Research on cryosestic communities in Svalbard: the snow algae of temporary snowfields in Petuniabukta, Central Svalbard

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Abstract

Although the observations of the colored snow in Svalbard are dated from 17th century, the research in cryosestic algae during last 50 years was focused to NW part of Svalbard, Hornsund and Sveagruva areas. No observations have been reported for the Central or East Svalbard yet, with exception of Longyearbyen and Sveagruva areas. In Petuniabukta, two types of possible cryoseston habitats were recognized: 1) temporal snow fields that melt-away in summer completely, and 2) perennial glacier surfaces. During summer seasons 2009 - 2011, ten temporary snow field samples were sampled in the Petuniabukta area. The cryosestic communities did not cause visible snow coloration, however the presence of snow algae was revealed by light microscope. In samples, zygospores of *Chlamydomonas* cf. *nivalis*, were dominant. Other found species included *Chlamydomonas nivalis*, *Chloromonas nivalis*, *Cryodactylon glaciale*, and cf. *Chainomonas* sp. No motile stages of snow algae were observed. Due to low cell concentration and association of the cells with dust grains, wind transport of snow algae to the snow fields seems to be more possible than presence of a stable cryosestic community growing *in situ*.

Key words: Snow fields, cryoseston

Introduction

The cryosestic communities are regularly found in alpine and the polar regions where temporary or permanent snow fields develop, and demonstrate themselves as conspicuous red, orange, green colored snow. The first record of colored snow in Svalbard archipelago originates from 1671 (Martens 1675), however the scientific research on Svalbard cryoseston dates from 1838 when the first microscopic observation of red snow were performed and the first scientific study on identification *Chlamydomonas nivalis* was published (Meyen 1840). The observation of the green snow was recorded in 1838 (Meyen 1840).

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Fig. 1. The localities in Svalbard where research on cryosestic communities has been performed during last 50 years.

The first floristic studies in the last quarter of the 19th and in the beginning of the 20th centuries revealed 29 species, but only ten of them were considered as true cryobionts (*see* Kol et Eurola (1974) for review). Kol et Eurola (1974) found 12 species in cryosestic communities in Sveagruva area, Central Svalbard (Fig. 1). Skulberg (1996) reported 766 species of terrestrial and freshwater cyanobacteria and algae in Svalbard of which only approximately ten could be considered as cryosestic. However these data on snow species in Skulberg (1996) were limited and were taken from Kol (1968) and Kol et Eurola (1974) and, of course, cannot reflect the changes in taxonomic positions of some species of *Scotiella* and *Trochiscia* genera afterwards (Hoham 1974, Hoham 1975, Hoham et al. 2002, Hoham et Mullet 1977, Hoham et Mullet 1978, Hoham et al. 1979). During last 15 years, the research on snow algae was focused on their ecophysiology (Leya et al. 2000, Müller et al. 1998, Stibal et al. 2007) or was included in ecological studies (Matula et al. 2007, Müller et al. 2001, Remias et al. 2012, Remias et al. 2009, Säwström et al. 2002, Stibal et al. 2006). The updated list of cyanobacteria and algae found in snow and/or glacier ecosystems in Svalbard is summarized in Table 1.

The genera typical for cryosestic habitats, *i.e. Ancylonema nivale*, *Chlamydomonas* spp., *Chloromonas* spp., *Mesoteenium bergrenii Raphidonema* spp. *Tetraspora* sp. (Hoham et Duval 2001, Kol 1968, Komárek et Nedbalová 2007) are common, however majority of observed species/genera are not considere to belong to snow algae and could originate from cryoconites or other habitats.

Although the cryovegetation is supposed to be widespread in Svalbard, the research on the snow algae was restricted to only five areas - the Northwest Svalbard, Ny Ålesund, Hornsund and Sveagruva and Longyearbyen areas during last 50 years (Fig. 1). No observations have been reported from Central or Eastern Svalbard, with exception of Sveagruva area almost 50 years ago (Kol et Eurola 1974) and Longyerbreen in 2010 (Remias et al. 2012).

The Czech polar station, located in Petuniabukta, Central Svalbard, is a site where no studies on snow-fields and cryosestic vegetation have been performed yet. The aim of this study was to find possible suitable habitats for cryovegetation in this area and to characterize community of the snow algae there.

