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Ecological background of cyanobacterial assemblages of the northern part of James Ross Island, Antarctica

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Abstract: An investigation of cyanobacterial microflora in the northern, deglaciated part of James Ross Island in the NW part of the Weddell Sea, Antarctica, was conducted during the Antarctic summer season 2005–2006. Five main types of habitats with dominant cyanobacterial assemblages were analyzed (soils, seepages, streams, wetted rocky walls and lakes), and main ecological variables were measured (pH, temperature, intensity of global radiation, conductivity and nutrients), as a background for further ecological and ecophysiological studies. The definable traditional cyanobacterial morphospecies were identified.

Key words: Antarctica, cyanobacteria, ecology, environmental conditions, distribution.

Introduction

Construction of the Czech scientific station *J.G. Mendel* was completed in the Antarctic summer season December 2005 – March 2006, on the north coast of James Ross Island, which is located in north-western part of the Weddell Sea, in coastal Antarctica (Fig. 1). Meteorological monitoring and several climatological and biological studies were started during the first season. Pilot investigations of phototrophic microorganisms and edaphon biodiversity were conducted in the deglaciated areas around the station as a background for studies of adaptation processes and colonisation of deglaciated habitats. The ecological background, which influences the development of characteristic cyanobacterial assemblages (which are the most important part of the phototrophic microvegetation in the Antarctica), is analysed in this article. This information is essential for understanding the ecology of the cyanobacterial and algal Antarctic communities.

James Ross Island is situated in the "shade" of Antarctic Peninsula and has large continental deglaciated area. Several habitats are similar to that found in

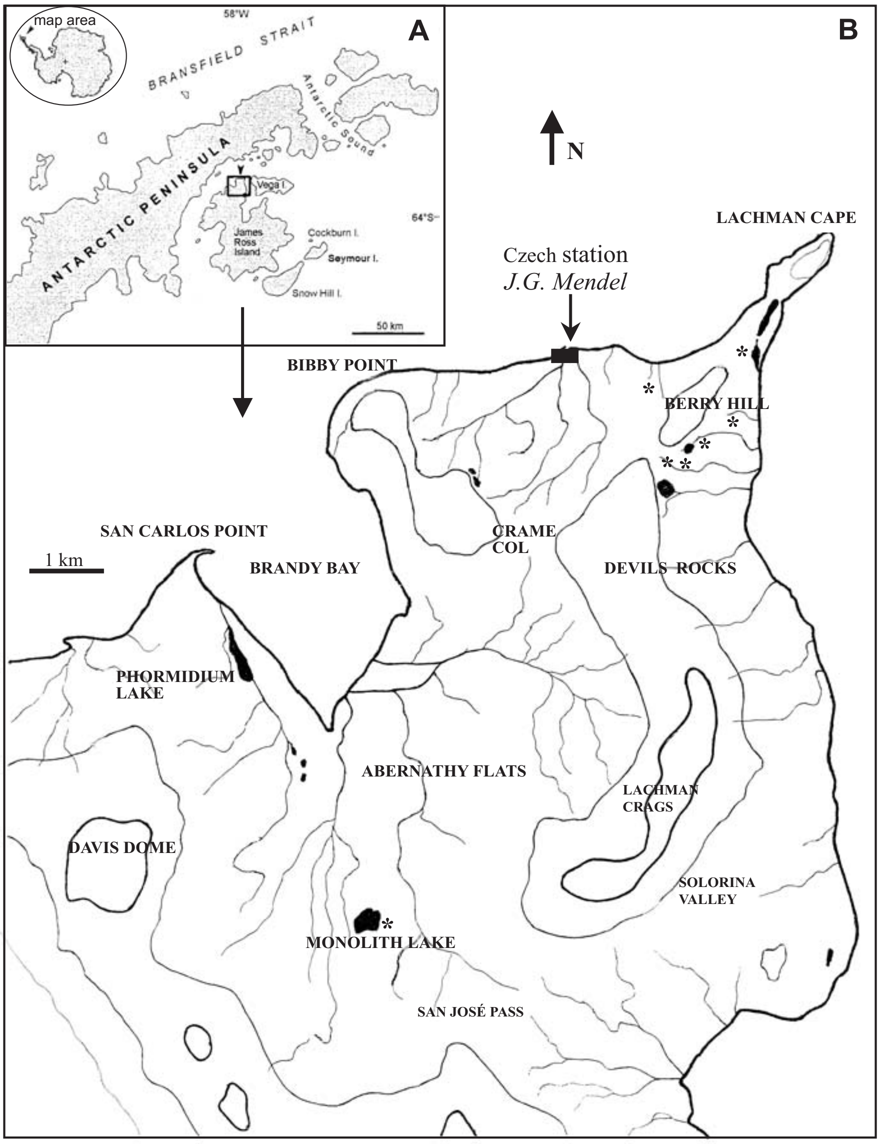

Fig. 1. Map of the northern part (Ulu Peninsula) of James Ross Island, NW Weddell Sea, Antarctica. The map illustrates the studied deglaciated area with main localities (streams, lakes and seepages – *). The soil samples were collected from the whole area. The communities of cyanobacteria from wet stony walls were studied mainly on the locality Devils Rocks.

maritime Antarctica, but main cyanobacterial species are developed with different frequency. The special character of the area causes the development of distinct algal and cyanobacterial communities. The streams, up to several km long, are active over the whole summer season. Seepages are less developed than in the maritime Antarctica, and more isolated. In the area, there occur high stony walls with specialised developed epilithic communities. Also there occur several types of lakes: flat coastal (brackish), periodical, deep moraine pools and small lakes, as well as continental deep lakes (periodically melting or permanently frozen). The character of algal and cyanobacterial communities of these last permanent lakes is intermediate between the lakes from maritime and from lakes of continental Antarctica which are permanently frozen.

