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Fossil zygospores of Zygnemataceae and other microremains of freshwater algae from two Miocene palaeosinkholes in the Opole region, SW Poland

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ABSTRACT. Algal microremains were encountered during palynological investigation of deposits filling two Miocene palaeosinkholes excavated in the Tarnów Opolski and Górażdże quarries. Algal microfossils of 40 species were identified, most of which are frequent non-pollen palynomorphs occurring in Neogene deposits. The microfossils most frequently found in all studied samples belong to the genera *Sigmopollis* and *Botryococcus*. Both algal assemblages contain a significant proportion of resting cells (zygospores = hypnozygotes) such as *Cycloovoidites*, *Diagonalites*, *Megatetrapidites*, *Ovoidites*, *Stigmozygodites*, and *Tetrapidites*, probably fossil zygospores of members of the Zygnemataceae family (*Mougeotia*, *Spirogyra*, *Zygnema*). Some specimens probably related to desmid zygospores (*Closteritetrapidites*, *Monopunctites*, *Planctonites*), freshwater dinoflagellate cysts, and Prasinophyceae (*Leiosphaeridia*) were found. Most of the identified fossilised remains of algae are often seen in sediments indicating meso- to eutrophic conditions and are characteristic for stagnant or slowly flowing shallow waters. Fossil algae of *Pediastrum* and *Tetraedron* genera were recorded in samples from the Górażdże palaeosinkhole, suggesting small differences in the aquatic habitat (e.g. water depth) between ponds in the sinkholes. Three new fossil species related to zygospores of the Zygnemataceae are described: *Ovoidites vangeelii* sp. nov., *Tetrapidites grandis* sp. nov., and *Tetrapidites opolensis* sp. nov.

KEYWORDS: fossil freshwater microalgae, zygospores, Conjugatophyceae (=Zygnematophyceae), non-pollen palynomorphs (NPP), palaeoenvironment, Miocene, Poland

INTRODUCTION

Algal microfossils are important palynomorphs occurring in various sediments. The best-known organic-walled fossil algae probably are cysts of Dinophyta (=Dinoflagellata), which are of key importance in marine deposits. Most dinocysts are preserved in fossil material because their walls contain a highly resistant organic substance called dinosporin (Bogus et al. 2012). Although the extant dinoflagellates are quite common in marine environments, freshwater dinoflagellates are represented by ca 220 extant species; they can be of value in characterising water conditions (Bourrelly 1970, Herrmann 2010, McCarthy et al. 2011, Worobiec et al. 2013).

Some microremains of vegetative stages of green algae can also be preserved in fossil material because of the presence of decay- and acid-resistant substances in their walls. Most commonly these are algaenans – aliphatic biomacromolecules (Blokker 2000, Versteegh & Blokker 2004, Poulíčková et al. 2007). For example, in vegetative stages the algaenans are present in *Botryococcus braunii* Kützing (van Bergen et al. 1995, Kadouri et al. 1988, De Leeuw et al. 2006) as well as *Pediastrum* Meyen, *Scenedesmus* Meyen, and *Tetraedron* Kützing species (Blokker et al. 1998).

Some green algae do not fossilise in vegetative stages but have their fossil record because they produce various specialised thick-walled resting cells (akinetes, hypnospores or hypnozygotes) which can survive. Thick-walled zygotes occur in Volvocales, Oedogoniales, Zygnematales, and Chlorococcales (Coleman 1983). For example, the Zygnemataceae produce resting cells that enable them to survive through unfavourable growth conditions (e.g. desiccation) without damage to the living content of the dormant spores. The Zygnemataceae reproduce using four types of resting cells ("spores"), but only zygospores (formed during conjugation) and probably aplanospores are chemically resistant and are preserved in the fossil record. The majority of extant species of Zygnemataceae have zygospores (hypnozygotes) of constant form. The shape and sculpture are very important features for identifying both recent and fossil species. The zygospores normally have a three-layered wall (exospore, mesospore, endospore) but only the mesospore contains chemically resistant biopolymers (probably algaenans), and usually only this layer is preserved in the fossil state. The mesospore layer is smooth or ornamented with various sculpture (Kadłubowska 1972, Grenfell 1995, Rundina 1998). Microfossils of Zygnemataceae are sometimes very common among palynomorphs but have often been described as fossil taxa of unknown botanical affinity, especially when found in pre-Quaternary deposits. In the past some authors have misidentified zygnemataceous spores as pollen grains of flowering plants. Palynomorphs of probable zygnematacean affinity occur in sediments of Carboniferous (or even older) to Holocene age (van Geel 1979, Colbath & Grenfell 1995, van Geel & Grenfell 1996). Recognition of the zygnemataceous origin of various palynomorph types in palynological slides began with a study by van Geel in 1976 (van Geel 2001).

Similarly, in desmids conjugation gives rise to a zygospore that may bear a chemically resistant cell wall. Zygospores of desmids usually have a constant form (spherical, polygonal or irregular) and ornamentation, often with spines or protuberances (Graham 1971, Head 1992). The fossil records of these algae are poorly known but possibly traceable to the Devonian. Neogene records are quite common (e.g. Krutzsch & Pacltová 1990, Head 1992) but seldom investigated in depth.

The Zygnematales are among the potential algal ancestors of land plants (Graham 1993). Their microfossils may have been present as early as during the Proterozoic even if they have been identified only as acritarchs (Martín-Closas 2003). The first unmistakable conjugate zygospores are known from the Carboniferous (van Geel & Grenfell 1996). Carboniferous zygospores of the genera *Tetraporina*, *Brazilea*, and *Lacunalites* seem ancestral to extant *Mougeotia*, *Spirogyra*, and *Zygnema*, respectively. The origin of conjugation as a special mechanism for producing zygospores is significant, as it represents the first adaptation of a green alga to survive desiccation of ephemeral ponds on land (Stebbins & Hill 1980). During the Early Permian the Zygnematales underwent a short radiation period (van Geel & Grenfell 1996) which may reflect speciation related to the extension of small ephemeral ponds during this period of general aridity. Neogene Zygnematales already show morphologies similar to extant genera to which they can be assigned. For example, *Spirogyra* and *Mougeotia* were especially abundant in the Palaeogene and Neogene fossil record. For the Neogene and Quaternary the Zygnematales are useful as indicators of early colonisation of freshwater substrates (van Geel & Grenfell 1996, Martín-Closas 2003).

This paper presents two examples of Neogene assemblages of freshwater organic-walled algal microremains. The studied assemblages are remains of freshwater algal communities occurring in two ponds developed in the Middle and Late Miocene. Many of the algal microremains presented below are often recorded in pollen slides from various Cenozoic deposits. Such freshwater microalgae assemblages from Neogene deposits are rarely examined in detail. Usually these microfossils are reported (or only mentioned) in palynological works. Freshwater microalgae from Neogene deposits are described in detail in some publications (e.g., Nagy 1965, Krutzsch & Vanhoorne 1977, Song et al. 1985, Song 1988, Krutzsch & Pacltová 1990, Head 1992, Lyubomirova & Rundina 1993, Zamaloa 1996, Mautino 2007, Worobiec & Worobiec 2008, Worobiec 2010, 2011). More numerous are studies of Quaternary freshwater algae included among the non-pollen palynomorphs – NPPs (e.g. van Geel 1976, van Geel et al. 1981, 1983, Jankovská & Komárek 2000, Komárek & Jankovská 2001, Carrión 2002, Medeanic 2006). Miola (2012) gave a list of Quaternary non-pollen palynomorph types and also the literature in English from 1972–2011.

GEOLOGICAL SETTING

The studied deposits originate from two palaeosinkholes developed within Middle Triassic limestone outcropped in the Tarnów Opolski and Górażdże quarries in the western part of the Upper Silesian Upland, SW Poland (Fig. 1).

The sinkholes visible in the Tarnów Opolski quarry form depressions developed in reefal and bioclastic carbonates of the Karchowice and Diplopora Beds and range from 10 to 150 m in diameter, reaching 30 m depth. The downward progress of the sinkholes was constrained by underlying impermeable marl deposits of the Terebratula Beds. The sinkholes are filled with variegated clayey and sandy clastics, sometimes with lignites (Worobiec & Szulc 2010a, b).

The Górażdże sinkhole developed in thick-bedded and coarse-grained bioclastic, oncoidal and ooidal limestone, interbedded with fine-grained nodular limestone, building a 15 m thick succession of the Górażdże Beds. These pure limestones are underlain by poorly permeable marly sediments of the Upper Gogolin Beds, limiting the downward progress of karstic processes. The Górażdże sinkhole has an hourglass shape, reaching 17 m across and more than 12 m deep. Its final depth is unknown due to scree covering the lowest part of the outcrop (Szulc & Worobiec 2012). The Górażdże sinkhole is a solution sinkhole which originated through subsidence of surficial deposits into an underlying cave system. During the initial stage of sinkhole evolution, subterranean and surface karstification proceeded concurrently. As result a cavern system originated in the underlying bedrock. Afterwards, both systems became connected and the surface karst deposits sank down into the underlying cavern. This in turn involved the formation of a depression in the land surface. With time, meteoric water accumulated in the sinkhole, giving rise to a small pond. The pond was filled with plant material, which underwent lignite formation. During the final stage the sinkhole was completely filled with moulding sands derived from eroded Upper Cretaceous sandstones and marls (Szulc & Worobiec 2012, Worobiec in press).

RESULTS OF PREVIOUS CLASSICAL POLLEN ANALYSIS

Pollen analysis confirmed the presence of shallow water bodies (ponds) in both studied sinkholes.

TARNÓW OPOLSKI

At Tarnów Opolski, *Nuphar*, *Potamogeton*, *Utricularia* and probably *Aldrovanda* occurred among the plants floating on the water surface and fixed to the bottom. *Typha* and *Sparganium* grew in shallow water and in the marginal zone. The water body was surrounded by swamp-aquatic vegetation composed of herbs

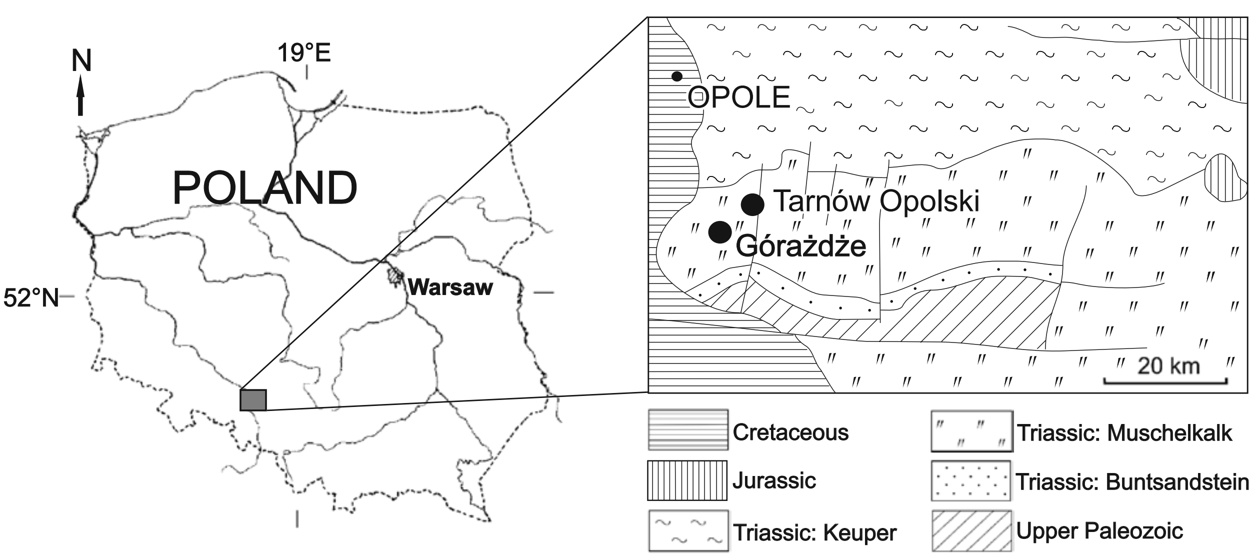

Fig. 1. Location of the Tarnów Opolski and Górażdże quarries in Poland and on general geological map of the region (modified from Worobiec & Szulc 2010a, b; Worobiec 2011)

(including members of the families Cyperaceae, Poaceae, Apiaceae, Polygonaceae, Lamiaceae, Chenopodiaceae, and Asteraceae), as well as riparian forests, probably dominated by *Carya* and *Pterocarya*, accompanied by *Liquidambar*, *Alnus*, *Ulmus*, *Juglans*, *Salix*, and *Acer*. In drier habitats there were mixed forests composed of *Carpinus*, *Quercus*, *Fagus*, *Cercidiphyllum*, Tilioideae, and conifers, with an admixture of thermophilous taxa (e.g. *Castanea*, *Engelhardia*, *Platycarya*, *Reevesia*, *Symplocos*). The undergrowth of these forests consisted of taxa such as *Ilex* and probably pollen-producing plants of the fossil species *Tricolporopollenites fallax* and *T. liblarensis* (Worobiec & Szulc 2010b).

Vertical changes in the composition of sporomorph and algal assemblages of the sinkhole fill clearly reflect a facies succession from open aquatic (in this phase the sinkhole was completely filled with water) to marshy conditions. In the second phase, swamp forests composed of *Taxodium*, *Glyptostrobus*, *Nyssa*, and probably *Alnus*, played a considerable role, although some remnant water body still existed, as confirmed by the continuous presence of algal microfossils and pollen of aquatic plants.

Pollen analysis of deposits from Tarnów Opolski indicate that the climate was warm-temperate and moderately wet. The composition of pollen spectra and the frequency of palaeotropical and arctotertiary elements point to Middle Miocene age of the deposits (Worobiec & Szulc 2010a, b, Worobiec 2011).

GÓRAŻDŻE

Floating and rooted macrophytes such as *Nuphar*, *Nymphaea*, and *Potamogeton* grew in the pond at Górażdże, and probably *Lemna* also. The pond was surrounded by vegetation composed of herbs and riparian forests. *Typha* (e.g. *T. latifolia*) and *Sparganium*, as well as members of the families Alismataceae (*Sagittaria*), Cyperaceae, Poaceae, Apiaceae, Polygonaceae (*Polygonum*), Lamiaceae, Chenopodiaceae, Caryophyllaceae, Asteraceae, Urticaceae, Onagraceae, and *Thalictrum* occurred in shallow waters and along the margin.

The riparian forests were dominated by *Alnus*, *Salix*, *Ulmus*, *Pterocarya*, and *Carya*. Drier terrain presumably was covered by mixed forests composed of *Pinus*, *Tsuga*, *Picea*, *Quercus*, *Carpinus*, *Fagus*, *Betula*, and others, with only a small admixture of thermophilous plants such as *Castanea*. The Ericaceae presumably formed their own open dwarf-shrub communities such as bush swamp or heathland which occurred in the vicinity. Swamp forests with *Taxodium* and *Nyssa* were not significant plant communities at that time (Szulc & Worobiec 2012, Worobiec in press).

The composition of pollen spectra from the Górażdże palaeosinkhole and the frequency of palaeotropical and arctotertiary elements in the studied samples indicate a warm-temperate and mild (without severe winters) climate (cooler than during the Early and Middle Miocene). A comparison of the sporomorph association from the sinkhole with those from other Neogene sites provides evidence of its Late Miocene age (Szulc & Worobiec 2012, Worobiec in press).

The composition of pollen of aquatic plants and herbs surrounding the water in the Tarnów Opolski and Górażdże palaeosinkholes is similar. Both water bodies were small ponds overgrown by, for example, Nymphaeaceae (mainly *Nuphar*) and *Potamogeton*. In shallow waters and along the margins of the ponds, *Typha*, *Sparganium*, Alismataceae, Cyperaceae, Poaceae, Apiaceae, Polygonaceae, and others occurred (Worobiec 2011, Worobiec in press). The main differences between the palynoflora from these two sinkholes lie in the composition of the forest taxa. Swamp forests were important components of the vegetation during sedimentation of the deposits from Tarnów Opolski (Worobiec & Szulc 2010a, b, Worobiec 2011), whereas taxa characteristic of mesophytic and riparian forests dominate the Górażdże palynoflora. Herbs and Ericaceae are also distinctly more frequent in the Górażdże palynoflora, presumably connected with the presence of open dwarf-shrub communities (Worobiec in press).

MATERIALS AND METHODS

Samples for palynological analysis were collected in May 2009 from sediments filling two palaeosinkholes excavated in the Tarnów Opolski and Górażdże quarries. Sixteen samples were taken from the palaeosinkhole at Tarnów Opolski. They were collected at 35 cm intervals from coaly deposits at depths between ca 100 and 625 cm (Worobiec & Szulc 2010a, b). Fifteen samples were collected from the palaeosinkhole at Górażdże, including 13 samples from dark coaly sediment visible in the walls of the sinkhole and two samples from yellow sediment in the middle part of the sinkhole (Szulc & Worobiec 2012).

Samples for pollen analysis were prepared according to a variant of Erdtman's acetolysis method (Moore et al. 1991) using hydrofluoric acid to remove mineral matter. Additionally the material was sieved through 5 µm nylon mesh. Microscope slides were made using glycerine jelly as mounting medium.

Depending on pollen and algae frequency, 1–4 slides from each sample were examined. Results from classical spore-pollen analysis were used to date the palaeosinkhole deposits (Worobiec & Szulc 2010a, b, Szulc & Worobiec 2012). Afterwards, all slides from the Tarnów Opolski sinkhole were re-examined for organic-walled microalgae. Six samples from the Górażdże sinkhole were selected for detailed palynological study including analysis of organic-walled algal microfossils, because in the other samples from the sinkhole the frequency of palynomorphs was very low or the slides were barren.

The identified fossil genera have been arranged according to their possible botanical affinity. The classification used here follows Guiry (2013) and the AlgaeBase (Guiry 2014). The fossil species within genera are arranged in alphabetical order except for the type species, which is placed directly after the genus. Selected synonyms from various localities and various periods as well as short descriptions are given for each identified fossil species. When possible the morphological terminology follows Punt et al. (2007). Differences in the origin and morphology of the algal fossils and pollen grains and spores required some modifications of the terminology. The botanical affinities of the fossil taxa are based on the morphological similarity of the microfossils to extant taxa. Microphotographs of selected identified taxa were taken with a Nikon Eclipse microscope fitted with a Canon digital camera (Plates I–V).

RESULTS OF ALGAL ANALYSIS

Organic-walled algal microremains were found in all the samples examined. The frequency of algal microfossils in Tarnów Opolski ranged from ca 4% in the upper part of the section to almost 43% in the lower part of the section; in Górażdże their frequency ranged from 12% to 32%. In the 16 samples from Tarnów Opolski almost 2500 specimens of organic-walled algal microfossils were encountered. In six samples selected from Górażdże almost 1000 specimens of these microfossils were noted.

