacial tills 1.3 m thick, deposited within the Central Polish complex (Ber et al. 2007). Lacustrine-river-swamp deposits are developed as sands, siltstones and peats. The sediments were described in detail by Stanisław Lisicki and Hanna Winter.

METHODS

The plant macroremains analyses used 120 samples from the 129.0–98.0 m depth interval collected in strict correlation with previously analysed pollen samples. The samples were analysed at various resolutions depending on the frequency of the macroremains, and samples were collected more densely in places where climate optima were distinguished or across facies changes. The pollen analysis used samples from the 129.25–90.5 m depth interval; resolution depended on the lithology of the sediment and the presence of pollen (Winter et al. in press).

Sediment samples of (100–150 ml vol.) were soaked in water for 24 h, then boiled with added KOH. After boiling, the samples were elutriated using a sieve (ϕ 0.2 mm mesh). The material on the sieve was viewed under a stereoscopic microscope; recognisable plant remains were picked out and inserted in a 1:1:1 mixture of glycerine, water and ethyl alcohol with thymol added. Macroremains were identified using keys, atlases (Beijerinck 1947, Berggren 1969, Cappers et al. 2006, Kats et al. 1965, Velichkevich & Zastawniak 2006, 2008), other reports and publications, a comparative collection of recent seeds and fruits, and a collection of fossil floras belonging to the Palaeobotanical Museum of the W. Szafer Institute of Botany, Polish Academy of Sciences in Kraków.

Qualitative and quantitative results of the analysis are presented in a diagram (Fig. 2) plotted with POLPAL software for Windows (Nalepka & Walanus 2003). In the diagram of macroscopic plant remains plotted for the Domuraty 2 section, local macrofossil assemblage zones (L MAZ) were distinguished, numbered from base to top and labelled D-1 L MAZ to D-13 L MAZ respectively. The subdivision is based on the occurrence of one or several of the most abundant, characteristic, or diagnostic taxa in the zone. The zone boundaries of the zones were determined on the basis of the appearance, disappearance, strong increase, or strong decrease in the number of taxa of significant quantitative or indicative value (Table 1).

Table 1. Description of local macrofossil assemblage zones in the Domuraty 2 section

Local macrofossil assemblage zone	Depth (m)	Description of zone
D-1 L MAZ	129.00–120.04 33 samples	A few sclerotia of <i>Cenococcum geophilum</i> . Single appearances of <i>Chenopodium t. album</i> fruits. Numerous wood and charcoal fragments present. Upper boundary marked by the appearance of numerous plant macrofossils in all distinguished ecological groups
D-2 L MAZ	119.98–114.35 5 samples	Nutlets and testa of <i>Betula nana</i> and <i>B. sect. Albae</i> , nutlets of <i>B. humilis</i> , and seeds of <i>Arctostaphylos uva-ursi</i> . Terrestrial vegetation represented by fruits of <i>Urtica dioica</i> , <i>Chenopodium t. album</i> , <i>Polygonum lapathifolium</i> , and <i>Ranunculus acris</i> . In the most abundant group, swamp plants, base of zone dominated by fruits of <i>Carex sp. trigonous</i> , <i>C. elata</i> , and <i>C. rostrata</i> , and top of zone dominated by <i>Carex sp. biconvex</i> . Close to the reservoir margins grew <i>Ranunculus sceleratus</i> and <i>Rumex maritimus</i> ; single occurrence of <i>Oenanthe aquatica</i> also noted. Reed bed vegetation included the rare <i>Typha sp.</i> , <i>Phragmites australis</i> , and <i>Schoenoplectus lacustris</i> . Aquatic plants include seeds of <i>Stratiotes cf. goretzkyi</i> , spines of <i>Stratiotes sp.</i> , diaspores of <i>Alisma plantago-aquatica</i> , <i>Batrachium sp.</i> , <i>Potamogeton natans</i> , <i>P. praelongus</i> , and <i>Potamogeton sp.</i> Sclerotia of <i>Cenococcum geophilum</i> and wood fragments also present. Upper part of zone marked by decrease of plant macrofossils in all ecological groups
D-3 L MAZ	119.05–117.30 5 samples	Forest stand around reservoir still contains <i>Betula nana</i> , <i>B. humilis/nana</i> , <i>Populus tremula</i> , and single <i>Sambucus sp.</i> Herbaceous vegetation still includes <i>Urtica dioica</i> ; <i>Bidens sp.</i> , <i>Potentilla anserina</i> , <i>Rorippa palustris</i> , and <i>Stellaria palustris</i> appear for the first time. Share of swamp vegetation distinctly lower than in previous zone. <i>Carex sp. trigonous</i> and <i>Carex sp. biconvex</i> dominate; <i>Eleocharis praemaximoviczii</i> and <i>Juncus sp.</i> also present. Terrestrial vegetation still dominated by <i>Ranunculus sceleratus</i> ; single occurrences of <i>Oenanthe aquatica</i> . Reed bed flora less rich: only <i>Typha sp.</i> Occurs. High share of <i>Stratiotes sp.</i> and <i>Alisma plantago-aquatica</i> among aquatic plants. One megaspore of <i>Azolla filiculoides</i> found in top of zone. Wood and charcoal fragments. Upper boundary of zone is marked by increased diaspore abundance, particularly for aquatic and reed bed plants
D-4 L MAZ	117.20–116.40 4 samples	Zone characterised by lack of trees and shrubs. Terrestrial vegetation relatively less abundant and represented mainly by fruits of <i>Urtica dioica</i> , <i>Potentilla supina</i> , <i>Rorippa palustris</i> , and <i>Campanula sp.</i> Also present are <i>Ranunculus sceleratus</i> , <i>R. gailensis</i> , and <i>Oenanthe aquatica</i> . Swamp vegetation dominated by Cyperaceae, including <i>Carex sp. biconvex</i> , <i>Carex sp. trigonous</i> , and <i>C. paucifloroides</i> . Reed bed vegetation dominated by <i>Typha sp.</i> , <i>Phragmites australis</i> , and <i>Schoenoplectus lacustris</i> . Aquatic plants include <i>Alisma plantago-aquatica</i> , <i>A. plantago-minima</i> , <i>Najas minor</i> , <i>Callitriche autumnalis</i> , <i>Potamogeton pectinatus</i> , and <i>Potamogeton sp.</i> Base of zone contains numerous megaspores of <i>Azolla filiculoides</i> and <i>Salvinia natans</i> . Sclerotia of <i>Cenococcum geophilum</i> and fragments of woods and charcoal also present. Upper boundary of zone marked by increased abundance of plant macroremains in all ecological groups
D-5 L MAZ	116.10–115.70 3 samples	<i>Betula sect. Albae</i> appears again around reservoir. Share of terrestrial vegetation significantly higher than in previous zones, and dominated by <i>Urtica dioica</i> , <i>Ranunculus sceleratus</i> , and <i>R. gailensis</i> ; remains of <i>Bidens sp.</i> , <i>Potentilla anserina</i> , <i>P. supina</i> , and <i>Potentilla sp.</i> also present. <i>Chenopodium t. album</i> , <i>Ch. urbicum</i> , <i>Stellaria palustris</i> , and <i>Campanula sp.</i> present. Increased share of swamp vegetation. <i>Carex sp. biconvex</i> , <i>Carex sp. trigonous</i> , <i>C. elata</i> , <i>C. rostrata</i> , <i>C. paucifloroides</i> , <i>Eleocharis palustris</i> , <i>Scirpus atroviroides</i> , <i>S. sylvaticus</i> , and <i>Cyperus glomeratus</i> dominate. Reed bed vegetation equally rich; most numerous are <i>Typha sp.</i> , <i>T. pliocenica</i> , <i>Oenanthe aquatica</i> , <i>Schoenoplectus lacustris</i> , <i>Phragmites australis</i> , and <i>Lycopus europaeus</i> . Increased diversity of aquatic plants, with dominant <i>Alisma plantago-aquatica</i> , <i>A. plantago-minima</i> , <i>Sagittaria sagittifolia</i> , <i>Potamogeton pusillus</i> , and <i>Potamogeton sp.</i> Most abundant are <i>Zannichellia palustris</i> , <i>Elatine hydropiper</i> , and <i>Callitriche autumnalis</i> . As in previous zone, megaspores of <i>Azolla filiculoides</i> and <i>Salvinia natans</i> abundant. Single oospores of Characeae, and wood fragments. Upper boundary of zone marked by decreased diaspore abundance, particularly among aquatic, reed bed, and swamp plants
D-6 L MAZ	115.40–112.80 10 samples	Fragments of trees and shrubs, including nutlets of <i>Betula sect. Albae</i> and <i>B. nana</i> . Terrestrial plants still include abundant <i>Urtica dioica</i> and <i>Chenopodium t. album</i> ; also in this group are remains of <i>Ranunculus gmelini</i> , <i>Rorippa palustris</i> , and <i>Campanula sp.</i> In top of zone are <i>Fragaria vesca/viridis</i> and fragments of <i>Bidens sp.</i> , <i>Potentilla anserina</i> , and <i>P. supina</i> . Habitats around reservoir include <i>Ranunculus sceleratus</i> and <i>Rumex maritimus</i> . Swamp vegetation represented by <i>Carex sp. biconvex</i> , <i>Carex sp. trigonous</i> , <i>C. elata</i> , <i>C. paucifloroides</i> , <i>Menyanthes trifoliata</i> , <i>Scirpus atroviroides</i> , <i>Mentha aquatica</i> , and <i>Thelypteris palustris</i> . Reed bed vegetation slightly less diverse than in previous zone. <i>Typha sp.</i> and <i>Phragmites australis</i> present. Aquatic plants diverse but poorer than in the previous zone, with <i>Batrachium sp.</i> , <i>Najas marina</i> , <i>Potamogeton pusillus</i> , <i>P. pectinatus</i> , and <i>Potamogeton sp.</i> <i>Zannichellia palustris</i> , <i>Elatine hydropiper</i> , and <i>Hippuris vulgaris</i> also found in base of zone. Single appearances of <i>Lemna trisulca</i> . Fragments of fish skeletons, wood and charcoal. Upper boundary marked by significantly increased diaspore abundance, particularly among reed bed and swamp plants