Investigated area, material and methods

The investigated region is located in the northern part of James Ross Island, NW part of the Weddell Sea, east of the north end of the Antarctic Peninsula (63°48’02” S, 57°52’57” W) (Fig. 1A). Geographically, it is maritime Antarctic, but the peninsular mountains protect this area from the direct influence of western winds from the southern Pacific Ocean. In comparison with the South Shetland Islands, this locality is more arid with extremely rare precipitation, usually in form of snow, during the summer season. Almost the whole studied area is deglaciated with the exception of the tops of the highest hills. It covers approximately 109 km^2, and is interspersed with hills, which attain over 400 m at the highest points (Lachman Crags, Davis Dome) (Fig. 1C).

The mean monthly air temperature exceeds 0°C in the summer season, from November to February, but is under 3°C according to recent measurements (Fig. 2; derived from original data of Láska and Prošek). The maximal air temperature was

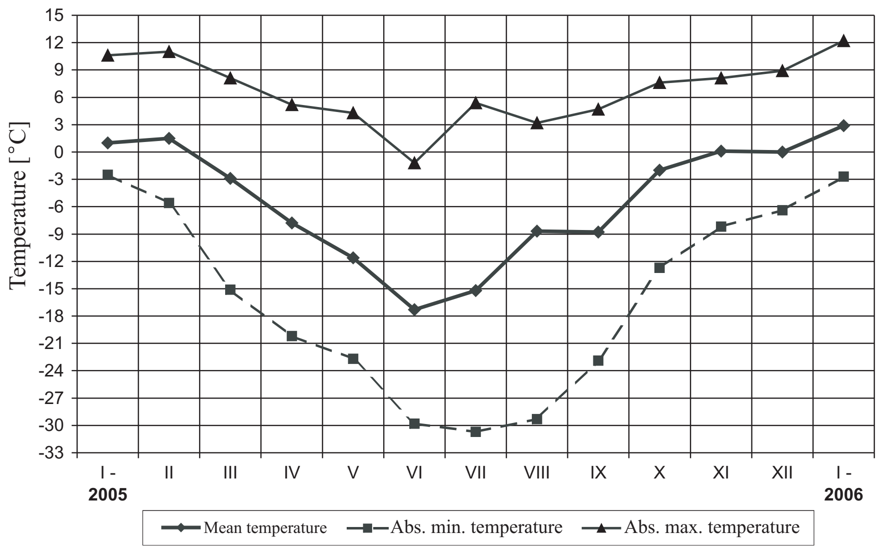

Fig. 2. Average mean and extreme monthly air temperatures [°C] in 2 m above the soil surface during the year 2005 to January 2006. – According to original data of K. Láska and P. Prošek, published with permission.

