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Middle Miocene palynoflora from the Adamów lignite deposit, central Poland

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ABSTRACT
The first mid-Polish group is the youngest among the main Neogene lignite seams in Poland. Lignites of this group developed in the middle Miocene over almost the whole of Poland, and therefore they are an important correlation horizon throughout much of the Polish Lowlands. A total of 30 palynological samples from the 3-metre seam from the Adamów deposit (central Poland) were studied in detail. The results revealed the presence of wetland and mesophytic vegetation during the time of sedimentation. The study area was overgrown by palustrine wetland communities similar in their composition to modern pocosins. The climate was warm temperate and humid, which was inferred from the palynoflora composition, including frequency of palaeotropical and palaeotropical/warm-temperate taxa, and the presence of epihyllous fungi. The estimated mean annual temperature (MAT) for the lignite seam at Adamów is 15.7–18.0 °C. Comparison with other palynofloras from the first mid-Polish lignite seam group shows that the climate was more or less homogenous within the entire Polish Lowlands during formation of the group of seams. The MAT ranges are also similar to other results from middle Miocene of Central Europe. The differences between the Adamów palynoflora and palynofloras from central and western Poland, dominated by swamp forests, most probably reflect the succession of plant communities in different hydrological and trophic conditions.

KEYWORDS
lignite; palaeoenvironment; palaeovegetation; palaeoclimate; Miocene; Poland

1. Introduction

In Poland, five main lignite seam groups of major economic significance of early Oligocene to middle Miocene age are present (Kasiński and Słodkowska 2016). Among them, the first mid-Polish group is the youngest. Lignites of this group developed in the middle Miocene across Poland, excluding the Carpathian Mountains (Piwocki 1998). Lignites of the first mid-Polish seam formed under continental conditions as swamps, bogs, and backwaters developed within extensive alluvial plains. Recently, the first mid-Polish lignite group has been documented across an area of ca. 70,000 km^2 in western and central Poland. In most lignite deposits the seam is relatively thin (up to a few metres) and has little economic value. In central Poland, due to the shallow depth of occurrence and relatively significant thickness (up to 20 m thick in the deposits of the Konin region), these lignites are exploited in several opencast mines in the area of Konin and Turek. The lignite seam is also an important correlation horizon throughout much of the Polish Lowlands (Piwocki 1998; Kasiński et al. 2010; Kasiński and Słodkowska 2016).

The aim of the present study is to reconstruct the plant communities and determine which represent the source of material for the formation of the Adamów lignite deposit (central Poland), by means of detailed palynological analysis. We also used spore-pollen analysis and non-pollen palynomorphs (freshwater algae and fungal microremains) as a source of data for palaeoclimatic and palaeoenvironmental interpretations.

2. Geological setting

The Adamów lignite deposit is located 2–8 km east of the city of Turek in central Poland (52°01′17″N 18°37′45″E; Figure 1). It covers a relatively shallow, fault-bounded graben-like depression, which is up to a few decametres deep. In the study area, the top of the Mesozoic is comprised of marl, gaize and limestone of Late Cretaceous age (Figure 2; Widera 2007). Above the Mesozoic bedrock the incomplete Cenozoic succession rests. Thus, the oldest Paleogene sediments in the area of the Adamów lignite deposit and in its surroundings are of early Oligocene age. They are predominantly composed of mud, 'blue clays', and occasionally of marine glauconitic sand and beach gravel, also known as the 'Koźmin Gravels' (Widera and Kita 2007; Widera 2010). In the latter case, the gravels are redeposited into the Neogene deposits (Figure 2).

The Neogene sedimentation began after the late Oligocene regional tectonic uplift of central Poland. At that time two main lithostratigraphical units were deposited – the Koźmin and Poznań formations (Figure 2). The Koźmin Formation, consisting of sub-lignite fluvial sands and sandstones with coaly intercalations of early- to mid-Miocene age, was formed first. The deposition of the overlying

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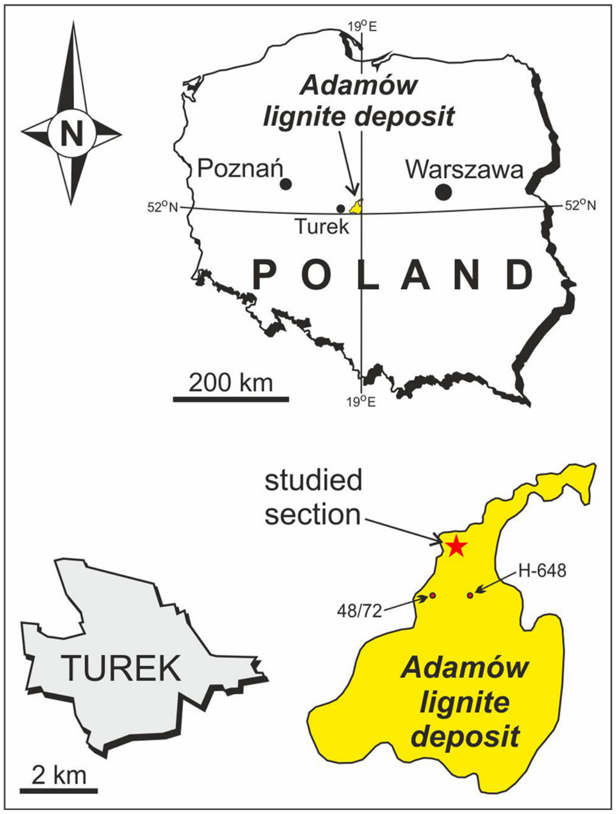

Figure 1. Location map of the studied section (the first mid-Polish lignite seam) in the background of the Adamów lignite deposit in central Poland. Note location of the boreholes 48/72 and H-648 presented in Figure 2. Source: Marek Widera (co-author).

Poznań Formation, of mid-Miocene to early Pliocene age, occurred subsequently. Traditionally, the Poznań Formation is divided into the lower Grey Clays Member and the upper Wielkopolska Member (Piwocki and Ziembińska-Tworzydło 1997; Widera 2007).

The Grey Clays Member contains the examined first mid-Polish (first Lusatian) lignite seam in its lower part and the 'grey clays' in its upper part. This lignite seam, which is currently being exploited by the Adamów Lignite Mine, is up to several metres thick. It was deposited about 15 ± 1.5 Ma during the last peak of the Mid-Miocene Climatic Optimum (Zachos et al. 2001; Bruch et al. 2007; Bechtel et al. 2019), namely in the middle part of the mid-Miocene (Piwocki and Ziembińska-Tworzydło 1997; Kasiński and Słodkowska 2016). The accumulation of peat, from which the investigated lignite seam was created, took place as low-lying mires in the overbank zone of a mid-Miocene fluvial system (Widera 2016a).

The Wielkopolska Member ends the Neogene succession in the study area. It consists mainly of overbank muds ('green clays' and 'flaming clays') with channel-fill sandy-muddy deposits. These muds are often eroded, glaciotectonically disturbed and preserved in residual form; hence, they occur only in a few boreholes, e.g. in borehole 48/72 (Figure 2). In general, the aforementioned deposits, representing the upper part of the 'Poznań Clays', were accumulated in the environment of the late Neogene river system (Maciaszek et al. 2019; Widera et al. 2019). The Neogene is capped by glaciogenic sediments of Quaternary age. In the

