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Spore-pollen and phytoplankton analysis of the Upper Miocene deposits from Józefina (Kraków–Silesia Upland, Poland)

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Pollen grains, spores and phytoplankton from the Neogene succession of a borehole at Józefina (northern part of the Kraków–Silesia Upland, Poland) have been studied. The composition of the pollen spectra and the mutual ratio of palaeotropical and arctotertiary elements suggest a Late Miocene age. Among the pollen grains, there are significant elements characteristic of riparian forests (*Pterocarya*, *Carya* and *Liquidambar*) and mixed mesophytic forests (*Pinus*, *Fagus* and *Carpinus*). Such a pollen and spore association suggests a temperate and mid-wet climate, cooler than during the Early and Mid Miocene period, but still warmer than the present-day climate of Poland. This makes the pollen-spore association from Józefina comparable with XII climatic phase represented by the *Carpinipites*-Juglandaceae spore-pollen zone. The occurrence of aquatic plants and freshwater algae (e.g., *Sigmopollis*, Zygnemataceae and desmids) indicates a lacustrine palaeoenvironment.

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Key words: Poland, Miocene, palaeoenvironment, stratigraphy, freshwater algae, pollen grains.

INTRODUCTION

The stratigraphy of epicontinental Miocene strata in Polish Lowlands (Fig. 1) is based primarily on lithostratigraphy, including coal seam correlation, and subordinately on pollen and spore biostratigraphy (e.g., Piwocki and Ziembińska-Tworzydło, 1997; Ziembińska-Tworzydło, 1998). Palaeobotanical studies of these strata, deposited mainly in continental palaeoenvironments, have shown climatic fluctuation throughout this time interval (e.g., Słodkowska, 1998; Ziembińska-Tworzydło, 1998). Lower and Middle Miocene strata, deposited generally during warm and wet climatic phases, have well-documented palaeobotanical evidence studied from numerous sections (e.g., Kohlman-Adamska, 1998). By contrast, Upper Miocene strata, which originated during cooler and less humid climatic conditions, have much poorer palaeobotanical evidence studied from rare sections of that age. The latter are known from southwestern (e.g., Stachurska *et al*., 1971, 1973), Southern (Oszast and Stuchlik, 1977), Central (Stuchlik *et al.*, 1990), and Northern Poland (e.g., Doktorowicz-Hrebnicka, 1957).

This makes the Józefina succession, located on the southern border of Late Miocene epicontinental basin (Fig. 2A), an important site for palaeoenvironmental reconstruction. Our study presented in this paper involves palynological analysis of very well preserved pollen, spore and phytoplankton associations from a dark-coloured interval undertaken for age interpretation of the deposits in question. A high taxonomical diversity of sporomorph associations allowed reconstruction of plant communities, and, on their basis, we have attempted to reconstruct palaeoclimatic conditions.

GEOLOGICAL BACKGROUND

Miocene strata in Poland were deposited in two, mostly mutually isolated basins. The marine basin in the Carpathian Foredeep (South Poland), was a part of the Paratethyan basin system, a remnant of the Tethyan Ocean closing by Alpine Belt folding during the Miocene. The bulk of Poland territory was occupied by an epicontinental basin filled with mainly continental strata. These two basins were separated by an uplifted

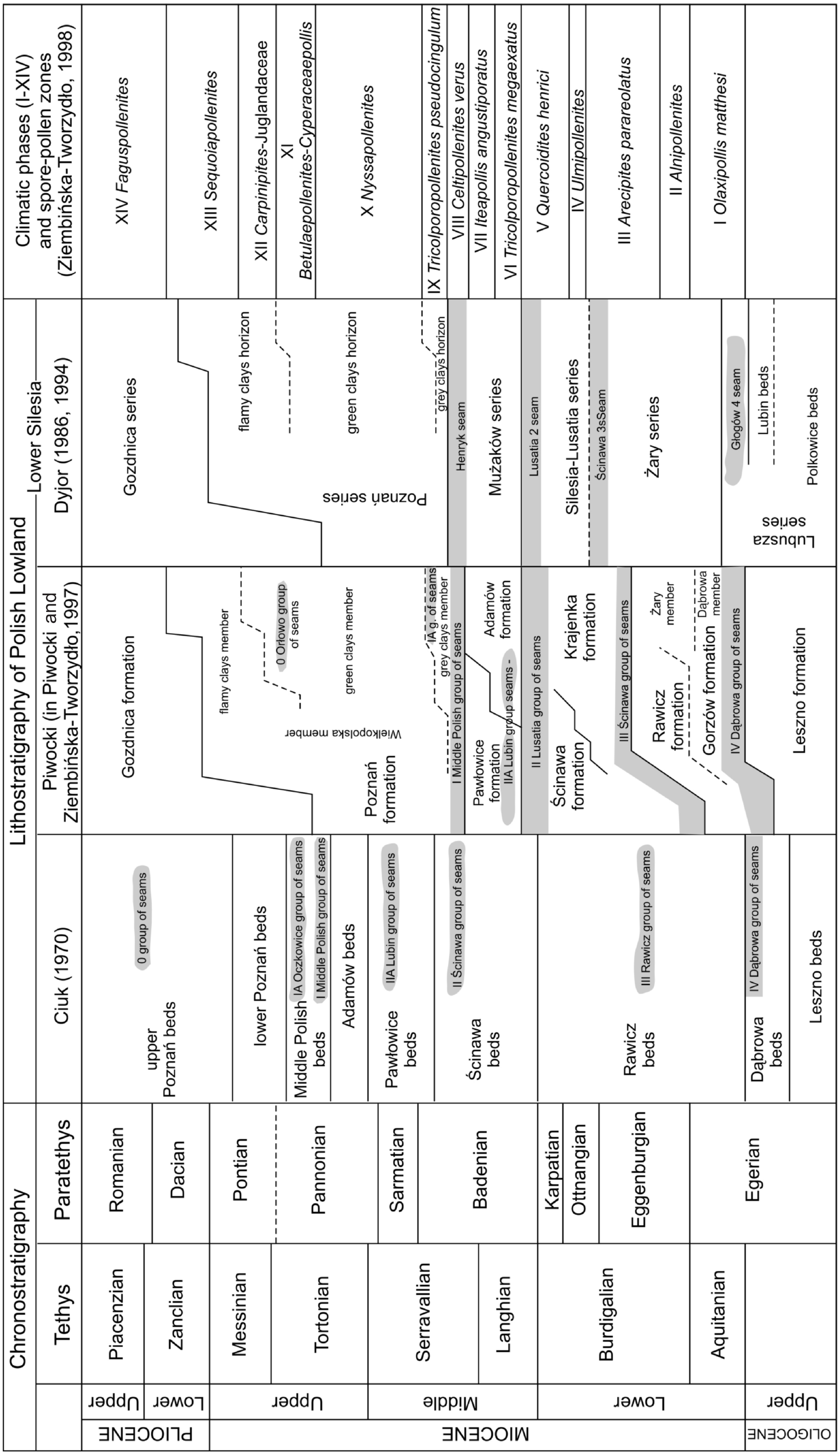

Fig. 1. Lithostratigraphic divisions of the Neogene of the Polish Lowlands correlated with climatic phases and spore-pollen zones (from Piwocki and Ziembińska-Tworzydło, 1997)