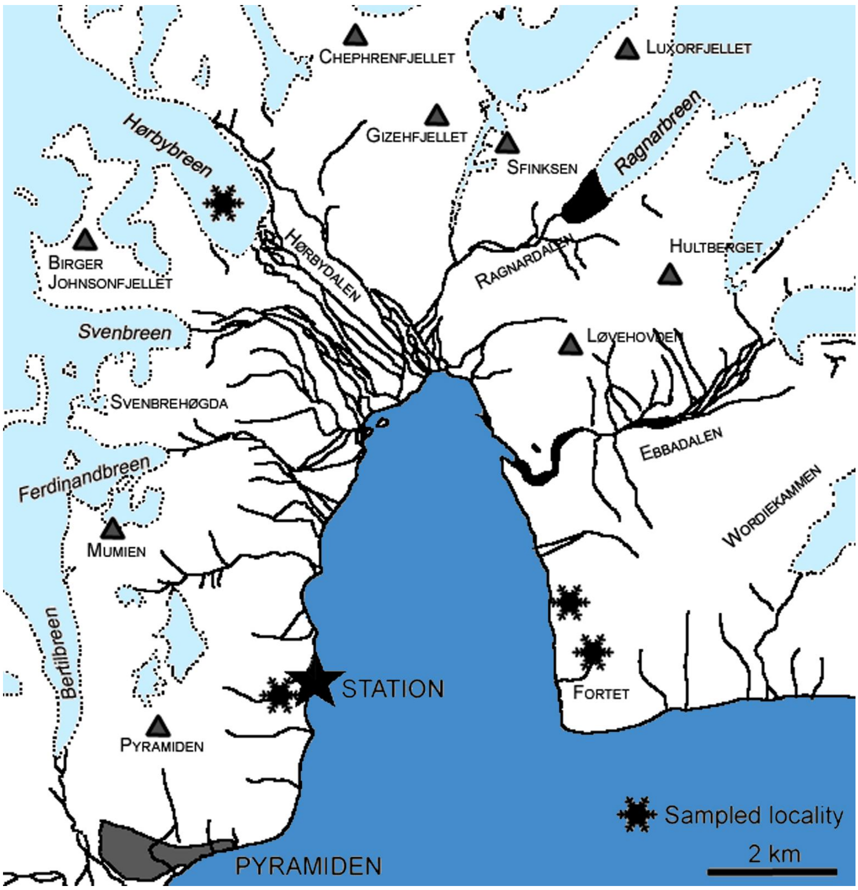

Fig. 2. Sampled areas in Petuniabukta. Dark blue – sea, Pale blue – glaciers. Hørbybreen was sampled by Komárek and Strunecký.

Material and Methods

Sampling site

The samples were collected from temporal snow fields in the vicinity of the Czech polar station in Petuniabukta (N 78° 40′ 49.3′′, E 16° 27′ 18.1′′) in July - August 2009 - 2011. The sampling areas are shown in Fig. 2. The samples of ca 100 ml snow were collected and kept in cold dark place till return to Třeboň or evaluated at the station.

Genera/Species determination

A 1.5 ml of sample thickened by sedimentation of 50 ml snow sample was fixed by a drop of 3 % formaldehyde + $CuSO_4.5H_2O$ solution. The species composition was evaluated by the light microscope Olympus BX-51 (Olympus C&S, Japan). The microphotographs were taken by digital camera Olympus DP71 (Olympus C&S, Japan) and processed by QuickPhoto Camera 2.3 software (Promicra, Czech Republic). The species/genera were determined according to Ettl (1983) and Ettl et Gärtner (1995).

