

Late Miocene freshwater phytoplankton from Józefina (Poland)

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ABSTRACT: The paper presents results of detailed investigation of freshwater microalgae from the Upper Miocene deposits from Józefina (Kraków-Silesia Upland, central Poland). During the studies 28 microphytoplankton species of the genera *Sigmopollis*, *Geiselodinium*, *Botryococcus*, *Ovoidites*, *Cycloovoidites*, *Stigmozygodites*, *Diagonalites*, *Tetraporina*, *Spintetrapidites*, *Closteritetrapidites*, *Planctonites*, *Cystidiopsis*, *Zygodites*, and *Pseudoschizaea* were identified. One new species *Closteritetrapidites paclovae* E. Worobiec sp. nov. has been proposed. Most of the recorded algae preferred meso- to eutrophic, stagnant or slowly flowing shallow waters. The presence of resting cells – e.g. zygospores of Zygnemataceae (*Mougeotia*, *Spirogyra*, and *Zygnema*) and desmids (*Closterium*), suggests that the water body (bodies) might periodically dried out. The occurrence of *Pseudoschizaea* is characteristic for warm climate, possibly with seasonal moisture fluctuations. Occurrence of determined species in various localities (listed in synonyms) suggests that these algae were widespread in the past.

INTRODUCTION

During the palynological investigations of Upper Miocene deposits from Józefina (central Poland), besides well-preserved rich pollen and spore assemblages, the occurrence of freshwater microplankton was noticed (Worobiec et al. 2009). Composition of pollen spectra shows a significant role of wetland and riparian vegetation, as well as presence of mixed mesophytic forests. These plant communities were dominated by warm-temperate and temperate taxa, with small admixture of subtropical plants. In addition, the occurrence of aquatic plants and algae confirm presence of water body (bodies). The freshwater phytoplankton was relatively frequent and taxonomically differentiated, with a significant share of resting cells (e.g. zygospores).

Such freshwater microalgae assemblages from Neogene deposits are rarely examined in detail. Usually, these microfossils are reported (or only mentioned) in papers concerning generally palynological investigations. Freshwater phytoplankton from the Neogene deposits from Europe is described in detail in few publications (e.g. Nagy 1965; Krutzsch and Pacltová 1990; Head 1992). More numerous are studies of the Holocene freshwater algae (e.g. van Geel 1976; van Geel et al. 1981, 1983; Jankovská and Komárek 2000; Carrión 2002). Some papers concern Neogene freshwater microalgae from other continents (e.g. Zamaloa 1996). The current paper presents results of the first detailed studies on these algae from the Polish Tertiary. It contains results of comprehensive investigation concerning the microphytoplankton from Józefina, and complements the studies concerning palynoflora and palaeoenvironment of this locality. The studied assemblage is an example of fossil freshwater algal community and shows changes in its composition in time.

MATERIAL AND METHODS

The material was collected from borehole Józefina near Wieluń, Kraków-Silesia Upland (text-figure 1). Samples were prepared using HCl, HF, heavy liquid ($\text{ZnCl}_2 + \text{HCl}$, density = 2g/cm^3) separation, rinsed on 15- μ filter cloth, and then

mounted in glycerine jelly on microscope slides. Ten samples (from depth 25.2–56.4 m) have been examined, but only three of them (taken from dark-greenish and black non-calcareous clays, depth 45.7–47.5 m) yielded well-preserved sporomorphs suitable for detailed pollen analysis (Worobiec et al. 2009). Two slides of each of these three samples were restudied for more comprehensive investigation of freshwater microalgae, and during the studies almost 1000 specimens of these microfossils were encountered. The identified morphological species have been arranged according to their possible botanical affinity. Classification used here follows the Catalogue of Life: 2005 Annual Checklist. For each identified species selected synonyms from various localities and various age have been given. Microphotographs of determined taxa were taken using NIKON Eclipse microscope fitted with Canon digital camera. For each taxon up to ten specimens were measured (when a few specimens recorded than all were measured).

SYSTEMATIC DESCRIPTIONS OF RECORDED PHYTOPLANKTON TAXA

Phyllum ?CYANOBACTERIA (?CYANOPHYTA)

Genus *Sigmopollis* Hedlund 1965

Type species: *Sigmopollis hispidus* Hedlund 1965

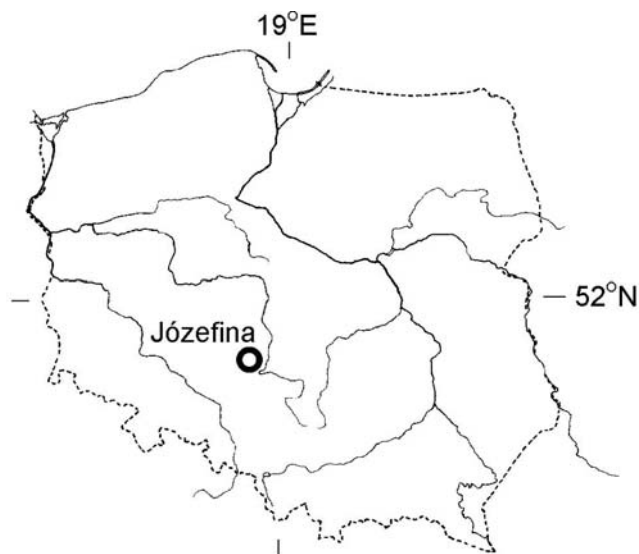
Synonym = *Monogemmites* KRUTZSCH 1970; p. 33.

Botanical affinity: The *Sigmopollis* microfossils are believed to be spores of freshwater algae (Srivastava 1984). They are morphologically similar to freshwater Cyanophyceae (Krutzsch and Pacltová 1990). Possibly they are fossil resting spores (?akinetes).

Ecology: Species of *Sigmopollis* are associated with eutrophic to mesotrophic open waters in Holocene deposits. The optimal environment for these algae is eutrophic slowly flowing water (Pals et al. 1980; van der Wiel 1982; van Geel et al. 1983).

Sigmopollis laevigatoides Krutzsch and Pacltová 1990

Plate 1, figure 1



TEXT-FIGURE 1

Location of borehole Józefina in Poland.

Sigmopollis laevigatoides KRUTZSCH and PACLTOVÁ 1990, pp. 387–388, text-figs 44a, b, pl. 8, figs 131–148 [Pliocene, Czech Republic].

Nymphaeaepollenites pseudosetarius (Krutzsch) PLANDEROVÁ 1990, p. 55, pl. 54, fig. 7 [Miocene, Slovakia].

Description: Microfossils circular in outline, 15–28µm in diameter, wall about 2µm thick, wall psilate. On wall surface arcuate crevice a half of the circumference long.

Remarks: In the examined material 140 specimens of this taxon were encountered.

Sigmopollis pseudosetarius (Weyland and Pflug 1957) Krutzsch and Pacltová 1990

Plate 1, figures 2a, b

Inaperturopollenites pseudosetarius WEYLAND and PFLUG 1957, p. 103, pl. 22, fig. 30 [Pliocene, Greece].

Nymphaeaceae? – *Pollenites pseudohirsutus* DOKTOROWICZ-HREBNICKA 1960, p. 238, pl. 44, fig. 236 [Middle Miocene, Poland].

?*Nymphaeaepollenites pannonicus* NAGY 1969, p. 169, pl. 41, fig. 5 [Miocene, Hungary].

Monogemmites pseudosetarius (Weyland and Pflug) KRUTZSCH 1970, p. 146, pl. 39, fig. 30 [Oligocene–Pliocene].

Type 128 – PALS et al. 1980, p. 407, pl. 2, figs 128a–e [Holocene, Netherlands].

Type 128A – VAN GEEL et al. 1983, p. 312, pl. 1, figs 128Aa, b [Holocene, Netherlands].

Nymphaeaepollenites pannonicus (Nagy) NAGY 1985, p. 157, pl. 90, figs 12–15 [Badenian–Pannonian, Hungary].

Sigmopollis pseudosetarius (Weyland and Pflug) KRUTZSCH and PACLTOVÁ 1990, pp. 388–389, text-fig. 46, pl. 9, figs 152–166B [Pliocene, Czech Republic].

Nymphaeaepollenites pseudosetarius (Krutzsch) PLANDEROVÁ 1990, p. 55, pl. 54, figs 8–11 [Miocene, Slovakia].

Sigmopollis pseudosetarius (Weyland and Pflug) Krutzsch and Pacltová – BRUCH 1998, pp. 105–106, pl. 15, figs 6–7 [Oligocene, Slovenia].

Description: Microfossils circular in outline, 20–30µm in diameter. Wall composed of two layers, about 1.0–1.5µm thick, psilate, densely covered with very thin spines. On wall surface arcuate crevice a half of the circumference long.

Remarks: In the examined material specimens of this taxon were very frequent (about 600 specimens were found).

Sigmopollis punctatus Krutzsch and Pacltová 1990

Plate 1, figures 5a, b

Type 128B – VAN DER WIEL 1982, p. 81, pl. 3, fig. 128B [Holocene, Netherlands].

Type 128B – VAN GEEL et al. 1983, pp. 312–313, pl. 1, figs 128Ba, b [Holocene, Netherlands].

Nymphaeaepollenites minor NAGY 1985, p. 157, pl. 90, figs 1–3, 5–11 [Badenian–Pannonian, Hungary].

Sigmopollis punctatus KRUTZSCH and PACLTOVÁ 1990, p. 388, text-figs 45a, b, pl. 9, figs 149–151 [Pliocene, Czech Republic].

Nymphaeaepollenites minor Nagy – PLANDEROVÁ 1990, p. 55, pl. 54, figs 12–14 [Miocene, Slovakia].

Type 128 – CARRIÓN and NAVARRO 2002, pl. 4, fig. 3 [Holocene, Spain].

Description: Microfossils circular in outline, 15–25µm in diameter, wall about 1.5µm thick. Wall densely covered with very thin and short spines.

Remarks: In the studied material several specimens of this taxon were found.

Phylum DINOPHYTA

Class DINOPHYCEAE

Order GYMNODINIALES

Genus *Geiselodinium* Krutzsch 1962

Type species: *Geiselodinium geiseltense* Krutzsch 1962

Geiselodinium cf. *miocaenicum* Nagy 1965

Plate 1, figures 4a, b

Geiselodinium miocaenicum NAGY 1965, p. 201, pl. 1, fig. 3, pl. 2 fig. 11 [Miocene, Hungary].

Geiselodinium cf. *miocaenicum* Nagy – KRUTZSCH and PACLTOVÁ 1990, pp. 354–356, text-fig. 5, pl. 2, figs 12–20 [Pliocene, Czech Republic].

Description: Dinoflagellate cysts spheroidal, about 57–60 × 40–42µm in size. Outer wall lying closely on the central cyst. Both walls psilate, hyaline, about 0.5µm thick. Walls secondarily highly folded.

Botanical affinity: These microfossils are close to the dinoflagellate cyst *Geiselodinium miocaenicum* Nagy (ordo Gymnodinales), described from Hungarian Miocene (Nagy 1965), but differ from them in more elongated shape.

Remarks: In the examined material 3 specimens of this freshwater dinocyst were recorded.

Phylum CHLOROPHYTA

Class CHLOROPHYCEAE

Order CHLOROCOCCALES

Family Dictyosphaeriaceae (Botryococcaceae)

Genus *Botryococcus* Kützing 1849

Type species: *Botryococcus braunii* Kützing 1849

Botryococcus cf. *braunii* Kützing 1849

Plate 1, figures 6a, b

Botryococcus cf. *B. braunii* Kützing – ZIPPI 1998, pp. 18–22, pl. 7, figs 1–9, pl. 8, figs 1–9 [Albian, Ontario].

Botryococcus cf. *braunii* Kützing – KRUTZSCH and PACLTOVÁ 1990, pp. 350–352, text-fig. 1, pl. 1, figs 1–3 [Pliocene, Czech Republic].

Description: Multicellular colonial algae, cells aggregate irregular in shape, about $30\text{--}60 \times 20\text{--}40\mu\text{m}$ in size. Cells embedded in the colonial wall. Cell body ovoid.

Botanical affinity: Morphologically these microfossils are identical with the modern *Botryococcus* microalgae colonies.

Ecology: The modern *Botryococcus* is widespread, variable in forms, and apparently has a number of local and geographical races. Generally this algae lives in freshwater bogs, temporary pools, ponds and lakes, but according to many authors (e.g. Batten and Grenfell 1996; Testa et al. 2001) forms tolerating variable salinity/brackish habitats are also known. From the other hand, Vazquez-Duhalt and Arredondo-Vega (1991, in: Zippi 1998) have reported that under experimental conditions *B. braunii* is unable to reproduce in salinities approaching that of normal marine conditions, and in brackish conditions its growth rate is dramatically reduced. Morphological diversity of fossil *Botryococcus* colonies may reflect developmental stages of the algae related to environmental conditions and/or seasonal changes (Guy-Ohlson 1992, 1998; Batten and Grenfell 1996). According to Jankovská and Komárek (2000), identification of fossil *Botryococcus* species play an important role in palaeoenvironmental studies since the fossil species differ by their ecology.

Remarks: The genus *Botryococcus* occurs in sediments since the Palaeozoic, and only limited evolution within Botryococcaceae is observed, so the occurrence of *Botryococcus* in palynological assemblages has generally little or no stratigraphic significance (Batten and Grenfell 1996). In the sediment under study 3 specimens of *Botryococcus* were found.

Class ZYGNEMATOPHYCEAE

Order ZYGNEMATALES

Family Zygnemataceae

Genus *Ovoidites* Potonié 1951 ex Thomson and Pflug 1953 emend. Krutzsch 1959

Type species: *Ovoidites ligneolus* Potonié ex Krutzsch 1959

Ovoidites POTONIÉ 1951, p. 151, pl. 21, fig. 185.

Ovoidites Potonié ex THOMSON and PFLUG 1953, p. 113.

Schizosporis COOKSON and DETTMANN 1959, pp. 213–214.

Brazilea TIWARI and NAVALE 1967, p. 593.

Psiloschizosporis JAIN 1968, p. 31.

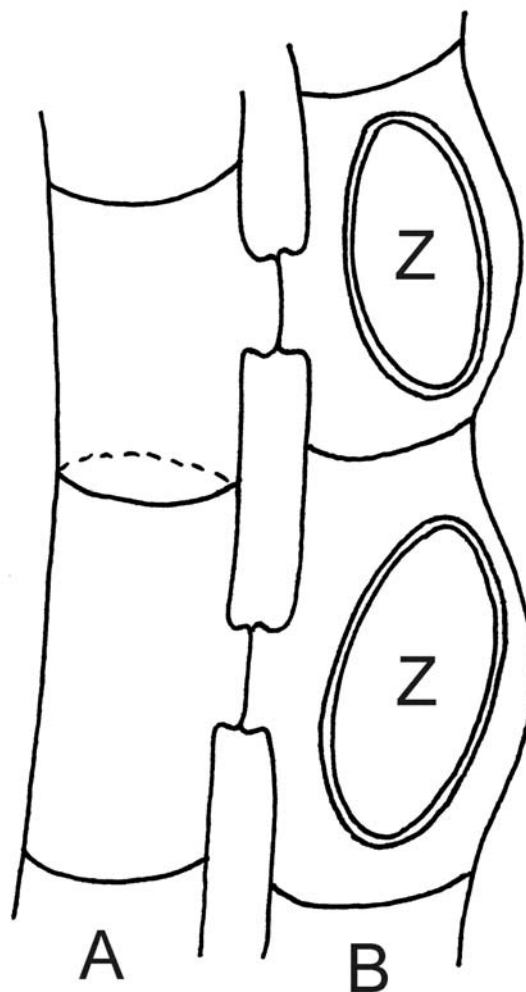
Pilospora VENKATACHALA and KAR 1968, pp. 442–443.