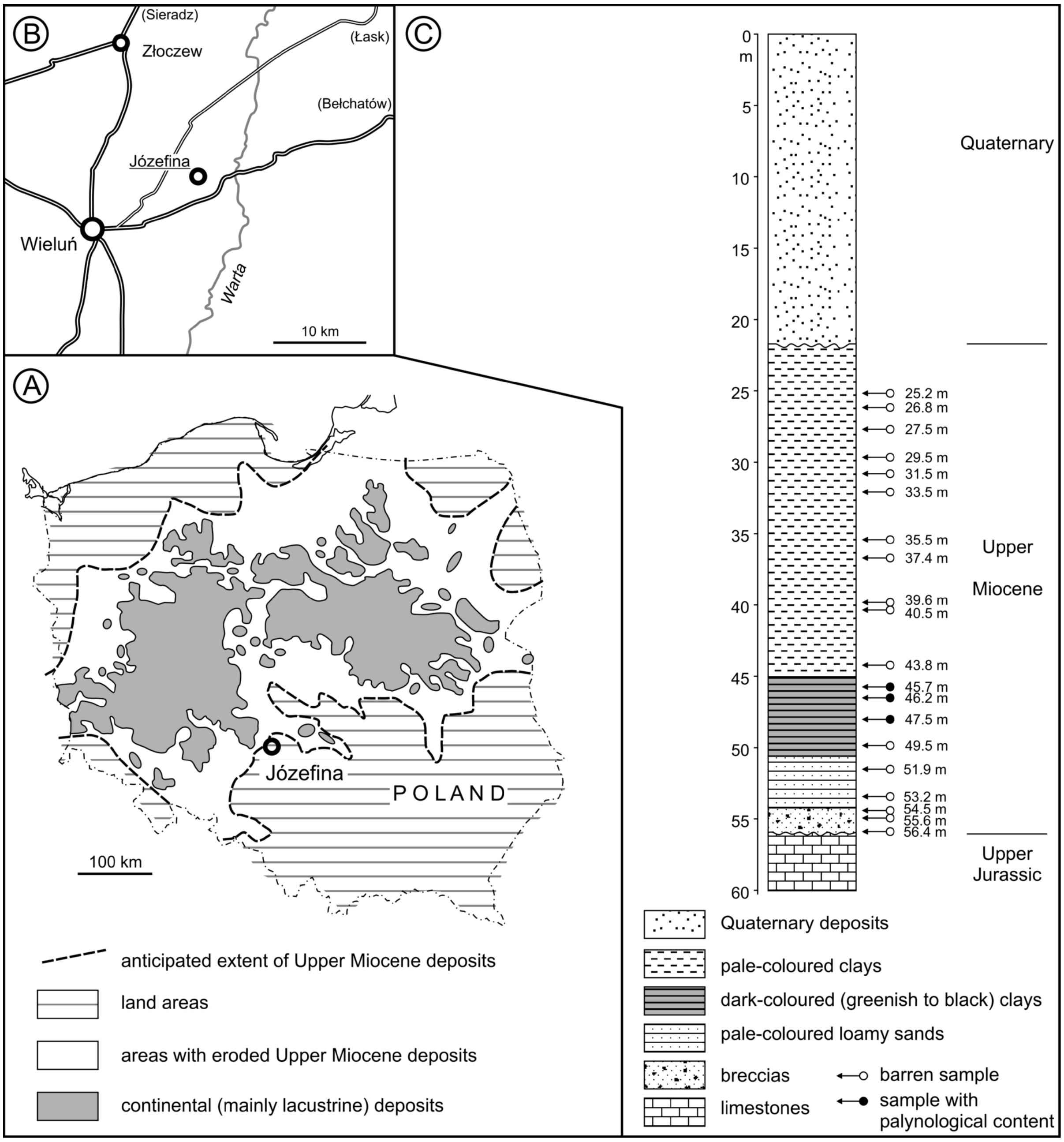

Fig. 2. Location of the Józefina borehole and its lithological profile with indicated positions of samples studied for palynology

A – location of Józefina on a geological map showing the Late Miocene palaeogeography (geological map from Piwocki, 1998); **B** – location of Józefina; **C** – lithological log of the Józefina borehole (after Głazek *et al.*, submit.) and sample positions

area, the so-called Meta-Carpathian Swell. The studied Miocene succession of the Józefina borehole was deposited on its northernmost limits.

Lower to Upper Miocene strata of the Polish Lowlands consist of loamy and sandy deposits, mainly of fluvial, lacustrine and marsh origin. Biogenic sedimentation in the latter environments left brown coal seams that occur in four to five main seam groups (e.g., Słodkowska, 1998). Their appearance was associated with a warm-temperate, mainly wet climate that generally prevailed during the Early and Mid Miocene. Climatic cooling and aridation during the Late Miocene ceased organic-rich sedimentation (including lignite deposition), and led to sedimentation of organic-poor, pale-coloured, mainly loamy deposits of the so-called Poznań clays (e.g., Piwocki, 1998; Stuchlik, 1998; Ziembińska-Tworzydło, 1998).

The thickness of Miocene strata is variable, mainly up to 20–350 m, with maximal values in tectonic trenches – over 500 m. The thickness of the Miocene at the southern limits of its outcrop ranges from 20 to 60 m (Piwocki *et al.*, 2004).

MATERIAL AND METHODS

A borehole at Józefina near Wieluń was drilled some 2 km west of the village (Fig. 2B). It was situated on the northern limits of the Kraków–Silesia Upland. During Late Miocene this site was a peripheral area of the epicontinental basin, which makes the Józefina borehole succession genetically related to the terrestrial basin of the Polish Lowlands (Fig. 2A).

The Józefina borehole was drilled for geological mapping purposes (Głazek *et al*., submit.). It penetrated 60 m, and was stopped in Mesozoic strata (Upper Jurassic limestone), which occurred at a depth of some 57 m (Fig. 2C). The Józefina borehole succession includes: Holocene sandy soil (at depth interval 0–1 m), pre-Holocene Quaternary (glacial) deposits (at depth interval 1–25 m), Miocene strata (at depth interval 25–57 m) and Upper Jurassic limestone (at depth interval 57–60 m). Twenty three samples from Miocene and Jurassic strata were previously studied for palynology by P. Gedl (unpubl. data); the Miocene sample distribution is shown on Figure 2C.

The Miocene succession starts with conglomerates almost 4 m thick built of limestone clasts derived from underlying Jurassic rocks. In its basal part (at depth 56.4 m), limestone clasts (up to a few cm in diameter) are coated in non-calcareous grey clays. Higher (depth 55.6 m), they are smaller (up to 1 cm) and they are embeded in a non-calcareous pale-greyish loamy matrix with glauconitic grains. Above the conglomerate, an interval of pale-coloured sandy-loamy deposit devoid of limestone clasts occurs (depth interval 53.5–51 m). Higher, dark-coloured (dark greenish and black) non-calcareous clays occur (depth interval 51–45 m). The 20 m thick topmost part of the Miocene succession (depth interval 45–25 m) consists of monotonous pale-coloured (pale-grey-greenish to willow-green) non-calcareous clays.

The samples were processed in the Micropalaeontological Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków, according to a standard palynological procedure involving 38% hydrochloric acid (HCl) treatment, 40% hydrofluoric acid (HF) treatment, heavy liquid ($ZnCl_2$ + HCl; density 2.0 g/cm^3) separation, ultrasound for 10–15 s, and sieving at 15 μm on a nylon mesh. A total of twenty samples (Fig. 2C) have been prepared, and two microscope slides were made from each sample using glycerine jelly as a mounting medium. The quantity of rock processed varied from 50 to 100 g. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

Microphotographs of selected taxa (Figs. 3–5) were taken using a *NIKON Eclipse* microscope fitted with a *Canon* digital camera.

