

VEGETATION RESPONSE TO ENVIRONMENTAL CHANGES BASED ON PALYNOLOGICAL RESEARCH ON THE MIDDLE MIOCENE LIGNITE AT THE JÓŹWIN IIB OPEN-CAST MINE (KONIN REGION, CENTRAL POLAND)

Barbara SŁODKOWSKA^{1*} & Marek WIDERA²

¹ *Polish Geological Institute-National Research Institute,
4, Rakowiecka Str., 00-975 Warsaw, Poland;
e-mail: barbara.slodkowska@pgi.gov.pl*

² *Institute of Geology, A. Mickiewicz University, 12, Krygowski Str.
62-028 Poznań, Poland; e-mail: marek.widera@amu.edu.pl*

* *Corresponding author*

Słodkowska, B. & Widera, M., 2021. Vegetation response to environmental changes based on palynological research on the Middle Miocene lignite at the Józwin IIB open-cast mine (Konin region, central Poland). *Annales Societatis Geologorum Poloniae*, 91: 149–166.

Abstract: Palynological research was performed on the first Mid-Polish lignite seam (MPLS-1) at the Józwin IIB open-cast mine. The extremely rich pollen assemblages allowed investigation of the development of phytogenic sedimentation and the succession of plant communities. The vegetation cover, representing peat accumulation and adjacent areas, was reconstructed in the homogeneous lignite seam. Despite the lack of clear macroscopic differences in the lignite lithology and a similar floristic composition, a similar succession of plant communities was observed in three repetitions in the profile. The plant communities described were grouped into five cycles. Changes in the succession resulted mainly from oscillations of the groundwater level. On the basis of the vegetation composition, the climatic conditions predominant during the peat-forming sedimentation were reconstructed. Climate changes are most precisely recorded in the mixed mesophilous forest community. Its floristic composition shows that the climate was warm-temperate and humid at that time. The lower part of the profile contains more taxa with high thermal requirements: Araliaceae, Mastixiaceae, Anacardiaceae, Hammamelidaceae, Cornaceae, Symplocaceae, *Ilex*, *Itea*, *Engelhardia*, etc. It is related to the Middle Miocene Climatic Optimum (MMCO). In the upper part of the profile, the vegetation composition reflects the beginning of a cooling trend. This is indicated by the reduced number of highly thermophilous taxa and the decreased taxonomic diversity of forest communities. The changing climatic and environmental conditions interrupted peat-bog sedimentation and caused termination of the development of thicker lignite seams.

Key words: Palynology, lignite seam, palaeofloristic reconstruction, climatic changes, Neogene of Poland.

Manuscript received 17 September 2020, accepted 23 March 2021

INTRODUCTION

In the Lower and Middle Miocene, the area of the Polish Lowlands was dominated by a warm and humid climate, favourable for the development of extensive mires and the accumulation of large amounts of phytogenic matter. During that time, optimal conditions for the development of vast, low-lying mires were repeated five times. As a result, lignite seams of high economic value developed. Five main lignite seams, marked from the 4th to 0 (zero) in stratigraphic order, can be distinguished in the Polish Neogene. Therefore, the Miocene lignites in the Polish Lowlands may

serve as precise correlation levels (e.g., Słodkowska, 1998; Kasiński and Słodkowska, 2016). Palynological studies of lignite and coaly sediments that make up individual seams allow determination of the floristic composition of plant communities from peat bogs and adjacent areas and provide their biostratigraphic dating.

The first Mid-Polish lignite seam (MPLS-1) is the most widespread lignite horizon in the Polish Lowlands (Piwocki, 1998; Piwocki *et al.*, 2004). In the vicinity of Konin, it is fully developed, with a thickness of up to 20 m. Lignite of

the MPLS-1 was created in a continental regime on alluvial plains (e.g., Piwocki *et al.*, 2004; Widera, 2007; Kasiński and Słodkowska, 2016).

During the entire sedimentation interval, temperature and humidity were favourable for the development of lush peat-bog vegetation, as evidenced by the relatively uniform nature of the seam. Despite relatively stable conditions favouring phytogenic sedimentation, clastic deposits occur in the lignite profile (e.g., Widera, 2016; Chomiak *et al.*, 2019, 2020). Their sedimentation was influenced by geodynamic factors disturbing the balance between the rate of subsidence of the depositional surface and the rate of accumulation of phytogenic matter (Kasiński and Słodkowska, 2016). Increased inflow of terrigenous material is related to the lowering of the erosive base and/or the ephemeral activity of rivers, causing sedimentary changes in the fluvial environment. Water-level oscillations are recorded in the facies succession from swamps to lakes and finally to oxbow lakes (Widera, 2016; Chomiak *et al.*, 2019, 2020).

The MPLS-1, widespread in central Poland, has a palynological definition at numerous localities. In the Konin region, palynological studies have been conducted since the 1950s (Kremp, 1949; Mamczar, 1960; Ciuk and Grabowska, 1991; Sadowska and Giża, 1991) as well as quite recently (Słodkowska and Paruch-Kulczycka, 2008; Kasiński *et al.*, 2010; Worobiec *et al.*, 2020). In the Wielkopolska and Kujawy areas (central Poland), Ziemińska-Tworzydło (1974) found the presence of pollen assemblages, characteristic for the MPLS-1, with a significant contribution of warm-temperate-climate plants at Oczkowiec, Gierlachowo, Gołębin Stary, Ślepuchowo, Nowa Wieś and Mosina. Furthermore, Kohlman-Adamska (1993) described rich pollen spectra with numerous swamp-forest plants in the Karolewo-Dąbki 3 and 4 wells. In the Pomeranian Lake District (N Poland), Słodkowska (2004) distinguished pollen communities in lignite and clastic sediments, developed during the formation of the MPLS-1. In the profiles from Komorza, Łosiny and Gostycyn, communities of marsh, riparian or mesophilous forests dominated, depending on the soil moisture. The MPLS-1 was also defined at many localities in Lower Silesia (SW Poland): Legnica (Worobiec *et al.*, 2008; Worobiec, 2009), Jarosów (Sadowska, 1977), Ustronie (Ziemińska-Tworzydło, 1974) and in the Lubuskie region (W Poland): Mirostowice, Tuplice (Sadowska, 1977), Babina, Nowe Czaple (Kościelniak and Wanat, 1974). Much less often, the MPLS-1 was recorded in the Warmia and Mazury area (NE Poland): Sąplaty (Słodkowska, 2009) and Wysoka Wieś (Słodkowska and Gałązka, 2015).

GEOLOGICAL SETTING

The Józwin IIB lignite open-cast mine covers the eastern part of the Pątnów IV deposit, which is located ~20 km to the north of the city of Konin, in central Poland (Fig. 1). Both the open-cast mine and the lignite deposit fill the northernmost segment of the so-called Kleczew Graben (Widera, 2007). This is a fault-bounded depression in the Mesozoic bedrock, with a depth of up to several tens of metres. The top of the Mesozoic is made up of Upper Cretaceous calcareous

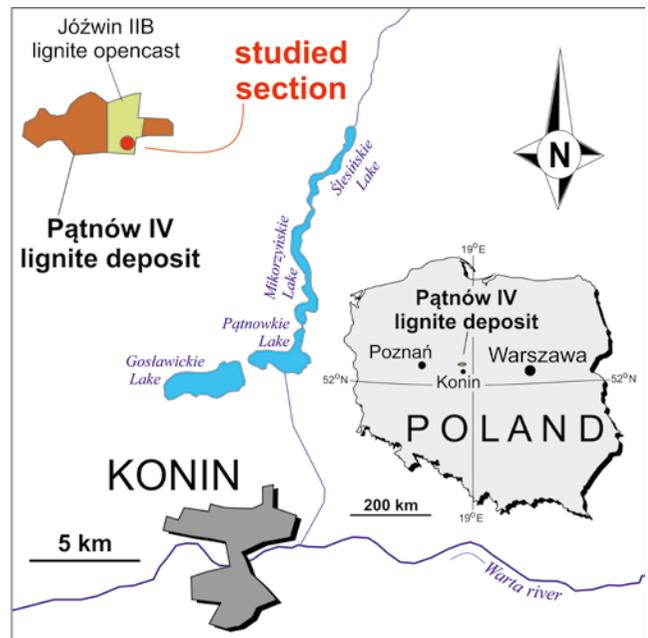


Fig. 1. Location map of the studied section of the first Mid-Polish lignite seam (MPLS-1) with regard to the Pątnów IV lignite deposit and the Józwin IIB open-cast lignite mine in central Poland.

sandstones and marls (e.g., Dadlez *et al.*, 2000; Widera *et al.*, 2017). The Cenozoic succession is incomplete and contains several stratigraphic gaps in the study area. For example, Palaeogene deposits have not been documented yet in the vicinity of the Pątnów IV deposit (Widera and Kita, 2007). Hence, the Neogene succession rests directly on the Mesozoic bedrock.