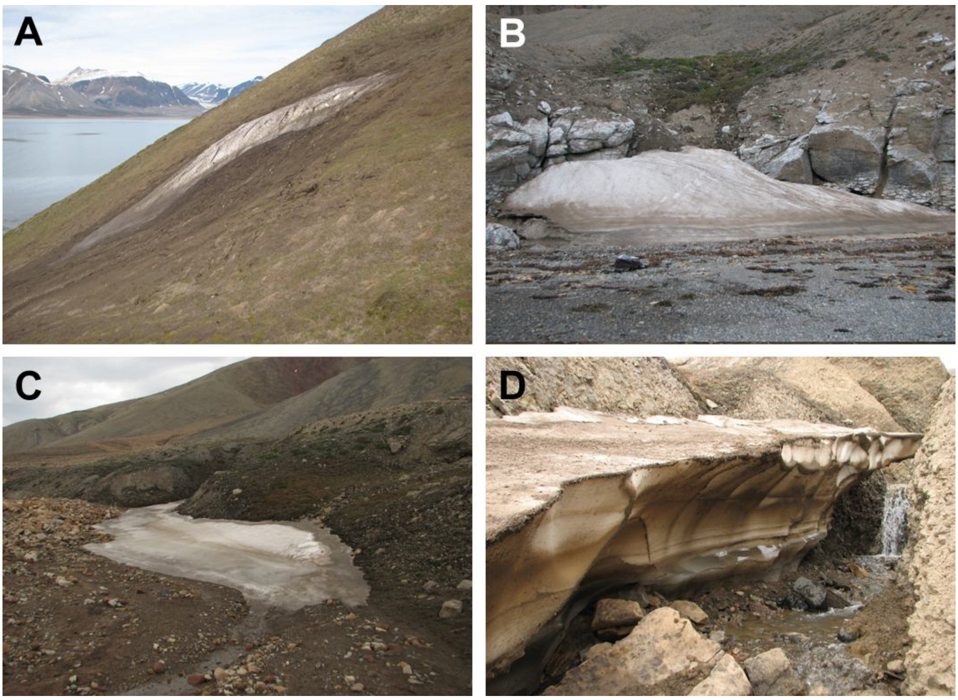

Fig. 3. The different temporal snow fields in the coastal zone of Petuniabukta. A – snowfield in the slope, B – snowfield at the seashore, C – snowfield at a source of a stream below a terrace, D – snowfield in a ravine with layered deposits of snow and sediment.

Results and Discussion

Possible cryosestic habitats

The possible cryosestic habitats in Petuniabukta should be divided in two distinct types: 1) temporal snow fields that melt-away in summer completely, and 2) perennial glacier surfaces. The temporal snowfields were located near the west and east coasts of the Petuniabukta bay (*see* Fig. 2 for the exact position of sampling sites) at elevations in range 0 to 50 m a.s.l. and their area was usually several to tens m^2. These snowfields were formed in terrain depressions like ravines or deeply-cut stream beds where the snow had accumulated in winter (Fig. 3) and usually melted away in late July – early August. The surface of the temporal snowfields was covered by soil deposits up to several mm thick. The soil was probably carried by wind and the concentration of the soil particles on the surface was probably caused by melting (Hošek et Kaufman 1995). Repeated snow and soil depositions and thaw-freeze cycles could result in layered structure (Fig. 3).

The temporal snowfields were recorded at the Svalbard west coast (Müller et al. 2001). The seasonal dynamics of these snowfields is similar to the snowfields in low-altitude (below ca 1500 m a.s.l.) alpine regions like in the Giant Mountains, Czech Republic (Kvíderová 2010, Kvíderová et Kociánová 2011). Since there were found cryosestic communities in the alpine regions (Kvíderová 2010, Kvíderová et Kociánová 2011, Nedbalová et al. 2008), the temporal snowfiels seems to be a novel habitat for the snow algae in the polar regions. Further investigations similar to Kvíderová (2010) are necessary to describe these snowfileds in detail.

Contrary to temporal snowfields, the glacier surfaces represent persistent habitats where the snow algae could be found regularly (Leya et al. 2001, Müller et al. 1998, Müller et al. 2001, Newton 1982, Remias et al. 2012, Stibal et al. 2007, Stibal et al. 2006). These habitats could be found on the surface of surrounding glaciers (Hørbybreen, Ferdinadbreen, Svenbreen, Elsabreen, Ragnarbreen, Ebbabreen, Pollockbreen), however these glaciers in Petuniabukta area were not coloured intensively as those at Svalbard west coast (Leya et al. 2001, Müller et al. 1998, Müller et al. 2001, Newton 1982, Stibal et al. 2007, Stibal et al. 2006) or in Longyearbyen (Remias et al. 2012) and Sveagruva (Kol et Eurola 1974) areas. The cryosestic communities on glacier surfaces should localized in patches, as in the Giant Mountains, Czech Republic (Kvíderová 2010, Nedbalová et al. 2008). Although Komárek and Strunecký (pers. com.) observed cryosestic communities at Hørbybreen, detailed survey of the glaciers is necessary in order to determine percentage of the glacier area covered by cryosestic communities and to characterize the condition of occurrence of the snow algae.

