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Miocene palynoflora from the KRAM-P 218 leaf assemblage from the Bełchatów Lignite Mine (Central Poland)

ELŻBIETA WOROBIEC and GRZEGORZ WOROBIEC

W. Szafer Institute of Botany, Polish Academy of Sciences, Lubicz 46, 31-512 Kraków, Poland;
e-mails: e.worobiec@botany.pl, g.worobiec@botany.pl

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ABSTRACT. During a palynological analysis of four samples from the Bełchatów KRAM-P 218 collection of plant macroremains 95 fossil species of sporomorphs were identified. Among the non-pollen palynomorphs was the fossil species *Desmidiaceaesporites cosmarioformis*, previously not reported from fossil floras of Poland, most probably related to the zygospores of desmids. The pollen analysis indicates the presence of a freshwater body (probably an oxbow lake) and shows the dominant role of wetland, predominantly riparian vegetation, at the time of sedimentation. The riparian forests probably consisted of *Carya*, *Pterocarya*, *Celtis*, and *Ulmus*, accompanied by *Alnus*, *Acer*, *Fraxinus*, *Juglans*, *Liquidambar*, *Vitis*, *Zelkova*, and *Salix*. In mixed forests there probably were *Fagus*, *Quercus*, *Carpinus*, *Eucommia*, *Corylus*, Tilioideae, and conifers, as well as some thermophilous taxa (e.g. *Castanea*, *Symplocos*, *Reevesia*, Mastixiaceae, and plants producing pollen of the fossil species *Tricolporopollenites pseudocingulum*). *Taxodium*, *Nyssa*, and presumably *Glyptostrobus* and *Alnus* were components of swamp communities that might have overgrown the adjacent area with higher groundwater. Members of the families Ericaceae, Cyrillaceae, and Clethraceae, as well as *Myrica* and probably also *Ilex*, may have been components of swamp forests and bush swamps. Our analysis indicates that the climate was warm temperate and moderately wet. The palynoflora is most similar in composition to the spore-pollen spectra of the X climatic phase – the *Nyssapollenites* spore-pollen zone. Deposits bearing assemblages of the *Nyssapollenites* spore-pollen zone were deposited during the Sarmatian and early Pannonian. Our results are consistent with those from plant macroremains from the same collection.

KEYWORDS: palynology, palaeovegetation, palaeoenvironment, palynostratigraphy, Miocene, Poland

INTRODUCTION

In Poland the lower to middle Miocene strata deposited generally during warm and wet climatic phases have well-documented palaeobotanical evidence, examined from numerous sections (e.g. Grabowska & Słodkowska 1993, Stuchlik et al. 2014). The same cannot be said of the uppermost middle Miocene and upper Miocene strata, which originated during cooler and less humid climatic conditions; there is only sparse palaeobotanical evidence, from far fewer sections of that age. Miocene strata in Poland were deposited in two mostly mutually isolated basins. The marine basin in the Carpathian Foredeep in the south of Poland was part of the Paratethyan basin system, whereas the majority of Polish territory toward the north (Polish Lowlands) was occupied by an epicontinental basin filled with mainly continental strata. The Bełchatów site is located at the southern border of the middle and late Miocene epicontinental basin (Piwocki 1998); this makes the palynoflora interesting for palaeoenvironmental reconstructions.

In the Bełchatów area a series of drillings was done and samples from outcrops at the Bełchatów Lignite Mine were collected, and some profiles from the region were palynologically elaborated in some detail (Stuchlik et al.

1990). Also studied were the palynoflora co-occurring with the late Miocene KRAM-P 250 collection of plant macroremains (Worobiec et al. 2012) and some fossil zygospores of Zygnemataceae algae (Chlorophyta) from the late Miocene of the Bełchatów Lignite Mine (Worobiec & Worobiec 2008).

The KRAM-P 218 leaf assemblage was found in 1995 on the western slope of the open pit of the Bełchatów Lignite Mine. Deposits with the fossil assemblage (grey silts with accumulation of leaf macroremains) were left in an eroded depression and represent abandoned channel fill. The composition of leaf assemblage KRAM-P 218 and its geological setting suggest Miocene age (latest middle Miocene to earliest late Miocene) (Worobiec & Szynkiewicz 2016).

This paper presents the results of a palynological analysis of an assemblage of pollen, spores, and non-pollen palynomorphs co-occurring with the Bełchatów KRAM-P 218 collection of plant macroremains (Worobiec & Szynkiewicz 2016). The relatively high taxonomical diversity of this well-preserved sporomorph association allowed a reconstruction of the plant communities. The results also contribute information on the age of the fossil flora, complement the data on the palaeoflora and palaeovegetation obtained from previous studies of plant macroremains (Worobiec & Szynkiewicz 2016), and shed more light on the palaeoenvironment.

MATERIALS AND METHODS

For palynological analysis, four samples from the KRAM-P 218 collection of plant macroremains from the specimens (rock samples with leaf macroremains) were taken (nos. 85, 104, 109A, 109B). The palynological samples were processed in the laboratory of the W. Szafer Institute of Botany, Polish Academy of Sciences, using hydrochloric acid and sulfuric acid (Moore et al. 1991). Additionally, hydrofluoric acid was used to remove mineral matter and the residuum was sieved through nylon mesh (5 µm). Five microscope slides were made from each sample, using glycerine jelly as mounting medium. On all slides the pollen grains, spores of plants, and non-pollen palynomorphs (NPPs) such as algal remains and microfungal fructifications were studied. In each sample were identified more than 600 pollen grains and spores (2600 sporomorphs altogether) as well as all co-occurring non-pollen palynomorphs. The specimens with leaf remains, palynological residues, and slides are stored in the W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

The identified sporomorph taxa were classified mainly on the basis of the *Atlas of Pollen and Spores of the Polish Neogene* (Stuchlik et al. 2001, 2002, 2009, 2014). We distinguished the following palaeofloristic elements: palaeotropical (P), including tropical (P1) and subtropical (P2); arctotertiary (A), including warm-temperate (A1) and temperate (A2); and cosmopolitan (P/A).

Micrographs of selected sporomorphs and non-pollen palynomorphs (Plates 1–5) were taken using a Nikon Eclipse E400 microscope fitted with a Canon A640 digital camera.

PALYNOLOGICAL RESULTS

All studied samples yielded well-preserved sporomorphs suitable for detailed palynological analysis. A total of 95 fossil species of sporomorphs, including 12 species of plant spores, 25 species of gymnosperm pollen, and 58 species of angiosperm pollen, were identified (Tab. 1). Pollen grains of conifers and angiosperms were very frequent in all samples; spores of plants were scarce (Tab. 1).

Among the conifers, most frequent were bisaccate pollen grains, including *Pinus sylvestris* type (mainly *Pinuspollenites labdacus*, mean 20.94% for all samples), *Cathaya* (*Cathayapollis potoniei*, *C. pulaensis*, *C. wilsonii*, *Cathayapollis* sp., together 6.34%), *Abies* (*Abiespollenites* sp., 0.96%), *Picea* (*Piceapollis* sp., 0.65%), *Keteleeria* (*Keteleeriapollenites dubius*, 0.27%), and *Cedrus* (*Cedripites* sp., 0.04%). Non-bisaccate pollen grains of gymnosperms were represented by *Taxodium*/*Glyptostrobus* (*Inaperturopollenites concedipites*, *I. dubius*, together 7.11%), *Sequoia* (*Sequoiapollenites polyformosus*, *S. rugulus*, *Sequoiapollenites* sp., together 4.26%), other Cupressaceae (*Cupressacites* sp., 0.23%), and *Tsuga* (*Zonalapollenites pliocaenicus*, *Z. spectabilis*, *Z. verrucatus*, *Zonalapollenites* sp., together 2.96%).