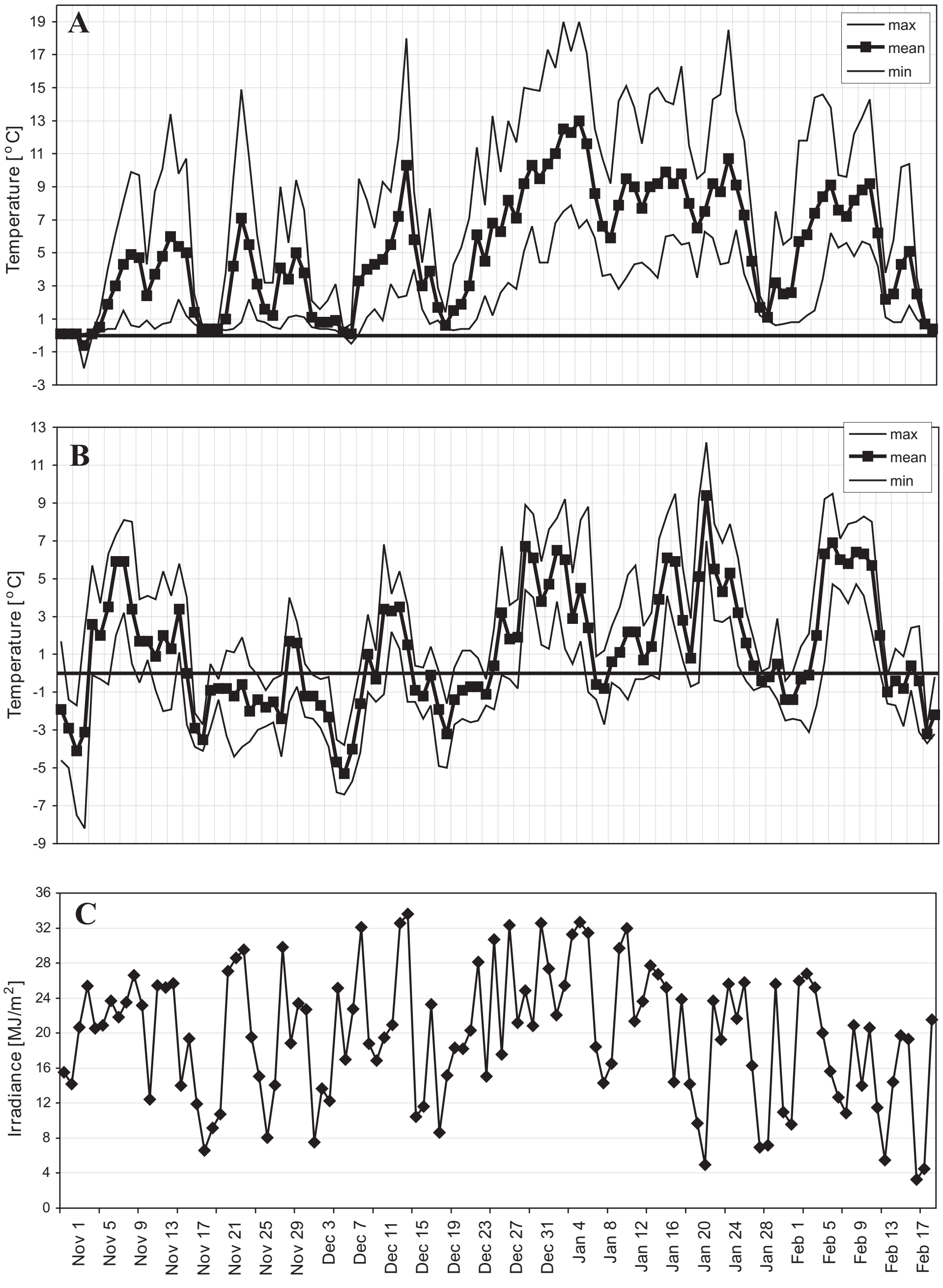

Fig. 3. Mean and extreme daily temperatures in soils (5 cm below surface) (**A**), air temperature 2 m above the soil surface (**B**) and daily intensities of global irradiance [MJ/m^2] (**C**) during Antarctic summer season (November 1st 2005 – February 20th 2006) on the station *J.G. Mendel* (James Ross Island). – According to original data of K. Láska and P. Prošek, published with permission.

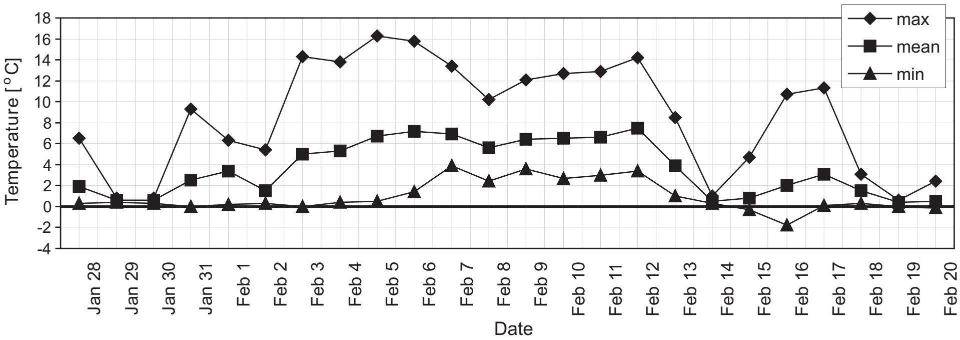

Fig. 4. Temperature values of water in seepages (northern slopes below Berry Hill) observed in the period of our studies (28.1.–20.2.2006). Values selected from 4 parallely measured locations. According to original data of K. Láska and P. Prošek, published with permission.

measured in January and February (over 10°C; Fig. 2). The daily average and extreme temperatures in soil (5 cm below surface), air (2 m above soil surface) and daily intensities of global radiation [MJ/m^2] at the *J.G. Mendel* station during the Antarctic summer months are presented in Fig. 3. In the season 2005/2006, January was distinctly warmer than the other summer months in the studied area. Water temperatures in seepages are presented in Fig. 4. Aquatic habitats (streams, lakes, seepages) keep temperatures above 0°C over almost the whole second half of the summer, enabling the rapid development of cyanobacterial and algal communities during this season.

Geologically, the northern part of James Ross Island (Czech Peninsula) is composed of Quaternary sediments and rocks, mixed with Tertiary volcanites with connected intrusive rocks. Large parts are covered with Cretaceous sediments (Nývlt and Mixa 2003).

Natural samples were studied when alive with optical microscopy, measured, and documented by drawing and microphoto techniques. All samples were preserved in formaldehyde and deposited at the Institute of Botany of the Academy of Sciences in Třeboň, Czech Republic. Dominant types were transferred to agar plates with BG11 medium and cultured under illumination (by fluorescent tubes Fluora L30W/77; Osram, Germany) with the range of 40–50 µmol.m^{-2}.s^{-1}. Temperatures ranged between 10–20°C. The detailed study of phenotype diversity and the results of cultivation are the subject of other articles (*cf.* Komárek *et al.* in press).

Main climatological data and physico-chemical parameters of waters and soil (temperature, pH, conductivity, tot N and tot P) were measured during the summer seasons (January – February) in 2004 and 2006. The nitrogen was determined according to European Standard EN ISO 13395: 1996, phosphorus according to European Standard EN ISO 15681-1: 2004, conductivity according to European Standard EN 27888: 1993.