Table 1. Continued

Local macrofossil assemblage zone	Depth (m)	Description of zone
D-7 L MAZ	112.50–112.05 4 samples	Zone still contains nutlets of <i>Betula</i> sect. <i>Albae</i> , and terrestrial plants include <i>Urtica dioica</i> , <i>Ranunculus sceleratus</i> , <i>R. gmelini</i> , <i>R. flammula</i> , <i>Rumex maritimus</i> , and <i>Stellaria palustris</i> . Swamp vegetation more diverse but only in basal part of zone. Fruits of <i>Carex</i> sp. <i>trigonous</i> , <i>Carex</i> sp. <i>biconvex</i> , <i>C. rostrata</i> , and <i>C. paucifloroides</i> present. Fruits of <i>Menyanthes trifoliata</i> , <i>Scirpus atroviroides</i> , and <i>Cyperus glomeratus</i> noted. Stems of brown mosses present. The reed bed habitats dominated by <i>Typha</i> sp. and <i>Phragmites australis</i> ; less frequent are <i>Lycopus europaeus</i> and <i>Schoenoplectus lacustris</i> . Aquatic plants include <i>Alisma plantago-aquatica</i> , <i>Zannichellia palustris</i> , and <i>Lemna trisulca</i> . Upper boundary marked by significant increase of plant macrofossils in all ecological groups
D-8 L MAZ	111.00–112.00 13 samples	Increased shares of plant macrofossils in all ecological groups. In the group of trees and shrubs are, besides fruits of <i>Betula</i> sect. <i>Albae</i> , also <i>Alnus glutinosa</i> and seeds of <i>Larix</i> sp. Terrestrial plant macrofossils show increased abundance of fruits of <i>Urtica dioica</i> , <i>U. angustifolia</i> , <i>Ranunculus sceleratus</i> , <i>R. gailensis</i> , and <i>R. acris</i> ; <i>Rumex maritima</i> , <i>Chenopodium t. album</i> , <i>Chenopodium</i> sp., <i>Polygonum lapathifolium</i> , <i>Bidens</i> sp., <i>Impatiens parviflora</i> , and Asteraceae occur rarely. Higher share of Cyperaceae in swamp vegetation, including <i>Carex</i> sp. <i>biconvex</i> , <i>Carex</i> sp. <i>trigonous</i> , <i>C. rostrata</i> , and <i>C. paucifloroides</i> . Particularly common are fruits of <i>Cyperus fuscus</i> , <i>C. glomeratus</i> , <i>Eleocharis praemaximoviczii</i> , and <i>Mentha aquatica</i> , and megaspores of <i>Thelypteris palustris</i> . Significant shares of fruits of <i>Scirpus atroviroides</i> , <i>S. sylvaticus</i> , <i>Eleocharis palustris</i> , <i>Menyanthes trifoliata</i> , <i>Stachys palustris</i> , <i>Oenanthe aquatica</i> , <i>Juncus</i> sp., and <i>Dulichium arundinaceum</i> . Very numerous brown moss stems. Reed bed plants dominated by <i>Typha</i> sp., <i>T. plicenica</i> , and <i>Phragmites australis</i> ; less common are <i>Schoenoplectus lacustris</i> , <i>Lycopus europaeus</i> , and <i>Carex pseudocyperus</i> . Aquatic plants more diverse and dominated by spines and seeds of <i>Stratiotes</i> cf. <i>goretzkyi</i> , <i>Stratiotes</i> sp., <i>Alisma plantago-aquatica</i> , <i>Sagittaria sagittifolia</i> , <i>Scirpus kreczetoviczii</i> , <i>Najas minor</i> , <i>N. marina</i> , <i>Batrachium</i> sp., <i>Zannichellia palustris</i> , and <i>Elatine hydropiper</i> . Endocarps of Potamogetonaceae present, particularly <i>Potamogeton pusillus</i> , <i>P. pectinatus</i> , and <i>Potamogeton</i> sp.; <i>P. alpinus</i> and <i>Hippuris vulgaris</i> appear in top of zone. Macrophytes include <i>Nymphaea alba</i> and <i>Ceratophyllum demersum</i> . Common in entire zone are megaspores of <i>Salvinia natans</i> and <i>Azolla filiculoides</i> , and co-occurring <i>Lemna trisulca</i> . Single oospores of Characeae appear in top of zone. Upper boundary of zone marked by decreased diaspore abundance in all plant groups
D-9 L MAZ	110.95–107.60 11 samples	Zone characterised by impoverishment and abundance of plant remains and complete disappearance of many taxa, and reappearance of fruit and fruit scales of <i>Betula nana</i> . Herbaceous plants represented by single specimens of <i>Urtica dioica</i> , Asteraceae, <i>Eupatorium cannabinum</i> , <i>Rumex maritimus</i> , and <i>Oenanthe aquatica</i> . Share of swamp plants much lower than in previous zones. Single occurrences of <i>Carex</i> sp. <i>trigonous</i> , <i>Carex</i> sp. <i>biconvex</i> , <i>C. rostrata</i> , <i>C. paucifloroides</i> , <i>Menyanthes trifoliata</i> , <i>Eleocharis palustris</i> , and <i>Viola palustris</i> . Single fruits of <i>Mentha aquatica</i> and <i>Oenanthe aquatica</i> . Reed swamp and aquatic plants also decline. Rare seeds of <i>Typha</i> sp., <i>Phragmites australis</i> , and <i>Schoenoplectus lacustris</i> are noted. Aquatic plants include seed fragments of <i>Stratiotes</i> sp., seeds of <i>Alisma plantago-aquatica</i> , <i>Sagittaria sagittifolia</i> , <i>Batrachium</i> sp., <i>Potamogeton praelongus</i> , <i>P. pectinatus</i> , <i>P. rutilus</i> , <i>P. filiformis</i> , <i>P. gramineus</i> , <i>P. alpinus</i> , and <i>Potamogeton</i> sp. Also present are <i>Zannichellia palustris</i> , <i>Elatine hydropiper</i> , <i>Myriophyllum spicatum</i> , <i>M. verticillatum</i> , and <i>Callitriche autumnalis</i> . Zone includes megaspores of <i>Salvinia natans</i> and <i>Azolla filiculoides</i> , and fruits of <i>Lemna trisulca</i> . Top of zone contains numerous oospores of Characeae. Sclerotia of <i>Cenococcum geophilum</i> , statoblasts of <i>Cristatella mucedo</i> , ephippia of <i>Daphnia</i> and wood fragments noted. Upper boundary of zone marked by decreased diaspore abundance in all plant groups
D-10 L MAZ	107.30–106.10 4 samples	Tree and shrub remains include nutlets of <i>Carpinus betulus</i> and <i>Sambucus</i> sp. Terrestrial plants still contain <i>Urtica dioica</i> , <i>Chenopodium t. album</i> , <i>Ch. rubrum</i> , <i>Stellaria palustris</i> , and <i>Rumex maritimus</i> . Rare fragments of swamp and reed bed plants, particularly <i>Carex</i> sp. <i>biconvex</i> , <i>Carex</i> sp. <i>trigonous</i> , <i>Cyperus fuscus</i> , <i>Eleocharis praemaximoviczii</i> , <i>Scirpus sylvaticus</i> , <i>Mentha aquatica</i> , <i>Menyanthes trifoliata</i> , and <i>Stachys palustris</i> . Aquatic plants include rare seeds of <i>Alisma plantago-aquatica</i> , <i>Batrachium</i> sp., <i>Scirpus kreczetoviczii</i> , <i>Potamogeton praelongus</i> , <i>P. pectinatus</i> , <i>P. rutilus</i> , <i>P. filiformis</i> , <i>Najas marina</i> , and <i>N. minor</i> , single spines of <i>Stratiotes</i> sp., endocarps of <i>Potamogeton perforatus</i> and <i>Potamogeton</i> sp., as well as <i>Zannichellia palustris</i> , <i>Nymphaea cinerea</i> , and <i>Nymphoides peltata</i> . Megaspores of <i>Azolla filiculoides</i> and fruits of <i>Lemna trisulca</i> relatively rare. Sclerotia of <i>Cenococcum geophilum</i> , statoblasts of <i>Cristatella mucedo</i> , very numerous fragments of wood and charcoal. Upper boundary of zone marked by further decrease of diaspore abundance