The angiosperms were more diversified. Deciduous trees and shrubs were represented mainly by *Fagus* (mainly the fossil species *Faguspollenites bockwitzensis*, 12.06%), Ericaceae (*Ericipites callidus*, *E. ericius*, *Ericipites* sp., together 3.96%), *Ilex* (*Ilexpollenites margaritatus*, *I. iliacus*, together 2.69%), *Carya* (*Caryapollenites simplex*, 2.65%), plants producing pollen of the fossil species *Tricolporopollenites pseudocingulum* (2.42%), *Quercus* (*Quercopollenites*, 2.02%; *Quercoidites henrici*, 0.65%), *Betula* (*Trivestibulopollenites betuloides*, 1.81%), *Carpinus* (*Carpinipites*

Table 1. Results of palynological analysis of samples from the KRAM-P 218 collection of plant macroremains. Number and mean percentage of palynomorphs

Fossil taxon	Botanical affinity	Element	Number of sample				Mean [%]
			85	104	109A	109B	
Spores of plants							
Baculatisporites major (Wolff) Pflug et Thomson + *B. nanus* (Wolff) Krutzsch + *Baculatisporites* sp.	Osmundaceae: *Osmunda*	P/A	8	4	4	9	0.96
Distancoraesporis sp. + *Stereisporites minor* (Raatz) Krutzsch + *Stereisporites* sp.	Sphagnaceae: *Sphagnum*	P/A	4	4	10	4	0.85
Laevigatosporites sp.	Polypodiaceae, Davalliaceae, and other ferns	P/A	6	5	12	5	1.06
Leiotriletes sp.	Lygodiaceae and other ferns	P	1		2	1	0.15
Neogenisporis sp.	Gleicheniaceae, Cyatheaceae	P1		1			0.04
Retitriletes annotinioides Krutzsch + *R. frankfurtensis* Krutzsch	Lycopodiaceae: *Lycopodium*	A	1		2	2	0.19
Triplanosporites sp.	unknown	P	1				0.04
Gymnosperms							
Abiespollenites sp.	Pinaceae: *Abies*	A	10	3	5	7	0.96
Cathayapollis potoniei (Sivak) Ziembińska-Tworzydło + *C. pulaensis* (Nagy) Ziembińska-Tworzydło + *C. wilsonii* (Sivak) Ziembińska-Tworzydło + *Cathayapollis* sp.	Pinaceae: *Cathaya*	A1	35	38	48	44	6.34
Cedripites sp.	Pinaceae: *Cedrus*	A1			1		0.04
Cupressacites sp.	Cupressaceae	A1	1	1	2	2	0.23
Inaperturopollenites concedipites (Wodehouse) Krutzsch + *I. dubius* (Potonié et Venitz) Thomson et Pflug	Cupressaceae: *Taxodium*, *Glyptostrobus*	P2/A1	44	59	47	35	7.11
Keteleeriapollenites dubius (Khlonova) Słodkowska	Pinaceae: *Keteleeria*	A1	1	2	1	3	0.27
Piceapollis sp.	Pinaceae: *Picea*	A	5	6	4	2	0.65
Pinuspollenites labdacus (Potonié) Raatz + *Pinuspollenites* sp.	Pinaceae: *Pinus sylvestris* type	A	152	126	138	129	20.94
Sciadopityspollenites crassus Krutzsch + *S. miniverrucatus* Kohlman-Adamska + *S. serratus* (Potonié et Venitz) Raatz + *S. verticillatiformis* (Zauer) Krutzsch + *Sciadopityspollenites* sp.	Sciadopityaceae: *Sciadopitys*	A1	24	30	22	32	4.14
Sequoiapollenites polyformosus Thiergart + *S. rugulus* Krutzsch + *Sequoiapollenites* sp.	Cupressaceae: *Sequoia*, *Sequoiadendron*, *Metasequoia*	A1	39	19	24	29	4.26
Zonalapollenites pliocaenicus Krutzsch + *Z. spectabilis* (Doktorowicz-Hrebnicka) Ziembińska-Tworzydło + *Z. verrucatus* Krutzsch + *Zonalapollenites* sp.	Pinaceae: *Tsuga*	A	26	9	13	29	2.96
Angiosperms							
Aceripollenites striatus (Pflug) Thiele-Pfeiffer + *Aceripollenites* sp.	Sapindaceae: *Acer*	A1	6	1	2		0.35
Alnipollenites verus Potonié	Betulaceae: *Alnus*	P2/A	4	6	9	5	0.92
cf. *Araliaceoipollenites euphorii* (Potonié) Potonié	Araliaceae	P/A1		1			0.04
Caprifoliipites andreanszkyi Nagy	Adoxaceae: *Viburnum*	P/A1		1	5	1	0.27
Caprifoliipites sp.	Adoxaceae: *Sambucus*, *Viburnum*	P/A1			1		0.04
Carpinipites carpinoides (Pflug) Nagy	Betulaceae: *Carpinus*	P2/A1	10	20	13	4	1.81
Caryapollenites simplex (Potonié) Raatz	Juglandaceae: *Carya*	A1	25	17	19	8	2.65
Celtipollenites intrastructurus (Krutzsch et Vanhoorne) Thiele-Pfeiffer + *Celtipollenites* sp.	Ulmaceae: *Celtis*	P/A1	8	11	8	8	1.34
Cornaceaepollis satzveyensis (Pflug) Ziembińska-Tworzydło	Mastixiaceae	P1	2	3	7	5	0.65
Cupuliferoipollenites oviformis (Potonié) Potonié + *C. pusillus* (Potonié) Potonié	Fagaceae: *Castanea*, *Castanopsis*, *Lithocarpus*	P2/A1		1	2		0.12
Cyperaceaepollis neogenicus Krutzsch + *C. piriformis* Thiele-Pfeiffer	Cyperaceae	P/A	11	4	22	14	1.96
Cyrillaceaepollenites brühlensis (Thomson) Durska	Cyrillaceae, Clethraceae	P			2		0.08
Cyrillaceaepollenites exactus (Potonié) Potonié	Cyrillaceae, Clethraceae	P			2	1	0.12
Cyrillaceaepollenites megaexactus (Potonié) Potonié	Cyrillaceae, Clethraceae	P	3	4	4	2	0.50