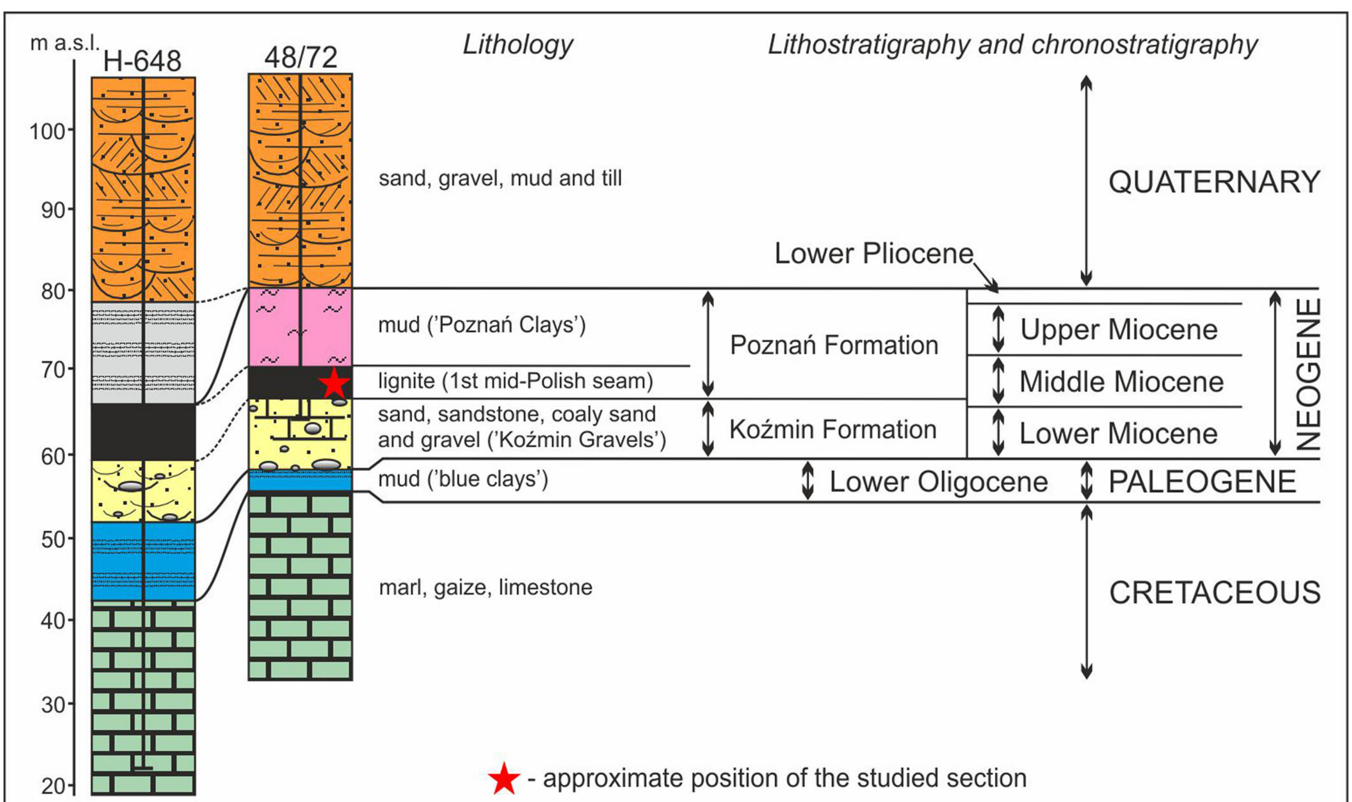

Figure 2. Compilation of selected boreholes from the area of the Adamów lignite deposit showing lithostratigraphy of the Cenozoic succession and approximate position of the studied first mid-Polish (Lusatian) lignite seam. Location of boreholes H-648 and 48/72 in Figure 1.

study area, they are mainly sand-gravel, and subordinately also mud and till. Relatively often, as in borehole H-648, the Quaternary deposits lie directly at the top of the examined lignite seam (Figure 2).

The first mid-Polish (first Lusatian) lignite seam from the Adamów deposit contains the following lignite lithotypes: xylodetritic, detroxylitic, detritic and weathered (Widera 2016b; Bechtel et al. 2019). From a macropetrographic point of view, the listed lithotypes may represent the initial and subsequent stages of mire development including the establishment of bush moor, wet forest swamp and fen or open water, with periods of low and high groundwater tables (e.g. Teichmüller 1989; Markič and Sachsenhofer 1997).

3. Materials and methods

Palynological samples were taken in the field from the Adamów lignite deposit at the Adamów Lignite Mine from the 3-metre thick lignite seam belonging to the first mid-Polish group (Figures 1 and 2). A total of 30 samples were taken at 10 cm intervals. Most samples were lignitic. The lowermost sample represents sandy coaly sediment, while two of the uppermost samples represent ‘grey clays’. The samples were processed in the Laboratory of the W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków, according to the following procedure. A portion of about 1 cm^3 of cleaned and crushed rock was treated successively with 10% hydrochloric acid (HCl) to remove carbonates, 10% potassium hydroxide (KOH), 40% hydrofluoric acid (HF) for four days to remove silicates (HF was heated at the beginning of the treatment), and subsequently 10% hydrochloric acid (HCl) to remove silicofluorides (Moore et al. 1991). Additionally, the residue was sieved at 5 µm on a nylon mesh. From each sample 2–5 microscope slides were made, using glycerine jelly as a mounting medium. In all of the slides, pollen grains, plant spores and non-pollen palynomorphs (NPPs), such as algal remains and fungal remains, were studied.

The sporomorph taxa identified were classified on the basis of the ‘Atlas of pollen and spores of the Polish Neogene’ (Stuchlik et al. 2001, 2002, 2009, 2014). In the material studied, the following palaeofloristical 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). The mean annual temperature (MAT) reconstruction in this work is based on the Coexistence Approach (CA) method (Utescher et al. 2014; Prader et al. 2017). The nearest living relatives and their MAT ranges follow The Palaeoflora Database (Utescher and Mosbrugger 2015).

Data from the palynological spectra were used to construct a simplified palynological diagram. In the diagram the percentages of the pollen and spore taxa were calculated from the total sum of pollen grains and spores; the proportion of non-pollen palynomorphs was computed separately in relation to the total sum using the POLPAL computer programme (Nalepka and Walanus 2003).

Microphotographs of selected sporomorphs and non-pollen palynomorphs (Plates 1 and 2) were taken, using a Nikon Eclipse E400 microscope fitted with a Canon A640 digital camera. The palynological residues and slides are stored in the W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

4. Results

All studied samples yielded well-preserved pollen grains and spores suitable for detailed palynological analysis (Plate 1). In the samples taken from weathered (shortly after accumulation of fresh peat) lignite the pollen and spores were slightly less frequent and not preserved so well, but they were likewise suitable for analysis. In most samples, 400–600 pollen grains and spores (min. 200 sporomorphs in sample 23), as well as all co-occurring non-pollen palynomorphs, were identified. A total of 122 fossil species (including 12 species of plant spores, 26 species of gymnosperm pollen, and 84 species of angiosperm pollen) were identified (Table 1). Among pollen grains of gymnosperms *Sequoia/Sequoiadendron/Metasequoia*, *Pinus* and *Cathaya* are most common. In addition, *Taxodium/Glyptostrobus*, *Sciadopitys*, *Tsuga*, *Abies*, *Picea*, plus single pollen grains of *Keteleeria* and *Cedrus* occur (Figure 3).

Angiosperms are more diversified and represented mainly by trees and shrubs, whereas herbs are very rare. Most common are pollen grains of Ericaceae, fossil species *Tricolporopollenites pseudocingulum*, *Nyssa* (*Nyssapollenites* and *Nyssoidites rodderensis*), *Quercus* (*Quercoidites henricii* and *Quercopollenites*), *Fagus*, Mastixiaceae (*Cornaceaepollis satzveyensis*), and fossil genus *Edmundipollis*. Pollen grains of *Alnus*, *Betula*, *Myrica*, *Ilex*, Cyrillaceae/Clethraceae, *Fraxinus*, *Acer*, *Castanea/Castanopsis/Lithocarpus*, *Carpinus*, *Ulmus*, *Carya*, *Pterocarya*, *Salix*, *Liquidambar*, *Zelkova*, *Vitis*, Adoxaceae, Fabaceae (mainly *Tricolporopollenites fallax* and *T. liblarensis*), *Eucommia*, *Arceuthobium*, *Celtis*, and Tilioideae, are recorded regularly. In addition, single pollen grains of *Juglans*, Araliaceae, Rhamnaceae, *Itea*, Vitaceae (*Parthenopollenites marcodurensis*), and a few others are encountered. Among herbs only Cyperaceae are present in most samples. In addition, a few pollen grains of Sparganiaceae/Typhaceae and other herbs are present.