In the study area, the Neogene consists of two main lithostratigraphic units, i.e., the Koźmin and Poznań formations (Fig. 2). The lower Koźmin Formation is composed of fluvial sands and sandstones, with coaly intercalations of early- to mid-Miocene age (Widera, 2007). The upper Poznań Formation is traditionally subdivided into the Grey Clays Member and the Wielkopolska Member. The age of this formation (and both members) ranges from the late mid-Miocene to the earliest Pliocene (Piwocki and Ziemińska-Tworzydło, 1997; Widera, 2007).

The first Mid-Polish (first Lusatian) lignite seam (MPLS-1) studied corresponds entirely to the Grey Clays Member (Fig. 2). However, the so-called 'grey clays' with xylites, the name of which indicates that they belong to the same lithostratigraphic unit, were found locally in the roof of the MPLS-1 in other parts of the Pątnów IV lignite deposit. The lignite seam studied is currently being exploited by the Konin Lignite Mine. Its average thickness is below 10 m. The MPLS-1 was accumulated ~15 Ma ago, during the last peak of the mid-Miocene Climatic Optimum (e.g., Zachos *et al.*, 2001; Bruch *et al.*, 2007; Bechtel *et al.*, 2019, 2020). Therefore, the age of this lignite seam (MPLS-1) is defined as the middle part of the mid-Miocene (Piwocki and Ziemińska-Tworzydło, 1997; Kasiński and Słodkowska, 2016; Słodkowska and Kasiński, 2016). The occurrence of siliciclastic intercalations in the MPLS-1 (Fig. 2), interpreted

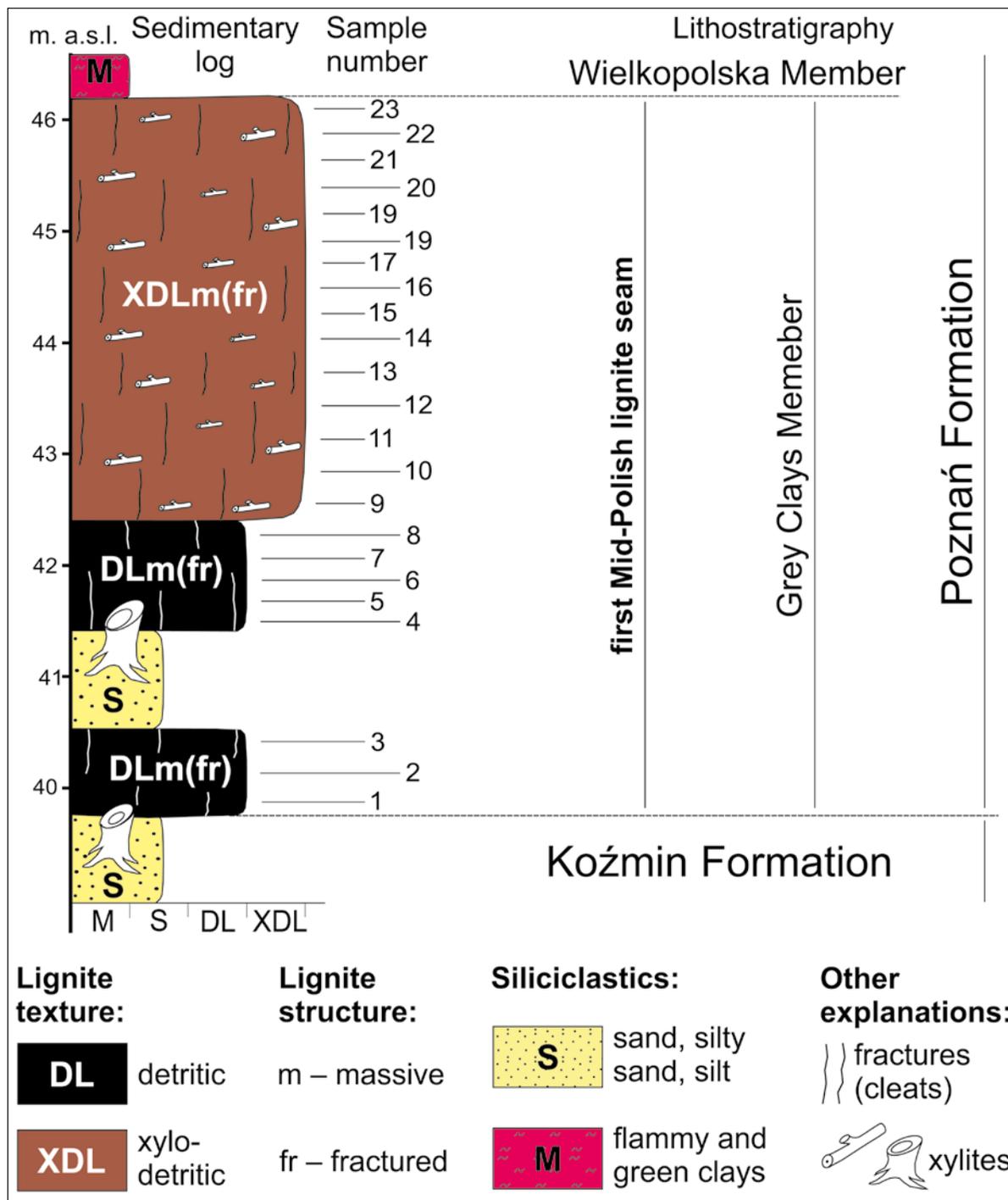


Fig. 2. Detailed sketch-map of the studied section showing the macropetrography, stratigraphy and location of samples in the first Mid-Polish (first Lusatian) lignite seam (MPLS-1) examined at the Józwin IIB open-cast mine (Pańków IV lignite deposit, central Poland). For the location of the section studied, see Figure 1.

as typical of crevasse-splay deposits, may be evidence of at least temporary development of backswamps (low-lying mires) in the overbank zone of mid-Miocene rivers (Widera, 2016; Chomiak *et al.*, 2019).

The Wielkopolska Member rests on the top of the Grey Clays Member with the MPLS-1 examined (Fig. 2). It is generally composed of muddy (>95 vol.%) and sandy-muddy deposits (<5 vol.%). The muds represent overbank deposits, while the sandy-muddy sediments represent the infilling of the river channel. In recent years, deposits of the

Wielkopolska Member have been interpreted as typical of anastomosing rivers (Widera *et al.*, 2017, 2019; Maciaszek *et al.*, 2019, 2020) or anastomosing-to-meandering rivers of late Neogene age (Zieliński and Widera, 2020). A continuous layer of glaciogenic Quaternary deposits occurs on the top of the Wielkopolska Member.

The first Mid-Polish lignite seam (MPLS-1) examined represents a humic ortholignite of low-coal-rank lignite B. This is confirmed by its mean reflectance coefficient (Rr^o) of eulminite B at <0.3% and a carbon content (C^{daf}) in the range

of 60–70% (Kwiecińska and Wagner, 2001). Moreover, the MPLS-1 is characterised by a low to high average ash yield, i.e. from <10 to >20 wt% (Kwiecińska and Wagner, 1997; Chomiak, 2020), as well as a low average sulphur content at <1.2 wt% (Kwiecińska and Wagner, 1997; Bechtel *et al.*, 2019, 2020). Macropetrographically, the section studied in the Pańków IV deposit (Józwin IIB opencast mine) consists of only two lignite lithotypes, i.e. xylodetrinitic and detritic with a fractured structure (Fig. 2). These lithotypes may represent the initial types of mire development, such as bush moor and fen or open water, with periods of low and high groundwater levels (e.g., Teichmüller, 1989; Markič and Sachsenhofer, 1997; Widera, 2012).

MATERIALS AND METHODS

Twenty-three samples (1–23) from the wall of the Józwin IIB open-cast mine in the Konin Lignite Basin were subjected to palynological research. The analysed samples analysed come from an over 6-m-high wall in two lignite benches. Three samples (1–3) were collected from the lower lignite bench and the remaining twenty samples (4–23) – from the upper lignite bench (Fig. 2). The lower part of the section, i.e., the entire lower bench and the lower part of the upper bench, are developed in the form of lignite with a massive and fractured structure – eight samples come from there. In the upper part of the upper lignite bench, the material examined was taken from xylodetrinitic lignite.

