Annales Societatis Geologorum Poloniae (2020), vol. 90: 495 – 504 doi: https://doi.org/10.14241/asgp.2020.26

PALYNOLOGY OF OLIGOCENE LIGNITES IN TWO KARST PALAEOSINKHOLES AT GÓRAŻDŻE, UPPER SILESIA, POLAND

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Worobiec, E. & Szulc, J., 2020. Palynology of Oligocene lignites in two karst palaeosinkholes at Górażdże, Upper Silesia, Poland. *Annales Societatis Geologorum Poloniae*, 90: 495 – 504.

Abstract: A palynological analysis was carried out on about 115 samples from two borehole cores, containing the infills of two palaeosinkholes at Górażdże. In both sinkholes, well preserved palynofloras were found in several lignite samples. A total of 54 fossil species, including 5 species of cryptogam spores, 7 species of gymnosperm pollen and 42 species of angiosperm pollen, were identified. No marine palynomorphs or microremains re-deposited from older sediments have been found in these samples. The spore-pollen assemblage made it possible to date the sinkhole deposits. The composition of the assemblage (e.g., abundance of small tricolporate pollen grains of the Fagaceae family, including *Cupuliferoipollenites pusillus*, *Fususpollenites fusus*, and *Quercoidites microhenricii*) indicates that the age of the lignites in both sinkholes is early Oligocene. Thus, the deposits at Górażdże correspond to the 5th Czempiń lignite seam group. The 5th seam occurs mainly in northwestern Poland and its lignites were deposited in isolated wetland basins with marine influences. The terrestrial Górażdże palynoflora without any marine influence shows mainly local early Oligocene vegetation from the surrounding area. The results are also direct evidence of the multiphase palaeokarst of the Silesian-Cracow Upland, including the deposition of lignites of various ages.

Key words: Palynostratigraphy, palaeokarst, sinkhole deposits, coal, pollen grains, Palaeogene.

Manuscript received 4 July 2020, accepted 28 December 2020

INTRODUCTION

The Middle Triassic limestone bedrock of the Upper Silesian-Cracow Upland, SW Poland, display numerous palaeokarstic forms, filled with a variety of internal sediments. The palaeokarst phenomena include both covered and uncovered karst forms, filled with flowstones and clastic and organic deposits (Głazek, 1989; Szulc and Worobiec, 2012). The most common palaeokarstic forms are sinkholes (dolines) developed in reefal and bioclastic carbonates of the Lower Muschelkalk. The sinkholes range from 10 to 150 m in diameter and reach 30 metres in depth. They are filled with variegated, clayey and sandy clastics, and commonly also with lignites. The latter line the bottom and sidewalls of the depression or form layered intercalations in the clastic fill (Szulc and Worobiec, 2012).

Palynological studies of the deposits from palaeosinkholes, outcropping in the Tarnów Opolski and Górażdże quarries, started in 2009. During the palynological investigation of those deposits, well preserved, rich pollen and spore assemblages and abundant freshwater algal microfossils (mainly green algae), were recorded. The taxonomical composition of the pollen and spore assemblages and the excellent state of preservation of most of the sporomorphs (pollen grains and plant spores) indicate an *in situ* mode of occurrence. They made it possible to date the sinkhole deposits and allowed the detailed palaeoenvironmental reconstructions of Miocene vegetation in this region (Worobiec and Szulc, 2010a, b; Szulc and Worobiec, 2012).

Palynological analysis confirmed the presence of shallow-water bodies (ponds) in both of the sinkholes studied (Worobiec, 2014a). The water body at Tarnów Opolski was surrounded by swamp-aquatic vegetation, composed of herbs and swamp forests and riparian forests. In drier habitats, there were mesophytic forests, with an admixture of thermophilous taxa. The climate during deposition of the sediments was warm-temperate and humid. The composition of pollen spectra and frequencies of palaeotropical and arctotertiary elements, when compared with data from other pollen sites in Poland, indicate the middle Miocene age of the deposit; the lignites in that sinkhole correspond to the 1st mid-Polish lignite group (Worobiec and Szulc, 2010a). At present, similar plant communities occur in the Mississippi River Delta, Florida, Georgia, North Carolina and the Gulf of Mexico coast. There are some similarities between the middle Miocene landscape of the study area and present-day west-central Florida (USA), where numerous sinkholes and other karst features occur (Worobiec and Szulc, 2010a, b; Worobiec, 2011).

The results of pollen analysis from the sinkhole outcropping at Górażdże indicated the presence of a water body (pond), surrounded by herbaceous and riparian vegetation and mixed mesophytic forests. The climate during deposition of the sediments in the sinkhole was warm-temperate – cooler than during the middle Miocene, but still warmer than the present-day climate of Poland (Szulc and Worobiec, 2012; Worobiec, 2014b). The composition of the Górażdże palynoflora indicated a late Miocene age. Differences between the palynofloras from the Górażdże and Tarnów Opolski sinkholes were mainly quantitative. The composition of algal assemblages and that of the pollen of aquatic plants and herbs surrounding the water body, was similar in both palaeosinkholes (Worobiec, 2014a). The differences between the palynofloras from those two sinkholes were clearly visible in the compositions ofthe forest taxa, reflecting changes in the climate and vegetation of the surrounding area during the middle and late Miocene (Szulc and Worobiec, 2012; Worobiec, 2014b).