Cryptogams are represented mainly by spores of ferns, including *Osmunda* (*Baculatisporites* and *Rugulatisporites quintus*), fossil-genus *Laevigatosporites*, and others. Spores of *Sphagnum* occur regularly. Several spores of *Lycopodium* are also present.

Among non-pollen palynomorphs 13 fossil species of algae are recorded (Table 2; Plate 2). *Desmidiaceaesporites cosmarioformis*, most probably related to desmids, is most common and it is present in most samples (Figure 3). Single zygospores of *Spirogyra* (fossil genus *Ovoidites*) are also encountered regularly. As a contrast, other Zygnemataceae (*Cycloovoidites cyclus*, *Diagonalites diagonalis*, *Megatetrapidites megatetroides*, *Stigmozygodites*, and *Tetrapidites*) as well as *Sigmopollis pseudosetarius*, *Spintetrapidites quadriformis*, and *Pediastrum* are present only in two of the uppermost

Plate 1. Spores and pollen grains from Adamów. Figure 1. *Baculatisporites primarius* (Wolff) Thomson & Pflug, sample 6. Figure 2. *Stereisporites* sp., sample 28. Figure 3. *Sequoiapollenites rugulus* Krutzsch, sample 18. Figure 4. *Sciadopityspollenites crassus* Krutzsch, sample 13. Figure 5. *Polyatriopollenites stellatus* (Potonié) Pflug, sample 2. Figures 6, 7. *Edmundipollis edmundii* (Potonié) Konzalová, Słodkowska & Ziembińska-Tworzydło, same specimen, various foci, sample 6. Figure 8. *Tricolporopollenites* sp., sample 15. Figure 9. *Nyssapollenites accessorius* (Potonié) Potonié, sample 4. Figures 10, 11. *Aceripollenites microrugulatus* Thiele-Pfeiffer, same specimen, various foci, sample 20. Figure 12. *Faguspollenites verus* Raatz, sample 20. Figure 13. *Quercoidites henricii* (Potonié) Potonié, Thomson & Thiergart, sample 18. Figure 14. *Quercopollenites rubroides* Kohlman-Adamska & Ziembińska-Tworzydło, sample 24. Figure 15. *Tricolporopollenites pseudocingulum* (Potonié) Thomson & Pflug, sample 29. Figure 16. *Fraxinipollis sinuosimuratus* (Trevisan) Słodkowska, sample 22. Figure 17. *Cupuliferoipollenites oviformis* (Potonié) Potonié, sample 28. Figure 18. *Cyrillaceaepollenites exactus* (Potonié) Potonié, sample 25. Figure 19. *Ilexpollenites margaritatus* (Potonié) Thiergart, sample 6. Figure 20. *Ericipites callidus* (Potonié) Krutzsch, sample 13. Figure 21. *Ericipites callidus* (Potonié) Krutzsch, sample 10. Figure 22. *Ericipites ericius* (Potonié) Potonié, sample 8. Scale bar in figure 1 refers to all figures.

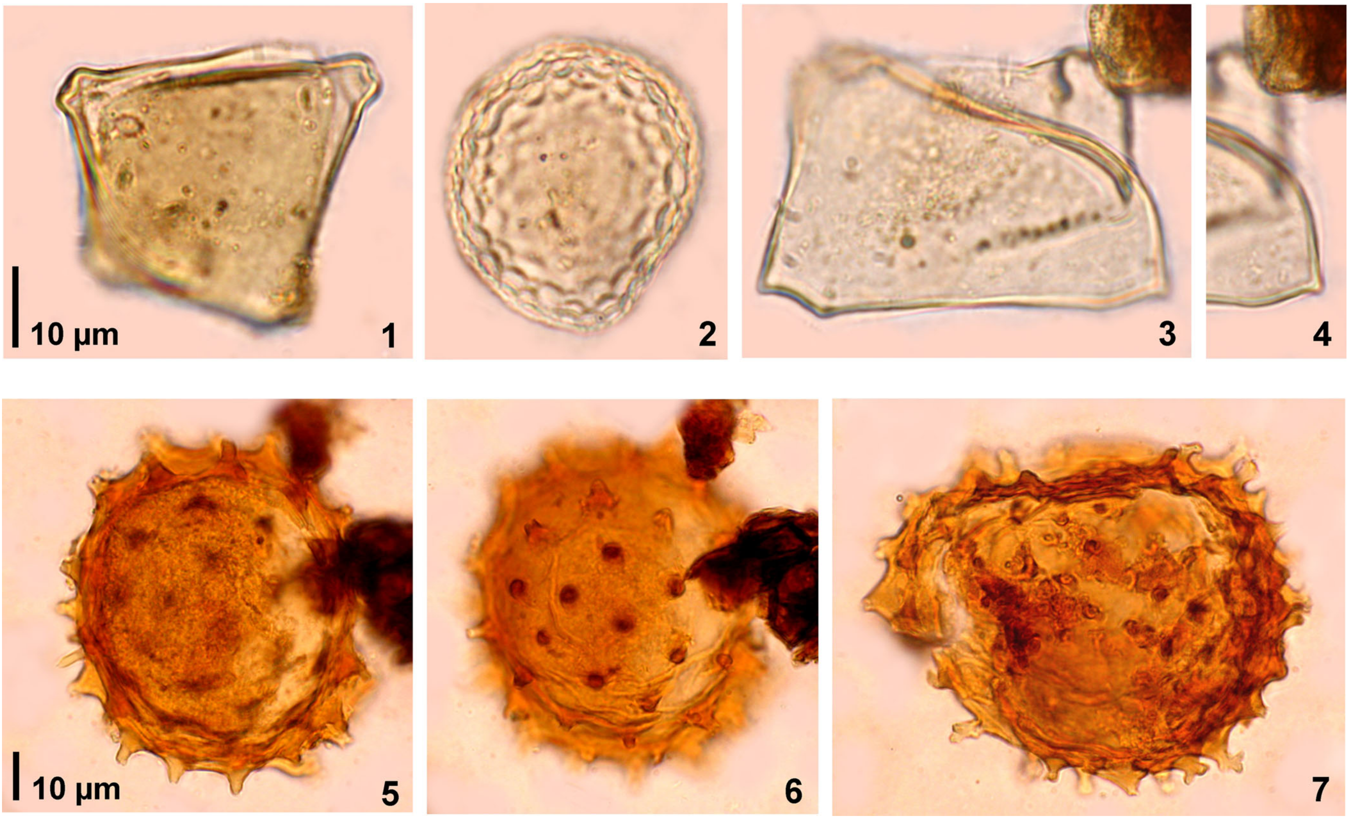

Plate 2. Freshwater algae from Adamów. Figure 1. *Tetrapidites* sp., sample 2. Figure 2. *Stigmozygodites* sp., sample 1. Figures 3, 4. *Closteritetrapidites magnus* Krutzsch & Pacltová, sample 6. Figures 5, 6. *Desmidiaceaesporites cosmarioformis* Hunger, same specimen, various foci, sample 20. Figure 7. *Desmidiaceaesporites cosmarioformis* Hunger, sample 20. Scale bar in figure 1 refers to figures 1–4. Scale bar in figure 5 refers to figures 5–7.

samples. Most of the identified fossil species of algae (except *Pediastrum*) represent their resting cells (Worobiec 2014). In most samples fungal microfossils, including the remains of epiphyllous fungi with fossil species *Callimothallus pertusus* and cephalothecoid fungi related to the recent Cephalothecaceae family, were found as well.