Schizophaeus PIERCE 1976, p. 30.

List of synonyms has been given by Zippi (1998).

Botanical affinity: Morphologically these microfossils resemble zygospores and aplanospores of several species of *Spirogyra* (text-figure 2). They are also similar to zygospores of the extant genera *Zygogonium* (Zippi 1998; Mahmoud 2000) and *Sirogonium* (van Geel 1976). Fossil algal filaments of Zygnematales with zygospores *Ovoidites* were found in Cenomanian amber from France (Breton 2007). Oval zygospores occur also in some genera of desmids, e.g. in genus *Desmidium* (Förster 1982).

Ecology: *Ovoidites* microfossils are widely dispersed, but restricted to freshwater habitats (Rich et al. 1982).



TEXT-FIGURE 2

Conjugation and zygospore formation in the extant genus *Spirogyra* calcarea Transeau (after Kadłubowska 1972): A, B . conjugating filaments; Z . zygospore.

Ovoidites elongatus (Hunger 1952) Krutzsch 1959

Plate 1, figure 9; Plate 2, figure 1

Sporites elongatus HUNGER 1952, p. 193, pl. 1, fig. 12 [Miocene, Germany].

Ovoidites elongatus (Hunger) KRUTZSCH 1959, p. 252 [Pliocene, Germany].

Schizosporis parvus COOKSON and DETTMANN 1959, p. 216, pl. 1, figs 15–20 [Cretaceous, Australia].

Schizosporis laevigatus STANLEY 1965, pp. 268–269, pl. 23, figs 6–7, pl. 37, figs 4–5 [Cretaceous–Palaeocene?, S Dakota].

Ovoidites parvus (Cookson and Dettmann) NAKOMAN 1966, p. 91 [Tertiary, Turkey].

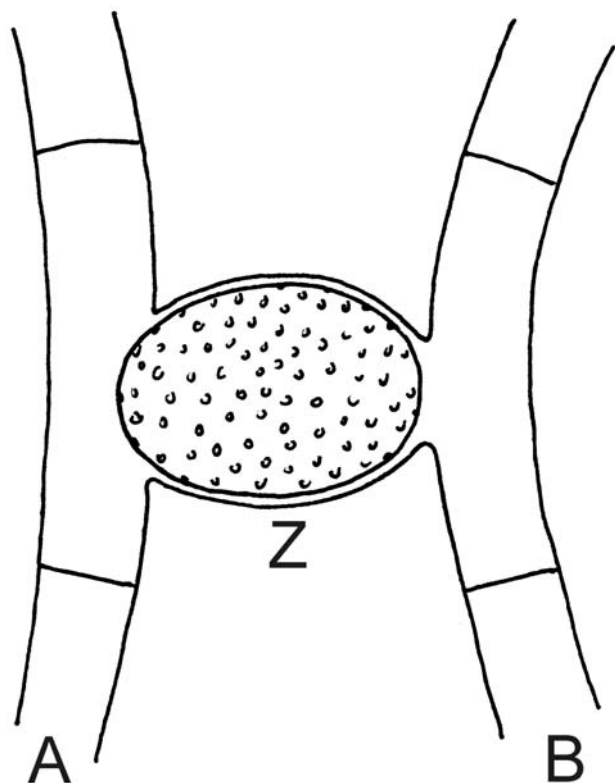
Psiloschizosporis parvus JAIN 1968, p. 31 [Middle Triassic, Argentina].

Schizosporis parvus Cookson and Dettmann – AGASIE 1969, p. 28, pl. 4, fig. 15 [Cenomanian, Arizona].

Schizophaeus parvus (Cookson and Dettmann) PIERCE 1976, p. 30. Spore Type C (*Spirogyra* spec.) – VAN GEEL 1976, p. 342, pl. 1, figs 5, 8, 10 [Holocene, Netherlands].

Ovoidites elongatus (Hunger) Krutzsch – KRUTZSCH and VANHOORNE 1977, p. 6, pl. 2, figs 3, 4 [Eocene, Belgium].

Spirogyra sp. (Type 1) – VAN GEEL and VAN DER HAMMEN 1978, pp. 385–386, pl. 3, figs 34, 37, 40, 41 [Quaternary, Colombia].



TEXT-FIGURE 3

Conjugation and zygospore formation in the extant species *Zygnema adpectinatum* Transeau (after Kad.ubowska 1972): A, B – conjugating filaments; Z – zygospore.

Ovoidites elongatus (Hunger) Krutzsch – KRUTZSCH and PACLTOVÁ 1990, p. 360, text-fig. 8, pl. 3, figs 26–27 [Pliocene, Czech Republic].

Ovoidites elongatus (Hunger) Krutzsch subsp. *elongatus* – ASHRAF and MOSBRUGGER 1996, p. 24, pl. 4, fig. 18 [Miocene, Germany].

Ovoidites parvus (Cookson and Dettmann) Nakoman (= *Schizosporis* sp. aff. *S. parvus* Cookson and Dettmann sensu Mahmoud 1996, fig. 4S) – MAHMOUD 2000, pp. 104–105, pl. 1, figs 4, 9 [Plio-Pleistocene, Egypt].

Schizosporis parvus Cookson and Dettmann – BETTAR and MÉON 2006, pl. 5, fig. 1 [Albian, Morocco].

Ovoidites elongatus (Hunger) Krutzsch – WOROBIEC and WOROBIEC 2008, p. 1003, fig. 5C [Upper Miocene, Poland].

Description: Zygospores (? or aplanospores) elongate, narrowly ellipsoidal in outline, 70–100µm long and 30–50µm wide. Wall surface psilate or very finely punctate. Wall about 2–3µm thick. Zygospores split longitudinally into two equal halves.

Remarks: In the studied material *Ovoidites elongatus* and *O. minoris* were counted together, and about 45 specimens of these taxa were recorded.

Ovoidites minoris Krutzsch and Pacltová 1990

Plate 1, figures 10, 11

cf. *Sporites immemoratus* – DOKTOROWICZ-HREBNICKA 1961, p. 193, pl. 3, fig. 28 [Middle Miocene, Poland].

Spore Type C (*Spirogyra* spec.) – VAN GEEL 1976, p. 342, pl. 1, figs 6, 7, 9 [Holocene, Netherlands].

Spirogyra sp. (Type 1) – VAN GEEL and VAN DER HAMMEN 1978, pp. 385–386, pl. 3, figs 35, 36, 38, 39, pl. 4, fig. 42 [Quaternary, Colombia].

Type 130: *Spirogyra* sp. – PALS et al. 1980, p. 407, pl. 3, figs 130a, b [Holocene, Netherlands].

Ovoidites minoris KRUTZSCH and PACLTOVÁ 1990, pp. 358–360, text-fig. 7, pl. 3, fig. 25 [Pliocene, Czech Republic].

Brazilea parva (Cookson and Dettmann) Tiwari and Navale – YI 1997, p. 520, figs 11e, f [Upper Cretaceous, Korea].

Spirogyra type 1 – MEDEANIC 2006, p. 92, pl. 3, figs 1–3, 5–8 [Holocene, Brazil].

Description: Zygospores (? or aplanospores) elongate, narrowly ellipsoidal in outline, about 50–60µm long. Wall psilate, about 1.0–1.5µm thick. Zygospores split longitudinally into two equal halves.

Remarks: In the studied material about 45 specimens of *Ovoidites elongatus* and *O. minoris* were recorded.

Ovoidites grandis (Pocock 1962) Zippi 1998

Plate 1, figures 7, 8a, b

Sporites immemoratus DOKTOROWICZ-HREBNICKA 1960, p. 226, pl. 17, fig. 18 [Middle Miocene, Poland].

Pollenites peramplus – DOKTOROWICZ-HREBNICKA 1960, pl. 44, fig. 238 [Middle Miocene, Poland].

Schizosporis grandis POCKOCK 1962, p. 76, pl. 13, fig. 199 [Lower Cretaceous, Canada].

Schizosporis majusculus HEDLUND 1966, p. 32, pl. 10, figs 1a, b [Cenomanian, Oklahoma].

Schizophacus majusculus (Hedlund) PIERCE 1976, p. 30.

Psiloschizosporis maximus SONG and LIU 1982, p. 178, pl. 2, fig. 21 [Eocene–Oligocene, China]. Type 130:

Spirogyra psilate spore – VAN GEEL et al. 1983, p. 313, pl. 1, fig. 130 [Holocene, Netherlands].

Spirogyra sp. Tipo A – ZAMALOA 1996, p. 182, pl. 1, figs 17–19 [Middle Tertiary, Argentina].

Brazilea majuscula (Hedlund) n. comb. [*Brazilea majusculus*? (Hedlund) n. comb.] YI 1997, pp. 519–520, fig. 11d [Upper Cretaceous, Korea].

Ovoidites grandis (Pocock) ZIPPI 1998, pp. 38–40, pl. 17, figs 1–6 [Albian, Ontario].

Description: Zygospores ellipsoidal in outline, more than 100–165µm long. Wall surface psilate. Wall about 2–3µm thick. Zygospores split longitudinally into two equal halves.

Remarks: In the examined material 5 specimens of *Ovoidites grandis* were recorded. Since *Ovoidites grandis* differs from *O. elongatus* (= *O. parvus*) only in size, and is less frequent than the smaller species, it may be a polyploid variant of smaller species according to Zippi (1998). Polyploidy is common in living Zygnemataceae, and results in various morphotypes (i.e. differing in filament width and zygospore size). These morphotypes could be identified as various species of *Spirogyra* by conventional taxonomic criteria (Hoshaw et al. 1985; Wang et al. 1986; Hoshaw 1987; McCourt and Hoshaw 1990). Polyploidy may have caused widespread occurrence of *Spirogyra*, and associated morphological plasticity may account for the high apparent species diversity and survival of the genus in a wider variety of microhabitats than occupied by other Zygnemataceae (McCourt et al. 1986). Some modern *Spirogyra* species (e.g. *S. crassoidea*, *S. elliptica*, *S. ellipsospora*, and *S. splendida*) produce smooth-wall zygospores, even more than 200µm long (Kadłubowska 1972, 1984).

Ovoidites gracilis Krutzsch and Pacltová 1990

Plate 1, figures 12a–c

Ovoidites gracilis KRUTZSCH and PACLTOVÁ 1990, p. 360, text-fig. 9, pl. 3, fig. 28–32 [Pliocene, Czech Republic].
Spirogyra sp. Tipo C – ZAMALOA 1996, pp. 182–183, pl. 1, figs 23–24 [Middle Tertiary, Argentina].

Description: Zygosporangia ellipsoidal in outline, about 65–80 µm long. Wall about 1 µm thick, hyaline, with poorly visible rugule. Zygosporangia folded longitudinally.

Remarks: In the sediment under study 2 specimens of *Ovoidites gracilis* were found.

Ovoidites spriggii (Cookson and Dettmann 1959) Zippi 1998
 Plate 2, figures 2a, b

Schizosporis spriggii COOKSON and DETTMANN 1959, p. 216, pl. 1, figs 10–14 [Cretaceous, Australia].
Psiloschizosporis cacheutensis JAIN 1968, p. 31, pl. 9, fig. 127 [Triassic, Argentina].
Schizophaeus spriggii (Cookson and Dettmann) PIERCE 1976, p. 30.
Brazileia spriggii (Cookson and Dettmann) YI 1997, p. 520, fig. 11g [Upper Cretaceous, Korea].
Ovoidites spriggii (Cookson and Dettmann) ZIPPI 1998, p. 40, pl. 15, figs 7–12, pl. 16, figs 10–15 [Albian, Ontario].
Schizosporis spriggii Cookson and Dettmann – BETTAR and MÉON 2006, pl. 5, fig. 3 [Albian, Morocco].
Ovoidites spriggii (Cookson and Dettmann) Zippi – ZAVATTIERI and PRÁMPARO 2006, pp. 1198–1199, pl. 3, figs 1–5 [Triassic, Argentina].

Description: Zygosporangia circular to broadly ovoidal, about 60–110 µm in size. Wall psilate to finely granulate, about 2–4 µm thick. Zygosporangia often split longitudinally into two equal halves.

Botanical affinity: These microfossils are close to the recent *Spirogyra* (e.g. *S. majuscula*) as well as some *Mougeotia* (e.g. *M. macrospora*) zygosporangia (see Kadłubowska 1972, 1984).

Remarks: In the studied material 20 specimens of this species were encountered.

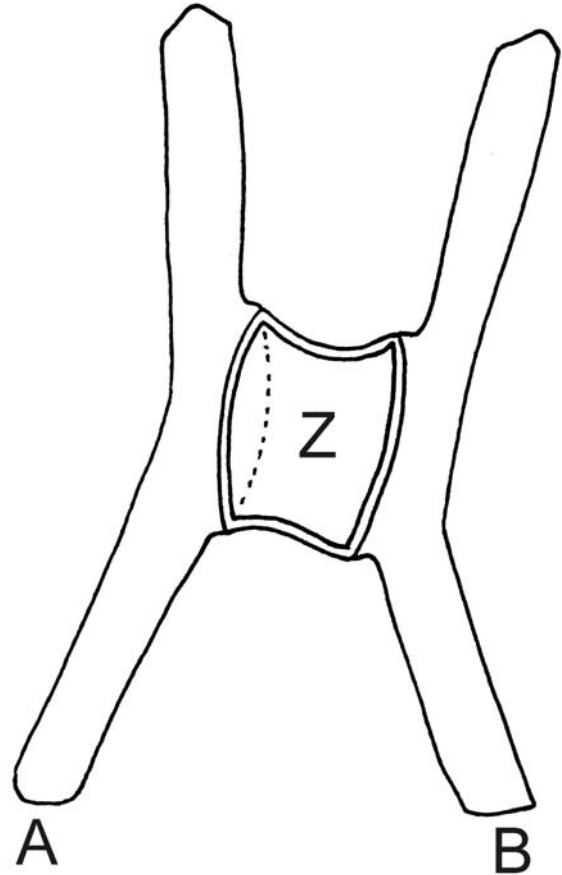
Genus *Cycloovoidites* Krutzsch and Pacltová 1990
 Type species: *Cycloovoidites cycclus* (Krutzsch 1959) Krutzsch and Pacltová 1990

Cycloovoidites cycclus (Krutzsch 1959) Krutzsch and Pacltová 1990
 Plate 2, figures 3a, b, 4, 5a, b

Ovoidites cycclus KRUTZSCH 1959, p. 251 [Pliocene, Germany].
Schizosporis rugulatus COOKSON and DETTMANN 1959, p. 216, pl. 1, figs 5–9 [Cretaceous, Australia].
 Type 341B: algal spore (cf. Zygnemataceae) – VAN GEEL et al. 1981, p. 432, pl. 8, figs 341Ba, b [Quaternary, Netherlands].
Cycloovoidites cycclus (Krutzsch) ssp. *minor* KRUTZSCH and PACLTOVÁ 1990, pp. 362–363, text-fig. 13, pl. 4, fig. 44 [Pliocene, Czech Republic].
Ovoidites cycclus Krutzsch – ASHRAF and MOSBRUGGER 1996, p. 24, pl. 4, fig. 19 [Miocene–Pliocene, Germany].