In recent years, palynological analysis of several dozen sediment samples from karst forms (including palaeosinkholes, caves, and fluvioglacial deposits), outcropping in the Opole region, was carried out to reconstruct the karst process phases in the study area. It seems that particularly intensive karst denudation processes took place in the Neogene, as evidenced by the taxonomically rich assemblages of well-preserved sporomorphs and microfossils of freshwater algae, found in sinkhole deposits in the western part of the Silesian Upland (Worobiec and Szulc, 2010a, b, 2012; Worobiec, 2011, 2014a, b; Szulc and Worobiec, 2012). In addition to the middle and upper Miocene palynofloras, Pliocene spore-pollen assemblages were found (unpublished data). The last phase of karstification is represented by the Quaternary karst, with very interesting forms of subglacial karst (Szulc *et al.*, 2015).

These very interesting results were the main motivation for conducting palynological research on drill-core materials. Several boreholes were drilled at Górażdże and Tarnów Opolski in 2014 and about 200 palynological samples were studied. The results were to be published in a comprehensive summary article. Unfortunately, the untimely death of Joachim Szulc thwarted this plan. This paper presents the results of the palynological analysis of two borehole cores from Górażdże and is confined to the Palaeogene sediments, including the lignites.

GEOLOGICAL SETTING

In the western part of Upper Silesia, numerous palaeokarstic forms developed in the Middle Triassic Muschelkalk carbonates. They occur mainly in the Górażdże Beds and the Karchowice-Diplopora Beds. Such a distribution is controlled by the lithological properties of the rocks that are composed of pure limestones, underlain by less permeable marly deposits. At Górażdże, the sinkholes developed in thick-bedded and coarse-grained, bioclastic, oncolithic and oolitic limestones, interbedded with fine-grained, nodular limestones, making up a succession 15 m thick in the Górażdże Beds. These pure limestones are underlain by marly sediments of the Upper Gogolin Beds. The marls form a poorly permeable horizon, which restricted the circulation of descending ground water and thus limited the downward progress of karst processes (Szulc and Worobiec, 2012).

MATERIALS AND METHODS

For palynological analysis, about 115 samples were taken from two borehole cores (GOR-1-B and GOR-2) at Górażdże (50°32′N, 18°02′E; Fig. 1). The boreholes penetrated the entire infills of two palaeosinkholes, including clays, sand and lignites (Figs 2, 3). About 100 samples were collected from GOR-1-B (at ca. 10 cm intervals from depths between 0.10–9.90 m) and 15 samples from GOR-2 (at ca. 20 cm intervals from depths between 9.20–12.00 m).

The palynological samples were processed in the Laboratory of the W. Szafer Institute of Botany, Polish Academy

Fig. 1. Location map of Górażdże and geographical extent of the 5th Czempiń lignite seam (simplified, after Kasiński and Słodkowska, 2016; supplemented by Gedl *et al.*, 2016). Lower Oligocene localities mentioned in the text: 1 – Pomeranian Lakeland area; 2 – Warmia and Mazury; 3 – Warszyce 19 borehole, Rogóźno deposit; 4 – Middle Vistula River valley; 5 – Łukowa-4 borehole.

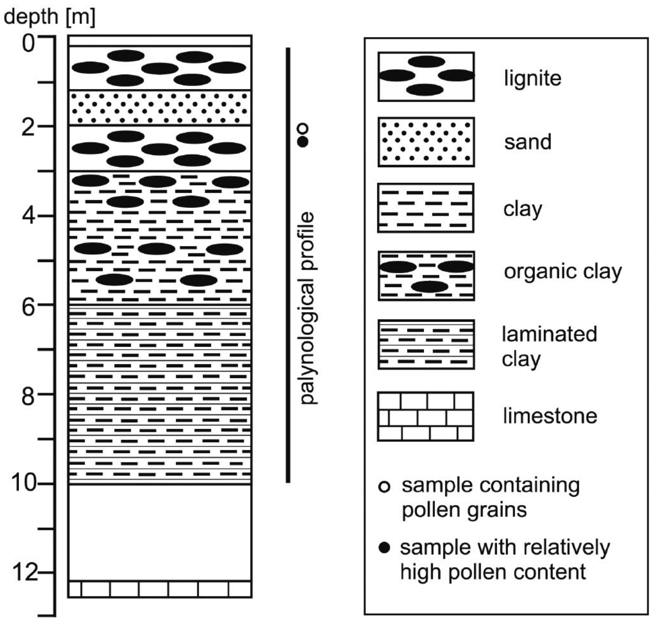

Fig. 2. Lithology and sample locations in the GOR-1-B borehole.