Table 1. Continued

Fossil taxon	Botanical affinity	Element	Number of sample				Mean [%]
			85	104	109A	109B	
Diervillapollenites sp.	Caprifoliaceae: *Diervilla*, *Weigela*	P2/A1		1		1	0.08
Edmundipollis vitiosus (Mamczar) Słodkowska et Ziembińska-Tworzydło + *Edmundipollis* sp.	Araliaceae	P/A1	11	1	8	3	0.88
Ericipites callidus (Potonié) Krutzsch + *E. ericius* (Potonié) Potonié + *Ericipites* sp.	Ericaceae	A	30	18	23	32	3.96
Eucommiapollis minor Menke	Eucommiaceae: *Eucommia*	A1	3	5	2		0.38
Faguspollenites bockwitzensis (Walter et Zetter) Kohlman-Adamska et Ziembińska-Tworzydło + *Faguspollenites* sp.	Fagaceae: *Fagus*	A	70	124	62	58	12.06
Fraxinipollis sp.	Oleaceae: *Fraxinus*	P/A	1	2	2	1	0.23
Graminidites pseudogramineus Krutzsch + *Graminidites* sp.	Poaceae: Pooideae	P/A	2		1	1	0.15
Ilexpollenites iliacus (Potonié) Thiergart	Aquifoliaceae: *Ilex*	P/A1	6	5	5	7	0.88
Ilexpollenites margaritatus (Potonié) Thiergart	Aquifoliaceae: *Ilex*	P2	4	14	15	14	1.81
Intratriporopollenites instructus (Potonié) Thomson et Pflug + *Intratriporopollenites* sp.	Malvaceae: Brownlowioideae, Tilioideae	P/A1	5	3	1	3	0.46
Juglanspollenites sp.	Juglandaceae: *Juglans*	A1	1	3	1		0.19
Myricipites sp.	Myricaceae: *Myrica*	P2/A1	2	6	3	2	0.50
Nyssapollenites analepticus (Potonié et Venitz) Planderová + *Nyssapollenites* sp.	Nyssaceae: *Nyssa*	P2/A1	2	7	9	8	1.00
Quercoidites henrici (Potonié) Potonié, Thomson et Thiergart	Fagaceae: *Quercus*	P2/A1	1	3	6	7	0.65
Quercopollenites rubroides Kohlman-Adamska et Ziembińska-Tworzydło + *Quercopollenites* sp.	Fagaceae: *Quercus*	A1	16	11	16	20	2.02
Periporopollenites stigmosus (Potonié) Thomson et Pflug	Altingiaceae: *Liquidambar*	A1	1		2	3	0.23
Polyatriopollenites stellatus (Potonié) Pflug	Juglandaceae: *Pterocarya*	A1	8	12	13	11	1.69
Potamogetonacidites ovalis Grabowska et Ważyńska	Potamogetonaceae: *Potamogeton*	P/A	1			1	0.08
Reevesiapollis triangulus (Mamczar) Krutzsch	Malvaceae: *Reevesia*	P			1		0.04
Salixipollenites sp.	Salicaceae: *Salix*	A			1	1	0.08
Sparganiaceaepollenites sp.	Sparganiaceae, Typhaceae	P/A	1	2	2	2	0.27
Spinulaepollis arceuthobioides Krutzsch	Santalaceae: *Arceuthobium*	P2/A1	3		3	2	0.31
Symplocoipollenites vestibulum (Potonié) Potonié	Symplocaceae: *Symplocos*	P		1	2	1	0.15
Tricolporopollenites liblarensis (Thomson) Hochuli	Fabaceae	P/A				1	0.04
Tricolporopollenites pseudocingulum (Potonié) Thomson et Pflug	Fagaceae?, Styracaceae?	P/A1	8	12	27	16	2.42
Triporopollenites coryloides Pflug	Betulaceae: *Corylus*	A	2	1	1	3	0.27
Trivestibulopollenites betuloides Pflug	Betulaceae: *Betula*	A	9	13	18	7	1.81
Ulmipollenites undulosus Wolff + *Ulmipollenites* sp.	Ulmaceae: *Ulmus*	A2	7	14	5	7	1.27
Vaclavipollis pacltovae Krutzsch	Caryophyllaceae	P/A	1	1			0.08
Vitispollenites tener Thiele-Pfeiffer	Vitaceae: *Vitis*	P2/A1	5		1	3	0.35
Zelkovaepollenites thiergartii Nagy	Ulmaceae: *Zelkova*	A1		4	1	1	0.23
corroded pollen grains	unknown	unknown	15	15	19	30	3.03
Sum of pollen grains and spores			**642**	**654**	**681**	**627**	**100.00**
Selected non-pollen palynomorphs							
Botryococcus braunii Kützing	Dictyosphaeriaceae: *Botryococcus braunii* Kützing	X				1	
Desmidiaceaesporites cosmarioformis Hunger	Desmidiaceae	X		1	2		
Ovoidites minoris Krutzsch et Pacltová	Zygnemataceae: *Spirogyra*	X				1	
Sigmopollis pseudosetarius (Weyland et Pflug) Krutzsch et Pacltová	?Chlorophyta, ?other algae	X		1	2		
Sporocarps of epiphyllous fungi	Ascomycota	X	2	1	1	2	
Sum			**644**	**657**	**686**	**631**	

carpinoides, 1.81%), *Pterocarya* (*Polyatriopollenites stellatus*, 1.69%), *Celtis* (mainly *Celtipollenites intrastructurus*, 1.34%), *Ulmus* (mainly *Ulmipollenites undulosus*, 1.27%), and *Nyssa* (mainly *Nyssapollenites analepticus*, 1.00%). Pollen grains of *Acer* (mainly *Aceripollenites striatus*), *Alnus* (*Alnipollenites verus*), Adoxaceae (*Caprifoliipites andreanszkyi*, *Caprifoliipites* sp.), Araliaceae (mainly *Edmundipollis vitiosus*), *Arceuthobium* (*Spinulaepollis arceuthobioides*), *Castanea*/*Castanopsis* (*Cupuliferoipollenites oviformis*, *C. pusillus*), *Corylus* (*Triporopollenites coryloides*), Cyrillaceae/Clethraceae (*Cyrillaceaepollenites brühlensis*, *C. exactus*, *C. megaexactus*), *Eucommia* (*Eucommiapollis minor*), *Fraxinus* (*Fraxinipollis* sp.), *Juglans* (*Juglanspollenites* sp.), *Liquidambar* (*Periporopollenites stigmosus*), Mastixiaceae (*Cornaceaepollis satzveyensis*), *Myrica* (*Myricipites* sp.), *Symplocos* (*Symplocoipollenites vestibulum*), Tilioideae (mainly *Intratriporopollenites instructus*), *Vitis* (*Vitispollenites tener*), and *Zelkova* (*Zelkovaepollenites thiergartii*) were recorded regularly in amounts lower than 1%. Single pollen grains of *Diervilla*/*Weigela* (*Diervillapollenites* sp.), Fabaceae (*Tricolporopollenites liblarensis*), *Reevesia* (*Reevesiapollis triangulus*), and *Salix* (*Salixipollenites* sp.) were also encountered

Among the herbs, Cyperaceae (*Cyperaceaepollis neogenicus*, *C. piriformis*, together 1.96%), Sparganiaceae/Typhaceae (*Sparganiaceaepollenites* sp., 0.27%), Poaceae (*Graminidites pseudogramineus*, *Graminidites* sp., together 0.15%), Caryophyllaceae (*Vaclavipollis pacltovae*, 0.08%), and *Potamogeton* (*Potamogetonacidites ovalis*, 0.08%) were present.