Algal communities

Although massive blooms of the snow algae were reported in Ny Ålesund and Horsund areas (Leya et al. 2001, Müller et al. 1998, Müller et al. 2001, Newton 1982, Stibal et al. 2007, Stibal et al. 2006), such these blooms were not observed in Petuniabukta at the same period of year (July-August).

Reference #	1	2	3	4	5	6	7	8	9	10	11	12
Cyanophyta												
Chlorogloea sp.									+			
Leptolyngbya sp.											+	
Leptolyngbya cf. *deliactula* (Compere) Anagnostidis 2001									+			
Leptolyngbya foveolarum (Rabenhorst ex Gomont) Anagnostidis et Komárek 1988									+			
Leptolyngbya hansgirgiana Komárek in Anagnostidis 2001									+			
Leptolyngbya cf. *notata (Schmidle)* Anagnostidis et Komárek 1988									+			
Microcoelus vaginatus (Vaucher) Gomont 1892									+			
Nostoc sp.		+						+	+			
Oscillatoria sp.		+									+	
cf. *Pseudanabaena* sp.									+		+	
Pseudophormidium sp.									+			
Phormidium sp.		+						+			+	
Phormidium amoenum Kützing ex Anagnostidis et Komárek 1988									+			
Chlorophyta												
Chlorophyceae												
Bracteacoccus sp.									+			
cf. *Chlainomonas* sp.												+
Chlorococcum sp.		+										
cf. *Chlorococcum* sp.									+			
Chlamydomonas sp.		+		+	+							+
Chlamydomonas nivalis (Bauer) Wille 1903	+	+	+	+	+	+	+	+	+	+	+	+
Chloromonas sp.		+		+	+							
cf. *Chloromonas* sp.		+										
Chloromonas bolyaiana (Kol) Gerloff & Ettl 1970	+											
= *Chlamydomonas bolyaiana* var. *Svalbardensis* Kol & Eurola 1974												
Chloromonas brevispina (Fritsch) Hoham, Roemer & Mullet 1979	+	+		+								
= *Cryocystis brevispina* f. *fennoscandica* Kol & Eurola 1974												
= *Trochiscia nivale* Lagerheim 1892												
Chloromonas nivalis (Chodat) Hoham & Mullet 1978	+	+		+		+				+		+
= *Scotiella nivalis* (Chodat) Fritsch 1912												
= *Scotiella antarctica* f. *svalbardensis* Kol & Eurola 1974												
Coenochloris sp.		+										
Coleochlamys cuccumis (Reisigl) Ettl & Gärtner 1995									+			
Cryodactylon glaciale Chodat 1921								+				+
Cylindromonas sp.								+				
Cystomonas sp.		+						+				
cf. *Desmococcus* sp.		+										
Gloeocystis polydermatica (Kützing) Hindák 1978			+									
Hazenia mirabilis Bold 1958		+										
Macrochloris sp.		+										
Myrmecia biatorellae (Tschermak-Woess & Plessl) Petersen 1956		+										
Protoderma cohaerens (Wittrock) Printz 1964	+											
= *Pleurococcus vulgaris* var. *cohaerens* Wittrock 1883												
cf. *Rhexinema* sp.		+										
Scotiella sp.	+								+			
Tetracystis sp.		+										
cf. *Tetraspora* sp.		+										
Tetraedron valdezi Kol 1942	+											
cf. *Troichisciopsis* sp.									+			
Trebouxiophyceae												
Chlorella sp.		+						+	+			
Chlorella homosphaera Skuja 1948									+			
Chlorella minutissima Fott & Nováková 1969									+			

