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ALGAE AND CYANOBACTERIA IN CAVES OF THE POLISH JURA

JOANNA CZERWIK-MARCINKOWSKA & TERESA MROZIŃSKA

Abstract. The mass occurrence of aerophytic cyanobacteria and algae in 25 caves of the Polish Jura (S. Poland) was studied in 2006–2009, focusing mostly on epilithic taxa and their subaeric habitats (rock faces within caves, walls at cave entrances and lampflora assemblages). We identified 82 species, mostly aerophytic and tolerant of low light intensity. The largest group was formed by cyanobacteria (33 species) and the division Chlorophyta (30 species). Dinophyta (2 species) formed the smallest group. Among the collected algae, the following are rare and specific to these caves: *Bracteacoccus minor* (Chodat) Petrová, *Eustigmatos magnus* (Petersen) Hibberd, *Grunowia tabellaria* (Grunow) Rabenhorst, *Luticola mutica* (Kützing) D. G. Mann, *Muriella decolor* Vischer, *Nodularia harveyana* (Thuret) Bornet & Flahault, *Thelesphaera alpina* Pascher, *Trachychloron simplex* Pascher, *Tetracystis intermedia* (Deason & Bold) Brown & Bold, and *Tetracystis* cf. *isobilateralis* Brown & Bold (first record for Europe). Examination of cell ultrastructure provided an array of further features increasing the precision of species identification. Using morphological and ultrastructural analyses we were able to recognize that epilithic cyanobacteria and algae are almost the only component of the cave microflora. The morphological and ecological variability of the cyanobacteria and algae are illustrated with TEM, SEM and LM micrographs.

Key words: algae, cyanobacteria, cave, taxonomy, ecology, distribution, Wyżyna Krakowsko-Wieluńska upland, Poland

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INTRODUCTION

The biodiversity of cave habitats at the intra- and interpopulation, interspecies and ecosystem level is an essential focus for current environmental protection strategies. The scientific, practical and aesthetic values of caves provide criteria for assessing them as well as motivation for efforts to protect them (Urban 2006). The diversity and peculiarities of cave habitats exposes them to a host of hazards (e.g., water and air pollution, microclimatic changes, dripstone damage), particularly since caves generally are characterized by extreme conditions and low nutrient availability (Pedersen 2000; Mulec *et al.* 2008). Nevertheless, some organisms prefer those conditions for colonization and growth. Sparse vascular plants and prevailing aerophytic (Dobat 1970; Mulec 2005; Mulec *et al.* 2008) and aquatic (Kuehn *et al.* 1992; Sanchez *et al.* 2002) algae are the most common flora of caves. Aerophytic algae, principally cyanobacteria, often occur on limestone walls and rocks in caves, particularly in the entrance zone where growth conditions are best for them (Mulec 2005; Mulec *et al.* 2008). Apart from vascular plants, cyanobacteria and algae frequently play a key role in the trophic networks and colonization processes of rocky habitats, producing colorful patches on cave walls (Golubić 1967; Mulec 2008). These processes are usually facilitated by the stability of environmental conditions in caves. Average annual temperature in caves is usually correlated with bedrock temperature, and its annual fluctuations are small (ambient temperature in caves ranges from 5 to 8°C). Humidity in caves is also in narrow range (85–95%); light, both natural and electric, is a decisive factor for development of algae and cyanobacteria (Golubić 1967; Martinčič *et al.* 1981; Chang & Chang-Schneider 1991). These cave conditions attract cosmopolitan species, leading to the gradual elimination of particularly sensitive native species (Mulec *et al.* 2008). Poland, with its wide plains and large areas overlain by postglacial deposits, does not have an abundance of caves. More

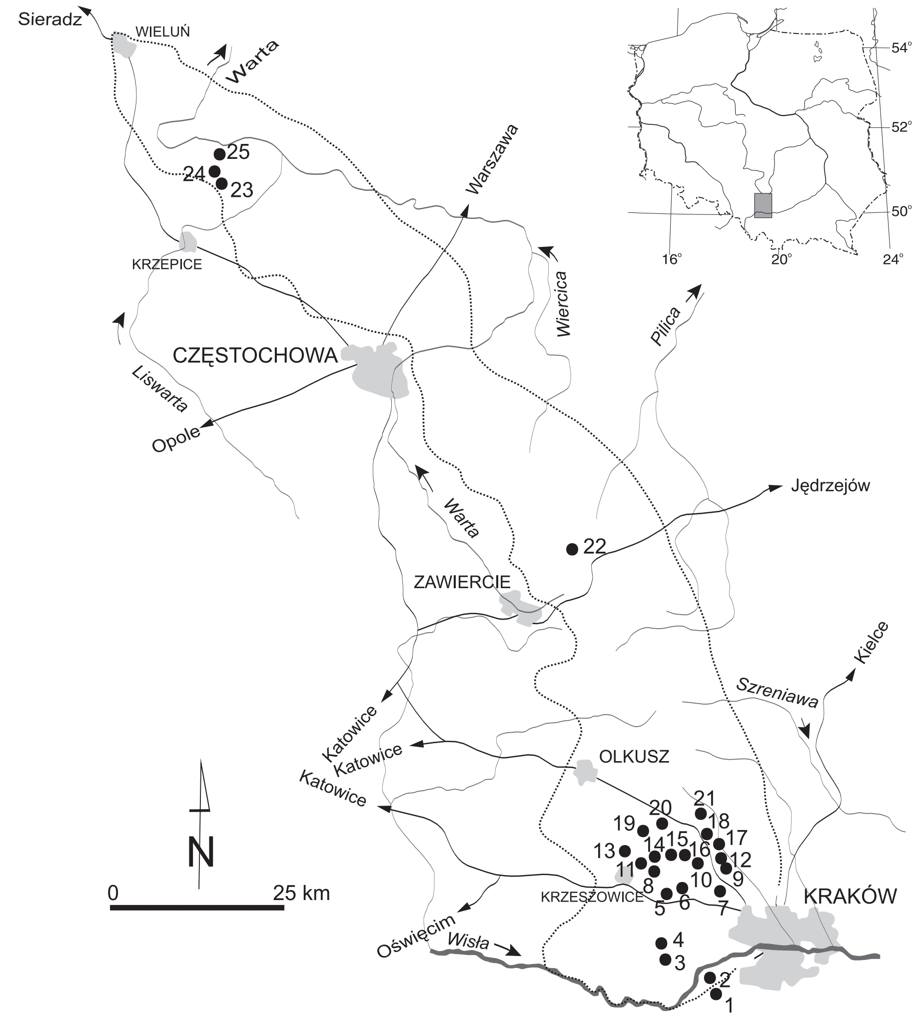

Fig. 1. Location of studied area. 1 – Jaskinia Twardowskiego cave, 2 – Jaskinia Jasna cave, 3 – Jaskinia nad Matką Boską cave, 4 – Jaskinia na Łopiankach cave, 5 – Jaskinia Koziarnia cave, 6 – Jaskinia Łokietka cave, 7 – Jaskinia Sypialnia cave, 8 – Jaskinia Łabajowa cave, 9 – Jaskinia Sąspowska cave, 10 – Jaskinia Dzika cave, 11 – Jaskinia na Tomaszówkach Dolnych cave, 12 – Jaskinia Zbójecka cave, 13 – Jaskinia Żarska cave, 14 – Jaskinia Nietoperzowa cave, 15 – Jaskinia Ciemna cave, 16 – Jaskinia Mamutowa cave, 17 – Jaskinia Krakowska cave, 18 – Jaskinia Biała cave, 19 – Jaskinia Złodziejska cave, 20 – Jaskinia Okopy Wielka Dolna cave,21 – Jaskinia Ostrężnicka cave, 22 – Jaskinia Głęboka cave, 23 – Jaskinia Szachownica I cave, 24 – Jaskinia Szachownica II cave, 25 – Jaskinia za Kratą cave.

than 4200 caves have been found in Poland, the majority of them small (Gradziński & Kicińska 2009). The majority are karstic in origin, and many are in the West Tatra Mts (more than 805, including the largest and deepest one). They also occur in the Góry Świetokrzyskie Mts (*ca* 130), the Polish lowlands and the Niecka Nidziańska basin (*ca* 115, formed in gypsum). The caves in the Pieniny Mts (*ca* 90) and the Flysch Carpathians (more than 1000) originated due to tectonic movement. Over 1850 caves have been discovered in the Wyżyna Krakowsko-Wieluńska upland (Szelerewicz & Górny 1986; Gradziński & Szelerewicz 2004). A few caves in the Polish lowlands (near Gdańsk) are pseudo-karstic in origin. The first reports of algae (order Dinococcales) encountered in

Table 1. Characteristics of the studied caves. Data after Szelerewicz and Górny (1986), Bisek *et al.* (1992), Gradziński *et al.* (1995a, b, 1996, 1998, 2007), and Górny and Szelerewicz (2008).

No.	Name of cave	Length	Altitude a.s.l.	Exposition
1	Jaskinia Twardowskiego	430 m	220 m	SW
2	Jaskinia Jasna in Strzegowa	81 m	430 m	NW, SW
3	Jaskinia nad Matką Boską	54 m	280 m	N, NE
4	Jaskinia na Łopiankach	70 m	260 m	W
5	Jaskinia Koziarnia	90 m	385 m	W
6	Jaskinia Łokietka	320 m	452 m	NW
7	Jaskinia Sypialnia	44 m	342 m	S
8	Jaskinia Łabajowa	40 m	410 m	NW
9	Jaskinia Sąspowska	100 m	370 m	E
10	Jaskinia Dzika	61 m	390 m	SW, NW
11	Jaskinia na Tomaszówkach Dolnych	100 m	435 m	NE, SW
12	Jaskinia Zbójecka	189 m	370 m	NW, W, vertical
13	Jaskinia Żarska	74 m	410 m	SW
14	Jaskinia Nietoperzowa	326 m	447 m	W
15	Jaskinia Ciemna	209 m	372 m	NW, S
16	Jaskinia Mamutowa	100 m	380 m	SW, N
17	Jaskinia Krakowska	96 m	410 m	NW
18	Jaskinia Biała	84 m	400 m	NW
19	Jaskinia Złodziejska	45 m	380 m	E, N
20	Jaskinia Okopy Wielka Dolna	138 m	380 m	W, vertical
21	Jaskinia Ostrężnicka	98 m	350 m	NE, NW, SE
22	Jaskinia Głęboka	160 m	380 m	NW, SW, N, E
23	Jaskinia Szachownica I	690 m	215 m	E, S, vertical
24	Jaskinia Szachownica II	200 m	215 m	E
25	Jaskinia za Kratą	70 m	215 m	NE

Jaskinia Twardowskiego cave were published by Karol Starmach in 1963. In 2004 we described 70 algal and cyanobacterial species developing in 10 caves scattered through the Wyżyna Krakowsko-Częstochowska upland (Mrozińska-Broda & Czerwik-Marcinkowska 2004; Czerwik-Marcinkowska & Mrozińska 2008, 2009, 2010a, b). Our studies of phycoflora in 2008 continued the earlier work, including the area of Ojców National Park. Polish studies of algae and cyanobacteria inhabiting caves are not as complete as, for example, the work done on algal flora from the Czech Republic (Poulíčková & Hašler 2007), Denmark (Pedersen 2000), Hungary (Kol 1964; Palik 1964a, b; Hajdu 1966; Komáromy 1977), Spain (Gracia-Alonso 1974; Aboal *et al.* 1994; Hernández-Mariné & Canals 1994; Asencio & Aboal 1996, 2000a, b; Asencio *et al.* 1996; Hernández-Mariné *et al.* 1999; Cañaveras *et al.* 2001; Martinez & Asencio 2010), the United Kingdom (Pentecost & Zhang 2001) or the U.S.A. (Jones 1964). Further exploration of cave algal and cyanobacterial communities is by all means warranted. We studied algae and cyanobacteria in caves that were left in their natural state and also in caves adapted for tourism. The latter are artificially illuminated, eliminating the natural complete darkness characteristic of caves. The human-caused changes in temperature and humidity in the latter type of cave should be examined, and we have done so here.

Study area

The Wyżyna Krakowsko-Wieluńska upland is an eastern component of the Wyżyna Śląsko-Krakowska upland. It is 80 km long and stretches from Kraków to Wieluń, where a range of hills rises 300–515 m a.s.l. (Fig. 1). This area is built mostly of Jurassic marine limestone exceeding 300 m in depth. Karst-forming processes in Jurassic limestone accelerated several times (Kondracki 1981). Over 1850 caves have been discovered in this area (Szelerewicz & Górny 1986; Gradziński & Szelerewicz 2004). Ojców National Park (ONP) includes the southern, geomorphologically very diverse part of the Wyżyna Krakowsko-Wieluńska upland. Underground water, dissolving limestone, has created the caves that form one of the most characteristic components of the natural environment of ONP and its surroundings (Table 1). So far, 650 caves have been inventoried in the park (data from ONP management). All of the park's caves developed in a variety of Jurassic limestone. Precipitation water penetrates the caves through cracks and fissures, gradually widening them by dissolving the rock (Starzecki 1959; Michalik & Partyka 1992). Among the most attractive caves, with corridors longer than 50 m, Jaskinia Łokietka, Jaskinia Ciemna, Jaskinia Zbójecka, Jaskinia Okopy, Jaskinia Wielka Dolna, Jaskinia Sąspowska, Jaskinia Krakowska, Jaskinia Biała and Jaskinia Koziarnia caves. The largest cluster of large caverns is in Wąwóz Jamki gorge. Some cave entrances are visible but most are difficult to distinguish among the rocks.

Description of the studied caves

Jaskinia Twardowskiego cave Fig. 2: 1

This is quite a large karstic cave located within the city of Kraków in the northwestern part of the Dębnickie Krzemionki horst called Skałki Twardowskiego rocks close to the Vistula River (Szelerewicz & Górny 1986). Behind the 2 m high entrance is a chamber with the floor declining as one enters further. The walls are partly covered with dripstone formations. The floor of the corridors is part clay and part sand. The first mention of the cave dates to 1865.

Jaskinia Jasna cave in Strzegowa Fig. 2: 2

This cave is in rocks south of Strzegowa village (Szelerewicz & Górny 1986). The cave is a large chamber. The floor is covered with clay. Dripstone formations are sparse.

Jaskinia nad Matką Boską cave Fig. 2: 3

This cave, with many entrances, is on the right slope of the Dolina Mnikowska valley, in the gap of the Dolina Sanki valley (Szelerewicz & Górny 1986). Most of the entrances are large and most of the cave interior is within reach of diffuse daylight. The cave is dry. Dripstone is sparse and weathered. The cave has been known for a long time.

Jaskinia na Łopiankach cave Fig. 2: 4

This cave is in the lower part of the Wąwóz Półrzeczki gorge, a branch of the Dolina Sanki valley (Szelerewicz & Górny 1986). The large entrance is partly blocked by a huge rock. The floor near the entrance is covered with humus, and the floor of the interior with clay. Dripstone is sparse. Humidity is high.

Jaskinia Koziarnia cave Fig. 2: 5

This cave is in Wąwóz Koziarnia gorge, a side branch of the Dolina Sąspowska valley within Ojców National Park (Bisek *et al.* 1992). The cave has a wide entrance and a roomy corridor. The floor is clayey with limestone rubble. Dripstone cover includes flowstone formations and stalactites. The cave interior is wet and dark. Since 1990 the cave has been sealed with a bat gate.

Jaskinia Łokietka cave Fig. 2: 6

This cave is in the Dolina Sąspowska valley on the northwestern slope of Góra Chełmowa Mt. within Ojców National Park (Gradziński *et al.* 1996). It was earlier known as Jaskinia Królewska cave. Dripstone formations include flowstone, stalagmites and small stalactites. The

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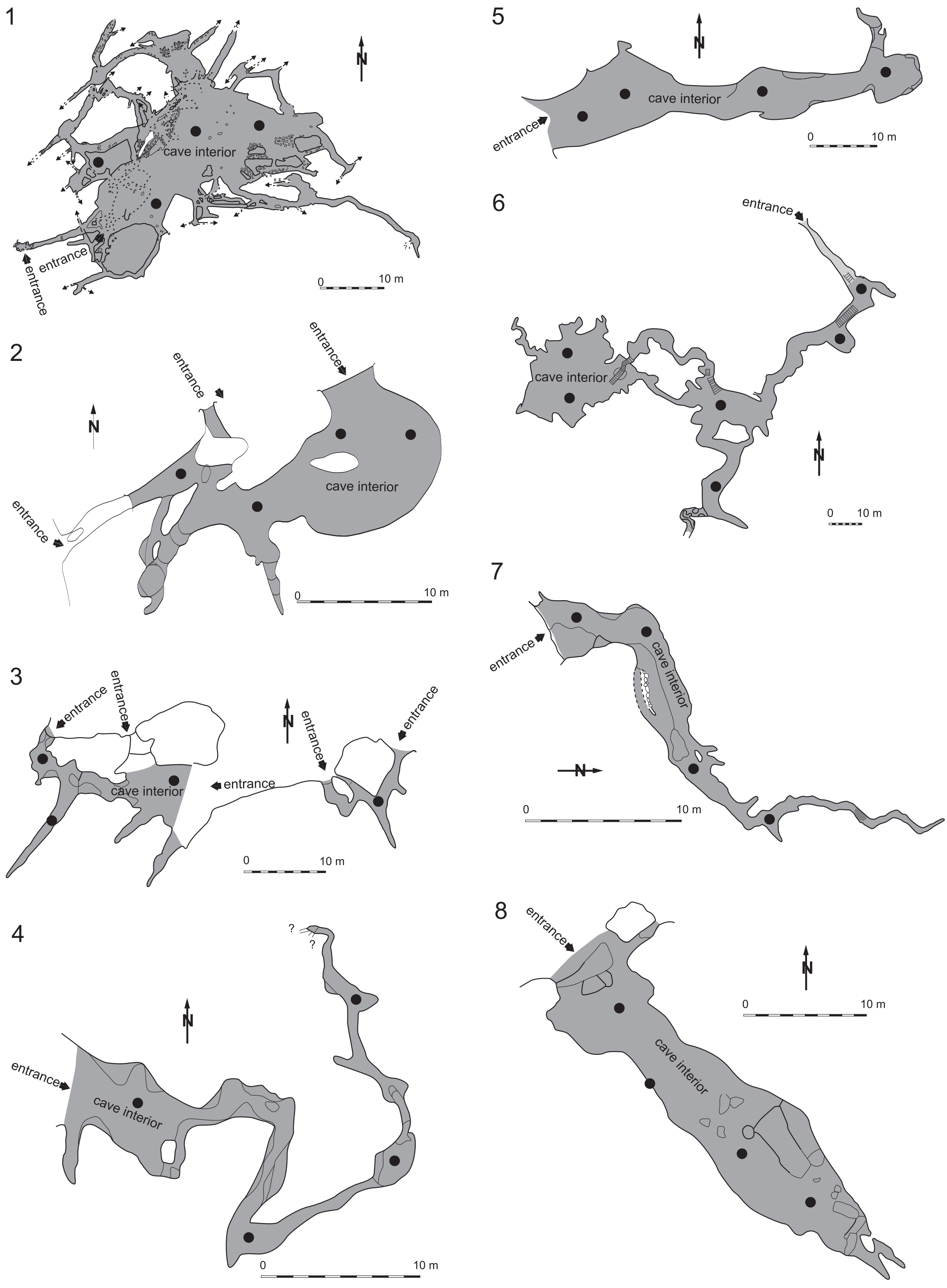
Fig. 2. Investigated caves. 1 – Jaskinia Twardowskiego cave, 2 – Jaskinia Jasna cave, 3 – Jaskinia nad Matką Boską cave, 4 – Jaskinia na Łopiankach cave, 5 – Jaskinia Koziarnia cave, 6 – Jaskinia Łokietka cave, 7 – Jaskinia Sypialnia cave, 8 – Jaskinia Łabajowa cave. ● – sampling sites.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dripstone cover is mostly damaged. Average temperature has been estimated at 6.6°C, and humidity at 96%. The cave's interior is generally dark. It is electrically illuminated only when open to tourists.

Jaskinia Sypialnia cave Fig. 2: 7

This cave is in Wąwóz Stodoliska gorge in Ojców National Park (Gradziński *et al.* 1998). The dripstone cover is quite sparse and comprises flowstone from milk of lime and mushroom-like dripstone formations. Further from the entrance the floor is covered with clayey limestone rubble. The cave is dark and wet. Water periodically is dripping down from the ceiling.

Jaskinia Łabajowa cave Fig. 2: 8

This cave is in Łabajowa Skała rock in the Dolina Będkowska valley (Szelerewicz & Górny 1986). The cave's wide entrance is partly occluded by a boulder. A vertical hole is in the cave ceiling.