Forty species of algal microfossils were identified (Tab. 1), including 32 species from 16 genera in samples from Tarnów Opolski, and 34 species from 17 genera in samples from Górażdże. Some poorly preserved specimens were determined to genus level only. In all samples the most frequently encountered microfossils belong to the genera *Sigmopollis* (ca 1800 specimens) and *Botryococcus* (ca 800 specimens). The algal assemblages contain significant shares of resting cells (zygospores = hypnozygotes). Microfossils of the genera *Cycloovoidites*, *Diagonalites*, *Megatetrapidites*, *Ovoidites*, *Stigmozygodites*, and *Tetrapidites*, most probably representing fossil zygospores of the Zygnemataceae family (*Mougeotia*, *Spirogyra*, and *Zygnema*), were common in all samples. Also noted were some specimens most probably related to desmid zygospores (*Closteritetrapidites*, *Monopunctites*, and *Planctonites*), freshwater dinoflagellate cysts, and Prasinophyceae (*Leiosphaeridia*). Representatives of *Pediastrum* and *Tetraedron* were recorded in samples from Górażdże. All identified algae from both palaeosinkholes are freshwater taxa.

SYSTEMATIC DESCRIPTIONS OF SELECTED ALGAL FOSSIL TAXA

Classis CONJUGATOPHYCEAE Engler (=Zygnematophyceae)

Ordo ZYGNEMATALES C.E.Bessey

Familia ZYGNEMATACEAE Kützing

Ovoidites Potonié 1951 emend. Krutzsch 1959

Type. *Ovoidites ligneolus* Potonié (1931) Thomson & Pflug 1953

1951a *Ovoidites* Potonié.
1953 *Ovoidites* Potonié 1951 ex Thomson & Pflug.
1959 *Schizosporis* Cookson & Dettmann.
1967 *Brazilea* Tiwari & Navale.
1968 *Psiloschizosporis* Jain.
1968 *Pilospora* Venkatachala & Kar.
1976 *Schizophacus* Pierce.
1982 pro parte *Schizosporis* (Cookson & Dettmann) Takahashi & Jux.

List of synonyms was given by Zippi (1998).

Botanical affinity. Morphologically these microfossils resemble zygospores and aplanospores of several species of *Spirogyra* Link as well as *Sirogonium* Kützing, *Hallasia* Rosenvinge, *Pleurodiscus* Lagerheim, and *Zygnema* C.Agardh (van Geel 1976, Krutzsch & Pacltová 1990). They are also similar to zygospores of the extant genus *Zygogonium* Kützing (Zippi 1998, Mahmoud 2000). Oval zygospores also occur in some genera of desmids, as in the genus *Desmidium* C.Agardh (Förster 1982).

Table 1. Semiquantitative distribution of algal palynomorphs recovered in this study (* = 1–10, ** = 11–50, *** = 51–100, **** = more than 100 specimens)

Taxon	Botanical affinity	Indication	Frequency	
			Tarnów Opolski	Górażdże
Chlorophyta – vegetative stage				
Botryococcus braunii Kützing + *Botryococcus* sp.	Dictyosphaeriaceae: *Botryococcus* Kützing	open water, fresh and probably brackish waters	****	****
Pediastrum boryanum (Turp.) Menegh. var. *boryanum*	Hydrodictyaceae: *Pediastrum boryanum* (Turp.) Menegh. var. *boryanum*	eutrophic fresh waters, open water surface	*	***
Pediastrum integrum Nägeli	Hydrodictyaceae: *Pediastrum integrum*	fresh waters, also oligotrophic and dystrophic biotopes		*
Pediastrum sp.	Hydrodictyaceae: *Pediastrum*	eutrophic to mesotrophic fresh waters, open water surface		*
Tetraedron minimum (A.Braun) Hansgirg	Chlorococcaceae: *Tetraedron minimum*	shallow, enriched lakes, ponds and rivers		*
Tetraedron sp.	Chlorococcaceae: *Tetraedron*	shallow, enriched lakes, ponds and rivers		*
Chlorophyta – resting cells				
Closteritetrapidites magnus Krutzsch & Pacltová	Closteriaceae: *Closterium*	oligo- to eutrophic fresh waters	*	*
Closteritetrapidites reductus Krutzsch & Pacltová	Closteriaceae: *Closterium*	oligo- to eutrophic fresh waters	*	
Cycloovoidites cyclus (Krutzsch) Krutzsch & Pacltová	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	*	*
Diagonalites diagonalis Krutzsch & Pacltová	Zygnemataceae: *Mougeotia laetevirens* type	shallow, stagnant, oxygen-rich fresh waters, lake margins	**	*
Lecaniella forma 4 Head	Zygnemataceae: *Debarya*, *Zygnemopsis*	shallow, mesotrophic fresh waters, small temporary pools	*	
Megatetrapidites megatetroides Krutzsch & Pacltová + *Megatetrapidites* sp.	Zygnemataceae: *Mougeotia*	shallow, stagnant, oxygen-rich fresh waters, lake margins	**	***
Monopunctites crassipunctus Krutzsch & Pacltová	Closteriaceae: *Closterium*	more or less mesotrophic, open fresh waters	*	
Ovoidites elongatus (Hunger) Krutzsch	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	**	**
Ovoidites gracilis Krutzsch & Pacltová	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	**	
Ovoidites grandis (Pocock) Zippi	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	*	*
Ovoidites ligneolus (Potonié) Tomson & Pflug	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	**	**
Ovoidites minoris Krutzsch & Pacltová	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	*	*
Ovoidites spriggii (Cookson & Dettmann) Zippi	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	**	*
Ovoidites vangeelii E.Worobiec sp. nov.	Zygnemataceae: *Spirogyra scrobiculata* type	shallow, stagnant, oxygen-rich fresh waters, lake margins	cf.	*
Ovoidites sp. 1	Zygnemataceae: *Spirogyra*	shallow, stagnant, oxygen-rich fresh waters, lake margins	*	
Planctonites stellarius (Potonié) Krutzsch + *P.* cf. *stellarius* (Potonié) Krutzsch	Zygnematales: desmids	fresh and probably brackish waters	*	cf.
Spintetrapidites longicornutus Krutzsch & Pacltová	?Zygnematales: ?desmids, ?Zygnemataceae	oligo- to eutrophic fresh waters	*	
Spintetrapidites quadriformis Krutzsch & Pacltová	?Zygnematales: ?desmids, ?Zygnemataceae	oligo- to eutrophic fresh waters	*	*
Stigmozygodites mediostigmosus Krutzsch & Pacltová	Zygnemataceae: *Zygnema*	shallow, meso- to eutrophic, open fresh waters	*	**
Stigmozygodites megastigmosus Krutzsch & Pacltová	Zygnemataceae: *Zygnema*	shallow, meso- to eutrophic, open fresh waters	*	*
Stigmozygodites ministigmosus Krutzsch & Pacltová	Zygnemataceae: *Zygnema*	shallow, meso- to eutrophic, open fresh waters	***	

Tab. 1. Continued

Taxon	Botanical affinity	Indication	Frequency	
			Tarnów Opolski	Górażdże
Stigmozygodites multistigmosus Krutzsch & Pacltová	Zygnemataceae: *Zygnema*	shallow, meso- to eutrophic, open fresh waters	*	
Stigmozygodites sp. (undivided)	Zygnemataceae: *Zygnema*	shallow, meso- to eutrophic, open fresh waters		**
Tetrapidites grandis E.Worobiec sp. nov.	Zygnemataceae: *Mougeotia*	shallow, stagnant, oxygen-rich fresh waters, lake margins	*	
Tetrapidites laevigatus Krutzsch & Vanhoorne	Zygnemataceae: *Mougeotia*	shallow, stagnant, oxygen-rich fresh waters, lake margins	*	
Tetrapidites opolensis E.Worobiec sp. nov.	Zygnemataceae: *Mougeotia*	shallow, stagnant, oxygen-rich fresh waters, lake margins	*	*
Other fossil taxa				
Sigmopollis laevigatoides Krutzsch & Pacltová	?Chlorophyta, ?other algae	eutrophic to mesotrophic open fresh waters	****	***
Sigmopollis pseudosetarius (Weyland & Pflug) Krutzsch & Pacltová	?Chlorophyta, ?other algae	eutrophic to mesotrophic open fresh waters	****	****
Sigmopollis punctatus Krutzsch & Pacltová	?Chlorophyta, ?other algae	eutrophic to mesotrophic open fresh waters	****	***
Zygodites medius (Rshanikova) Krutzsch & Pacltová + *Zygodites* sp.	?Chlorophyta: ?Zygnematales	oligo- to eutrophic fresh waters	****	**
Leiosphaeridia sp.	Prasinophyceae	fresh waters	**	*
freshwater dinocysts	Dinophyceae	fresh waters	*	*
?other algae	?algae	unknown		*

Ecology and geographical distribution. *Ovoidites* microfossils are widely dispersed but restricted to freshwater habitats (Rich et al. 1982). Algae of the extant genus *Spirogyra* (507 species) are very common in relatively clean eutrophic water, developing slimy filamentous green masses. They are reported from all continents and from tropical to arctic climate. They form annual filaments, with a growth burst in spring. The filaments are usually found as free-floating masses and also frequently found attached to substrate. Habitats of *Spirogyra* include ponds, slow-flowing streams, backwaters, roadside ditches, and swift-flowing rivers. It occurs frequently in stagnant but aerobic habitats, in floating or submerged mats. Occasional blooms are reported. Fossil zygospores of *Spirogyra* and other Zygnemataceae are common. The oldest ones are reported from the Carboniferous (van Geel 1979, van Geel & Grenfell 1996, Guiry 2014). Fossil algal filaments of Zygnematales with *Ovoidites* zygospores were found in Cenomanian amber from France (Breton 2007). Zygospores of *Spirogyra* are used in palaeoecological studies as markers for clean, oxygen-rich, shallow stagnant, mesotrophic water in habitats subject to seasonal warming (van Geel 2001, Guiry 2014). *Sirogonium* (23 species) occurs in freshwater habitats on all continents (unreported for Antarctica), but is rarer than *Spirogyra*, *Mougeotia*, or *Zygnema*. Filaments of *Sirogonium* are usually found as free-floating masses. Filamentous algae of the genus *Zygogonium* (34 species) occur in North America, South America, Africa, Asia, and Australia. They are amphibious or terrestrial, and often occur on acidic substrates and in moderately warm thermal springs. *Hallasia* (4 species?) and *Pleurodiscus* (3 species?) are poorly known genera and need taxonomical verification (Guiry 2014).

Ovoidites ligneolus Potonié (1931) Thomson & Pflug 1953

Pl. 2, figs 3–5

1931 *Pollenites* (*?*) *ligneolus* n. sp.; Potonié, p. 28, pl. 2, fig. V25a (Tertiary, Germany).

1934 *Sporites ligneolus* Potonié; Potonié & Venitz, p. 15, pl. 4, figs 127, 128 (Miocene, Germany).

1937 *Sporites ligneolus* Potonié; Thiergart, p. 294, pl. 22, fig. 11 (?Miocene, Germany).

1937 *Sporites ligneolus* Potonié f. *major* n. f.; Raatz, p. 13, pl. 1, fig. 1 (Miocene, Germany).

1951a *Ovoidites ligneolus* Potonié; Potonié, pl. 21, fig. 85.

1953 *Ovoidites ligneolus* Potonié; Thomson & Pflug, p. 113, pl. 15, fig. 100 (Tertiary, Germany).

1959 *Ovoidites ligneolus* (Potonié) subfsp. *ligneolus* Krutzsch; Krutzsch, p. 250.

1959 *Sporites* (*Ovoidites*) *ligneolus* Potonié; Altehenger, p. 51, pl. 6, figs 1–5, 10–19 (Neogene, Germany).

1960 *Sporites ligneolus* Potonié forma *acuta*; Mamczar, pp. 24, 143, 198, pl. 2, fig. 13a, b (Miocene, Poland).

1960 *Sporites ligneolus* Potonié forma *ovalis*; Mamczar, pp. 24, 142, 198, pl. 1, fig. 12a, b (Miocene, Poland).

1960 *Sporites ligneolus* Potonié forma *signata*; Mamczar, pp. 25, 143, 198, pl. 2, fig. 14 (Miocene, Poland).

1960 *Sporites ligneolus* Potonié forma *signata*; Doktorowicz-Hrebnicka, pp. 75, 170, 225, pl. 17, fig. 17 (Miocene, Poland).

1961 *Sporites ligneolus* Potonié; Romanowicz, p. 335, pl. 3, fig. 28 (Miocene, Poland).

1964 *Sporites ligneolus* Potonié forma *superba*; Doktorowicz-Hrebnicka, p. 29, pl. 1, fig. 3 (Miocene, Poland).

1964 *Ovoidites ligneolus* Potonié; Stuchlik, p. 81, pl. 25, fig. 14 (Miocene, Poland).

1966 *Ovoidites* fsp. 6; Sontag, pl. 79, figs 1a–1d (Neogene, Germany).

1966 *Sporites ligneolus* Potonié; Ziembińska & Niklewski, p. 34, pl. 2, figs 11–13 (Miocene, Poland).

1969 *Ovoidites ligneolus* Potonié; Kedves, pl. 22, fig. 26 (Eocene, Hungary).

1977 *Ovoidites ligneolus intermedius* Raatz; Krutzsch & Vanhoorne (Palaeogene, Belgium).

1985 *Ovoidites ligneolus* Potonié; Song et al., p. 49, pl. 8, figs 7, 8; pl. 13, figs 12, 13 (Cenozoic, China).

1988 *Ovoidites ligneolus* Potonié type 2; Song, p. 33, pl. 4, fig. 12 (Neogene, China).

1990 *Ovoidites ligneolus*–Gruppe; Krutzsch & Pacltová, p. 362, text-fig. 12, pl. 4, figs 39–43 (Pliocene, Czech Republic).

1996 *Ovoidites ligneolus* (Potonié) Potonié subsp. *intermedius* Raatz; Ashraf & Mosbrugger, p. 23, pl. 4, fig. 15 (Neogene, Germany).

1996 *Ovoidites ligneolus* (Potonié) Potonié subsp. *major* Raatz; Ashraf & Mosbrugger, p. 23, pl. 5, fig. 1 (Neogene, Germany).

1996 *Spirogyra* sp. Tipo B; Zamaloa, p. 182, pl. 1, fig. 10 (Middle Tertiary, Argentina).

1996b *Ovoidites ligneolus* (Potonié) subfsp. *ligneolus* Krutzsch; Grabowska, p. 778, pl. 259, fig. 17 (Upper Miocene, Poland).

1997 *Ovoidites ligneolus* Potonié ex Krutzsch; Yi, p. 524, fig. 13c (Upper Cretaceous, Korea).

1997 *Ovoidites ligneolus* (Potonié) Potonié; Grabowska & Ważyńska, pl. 9, fig. 15 (Middle Miocene, Poland).

1997 Type 417B: *Spirogyra* spore; Kuhry, p. 219, pl. 4, fig. 417B (Holocene, Canada).

2009 *Ovoidites ligneolus* (Potonié) Krutzsch; Słodkowska, fig. 8E (Middle Miocene, Poland).

2009 Ovoidites ligneolus Potonié ex Krutzsch; Worobiec, p. 63, pl. 21, fig. 6a, b (Middle Miocene, Poland).

2011 *Ovoidites ligneolus* Potonié ex Krutzsch; Worobiec, fig. 3.19 (Middle Miocene, Poland).

2012 *Spirogyra* zygospore; Szulc & Worobiec, fig. 9H (Upper Miocene, Poland).

Description. Zygospores (? or aplanospores) elongate, more or less narrowly ellipsoidal in outline, 100–170 µm long and 45–90 µm wide. Very distinct rugulate sculpture on surface. Rugulae of various lengths, mainly arranged longitudinally, sometimes forming a reticulate pattern. Wall 2.5–3.5 µm thick. Zygospores split longitudinally into two halves.

Botanical affinity. See genus *Ovoidites*. Morphologically these microfossils are similar to zygospores of the extant species *Spirogyra verrucosa* (C.B.Rao) Krieger, as well as *S. brunnea* Czurda, *S. pulchrifigurata* C.-C.Jao and *S. quezelli* Gauthier-Lièvre (see Kadłubowska 1972, 1984).

Remarks. *Ovoidites ligneolus* differs from other species of this genus mainly by its very distinct rugulate sculpture. Raatz (1937) distinguished three subspecies differing in size: *major*, *intermedius* and *minor*. Specimens recorded in the studied material were similar to subspecies *major* (Pl. 2, figs 4, 5) and rarely to subspecies *intermedius* (Pl. 2, fig. 3). Krutzsch (1959) distinguished four subspecies: *major*, *intermedius*, *minor*, and *ligneolus*, differing mainly in size and also slightly in sculpture. "Forms" distinguished by Mamczar (1960) differ mainly in outline (gradually or sharply tapering ends), what is caused by the split of the zygospores. In addition, "forma *signata*" has slightly larger and thicker rugulae.

Ecology and geographical distribution. *Spirogyra verrucosa* and *S. brunnea* occur in Asia (India) and Africa, *S. pulchrifigurata* grows in paddy fields in Asia (China), and *S. quezelli* occurs in Africa (Kadłubowska 1972, 1984).

Occurrence in the material studied. 47 specimens of this species were recorded (Tarnów Opolski – 27, Górażdże – 20).

Ovoidites elongatus (Hunger 1952) Krutzsch 1959

Pl. 2, fig. 2

1952 *Sporites elongatus* n. sp.; Hunger, p. 193, pl. 1, fig. 12 (Miocene, Germany).

1959 *Cycadeoidea* sp.?; Macko, pl. 23, figs 2, 3 (Miocene, Poland).

1959 *Ovoidites elongatus* (Hunger) n. comb.; Krutzsch, p. 252 (Pliocene, Germany).

1959 *Schizosporis parvus* n. sp.; Cookson & Dettmann, p. 216, pl. 1, figs 15–20 (Cretaceous, Australia).

1960 *Sporites immemoratus* n. spm.; Doktorowicz-Hrebnicka, pp. 75, 171, 226, pl. 17, fig. 18 (Miocene, Poland).

1965 *Schizosporis laevigatus* n. sp.; Stanley, p. 268, pl. 23, figs 6, 7, pl. 37, figs 4, 5 (Cretaceous–Palaeocene?, USA).

1966 *Ovoidites parvus* (Cookson & Dettmann) n. comb.; Nakoman, p. 91 (Tertiary, Turkey).

1968 *Psiloschizosporis parvus* n. comb.; Jain, p. 31 (Middle Triassic, Argentina).

1969 *Schizosporis parvus* Cookson & Dettmann; Agasie, p. 28, pl. 4, fig. 15 (Cenomanian, USA).