Table 1. Continued

Local macrofossil assemblage zone	Depth (m)	Description of zone
D-11 L MAZ	105.90–98.90 15 samples	Zone characterised by higher abundance of tree and shrub fragments. Nutlets and fruit scales of <i>Betula</i> sect. <i>Albae</i> , <i>Betula</i> sp., bud scales of <i>Pinus sylvestris</i> , nuts of <i>Alnus glutinosa</i> , and seeds of <i>Rubus</i> sp. Terrestrial vegetation highly diverse but abundance low, with <i>Urtica dioica</i> , <i>Ranunculus sceleratus</i> , <i>Rumex maritimus</i> ; <i>Chenopodium t. album</i> , <i>Polygonum lapathifolium</i> , <i>Potentilla anserina</i> , <i>P. supina</i> , <i>Rorippa palustris</i> , <i>Thalictrum lucidum</i> , and <i>Sonchus arvensis</i> , and megaspores of <i>Selaginella</i> sp. Swamp vegetation shows similar trend. Fruits of <i>Carex</i> sp. <i>biconvex</i> , <i>Carex</i> sp. <i>trigonous</i> , <i>C. rostrata</i> , <i>Eleocharis palustris</i> , as well as <i>Scirpus sylvaticus</i> and <i>Ranunculus repens</i> . Also noted are shares of <i>Stachys palustris</i> , <i>Stachys</i> sp., <i>Oenanthe aquatica</i> , and <i>Cicuta virosa</i> . No fragments of swamp vegetation. As in previous zone, aquatic plants represented by rare seeds of <i>Alisma plantago-aquatica</i> , <i>Batrachium</i> sp., <i>Sagittaria sagittifolia</i> , <i>Stratiotes</i> sp., and <i>Scirpus kreczetoviczii</i> . Genus <i>Potamogeton</i> comprises endocarps of <i>Potamogeton perforatus</i> , <i>P. rutilus</i> and <i>Potamogeton</i> sp., as well as <i>Najas minor</i> , <i>N. tenuissima</i> , and <i>Najas</i> sp., with single spines of <i>Stratiotes</i> sp. and fruits of <i>Zannichellia palustris</i> , <i>Sparganium emersum</i> , and <i>Myriophyllum spicatum</i> . Sclerotia of <i>Cenococcum geophilum</i> and numerous fragments of wood and charcoal. Upper boundary of zone marked by slight increase of diaspore abundance
D-12 L MAZ	98.60–96.0 5 samples	Trees and shrubs again contain nutlets of <i>Betula nana</i> , needles of <i>Larix</i> sp., and nutlets of <i>Betula</i> sect. <i>Albae</i> . Terrestrial plants include fruits of <i>Urtica dioica</i> , <i>Polygonum lapathifolium</i> , and <i>Potentilla</i> sp., as well as megaspores of <i>Selaginella helvetica</i> . Rare fragments of swamp plants, including <i>Carex</i> sp. <i>biconvex</i> , <i>C. elata</i> , <i>Eleocharis palustris</i> , <i>Menyanthes trifoliata</i> , <i>Viola palustris</i> , and <i>Juncus</i> sp. Common <i>Oenanthe aquatica</i> . Lack of swamp plant fragments. Aquatic plants have highest share, with <i>Stratiotes</i> sp., very common <i>Batrachium</i> sp., <i>Potamogeton natans</i> , <i>P. pusillus</i> , <i>P. praemaackianus</i> , <i>P. obtusifolius</i> , and <i>P. dvinensis</i> . <i>Sparganium minimum</i> and <i>Caulinia macrosperma</i> also noted. Oospores of Characeae and sclerotia of <i>Cenococcum geophilum</i> , very numerous statoblasts of <i>Cristatella mucedo</i> , and fragments of fish skeletons. Upper boundary marked by decreased diaspore abundance, particularly among aquatic plants.
D-13 L MAZ	90.40–96.10 6 samples	Zone characterised by boreal elements such as <i>Betula nana/humilis</i> . Terrestrial plants include only <i>Potentilla supina</i> and <i>Potentilla</i> sp., and among swamp plants are single fruits of <i>Carex</i> sp. <i>trigonous</i> , <i>Carex</i> sp. <i>biconvex</i> , <i>C. elata</i> , <i>C. rostrata</i> , and <i>Eleocharis palustris</i> . Reed bed vegetation shows only <i>Typha</i> sp. Aquatic plants have highest share in this zone, with endocarps of <i>Potamogeton pectinatus</i> , <i>P. filiformis</i> , and <i>Potamogeton</i> sp., and megaspores of <i>Azolla filiculoides</i> . Oospores of Characeae are most common in this zone; numerous sclerotia of <i>Cenococcum geophilum</i> , statoblasts of <i>Cristatella mucedo</i> , and wood fragments. Upper boundary of zone is top of organic deposits.

ENVIRONMENTAL CONDITIONS AND CLIMATE CHANGES

NIDANIAN GLACIATION

This series of clayey silt from 129.00–124.70 m depth (**D-1 L MAZ**) and fine-grained sand with peat and silt interbedding from 124.60–120.75 m depth contains almost no diaspores except for single fruits of *Chenopodium t. album*, and also a few fragments of wood and charcoal which in many cases bears traces of transport. The sporadic occurrence of plant remains, the presence of *Cenococcum geophilum* sclerotia, and the type of sediment may point to strong solifluction processes and the absence of compact vegetation cover around the water reservoir. This type of macroflora indicates cold glacial periods.

WARM UNIT DOM I

The deposits from 120.60–120.40 m depth (**top of D-1 L MAZ**), in which the first warm interval of the Domuratovian interglacial was distinguished by pollen analysis at 120.50 m (Winter et al. in press), does not contain any plant macroremains. The finding of very few plant remains in deposits of the Nidanian glaciation and the complete lack of a record in Warm unit Dom I may indicate that during this interval the lake was a wide, deep reservoir, and that the few plant remains reaching it derived from a distant shallow reed bed zone or from the lake margins.

