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Algae, lichens and fungi in La Gorce Mountains, Antarctica

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Abstract: Two species of lichens, six cyanobacteria, one diatom, 10 chlorophytes and two mycelial fungi were found at La Gorce Mountains (86°30'S, 147°W) at an altitude of about 1750 m. The lichens *Lecidea cancriformis* and *Carbonea vorticosa* occurred at a single site which is the most southerly record of lichens. Thousands of small ponds covered extensive ice-cored moraine. Nine ponds sampled had about 30 cm of ice overlying about 26 cm of water and contained algal mats dominated by *Phormidium autumnale* and cf. *Leptolyngbya fragilis*. The very low conductivity waters had high nitrate and low dissolved reactive phosphorus concentrations. Of 124 soil samples, five contained visible algae. In 32 there were only microscopic growths but no algae were detected in 87 samples, possibly because of lack of water for much of summer. A visible mat dominated by *Hammatoidea normanni* occurred in a rock fissure at the lichen site. At Price Bluff, green patches of *Desmococcus* cf. *olivaceus*, up to 20 cm^2, were scattered over the moraine. Growths were revealed at the soil–ice interface when overlying soil up to one centimetre thick was removed. It is suggested that although dispersal of algae from local populations may be readily achieved establishment of populations is a rare event outside the pond environment.

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Key words: algae, dispersal, fungi, lichens, ponds, soil

Introduction

Antarctica is one of the most remote and harsh environments for terrestrial life. Abundance and diversity of organisms decreases with progression south from the Maritime to the Continental Antarctic Zone, and within the latter with increasing altitude and latitude from the Coast to the Ice Slope Region (Pickard & Seppelt 1984, Kappen 1993, Broady 1996) due to increasingly severe conditions and isolation from rich propagule sources. We considered it would be of great interest to search for organisms at a high altitude, high latitude location in order to establish which are able to disperse to, and establish populations in, such a rigorous environment.

During January 1997, 18 days were spent at La Gorce Mountains (86°30'S, 147°W), a small range in Queen Maud Mountains (Fig. 1). The study area was at an altitude of *c.* 1750 m at the head of Scott Glacier, about 90 km north of the furthest south rock outcrop, Mount Howe (87°21'S 149°18'W), which is itself some 330 km from the South Pole. The geology of the area is dominated by granites to the north of Robison Glacier and by greywacke-shales and silicic porphyry to the south (Stump *et al.* 1986). Cameron (1972a) provides a physico-chemical analysis of a single soil sample from the region.

There have been few surveys of microbes and vegetation at latitudes greater than 82°S. An early report (Wise & Gressitt 1965) noted unidentified algae from the region of Shackleton Glacier (85°09'S, 174°57'W, Fig. 1). Two samples of soil from La Gorce Mountains collected by Claridge *et al.* (1971) produced no organisms in culture. Farther north along Scott Glacier they found seven species of algae and unspecified numbers of yeasts and mycelial fungi. During a brief helicopter visit to La Gorce Mountains, Cameron (1972a) noted the presence of frozen ponds and three species of algae in fragments of mat from below the ice but found no fungi in soil cultures. At Mount Howe (Fig. 1), Cameron *et al.* (1971) were unable to culture algae from 11 soil samples although low numbers of bacteria and one species of yeast were obtained. Cultures of seven soil samples from the Pensacola Mountains (83°S, 50°W) produced six algae and yeasts (Parker *et al.* 1982a).

Far south reports of lichens are summarized by Kappen (1993). The southernmost locations are in Horlick Mountains and Queen Maud Mountains, with the extreme being in the latter range near Mount Blackburn (86°13'S 147°W) and on the summit of an unnamed peak near Mount Czega (86°20'S 148°30'W). The latter observations were made by Claridge *et al.* (1971) who also noted five lichen species to be more common on rocks and soils at lower altitudes and latitudes farther down Scott Glacier near to the Ross Ice Shelf. Additionally, at least six species of crustose lichen have been found at sites between 85°03'–85°25'S, at altitudes of 1805–2240 m in Thiel Mountains, Ellsworth Land (R.I. Lewis Smith, personal communication 1998).

The sparsity of previous collections suggested that a more detailed survey would be worthwhile. This study establishes a new farthest south occurrence of lichen and mycelial fungi and shows the far south algal flora to be richer than previously recorded.