Jaskinia Sąspowska cave Figs 2: 9 & 3

This cave is in the Dolina Sąspowska valley in Ojców National Park (Gradziński *et al.* 1995b). Behind the large entrance is a narrow passage leading to spacious deeper parts with abundant dripstone formations. At the entrance the floor cover is humic with leaves, and deeper inside it is clayey. The cave interior is dark and wet.

Jaskinia Dzika cave Fig. 2: 10

This cave is in the Dolina Kluczwody valley above Jaskinia Mamutowa cave, near Wierzchów village (Szelerewicz & Górny 1986). Both entrances are relatively wide. The walls are covered with diverse but damaged dripstone formations: abundant flowstone and stalactites. The floor is covered with clay. It is the most humid of all the caves.

Skała na Tomaszówkach Dolnych cave Fig. 2: 11

This cave is in the upper part of the Dolina Będkowska valley (Szelerewicz & Górny 1986). The cave has three entrances, two of which are wide. The floor contains clayey limestone rubble. Dripstone in the rear of the cave is relatively rich and diverse.

Jaskinia Zbójecka cave Fig. 2: 12

This cave is in Wąwóz Jamki gorge, a side branch of the Dolina Sąspowska valley in Ojców National Park (Gradziński *et al.* 1995a; Chardez & Delhez 1981). The cave is a long corridor with several bends. The dripstone cover is mostly flowstone and mushroom-like dripstone formations. The floor is clayey with limestone rubble, and the cave is humid and dark.

Jaskinia Żarska cave Fig. 2: 13

This cave is in the Las Pisarski forest between the southern edges of Żary and Szklary villages in Wąwóz Żary gorge joining the Dolina Racławki valley (Szelerewicz & Górny 1986). The cave is a spacious but low chamber behind a wide opening. Dripstone cover is quite sparse, composed of small stalactites and strands. The floor is clayey with a blanket of leaves near the entrance.

Jaskinia Nietoperzowa cave Fig. 2: 14

This cave, earlier called Jaskinia Jerzmanicka cave or Jaskinia Księża cave, is in the Dolina Będkowska valley (Szelerewicz & Górny 1986). The cave has a very spacious entrance opening to a roomy corridor with two larger chambers. The cave is abundant in dripstone cover, including a dripstone fall, flowstone and small stalactites. The floor comprises clayey limestone rubble with bat guano beneath walls where bat colonies lived in the past. The cave is open to tourists and furnished with electric lighting.

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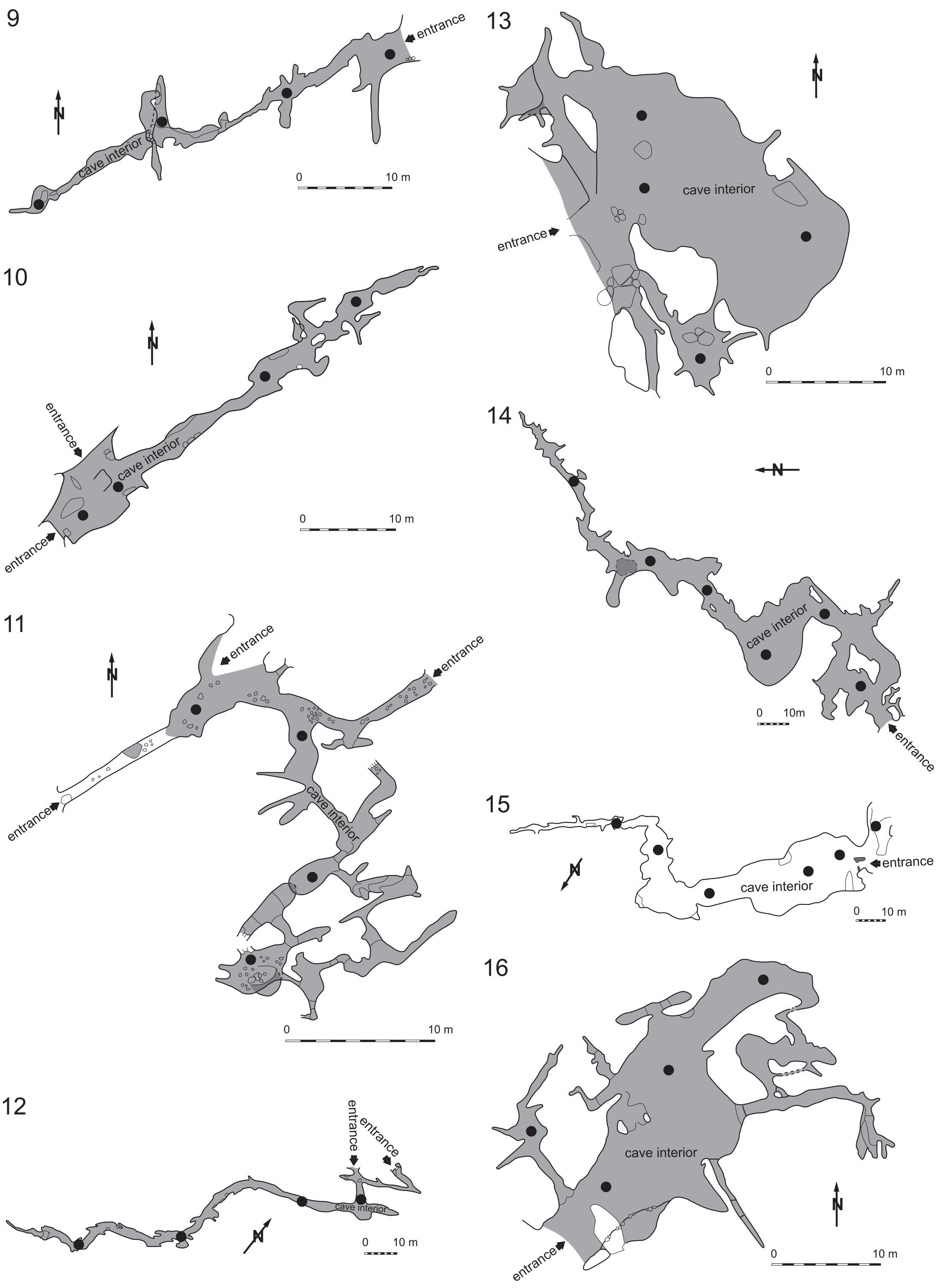
Fig. 2. *Continued.* 9 – Jaskinia Sąspowska cave, 10 – Jaskinia Dzika cave, 11 – Jaskinia na Tomaszówkach Dolnych cave, 12 – Jaskinia Zbójecka cave, 13 – Jaskinia Żarska cave, 14 – Jaskinia Nietoperzowa cave, 15 – Jaskinia Ciemna cave, 16 – Jaskinia Mamutowa cave. ● – sampling sites.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Jaskinia Ciemna cave Fig. 2: 15

This cave is in the Dolina Prądnika valley in Ojców National Park (Gradziński *et al.* 2007). The entrance is *ca* 62 m above the valley bottom. A short tunnel opens up into the main chamber. The chamber is the largest one among the caves of the Wyżyna Krakowsko-Wieluńska upland. Dripstone cover is diverse. Stalagmites up to 1 m high are concentrated in the middle of the chamber floor, and the ceiling is covered with numerous tube stalactites. This cave is inhabited by bats and a variety of invertebrate species such as moths and spiders. Air temperature ranges from 6 to 9°C. The interior is wet and completely dark.

Jaskinia Mamutowa (Wierzchowska Dolna) cave Fig. 2: 16

This cave is in the Dolina Kluczwody valley in the Berdo rock complex (Szelerewicz & Górny 1986). The main part of the cave is a wide chamber behind the large entrance. The chamber is dry and lit with diffuse daylight.

Jaskinia Krakowska cave Fig. 2: 17

This cave is in Wąwóz Jamki gorge, a side branch of the Dolina Sąspowska valley in Ojców National Park (Gradziński *et al.* 1995a). The entrance is 2 m high and leads to a large passage with slight widenings and short branches. The floor is clayey. The dripstone formations are mainly flowstone. The cave is wet and dark.

Jaskinia Biała cave Fig. 2: 18

This cave is in Wąwóz Jamki gorge, a side branch of the Dolina Sąspowska valley in Ojców National Park (Gradziński *et al.* 1995a). Its low entrance extends into wider corridors. The plant cover is relatively poor, except on dripstone falls developed from hardened pure-white milk of lime, and noodles. The floor is clayey with a large amount of limestone rubble. The cave is dark and wet.

Jaskinia Złodziejska cave Fig. 2: 19

This cave is also in Wąwóz Jamki gorge, a side branch of the Dolina Sąspowska valley in the Ojców National Park (Gradziński *et al.* 1995a). The main entrance is large, extending into a narrowing corridor. The floor initially is covered with humus and leaves, and further inside with limestone rubble. Dripstone formations include milk of lime. The deeper parts are wet and dark.

Jaskinia Okopy Wielka Dolna cave Fig. 2: 20

This cave is in the Dolina Prądnika valley in Ojców National Park (Gradziński *et al.* 2007). The cave has two very wide entrances. The greater part of the cave is lit with diffuse light. Dripstone cover is very sparse. The floor of the chamber contains humus and stones, with clay towards the rear.

Jaskinia Ostrężnicka cave Fig. 2: 21

This cave is in the Dolina Wiercicy valley near Ostrężnik village. The cave consists of small chambers joined by corridors. The floor is sandy-clayey.

Jaskinia Głęboka cave Fig. 2: 22

This cave is in the Góra Zborów Mt. Nature Reserve near Podlesice village (Szelerewicz & Górny 1986). It was discovered in 1942 during limestone quarrying. The ceiling is covered with colorful dripstone formations. The floor is clayey with large boulders. The cave is open to visitors.

Jaskinia Szachownica I and II caves Fig. 2: 23 & 24

This cave is on Krzemienna Góra Mt. in the northern part of the Wyżyna Krakowsko-Wieluńska upland (Szelerewicz & Górny 1986). It is protected as the Szachownica Nature Reserve. It is a system of 5 caves with 12 entrances, probably once connected and then separated as a result of limestone

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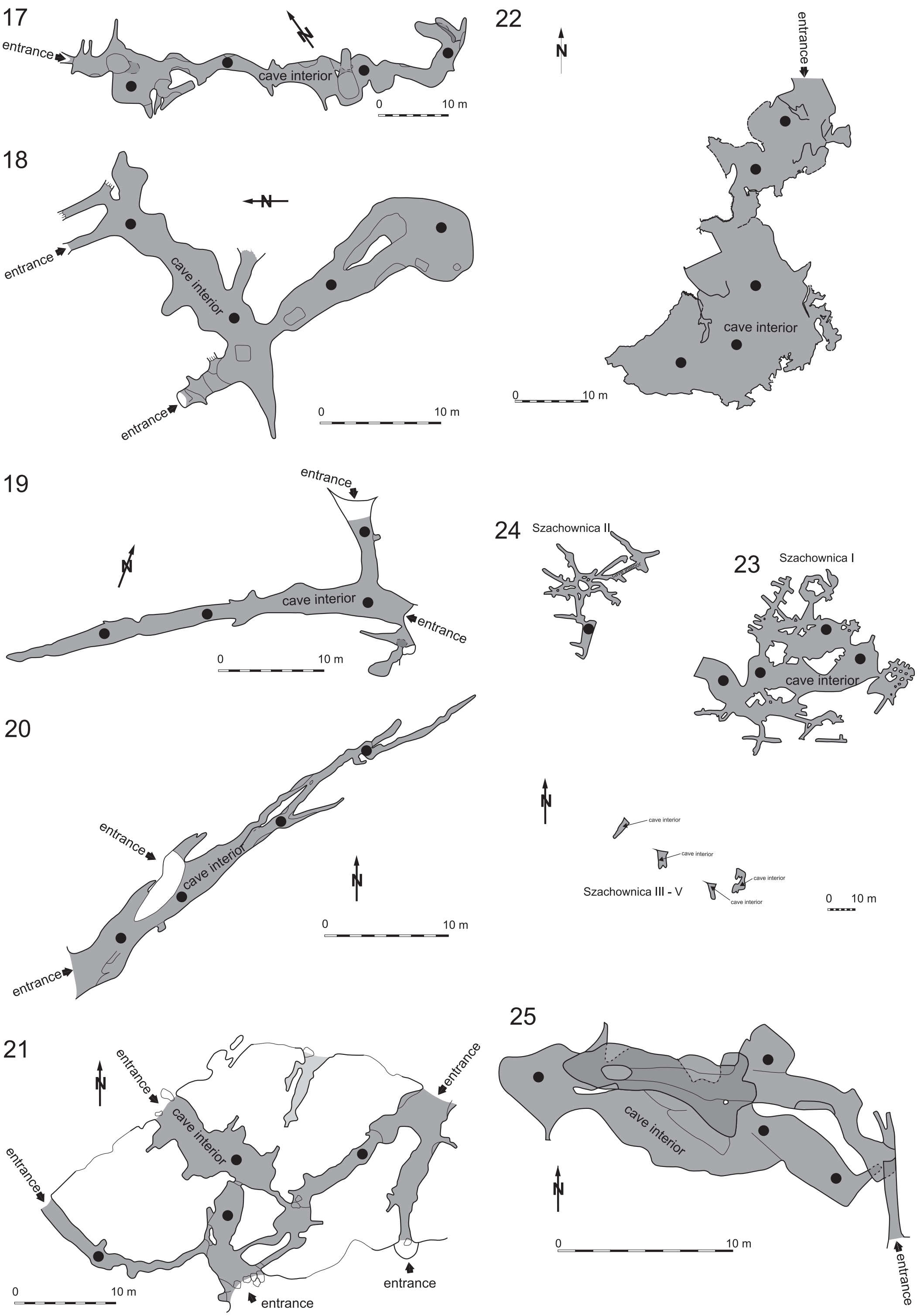
Fig. 2. *Continued.* 17 – Jaskinia Krakowska cave, 18 – Jaskinia Biała cave, 19 – Jaskinia Złodziejska cave, 20 – Jaskinia Okopy Wielka Dolna cave, 21 – Jaskinia Ostrężnicka cave, 22 – Jaskinia Głęboka cave, 23 – Jaskinia Szachownica I cave, 24 – Jaskinia Szachownica II cave, 25 – Jaskinia za Kratą cave. ● – sampling sites.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quarrying. Jaskinia Szachownica cave I is the main cave of the system, in the eastern part of Krzemienna Góra Mt. Jaskinia Szachownica cave II is in the western part of Krzemienna Góra Mt. Its dripstone cover is sparse. The floor is covered mostly with limestone rubble.

Jaskinia za Kratą cave Fig. 2: 25

This cave is in the Węże Geological Nature Reserve on Góra Zelka Mt. south of the Warta River in the vicinity of Bobrowniki village in the northern part of the Wyżyna Krakowsko-Wieluńska upland. Its dripstone formations are interesting and well preserved. The floor is clayey-sandy.

Materials and methods

Samples for algological studies were collected in spring (April, May), summer (June) and autumn (September, October) from 2006 to 2009 from Jaskinia Sąspowska, Jaskinia Złodziejska, Jaskinia Zbójecka, Jaskinia Krakowska, Jaskinia Biała, Jaskinia Ciemna, Koziarnia, Jaskinia Okopy Wielka Dolna, Jaskinia Łokietka and Jaskinia Sypialnia caves in Ojców National Park (Fig. 1, Table 1), and from 2007 to 2009 from Jaskinia Szachownica I and II, Jaskinia za Kratą, Jaskinia Ostrężnicka, Jaskinia Głęboka, Jaskinia Jasna in Strzegów, Jaskinia Żarska, Jaskinia na Tomaszówkach Dolnych, Jaskinia Łabajowa, Jaskinia Mamutowa, Jaskinia na Łopiankach, Jaskinia nad Matką Boską, Jaskinia Twardowskiego, Jaskinia Nietoperzowa and Jaskinia Dzika caves in the Wyżyna Krakowsko-Wieluńska upland. A total of 25 caves were examined. Algae and cyanobacteria growing on the cave walls (Fig. 3) were scraped off with a scalpel or else a piece of rock was collected in order to preserve the natural form of the community. In the caves open to tourists, such as Jaskinia Nietoperzowa, Jaskinia Łokietka and Jaskinia Ciemna caves, samples were also collected from surfaces around artificial light sources, at different distances from the source, and from sites of the most intensive growth. The samples were transferred to a plastic container. Two zones were distinguished in each cave: (*i*) the light zone, comprising the entrance (usually lit by sunlight and well-oxygenated); and (*ii*) the dark zone of further chambers and rooms illuminated only by weak natural daylight or artificial light. Live material was inoculated on solid agar medium enriched, when necessary, with Bristol's medium, and was maintained in appropriate temperature and light conditions. Laboratory work was aimed at achieving the full spectrum of developmental stages. The samples were examined with a light microscope (JENAMED 2) and transmission electron microscope (TESLA BS 500). For transmission electron microscopy (TEM) the cells were fixed as previously described (Massalski *et al.* 1995). Ultrathin sections were prepared as described by Reynolds (1963). For scanning electron microscopy (SEM) the samples were treated with HCl, washed several times with distilled water and boiled in concentrated H_2O_2 with small amounts of $KClO_3$ in order to remove organic matter. SEM micrographs were taken in the Laboratory of Field Emission Microscopy, Scanning Electron Microscopy and Microanalysis (Institute of Geological Sciences of the Jagiellonian University). Taxonomic analysis of algal flora was based on identification of diatoms (Bacillariophyceae), chlorophytes (Chlorophyta), heterokonts (Heterokontophyta), dinophytes (Dinophyta) and cyanobacteria (Cyanophyta) occurring most frequently and most abundantly in the caves under study. The accuracy of identification of different algal and cyanobacterial species was based on morphological features. In general we noted that the methodology of cave lampflora studies is not sufficiently developed. Nomenclature follows mainly Anagnostidis and Komárek (1988), Komárek and Anagnostidis (1986, 1989, 2005), Dodge (1984), Ettl (1978), Ettl and Gärtner (1988, 1995), Brown and Bold (1965), Brown and Lean (1969), Starmach (1966), Krammer and Lange-Bertalot (1986, 1991), John *et al.* (2002), Wehr and Sheath (2003) and Uzunov *et al.* (2008). Notes on ecology and distribution, mainly for diatoms, follow Van Dam *et al.* (1994). The material studied is deposited in the collection of the Department of Botany, Institute of Biology, Jan Kochanowski University, Kielce.

Results

PROKARYOTA
Cyanophyta
Cyanophyceae

Anabaena cf. ***oscillarioides*** Bory de Saint-Vincent 1831

Filaments composed of bent and tangled trichomes. Heterocytes barrel-shaped, located inside the trichome.

Distribution. In the Wyżyna Krakowsko-Wieluńska upland the species was found in Jaskinia Głęboka cave; in Europe, described in caves in Bulgaria (Uzunov *et al.* 2008).

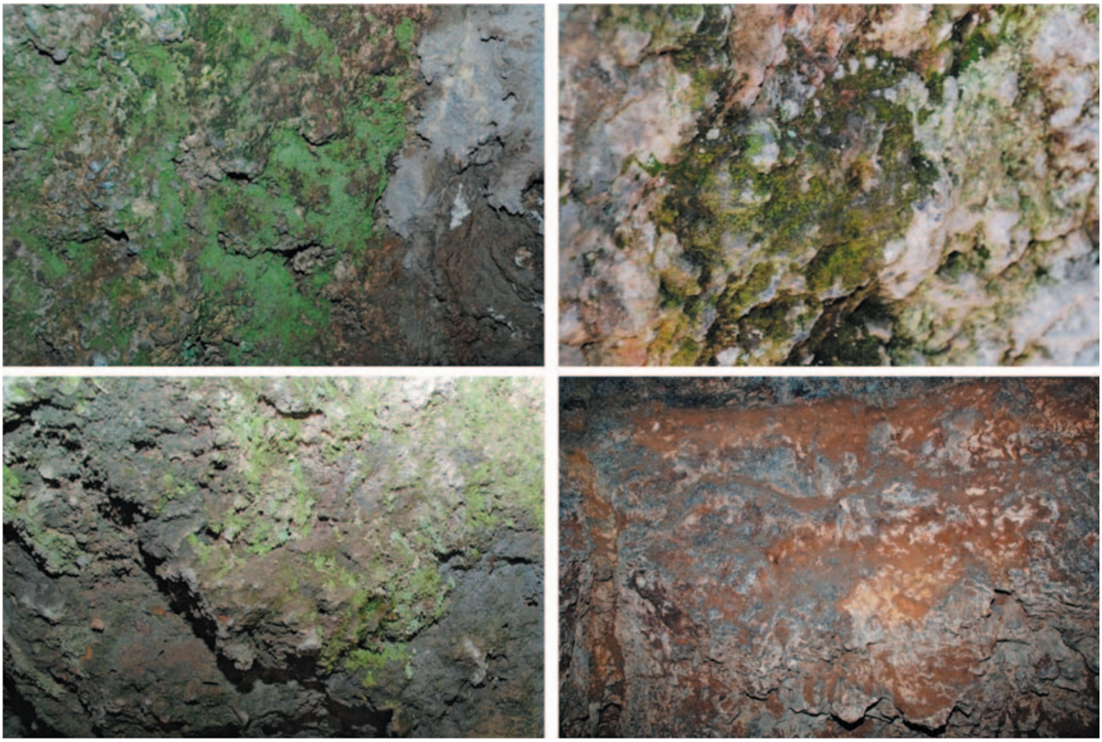

Fig. 3. Epilithic algae and their subaeric habitats (Jaskinia Sąspowska cave).