Samples selected for studies were subjected to the standard laboratory procedures of palynologic maceration (Fegri and Iversen, 1978). HCl was used to eliminate carbonates, followed by KOH to remove humic compounds. The organic and mineral fractions were separated, using density separation by ZnCl₂ with a density of 2.21 g/cm³. Finally, cellulose was removed, using acetolysis according to Erdtman (1954). From the macerates obtained using this procedure, microscope preparations with dimensions of 20 x 20 mm were made, analysed under the ARISTOPLAN biological microscope at 400x and 640x magnifications. In the microscopic samples, the complete palynological matter assemblage, including palynomorphs (sporomorphs) and phytoclasts (wood fragments, cuticles), was analysed. In most samples, the state of preservation of the specimens was good. Spores and pollen grains were determined, using morphological systematics associated when possible by linking the botanical affinities of fossil taxa with the pollen of modern plants (Stuchlik *et al.*, 2001, 2002, 2009, 2014). The Neogene pollen-spore zones were correlated with the palynologic scheme for Poland (Piwocki and Ziemińska-Tworzydło, 1997).

RESULTS

In the over 6-m-long profile at the Józwin IIB open-cast mine, all samples analysed represent the same palynostratigraphic interval. In the palynostratigraphic scheme of the spore-pollen zones for the Polish Lowlands Neogene, the first Mid-Polish lignite seam (MPLS-1) is correlated with the VIII *Celtipollenites* versus Zone (Piwocki and Ziemińska-Tworzydło, 1997; Słodkowska, 1998;

Ziemińska-Tworzydło, 1998). The palynomorph frequency was very high.

The palynomorphs and palynoclasts identified are listed in Table 1. A total of 105 spore and pollen grains, and phytoplankton taxa, with 10 taxa of spores, 21 taxa of Gymnosperms and 74 taxa of Angiosperms have been determined (Tab. 1). They show the percentage contribution of sporomorphs in the spectrum; the occurrence of phytoclasts was recorded without percentage counts.

The fossil pollen taxa distinguished in the Józwin IIB open-cast lignite mine were compared to their respective contemporary, botanical taxa (Tab. 2). The following palaeofloristic elements were distinguished: palaeotropical (P), including tropical (P1) and subtropical (P2); ‘arctotertiary’ (A), including warm temperate (A1) and temperate (A2); as well as cosmopolitan (P/A) taxa (Planderova *et al.*, 1993; Ziemińska-Tworzydło *et al.*, 1994, Stuchlik *et al.*, 2001, 2002, 2009, 2014). The quantitative contribution of individual palaeofloristic elements allows the reconstruction of the palaeoclimate and the fossil plant communities (Tab. 2).

In the entire profile of the Józwin IIB open-cast mine, the sporomorph communities of bryophytes and ferns were of minor importance (Tab. 1). Spores of peat mosses (Sphagnaceae) and ferns of the Davaliaceae, Polypodiaceae and Osmundaceae families were few. Pollen grains of gymnosperms had a higher percentage contribution, with the most numerous representing: *Pinuspollenites*, *Sciadopityspollenites*, *Sequoiapollenites*, *Cathayapollis* and less numerous representatives of the Taxodiaceae subfamily – *Taxodium* and *Glyptostrobus* (fossil taxa *Inaperturopollenites concedipites*, *I. dubius*). The pollen complex of angiosperms was characterised by a high percentage abundance and taxonomic diversity with abundant pollen of: *Nyssa*, Ericaceae, Fagaceae (*Fagus* and *Quercus* with the highly thermophilous fossil species *Quercoidites henrici*, *Q. microhenrici*), *Ilex* and *Myrica*. Highly thermophilous fossil species from the families Araliaceae, Cornaceae and Mastixiaceae (*Edmundipollis edmundi*, *E. grossularius*, *E. mastxioides*, *E. vitiosus*, *Araliaceopollenites euphorii*) appeared in small percentage numbers, but occurred regularly. There also were other fossil species, considered to be thermophilous: *Tricolporopollenites pseudocingulum*, *Cupuliferoipollenites brühlensis*, *C. oviformis*, *Platanipollis ipelensis*, *Tricolporopollenites dolium*, *T. fallax*, *T. liblarenensis*, *T. mangiferoidies*, *T. staresedloensis*. Herbaceous pollen was extremely percentage rare (Tab. 1).

On the basis of the percentage contribution of pollen, individual stages of development of plant communities and the predominant hydrodynamic conditions can be traced in the profile succession analysed. A clear cyclicity was observed in this fairly uniform, microfloral complex (Fig. 3).

The oldest, rich and diverse sporomorph assemblage was described from detritic lignite with a massive, fractured structure (samples 1–8, cycle I). Of greatest percentage importance was pollen, representing mixed forest vegetation: *Pinus*, *Sciadopitys*, *Sequoia*, *Cathaya*, *Tsuga*, *Fagus*, *Quercus* and Ericaceae, Oleaceae shrubs. There was also a significant percentage presence of pollen from highly thermophilous plants: Cornaceae, Cyrillaceae, Mastixiaceae, Symplocaceae and Anacardiaceae. The detritic lignite

Lithology			Components of plant assemblages	Dominant plant communities/ Environmental cycles	Cycles
m a.s.l.	Sedimentary log	Sample number			
46		23	<i>Nyssa</i> , <i>Cornaceae</i> , <i>Quercoidites henrici</i> , <i>Tricolporopollenites pseudocingulum</i> , <i>Pinus</i> , <i>Fagus</i> and: <i>Ilex</i> , <i>Ericaceae</i> , <i>Cyrillaceae</i> at the top of the profile	Mesophilous forest becoming swampy/riparian, and replaced by a mire in the top	V
		22			
		21	Single destroyed sporomorphs, very numerous phytoclasts	Drying and strong aeration of the mire	IV
		20			
		19	<i>Sequoia</i> , <i>Tricolporopollenites pseudocingulum</i> , <i>Pinus</i> , <i>Sciadopitys</i> , <i>Fagus</i> , <i>Taxodium</i> , <i>Glyptostrobus</i> , <i>Nyssa</i> and <i>Ericaceae</i> , <i>Cyrillaceae</i> , <i>Ilex</i> , <i>Oleaceae</i> in the top of the profile	Mesophilous forest turning into a mire	III
		18			
		17	Single sporomorphs, low taxonomic diversity, very numerous phytoclasts	During floods large amounts of the plant matter were supplied to the mire	II
		16			
		15	Major taxonomic diversity: <i>Pinus</i> , <i>Sciadopitys</i> , <i>Sequoia</i> , <i>Cathaya</i> , <i>Ericaceae</i> , <i>Fagus</i> , <i>Quercus</i> , <i>Tricolporopollenites pseudocingulum</i> , numerous thermophilous taxa: <i>Araliaceae</i> , <i>Arecipites</i> , <i>Castanea</i> , <i>Cornaceae</i> , <i>Mastixiaceae</i> , <i>Symplocaceae</i> , <i>Anacardiaceae</i> and: <i>Nyssa</i> , <i>Liquidambar</i> , <i>Ulmus</i> , <i>Oleaceae</i> , <i>Ericaceae</i> in the top of the profile	Mesophilous forest becoming riparian, which indicates increase in humidity. At the top assemblage becomes poorer	I
	14				
	13				
	12				
	11				
	10				
	9				
	8				
	7				
	6				
	5				
	4				
	3				
	2				
	1				

Fig. 3. Palaeofloristic cycles determined on the basis of the components of plant assemblages and the dominant plant communities, as well as palaeoenvironmental reconstruction. Explanation as in Figure 2

deposits between samples 3 and 4 studied are separated by inter-lignite sands with a thickness of approx. 1 m, subdividing the lignite seam into two benches, i.e., lower and upper. No samples were taken from this sandy sediment. In the higher part of the section (samples 4–8), elements of a riparian forest begin to gain percentage significance:

Ulmus, *Liquidambar*, *Fraxinus*, and the abundance of *Nyssa* – a tree very common in swamp forests – also increases in percentage. All these observations indicate changes in the peat-forming plant communities, manifested also in community depletion, which was clearly recorded in sample 8 (Fig. 3; Tab. 1).

Taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
<i>Sequoiapollenites undulatus</i> Kohlman-Adamska	1.4																						
<i>Zonalapollenites gracilis</i> Krutzsch	1.1	0.8	1.2			1.3	0.4								0.3								1.7
<i>Zonalapollenites igniculus</i> (Potonié) Thomson & Pflug		0.3	0.4		0.1	0.4						0.3											
<i>Zonalapollenites maximus</i> Krutzsch	0.7	1.3	0.8	0.8	0.4	0.4						0.8										0.3	
<i>Zonalapollenites spinosus</i> (Doktorowicz-Hrebnička) Ziemińska-Tworzydło	0.4	0.2	0.4		0.3																		
Angiosperms																							
<i>Aceripollenites</i> sp.		0.5					0.4														0.3		0.6
<i>Alnipollenites verus</i> (Potonié) Potonié	3.6	1.8	1.7	3.1	2.3	1.2	2.5	1.3			+	0.8	3.7	4.4		+				1	3.6	3.4	
<i>Araliaceoipollenites amplus</i> Słodkowska	0.1			0.2																			
<i>Araliaceoipollenites euphorii</i> (Potonié) Potonié							0.2					0.5			0.6								0.3
<i>Arecipites</i> sp.			0.1																	0.3			
<i>Caprifoliipites</i> sp.												0.3										1.1	
<i>Carpinipites</i> sp.	0.6	0.6	0.6	1.8	1.6	2	1.5					4.7		1.3			+	+		2.4			0.9
<i>Caryapollenites simplex</i> (Potonié) Raatz	0.4	0.8	0.6	2.3	4.9	0.8	1.7					1.1	1							1	0.3		0.6
<i>Celtipollenites bobrowskae</i> Kohlman-Adamska & Ziemińska-Tworzydło	0.1	0.3	0.3	0.8	0.3	0.5			+			0.5										0.8	
<i>Cornaceaepollis ovalis</i> Słodkowska & Ziemińska-Tworzydło	0.1		1	0.4		0.1																	
<i>Cornaceaepollis satzveyensis</i> (Pflug) Ziemińska-Tworzydło			0.3		0.3	0.1						1.6		0.9	0.9							5.1	0.6
<i>Corylopsispollenites</i> sp.		1.3				0.9									0.3							0.6	
<i>Cupuliferoipollenites oviformis</i> (Potonié) Potonié			0.3	0.6	0.3	0.4	0.2					0.5	0.7	0.3	1.2					0.7	1.1		0.9
<i>Cupuliferoipollenites pusillus</i> (Potonié) Potonié				0.4		0.4						0.3		0.3	0.6				+	1.4	0.3		0.6
cf. <i>Cyperaceaepollis</i>							1.3																
<i>Cyrillaceapollenites brühlensis</i> (Thomson) Durska			0.4																			0.3	
<i>Cyrillaceapollenites exactus</i> (Potonié) Potonié	0.4	0.3	0.4									0.8	0.7		1.5						1.7	1.4	0.3
<i>Cyrillaceapollenites megaexactus</i> (Potonié) Potonié		1.1	1.2		0.3		1.3	1.3			+	1.9	1.7		1.8						2.7	1.4	
<i>Edmundipollis edmundi</i> (Potonié) Słodkowska & Ziemińska-Tworzydło	0.1				0.1	0.1	0.2								0.6							0.6	
<i>Edmundipollis grossularius</i> (Potonié) Słodkowska & Ziemińska-Tworzydło	0.1																						
<i>Edmundipollis mastixioides</i> Słodkowska & Ziemińska-Tworzydło												0.5	0.2		0.3							1.4	0.6

Taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
<i>Edmundipollis vitiosus</i> (Mamczar) Słodkowska & Ziembińska-Tworzydło	0.1											1.1		0.3									
<i>Ericipites callidus</i> (Potonié) Krutzsch	0.6				1	0.5	1.3					1.9											
<i>Ericipites ericius</i> (Potonié) Potonié	4.4	2.4	7.4	3.7	4.6	6.8	8.1	3.9	+		+	1.6	2.9	2.8	7.1	+	+	+	+	4.1	4.5	20.3	12.4
<i>Ericipites roboreus</i> (Potonié) Krutzsch			0.1										0.2		0.6								
<i>Eucommiapollis</i> sp.	0.8																				0.3		
<i>Eucommiapollis eucommi</i> (Planderova) Kohlman-Adamska & Ziembińska--Tworzydło		0.3		0.6	0.3	0.1							0.2				+						
<i>Faguspollenites</i> sp.	8.8	16.5	10.8	8.4	8.2	7.5	5.9	5.2				4.9	4.4	1.6	4.8	+	+	+		4.4	3.6	3.4	4.3
<i>Faguspollenites minor</i> Nagy	1																						
<i>Fraxinipollis oblatius</i> Słodkowska		1.3	0.4	0.6	0.4	0.7	0.6																
<i>Fraxinipollis sinuosimuratus</i> (Trevisan) Słodkowska					0.1																		
<i>Graminidites</i> sp.	0.8	0.2			0.3																		
<i>Ilexpollenites iliacus</i> (Potonié) Potonié	1.5		0.3	0.2											0.6								
<i>Ilexpollenites margaritatus</i> (Potonié) Raatz	0.6	0.3	0.5	0.4		0.4	0.6		+			1.6	0.2		3						9.2	5.1	3.8
<i>Ilexpollenites propinquus</i> (Potonié) Potonié	0.4		0.1		0.3		0.2					1.4	2.4	2.5	1.2					0.3	0.8		2.3
<i>Intratropipollenites instructus</i> (Potonié) Thomson & Pflug				0.2		0.1									0.3	+							
<i>Iteapollis angustiporatus</i> (Schneider) Ziembińska-Tworzydło			0.1	1.2	0.3	0.5							0.2										
<i>Juglandipollis</i> sp.						0.3															0.3		
<i>Liriodendroipollis verrucatus</i> Krutzsch			0.1																				
<i>Momipites punctatus</i> (Potonié) Nagy	0.1		0.3	1		0.4	1.7	3.9	+				0.2	0.3	0.9							1.7	
<i>Myricipites bituitus</i> (Potonié) Nagy	0.3	0.2	0.3	1	0.9	0.5	0.8		+			0.3			0.3					0.3	0.3		0.6
<i>Nyssapollenites</i> sp.	1.9	2.2	2.3	8.2	6.7	7.1	4.2	3.9	+	+	+	10.2	9.3	13	15.8	+		+	+	26.5	22.9	22	27.7
<i>Nyssoidites rodderensis</i> Thiergart															0.9								
<i>Oleoidearumpollenites</i> sp.												0.3		0.6							0.3	0.3	1.7
<i>Oleoidearumpollenites microreticulatus</i> (Pflug & Thomson) Ziembińska--Tworzydło						0.9	0.4					1.6											
<i>Oleoidearumpollenites reticulatus</i> Nagy			0.1	1.4		0.8																	
<i>Oligopollis</i> sp.															0.3								
<i>Parthenopollenites marcodurensis</i> (Pflug & Thomson) Traverse				0.2		0.1						0.3											
<i>Periporopollenites stigmaticus</i> (Potonié) Thomson & Pflug	0.1	0.8	0.8	1.2	4.3	2.3	1.3													0.3			
<i>Platanipollis ipelensis</i> (Pacltová) Grabowska			0.4	0.8	0.1	0.8	0.2																
<i>Polyatriopollenites</i> sp.	0.7	1.3	0.5	1.4	1.1	0.8	4.7					0.3			0.6						1		

Taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
<i>Quercoidites henrici</i> (Potonié) Potonié, Thomson & Thiergart	1.4	0.8	0.6		2.4							3.3		3.8	2.1					7.5	7.5	3.4	3.2	
<i>Quercoidites microhenrici</i> (Potonié) Potonié, Thomson & Thiergart			0.4			0.5							2.7	0.9	2.4					2.4	2		2.3	
<i>Quercopollenites</i> sp.													1.5	1.3				+						
<i>Quercopollenites asper</i> (Thomson & Pflug) Kohlman-Adamska & Ziemińska-Tworzydło	11.8	9.3	7.2	8.4	3.7	5	3.4																	
<i>Quercopollenites rubroides</i> Kohlman-Adamska & Ziemińska-Tworzydło	2.5	6.1	6.3		7	6	5.7	6.5			+													
<i>Salixipollenites</i> sp.	0.3		0.4			0.4	0.4	1.3																
<i>Sparganiaceapollenites</i> sp.													0.2	0.3				+						
<i>Spinulaepollis arceuthobioides</i> Krutzsch	0.1	0.2	0.1			0.1						0.8	0.5		0.3								0.3	
<i>Symplocoipollenites</i> sp.														0.3										
<i>Symplocoipollenites vestibulum</i> (Potonié) Potonié						0.1	0.2																	
<i>Triatriopollenites rurensis</i> Pflug & Thomson										+														
<i>Tricolporopollenites dolium</i> (Potonié) Thomson & Pflug	0.3												5.8	13	2.8	2.4					1.4	0.3		
<i>Tricolporopollenites fallax</i> (Potonié) Krutzsch			0.1														+							
<i>Tricolporopollenites liblarensis</i> (Thomson & Pflug) Hochuli			0.3		0.3							1.4												
<i>Tricolporopollenites mangiferoides</i> Słodkowska					0.1																			
<i>Tricolporopollenites pseudocingulum</i> (Potonié) Thomson & Pflug	2.2	3	1.8	4.3	5.9	5.8	9.3	7.8			+	17	22.5	12.3	13.7		+	+			17.7	11.2	3.4	4.9
<i>Tricolporopollenites staresedloensis</i> Krutzsch & Pacltová													0.2											
<i>Tricolporopollenites villensis</i> (Thomson) Thomson													2.2	0.9										
<i>Tripoporopollenites coryloides</i> Pflug								6.5		+												0.3		
<i>Trivestibulopollenites betuloides</i> Pflug	3	1.4	2.2		3	3.1	1.3	1.3					1.4	3.9	2.5	3.6	+			+	2	1.1	3.4	
<i>Ulmipollenites undulosus</i> Wolff	2.3	1.6	1.2	2.3	3.3	2.8	5.1	6.5					1.4	4.4	2.2	1.2		+			0.7	0.8	6.8	2.3
<i>Vitipites</i> sp.	0.1													0.3	0.6									
Phytoclasts																								
brown wood debris	++	++	++	+	+++	++	++	+++	++	+++	+++	++	+++	+++	+++	+++	++		++	++	+++	+++	+++	
black wood debris	++	++	++	+	+++	+	+	++	++	+++		++	+++	++	++	+++		++						
cuticle	+		+		++		+				++	++	+	++	++	+	+	++	+	+	++	++	++	

Table 2

Fossil taxa and their botanical affinity, according to Stuchlik *et al.* (2001, 2002, 2009, 2014). The following palaeofloristic elements were distinguished: palaeotropical (P), including: tropical (P1) and subtropical (P2), 'arctotertiary' (A), including: warm-temperate (A1) and temperate (A2), as well as cosmopolitan (P/A), I–V palaeofloritic cycles.