Cryptogams were represented mainly by spores of ferns, including *Osmunda* (*Baculatisporites major*, *B. nanus*, *Baculatisporites* sp., together 0.96%), the fossil genera *Laevigatosporites* (1.06%) and *Leiotriletes* (0.15%), as well as *Sphagnum* (*Distancoraesporis* sp., *Stereisporites minor*, *Stereisporites* sp., together 0.85%) and *Lycopodium* (*Retitriletes annotinioides*, *R. frankfurtensis*, together 0.19%).

Non-pollen palynomorphs were scarce. Among them were single microremains of freshwater algae (*Botryococcus braunii*, fossil species *Desmidiaceaesporites cosmarioformis*, *Ovoidites minoris*, *Sigmopollis pseudosetarius*) and several fructifications of epiphyllous fungi.

The composition of the sporomorph association from the samples shows the apparent predominance of arctotertiary (including warm-temperate and temperate) and cosmopolitan palaeofloristic elements (Tab. 1). The palaeotropical elements were represented by single specimens. More frequent were some palaeotropical/warm-temperate taxa. The palaeotropical and palaeotropical/warm-temperate taxa were represented by, for example, single spores of *Leiotriletes* sp., *Neogenisporis* sp., and *Triplanosporites* sp., as well as pollen grains of *Inaperturopollenites concedipites*, *I. dubius*, *Cornaceaepollis satzveyensis*, *Cupuliferoipollenites oviformis*, *C. pusillus*, *Cyrillaceaepollenites brühlensis*, *C. exactus*, *C. megaexactus*, *Edmundipollis vitiosus*, *Edmundipollis* sp., *Ilexpollenites iliacus*, *I. margaritatus*, *Intratriporopollenites instructus*, *Myricipites* sp., *Nyssapollenites analepticus*, *Nyssapollenites* sp., *Quercoidites henrici*, *Reevesiapollis triangulus*, *Spinulaepollis arceuthobioides*, *Symplocoipollenites vestibulum*, *Tricolporopollenites pseudocingulum*, and *Vitispollenites tener*.

PLANT COMMUNITIES AND PALAEOENVIRONMENT AS INFERRED FROM PALYNOLOGICAL ANALYSIS

The pollen analysis indicates the dominant role of wetland, predominantly riparian vegetation, at the time of sedimentation. The occurrence of some freshwater algae as well as pollen of *Potamogeton* and Sparganiaceae/Typhaceae points to the presence of a freshwater body, probably an abandoned channel of a meandering or braided river (oxbow lake?). The fossil species *Desmidiaceaesporites cosmarioformis*, not previously reported from fossil floras of Poland, is most probably related to the zygospores of desmids such as *Cosmarium*, *Euastrum*, *Staurastrum*, or *Xanthidium* (Hunger 1953). Extant Desmidiaceae usually occur in clear, relatively nutrient-poor waters with low abundance of algae, often in small reservoirs like pits in bogs (Coesel & Meesters 2007). The waterbody probably was surrounded by swamp vegetation composed of herbs (including members of the family Cyperaceae), as well as riparian forests probably composed of *Carya*, *Pterocarya*, *Celtis*, and *Ulmus*, accompanied by *Alnus*, *Acer*, *Fraxinus*, *Juglans*, *Liquidambar*, *Vitis*, *Zelkova*, and *Salix*. In mixed forests there may have been *Fagus*, *Quercus*, *Carpinus*, *Eucommia*, *Corylus*, Tilioideae, and conifers, as well as some thermophilous taxa (e.g. *Castanea*, *Symplocos*, *Reevesia*, Mastixiaceae). *Ilex* and probably plants producing pollen of the fossil species *Tricolporopollenites pseudocingulum* and *T. liblarensis* probably also were components of these forests. On conifers (probably *Pinus*) lived the parasitic *Arceuthobium*. Species of many genera recorded in the material (e.g. *Acer*, *Betula*, *Celtis*, *Eucommia*, *Fagus*, *Fraxinus*, *Quercus*, *Ulmus*) can grow both in wetland (especially riparian) and mesophytic plant communities. Some pollen grains of Pinaceae (*Pinus*, *Abies*, *Picea*, *Tsuga*) possibly come from plant communities growing on elevated terrain at some distance from the water body (Mai 1981, 1995, Worobiec 2009). On the other hand, some Pinaceae pollen grains may have originated from trees growing as an admixture in mixed mesophytic or wet forests (Sadowska 1977, Mai 1981). Some *Pinus* species and *Sciadopitys* could also have been growing in the vicinity of the waterbody (Mosbrugger et al. 1994, Figueiral et al. 1999). *Taxodium*, *Nyssa*, and presumably *Glyptostrobus* and *Alnus* were components of swamp communities that most likely overgrew the adjacent area with higher groundwater. Members of the families Ericaceae, Cyrillaceae, and Clethraceae, as well as *Myrica* and possibly *Ilex* could have been components of swamp forests and bush swamps.

The results indicate that the climate was warm temperate and moderately wet.

AGE OF PALYNOFLORA AS INFERRED FROM PALYNOLOGICAL ANALYSIS

The composition of the spore-pollen assemblage from the KRAM-P 218 collection of plant macroremains is generally similar to the middle to late Miocene palynofloras from Poland (Grabowska 1998). The whole assemblage was dominated by arctotertiary elements, whereas the palaeotropical elements were represented by single specimens. In all samples, pollen grains of *Fagus* (mainly fossil species *Faguspollenites bockwitzensis*) dominated among the angiosperms. These features make the palynoflora similar to late Miocene spore-pollen assemblages.

From the Polish Lowlands few late Miocene palynofloras have been studied, mainly from northern (e.g. Doktorowicz-Hrebnicka 1957, Słodkowska 2009), central (Stuchlik et al. 1990, Worobiec et al. 2009, Worobiec & Gedl 2010), and south western areas (e.g. Stachurska et al. 1971, 1973, Sadowska 1991, Szulc & Worobiec 2012, Worobiec 2014). The KRAM-P 218 spore-pollen assemblage shows some similarities to previously investigated late Miocene palynofloras from the Bełchatów Lignite Mine, for example from the Bełchatów VI profile (Stuchlik et al. 1990) and from fossil plant assemblage KRAM-P 250 (Worobiec et al. 2012). Those palynofloras were also rich in pollen grains representing arctotertiary elements, including *Fagus*, *Carpinus*, *Quercus*, *Ulmus*, and *Pterocarya*, but they contain only scarce sporomorphs representing the palaeotropical and palaeotropical/warm-temperate elements. In contrast to those assemblages, the KRAM-P 218 palynoflora contains relatively numerous pollen grains of such taxa as *Cornaceaepollis satzveyensis*, *Quercoidites henrici*, *Tricolporopollenites pseudocingulum*, and *Symplocoipollenites vestibulum* (Tab. 1). The KRAM-P 250 and Bełchatów VI assemblages were also richer in other arctotertiary and cosmopolitan taxa, including *Alnus* and *Betula* as well as herbs. The relative richness of palaeotropical/warm-temperate taxa in the studied palynoflora points to slightly older age than the KRAM-P 250 and Bełchatów VI assemblages. Similarly, the KRAM-P 218 spore-pollen association is richer in palaeotropical/warm-temperate taxa and most probably is also older than another palynoflora from central Poland – Józefina (Worobiec et al. 2009, Worobiec & Gedl 2010).