ECOLOGY. Apart from caves, it has been found as an endophyte on wet soil surface, mosses, wet rocks and walls.

Aphanocapsa parietina Nägeli 1849

Colonies small, forming shapeless, gelatinous thalli. Cells spherical, 4.5–5.5 μm diam., brown-green.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found only in Jaskinia Sąspowska cave; reported also from caves in the Czech Republic (Poulíčková & Hašler 2007), Slovenia (Mulec *et al.* 2007, 2008), Hungary (Pócs 2009) and Spain (Roldán & Hernández-Mariné 2009).

ECOLOGY. Apart from caves, according to Komárek and Anagnostidis (1998) the species occurs usually on limestone rocks and alkaline soils; it is characteristic of the periphyton and benthos of inland biotopes (usually common in lakes); reported also from marine littoral (psammon, periphyton), hot springs, and as a subaerophytic or endolithic species. It is a very characteristic species growing subaerophytically on wet rocks and walls or among mosses in moors and peaty bogs.

Calothrix fusca (Kützing) Bornet & Flahault 1886

Filaments single or in small groups (up to 0.3 μm long), not branched or sporadically seemingly branched. Trichomes straight or bent with end cells 7–8 μm wide, shorter than wide; colorless sheath showing narrow layered structure. Heterocysts basal (9–11 μm diam.), single, sometimes double. Lower vegetative cells mostly heterocysts.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Zbójecka cave; also encountered in Zbrašov cave in the Czech Republic (Poulíčková & Hašler 2007).

ECOLOGY. Apart from caves, a freshwater

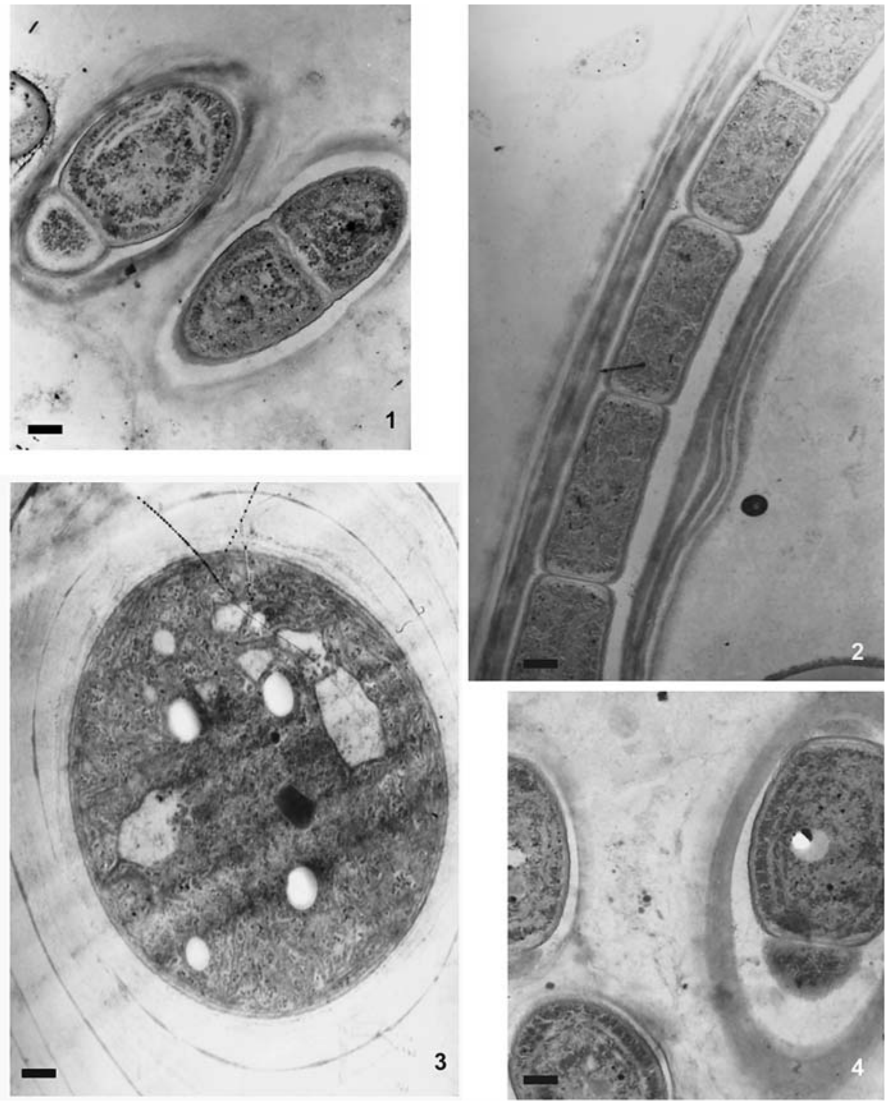

Fig. 4. *Calothrix parietina* (Nägeli) Thuret. 1 – cross section of cells, 2 – longer trichomes with cell wall layers, 3 – cross section showing polyhedral bodies or carboxisomes. All TEM. Scale bars = 0.5 μm.

species found in gelatinous structures of other algae (e.g., *Chaetophora*), also among species forming tufaceous limestone.

Calothrix parietina (Nägeli) Thuret 1875

Fig. 4

Filaments short, up to 1 mm long, sometimes even shorter, some slightly widened towards the base. Sheaths yellowish-brown, sometimes colorless, usually wide at the branching site, comprising 2 trichomes each. Colonies brown, incrusted by carbonates. Trichomes usually lamellate, with outer layered structure diverging. Trichomes indented or not constricted at transverse walls. Cell size at the base of trichome 5–10 × 4–9 μm, in the middle zone 5–10 × 5–10 μm. Heterocysts basal, single, rarer in groups of 2–3, usually semicircular. Hormogonia single or in groups of several.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Nietoperzowa and Jaskinia Mamutowa caves; in Europe, described from Spain (Ballesteros & Romero 1982; Aboal & Llimona 1984; Aboal 1988, 1989, 1996; Alvarez-Cobelas & Gallardo 1988; Aboal *et al.* 1996; Cantoral Uiza & Aboal Sanjurjo 2001).

ECOLOGY. Apart from caves, it was recorded as a cosmopolitan species from rocky and limestone streams by Drouet (1939, 1943), on wet rocks and in pools by Copeland (1936) and by Kann (1978), from wetted limestone by Ercegović (1925) and by Golubić (1967), and on moist soil, stones, wood and rocks by Koster (1960).

Calothrix sp. Fig. 5

Filaments single or in small groups, unbranched or occasionally falsely branching. Trichome straight or bent, ending in a distinct hair; cells near base 7–8 µm wide, shorter than wide; colorless sheath. Heterocyst basal.

Fig. 5. *Calothrix* sp. TEM. Scale bar = 20 µm.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Zbójecka and Jaskinia Mamutowa caves.

Chroococcus cf. ***ercegovicii*** Komárek & Anagnostidis 1994

Chroococcus schizodermaticus f. *pallida* Ercegovič 1925

Colonies microscopic in size, usually of (1–)2–4(–8) cells, spherical or irregularly spherical. Cells and cell groups embedded in gelatinous, colorless or lightly yellow, distinctly lamellate sheath.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Sąspowska and Jaskinia Łabajowa caves. Described from Škocjanske Jame caves in Slovenia (Mulec *et al.* 2007).

ECOLOGY. Apart from caves, it was identified on limestone of Slovenský Raj (Uher & Kováčik 2002).

Chroococcus tenax (Kirchner) Hieronymus 1892

Chroococcus turgidus var. *tenax* Kirchner 1878; *Gloeocapsa tenax* (Kirchn.) Hollerb. *in* Elenkin 1949

Cells 10–14–20 µm diam., with sheath 20–26 µm diam. Sheaths usually quite thin, with sharp contours, usually distinctly lamellate, colorless, yellowish or brown.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was discovered in Jaskinia Sąspowska cave. Starmach identified this species in the Dolina Białej Wody valley in the Tatras in 1981. Described from Leontari cave in Greece (Lamprinou *et al.* 2009), also from caves in Bulgaria (Uzunov *et al.* 2008), the Czech Republic (Hauer 2007) and Belgium (Garbacki *et al.* 1999).

ECOLOGY. Apart from caves, it occurs on wet rocks and in standing water, sometimes also in plankton. Subaerophytic.

Chlorogloea novacekii Komárek & Montejano 1994

Colonies mucilaginous, micro- and macroscopic in size, small, from more or less spherical to amorphous, yellow, dark grayish green or black, with densely and irregularly packed cells encircled by a slightly dissolving sheath. Mucilage colorless, in older colonies more often yellowish-brown. Cells after division separate from each other and develop individual wide sheaths. Cells spherical, subspherical, 2.0–2.5 µm diam. or distinctly elongate (7 μm long) before division. Gelatinous sheath around a single cell 8.5–12.0 μm diam.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was discovered in Jaskinia Głęboka and Jaskinia Pustelnia caves.

ECOLOGY. Apart from caves, it occurs on wet limestone rocks, usually in the dark. Aerophilic species.

Cyanosarcina sp.

Colonies microscopic, subspherical-irregular, forming an agglomeration of mats. Cells oval when young, later irregular, blue-green, enveloped by thin mucilaginous sheaths.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was identified in Jaskinia Nietoperzowa cave.

Gloeocapsa alpina (Nägeli) F. Brand 1900

Gloeocapsa ambigua Nägeli in Kützing 1849; *Gloeocapsa fuscolutea* Kirchner 1878

Colonies microscopic, spherical or elliptic, composed of a 2–4, sometimes up to 8-celled, irregular blackish mass. Cells of subcolony with blue to dark violet mucilage. Spherical cells 4–8 μm, surrounded by wide colorless sheaths (sometimes delicately granulated, rarely layered). Its cell sheath development and colony shapes are very characteristic.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was identified in Jaskinia Zbójecka, Jaskinia Ciemna and Jaskinia Łokietka caves. Also reported from Javoříčko cave in the Czech Republic (Poulíčková & Hašler 2007) and Spain (Aboal 1988; Alvarez-Cobelas & Gallardo 1988); recently noted in caves in Bulgaria (Uzunov *et al.* 2008).

ECOLOGY. Apart from caves, it occurs in wet soil among mosses, on wet limestone rocks, cliffs and walls. It forms black spots and streaks on limestone, probably also on wooden walls, less frequently on snow. According to Ettl and Gärtner (1995) it occurs in the Alps and montane alpine zone. Subaerophytic.

Gloeocapsa biformis Ercegović 1925

Colonies microscopic, less frequently macroscopic in size, irregular, dark yellow or brown, composed of small subcolonies. Single cell spherical, light blue-yellow, 0.8–3.0 μm diam., embedded in gelatinous, colorless or yellow non-layered sheath. Colonies 32–42 μm thick. There are also cells 1.6–2.4 μm diam. enclosed in a hyaline wall.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Łabajowa, Jaskinia Twardowskiego and Jaskinia Nietoperzowa caves. Also reported from Gelda Cave in Spain (Martinez & Asencio 2010) and Leontari Cave in Greece (Lamprinou *et al.* 2009). Golubić (1967) found it inside a cave in Croatia. Anagnostidis *et al.* (1981) noted it in Perma Cave (Greece), Chang and Chang-Schneider (1991) found it in caves in Germany, Asencio and Aboal (1996) in a cave in Murcia (Spain) and Garbacki *et al.* (1999) in a cave in Belgium.

ECOLOGY. Apart from caves, found on wet limestone rocks; an aerophytic species known from the Alps, Carpathians and eastern Balkans, from Greece and Spain (Golubić 1967; Anagnostidis *et al*. 1983) and also from serpentine in the Czech Republic (Hauer 2008).

Gloeocapsa cf. ***decorticans*** (A. Braun) Richter 1925

Cells spherical or oval, single or 2–4 together. Single cells 8.0 μm diam. without sheath and 19 μm diam. with sheath, sheath thick and distinctly lamellate.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Mamutowa, Jaskinia Łokietka and Jaskinia Ciemna caves. Also reported to occur on limestone (Vilar de Frades church, Barcelos) in Portugal (Macedo *et al.* 2009).

ECOLOGY. Apart from caves, known from wet or dry, periodically moist stony and rocky walls and from rocks sprinkled with water (Komárek & Anagnostidis 1998).

Gloeocapsa rupicola Kützing 1849

Cells spherical, surrounded by a lamellate, 6.0 μm diam., reddish sheath.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Nietoperzowa and Jaskinia Twardowskiego caves. Also reported to occur in Gelada cave in Spain (Martinez & Asencio 2010).

ECOLOGY. Komárek and Anagnostidis (1998) classified it as an aerophytic species on periodically damp rocks and on mountain walls in Central Europe. Also reported as dominant on wet walls in Venezuela (Kaštovský *et al.* 2011).

Gloeocapsopsis cf. ***magma*** (Brébisson) Komárek & Anagnostidis 1986

Gloeocapsa magma (Brébisson) Kützing *emend.* Hollerbach 1924

Cells often polygonal, surrounded by mucilaginous envelopes, 3–6(–15) μm. Enlarged cells with cyanophycin granules, small colonies subspherical, usually 30–55 μm. It does not possess a yellow-brown sheath (in this respect it is similar to, e.g., *Gloeocapsopsis pleurocapsoides*).

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was discovered in Jaskinia Mamutowa and Jaskinia Żarska caves. Known from Ballica cave (Tokat, Turkey) (Selvi & Altuner 2007); also reported from the Cave of Bats in Spain (Roldán & Hernández-Mariné 2009).

ECOLOGY. According to Komárek and Anagnostidis (1998) it grows subaerophytically on wet or periodically moist noncalcareous rocks, walls and wooden substrates. It includes nitrogen-fixing strains (John *et al.* 2002).

Gloeothece sp. Fig. 6

Colonies small, composed of sheathed cells, colorless, violet or yellow-brown with gelatinous envelopes. Cells oval, blue-green or olive-green.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia nad Matką Boską cave.

Fig. 6. *Gloeothece* sp. TEM. Scale bar = 5 μm.

Hapalosiphon sp.

Cells cylindrical, filaments irregularly arcuate with uniserial trichomes, sheaths thin, colorless.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia nad Matką Boską cave.

Leptolyngbya sp.

Filaments long, solitary, 0.5–2.6 μm wide, thin. Cells cylindrical, olive-green; end of cells without thickened cell walls.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was identified in Jaskinia Krakowska cave.

Microcystis sp.

Cells spherical, 2–4 μm diam., blue-green or yellow-green, sometimes embedded in gelatinous sheaths.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Żarska and Jaskinia Twardowskiego cave.

Nodularia harveyana Thuret *ex* Bornet & Flahault 1875 Fig. 7: 1, 3, 4

Cells 1/3 to 2/3 as long as wide. Sheath colorless. Filaments usually in small flocs, 4–6 μm wide. Terminal cells of young trichomes usually conical. Akinetes discoid with brown wall.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Pustelnia cave.

ECOLOGY. Brackish standing water, also in moist aerophytic communities, on wet soil, ditches and among mixed algal communities at the base of trees. According to Komárek and Anagnostidis (1989), probably cosmopolitan.

Nodularia sp.

Cells shortly barrel-shaped, thylakoids irregularly coiled. It forms solitary filaments or groups of filaments, rarely mats. Trichomes cylindrical. Heterocytes the same shape as cells.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was discovered in Jaskinia Biała, Jaskinia Ciemna and Jaskinia Łokietka caves.

ECOLOGY. Unknown.

Nostoc commune Vaucher *ex* Bornet & Flahault 1888

Cells shortly barrel-shaped, 4–6 µm wide. Colony spherical, olive-green to yellowish, heterocysts nearly spherical.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was discovered in Jaskinia Sąspowska, Jaskinia Łokietka and Jaskinia Ciemna caves. Reported also from caves in Turkey (Selvi & Altuner 2007) and the Czech Republic (Poulíčková & Hašler 2007).

ECOLOGY. Colonies occur on soil, among mosses and grasses, and in depressions on limestone surfaces, especially where these occasionally hold water for short periods (John *et al.* 2002).

Nostoc cf. ***microscopicum*** Carmichael 1833

Colonies most often microscopic, spherical or less frequently elliptical. Cells barrel-shaped, 5.2–5.6–6.8 µm long. Heterocysts intercalary, 6.8–7.0–7.5 µm long, 6.5–6.8–7.0 µm wide.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Zbójecka cave. Reported also from caves in Turkey (Selvi & Altuner 2007).

ECOLOGY. Apart from caves, this alga commonly occurs on wet rocks (usually together with mosses and other algae) and in soil.

Nostoc punctiforme (Kützing *ex* Hariot) Hariot 1891

Unbranched filamentous species. Cells cylindrical, trichomes isopolar.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia nad Matką Boską cave. Reported also from caves in Spain (Roldán & Hernández-Mariné 2009).

ECOLOGY. According to Komárek and Anagnostidis (1989), an epilithic and epiphytic species, growing in or on different soils.

Nostoc sp.

Thallus gelatinous, cells cylindrical, blue-green or olive green, heterocytes solitary. The mucilaginous sheaths are firm and wide, yellow, brown or black.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was encountered in Jaskinia Biała cave.

Phormidium amoenum Kützing *ex* Gomont & Komárek 1988

Oscillatoria amoena (Kützing) Gomont 1892

Cells 4.0–6.5 µm wide, 1.5–3.0 long, with fine granulation and with coiled thylakoids. End cell rounded-conical, calyptras absent. Forming sometimes quite extensive mats. Trichomes abruptly or gradually narrowed towards ends.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was collected in Jaskinia Głęboka cave. Also reported also from a cave in Turkey (Selvi & Altuner 2007).

ECOLOGY. Fresh and brackish water, on wet mud and moist walls. Hašler and Poulíčková (2005) reported it from the Western Carpathian Mts.

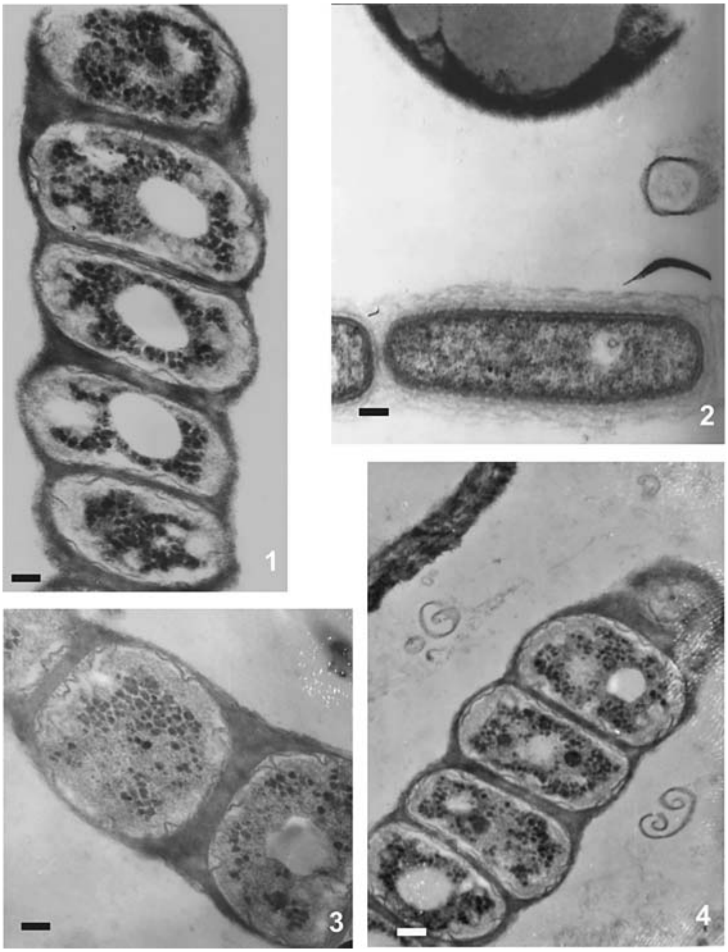

Fig. 7. 1, 3 & 4 – *Nodularia harveyana* (Thuret) Bornet & Flahault. 2 – *Synechococcus elongatus* Nägeli. All TEM. Scale bars = 5 µm.