1974 cf. *Tulipa* sp.; Tran Dinh Nghia, p. 70, pl. 12, fig. 4 (Miocene, Poland).

1976 *Schizophacus parvus* (Cookson & Dettmann) n. comb.; Pierce, p. 30.

1976 Spore Type C (*Spirogyra* spec.); van Geel, p. 342, pl. 1, figs 5, 8, 10 (Holocene, The Netherlands).

1977 *Ovoidites elongatus* (Hunger) Krutzsch; Krutzsch & Vanhoorne, p. 6, pl. 2, figs 3, 4 (Palaeogene, Belgium).

1978 *Spirogyra* sp. (Type 1); van Geel & van der Hammen, p. 385, pl. 3, figs 34, 37, 40, 41 (Quaternary, Colombia).

1988 *Psiloschizosporis parvus* (Cookson & Dettmann) Jain; Song, p. 34, pl. 5, figs 4, 5 (Neogene, China).

1990 ? *Cycadopites* sp.; Planderová, p. 38, pl. 26, fig. 16 (Miocene, Slovakia).

1990 *Ovoidites elongatus* (Hunger) Krutzsch; Krutzsch & Pacltová, p. 360, text-fig. 8, pl. 3, figs 26, 27 (Pliocene, Czech Republic).

1996 *Ovoidites elongatus* (Hunger) Krutzsch subsp. *elongatus*; Ashraf & Mosbrugger, p. 24, pl. 4, fig. 18 (Miocene, Germany).

1996 Psilate zygospore or aplanospore of *Spirogyra* sp., van Geel & Grenfell, pl. 2, fig. 1 (Quaternary, Colombia).

1997 Type 417A: *Spirogyra* spore; Kuhry, p. 219, pl. 4, fig. 417A (Holocene, Canada).

1998 *Ovoidites parvus* (Cookson & Dettmann) Nakoman; Zippi, p. 38, pl. 14, figs 1–12, pl. 15, figs 1–6 (Albian, Canada).

2000 *Ovoidites parvus* (Cookson & Dettmann) Nakoman (=*Schizosporis* sp. aff. *S. parvus* Cookson & Dettmann sensu Mahmoud 1996, fig. 4S); Mahmoud, p. 104, pl. 1, figs 4, 9 (Plio-Pleistocene, Egypt).

2000 *Spirogyra*; Carrión et al., fig 3.16 (Holocene, Southern Africa).

2001 *Spirogyra* zygospore or aplanospore; van Geel, fig. 1.6 (Quaternary).

2003 *Spirogyra* type; Medeanic et al., pl. 1, fig. 16 (Holocene, Brazil).

2006 *Schizophacus* sp.; Nichols et al., fig. 10B (Cretaceous, Mongolia and China).

2006 *Schizosporis parvus* Cookson & Dettmann; Bettar & Méon, pl. 5, fig. 1 (Albian, Marocco).

2008 *Ovoidites elongatus* (Hunger) Krutzsch; Worobiec & Worobiec, p. 1003, fig. 5C (Upper Miocene, Poland).

2009 *Ovoidites elongatus* (Hunger) Krutzsch; Worobiec, p. 63, pl. 21, fig. 7 (Middle Miocene, Poland).

2009 *Schizophacus laevigatus* (Stanley) Nichols & Brown; Bercovici et al., fig. 15.8 (Cretaceous-Tertiary boundary, USA).

2010 *Ovoidites elongatus* (Hunger) Krutzsch; Worobiec, p. 519, pl. 1, fig. 9; pl. 2, fig. 1 (Upper Miocene, Poland).

2010 *Ovoidites elongatus* (Hunger) Krutzsch; Worobiec & Gedl, fig. 3E (Upper Miocene, Poland).

2010 *Spirogyra* type 1; Li et al., pl. 2, fig. 1 (Pliocene, China).

2011 *Ovoidites elongatus* (Hunger) Krutzsch; Worobiec, fig. 3.21 (Middle Miocene, Poland).

2012 HdV 130; Miola, p. 151 (Quaternary).

2012 *Ovoidites elongatus* (Hunger) Krutzsch; Worobiec, p. 189, fig. 9 (Upper Miocene, Poland).

2013 *Ovoidites elongatus*; Worobiec et al., fig. 5P (Upper Neogene, USA).

2013 *Spirogyra* type; Demske et al., figs 64.1, 64.2, 64.4 (Quaternary, Japan).

Description. Zygospores (? or aplanospores) elongate, narrowly ellipsoidal in outline, 70–100 µm long and 30–50 µm wide. Wall surface psilate or very finely granulate, ca 3.0 µm thick. Zygospores split longitudinally into two equal halves.

Botanical affinity. See genus *Ovoidites*.

Remarks. *Ovoidites elongatus* differs from other species of this genus mainly by its psilate or very finely granulate wall, and by size from the nearest species *Ovoidites grandis* (Pocock) Zippi and *Ovoidites minoris* Krutzsch & Pacltová. Smooth zygospores or aplanospores of *Spirogyra* type are identified in Quaternary deposits as "*Spirogyra* 1", "*Spirogyra* type 130", "*Spirogyra* type 315", or "*Spirogyra* type C" (Pals et al. 1980, van der Wiel 1982, van Geel et al. 1983) containing specimens of various size. Miola (2012) named them HdV 130.

Ecology and geographical distribution. See genus *Ovoidites*.

Occurrence in the material studied. 47 specimens of this species were recorded (Tarnów Opolski – 26, Górażdże – 21).

Ovoidites gracilis Krutzsch & Pacltová 1990

Pl. 2, fig. 6a, 6b

1990 *Ovoidites gracilis* n. sp.; Krutzsch & Pacltová, p. 360, text-fig. 9, pl. 3, fig. 28–32 (Pliocene, Czech Republic).

1996 *Spirogyra* sp. Tipo C; Zamaloa, p. 182, pl. 1, figs 23, 24 (Middle Tertiary, Argentina).

2010 *Ovoidites gracilis* Krutzsch & Pacltová; Worobiec, p. 520, pl. 1, fig. 12a–c (Upper Miocene, Poland).

2010a *Ovoidites gracilis* Krutzsch & Pacltová; Worobiec & Szulc, fig. 4U (Middle Miocene, Poland).

2010b *Ovoidites gracilis*; Worobiec & Szulc, pl. 3, fig. 10 (Middle Miocene, Poland).

2011 *Ovoidites gracilis* Krutzsch & Pacltová; Worobiec, figs 4.2, 4.3 (Middle Miocene, Poland).

2012 *Ovoidites gracilis* Krutzsch & Pacltová; Worobiec, p. 189, figs 13, 14 (Upper Miocene, Poland).

Description. Zygospores (? or aplanospores) fusiform in outline, 65–80 μm long. Wall ca 1.0 μm thick, hyaline, with well-visible short, straight and flat rugulae arranged more or less longitudinally.

Botanical affinity. See genus *Ovoidites*.

Remarks. *Ovoidites gracilis* differs from other species of this genus mainly by its rugulate sculpture with short and straight rugulae.

Ecology and geographical distribution. See genus *Ovoidites*.

Occurrence in the material studied. 18 specimens of this species were recorded from the Tarnów Opolski palaeosinkhole.

Ovoidites grandis (Pocock 1962) Zippi 1998

Pl. 1, fig. 3

1959 *Cycadeoidea* sp.?; Macko, pl. 23, fig. 1 (Miocene, Poland).

1960 *Pollenites peramplus* n. spm.; Doktorowicz-Hrebnicka, p. 115, pl. 44, fig. 238 (Miocene, Poland).

1962 *Schizosporis grandis* n. sp.; Pocock, p. 76, pl. 13, fig. 199 (Lower Cretaceous, Canada).

1966 *Schizosporis majusculus* n. sp.; Hedlund, p. 32, pl. 10, fig. 1a, b (Cenomanian, USA).

1974 cf. *Leiofusa* sp.; Tran Dinh Nghia, p. 71, pl. 12, figs 12, 13 (Miocene, Poland).

1974 *Ovoidites* fsp. 1; Gruas-Cavagnetto, pl. 2, fig. 20 (Eocene–Oligocene, France).

1976 *Schizophacus majusculus* (Hedlund) n. comb.; Pierce, p. 30.

1982 *Psiloschizosporis maximus*; Song & Liu, p. 178, pl. 2, fig. 21 (Eocene–Oligocene, China).

1983 Type 130: *Spirogyra* psilate spore; van Geel et al., p. 313, pl. 1, fig. 130 (Holocene, The Netherlands).

1985 *Psiloschizosporis maximus* Song & Liu; Song et al., p. 51, pl. 8, figs 12, 13 (Cenozoic, China).

1985 *Psiloschizosporis parvus* (Cookson & Dettmann) Jain; Song et al., p. 51, pl. 8, fig. 11 (Cenozoic, China).

1988 *Psiloschizosporis* sp. 1; Song, p. 35, pl. 5, figs 6, 7 (Neogene, China).

1988 *Psiloschizosporis* sp. 2; Song, p. 35, pl. 5, fig. 8 (Neogene, China).

1988 *Psiloschizosporis* sp. 3; Song, p. 35, pl. 5, fig. 9 (Neogene, China).

1990 *Ovoidites* sp.; Kaouras & Velitzelos, pl. 5, fig. 6 (Pliocene, Greece).

1996 *Spirogyra* sp. Tipo A; Zamaloa, p. 182, pl. 1, figs 17–19 (Middle Tertiary, Argentina).

1997 *Brazilea majuscula* (Hedlund) n. comb. [*Brazilea majusculus*? (Hedlund) n. comb.]; Yi, p. 519, fig. 11d (Upper Cretaceous, Korea).

1998 *Ovoidites grandis* (Pocock) n. comb.; Zippi, p. 38, pl. 17, figs 1–6 (Albian, Canada).

2007 *Ovoidites grandis* Zippi; Mautino, p. 93, pl. 2, figs 8, 10 (Miocene, Argentina).

2008 *Magnolia*, Shu et al., pl. 3, fig. 18 (Neogene, China).

2010 *Ovoidites grandis* (Pocock) Zippi; Worobiec, p. 520, pl. 1, figs 7, 8a, b (Upper Miocene, Poland).

2011 *Ovoidites grandis* (Pocock) Zippi; Worobiec, fig. 4.1 (Middle Miocene, Poland).

2012 *Ovoidites grandis* (S.A.J. Pocock) Zippi; Worobiec, p. 189, fig. 12 (Upper Miocene, Poland).

2013 *Ovoidites grandis* (Pocock) Zippi; Birkenmajer & Worobiec, fig. 8E (Pliocene, Poland).

2013 *Ovoidites grandis*; Worobiec et al., fig. 5Q (Upper Neogene, USA).

2013 *Spirogyra* type; Demske et al., fig. 64.3 (Quaternary, Japan).

Description. Zygospores (? or aplanospores) ellipsoidal in outline, often preserved as narrow ellipsoidal or fusiform, 100–165 μm long and 55–65 μm wide. Wall surface psilate, 1.0–3.0 μm thick. Zygospores split longitudinally into two equal halves.

Botanical affinity. Since *Ovoidites grandis* differs from *O. elongatus* (Hunger) Krutzsch only in size and is less frequent than the smaller species, it may be a polyploid variant of the smaller species (Zippi 1998). Some modern *Spirogyra* species (e.g. *S. crassoidea* Transeau, *S. elliptica* C.-C.Jao, *S. ellipsospora* Transeau, *S. splendida* G.S.West) produce smooth-walled zygospores reaching even more than 200 μm long (Kadłubowska 1972, 1984, Rundina 1998).

R e m a r k s. *Ovoidites grandis* differs from other species of this genus mainly by its psilate surface, and from the nearest species *Ovoidites elongatus* (Hunger) Krutzsch differs by its distinctly larger size.

E c o l o g y a n d g e o g r a p h i c a l d i s t r i b u t i o n. See genus *Ovoidites*.

O c c u r r e n c e i n t h e m a t e r i a l s t u d i e d. Six specimens of this species were recorded (Tarnów Opolski – 4, Górażdże – 2).

Ovoidites minoris Krutzsch & Pacltová 1990

Pl. 2, fig. 1

1959 *Cycadeoidea* sp.?; Macko, pl. 23, fig. 4 (Miocene, Poland).

1961 cf. *Sporites immemoratus* J. Doktorowicz-Hrebnicka; Doktorowicz-Hrebnicka, p. 193, pl. 3, fig. 28 (Oligocene, Poland).

1974 cf. *Tulipa* sp.; Tran Dinh Nghia, p. 70, pl. 12, fig. 3 (Miocene, Poland).

1976 indéterninés; Roche & Schuler, pl. 12, figs 17, 18 (Tertiary, Belgium).

1976 Spore Type C (*Spirogyra* spec.); van Geel, p. 342, pl. 1, figs 6, 7, 9 (Holocene, The Netherlands).

1978 *Spirogyra* sp. (Type 1); van Geel & van der Hammen, p. 385, pl. 3, figs 35, 36, 38, 39; pl. 4, fig. 42 (Quaternary, Colombia).

1980 Type 130: *Spirogyra* sp.; Pals et al., p. 407, pl. 3, figs 130a, b (Holocene, The Netherlands).

1990 *Cycadopites* cf. *follicularis* Wilson & Webster; Planderová, p. 38, pl. 26, figs 6, 7 (Miocene, Slovakia).

1990 *Ovoidites minoris* n. sp.; Krutzsch & Pacltová, p. 358, text-fig. 7, pl. 3, fig. 25 (Pliocene, Czech Republic).

1992 *Ovoidites* type 1; Collinson et al., pl. 20, figs 3–5 (Upper Eocene, England).

1996 Psilate zygospore or aplanospore of *Spirogyra* sp., van Geel & Grenfell, pl. 1, figs 9, 13 (Quaternary, The Netherlands).

1997 *Brazilea parva* (Cookson & Dettmann) Tiwari & Navale; Yi, p. 520, figs 11e, 11f (Upper Cretaceous, Korea).

2006 *Spirogyra* type I; Medeanic, p. 92, pl. 3, figs 1–3, 5–8 (Holocene, Brazil).

2007 *Ovoidites parvus* (Cookson & Dettmann) Nakoman; Mautino, p. 92, pl. 2, figs 5, 6 (Miocene, Argentina).

2010 *Ovoidites minoris* Krutzsch & Pacltová; Worobiec, p. 520, pl. 1, figs 10, 11 (Upper Miocene, Poland).

2010 *Spirogyra* type 2; Li et al., pl. 2, fig. 2 (Pliocene, China).

2010b *Ovoidites minoris*; Worobiec & Szulc, pl. 3, fig. 13 (Middle Miocene, Poland).

2011 *Ovoidites minoris* Krutzsch & Pacltová; Worobiec, fig. 3.20 (Middle Miocene, Poland).

2012 *Ovoidites minoris* Krutzsch & Pacltová; Worobiec, p. 189, figs 10, 11 (Upper Miocene, Poland).

D e s c r i p t i o n. Zygospores (? or aplanospores) elongate, narrowly ellipsoidal in outline, 40–60 µm long and 20–30 µm wide. Wall psilate, 1.0–1.5 µm thick. Zygospores often split longitudinally.

B o t a n i c a l a f f i n i t y. See genus *Ovoidites*.

R e m a r k s. *Ovoidites minoris* differs from other species of this genus mainly by its psilate surface, and from the nearest species *Ovoidites elongatus* (Hunger) Krutzsch by its smaller size.

E c o l o g y a n d g e o g r a p h i c a l d i s t r i b u t i o n. See genus *Ovoidites*.

O c c u r r e n c e i n t h e m a t e r i a l s t u d i e d. Four specimens of this species were recorded (Tarnów Opolski – 3, Górażdże – 1).

Ovoidites spriggii (Cookson & Dettmann 1959) Zippi 1998

Pl. 3, fig. 1

1959 Klappiges Objekt; Altehenger, pl. 7, fig. 16 (Neogene, Germany).

1959 *Schizosporis spriggii* n. sp.; Cookson & Dettmann, p. 216, pl. 1, figs 10–14 (Cretaceous, Australia).

1968 *Psiloschizosporis cacheutensis* n. sp.; Jain, p. 31, pl. 9, fig. 127 (Triassic, Argentina).

1976 *Schizophacus spriggii* (Cookson & Dettmann) n. comb.; Pierce, p. 30.

1995 *Ovoidites*; Hooker et al., fig. 9O (Eocene–Oligocene, England).

1996 *Ovoidites cyclus* Krutzsch; Ashraf & Mosbrugger, p. 24, pl. 4, fig. 19 (Neogene, Germany).

1997 *Brazilea spriggii* (Cookson & Dettmann) n. comb.; Yi, p. 520, fig. 11g (Upper Cretaceous, Korea).

1998 *Ovoidites spriggii* (Cookson & Dettmann) n. comb.; Zippi, p. 40, pl. 15, figs 7–12, pl. 16, figs 10–15 (Albian, Canada).

2006 *Schizosporis spriggii* Cookson & Dettmann; Bettar & Méon, pl. 5, fig. 3 (Albian, Morocco).

2006 *Ovoidites spriggii* (Cookson & Dettmann) Zippi; Zavattieri & Prámparo, p. 1198, pl. 3, figs 1–5 (Triassic, Argentina).

2007 *Ovoidites spriggii* (Cookson & Dettmann) Zippi; Mautino, p. 93, pl. 2, fig. 4 (Miocene, Argentina).

2009 *Ovoidites* spp.; Scafati et al., p. 42, figs 6E, 6F (Palaeogene, Argentina).

2010 *Ovoidites spriggii* (Cookson & Dettmann) Zippi;

Worobiec, p. 521, pl. 2, fig. 2a, b (Upper Miocene, Poland).

2012 *Ovoidites spriggii* (Cookson & M.E. Dettmann) Zippi; Worobiec, p. 189, fig. 8 (Upper Miocene, Poland).

Description. Zygospores (? or aplanospores) circular to broadly ovoidal in outline, 60–110 µm in size. Wall psilate to finely granulate, 1.5–3.0 µm thick. Zygospores often split longitudinally into two equal halves.

Botanical affinity. These microfossils resemble the extant *Spirogyra* e.g. *S. majuscula* Kützing as well as some *Mougeotia* e.g. *M. macrospora* (Wolle) De Toni zygospores (Kadłubowska 1972, 1984).

Remarks. *Ovoidites spriggii* differs from other species of this genus mainly by its circular outline.

Ecology and geographical distribution. *Spirogyra majuscula* occurs in Europe (e.g. Britain, Portugal, Romania, Slovenia, Spain), North America (California), Southwestern Asia, Australia, and New Zealand (Guiry 2014) in shallow temporary water bodies (Kadłubowska 1972). *Mougeotia macrospora* occurs in North America (Kadłubowska 1972).