Table 1

List of cyanobacterial morphotypes found in the studied area with habitats of their occurrence. Habitats: S = soils, P = seepages, R = streams, W = wet rocks, L = lakes.

	Number of morphotypes	Habitats				
		S	P	R	W	L
Coccoid types						
Aphanothece spp.	2		+			
Asterocapsa sp.	1				+	
Chamaesiphon spp.	2			(+)	+	
Chlorogloea sp.	1		+	(+)		
Aphanocapsa sp.	1		+			
Chroococcus spp.	3	(+)	+			
Cyanosarcina sp.	1		+			
Cyanothece cf. *aeruginosa* (Nägeli) Komárek	1		+			(+)
Eucapsis sp.	1		+			
Gloeocapsa sp.	1		+			
Gloeocapsopsis aurea Mataloni *et* Komárek	1		+	(+)		
Pleurocapsa? sp.	1			+		
Filamentous types without heterocytes						
Blennothrix spp.	1		+	(+)		
Geitlerinema spp.	2	(+)	+	+	(+)	(+)
Leptolyngbya antarctica (W.West *et* G.S.West) Anagnostidis *et* Komárek	1					+
Leptolyngbya erebii (W.West *et* G.S.West) Anagnostidis *et* Komárek	1	(+)	(+)	+	(+)	
Leptolyngbya nigrescens Komárek	1				+	
Leptolyngbya sp. 1	1		(+)		+	
Leptolyngbya sp. div.	8		+	+		
Lyngbya aestuarii Liebmann ex Gomont (halophilic)	1					+
Lyngbya cf. *shackletonii* W.West *et* G.S.West	1			+		
Microcoleus antarcticus Casamatta *et* Johansen	1			+		
Microcoleus spp.	2	+	(+)		(+)	(+)
Oscillatoria cf. *fracta* Carlson	1	+	(+)			(+)
Oscillatoria spp.	3		+	+		(+)
Phormidium type *autumnale* (Agardh) Trevisan ex Gomont	7	(+)	+	+	(+)	
Phormidium murrayi (W.West *et* G.S.West) Anagnostidis *et* Komárek	1		+			(+)
Phormidium priestleyi Fritsch	1			+		
Porphyrosiphon sp.	1	(+)	+	(+)		
Pseudanabaena spp.	2		+	+		
Romeria nivicola (Kol) Komárek O. *et* Komárek J.	1		(+)			
Schizothrix spp.	3		+	+	(+)	
Symplocastrum sp.	1		+			
Trichocoleus sp.	1	+		+		
Filamentous heterocytous types						
Anabaena/Hydrocoryne-type	1	+	(+)	+		+
Anabaena sp.	1		+	(+)		(+)
Calothrix spp.	3		+		(+)	+
Coleodesmium sp.	1				+	
Dichothrix sp.	1					+
Microchaete sp.	1				+	
Nodularia quadrata Fritsch	1		+	(+)		(+)
Nostoc commune-type Vaucher ex Bornet *et* Flahault	5	(+)	+	+	(+)	
Tolypothrix/Hassallia-type	1		+			
Tolypothrix spp.	2				+	+

Table 2

Physico-chemical characteristics of main habitats with cyanobacterial microflora in James Ross Island in summer seasons (January – February) in 2004 and 2006. (The numbers in parentheses are the extreme values, which were measured only exceptionally. pH was measured directly from water samples, in soils from water extract).

Summer season (Jan–Feb 2004) (Jan–Feb 2006)	Temperature [°C]	pH	Conductivity [μS.cm^{-1}]	Total N [μg.l^{-1}]	Total P [μg.l^{-1}]
Soils extracts	-9(21)	6.3–8.0 (extract)	240–10880		
Seepages	0.1–17.4(19.3)	6.8–7.4(8.5)	(28)–114–357	144–241 347–948	48–54 72–159
Streams	0.1–7.6 (-14.3)	(6.8)7.3–8.6(9.3)	(36)92–347(850)	117–390(821) 121–206(392)	30–72(92) 41–56(84)
Wet rocks	0.2–5.2	7.1–7.3	121–147	376–455	56–138
Lakes – coastal		6.8–9.4	128–730(7500)	275–870	48–67
Periodical moraine lakes	0.1–6.8	7.3–8.6	24–103	145–493	55–89(121)

Results and discussion

Five distinctly different habitats with characteristically developed cyanobacterial assemblages were recognised in the area: soils (S), seepages (P), streams (R), wet rocky walls (W), and lakes (L) (Table 1). The pH values in water habitats were slightly alkaline, and ranged from 7.3 to 8.6 in streams, and from 6.8 to 9.4 in lakes and pools. Values below 7 and over 8 were found only in small lakes and pools with more developed and diversified cyanobacteria and algae vegetation. Conductivity in inland water habitats was usually low (90–350 μS), but increased in lakes and water habitats near the coast-line, which are influenced by sea water. The limit values (range) are presented in the Table 2.

In the studied area 65 cyanobacterial morphospecies and 10 morphological modifications of uncertain taxonomic status were found (Table 1).