Phormidium breve (Kützing *ex* Gomont) Anagnostidis & Komárek 1988

Oscillatoria brevis (Kützing) Gomont 1892

Trichomes straight, 4.0–6.5 µm wide, unindented at transverse walls, tapering towards apices, usually more or less hook-shaped. Cells 1.5–3.0 µm long, 2–3 times as short as wide, with distinct granules at transverse walls or without granulation. Apices rounded-conical. Forming mats.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was collected in Jaskinia Zbójecka cave.

ECOLOGY. Apart from caves, occurs in fresh and brackish standing water, in lake mud and on wet rocks, mud, also moist walls (John *et al.* 2002).

Phormidium sp.

Filaments long, cylindrical, uniseriate trichomes. Thin, firm sheaths (dark green to brown), rectangular (5–6 µm); usually the thylakoids are arranged radially within the cell.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was collected in Jaskinia nad Matką Boską cave.

Plectonema cf. ***puteale*** (Kirchner) Hansgirg 1885

Filaments long (3–7 µm), colorless sheaths. Cells blue-green (2–4 µm), end cells widely rounded.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was collected in Jaskinia Nietoperzowa cave. Reported also from Račiške ponikve cave in Slovenia (Mulec & Kosi 2008; Mulec *et al.* 2008) and from Lők-völgyi-barlang cave in Hungary (Rajczy *et al.* 1986; Rajczy 1989).

ECOLOGY. Apart from caves, occurs in water basins, springs or creeks (Komárek & Anagnostidis 2005).

Pseudocapsa dubia Ercegović 1925

Cells spherical (few-celled colonies), 6–9 µm diam., surrounded by hyaline sheath. Colonies were covered by mucilage. Nanocytes 1.5–2.0 µm diam.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was collected in Jaskinia Sąspowska, Jaskinia Łabajowa and Jaskinia Nietoperzowa caves. Palik (1938) noted it in a cave in Hungary and Skuja (1970) observed it in a cave in Italy. Ariño *et al.* (1997) found it on Roman tombs in Seville (Spain) and Asencio (1997) cited it as an epilithic and chasmoendolithic species in several caves in Murcia (Spain).

ECOLOGY. Aerophytic, epilithic and chasmoendolithic species. According to Komárek and Anagnostidis (1998), known from subaerophytic localities in limestone areas and mountains.

Schizothrix sp.

Thalli olive-green or blue-green, up to 1 µm high, filaments bent, sheaths colorless, trichomes several to a dozen or so in one sheath, pale blue-green.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Żarska cave; reported also from caves in the Czech Republic (Poulíčková & Hašler 2007).

Synechococcus elongatus Nägeli 1849 Fig. 7: 2

Cells cylindrical, 1–3 µm wide, 2–9 µm long, occasionally with a thin layer of mucilage. Thylakoids along cell walls.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Twardowskiego, Jaskinia Łokietka and Jaskinia Ciemna caves.

ECOLOGY. According to John *et al.* (2002), prefers wet soil or firm substratum such as rocks or wet walls.

Tolypothrix tenuis Kützing *ex* Bornet & Flahault 1843 Fig. 8

Filaments 8–12 µm wide, sheaths thin, colorless or yellow-brown. Cells cylindrical.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Zbójecka

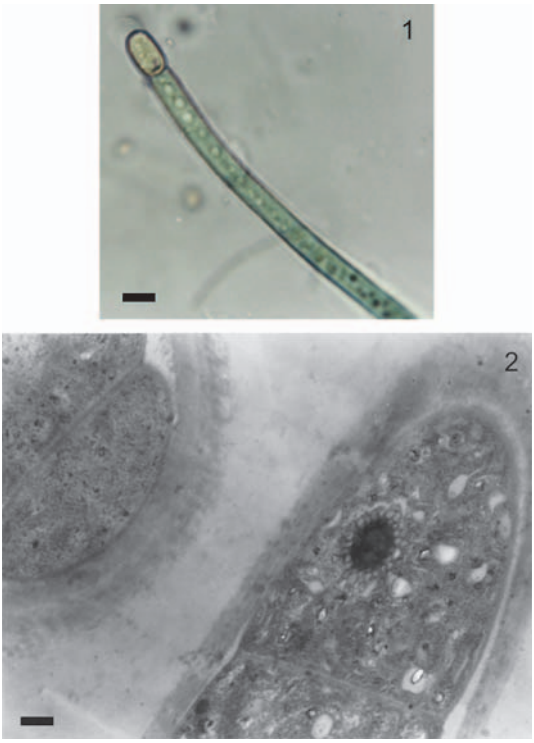

Fig. 8. *Tolypothrix tenuis* Kützing. 1 – LM (scale bar = 10 µm), 2 – TEM (scale bar = 5 µm).

and Jaskinia Pustelnia caves; in Europe, described from caves in Spain (Aboal 1988, 1989) and Bulgaria (Uzunov *et al.* 2008).

ECOLOGY. Apart from caves, grows on wet rocks. Komárek & Anagnostidis (1989) cited reports from aerophytic habitats (wet sand, soils, bark of trees, wet stones, calcareous substrate).

Tolypothrix sp.

Filaments heteropolar, sheaths thin, yellow-brown, open at the apex. Cells cylindrical, blue-green, olive-green.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was discovered in Jaskinia Mamutowa cave.

EUCARYOTA
CHLOROPHYTA
Chlamydophyceae

Chlamydomonas sp.

Unicellular thalli, typically spherical to subspherical. Each cell with two flagella, chloroplast single with one pyrenoid.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was identified in Jaskinia Głęboka, Jaskinia Krakowska, Jaskinia Pustelnia, Jaskinia za Kratą and Jaskinia Szachownica II caves.

Tetracystis intermedia (Deason & Bold) Brown & Bold 1965

Chlorococcum intermedium Deason & Bold 1960

Vegetative cells 12–20 μm diam., longitudinally ovoid or ovoid-elliptical (young) or elliptical-spherical to spherical (mature forms). Cells grouped in tetrads or arranged in 16–64-cell packets, cell wall usually thin. Chloroplast massive, with many indentations, forming irregular lobes or ribbons. Pyrenoid surrounded by two semispherical starch scales. One or two vacuoles and the nucleus in the chloroplast-free space. Reproduction by zoospores (9–11 μm long, 2–4 μm wide).

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Zbójecka and Jaskinia Pustelnia caves.

ECOLOGY. Apart from caves, it occurs as a terrestrial alga developing in tree stands, for example in *Quercus stellata* in Texas (Ettl & Gärtner 1995); reported also from soils in Fahrenwaldern forest in southern Tyrol (Italy) and from different soils in Japan and Russia.

Tetracystis cf. ***isobilateralis*** Brown & Bold 1965 Fig. 9

Vegetative cells 14–19 μm diam., elliptic (young) or wider elliptic to spherical (older). Cells grouped in pairs or tetrads, sometimes in bigger complexes. Chloroplast massive, filling almost the whole cell, with many indentations. Pyrenoid in the central part of the chloroplast, surrounded by numerous starch grains. Two large vacuoles and

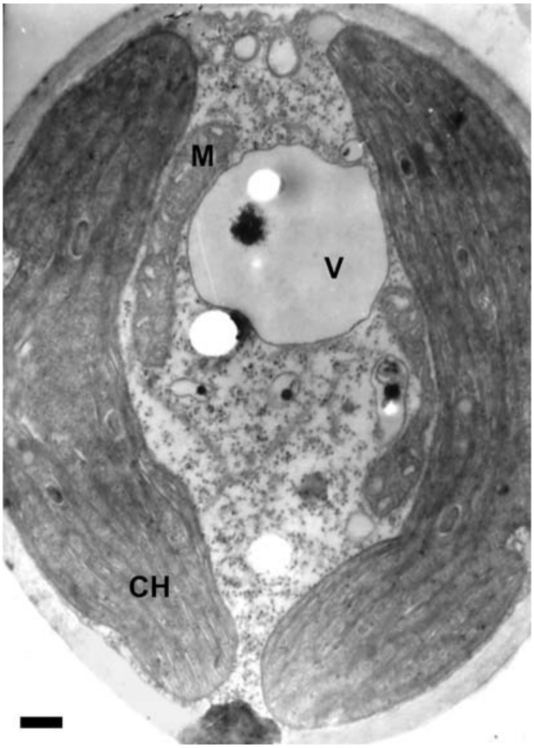

Fig. 9. *Tetracystis* cf. *isobilateralis* Brown & Bold. TEM (CH – chloroplast, M – mitochondrion, V – vacuole). Scale bar = 1 μm.

the nucleus are located in the chloroplast-free space. Reproduction by zoospores 8–10 µm long and 3–6 µm wide, longitudinally elliptical or ovoid.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it occurs in Fahrenwaldern Jaskinia Zbójecka and Jaskinia Pustelnia caves. Also found in German caves (Chang & Chang-Schneider 1991). Apart from caves, it is known as a terrestrial alga collected in the Blackland Prairie Region, Wilkamson County, Texas (Ettl & Gärtner 1995).

Tetracystis cf. ***texensis*** Brown & Bold 1965

Single young cells (tetrads) ellipsoidal or ovoid. Cell wall thin, the chloroplast often massive but perforated by slits or dissected lobes. A single pyrenoid located in the basal part of the cell.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it occurs in Jaskinia Zbójecka and Jaskinia Pustelnia caves.

ECOLOGY. Typically found in soils, rarely recorded; some reports from soils in North Carolina (Wehr & Sheath 2003) and the Caribbean.

CHLOROPHYCEAE

Bracteacoccus minor (Chodat) Petrová 1931 Figs 10 & 19: 2, 4, 5

Botrydiopsis minor Chodat 1913

Vegetative cells forming aggregates on agar. Zoenoblasts 4.5–30.0(–85.0) µm diam., usually spherical, embedded in a distinct, sometimes slightly thickened wall. Chloroplasts are thick discoid plates, numerous, parietal, shield-shaped. Orange-red drops of lipids in older cells. Zoospores 5–9 µm long, 1.5–4.5 µm wide. Autospores 4–5 µm diam.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Łabajowa, Jaskinia Żarska, Jaskinia Głęboka, Jaskinia Zbójecka, Jaskinia Ciemna and Jaskinia Pustelnia caves. Also found in Belgian caves: Grott de Remouchamps and Grotte gauche de Fonds de Forêt (Garbacki *et al.* 1999).

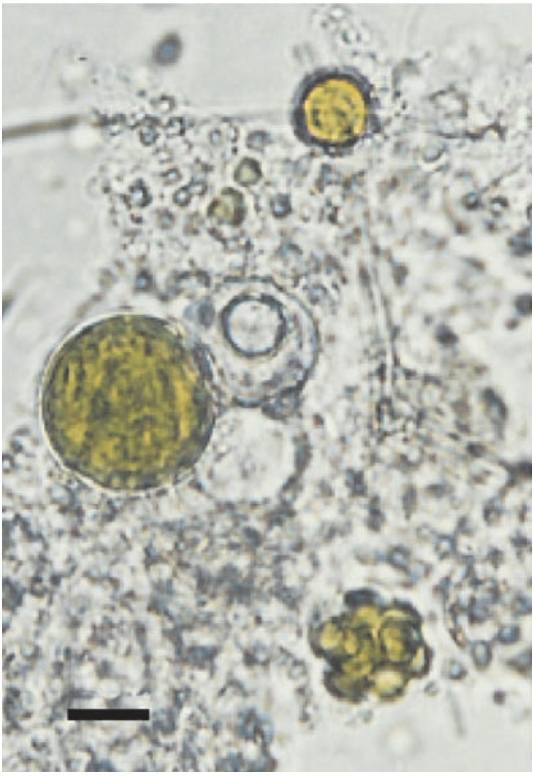

Fig. 10. *Bracteacoccus minor* (Chodat) Petrová. LM. Scale bar = 10 µm.

ECOLOGY. Apart from caves, it was isolated from different soil samples and subaerophytic habitats (Khaybullina *et al.* 2010). According to Andreyeva (1998), the most common soil species. Kostikov *et al.* (2001) found it in forests (Ukrainian Carpathians, Crimean mountains). Cosmopolitan but also reported as an aerophytic alga growing on tree bark in Japan (Ettl & Gärtner 1995).

Characium strictum A. Braun 1855

Characium brunnthaleri Printz 1916

Cells 4.8–8.2 µm wide, 14.5–30.0 µm long, slightly club-shaped or ellipsoidal, later linearly spindle-shaped to cylindrical, apex leveled, tapering towards the basal part and forming the foot. Chloroplast parietal, coat-shaped, pyrenoid located on chloroplast in the middle of the cell. Multiplication by zoospores and aplanospores.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Nietoperzowa, Jaskinia nad Matką Boską and Jaskinia za Kratą caves.

ECOLOGY. Apart from caves, this species is known as a terrestrial species mostly from the Sudety Mts, Czech Republic, and also from Slovakia (Ettl & Gärtner 1995), Spain (Aboal 1988, 1996) and Ukraine (Kostikov *et al.* 2001).

Chlorella vulgaris Beijerinck 1890

Chlorella terricola Hollerbach 1936

Cells 7.5–10.0(–13.0) µm diam., solitary or in groups, widely elliptic to spherical. Cell wall thin. Chloroplast bowl- or ribbon-shaped. Pyrenoid distinct, parietal. Multiplication by large ellipsoidal autospores (2–16) of the same size.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Ciemna, Jaskinia Sąspowska and Jaskinia Zbójecka caves. Also reported from caves in Germany (Chang & Chang-Schneider 1991), the Czech Republic (Poulíčková & Hašler 2007) and Turkey (Selvi & Altuner 2007).

ECOLOGY. Apart from caves, it occurs also on wet soils, tree bark, wet rock surfaces and walls in the Tyrolean Alps (Austria), on Gurstey Island (Iceland), on volcanic soil in Japan and Himalaya (Nepal), having a wide distribution range (Ettl & Gärtner 1995). This algae is known as a dominant in forests of the former USSR (Aleksahina & Shtina 1984) and is considered to be cosmopolitan (Andreyeva 1998).

Chlorococcum nivale Archibald 1979 Fig. 11

Chlorococcum infusionum (Schrank) Meneghini 1842

Vegetative cells solitary, cells ellipsoidal to spherical (7–15 µm). Cell walls smooth, parietal chloroplast with a single (usually) pyrenoid surrounded by an apparently continuous starch sheath.

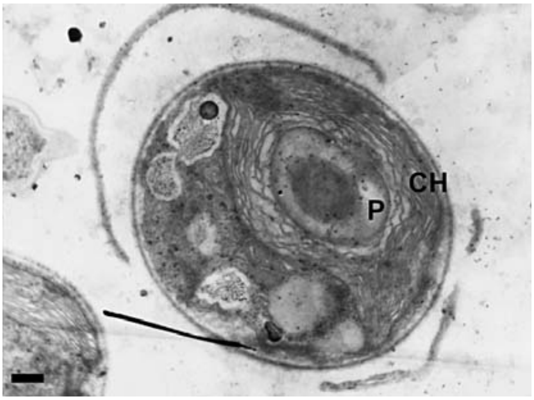

Fig. 11. *Chlorococcum nivale* Archibald. TEM (CH – chloroplast, P – pyrenoid). Scale bar = 0.5 µm.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Sąspowska cave.

ECOLOGY. Known from soil (Ettl & Gärtner 1995) as an edaphic species and from snow detritus in the High Tatra Mts (Archibald 1979).

Chlorosarcina longispinosa Chantanachat & Bold 1962 Fig. 12

Pleurastrosarcina longispinosa (Chantanachat & Bold) Sluiman & Blommers 1990

Vegetative cells up to 12 µm diam., spherical, enclosed in a thin cell wall and possessing a pyrenoid. Chloroplast parietal, usually composed

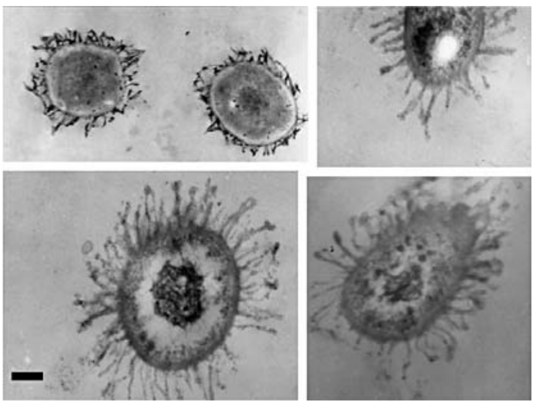

Fig. 12. *Chlorosarcina longispinosa* Chantanachat & Bold. All TEM. Scale bar = 1 µm.

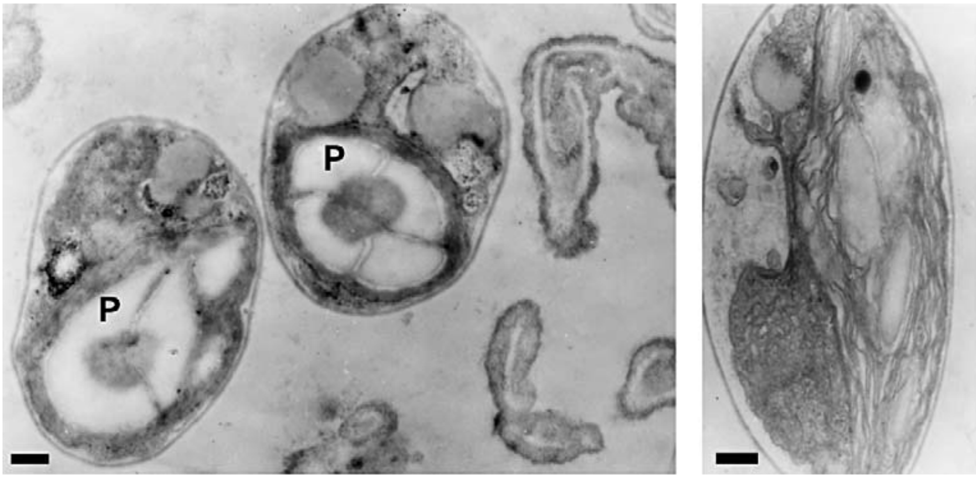

Fig. 13. *Coleochlamys perforata* (Lee & Bold) Ettl & Gärtner (a vegetative cell with pyrenoid). P – pyrenoid. TEM. Scale bars = 1 μm.

of 2–4 parts. Zoospores without stigma, with nucleus in frontal part. Hypnoblast enclosed in a thick wall with long (up to 9 μm) spines on the outer wall. Four vegetative cells formed in a hypnoblast are arranged in packets and released by wall rupture. Zoospores 8–10 μm long, 3–5 μm wide.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Łabajowa, Jaskinia nad Matką Boską and Jaskinia Szachownica I cave. It is known from caves of Slovenia (Mulec *et al.* 2008).

ECOLOGY. Apart from caves, known from surface soil samples in the Czech Republic and Arizona (U.S.A.) (Ettl & Gärtner 1995).

Choricystis minor (Skuja) Fott 1976
incl. var. ***gallica*** (Bourrelly) Komárek 1979

Cells 1.5–6.0 μm long, 1–3 μm wide, broadly elliptical or narrowly ovoid, sometimes bent. Chloroplast a parietal band, without pyrenoid.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Sąspowska and Jaskinia Głęboka caves.

ECOLOGY. Apart from caves, Ettl and Gärtner (1995) characterized this taxon as aerophilic on tree bark and on wet soil in the Czech Republic and Japan. Reported in forest-steppe communities in Ukraine (Kostikov *et al.* 2001).

Coleochlamys perforata (Lee & Bold) Ettl & Gärtner 1995 Fig. 13

Characium perforatum Lee & Bold 1974; *Fusochloris perforata* (Lee & Bold) Floyd & Walm. 1993

Cells 25–60 μm long, 10–20 μm wide, mostly spindle-shaped, sometimes ovoid to ellipsoidal, often irregular. Cell wall thin, chloroplast parietal. Pyrenoid parietal. Reproduction usually by zoospores (64), also by aplanospores. Zoospores 7–9 × 3–4 μm, aplanospores 3.5 μm.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Ciemna, Jaskinia Sąspowska, Jaskinia Nietoperzowa, Jaskinia nad Matką Boską, Jaskinia Zbójecka and Jaskinia Twardowskiego caves.

ECOLOGY. Apart from caves, it was isolated from snow detritus in the High Tatra Mts in Slovakia (Ettl & Gärtner 1995).

Desmococcus olivaceum (Persoon *ex* Archerson) Laudon 1985

Pleurococcus vulgaris Meneghini *emend.* Geitler 1842 *sensu* Nägeli 1847; *Pleurococcus naegelii* Chodat 1902; *Desmococcus vulgaris* Brand 1925

Cells 4–8(–11) µm, large, arranged in cubic packets located parietally, in which cell divisions in agar culture create short-branched easily disintegrating filaments. Chloroplast parietal. Pyrenoid not covered by starch granules. Sporangia with spines, containing aplanospores. Zoospores unknown.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Ciemna, Jaskinia Krakowska, Jaskinia Zbójecka and Jaskinia Pustelnia caves; reported also from caves in the Czech Republic (Poulíčková & Hašler 2007).