In all samples pollen grains and spores representing 'arctoteriary' (with numerous warm-temperate taxa) and cosmopolitan palaeofloristical elements prevail (Table 1). Palaeotropical elements are represented by single specimens, whereas the representation of the palaeotropical/warm-temperate taxa is significant. Although frequencies of particular taxa change from sample to sample, proportions of the palaeotropical and palaeotropical/warm-temperate taxa are similar in the whole diagram. For example, pollen grains of *Edmundipollis* are more common in the lower and upper parts of the section, whereas in the middle part they are replaced by *Cornaceaepollis satzveyensis*. Single specimens of other palaeotropical species *Ilexpollenites margaritatus*, *Iteapollis angustiporatus* and *Momipites punctatus* are recorded in samples from various depths.

5. Discussion

5.1. Plant communities and palaeoenvironment

The results of the palynological analysis indicate the presence of wetland and mesophytic vegetation at the time of sedimentation. Various members of the Ericaceae family as well as Cyrillaceae, Clethraceae, *Ilex*, and *Myrica* probably were components of shrub bog communities most similar in their composition to modern pocosins. Pocosins are classified as palustrine wetland ecosystems and nowadays they occur on the south-eastern coastal plain of the USA from Virginia to north Florida and once covered more than one million hectares in North Carolina (Richardson 2003). The modern pocosins include the classic shrub-scrub 'short pocosin' (or 'low pocosin') and pond-pine-dominated 'tall pocosin' (or 'high pocosin'). Some authors have also distinguished other types of these communities (Weakley and Schafale 1991). Modern short pocosins consist of a dense shrub layer, usually less than 1.5 metres tall (up to 4–6 m), with openings where *Carex striata*, ferns *Woodwardia virginica*, *Sphagnum* and others occur. Currently, the most characteristic elements of pocosins are Ericaceae (*Chamaedaphne calyeulata* var. *angustifolia*, *Gaylussacia frondosa*, *Kalmia carolina*, *Kalmia cuneata*, *Lyonia ligustrina* var. *foliosiflora*, *Lyonia lucida*, *Vaccinium corymbosum*, and *Zenobia pulverulenta*), *Clethra alnifolia*, *Cyrilla racemiflora*, *Ilex coriacea*, *Ilex glabra*, plus *Aronia arbutifolia*, *Arundinaria tecta*, *Chamaecyparis thyoides*, *Gordonia lasianthus*, *Magnolia virginiana*, *Persea palustris*, *Smilax laurifolia*, *Toxicodendron vernix*, and others. *Pinus serotina* (pond pine) is the most characteristic tree of modern pocosins (Sharitz and Gibbons 1982; Weakley and Schafale 1991).

Nowadays, short pocosins occupy the centres of domed peatlands and are higher than the surrounding lands. Their

Table 1. Spores and pollen grains recorded in the deposits from Adamów.

Fossil taxa	Botanical affinity	Element
Plant spores:		
Baculatisporites nanus (Wolff) Krutzsch	Osmundaceae: *Osmunda*	P/A
Baculatisporites primarius (Wolff) Thomson & Pflug	Osmundaceae: *Osmunda*	P/A
Baculatisporites sp.	Osmundaceae: *Osmunda*	P/A
Distancoraesporis sp.	Sphagnaceae: *Sphagnum*	P/A
Laevigatosporites haardti (Potonié & Venitz) Thomson & Pflug	Polypodiaceae, Davalliaceae, and other ferns	P/A
Laevigatosporites sp.	Polypodiaceae, Davalliaceae, and other ferns	P/A
Leiotriletes sp.	Lygodiaceae and other ferns	P
Monoleiotriletes sp.	ferns	unknown
Retitriletes sp.	Lycopodiaceae: *Lycopodium*	A
Rugulatisporites quintus Pflug & Thomson	Osmundaceae: *Osmunda*	P/A
Stereisporites sp.	Sphagnaceae: *Sphagnum*	P/A
Verrucatosporites sp.	Davalliaceae, Polypodiaceae, and other ferns	P/A
Gymnosperm pollen:		
Abiespollenites absolutus Thiergart	Pinaceae: *Abies*	A
Abiespollenites sp.	Pinaceae: *Abies*	A
Cathayapollis cf. *pulaensis* (Nagy) Ziembińska-Tworzydło	Pinaceae: *Cathaya*	A1
Cathayapollis vancampoae (Sivak) Ziembińska-Tworzydło	Pinaceae: *Cathaya*	A1
Cathayapollis sp.	Pinaceae: *Cathaya*	A1
Cedripites sp.	Pinaceae: *Cedrus*	A1
Cupressacites sp.	Cupressaceae	A1
Inaperturopollenites concedipites (Wodehouse) Krutzsch	Cupressaceae: *Taxodium*, *Glyptostrobus*	P2/A1
Inaperturopollenites dubius (Potonié & Venitz) Thomson & Pflug	Cupressaceae: *Taxodium*, *Glyptostrobus*	P2/A1
Inaperturopollenites verrupapilatus Trevisan	Cupressaceae: *Taxodium*, *Glyptostrobus*	P2/A1
Keteleeriapollenites dubius (Khlonova) Słodkowska	Pinaceae: *Keteleeria*	A1
Piceapollis planoides Krutzsch	Pinaceae: *Picea*	A
Piceapollis tobolicus (Panova) Krutzsch	Pinaceae: *Picea*	A
Piceapollis sp.	Pinaceae: *Picea*	A
Pinuspollenites labdacus (Potonié) Raatz	Pinaceae: *Pinus sylvestris* type	A
Pinuspollenites sp.	Pinaceae: *Pinus*	A
Sciadopityspollenites crassus Krutzsch	Sciadopityaceae: *Sciadopitys*	A1
Sciadopityspollenites serratus (Potonié & Venitz) Raatz	Sciadopityaceae: *Sciadopitys*	A1
Sciadopityspollenites verticillatiformis (Zauer) Krutzsch	Sciadopityaceae: *Sciadopitys*	A1
Sciadopityspollenites sp.	Sciadopityaceae: *Sciadopitys*	A1
Sequoiapollenites gracilis Krutzsch	Cupressaceae: *Sequoia*, *Sequoiadendron*, *Metasequoia*, *Cryptomeria*	A1
Sequoiapollenites polyformosus Thiergart	Cupressaceae: *Sequoia*, *Sequoiadendron*, *Metasequoia*	A1
Sequoiapollenites rugulus Krutzsch	Cupressaceae: *Sequoia*, *Sequoiadendron*, *Metasequoia*	A1
Sequoiapollenites sp.	Cupressaceae: *Sequoia*, *Sequoiadendron*, *Metasequoia*, *Cryptomeria*	A1
Zonalapollenites verrucatus Krutzsch	Pinaceae: *Tsuga*	A
Zonalapollenites sp.	Pinaceae: *Tsuga*	A
Angiosperm pollen:		
Aceripollenites microrugulatus Thiele-Pfeiffer	Sapindaceae: *Acer*	A
Aceripollenites reticulatus Nagy	Sapindaceae: *Acer*	A
Aceripollenites sp.	Sapindaceae: *Acer*	A
Alnipollenites verus Potonié	Betulaceae: *Alnus*	P2/A
Araliaceoipollenites amplus Słodkowska	Araliaceae	P/A1
Araliaceoipollenites euphorii (Potonié) Potonié	Araliaceae	P/A1
Arecipites butomoides Krutzsch	Butomaceae, Araceae, Arecaceae	P/A
Caprifoliipites viburnoides (Gruas-Cavagnetto) Kohlman-Adamska	Adoxaceae: *Viburnum*	P/A1
Caprifoliipites sp.	Adoxaceae: *Sambucus*, *Viburnum*	P2/A1
Carpinipites carpinoides (Pflug) Nagy	Betulaceae: *Carpinus*	P2/A1
Caryapollenites simplex (Potonié) Raatz	Juglandaceae: *Carya*	A1
Celtipollenites sp.	Ulmaceae: *Celtis*	P/A1
Cornaceaepollis satzveyensis (Pflug) Ziembińska-Tworzydło	Mastixiaceae: *Mastixia*	P1
Cornaceaepollis sp.	Cornaceae: *Cornus*	P/A
Corylopsispollenites microreticulatus E.Worobiec	Hamamelidaceae: *Corylopsis*	A1
Cupuliferoipollenites oviformis (Potonié) Potonié	Fagaceae: *Castanea*, *Castanopsis*, *Lithocarpus*	P2/A1
Cupuliferoipollenites pusillus (Potonié) Potonié	Fagaceae: *Castanea*, *Castanopsis*, *Lithocarpus*	P2/A1
Cyperaceaepollis neogenicus Krutzsch	Cyperaceae	P/A
Cyrillaceaepollenites brühlensis (Thomson) Durska	Cyrillaceae, Clethraceae	P
Cyrillaceaepollenites exactus (Potonié) Potonié	Cyrillaceae, Clethraceae	P
Cyrillaceaepollenites megaexactus (Potonié) Potonié	Cyrillaceae, Clethraceae	P
Edmundipollis edmundii (Potonié) Konzalová, Słodkowska & Ziembińska-Tworzydło	Mastixiaceae	P1
Edmundipollis megagranatus (Mamczar) Słodkowska & Ziembińska-Tworzydło	Araliaceae	P
Edmundipollis vitiosus (Mamczar) Słodkowska & Ziembińska-Tworzydło	Araliaceae	P/A1
Edmundipollis sp.	Cornaceae, Mastixiaceae, Araliaceae	P/A
Ericipites callidus (Potonié) Krutzsch	Ericaceae	A
Ericipites ericius (Potonié) Potonié	Ericaceae	A
Ericipites roboreus (Potonié) Krutzsch	Ericaceae	A
Ericipites sp.	Ericaceae	A
Eucommiapollis minor Menke	Eucommiaceae: *Eucommia*	A1
Faguspollenites verus Raatz	Fagaceae: *Fagus*	A
Faguspollenites sp.	Fagaceae: *Fagus*	A
Fraxinipollis oblatus Słodkowska	Oleaceae: *Fraxinus*	A