Habitats with stable cyanobacterial communities

Soils (S) (Fig. 5). — The microflora of Antarctic soils has recently been studied (Broady 1986, 1996; Broady and Ohtani 1990; Ohtani *et al.* 1991; Cavacini 2001). The surface of the wide deglaciated northern area of James Ross Island is covered mostly by gravel fields. Microvegetation develops mainly in aquatic habitats. It colonizes also more arid places in areas with deposits of fine material and detritus with higher humidity and warmed by solar radiation. Salt precipitation is frequent, forming whitish coats on the surface. The pH ranged between 6.2–8.0, conductivity values in soil extracts were usually over 1080 μS. Solar radiation is high, average temperature during the summer season (1.11–20.2) is 5.2°C, but occasionally can reach 19–20°C on the surface on sunny days. Microbial crusts of different kinds develop on such places, which contain, however, only a few cyanobacterial morphotypes. A total of fifteen taxa were recognised in soil samples,

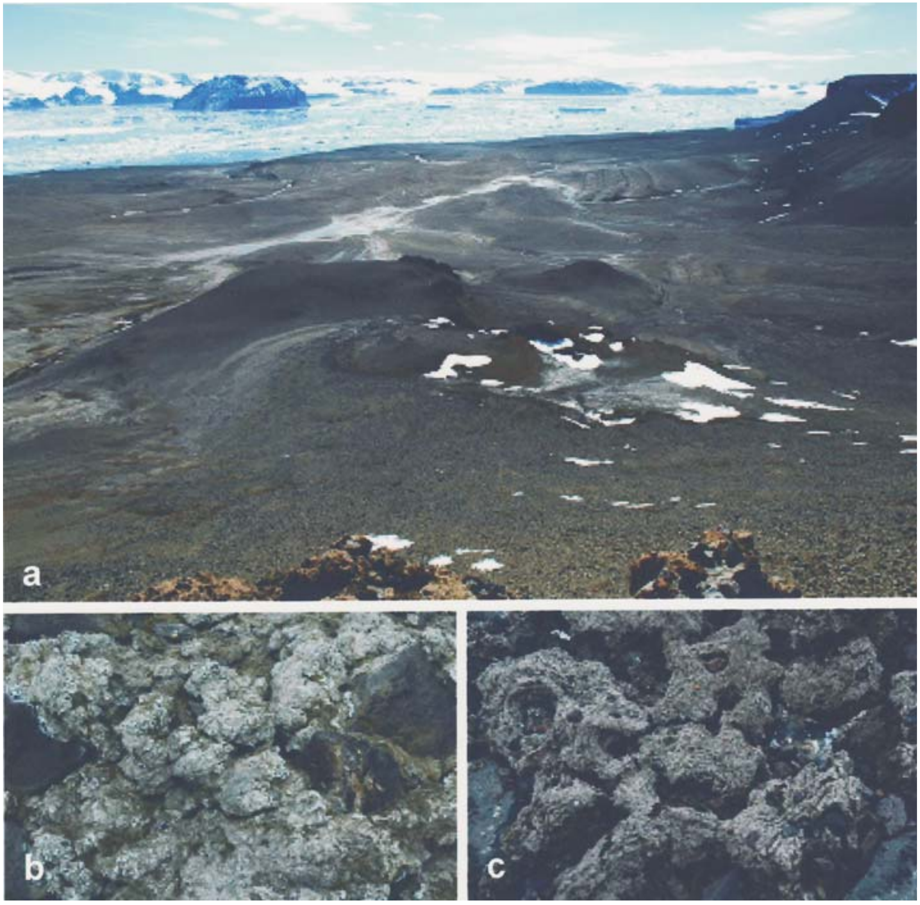

Fig. 5. Soils of the northern part of the James Ross Island (Ulu Peninsula): a – view of northern part of the territory, b–c – different kinds of crusts with communities of soil cyanobacteria.

from which only two were dominant (*Microcoleus* sp./green, *Nostoc* sp.). Characteristic species were also *Microcoleus* sp./grey and, less frequently, *Leptolyngbya erebi*, *L. glacialis*, *Phormidium* sp. 1 and *Anabaena/Hydrocoryne*-type. This last species occurs, however, more commonly in streams or seepages, and its presence in soils seems to be rather secondary. Development of microorganisms is evidently dependent on temperatures above 0°C, humidity and suitable levels of nutrients.

Seepages (P) (Fig. 6). — Seepages are characteristic habitats of coastal polar regions. They are shallow wetland ecosystems on soil (with permafrost in the lower soil layers), supplied by melting water for a longer period during the summer, sometimes with a slow flow. They arise on places with deglaciated substrate, where the water regime supplies a minimum necessary inflow of nutrients. In maritime Antarctica, communities with special species composition and structure in the form of mats develop in seepages (Wharton *et al.* 1983; Vincent *et al.* 1993a, b; Komárek

Fig. 6. Seepages situated north of Berry Hill: a – general view, b – typical developed community with orange mats of *Leptolyngbya vincentii* (superficial layer), c – subaerophytic community with dominant *Leptolyngbya borchgrevinkii* (Lb), *Phormidium pseudopriestleyi* (Pp) and blackish superficial colonies of *Nostoc* cf. *commune* (Nc).