ECOLOGY. Apart from caves, it occurs on tree bark, walls, wooden house walls, on soil; considered cosmopolitan (Ettl & Gärtner 1995).

Dilabifilum arthopyreniae (Vischer & Klement) Tschermak-Woess 1953

Pseudopleurococcus arthopyreninae Vischer & Klement in Vischer 1953

Cells cylindrical, 3–4 µm wide, 3–10 times longer than width. Young thalli composed of branched filaments built by oblong to cylindrical cells. Chloroplast single, parietal, trough-shaped, with one pyrenoid. Isodiametric cells 10–18 µm long, 5–12 µm wide.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Ostrężnicka, Jaskinia Zbójecka and Jaskinia Pustelnia caves.

ECOLOGY. Apart from caves, it occurs as a phycobiont in *Verrucaria aquatilis* growing on limestone rocks near the Zunz River, Austria (Ettl & Gärtner 1995).

Gloeocystis polydermatica (Kützing) Hindák 1978

Gloeocystis vesiculosa Nägeli *sensu* Fott 1956; *Palmoglosa protuberans* (Smith & Sawbery) Kütz. *sensu* Fott & Nováková 1971

Colonies forming gelatinous masses, irregularly papillary, patchy or diffuse. Vegetative cells 3.5–11.2 µm long, 2.5–8.0 µm wide, with distinctly concentric lamellae and gelatinous sheaths. Cells elliptical, more convex on one side. Chloroplast parietal, pyrenoid present but vaguely visible.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was discovered in Jaskinia Nietoperzowa, Jaskinia Dzika, Jaskinia Jasna in Strzegowa, Jaskinia Głęboka, Jaskinia Sypialnia, Jaskinia Zbójecka and Jaskinia Ostrężnicka caves; also known from caves in Slovenia (Mulec *et al.* 2008). The species *Gloeocystis rupestris* was reported from caves in Germany (Chang & Chang-Schneider 1991).

ECOLOGY. Apart from caves, it occurs also on wet rocks (granite, gneiss, sandstone), less frequently on wood or mosses. Sporadically found also on a lichen (resembling *Bryophagus*) in soil of Central Europe, Japan and New Guinea (Ettl & Gärtner 1995).

Interfilum paradoxum Chodat & Topali 1922 Fig. 14

Radiofilum paradoxum (Chodat & Topali) Printz 1964

Cells up to 12 µm long, 4–7 µm wide, solitary, forming pairs or short chains usually composed of sparse cells connected by narrow gelatinous links and immerged in a common gelatinous mass. Single vegetative cells spherical or elliptical. Cell wall double. Chloroplast bowl-shaped with a single pyrenoid.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found only in Jaskinia Nietoperzowa cave.

ECOLOGY. Ettl and Gärtner (1995) classified it as a terrestrial species.

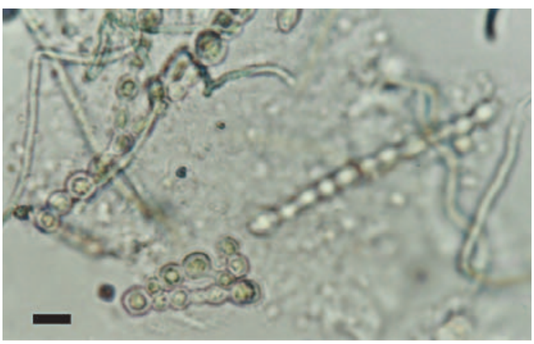

Fig. 14. *Interfilum paradoxum* Chodat & Topali. LM. Scale bar = 1 µm.

Leptosira terricola (Bristol) Printz 1964

Thallus composed of a pseudoparenchymatic foot and widely branched creeping filaments. The latter composed of almost spherical or irregular cells. Spherical cells 15–22 μm diam.; filament cells 6–15 μm wide, 10–18(–21) μm long. The latter give rise to bushy-branched short filaments formed of more cylindrical to barrel-shaped, bluntly rounded cells. Chloroplast parietal, trough-shaped or lobed with 1–2 pyrenoids. Zoospores formed on prostrate or straight filaments, spherical or ovoid, very large. Spherical aplanospores also known. Zoosporangia 14–18 μm wide, zoospores 11–12 × 4–5 μm, large.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Nietoperzowa, Jaskinia nad Matką Boską and Jaskinia za Kratą caves.

ECOLOGY. Apart from caves, described as a terrestrial alga occurring in Europe and Asia. Also present on lichens and mineral soils in Canada (Ettl & Gärtner 1995).

Leptosira vischeri Reisigl 1964 Fig. 15

Filaments very short, composed of sparse cells. Vegetative cells 12–20 μm diam., solitary, spherical or ovoid, enclosed in a thick wall. Chloroplast parietal, massive, with numerous fissures, almost reticuloid, with 1–2(–3) pyrenoids. Zoospores 3.5 × 8.5 μm, 16–32 in number. Develops aplanospores, usually 2.

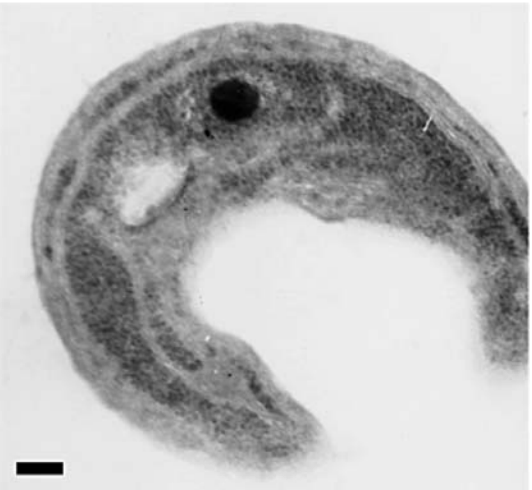

Fig. 15. *Leptosira vischeri* Reisigl. TEM. Scale bar = 1 μm.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Łabajowa, Jaskinia Nietoperzowa and Jaskinia Głęboka caves.

ECOLOGY. Apart from caves, known from alpine terrain in Őtztal, Tyrol, Austria (Ettl & Gärtner 1995).

Muriella decolor Vischer 1936 Fig. 16

Cells 3.5–7.0 μm diam., solitary, spherical, enclosed in a delicate cell wall. Chloroplast parietal, in young cells cup- or trough-like, adult cells usually with 2 chloroplasts. Autospores 2.0–3.5 μm, large.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was in 12 studied caves: Jaskinia Ciemna, Jaskinia Nietoperzowa, Jaskinia Krakowska, Jaskinia Dzika, Jaskinia Twardowskiego, Jaskinia Jasna, Jaskinia Głęboka, Jaskinia za Kratą, Jaskinia na Łopiankach, Jaskinia Biała, Jaskinia Zbójecka and Jaskinia Pustelnia. Reported also from caves in Slovenia (Mulec *et al.* 2008) and the Czech Republic (Poulíčková & Hašler 2007).

ECOLOGY. Apart from caves, this species occurs on wet wood, walls and tree bark (Ettl & Gärtner 1995).

Neocystis subglobosa (Pascher) Hindák 1988

Cells oval, 3–10 μm long, thalli spherical, colonies 14–65 μm diam., with 4 to many cells mostly clustered at the center of homogeneous mucilage. Chloroplast single without pyrenoid.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was identified in 11 of the studied caves: Jaskinia Nietoperzowa, Jaskinia Krakowska, Jaskinia Dzika, Jaskinia Łabajowa, Jaskinia Twardowskiego, Jaskinia Jasna in Strzegowa, Jaskinia Głęboka, Jaskinia za Kratą, Jaskinia

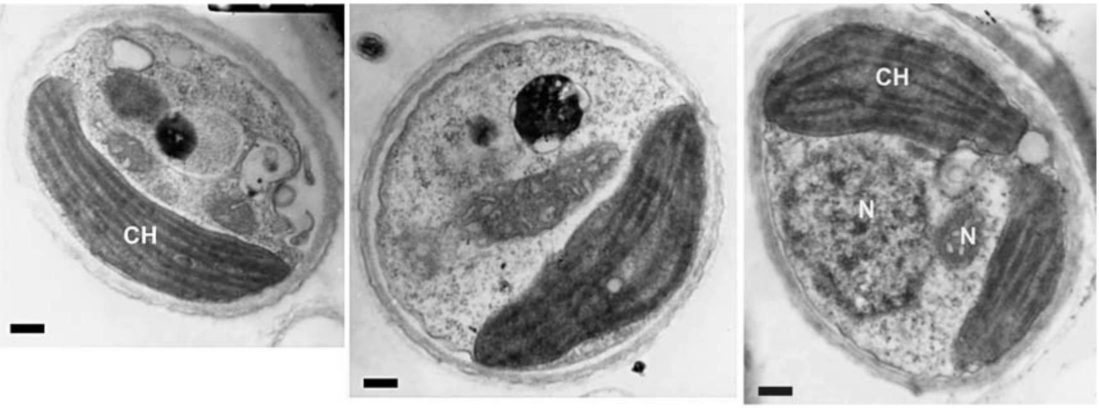

Fig. 16. *Muriella decolor* Vischer – mature vegetative cells (CH – chloroplast, N – nucleus). All TEM. Scale bars = 1 μm.

na Łopiankach, Jaskinia Zbójecka and Jaskinia Pustelnia.

ECOLOGY. Aerophytic species.

Podohedra bicaudata Geitler 1965

Cells 16–23 μm long, 4–6 μm wide, widely spindle-shaped to oval, straight or slightly curved, tapering towards the apical part to form a short blade, short foot in the basal part. Chloroplast parietal with a distinct pyrenoid covered with coarse starch granules.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Krakowska, Jaskinia Nietoperzowa, Jaskinia nad Matką Boską, Jaskinia Twardowskiego and Jaskinia za Kratą caves.

ECOLOGY. Apart from caves, it occurs in gelatinous algal coatings in Bad Ischl town in Austria (Ettl & Gärtner 1995).

Scotiellopsis terrestris (Reisigl) Punčochářová & Kalina 1981

Scotiella terrestris Reisigl 1964; *Scotiellopsis terrestris* (Reisigl) Fott 1976

Cells (6–)14–30 μm long, (4–)11–20 μm wide, spindle-shaped, usually slightly asymmetrical. Cell wall thickened at apices and composed of 6–12 (infrequently more) straight or slightly spiral transapical ribs. Chloroplast parietal, initially straight, then lobed. Pyrenoid with numerous starch granules. Vacuoles only in old cells.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia nad Matką Boską, Jaskinia Zbójecka, Jaskinia Ciemna, Jaskinia na Tomaszówkach and Jaskinia Sypialnia caves; collected also in caves at Mladeč, Czech Republic (Poulíčková & Hašler 2007).

ECOLOGY. Apart from caves, found in soil samples from *Silene acaulis* in the Tyrolean Alps (3460 m), Austria; also known from the High Tatra Mts (Slovakia) and Giant Mts (Czech Republic), from Bruneck and Brixen (southern Tyrol, Italy) and from Braunschweig, Germany (Ettl & Gärtner 1995).

Thelesphaera alpina Pascher 1943

Figs 17 & 18: 5

Cells 10–12 μm diam., solitary, spherical to ellipsoidal, rarely flattened. Cell wall relatively thick with conical to almost semispherical protrusions, up to 0.5 μm long. When cell structure is regular and bipolar there are usually 3 protrusions at each apex, radially arranged. Chloroplast parietal, trough-shaped. Multiplication by 2 autospores released through sporangium wall rupture.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was identified only in Jaskinia Sąspowska cave.

Fig. 17. *Thelesphaera alpina* Pascher. TEM. Scale bar = 1 μm.

ECOLOGY. Apart from caves, known as an aerophytic occurring in wet rocks in Steiermark and Tyrol, Austria (Ettl & Gärtner 1995).

TREBOUXIOPHYCEAE

Keriochlamys styriaca Pascher 1943

Fig. 18: 1–3

Cells spherical to broadly ellipsoidal, 8–10 μm diam. Cell walls thick; parietal chloroplast single with one pyrenoid. Produces two autospores with homogenous walls.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was identified only in Jaskinia Sąspowska cave.

ECOLOGY. Apart from caves, known from the central Alps in Austria (Ettl & Gärtner 1995).

KLEBSORMIDIOPHYCEAE

Klebsormidium flaccidum (Kützing) Silva, Mattox & Blackwell 1972

Hormidium flaccidum (Kützing) Braun *in* Rabenh. 1876; *Stichococcus flaccidus* (Kützing) Gay 1891

Filaments usually long. Cells 8(–14) μm wide, up to 3 times longer than wide, cylindrical, with trough-shaped parietal chloroplast containing a pyrenoid. Nucleus on the plasmatic bridge. Asexual multiplication by zoospores and aplanospores. Sexual reproduction by isogamy. Vegetative multiplication by filament breakage or by hypnoblasts.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Nietoperzowa, Jaskinia Żarska, Jaskinia Mamutowa, Jaskinia Dzika, Jaskinia Głęboka, Jaskinia Zbójecka, Jaskinia Jasna in Strzegowa, Jaskinia za Kratą and Jaskinia Pustelnia caves; reported also from caves in Slovenia (Mulec *et al.* 2008) Mladeč, Javoříčko and Zbrašov in the Czech Republic (Poulíčková & Hašler 2007) and the Cave of Bats in Spain (Roldán & Hernández-Mariné 2009).

ECOLOGY. Apart from caves, occurs on soil, rocks, walls and tree bark. A common species (Ettl & Gärtner 1995).

Klebsormidium montanum (Skuja) Watanabe 1983

Hormiscia flaccida Lagerheim var. *montana* Hansgirg 1888; *Hormidium montanum* (Hansgirg) Skuja 1964

Cells 3–13(–20) μm long, 9.0–15.5 μm wide, cylindrical. In agar culture it forms rather short filaments composed of less than 20 cells; in liquid medium, the filaments contain more than 100 cells. Chloroplast ribbon- or trough-shaped, occupying 2/3 of the cell, with one pyrenoid. Asexual multiplication involves zoospores, and vegetative multiplication by filament breakage. Zoospores 12–15 × 5–7 μm, large.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Głęboka and Jaskinia Pustelnia caves.

ECOLOGY. Apart from caves, occurs on sand or wet rocks in Sweden and Japan; known also from the alpine zone in the Dolomites (southern Tyrol, Italy) (Ettl & Gärtner 1995).

Stichococcus allas Reisigl 1964

Filaments short (max. 8 cells). Single cells 1.5 to 3 μm wide and 3.5 to 12 μm long, curved. Old cells usually sigmoidal, with numerous lipid droplets. Chloroplast trough-shaped, yellow-green, without a pyrenoid. Starch absent.

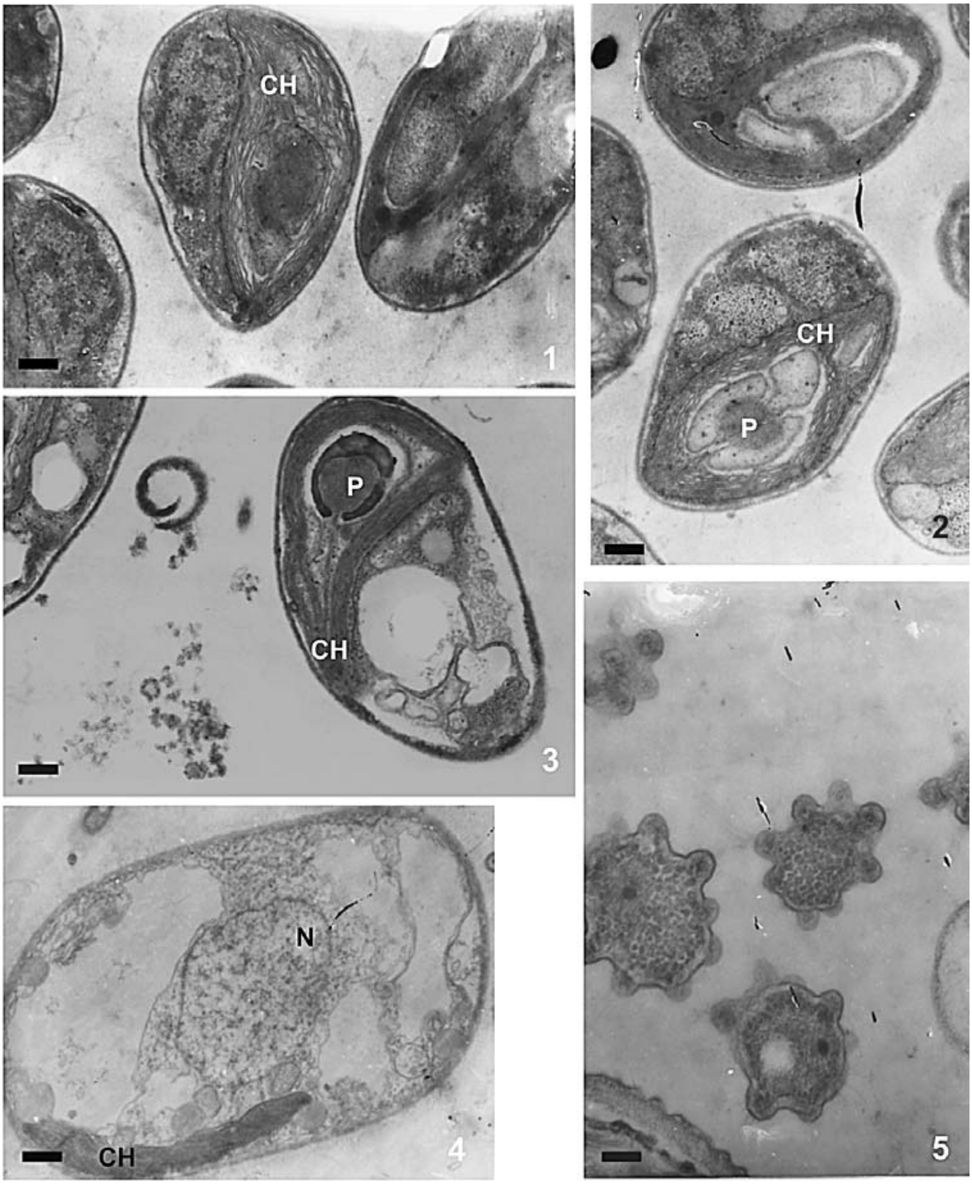

Fig. 18. 1–3 – *Keriochlamys styriaca* Pascher. 4 – *Trachychloron simplex* Pascher – vegetative cell with nucleus. 5 – *Thelesphaera alpina* Pascher (CH – chloroplast, N – nucleus, P – pyrenoid). All TEM. Scale bars = 1 μm.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Głęboka, Jaskinia za Kratą and Jaskinia Pustelnia caves.

ECOLOGY. Apart from caves, identified in surface soil samples from Otztaler in the Alps (3739 m a.s.l.), forming white balls.

Stichococcus bacillaris Nägeli 1849

Stichococcus minor Nägeli 1849

In agar culture it forms light green to yellow-green colonies composed of short filaments containing 2–10 cells and easily breaking into single cells. Cells 2.0–2.5(–3.0) μm wide, 3.5–6.0(–12.0) μm long, cylindrical, apices rounded. Chloroplast trough-shaped, covering 2/3 of the cell surface, with one slightly visible, bare pyrenoid. Vacuole apical, usually single in mature cells.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Nietoperzowa, Jaskinia za Kratą, Jaskinia Zbójecka, Jaskinia Ostrężnicka and Jaskinia Pustelnia caves. Known also from caves in the Czech Republic (Poulíčková & Hašler 2007), Slovenia (Mulec *et al.* 2008) and Germany (Chang & Chang-Schneider 1991).

ECOLOGY. Apart from caves, grows on soil, rocks, tree bark; cosmopolitan and aerophytic (Ettl & Gärtner 1995).

Stichococcus sp.

Cells ovoid with rounded apices (usually 2 or 4-celled). The cell wall is granular, the chloroplast parietal with a single pyrenoid.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Głęboka, Jaskinia za Kratą and Jaskinia Sypialnia caves.

Trentepohliophyceae

Trentepohlia aurea (Linné) Martius 1817

Trentepohlia velutina Kützing 1843; *Trentepohlia maxima* Karsten 1891; *Trentepohlia germanica* Gluck 1896

Cells 10–24(–30) μm wide, 1.5–3 times longer than wide. Creeping filaments with cylindrical swollen cells, straight filaments also with cylindrical cells, usually generously branched. Cell wall lamellate, with apical cells possessing pectin sheaths, usually more cylindrical, often moved aside during growth. Zoosporangia 27–40 × 25–30 μm, large, ovoid, usually solitary, less frequently in pairs. Gametangia 9–18(–40) μm diam., spherical or ellipsoidal, located terminally, less frequently intercalarily.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Ciemna, Jaskinia Głęboka and Jaskinia Zbójecka caves. Known also from caves in Slovenia (Mulec *et al.* 2007, 2008), Mladeč cave in the Czech Republic (Poulíčková & Hašler 2007) Germany (Chang & Chang-Schneider 1991) and Bulgaria (Uzunov *et al.* 2008).