(*continued*)

Table 1. Continued.

Fossil taxa	Botanical affinity	Element
Fraxinipollis sinuosimuratus (Trevisan) Słodkowska	Oleaceae: *Fraxinus*	A
Graminidites sp.	Poaceae: Pooideae	P/A
Ilexpollenites iliacus (Potonié) Thiergart	Aquifoliaceae: *Ilex*	P/A1
Ilexpollenites margaritatus (Potonié) Thiergart	Aquifoliaceae: *Ilex*	P2
Intratriporopollenites instructus (Potonié) Thomson & Pflug	Malvaceae: Tilioideae	A
Intratriporopollenites sp.	Malvaceae: Brownlowioideae, Tilioideae	P/A
Iteapollis angustiporatus (Schneider) Ziembińska-Tworzydło	Iteaceae: *Itea*	P
Juglanspollenites verus Raatz	Juglandaceae: *Juglans*	A1
Liriodendroipollis semiverrucatus Krutzsch	Magnoliaceae: *Liriodendron*	P2/A1
Liriodendroipollis verrucatus Krutzsch	Magnoliaceae: *Liriodendron*	P2/A1
Magnoliaepollenites sp.	Magnoliaceae: *Magnolia*	P/A1
Momipites punctatus (Potonié) Nagy	Juglandaceae: *Engelhardia*, *Alfaroa*, *Oreomunnea*	P2
Myricipites coryphaeus (Potonié) Potonié	Myricaceae	P2/A1
Myricipites sp.	Myricaceae	P2/A
Nymphaeacidites typicus Sah	Nymphaeaceae: *Nymphaea*	P/A
Nyssapollenites accessorius (Potonié) Potonié	Nyssaceae: *Nyssa*	A1
Nyssapollenites analepticus (Potonié & Venitz) Planderová	Nyssaceae: *Nyssa*	P/A1
Nyssapollenites contortus (Pflug & Thomson) Nagy	Nyssaceae: *Nyssa*	P2/A1
Nyssapollenites pseudocruciatus (Potonié) Thiergart	Nyssaceae: *Nyssa*	P/A1
Nyssapollenites sp.	Nyssaceae: *Nyssa*	P/A1
Nyssoidites rodderensis Thiergart	Nyssaceae: *Nyssa*	P/A1
Oleoidearumpollenites sp.	Oleaceae	P2/A1
Orapollis potsdamensis Krutzsch	Alismataceae: *Alisma*	P/A
Ostryoipollenites rhenanus (Thomson) Potonié	Betulaceae: *Ostrya*	A1
Parthenopollenites marcodurensis (Pflug & Thomson) Traverse	Vitaceae	P/A1
Periporopollenites stigmosus (Potonié) Thomson & Pflug	Altingiaceae: *Liquidambar*	A1
Polyatriopollenites stellatus (Potonié) Pflug	Juglandaceae: *Pterocarya*	A1
Polycolpites hexaradiatus (Nakoman) Durska	Lamiaceae	P/A
Quercoidites henricii (Potonié) Potonié, Thomson & Thiergart	Fagaceae: *Quercus*	P2/A1
Quercopollenites rubroides Kohlman-Adamska & Ziembińska-Tworzydło	Fagaceae: *Quercus*	A1
Quercopollenites sculptus Kohlman-Adamska & Ziembińska-Tworzydło	Fagaceae: *Quercus*	A1
Quercopollenites sp.	Fagaceae: *Quercus*	A1
Rhamnaceaepollenites triquetrus Thiele-Pfeiffer	Rhamnaceae	P2/A
Salixipollenites capreaformis Planderová	Salicaceae: *Salix*	A
Salixipollenites densibaculatus Nagy	Salicaceae: *Salix*	A
Salixipollenites sp.	Salicaceae: *Salix*	A
Sparganiaceaepollenites sp.	Sparganiaceae, Typhaceae	P/A
Spinulaepollis arceuthobioides Krutzsch	Santalaceae: *Arceuthobium*	P2/A1
Symplocoipollenites vestibulum (Potonié) Potonié	Symplocaceae: *Symplocos*	P
Tricolporopollenites fallax (Potonié) Krutzsch	Fabaceae	P/A
Tricolporopollenites liblarensis (Thomson) Hochuli	Fabaceae	P/A
Tricolporopollenites mangiferoides Słodkowska	Anacardiaceae: *Mangifera*	P1
Tricolporopollenites quisqualis (Potonié) Krutzsch	Fabaceae	P/A
Tricolporopollenites pseudocingulum (Potonié) Thomson & Pflug	Fagaceae?, Styracaceae?	P/A1
Tricolporopollenites sp.	Fagaceae?	unknown
Triporopollenites urticoides Nagy	Urticaceae	P/A
Trivestibulopollenites betuloides Pflug	Betulaceae: *Betula*	A
Ulmipollenites undulosus Wolff	Ulmaceae: *Ulmus*	A2
Vitispollenites tener Thiele-Pfeiffer	Vitaceae: *Vitis*	P2/A1
Zelkovaepollenites potoniei Nagy	Ulmaceae: *Zelkova*	A1
Zelkovaepollenites sp.	Ulmaceae: *Zelkova*	A1

Taxonomy and botanical affinity according to Stuchlik et al. (2001, 2002, 2009, 2014). The following palaeofloristical elements have been distinguished: palaeotropical (P), including: tropical (P1) and subtropical (P2), and 'arctotertiary' (A), including: warm-temperate (A1) and temperate (A2), as well as cosmopolitan (P/A).

hydrology is palustrine, seasonally flooded or saturated. As they are primarily watered by rainfall, they are nutrient poor (ombrotrophic). Phosphorus is the proximal limiting nutrient in pocosins (Weakley and Schafale 1991; Richardson 2003). The peat in modern pocosins is deep and saturated to the point that the plant roots never reach mineral soil; small permanently flooded depressions may occur (Weakley and Schafale 1991). In the Adamów profile the fossil-species *Desmidiaceaesporites cosmarioformis* occurs regularly. This taxon 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 a low abundance of algae, often in small reservoirs like pits in bogs (Coesel and Meesters 2007). The presence of *Desmidiaceaesporites cosmarioformis* and the very low frequency of other algal remains (most of them are restricted to two uppermost samples) support the interpretation of the results of the spore-pollen studies.