and Komárek 2003). According to these results, similar mats in the Arctic region have a different morphospecies composition. The richness of cyanobacterial vegetation is controlled particularly by the continuous supply of water over the growth season (typical communities never develop in periodically drying seepages), exposure to light in flat and open localities, and temperatures ranging from 0 to 17–18°C on sunny days. In our sampling sites pH ranged from 6.8 to 7.4, and conductivity from less than 100 to about 360 μS at our sampling sites. In typical cases in coastal Antarctica, the upper intensely orange layer is formed by a special morphospecies, *Leptolyngbya vincentii,* co-dominated by green *Leptolyngbya glacialis* in lower layers (Komárek and Komárek 2003; Komárek 2007). While *L. vincentii* seems to be very specific just for the upper layers of mats in seepages, *L. glacialis* occurs sporadically also on the edges of streams and in soils. The lowest parts of mats are colonised by more species, sometimes by coccoid types. Seepages are the richest habitats of cyanobacterial morphotypes in the whole area. On James Ross Island, 52 morphospecies were found (from 65 species registered), with 7 dominating types which occured abundantly in different periods and different microhabitats and formed characteristic assemblages (*Geitlerinema* cf. *deflexum*, *Leptolyngbya borchgrevinkii*, *L. glacialis*, *L. vincentii*, *Phormidium autumnale* „typical form“, *P. pseudopriestleyi*, *Oscillatoria subproboscidea*, *Nodularia quadrata*, etc.). It is possible to designate 18 species as characteristic for this habitat. Some other species appeared at the end of the season (*Nostoc commune* sensu lato, *Tolypothrix* sp., etc.), but only *Nostoc commune* (type 2) was found regularly, being probably obligatory in seepages. Moss communities develop sometimes at the margin of stabilised, several-years old seepages as a climax-stage.

Streams (R) (Fig. 7). — Antarctic streams represent a habitat with special conditions for development of algal microflora (Howard-Williams *et al.* 1986; Vinocur and Pizzaro 1995; Pizzaro *et al.* 1996; Elster and Komárek 2003). All creeks in the area of James Ross Island are the result of the snow-melted and glacial streams, and are never of geothermal origin. They flow therefore only when temperatures exceed 0°C. The intensity of flow changes over the season and depends on the intensity of melting snow fields, permafrost and especially of ice corns in moraine deposits. The streams are usually characterised by a system of small and shallow furrows, which usually occur in the upper part, but which can be formed anywhere along the stream depending on the changing configuration of the terrain. The character of streams changes often into seepages in flat valleys. Temperature is usually very low near the water source (0–4°C), and irregularly fluctuates from 0–9°C along the stream and during the vegetation season. The temperature occasionally increases to 10°C (exceptionally to 15°C) in extremely sunny days in rather stagnant water and when the stream has a character of seepages. In contrast, streams can freeze several times during the summer vegetation period. The pH ranges between 7.3 to 8.6 (partly depending on the intensity of bottom vegetation). The conductivity is very low from the melting snow (often below 100 µS), but increases up to 390 µS (exceptionally up to 850 µS) with inflow of water from moraine deposits. Microvegetation changes during the season and forms characteristic communities and climax stages in January and February. In typical cases, the upper part of streams is dominated by the diatom *Planothidium quadripunctatum*, which has a typical yellow-brownish colour in fine, flat colonies, and the cyanobacteria *Schizothrix* sp. 1 is found, sometimes combined with *Leptolyngbya fritschiana.* Both cyanobacterial species form characteristic greyish coats (biofilms) on the surface of stones. In the middle and lower parts of streams, mosaics of several characteristic species usually develop on the stony bottom, composed mostly by two morphotypes of *Phormidium autumnale, Leptolyngbya borchgrevinkii* (narrow type)*, Phormidium* sp. 3, sometimes alternating with *Nostoc commune* type 3 or the green alga *Prasiola* cf. *calophylla* (cf. Table 1). The