ECOLOGY. Apart from caves, occurs on limestone and silicate on old wood, also mosses and tree bark; common in Central Europe but very variable, occurring in many forms and varieties (Printz 1939, quoted in Ettl & Gärtner 1995).

HETEROKONTOPHYTA
Xanthophyceae

Chlorobotrys simplex Pascher 1932

Colonies composed of 2 or less frequently 4 cells. Single cells *ca* 7 μm, large, usually spherical, embedded in gelatinous sheath. Cell wall brown. Chloroplast single, cup-shaped.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Głęboka cave.

ECOLOGY. Apart from caves, found on wet soil (as a terrestrial alga), reported from the Czech Republic and Ukraine (Ettl & Gärtner 1995) and among wet mosses in tundra (Matuła *et al.* 2007).

Chlorobotrys terrestris Pascher 1939

Colonies usually composed of two, rarely four cells, embedded in gelatinous easily dissolving sheath. Single cells spherical, 4 μm diam., enclosed in red cell wall. Chloroplast single, gulf-shaped.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Głeboka cave.

ECOLOGY. Apart from caves, a terrestrial species occurring on wet rocks, walls and trees (Ettl & Gärtner 1995) in the Czech Republic, Austria and Russia.

Chlorobotrys sp.

Spherical unicells, usually paired. Cell wall smooth, thin, surrounded by lamellate mucilage. Single yellow-green chloroplast with one pyrenoid.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Nietoperzowa cave.

Gloeobotrys piriformis Reisigl 1964

Vegetative cells up to 15 µm long, 10–11 µm broad, irregular in shape (asymmetric), embedded in a gelatinous sheath. Single cells pear-shaped or ovoid, swelled at one end and tapered at the other. Cell wall delicate. Parietal chloroplasts, without pyrenoids. Multiplication by autospores grouped in eights.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Głęboka cave; encountered also in Škocjanske Jame, Slovenia (Mulec *et al.* 2007).

ECOLOGY. Apart from caves, forms green coatings on trees (*Curvuletum* associations) growing above 3160 m a.s.l. in the Tyrolean Alps; reported as an aerophytic species developing on *Pinus densiflora* and *Ginkgo biloba* in North Korea (Mrozińska 1990; Ettl & Gärtner 1995).

Heterococcus caespitosus Vischer 1936

Filaments branched, creeping in all directions. Young filaments cylindrical, 50 µm long, 5–6 µm wide. Cells divide in all directions and can transform to hypnoblasts. Older filaments shorter, rounded, size as in young ones, also sometimes transforming to hypnoblasts. Cells form zoosporangia giving rise to zoospores with one or two chloroplasts and a stigma.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Mamutowa, Jaskinia Głęboka and Jaskinia Szachownica I caves; noted also in Serreta cave in Spain (Asencio & Aboal 2000b).

ECOLOGY. Apart from caves, occurs also in southern Swartzwald near Freiburg, Germany; noted also in soils of Antarctica, limestone soil in England, and soils in the Paws Peninsula in Croatia. Observed to form green coatings in the Dolomites with *Saxifraga bryoides, Arabis pumila* and *Trisetum distihophyllum* at 2350 m a.s.l.; known as a phycobiont occurring jointly with *Verrucaria elaeomelaena* and *V. laevata* (Ettl & Gärtner 1995).

Trachychloron biconicum Pascher 1973

Vegetative cells 9–16 µm long, 8 µm broad. Chloroplast single but deeply incised, parietal. Pyrenoid polyhedral.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Żarska, Jaskinia Mamutowa and Jaskinia Głęboka caves.

ECOLOGY. Aerophilic species. Earlier known only from the Czech Republic and Austria (Ettl & Gärtner 1995).

Trachychloron simplex Pascher 1973
Figs 18: 4 & 19: 1–3

Vegetative cells 5–7 µm broad, 8–10 µm long. Chloroplast parietal, trough-shaped or lobed with 1–2 pyrenoids.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Mamutowa and Jaskinia Głęboka caves. Earlier known only from an old riverbed of the River Traun (Austria) and from a pond near Prague (Czech Republic).

ECOLOGY. Calciphilous species

Eustigmatophyceae

Eustigmatos magnus (Petersen) Hibberd 1981
Fig. 20

Pleurochloris magna J. B. Petersen 1932

Cells solitary, 14(–34) µm diam., rounded, enclosed in a delicate call wall sometimes gelatinizing. Chloroplast single but deeply incised, parietal. Pyrenoid polyhedral. Multiplication by autospores, rarely by zoospores 7–12(–21) µm in size.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia

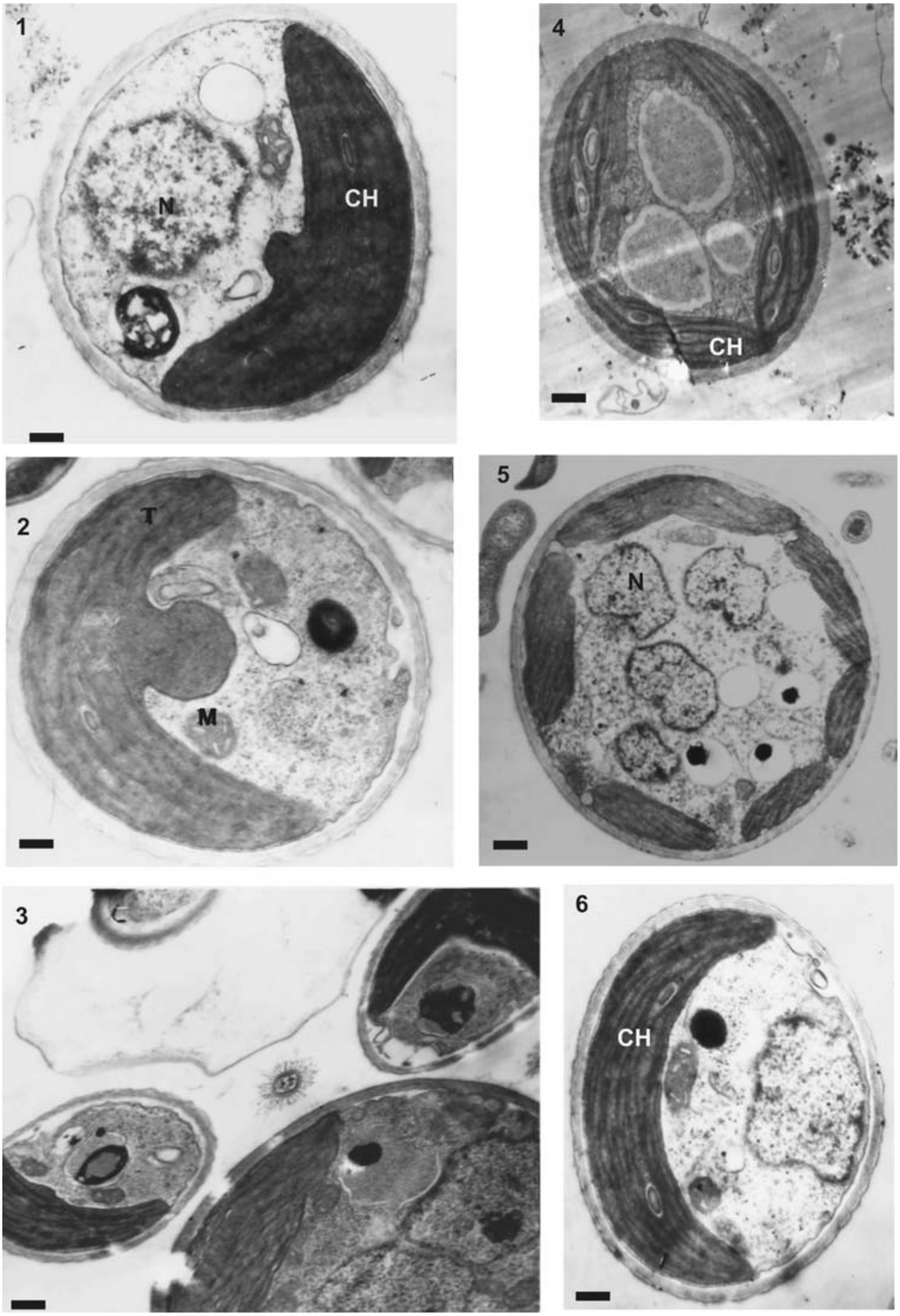

Fig. 19. 1–3 – *Trachychloron simplex* Pascher – vegetative cell, with chloroplast (thylakoids), nucleus and mitochondrion. 4–6 – *Bracteacoccus minor* (Chodat) Petrová – vegetative cell with chloroplast, Golgi body, nucleus and vacuole (CH – chloroplast, M – mitochondrion, N – nucleus, T – thylacoids). All TEM. Scale bars = 0.5 µm.

Łabajowa, Jaskinia Nietoperzowa, Jaskinia nad Matką Boską, Jaskinia Żarska, Jaskinia Dzika, Jaskinia Twardowskiego, Jaskinia Głęboka, Jaskinia na Tomaszówkach and Jaskinia za Kratą caves.

ECOLOGY. Apart from caves, isolated from cultivable soil, meadows (soil pH 4.7–7.5) and volcanic soils in uninhabited areas (Ettl & Gärtner 1995); spreading principally as a terrestrial species mostly in Denmark, Switzerland, Slovenia, Russia and Spain (Gomez *et al.* 2003).

Bacillariophyceae

Aulacoseira cf. ***italica*** (Ehrenberg) Simonsen 1979

Gallionella italica Ehrenb. 1839; *Melosira italica* (Ehrenb.) Kütz. 1844

Cells cylindrical, adjoining to form long, tightly closed chains. Cell wall relatively thin. Interconnecting spines large. Chloroplasts lobed.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia nad Matką Boską and Jaskinia Mamutowa caves.

ECOLOGY. Apart from caves, common in the littoral of fresh waters, in eutrophic waters (ditches, ponds, rivers, lakes), flowing waters and wet places. Cosmopolitan. According to Van Dam *et al.* (1994), a nitrogen-autotrophic taxa, α-mesosaprobous, meso-eutraphentic and fresh brackish water species, occurring mainly in water bodies, also rather regularly in wet and moist places.

Caloneis silicula (Ehrenberg) Cleve 1884

Navicula silicula Ehrenb. 1838; *Caloneis ventricosa* (Ehrenb.) Meister 1912

Valves elongate-linear to elongate-lanceolate, more or less widening in the middle and at both apices, apices wedge-shaped or slightly rounded.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia nad Matką Boską cave.

ECOLOGY. Apart from caves, a freshwater species, widely distributed and usually common in all types of waters; characteristic of standing waters with alkaline pH. Classified by Krammer and Lange-Bertalot (1986) as a cosmopolitan diatom in waters of moderate conductivity. According to Van Dam *et al.* (1994), an alkaliphilous, oligosaprobous and meso-eutraphentic species.

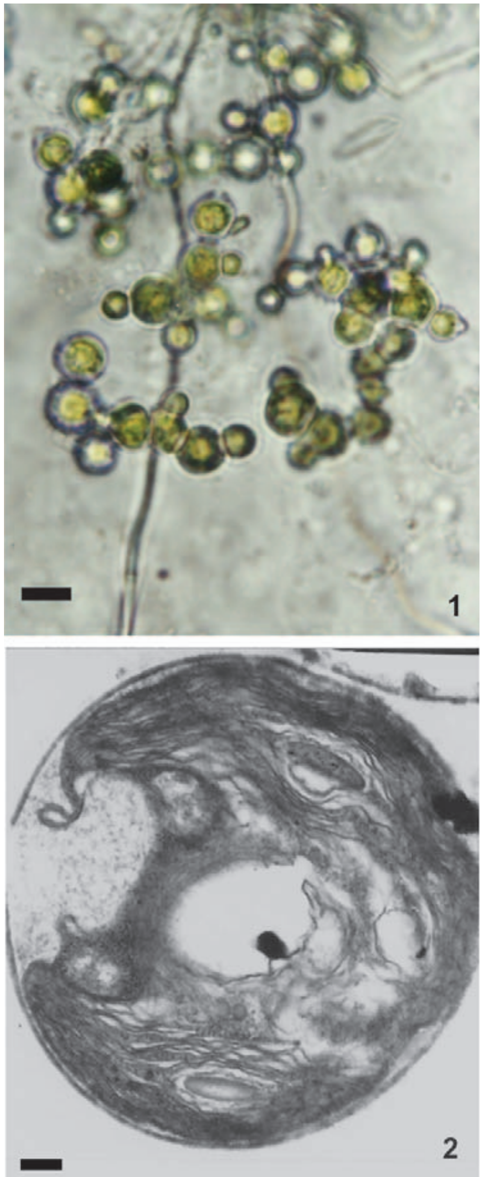

Fig. 20. *Eustigmatos magnus* (Petersen) Hibberd. 1 – LM (scale bar = 1 μm), 2 – TEM (scale bars = 1 μm).

Diadesmis contenta (Grunow *in* Van Heurck) D. G. Mann *in* Round *et al.* 1990

Navicula contenta Grunow *in* Van Heurck 1885

Valves 6.8–8.1 µm long, 2.4 µm wide, with 26 striae per 10 µm.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia nad Matką Boską, Jaskinia Mamutowa, Jaskinia Jasna, Jaskinia Głęboka, Jaskinia za Kratą, Jaskinia na Łopiankach, Jaskinia Zbójecka and Jaskinia Ostrężnicka caves. Also reported from caves in Belgium (Garbacki *et al.* 1999), Mladeč and Zbrašov caves in the Czech Republic (Poulíčková & Hašler 2007), a cave in Turkey (Selvi & Altuner 2007), Spain (Aboal *et al.* 1994; Roldán & Hernández-Mariné 2009) and Mammoth Cave National Park, Kentucky (Smith & Olson 2007). Reported from Austria, the United Kingdom and Iceland (Ettl & Gärtner 1995).

ECOLOGY. Cosmopolitan, aerophilic species (Krammer & Lange-Bertalot 1986).

Gomphonema italicum Kützing 1844

Fig. 21: 7

Valves 20–38 µm long, 10.0–13.5 µm wide, with 12–13 striae per 10 µm.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia nad Matką Boską and Jaskinia Mamutowa caves. Also found in caves in Spain (Aboal *et al.* 2003a).

ECOLOGY. Cosmopolitan, occurring in mesotrophic waters (Krammer & Lange-Bertalot 1986).

Grunowia tabellaria (Grunow) Rabenhorst 1864

Fig. 21: 3

Nitzschia sinuata var. *tabellaria* (Grunow) Grunow *in* Heurck 1881

Valve 13.5–26.5 µm long, 4.5–7.5 µm wide.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Mamutowa, Jaskinia Głeboka and Jaskinia za Kratą caves.

ECOLOGY. Cosmopolitan (Krammer & Lange-Bertalot 1988). According to Van Dam *et al.* (1994), a neutrophilous species, α-mesosaprobous, mesotraphentic and freshwater species.

Hantzschia amphioxys (Ehrenberg) Grunow 1880

Eunotia amphioxys Ehrenb. 1843

Cells solitary, frustules and valves dorsiventral. Valves 15.1–35.2 µm long, 4.1–7.1 µm wide.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Sąspowska, Jaskinia Mamutowa, Jaskinia Krakowska, Jaskinia Sypialnia, Jaskinia Jasna in Strzegowa and Jaskinia Głęboka caves. Reported also from caves in Belgium (Garbacki *et al.* 1999), Mladeč and Zbrašov caves in the Czech Republic (Poulíčková & Hašler 2007), and caves in Spain (Alvarez-Cobelas & Estévez Garcia 1982; Aboal & Llimona 1984; Aboal 1988; Aboal *et al*. 1994, 1998, 2003a; Asencio & Aboal 2000a, b; Uher *et al*. 2005); recently noted in a cave in Turkey (Selvi & Altuner 2007).

ECOLOGY. Apart from caves, a freshwater alga. One of the most widely distributed freshwater diatom species, with high adaptability, occurring often at the bottom of different water bodies, mostly in alkaline waters, encountered also on mosses and wet soil. Krammer and Lange-Bertalot (1988) classified it as cosmopolitan; one of the most frequently reported diatoms from aerophytic habitats. A neutrophilous, α-mesosaprobous, eurytraphentic and fresh brackish water species (Van Dam *et al.* 1994).

Luticola mutica (Kützing) D. G. Mann 1990

Navicula mutica Kützing 1844

Valves rhombic-elliptical to broadly elliptical or rhombically lanceloate with apices wide- or blunt-ended, 6–30(–40) µm long, 4–9(–12) µm wide. Striae radiate, 14–20(–25)/10 µm, areolae visible.

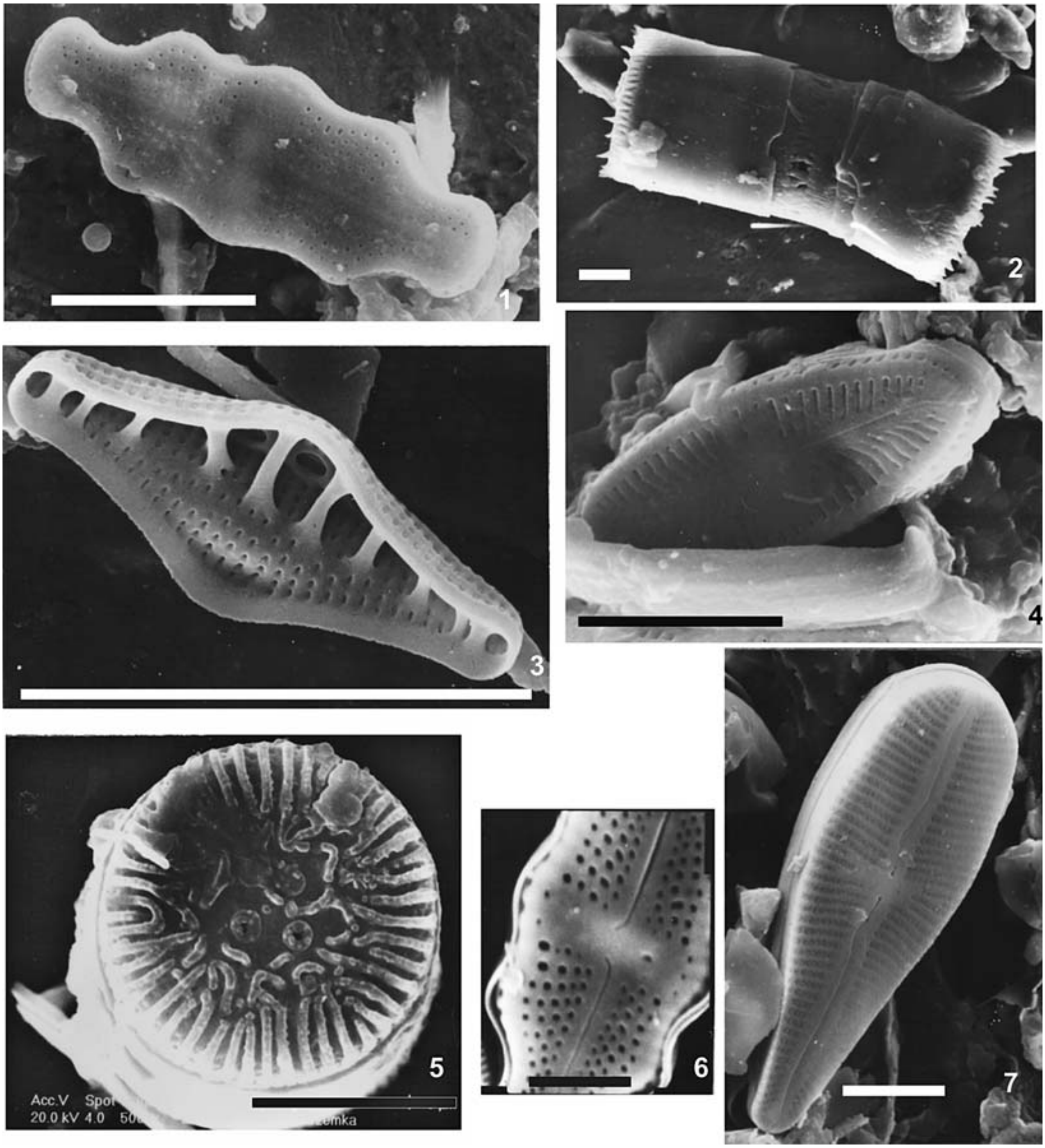

Fig. 21. 1, 4 & 6 – *Luticola nivalis* (Ehrenb.) D. G. Mann (1 & 6 – external view, and 4 – internal view). 2 & 5 – *Orthoseira roseana* (Rabenhorst) O'Mara (2 – girdle view, and 5 – external view 5). 3 – *Grunowia tabellaria* (Grunow) Rabenhorst (internal view). 7 – *Gomphonema italicum* Kützing (external view); all SEM. Scale bars: 1, 2, 4–6 = 5 µm; 3 = 15 µm; 7 = 5 µm.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found only in Jaskinia Mamutowa and Jaskinia Głęboka caves; observed also in Mladeč and Zbrašov caves, Czech Republic (Poulíčková & Hašler 2007); reported from caves in Slovenia (Mulec *et al.* 2008) and Turkey (Selvi & Altuner 2007).