In places with intermediate to long hydroperiods *Nyssa*, *Taxodium* and/or *Glyptostrobus*, *Acer*, *Alnus*, as well as *Carya*, *Pterocarya*, *Liquidambar*, *Fraxinus*, *Salix*, *Ulmus*, *Zelkova*, *Celtis*, *Vitis*, and *Osmunda* grew. Presently, bay forests with *Acer rubrum*, *Nyssa sylvatica* var. *biflora*, *Taxodium ascendens*, *Cyrilla racemiflora*, *Lyonia lucida*, and *Woodwardia virginica* occur in the south Atlantic coastal plain of the USA (Sharitz and Gibbons 1982; Christensen 2000). *Sequoia* presumably also could have grown in wet places; some authors consider

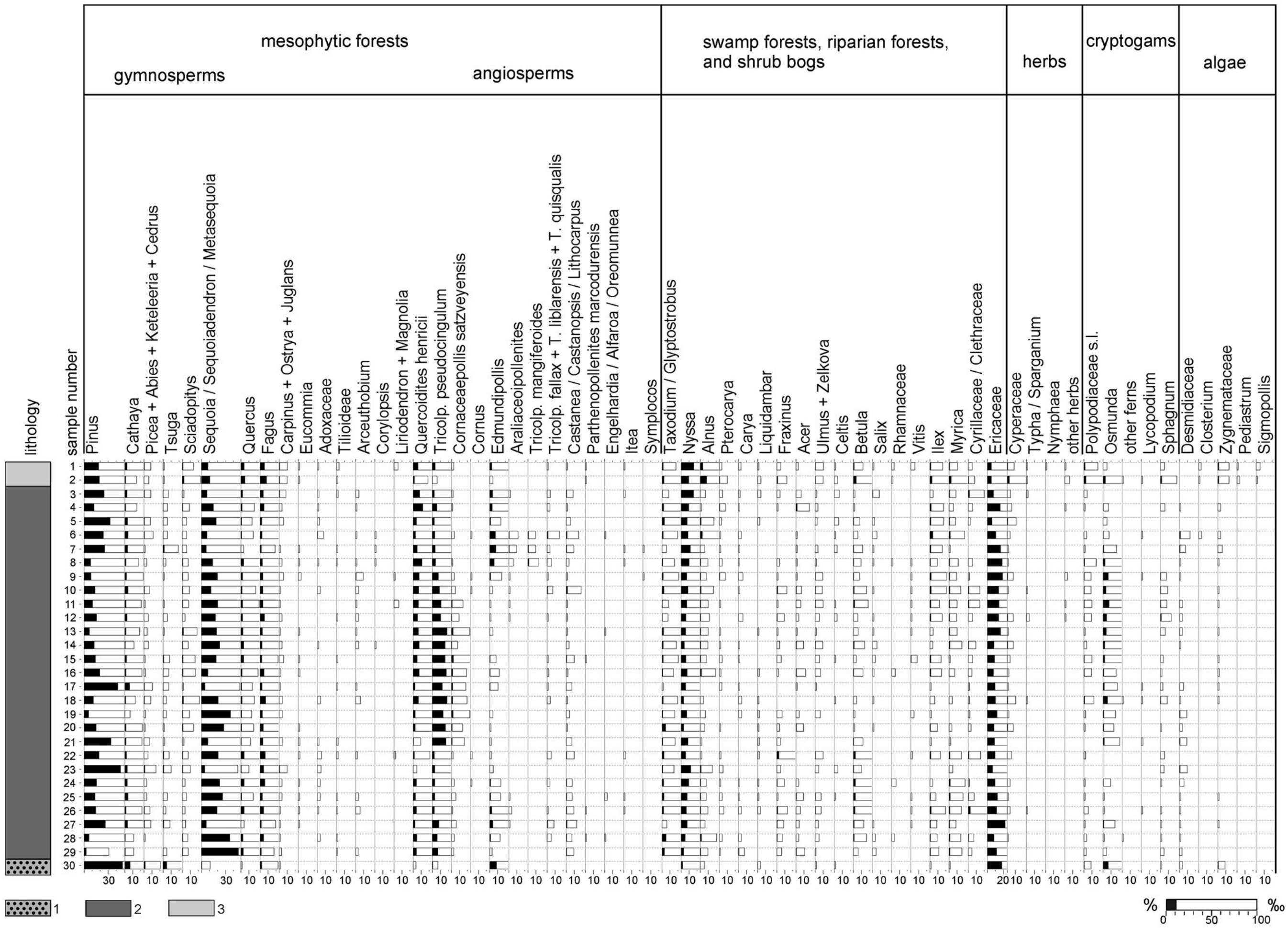

Fig. 3

Figure 3. Simplified percentage diagram of pollen and spores of plants as well as freshwater algae from Adamów. Numbers in the bottom of the diagram show ranges of percentages for each taxon separately. Black bars show percentages (%), white bars show percentages ×10 (‰). Lithology: 1. sandy coaly sediment, 2. lignite, 3. 'grey clays'.

it as a riparian element (Kovar-Eder et al. 2001). Schneider (1992) placed *Sequoia*, among others, in A Facies ('bush swamp') together with abundant angiosperms, including *Quercus* and Ericaceae, plus *Cathaya*, *Cunninghamia*, and *Taiwania*. Extant *Sequoia sempervirens* grows usually in the alluvial flats of the Coastal Range Mountains, mainly in California, in a warm-summer Mediterranean climate where summer fogs occur (Roy 1966). The high frequency of *Sequoia* type pollen grains, observed in most samples from Adamów, confirms the opinion about the presence of *Sequoia* on or near peat.

Members of the genera *Quercus* (also thermophilous trees producing pollen of fossil-species *Quercoidites henricii*), *Fagus*, *Carpinus*, *Eucommia*, *Corylopsis*, *Itea*, *Symplocos*, as well as members of the Araliaceae, Cornaceae, Mastixiaceae, Adoxaceae, Castaneoideae, Tilioideae, Fabaceae and Magnoliaceae families, plus conifers probably grew in mesophytic forests. The parasitic *Arceuthobium* lived on conifers (probably *Pinus*).

Many of the taxa recorded in the Adamów profile should not be connected with one particular vegetation type (cf. Worobiec and Szynkiewicz 2016). For example, *Acer*, *Betula*, *Celtis*, *Eucommia*, *Fagus*, *Fraxinus*, *Quercus*, and *Ulmus* could grow both in wetland and mesophytic plant communities. Some pollen grains from Pinaceae (*Pinus*, *Abies*, *Cedrus*, *Keteleeria*, *Picea*, and *Tsuga*) possibly come from plant communities growing on elevated terrains in the distance. On the other hand, most pollen grains of Pinaceae could originate from trees growing as an admixture in mesophytic forests or pocosins. Some *Pinus* species and *Sciadopitys* could grow in the vicinity, in the margins of peat bogs (Mosbrugger et al. 1994; Figueiral et al. 1999).

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 summer) in the Köppen-Geiger climate classification (Kottek et al. 2006). Frequency of the palaeotropical and palaeotropical/warm-temperate taxa is relatively significant and similar in the whole diagram (Figure 3). The estimated mean annual temperature (MAT) for the first mid-Polish lignite seam at Adamów is 15.7–18.0 °C (Supplementary material). In the palynological profile some fossil microfungi were also found, which could be a source of data for palaeoclimatic and palaeoenvironmental interpretations as well. From the palaeoecological point of view, the diversified group of epiphyllous fungi is

Table 2. Freshwater algae recorded in deposits from Adamów (number of specimens).