The palynoflora we studied is most similar in composition to the spore-pollen spectra of the X climatic phase – the *Nyssapollenites* spore-pollen zone (Piwocki & Ziembińska-Tworzydło 1995, 1997, Ziembińska-Tworzydło 1998). Deposits bearing such assemblages were accumulated during the Sarmatian and early Pannonian. Representatives of palaeotropical vegetation appear in the *Nyssapollenites* spore-pollen zone only sporadically. The arctotertiary element is much more frequent and diversified, and consists of species of both warm-temperate and temperate elements. During the X climate phase the vegetation was dominated by deciduous riparian forests with a small share of evergreen plants (Piwocki & Ziembińska-Tworzydło 1997). Sediments with the X spore-pollen assemblage are known from a few localities in the Polish Lowlands, for example from Gozdnica, SW Poland (Stachurska et al. 1971). The studied palynoflora is very close in composition to the pollen assemblage from Gozdnica profile 4.

COMPARISON OF PALYNOLOGY WITH PLANT MACROREMAINS

Among the plant macroremains from the Bełchatów KRAM-P 218 collection, 18 species of the genera *Acer*, *Carya*, *?Crataegus*, *Dicotylophyllum*, *Eucommia*, *Fagus*, *Laria*, *Laurophyllum*, *Liquidambar*, *Pinus*, *Populus*, *Pterocarya*, *Quercus*, *Salix*, *Salvinia*, *Taxodium*, *Ulmus*, *Vitis*, and *Zelkova* have been identified (Worobiec & Szynkiewicz 2016). Most of the macroremains genera are also represented by pollen grains (Tab. 1), except for *Populus* and Lauraceae producing pollen grains that do not become preserved in a fossil state. *Fagus* remains dominate among angiosperms in both associations.

Despite considerable differences in taxonomical richness, the pollen analysis results are consistent with those for the plant macroremains from KRAM-P 218. This coherence is seen in the plant community types and in the palaeoclimatic deductions. Both studies point to the dominant role of riparian vegetation and show the presence of mesophytic upland communities and swamp forests. The fossil plant assemblage presumably was formed in deposits of a sedimentary reservoir of an abandoned channel of a meandering or braided river, or an oxbow lake (Worobiec & Szynkiewicz 2016). Thus, plants from the vicinity of the water reservoir dominate the macroremains (Ferguson 1985). The palynoflora is much more abundant in taxa than the macrofossil assemblage, containing also pollen grain and spores of plants growing some distance from the sedimentary reservoir. For example, some pollen grains of Pinaceae (including *Abies*, *Picea*, and *Tsuga*) possibly come from plant communities growing on elevated terrain distant from the water body. Members of the families Ericaceae, Cyrillaceae, and Clethraceae, as well as *Myrica* and probably also *Ilex*, could have been components of both swamp forests and bush swamps in the vicinity. Herbs were almost absent from the macroremains assemblage, whereas the palynoflora showed single pollen grains of Cyperaceae, Sparganiaceae/Typhaceae, Poaceae, Caryophyllaceae, and *Potamogeton*. Cryptogams were represented by macroremains of floating leaves of the water fern *Salvinia*, fragments of presumably moss leaves, and several spores of ferns including *Osmunda* as well as *Sphagnum* and *Lycopodium* which also grew in the vicinity.

Both the macro- and microfloras were dominated by warm temperate taxa and contained several thermophilous elements such as fossil leaves of Lauraceae and the fossil genus *Laria*, and pollen grains of Mastixiaceae. The relative richness of pollen grains of thermophilous taxa is related to the occurrence of those plants in more distant mesophytic plant communities or to the observed preference of evergreen taxa in riparian forests to concentrate in the understory of forest (Ito et al. 2015). Here we mention that evergreen trees and shrubs infrequently lose leaves and are less likely to be preserved in a macrofossil assemblage than abundantly produced pollen grains are. Despite the differences in thermophilous taxa richness, the floristic composition of both the leaf and spore-pollen floras points to warm temperate climate with mild winters.

The macrofloristic and microfloristic studies as well as the stratigraphic position of the KRAM-P 218 assemblage suggest its middle or late Miocene age (late Sarmatian or early Pannonian).

CONCLUSIONS

• In this palynological analysis of four samples taken from the Bełchatów KRAM-P 218 collection of plant macroremains, well-preserved sporomorphs were recorded in all samples studied. A total of 95 fossil-species of sporomorphs (12 species of plant spores, 25 species of gymnosperm pollen, 58 species of angiosperm pollen) were identified. The composition of the sporomorph association in the samples shows the apparent predominance of arctotertiary (including warm-temperate and temperate) and cosmopolitan palaeofloristic elements. Palaeotropical elements were represented by single specimens. More frequent were some palaeotropical/warm-temperate taxa.

• The occurrence of some freshwater algae, as well as pollen grains of *Potamogeton* and Sparganiaceae/Typhaceae, points to the presence of a freshwater body, probably an oxbow lake. The fossil species *Desmidiaceaesporites cosmarioformis*, not previously reported from fossil floras of Poland, most probably is related to the zygospores of desmids (Hunger 1953). Extant Desmidiaceae usually occur in clear, relatively nutrient-poor waters with low abundance of algae (Coesel & Meesters 2007).

• The pollen analysis shows the dominant role of wetland, predominantly riparian vegetation, at the time of sedimentation. The riparian forests probably were composed of *Carya*, *Pterocarya*, *Celtis*, and *Ulmus*, accompanied by *Alnus*, *Acer*, *Fraxinus*, *Juglans*, *Liquidambar*, *Vitis*, *Zelkova*, and *Salix*. In mixed forests probably there were *Fagus*, *Quercus*, *Carpinus*, *Eucommia*, *Corylus*, Tilioideae, and conifers, as well as some thermophilous taxa (e.g. *Castanea*, *Symplocos*, *Reevesia*, Mastixiaceae). *Ilex* and presumably plants producing pollen of the fossil species *Tricolporopollenites pseudocingulum* and *T. liblarensis* also were components of these forests. Various species of some genera recorded in the studied material (e.g. *Acer*, *Betula*, *Celtis*, *Eucommia*, *Fagus*, *Fraxinus*, *Quercus*, *Ulmus*) could have grown in both wetland (riparian) and mesophytic plant communities. Some *Pinus* species and *Sciadopitys* could also have grown in the vicinity of the waterbody. *Taxodium*, *Nyssa*, and presumably *Glyptostrobus* and *Alnus*, were components of swamp communities of the neighbouring area with higher groundwater. Members of the families Ericaceae, Cyrillaceae and Clethraceae, as well as *Myrica* and probably also *Ilex*, could have been components of swamp forests and bush swamps.

• This pollen analysis suggests warm temperate and moderately wet climatic conditions.

• The relative richness in palaeotropical/warm-temperate taxa of the palynoflora points to a slightly older age than those of the KRAM-P 250 and Bełchatów VI assemblages. The palynoflora is most similar in composition to the spore-pollen spectra of the X climatic phase – the *Nyssapollenites* spore-pollen zone (Piwocki & Ziembińska-Tworzydło 1995, 1997, Ziembińska-Tworzydło 1998), especially Gozdnica profile 4 (Stachurska et al. 1971). Deposits bearing plant assemblages of the *Nyssapollenites* spore-pollen zone were deposited during the Sarmatian and early Pannonian.