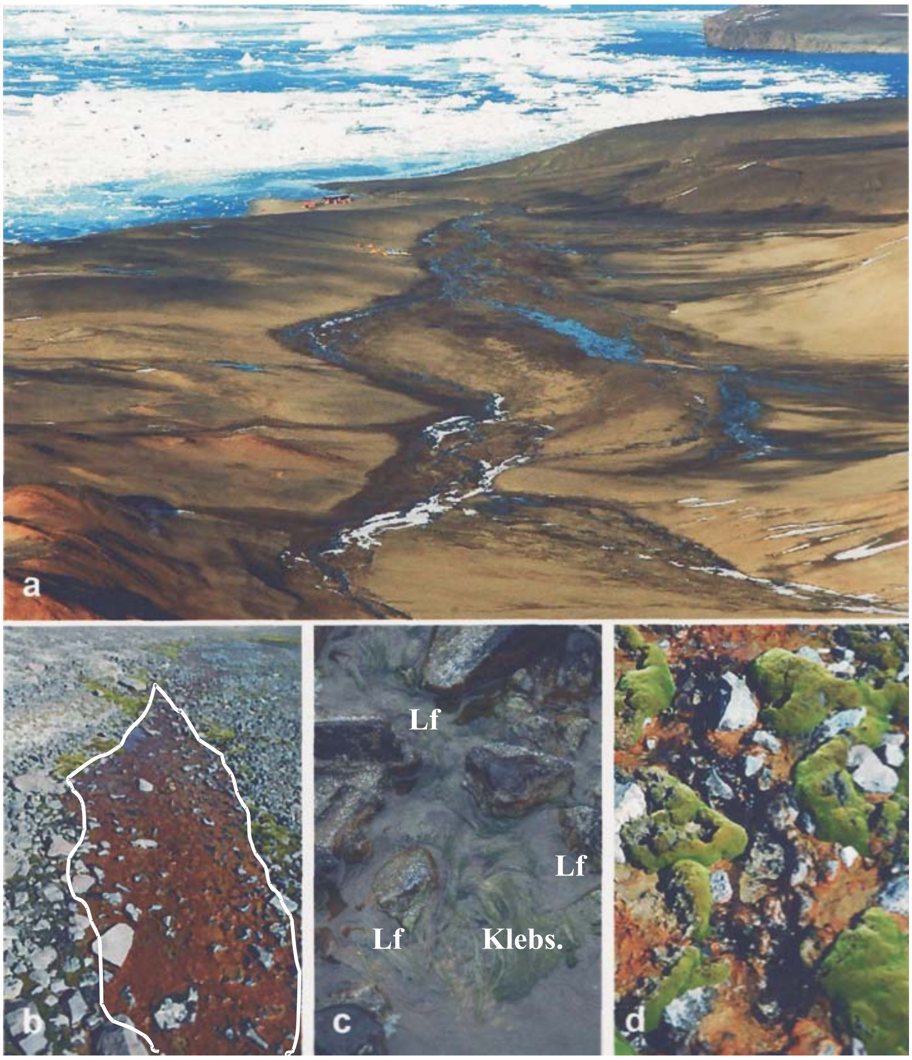

Fig. 7. Streams of the northern coast of James Ross Island: a – glacial Water-Supply Creek, b – community of diatoms, *Leptolyngbya fristchiana* and *Schizothrix* sp. from the upper part of streams, c – benthic mats from the central part of streams with dominant *Phormidium autumnale, Leptolyngbya fritschiana* (Lf) and green alga *Klebsormidium* sp. (Klebs.), d – edge of the lower stream of creeks with dominant *Phormidium autumnale, Leptolyngbya borchgrevinkii* (smaller form) and invading mosses.

green alga *Klebsormidium* sp. and the diatoms *Nitzschia gracilis* and *Luticola muticopsis* are dispersed along the whole streams. *Leptolyngbya borchgrevinkii* usually dominates in form of typical yellow-orange mats in places of the seepage character. *Phormidium priestleyi* (probably taxonomically related to *Schizothrix* sp. 1) is common exclusively in lower parts of streams with continual and intensely flowing water.

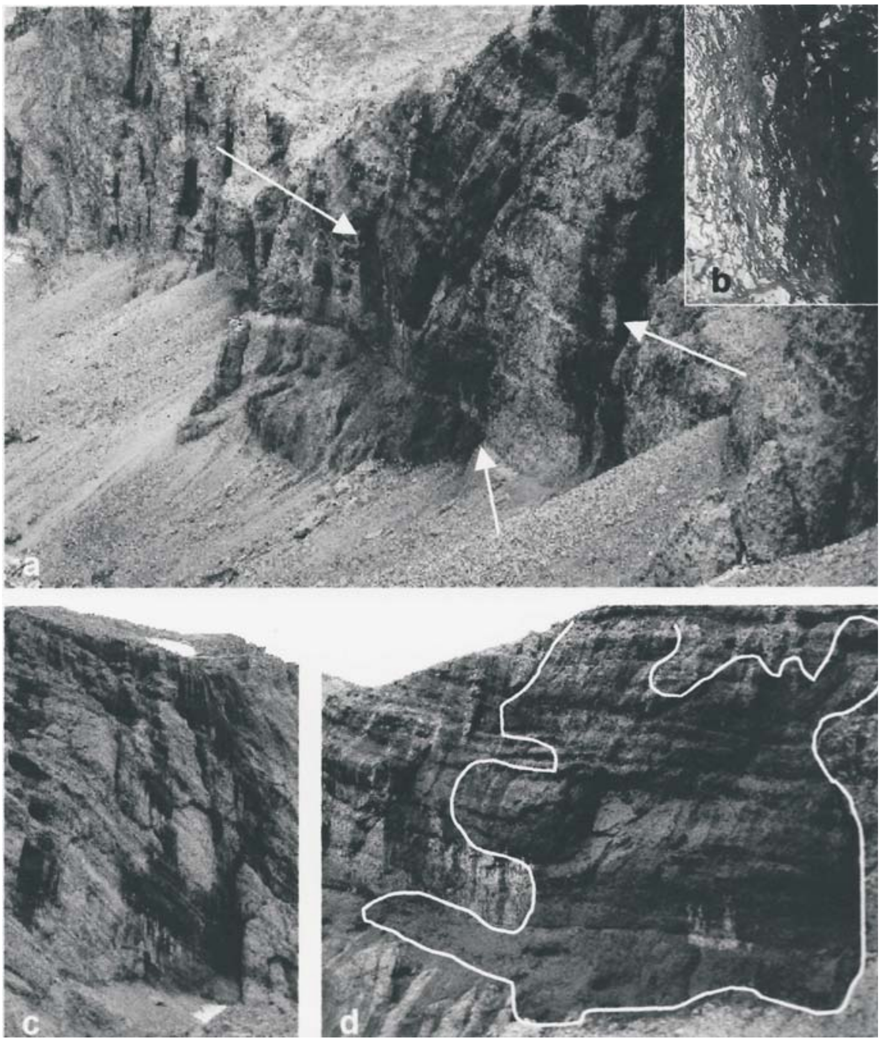

Fig. 8. Wet rocks with special microflora of epilithic cyanobacteria in dripping, periodically frozen, melting glacial water: a–d – Devils Rocks (eastern walls of Lachman Crags), b – detail of mats.