Reference #	1	2	3	4	5	6	7	8	9	10	11	12
Chlorella vulgaris Beijerinck 1890			+						+			
Muriella sp.									+			
Muriella terrestris Petersen 1932									+			
Pseudococcomyxa simplex (Mainx) Fott 1981									+			
Raphidonema sp.				+	+					+		
Raphidonema bernium Kol 1935		+										
Raphidonema nivale Lagerheim 1892	+										+	
Raphidonema tatrae Kol 1933		+										
Stichococcus sp.		+										
Stichococcus bacillaris Nägeli 1849	+	+		+		+			+			
= *Stichococcus nivalis* Chodat 1917												
Stichococcus cf. *chlorelloides* Grintzesco & Péterfi 1932									+			
Stichococcus minutus Grintzesco & Peterfi 1932									+			
Stichococcus cf. *undulatus* Vinatzer 1975		+										
cf. *Trebouxia* sp.		+										
Ulvophyceae												
Gloeotila cf. *protogenita* Kützing 1849	+											
Streptophyta												
Klebsormidiophyceae												
Klebsormidium sp.									+			
Klebsormidium flaccidum (Kützing) Silva, Mattox & Blackwell 1972		+							+			
Klebsormidium cf. *scopulinum* (Hazen) Ettl & Gärtner 1995		+										
Zygnematophyceae												
Ancylonema nordenskiöldii Berggern 1871	+	+					+				+	
+*Cosmarium debaryii* Archer 1861		+										
Cosmarium cf. *goniostichum* Skuja 1964		+										
Cosmarium cf. *hammeri* var. *homalodernum* (Nordstedt) West & West 1905		+										
Cosmarium holmiense Lundell 1871		+										
Cosmarium ralfsii Brébisson ex Ralfs 1848		+										
Cylindrocystis sp.									+			
Cylindrocystis brebissonii f. *cryofila* (Ralfs) de Bary 1858	+											
Mesotaenium berggrenii (Wittrock) Lagerheim 1892	+											
Mesotaenium berggrenii var. *alaskana* Kol 1942							+					
Chromophyta												
Bacillariophyceae												
Gyrosigma sp.		+										
Melosira sp.		+										
Nitzschia sp.		+										
Pinnularia sp.		+										
pennate diatoms									+			
Xanthophyceae												
cf. *Chlorellidiopsis* sp.									+			
cf. *Gloeobotrys* sp.									+			
Heterococcus sp.									+			
Xanthonema cf. *sessile* (Vinatzer) Ettl & Gärtner 1995									+			
Dinophyta												
Gymnodinium sp.		+										

Table 1. The list of cyanobacterial and algal species found in glacial and snow ecosystems in Svalbard. The numbers indicate following references: 1 – Kol et Eurola (1974), 2 – Leya et al. (2000), 3 – Matula et al. (2007), 4 – Müller et al. (1998), 5 – Müller et al. (2001), 6 – Newton (1982), 7 – Remias et al. (2012), 8 – Säwström et al. (2002), 9 – Stibal et al. (2006), 10 – Stibal et al. (2007), 11 – Komárek and Strunecký, pers. com., 12 – This study.

At the Svalbard west coast, the cell densities reach order of magnitude of 10^4-10^6 cells ml^{-1} (Müller et al. 1998, Müller et al. 2001, Stibal et al. 2007).

These values are comparable with alpine regions in temperate zone (Hoham et Duval 2001, Kvíderová 2010). In Longyearbyen and Sveagruva, the cell density is 10^3-10^4 cells ml^{-1} (Kol et Eurola 1974, Remias et al. 2012), one or two orders of magnitude lower than in the coastal area. In my samples, the cell density did not exceed 10^3 cells ml^{-1}, indicating thus less favorable growth conditions. Larger studies with snow samples from different parts of Svalbard seem to be necessary to determine the effects of local climate and microhabitat conditions on the occurrence of snow algae.

The found species are listed in Table 1. Despite of low cell density, the green, orange and dark-red zygospores (cysts) of *Chlamydomonas* cf. *nivalis* of diameter of 10 to 30 µm were dominant in the samples from temporal snow-fields (Fig. 4A-F). Zoospores of *Chlm.* cf. *nivalis* were not observed. The different cell color indicates different intracellular concentrations of secondary carotenoids (Leya et al. 2009, Remias et al. 2005) and could reflect diffrerent phases of cyst formation (Remias et al. 2010). The cells were attached to dust grains (Fig. 5).