Description: Zygosporangia circular to broadly ovoidal, about 60–120 µm in size. Wall about 1.5–2.5 µm thick, with an irregular reticuloid pattern of ridges on the surface. Zygosporangia split longitudinally into two equal halves.

Botanical affinity: As the genus *Ovoidites* these microfossils are referable to the extant genus *Spirogyra*. Recently similar circular, ornamented zygosporangia occur e.g. in species *Spirogyra megaspora* and *S. lenticularis* (Kadłubowska 1972, 1984; Simons et al. 1982).



TEXT-FIGURE 4

Conjugation and zygosporangium formation in the extant species *Mougeotia laetevirens* (A. Br.) Wittrock (after Kadłubowska 1972): A, B – conjugating filaments; Z – zygosporangium.

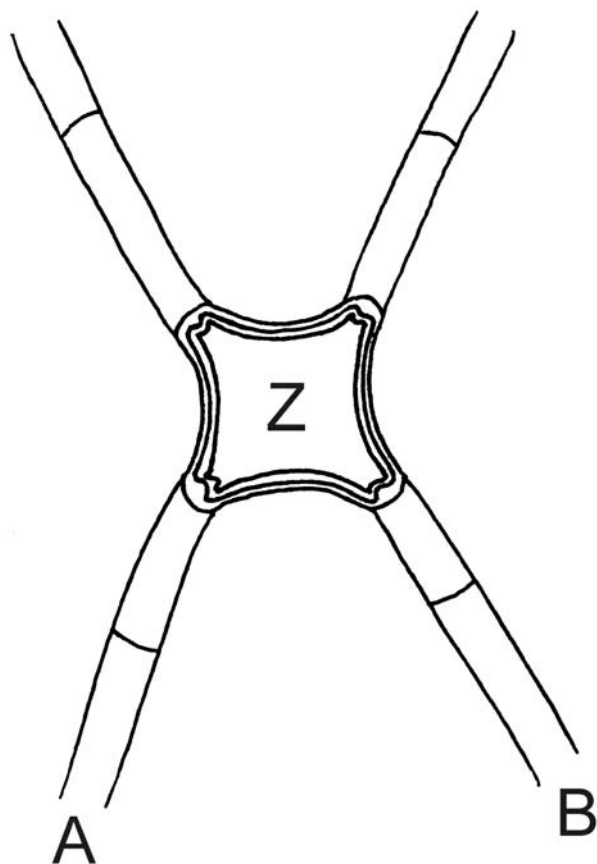
Remarks: In the studied material 10 specimens of this species were encountered.

Very similar microfossils differing only in size (140 µm in diameter), were described by Nagy (1965) from the Middle Miocene of Hungary as *Cooksonella circularis* Nagy.

Genus *Stigmozygodites* Krutzsch and Pacltová 1990
 Type species: *Stigmozygodites multistigosus* (Potonié 1931) Krutzsch and Pacltová 1990

Stigmozygodites microfoveolatus Krutzsch and Pacltová 1990
 Plate 2, figures 6a, b

Type 314: *Zygnema* Type – VAN GEEL et al. 1981, p. 427, pl. 5, fig. 314c [Quaternary, Netherlands].
Stigmozygodites microfoveolatus KRUTZSCH and PACLTOVÁ 1990, pp. 380–381, text-fig. 36, pl. 7, figs 106–108 [Pliocene, Czech Republic].
Zygnema type – COLLINSON et al. 1993, pl. 20, fig. 6 [Eocene, England].
Zygnema sp. Tipo A – ZAMALOA 1996, p. 183, pl. 1, figs 20–22 [Middle Tertiary, Argentina].
Zygnema C.A. Agardh – LEONHARDT and LORSCHTEITZ 2007, p. 50, fig. 29 [Quaternary, Brazil].



TEXT-FIGURE 5

Conjugation and zygospore formation in the extant species *Mougeotia viridis* (Kützinger) Wittrock (after Kadłubowska 1972): A, B – conjugating filaments; Z – zygospore.

Description: Zygospores circular to broadly ovoidal, about 40–60 × 40–44 μm in size. Wall thin, densely covered with fovea (about 2–3 μm in diameter). Zygospores often deformed.

Botanical affinity: The morphological features of *Stigmatodites* are consistent with zygospores of Zygnemataceae. They are referable to the extant genus *Zygnema* (text-figure 3), although circular-oval zygospores with foveolate sculpture occur also in *Mougeotia* (section *Mesocarpus*; e.g. *M. megaspora*, *M. robusta*, and *M. sanfordiana*) and *Zygogonium* (e.g. *Z. indicum*) genera (Kadłubowska 1972, 1984), as well as in some desmids (e.g. *Xanthidium armatum* and *Pleurotaenium*; see Handke 1996).

Ecology: The occurrence of these microfossils indicates shallow, mesotrophic to eutrophic, open water (van Geel et al. 1981).

Remarks: In the examined material 9 specimens of this taxon were found. Similar microfossils, but with distinctly bigger fovea, were described as *Lacunalites* Hemer and Nygreen (Grenfell 1995) and *Gelasinicysta* Head (Head 1992).

Genus *Diagonalites* Krutzsch and Pacltová 1990
Type species: *Diagonalites diagonalis* Krutzsch and Pacltová 1990
Kachiisporis YI 1997, p. 522.

Diagonalites diagonalis Krutzsch and Pacltová 1990
Plate 3, figures 1–4; opercula Plate 3, figures 5a, b, 7a, b

Pollen grains and spores indetermined – MACKO 1956, pl. 26, figs 34, 35, (3?) [Miocene, Poland].

Mougeotia cf. *M. laetevirens* (A. Braun) Wittrock (Type1) – VAN GEEL and VAN DER HAMMEN 1978, p. 383, pl. 1, figs 1–9 [Pleistocene, Colombia].

Tetraporina diagonalis LINDGREN 1980, p. 350, pl. 2, fig. A [Upper Cretaceous, Sweden].

Type 373: zygospore of *Mougeotia* cf. *laetevirens* (A. Braun) Wittrock – VAN GEEL et al. 1981, p. 439, pl. 11, figs 373a, b [Quaternary, Netherlands].

Diagonalites diagonalis KRUTZSCH and PACLTOVÁ 1990, pp. 383–385, text-fig. 41, pl. 8, figs 122–125 [Pliocene, Czech Republic].
Mougeotia sp. cf. *M. laetevirens* (A. Braun) Wittrock – ZAMALOA 1996, p. 180, pl. 1, figs 1–5 [Middle Tertiary, Argentina].

Kachiisporis bivalvus YI 1997, p. 522, text-fig. 4, figs 12b–e [Upper Cretaceous, Korea].

Mougeotia sp. cf. *M. laetevirens* (Braun) Wittrock – ZIPPI 1998, pp. 30–34, text-fig. 14, pl. 13, fig. 1 [Albian, Ontario].

Mougeotia sp. – MAHMOUD 2000, p. 104, pl. 1, fig. 6, (1?); pl. 1, figs 5, 12 – two opercula of *Mougeotia* sp. 5 [Plio-Pleistocene, Egypt].

Mougeotia sp. aff. *M. laetevirens* (Braun) Wittrock in Wittrock and Norstedt – ZAVATTIERI and PRÁMPARO 2006, p. 1198, pl. 2, figs 11–13 [Triassic, Argentina].

Description: Zygospores cylindrical or conical, often compressed, with two valvate openings. Wall about 2 μm thick, psilate. Cylindrical part about 46–52 μm long and about 35–45 μm wide, with two opercula. Operculum circular, about 33–48 μm in diameter, in some specimens a central pore visible. Often dispersed opercula present.

Botanical affinity: *Diagonalites*-like microfossils are usually related to the recent zygospores of *Mougeotia laetevirens* (text-figure 4; van Geel and van der Hammen 1978; van Geel et al. 1981; Zippi 1998; Zavattieri and Prámparo 2006), but they are also morphologically close to zygospores of the other *Mougeotia* species from section *Mesocarpus* (e.g. *M. acadiana* and *M. varians*).

Ecology: *Mougeotia laetevirens* is a cosmopolitan filamentous freshwater algae, occurring in small water bodies, such as ponds, river and lake margins, and paddy fields (Kadłubowska 1972, 1984).

Remarks: In the examined material 14 specimens of cylindrical part and 17 specimens of dispersed opercula were found.

Genus *Tetraporina* Naumova 1939 ex Bolkhovitina 1953
Type species: *Tetraporina antiqua* Naumova 1950
Synonyms

Tetraporina NAUMOVA 1939, p. 357.

Tetrapidites Klaus ex MEYER 1956, p. 107.

Tetraporopollenites FRANTZ 1960, p. 559.

Balmeilla PANT and MEHRA 1963, p. 116.

Tetraporina Naumova emend. LINDGREN 1980, pp. 346–347.

Remarks: Quadrate zygospores resembling recent zygospores of the genus *Mougeotia* occur in sediments of various age. From the Cainozoic deposits they are often reported as *Tetrapidites* (Krutzsch and Pacltová 1990). These microfossils have more or less concave sides, various wall thickness (about 0.5–2.0 μm) and sculptures (smooth, pitted or covered in small fovea). So, numerous species of the morphological genus *Tetraporina* or

types of *Mougeotia* zygospores are distinguished (see Jarzen 1979; Pals et al. 1980; van Geel et al. 1981; van der Wiel 1982; Krutzsch and Pacltová 1990). Some *Tetraporina* species distinguished by Lindgren (1980) have probably different botanical affinity (possibly they are fossil zygospores of desmids).

Tetraporina sp. 1

Plate 3, figures 8–11b

Type 135: *Mougeotia* sp. – PALS et al. 1980, p. 409, pl. 4, fig. 135 [Holocene, Netherlands].

Tetrapidites foveolatus KRUTZSCH and PACLTOVÁ 1990, p. 373, text-fig. 25, pl. 6, figs 76–78 [Pliocene, Czech Republic].

Description: Zygospores quadrate in outline, with concave sides, about 30–40 µm in size. Wall about 0.5–1.0 µm thick. Small fovea (about 0.5–1.0 µm in diameter) present all over the surface of the zygospore wall.

Botanical affinity: Morphologically these microfossils are close to zygospores of the genus *Mougeotia* (text-figure 5), especially to the recent section *Staurospermum* (e.g. *M. quadrangulata* and *M. punctata*).

Ecology: Today *Mougeotia quadrangulata* and *M. punctata* occur in shallow stagnant waters, such as small lakes, ponds, ditches, and paddy fields (Kadłubowska 1972, 1984).

Remarks: In the studied material 14 specimens of this type of structure were encountered.

Tetraporina sp. 2

Plate 3, figures 6a, b

Tetraporina quadrata Bolchovitina – NAGY 1969, pp. 310–311, pl. 2, fig. 5 [Miocene, Hungary].

Zygospore Type A (*Mougeotia* cf. *punctata*) – VAN GEEL 1976, p. 342, pl. 1, figs 1–3 [Holocene, Netherlands].

Tetrapidites laevigatus KRUTZSCH and VANHOORNE 1977, pp. 4–5, pl. 1, figs 14–15 [Eocene, Belgium].

Mougeotia spec. (Type 2) – VAN GEEL and VAN DER HAMMEN 1978, p. 383, pl. 1, figs 10–12, pl. 2, fig. 18 [Quaternary, Colombia].

Type 136: *Mougeotia* sp. – PALS et al. 1980, p. 409, pl. 4, fig. 136 [Holocene, Netherlands].

Type 313F: *Mougeotia* cf. *punctata* – VAN GEEL et al. 1983, p. 331, pl. 9, fig. 313F [Holocene, Netherlands].

Tetraporina quadrata Bolchovitina – GRABOWSKA 1996, p. 390, pl. 127, figs 5–6 [Eocene–Oligocene, Poland].

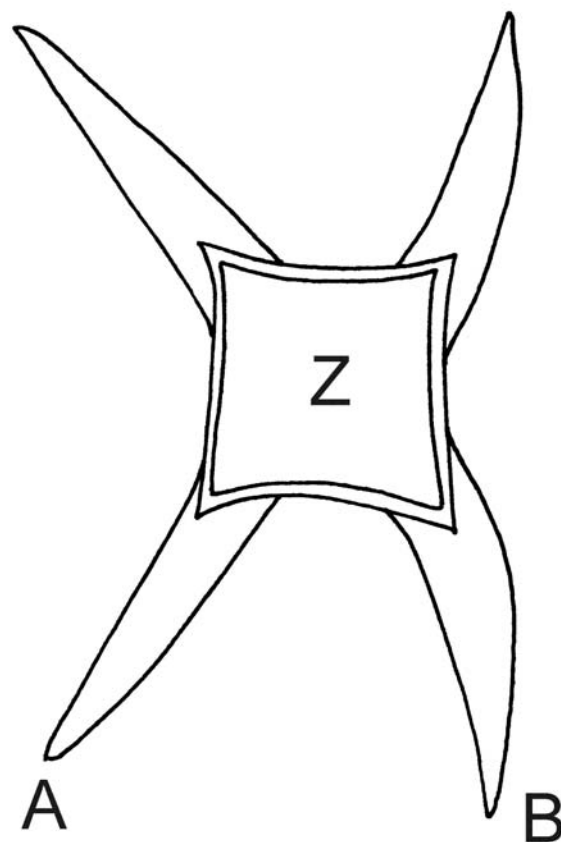
Mougeotia sp. – ZAMALOA 1996, pp. 180–182, pl. 1, figs 6–9 [Middle Tertiary, Argentina].

Description: Zygospores quadrate in outline, about 30–45 µm in size, with straight to slightly concave sides. Wall about 0.5–1.0 µm thick, hyaline, psilate to punctate.

Botanical affinity: Similar zygospores occur in the extant genus *Mougeotia*, as well as in *Closterium setaceum* (see Kadłubowska 1972, 1984; Ružicka 1977; Förster 1982).

Ecology: *Closterium setaceum* is an oligo-eutrophic cosmopolitan desmid (Croasdale and Flint 1986).

Remarks: In the examined material 4 specimens of this type were found.



TEXT-FIGURE 6

Conjugation and zygospore formation in the extant species *Closterium tumidulum* Gay (after Ružicka 1977): A, B – conjugating desmids; Z – zygospore.