Fossil taxa	Botanical affinity	Paleofloristic element	I	II	III	IV	V
Spores							
<i>Baculatisporites</i> sp.	Osmundaceae: <i>Osmunda</i>	P/A	+		+		
<i>Baculatisporites primarius</i>	Osmundaceae: <i>Osmunda</i>	P/A	+				
<i>Laevigatosporites haardti</i>	Polypodiaceae, Davaliaceae	P/A	+		+		+
<i>Retitriletes</i> sp.	Lycopodiaceae: <i>Lycopodium</i>	P/A	+				
<i>Stereisporites</i> sp.	Sphagnaceae: <i>Sphagnum</i>	P/A			+		
<i>Stereisporites cyclus</i>	Sphagnaceae: <i>Sphagnum</i>	P/A			+		
<i>Stereisporites involutus</i>	Sphagnaceae: <i>Sphagnum</i>	P/A	+	+			+
<i>Stereisporites minor</i>	Sphagnaceae: <i>Sphagnum</i>	P/A	+		+		+
<i>Stereisporites stereoides</i>	Sphagnaceae: <i>Sphagnum</i>	P/A	+		+		
<i>Verucatosporites</i> sp.	Davaliaceae, Polypodiaceae	P/A			+		
Gymnosperms							
<i>Abiespollenites</i> sp.	Pinaceae: <i>Abies</i>	A	+				+
<i>Cathayapollis potonie</i>	Pinaceae: <i>Cathaya</i>	A1	+				
<i>Cunninghamiapollenites janinae</i>	Cupressaceae: <i>Cunninghamia</i>	A1	+	+	+		
<i>Cunninghamiapollenites lignitus</i>	Cupressaceae: <i>Cunninghamia</i>	A1			+		
<i>Cupressacites bockwitzensis</i>	Cupressaceae: <i>Cupressus arizonica</i>	A1	+		+		+
<i>Inaperturopollenites concedipites</i>	Cupressaceae: <i>Taxodium, Glyptostrobus</i>	P2/A1	+		+		+
<i>Inaperturopollenites dubius</i>	Cupressaceae: <i>Taxodium, Glyptostrobus</i>	P2/A1	+	+	+		+
<i>Piceapollis</i> sp.	Pinaceae: <i>Picea</i>	A	+				
<i>Pinuspollenites</i> sp.	Pinaceae: <i>Pinus sylvestris</i> type	A	+	+	+	+	+
<i>Sciadopityspollenites</i>	Sciadopityaceae: <i>Sciadopitys</i>	A1	+		+		+
<i>Sequoiapollenites</i> sp.	Cupressaceae: <i>Sequoia, Sequoiadendron, Metasequoia, Cryptomretia</i>	A1			+	+	+
<i>Sequoiapollenites major</i>	Cupressaceae: <i>Sequoia, Sequoiadendron, Metasequoia, Cryptomretia</i>	A1	+				
<i>Sequoiapollenites megaligulus</i>	Cupressaceae: <i>Sequoiadendron</i>	A1	+				
<i>Sequoiapollenites polyformosus</i>	Cupressaceae: <i>Sequoia, Sequoiadendron, Metasequoia</i>	A1	+				
<i>Sequoiapollenites rotundus</i>	Cupressaceae: <i>Sequoia, Sequoiadendron, Metasequoia</i>	A1	+				
<i>Sequoiapollenites rugulus</i>	Cupressaceae: <i>Sequoia, Sequoiadendron, Metasequoia</i>	A1	+				
<i>Sequoiapollenites undulatus</i>	Cupressaceae: <i>Sequoia, Sequoiadendron, Metasequoia</i>	A1	+				
<i>Zonalapollenites gracilis</i>	Pinaceae: <i>Tsuga canadensis</i>	A	+		+		+
<i>Zonalapollenites igniculus</i>	Pinaceae: <i>Tsuga</i>	A	+		+		
<i>Zonalapollenites maximus</i>	Pinaceae: <i>Tsuga</i>	A	+		+		+
<i>Zonalapollenites spinosus</i>	Pinaceae: <i>Tsuga forrestii</i>	A	+				
Angiosperms							
<i>Aceripollenites</i> sp.	Sapindaceae: <i>Acer</i>	A	+				+

Fossil taxa	Botanical affinity	Paleofloristic element	I	II	III	IV	V
<i>Alnipollenites verus</i>	Betulaceae: <i>Alnus</i>	P2/A	+	+	+	+	+
<i>Araliaceoipollenites amplus</i>	Araliaceae: <i>Dendropanax</i> , <i>Tetrapanax</i>	P/A1	+				
<i>Araliaceoipollenites euphorii</i>	Araliaceae: <i>Acantopanax spinosus</i> , <i>Aralia cordata</i>	P/A1	+		+		+
<i>Arecipites</i> sp.	Amaryllidaceae, Araceae, Arecaceae, Butomaceae	P/A	+				+
<i>Caprifoliipites</i> sp.	Adoxaceae: <i>Sambucus</i> , <i>Viburnum</i>	P2/A1			+		+
<i>Carpinipites</i> sp.	Betulaceae: <i>Carpinus</i>	P2/A1	+		+	+	+
<i>Caryapollenites simplex</i>	Juglandaceae: <i>Carya</i>	P/A1	+		+		+
<i>Celtipollenites bobrowskae</i>	Ulmaceae: <i>Celtis</i>	P/A1	+	+	+		+
<i>Cornaceaeipollis ovalis</i>	Cornaceae: <i>Cornus mas</i>	A	+				
<i>Cornaceaeipollis satzveyensis</i>	Mastixiaceae: <i>Mastixia</i>	P	+		+		+
cf. <i>Cyperaceaeipollis</i>	Cyperaceae	P/A	+				
<i>Corylopsispollenites</i> sp.	Hammamelidaceae: <i>Corylopsis</i>	A1	+		+		+
<i>Cupuliferoipollenites oviformis</i>	Fagaceae: <i>Castanea</i> , <i>Castanopsis</i> , <i>Lithocarpus</i>	P2/A1	+		+		+
<i>Cupuliferoipollenites pusillus</i>	Fagaceae: <i>Castanea</i> , <i>Castanopsis</i> , <i>Lithocarpus</i>	P2/A1	+		+	+	+
<i>Cyrillaceaeipollenites bruhlensis</i>	Cyrillaceae, Clethraceae	P	+				+
<i>Cyrillaceaeipollenites exactus</i>	Cyrillaceae, Clethraceae: <i>Cyrilla</i> , <i>Purdiaea</i> , <i>Cliftonia</i> , <i>Clethra</i>	P	+		+		+
<i>Cyrillaceaeipollenites megaexactus</i>	Cyrillaceae, Clethraceae: <i>Cyrilla</i> , <i>Purdiaea</i> , <i>Cliftonia</i> , <i>Clethra</i>	P	+	+	+		+
<i>Edmundipollis edmundii</i>	Cornaceae, Mastixiaceae: <i>Diplopanax</i>	P1	+		+		+
<i>Edmundipollis grossularius</i>	Araliaceae: <i>Aralia</i> , <i>Panax</i>	P/A	+				
<i>Edmundipollis mastixioides</i>	Mastixiaceae: <i>Mastixia tetrandra</i>	P			+		+
<i>Edmundipollis vitiosus</i>	Araliaceae: <i>Aralia</i> , <i>Panax</i>	P/A1	+		+		
<i>Ericipites callidus</i>	Ericaceae: <i>Calluna</i> , <i>Vaccinium</i>	A	+		+		
<i>Ericipites ericius</i>	Ericaceae: <i>Calluna</i> , <i>Daboecia</i> , <i>Vaccinium</i>	A	+	+	+	+	+
<i>Ericipites roboreus</i>	Ericaceae: <i>Rhododendron</i> , <i>Andromeda</i>	A	+		+		
<i>Eucommiapollis</i> sp.	Eucommiaceae: <i>Eucommia</i>	A1	+				+
<i>Eucommiapollis eucommi</i>	Eucommiaceae: <i>Eucommia</i>	A1	+		+	+	
<i>Fagusipollenites</i> sp.	Fagaceae: <i>Fagus</i>	A	+		+	+	+
<i>Fagusipollenites minor</i>	Fagaceae: <i>Fagus japonica</i>	A	+				
<i>Fraxinipollis oblatus</i>	Oleaceae: <i>Fraxinus americana</i>	A	+				
<i>Fraxinipollis sinuosimuratus</i>	Oleaceae: <i>Fraxinus</i>	A	+				
<i>Graminidites</i> sp.	Poaceae	P/A	+				
<i>Ilexipollenites iliacus</i>	Aquifoliaceae: <i>Ilex aquifolium</i> , <i>I. macrocarpa</i>	P/A1	+		+		
<i>Ilexipollenites margaritatus</i>	Aquifoliaceae: <i>Ilex asptella</i>	P2	+	+	+		+
<i>Ilexipollenites propinquus</i>	Aquifoliaceae: <i>Ilex</i>	P/A1	+		+		+
<i>Intratrirporopollenites instructus</i>	Malvaceae: Tilioidae: <i>Tilia</i> , <i>Burretia</i>	P/A	+		+	+	
<i>Iteapollis angustiporatus</i>	Iteaceae: <i>Itea</i>	P	+		+		
<i>Juglandipollis</i> sp.	Juglandaceae: <i>Juglans</i>	A1	+				+
<i>Liriodendroipollis verrucatus</i>	Magnoliaceae: <i>Liriodendron</i>	P2/A1	+				
<i>Momipites punctatus</i>	Juglandaceae: <i>Engelhardia</i> , <i>Alfaroa</i> , <i>Oeromunnea</i>	P2	+	+	+		+
<i>Myricipites bituitus</i>	Myricaceae: <i>Myrica gale</i> , <i>M. javanica</i>	P2/A1	+		+		+