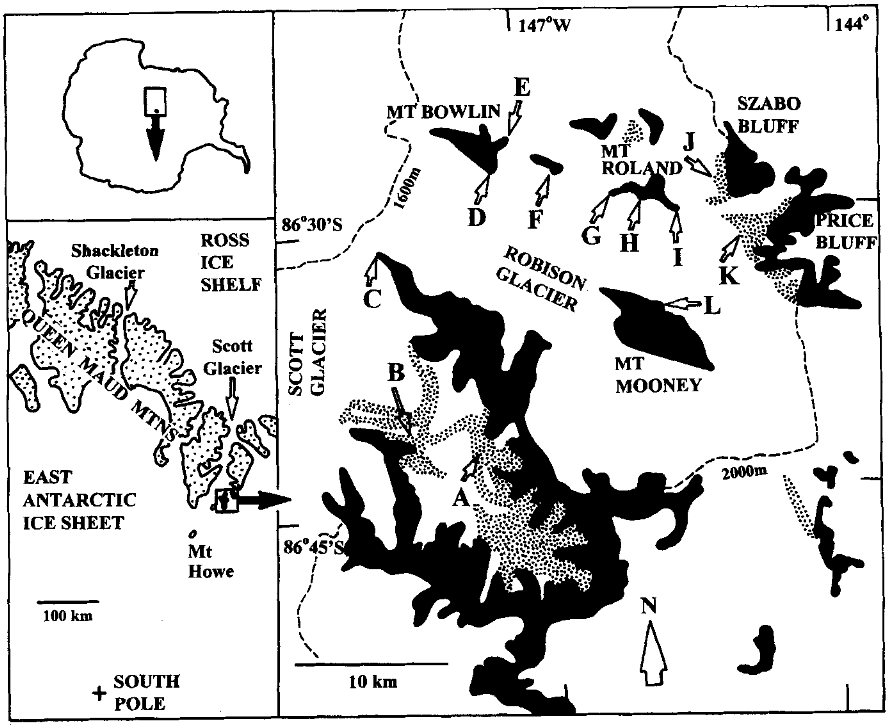

Fig. 1. Location of region of study and of sample sites at La Gorce Mountains. The top inset shows the location of Queen Maud Mountains in Antarctica and the bottom inset the location of La Gorce Mountains at the head of Scott Glacier. Sites A–L are rock and moraine exposures which were investigated. Block shading indicates nunataks and stippling shows major areas of ice-cored moraines. Map of La Gorce Mountains taken from 1:250 000 Reconnaissance Series, Mount Blackburn, Antarctica, SV 1-10/11, US Geological Survey (1968).

Materials and methods

The 12 study sites were on glacial moraines (Fig. 1, sites A, B, J and K) and the country rock of nunataks (sites B–I and L) to the north and south of Robison Glacier (Fig. 1) at altitudes between 1600 and 2000 m.

We travelled by skidoo and sledge and were limited to the chosen study sites due to ease of travel, safety considerations and time available. The duration at a site varied from 1–5 h (sites A and C–L) to 3 d (site B) and the area of ground covered at each was from a few hundred square metres (sites C–I and L) to several hectares (sites A, B, J and K).

General visual survey was made for macroscopic vegetation. Particular care was taken to examine the most favourable niches, i.e. those protected from the prevailing south-easterly winds, exposed to full sun and where meltwater was found or likely to be supplied. At all sites, the most promising rock surfaces were broken open with a hammer in order to search for endolithic organisms.

For analysis of algae, 124 soil samples, each of *c.* 2 g were transferred using aseptic precautions from the upper 1 cm of soils into pre-sterilized polycarbonate tubes. For each, a small spoon was surface cleaned with 70% ethanol and then repeatedly inserted into soil adjacent to where the sample was subsequently removed. In addition, five samples of freeze-dried algal mat were taken from moraine adjacent to ponds and eight samples of sediment were recovered from below the ice of frozen ponds through holes drilled for water sampling. All samples remained frozen until treated in the laboratory up to four weeks later.

All 137 samples were microscopically examined using bright-field illumination on an Olympus BHX microscope at magnifications up to 2000x. Approximately 0.5 g of each sample was spread over the surface of 1% agarized BG-11 medium (Rippka *et al.* 1979). These cultures were incubated at 8°C on a 16:8h light:dark cycle illuminated by cool-white fluorescent lamps (13W, Phillips "TL") giving *c.* 50 μmol photons m^{-2} s^{-1} at the culture surface. Cultures were examined regularly for up to 40 weeks. Colonies were counted and the full diversity of algae was isolated into unialgal cultures for subsequent characterization.

For analysis of fungi, 80 duplicate soil samples of *c.* 2 g each, sampled from microsites consisting of moist soil, were collected as described above. Samples were transported frozen to the UK for analysis but were subjected to up to several days storage at temperatures above freezing. This may have affected recovery of fungi from the soil. Approximately 0.5 g of each sample was spread in triplicate onto 1% malt extract agar with added 0.15% mycological peptone and 0.15% yeast extract (pH 5.9). Cultures were incubated at 10°C for up to 20 weeks. Optimum temperatures for growth of isolates were tested by incubation at -4, 0, 5, 10, 15, 20 and 25°C.