The taxa have been classified to the appropriate palaeofloristic element (see Table 1), mainly on the basis of the checklist of selected pollen and spore taxa from the Neogene deposits proposed by Ziembińska-Tworzydło *et al*. (1994), and the atlas of pollen and spores of the Polish Neogene (Stuchlik *et al*., 2001, 2002, 2009).

RESULTS OF PALYNOLOGICAL STUDIES

Samples from the lowermost interval of the studied succession (conglomerates and pale-coloured loamy deposits – 57–51 m; Fig. 2C) were barren or they yielded a palynofacies composed of large phytoclasts, devoid of palynomorphs.

Rich and very well-preserved sporomorphs have been found in three samples (45.7–47.5 m) collected from the dark-coloured interval (51–45 m; Figs. 2C, 3–5). About 600–800 pollen grains and spores, as well about 60–260 specimens of freshwater phytoplankton, were encountered in each of these samples. Pollen spectra from these samples are taxonomically highly diverse: 40–50 taxa of pollen, spores and phytoplankton occur in each sample. A total of 77 taxa of pollen and spores, as well as 18 taxa of freshwater algae have been determined (their listing, botanical affinity and palaeofloristic element are given in Appendix and Table 1).

In all samples pollen grains of *Pinuspollenites* (mainly *P. labdacus*) strongly dominate. Additionally, frequent pollen grains of *Tsuga* (*Zonalapollenites maximus* and *Z. verrucatus*), *Sciadopitys* (mainly *Sciadopityspollenites serratus*), as well as *Abies* (*Abiespollenites absolutus* and *Abiespollenites* sp.), *Picea* (mainly *Piceapollis tobolicus*), *Cathaya* (*Cathayapollis pulaensis*, *C. wilsonii* and *Cathayapollis* sp.), and other conifers from the Pinaceae family occur. Pollen grains of Cupressaceae type are rare – only a few specimens of *Inaperturopollenites* sp. and *Sequoiapollenites* sp. have been found. Relative frequent are pollen grains of deciduous trees: *Fagus* (*Faguspollenites verus*), *Carpinus* (*Carpinipites carpinoides*), *Pterocarya* (*Polyatriopollenites stellatus*), *Carya* (*Caryapollenites simplex*), *Liquidambar* (*Periporopollenites stigmosus*) and others. Herbs are represented by grasses (*Graminidites pseudogramineus* and *Graminidites* sp.), Chenopodiaceae (*Chenopodipollis multiplex*), Nymphaeaceae (*Nymphaeapollenites* sp.), Asteraceae (*Cichoreacidites gracilis* and *Tubulifloridites granulosus*) and others. Fern spores have been found sporadically.

Relatively frequent are also freshwater phytoplankton taxa, including mainly *Sigmopollis* (*S. laevigatoides*, *S. pseudosetarius* and *S. punctatus*), Zygnemataceae zygospores (*Cycloovoidites cyclus*, *Diagonalites diagonalis*, *Ovoidites elongatus*, *O. gracilis*, *O. grandis*, *O. spriggii*, *Tetraporina* sp., and *Stigmozygodites microfoveolatoides*), desmids (e.g., *Closteritetrapidites magnus*), as well as *Spintetrapidites* (e.g., *S. quadriformis*), and others. In addition, single specimens of fungi (Microthyriaceae and *Tetraploa* type) as well as fragments of moss tissues, dispersed stomata of Pinaceae and Cupressaceae type, and dispersed cuticles of arthropods have been found.

In the material studied the following palaeofloristic elements have been distinguished: palaeotropical (P), including: tropical (P1) and subtropical (P2), and arctotertiary (A), including: warm-temperate (A1) and cool-temperate (A2), as well as cosmopolitan (P/A). The composition of sporomorph associations from the samples studied shows an apparent dominance of arctotertiary (including warm-temperate and cool-temperate) palaeofloristic elements (Fig. 6). Palaeotropical elements are represented by a few taxa only (mainly subtropical), all occurring as rare specimens (spores of *Leiotriletes maxoides*/*maximus*, *L. wolffi*, *Leiotriletes* sp., and pollen grains of *Araliaceoipollenites edmundi*, *Arecipites pseudoconvexus*, *Graminidites bambusoides*, *Tricolporopollenites pseudocingulum* and *T. staresedloensis*). The most frequent in this

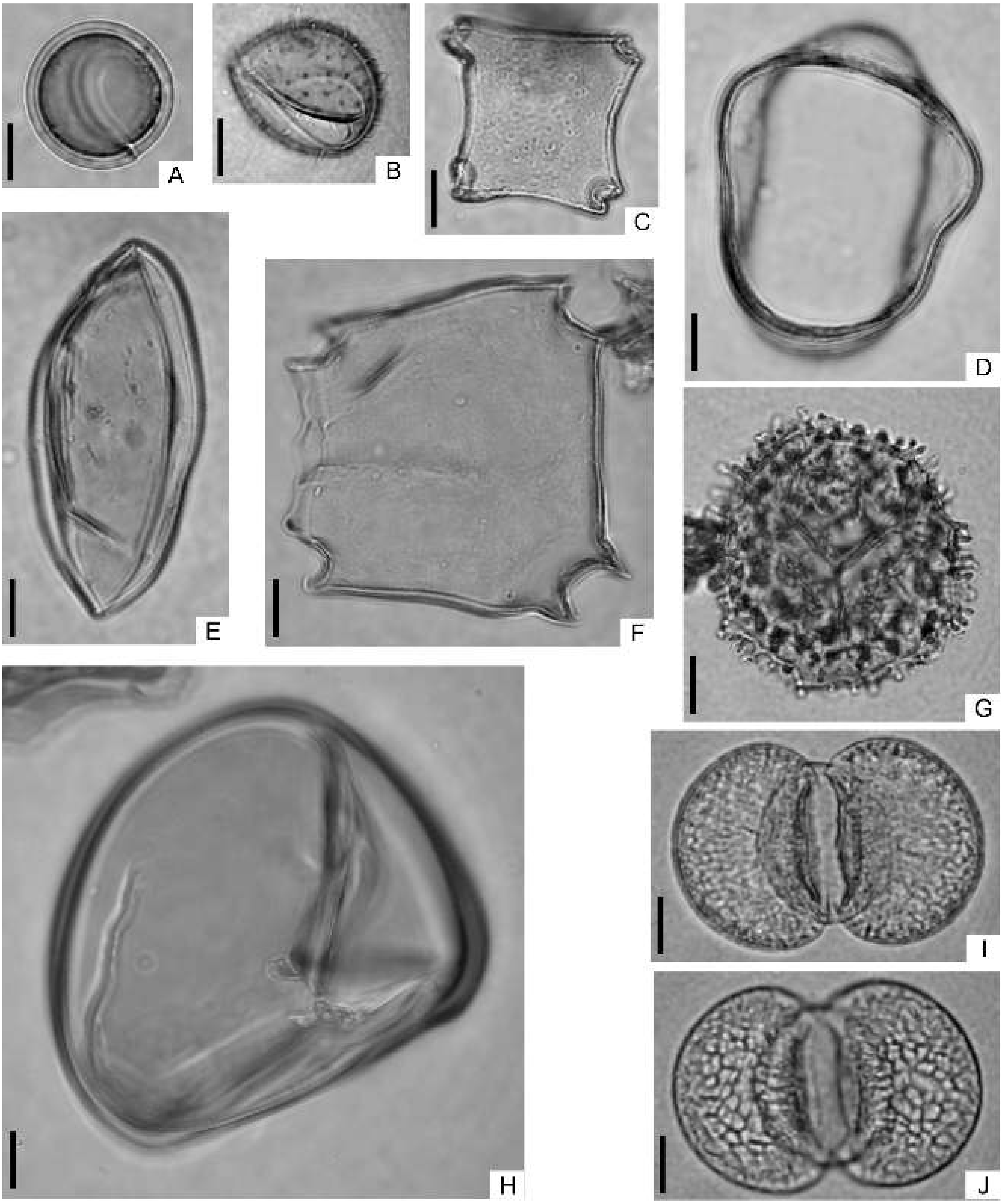

Fig. 3. Freshwater algae and sporomorphs from the Miocene of the Józefina borehole