Fossil taxa	Botanical affinity	Paleofloristic element	I	II	III	IV	V
<i>Nyssapollenites</i>	Nyssaceae: <i>Nyssa</i>	P/A1	+	+	+	+	+
<i>Nyssoidites rodderensis</i>	Nyssaceae: <i>Nyssa</i>	P/A1			+		
<i>Oleoidearumpollenites</i>	Oleaceae: <i>Olea</i>	P2/A1			+		+
<i>Oleoidearumpollenites microreticulatus</i>	Oleaceae: <i>Olea</i>	P2/A1	+		+		
<i>Oleoidearumpollenites reticulatus</i>	Oleaceae: <i>Olea</i>	P2/A1	+				
<i>Oligopollis</i> sp.	unknown	unknown			+		
<i>Parthenopollenites marcodurensis</i>	Vitaceae: <i>Parthenocissus</i> , <i>Ampelopsis</i> , <i>Cayratia</i> , <i>Leea</i>	P/A1	+		+		
<i>Periporopollenites stigmosus</i>	Alangiaceae: <i>Liquidambar</i>	A1	+				+
<i>Platanipollis ipelensis</i>	Platanaceae: <i>Platanus</i>	P/A1	+				
<i>Polyatriopollenites</i>	Juglandaceae: <i>Pterocarya</i>	A1	+		+		+
<i>Quercoidites henrici</i>	Fagaceae: <i>Quercus</i>	P2/A1	+		+		+
<i>Quercoidites microhenrici</i>	Fagaceae: <i>Quercus</i>	P2/A1	+		+		+
<i>Quercopollenites</i> sp.	Fagaceae: <i>Quercus</i>	P2/A1			+	+	
<i>Quercopollenites asper</i>	Fagaceae: <i>Quercus</i>	A1	+				
<i>Quercopollenites rubroides</i>	Fagaceae: <i>Quercus</i>	A1	+	+			
<i>Salixipollenites</i> sp.	Salicaceae: <i>Salix</i>	A	+				
<i>Sparganiaceapollenites</i>	Sparganiaceae, Typhaceae	P/A			+	+	
<i>Spinulaepollis arceuthobioides</i>	Santalaceae: <i>Areuthobium</i>	P	+		+		+
<i>Symplocoipollenites</i> sp.	Symplocaceae: <i>Symplocos</i>	P			+		
<i>Symplocoipollenites vestibulum</i>	Symplocaceae: <i>Symplocos alata</i> , <i>S. cratigioides</i>	P	+				
<i>Triatriopollenites rurensis</i>	Myricaceae: <i>Myrica</i>	P2/A1		+			
<i>Tricolporopollenites dolium</i>	Fagaceae?	unknown	+		+		+
<i>Tricolporopollenites fallax</i>	Fabaceae: <i>Anagyris</i> , <i>Dalea</i> , <i>Taverniera</i>	P/A	+			+	
<i>Tricolporopollenites liblarensis</i>	Fabaceae: <i>Anagyris</i> , <i>Dalea</i> , <i>Taverniera</i>	P/A	+		+		
<i>Tricolporopollenites mangiferoides</i>	Anacardiaceae: <i>Mangifera indica</i>	P1	+				
<i>Tricolporopollenites pseudocingulum</i>	Fagaceae, Styracaceae	P/A1	+	+	+	+	+
<i>Tricolporopollenites staresedloensis</i>	Hammamelidaceae: <i>Parrotia</i> , <i>Distylium</i>	P2			+		
<i>Tricolporopollenites villensis</i>	Fagaceae?	?			+		
<i>Tripoporopollenites coryloides</i>	Betulaceae: <i>Corylus</i>	A	+	+			+
<i>Trivestibulopollenites betuloides</i>	Betulaceae: <i>Betula</i>	A	+		+	+	+
<i>Ulmipollenites undulosus</i>	Ulmaceae: <i>Ulmus</i>	A2	+		+	+	+
<i>Vitisipollenites</i> sp.	Vitaceae: <i>Vitis</i>	P2/A1			+		

Between samples 8 and 9 there was a change in the lignite lithotype into a xylodetrific one with a massive and fractured structure. Changes in the composition and character of the subsequent sporomorph assemblage described from samples 9–11, cycle II also were recorded. This assemblage, unlike the one below, is strongly impoverished, both in sporomorph abundance and taxonomic diversity. Pollen grains occur singly, while phytoclasts appear abundantly in the form of brown and black wood fragments and cuticles, often with stomata. The sporomorphs are not destroyed.

The subsequent sporomorph complex, described in samples 12–15, cycle III from the same lignite lithotype, was likewise rich and diverse, qualitatively similar to the oldest

complex, but less diverse taxonomically. The pollen of plants, representing a mixed mesophilous forest percentage predominated here also, with a clear contribution of gymnosperms from the Cupressaceae family: *Sequoiapollenites* and *Cupressacites bockwitzensis*. Important elements were fossil thermophilous species: *Tricolporopollenites pseudocingulum*, *T. dolium*, *Quercoidites henrici* and *Q. microhenrici*. There were also representatives of the Taxodiaceae subfamily – *Taxodium* and *Glyptostrobus*, as well as *Nyssa*. Pollen of *Pinus*, *Fagus* and *Ilex* appeared in great numbers. The contribution of Ericaceae and Cyrillaceae, Clethraceae, Oleaceae pollen increased in the upper part of the analysed profile analysed (Fig. 3; Tab. 1).

Samples 16–19, cycle IV, characterised by trace quantities of pollen, record an episode related to the depletion of pollen material. Single grains were very poorly preserved, damaged, crumpled and incomplete, with traces of corrosion on the surface.

The last of the intervals of the section studied, in samples 20–23, cycle V, again records the development of a mixed mesophilous forest. Pollen of *Fagus* had a constant contribution and *Nyssa* is percentage abundant. In the initial phase, the assemblage contains a large number of thermophilous elements: *Tricolporopollenites pseudocingulum*, *T. dolium*, *Quercoidites henrici*, *Q. microhenrici* and the Cyrillaceae family. At the top of the section, riparian forest plants and Ericaceae, Cyrillaceae, Oleaceae, *Ilex*, *Myrica* shrub communities made a greater contribution (Fig. 3; Tab. 1). This part of the section is similar to that described for samples 12–15. However, it differs in the smaller variety of thermophilous components.

DISCUSSION

The entire pollen complex from the Józwin IIB open-cast mine, despite a very similar floristic composition, is a set of floristic elements, in which small fluctuations of external factors, mainly humidity, are recorded as changes in the dominant plant communities. On the basis of the reconstruction of these communities, it is possible to reveal the course of sedimentation of lignite-forming sediments, which took place in vast wet areas, periodically flooded by rivers. These changes in the dominant plant communities are manifested as oscillations of ground- and surface water levels. Typically, the environment of an anastomosing or meandering river is ephemeral and unstable, as documented in the MPLS-1 at the Józwin IIB open-cast mine (e.g., Chomiak *et al.*, 2019).