Water was obtained from nine, randomly chosen, typical ponds at site B by drilling through about 30 cm of ice using a Kovacs ice auger with a 51 mm diameter drill bit. Duplicate samples of water were collected from just above the pond sediments into acid-washed polythene bottles. Within a few hours of collection this was filtered through glass fibre filters (Whatman GF-F) into clean, acid-washed polythene bottles and frozen until chemical analysis using methods described by

Howard-Williams *et al.* (1986).

Spot temperatures of soil surfaces and pond water were measured using a digital thermometer with a tip sensitive thermistor probe. Ambient air temperatures were measured up to three times per day using a spinning mercury in glass thermometer and observations of wind direction, velocity and cloud cover were made.

Results

Meteorological observations

Between 3–20 January 1997 the mean air temperature was -14.1°C (sd = 3.4) with a range of -7.5 to -20.0°C. Winds were mostly light, of 5–20 km h^{-1}, and predominantly from the south-east. Only one calm day and one with a north-west breeze were experienced. Cloud cover was >50% on only 17%, and was 25% or less on 66% of occasions.

Lichens

Despite a careful search at all sites, lichens were encountered at only Mount Roland. At site H a few chasmoendolithic growths occurred in cracks in the granitic rock whilst at site G these were more frequent. Here, on a single, west-oriented rock face (Fig. 2) they expanded to form grey and black epilithic growths with a cover of approximately 1% within an area of no more than 2 m^2. Two species have been identified; *Lecidea cancriformis* Dodge and Baker and *Carbonea vorticosa* (Floerke) Hertel. Microscopic examination revealed *Trebouxia*-like phycobionts. Herbarium specimens have been placed with Landcare Research, Christchurch, NZ (CHR 401420) and at the British Antarctic Survey, Cambridge, UK (AAS as RILS 10057 and RILS 10058).

Diversity of algae

Six cyanobacteria, one diatom and 10 chlorophytes have been identified (Table I). Their abundance in direct microscopic examination and in spread cultures of sample material is summarized in Table I and a comparison of their frequency of occurrence between different sites and types of sample material is shown in Table II.

Eight of the chlorophytes were identified only in cultures and probably comprised the "unidentified unicells" category in direct microscopic examination of samples. Six of the cultured chlorophytes occurred in low numbers, producing less than 10 colonies on each spread plate culture of sample material. In contrast, only two cyanobacteria have been successfully cultured. During direct microscopic examination, note was also taken of the dead remains of algae, specifically empty mucilaginous sheaths of cf. *Leptolyngbya fragilis* and *Gloeocapsa* cf. *kuetzingiana* and the empty frustules of the diatom *Luticola muticopsis*. These were all observed in more samples than the living equivalent.

Terrestrial algae and their habitats

At sites B–I and L, fine to coarse-grained lithosols were frequent in patches on exposures of country rock, amongst boulders on talus slopes and on rock ledges. At sites A, B, J and K there were extensive areas of similar lithosols amongst boulders on ice-cored moraines (Fig. 3). Here, the veneer of mineral material was from a few millimetres to *c.* 3 cm thick.

At all sites, patches of soil were often found to be moist where they were in full sun. In these circumstances surface temperatures of +1 to +7°C were recorded regularly and were sufficient to melt the underlying ice. The warmest surface was of a dry soil at +12.6°C when ambient air was -7.5°C. Shading

Fig. 2. A general view of the granitic rock outcrops at Mount Roland (site G), the only site to have epilithic lichens. The rock-face with the lichen growths is marked with an arrow. An ice-axe and rucksack on the snow in front and to the left of the rock provide scale.

Table I. Comparison of the number of samples containing algae at different estimated levels of abundance in direct microscopic examination and culture of 137 samples from La Gorce Mountains.

Alga	Total samples with alga	Number of samples containing alga at each level of abundance							
		microscopic examination				no. of colonies in cultures			
		ab	fr	oc	ra	51–500	11–50	2–10	1
Cyanobacteria									
Gloeocapsa cf. *kuetzingiana* Naeg.	1		1						
Gloeocapsa cf. *ralfsiana* (Harv.) Kuetz.	2			1	1				
cf. *Aphanocapsa* sp.	2			1	1				
cf. *Leptolyngbya fragilis* (Gom.) Anag. & Kom.	9			5			2	5	1
Phormidium autumnale (Ag.) Gom.	9	4*		1	2				2
Hammatoidea normanni W. & G.S. West	1	1*							
Heterokontophyta									
Bacillariophyceae									
Luticola muticopsis (v. Heurck) D.G. Mann	2			1	1				
Chlorophyta									
Chlamydomonas sp. A	7					1	1	4	1
Chlamydomonas sp. B	1								1
Chlorococcum cf. *elkhartiense* Archibald & Bold	8							5	3
cf. *Coenochloris* sp.	1				1				
Tetracystis cf. *fissurata* Nakano	3								3
Stichococcus bacillaris Naeg.	10					2	2	4	2
cf. *Gloeotila* sp.	2							2	
cf. *Elliptochloris* sp.	1							1	
Desmococcus cf. *olivaceus* (Pers. ex Ach.) Laundon	9	4*	1	1	1	6		2	
cf. *Chlorella*	1							1	
Unidentified green unicells	16	1	2	5	8				
Remains of dead algae									
Empty mucilage sheaths of *G.* cf. *kuetzingiana*	7		3		4	ND			
Empty mucilage sheaths of cf. *L. fragilis*	58	7*	2	21	28	ND			
Empty frustules of *L. muticopsis*	8			1	7	ND			