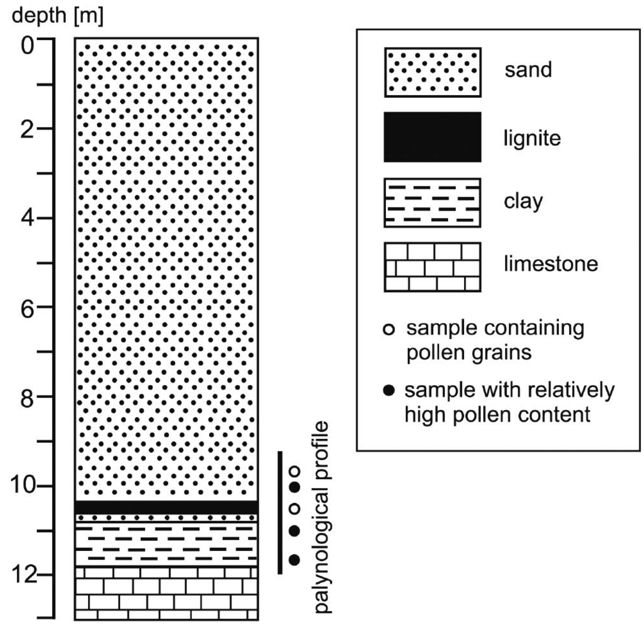

Fig. 3. Lithology and sample locations in the GOR-2 borehole.

of Sciences, Kraków. The portions of crushed rock were treated successively with 10% hydrochloric acid (HCl) to remove carbonates, 10% potassium hydroxide (KOH), 40% hydrofluoric acid (HF) for four days to remove silicates, and 10% hydrochloric acid (HCl) to remove silicofluorides (Moore *et al.*, 1991). In addition, the residuum was sieved at 5 µm on a nylon mesh. The microscope slides were made, using glycerine jelly or glycerine as a mounting medium and coverslips 24 × 24 mm. Depending on the frequency of the sporomorphs (pollen grains and spores of plants), 2–8 microscope slides from each sample were studied. The rock samples, palynological residues and slides are stored in the W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

The sporomorph taxa identified were classified according to an appropriate palaeofloristical element, mainly with reference to 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); and cosmopolitan (P/A). Microphotographs of selected pollen grains were taken using a NIKON Eclipse microscope, fitted with a Canon digital camera.

RESULTS OF THE PALYNOLOGICAL STUDIES

Most of the samples studied were barren or yielded only sparse sporomorphs. Nevertheless, in several samples very interesting spore-pollen assemblages were recorded. One sample from the GOR-1-B borehole, taken from a depth of 2.30 m, as well as three samples from the GOR-2 borehole, taken from depths of 10.00 m, 11.20 m and 11.80 m (Figs 2, 3), yielded rich and well preserved sporomorphs. These samples were taken from dark sediment, including lignites (Fig. 4). Pollen spectra from these samples are taxonomically diversified and they are similar in composition (Tab. 1). In a few other neighbouring samples (e.g., from a sample taken from a depth of 1.90 m from the GOR-1-B borehole and from samples taken from depths of 9.60 m and 10.40 m from the GOR-2 borehole), the same taxa were found in the best four samples, but the frequencies of the sporomorphs were distinctly lower. A total of 54 fossil species, including 5 species of cryptogam spores, 7 species of gymnosperm pollen and 42 species of angiosperm pollen, were identified (Tab. 1; Fig. 5).

In all these samples pollen grains of angiosperms distinctly predominate (Tab. 1). There are mainly small tricolporate pollen grains from the Fagaceae family (mainly fossil species *Cupuliferoipollenites pusillus*, *Fususpollenites fusus*, and *Quercoidites microhenricii*) and Cyrillaceae/Clethraceae (*Cyrillaceaepollenites exactus*, *C. megaexactus*, and *C. brühlensis*). Other trees and shrubs are represented by Fabaceae (*Tricolporopollenites liblarensis*, *T. fallax*, and *T. quisqualis*), Juglandaceae (*Momipites quietus*, *M. punctatus*, *Platycaryapollenites* sp., and *Caryapollenites* cf. *triangulus*), Betulaceae (mainly *Alnipollenites* and *Trivestibulopollenites betuloides*) and Aquifoliaceae (*Ilexpollenites margaritatus* and *Ilexpollenites* cf. *propinquus*), Sapotaceae, Platanaceae (*Platanipollis ipelensis*), Arecaceae (palms), Ericaceae, Malvaceae (*Reevesiapollis* cf. *microreticulatus* and *Intratriporopollenites* cf. *microreticulatus*), Oleaceae, Myricaceae, Nyssaceae, Ulmaceae, Hamamelidaceae (*Tricolporopollenites staresedloensis*), Salicaceae and Mastixiaceae (*Cornaceaepollis satzveyensis*). In addition, a few pollen grains of the fossil species *Triporopollenites megagranifer*, and *Plicapollis* sp. from the Normapolles group, plus one pollen grain of *Emmapollis pseudoemmaensis* were recorded.

Table 1

Results of palynological analysis (number of palynomorphs) of the samples from the GOR-1-B and GOR-2 boreholes.