Differences in the composition of taxa visible in the samples indicated different stages of development of the sedimentary basin, related mainly to the changing water dynamics and other hydrological factors, and to a lesser extent to changes in ambient temperature. Very rich pollen communities allow following in detail the development of phytogenic sedimentation and community succession. The pollen preserved came from both the peat-forming habitats and the forests covering the area in the neighbourhood of the mire. Peat-forming communities of water plants, moss and rush vegetation, swamp forests and, to a lesser extent, shrub bogs, generally represent azonal vegetation, not sensitive to thermal changes. Owing to similar sedimentation conditions, the peat-forming communities recorded in the entire section studied had a similar floristic composition. On the other hand, the contribution of climate-related elements in the mixed mesophilous forests, growing in the neighbourhood of the mire, was variable.

In an area of peat accumulation, there are various plant communities that tolerate high soil moisture. Fluctuations in the groundwater level lead to the transformation of these communities. With a relatively low water level, a rich, mixed mesophilous forest develops in the areas outside the mire, with a high contribution of thermophilous species. With rising water level, riparian forests and shrubs gain greater

importance on the river banks. With further deepening of the basin, a swamp forest starts to dominate. These communities are natural areas of peat accumulation and often interpenetrate, creating a mosaic characteristic of ephemeral fluvial settings.

At the Józwin IIB open-cast mine, the natural succession of plant communities was recorded three times. At the beginning of each cycle, in the deposition zone of the peat-forming basin, there was a high contribution of pollen of mixed mesophilous forests, growing in dry and moderately humid areas located far from the mire. The pollen of thermophilous plants came from dense forest communities of the mesophilous forest, in which the contribution of individual taxa in subsequent parts of the section was variable. When the water level rose, the contribution of pollen from riparian and swamp forests increased. Each peat-forming cycle ended with the encroachment of shrubs on the bog and inhibition of its growth. Lowering of the groundwater level and drying out of the mire disrupted the cycle of its development. This stage is registered twice in the section analysed. This indicates periodic drying up of the sediment or the mire surface and the interruption of a continuous phytogenic sedimentation cycle.

Analysis of the pollen composition allowed reconstruction of the succession and trends in the development of plant communities at the time of peat sedimentation, later transformed into the lignite seam studied. On this basis, five successive cycles (I–V) were distinguished (Tab. 2; Fig. 3).

The oldest, floristic complex (cycle I) is taxonomically the most diverse and includes: *Pinus*, *Sciadopitys*, *Sequoia*, *Cathaya*, Ericaceae, *Fagus*, *Quercus*, *Tricolporopollenites pseudocingulum*, and contains the largest number of thermophilous plant taxa (approx. 49% of taxa), representing the Araliaceae, Cornaceae, Mastixiaceae, and *Castanea*. A mixed mesophilous forest community is clearly recorded in the pollen spectrum. Towards the top of this part of the section, owing to humidity increase, plants of the mesophilous forest located at some distance from the peat bog are less common in the pollen spectrum. In turn, the pollen of riparian forests, including *Liquidambar* and *Ulmus*, and swamp forests with *Nyssa*, became more significant (Fig. 3). During the sedimentation of the peat-forming matter in cycle I, a short episode of supply of sandy material to the reservoir occurred, caused by a flood, resulting in the sudden deposition of the sand layer, approximately 1 m thick. This was probably a short-term episode, which did not disturb fen development. In the latest part of cycle I, bush plants with Ericaceae and Oleaceae entered the mire, owing to a decrease in humidity.

In the succeeding cycle (II), the number of pollen taxa dropped drastically, while the contribution of phytoclasts increased significantly (Fig. 3). This probably was caused by hydrological factors. Owing to the fact that such an episode is recorded in xylodetritic lignite, it may indicate that as a result of floods, large amounts of xylites and very small fragments of plant matter were delivered to the mire, or, alternatively, a change of the mire into a swamp forest took place.

The next cycle (III) records again undisturbed phytogenic sedimentation. It is characterised by a very rich sporomorph assemblage. Compared to the previous cycles, there were

fewer thermophilous plant taxa (41%) in the entire complex. The mesophilous forest was characterised by the lower abundances of *Pinus*, *Fagus* and *Sciadopitys*, and higher abundances of *Quercoidites henrici*, *Q. microhenrici*, *Tricoloropollenites dolium* and *T. pseudocingulum*. Swamp forest plants with *Nyssa* are quite numerous. In the top of the section occur plants of scrub bogs: *Cyrillaceae* and *Ilex* (Fig. 3). The floristic assemblage presented indicates that at first the mire became moist and wide and later, as a result of a lowering of water level, was gradually drained.

The following cycle (IV) records another episode of drying and strong aeration of the mire and its disappearance, which is indicated by very low sporomorph frequency and very damaged pollen material (Fig. 3).

The last cycle (V) as in cycle III is characterised by calm sedimentation of organic matter. Thermophilous taxa are less abundant (approx. 33%). The mesophilous forest was still the most numerously represented community, although with a lower abundance of the pollen of thermophilous plants: *Quercoidites henrici*, *Tricoloropollenites pseudocingulum*, etc. (Fig. 3). Trees of swamp and riparian forests, *Nyssa* and *Ulmus*, gained significance. In the upper part of the cycle, a stage of encroachment of *Ericaceae* and *Ilex* shrubs on the bog is recorded.

Analysis of the succession of plant communities in the section from the Józwin IIB open-cast mine shows a similar sequence of events. At the beginning of cycles I, III and V, the peat accumulation basin contained numerous thermophilous components of a mixed mesophilous forest. When the groundwater level rose, components of riparian and swamp forests became more important, and eventually, as a result of the drying out of the reservoir, it became transformed into a shrub bog.

In subsequent cycles, the number of highly thermophilous taxa was reduced; likewise, the taxonomic diversity of forest communities decreased (Tabs 3, 4). The plant succession, recording the development of rich multispecies forests, was twice separated by intervals, in which phyto-genic sedimentation was reduced significantly and its record was fragmentary. The frequency and state of preservation of sporomorphs testify to the higher water dynamics of the sedimentary basin. This also may be related to the development of crevasse splays and the resulting selection and rapid accumulation of pollen material.

Development cycles III and V of the plant communities are full and complete. Only cycle I is bipartite, separated by a complex of sands, approx. 1 m thick, although without any influence on the cycle. At the boundary between cycles I and

Table 3

The contribution of fossil thermophilous taxa in individual palaeofloristic cycles in the lignite seam (MPLS-1) with the Mean Annual Temperature (MAT) of their corresponding modern taxa (MAT after Utescher and Mosbrugger, 2015).

Taxa	Near living relatives (NLR)	Palaeofloristic element	MAT [°C]	Presence of taxa into palaeofloristic cycles of the lignite seam (MPLS-1)		
				I	III	V
<i>Edmundipollis</i> group	<i>Diplopanax</i> sp. <i>Schefflera</i> sp. <i>Panax</i> sp. <i>Fatsia japonica</i>	P1	16.8–22.2 14.7–27.0 7.6–25.7 12.1–20.5	+	+	+
<i>Tricolporopollenites mangiferoides</i>	<i>Mangifera</i> sp.	P1	15.7–28.1	+	—	—
<i>Cornaceapollis satzveyensis</i>	<i>Mastixia</i> sp.	P	17.7–27.8	+	+	+
<i>Cyrillaceapollenites</i> group	<i>Cyrilla</i> sp. <i>Clethra</i> sp.	P	13.6–23.9 7.4–27.7	+	+	+
<i>Iteapollis angustiporatus</i>	<i>Itea</i> sp.	P	7.7–27.7	+	+	—
<i>Spinulaepollis arceuthobioides</i>	<i>Arceuthobium</i> sp.	P	-5.5–27.7	+	+	+
<i>Symplocoipollenites</i> group	<i>Symplocos</i> sp.	P	13.6–27.7	+	+	—
<i>Ilexpollenites</i> group	<i>Ilex</i> sp.	P2	-0.4–27.7	+	+	+
<i>Tricolporopollenites staresedloensis</i>	<i>Parrotia</i> sp. <i>Distylium</i> sp.	P2	11.6–16.8 13.8–27.7	—	+	—
<i>Araliaceoipollenites</i> group	<i>Aralia</i> sp. <i>Aralia spinosa</i>	P/A1	-5.5–27.7 12.5–20.8	+	+	+
<i>Platanipollis ipelensis</i>	<i>Platanus</i> sp.	P/A1	6.6–27.4	+	—	—
<i>Cupuliferoipollenites oviformis</i> , <i>Cupuliferoipollenites pusillus</i>	<i>Castanea</i> sp. <i>Castanopsis</i> sp. <i>Lithocarpus</i> sp.	P2/A1	7.6–24.2 6.9–27.9 7.0–27.1	+	+	+
<i>Liriodendroipollis verrucatus</i>	<i>Liriodendron</i> sp.	P2/A1	6.0–24.0	+	—	—

Table 4

Contribution of taxa of palaeofloristic elements in particular palaeofloristic cycles in the lignite seam (MPLS-1).