The green oval cells of ca 25x10 µm lacking flagellas should be identified as newly formed zygospores of *Chloromonas nivalis* (Fig. 4G). The orange oval of cells 15x10 µm should belong to cf. *Cryodactylon glaciale* (Fig. 4H-I), however *Cryodactylon glaciale* is also considered as zygospore of *Chloromonas brevispina* after loss of primary cell wall (Hoham et al. 1979). The small orange-golden spherical cells of diameter of ca 5-8 µm, but not above 10 µm could be identified as *Chlamydomonas* sp. zygospores (Fig. 4J-K), however they could represent *Desmotetra* sp. Cultivation experiments and sequencing are necessary to confirm these observation. The large oval cells of 40x25 µm with visible papilla should be representative of *Chainomonas* sp. (Fig. 4L).

The cryoseston of the perennial glacier also dominated by red zygospores of *Chlamydomonas* cf. *nivalis* and orange zygospores of *Chlamydomonas* sp. Contrary to temporal snow fields, *Ancylonema nordeskioeldii*, *Raphidonema nivale* and filamentous cyanobacteria were observed (Komárek and Strunecký, pers. com.).

Low cell density and presence of only small cells attached to dust grains in temporal snow fields imply wind transportation from other localities and/or from soil seed bank. The source of the cells remainds unknown, however anemo-orographical systems in Svalbard should be considered. Annual cell circulation in a small scale and possible long-distance wind transport have been suggested by Müller et al. (2001). According to prevailing winds in Petuniabukta from south (Láska et al. 2012), the cells sources could be located at Isfjord coast or Longyearbyen area.

Although the cryosestic communities are not dominant in Petuniabukta, Central Svalbard, their observation in Central Svalbard should bring a new perspective on their distribution in the polar regions. Genetic analyses for comparison of populations from different parts of Svalbard should reveal if the cells were transported to this area or they form a local population. The analyses atmosphere samples could confirm or deny the hypothesis on wind transport.