Fossil taxa	Botanical affinity	Element	GOR-1-B		GOR-2			
			2.30 m	mean [%]	10.00 m	11.20 m	11.80 m	mean [%]
Spores of cryptogams:								
Laevigatosporites sp.	Polypodiaceae, Davalliaceae and other ferns	P/A	6	1.51	2	2	1	0.89
Baculatisporites sp.	Osmundaceae	P/A			1			0.18
Stereisporites sp. + *Distancoraesporis* sp. + *Distverrusporis* sp.	Sphagnaceae: *Sphagnum*	P/A	7	1.77	1	2		0.54
Pollen grains of gymnosperms:								
Cathayapollis sp. + *Pinuspollenites* sp.	Pinaceae: *Cathaya*, *Pinus*	A1	2	0.50	2	4		1.07
Cupressacites sp.	Cupressaceae, Taxaceae	A1	5	1.26	6		4	1.79
Inaperturopollenites concedipites (Wodehouse) Krutzsch + *I. dubius* (Potonié et Venitz) Thomson et Pflug	Cupressaceae: *Taxodium*, *Glyptostrobus*	P2/A1	43	10.86	66	26	20	20.00
Sciadopityspollenites sp.	Sciadopityaceae: *Sciadopitys*	A1	1	0.25				
Sequoiapollenites sp.	Cupressaceae: *Sequoia*, *Sequoiadendron*, *Metasequoia*	A1	4	1.01	29	6	8	7.68
Pollen grains of angiosperms:								
Alnipollenites metaplasmus (Potonié) Potonié + *Alnipollenites* sp.	Betulaceae: *Alnus*	P2/A	21	5.30	2	4	1	1.25
Arecipites cf. *convexus* (Thiergart) Krutzsch	Arecaceae	P/A1			1			0.18
Arecipites sp.	Arecaceae?, Butomaceae?	P/A	2	0.50		1		0.18
Carpinipites sp.	Betulaceae: *Carpinus*	P2/A1				1		0.18
Caryapollenites cf. *triangulus* (Pflug) Krutzsch	Juglandaceae: *Carya*	P			2			0.36
Cornaceaepollis satzveyensis (Pflug) Ziembińska-Tworzydło	Mastixiaceae	P1	1	0.25			1	0.18
Cupuliferoipollenites oviformis (Potonié) Potonié	Fagaceae: *Castanea*, *Castanopsis*, *Lithocarpus*	P2/A1	5	1.26	8			1.43
Cupuliferoipollenites pusillus (Potonié) Potonié	Fagaceae: *Castanea*, *Castanopsis*, *Lithocarpus*	P2/A1	93	23.58	95	21	39	27.68
Cyrillaceaepollenites brühlensis (Thomson) Durska	Cyrillaceae, Clethraceae	P			2		1	0.54
Cyrillaceaepollenites exactus (Potonié) Potonié	Cyrillaceae, Clethraceae	P	51	12.88	56	7	6	12.32
Cyrillaceaepollenites megaexactus (Potonié) Potonié	Cyrillaceae, Clethraceae	P	6	1.51	4	1		0.89

Fossil taxa	Botanical affinity	Element	GOR-1-B		GOR-2			
			2.30 m	mean [%]	10.00 m	11.20 m	11.80 m	mean [%]
Emmapollis pseudoemmaensis Krutzsch	Chloranthaceae?	P1	1	0.25				
Ericipites sp.	Ericaceae	P/A			5	1		1.07
Fususpollenites fusus (Potonié) Kedves	Fagaceae: *Trigonobalanus s.l.* (incl. *Colombobalanus*)	P1	42	10.61	16	2	3	3.75
Ilexpollenites margaritatus (Potonié) Thiergart	Aquifoliaceae: *Ilex*	P2			11			1.96
Ilexpollenites cf. *propinquus* (Potonié) Potonié	Aquifoliaceae: *Ilex*	P/A1	2	0.50	1			0.18
Intratriporopollenites cf. *microreticulatus* Mai	Malvaceae: Tilioideae, Brownlowioideae	P	1	0.25				
Momipites quietus (Potonié) Nichols	Juglandaceae: *Engelhardia*, *Alfaroa*, *Oreomunnea*	P			4			0.71
Momipites punctatus (Potonié) Nagy	Juglandaceae: *Engelhardia*, *Alfaroa*, *Oreomunnea*	P2	4	1.01	1			0.18
Myricipites sp.	Myricaceae: *Myrica*	P2/A1			4		1	0.89
Nyssapollenites sp.	Nyssaceae: *Nyssa*	P2/A1	1	0.25	2	1		0.54
Oleoidearumpollenites cf. *microreticu-latus* (Pflug) Ziembińska-Tworzydło	Oleaceae	P2/A1	3	0.76			1	0.18
Oleoidearumpollenites sp.	Oleaceae	P2/A1			1	1		0.36
Quercoidites microhenricii (Potonié) Potonié, Thomson et Thiergart	Fagaceae: Quercoideae	P2/A1	8	2.02	1		1	0.36
Platanipollis ipelensis (Pacltová) Grabowska	Platanaceae: *Platanus*	P/A1	3	0.76		2	1	0.54
Platycaryapollenites sp.	Juglandaceae: *Platycarya*	P2/A1	12	3.03	1		1	0.36
Reevesiapollis cf. *microreticulatus* Krutzsch	Malvaceae: *Reevesia*	P	2	0.50	1		1	0.36
Salixipollenites sp.	Salicaceae	A			1			0.18
Sapotaceoidaepollenites sp.	Sapotaceae	P	6	1.51	1	2		0.54
Sparganiaceaepollenites sp.	Sparganiaceae, Typhaceae	P/A					1	0.18
Tricolporopollenites fallax (Potonié) Krutzsch	Fabaceae	P/A	6	1.51	2	2		0.71
Tricolporopollenites liblarensis (Thomson) Hochuli	Fabaceae	P/A	14	3.53	9	1		1.79
Tricolporopollenites quisqualis (Potonié) Krutzsch	Fabaceae	P/A	7	1.77		4	1	0.71
Tricolporopollenites staresedloensis Krutzsch et Pacltová	Hamamelidaceae: *Parrotia*, *Distylium*	P2	3	0.76				
Tricolporopollenites cf. *villensis* (Thomson) Thomson et Pflug	Fagaceae?	unk-nown			4	2		1.07