COLD UNIT DOM I/II

Cold unit Dom I/II distinguished by Winter et al. (in press) encompasses seven horizons of plant macroremains (**top of D-1 L MAZ** and

DOMURATY 2

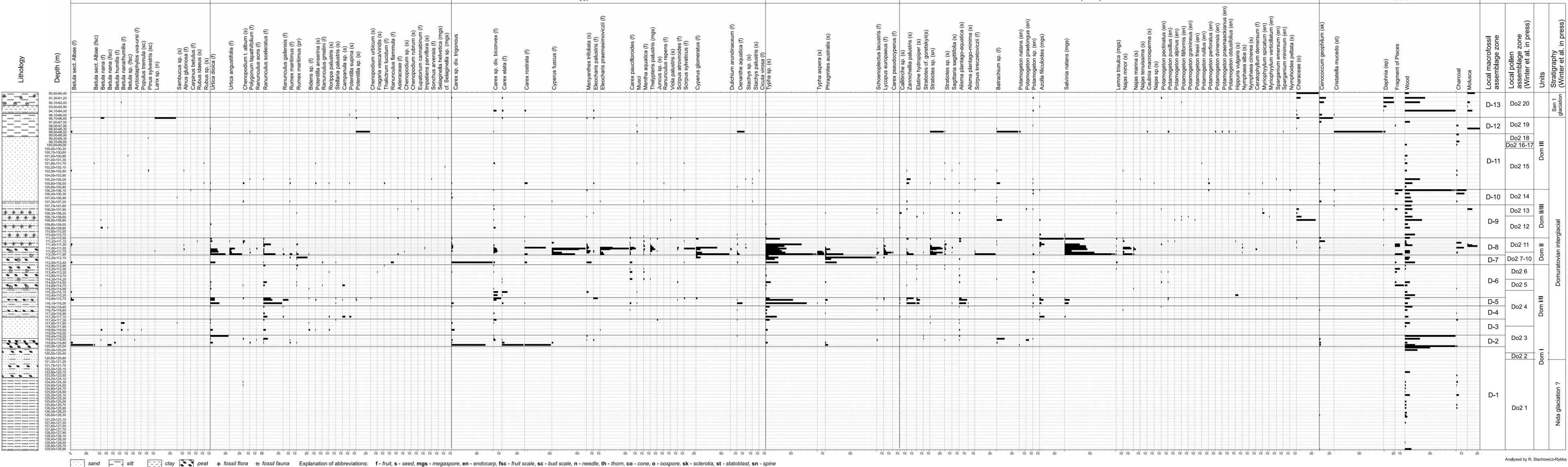


Fig. 2. Diagram plotted for plant macrofossils from the Domuraty 2 section

Analysed by R. Stachowicz-Rybka

D-2 L MAZ–D-7 L MAZ) and occurs in the 120.40–112.30 m depth interval.

The deposits from the top of the D-1 L MAZ do not contain diaspores, but very abundant fragments of wood. Sediments of fine-grained and very fine-grained sand, with interbedding of peat and sandy silt, indicate higher-energy sedimentary conditions. Due to gradual shallowing of the reservoir and increased eutrophication, the deposits from the D-2 L MAZ contain very numerous plant remains from the family Cyperaceae, with fruits of *Carex* sp. div. *trigonus*, *C. elata*, and *C. rostrata*, and *Eleocharis palustris* in the base. Humid habitats were overgrown by dwarf shrub tundra communities with *Betula nana* and *B. humilis*, whereas drier and open areas were overgrown by *Chenopodium t. album*. Periodically exposed reservoir margins rich in organic compounds most probably offered the best habitat for *Rumex maritimus* and *Ranunculus sceleratus*, species which presently often co-occur in *Rumicetum maritimi* communities. *Urtica dioica* and *U. angustifolia* occurred further from the margin, in humid habitats rich in nitrogen. In the reed bed zone grew *Phragmites australis*, *Typha* sp., *Schoenoplectus lacustris*, and *Alisma plantago-aquatica*. Remains of aquatic plants appear for the first time, dominated by nutlets of *Batrachium* sp. (for *Ranunculus* subgen., *Batrachium* Aalbersberg & Litt (1998) accept temperatures of $T_{m\text{jul}} +10^{\circ}\text{C}$) and *Potamogeton praelongus* occurring at $T_{m\text{jul}} +8^{\circ}\text{C}$ (Kolstrup 1980), *Callitriche* sp., with a few seeds of *Stratiotes cf. goretzkyi*. The vegetation in the D-2 L MAZ, representing the beginning of Cold unit Dom I/III, is characterised by the occurrence of dwarf shrub tundra, growing in low temperature ranges and under distinct shallowing of the reservoir. The horizon of peat and coarse detritic gyttia accumulated in a much calmer sedimentary setting.

The decrease of the abundance of plant remains in the D-3 L MAZ should be attributed to the transition to a different type of sediment. The horizon of peat and coarse detritic gyttia is overlain by a 2.2 m layer of sand with low organic content. The zone contains *Betula nana*, *B. humilis/nana*, *Rorippa palustris*, and also *Arctostaphylos uva-ursi*, which usually grows on deforested dunes and burned sites, and often behaves as a pioneer species, forming vast herbaceous blankets. The species are cryophilic and heliophilic, and indicate that

tundra habitats were still present; this means that the vegetation surrounding the reservoir was similar to that recorded from the D-2 L MAZ. Herbaceous plants again included *Urtica dioica*, whereas *Potentilla anserina* and *Stellaria palustris* appeared for the first time. The extinct *Eleocharis praemaximoviczii* (Fig. 4: 7, 8) was also present.

In the top part of the zone are remains of *Sambucus* sp. and *Azolla filiculoides* (Fig. 3: 4,5), taxa with high thermal requirements, indicating improvement of climatic conditions. Similarly, palynological analysis of samples from the same depth indicated an increased share of *Quercus* pollen, up to 1.9%, which Winter et al. (in press) relate to short-term warmer climate oscillations, also confirmed also by the presence of *Ligustrum* and *Sambucus* pollen (evidenced also by seeds). The presence of *Ligustrum* indicates a warm climate with warmer summers and not very frosty winters, reflected in the high abundance of *Azolla filiculoides* megaspores. Wong Fong Sang et al. (1987) reported that *A. filiculoides* endures field temperatures from -10 to -15°C . However, the conditions could not have been too severe based on the water temperature requirements of *Azolla*.

The two succeeding zones, D-4 L MAZ and D-5 L MAZ, change significantly in character; they contain taxa characteristic of warm climate, including *Azolla filiculoides*, *Salvinia natans* (Fig. 3: 1–3), and *Cyperus glomeratus* (Fig. 4: 1–3), which at present occurs at $T_{m\text{jul}} +20^{\circ}\text{C}$ (Aalbersberg & Litt 1998). The latter plant grows mainly in Southern Europe to the Caucasus and is also known from Iran, Uzbekistan, northern China, and Japan. In Middle Pleistocene floras it was common during climatic optima of the Augustovian interglacial II and slightly less frequent during Augustovian interglacial I (Stachowicz-Rybka 2011) and Ferdynandovian interglacial II (Stachowicz-Rybka 2015a, b). It grows on river margins, and at present occurs also in rice fields. The increase of thermal conditions is signalled by the retreat of *Betula nana* and *B. humilis*. The two zones can be correlated with the Do2 4 L PAZ, distinguished by Winter et al. (in press) and characterised by short-term warmer climate oscillations. The presence of megaspores of the water ferns *Azolla filiculoides* and *Salvinia natans* may indicate that winter-month temperatures could not have been too low.