Occurrence in the material studied. 54 specimens of this species were recorded (Tarnów Opolski – 48, Górażdże – 6).

Ovoidites vangeelii E.Worobiec **sp. nov.**

Pl. 1, fig. 4a, b

1981 Type 342: Spores of *Spirogyra* cf. *scrobiculata* (Stockmayer) Czurda; van Geel et al., p. 432, pl. 8, figs 342.a–342.d (Quaternary, The Netherlands).

1988 *Foveoinaperturites* sp. 2; Song, p. 32, pl. 5, figs 2, 3 (Neogene, China).

1989 Type 342: Spores of *Spirogyra* cf. *scrobiculata*; van Geel et al., p. 98, pl. 18, figs 342.a–342.c (Quaternary, The Netherlands).

2010 spore of *Spirogyra* cf. *scrobiculata*; Miola et al., fig. 3n (Holocene, Italy).

2012 HdV 342; Miola, p. 154 (Quaternary).

Holotype. Pl. 1, fig. 4a, b. Sample Górażdże 4c (3), slide location 45.6/101.0. Stored in W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków; collection Goraz. 2009/ No 4c(3).

Type locality. Górażdże, Upper Silesian Upland, SW Poland.

Type horizon. Upper Miocene.

Derivation of the name. In honour of the palynologist Dr. Bas van Geel for his pioneering work on fossil zygnemataceous spores.

Diagnosis. Zygospores ellipsoidal in outline, with rounded ends, 80–120 µm long and 50–55 µm wide. Wall 2.0–3.0 µm thick, regularly and densely covered with nearly circular foveolae (3.0–4.0 µm in diameter) forming a reticular pattern. Foveolae 1.0–2.0 µm apart. Zygospores often split longitudinally into two equal halves.

Botanical affinity. Morphologically these microfossils are very similar to zygospores of the extant species *Spirogyra scrobiculata* (Stockmayer) Czurda (van Geel et al. 1981, 1989, Miola et al. 2010). Kadłubowska (1972, 1984) illustrated similar zygospores of *Spirogyra collinsii* (Levis) Pritz, *S. punctata* Cleve, and *S. suomiana* Transeau.

Remarks. *Ovoidites vangeelii* differs from other species of this genus mainly by the numerous distinct foveolae present on its surface.

Ecology and geographical distribution. *Spirogyra scrobiculata* occurs in freshwater conditions in Europe (Kadłubowska 1972, 1984, Brook & Johnson 2002).

Occurrence in the material studied. Three specimens of this species were recorded from the Górażdże palaeosinkhole. Eight specimens of similar "*Ovoidites* sp. 1" (Worobiec 2011) were recorded from the Tarnów Opolski palaeosinkhole but their state of preservation was poor.

***Ovoidites* sp. 1**

Pl. 1, fig. 2

2011 *Ovoidites* sp. 2; Worobiec, fig. 4.5 (Middle Miocene, Poland).

Description. Zygospores (? or aplanospores) fusiform in outline, 85–95 µm long and 30–40 µm wide. Wall ca 1.0 µm thick, with delicate irregular narrow rugulae arranged in various directions. Zygospores split longitudinally.

Botanical affinity. See genus *Ovoidites*. Zygospores with irregular rugulae occur in, for example, the extant species *Spirogyra grossii* Schmidle (Kadłubowska 1972, 1984).

Remarks. *Ovoidites* sp. 1 differs from other species of this genus mainly by the narrow, delicate, irregular rugulae on its surface.

Ecology and geographical distribution. See genus *Ovoidites*.

Occurrence in the material studied. Three specimens of this species were recorded from the Tarnów Opolski palaeosinkhole.

Cycloovoidites Krutzsch & Pacltová 1990

Type. *Cycloovoidites cyclus* (Krutzsch 1959) Krutzsch & Pacltová 1990

Cycloovoidites cyclus (Krutzsch 1959) Krutzsch & Pacltová 1990

Pl. 1, fig. 1

1959 *Liriodendron tulipifera* L.; Macko, pl. 18, figs 1, 3 (Miocene, Poland).

1959 *Ovoidites cyclus* n. sp.; Krutzsch, p. 251 (Pliocene, Germany).

1959 *Schizosporis rugulatus* n. sp.; Cookson & Dettmann, p. 216, pl. 1, figs 5–9 (Cretaceous, Australia).

1959 *Sporites* (*Ovoidites*) *ligneolus* Potonié; Altehenger, p. 51, pl. 6, fig. 6 (Neogene, Germany).

1981 Type 341B: algal spore (cf. Zygnemataceae); van Geel et al., p. 432, pl. 8, figs 341Ba, 341Bb (Quaternary, The Netherlands).

1990 *Cycloovoidites cyclus* (Krutzsch) n. comb. ssp. *minor* n. ssp.; Krutzsch & Pacltová, p. 362, text-fig. 13, pl. 4, fig. 44 (Pliocene, Czech Republic).

1996 *Ovoidites cyclus* Krutzsch; Ashraf & Mosbrugger, p. 24, pl. 4, fig. 19 (Miocene–Pliocene, Germany).

2010 *Cycloovoidites cyclus* (Krutzsch) Krutzsch & Pacltová; Worobiec, p. 521, pl. 2, figs 3a, b, 4, 5a, b (Upper Miocene, Poland).

2011 *Cycloovoidites cyclus* (Krutzsch) Krutzsch & Pacltová; Worobiec, fig. 4.6 (Middle Miocene, Poland).

2012 *Cycloovoidites cyclus* (Krutzsch) Krutzsch & Pacltová; Worobiec, p. 189, fig. 7 (Upper Miocene, Poland).

Description. Zygospores circular to broadly ovoidal in outline, 60–110 µm in size. Wall 1.5–2.5 µm thick, sculpture rugulate. Rugulae long, forming an irregular reticuloid pattern. Zygospores often covered by a loose hyaline layer ca 1.0 µm thick. Zygospores split longitudinally into two equal halves.

Botanical affinity. Morphologically these microfossils are similar to zygospores of the extant genus *Spirogyra*. Similar circular and ornamented zygospores occur in, for example, *Spirogyra gobonensis* Gauthier-Lièvre, *S. megaspora* Transeau, and *S. lenticularis* Transeau (Kadłubowska 1972, 1984, Simons et al. 1982).

Remarks. *Cycloovoidites cyclus* differs from *Ovoidites* Potonié ex Thomson & Pflug emend. Krutzsch mainly by its circular to broadly ovoidal outline.

Ecology and geographical distribution. The same as the fossil genus *Ovoidites*. *Spirogyra gobonensis* grows in ditches in Central Africa, *S. megaspora* occurs in Europe, North America and Southern Africa, whereas *S. lenticularis* occurs in Southern Africa (Kadłubowska 1972, 1984).

Occurrence in the material studied. 13 specimens of this species were recorded (Tarnów Opolski – 5, Górażdże – 8).

Stigmozygodites Krutzsch & Pacltová 1990

Type. *Stigmozygodites multistigmosus* (Potonié 1931) Krutzsch & Pacltová 1990

1992 *Gelasinicysta* Head.

Botanical affinity. The morphological features of *Stigmozygodites* are consistent with zygospores of Zygnemataceae. They are referable to the extant genus *Zygnema* C.Agardh, although circular-oval zygospores with foveolate sculpture also occur in the genera *Mougeotia* C.Agardh (section Mesocarpus; e.g. *M. megaspora* Wittrock, *M. robusta* (De Bary) Wittrock, *M. sanfordiana* Tiffany) and *Zygogonium* Kützing (e.g. *Z. indicum* (Randhawa) Transeau) (Kadłubowska 1972, 1984; Rundina 1998), as well as in some desmids (e.g. *Xanthidium armatum* D.B. Williamson and *Pleurotaenium* Nägeli; see Handke 1996). Some zygospores with foveolate sculpture, usually oval in outline, occur also in the genus *Spirogyra* Link. Foveolate zygospores more or less circular in outline occur in, for example, *Spirogyra maghrebiana* Gauthier-Lièvre (Kadłubowska 1972, 1984).

Ecology and geographical distribution. *Zygnema* is one of three commonly encountered genera in Zygnemataceae, including the equally common *Mougeotia* and far more widespread and abundant *Spirogyra*. It has been collected from all continents, from sea-level to montane habitat, and from tropical to arctic climate. Habitats of *Zygnema* range widely from still to running water, and from fresh to brackish. Filaments of these algae usually form free-floating masses. Fossil zygospores of *Zygnema* type are known from the Holocene but may have diverged from other zygnematacean genera as early as the Carboniferous (Guiry 2014). The zygospores are used in palaeoecological studies as markers for clean, oxygen-rich, shallow stagnant, mesotrophic to eutrophic, open water in habitats subject to seasonal warming (van Geel et al. 1981, Guiry 2014).

Remarks. Similar microfossils, mainly with large foveolae, were described as *Gelasinicysta* Head from Pliocene deposits in south-western England (Head 1992).

Stigmozygodites multistigmosus (Potonié 1931) Krutzsch & Pacltová 1990

Pl. 3, fig. 6

1931 *Pollenites multistigmosus* n. sp.; Potonié, pl. 2, fig. V 17a (Miocene, Germany).
1934 *Pollenites multistigmosus* Potonié; Potonié & Venitz, p. 32, pl. 3, fig. 84 (Tertiary, Germany).
1959 Stark skulpturiertes, hyalines Objekt; Altehenger, pl. 7, fig. 20 (Neogene, Germany).
1960 *Polyporina multistigmosa*; Potonié, p. 134.
1978 "*Zygnema*-type"; van Geel & van der Hammen, p. 387, pl. 4, fig. 50 (Quaternary, Colombia).
1990 *Stigmozygodites multistigmosus* (Potonié) nov. comb.; Krutzsch & Pacltová, p. 379, text-fig. 35, pl. 7, figs 103–105 (Pliocene, Czech Republic).
1995 *Zygnema*-type; Hooker et al., figs 9R, 9S (Eocene–Oligocene, England).
1996 *Zygnema* sp. Tipo A; Zamaloa, p. 183, pl. 1, figs 20–22 (Middle Tertiary, Argentina).
1997 Type 419: *Zygnema*-type spore; Kuhry, p. 219, pl. 5, fig. 419 (Holocene, Canada).
2008 *Zygnema* 1; Roth & Lorscheitter, p. 74, fig. 16 (Quaternary, Brazil).
2011 *Stigmozygodites multistigmosus* Krutzsch & Pacltová; Worobiec, fig. 3.16 (Middle Miocene, Poland).
2012 *Zygnema* zygospore; Szulc & Worobiec, fig. 9K (Quaternary, Poland).

Description. Zygospores circular to broadly ovoidal in outline, 40–50 × 40–70 µm in size. Wall 0.5–1.0 µm thick. Zygospores often deformed, wall often folded making them fusiform in outline. Zygospores often split longitudinally into two halves. Sculpture foveolate, foveolae 2.0–3.0 µm in diameter, over the whole surface.

Botanical affinity. See genus *Stigmozygodites*.

Remarks. *Stigmozygodites multistigmosus* differs from other species of this genus mainly by its relatively small foveolae.

Ecology and geographical distribution. See genus *Stigmozygodites*.

Occurrence in the material studied. Six specimens of this species were recorded from the Tarnów Opolski palaeosinkhole.

Stigmozygodites mediostigmosus Krutzsch & Pacltová 1990

Pl. 3, figs 2, 3

1978 "*Zygnema*-type"; van Geel & van der Hammen, p. 387, pl. 4, figs 49, 51, pl. 5, fig. 52 (Quaternary, Colombia).
1985 *Foveoinaperturites* sp. 5; Song et al., p. 48, pl. 10, figs 16, 17 (Cenozoic, China).
1989 Type 213: *Zygnema* type, spores; van Geel et al., p. 98, pl. 6, figs 213.a, 213.b (Quaternary, The Netherlands).
1990 *Stigmozygodites mediostigmosus* n. sp.; Krutzsch & Pacltová, p. 381, text-fig. 37, pl. 7, figs 109–111 (Pliocene, Czech Republic).
2006 *Zygnema*-type zygospore; Chmura et al., fig. 3a (Holocene, USA).
2008 *Zygnema* 2; Roth & Lorscheitter, p. 74, figs 17, 18 (Quaternary, Brazil).
2009 *Zygnema*; Spalding & Lorscheitter, p. 224, figs 22, 23 (Quaternary, Brazil).
2010b *Stigmozygodites mediostigmosus*; Worobiec & Szulc, pl. 3, fig. 9 (Middle Miocene, Poland).
2011 *Stigmozygodites mediostigmosus* Krutzsch & Pacltová; Worobiec, fig. 3.15 (Middle Miocene, Poland).
2013 *Stigmozygodites mediostigmosus*; Worobiec et al., figs 6D, 6E (Upper Neogene, USA).
2013 *Zygnema* type; Demske et al., figs 64.9–64.14 (Quaternary, Japan).

Description. Zygospores circular to broadly ovoidal in outline, 30–50 × 50–65 µm in size. Wall ca 1.0 µm thick. Zygospores often deformed and split longitudinally into two halves. Sculpture foveolate, surface covered with loosely distributed distinct foveolae (4.0–6.0 µm in diameter) over the whole surface, foveolae 2.0–6.0 µm apart.

Botanical affinity. See genus *Stigmozygodites*.

Remarks. *Stigmozygodites mediostigmosus* differs from other species of this genus mainly by its loosely distributed distinct foveolae 4.0–6.0 µm in diameter.

Ecology and geographical distribution. See genus *Stigmozygodites*.

Occurrence in the material studied. 29 specimens of this species were recorded (Tarnów Opolski – 10, Górażdże – 19).

Stigmozygodites megastigmosus Krutzsch & Pacltová 1990

Pl. 3, fig. 5

1990 *Stigmozygodites megastigmosus* n. sp.; Krutzsch & Pacltová, p. 381, text-fig. 38, pl. 7, figs 112–116 (Pliocene, Czech Republic).

2003 *Zygnema* type; Medeanic et al., pl. 1, fig. 15 (Holocene, Brazil).

2010a *Stigmozygodites megastigmosus* Krutzsch & Pacltová; Worobiec & Szulc, fig. 4W (Middle Miocene, Poland).

2011 *Stigmozygodites megastigmosus* Krutzsch & Pacltová; Worobiec, fig. 3.17 (Middle Miocene, Poland).

Description. Zygospores circular to broadly ovoidal in outline, 35–50 × 50–60 µm in size. Wall ca 1.0 µm thick. Zygospores often split longitudinally into two halves, and often deformed. Sculpture foveolate, with large foveolae very densely covering the whole surface. Foveolae 8.0–10.0 µm in diameter, circular to polygonal in outline, forming a reticulate pattern.

Botanical affinity. See genus *Stigmozygodites*.

Remarks. *Stigmozygodites megastigmosus* differs from other species of this genus mainly by its large foveolae densely covering the surface.

Ecology and geographical distribution. See genus *Stigmozygodites*.

Occurrence in the material studied. Four specimens of this species were recorded (Tarnów Opolski – 2, Górażdże – 2).

Stigmozygodites ministigmosus Krutzsch & Pacltová 1990

Pl. 3, fig. 4

1959 Pollen grains and spores indeterminated; Macko, pl. 26, fig. 33 (Miocene, Poland).

1990 *Stigmozygodites ministigmosus* n. sp.; Krutzsch & Pacltová, p. 379, text-fig. 34, pl. 7, figs 100–102 (Pliocene, Czech Republic).

1992 *Gelasinicysta vangeelii* n. gen., n. sp.; Head, p. 248, pl. 1, figs 13, 14 (Pliocene, England).

2006 Type 74; Miola et al., pl. 3, figs 20, 21 (Pleistocene, Italy).

2007 *Zygnema*; Leonhardt & Lorscheitter, p. 50, figs 27, 28 (Quaternary, Brazil).

2010b *Stigmozygodites ministigmosus*; Worobiec & Szulc, pl. 3, fig. 12 (Middle Miocene, Poland).

2011 *Stigmozygodites ministigmosus* Krutzsch & Pacltová; Worobiec, fig. 3.18 (Middle Miocene, Poland).

Description. Zygospores circular to broadly ovoidal in outline, 18–25 × 25–30 µm in size. Wall ca 0.5 µm thick, densely covered with foveolae. Foveolae 5.0–6.0 µm in diameter, distributed over the whole surface.

Botanical affinity. See genus *Stigmozygodites*.

Remarks. *Stigmozygodites ministigmosus* differs from other species of this genus mainly by its considerably smaller size.

Ecology and geographical distribution. See genus *Stigmozygodites*.

Occurrence in the material studied. 76 specimens of this species were recorded from the Tarnów Opolski palaeosinkhole.

Diagonalites Krutzsch & Pacltová 1990

Type. *Diagonalites diagonalis* Krutzsch & Pacltová 1990

1993 pro parte *Rundinella* Lubm. in Fedorova et al. 1989 ex Lyubomirova & Rundina.

1997 *Kachiisporis* Yi.

Diagonalites diagonalis Krutzsch & Pacltová 1990

Pl. 3, fig. 10

1959 Pollen grains and spores indeterminated; Macko, pl. 26, figs 34, 35 (Miocene, Poland).

1959 *Triceratium* sp.; Macko, pl. 26, fig. 3 (Miocene, Poland).

1978 *Mougeotia* cf. *M. laetevirens* (A. Braun) Wittrock (Type 1); van Geel & van der Hammen, p. 383, pl. 1, figs 1–9 (Quaternary, Colombia).

1981 Type 373: zygospore of *Mougeotia* cf. *laetevirens* (A. Braun) Wittrock; van Geel et al., p. 439, pl. 11, figs 373a, 373b (Quaternary, The Netherlands).

1985 Chlorophyta form 1; Song et al., pl. 14, figs 1–4 (Cenozoic, China).

1988 Indeterminable form; Song, p. 39, pl. 7, fig. 7 (Neogene, China).

1989 Type 373: zygospore of *Mougeotia* cf. *laetevirens*; van Geel et al., pl. 19, fig. 373 (Quaternary, The Netherlands).

1990 *Diagonalites diagonalis* n. gen. n. sp.; Krutzsch & Pacltová, p. 383, text-fig. 41, pl. 8, figs 122–125 (Pliocene, Czech Republic).

1993 *Rundinella insignis* Lubm. sp. nov.; Lyubomirova & Rundina, p. 123, pl. 1, figs 1–6 (Oligocene, Russia).

1996 *Mougeotia* sp. cf. *M. laetivirens* (A. Braun) Wittrock; Zamaloa, p. 180, pl. 1, figs 1–5 (Middle Tertiary, Argentina).

1996 Zygospores of *Mougeotia* sp. cf. *M. laetevirens*; van Geel & Grenfell, pl. 2, figs 2, 3 (Pleistocene, Colombia).

1997 *Kachiisporis bivalvus* gen. et sp. nov.; Yi, p. 522, text-fig. 4, figs 12b–12e (Upper Cretaceous, Korea).