A – *Sigmopollis laevigatoides* Krutzsch et Pacltová, depth 47.5 m; **B** – *Sigmopollis pseudosetarius* (Weyland et Pflug) Krutzsch et Pacltová, depth 47.5 m; **C** – *Tetraporina* sp., depth 47.5 m; **D** – *Diagonalites diagonalis* Krutzsch et Pacltová, depth 47.5 m; **E** – *Ovoidites elongatus* (Hunger) Krutzsch, depth 46.2 m; **F** – *Closteritetrapidites* sp. 1, depth 47.5 m; **G** – *Rudolphisporis major* (Stuchlik) Stuchlik, depth 47.5 m; **H** – *Leiotriletes maxoides* Krutzsch, depth 47.5 m; **I**, **J** – *Cathayapollis pulaensis* (Nagy) Ziembińska-Tworzydło, depth 47.5 m; scale bars – 10 µm

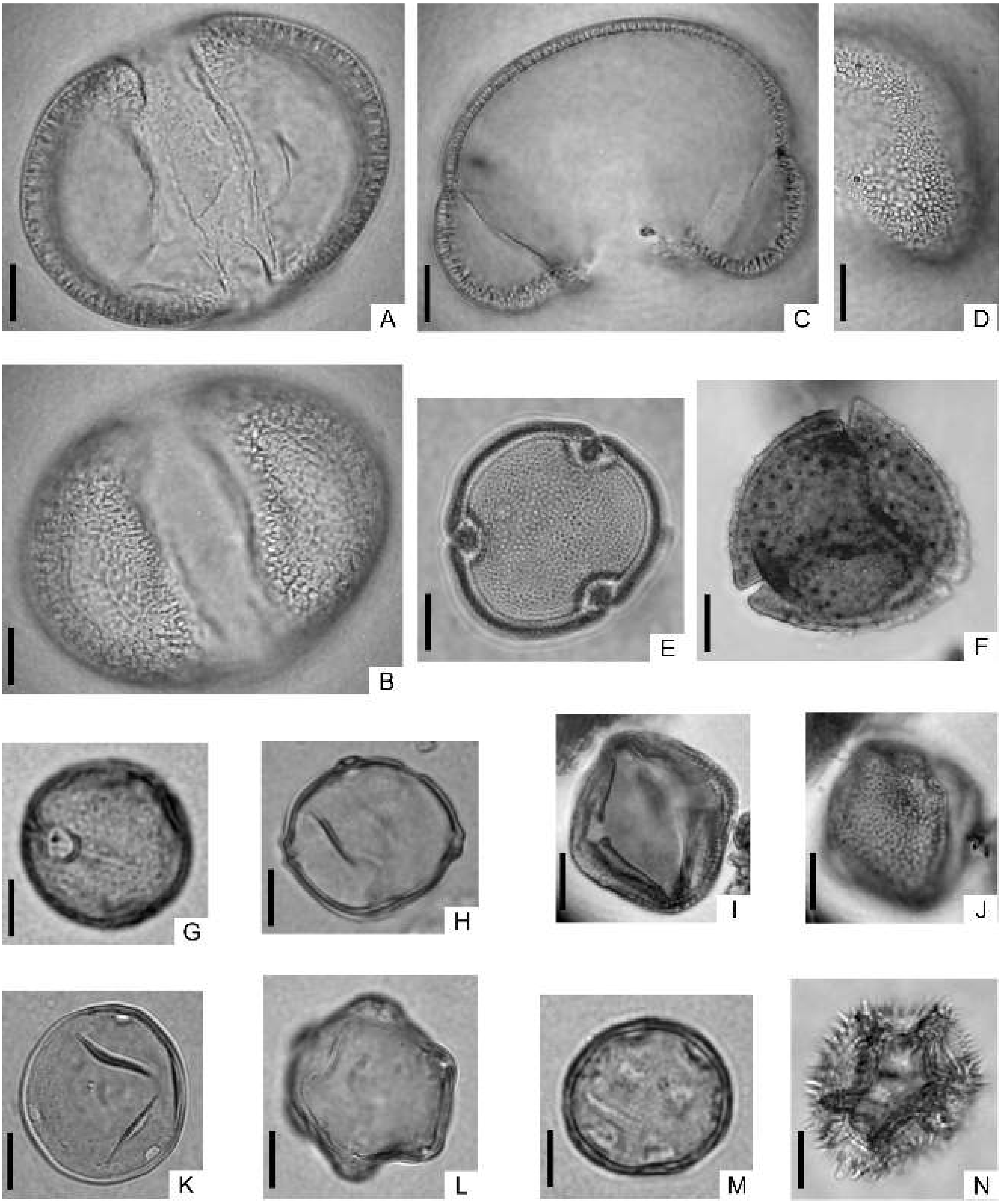

Fig. 4. Sporomorphs from the Miocene of the Józefina borehole

A, **B** – *Cathayapollis wilsonii* (Sivak) Ziembińska-Tworzydło, depth 47.5 m; **C**, **D** – *Cedripites parvisaccatus* (Zauer) Krutzsch, depth 47.5 m; **E** – *Intratriporopollenites instructus* (Potonié) Thomson et Pflug, depth 46.2 m; **F** – *Lonicerapollis gallwitzi* Krutzsch, depth 45.7 m; **G** – *Faguspollenites verus* Raatz, depth 47.5 m; **H** – *Carpinipites carpinoides* (Pflug) Nagy, depth 47.5 m; **I**, **J** – *Araliaceoipollenites edmundi* (Potonié) Potonié, depth 47.5 m; **K** – *Caryapollenites simplex* (Potonié) Raatz, depth 47.5 m; **L** – *Polyatriopollenites* sp., depth 47.5 m; **M** – *Celtipollenites* sp., depth 47.5 m; **N** – *Cichoreacidites gracilis* (Nagy) Nagy, depth 47.5 m; scale bars – 10 µm