Order ZYGNEMATALES

Family ?Closteriaceae, ?Zygnemataceae

Genus *Spintetrapidites* Krutzsch and Pacltová 1990

Type species: *Spintetrapidites longicornutus* Krutzsch and Pacltová 1990

Spintetrapidites quadriformis Krutzsch and Pacltová 1990

Plate 3, figures 13a, b, 14a, b

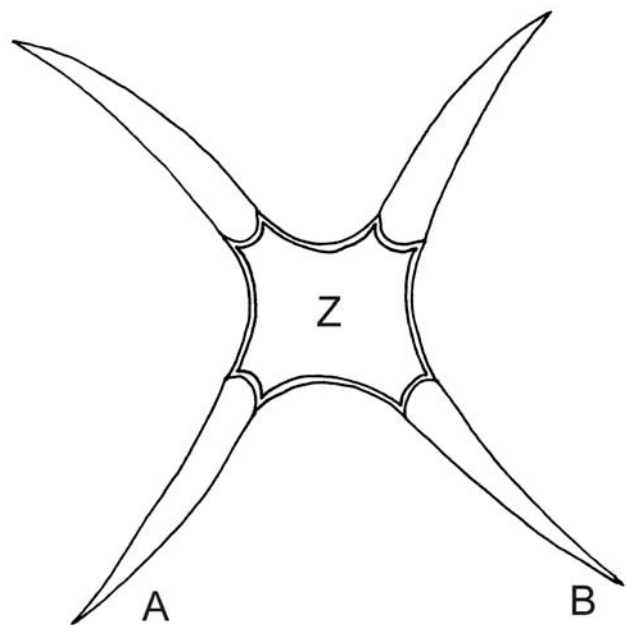
Type 167 algal (?) spores – VAN GEEL et al. 1983, p. 318, pl. 4, figs 167a–c [Holocene, Netherlands].

Spintetrapidites quadriformis KRUTZSCH and PACLTOVÁ 1990, p. 366, text-fig. 16, pl. 5, figs 51–52 [Pliocene, Czech Republic].

Spintetrapidites quadriformis Krutzsch and Pacltová – WOROBIEC and WOROBIEC 2008, p. 1002, fig. 5B [Upper Miocene, Poland].

Description: Zygospores (?) tetragonal, with straight or slightly concave sides, about 35–45 µm in size. Wall psilate, hyaline, about 0.5 µm thick.

Botanical affinity: In terms of their shape and lack of pseudopores these microfossils resemble zygospores of desmids (e.g. *Closterium cornu* and *C. tumidulum*; text-figure 6) as well as Zygnemataceae (genus *Mougeotia*).



TEXT-FIGURE 7
Conjugation and zygospore formation in the extant species *Closterium rostratum* Ehrenberg ex Ralfs (after Růžicka 1977): A, B – conjugating desmids; Z – zygospore.

Ecology: *Closterium cornu* is an oligo-eutrophic cosmopolitan desmid occurring in lakes and mires (Růžicka 1977; Förster 1982; Croasdale and Flint 1986; Handke 1996). According to van Geel and co-authors (1983) microfossil of Type 167 occur in stagnant, shallow, open water, in eutrophic conditions.

Remarks: In the studied material 7 specimens of this taxon were found.

***Spintetrapidites cf. verrulineatus* Krutzsch and Pacltová 1990**
Plate 3, figure 12

Spintetrapidites verrulineatus KRUTZSCH and PACLTOVÁ 1990, pp. 365–366, text-fig. 15, pl. 5, figs 48–50 [Pliocene, Czech Republic].

Description: Zygospore (?) tetragonal, with concave sides, spindle-shaped, about 32µm in size. Wall psilate, hyaline, about 0.5µm thick.

Botanical affinity: This microfossil resembles *Tetradron regulare* and *T. victoriae* microalgae (see Yamagishi 1992) as well as some desmid zygospores (e.g. *Closterium cornu*; Handke 1996).

Ecology: The mentioned *Tetradron* species occur mainly in ponds (fishponds) and lakes (Yamagishi 1992).

Remarks: In the studied material a single specimen of this taxon was recorded.

Spintetrapidites sp. 1
Plate 3, figures 16a, b

Tetraporina pulvinula LINDGREN 1980, pp. 348–349, pl. 1, figs B, C [Upper Cretaceous, Sweden].

cf. *Spintetrapidites* sp. – KRUTZSCH and PACLTOVÁ 1990, p. 366, text-fig. 17, pl. 5, figs 53–55 [Pliocene, Czech Republic].

Description: Zygospores (?) tetragonal, with rounded angles, about 35–45µm in size. Wall psilate, hyaline, about 0.5µm thick.

Botanical affinity: This microfossil resembles zygospores of Zygnemataceae (*Mougeotia* genus) and Closteriaceae (*Closterium* genus).

Remarks: In the examined material 2 specimens of this taxon were found.

Order ZYGNEMATALES
Family Closteriaceae

Genus ***Closteritetrapidites*** Krutzsch and Pacltová 1990
Type species: *Closteritetrapidites magnus* Krutzsch and Pacltová 1990

***Closteritetrapidites magnus* Krutzsch and Pacltová 1990**
Plate 3, figures 17a, b

Closteritetrapidites magnus KRUTZSCH and PACLTOVÁ 1990, p. 368, text-fig. 18, pl. 5, figs 56–57 [Pliocene, Czech Republic].

Description: Zygospores tetragonal, with pointed corners, about 60 × 45µm in size. Wall psilate, hyaline, about 0.5µm thick.

Botanical affinity: Morphologically these microfossils are close to the recent zygospores of *Closterium* algae.

Remarks: In the studied material 3 specimens of this taxon were found.

***Closteritetrapidites pacltovae* E. Worobiec sp. nov.**
Plate 4, figures 1a, b, 2, 3

Closterium cf. *C. kützingii* Brébisson (Desmidiaceae) zygospore – VAN GEEL and VAN DER HAMMEN 1978, pp. 383–385, pl. 2, fig. 20 [Quaternary, Colombia].

Type 372: zygospores of *Closterium* cf. *rostratum* Ehrenberg ex Ralfs – VAN GEEL et al. 1981; p. 439, pl. 11, figs 372a, b [Quaternary, Netherlands].

Holotype: Plate 4, figs 1a, b, sample Józefina 47.5(1), slide location 41.4/94.5. Stored in Institute of Geological Sciences, Cracow Research Centre, Polish Academy of Sciences, Senacka 1, Kraków.

Type locality: Józefina borehole, Kraków-Silesia Upland, central Poland.

Type stratum: Upper Miocene.

Derivation of name: In honour of Professor Blanka Pacltová, a famous Czech palynologist.

Diagnosis: Zygospores tetragonal, with distinctly truncate angles. Wall thin, hyaline, with smooth surface.

Description: Zygospores tetragonal, about 56–60 × 50–55µm in size (holotype 58 × 52µm in size), with truncate angles. Some of them with slightly concave sides. Wall psilate, hyaline, about 0.5–1.0µm thick.

Discussion: *Closteritetrapidites pacltovae* differs from other species of this genus by the distinctly truncate angles.

TABLE 1

Results of fossil freshwater phytoplankton analysis (number of specimens) of the Józefina material.

TAXON	BOTANICAL AFFINITY	45.7 m	46.2 m	47.5 m
<i>Botryococcus</i> cf. <i>braunii</i> Kützing	<i>Botryococcus</i> sp.		2	1
<i>Closteritetrapiidites magnus</i> Krutzsch & Pacltová	Closteriaceae (<i>Closterium</i>)		1	2
<i>Closteritetrapiidites pacltovae</i> sp. nov.	Closteriaceae (<i>Closterium</i>)		1	7
<i>Closteritetrapiidites reductus</i> Krutzsch & Pacltová	Closteriaceae (<i>Closterium</i>)			2
<i>Closteritetrapiidites</i> sp. 1	Closteriaceae (<i>Closterium</i>)			1
<i>Cycloovoidites cyclus</i> (Krutzsch) Krutzsch & Pacltová	Zygnemataceae (<i>Spirogyra</i>)	3	7	1
<i>Cystidiopsis conicus</i> Grabowska	?Zygnematales (?desmids)			1
<i>Diagonalites diagonalis</i> Krutzsch & Pacltová (+ dispersed opercula)	Zygnemataceae (<i>Mougeotia</i>)	1	8 (+10)	5 (+7)
<i>Geiselodinium</i> cf. <i>miocaenicum</i> Nagy	Dinophyceae (Gymnodiniales)		1	2
<i>Ovoidites elongatus</i> (Hunger) Krutzsch + <i>O. minoris</i> Krutzsch & Pacltová	Zygnemataceae (<i>Spirogyra</i>)	4	36	5
<i>Ovoidites gracilis</i> Krutzsch & Pacltová	Zygnemataceae (<i>Spirogyra</i>)	2		
<i>Ovoidites grandis</i> (Pocock) Zippi	Zygnemataceae (<i>Spirogyra</i>)	1	3	1
<i>Ovoidites spriggii</i> (Cookson & Dettmann) Zippi	Zygnemataceae (<i>Spirogyra</i>)	2	17	1
<i>Planctonites</i> cf. <i>stellarius</i> (Potonié) Krutzsch	Zygnematales (desmids)			1
<i>Pseudoschizaea rubina</i> Rossignol ex Christopher	?algae (?Zygnemataceae)			2
<i>Sigmopolis laevigatoides</i> Krutzsch & Pacltová	?Cyanobacteria	5	3	132
<i>Sigmopolis pseudosetarius</i> (Weyland & Pflug) Krutzsch & Pacltová + <i>S. punctatus</i> Krutzsch & Pacltová	?Cyanobacteria	150	146	378
<i>Spintetrapidites quadriformis</i> Krutzsch & Pacltová + <i>Spintetrapidites</i> sp. 1	Zygnematales (?desmids, ?Zygnemataceae)		3	6
<i>Spintetrapidites</i> cf. <i>verruineatus</i> Krutzsch & Pacltová	?Zygnematales (?desmids, ?Zygnemataceae), ? <i>Tetraedron</i>		1	
<i>Stigmozygodites microfoveolatus</i> Krutzsch & Pacltová	Zygnemataceae (<i>Zygnema</i>)	1	2	6
<i>Tetraporina</i> sp. 1	Zygnemataceae (<i>Mougeotia</i>)		5	9
<i>Tetraporina</i> sp. 2	Zygnemataceae (<i>Mougeotia</i>)	1	1	2
<i>Zygodites medius</i> (Rshnikova) Krutzsch & Pacltová + <i>Zygodites</i> sp.	?Zygnematales	7	17	8
? <i>Tythydiscus</i> sp.	?algae	1	2	
	SUM	177	246	568

Botanical affinity: Morphologically these microfossils are closely related to zygospores of the recent genus *Closterium*, especially to *C. kützingii* and *C. rostratum* (text-figure 7; see Růžicka 1977; Förster 1982; Croasdale and Flint 1986; Handke 1996).

Ecology: *Closterium kützingii* is a very tolerant planktonic desmid existing in a variety of habitats, e.g. in mires (Croasdale and Flint 1986).

Remarks: In the examined material 8 specimens of this taxon were recorded. All specimens were measured.

Closteritetrapiidites reductus Krutzsch and Pacltová 1990
Plate 3, figures 15a, b

Tetraporina mammillata LINDGREN 1980, p. 349, pl. 1, figs G, H [Upper Cretaceous, Sweden].

Closteritetrapiidites reductus KRUTZSCH and PACLTOVÁ 1990, pp. 368–369, text-fig. 20, pl. 5, figs 59–60 [Pliocene, Czech Republic].

Description: Zygosporangia tetragonal, about 55–60 × 40–55 µm in size. Sides straight, angles with a small (about 1–2 µm long) papilla. Wall psilate, hyaline, about 0.5 µm thick.

Botanical affinity: Morphologically these microfossils are close to the recent zygosporangia of *Closterium*.

Remarks: In the studied material 2 specimens of this taxon were recorded.

***Closteritetrapiidites* sp. 1**
Plate 4, figures 4a, b

Description: Zygosporangia tetragonal, about 56 × 50 µm in size. Wall punctate, about 0.5 µm thick.

Botanical affinity: Morphologically this microfossil is close to the recent zygosporangia of *Closterium* algae.

Remarks: In the studied material a single specimen of this taxon was found.

Order ZYGNEMATALES
Family uncertain

Genus *Planctonites* Krutzsch in Krutzsch, Pchalek and Spiegler 1960

Type species: *Planctonites stellarius* (Potonié 1934) Gruas-Cavagnetto 1968

Synonym = *Deflandridium* NAGY 1969, p. 294.

Planctonites* cf. *stellarius (Potonié 1934) Krutzsch in Krutzsch, Pchalek and Spiegler 1960
Plate 4, figure 5

Sporites stellarius POTONIÉ 1934, p. 46, pl. 1, fig. 26, pl. 6, fig. 3 [Eocene, Germany].

Planctonites stellarius (Potonié) Krutzsch – KRUTZSCH et al. 1960, p. 141 [Eocene–Oligocene, Germany].

Planctonites stellarius (Potonié) GRUAS-CAVAGNETTO 1968, p. 81, pl. 11, fig. 10 [Palaeocene, France].

Planctonites stellarius (Potonié) Gruas-Cavagnetto – HEAD 1992, pp. 252–254, pl. 4, figs 26–27 [Pliocene, England].

Algal spore – CHMURA et al. 2006, fig. 3c [Holocene, Florida].

Description: Zygosporangia (?) circular-polygonal in outline, about 42 × 44 µm in size, with numerous short conical protuberances. Wall about 1 µm thick, psilate, hyaline. **Botanical affinity:** *Planctonites stellarius* is a fossil algal spore of fresh and probably brackish waters (Krutzsch et al. 1960; Head 1992). Recently this type of zygosporangia occurs in desmids, e.g. *Closterium colosporum*, *Penium* and *Pleurotaenium* (Růžicka 1977). **Remarks:** In the examined material a single specimen of this morphotype was found. It differs from *Planctonites stellarius* in size and number of protuberances. Similar microfossils referable to morphological genus *Planctonites* have been recorded from Tertiary of Germany (Krutzsch et al. 1960), France (Gruas-Cavagnetto 1968), Hungary (Nagy 1969 – *Deflandri-*

dium stellatum Nagy), Czech (Kruttsch and Pacltová 1990), England (Head 1992) as well as Quaternary of Netherlands (Van Geel et al. 1981 – Type 333). Within this group of microfossils several different morphotypes, comparable with the zygospores of extant genera of desmids, can be recognized (see Head 1992).

Genus *Cystidiopsis* Nagy 1965

Type species: *Cystidiopsis certus* Nagy 1965

Cystidiopsis conicus Grabowska 1996

Plate 4, figures 6a, b

Cystidiopsis conicus GRABOWSKA 1996, pp. 391–392, pl. 129, figs 2–3 [Eocene, Poland].

Description: Zygosporangium (?) spherical, about 35 µm in size. Central body circular in outline, about 25 µm in diameter, densely covered with conical protuberances. Wall composed of a few layers, about 1 µm thick, surface psilate. Protuberances about 4–7 µm long, with rounded bases about 5–8 µm in diameter.

Botanical affinity: Morphologically this microfossil is comparable with zygospores of the extant *Actinotaenium cucurbita* (see Růžička 1981; pl. 50, fig. 18).

Ecology: *Actinotaenium cucurbita* is an adaptable desmid, widespread in mires, often among *Sphagnum*, as well in acid oligotrophic ponds, lakes and rivers (Croasdale and Flint 1986).

Remarks: In the examined material a single specimen of this species was recorded.

Genus *Zygodites* Kruttsch and Pacltová 1990

Type species: *Zygodites medius* (Rshnikova ?1956) Kruttsch and Pacltová 1990

Zygodites medius (Rshnikova ?1956) Kruttsch and Pacltová 1990 Plate 4, figures 8, 10

Type 119 – PALS et al. 1980, p. 405, pl. 1, figs 119a–d [Holocene, Netherlands].