Fossil taxa	Botanical affinity	Element	GOR-1-B		GOR-2			
			2.30 m	mean [%]	10.00 m	11.20 m	11.80 m	mean [%]
Tricolporopollenites sp.	unknown	unk-nown			1			0.18
Triporopollenites megagranifer (Potonié) Thomson et Pflug	Betulaceae?, Ulmaceae?	P2/A1	1	0.25	1			0.18
Trivestibulopollenites betuloides Pflug	Betulaceae: *Betula*	A	5	1.26	5	2	2	1.61
Ulmipollenites undulosus Wolff + *Ulmipollenites* sp.	Ulmaceae: *Ulmus*	A	2	0.50	1	1		0.36
Normapolles group: *Plicapollis* sp.	Rhoipteleaceae	P1	3	0.76			1	0.18
other pollen grains	unknown	unk-nown	23	5.81	8	3	3	2.50
Fungi:								
fungal spores	Fungi	unk-nown	3	0.76	3	3		1.07
Total:			396	100.0	358	99	98	100.0

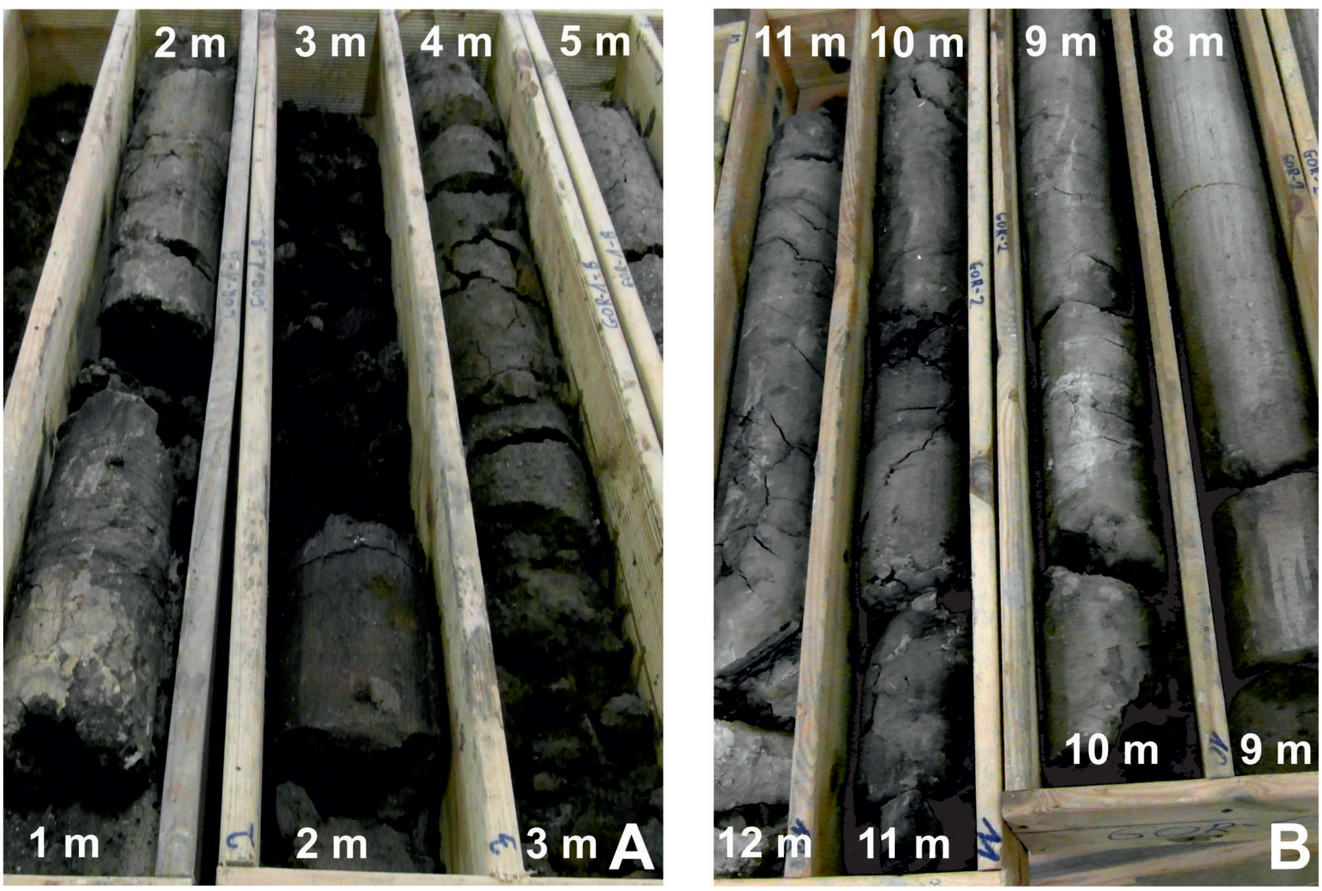

Fig. 4. Fragments of borehole cores from Górażdże with lignites. **A.** GOR-1-B. **B.** GOR-2.