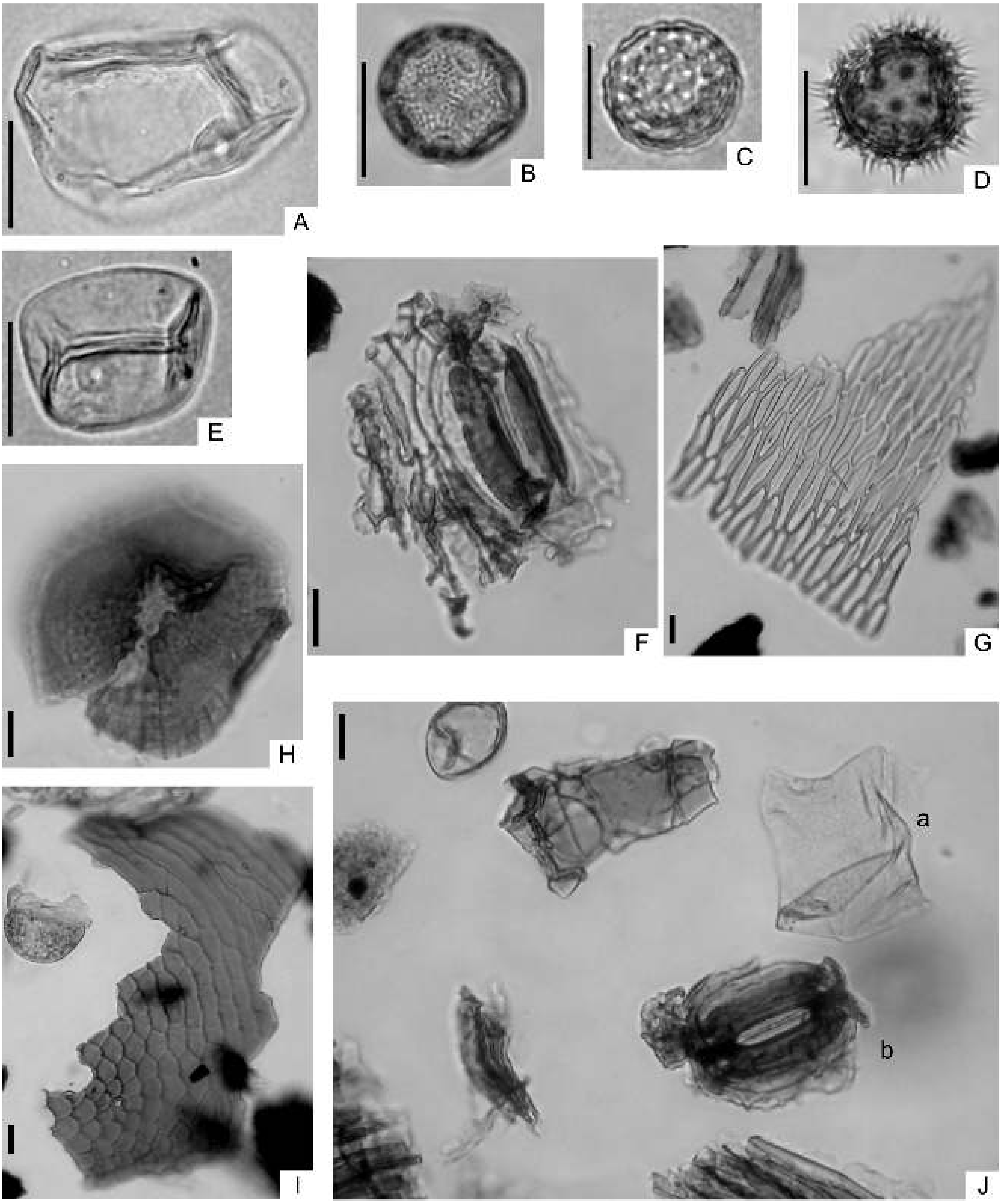

Fig. 5. Sporomorphs and phytoclasts from the Miocene of the Józefina borehole

A – *Graminidites bambusoides* Stuchlik, depth 47.5 m; **B** – *Vaclavipollis pacltovae* Krutzsch, depth 47.5 m; **C** – *Chenopodipollis multiplex* (Weyland et Pflug) Krutzsch, depth 47.5 m; **D** – *Tubulifloridites granulosus* Nagy, depth 47.5 m; **E** – *Graminidites* sp., depth 47.5 m; **F** – stoma of Pinaceae, depth 47.5 m; **G** – fragment of moss tissue, depth 47.5 m; **H** – sporocarp of Microthyriaceae fungi, depth 47.5 m; **I** – fragment of arthropod cuticle, depth 47.5 m; **J** – a: *Closteritetrapidites* sp. 2; b: stoma of conifer, depth 47.5 m; scale bars – 20 μm

Table 1

Results of palynological analysis (number of palynomorphs) in samples from the Józefina borehole

	TAXON/botanical affinity	ELEMENT	45.7 m	46.2 m	47.5 m
S	*Baculatisporites* spp. (Osmundaceae)	P/A	1	11	2
S	*Corrusporis* sp. (Bryales)	P/A		1	1
S	*Echinatisporis* sp. (*Selaginella*)	P/A		1	2
S	*Foveotriletes* spp. (unknown botanical affinity)	unknown	2	1	
S	*Laevigatosporites* spp. (Polypodiaceae/Davalliaceae)	P/A	9	4	10
S	*Leiotriletes maxoides/maximus* (Schizaeaceae/Cyatheaceae)	P	2	1	1
S	*Leiotriletes* spp. (Schizaeaceae/Cyatheaceae)	P	7	3	2
S	*Retitriletes frankfurtensis* Krutzsch (*Lycopodium*)	A		1	1
S	*Rudolphisporis* sp. (Anthocerotaceae)	P/A	1		1
S	*Rugulatisporites quintus* Pflug et Thomson (*Osmunda*)	P2/A1			1
S	*Stereisporites* sp. (*Sphagnum*)	P/A		1	
S	*Verrucatosporites* spp. (Dennstaedtiaceae)	P/A	2	2	
G	*Abiespollenites* spp. (*Abies*)	A	31	28	12
G	*Cathayapollis* spp./ *Pinus haploxylon* type (Pinaceae, *Cathaya*, *Pinus*)	A1	94	102	76
G	*Cedripites* sp. (*Cedrus*)	A1		1	6
G	*Inaperturopollenites* sp. (Cupressaceae)	A1			3
G	*Keteleeriapollenites* sp. (*Keteleeria*, *Pseudolarix*)	A1	4	3	4
G	*Piceapollis* spp. (*Picea*)	A	24	18	9
G	*Pinuspollenites* sp. - *Pinus sylvestris* type (Pinaceae, *Pinus*)	A	316	300	212
G	*Sciadopityspollenites* sp. (*Sciadopitys*)	A1	28	12	28
G	*Sequoiapollenites* sp. (*Sequoia*/?*Cryptomeria*)	A1			1
G	*Zonalapollenites* spp. (*Tsuga*)	A1	58	31	40
An	*Aceripollenites* sp. (*Acer*)	A1			1
An	*Alnipollenites verus* Potonié (*Alnus*)	A1	1	2	2
An	*Araliaceoipollenites edmundi* (Potonié) Potonié (Araliaceae)	P2	1		1
An	*Arecipites pseudoconvexus* Krutzsch (Arecaceae)	P2			1
An	*Carpinipites carpinoides* (Pflug) Nagy (*Carpinus*)	A1	15	5	28
An	*Caryapollenites simplex* (Potonié) Raatz (*Carya*)	A1	38	7	15
An	*Celtipollenites* sp. (*Celtis*)	A1	3		4
An	*Cercidiphyllites minimireticulatus* (Trevisan) Ziembińska-Tworzydło (*Cercidiphyllum*)	A1			1
An	*Chenopodipollis multiplex* (Weyland et Pflug) Krutzsch (Chenopodiaceae)	A1	1		7
An	*Cichoreacidites gracilis* (Nagy) Nagy (Asteraceae, Cichorioideae)	A2		2	
An	*Corsinipollenites ludwigioides* Krutzsch (Oenotheraceae)	A1		1	
An	*Cyperaceaepollis neogenicus* Krutzsch (Cyperaceae)	A	2		
An	*Diervillapollenites* sp. (*Diervilla*/*Weigela*)	A2	1		
An	*Ericipites callidus* (Potonié) Krutzsch (*Calluna*)	A		1	1
An	*Ericipites ericius* (Potonié) Potonié (*Erica*)	A	3	1	1
An	*Ericipites roboreus* (Potonié) Krutzsch (*Rhododendron*/*Arbutus unedo*)	A	1	2	2
An	*Faguspollenites verus* Raatz (*Fagus*)	A2	136	21	47
An	*Graminidites bambusoides* Stuchlik (Poaceae, Bambusoideae)	P2		1	28
An	*Graminidites* spp. (Poaceae, Pooideae)	A	4	3	11
An	*Intratriporopollenites cordataeformis* (Wolff) Mai (*Tilia*)	A2	1	1	4
An	*Intratriporopollenites instructus* (Potonié) Thomson et Pflug (Tilioideae)	A1		1	
An	*Juglanspollenites* sp. (*Juglans*)	A1	3		5
An	*Lonicerapollis gallwitzi* Krutzsch (Caprifoliaceae, *Lonicera*)	A	6	2	
An	*Nymphaeapollenites* sp. (Nymphaeaceae)	A2	5	2	
An	*Nyssapollenites* sp. (*Nyssa*)	A1			4
An	*Periporopollenites stigmosus* (Potonié) Thomson et Pflug (*Liquidambar*)	A1	30	3	5
An	*Persicarioipollis* sp. (*Polygonum*)	A			1
An	*Polyatriopollenites stellatus* (Potonié) Pflug (*Pterocarya*)	A1	31	17	28
An	*Quercoidites* sp. (*Quercus*)	A	4		1
An	*Ranunculacidites* sp. (Ranunculaceae)	A2			2
An	*Salixipollenites* sp. (*Salix*)	A2			1
An	*Tricolporopollenites pseudocingulum* (Potonié) Thomson et Pflug (Fagaceae, Fagoideae)	P2	1		
An	*Tricolporopollenites staresedloensis* Krutzsch et Pactlová (Hamamelidaceae)	P2			1
An	*Trivestibulopollenites betuloides* Pflug (*Betula*)	A1			4
An	*Tubulifloridites granulosus* Nagy (Asteraceae, Asteroideae)	A2			1
An	*Ulmipollenites undulosus* Wolff (*Ulmus*)	A2	2	1	8
An	*Vaclavipollis pactlovae* Krutzsch (Caryophyllaceae)	A2			1
An	*Vitispollenites* sp. (Vitaceae)	A1		1	
V	Varia (pollen and spores indet.)	?	3		6
V	Reworked palynomorphs	X	3	1	
P	*Botryococcus* sp.	X		2	
P	*Closteritetrapidites* spp. (Desmidiales, *Closterium*)	X		1	2
P	*Diagonalites diagonalis* Krutzsch et Pactlová (Zygnemataceae, *Mougeotia*)	X	1	5	3
P	Dinoflagellate cysts	X		3	7
P	*Ovoidites* spp. + *Cycloovoidites cyclus* (Krutzsch) Krutzsch et Pactlová (Zygnemataceae, *Spirogyra*)	X	3	17	4
P	*Pseudoschizaea rubina* (Rossignol) Christopher (?algae, ?Zygnemataceae)	X			2
P	*Sigmopollis* spp. (fresh-water plankton, ?Cyanophyta, ?Chlorophyta)	X	75	23	225
P	*Spintetrapidites* spp. (?Desmidiales, ?Zygnemataceae)	X		2	3
P	*Stigmozygodites microfoveolatoides* Krutzsch et Pactlová (Zygnemataceae, *Zygnema*)	X	1	2	4
P	*Tetraporina*=*Tetrapidites* sp. (Zygnemataceae, *Mougeotia*)	X	1	4	7
P	*Zygodites* sp. (?Desmidiales, ?Zygnematales)	X	5	9	4
F	Microthyriaceae indiff.	X			2
F	*Tetraploa* cf. *aristata* Berkeley et Broome	X			1
	SUM		960	664	898