• These results are consistent with results for the plant macroremains from the KRAM-P 218 fossil assemblage (Worobiec & Szynkiewicz 2016). The palynological analysis enriches our knowledge of the palaeoflora, palaeovegetation and, in turn, the palaeoenvironment of the KRAM-P 218 fossil flora. Both the macrofloristic and microfloristic analyses as well as the stratigraphic position of the KRAM-P 218 assemblage suggest its middle or late Miocene age (late Sarmatian or early Pannonian).

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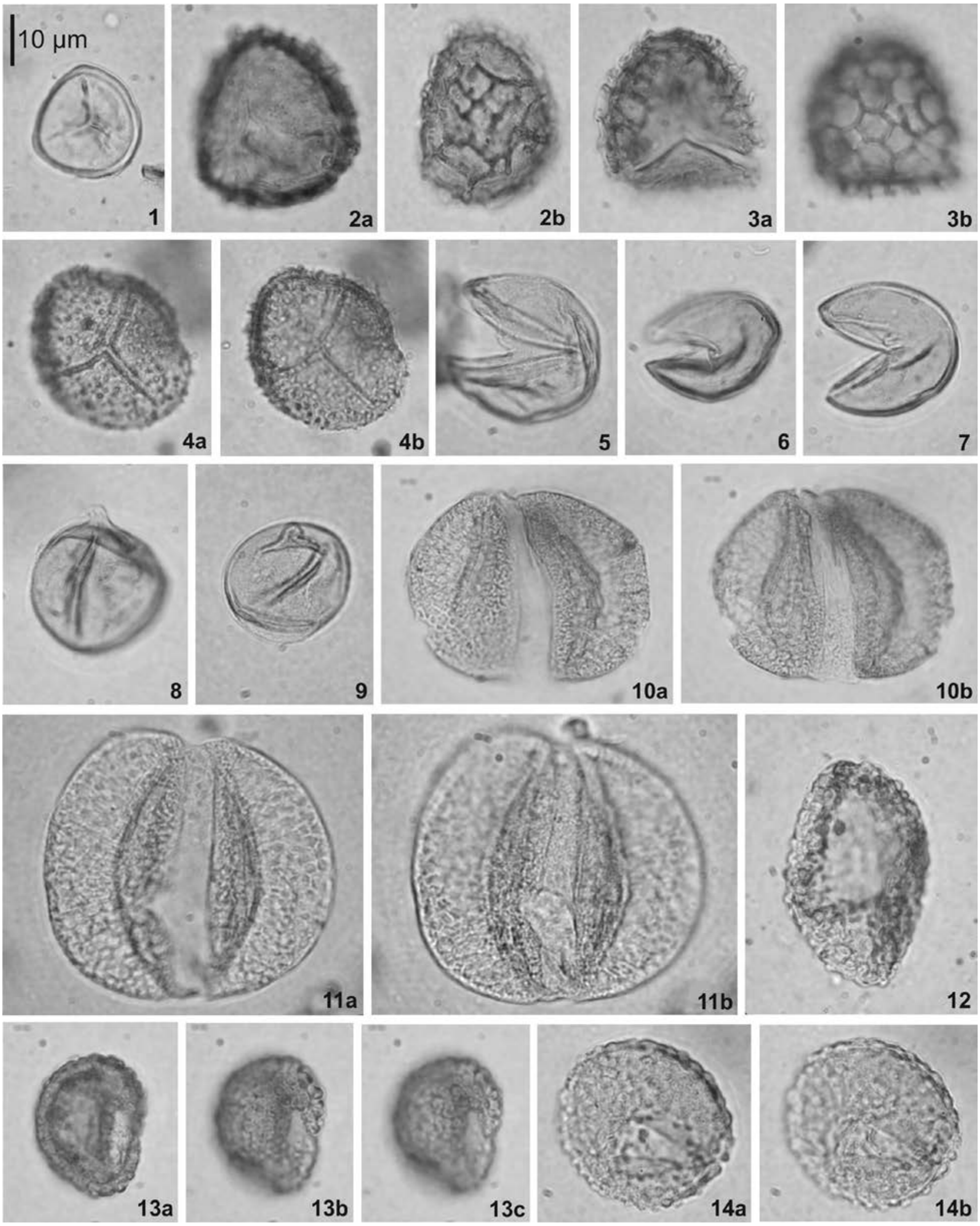
PLATES

Plate 1

1. *Stereisporites minor* (Raatz) Krutzsch, sample 109B
2a,b. *Retitriletes annotinioides* Krutzsch, sample 85
3a,b. *Retitriletes frankfurtensis* Krutzsch, sample 85
4a,b. *Baculatisporites nanus* (Wolff) Krutzsch, sample 109B
5. *Inaperturopollenites concedipites* (Wodehouse) Krutzsch, sample 85
6. *Inaperturopollenites dubius* (Potonié et Venitz) Thomson et Pflug, sample 104
7. *Inaperturopollenites dubius* (Potonié et Venitz) Thomson et Pflug, sample 85
8. *Sequoiapollenites polyformosus* Thiergart, sample 85
9. *Sequoiapollenites* cf. *rugulus* Krutzsch, sample 85
10a,b. *Cathayapollis potoniei* (Sivak) Ziembińska-Tworzydło, sample 85
11a,b. *Cathayapollis wilsonii* (Sivak) Ziembińska-Tworzydło, sample 85
12. *Sciadopityspollenites serratus* (Potonié et Venitz) Raatz, sample 109B
13a–c. *Sciadopityspollenites crassus* Krutzsch, sample 85
14a,b. *Sciadopityspollenites verticillatiformis* (Zauer) Krutzsch, sample 85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14a
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Plate 2

1a,b. *Zonalapollenites* sp., sample 109B

2a,b. *Zonalapollenites pliocaenicus* Krutzsch, sample 109B

3. *Zonalapollenites spectabilis* (Doktorowicz-Hrebnicka) Ziembińska-Tworzydło, sample 109A