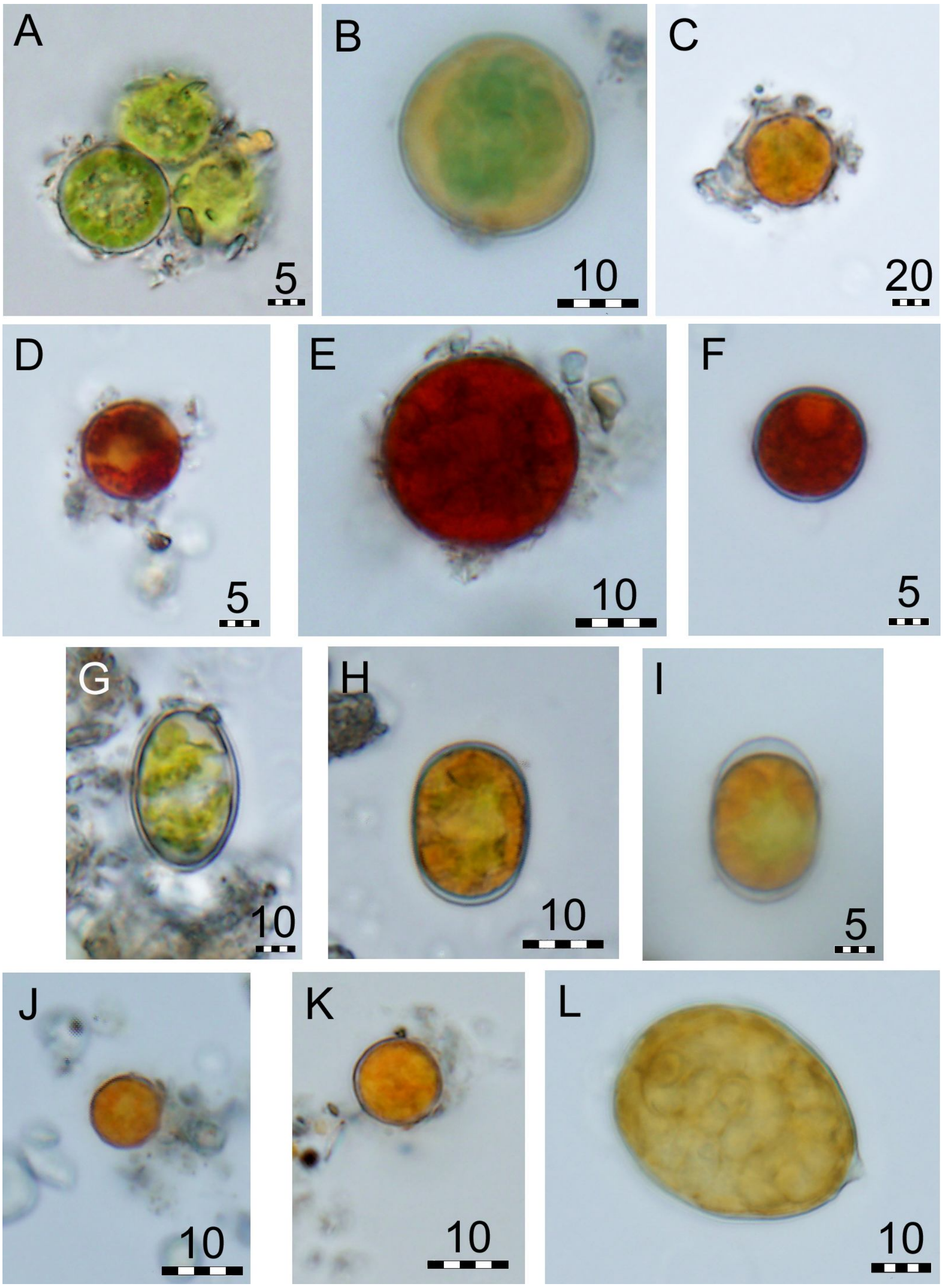

Fig. 4. The species and genera of snow algae found in Petuniabukta samples. The number indicates the size of the scale in µm A-F – zygospores of *Chlamydomonas* cf. *nivalis*, G – newly formed zygospore of cf. *Chloromonas nivalis*, H-I – cf. *Cryodactylon glaciale* (? *Chlamydomonas brevispina*), J-K – zygospores of *Chlamydomonas* sp., L – cf. *Chlainomonas* sp.

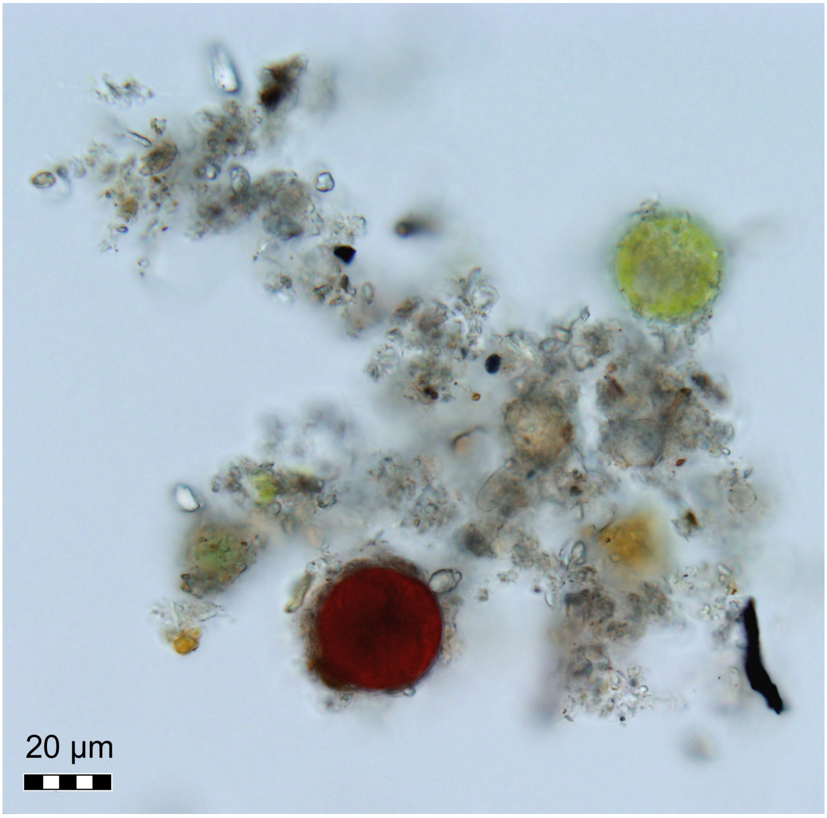

Fig. 5. Attachement of green and red cells of *Chlamydomonas* cf. *nivalis* to dust grains.

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