S – spores, G – Gymnospermae, An – Angiospermae, V – varia, P – phytoplankton, F – fungi

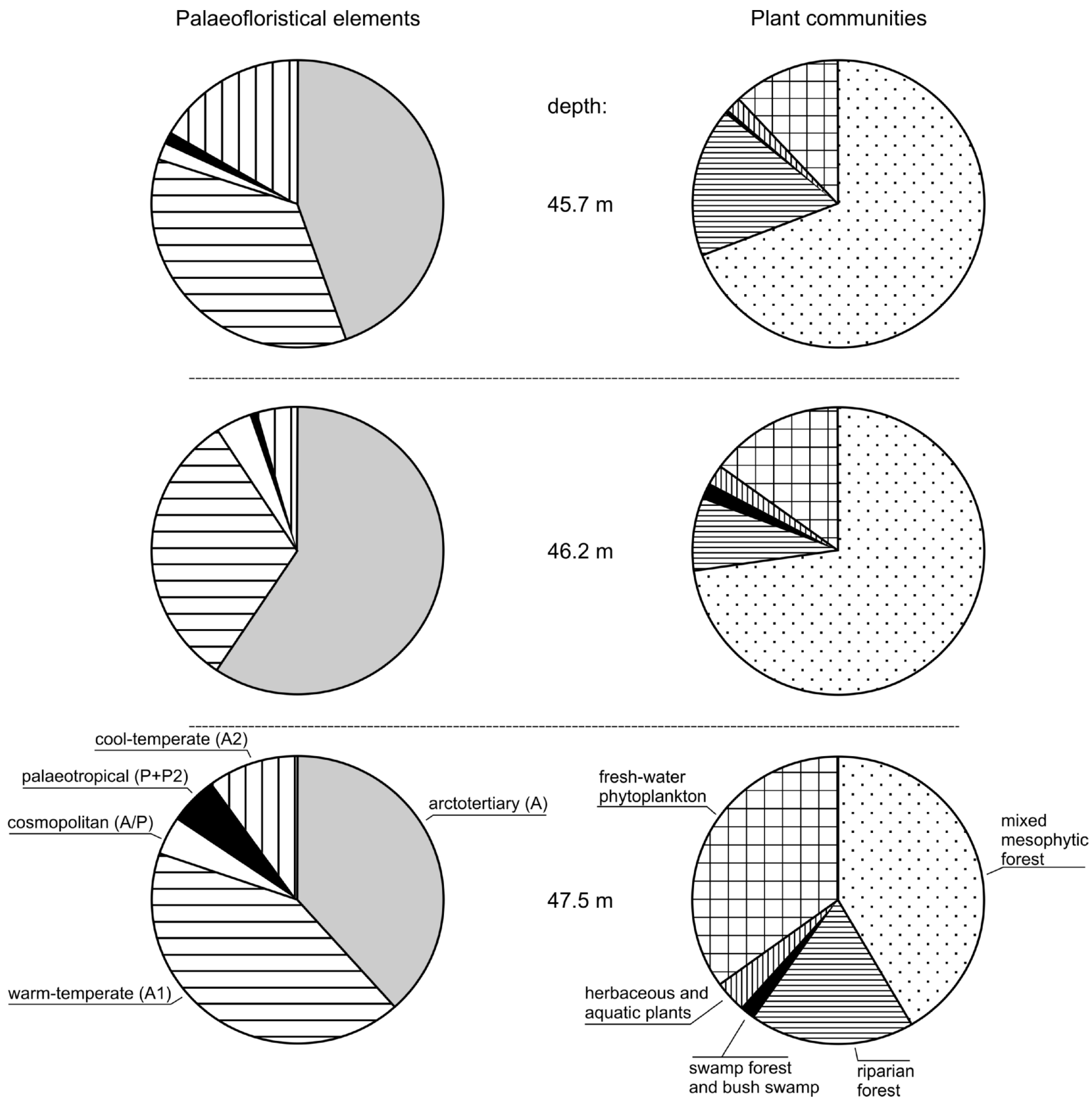

Fig. 6. Ratios of palaeofloristic elements and plant communities in the samples studied from the Józefina borehole

group are *Graminidites bambusoides* pollen grains, which represent 4.5% of the spore-pollen sum in a sample from depth 47.5 m (28 specimens counted).