Zygodites medius (Rshnikova) KRUTTSCH and PACLTOVÁ 1990, pp. 389–390, text-fig. 47, pl. 9, figs 167–175 [Pliocene, Czech Republic].

Description: Microfossils circular in outline, about 30–45 µm in diameter. Wall psilate, about 1 µm thick. Some specimens split into two halves.

Botanical affinity: Morphologically these microfossils are similar to zygospores of recent desmids (e.g. *Closterium*, *Gonatozygon* and *Pleurotaenium*) as well as zygospores of Zygnemataceae: *Mougeotia* (section *Mesocarpus*, e.g. *M. parvula*, *M. recurva* and *M. scalaris*), some species of *Spirogyra* (*S. circumcissa* and *S. frankliniana*) and *Zygnema* (*Z. gangesicum*).

Ecology: Today the above mentioned *Mougeotia* species occur in ditches, ponds, small water bodies, rivers, lakes, paddy fields and peat-bogs all over the world (Kadłubowska 1972, 1984). According to Pals and co-authors (1980) occurrence of microfossils of this type (Type 119) in Holocene of Netherlands is restricted to the lake deposits.

Remarks: In the analysed material 32 specimens of this taxon were encountered.

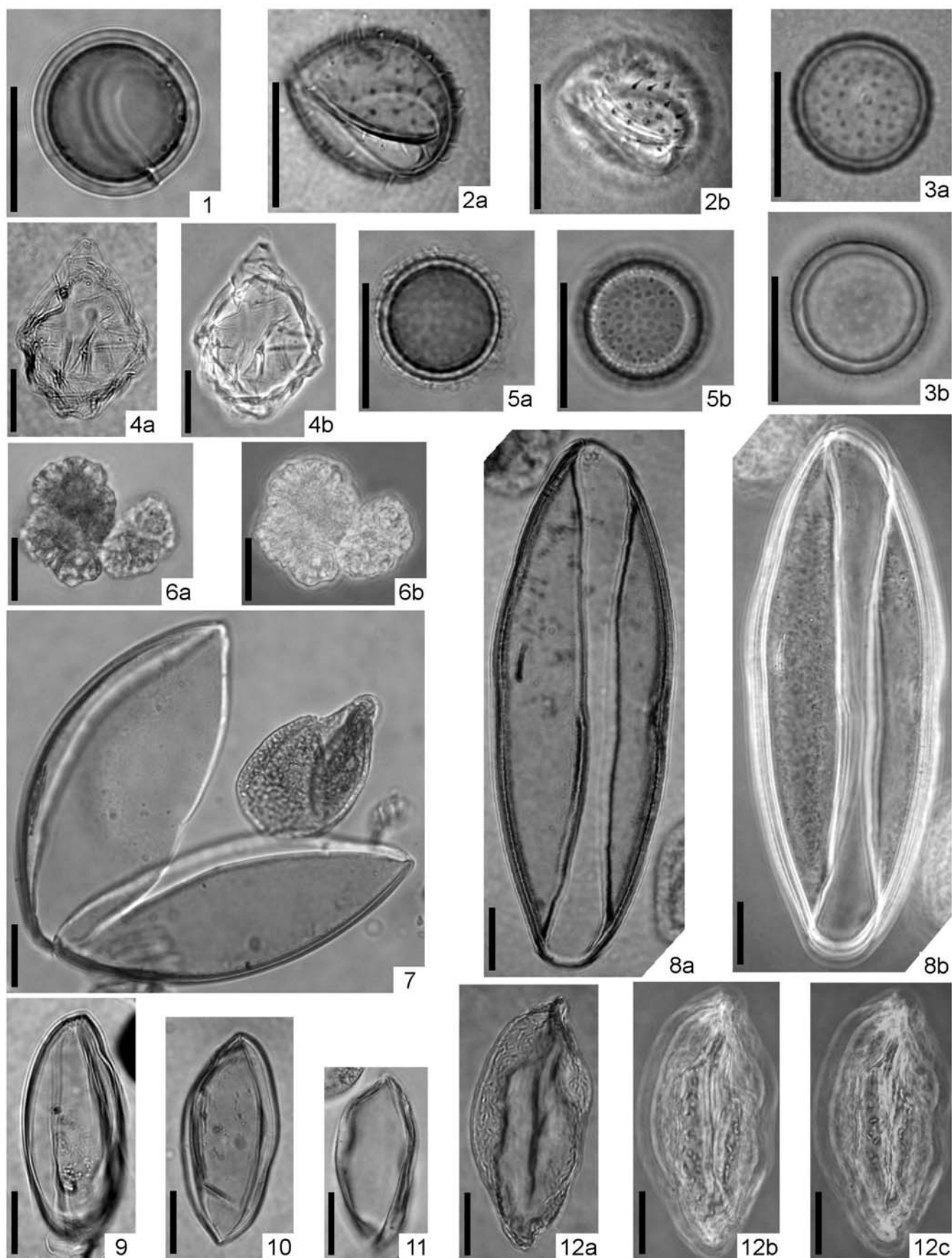
cf. *Zygodites* sp.

Plate 4, figures 9a, b

PLATE 1

Photography: G. Worobiec; scale bar 20 µm.

- | | |
|---|---|
| 1 <i>Sigmopollis laevigatoides</i> Kruttsch and Pacltová, borehole Józefina, depth 47.5m. | 7 <i>Ovoidites grandis</i> (Pocock) Zippi, borehole Józefina, depth 46.2m. |
| 2a,b <i>Sigmopollis pseudosetarius</i> (Weyland and Pflug) Kruttsch and Pacltová, borehole Józefina, depth 47.5m. | 8a,b <i>Ovoidites grandis</i> (Pocock) Zippi, borehole Józefina, depth 46.2m; b-phase contrast. |
| 3a,b <i>Sigmopollis</i> sp., borehole Józefina, depth 47.5m; b-phase contrast. | 9 <i>Ovoidites elongatus</i> (Hunger) Kruttsch, borehole Józefina, depth 46.2m. |
| 4a,b <i>Geiselodinium</i> cf. <i>miocaenicum</i> Nagy, borehole Józefina, depth 47.5m; b-phase contrast. | 10 <i>Ovoidites minoris</i> Kruttsch and Pacltová, borehole Józefina, depth 46.2m. |
| 5a,b <i>Sigmopollis punctatus</i> Kruttsch and Pacltová, borehole Józefina, depth 47.5m. | 11 <i>Ovoidites minoris</i> Kruttsch and Pacltová, borehole Józefina, depth 45.7m. |
| 6a,b <i>Botryococcus</i> cf. <i>braunii</i> Kutzing, borehole Józefina, depth 46.2m; b-phase contrast. | 12a-c <i>Ovoidites gracilis</i> Kruttsch and Pacltová, borehole Józefina, depth 45.7m; b, c-phase contrast. |



Description: Microfossil circular in outline, about 58µm in diameter. At the centre of the microfossil visible ring, about 25µm in diameter. Wall psilate, about 1µm thick.

Remarks: In the examined material a single specimen of this type was recorded.

?Zygodites sp., ?Ovoidites spriggii (Cookson and Dettmann 1959) Zippi 1998
Plate 4, figures 11, 12

Description: Microfossils circular in outline, about 60–130µm in diameter. Wall psilate, about 1.0–1.5µm thick. Some specimens split into two halves.

Remarks: These microfossils are similar to the fossil species *Zygodites medius*, but they are distinctly bigger. They differ from *Ovoidites spriggii* in thinner wall. In the analysed material a few specimens of this type were recorded.

INCERTE SEDIS
?algae

Genus ***Pseudoschizaea*** Thiergart and Frantz 1962 ex Potonié emend. Christopher 1976
Type species: *Pseudoschizaea circula* (Wolff 1934) Christopher 1976
Synonyms = *Concentricystes* ROSSIGNOL 1962, p. 134.
Pseudoschizaea THIERGART and FRANTZ 1962, p. 84.
Pseudoschizaea Thiergart and Frantz ex POTONIÉ 1966, p. 56.

Pseudoschizaea rubina (Rossignol 1962) Christopher 1976
Plate 4, figures 7a, b

Concentricystes rubinus ROSSIGNOL 1962, p. 134, pl. 2, figs 5–6 (in part) [Quaternary, Israel].
Sporites circulus Wolff – ROSSIGNOL 1964, pp. 94–98, pl. 3, figs 17–18 [Quaternary, Mediterranean area].
Chomotriletes fragilis Pocock – AGASIE 1969, p. 20, pl. 2, fig. 13 [Upper Cretaceous, Arizona].
Pseudoschizaea rubina Rossignol ex Christopher – CHRISTOPHER 1976, pp. 147–148, pl. 1, figs 1–10, 21 [Pleistocene, Alabama].
Pseudoschizaea rubina (Rossignol) Christopher – TAKAHASHI 1979, p. 45, pl. 1, figs 5–7 [Pleistocene, Japan].
Concentricystes rubinus Rossignol – WANG KAI-FA and HAN XIN-BIN 1983, p. 469, pl. 2, figs 11–12 [Cainozoic, East China].

Pseudoschizaea sp. – SCOTT 1992, pp. 349–354, fig. 1 [Quaternary, South Africa].
Pseudoschizaea sp. – MEDEANIC 2006, p. 92, pl. 3, figs 9–10 [Holocene, Brazil].
Concentricystes – SHU et al. 2008, pl. 1, fig. 10 [Neogene, NE China].

Description: Microfossil circular-oval in outline, 35–38µm in size. Wall about 1.0–1.5µm thick. Central area ornamented with a series of anastomosing and bifurcating muri, surrounded by a series of concentric ribs.

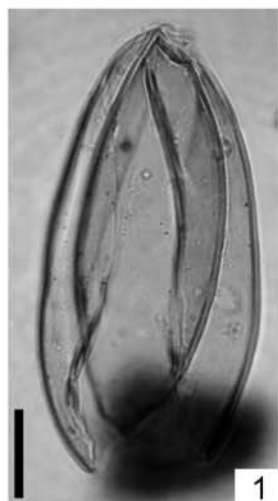
Botanical affinity: These microfossils are tentatively placed in the Zygnemataceae, even though they have never been collected alive (Grenfell 1995). According to Zippi (1998) many oospores of Oedogoniaceae are ornamented similarly to the described above. These microfossils are usually classified under the algae (Rossignol 1962; Christopher 1976), although it has been questioned by Scott (1992), as they could be resting stages of other organisms (invertebrates).

Remarks: In the studied material 2 specimens of *Pseudoschizaea rubina* were recorded. Similar microfossils are described under various names such as *Chomotriletes* Naumova, *Circulisporites* de Jersey, and *Concentricystes* Rossignol. They have two types of ornamentation: consisting of a number of simple concentric ribs – *Circulisporites*, or having ribs which may spiral or bifurcate and a polar area with complex muri – *Concentricystes* (Grenfell 1995). According to Christopher (1976) these two types of ornamentation represent two species within *Pseudoschizaea* genus. Some authors noticed that these microfossils sometimes split into two equal hemispheres along the equatorial lane. Pocock (1970) mentioned that ornamentation of proximal and distal faces may vary – “on the (?) proximal side ribs are distributed in a band running obliquely across the spore and folding back on themselves to form a type of groove which may function as a leptoma, while ribs on the (?) distal face are distributed in continuous circles or ovals parallel to the equatorial margin.” Devonian specimens described as *Chomotriletes* (Naumova 1953) differ from studied microfossils in having a trilete mark, so Devonian forms could represent spores of ancient land plants (Scott 1992). Younger microfossils of described above structure are known from many localities of various age, especially from Jurassic to Quaternary deposits.

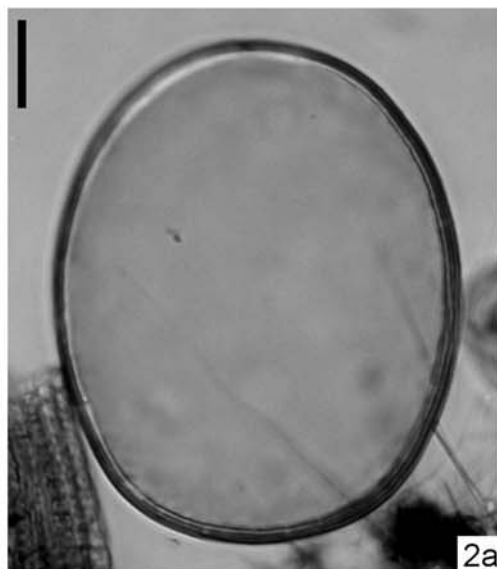
PLATE 2

Photography: G. Worobiec; scale bar 20µm.

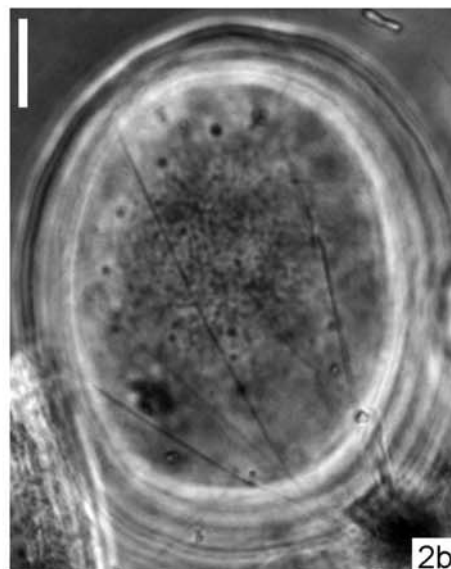
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| <p>1 <i>Ovoidites elongatus</i> (Hunger) Krutzsch, borehole Józefina, depth 46.2m.</p> <p>2a,b <i>Ovoidites spriggii</i> (Cookson and Dettmann) Zippi, borehole Józefina, depth 47.5m; b-phase contrast.</p> <p>3a,b <i>Cycloovoidites cyclus</i> (Krutzsch) Krutzsch and Pacltová, borehole Józefina, depth 45.7m; b-phase contrast.</p> | <p>4 <i>Cycloovoidites cyclus</i> (Krutzsch) Krutzsch and Pacltová, borehole Józefina, depth 46.2m; phase contrast.</p> <p>5a,b <i>Cycloovoidites cyclus</i> (Krutzsch) Krutzsch and Pacltová, borehole Józefina, depth 46.2m; b-phase contrast.</p> <p>6a,b <i>Stigmozygodites microfoveolatoides</i> Krutzsch and Pacltová, borehole Józefina, depth 47.5m; b-phase contrast.</p> |
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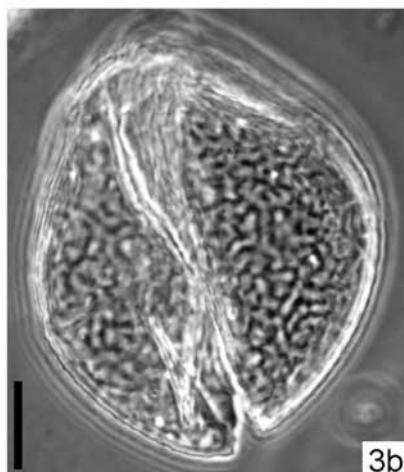
2a