1998 *Mougeotia* sp. cf. *M. laetevirens* (Braun) Wittrock; Zippi, p. 30, text-fig. 14, pl. 13, fig. 1 (Albian, Canada).

2000 *Mougeotia* sp.; Mahmoud, p. 104, pl. 1, fig. 6 (Plio-Pleistocene, Egypt).

2006 *Mougeotia* sp. aff. *M. laetevirens* (Braun) Wittrock in Wittrock & Norstedt; Zavattieri & Prámparo, p. 1198, pl. 2, figs 11–13 (Triassic, Argentina).

2008 *Mougeotia*; Medeanic et al., pl. 1, fig. 4 (subfossil, Costa Rica).

2009 Unidentified algal cyst; Bercovici et al., fig. 15.9 (Cretaceous-Tertiary boundary, USA).

2010 *Diagonalites diagonalis* Krutzsch & Pacltová; Worobiec, p. 522, pl. 3, figs 1–4 (Upper Miocene, Poland).

2010 zygospore of *Mougeotia* cf. *laetevirens*; Miola et al., fig. 3m (Holocene, Italy).

2010 *Diagonalites diagonalis* Krutzsch & Pacltová; Worobiec & Gedl, fig. 3D (Upper Miocene, Poland).

2010a *Diagonalites diagonalis* Krutzsch & Pacltová; Worobiec & Szulc, fig. 4X (Middle Miocene, Poland).

2010b *Diagonalites diagonalis*; Worobiec & Szulc, pl. 3, fig. 15 (Middle Miocene, Poland).

2011 *Diagonalites diagonalis* Krutzsch & Pacltová; Worobiec, fig. 3.11 (Middle Miocene, Poland).

2012 *Diagonalites diagonalis* Krutzsch & Pacltová; Worobiec, p. 189, fig. 5 (Upper Miocene, Poland).

Description. Zygospores cylindrical or conical, often compressed, with two oval openings on the ends. Wall 1.5–2.5 μm thick, psilate. Cylindrical part 40–55 μm long and 35–60 μm wide. In some cases with two opercula. Operculum circular, 33–48 μm in diameter, in some specimens a central pore visible. Some dispersed opercula present.

Botanical affinity. *Diagonalites*-like microfossils are usually related to the zygospores of extant *Mougeotia laetevirens* (A.Braun) Wittrock (van Geel & van der Hammen 1978, van Geel et al. 1981, Lyubomirova & Rundina 1993, Zippi 1998, Zavattieri & Prámparo 2006), but they are also morphologically close to zygospores of other *Mougeotia* species of section Mesocarpus (e.g. *M. acadiana* Transeau and *M. varians* (Wittrock) Czurda).

Remarks. Zippi (1998) presented stages of compression of a cylindrical zygospore of *Mougeotia laetevirens* forming a flattened rectangular outline with a slit-like aperture on each side.

Ecology and geographical distribution. *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) in Europe (e.g., Britain, Portugal, Romania, Slovenia, Spain), Asia, Australia, and New Zealand (Kadłubowska 1972, Guiry 2014). *M. acadiana* occurs in Australia and New Zealand, and *M. varians* occurs in Europe and South America (Guiry 2014).

Occurrence in the material studied. 26 specimens of this species were recorded (Tarnów Opolski – 21, Górażdże – 5).

Tetrapidites Klaus 1950 ex Meyer 1956

Type. *Tetrapidites psilatus* Klaus 1950, p. 529, fig. 522.

1953 pro parte *Tetraporina* Naumova ex Bolkhovitina.

1980 pro parte *Tetraporina* Naumova emend. Lindgren.

Botanical affinity. Morphologically these microfossils are very similar to zygospores of the extant genus *Mougeotia* C.Agardh from section Staurospermum (Kützing) Wittrock (see Kadłubowska 1984).

Remarks. Quadrate zygospores resembling zygospores of the extant genus *Mougeotia* occur in sediments of various age. From Cenozoic deposits they are often reported as *Tetrapidites*, whereas in older deposits they are usually identified as *Tetraporina*. The pre-Cenozoic microfossils are usually bigger and they have thicker walls. These microfossils have more or less concave sides and vary in wall thickness (0.5–2.0 μm) and sculpture (smooth, pitted or covered in small fovea). Numerous species of the morphological genera *Tetrapidites* and *Tetraporina* or types of *Mougeotia* zygospores are distinguished (Jarzen 1979, Pals et al. 1980, van Geel et al.

1981, van der Wiel 1982, Krutzsch & Pacltová 1990).

Ecology and geographical distribution. Recent representatives of the genus *Mougeotia* (166 species) are widespread in freshwater habitats worldwide. Filaments of these algae are usually found as free-floating masses. Along with *Zygnema*, this genus is one of three most commonly encountered genera in Zygnemataceae; *Spirogyra* is by far the most common. Some *Mougeotia* species are common in some acidified lakes of Canada. In fossil studies, zygospores of this genus are used as a marker for clean, oxygen-rich, shallow stagnant, mesotrophic water in habitats subject to seasonal warming (Guiry 2014).

Tetrapidites grandis E.Worobiec **sp. nov.**

Pl. 3, fig. 7

2010a *Tetraporina* sp. 1; Worobiec & Szulc, fig. 4T (Middle Miocene, Poland).

2010b *Tetraporina* sp.; Worobiec & Szulc, pl. 3, fig. 14 (Middle Miocene, Poland).

2011 *Tetraporina* sp. 1; Worobiec, fig. 3.12 (Middle Miocene, Poland).

Holotype. Pl. 3, fig. 7. Sample Tarnów Opolski 450 (3), slide location 31.0/97.5. Stored in W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków; collection T.Op. 2009/ No 450(3).

Type locality. Tarnów Opolski, Upper Silesian Upland, SW Poland.

Type horizon. Middle Miocene.

Derivation of the name. After the large size (Lat. *grandis*) of the zygospore.

Diagnosis. Zygospores bilaterally symmetrical, tetragonal in outline, with truncated corners, 45–60 µm in size. Distinctly concave walls on two opposite sides. At the corners are cavities 9.0–11.0 µm in diameter. Wall ca 1.0 µm thick, psilate.

Botanical affinity. Morphologically these microfossils are very similar to zygospores of the extant genus *Mougeotia* C.Agardh from section Staurospermum (Kützing) Wittrock (see Kadłubowska 1972, 1984).

Remarks. *Tetrapidites grandis* differs from other species of this genus mainly by its larger size.

Ecology and geographical distribution. See genus *Tetrapidites*.

Occurrence in the material studied. Six specimens of this species were recorded from the Tarnów Opolski palaeosinkhole.

Tetrapidites laevigatus Krutzsch & Vanhoorne 1977

Pl. 3, fig. 8

1959 Korrodiertes Objekt (mit Poren?); Altehenger, pl. 7, fig. 12 (Neogene, Germany).

1964 *Triceratium* sp.; Stuchlik, p. 81, pl. 25, figs 3, 4 (Miocene, Poland).

1969 *Tetraporina quadrata* Bolkhovitina; Nagy, p. 310, pl. 2, fig. 5 (Miocene, Hungary).

1974 *Tetraporina quadrata* Bolkhovitina; Grabowska, pl. 9, fig. 1 (Palaeogene, Poland).

1976 Zygospore Type A (*Mougeotia* cf. *punctata*); van Geel, p. 342, pl. 1, figs 1–3 (Holocene, The Netherlands).

1977 *Tetrapidites laevigatus* n. fsp.; Krutzsch & Vanhoorne, p. 4, pl. 1, figs 14, 15 (Palaeogene, Belgium).

1978 *Mougeotia* spec. (Type 3); van Geel & van der Hammen, p. 383, pl. 1, figs 13–15, pl. 2, fig. 16 (Quaternary, Colombia).

1983 Type 313F: *Mougeotia* cf. *punctata*; van Geel et al., p. 331, pl. 9, fig. 313F (Holocene, The Netherlands).

1985 *Tetrapidites ichsensis* (Frantz) Song comb. nov.; Song et al., p. 51, pl. 11, figs 13, 14 (Cenozoic, China).

1988 *Tetrapidites ichsensis* (Frantz) comb. nov.; Song, p. 36, pl. 4, figs 5, 6 (Neogene, China).

1996a *Tetraporina quadrata* Bolkhovitina; Grabowska, p. 390, pl. 127, figs 5, 6 (Eocene–Oligocene, Poland).

1996 *Mougeotia* sp.; Zamaloa, p. 180, pl. 1, figs 6–9 (Middle Tertiary, Argentina).

1997 *Tetraporina quadrata* Bolkhovitina; Grabowska & Ważyńska, pl. 9, fig. 6 (Middle Miocene, Poland).

2001 *Mougeotia* zygospore; van Geel, fig. 1.1 (Quaternary).

2003 *Tetraporina quadrata* Bolkhovitina; Grabowska, pl. 57, fig. 2.

2007 *Mougeotia*; Leonhardt & Lorscheitter, p. 49, fig, 23 (Quaternary, Brazil).

2010 *Tetraporina* sp. 2; Worobiec, p. 523, pl. 3, fig. 6a, b (Upper Miocene, Poland).

2010a *Tetraporina* sp. 2; Worobiec & Szulc, fig. 4V (Middle Miocene, Poland).

2011 *Tetraporina* sp. 2; Worobiec, fig. 3.13 (Middle Miocene, Poland).

2012 HdV 313 F; Miola, p. 153 (Quaternary).

2012 *Tetraporina* sp. 1; Worobiec, p. 190, fig. 22 (Upper Miocene, Poland).

D e s c r i p t i o n. Zygospores quadrate in outline, 30–45 µm in size, with straight to slightly concave sides. At the corners are cavities 4.0–6.0 µm in diameter. Wall 0.5–1.0 µm thick, hyaline, psilate to punctate.

B o t a n i c a l a f f i n i t y. Morphologically these microfossils are very similar to zygospores of the extant genus *Mougeotia* C.Agardh from section Staurospermum (Kützing) Wittrock, for example *Mougeotia viridis* (Kützing) Wittrock (see Kadłubowska 1972, 1984).

R e m a r k s. *Tetrapidites laevigatus* differs from other species of this genus mainly by its quadrate outline with straight to only slightly concave sides.

E c o l o g y a n d g e o g r a p h i c a l d i s t r i b u t i o n. See genus *Tetrapidites*. *Mougeotia viridis* is a common species occurring in peat-bogs, ditches, small water bodies, wet meadows, lakes and paddy fields in Europe, North America, Asia and Africa (Kadłubowska 1972, 1984).

O c c u r r e n c e i n t h e m a t e r i a l s t u d i e d. Four specimens of this species were recorded from the Tarnów Opolski palaeosinkhole.

Tetrapidites opolensis E.Worobiec **sp. nov.**

Pl. 3, fig. 9a, b

- 1980 Type 135: *Mougeotia* sp.; Pals et al., p. 409, pl. 4, fig. 135 (Holocene, The Netherlands).
- 2001 *Mougeotia* zygospore; van Geel, fig. 1.3 (Quaternary).
- 2008 *Mougeotia* (zygospore); Stefanova et al., pl. 2, fig. 17 (Pliocene, Bulgaria).
- 2010 *Tetraporina* sp. 1; Worobiec, p. 523, pl. 3, figs 8–11 (Upper Miocene, Poland).
- 2012 *Tetraporina* sp. 2; Worobiec, p. 190, figs 23, 24 (Upper Miocene, Poland).

H o l o t y p e. Pl. 3, fig. 9a, b. Sample Górażdże 4c (1), slide location 47.2/95.6. Stored in W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków; collection Goraz. 2009/ No 4c(1).

T y p e l o c a l i t y. Górażdże, Upper Silesian Upland, SW Poland.

T y p e h o r i z o n. Upper Miocene.

D e r i v a t i o n o f t h e n a m e. After the Opole region where the zygospores were found.

D i a g n o s i s. Zygospores bilaterally symmetrical, tetragonal in outline, with concave sides, 20–25 µm in size. At the corners are cavities 2.5–3.0 µm in diameter. Wall ca 0.5 µm thick. Small foveolae (0.5–1.0 µm in diameter) present over the whole surface.

B o t a n i c a l a f f i n i t y. Morphologically these microfossils are very similar to zygospores of the extant genus *Mougeotia* C.Agardh from section Staurospermum (Kützing) Wittrock, e.g. *M. punctata* Wittrock (see Kadłubowska 1972, 1984).

R e m a r k s. *Tetrapidites opolensis* differs from other species of this genus mainly by its outline with distinctly concave sides, small size, and small foveolae over the surface.

E c o l o g y a n d g e o g r a p h i c a l d i s t r i b u t i o n. See genus *Tetrapidites*. Today *Mougeotia punctata* occurs in shallow stagnant waters such as small lakes, ponds, ditches, paddy fields, wet meadows and peat-bogs in Central and Northern Europe, North America, and Africa (Kadłubowska 1972, 1984).

O c c u r r e n c e i n t h e m a t e r i a l s t u d i e d. Five specimens of this species were recorded (Tarnów Opolski – 2, Górażdże – 3).

Megatetrapidites Krutzsch & Pacltová 1990

T y p e. *Megatetrapidites megatetroides* Krutzsch & Pacltová 1990

Megatetrapidites megatetroides Krutzsch & Pacltová 1990

Pl. 3, figs 13

- 1990 *Megatetrapidites megatetroides* n. sp.; Krutzsch & Pacltová, p. 385, text-fig. 42, pl. 8, fig. 126 (Pliocene, Czech Republic).
- 2011 *Megatetrapidites megatetroides* Krutzsch & Pacltová; Worobiec, fig. 3.14 (Middle Miocene, Poland).

D e s c r i p t i o n. Zygospores tetragonal, asymmetric in outline, 45–65 µm in size, often with distinctly concave sides and distended corners rounded at their ends. Wall 1.0–1.5 µm thick, psilate. Zygospores often split.

B o t a n i c a l a f f i n i t y. Morphologically these microfossils resemble zygospores of algae from the family Zygnemataceae, for example the extant species *Mougeotia capucina* C.Agardh.

R e m a r k s. *Megatetrapidites megatetroides* differs from species of the genus *Tetrapidites*

Klaus ex Meyer mainly by its lack of pseudopores at the corners.

Ecology and geographical distribution. *Mougeotia capucina* occurs in rivers and peat-bogs, and on damp rocks, in Europe, New Zealand, Tasmania, and the Hawaiian Islands (Kadłubowska 1972, Guiry 2014)

Occurrence in the material studied. 99 specimens of this species were recorded (Tarnów Opolski – 41, Górażdże – 58). In the Górażdże palaeosinkhole, other specimens resembling *Megatetrapidites megatetroides* were also present (Pl. 3, figs 11, 12).

Lecaniella Cookson & Eisenack 1962

Type. *Lecaniella margostriata* Cookson & Eisenack 1962, p. 269, pl. 37, fig. 16.

***Lecaniella* forma 4** Head 1992

Pl. 4, fig. 8

1992 *Lecaniella* forma 4; Head, p. 246, pl. 3, figs 8–10 (Pliocene, England).

2011 *Lecaniella* forma 4 sensu Head 1992; Worobiec, fig. 4.7 (Middle Miocene, Poland).

Description. Microfossils flat, circular in outline, 40–45 µm in diameter, with circumpolar ridge. Wall 1.5–2.0 µm thick, psilate.

Botanical affinity. Morphologically these microfossils slightly resemble zygospores of the extant genera *Debarya* Wittrock and *Zygnemopsis* (Skuja) Transeau, mainly in the presence of a circumpolar ridge (Head 1992).

Remarks. This microfossil probably represents half of a zygospore.

Ecology and geographical distribution. Algae of the extant genus *Debarya* occur in fresh waters (27 species and infraspecific names in the database at present, of which one, *Debarya smithii* Transeau, has been flagged as currently accepted taxonomically.) Algae of the genus *Zygnemopsis* (67 species) are widely distributed in fresh waters of North America, Asia, Europe, and Africa, but are much less common than species of *Spirogyra* Link, *Mougeotia* C.Agardh, and *Zygnema* C.Agardh (Kadłubowska 1972, Guiry 2014).

Occurrence in the material studied. Three specimens of this species were recorded from the Tarnów Opolski palaeosinkhole.

Ordo ?DESMIDIALES C.E.Bessey, ?ZYGNEMATALES C.E.Bessey

Familia ?Closteriaceae C.E.Bessey, ?Zygnemataceae Kützing

Spintetrapidites Krutzsch & Pacltová 1990

Type. *Spintetrapidites longicornutus* Krutzsch & Pacltová 1990

Spintetrapidites longicornutus Krutzsch & Pacltová 1990

Pl. 4, fig. 1a, b

1990 *Spintetrapidites longicornutus* n. sp.; Krutzsch & Pacltová, p. 379, text-fig. 14, pl. 5, figs 45–47 (Pliocene, Czech Republic).

2011 *Spintetrapidites longicornutus* Krutzsch & Pacltová; Worobiec, figs 4.10, 4.11 (Middle Miocene, Poland).

Description. Zygospore (?) elongated, tetragonal in outline, with strongly distended, pointed corners, 16 × 50 µm in size. Wall ca 0.5 µm thick, psilate, hyaline.

Botanical affinity. Morphologically this microfossil slightly resembles zygospores of the extant genus *Closterium* Nitzsch ex Ralfs.

Remarks. *Spintetrapidites longicornutus* differs from *S. quadriformis* Krutzsch & Pacltová mainly by its elongated outline and strongly distended, pointed corners.

Ecology and geographical distribution. Algae of the genus *Closterium* (141 species) are unicellular, crescent-shaped or elongate desmids. These cosmopolitan algae occur in the periphyton of acidic, oligotrophic lakes and ponds, and rarely in more alkaline, eutrophic environments. Some species of this genus (e.g. *Closterium aciculare* T.West) are planktonic (Guiry 2014).

Occurrence in the material studied. One specimen of this species was recorded from the Tarnów Opolski palaeosinkhole.

Spintetrapidites quadriformis Krutzsch & Pacltová 1990

Pl. 4, fig. 2

1983 Type 167 algal (?) spores; van Geel et al., p. 318, pl. 4, figs 167.a–167.c (Holocene, The Netherlands).

1990 *Spintetrapidites quadriformis* n. sp.; Krutzsch

& Pacltová, p. 366, text-fig. 16, pl. 5, figs 51, 52 (Pliocene, Czech Republic).

2008 *Spintetrapidites quadriformis* Krutzsch & Pacltová; Worobiec & Worobiec, p. 1002, fig. 5B (Upper Miocene, Poland).

2010 *Spintetrapidites quadriformis* Krutzsch & Pacltová; Worobiec, p. 523, pl. 3, figs 13a, b, 14a, b (Upper Miocene, Poland).