4. *Zonalapollenites verrucatus* Krutzsch, sample 109A

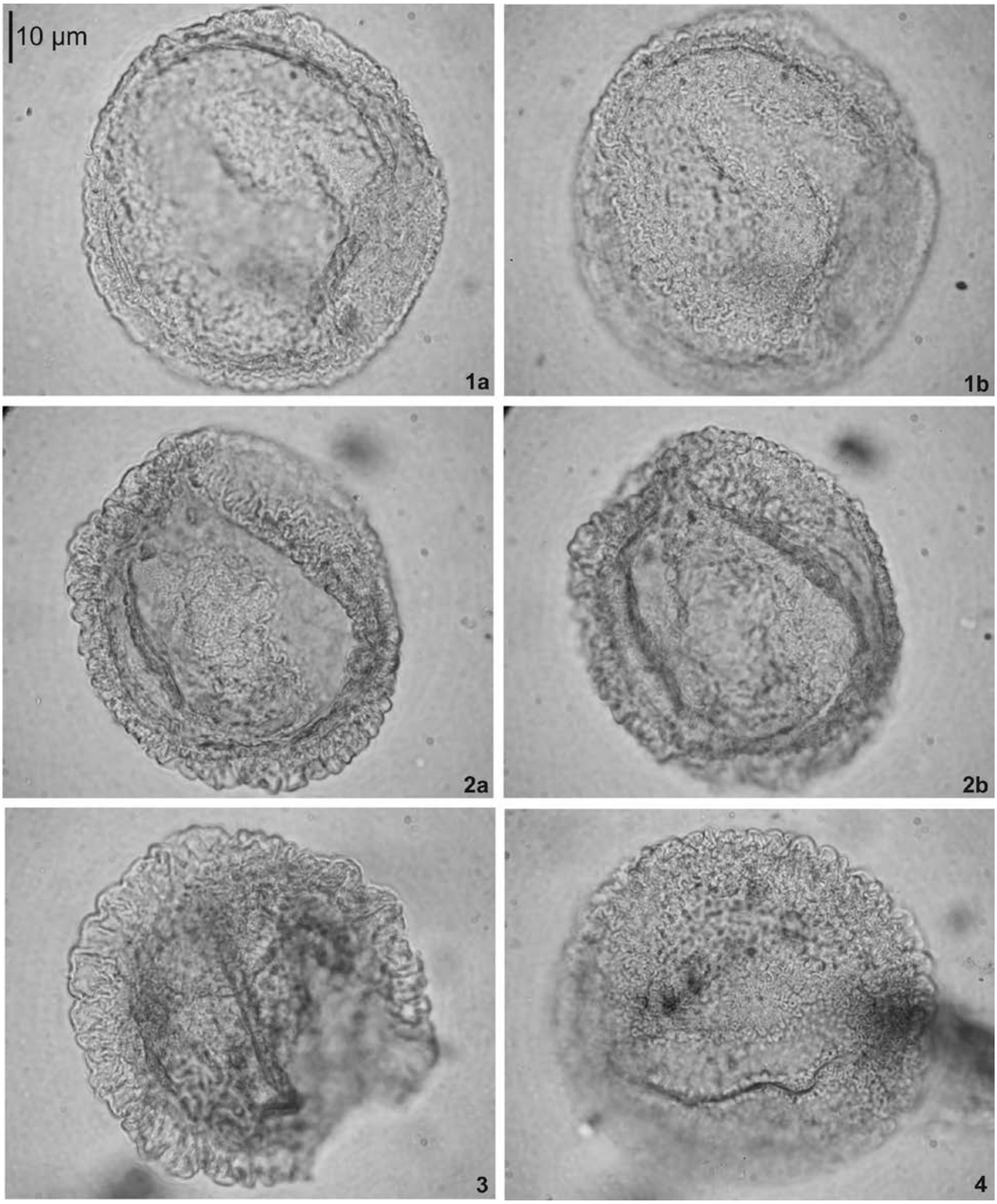
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Plate 3

1. *Polyatriopollenites stellatus* (Potonié) Pflug, sample 104
2. *Caryapollenites simplex* (Potonié) Raatz, sample 85
3. *Ulmipollenites undulosus* Wolff, sample 85
4. *Zelkovaepollenites thiergartii* Nagy, sample 109A
5. *Celtipollenites intrastructurus* (Krutzsch et Vanhoorne) Thiele-Pfeiffer, sample 104
6. *Carpinipites carpinoides* (Pflug) Nagy, sample 85
7. *Triporopollenites coryloides* Pflug, sample 109B
8. *Periporopollenites stigmosus* (Potonié) Thomson et Pflug, sample 104
9. *Eucommiapollis minor* Menke, sample 104
10. *Eucommiapollis minor* Menke, sample 85

11a,b. *Ilexpollenites margaritatus* (Potonié) Thiergart, sample 109A

12a,b. *Ilexpollenites iliacus* (Potonié) Thiergart, sample 109B

13. *Aceripollenites* sp., sample 85

14a,b. *Aceripollenites striatus* (Pflug) Thiele-Pfeiffer, sample 85

15. *Aceripollenites striatus* (Pflug) Thiele-Pfeiffer, sample 85

16a,b. *Aceripollenites* cf. *striatus* (Pflug) Thiele-Pfeiffer, sample 104

17a,b. *Quercopollenites rubroides* Kohlman-Adamska et Ziembińska-Tworzydło, sample 85

18. *Quercopollenites rubroides* Kohlman-Adamska et Ziembińska-Tworzydło, sample 85

19a,b. *Quercoidites henrici* (Potonié) Potonié, Thomson et Thiergart, sample 104


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Plate 4

1. *Faguspollenites bockwitzensis* (Walter et Zetter) Kohlman-Adamska et Ziembińska-Tworzydło, sample 85
2a,b. *Faguspollenites bockwitzensis* (Walter et Zetter) Kohlman-Adamska et Ziembińska-Tworzydło, sample 85
3. *Faguspollenites bockwitzensis* (Walter et Zetter) Kohlman-Adamska et Ziembińska-Tworzydło, two pollen grains, sample 109A
4. *Faguspollenites bockwitzensis* (Walter et Zetter) Kohlman-Adamska et Ziembińska-Tworzydło, sample 109B
5. *Faguspollenites bockwitzensis* (Walter et Zetter) Kohlman-Adamska et Ziembińska-Tworzydło, sample 85
6. *Faguspollenites bockwitzensis* (Walter et Zetter) Kohlman-Adamska et Ziembińska-Tworzydło, sample 85
7a,b. *Tricolporopollenites liblarensis* (Thomson) Hochuli, sample 109B
8a,b. *Tricolporopollenites pseudocingulum* (Potonié) Thomson et Pflug, sample 85
9a,b. *Tricolporopollenites pseudocingulum* (Potonié) Thomson et Pflug, sample 85
10a,b. *Nyssapollenites analepticus* (Potonié et Venitz) Planderová, sample 104
11a,b. *Ericipites callidus* (Potonié) Krutzsch, sample 109B
12. *Ericipites* sp., sample 104
13. *Ericipites callidus* (Potonié) Krutzsch, sample 109B
14a,b. *Ericipites ericius* (Potonié) Potonié, sample 109B