Wet rocks (W) (Fig. 8). — Wet and dripping rocks represent a well developed special habitat, which is common in the northern part of James Ross Island, with its numerous „table mountains" containing vertical marginal rocks up to about 100 m high. Water from melting snow fields and small glaciers on the top of mountains flows along the sedimentary rocks and creates a special habitat for algal and cyanobacterial vegetation. These localities are characterised by periodical (sometimes daily) fluctuation water supply and freeze quickly at temperatures below 0°C; however, melting, which depends on insolation, can also be very rapid. Waterfalls can remain frozen for a longer time in shaded localities. Commonly, temperature of the melting water usually does not exceed 1–3° C (rarely up to about 5° C), which is characteristic for all continually shaded dripping rocks. However, the total intensity of light radiation is high under conditions of long polar days. The pH values are usually stable and range between 7 and 7.5. Conductivity of melting snow is also low and does not change considerably (usually between 120–150 μS). Despite this, the composition of the biocenoses on wet rocks is species specific, similarly as that of wet rock localities worldwide. Our results were obtained mainly from south and SE oriented marginal rocks of Lachman Crags, mainly from the intensely dripping Devils' Rocks with many blackish stripes with cyanobacterial vegetation (Fig. 8). Eight morphospecies were found to be characteristic only of this habitat, namely the species from the genera *Microchaete* or *Coleodesmium*, which were never found in any other locality in the whole area. Only 2 of 27 identified morphospecies, were recognisable as dominating in this habitat (*Phormidium* sp. 2, *Tolypothrix* sp. 1). The more widely distributed cyanobacterial species *Schizothrix* sp. 1 and *Phormidium* cf. *autumnale*, commonly found in creeks and streams, also occur in these subaerophytic habitats.

Lakes (L) (Fig. 9). — Microvegetation of Antarctic perennial water bodies has been described in numerous articles (Komárek and Růžička 1966; Parker *et al.* 1981; Tell *et al.* 1995; Fritsen and Priscu 1996, 1998; Gordon *et al.* 1996; Mataloni *et al.* 1998; Priscu *et al.* 1998; Nadeau and Castenholz 2000; Taton *et al.* 2003; and others). Permanently frozen lakes, which are characteristic for Antarctic continent, do not occur in the northern area of James Ross Island. However, four different types of stagnant water bodies occur there:

Flat and drying lakes with well developed populations of green algae (*e.g. Zygnema* sp.) on coastal terraces, *e.g.* the lakes on Lachman Peninsula and the Phormidium-lake from Brandy Bay. Periodical drying and freezing is the most important ecological phenomenon in these lakes. Sometimes rich populations of Copepods and Branchiopods were found in these water bodies. Temperature can reach over 10°C, pH changes over a relatively wide range 6.8–9.4, and the conductivity is sometimes high (up to 7500 μS), especially in drying pools with inflow of marine water.

Small periodic lakes with stony bottoms in moraines. These are usually very unstable and can disappear as a consequence of the melting of morain icy cores and following the movement of stony material. In spite of this, massive mats of cyanobacteria can develop on the bottom, mainly of phormidiacean and oscillatoriacean types. However, the composition of such mats is variable, and a community of distinct species cannot be designated as typical for this habitat. The temperature is always below 7°C, with very low conductivity (24–103 μS).

Stable lakes near glacier fronts or in higher positions near mountain ridges (*e.g.*, lakes near Windy Pass, Southern Rožmberk Pond). These are deep, frozen for a long time, including part of the summer season, and their microvegetation is poor and restricted sporadically to stones in the near littoral. Usually only frag-

Fig. 9. Lakes with benthic mats: **a**, **b** – moraine lakes from the vicinity of Windy Pass, with massive ephemeric mats of oscillatorialean cyanobacteria; **c**, **d** – deep inland lakes, partly or continually frozen, with benthic dominant *Leptolyngbya antarctica* (Monolith Lake); **e**, **f** – flat coastal lakes with higher conductivity (Phormidium Lake).

ments of oscillatorialean mats, similar to those in periodical moraine lakes develop on such stones.

Stable, continuous lakes on central elevations. Typical example of such lakes is the Monolith Lake and several small lakes from gravel terraces on the SW part of the Abernathy Flats. It is interesting that mats with characteristic morphospecies develop here. Such mats are known from continually frozen lakes in continental Antarctica, and are mainly composed of the dominant *Leptolyngbya antarctica* (taxonomically not yet finally determined – molecular sequencing of this morphotype is necessary). In addition to this dominant species, which in the island lakes develops mats with distinctly lower biomass than that in continental lakes, several peculiar and not yet described morphospecies were found, such as, *e.g.*, one narrow *Oscillatoria* and special *Dichothrix* and *Tolypothrix* morphospecies. Other commonly occurring species include a thinner morphotype of *Phormidium* cf. *autumnale*, *Phormidium* sp. 3, and *Anabaena/Hydrocoryne* type. Commonly, the temperature of these lakes changes from 0 up to 4°C.

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