2011 *Spintetrapidites quadriformis* Krutzsch & Pacltová; Worobiec, fig. 4.9 (Middle Miocene, Poland).

2012 HdV 167; Miola, p. 151 (Quaternary).

2012 *Spintetrapidites quadriformis* Krutzsch & Pacltová; Worobiec, p. 190, fig. 21 (Upper Miocene, Poland).

2013 *Spintetrapidites quadriformis*; Worobiec et al., fig. 5M (Upper Neogene, USA).

Description. Zygospores (?) tetragonal in outline, more or less quadrate with straight or slightly concave sides, 35–45 µm in size. Wall ca 0.5 µm thick, psilate, hyaline.

Botanical affinity. In their shape and lack of pseudopores these microfossils resemble zygospores of desmids (e.g. *Closterium cornu* Ehrenberg ex Ralfs, *C. tumidulum* F.Gay) as well as Zygnemataceae (genus *Mougeotia* C.Agardh).

Remarks. *Spintetrapidites quadriformis* differs from *S. longicornutus* Krutzsch & Pacltová mainly by its more quadrate outline and lack of distended corners.

Ecology and geographical distribution. *Closterium cornu* is an oligo-eutrophic cosmopolitan desmid occurring in lakes and mires (Růžička 1977, Förster 1982, Croasdale & Flint 1986, Handke 1996). According to van Geel and co-authors (1983), microfossils of Type 167 occur in stagnant, shallow, open water, in eutrophic conditions. *Closterium tumidulum* occurs in Europe (e.g. Austria, Britain, Czech Republic, France, Italy, the Netherlands, Romania, Turkey), North America, and Africa (Guiry 2014).

Occurrence in the material studied. Nine specimens of this species were recorded (Tarnów Opolski – 2, Górażdże – 7).

Ordo DESMIDIALES C.E.Bessey

Familia Closteriaceae C.E.Bessey

Closteritetrapidites Krutzsch & Pacltová 1990

Type. *Closteritetrapidites magnus* Krutzsch & Pacltová 1990

Closteritetrapidites magnus Krutzsch & Pacltová 1990

Pl. 4, figs 3, 4

1990 *Closteritetrapidites magnus* n. sp.; Krutzsch & Pacltová, p. 368, text-fig. 18, pl. 5, figs 56, 57 (Pliocene, Czech Republic).

2010 *Closteritetrapidites magnus* Krutzsch & Pacltová; Worobiec, p. 524, pl. 3, fig. 17a, b (Upper Miocene, Poland).

2011 *Closteritetrapidites magnus* Krutzsch & Pacltová; Worobiec, fig. 4.15 (Middle Miocene, Poland).

2012 *Closteritetrapidites magnus* Krutzsch & Pacltová; Worobiec, p. 187, fig. 2 (Upper Miocene, Poland).

Description. Zygospores tetragonal in outline, with pointed corners, ca 60 × 45 µm in size. Wall ca 1.0 µm thick, psilate, hyaline.

Botanical affinity. Morphologically these microfossils resemble zygospores of the extant genus *Closterium* Nitzsch ex Ralfs.

Remarks. *Closteritetrapidites magnus* differs from *C. reductus* Krutzsch & Pacltová mainly by its more tetragonal outline with four pointed corners.

Ecology and geographical distribution. Algae of the genus *Closterium* (141 species) are unicellular crescent-shaped or elongate desmids. These cosmopolitan algae occur in the periphyton of acidic, oligotrophic lakes and ponds, and rarely in more alkaline, eutrophic environments. Some species of this genus (e.g. *Closterium aciculare* T.West) are planktonic (Guiry 2014).

Occurrence in the material studied. Five specimens of this species were recorded (Tarnów Opolski – 1, Górażdże – 4).

Closteritetrapidites reductus Krutzsch & Pacltová 1990

Pl. 4, fig. 5

1980 *Tetraporina mammillata* n. sp.; Lindgren, p. 349, pl. 1, figs G, H (Upper Cretaceous, Sweden).

1990 *Closteritetrapidites reductus* n. sp.; Krutzsch & Pacltová, p. 368, text-fig. 20, pl. 5, figs 59, 60 (Pliocene, Czech Republic).

2010 *Closteritetrapidites reductus* Krutzsch & Pacltová; Worobiec, p. 525, pl. 3, fig. 15a, b (Upper Miocene, Poland).

2010b *Closteritetrapidites reductus*; Worobiec & Szulc, pl. 3, fig. 11 (Middle Miocene, Poland).

2011 *Closteritetrapidites reductus* Krutzsch & Pacltová; Worobiec, fig. 4.14 (Middle Miocene, Poland).

2012 *Closteritetrapidites reductus* Krutzsch & Pacltová; Worobiec, p. 189, fig. 4 (Upper Miocene, Poland).

Description. Zygospore oval-octagonal in outline, ca 65 × 50 µm in size. Sides straight or slightly convex, corners slightly pointed. Wall 0.5–1.0 µm thick, psilate, hyaline.

Botanical affinity. Morphologically this microfossil resembles zygospores of the extant genus *Closterium* Nitzsch ex Ralfs.

Remarks. *Closteritetrapidites reductus* differs from *C. magnus* Krutzsch & Pacltová mainly by its more oval-octagonal outline.

Ecology and geographical distribution. Algae of the genus *Closterium* (141 species) are unicellular, crescent-shaped or elongate desmids. These cosmopolitan algae occur in the periphyton of acidic, oligotrophic lakes and ponds, and rarely in more alkaline, eutrophic environments. Some species of this genus (e.g. *Closterium aciculare* T.West) are planktonic (Guiry 2014).

Occurrence in the material studied. One specimen of this species was recorded from the Tarnów Opolski palaeosinkhole.

Monopunctites Krutzsch 1970

Type. *Monopunctites crassipunctus* Krutzsch 1970

Monopunctites crassipunctus Krutzsch 1970

Pl. 4, fig. 7a, b

1970 *Monopunctites crassipunctus* n. sp.; Krutzsch, p. 144, pl. 38, figs 10–13 (Tertiary).

1978 Type 60; van Geel, p. 84, pl. 12, figs 60a, 60b (Holocene, Germany and The Nertherlands).

1981 Type 60: zygospores of *Closterium idiosporum*; van Geel et al., p. 420, pl. 2, figs 60a–60d (Quaternary, The Nertherlands).

1990 *Monopunctites crassipunctatus* Krutzsch; Krutzsch & Pacltová, p. 376, text-figs 30, 31, pl. 7, figs 85–87 (Pliocene, Czech Republic).

2002 *Closterium*; Carrión & Navarro, figs 2.1, 2.2 (Quaternary, Spain).

2011 *Monopunctites crassipunctus* Krutzsch & Pacltová; Worobiec, figs 4.12, 4.13 (Middle Miocene, Poland).

Description. Zygospores elongated in outline, with slightly split ends, 50–60 × 20–35 µm in size. Wall hyaline, thin, densely covered by granulae less than 0.5 µm in diameter.

Botanical affinity. Morphologically these microfossils resemble zygospores of the extant genus *Closterium* Nitzsch ex Ralfs. They are most similar to zygospores of *C. idiosporum* West & G.S.West (e.g., pl. 2, fig. 6 in Kouwets 1987).

Remarks. Růžička (1977) noted that there are transitional forms between the zygospores of the varieties *Closterium idiosporum punctatum* (Skuja) W.Krieger (with long appendages) and *C. idiosporum idiosporum* (more ellipsoidal in outline). This was also observed in the fossil material (van Geel et al. 1981). Only zygospores with very short appendages occurred in the material from Tarnów Opolski.

Ecology and geographical distribution. Type 60 microfossils were found in phases of more or less mesotrophic open water (van Geel et al. 1981). According to Růžička (1977), *Closterium idiosporum* is probably acidophilous.

Occurrence in the material studied. Six specimens of this species were recorded from the Tarnów Opolski palaeosinkhole.

Familia incertes

Planctonites Krutzsch in Krutzsch, Pchalek & Spiegler 1960

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

1969 *Deflandridium* Nagy.

Remarks. Nomenclatural notes concerning the fossil genus *Planctonites* were given by Jansonius and Hills (1980, card no. 3743) and Head (1992). According to them, Krutzsch (in Krutzsch et al. 1960) did not effect a valid transfer of the type species when erecting the fossil genus *Planctonites* because he failed to include basionym information as required by the ICBN. This was done by Gruas-Cavagnetto (1968). Krutzsch did, however, designate the nomenclatural type (*Planctonites stellarius*) and thus fulfilled all ICBN requirements for valid publication of the genus (Head 1992).

Similar microfossils referable to the morphological genus *Planctonites* have been recorded from the Tertiary of Germany (Krutzsch et al., 1960), France (Gruas-Cavagnetto 1968), Hungary (Nagy 1969 – *Deflandridium stellatum* Nagy = *Planctonites nagyae* (Nagy) Head), Czech Republic (Krutzsch & Pacltová 1990), and England (Head 1992), as well as from the Quaternary of the Netherlands (Van Geel et al. 1981 – Type 333). Several different morphotypes comparable with the zygospores of extant desmid genera can be recognised within this group of microfossils (see Head 1992).

Planctonites stellarius (Potonié 1934) Krutzsch in Krutzsch, Pchalek & Spiegler 1960

Pl. 4, fig. 6a, b

1934 *Sporites*? *stellarius* n. sp.; Potonié, p. 46, pl. 1, fig. 26, pl. 6, fig. 3 (Eocene, Germany).

1951b *Sporites stellarius* Potonié; Potonié, pl. 1, fig. 12 (Tertiary, Germany).

1959 *Inaperturo-pollenites stellarius* (Potonié) n. comb.; Krutzsch, p. 240, pl. 44, figs 492–494 (Tertiary, Germany).

1960 *Planctonites stellarius* (Potonié) Krutzsch n. comb.; Krutzsch et al., p. 141 (Eocene–Oligocene, Germany).

1968 *Planctonites stellarius* (Potonié) Gruas-Cavagnetto; Gruas-Cavagnetto, p. 81, pl. 11, fig. 10 (Palaeocene, France).

1981 Type 333: cf. *Penium*, zygospore; van Geel et al., p. 430, pl. 7, figs 333.a, 333.b (Quaternary, The Netherlands).

1992 *Planctonites stellarius* (Potonié) Gruas-Cavagnetto; Head, p. 252, pl. 4, figs 26, 27 (Pliocene, England).

2006 Algal spore; Chmura et al., fig. 3c (Holocene, Florida).

2010a *Planctonites stellarius* (Potonié) Krutzsch; Worobiec & Szulc, fig. 4R (Middle Miocene, Poland).

2011 *Planctonites stellarius* (Potonié) Krutzsch; Worobiec, figs 4.16, 4.17 (Middle Miocene, Poland).

2012 HdV 333; Miola, p. 154 (Quaternary).

Description. Zygospores (?) circular-polygonal, stellate in outline, 40–45 µm in diameter, with numerous (20 or more) short conical protuberances regularly distributed on the surface. Wall 0.5–1.0 µm thick, psilate, hyaline.

Botanical affinity. *Planctonites stellarius* is a fossil algal spore (Head 1992). This type of zygospore occurs in extant desmids such as *Closterium colosporum* Wittrock, *Penium* Brébisson ex Ralfs, *Pleurotaenium* Nägeli, and *Haplotaenium* Bando (e.g., Ichimura & Watanabe 1974, Růžička 1977).

Ecology and geographical distribution. *Planctonites stellarius* is a fossil algal spore of fresh and probably also brackish waters (Head 1992).

Occurrence in the material studied. Five specimens of this species were recorded from the Tarnów Opolski palaeosinkhole. Seven specimens of this morphotype were found in the material from Górażdże. The latter are poorly preserved or slightly differ from *Planctonites stellarius* in size and number of protuberances.

Classis ?CONJUGATOPHYCEAE Engler (=Zygnematophyceae)

Ordo uncertain

Zygodites Krutzsch & Pacltová 1990

Type. *Zygodites medius* (Rshanikova ?1956) Krutzsch & Pacltová 1990

Zygodites medius (Rshanikova ?1956) Krutzsch & Pacltová 1990

Pl. 4, fig. 9

?1956 *Azonaletes medium*; Rshanikova, pl. 14, fig. 2 (Eocene–Miocene, Kazakhstan).

1990 *Zygodites medius* (Rshanikova) n. comb.; Krutzsch & Pacltová, p. 389, text-fig. 47, pl. 9, figs 167–175 (Pliocene, Czech Republic).

2010 *Zygodites medius* (Rshanikova) Krutzsch & Pacltová; Worobiec, p. 526, pl. 4, figs 8, 10 (Upper Miocene, Poland).

2011 *Zygodites medius* (Rshanikova) Krutzsch & Pacltová; Worobiec, fig. 4.8 (Middle Miocene, Poland).

2012 *Zygodites medius* (Rshanikova) Krutzsch & Pacltová; Worobiec, p. 190, fig. 26 (Upper Miocene, Poland).

Description. Microfossils circular in outline, 30–45 µm in diameter. Wall psilate, 0.5–1.0 µm thick. Some specimens are deformed or split into two halves.

Botanical affinity. Morphologically these microfossils are similar to zygospores of extant desmids (e.g. *Closterium* Nitzsch ex Ralfs, *Gonatozygon* De Bary, *Pleurotaenium* Nägeli) as well as zygospores of Zygnemataceae: *Mougeotia* C.Agardh (section Mesocarpus, e.g. *M. parvula* Hassall, *M. recurva* (Hassall) De Toni, and *M. scalaris* Hassall), some species of *Spirogyra* Link (*S. circumcissa* Czurda and *S. frankliniana* Tiffany), *Zygnema* C.Agardh (*Z. gangeticum* Bhashyakarla Rao), and probably many others.

Remarks. *Zygodites medius* differs from the morphologically similar species *Ovoidites* *spriggii* (Cookson & Dettmann) Zippi by its smaller size and thinner wall.

Ecology and geographical distribution. These microfossils probably represent freshwater algae (see botanical affinity).

Occurrence in the material studied. 176 specimens of this species were recorded (Tarnów Opolski – 135, Górażdże – 41).

INCERTE SEDIS

Sigmopollis Hedlund 1965

Type. *Sigmopollis hispidus* Hedlund 1965, p. 92, pl. 1, fig. 3.

1970 *Monogemmites* Krutzsch.

Botanical affinity. The fossil genus *Sigmopollis* (in Quaternary deposits often determined as Type 128; e.g., van der Wiel 1982, van Geel et al. 1983, 1989, Miola et al. 2006) remains of unknown systematic affinity although these microfossils are valuable palaeoenvironmental indicators and in some samples are very frequent. The *Sigmopollis* microfossils are believed to be spores of freshwater algae (Srivastava 1984). These microfossils are usually regarded as Cyanobacteria (Cyanophyta) or green algae. Probably at least *Sigmopollis laevigatoides* is related to Chlorophyta (it resembles e.g. zygospores of the extant *Carteria* Diesing). Possibly the various species of *Sigmopollis* have different botanical affinities.

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

Sigmopollis laevigatoides Krutzsch & Pacltová 1990

Pl. 4, fig. 11

1990 *Sigmopollis laevigatoides* n. sp.; Krutzsch & Pacltová, p. 387, text-figs 44a, b, pl. 9, figs 131–148 (Pliocene, Czech Republic).

1990 *Nymphaeaepollenites pseudosetarius* (Krutzsch) n. comb.; Planderová, p. 55, pl. 54, fig. 7 (Miocene, Slovakia).

2006 Unidentified microfossil with S-shaped furrow; Miola et al., pl. 3, fig. 14 (Pleistocene, Italy).

2010 *Sigmopollis laevigatoides* Krutzsch & Pacltová; Worobiec, p. 517, pl. 1, fig. 1 (Upper Miocene, Poland).

2010 *Sigmopollis laevigatoides* Krutzsch & Pacltová; Worobiec & Gedl, fig. 3A (Upper Miocene, Poland).

2010b *Sigmopollis laevigatus*; Worobiec & Szulc, pl. 3, fig. 6 (Middle Miocene, Poland).

2011 *Sigmopollis laevigatoides* Krutzsch & Pacltová; Worobiec, fig. 3.8 (Middle Miocene, Poland).

2012 *Sigmopollis laevigatoides* Krutzsch & Pacltová; Worobiec, p. 190, fig. 15 (Upper Miocene, Poland).

2013 *Sigmopollis laevigatoides* Krutzsch & Pacltová; Birkenmajer & Worobiec, fig. 8D (Pliocene, Poland).

Description. Microfossils circular in outline, 15–28 µm in diameter. Wall ca 2.0 µm thick, psilate. Arcuate crack running half the circumference of the wall surface.

Botanical affinity. *Sigmopollis laevigatoides* is similar to zygospores of, for example, the extant genus *Carteria* Diesing.

Remarks. *Sigmopollis laevigatoides* differs from other species of this genus mainly by its psilate surface.

Ecology and geographical distribution. See genus *Sigmopollis*. The extant *Carteria* algae (38 species) are widely distributed in freshwater and terrestrial habitats including soil, temporary pools and eutrophic lakes (Guiry 2014).

Occurrence in the material studied. 370 specimens of this species were recorded (Tarnów Opolski – 299, Górażdże – 71).

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

Pl. 4, figs 12a, b; 13a, b; 14

1957 *Inaperturopollenites pseudosetarius* n. sp.; Weyland & Pflug, p. 103, pl. 22, figs 29–31 (Pliocene, Greece).

1957 Nymphaeaceae – *Pollenites pseudohirsutus* f. nov.; Doktorowicz-Hrebnicka, p. 157, pl. 19, figs 7, 8 (Miocene, Poland).

1957 *Sagittaria rigida* Pursh – type; Macko, p. 91, pl. 61, figs 19–23, 25–28 (Miocene, Poland).

1959 *Sagittaria rigida* Pursh. – type; Macko, pl. 21, figs 33–39 (Miocene, Poland).

1959 Pollen grains and spores indeterminated; Macko, pl. 26, figs 15–21 (Miocene, Poland).

1960 Nymphaeaceae? – *Pollenites pseudohirsutus* J. Doktorowicz-Hrebnicka; Doktorowicz-Hrebnicka, p. 238, pl. 44, fig. 236 (Middle Miocene, Poland).

1969 *Nympheaepollenites pannonicus* n. g. n. sp.; Nagy, p. 169, pl. 41, fig. 5 (Miocene, Hungary).

1970 *Monogemmites pseudosetarius* (Weyland & Pflug) n. comb.; Krutzsch, p. 146, pl. 39, figs 21–25 (Oligocene–Pliocene).

1976 *Monogemmites pseudosetarius* (Weyland & Pflug) Krutzsch; Konzalová, p. 41, pl. 20, figs 7–9 (Lower Miocene, Czech Republic).