Taxa	Botanical affinity	Indication	Number of specimens
Chlorophyta - vegetative stage:			
Pediastrum sp.*	Hydrodictyaceae: *Pediastrum*	eutrophic to mesotrophic fresh waters, open water surface	3
Chlorophyta - resting cells:			
Closteritetrapidites magnus Krutzsch & Pacltová	Closteriaceae: *Closterium*	oligo- to eutrophic fresh waters	4
Cycloovoidites cyclus (Krutzsch) Krutzsch & Pacltová*	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	1
Desmidiaceaesporites cosmarioformis Hunger	Desmidiaceae: *Cosmarium*, *Euastrum*, *Staurastrum*, *Xanthidium*	clear, relatively nutrient-poor waters with low abundance of algae	48
Diagonalites diagonalis Krutzsch & Pacltová*	Zygnemataceae: *Mougeotia laetevirens* type	shallow, stagnant, oxygen-rich fresh waters, lake margins	1
Megatetrapidites megatetroides Krutzsch & Pacltová*	Zygnemataceae: *Mougeotia*	shallow, stagnant, oxygen-rich fresh waters, lake margins	3
Ovoidites elongatus (Hunger) Krutzsch	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	12
Ovoidites ligneolus (Potonié) Tomson & Pflug	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	7
Ovoidites minoris Krutzsch & Pacltová	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	3
Spintetrapidites quadriformis Krutzsch & Pacltová*	Zygnematales?: desmids?, Zygnemataceae?	oligo- to eutrophic fresh waters	1
Stigmozygodites sp.*	Zygnemataceae: *Zygnema*	shallow, meso- to eutrophic, open fresh waters	6
Tetrapidites sp.*	Zygnemataceae: *Mougeotia*	shallow, stagnant, oxygen-rich fresh waters, lake margins	2
other fossil taxa:			
Sigmopollis pseudosetarius (Weyland & Pflug) Krutzsch & Pacltová*	Chlorophyta?, other algae?	eutrophic to mesotrophic open fresh waters	4

Botanical affinity and indication according to Coesel and Meesters (2007) and Worobiec (2014 and literature cited herein). Asterisks indicate species found only in the two uppermost samples.

particularly important. They are considered as a good proxy for past climates as extant relatives of epiphyllous taxa recorded in the Adamów samples show the highest abundance and taxonomic diversity in warm and humid subtropical and tropical regions (Reynolds and Gilbert 2005; Thaung 2006; Hofmann 2010; Piepenbring et al. 2011). Of special importance is the presence of some sporodochia of epiphyllous fossil-species *Callimothallus pertusus*. The remains of *Callimothallus*, along with other epiphyllous fungi, confirm warm and probably humid climatic conditions (Worobiec and Worobiec 2017). Some of the other fungi (cephalothecoid) were probably associated with decaying wood (Worobiec et al. 2017).

Fluctuations in the frequency of *Pinus* and *Sequoia/Sequoiadendron/Metasequoia* probably reflect fluctuations in the water level. In the idealized cycle for the lignites, transition from reed marsh (i.e. the wettest peat-forming environment) into the *Taxodium–Nyssa–Pinus* swamp forest, then to the *Cyrilla–Myrica–Pinus* swamp forest, and subsequently into the *Quercus–Sequoia* swamp forest (i.e. the driest peat-forming environment) can be distinguished. Those changes in plant communities are reflected in the colour of lignites (Holdgate et al. 2016). In the Adamów lignite the fluctuations in frequency of the taxa are very small and that cycle is not observed. In addition, proportions of the palaeotropical and palaeotropical/warm-temperate taxa are similar in the whole diagram. Therefore, we can only assume that the fluctuations reflect changes in hydrological rather than climatic conditions. Also, the state of preservation of pollen grains (more crumpled and shrunken specimens) probably reflects periodic drying of the substrate. The presence of *Pediastrum*, zygospores of filamentous green algae from the Zygnemataceae family (*Mougeotia*, *Spirogyra*, and *Zygnema*), as well as the fossil-species *Sigmopollis pseudosetarius* and *Spintetrapidites quadriformis* in two the uppermost samples points to lacustrine sedimentation at the end of the studied succession.

5.2. Comparison of the Adamów palynoflora with results from previous studies of the first mid-Polish lignite seam and some palaeoclimatic considerations

The first mid-Polish seam has relatively good palynological documentation, because lignites of this group were formed in a large area of Poland (Kasiński et al. 2010; Kasiński and Słodkowska 2016). Numerous palynofloras were studied from the Polish Lowlands (Ziembińska and Niklewski 1966; Ziembińska-Tworzydło 1974; Dyjor and Sadowska 1977; Sadowska and Giża 1991; Grabowska and Słodkowska 1993; Kohlman-Adamska 1993; Worobiec 2009), mainly from lignite deposits, but also from karst sinkholes (Worobiec and Szulc 2010). In the scheme of the spore-pollen zones of the Neogene in the Polish Lowlands the first mid-Polish lignite seam is correlated with the VIII *Celtipollenites verus* zone (Piwocki and Ziembińska-Tworzydło 1997; Słodkowska 1998; Ziembińska-Tworzydło 1998).

In the Fore-Sudetic region, SW Poland, this lignite seam (so-called 'Henryk seam') was found in many profiles from the Legnica deposit complex (Wacnik and Worobiec 2001; Worobiec et al. 2008; Worobiec 2009; Ivanov and Worobiec 2017). The Legnica lignite resource complex is a platform-type deposit that extends over a large area in the Legnica Depression. In the Legnica and Ruja deposits the first mid-

Polish seam has a small influence on the scale of the coal resources, whereas the second Lusatian seam has the largest extent and thickness. The first seam is present there in the form of a thin horizon or lenses of lignites, or it is divided into two or more very thin horizons (Worobiec 2009). Therefore, most of the palynological studies were carried out on the second lignite seam; although usually a few samples were also analysed from the first lignite seam.

The results of pollen analysis from Legnica profiles revealed that the pollen of *Taxodium/Glyptostrobus* (Taxodiaceae/Cupressaceae in previous studies; max. 60%) with *Sequoia*, as well as *Pinus*, *Nyssa*, *Alnus* (up to 30–35%), *Quercus*, *Tricolporopollenites pseudocingulum*, *Fagus*, and *Celtis* (up to 8–10%) were the most frequent. Some pollen grains of *Myrica*, *Liquidambar*, *Salix*, *Ilex*, Ericaceae, *Abies*, *Castanea*, *Ulmus*, *Acer*, *Carya*, *Pterocarya*, Cyrillaceae/Clethraceae, Rosaceae, Fabaceae, *Symplocos*, *Engelhardia*, and *Quercoidites henricii* occured. In addition, spores of Polypodiaceae s.l. and *Osmunda* were numerous (Worobiec 2009). In the Legnica region swamp forests, riparian forests, bush swamps (shrub bogs or swamps), and mesophytic forests grew. Swamp forests were dominated by *Taxodium*, *Glyptostrobus* and *Nyssa*, probably enriched in *Alnus*. The *Taxodium/Glyptostrobus–Nyssa* swamp forests were widespread in Europe during the Oligocene to Pliocene as one type of Neogene peat bog vegetation and they evolved in slowly subsiding tectonic basins or along the coast during some phases of the sea level change. For example, their role was significant in the formation of Oligocene–Miocene lignites in Germany, including Rhenish and Lusatian coals (Mai 1981; Schneider 1992; Holdgate et al. 2016). In the Polish Lowlands they had the most favorable conditions in the early and middle Miocene (Kasiński and Słodkowska 2016). Presently, similar *Taxodium–Nyssa* forests occur along the lower Atlantic Coastal Plain from southern Delaware to southern Florida and along the lower Gulf Coast Plain to southeastern Texas including the Mississippi River delta (Wilhite and Toliver 1990; Barnes 1991). Those hygrophytic forest palaeocoenoses were sources for lignites of the first seam in the Legnica deposits. The plant communities, both swamp and mesophilous forests outside the marsh basins, were dominated by plants representing a warm-temperate palaeoclimatical element. In drier terrains there existed favourable conditions for mixed mesophytic forests with the domination of warm-temperate taxa, and with an admixture of evergreen plants, mainly forming the undergrowth (Worobiec 2009). The mean annual temperature (MAT) coexistence intervals for the first lignite seam from Legnica range mainly between 15.6–16.6 °C (Ivanov and Worobiec 2017).