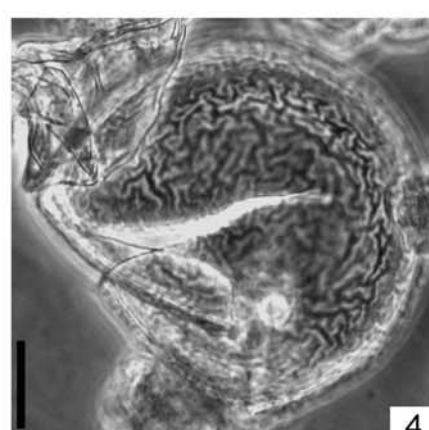
2b



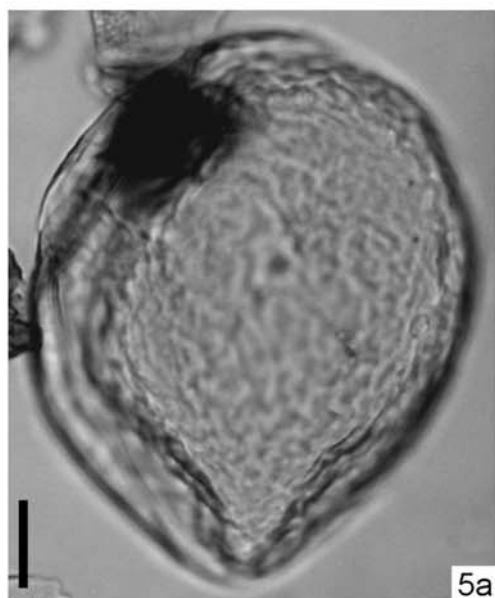
3a



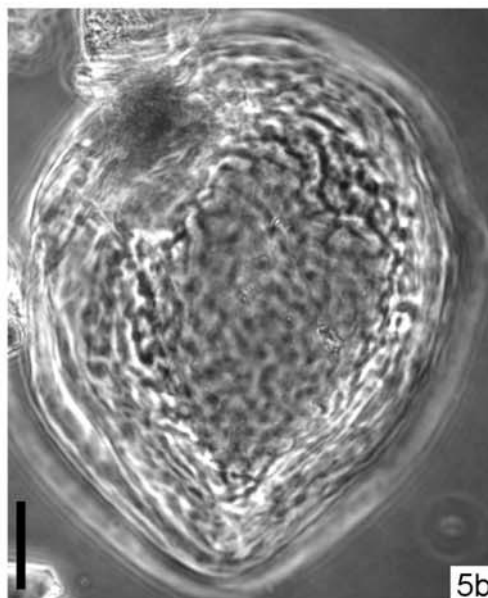
3b



4



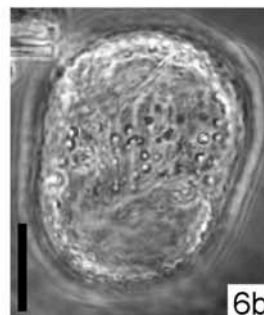
5a



5b



6a



6b

Ecology: The Quaternary *Pseudoschizaea* is distributed in relatively warm terrestrial areas with strong seasonal moisture fluctuations. Its occurrence is strongest in springs, swamps, and alluvial areas, showing a relationship with damp soil (Scott 1992). Fossil *Pseudoschizaea* was recorded e.g. in the Holocene lagoon sediments and peat deposits in Brazil (Medeanic 2006), as well in Late Pleistocene hyena coprolites from cave in Sicily, Italy (Yll et al. 2006) and badger coprolites in Holocene deposits from Spain (Carrión et al. 2005). This microfossil is often accompanied by such freshwater algae as Zygnemataceae (*Spirogyra*, *Mougeotia* and *Zygnema*), *Closterium*, *Scenedesmus*, *Botryococcus*, and others (Carrión et al. 2005; Medeanic 2006). All these observations suggest that fossil *Pseudoschizaea* is a resting stage of a shallow freshwater or damp-soil microorganism (?algae, ?invertebrate). In lacustrine and marine deposits it could be of allochthonous origin. Its presence in subtropical and Mediterranean environments suggests that this microfossil could be an indicator of warm climate, possibly with local seasonal drying (Scott 1992).

Genus ?*Tythyodiscus* Norem 1955

Type species: *Tythyodiscus californiensis* Norem 1955?

?*Tythyodiscus* sp.

Plate 4, figures 13a, b

? *Tythyodiscus mecsekensis* NAGY 1965, p. 206, pl. 3, figs 12–14 [Miocene, Hungary].

Description: Microfossils circular-oval in outline, about 40–50 µm in size. Wall very thick, densely covered in pores

about 1.0–1.5 µm in diameter. In top-view a foveolate network visible.

Botanical affinity: According to Nagy (1965) the genus *Tythyodiscus* is connected with family Leiosphaeridae. These microfossils resemble also eggs of invertebrates.

Remarks: In the studied material 3 specimens of this microfossil were recorded.

RESULTS OF PHYTOPLANKTON ANALYSIS

The studied spectra were rich in freshwater algae and morphologically differentiated. Almost 1000 specimens were recorded and 28 species of freshwater phytoplankton were identified. List of the determined taxa, and their botanical affinity are given in Table 1. In all samples microfossils of genus *Sigmopollis* as well as zygosporae of Zygnemataceae (*Mougeotia*, *Spirogyra* and *Zygnema*) and desmids (*Closterium*) dominate. Most desmid zygosporae occurred in the bottom sample (depth 47.5 m), while in the above-lying samples (depth 46.2 m and 45.7 m) desmids were replaced by Zygnemataceae (*Spirogyra* and *Mougeotia* types).

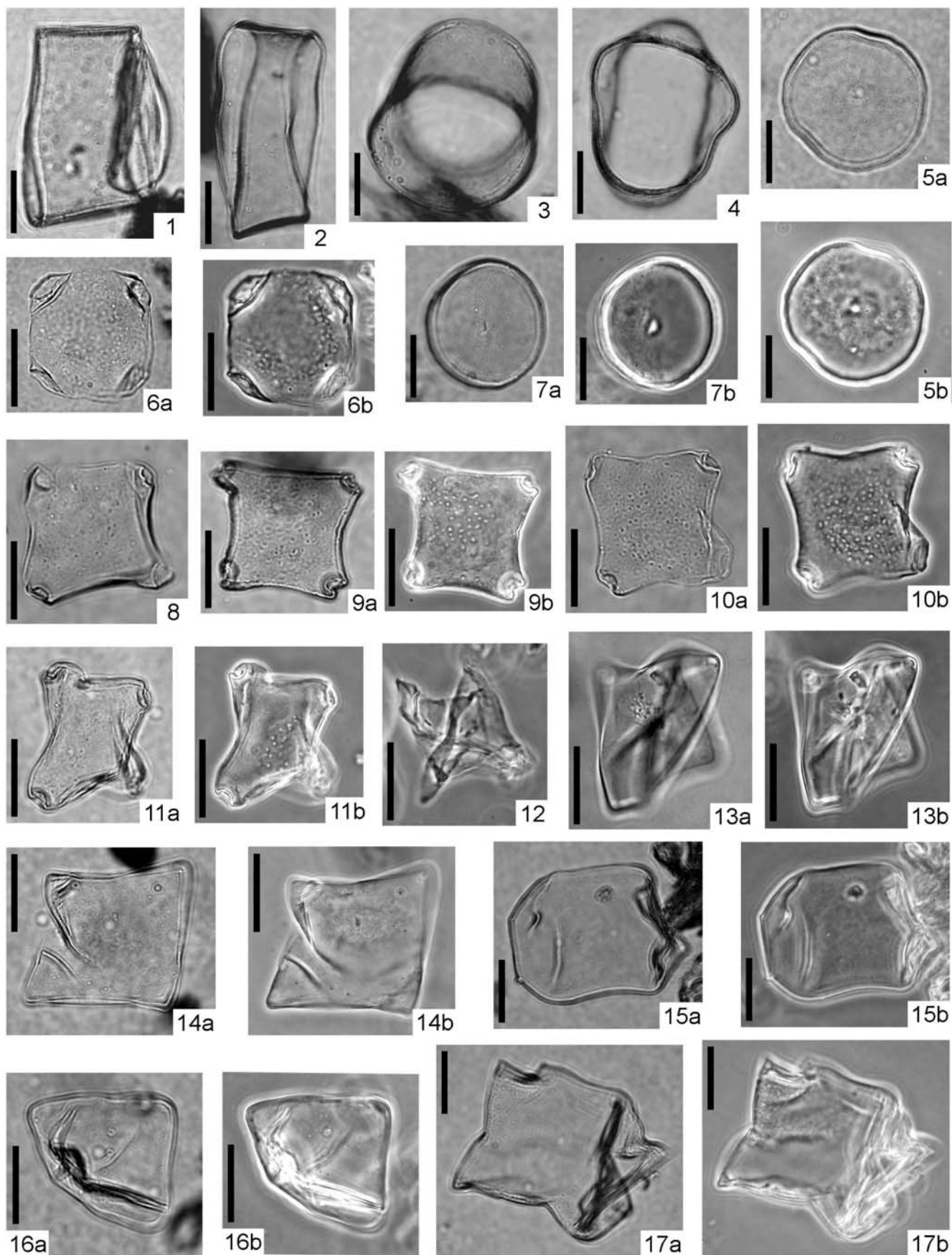
DISCUSSION

Although in Zygnemataceae limited evolution is observed and the stratigraphic value of the zygosporae is not well understood, they are valuable paleoenvironmental indicators. The occurrence of algal remains, mainly resting cells (zygosporae of Zygnemataceae and desmids, as well as *Sigmopollis*) suggests presence of the freshwater habitats. Most of the identified algae preferred meso- to eutrophic conditions, and are characteristic

PLATE 3

Photography: G. Worobiec; scale bar 20 µm.

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| 1 | <i>Diagonalites diagonalis</i> Krutzsch and Pacltová, specimen with one operculum attached, borehole Józefina, depth 46.2m. | 11a,b | <i>Tetraporina</i> sp. 1, borehole Józefina, depth 45.7m; b-phase contrast. |
| 2 | <i>Diagonalites diagonalis</i> Krutzsch and Pacltová, borehole Józefina, depth 46.2m. | 12 | <i>Spintetrapidites</i> cf. <i>verru-lineatus</i> Krutzsch and Pacltová, borehole Józefina, depth 46.2m; phase contrast. |
| 3,4 | <i>Diagonalites diagonalis</i> Krutzsch and Pacltová, borehole Józefina, depth 47.5m. | 13a,b, 14a,b | <i>Spintetrapidites quadriformis</i> Krutzsch and Pacltová, borehole Józefina, depth 47.5 m; b-phase contrast. |
| 5a,b, 7a,b | Opercula of <i>Diagonalites diagonalis</i> Krutzsch and Pacltová, borehole Józefina, depth 46.2m; b-phase contrast. | 15a,b | <i>Closteritetrapidites reductus</i> Krutzsch and Pacltová, borehole Józefina, depth 47.5m; b-phase contrast. |
| 6a,b | <i>Tetraporina</i> sp. 2, borehole Józefina, depth 47.5m; b-phase contrast. | 16a,b | <i>Spintetrapidites</i> sp. 1, borehole Józefina, depth 46.2m; b-phase contrast. |
| 8 | <i>Tetraporina</i> sp. 1, borehole Józefina, depth 47.5m. | 17a,b | <i>Closteritetrapidites magnus</i> Krutzsch and Pacltová, borehole Józefina, depth 47.5 m; b-phase contrast. |
| 9a,b, 10a,b | <i>Tetraporina</i> sp. 1, borehole Józefina, depth 47.5 m; b-phase contrast. | | |



for stagnant or slowly flowing shallow water. Zygnemataceae are among the most common algae in fresh waters. Most representatives of this cosmopolitan group of algae occur in shallow, stagnant, clean, oxygen-rich waters. They may also occur near the margins of lakes, in flowing water and in moist soils or bogs (Kadłubowska 1972, 1984; van Geel and Grenfell 1996). Desmids are cosmopolitan, tolerant planktonic microalgae existing in a variety of aquatic habitats, often in oligo- to mesotrophic lakes, rivers, ponds and mires (Croasdale and Flint 1986). According to Tappan (1980, in: Head 1992) the presence of fossil desmids points at deposition in somewhat acid swampy conditions. In the Józefina material desmid zygospores were replaced by Zygnemataceae (Tab. 1). This is possibly caused by the eutrophication of the water body. Similar successional trends have been observed in Late Quaternary deposits from southwestern Europe (Carrión 2002), where assemblages dominated by *Sigmopollis* (Type 128) and desmids were replaced by Zygnemataceae (in turns: *Zygnema* + *Debarya*, and *Spirogyra* + *Mougeotia*). The presence of resting cells (zygospores or possibly aplanospores) of Zygnemataceae (*Mougeotia*, *Spirogyra* and *Zygnema*) and desmids (*Closterium*) suggests that the water body (bodies) might periodically dried out and be subject to seasonal warming.

The resting cells may occur in fossil material because of presence of a decay and acid-resistant substance (most probably algaenans) in the zygospore wall. Until now the chemistry of Zygnemataceae zygospores was not examined in detail. Most possibly zygospore consist of algaenans (Blokke 2000; Pouličková et al. 2007), that are aliphatic biomacromolecules, common in Chlorophyta (Versteegh and Blokke 2004), e.g. in the genera *Pediastrum*, *Scenedesmus* and *Tetraedron* (Blokke et al. 1998). In *Botryococcus braunii* algaenans were found both in fossil and recent specimens (van Bergen et al. 1995; Kadouri et al. 1988; De Leeuw et al. 2006). Algaenans are im-

portant initial substances in kerogen formation (Tegelaar et al. 1989, in: van Bergen et al. 1995).

It is interesting that similar phytoplankton assemblages are observed in deposits of various age. For example in northeastern Italy in Last Glacial Maximum sediments zygospores of Zygnemataceae, *Closterium*, *Sigmopollis* (Type 128A and 128B), and *Botryococcus* occurred (Miola et al. 2006). Similarly, in Holocene deposits from Brazil zygospores of *Spirogyra*, *Mougeotia* and *Zygnema*, as well as *Botryococcus* and *Pseudoschizaea* were recorded (Leonhardt and Lorscheitter 2007). Also in the Middle Tertiary deposits from Argentina (Zamaloa 1996) zygospores of *Mougeotia* (two types), *Spirogyra* (three types) and *Zygnema* (two types) were encountered. The most similar freshwater microphytoplankton was described from the Pliocene Cheb Basin sediments (Krutzsch and Pacltová 1990). In this assemblage all groups of algal microfossils distinguished in the Józefina material occurred. Similar phytoplankton assemblage was illustrated (unfortunately not determined) by Macko (1959) from the Miocene brown coals from Lower Silesia (southwestern Poland). In this paper e.g. zygospores of *Mougeotia*, *Spirogyra* (two types) and *Zygnema*, as well as *Sigmopollis* (with various sculpture) were illustrated. Lists of synonyms show that similar microfossils occur in sediments of various age (mainly in Cainozoic, some of them also in Mesozoic) in many localities. So, these groups of algae were widespread also in the past.