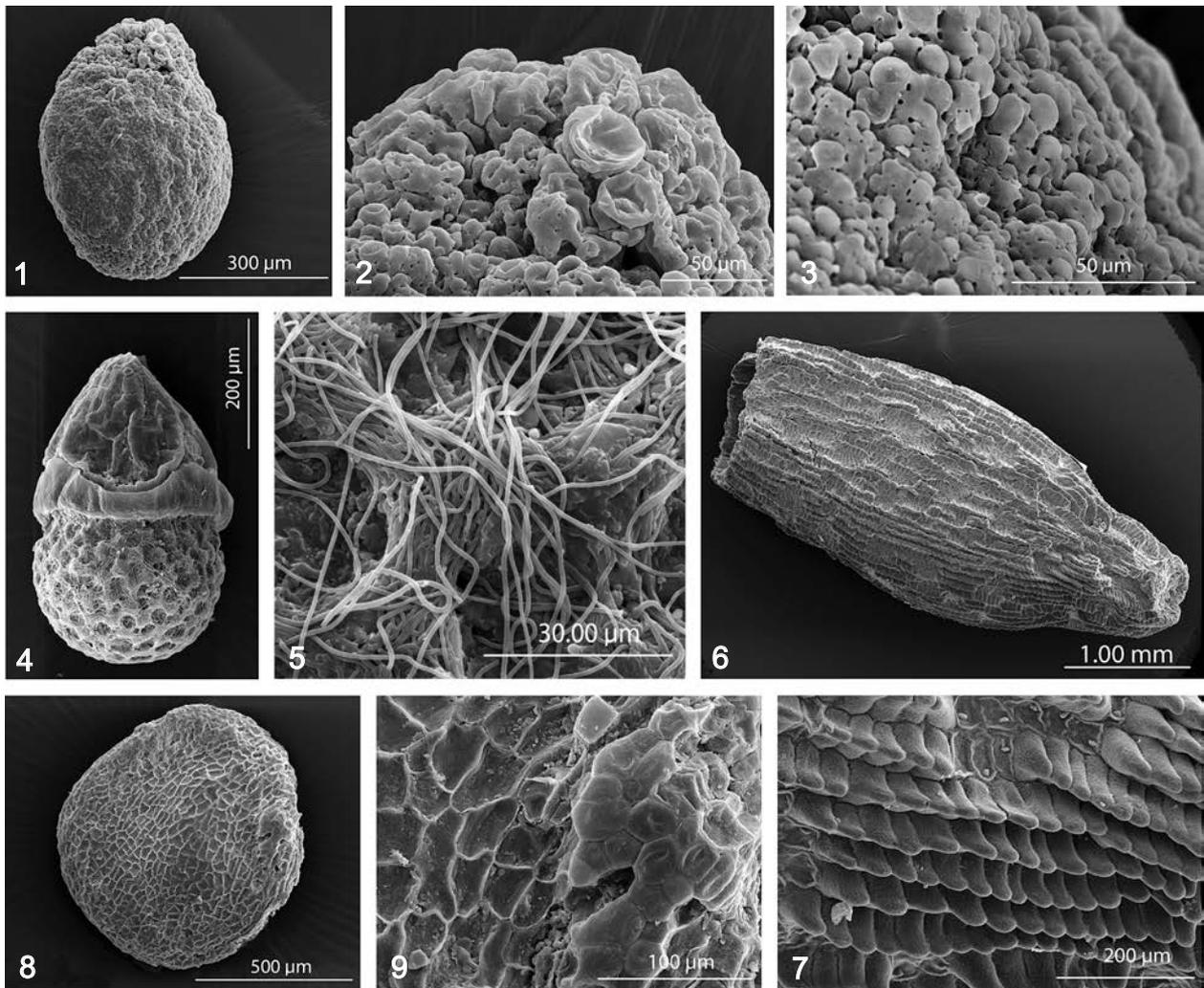


Fig. 3. 1. *Salvinia natans* L., megaspore; 2, 3. *Salvinia natans* L., megaspore, detail of surface; 4. *Azolla filiculoides* Lam., megaspore; 5. *Azolla filiculoides* Lam., megaspore, detail of surface; 6. *Impatiens parviflora* DC., seed; 7. *Impatiens parviflora* DC., seed, detail of surface; 8. *Ranunculus gailensis* E.M. Reid, fruit; 9. *Ranunculus gailensis* E.M. Reid, fruit, detail of surface

These changes are also marked by water level oscillations. In the D-5 L MAZ the abundance of diaspores of *Zannichellia palustris*, *Oenanthe aquatica*, *Ranunculus sceleratus*, and *Rumex maritimus* increases; these are species indicating habitats with oscillating water levels, high salinity, or high trophic levels.

The last zone, the D-6 L MAZ, belonging in the chronostratigraphic scheme to Cold unit Dom VII, is again characterised by a decrease of plant remains and the retreat of the thermophilic plants of the two older zones, the D-4 and D-5 L MAZ. Terrestrial plants again include *Betula nana*, *Ranunculus gmelini*, and *Rorippa palustris*, characteristic of boreal climate. Another Holarctic element, *Hippuris vulgaris*, is common; at present it occurs at a minimum July temperature of +10°C and frequently is one of the first plants in the initial phases of water reservoirs at the beginning of the Late Glacial

(Wasylikowa 1964). Around the water reservoir grew woody birches, *Betula* sect. *Albae*, and the wet margins were overgrown by peatland vegetation with *Carex elata*, *C. paucifloroides* (Fig. 4: 11,12), *Menyanthes trifoliata*, *Scirpus atroviroides*, *Mentha aquatica*, and *Telypteris palustris*. The presence of rare fruits of *Lemna trisulca* in the top part of the zone suggests increased trophicity and calcium carbonate content in the water reservoir (Szozkiewicz et al. 2010). Moreover, fruiting of *Lemna trisulca* points to a significant temperature increase, a key factor influencing the flowering and formation of fruit. *Lemna* sp. develops fruit when the air temperature is at 25–30°C for at least 14 consecutive days (Czopek 1960, Szczepanek 1971). Thus, the top of the D-6 L MAZ witnesses a gradual improvement of climate related to the approach of the warmest phase of the Domurtovian interglacial.

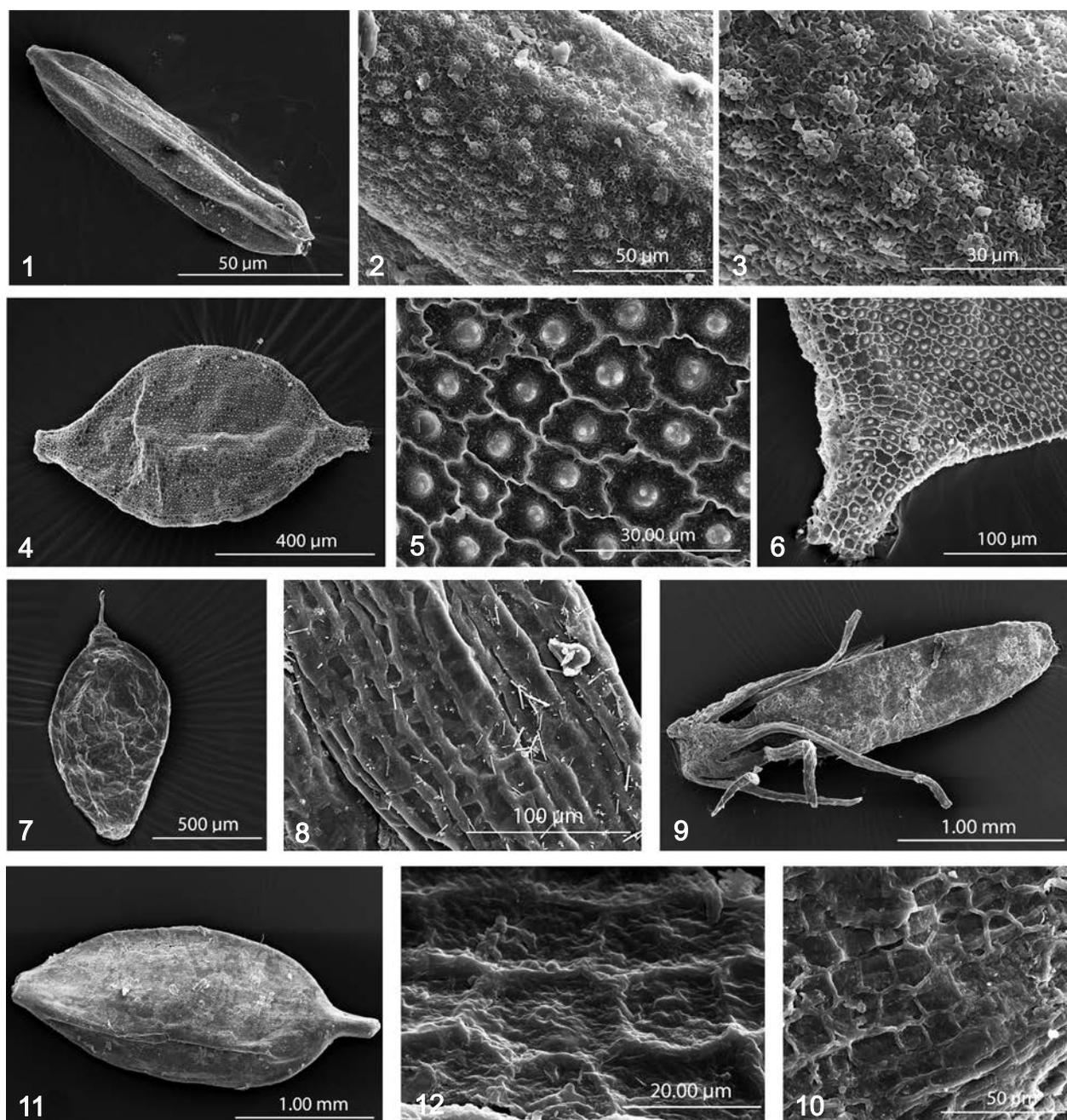


Fig. 4. 1. *Cyperus glomeratus* L., fruit; 2, 3. *Cyperus glomeratus* L., fruit, detail of surface; 4. *Cyperus fuscus* L. fruit; 5, 6. *Cyperus fuscus* L., fruit, detail of surface; 7. *Eleocharis praemaximoviczii* Dorof., fruit; 8. *Eleocharis praemaximoviczii* Dorof., fruit, detail of surface; 9. *Dulichium arundinaceum* (L.) Britt., fruit; 10. *Dulichium arundinaceum* (L.) Britt., fruit, detail of surface; 11. *Carex paucifloroides* Wieliczk., fruit; 12. *Carex paucifloroides* Wieliczk., fruit, detail of surface

WARM UNIT DOM II

The second warm unit distinguished by Winter et al. (in press) encompasses two zones, the **D-7 L MAZ** and **D-8 L MAZ**, showing the highest taxonomic diversity in the entire succession.