1980 Type 128; Pals et al.; p. 407, pl. 2, figs 128a–128e (Holocene, The Netherlands).

1983 Type 128A; van Geel et al., p. 312, pl. 1, figs 128A.a, 128A.b (Holocene, The Netherlands).

1985 *Nymphaeaepollenites minor* n. sp.; Nagy, p. 157, pl. 90, figs 1–3, 5–11 (Badenian–Pannonian, Hungary).

1989 Type 128A; van Geel et al., p. 92, pl. 2, figs 128A.a, 128A.b (Quaternary, The Netherlands).

1990 *Sigmopollis pseudosetarius* (Weyland & Pflug) n. comb.; Krutzsch & Pacltová, p. 388, text-fig. 46, pl. 9, figs 152–166B (Pliocene, Czech Republic).

1990 *Nymphaeaepollenites pseudosetarius* (Krutzsch) n. comb.; Planderová, p. 55, pl. 54, figs 8–11 (Miocene, Slovakia).

1996b *Monogemmites pseudosetarius* (Weyland & Pflug) Krutzsch; Grabowska, p. 778, pl. 259, fig. 16 (Upper Miocene, Poland).

1996 *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch in Krutzsch & Pacltová; Ashraf & Mosbrugger, p. 17, pl. 3, figs 18–21 (Neogene, Germany).

1998 *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová; Bruch, p. 105, pl. 15, figs 6, 7 (Oligocene, Slovenia).

2000 Type 128; Carrión et al., fig 3.21 (Holocene, Southern Africa).

2006 Type 128A; Miola et al., pl. 3, fig. 16 (Pleistocene, Italy).

2009 *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová; Worobiec, p. 63, pl. 20, fig. 3a, b (Middle Miocene, Poland).

2010 *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová; Worobiec, p. 518, pl. 1, fig. 2a, b (Upper Miocene, Poland).

2010 *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová; Worobiec & Gedl, fig. 3B (Upper Miocene, Poland).

2010a *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová; Worobiec & Szulc, fig. 4S (Middle Miocene, Poland).

2010b *Sigmopollis pseudosetarius*; Worobiec & Szulc, pl. 3, figs 7, 8 (Middle Miocene, Poland).

2011 *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová; Worobiec, figs 3.9, 3.10 (Middle Miocene, Poland).

2012 HdV 128A; Miola, p. 151 (Quaternary).

2012 *Sigmopollis pseudosetarius*; Szulc & Worobiec, fig. 9F (Upper Miocene, Poland).

2012 *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová; Worobiec, p. 190, fig. 16 (Upper Miocene, Poland).

2013 *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová; Birkenmajer & Worobiec, fig. 8C (Pliocene, Poland).

2013 *Sigmopollis pseudosetarius*; Worobiec et al., figs 5J, 5K (Upper Neogene, USA).

Description. Microfossils circular in outline, 20–30 µm in diameter. Wall 1.0–1.5 µm thick, densely covered with very thin spines up to 3.0 µm long. Arcuate crack running half the circumference of the wall surface.

Botanical affinity. See genus *Sigmopollis*.

Remarks. *Sigmopollis pseudosetarius* differs from other species of this genus mainly by its very thin and relatively long spines covering its surface.

Ecology and geographical distribution. See genus *Sigmopollis*.

Occurrence in the material studied. 1207 specimens of this species were recorded (Tarnów Opolski – 934, Górażdże – 273).

Sigmopollis punctatus Krutzsch & Pacltová 1990

Pl. 4, fig. 10a, b

1957 *Trachycarpus excelsa* H. Wendl. – type; Macko, p. 82, pl. 8, figs 15–17 (Miocene, Poland).

1959 *Trachycarpus excelsa* H. Wendl. – type; Macko, pl. 21, figs 13–24 (Miocene, Poland).

1982 Type 128B; van der Wiel, p. 81, pl. 3, fig. 128B (Holocene, The Netherlands).

1983 Type 128B; van Geel et al., p. 312, pl. 1, figs 128B.a, 128B.b (Holocene, The Netherlands).

1985 *Nymphaeaepollenites minor* n. sp.; Nagy, p. 157, pl. 90, figs 1–3, 5–11 (Badenian–Pannonian, Hungary).

1989 Type 128B; van Geel et al., p. 92, pl. 2, figs 128B.a–128B.c (Quaternary, The Netherlands).

1990 *Sigmopollis punctatus* n. sp.; Krutzsch & Pacltová, p. 388, text-figs 45a, b, pl. 9, figs 149–151 (Pliocene, Czech Republic).

1990 *Nymphaeaepollenites minor* Nagy; Planderová, p. 55, pl. 54, figs 12–14 (Miocene, Slovakia).

2000 Type 128; Carrión et al., fig 3.22 (Holocene, Southern Africa).

2002 Type 128; Carrión & Navarro, pl. 4, fig. 3 (Holocene, Spain).

2006 Type 128B; Miola et al., pl. 3, fig. 17 (Pleistocene, Italy).

2008 Palynomorph Type 128B; Stefanova et al., pl. 2, fig. 16 (Pliocene, Bulgaria).

2009 *Sigmopollis punctatus* Krutzsch & Pacltová; Worobiec, p. 63, pl. 20, fig. 4 (Middle Miocene, Poland).

2010 *Sigmopollis punctatus* Krutzsch & Pacltová;

Worobiec, p. 518, pl. 1, fig. 5a, b (Upper Miocene, Poland).

2012 HdV 128B; Miola, p. 151 (Quaternary).

2012 *Sigmopollis punctatus* Krutzsch & Pacltová; Worobiec, p. 192, figs 17, 18 (Upper Miocene, Poland).

Description. Microfossils circular in outline, 15–25 µm in diameter. Wall ca 1.5 µm thick, densely covered with very thin spines less than 1.0 µm long. Arcuate crack on wall surface.

Botanical affinity. See genus *Sigmopollis*.

Remarks. *Sigmopollis punctatus* differs from other species of this genus mainly by the very thin, short spines covering its surface.

Ecology and geographical distribution. See genus *Sigmopollis*.

Occurrence in the material studied. 240 specimens of this species were recorded (Tarnów Opolski – 172, Górażdże – 68).

DISCUSSION

The occurrence of abundant algal microremains points to the presence of water bodies in the Tarnów Opolski and Górażdże palaeosinkholes. The algal assemblages display many similarities to each other (Worobiec 2011, Worobiec in press). Both assemblages are dominated by *Sigmopollis* (mainly *S. pseudosetarius*), *Botryococcus* and various zygospores of Zygnemataceae algae. Some zygospores of desmids, Prasinophyceae and sparse freshwater dinocysts occur in both palaeosinkholes. This reflects similarities in the ecology of the water bodies developed in these two palaeosinkholes. The presence of resting cells (zygospores or possibly aplanospores) of Zygnemataceae (*Mougeotia*, *Spirogyra*, and *Zygnema*) and desmids (*Closterium*) suggests that both may have dried out periodically and been subject to seasonal warming. The main difference between the Górażdże and Tarnów Opolski fossil algal assemblages is the presence of relatively abundant and diverse planktonic algae such as *Pediastrum* and *Tetraedron* in the samples from the Górażdże sinkhole. This suggests small habitat differences (e.g. water depth) between the water bodies (Worobiec in press).

The Zygnemataceae are among the most common algae in fresh waters, and are very important components of many freshwater habitats including lakes, ponds, streams, water-filled ditches, and paddy fields (Transeau 1951, Randhawa 1959, Kadłubowska 1972, 1984, Hoshaw & McCourt 1988, Head 1992). Most representatives of this cosmopolitan group of unbranched filamentous 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, Hoshaw & McCourt 1988, Colbath & Grenfell 1995, van Geel & Grenfell 1996). Filaments of *Spirogyra*, *Mougeotia*, and *Zygnema* are often found tangled together. The occurrence of their zygospores in Quaternary deposits indicates a shallow eutrophic water body with warm pluvial periods which supplied fluvial sediments (Medeanic 2006, van Geel et al. 1989). In the Zygnemataceae, zygospore formation occurs mostly in the spring in clean, oxygen-rich, shallow fresh water (van Geel 1976). The optimal temperature for *Zygnema* is 15–20°C, and for most species of *Spirogyra* the optimum is 14–22°C (Hoshaw 1968). Such high temperatures are easily reached in shallow water exposed to direct solar radiation, at least during the warm season (van Geel 1978). A pH value of 7.0–8.0 was inferred from the zygospores of *Spirogyra* (Grote 1977). Unfortunately, little is known about the ecology of the individual species of Zygnemataceae (Medeanic 2006, van Geel et al. 1989, Li et al. 2010).

Desmids are predominantly unicellular freshwater green algae. They are cosmopolitan, tolerant planktonic microalgae existing in a variety of aquatic habitats, often in oligo- to mesotrophic lakes, rivers, ponds and mires (Croasdale & Flint 1986). According to Tappan (1980, in: Head 1992) the presence of fossil desmids points to deposition in somewhat acidic swampy conditions.

Botryococcus (Pl. 5, figs 1, 2) is one of the most common palynomorphs of coccal algae in lagoonal and lacustrine sediments (Medeanic 2006). It has changed little through time (Guy-Ohlson 1992, Li et al. 2010). The modern *Botryococcus* is widespread, variable in form, and apparently has a number of local and geographical races. Generally, these algae live in freshwater bogs, temporary pools, ponds, and lakes. Although forms tolerating variable salinity/brackish habitats are also known (Batten & Grenfell 1996, Testa et al. 2001).

Under experimental conditions *Botryococcus braunii* is unable to reproduce under salinity approaching that of normal marine conditions, and in brackish conditions its growth rate is dramatically reduced (Vazquez-Duhalt & Arredondo-Vega 1991, in: Zippi 1998). The 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 & Grenfell 1996). According to Jankovská and Komárek (2000), identification of fossil *Botryococcus* species plays an important role in palaeoenvironmental studies since the fossil species differ in their ecology. *Botryococcus* is distributed mainly in temperate and tropical regions. Its predominance indicates shallow water and clear, mesotrophic conditions (Reynolds et al. 2002, Medeanic et al. 2003, Li et al. 2010).

Species of *Sigmopollis* (often identified as Type 128) are associated with eutrophic to mesotrophic open waters in Holocene deposits. The optimal environment for these algae is eutrophic slowly flowing or stagnant water (Pals et al. 1980, van der Wiel 1982, van Geel et al. 1983).

According to van Geel et al. (1983), microfossils of Type 167 (identified here as *Spintetrapidites quadriformis*) also occur in stagnant, shallow, open water, in eutrophic conditions.

Fossil *Pediastrum* in the pollen slides would indicate a wide range of environmental conditions. The genus has been widely used as a biological indicator for freshwater environments and temperate (or warm) climate (Jankovská & Komárek 2000, Zamaloa & Tell 2005), but each *Pediastrum* species has specific ecological requirements. For example, *Pediastrum boryanum* (Pl. 5, fig. 5) is the most common cosmopolitan species and there are more than nine varieties recorded. Some of these may be indicators of tropical conditions. Fossil *P. boryanum* is well known in Europe from the Pliocene, Pleistocene, Late Glacial, and Holocene, and in America from the Late Cretaceous (Komárek & Jankovská 2001, Tell & Zamaloa 2004, Li et al. 2010). At present, *P. boryanum* var. *boryanum* occurs in mesotrophic to eutrophic waters, whereas *Pediastrum integrum* can be found mainly in oligotrophic and dystrophic water biotopes (Komárek & Jankovská 2001).

Interestingly, similar fossil organic-walled algal assemblages are observed in Cenozoic freshwater deposits. Lists of synonyms show that similar microfossils occur in sediments of various age (mainly in the Cenozoic, some also in the Mesozoic) in many localities. So these groups of algae were widespread also in the past. From Neogene freshwater deposits only a few organic-walled algal assemblages are described but there are many similarities in their composition. For example, similar algal microfossils were illustrated (unfortunately not identified) from Miocene brown coals in Lower Silesia, south-western Poland (Macko 1959). In that paper, zygospores of *Mougeotia*, *Spirogyra* (two types), and *Zygnema*, as well as *Sigmopollis* (with various sculpture) were illustrated. The studied algal assemblage also resembles one described from Upper Miocene sediments at Józefina, central Poland (Worobiec 2010), but in the samples from Tarnów Opolski and Górażdże there were more taxa recorded and *Botryococcus* was more dominant.

A similar algal assemblage was described from Pliocene Cheb Basin sediments (Krutzsch & Pacltová 1990). All groups of algal microfossils recorded from the deposits of the Tarnów Opolski and Górażdże palaeosinkholes were found in the Cheb Basin sediments. From Palaeocene deposits in Belgium, Krutzsch and Vanhoorne (1977) described a freshwater algal assemblage with zygospores of *Mougeotia*, and *Spirogyra* (a few types), as well as *Botryococcus* and *Pediastrum*. Very similar algal assemblages were reported by Song et al. (1985) and Song (1988). Various zygospores of *Spirogyra*, *Mougeotia*, and *Zygnema*, as well as *Pediastrum* and *Botryococcus*, occurred in Cenozoic deposits of China. In middle Tertiary deposits from Argentina (Zamaloa 1996), zygospores of *Mougeotia* (two types), *Spirogyra* (three types), and *Zygnema* (two types) were encountered.

Quaternary freshwater deposits contain many elements recorded from the Tarnów Opolski and Górażdże samples. For example, sediments in north-eastern Italy from the Last Glacial Maximum contained zygospores of Zygnemataceae, *Closterium*, *Sigmopollis* (Types 128A and 128B), and *Botryococcus* (Miola et al. 2006). Zygospores of *Spirogyra*, *Mougeotia*, and *Zygnema*, as well as *Botryococcus*, were recorded from Holocene deposits in Brazil (Leonhardt & Lorscheitter 2007).

In contrast, freshwater dinocysts were frequent or even dominated in algal assemblages from late Neogene palaeosinkholes at the Gray

Fossil Site, Tennessee, USA (Worobiec et al. 2013). Zygospores of *Spirogyra* and *Zygnema* as well as Prasinophyceae and sparse *Sigmopollis* were present, whereas only a few species of *Botryococcus* were recorded. This absence of *Botryococcus* algae in the three pits and their sparse presence in one pit, as well as the simultaneous abundance of freshwater dinoflagellates in all four pits, presumably indicate a depositional environment of alkaline water conditions.

There was a silica layer at the bottom of one of the palaeosinkholes at Tarnów Opolski. Microscopic analysis of the studied sediment also revealed local silification. Diatoms have not yet been found in the Górażdże and Tarnów Opolski deposits collected for study. Microscopic analysis of the sediments from both sinkholes revealed the complete absence of diatom opal frustules. Diatoms, which are an ubiquitous component of Cenozoic freshwater algae assemblages, very likely existed in the sinkholes, but their frustules dissolved under high pH following their deposition in the sediments. Dissolved diatom-derived silica may have been re-precipitated as the chalcedony cements and aggregates commonly found in the lignite deposits. This process indicates fluctuating pH conditions within the sinkhole environment, from more or less acidic in the pond to alkaline ones (Worobiec 2011, Szulc & Worobiec 2012). This would be in accord with the observations of algal assemblages from both palaeosinkoles studied. The abundance of *Botryococcus*, the presence of zygospores of desmids, as well as the virtual absence of dinocysts presumably indicates a depositional environment of more or less acidic water conditions (Herrmann 2010). Such conditions in the ponds were not conducive to bone preservation. It is very probable that during the latter phase of sedimentation in the palaeosinkholes the alkaline groundwater changed its pH and dissolved the delicate diatom frustules. Later the pH again became acidic or neutral, leading to re-precipitation of silica as microconcretions (Szulc & Worobiec 2012).

CONCLUSIONS

The paper presented two Neogene assemblages of freshwater organic-walled algal microremains. The assemblages studied are remains of the freshwater algal communities occurring in two ponds, one developed in the Middle and one in the Late Miocene. Samples for palynological analysis were collected from sediments filling two palaeosinkholes excavated in the Tarnów Opolski and Górażdże quarries. Sixteen samples were taken from the palaeosinkhole at Tarnów Opolski, and six from the palaeosinkhole at Górażdże were selected.

During the studies forty species of algal microfossils were identified, including 32 species from 16 genera in the Tarnów Opolski samples and 34 species from 17 genera in the Górażdże samples. Three new fossil species related to zygospores of the Zygnemataceae – *Ovoidites vangeelii* sp. nov., *Tetrapidites grandis* sp. nov., and *Tetrapidites opolensis* sp. nov. – are proposed.

The algal assemblages resemble each other in many respects. Both assemblages are dominated by *Sigmopollis*, *Botryococcus*, and various zygospores of Zygnemataceae. Both palaeosinkholes contain some zygospores of desmids, Prasinophyceae, and sparse freshwater dinocysts. This reflects similarities in ecology between the water bodies developed in these two palaeosinkholes. The presence of resting cells of Zygnemataceae and desmids suggests that both of these water bodies periodically dried out and were subject to seasonal warming. The main difference between the Górażdże and Tarnów Opolski fossil algal assemblages is the presence of relatively abundant and diverse planktonic algae, such as *Pediastrum* and *Tetraedron*, in samples from the Górażdże sinkhole. This suggests small differences in the water bodies' habitats (e.g. water depth).

Similar fossil organic-walled algal assemblages are reported from Cenozoic freshwater deposits. Lists of synonyms show that similar microfossils occur in sediments of various age (mainly Cenozoic, some also Mesozoic) in many localities, suggesting that these groups of algae were widespread also in the past.

Freshwater organic-walled algal microremains potentially are valuable palaeoenvironmental indicators (Graham 1971, van Geel 2001, Worobiec & Worobiec 2008, Medeanic & Silva 2010) but they require more study. This kind of work can benefit hugely from cooperation between palynologists and scientists working with extant algae.