ECOLOGY. Apart from caves, a common freshwater and brackish species, occurring often at river mouths, in inland waters, ponds, lakes, ditches and rivers. Krammer and Lange-Bertalot (1986) classified it as a cosmopolitan, aerophilic diatom. A neutrophilous, α-mesosaprobous, eutraphentic and brackish fresh water species (Van Dam *et al.* 1994).

Luticola nivalis (Ehrenberg) D. G. Mann 1990
Fig. 21: 1, 4, 6

Navicula nivalis Ehrenb. 1854

Valves linear in smaller forms, linearly elliptical with distinctly undulate edges in larger forms, 12–42 µm long, 5.5–13.0 µm wide. Striae radiate, distinct, 17–20(24)/10 µm, with relatively uniformly distributed puncta. Transapical puncta usually slightly elongate, 15–20/10 µm.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Łabajowa, Jaskinia Mamutowa and Jaskinia Głęboka caves; noted also in Mladeč and Zbrašov caves in the Czech Republic (Poulíčková & Hašler 2007).

ECOLOGY. Apart from caves, it is a fresh and brackish water species, encountered usually in river mouths, ponds and lakes. Cosmopolitan, aerophilic species (Krammer & Lange-Bertalot 1986). According to Van Dam *et al.* (1994) a neutrophilous, α-mesosaprobous, eutraphentic and brackish fresh water diatom.

Orthoseira roeseana (Rabenhorst) O'Meara 1876
Fig. 21: 2, 5

Melosira roeseana Rabenhorst 1852

Cells cylindrical with flat, marginal, rounded apical faces connected to form a long, tight chain. Valves 8–70 µm diam., 6–13 µm high, frustule height-to-diameter ratio usually >1.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Krakowska, Jaskinia Mamutowa, Jaskinia Głęboka, Jaskinia za Kratą, Jaskinia Zbójecka, Jaskinia Ostrężnicka and Jaskinia Pustelnia caves. Also occurs in caves in Belgium (Garbacki *et al.* 1999), the Cave of Bats, Nerja cave and Salpetre cave in Spain (Roldán & Hernández-Mariné 2009) and in Mladeč, Javořičko and Zbrašov caves in the Czech Republic (Poulíčková & Hašler 2007).

ECOLOGY. Apart from caves, found at wet sites (e.g., rocks or mosses sprinkled by flowing water), on tree bark (on the side closer to a creek or river), frequent in mountains (Ettl & Gärtner 1995). An aerophilic diatom (Krammer & Lange-Bertalot 1986).

Pinnularia borealis Ehrenberg 1843

Valves of variable shape from narrowly linear through widely linear to linearly elliptic, with parallel, weakly convex, concave or undulated margin, (24)–30–60(–110) µm long, 5–18 µm wide.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia nad Matką Boską, Jaskinia Mamutowa, Jaskinia Jasna in Strzegowa, Jaskinia Głęboka and Jaskinia na Łopiankach caves; noted also in a cave in Belgium (Garbacki *et al.* 1999), Mladeč cave in the Czech Republic (Poulíčková & Hašler 2007), Ballica cave (Tokat, Turkey) (Selvi & Altuner 2007), caves in Slovenia (Mulec *et al.* 2008) and in Bulgaria (Uzunov *et al.* 2008).

ECOLOGY. Apart from caves, a freshwater cosmopolitan species common in mountains but found also in lowlands. Krammer and Lange-Bertalot (1986) classified it as an aerophilic species. A neutrophilous, α-mesosaprobous, oligomesotraphentic, fresh brackish water diatom (Van Dam *et al.* 1994).

DINOPHYTA
Dinophyceae

Gloeodinium cracoviense Starmach 1963

Cells spherical with cell walls slightly covered with a gelatinous mass. Chloroplasts fuzzy, brown. Multiplication only by aplanospores. Cells without gelatinous sheath, 7.0–10.5(–14.0) µm diam.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Nietoperzowa and Jaskinia Twardowskiego caves.

ECOLOGY. Starmach (1963) described it in Jaskinia Twardowskiego cave among cyanobacteria of the genera *Microcystis* and *Aphanocapsa*.

Phytodinium aureum Starmach 1963

Cells ellipsoidal or bean-shaped, cell wall very thick, in adult cells lamellate, chloroplast shield-shaped, cells 14–24 µm long and 8–12 µm wide.

DISTRIBUTION. In the Wyżyna Krakowsko-Wieluńska upland it was found in Jaskinia Nietoperzowa and Jaskinia Twardowskiego caves.

ECOLOGY. Starmach (1963) identified it at the entrance to Jaskinia Twardowskiego cave among other aerophytic cyanobacteria.

DISCUSSION

This survey covered 25 caves in the Wyżyna Krakowsko-Wieluńska upland and identified 82 algal species, including 33 species of procaryotic algae (cyanobacteria) and 49 species of eucaryotic algae. The latter group was represented by Chlorophyceae (29 species), Bacillariophyceae (10 species), Xanthophyceae (7 species), Dinophyceae (2 species) and Eustigmatophyceae (1 species). Chlorophytes were dominant (32.9% of all identified species); diatoms (11.8%) and xanthophytes (9.0%) were the least abundant. The most common species among cyanobacteria were *Aphanocapsa parietina, Calothrix fusca, Chroococcus minor* and *Nostoc commune*. Cyanobacteria were most often observed in places lit by natural daylight at entrances to caves and slightly deeper parts (as lampflora), where they were prominent due to massive growth. *Nodularia sanguinea, Gloeocapsa* cf. *decorticans*, *G. alpina, Nostoc commune* and *Synechococcus elongatus* dominated among the cyanobacteria in caves illuminated by artificial light (open to tourists): Jaskinia Łokietka and Jaskinia Ciemna caves.

Cyanobacteria were interspersed with other alga such as *Chlorobotrys simplex* and *Ch. terrestris* (Xanthophyceae). This mode of distribution was described by Starmach (1963), who discovered two species undescribed up to that time, belonging to Dinophyceae: *Phytodinium aureum* and *Gloeodinium cracoviense*, on wet walls of Jaskinia Twardowskiego cave. They grew among the cyanobacteria *Microcystis parietina*, *Gloeocapsa biformis*, *G. rupicola*, and *Chloroglea novacekii*. Other species belonging to Xanthophyceae, such as *Chlorobotrys simplex*, occurred in this community as well.

Chlorophytes, another important algal group living in the studied caves, concentrated around artificial light sources. The most interesting species in this group are *Bracteacoccus minor*, *Desmococcus olivaceum*, *Scotiellopsis terrestris*, *Muriella decolor* and *Trentepohlia aurea*. *Chlorella vulgaris*, *Coleochlamys perforata* and *Klebsormidium flaccidum* lived on well-illuminated surfaces. These species were most abundant in Jaskinia Zbójecka and Jaskinia Ciemna caves.

Diatoms were present in places near direct or scattered light. They usually preferred wet habitats (wet rocks or places periodically sprinkled by 'cave rain'). No diatoms were identified in Jaskinia Ciemna cave.

The most common species, occurring in almost the whole study area, included *Neocystis subglobosa* (in 11 caves), *Klebsormidium flaccidum* and *Eustigmatos magnus* (in 9 caves), *Gloeocystis polydermatica*, *Hantzschia amphioxys* and *Orthoseira roseana* (in 7 caves), and *Podohedra bicaudata* and *Pinnularia borealis* (in 5 caves).

All three groups – chlorophytes, diatoms and cyanobacteria – were crucial components of the flora developing in caves of the Polish Jura. The largest number of algal and cyanobacterial species were on rock surfaces and in depressions closest to the entrance (light zone), as observed in Jaskinia Zbójecka (19 taxa), Jaskinia Ciemna (16), Jaskinia Sąspowska (13), Jaskinia Krakowska (11) and Jaskinia Łokietka (10) caves. The alga occurred directly under or next to the light source, growing quite deeply into the stony rim. Mosses (e.g., of the genus *Crotoneuron*) or liverworts (of the genus *Polysiphonia*) living in characteristic abundant conglomerations were accompanied by aerophilic diatoms and chlorophytes including *Diadesmis contenta*, *Gomphonema italicum*, *Chlorella vulgaris*, *Trentepohlia aurea* and *Stichococcus bacillaris*. No algal or cyanobacterial growth was observed on dripstone formations. In the entrance zone and around depressions illuminated by electric light (in Jaskinia Łokietka and Jaskinia Ciemna caves), cyanobacteria (especially *Calothrix parietina*, *Gloeocapsopsis magma*, *Nostoc commune*, *Oscillatoria brevis* and *Tolypothrix tenuis*) competed for the best surfaces with other algae (e.g., *Chlamydomonas* sp., *Muriella decolor*, *Klebsormidium flaccidum*), and with mosses and pteridophytes. In deep niches they were the only phototrophs, in line with observations by Round (1981). Algal development in caves (appearing as a green growth) was undoubtedly connected with light availability, the specific microclimate (determined by air circulation, hydrological conditions, isolation from external thermal influences, and also tourism, which usually raises the existing constant temperature) and adaptation to winter conditions (chlorophytes dominating in cave flora can survive winter in the form of spores of different types). It was noted that the abundance of algae and diatoms in the caves of the Polish Jura rose with increasing humidity. As reported by Asencio and Aboal (2000a, b) and Poulíčková and Hašler (2007), the majority of European caves are characterized by humidity suitable for that growth, so the walls of their entrance zones are covered by chlorophytes and cyanobacteria. Habitat conditions in passages linking chambers lit by electric light in the caves open to tourists (Jaskinia Łokietka and Jaskinia Ciemna caves) are presumably similar, which explains the similar algal and cyanobacterial species composition. According to Round (1981), type of rock is an important determinant of the species composition and structure of algal communities. It was observed that cyanobacteria such as *Anabaena oscillarioides*, *Microcystis parietina* and *Nostoc* cf. *microscopicum*, and aerophilic algae (e.g., *Diadesmis contenta*, *Hantzschia amphioxys*, *Luticola mutica*, *L. nivalis*, *Orthoseira roseana*) were particularly sensitive to rock surface structure, temperature, light and humidity, in line with Pentecost's (1992) report. They prefer wet places, where they grow more intensively. They also show high resistance to drying out and to low ambient temperature in winter; the mechanism of algal adaptation to low temperatures is not understood in detail.

As in other surveys of cave algae, aerophilic algae and especially cyanobacteria were abundant in cave areas within the reach of natural daylight. It was usually the wall at the entrance and the slightly deeper area still illuminated by sunlight. Mulec *et al.* (2008) suggested that some species such as *Pediastrum boryanum* show not only the ability to penetrate rocky surface but also to choose the most appropriate ecological niche. To verify that, they developed a research procedure involving biofilms. The biofilm method is based on one or more species of microorganisms inhabiting the same site. The biofilm method analyzes microorganisms in different developmental stages that interact with each other, facilitating adaptation to different (changeable) conditions (Golubić & Schneider 2003; Prakash *et al.* 2003). According to Kol (1964, 1966), high species biodiversity in different caves is probably the result of the diverse light conditions in caves and specific adaptations of algae. Our present results in the Polish Jura support that.

Many authors have focused on the ecology of cave algae. Jones (1964) suggested analyzing three aspects: (*i*) whether cave algae show an active mode of multiplication, only a vegetative mode, or whether only spores are found; (*ii*) what energy source is used by algae for photosynthetic activity since they normally grow in darkness; and (*iii*) the most important problem, how they got into the caves. These questions have been addressed by Claus (1962a, b, 1964), Palik (1960, 1964a, b), Hellebust (1974), Suba (1957) and Jones (1964). The problems with assimilation that algae encounter in caves eliminated or limited phototrophism; thus, it is believed that algae developing in caves are mostly chemoautotrophs or heterotrophs. Conservation efforts focused on caves open to visitors (i.e., Jaskinia Łokietka and Jaskinia Ciemna) should identify existing and potential hazards. Local monitoring of dripstone formations in these caves will be aimed at recognizing any risks and documenting the most important dangers (e.g., development of algae on different dripstone formations) and rationally planning and implementing protection measures. Species conservation should concentrate on protecting rare, endemic or endangered native cave species. Protecting the natural environment of caves is an important problem which has proved difficult to solve.

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REFERENCES

ABOAL M. 1988. Aportación al conocimiento de las algas epicontinentales del Sudeste de España. III. Cianofíceas (Cyanophyceae Schaffner 1909). *Anales Jard. Bot. Madrid* **45**(1): 3–46.

ABOAL M. 1989. Flora algal del río Benamor (Cuenca del Segura, SE de España). *Limnética* **5**: 1–11.

ABOAL M. 1996. Epipelic algal communities in irrigation chanels of Southeastern Spain. *Algol. Stud.* **82**: 117–131.

ABOAL M. & LLIMONA X. 1984. Aportación al estudio algológico del sistema de Sierras de Ponce y Quipar (NO de Murcia, SE de España). *Anales Biol., Fac. Biol., Univ. Murcia* **2**: 1–17.

ABOAL M., PUIG M. & PREFASI 1998. Diatom assemblages in springs in Castellón province (Eastern Spain). *Algol. Stud.* **90**: 79–95.

ABOAL M., ASENCIO A. D. & LÓPEZ-JIMÉNEZ E. 2003a. Morphological, ultrastructural and ecological study of *Asterocapsa divina* Komárek (Chroococcaceae, Cyanobacteria) from a cave of Southeastern Spain. *Algol. Stud.* **109**: 57–65.

ABOAL M., ASENCIO A. D. & PREFASI M. 1994. Studies on cave cyanophytes from southwestern Spain: *Scytonema julianum* (Menegh. & Franck) Richter. *Algol. Stud.* **75**: 31–36.

ABOAL M., PREFASI M. & ASENCIO A.D. 1996. The aquatic microphytes and macrophytes of the Trasvase Tajo-Segura irrigation systems, southeastern Spain. *Hydrobiologia* **340**: 101–107.

ABOAL M., ALVAREZ COBELAS M., CAMBRA J. & ECTOR L. 2003b. Floristic list of non-marine diatoms (Bacillariophyceae) of Iberian Peninsula, Balearic Islands and Canary Islands. Updated taxonomy and bibliography. *Diatom Monographs* **4**: 1–639.

ALEKSAHINA T. I. & SHTINA E. A. 1984. Terrestrial algae of forest biogeocoenoses. Nauka, Moskva (in Russian).

ALVAREZ COBELAS M. & ESTEVEZ GARCIA A. 1982. Catalogo de las algas continentales espanolas. I. Diatomophyceae Rabenhorst 1864. *Lazaroa* **4**: 269–285.

ALVAREZ-COBELAS M. & GALLARDO T. 1988. Catálogo de las algas continentales españolas V. *Cyanophyceae* Schaffner 1909. *Acta Bot. Malacit.* **13**: 53–76.

ANAGNOSTIDIS K. & KOMÁREK J. 1988. Modern approach to the classification system of cyanophytes, 3 – Oscilatoriales. *Algol. Stud.* **50–53**: 327–472.

ANAGNOSTIDIS K., ECONOMOU-AMILLI A. & PANTAZIDOU A. 1981. Studies in the microflora of the cave Perma, Ioannina, Greece. *Bulletin, Society Speleological Greece* **18**: 458–530.

ANAGNOSTIDIS K., ECONOMOU-AMILLI A. & ROUSSOMOUSTAKAKI M. 1983. Epilithic and chasmolithic microflora (Cyanophyta, Bacillariophyta) from marbles of the Parthenon (Acropolis-Athens, Greece). *Nova Hedwigia* **38**: 227–287.

ANDREYEVA V. M. 1998. Terrestrial and aerophilic green algae – Chlorophyta: Tetrasporales, Chlorococcales, Chlorosarcinales. Nauka, St. Petersburg.

ARCHIBALD P. 1979. Descriptions of new edaphic and aquatic species of *Chlorococcum* Meneghini (Chlorococcales). *Brit. Phycol. J.* **14**: 305–312.

ARIÑO X., HERNÁNDEZ-MARINÉ M. & SAIZ-JIMÉNEZ C. 1997. Preliminary investigations on epilithic cyanophytes from a Roman necropolis. *Algol. Stud.* **75**: 71–74.

ASENCIO A. D. 1997. Flora algal y condiciones ambientales de las cuevas y abrigos con pinturas rupestres de la Región de Murcia (SE España). Ph.D.Thesis, Universidad de Murcia, Murcia.

ASENCIO A. D. & ABOAL M. 1996. Cyanophytes from *Andragulla abrigo* (Furcia, SE Spain) and their environmental conditions. *Algol. Stud.* **83**: 55–72.

ASENCIO A. D. & ABOAL M. 2000a. A contribution to knowledge of chasmoendolithic algae in cave-like environments. *Algol. Stud.* **98**: 133–151.

ASENCIO A. D. & ABOAL M. 2000b. Algae from Serreta cave (Murcia, SE Spain) and their environmental conditions. *Algol. Stud.* **96**: 59–78.

ASENCIO A. D., ABOAL M. & HOFFMANN L. 1996. A new cave-inhabiting blue-green alga: *Symphyonema cavernicolum* sp. Nova (Mastigocladacae, Stigonematales). *Algol. Stud.* **83**: 73–82.

BALLESTEROS E. & ROMERO J. 1982. Catálogo de las algas bentónicas (con exclusión de las diatomeas) de la Costa Catalana. *Collectanea Botanica a Barcinonensi Botanico Instituto* **13**(2): 723–765.

BISEK K., GRADZIŃSKI M. & WAWRYKA M. 1992. Jaskinie Ojcowskiego Parku Narodowego, Wąwóz Koziarnia. Ojcowski Park Narodowy, Muzeum im. Prof. Władysława Szafera, Ojców.

BROWN R. M. JR. & BOLD H. C. 1965. Comparative studies of the algal genera *Tetracystis* and *Chlorococcum*. *J. Phycol.* **1**(2): 1–213.

BROWN R. M. JR. & LEAN R. J. 1969. New taxonomic criteria in classification of *Chlorococcum* species. II. Pyrenoid fine structure. *J. Phycol*. **5**: 114–118.

CAÑAVERAS J. C., SÁNCHEZ-MORAL S., SOLER V. & SAIZ-JIMÉNEZ C. 2001. Microorganisms and microbially induced fabrics in cave walls. *Geomicrobiology Journal* **18**: 223–240.

CANTORAL UIZA E. A. & ABOAL SANJURJO M. 2001. El marjal Pego-Oliva: evolución temporal de la flora de macroalgas. *Limnetica* **20**(1): 159–171.

CHANG T. P. & CHANG-SCHNEIDER H. 1991. Algen in vier süddeutschen Höhlen. *Ber. Bayer. Bot. Ges*. **62**: 221–229.

CHARDEZ D. & DELHEZ F. 1981. Przyczynek do znajomości mikroorganizmów jaskiń Polski. *Rocznik Muzeum Okręgowego w Częstochowie* **5**: 9–13.

CLAUS G. 1962a. Data on the ecology of the algae of the Peace Cave in Hungary. *Nova Hedwigia* **4**: 55–80.

CLAUS G. 1962b. Beiträge zur Kenntnis der Algenflora der Abaligeter Höhle. *Hydrobiologia* **19**: 192–222.

CLAUS G. 1964. Algae and their mode of life in the Baradla Cave at Aggtelek II. *International Journal of Speleology* **1**: 13–17.

COPELAND J. J. 1936. Yellowstone thermal Myxophyceae. *Ann. New York Acad. Sci.* **36**: 1–229.

CZERWIK-MARCINKOWSKA J. & MROZIŃSKA T. 2008. Glony i sinice wybranych jaskiń Ojcowskiego Parku Narodowego. In: M. BAŚCIK & J. PARTYKA (eds), *Wody na obszarach chronionych. Materiały konferencji naukowej Pieskowa Skała, 12–14 czerwca 2008 r. Streszczenia referatów i przewodnik sesji terenowych*, p. 54. Ojcowski Park Narodowy, Ojców.

CZERWIK-MARCINKOWSKA J. & MROZIŃSKA T. 2009. Epilithic algae from caves of the Krakowsko-Częstochowska Upland (Southern Poland). *Acta Soc. Bot. Poloniae* **78**(4): 301–309.