Among the gymnosperms, pollen grains of the Cupressaceae family, including *Taxodium/Glyptostrobus* (fossil genus *Inaperturopollenites*), *Sequoia/Sequoiadendron/Metasequoia* and other Cupressaceae/Taxaceae are the most frequent. Other conifers are represented by the rare pollen grains of the Pinaceae family and *Sciadopitys*. Cryptogams are represented only by the rare spores of ferns (fossil genera *Laevigatosporites* and *Baculatisporites*) and *Sphagnum*. Non-pollen palynomorphs are very rare; only several fungal spores were recorded in most samples. No marine

Fig. 5. Pollen grains from the GOR-1-B and GOR-2 boreholes. Botanical affinity in brackets. One scale for all photographs. **A.** *Inaperturopollenites concedipites* (*Taxodium*, *Glyptostrobus*), GOR-1-B, depth 2.30 m. **B.** *Inaperturopollenites dubius* (*Taxodium*, *Glyptostrobus*), GOR-1-B, depth 2.30 m. **C.** *Sequoiapollenites* sp. (*Sequoia*, *Sequoiadendron*, *Metasequoia*), GOR-2, depth 10.00 m. **D.** triporate pollen grain, GOR-2, depth 10.00 m. **E.** *Myricipites* sp. (*Myrica*), GOR-2, depth 10.00 m. **F.** *Alnipollenites metaplasmus* (*Alnus*), GOR-1-B, depth 2.30 m. **G.** *Ulmipollenites undulosus* (*Ulmus*), GOR-2, depth 10.00 m. **H, I.** *Cyrillaceaepollenites exactus* (Cyrillaceae, Clethraceae), GOR-2, depth 10.00 m. **J.** *Cyrillaceaepollenites megaexactus* (Cyrillaceae, Clethraceae), GOR-2, depth 10.00 m. **K, L.** *Fususpollenites fusus* (*Colombobalanus*), GOR-2, depth 10.00 m – same specimen, various foci. **M–O.** *Fususpollenites fusus* (*Colombobalanus*), GOR-2, depth 10.00 m – same specimen, various foci. **P.** *Fususpollenites fusus* (*Colombobalanus*), GOR-1-B, depth 2.30 m. **Q–S.** *Tricolporopollenites* sp. (unknown botanical affinity), GOR-2, depth 10.00 m – same specimen, various foci. **T, U.** *Cupuliferoipollenites pusillus* (Castaneoideae), GOR-1-B, depth 2.30 m – same specimen, various foci. **V.** *Tricolporopollenites liblarensis* (Fabaceae), GOR-1-B, depth 2.30 m.

palynomorphs or microremains re-deposited from older sediments have been found in these samples. Several small fragments of plant tissues were encountered.

The composition of the sporomorph association from the samples studied shows an apparent dominance of palaeotropical (including tropical and subtropical) and palaeotropical/warm-temperate palaeofloristical elements (Tab. 1; Fig. 6). These elements are represented, for example, by pollen grains of *Inaperturopollenites concedipites*, *I. dubius*, *Arecipites* cf. *convexus*, *Cupuliferoipollenites oviformis*, *C. pusillus*, *Cyrillaceaepollenites brühlensis, C. exactus*, *C. megaexactus*, *Fususpollenites fusus*, *Ilexpollenites margaritatus*, *Ilexpollenites* cf. *propinquus*, *Intratriporopollenites* cf. *microreticulatus*, *Momipites quietus*, *M. punctatus*, *Myricipites* sp., *Nyssapollenites* sp., *Oleoidearumpollenites* cf. *microreticulatus*, *Oleoidearumpollenites* sp., *Quercoidites microhenricii*, *Platanipollis ipelensis*, *Platycaryapollenites* sp., *Reevesiapollis* cf. *microreticulatus*, *Sapotaceoidaepollenites* sp., *Tricolporopollenites staresedloensis*, *Triporopollenites megagranifer*, and *Plicapollis* sp.