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PLATES

Plate 1

1. *Cycloovoidites cyclus* (Krutzsch) Krutzsch & Pacltová; Tarnów Opolski, depth 170 cm
2. *Ovoidites* sp. 1; Tarnów Opolski, depth 170 cm
3. *Ovoidites grandis* (Pocock) Zippi; Tarnów Opolski, depth 520 cm

4a, b. *Ovoidites vangeelii* E.Worobiec sp. nov.; holotype (same specimen, various foci); Górażdże, sample 4c

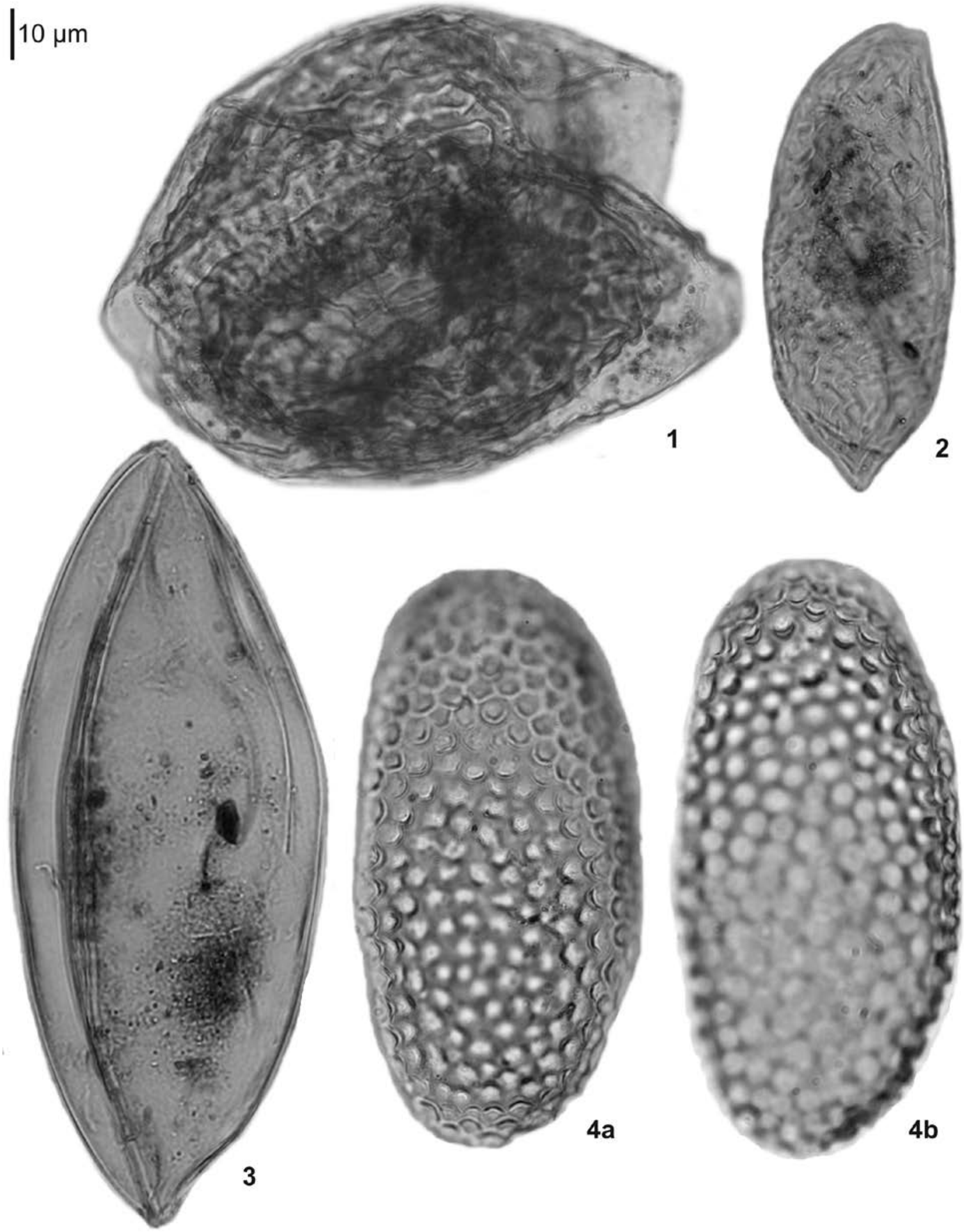

10 µm
1
2
3
4a
4b

Plate 2

1. *Ovoidites minoris* Krutzsch & Pacltová; Tarnów Opolski, depth 625 cm
2. *Ovoidites elongatus* (Hunger) Krutzsch; Tarnów Opolski, depth 240 cm
3. *Ovoidites ligneolus* (Potonié) Tomson & Pflug; Górażdże, sample 3b
4. *Ovoidites ligneolus* (Potonié) Tomson & Pflug; Tarnów Opolski, depth 485 cm
5. *Ovoidites ligneolus* (Potonié) Tomson & Pflug; Górażdże, sample 4c

6a, b. *Ovoidites gracilis* Krutzsch & Pacltová (same specimen, 6b – phase contrast); Tarnów Opolski, depth 135 cm


10 µm
1
2
3
4
5
6a
6b

Plate 3

1. *Ovoidites spriggii* (Cookson & Dettmann) Zippi; Górażdże, Tarnów Opolski, depth 520 cm
2. *Stigmozygodites mediostigmosus* Krutzsch & Pacltová; Górażdże, sample 2b
3. *Stigmozygodites mediostigmosus* Krutzsch & Pacltová; Tarnów Opolski, depth 415 cm
4. *Stigmozygodites ministigmosus* Krutzsch & Pacltová; Tarnów Opolski, depth 520 cm
5. *Stigmozygodites megastigmosus* Krutzsch & Pacltová; Tarnów Opolski, depth 520 cm
6. *Stigmozygodites multistigmosus* (Potonié) Krutzsch & Pacltová; Tarnów Opolski, depth 520 cm
7. *Tetrapidites grandis* E.Worobiec sp. nov.; holotype; Tarnów Opolski, depth 450 cm
8. *Tetrapidites laevigatus* Krutzsch & Vanhoorne; Tarnów Opolski, depth 380 cm

9a, b. *Tetrapidites opolensis* E.Worobiec sp. nov.; holotype (same specimen, various foci); Górażdże, sample 4c

10. *Diagonalites diagonalis* Krutzsch & Pacltová; Tarnów Opolski, depth 520 cm
11. cf. *Megatetrapidites megatetroides* Krutzsch & Pacltová; Górażdże, sample 3c
12. cf. *Megatetrapidites megatetroides* Krutzsch & Pacltová; Górażdże, sample 4c
13. *Megatetrapidites megatetroides* Krutzsch & Pacltová; Tarnów Opolski, depth 555 cm

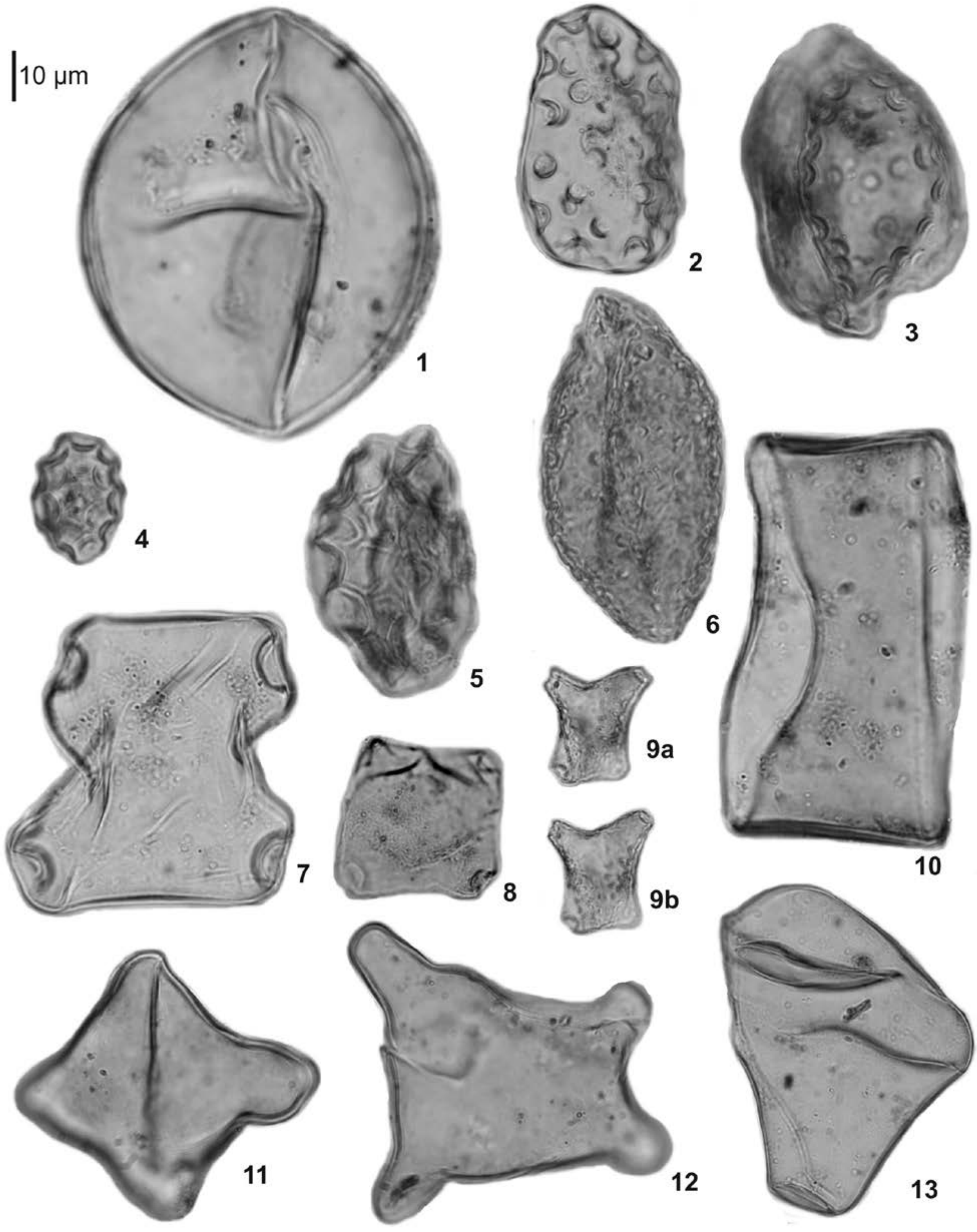

10 μm
1
2
3
4
5
6
7
8
9a
9b
10
11
12
13

Plate 4

1a, b. *Spintetrapidites longicornutus* Krutzsch & Pacltová (same specimen, various foci); Tarnów Opolski, depth 380 cm

2. *Spintetrapidites quadriformis* Krutzsch & Pacltová; Górażdże, sample 2a

3. *Closteritetrapidites magnus* Krutzsch & Pacltová; Tarnów Opolski, depth 520 cm

4. *Closteritetrapidites magnus* Krutzsch & Pacltová; Górażdże, sample 3b

5. *Closteritetrapidites reductus* Krutzsch & Pacltová; Tarnów Opolski, depth 520 cm

6a, b. *Planctonites stellarius* (Potonié) Krutzsch (same specimen, various foci); Tarnów Opolski, depth 520 cm

7a, b. *Monopunctites crassipunctatus* Krutzsch (same specimen, 7b – phase contrast); Tarnów Opolski, depth 485 cm

8. *Lecaniella* forma 4 Head; Tarnów Opolski, depth 520 cm

9. *Zygodites medius* (Rshanikova) Krutzsch & Pacltová; Tarnów Opolski, depth 240 cm

10a, b. *Sigmopollis punctatus* Krutzsch & Pacltová (same specimen, various foci); Górażdże, sample 4c

11. *Sigmopollis laevigatoides* Krutzsch & Pacltová; Tarnów Opolski, depth 625 cm

12a, b. *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová (same specimen, various foci); Górażdże, sample 4c

13a, b. *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová (same specimen, various foci); Tarnów Opolski, depth 485 cm

14. *Sigmopollis pseudosetarius* (Weyland & Pflug) Krutzsch & Pacltová; Górażdże, sample 2b

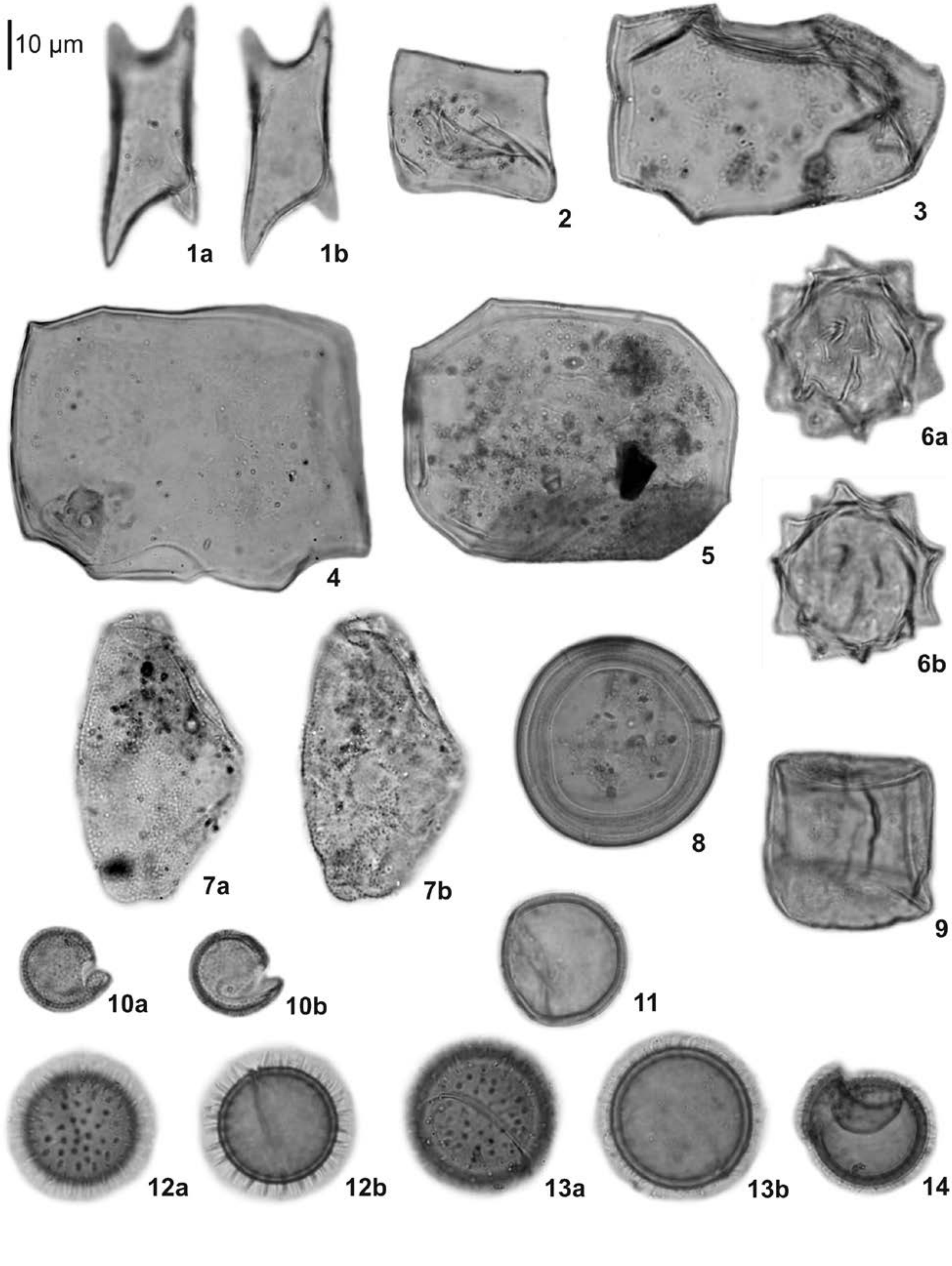

10 µm
1a
1b
2
3
4
5
6a
6b
7a
7b
8
9
10a
10b
11
12a
12b
13a
13b
14

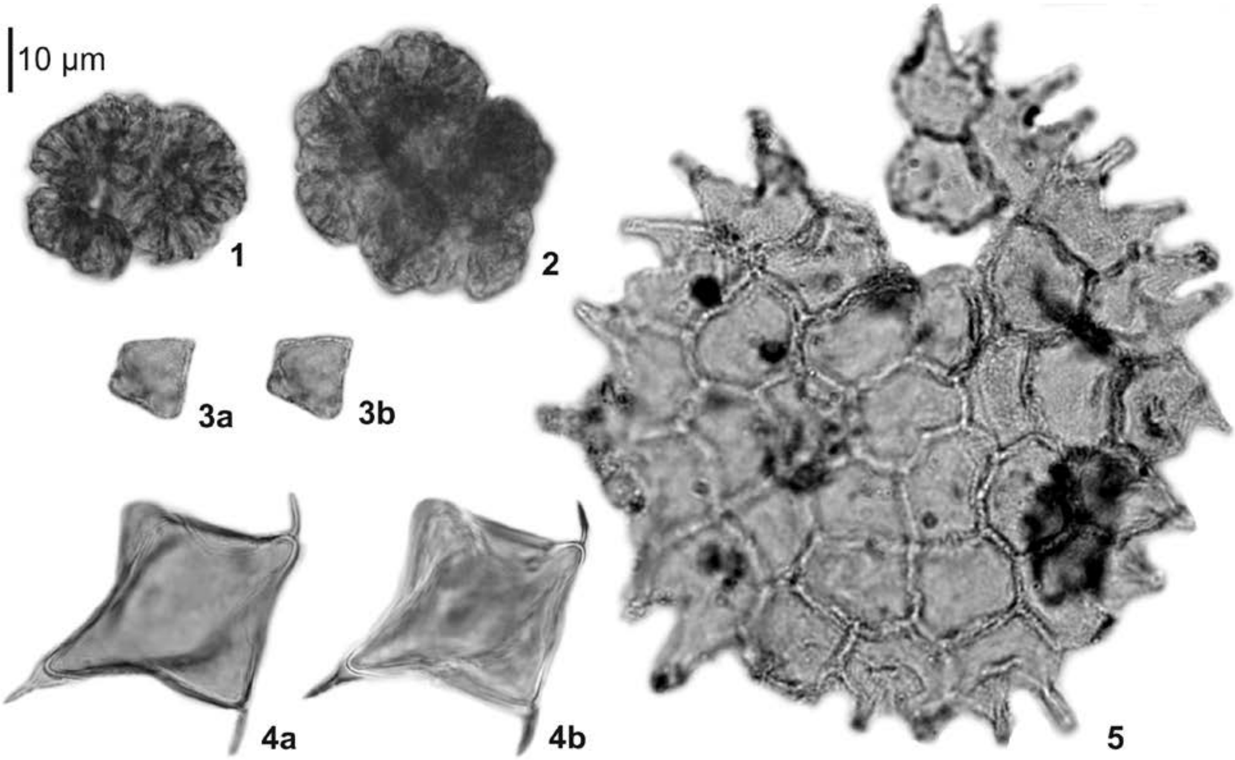
Plate 5

1. *Botryococcus braunii* Kützing; Górażdże, sample 3a
2. *Botryococcus braunii* Kützing; Górażdże, sample 3b

3a, b. *Tetraedron minimum* (A.Braun) Hansgirg (same specimen, various foci); Górażdże, sample 2a

4a, b. *Tetraedron* sp. (same specimen, 4b – phase contrast); Górażdże, sample 3a

5. *Pediastrum boryanum* (Turp.) Menegh. var. *boryanum*; Tarnów Opolski, depth 380 cm


10 µm
1
2
3a
3b
4a
4b
5