CZERWIK-MARCINKOWSKA J. & MROZIŃSKA T. 2010a. Ochrona różnorodności biologicznej ekstremalnych siedlisk jaskiniowych Ojcowskiego Parku Narodowego. In: J. PARTYKA (ed.), *Granice ingerencji człowieka na obszarach chronionych. Streszczenia referatów i przewodnik sesji terenowych. Materiały konferencji naukowej Ojców, 17–19 czerwca 2010*, p. 35. Ojcowski Park Narodowy, Ojców.

CZERWIK-MARCINKOWSKA J. & MROZIŃSKA T. 2010b. The protection of pro- and eukaryotic algae of extreme caves habitat in the Ojców National Park. *Prądnik* **20**: 165–174 (in Polish with English summary).

DOBAT K. 1970. Considérations sur la vegetation cryptogamique des grottes du Jura Souabe(sud-ouest de l'Allemagne). *Annales de Spéléologie* **25**(4): 872–907.

DODGE J. D. 1984. Dinoflagellate taxonomy. In: D. L. SPECTOR (ed.), *Dinoflagellates*, pp. 17–42. Academic Press, Orlando, FL.

DROUET F. 1939. Francis Wolle's Filamentous Myxophyceae. *Field Mus. Nat. Hist., Bot.* **20**: 17–64.

DROUET F. 1943. Myxophyceae of eastern California and western Nevada. *Field Mus. Nat. Hist., Bot.* **20**: 145–176.

ERCEGOVIĆ A. 1925. Litofitska vegetacija vap-nenacai dolomite u Hrvatskoj (La végéteation des lithophytes sur les calcaires et les dolomites en Croatie). *Acta Botanica Instituti Botanici Universitatis Zabrabensis* **1**: 64–114.

ETTL H. 1978. Xanthophyceae 1. In: H. ETTL, J. GERLOFF, H. HEYNIG & D. MOLLENHAUER (eds), *Süsswasserflora von Mitteleuropa*. **3**(1): 1–530. G. Fischer Verlag, Stuttgart, New York.

ETTL H. & GÄRTNER G. 1988. Tetrasporales, Chlorococcales, Gloeodendrales, Chlorophyta II. In: H. ETTL, J. GERLOFF, H. HEYNIG & G. FISCHER (eds), *Süswasserflora von Mitteleuropa*. **10**: 1–453. Verlag, Stuttgart, New York.

ETTL H. & GÄRTNER G. 1995. Syllabus der Boden-, Luft und Flechtenalgen. G. Fischer Verlag. Stuttgart, Jena, New York.

GARBACKI N., ECTOR L., KOSTIKOV I. & HOFFMANN L. 1999. Contribution à l'étude de la flore des grottes de Belgique. *Belg. J. Bot.* **132**: 43–76.

GOLUBIĆ S. 1967. Algenvegetation der Felsen. Eine Ökologische Algenstudien im Dinarischen Karstgebiet. In: H. J. ELSTER & W. OHLE (eds), *Die Biennengewässer.* **22**: 1–183. Schweitzerbart'sche Verlagsbuchhandlung, Stuttgart.

GOLUBIĆ S. & SCHNEIDER J. 2003. Microbial endoliths as internal biofilms. In: W. E. KRUMBEIN, T. DORNIEDEN, M. VOLKMANN, D. M. PATERSON & G. A. ZAVARZIN (eds), *Fossil and recent biofilms. A natural history of hife on earth*, pp. 249–263. Kluwer, Dordrecht.

GOMEZ S. R., JOHANSEN J. R. & LOWE R. L. 2003. Epilithic aerial algae of Great Smoky Mountains National Park. *Biologia* (*Bratislava*) **58**: 603–615.

GÓRNY A. & SZELEREWICZ M. 2008. Jaskinia Szachownica od nowa. *Jaskinie* **53**: 30–32.

GRACIA-ALONSO C. A. 1974. *Geitleria calcarea* Friedmann nueva alga cavernicola para España. *Speleon* **21**: 133–136.

GRADZIŃSKI M. & KICIŃSKA D. 2009. Caves in Poland. In: M. GRADZIŃSKI, D. KICIŃSKA & M. SZELEREWICZ (eds), *Polish caving*: *2005–2009*, pp. 3–5. Komisja Taternictwa Jaskiniowego Polskiego Związku Alpinizmu, Warszawa.

GRADZIŃSKI M. & SZELEREWICZ M. 2004. Jaskinie Wyżyny Krakowsko-Wieluńskiej – liczba i rozmieszczenie. In: J. PARTYKA (ed.), *Zróżnicowanie i przemiany środowiska przyrodniczo-kulturowego Wyżyny Krakowsko-Częstochowskiej*. **1**: 69–82. Ojcowski Park Narodowy, Ojców.

GRADZIŃSKI M., GÓRNY A. & SZELEREWICZ M. 1995a. Jaskinie Ojcowskiego Parku Narodowego, Wąwóz Jamki. Ojcowski Park Narodowy, Muzeum im. Prof. Władysława Szafera, Ojców.

GRADZIŃSKI M., MICHALSKA B., SZELEREWICZ M. & WAWRYKA M. 1998. Jaskinie Ojcowskiego Parku Narodowego, Dolina Prądnika, część południowo-zachodnia. Ojcowski Park Narodowy, Muzeum im. Prof. Władysława Szafera, Ojców.

GRADZIŃSKI M., MICHALSKA B., WAWRYKA M. & BISEK K. 1996. Jaskinie Ojcowskiego Parku Narodowego, Chełmowa Góra. Ojcowski Park Narodowy, Muzeum im. Prof. Władysława Szafera, Ojców.

GRADZIŃSKI M., MICHALSKA B., WAWRYKA M. & SZELEREWICZ M. 2007. Jaskinie Ojcowskiego Parku Narodowego, Dolina Prądnika, Góra Koronna, Góra Okopy. Ojcowski Park Narodowy, Muzeum im. Prof. Władysława Szafera, Ojców.

GRADZIŃSKI M., WAWRYKA M., BISEK K. & MICHALSKA B. 1995b. Jaskinie Ojcowskiego Parku Narodowego, Dolina Sąspowska, część zachodnia. Ojcowski Park Narodowy, Muzeum im. Prof. Władysława Szafera, Ojców.

HAJDU L. 1966. Algological studies in the Cave of Mátyás Mount, Budapest, Hungary. *International Journal of Speleol*ogy **2**: 137–149.

HAŠLER P. & POULÍČKOVÁ A. 2005. Cyanobacteria of the West Carpathian Mts spring fens: single samplings. *Czech Phycology* **5**: 43–55.

HAUER T. 2007. Rock-inhabiting cyanprokaryota from South Bohemia (Czech Republic). *Nova Hedwigia* **85**(3–4): 379–392.

HAUER T. 2008. Epilithic cyanobacterial flora of Mohelenská hascová steppe Nature Reserve (western Moravia, Czech Republic) 70 years ago and now. *Fottea* **8**(2): 129–132.

HELLEBUST J. A. 1974. Algal physiology and biochemistry. Blackwell Scientific Publications, Oxford.

HERNÁNDEZ-MARINÉ M. & CANALS T. 1994. *Herpyzonema pulverulentum* (Mastigocladaceae), a new cavernicolous atmophytic and lime-incrusted cyanophyte. *Algol. Stud.* **75**: 123–136.

HERNÁNDEZ-MARINÉ M., ASENCIO A. D., CANALS A., ARIÑO X., ABOAL M. & HOFFMANN L. 1999. Discovery of populations of the lime-incrusted cyanophyte. *Algol. Stud.* **94**: 121–138.

JOHN D. M., WHITTON B. A. & BROOK A. J. 2002. The freshwater algal flora of the British Isles: an identification guide to freshwater and terrestrial algae. The Natural History Museum, Cambridge University Press, Cambridge.

JONES H. J. 1964. Algological investigations in Mammoth Cave, Kenteucky. *International Journal of Speleology* **1**: 491–516.

KANN E. 1978. Systematik und Ökologie der Algen österreichischer Bergbäche. *Arch. Hydrobiol.* **53**: 405–643.

KAŠTOVSKÝ J., FUČIKOVÁ K., HAUER T. & BOHUNICKÁ M. 2011. Microvegetation on the top Mt. Roraima, Venezuela. *Fottea* **11**(1): 171–186.

KHAYBULLINA L. S., GAYSINA L. A., JOHANSEN J. R. & KRAUTOVÁ M. 2010. Examination of the terrestrial algae of the Great Smoky Mountains National Park, USA. *Fottea* **10**(2): 201–215.

KOL E. 1964. The microvegetation of a Small Ice-Cave in Hungary. *International Journal of Speleology* **1**: 19–24.

KOL E. 1966. Algal growth experiments in the Baradla Cave at Aggletek. *International Journal of Speleology* **2**: 457–474.

KOMÁREK J. & ANAGNOSTIDIS K. 1986. Modern approach to the classification system of cyanophytes 2 – Chroococcales. *Algol. Stud.* **43**: 157–226.

KOMÁREK J. & ANAGNOSTIDIS K. 1989. Modern approach to the classification system of cyanophytes 4 – Nostocales. *Algol. Stud.* **56**: 247–345.

KOMÁREK J. & ANAGNOSTIDIS K. 1998. Cyanoprocaryota 1. Chroococcales. In: H. ETTL, G. GÄRTNER, H. HEYNING & D. MOLLENHAUER (eds), *Süßwasserflora von Mitteleuropa.* **19**(1): 1–548. Gustav Fischer Verlag, Jena, Stuttgart, Lübek, Ulm.

KOMÁREK J. & ANAGNOSTIDIS K. 2005. Cyanoprokaryota. 2. Teil: Oscillatoriales. In: B. BÜDEL, G. GÄRTNER, L. KRIENITZ & M. SCHAGERL (eds), *Süßwasserflora von Mitteleuropa*. **19**(2): 1–759. Elsevier, München.

KOMÁROMY L. P. 1977. The algal flora of the Ördöglyuk Cave at Szoplak (Hungary). *Ann. Hist.-Nat. Mus. Natl. Hung.* **69**: 29–35.

KONDRACKI J. 1981. Geografia fizyczna Polski. Państwowe Wydawnictwo Naukowe, Warszawa.

KOSTER J. T. 1960. Caribbean brackish and freshwater Cyanophyceae. *Blumea* **10**: 323–366.

KOSTIKOV I. J., ROMANENKO P. O., DEMCHENKO E. M., DARIENKO T. M., MIKHAYLJUK T. I., RYBCHNNSKIY O. V. & SOLONENKO A. M. 2001. Soil algae of Ukraine. Phytosotsiologichniy Center, Kiev (in Ukrainian).

KRAMMER K. & LANGE-BERTALOT H. 1986. Bacillariophyceae. 1. Naviculaceae. In: H. ETTL, J. GERLOFF, H. HEYNING & D. MOLLENHAUER (eds), *Süßwasserflora von Mitteleuropa.* **2**(1): 1–876. G. Fischer Verlag, Stuttgart, New York.

KRAMMER K. & LANGE-BERTALOT H. 1988. Bacillariophyceae. 2. Bacillariaceae, Epithemiaceae, Surirellaceae. In: H. ETTL, J. GERLOFF, H. HEYNING & D. MOLLENHAUER (eds), *Süßwasserflora von Mitteleuropa.* **2**(2): 1–596. G. Fischer Verlag, Stuttgart, New York.

KRAMMER K. & LANGE-BERTALOT H. 1991. Bacillariophyceae. 3. Centrales, Fragilariaceae, Eunotiaceae. In: H. ETTL,

J. Gerloff, H. Heyning & D. Mollenhauer (eds), *Süßwasserflora von Mitteleuropa.* **2**(3): 1–576. G. Fischer Verlag, Stuttgart, Jena.

Kuehn K. A., Oneil R. M. & Koehn R. D. 1992. Viable photosynthetic microalgal isolates from aphotic environments of the Edwards aquifer (central Texas). *Stygologia* **7**(3): 129–142.

Lamprinou V., Pantazidou A., Papadogiannaki G., Radea C. & Economou-Amilli A. 2009. Cyanobacteria and associated invertebrates in Leontari Cave, Attica (Greece). *Fottea* **9**(1): 155–164.

Macedo M. F., Miller A. Z, Dionísio A. & Saiz-Jimenez C. 2009. Biodiversity of cyanobacteria and green algaeon monuments in the Mediterranean Basin: an overview. *Microbiology* **155**: 3476–3490.

Martinčič A., Vrhovšek D. & Batič F. 1981. Flora v jamah z umetno osvetlitvijo. *Biol. Vestn.* **29**(2): 27–56.

Martinez A. & Asencio A. D. 2010. Distribution of cyanobacteria at the Gelada Cave (Spain) by physical parameters. *Journal of Cave and Karst Studies* **72**(1): 11–20.

Massalski A., Mrozińska T. & Olech M. 1995. *Lobococcus irregularis* (Boye-Pet.) Reisigl var. nov. (Chlorellales, Chlorophyta) from King George Island, South Shetland Islands, Antarctica, and ist ultrastructure. *Nova Hedwigia* **61**(1–2): 199–206.

Matuła J., Pietryka M., Richter D. & Wojtuń B. 2007. Cyanoprokaryota and algae of arctic terrestrial ecosystems in the Hornsund area Spitsbergen. *Polish Polar Res*. **28**(4): 283–315.

Michalik S. & Partyka J. 1992. Scientific-didactic trail 'Chełmowa Mountain'. Ojców National Park. Krajowa Agencja Wydawnicza, Kraków.

Mrozińska T. 1990. Aerophytic algae from North Korea. *Algol. Stud.* **58**: 29–47.

Mrozińska-Broda T. & Czerwik-Marcinkowska J. 2004. Eukariotic (epilithic) algae found in caves in the Kraków-Częstochowa Upland. In: J. Partyka (ed.), *The diversification and transformation of natural and cultural environment of the Kraków-Częstochowa Upland*. **1**: 171–178. Ojcowski Park Narodowy, Ojców.

Mulec J. 2005. Algae in the karst caves of Slovenia. Ph.D. Thesis, University of Lubljana, Ljubljana.

Mulec J. 2008. Microorganisms in hypogeon: examples from Slovenian karst caves. *Acta Carsologica* **37**(1): 153–160.

Mulec J. & Kosi G. 2008. Algae in the aerophytic habitat of Račiške ponikve cave (Slovenia). *Natura Sloveniae* **10**(1): 39–49.

Mulec J., Kosi G. & Vrhovšek D. 2007. Algae promote growth of stalagmites and stalactites in karst caves (Škocjanske Jame, Slovenia). *Carbonates and Evaporites* **22**(1): 6–9.

Mulec J., Kosi G. & Vrhovšek D. 2008. Characterization of cave aerophytic algal communities and effects of irradiance levels on production of pigment. *Journal of Cave and Karst Studies* **70**(1): 3–12.

Palik P. 1938. Beiträge zur Kenntnis der Lithophyten Algenvegetation des Bükkgebirges. In: *Index Horti Botanici Universitatis Budapestinensis*. **3**: 143–150. Dunántúl Pécsi Egyetemi Könyvkiadó és Nyomda R.-T., Pécs (in Hungarian).

Palik P. 1960. Study into the algal flora of caves. *Hidrológiai Közlöny* **40**: 417–422.

Palik P. 1964a. Über die Algenwelt der Hühlen in Ungarn. *International Journal of Speleology* **1**(1–2): 35–44.

Palik P. 1964b. Eine neue Aulakochloris-Art. aus der Tropfsteinhühle von Abaliget. *International Journal of Speleology* **1**(1–2): 25–28.

Pedersen K. 2000. Exploration of deep intraterrestrial microbial life: current perspective. *MiniReview*: *FEMS Microbiology Letters* **185**: 9–16.

Pentecost A. 1992. A note on the colonization of limestone rocks by cyanobacteria. *Arch. Hydrobiol.* **124**: 167–172.

Pentecost A. & Zhang Z. 2001. The distribution o plants in Scoska Cave, North Yorkshire, and their relationship to light intensity. *International Journal of Speleology* **30**: 27–37.

Pócs T. 2009. Cyanobacterial crust types, as strategies for survival in extreme habitats. *Acta Bot. Hung.* **51**(1–2): 147–178.

Ponikiewicz A. 2008. Problems of protection natural environmental in Polish caves. In: *Materiały konferencji naukowej. Ekologiczne problemy XXI wieku*, pp. 15–21. Uniwersytet Warszawski, Warszawa.

Poulíčková A. 2008. Morphology, cytology and sexual reproduction in the aerophytic cave diatom *Luticola dismutica* (Bacillariophyceae). *Preslia* **80**: 87–99.

Poulíčková A. & Hašler P. 2007. Aerophytic diatoms from caves in central Moravia (Czech Republic). *Preslia* **79**: 185–204.

Prakash B., Veeregowda B. M. & Krishnappa G. 2003. Biofilms: a survival strategy of bacteria. *Curr. Sci.* **85**: 1299–1307.

Printz H. 1939. Vorarbeiten zu einer Monographie der Trentepohliaceae. *Nytt. Mag. Naturvidensk*. **80**: 137–210.

Rajczy M. 1989. The Flora of Hungarian caves. *Karsztés Barlang* (Special Issue): 69–72.

Rajczy M., Buczkó K. & Komáromy P. 1986. Contributions to the flora of the Hungarian caves I. Flora of the entrances of the caves Lők-völgyi-barlany and Szeleta-barlany. *Stud. Bot. Hung.* **9**: 79–88.

Reynolds E. 1963. The use of lead citrate at high pH as an electron-opaque stain in electron microscopy. *J. Cell Biol.* **17**(1): 208–212.

ROLDÁN M. & HERNÁNDEZ-MARINÉ M. 2009. Exploring the secrets of the three-dimensional architecture of phototrophic biofilms in caves. *International Journal of Speleology* **38**(1): 41–53.

ROUND F. E. 1981. The ecology of algae. Cambridge University Press, Cambridge, London, New York, New Rochelle, Melbourne, Sydney.

SANCHEZ M., ALCOCER J., ESCOBAR E. & LUGO A. 2002. Phytoplankton of cenotes and anchialine caves along a distance gradient from the northeastern coast of Quintana Roo, Yucatan Peninsula. *Hydrobiologia* **467**(1–3): 79–89.

SELVI B. & ALTUNER Z. 2007. Algae of Ballica Cave (Tokat-Turkey). *International Journal of Natural and Engineering Sciences* **1**(3): 99–103.

SKUJA H. 1970. Alghe cavernicole nelle zone illuminate delle grotte di Castellana (Murge di Bari). *Le Grotte d'Italia, Ser. 4* **2**: 193–202.

SMITH T. & OLSON R. 2007. A taxonomic survey of lamp flora (algae and cyanobacteria) in electrically lit passages within Mammoth Cave National Park, Kentucky. *International Journal of Speleology* **36**(2): 105–114.

STARMACH K. 1963. New species of the order Dinococcales (Pyrrophyta) from the Twardowski Cave in Kraków. *Acta Hydrobiol.* **3**(4): 342–377.

STARMACH K. 1966. Cyanophyta – Sinice, Glaucophyta – Glaukofity. Państwowe Wydawnictwo Naukowe, Warszawa.

STARZECKI W. 1959. Microclimatic research in caves of the southern part of Małopolska Highlands. *Ekol. Polska*, *Ser. A* **7**: 189–219.

SUBA E. 1957. Die Algen der Palvolgyes Höhle in Ungarn. *Verh. Zool.-Bot. Ges. Wien* **97**: 97–109.

SZELEREWICZ M. & GÓRNY A. 1986. Jaskinie Wyżyny Krakowsko-Wieluńskiej. Wydawnictwo „Kraj", Kraków.

UHER B. & KOVÁČIK L. 2002. Epilithic cyanobacteria of subaerial habitats in National Park Slovak Paradise (1998–2000). *Bulletin Slovenskej Botanickej Spoločnosti* **24**: 25–29.

UHER B., ABOAL M. & KOVÁČIK L. 2005. Epilithic and chasmoendolithic phycoflora of monuments and buildings in south-eastern Spain. Cryptogamie Algol. **26**: 275–358.

URBAN J. 2006. Legal and practical protection of caves in Poland. *Chrońmy Przyr. Ojczystą* **62**(1): 53–72 (in Polish with English summary).

UZUNOV B. A., STOYNEVA M. P. & GÄRTNER G. 2008. Review of the studies on aero-terrestrial cyanoprokaryotes and algae in Bulgaria with a checklist oft he recorded species. II. *Phytologia Balcan.* **14**(1): 11–18.

VAN DAM H., MARTENS A. & SINKELDAM J. 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. *Netherlands Journal of Aquatic Ecology* **28**: 117–133.

WEHR J. D. & SHEATH G. 2003. Freshwater algae of North America: ecology and classification. Academic Press, San Diego.

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