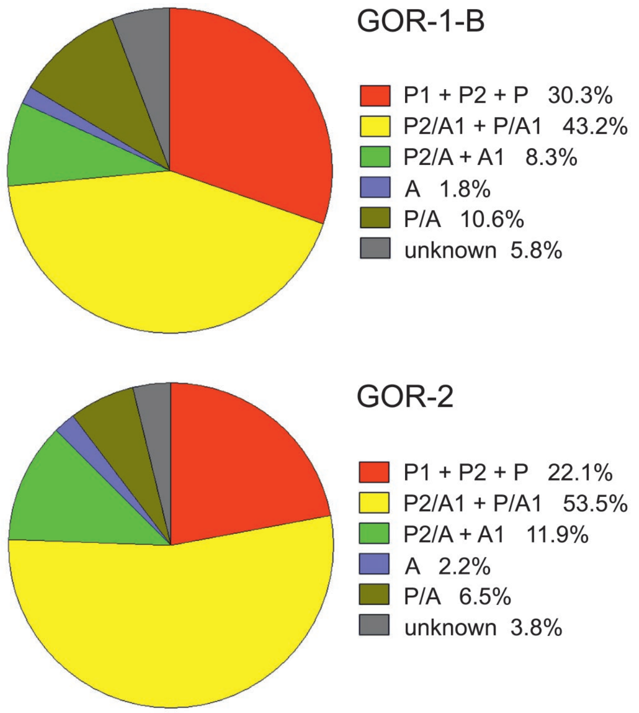

Fig. 6. Diagrams showing the proportions of sporomorphs of particular palaeofloristical elements in the samples from the GOR-1-B and GOR-2 boreholes.

DISCUSSION – PLANT COMMUNITIES, PALAEOENVIRONMENT AND AGE OF THE PALYNOFLORA

The results of the pollen analysis of the samples from both boreholes indicate the presence of evergreen forests. These forests were composed of thermophilous taxa, such as members of the Fagaceae family (probably members of the Castaneoideae subfamily, genera *Trigonobalanus/Colombobalanus*, evergreen *Quercus* and others), *Platycarya*, Engelhardioideae, *Platanus*, *Reevesia*, members of the Fabaceae and Sapotaceae families and others. *Taxodium*, *Nyssa*, and presumably *Glyptostrobus,* might have overgrown the neighbouring area with a higher groundwater level or the marginal zone of the sinkhole(s). Shrubs from the Cyrillaceae, Clethraceae, Ericaceae and Myricaceae families, *Ilex* and some palms also occurred in the vicinity. The predominance of tree genera, growing now under tropical and subtropical climatic conditions, is well demonstrated (Tab. 1). These observations indicate that the climate during the sedimentation of the infills of the sinkholes was very warm and humid. These conditions would have favoured karstification.

The palynoflora studied distinctly differs from both Miocene palynofloras, found in the palaeosinkholes outcropping at Górażdże (Szulc and Worobiec, 2012; Worobiec, 2014b) and Tarnów Opolski (Worobiec and Szulc, 2010a, b; Worobiec, 2011). It is rich in palaeotropical taxa and contains many species not present in Neogene deposits, whereas herbaceous plants are almost absent. Conversely, the palynoflora is most similar in its composition to the Palaeogene assemblages that are younger than the Paleocene (Grabowska, 1996). Changes in the composition of the Palaeogene palynofloras in Europe were related to significant changes in the Earth's climate. The warm and humid greenhouse climate of the early and middle Eocene changed to an icehouse climate through the late Eocene (Zachos *et al.*, 2001; Roth-Nebelsick *et al.*, 2004). Consequently, the late Paleocene to middle Eocene paratropical evergreen forest vegetation, characteristic for a tropical climate, changed in a stepwise manner to broadleaved, mixed deciduous and evergreen forests in the late Eocene. In the Oligocene, the vegetation changed to mixed mesophytic forests with a significant admixture of thermophilous taxa (Collinson and Hooker, 2003; Kvaček, 2010; Worobiec *et al.*, 2015; Kowalski *et al.*, 2020).

The Górażdże palynoflora is rich in tropical and subtropical elements but contains only a few Normapolles pollen grains. This is the main difference between the palynoflora studied here and the Paleocene and Eocene palynofloras, characterised by, for example, the presence and richness of pollen grains from the so-called Normapolles group. Pollen grains referable to the Normapolles were most numerous in a province which extended from what is now West Siberia across Europe to eastern North America. They first appeared during the Cenomanian, diversified rapidly through the remainder of the Cretaceous and during the early Palaeogene, but by the end of the Eocene they were almost extinct (Batten, 1981). In the early Oligocene, the Normapolles group was represented by rare specimens of *Plicapollis* only (Grabowska, 1996). *Fususpollenites fusus* and *Quercoidites microhenricii* are other taxa that are characteristic for the Oligocene palynofloras, as they are abundant in lower Oligocene deposits and sparse in the lower Miocene sediments. As a contrast, Miocene lignites are rich in *Quercoidites henricii*, *Tricolporopollenites pseudocingulum*, *Edmundipollis* and other taxa (Kasiński and Słodkowska, 2016). In addition, the stratigraphic range of *Emmapollis pseudoemmaensis* is confined to the early Eocene–early Oligocene (Grabowska, 1996). The composition of the palynological spectra, including the predominance of small tricolporate pollen grains from the Fagaceae family, the occurrence of other palaeotropical taxa and the presence of rare specimens of Normapolles pollen and *Emmapollis pseudoemmaensis*, clearly indicate an early Oligocene age of the palynoflora.