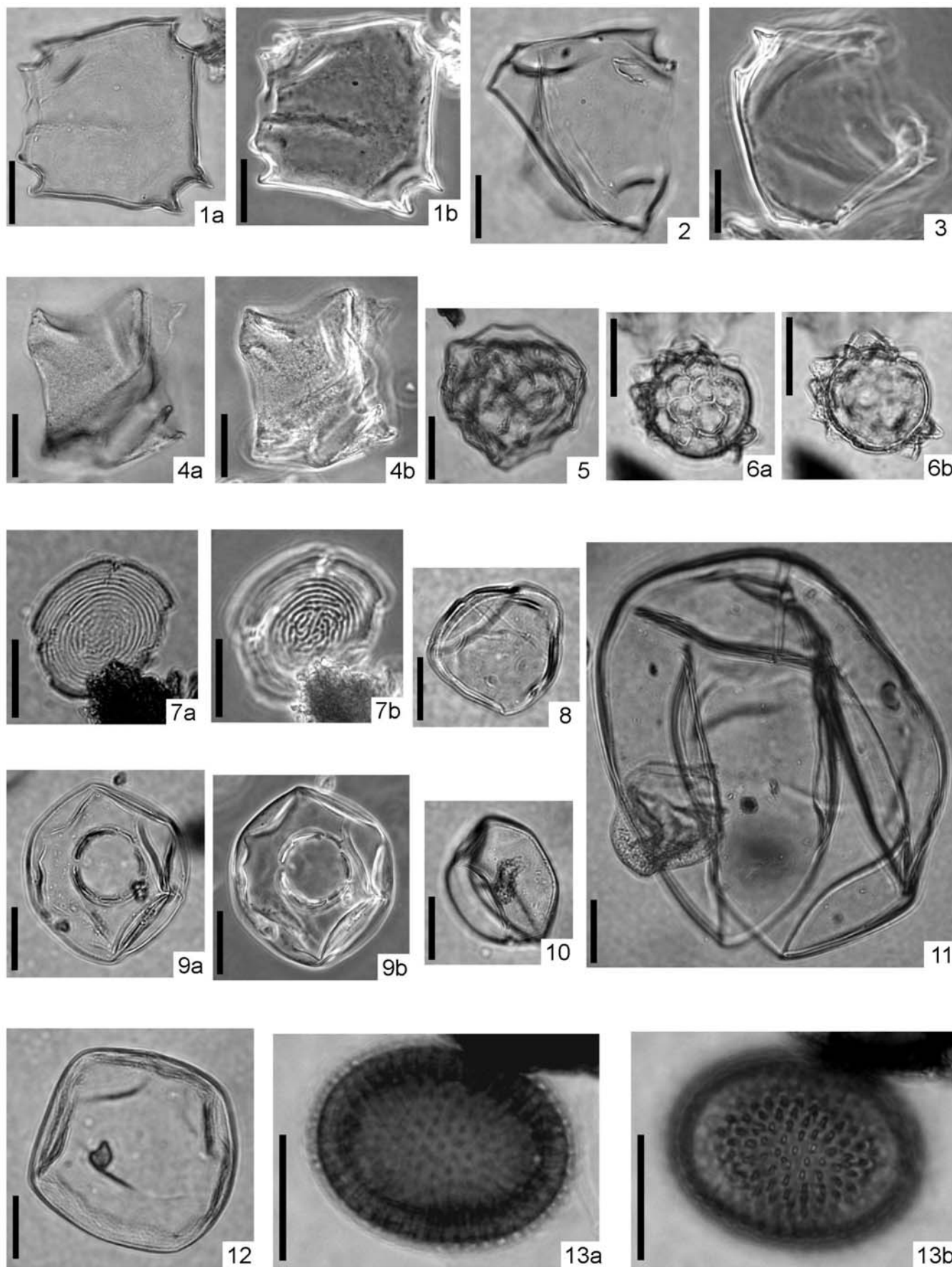
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PLATE 4

Photography: G. Worobiec; scale bar 20µm.

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| <p>1a,b <i>Closteritetrapidites pactovae</i> E. Worobiec sp. nov., holotype, borehole Józefina, depth 47.5m; b-phase contrast.</p> <p>2 <i>Closteritetrapidites pactovae</i> E. Worobiec sp. nov., borehole Józefina, depth 47.5m.</p> <p>3 <i>Closteritetrapidites pactovae</i> E. Worobiec sp. nov., borehole Józefina, depth 47.5m; phase contrast.</p> <p>4a,b <i>Closteritetrapidites</i> sp. 1, borehole Józefina, depth 47.5m; b- phase contrast.</p> <p>5 <i>Planctonites</i> cf. <i>stellarius</i> (Potonie) Krutzsch, borehole Józefina, depth 47.5m.</p> | <p>6a,b <i>Cystidiopsis conicus</i> Grabowska, borehole Józefina, depth 47.5m.</p> <p>7a,b <i>Pseudoschizaea rubina</i> (Rossignol) Christopher, borehole Józefina, depth 47.5m; b-phase contrast.</p> <p>8,10 <i>Zygodites medius</i> (Rshanikova) Krutzsch and Pacltová, borehole Józefina, depth 45.7m.</p> <p>9a,b cf. <i>Zygodites</i> sp., borehole Józefina, depth 47.5m; b-phase contrast.</p> <p>11,12 ?<i>Zygodites</i> sp., ?<i>Ovoidites spriggii</i> (Cookson and Dettmann) Zippi, borehole Józefina, depth 46.2m.</p> <p>13a,b ?<i>Tythyodiscus</i> sp., borehole Józefina, depth 46.2m.</p> |
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REFERENCES

- AGASIE, J. M., 1969. Late Cretaceous palynomorphs from northeastern Arizona. *Micropaleontology*, 15(1): 13–30.
- ASHRAF, A. R. and MOSBRUGGER, V., 1996. Palynologie und Palynostratigraphie des Neogenes der Niederrheinischen Bucht. Teil 2. Pollen. *Palaeontographica, Abteilung B*, 241(1–4): 1–98.
- BATTEN, D. J. and GRENFELL, H. R., 1996. Chapter 7D. *Botryococcus*. In: Jansonius, J. J. and McGregor, D. C., Eds. *Palynology: principles and applications Vol. 1*, 205–214. College Station, TX: American Association of Stratigraphic Palynologists Foundation.
- BETTAR, I. and MÉON, H., 2006. La palynoflore continentale de l'Albien du bassin d'Agadir-Essaouira (Maroc). *Revue de Paléobiologie*, 25: 593–631.
- BLOKKER, P., 2000. Structural analysis of resistant polymers in extant algae and ancient sediments. *Geologica Ultraiectina*, 193: 1–145.
- BLOKKER, P., SCHOUTEN, S., VAN DEN ENDE, H., DE LEEUW, J. W., HATCHER, P. G. and SINNINGHE DAMSTÉ, J. S., 1998. Chemical structure of algaenans from the fresh water algae *Tetraedron minimum*, *Scenedesmus communis* and *Pediastrum boryanum*. *Organic Geochemistry*, 29: 1453–1468.
- BRETON, G., 2007. La bioaccumulation de microorganismes dans l'ambre: analyse comparée d'un ambre céno-manien et d'un ambre sparnacien, et de leurs tapis algaires et bactériens. *C. R. Palevol*, 6: 125–133.
- BRUCH, A., 1998. Palynologische Untersuchungen im Oligozän Sloweniens – Paläo-Umwelt und Paläoklima im Ostalpenraum. *Tübinger Mikropaläontologische Mitteilungen*, 18: 1–193.
- CARRIÓN, J. S., 2002. Patterns and processes of Late Quaternary environmental change in a montane region of southwestern Europe. *Quaternary Science Reviews*, 21: 2047–2066.
- CARRIÓN, J. S. and NAVARRO, C., 2002. Cryptogram spores and other non-pollen microfossils as source of palaeoecological informations: case-studies from Spain. *Annales Botanicae Fennici*, 39: 1–14.
- CARRIÓN, J. S., GIL, G., RODRÍGUEZ, E., FUENTES, N., GARCÍA-ANTÓN, M. and ARRIBAS, A., 2005. Palynology of badger coprolites from central Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 226: 259–271.
- CATALOGUE OF LIFE: 2005 *Annual Checklist*. [http://www.catalogueoflife.org/annual-checklist/2005/browse_taxa.php].
- CHMURA, G. L., STONE, P. A. and ROSS, M. S., 2006. Non-pollen microfossils in Everglades sediments. *Review of Palaeobotany and Palynology*, 141: 103–119.
- CHRISTOPHER, R. A., 1976. Morphology and taxonomic status of *Pseudoschizaea* Thiergart and Frantz ex R. Potonié emend. *Micropaleontology*, 22: 143–150.
- COLLINSON, M. E., SINGER, R. L. and HOOKER, J. J., 1993. Vegetational change in the latest Eocene of southern England. In: Planderová, E., Konzalová, M., Kvaček, Z., Sitár, V., Snopková, P. and Suballyová, D., Eds. *Proceedings of the international symposium, Paleofloristic and paleoclimatic changes during Cretaceous and Tertiary*, Bratislava 1992, 81–87. Bratislava: Geologický Ústav Dionýza Stúra.
- COOKSON, I. C. and DETTMANN, M. E., 1959. On *Schizosporis*, a new form genus from Australian Cretaceous deposits. *Micropaleontology*, 5(2): 213–216.
- CROASDALE, H. and FLINT, E. A., 1986. *Flora of New Zealand. Vol. 1, Freshwater algae, Chlorophyta, Desmids, with ecological comments on their habitats*. Wellington: Government Printers, 132 pp.
- DE LEEUW, J. W., VERSTEEGH, G. J. M. and VAN BERGEN, P. F., 2006. Biomacromolecules of algae and plants and their fossil analogues. *Plant Ecology*, 182: 209–233.
- DOKTOROWICZ-HREBNICKA, J., 1960. Paralelizacja pokładów węgla brunatnego województwa bydgoskiego i poznańskiego (summary: Correlation of brown coal seams from the provinces of Poznań and Bydgoszcz). *Instytut Geologiczny Biuletyn*, 157: 69–138.
- , 1961. Paleobotaniczne podstawy paralelizacji pokładów węgla brunatnego ze złoża Rogóżno pod Łodzią (summary: Palaeobotanical bases for the correlation of brown coal seams the Rogóżno deposit near Łódź). *Instytut Geologiczny Biuletyn*, 158: 113–303.
- FÖRSTER, K., 1982. Conjugatophyceae. Zygnematales und Desmidiaceae (excl. Zygnemataceae) In: Huber-Pestalozzi, Ed., *Das Phytoplankton des Süßwassers: Systematik und Biologie*, 1–544. Stuttgart: E. Schweizerbart'sche Verlagsbuchhandlung.
- FRANTZ, U., 1960. Über das Vorkommen von Olacaceen-Pollenkörnern in der Braunkohle von Lohsa/Niederlausitz. *Deutsche Akademie der Wissenschaft der Berlin, Monatsbericht*, 2: 558–564.
- GRABOWSKA, I., 1996. Gromada Chlorophyta. Incerte sedis. In: Malinowska, L. and Piwocki, M., Eds., *Budowa Geologiczna Polski. t.III. Atlas skamieniałości przewodnich i charakterystycznych. Part 3a. Kenozoik. Trzeciorzęd. Paleogen*, 387–392. Warszawa: PIG, Polska Agencja Ekologiczna.
- GRENFELL, H. R., 1995. Probable fossil zygnematacean algal spore genera. *Review of Palaeobotany and Palynology*, 84: 201–220.
- GRUAS-CAVAGNETTO, C., 1968. Étude palynologique des divers gisements du Sparnacien du bassin de Paris. *Mémoires de la Société Géologique de France, (N.S.)*, 47: 1–144.
- GUY-OHLSON, D., 1992. *Botryococcus* as an aid in the interpretation of palaeoenvironment and depositional processes. *Review of Palaeobotany and Palynology*, 71: 1–15.
- , 1998. The use of the microalga *Botryococcus* in the interpretation of lacustrine environments at the Jurassic-Cretaceous transition in Sweden. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 140: 347–356.
- HANDKE, K., 1996. Zygosporen Saccodermes und Placodermes Desmidiaceen (Conjugatophyceae, Chlorophyta) in Aufsammlungen der Jahre 1971–1995 aus Europa, Asien und Amerika. *Mitteilungen aus dem Institut für Allgemeine Botanik Hamburg*, 26: 5–129.
- HEAD, M. J., 1992. Zygosporae of Zygnemataceae (Division Chlorophyta) and other freshwater algal spores from the uppermost Pliocene St. Erth Beds of Cornwall, southwestern England. *Micropaleontology*, 38: 237–260.
- HEDLUND, R. W., 1966. Palynology of the Red Branch Member of the Woodbine Formation (Cenomanian), Bryan County Oklahoma. *Oklahoma Geological Survey, Bulletin*, 112: 1–69.