In the Konin area, adjacent to the Adamów lignite deposit, the first mid-Polish seam was palynologically examined by Kremp (1949), Mamczar (1960), as well as Sadowska and Giża (1991). A recent profile that was studied in detail from the Józwin I opencast (Kasiński et al. 2010), belonging to the Konin Lignite Mine, is similar to the Legnica and Ruja profiles. The Józwin palynoflora is dominated by conifers: *Taxodium/Glyptostrobus* (up to 40%), Pinaceae (mainly *Pinus*, up to 30%) and *Sciadopitys*. Angiosperms are represented by *Nyssa* (up to 22%), *Alnus*, Cyrillaceae/Clethraceae (*Cyrillaceaepollenites megaexactus*), Ericaceae, *Castanea/Castanopsis/Lithocarpus*, *Quercoidites henricii*, and *Tricolporopollenites pseudocingulum*. Swamp forests with *Taxodium*, *Glyptostrobus*, *Nyssa*, and *Alnus* dominated. In addition, bush swamps (shrub bogs or swamps), riparian forests, and mesophytic forests grew. The MAT coexistence interval for the first lignite seam from Józwin was 15.0–18.5 °C (Kasiński et al. 2010).

The present results of the palynological studies of the Adamów profile slightly differ from the Józwin spore-pollen assemlage (Kasiński et al. 2010). In Józwin swamp forests with *Alnus*, *Nyssa*, and *Taxodium/Glyptostrobus* dominated, whereas in Adamów pollen grains of Ericaceae and *Sequoia* are more frequent. A similar, relatively high frequency of *Sequoia* pollen (maximum 30%) was recorded in the palynofloras from the Konin region (Kremp 1949; Mamczar 1960; Doktorowicz-Hrebnicka 1960) as well as from other localities in central and western Poland: Ustronie (Ziembińska and Niklewski 1966; Ziembińska-Tworzydło 1974), Jerzmanowa and Łojowice (Dyjor and Sadowska 1977), Rogóźno (Mamczar 1961), Lubstów (Ciuk and Grabowska 1991), and Legnica (Worobiec 2009). This relatively high frequency of *Sequoia* pollen was interpreted as a result of the temporary presence of *Sequoia* forests on the peat-bogs (Sadowska and Giża 1991) and sometimes was considered to be a characteristic feature of the first lignite seam, which found its expression in distinguishing the *Sequoia* phase (Raniecka-Bobrowska 1970) or *Sequoia–Nyssa–Quercus* phase (Ziembińska-Tworzydło and Ważyńska 1981).

A high percentage of pollen from the shrubs *Ilex*, *Myrica*, Cyrillaceae, Ericaceae, Rosaceae, and others, as well as *Tricolporopollenites pseudocingulum*, together with a low frequency of swamp taxa (mainly *Taxodium/Glyptostrobus*), was observed at Pątnów in the Konin region (Sadowska and Giża 1991). Similar in this respect are also several palynofloras from central and western Poland: Ustronie (Ziembińska and Niklewski 1966; Ziembińska-Tworzydło 1974); Mirostowice, Staszów, Jerzmanowa, Tarpno, Jaroszów (Sadowska 1977); and Ruszów (Dyjor and Sadowska 1977). The differences between palynofloras dominated by swamp forests (e.g. from Legnica) and palynofloras dominated by shrub bogs (e.g. from Adamów) are most probably a reflection of various plant communities developing in different hydrological and trophic conditions. Brown coal lithotypes with abundant *Sequoia* were formed in slightly drier conditions than those produced by reed marsh or the *Glyptostrobus–Taxodium–Nyssa* swamp forests (Holdgate et al. 2016).

Data from Adamów (MAT between 15.7–18.0 °C), Józwin (15.0–18.5 °C), and Legnica (15.6–16.6 °C) do not demonstrate differences in the mean annual temperature between the sites. Similarly, according to Kasiński and Słodkowska (2016) the temperature range for the first mid-Polish seam was 15.7–19.7 °C. Thus, it confirms that the climate was more or less homogenous within the entire Polish Lowlands during formation of the first mid-Polish lignite seam. The climate was warm temperate and humid. Large areas were then covered by slowly flowing waters, swamps, and peat bogs.

Therefore, lignites of the first mid-Polish group were formed in a large area.

The mean annual temperatures inferred from the first mid-Polish group of lignite seams do not demonstrate significant changes compared to the second Lusatian group (Langhian in age). The MAT coexistence intervals for second Lusatian seam from Legnica, SW Poland, range mainly between 15.6–18.6 °C, but intervals between 17.2–18.6 °C also occur (Ivanov and Worobiec 2017). The main trend of vegetation changes between the first and second seams is a general decrease in the abundance of palaeotropical and thermophilous elements and some reduction of macrothermic elements of semi-evergreen forests. Together with these changes, a corresponding increase in the role of 'arctotertiary' species took place within the plant communities (Ivanov and Worobiec 2017).

Results from Adamów are also similar to other middle Miocene MAT ranges from Central Europe. The temperature increased in late Burdigalian and a warm period persisted to earlier part of Serravallian. That corresponds to globally observed Mid-Miocene Climatic Optimum (Mosbrugger et al. 2005). Utescher et al. (2012) analysed climate variability in Northwest Germany during Burdigalian to Zanclean (early Miocene to early Pliocene). The MAT means in this time varied between 13 °C and 20 °C, with considerable small-scale variability. This variability appears to be lowest during the early Serravallian and in the Tortonian. From the latest Burdigalian to the Serravallian, a MAT of 18.3 °C results from the microfloras when averaging means obtained from all samples. This value is close to the macroflora-based temperature ranges (17.8–19.6 °C) from Germany (Utescher et al. 2009). Mean temperatures decreased during the Tortonian, and next warm phase near the top of the Tortonian is recorded. In the Polish Lowlands after the first lignite seam only small lenses of lignites, late Tortonian in age, are recorded (Słodkowska 1998). Above the first group of seam, in the late Serravalian or Tortonian (latest middle Miocene and late Miocene) leaf assemblages from the Bełchatów Lignite Mine, central Poland, the MAT range as 13.5 °C–16.5 °C was estimated (Worobiec and Szynkiewicz 2016; Worobiec and Worobiec 2019). For comparison, the present-day climate of the Konin area, adjacent to the Adamów lignite deposit, is characterized as cold and temperate and the mean annual temperature averages 8.3 °C (Climate-Data 2019).

6. Conclusions

Palynological analysis of the first mid-Polish lignite seam from Adamów revealed the presence of wetland and mesophytic vegetation. The study area was overgrown by palustrine wetland communities, similar in composition to the modern pocosins. In the Fore-Sudetic region, SW Poland (e.g. in the Legnica and Ruja deposits) and in some profiles from central Poland (also in the Konin area) swamp forests dominated. Contributions of pollen grains of mesophytic taxa are similar in individual diagrams, which indicates the growth of the mesophytic forests at a distance from the sedimentary basins. Comparison of various palynological profiles shows that the vegetation forming the first mid-Polish lignite seam group had the form of a mosaic, in which element arrangement depends on environmental conditions. In addition, differences resulting from floral succession and peatland aggradation may occur. The climate was warm temperate and humid; more or less homogenous within the entire Polish Lowlands during formation of the first mid-Polish lignite seam. The differences between the shrub bog dominated palynoflora from Adamów and the swamp forest dominated palynofloras from the first mid-Polish seam are most probably a reflection of various plant communities developing under different hydrological and trophic conditions.

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