Trees and bushes do not form a very abundant group, but a thermophilic element, *Sambucus* sp., also appears, along with a few remains of *Betula* sect. *Albae* and *Alnus glutinosa*, indicating the presence of riparian habitats. Very numerous fruits of *Urtica dioica*,

U. angustifolia, and *Impatiens parviflora* (Fig. 3: 6,7) confirm the riparian and strongly nitrophilous character of the reservoir surroundings. The very diverse and abundant group of peatland plants, particularly in the D-8 L MAZ, indicates that during the period of this interval the reservoir was shallowest and that its area was covered by fen or transitional vegetation comprising numerous species of the family Cyperaceae, such as *Carex rostrata*, *Cyperus fuscus* (Fig. 4: 4–6), and species also known from the Augustovian and

Ferdynandovian interglacials in Poland: *Cyperus glomeratus*, the extinct *Scirpus atroviroides*, *Eleocharis praemaximoviczii* (Stachowicz-Rybka 2011, 2015a, b), and *Dulichium arundinaceum* (Fig. 4: 9,10). At present the latter taxon is a North American species, which is common in Late Pliocene fossil floras (Mai & Walther 1998). It is also present in Pleistocene interglacial floras of the Cromerian Complex until the Holsteinian (Masovian interglacial). The shallow reservoir was surrounded by a well-developed reed bed zone, with the extinct species *Scirpus kreczetoviczii*. Morphologically its nutlets are similar to those of the present-day *Bolboschenus maritimus*, which grows along the margins of standing or slow-flowing waters in saline or strongly eutrophic habitats. In the Pleistocene of Poland it was encountered only in the Augustovian interglacial II at the Czarnucha site. It is most common in the climatic optima of interglacials. The species was determined for the first time in the flora from Kosciesza, representing the Byelovezhian interglacial (Velichkevich 1979). It is also known from the Lower Pleistocene of western Belarus and is very characteristic for the Korchevian interglacial, in which it is particularly abundant (Velichkevich 1982, 1986). The species was also determined in the Kemėnai interval in Lithuania (Velichkevich et al. 1998).

Periodic water level oscillations may have been marked by the appearance of habitats similar to the present-day *Rumicetum maritimi* community with *Rumex maritimus*, *Ranunculus sceleratus*, and the extinct *R. gailensis* (Fig. 3. 8, 9) on water-free margins. Along the margins were *Carex* reed beds with *Menyanthes trifoliata* and *Carex riparia*. The presence of reed beds is evidenced by the presence of seeds of *Typha* sp. and remains of *Phragmites australis*, *Oenanthe aquatica*, *Alisma plantago-aquatica*, and *Lycopus europaeus*, which formed communities similar to typical present-day reed beds. In strongly insolated bays excluded from wave action, probably there was a community similar to the present-day *Parvopotamo-Zannichellietum*, comprising *Zannichellia palustris*, *Najas marina*, and *Najas minor*. *Potamogeton pectinatus* was an accompanying species. The composition of aquatic plants in this zone may also indicate the presence of salt in the environment. The climatic optimum of this warm unit is best reflected

in the D-8 L MAZ by the clear domination of *Salvinia natans*, *Azolla filiculoides*, and *Lemna trisulca*. In this interval, as in the D-4 L MAZ and D-5 L MAZ, the reservoir surface was covered by pleuston assemblages, at first with domination by only *Salvinia natans*, and towards the end of the optimum also by *Azolla filiculoides* and *Lemna trisulca*. In Warm unit Dom II the assemblages were much more abundant. The water fern *Azolla filiculoides* had good growth conditions, with 15–20°C and very good insolation (Tung & Watanabe 1983, Watanabe & Berja 1983, Janes 1998). Wong Fong Sang et al. (1987) noted that 25°C is the optimal temperature for the development of this species. Similar conditions are preferred by *Salvinia natans*, another water fern, which usually grows in tropical climate and in the warm zone of suboceanic temperate climate (Holm et al. 1979). In Europe it is most common in the catchment areas of large rivers (Casper & Krausch 1980), in oxbow lakes, ditches and canals, shallow slow-flowing rivers, and eutrophic waters with a thick layer of organic substrate. Winter-month temperatures above 0°C are the key factor for the viability of microspores and megaspores of *Salvinia natans*, and spore development already initiates at temperatures exceeding 12°C (Święta-Musznicka et al. 2011).

Among the macrophytes were also numerous species of *Potamogeton*, such as *P. pectinatus*, *P. praelongus*, *P. pusillus*, *P. alpinus*, and *P. filiformis*.

Based on the determined macroflora it can be stated that the climatic conditions of Warm unit Dom II are the most favourable of the entire Domuratovian succession. However, the co-occurrence of species typical of warm climate, such as *Sambucus* sp., *Cyperus glomeratus*, *Lemna trisulca*, *Azolla filiculoides* foss., and *Salvinia natans*, together with species characteristic of cooler zones, such as *Larix* sp., *Potamogeton alpinus*, and *Hippuris vulgaris*, indicate that the temperatures of this optimum were not very high. Another explanation of the co-occurrence of taxa with dissimilar thermal requirements may be sediment redeposition, which is also suggested also by the presence of sandy deposits pointing to high-energy sedimentary settings in the top part of the D-8 L MAZ. Such redeposition of part of the material hampers a palaeoclimatic interpretation.

As compared with warmest intervals of other Middle Pleistocene interglacials, the Augustovian II and Ferdynandovian II interglacials, the share of thermophilic taxa in Warm unit Dom II of the Domuratovian interglacial is the lowest. Thus, it seems that Warm unit Dom II was cooler than the optima of the other interglacials, and the vegetation composition is closest to climatic optimum I of the Augustovian interglacial in the Żarnowo succession (Stachowicz-Rybka 2011).

COLD UNIT DOM II/III

The next cold unit Dom II/III, distinguished by Winter et al. (in press), encompasses two zones, **D-9 L MAZ** and **D-10 L MAZ**, in which the share of plant macroremains is distinctly lower. During a succeeding climate change to a cooler climate, the reservoir margins were again overgrown by *Betula nana* and the thermophilic *Rorippa palustris*. Surprising is the presence of diaspores of *Carpinus betulus* and *Sambucus* sp. in the D-10 L MAZ correlated with the Do2 14 L PAZ, which Winter's group assigns to the cold unit of the Domuratovian interglacial. Probably their presence is a result of redeposition, which is indicated by numerous sclerotia of *Cenococcum geophilum*, which in cold intervals indicate solifluction processes in the absence of dense vegetation cover. Moreover, the high share of sand in the sediment indicates a higher-energy depositional setting.

Remains of terrestrial, peatland and reed bed vegetation are significantly less abundant, restricted to a few fruits of *Urtica dioica*, *Carex rostrata*, *Cyperus fuscus*, *Menyanthes trifoliata*, *Eleocharis palustris*, and *Rumex maritimus*. The lake bottom was covered by Characeae meadows, whose presence is confirmed by numerous oospores of *Chara* sp., particularly in the D-9 L MAZ. The development of Characeae meadows may have been due to rising of the water level and a change in its chemistry caused by supply of water richer in calcium carbonate to the reservoir. Anchored in the silty bottom grew *Potamogeton filiformis*, *P. gramineus*, *P. alpinus*, *Myriophyllum verticillatum*, and *M. spicatum*. Among the aquatic plants was also *Callitriche* sp. The aquatic vegetation still contained thermophilic taxa such as *Azolla filiculoides* and *Lemna trisulca*. This is a feature typical of the terminal parts of interglacials, in which the water of lake reservoirs cooled more

slowly and retained a warm habitat for a longer time than the surrounding land.

WARM UNIT DOM III

The third warm unit distinguished by Winter et al. (in press) encompasses the **D-11 L MAZ** and **D-12 L MAZ**. The D-11 L MAZ is recorded almost entirely in organic-poor sands, due to which the plant macroremains are poorly preserved and very rare, although the high number of taxa points to high diversity of the vegetation of that time. The presence of several species of trees growing close to the lake margins is confirmed by fruits and scales of *Betula* sect. *Albae* and remains of *Pinus sylvestris*. They probably grew in depressions in humid and sandy habitats, because such conditions are preferred by pine-birch communities. On peatland in depressions close to the margins of the lake, *Alnus glutinosa* encroached, accompanied by *Rubus idaeus*, *Chenopodium t. album*, *Polygonum lapathifolium*, *Potentilla anserina*, *P. supina*, *Rorippa palustris*, *Thalictrum lucidum*, *Sonchus arvensis*, *Selaginella* sp., and *Urtica dioica*.