The lower Oligocene deposits (Czempiń/Rupel Formation) are widespread throughout the Polish Lowlands (Piwocki, 2004), and form an important correlation horizon. The Rupelian marine and brackish-water deposits are usually synchronous with brackish-lacustrine sediments, containing lignite interbeds of the 5th Czempiń lignite seam. The Czempiń seam is correlated with the 5th Lusatian seam in the southeastern territory of Germany (Widera, 2016). Lower Oligocene (Rupelian) strata have relatively rich palynological documentation from the numerous sections in the Polish Lowlands (Grabowska, 1996; Słodkowska, 2004a, b, 2009; Kasiński and Słodkowska, 2016), due to the presence of lignites of the 5th group, but the results of most of these studies are unpublished (Grabowska and Słodkowska, 1993).

The formation of the 5th Czempiń lignite seam marked the beginning of extensive lignite deposition in the Polish Lowlands. This seam has a limited extent and occurs mainly in northwestern Poland (Fig. 1), occupying a total area of ca. 7,700 km^2. Its thickness is usually small and does not exceed 1 m, but it reaches a considerable thickness in depressions in the salt dome caps. In extreme cases (e.g., in the Rogóźno and Wapno salt domes), its thickness may exceed 40 m. Lignites of the 5th seam originated within isolated wetland basins, surrounded by very lush and mostly mesophilous vegetation. In northern and central Poland, marine phytoplankton (dinoflagellate cysts) indicates the paralic character of the swamp basins, with a marine influence (Grabowska, 1996; Słodkowska, 2004a, b). In the mixed mesophilous forests, plants with highly thermophilous requirements predominated. The climate at that time was very warm, almost subtropical, with the mean annual temperature in the range of 17.2–23.9 °C. The palaeoclimate corresponded to a humid, subtropical climate (Cfa type) in the sub-division of Köppen (Kottek *et al.*, 2006), characterised by hot, usually humid, summers and mild winters (Kasiński and Słodkowska, 2016).

The Górażdże palynoflora is very similar to the spore-pollen assemblages from the 5th Czempiń seam in the Warszyce 19 borehole, central Poland (Grabowska, 1969 in Kasiński and Słodkowska, 2016) and to the lower Oligocene strata at localities in the Middle Vistula River valley (Słodkowska, 2004b), Pomeranian Lakeland area (Słodkowska, 2004a), and the Warmia and Mazury areas (Słodkowska, 2009). The main differences between the Górażdże assemblage and the lower Oligocene assemblages from northern Poland are the lack of marine palynomorphs and the very low frequency of bisaccate pollen grains in the Górażdże samples (Tab. 1). The presence of only sparse pollen grains of the Pinaceae family could have been caused by dense vegetation, composed of other taxa, covering the vicinity of the sinkholes. In addition, bisaccate pollen grains are always over-represented in marine sediments and the deposits at Górażdże were formed in terrestrial conditions.

The Górażdże palynoflora also shows a similarity to the assemblage from brown coal in the upper section of the Łukowa-4 borehole, SE Poland (Gedl *et al.*, 2016). In contrast to the marine/brackish lower Oligocene strata mentioned above, coal beds from Łukowa were deposited in a freshwater environment. Unfortunately, the Łukowa samples contained a poor palynological assemblage and, therefore, detailed comparisons between these palynofloras are impossible.

CONCLUSIONS

A palynological analysis was carried out on two borehole cores from Górażdże, containing the infills of two palaeosinkholes. Of the 115 samples analysed, only 7 contained pollen grains and spores. Nevertheless, the well preserved palynoflora in these samples made it possible to date the sinkhole deposits. The presence of *Emmapollis pseudoemmaensis* and rare specimens of *Plicapollis*, together with the overall composition of the assemblage (e.g., rich in small tricolporate pollen grains of the Fagaceae family), indicate that the age of the lignites in both sinkholes is early Oligocene. Thus, the deposits from Górażdże can be correlated with the 5th Czempiń seam group and they are the most south-westerly occurrence of lower Oligocene lignite in Poland. Moreover, this palynoflora is free from marine influences and, therefore, shows the local and zonal vegetation better, because the over-representation of bisaccate pollen (mainly *Pinus*) in marine samples often hides other elements of palynofloras. The results are also direct evidence of the multiphase palaeokarst of the Silesian-Cracow Upland, including the deposition of lignites of various ages (Oligocene and Miocene). Like the Miocene infills, the sediments analysed were formed during a warm and humid climatic phase, which favoured the processes of karstification.

Acknowledgements

This paper commemorates the late Professor Joachim Szulc as a geologist and friend. Joint fieldwork in the Opole region (especially in the Tarnów Opolski and Górażdże quarries) with him and my husband, the 46th Speleological Symposium (Góra Świętej Anny, 2012) and many discussions will remain in my memory forever. I thank my husband, Grzegorz Worobiec (W. Szafer Institute of Botany PAS), for his help in photographing pollen grains and Torsten Utescher, Adam Bodzioch and an anonymous reviewer for their comments on the manuscript. I am grateful to the authority of the Górażdże Heidelberg Cement Group for kindly allowing us to undertake fieldwork in the quarry. The study was supported by Polish National Science Centre (Grant No. 2011/01/B/ST10/04052) as well as by the W. Szafer Institute of Botany, Polish Academy of Sciences, through its statutory funds.

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