- HOSHAW, R. W., WANG, J.-C., McCOURT, R. M. and HULL, H. M., 1985. Ploidal changes in clonal cultures of *Spirogyra communis* and applications for species definition. *American Journal of Botany*, 72: 1005–1011.
- HOSHAW, R. W., WELLS, C. V. and McCOURT, R. M., 1987. A polyploid species complex in *Spirogyra maxima* (Chlorophyta, Zygnemataceae), a species with large chromosomes. *Journal of Phycology*, 23(2): 267–273.
- HUNGER, R., 1952. Die Pollenflora der Braunkohle von Seidewitz im Tümmelitzer Wald zwischen Leisnig und Grimma. *Bergakademie Berlin*, 4: 192–202.
- JAIN, R. K., 1968. Triassic pollen grains and spores from Minas Petroleo Beds of the Cacheuta Formation (Upper Gondwana), Argentina. *Palaeontographica, Abteilung B*, 122, 1–47.
- JANKOVSKÁ, V. and KOMÁREK, J., 2000. Indicative value of *Pediastrum* and other coccal green algae in palaeoecology. *Folia Geobotanica*, 35: 59–82.
- JARZEN, D. M., 1979. Zygospores of Zygnemataceae in the Palaeocene of southern Saskatchewan (Canada). *Review of Palaeobotany and Palynology*, 28: 21–25.
- KADŁUBOWSKA, J. Z., 1972. Chlorophyta V. Conjugales: Zygnemataceae. Zrośnicowate. In: Starmach, K. and Siemińska, J., Eds. *Flora słodkowodna Polski*, vol. 12A, 1–431. Krakow: PWN.
- , 1984. *Süßwasserflora von Mitteleuropa, Band 16, Chlorophyta VIII = Conjugatophyceae I (Zygnemales)*. Stuttgart: Gustav Fischer Verlag, 532 pp.
- KADOURI, A., DERENNE, S., LARGEAU, C., CASADEVALL, E. and BERKALOFF, C., 1988. Resistant biopolymer in the outer walls of *Botryococcus braunii*, B race. *Phytochemistry*, 27: 551–557.
- KRUTZSCH, W., 1959. Mikropaleontologische (sporen-paleontologische) Untersuchungen in der Braunkohle des Geiseltales. *Geologie*, 8: 1–425.
- , 1970. *Atlas der mittel- und jungtertiären dispersen Sporen und Pollen sowie der Mikroplanktonformen des nördlichen Mitteleuropas. VII*. Jena: VEB Gustav Fischer Verlag, 175 pp.
- KRUTZSCH, W. and PACLTOVÁ, B., 1990. Die Phytoplankton-Mikroflora aus den Pliozänen Süßwasserablagerungen des Cheb-Beckens (Westböhmen, ČSFR). *Acta Universitatis Carolinae - Geologica*, 4: 345–420.
- KRUTZSCH, W., PCHALEK, J. and SPIEGLER, D., 1960. Tieferes Paläozän (?Montien) in Westbrandenburg. *Proceedings XXI. International Geological Congress, Part VI*, 135–143. Copenhagen.
- KRUTZSCH, W. and VANHOORNE, R., 1977. Die Pollenflora von Epinois und Loksbergen in Belgien. *Palaeontographica, Abteilung B*, 163: 1–110.
- LEONHARDT, A. and LORSCHETTER, M. L., 2007. Palinomorfo de perfil sedimentar de uma turfeira em São Francisco de Paula, Planalto Leste do Rio Grande do Sul, Sul do Brasil. *Revista Brasileira de Botânica*, 30: 47–59.
- LINDGREN, S., 1980. Algal microfossils of the form genus *Tetraporina* from Upper Cretaceous clays, southern Sweden. *Review of Palaeobotany and Palynology*, 30: 333–359.
- MACKO, S., 1959. Pollen grains and spores from Miocene brown coals in Lower Silesia. I. *Prace Wrocławskiego Towarzystwa Naukowego, Ser. B*, 96: 1–177.
- MAHMOUD, M. S., 2000. Plio-Pleistocene palynology (freshwater algae, spores and pollen) and palaeoecology of the shallow subsurface section, West Assiut, Egypt. *Acta Universitatis Carolinae - Geologica*, 44: 101–114.
- McCOURT, R. M. and HOSHAW, R. W., 1990. Noncorrespondence of breeding groups, morphology, and monophyletic groups in *Spirogyra* (Zygnemataceae: Chlorophyta) and the application of species concepts. *Systematic Botany*, 15: 69–78.
- McCOURT, R. M., HOSHAW, R. W. and WANG, J.-C., 1986. Distribution, morphological diversity and evidence for polyploidy in North American Zygnemataceae (Chlorophyta). *Journal of Phycology*, 22: 307–315.
- MEDEANIC, S., 2006. Freshwater algal palynomorph records from Holocene deposits in the coastal plain of Rio Grande do Sul, Brazil. *Review of Palaeobotany and Palynology*, 141: 83–101.
- MEYER, B. L., 1956. Mikrofloristische Untersuchungen an jungtertiären Braunkohlen im östlichen Bayern. *Geologica Bavarica*, 25: 100–128.
- MIOLA, A., BONDESAN, A., CORAIN, L., FAVARETTO, S., MOZZI, P., PIOVAN, S. and SOSTIZZO, I., 2006. Wetlands in the Venetian Po Plain (northeastern Italy) during the Last Glacial Maximum: Interplay between vegetation, hydrology and sedimentary environment. *Review of Palaeobotany and Palynology*, 141: 53–81.
- NAGY, E., 1965. The microplankton occurring in the Neogene of the Mecsek Mountains. *Acta Botanica Academiae Scientiarum Hungaricae*, 11: 197–216.
- , 1969. Palynological elaborations of the Miocene layers of the Mecsek Mountains. *Annales Instituti Geologici Publici Hungarici*, 52: 237–650.
- , 1985. Sporomorphs of the Neogene in Hungary. *Geologica Hungarica, Series Palaeontologica*, 47: 1–470.
- NAKOMAN, E., 1966. Contribution à l'étude palynologique des formations tertiaires du Bassin de Thrace. *Annales de la Société Géologique du Nord*, 46: 65–107.
- NAUMOVA, S. N., 1939. Spores and pollen of the coals of the USSR. In: *Report of the International Geological Congress, 17th Session, Moscow, 1937, Rep. 1*, 353–364. Moscow.
- , 1953. *Sporovo-pyl'tseveye kompleksey verkhnevo Devona Russkoy platformy i ikh znachenie dlya stratigrafii (Spore-pollen complexes of the Upper Devonian of the Russian Platform and their stratigraphic value)*. Moscow: Akademia Nauk SSSR, Institut Geologicheskikh Nauk, Trudy. Seria Geologiki., 60: 154 pp. (in Russian).
- PALS, J. P., VAN GEEL, B. and DELFOS, A., 1980. Paleoeological studies in the Klokkeel bog near Hoogkarspel (prov. of Noord-Holland). *Review of Palaeobotany and Palynology*, 30: 371–418.
- PANT, D. D. and MEHRA, B., 1963. On the occurrence of glossopterid spores in the Bacchus Marsh tillite, Victoria, Australia. *Grana Palynologica*, 4: 111–120.
- PIERCE, S. T., 1976. Morphology of *Schizosporis reticulatus* Cookson and Dettmann 1959. *Geoscience and Man*, 15: 25–33.
- PLANDEROVÁ, E., 1990. *Miocene microflora of Slovak Central Paratethys and its biostratigraphical significance*. Bratislava: Dionýz Štúr Institute of Geology, 144 pp.

- POCOCK, S. A. J., 1962. Microfloral analysis and age determination of strata at the Jurassic-Cretaceous Boundary in the Western Canada Plains. *Palaeontographica, Abteilung B*, 111: 1–95.
- , 1970. Palynology of the Jurassic sediments of western Canada. Part I. Terrestrial species. *Palaeontographica, Abteilung B*, 130: 12–132.
- POTONIE, R., 1934. Zur Mikrobotanik der eozänen Humodils des Geiseltals. *Arbeiten aus dem Institut für Paläobotanik und Petrographie der Brennsteine*, 4: 25–125.
- , 1951. Revision stratigraphisch wichtiger Sporomorphen des mitteleuropäischen Tertiärs. *Palaeontographica, Abteilung B*, 91(5/6): 131–151.
- , 1966. Synopsis der Gattungen der Sporae dispersae. IV. *Geologisches Jahrbuch*, 72: 1–244.
- POULÍČKOVÁ, A., ŽIŽKA, Z., HAŠLER, P. and BENADA, O., 2007. Zygnematalean zygospores: morphological features and use in species identification. *Folia Microbiologica*, 52: 135–145.
- RICH, F. J., KUEHN, D. and DAVIES, T. D., 1982. The paleoecological significance of *Ovoidites*. *Palynology*, 6: 19–28.
- ROSSIGNOL, M., 1962. Analyse pollinique de sédiments marins quaternaires en Israël. II - Sédiments pleistocènes. *Pollen et Spores*, 4(1): 121–148.
- , 1964. Hystrichosphères du Quaternaire en Méditerranée orientale, dans les sédiments pleistocènes et les bones marines actuelles. *Revue de Micropaléontologie*, 7: 83–99.
- RŮŽIČKA, J., 1977. *Die Desmidiaceen Mitteleuropas. Band 1, Lieferung 1*. Stuttgart: E. Schweizerbart'sche Verlagsbuchhandlung, 292 pp.
- , 1981. *Die Desmidiaceen Mitteleuropas. Band 1, Lieferung 2*. Stuttgart: E. Schweizerbart'sche Verlagsbuchhandlung, pp. 293–736.
- SCOTT, L., 1992. Environmental implications and origin of microscopic *Pseudoschizaea* Thiergart and Frantz ex R. Potoniev emend. in sediments. *Journal of Biogeography*, 19: 349–354.
- SHU, J.-W., WANG, W.-M., LEOPOLD, E. B., WANG, J.-S. and YIN, D.-S., 2008. Pollen stratigraphy of coal-bearing deposits in the Neogene Jidong Basin, Heilongjiang Province, NE China: New insights on palaeoenvironment and age. *Review of Palaeobotany and Palynology*, 148: 163–183.
- SIMONS, J., VAN BEEM, A. P. and DE VRIES, P. J. R., 1982. Structure and chemical composition of the spore wall in *Spirogyra* (Zygnemataceae, Chlorophyceae). *Acta Botanica Neerlandica*, 31(5/6): 359–370.
- SONG, Z. and LIU, G., 1982. Early Tertiary palynoflora and its significance of paleogeography from northern and eastern Xizang. *Palaeontology of Xizang*, 5: 165–190.
- SRIVASTAVA, S. K., 1984. Genus *Sigmopollis* from the Maastrichtian Scollard Formation, Alberta (Canada), and its algal affinity. *Pollen et Spores*, 26: 519–530.
- STANLEY, E. A., 1965. Upper Cretaceous and Paleocene plant microfossils and Paleocene dinoflagellates and hystrichosphaerids from northwestern South Dakota. *Bulletins of American Paleontology*, 49: 179–384.
- TAKAHASHI, K., 1979. *Pseudoschizaea* from the Pleistocene sediments in the Ariake Sea area, West Kyushu. *Bulletin of Faculty of Liberal Arts, Nagasaki University. Natural Science*, 19: 39–49.
- TAPPAN, H., 1980. *The paleobiology of plant Protists*. San Francisco: W.H. Freeman and Company, 1028 pp.
- TEGELAAR, E. W., DE LEEUW, J. W., DERENNE, S. and LARGEAU, C., 1989. A reappraisal of kerogen formation. *Geochimica et Cosmochimica Acta*, 53: 3103–3106.
- TESTA, M., GERBAUDO, S. and ANDRI, E., 2001. Data report: *Botryococcus* colonies in Miocene sediments in the western Woodlark Basin, southwest Pacific (ODP Leg 180). In: Huchon, P., Taylor, B. and Klaus, A., Eds., *Proceedings of the Ocean Drilling Program, Scientific Results*, 180: 1–6.
- THIERGART, F. and FRANTZ, U., 1962. Some spores and pollen grains from a Tertiary brown coal deposit in Kashmir. *The Palaeobotanist*, 10: 84–86.
- THOMSON, P. W. and PFLUG, H., 1953. Pollen und Sporen des mitteleuropäischen Tertiärs. *Palaeontographica, Abteilung B*, 94: 1–138.
- TIWARI, R. S. and NAVALE, G. K. B., 1967. Pollen and spore assemblage in some coals of Brazil. *Pollen et Spores*, 9: 583–605.
- VAN BERGEN, P. F., COLLINSON, M. E., BRIGGS, D. E. G., DE LEEUW, J. W., SCOTT, A. C., EVERSLED, R. P. and FINCH, P., 1995. Resistant biomacromolecules in the fossil record. *Acta Botanica Neerlandica*, 44: 319–345.
- VAN DER WIEL, A. M., 1982. A palaeoecological study of a section from the foot of the Hazendonk (Zuid-Holland, The Netherlands), based on the analysis of pollen, spores and microscopic plant remains. *Review of Palaeobotany and Palynology*, 38: 35–90.
- VAN GEEL, B., 1976. Fossil spores of Zygnemataceae in ditches of a prehistoric settlement in Hoogkarspel (The Netherlands). *Review of Palaeobotany and Palynology*, 22: 337–344.
- VAN GEEL, B., BOHNCKE, S. J. P. and DEE, H., 1981. A palaeoecological study of an upper Late Glacial and Holocene sequence from "De Borchert", The Netherlands. *Review of Palaeobotany and Palynology*, 31: 367–448.
- VAN GEEL, B. and GRENFELL, H. R., 1996. Spores of Zygnemataceae. In: Jansonius, J. J. and McGregor, D. C., Eds. *Palynology: principles and applications, Vol. 1*, 173–179. College Station, TX: American Association of Stratigraphic Palynologists Foundation.
- VAN GEEL, B. and VAN DER HAMMEN, T., 1978. Zygnemataceae in Quaternary Colombian sediments. *Review of Palaeobotany and Palynology*, 25: 377–392.
- VAN GEEL, B., HALLEWAS, D. P. and PALS, J. P., 1983. A Late Holocene deposits under the Westfriese Zeedijk near Enkhuizen (Prov. Noord-Holland, The Netherlands): palaeoecological and archaeological aspects. *Review of Palaeobotany and Palynology*, 38: 269–335.
- VENKATACHALA, B. S. and KAR, R. K., 1968. *Pilospora* gen. nov., a new fossil pollen genus from the Mesozoic rocks of Kutch, W. India. *Current Science*, 37(15): 442–443.
- VERSTEEGH, G. J. M. and BLOKKER, P., 2004. Resistant macromolecules of extant and fossil microalgae. *Phycological Research*, 52: 325–339.

- VAZQUEZ-DUHALT, R. and ARREDONDO-VEGA, B. O., 1991. Haloadaptation of the green alga *Botryococcus braunii* (race A). *Phytochemistry*, 30: 2919–2926.
- WANG, J.-C., HOSHAW, R. W. and McCOURT, R. M., 1986. A polyploid species complex of *Spirogyra communis* (Chlorophyta) occurring in nature. *Journal of Phycology*, 22: 102–107.
- WANG, KAI-FA. and HAN, XIN-BIN, 1983. Study on the Cainozoic fossil *Concentricystes* of East China. *Acta Palaeontologica Sinica*, 22: 468–473.
- WEYLAND, H. and PFLUG, H. D., 1957. Die Pflanzenreste der pliozänen Braunkohle von Ptolomais in Nordgriechenland I. *Palaeontographica, Abteilung B*, 102: 96–109.
- WOROBIEC, E. and WOROBIEC, G., 2008. Kopalne zygospori glonów Zygnemataceae (Chlorophyta) z osadów górnego miocenu KWB, Bełchatów” (Fossil zygosporae of Zygnemataceae algae (Chlorophyta) from the Upper Miocene of the Bełchatów Lignite Mine). *Przegląd Geologiczny*, 56: 1000–1004. (In Polish with English summary).
- WOROBIEC, E., WOROBIEC, G. and GEDL, P., 2009. Occurrence of fossil bamboo pollen and a fungal conidium of *Tetraploa* cf. *aristata* in Upper Miocene deposits of Józefina (Poland). *Review of Palaeobotany and Palynology*, 157 (3–4): 211–217.
- YAMAGISHI, T., 1992. *Plankton algae in Taiwan (Formosa)*. Tokyo: Uchida Rokakuho, 252 pp.
- YI, S., 1997. Zygnematacean zygosporae and other freshwater algae from the Upper Cretaceous of the Yellow Sea Basin, southwest coast of Korea. *Cretaceous Research*, 18: 515–544.
- YLL, R., CARRIÓN, J. S., MARRA, A. C. and BONFIGLIO, L., 2006. Vegetation reconstruction on the basis of pollen in Late Pleistocene hyena coprolites from San Teodoro Cave (Sicily, Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 237: 32–39.
- ZAMALOA, M. C., 1996. Asociación de zigósporas de Zygnemataceae (Chlorophyta) en el Terciario medio de Tierra del Fuego, Argentina. *Ameghiniana (Revista Asociación. Paleontología de Argentina)*, 33: 179–184.
- ZAVATTIERI, A. M. and PRÁMPARO, M. B., 2006. Freshwater algae from the Upper Triassic Cuyana Basin of Argentina: palaeo-environmental implications. *Palaeontology*, 49: 1185–1209.
- ZIPPI, P. A., 1998. *Freshwater algae from the Mattagami Formation (Albian), Ontario: Paleocology, botanical affinities, and systematic taxonomy*. New York: Micropaleontology Press. Micropaleontology volume 44, supplement 1, 78 pp.

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