Palaeofloristic element		Total amount of taxa	Number of taxa into the palaeofloristic cycles of the lignite seam (MPLS-1)		
			I	III	V
P1	tropical	2	2	1	1
P	palaeotropical	9	7	6	6
P2	subtropical	3	2	3	2
P/A1	palaeotropical/warm temperate	12	9	9	7
P2/A1	subtropical/warm temperate	17	16	12	10
P2/A	subtropical/arctotertiary	1	1	1	1
P/A	cosmopolitan	18	13	10	3
A1	warm temperate	20	18	8	8
A	arctotertiary	19	19	9	8
A2	temperate	1	1	1	1

II, detritic lignite, formed on a flooded peatland, changed into xylo-detritic lignite that formed in a swamp forest (Kasiński *et al.*, 2010). The next interval (cycle IV), separating full, lignite-forming cycles, is characterised by very poor pollen material. It was not marked by a change in lithology, just as cycles III and V occurred within xylo-detritic lignite. Cycles with a limited pollen record (II and IV) were short-lived and probably represented quite abrupt episodes, encompassing from 0.5 to 1 m of the section.

When analysing previous reports from the Konin region, attention should be drawn to the palynological type section in Gosławice, in which Mamczar (1960) described Middle Miocene deposits on the basis of the pollen analysis of lignite from the MPLS-1. She distinguished three phases of vegetation development. A rich complex of thermophilous vegetation of mesophilous and swamp forests was recorded at the base of the seam; higher up, slight drainage occurred and trees of coniferous forests gained importance. In the uppermost part of the seam, Mamczar (1960) observed a mosaic arrangement of the plant communities, in which trees of mixed forests, swamps and shrubs had a similar contribution. Such interpenetrating communities characterise a fluvial environment with rapidly changing water levels. Doktorowicz-Hrebicka (1960) compared the pollen profiles from the Wielkopolska and Kujawy regions (central Poland) to this type section. Ziemińska-Tworzydło (in Kasiński *et al.*, 2010) described a 10-m lignite section at the Józwin I open-cast mine, in which, on the basis of a very rich pollen complex, the plant communities reconstructed were arranged according to their natural ecological succession and ranged from the most humid forests to dry upland forests. Pollen facies for the MPLS-1 also were compiled (Kasiński *et al.*, 2010).

On the basis of the analysis of sporomorph assemblages and proportions of palaeotropical and “arctotertiary” pollen taxa in the Józwin IIB section (Tab. 4), it should be noted that owing to a significant contribution of thermophilous taxa, the reconstructed climate had warm-temperate

features (P2/A1, P/A1, A1). The plant communities, including swamp and mesophilous forests in the neighbourhood of the mire basins, were dominated by plants representing warm-temperate palaeoclimatic elements (A1). Drier areas were characterised by conditions favourable for mixed mesophilous forests, with the domination of warm-temperate taxa (P2/A1) and with an admixture of evergreen plants (P, P1, P2) mainly forming the undergrowth. Many taxa with cosmopolitan, climatic requirements (P/A) also occurred (Tabs 2, 4). The contribution of thermophilous elements decreased in each subsequent cycle of plant community development, from 49% of the entire sporomorph complex in the I cycle, 41% in the III cycle, and 33% in the V cycle. There was a clear decrease in the number of thermophilous taxa, belonging to P1, P, P2, P / A1, P2 / A1 elements (Tab. 4). Reconstructing climate, especially temperature and humidity, requires relating these factors to contemporary, climatic conditions (Tabs 2, 4). The results of pollen analysis indicate that at the time of sedimentation, the climate was warm-temperate and humid, comparable to the Cfa climate type (warm temperate, fully humid with hot summers and mild winters) in the Köppen-Geiger climate classification (updated by Kottek *et al.*, 2006).

Thermal requirements of the fossil thermophilous taxa (P1 - P2 / A1) in the individual palaeofloristic cycles in the lignite at Józwin IIB, compared with their near living relatives (NLR), indicate a Mean Annual Temperature (MAT) of about 11.6–20.5 °C (Tab. 3).

The declining contribution of thermophilous flora is related to climatic changes following the Middle Miocene Climatic Optimum (MMCO, 15.97–13.65 Ma), in the form of an emerging cooling trend (Tab. 3). The Józwin IIB section records the onset of cooling, which is related to many global causes, primarily the expansion of ice caps in Antarctica (Frigola *et al.*, 2018), as well as the closure of circulation around the equatorial ocean gateways, due to geotectonic reconstruction in the mean latitudes and the resulting major reorganization of atmospheric circulation (Krapp,

2012; Methner *et al.*, 2020). Environmental and vegetation changes probably also were connected with orbital-scale climate dynamics (Jiménez-Moreno and Mandic, 2020). Warm-temperate, evergreen forests and deciduous, mixed forests predominated during the MMCO. At the end of this optimum, the Middle Miocene Climatic Transition (MMCT) took place, i.e., progressive cooling and aridisation of climate, recorded on a global scale as the Mi3b event. It took place at ~13.76 Ma, as evidenced by an oxygen isotope $\delta^{18}\text{O}$ increase and a carbon isotope $\delta^{13}\text{C}$ decrease in benthic foraminifera (Hernández-Ballarín and Peláez-Campomanes, 2017; Frigola *et al.*, 2018). The transition from the warmest climatic phase (MMCO) to progressive cooling also is indicated by Utescher *et al.* (2021) in the analysis of plant functional types (PFT) and their changes associated with eccentricity cycles, observed in the palynoflora of the Lower Rhine Basin.

CONCLUSIONS

Plant ecosystems, related mainly to peat-forming communities, predominate in the pollen spectrum of the first Mid-Polish lignite seam (MPLS-1) in the Józwin IIB section. The presence of vegetation from areas around the lignite-forming peat bogs is also clearly visible.

Swamp forests dominated by coniferous plants, i.e. *Glyptostrobus* and *Taxodium*, were a common element of the Middle Miocene landscape in central Poland during the development of the MPLS-1. They were accompanied by *Nyssa* and *Alnus* deciduous trees, *Sphagnum* peat mosses and Polypodiaceae and *Osmunda* ferns, present in the undergrowth of the swamp forest. Other plants of the peat-forming communities include bulrush, with *Sparganium* and Poaceae. Important elements in the development of fens were shrubs, including the Clethraceae, Cyrillaceae, Myricaceae, Oleaceae, Ericaceae and Salicaceae.

In the neighbourhood of the wetlands, diverse, mixed mesophilous forests developed, with evergreen plants and deciduous trees. In these communities, families and genera with high climatic requirements made a significant contribution: Araliaceae, Mastixiaceae, Anacardiaceae, Hammamelidaceae, Cornaceae, Symplocaceae, *Ilex*, *Itea*, *Engelhardia*, lianas and ferns. Trees preferring a warm-temperate climate grew in mixed forests, mainly: Cupressaceae, *Sequoia*, *Sciadopitys*, *Cunninghamia*, *Cryptomeria*, *Tsuga*, *Acer*, *Eucommia*, *Liriodendron*, *Liquidambar*, *Quercus*, *Betula*, *Cornus*, Juglandaceae, and Tiliaceae. All these plants occupied areas adjacent to the peat bogs during the formation of the lignite-forming biomass.

Plants of these forests record climatic changes (mainly fluctuations in temperature and humidity). In the section analysed, the beginning of a cooling trend of the Middle Miocene Climatic Transition (MMCT) at approximately 13.7 Ma (late Langhian) was observed after the last MMCO peak, as indicated by the floristic record of cycle V. This is also a declining stage in the development of mid-Miocene peat bogs.

Vegetation is a very sensitive indicator of environmental changes. Slight changes in groundwater level were recorded in the compact and macroscopically homogeneous lignite seam. These changes are more clearly visible in the

peat-forming communities and were recorded in three cycles: I, III, V. Floods caused the development of crevasse splays, as documented by cycle II, with a poor pollen spectrum. The phase of mire disappearance is reflected in the lignite (cycle IV). Temperature changes, shown as a decrease in the number of taxa with higher thermal requirements, are recorded in the mixed forest community, growing in areas located on high ground beyond the mire.

Acknowledgments

The authors kindly acknowledge Nela Dolaková and an anonymous reviewer for their valuable comments, suggestions and constructive remarks. The present study is a contribution to Research Project No. 2017/27/B/ST10/00001, funded by the National Science Centre, Poland.

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