All samples from the higher interval (45–25 m; Fig. 2B), consisting of pale-coloured monotonous clays, are barren.

PLANT COMMUNITIES – SEDIMENTARY SETTING AND PALAEOCLIMATE

Results of pollen analysis of the dark-coloured clay interval of the Józefina borehole point to the presence of mixed mesophytic forests, and show a significant role of wetland and riparian vegetation (Fig. 6). The large share of mesophilous taxa is emphasized by high pollen productivity of the Pinaceae. The occurrence of Nymphaeaceae pollen, Salviniaceae/Azollaceae microremains, and abundant freshwater algae (mainly *Sigmopollis* and morphologically differentiated zygospores of Zygnemataceae and desmids) points to sedimentation in a freshwater basin. Among the Zygnemataceae, the most frequent are zygospores related to the recent genera: *Spirogyra* (*Cycloovoidites* and *Ovoidites*), *Mougeotia* (*Diagonalites* and *Tetraporina*) and *Zygnema* (*Stigmozygodites*). The extant Zygnemataceae is a family of freshwater filamentous green algae, usually living in shallow, freshwater, oxygen-rich environments such as ponds, lake margins (paludal or low gradient fluvial), ditches and very slow-moving streams (Kadłubowska, 1972; Grenfell, 1995; van Geel and Grenfell, 1996). Therefore, the sedimentary setting of the dark-coloured clay interval could be reconstructed as a freshwater body (?meandering river, ?ox-bow lake, ?small lake) surrounded by swamp-aquatic vegetation, composed of herbs (including grasses), and riparian forests dominated by *Pterocarya*, *Carya* and *Liquidambar*, accompanied by *Ulmus*, *Juglans* and others. Drier, higher terrains were presumably covered by mixed mesophytic forests dominated by *Pinus*, *Fagus* and *Carpinus*, accompanied by *Tsuga*, *Sciadopitys*, *Abies*, *Picea*, *Cathaya* and others.

The predominance of trees of the genera growing now under temperate and warm temperate climatic conditions and the very low share of tropical plants is well marked (Fig. 6). However, many of the plant taxa encountered and *Tetraploa* fungus occur recently in areas with a mild climate (Farr *et al*., 2008). The presence of the Microthyriaceae fungi is an important palaeoecological index of high total annual rainfall – above 1000 mm (Elsik, 1978). All these observations indicate that the climate during deposition of the dark-coloured deposits of the Józefina borehole succession was temperate (cooler than during the Early and Mid Miocene interval, but still warmer than the present-day climate of Poland) and mid-wet. This interpretation fits well with the composition of spore-pollen spectra of the Late Miocene XII climatic phase. At that time, moist riparian forests as well as mixed forests with a high ratio of conifers (especially pine), and with scarce palaeotropical relics, grew (Ziembińska-Tworzydło, 1998).

A lack of palynological matter in the pale-coloured intervals studied of the Józefina borehole succession does not allow complex palaeoenvironmental reconstructions of the whole succession. These strata must have been deposited in environments that were not favourable for organic matter preservation. The lowermost part (57–51 m), consisting of conglomerates and loamy sands, was most likely deposited in a continental, high-energy environment. The topmost loamy interval (45–25 m) presumably represents sediment of lacustrine origin, deposited in an oxygen-rich environment with limited influx of terrestrial organic particles. All palynomorphs and phytoclasts, if present, were oxidized.

AGE OF THE PALYNOFLORA

The palynomorphs studied show clear similarities to the Late Miocene palynoflora from Sośnica, southwestern Poland (Stachurska *et al*., 1973), which also contains sparse palaeotropical elements: only a few pollen grains of *Ilex*, *Araliaceoipollenites edmundi*, *Tricolporopollenites pseudocingulum* and *Parrotia*, and spores of *Leiotriletes* have been found there. The main components of the Sośnica assemblage are arctotertiary (with a high ratio of temperate) genera of trees growing in mesophytic and riparian forests (e.g., *Pinus*, *Carpinus*, *Ulmus*, *Quercus*, *Betula*, *Fagus*, *Liquidambar*, *Pterocarya* and *Carya*); herbs are not numerous, but are taxonomically differentiated.

There are also many similarities between the palynoflora studied and assemblages from the relatively close locality of the Bełchatów Lignite Mine (Stuchlik *et al.*, 1990, profile VI).

The composition of the Józefina assemblage also resembles the fossil palynoflora from Gnojna, southwestern Poland (Sadowska, 1991). Differences between these two localities seem to be mainly facies-related.

The Józefina palynoflora is also slightly similar to the Late Miocene palynoflora from the Gozdnica (profile 4), southwestern Poland (Stachurska *et al*., 1971), which is also dominated by arctotertiary elements. The main component of Gozdnica palynoflora is *Pinus* (*Pinus* type *diploxylon*, up to 40%; and *Pinus* type *haploxylon*, including *Cathaya* – up to 50%). *Liquidambar*, *Fagus*, Clethraceae-Cyrillaceae, *Symplocos*, and *Ilex* dominate among the angiosperms. Pollen grains of *Araliaceoipollenites edmundi* and *Tricolporopollenites pseudocingulum* do not exceed 1–2% of pollen spectra. Herbs are represented mainly by grasses, but their grains are not numerous. The main difference between the Józefina and Gozdnica palynofloras is the abundance of *Ilex*, *Symplocos*, and Cupressaceae pollen grains in the latter.

On the other hand, the palynoflora from Józefina distinctly differs from the Pliocene flora from Ruszów (Stachurska *et al*., 1967), in which low values of *Pinus*, a permanent predominance of *Alnus*, and trace amounts of relict Miocene taxa are observed.

Therefore, a Late Miocene age for the Józefina palynoflora can be suggested. As compared with palynofloras from other localities, the assemblage studied is somewhat younger than the Late Miocene Gozdnica palynoflora and older than the Pliocene Ruszów palynoflora. Moreover, the Late Miocene age of the sediments in question is also indicated by the composition of pollen spectra and by the mutual ratio of palaeotropical (P) and arctotertiary (A) palaeofloristic elements (Fig. 6). The assemblage studied shows similarity with the XII climatic phase belonging to the *Carpinipites*-Juglandaceae spore-pollen zone *sensu* Ziembińska-Tworzydło (in Piwocki and Ziembińska-Tworzydło, 1995; see also Piwocki and Ziembińska-Tworzydło, 1997; Ziembińska-Tworzydło, 1998). Unfortunately, profiles with a well documented XII climatic phase are infrequent in Poland (see Piwocki and Ziembińska-Tworzydło, 1995). Deposits bearing such assemblages occur within the flamy clays member (top-part of the Poznań formation, or upper part of the Wielkopolska member) and within the lower part of the Gozdnica formation, deposited during the Pontian (Fig. 1). This age assessment, as well as the lithological characteristics of the deposits in question, indicating that the Józefina succession can be assigned to the Poznań formation.

CONCLUSIONS

1. A borehole drilled at Józefina (Kraków–Silesia Upland, Southern Poland) penetrated a 32 m thick succession of sandy-loamy deposits resting upon Upper Jurassic limestone, and covered by Quaternary deposits. It was studied for palynology. Of twenty samples, only three, collected from dark-coloured clays (depth 45.7–47.5 m), yielded rich and very well-preserved palynological material suitable for further study.