The composition of the peatland vegetation is poor. There are a few occurrences of fruit of *Carex* sp. *trigonous*, *Carex* sp. *biconvex*, *C. rostrata*, *Eleocharis palustris*, and *Scirpus sylvaticus*. Periodically flooded habitats were overgrown by *Stachys palustris*, *Stachys* sp., *Oenanthe aquatica*, *Cicuta virosa*, *Ranunculus repens*, and also *Ranunculus sceleratus* and *Rumex maritimus*.

Though less frequent, the remains of aquatic and reed bed vegetation represent many plant species growing in different parts of the lake reservoir. The communities of macrophytes were dominated by numerous species of *Potamogeton*, including *Potamogeton perforatus*, *P. rutilus*, and *Potamogeton* sp., and also *Batrachium* sp., *Najas minor*, *N. tenuissima* and *Najas* sp., single spines of *Stratiotes* sp., and fruits of *Zannichellia palustris*, *Sparganium emersum*, and *Myriophyllum spicatum*. In shallow nearshore waters, *Alisma plantago-aquatica*, *Sagittaria sagittifolia*, and *Scirpus kreczetoviczii* also occurred.

The end of Warm unit Dom III is best recorded at the base of the D-12 L MAZ, where more plant remains were preserved, probably due to the transition from sand to silt. In the corresponding zone (Do2 16-19 L PAZ),

pollen analysis (Winter et al. in press) indicates a distinct decrease of *Quercus* values correlated with increase of NAP. The area covered by forest began to shrink, and the forest structure changed. In place of the retreating *Acer*, *Juglans*, and *Carpinus*, there appeared *Larix* and *Betula*, whose presence close to lake margins is confirmed by macroremains: spines, scales and nutlets. Deterioration of climatic conditions resulted in the reappearance of *Betula nana*, *Selaginella helvetica*, and *Rorippa palustris*. Peatland vegetation, poorly represented by a few fruits of *Carex* sp. *biconvex*, *C. elata*, *Elocharis palustris*, *Menyanthes trifoliata*, *Viola palustris*, and *Juncus* sp., suggests restriction of peatland vegetation near the lake reservoir, whereas numerous *Oenanthe aquatica* fruits indicate an increasingly unstable water level. Very numerous fruits of *Batrachium* sp., and the appearance of numerous species of pondweed, including *Potamogeton natans*, *P. pusillus*, *P. praemaackianus*, *P. obtusifolius*, and *P. dvinensis*, may suggest a rise of the water level. At that time the extinct taxon *Caulinia macrosperma* also grew; it is characteristic of the Byelovezhyan interglacial of Belarus and of floras of that age (Velichkevich & Zastawniak 2008), determined also in the interstadial of the Sanian 2 glaciation (Stachowicz-Rybka 2015a, b). This species is closest to the extant *Caulinia tenuissima* and shows similar climatic requirements. A very high share of statoblasts of the bryozoan *Cristatella mucedo* indicates increased eutrophication (Birks et al. 1976) and water temperature. *Cristatella mucedo* occurs abundantly at temperatures below 16°C and pH <5.6 (Økland & Økland 2000).

SANIAN 1 GLACIATION

The glacial phase assigned to the Central Polish complex encompasses the **D-13 L MAZ** and is the last unit distinguished in the organic lake sediments of the Domuraty 2 section. Study of this part of the succession was done at low resolution, with sampling at about 1 m intervals, so the results are preliminary. As suggested by the composition of the recognised terrestrial plants, with *Betula nana* and *Larix* sp., the sediments accumulated in cool climate. This is also shown by the presence of the aquatic plant *Potamogeton filiformis*, occurring at +8°C minimum mean warmest-month temperature (Kolstrup 1980).

DISCUSSION

The Lower and Middle Pleistocene interglacial sequences were recognised in Poland and documented by palaeobotanical analyses as the Augustovian interglacial, correlated with MIS 19–21 (Ber 1996, Ber et al. 1998, Janczyk-Kopikowa 1996, Stachowicz-Rybka 2009, 2011, Winter 2001, 2008, 2009), and the Ferdynandovian interglacial correlated with MIS 13–15 (Ber et al. 2007, Lindner & Marks 2008, Janczyk-Kopikowa 1975, 1991, 1996, Pidek 2000, 2003, 2013, 2015, Pidek & Poska 2013, Winter 1992, 2006, Zagwijn 1996). In both cases the record of the succession was precisely correlated with cyclic changes of vegetation and climate. Based on high-resolution pollen analyses of many sites from Poland, both successions were reconstructed in detail. Pollen analyses indicating the two successions were confirmed by studies of plant macrofossils from sites of the Augustovian (Stachowicz-Rybka 2005, 2009, 2011) and Ferdynandovian interglacials (Janczyk-Kopikowa 1975, Stachowicz-Rybka 2015a, b).

First, the Domuratovian succession, different from the polymodal interglacials known so far, was correlated with the Małopolskian interglacial (Lisicki & Winter 2004, Winter & Lisicki 2005), and later with the Kozi Grzbiet (Domuratovian) interglacial (Ber et al. 2007, Głazek et al. 1977, Lindner & Marks 2008), and thus was correlated with MIS 19 located between the Nidanian and Sanian 1 glaciations (Ber et al. 2007, Lindner & Marks 2008). It should be emphasised that views on the stratigraphic position of this succession are varied and have changed much over recent years. The most recent reports (Lindner & Marks 2015, Lindner et al. 2013) situate the Augustovian and Domuratovian successions in the Podlasian interglacial between the Nidanian and Sanian 1 glaciations (Table 2).

Palaeobotanical data of the Domuraty succession document several successive, distinct changes in vegetation and climate in the interglacial and glacial units, which should be linked with oscillations caused by global changes and local events. With regard to interglacial vegetation changes, the three distinguished warm sequences distinctly differ in the development of forest and local vegetation, and thus in the climatic conditions prevailing at that time (Winter et al. in press).

Table 2. Correlation of the early Middle Pleistocene in Poland, Belarus, and western Europe after Lindner et al. 2013

Paleo-magnetism	Stratigraphy	Western Europe	Poland	Belarus	MIS	
Brunhes	Middle Pleistocene	Holsteinian	Mazovian	Alexandrian	11	
		Elsterian	Sanian 2	Berezinian	12	
		Cromerian IV	Ferdynandovian	Belovezhian	13	
					14	
					15	
Glacial C	Sanian 1	Yaseldinian	16			
Matuyama	Early Pleistocene	Cromerian III	Podlasian	Domuratovian	Korchevian	17
		Glacial B				18
		Cromerian II	Augustovian	Narevian	19	
		Glacial A			20	
		Cromerian I			21	
		Dorst	Nidanian	Narevian	22	

The succession of plant macroremains in Domuraty only partly reflects the vegetation changes observed in the pollen succession (Winter et al. in press), and does not document all distinguished units. The absence of plant macroremains in Warm unit Dom I results from the fact that in this interval the lake was a wide, deep reservoir, and the few seeds and fruits reaching it originated from a distant shallow reed bed zone and from the lake margins. The high share of sand deposits points to the presence of flows favouring their supply to the basin.

In Poland, Lower and Middle Pleistocene macrofloras have been studied at only a few sites. The Domuraty 2 succession can be compared to older floras of the Augustovian interglacial described from two sites, Czarnucha and Żarnowo (Stachowicz-Rybka 2005, 2007, 2009, 2011) ca 20–30 km north of the Domuraty site, and to younger floras of the Ferdynandovian interglacial documented in the Ferdynandów (Janczyk-Kopikowa 1975) and Łuków 3A sites (Stachowicz-Rybka 2015a, Pidek & Stachowicz-Rybka 2009, Stachowicz-Rybka & Pidek 2012) ca 25 km south of the Domuraty site. Sections with two warm units of the Ferdynandovian succession are recorded in lacustrine deposits within gyttia and peat, in which allochthonous material was not encountered.

With regard to the richness of taxa distinguished by the analysis of plant macroremains, the unit best represented in the Domuraty succession is Warm unit Dom II with the largest share of taxa having high thermal requirements. With regard to climate and taxonomy,

Warm unit Dom II is most similar to the second warm unit of the older Augustovian interglacial, Augustovian (A II), and to the second warm unit of the younger Ferdynandovian interglacial, Ferdynandovian (F II).