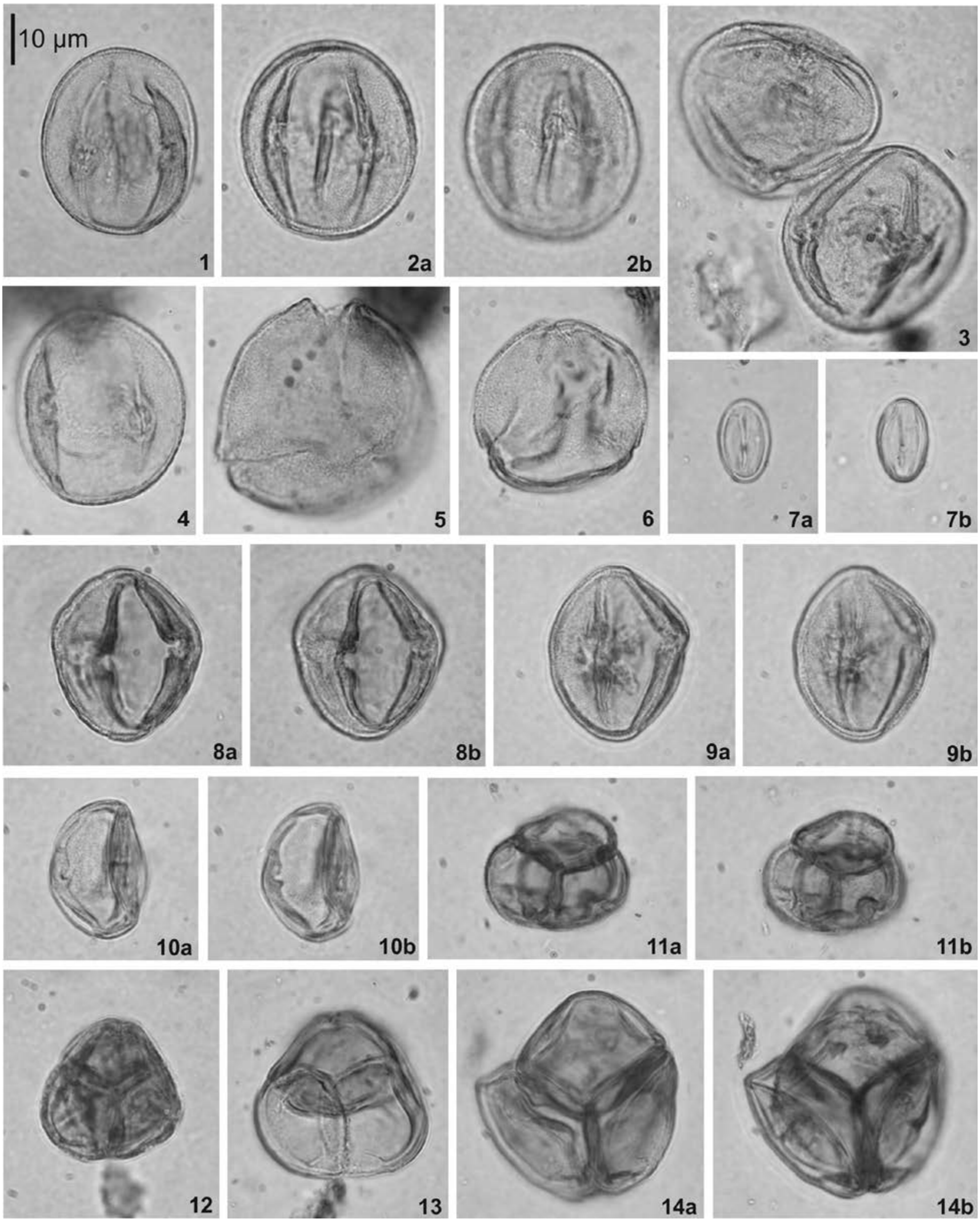
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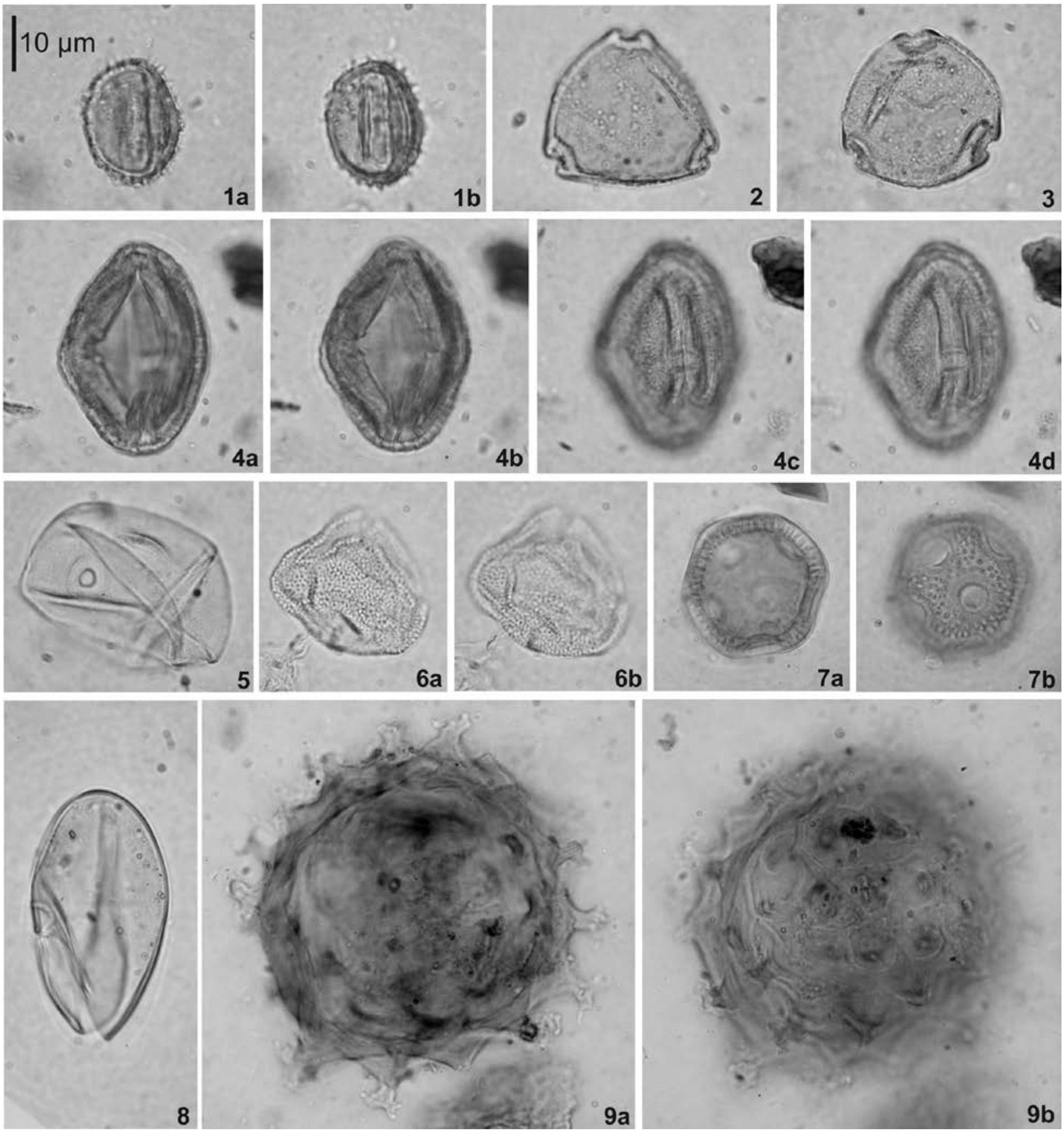
Plate 5

1a,b. *Spinulaepollis arceuthobioides* Krutzsch, sample 109B
2. *Diervillapollenites* sp., sample 104
3. *Diervillapollenites* sp., sample 109B
4a–d. *Edmundipollis vitiosus* (Mamczar) Słodkowska et Ziembińska-Tworzydło, sample 104
5. *Graminidites pseudogramineus* Krutzsch, sample 109A
6a,b. *Potamogetonacidites ovalis* Grabowska et Ważyńska, sample 85
7a,b. *Vaclavipollis pacltovae* Krutzsch, sample 104
8. *Ovoidites minoris* Krutzsch et Pacltová, sample 109B
9a,b. *Desmidiaceaesporites cosmarioformis* Hunger, sample 104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