2. A rich association consisting of 77 pollen and spore taxa, and 18 freshwater algae taxa have been found in these dark-coloured clays. The pollen-spore association is dominated by pollen grains of *Pinuspollenites*. Relatively frequent are pollen grains of other conifers from the Pinaceae family (*Tsuga*, *Abies*, *Picea* and *Cathaya*) and, less frequent, pollen grains of deciduous trees (*Fagus*, *Carpinus*, *Pterocarya*, *Carya* and *Liquidambar*). Herbs are represented mainly by grasses, Chenopodiaceae, Nymphaeaceae and Asteraceae. Among freshwater phytoplankton taxa, *Sigmopollis*, zygospores of

Zygnemataceae and desmids, as well as *Spintetrapidites* are most frequent.

3. A characteristic feature of the sporomorph association is an apparent dominance of arctotertiary (including A1 and A2) palaeofloristic elements. Palaeotropical elements (mainly subtropical, P2) are represented by rare specimens of a few taxa only, among which *Graminidites bambusoides* pollen grains are the most frequent.

4. Analysis of the spore-pollen association shows that plant communities growing at the freshwater basin margin were dominated by trees of genera growing recently under temperately warm climatic conditions. At the same time, a very low ratio of tropical plants has been observed. This suggests a temperate and mid-wet climate during deposition of the dark-coloured strata of the Józefina borehole succession.

5. Deposition of the Józefina borehole Miocene succession took place in changeable palaeoenvironmental conditions. The lowermost, barren part of the succession was presumably deposited in a high-energy continental environment that began Miocene sedimentation in this area. Later, a much calmer freshwater, presumably lacustrine environment appeared. At the beginning, certain palaeoenvironmental factors (rich vegetation, sedimentological conditions) made favourable conditions for preservation of palynological organic matter (reflected in the dark colouration). During this time interval, the freshwater body was surrounded by a swamp-aquatic vegetation, composed of herbs (including grasses), and riparian forests dominated by *Pterocarya*, *Carya* and *Liquidambar*. More dry, higher terrains were presumably covered by mixed mesophytic forests dominated by *Pinus*, *Fagus* and *Carpinus*. Later on, particular changes in the palaeoenvironment made the sedimentary setting unfavourable for preservation of palynological organic matter.

6. Comparison of the sporomorph association from the Józefina borehole with those from other Neogene sites suggests its Late Miocene age. Its composition makes it comparable to the *Carpinipites*-Juglandaceae spore-pollen zone typical of the XII climatic phase (Late Miocene). This allows classifying the deposits in question to the Upper Miocene Poznań formation.

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APPENDIX

Systematic listing of phytoplankton, spore and pollen taxa encountered in the Józefina borehole:

INCERTE SEDIS (?CYANOPHYTA, ?CHLOROPHYTA)

Sigmopollis laevigatoides Krutzsch et Pacltová
Sigmopollis pseudosetarius (Weyland et Pflug) Krutzsch et Pacltová
Sigmopollis punctatus Krutzsch et Pacltová

CHLOROPHYTA

Botryococcus sp.
Closteritetrapidites magnus Krutzsch et Pacltová
Closteritetrapidites sp.
Cycloovoidites cyclus (Krutzsch) Krutzsch et Pacltová
Diagonalites diagonalis Krutzsch et Pacltová
Ovoidites elongatus (Hunger) Krutzsch
Ovoidites gracilis Krutzsch et Pacltová
Ovoidites grandis (Pocock) Zippi
Ovoidites spriggii (Cookson et Dettmann) Zippi
Pseudoschizaea rubina (Rossignol) Christopher
Spintetrapidites quadriformis Krutzsch et Pacltová
Spintetrapidites sp.
Stigmozygodites microfoveolatoides Krutzsch et Pacltová
Tetraporina sp.
Zygodites sp.

TELOMOPHYTA
BRYOPHYTINA

Corrusporis sp.
Stereisporites sp.

ANTHOCEROPHYTINA

Rudolphisporis major (Stuchlik) Stuchlik
Rudolphisporis sp.

LYCOPHYTINA: LYCOPSIDA

Retitriletes frankfurtensis Krutzsch

LYCOPHYTINA: SELAGINELLOPSIDA

Echinatisporis sp.

PTEROPHYTINA

Baculatisporites major (Raatz) Krutzsch
Baculatisporites primarius (Wolff) Pflug et Thomson
Foveotriletes megafovearis (Krutzsch) Grabowska
Foveotriletes sp.
Laevigatosporites haardti (Potonié et Venitz) Thomson et Pflug
Laevigatosporites nitidus (Mamczar) Krutzsch
Leiotriletes maxoides Krutzsch
Leiotriletes maxoides/*maximus* type
Leiotriletes wolffi Krutzsch
Leiotriletes sp.
Rugulatisporites quintus Pflug et Thomson
Salviniaceae/Azollaceae
Verrucatosporites favus (Potonié) Thomson et Pflug
Verrucatosporites megafavus Krutzsch

GYMNOSPERMS

Abiespollenites absolutus Thiergart
Abiespollenites sp.
Cathayapollis pulaensis (Nagy) Ziembińska-Tworzydło
Cathayapollis wilsonii (Sivak) Ziembińska-Tworzydło
Cathayapollis sp.
Cedripites parvisaccatus (Zauer) Krutzsch
Cedripites sp.
Inaperturopollenites sp.
Keteleeriapollenites sp.
Piceapollis tobolicus (Panova) Krutzsch
Piceapollis sp.
Pinuspollenites labdacus (Potonié) Raatz
Pinuspollenites sp.
Sciadopityspollenites serratus (Potonié et Venitz) Raatz
Sciadopityspollenites sp.
Sequoiapollenites sp.
Zonalapollenites maximus (Raatz) Krutzsch
Zonalapollenites verrucatus Krutzsch

ANGIOSPERMS

Aceripollenites sp.
Alnipollenites verus Potonié
Araliaceoipollenites edmundi (Potonié) Potonié
Arecipites pseudoconvexus Krutzsch
Carpinipites carpinoides (Pflug) Nagy
Caryapollenites simplex (Potonié) Raatz
Celtipollenites sp.
Cercidiphyllites minimireticulatus (Trevisan) Ziembińska-Tworzydło
Chenopodipollis multiplex (Weyland et Pflug) Krutzsch
Cichoreacidites gracilis (Nagy) Nagy
Corsinipollenites ludwigioides Krutzsch
Cyperaceaepollis neogenicus Krutzsch
Diervillapollenites sp.
Ericipites callidus (Potonié) Krutzsch
Ericipites ericius (Potonié) Potonié
Ericipites roboreus (Potonié) Krutzsch
Faguspollenites verus Raatz
Graminidites bambusoides Stuchlik
Graminidites pseudogramineus Krutzsch
Graminidites sp.
Intratriporopollenites cordataeformis (Wolff) Mai
Intratriporopollenites instructus (Potonié) Thomson et Pflug
Juglanspollenites sp.
Lonicerapollis gallwitzi Krutzsch
Nymphaeapollenites sp.
Nyssapollenites sp.
Periporopollenites stigmosus (Potonié) Thomson et Pflug
Persicarioipollis sp.
Polyatryopollenites stellatus (Potonié) Pflug
Quercoidites sp.
Ranunculacidites sp.
Salixipollenites sp.
Tricolporopollenites pseudocingulum (Potonié) Thomson et Pflug
Tricolporopollenites staresedloensis Krutzsch et Pacltová
Trivestibulopollenites betuloides Pflug
Tubulifloridites granulosus Nagy
Ulmipollenites undulosus Wolff
Vaclavipollis pacltovae Krutzsch
Vitispollenites sp.