The climatic optimum of the Augustovian (A II) is reflected in the most diverse vegetation development of the entire interglacial and the simultaneous appearance of numerous megaspores of *Azolla filiculoides* and *Salvinia natans*, and the presence of *Ceratophyllum demersum*, *Trapa natans*, and *Euryale cf. ferox*. The unique richness and diversity of aquatic vegetation, and the presence of such taxa as *Cyperus glomeratus*, *Scirpus atroviroides*, and *Scirpus kreczetoviczii* along the lake margins, indicate a very warm and humid climate.

The second warm unit of the Ferdynandovian interglacial, Ferdynandovian (F II), is characterised by the presence of *Potamogeton praemaackianus*, *Nymphaea cinerea*, *Caulinia macrosperma*, and *Ceratophyllum demersum*; *Brasenia borysthena* and *Aldrovanda borysthena* were also determined.

A significant difference between the floras of Ferdynandovian and Augustovian age is the presence of *Azolla filiculoides*, *Salvinia natans*, *Selaginella cf. tetraedra*, *Scirpus kreczetoviczii*, *Stratiotes cf. goretskyi*, *Stratiotes cf. brevispermus*, and *Typha aspera* in the floras of the Augustovian interglacial. In turn, the floras of the Ferdynandovian interglacial comprise such taxa as *Brasenia borysthena*, *Aldrovanda borysthena*, *Caulinia macrosperma*, and *Potamogeton praemaackianus*.

Table 3. Comparison of extinct taxa and taxa characteristic for the Domuratovian interglacial of Domuraty 2 (in this text), and Korchevian interglacial (Yakubovskaya et al. 2014)

Taxa	Domuratovian interglacial	Korchevian interglacial
<i>Azolla filiculoides</i> (= <i>Azolla interglacialis</i>)	+	+
<i>Salvinia natans</i>	+	+
<i>Alnus barbata</i>		+
<i>Aldrovanda zusii</i>		+
<i>Alisma plantago-minima</i>	+	+
<i>Brasenia</i> sp.		+
<i>Bunias cochlearioides</i>		+
<i>Carex paucifloroides</i>	+	
<i>Caulinia antiqua</i>		+
<i>Caulinia macrosperma</i>	+	
<i>Cyperus glomeratus</i>	+	+
<i>Dulichium arundinaceum</i>	+	+
<i>Elatine hydropiperoides</i>		+
<i>Eleocharis praemaximoviczii</i>	+	
<i>Euryale</i> sp.		+
<i>Nymphaea cinerea</i>	+	
<i>Nymphaea</i> sp. <i>exot</i>		+
<i>Lycopus pliocenicus</i>		+
<i>Potamogeton dvinensis</i>	+	+
<i>Potamogeton praelongatus</i>		+
<i>Potamogeton panormitanoides</i>		+
<i>Potamogeton perforatus</i>	+	
<i>Potamogeton</i> cf. <i>tenuifolius</i>		+
<i>Potamogeton praemaackianus</i>	+	
<i>Potamogeton vaginatoides</i>		+
<i>Potamogeton paleofiliformis</i>		+
<i>Ranunculus gailensis</i> (= <i>R. sceleratoides</i>)		+
<i>Scirpus atroviroides</i>	+	+
<i>Scirpus kreczetoviczii</i>	+	+
<i>Stratiotes goretskyi</i>	cf. +	+
<i>Urtica platyphylla</i>		+
<i>Typha aspera</i>	+	

Common elements are extinct taxa and those that do not occur in the present-day flora of Poland, such as *Scirpus atroviroides*, *Cyperus glomeratus*, *Eleocharis praemaximoviczii*, *Nymphaea cinerea*, and *Ranunculus gailensis*.

A comparison of the flora of Warm unit Dom II from the Domuraty 2 section with the older and younger units described above shows that it is more similar to the Augustovian floras. This is confirmed by the presence of numerous megaspores of *Azolla filiculoides* and *Salvinia natans*, and fruits of *Scirpus sylvaticus*, *Scirpus kreczetoviczii*, *Cyperus glomeratus*, *Ranunculus gailensis*, and *Stratiotes* cf. *goretskyi* in the climatic optimum. The similarities may also result from the location of these sites in the same region, while the sites with the Ferdynandovian interglacial are more to the south. The flora from Domuraty does not contain *Euryale ferox* or *Potamogeton nodosus*,

typical of the Augustovian interglacial. The absence of these taxa in unit Dom II may suggest that it was colder than the optimum of the Augustovian (A II) and particularly the Ferdynandovian (F II).

Data derived from diatom analysis also indicate that the diatom succession from the Domuraty succession is closely related to the Augustovian succession of diatoms studied from the Czarnucha (Marciniak 2009) and Komorniki sections (Khursevich et al. 2005), and is clearly distinguished from the Ferdynandovian diatom succession in Poland (Khursevich 1999, Marciniak 1980, Marciniak & Lindner 2003) and both from the Byelovezhian and the Mogilevian interglacial successions in Belarus (Khursevich & Loginova 1986, Velichkevich et al. 1997, Khursevich 1999).

In comparing the macroflora of unit Dom II to the floras of the Korchevian interglacial

in Belarus (Yakubowskaya et al. 2014, Mamakowa & Rylova 2007, Velichkevich et al. 1997), correlated with the Małopolianian (Domuratovian) interglacial by Lindner and Yelovicheva (2001), note that that the Korchevian floras (Voznyachuk et al. 1977, Voznyachuk et al. 1978, Velichkevich 1986, Mamakowa & Rylova 2007, Yakubowskaya et al. 2014) highly resemble the Domuraty flora. Most of the taxa determined in unit Dom II that are extinct or not present in the present-day flora, such as *Azolla filiculoides*, *Salvinia natans*, *Alisma plantago minima*, *Caulinia macrosperma*, *Nymphaea cinerea*, *Potamogeton dvinensis*, *Potamogeton praemaackianus*, *P. perforatus*, *Scirpus kreczetoviczii*, *Stratiotes cf. goretskyi*, *Dulichium arundinaceum*, *Typha pliocenica*, *Cyperus glomeratus*, *Scirpus atroviroides*, *Carex paucifloroides*, and *Ranunculus gailensis (scelera-toides)*, are common to both the Korchevian and Domuratovian floras. Besides these taxa, the Korchevian floras contain many species that are not present in the Domuraty 2 succession, such as *Carex rostrata-pliedenica*, *Brasenia* sp., *Caulinia antiqua*, *Aldrovanda borysthenica*, and *A. zusii* (Tab. 3).

The Domuraty 2 site is the second site in the area showing a good palaeobotanical record. Further studies of successions will enable researchers to work out the age and stratigraphic position of the Domuratovian interglacial, which has been correlated with the Gottingen succession by Winter et al. (2008), and by Gröger (1996) with the Cromerian Complex. Winter et al. (2008) have also pointed out the similarity of the “Dom III warm stage” to the Cromerian interglacial III from Rosmalenn.

CONCLUSIONS

Plant macroremains from the Domuraty 2 succession record distinct changes of local vegetation related to climate oscillations. Research on this succession has delineated a sequence of lacustrine and swamp communities documenting climate change and oscillations of water level and trophy, and has distinguished horizons related to increased supply of allochthonous material to the reservoir. The results were compared with the sequence of changes in the Augustovian and Ferdynandovian interglacials. Warm unit Dom II, with the largest

share of taxa with high thermal demands, has the most diverse taxonomic representation. The unit was correlated with the older Augustovian (A II) and younger Ferdynandovian (F II) units.

The composition of the flora from Domuraty is comparable to that of the Augustovian interglacial. This is seen in the presence of numerous megaspores of *Azolla filiculoides* and *Salvinia natans*, and fruits of *Scirpus sylvaticus*, *Scirpus kreczetoviczii*, *Cyperus glomeratus*, and *Ranunculus gailensis* in the climatic optimum, but the flora from Domuraty lacks *Euryale ferox*, *Potamogeton nodosus*, and *Stratiotes cf. goretskyi*, which are characteristic of the Augustovian interglacial. The Dom II unit probably was slightly cooler than A II, and particularly F II. The similarities may also result from the location of the sites in the same region, while sites with the Ferdynandovian interglacial are more to the south.

A comparison between the macroflora of the Domuratovian interglacial and the flora of the Korchevian interglacial in Belarus shows large similarities between them, particularly for extinct taxa and taxa absent from the recent flora. Most of them are common to the Korchevian and Domuratovian floras. The flora from Domuraty lacks only a few species important for the Korchevian flora, such as *Stratiotes goretskyi*, *Carex rostrata-pliedenica*, *Brasenia* sp., *Caulinia antiqua*, *Aldrovanda borysthenica*, and *A. zusii*.

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