Subjective estimates of abundance in fresh mounts of sample for direct microscopic examination are: ab, abundant and dominating the sample; fr, frequent; oc, occasional; ra, rare. An asterisk indicates that these records include occurrences as the dominant alga in the only growths visible to the naked eye (see also Table II). For *P. autumnale* growths covered the culture surface making it impossible to count the number of original colonies. ND indicates no data as material was not alive.

Fig. 3. The ice-cored moraines of site B (foreground) viewed from a ridge to the south of the site. The campsite (arrow) in the top left provides scale. A dense scattering of ice-covered ponds, which are up to 10 m long, covers the site as well as the moraine to the right of the camp. The moraine between the ponds is covered by stones, boulders and a thin veneer of sandy mineral material up to about 3 cm thick overlying ice.

Table II. Comparison of frequency of occurrence of algae between different sample materials at five sites at La Gorce Mountains. See Fig. 1 for site locations. Totals of samples with algae do not include occurrences of remains of dead algae seen during microscopic examination of samples. Dominant algae in the only growths visible to the naked eye are marked by an asterisk (also see Table I).

Sample type	Moist soil					Dry soil					Freeze-dried mat	Pond sediments
Site	A	B	G[1]	K	K[2]	A	B	G	J	K	A	B
Total no. of samples	12	45	3	10	4	8	20	7	9	6	5	8
Total no. with algae	7	5	3	9	4	4	3	0	2	0	5	7
Microscopic examination of samples												
No. with algae	3	1	3	3	4	0	1	0	0	0	5	7
Gloeocapsa cf. *kuetzingiana*			1									
Gloeocapsa cf. *ralfsiana*			2									
cf. *Aphanocapsa* sp.			1									1
cf. *Leptolyngbya fragilis*											5	
Phormidium autumnale			1									5*
Hammatoidea normanni			1*									
Luticola muticopsis		1										1
Coenochloris sp.			1									
Desmococcus cf. *olivaceus*				3	4*							
Unidentified green unicells	3		3				1				5	4
Empty mucilaginous sheaths:												
G. cf. *kuetzingiana*	1			1			1				4	
L. cf. *fragilis*	12	21		6		2	8			4	5*	
L. muticopsis frustules	4					1	2					1
Culture of samples												
No. with algae	4	5	3	8	4	4	3	0	2	0	4	0
cf. *Leptolyngbya fragilis*	4										4	
Phormidium autumnale		1					1					
Chlamydomonas sp. A	2					2					4	
Chlamydomonas sp. B							1					
Chlorococcum cf. *elkhartiense*	1	3					2				1	
Tetracystis cf. *fissurata*		1					2					
Stichococcus bacillaris		1	3	6								
cf. *Gloeotila* sp.						2						
cf. *Elliptochloris* sp.			1									
cf. *Chlorella* sp.		1										
Desmococcus cf. *olivaceus*				2	4				2			

[1]Moist soil in fissure crossing rock-face. [2]Moist soil with green patch on underlying ice.

a soil produced an immediate response, e.g. a drop from +7.1 to -0.4°C in 10 min when the air was -8.6°C.

Visual searches for macroscopic growths of terrestrial algae were rarely successful. Epilithic, endolithic and hypolithic algae were not encountered. Soil algae were visible only at site G over a soil surface and at site K within soil and at the soil–ice interface.

The surface algal growth at site G was a thin black mat (part of herbarium specimen CHR 401420) covering no more than 10 cm^2 of a lithosol in a fissure that crossed the rock-face on which lichens were found. It was in full sun at the time of sampling which had melted adjacent ice and saturated the soil. The mat was dominated by interwoven filaments of *Hammatoidea normanni* with associated aggregates of *Gloeocapsa* spp. and cultures contained abundant *Stichococcus bacillaris* (20 to *c.* 100 colonies). Seven samples of dry soil from patches in gullies and on horizontal rock surfaces within 10 m of this algal mat failed to reveal any algae.

On the moraines to the west of Price Bluff (site K), vivid green growths of *Desmococcus* cf. *olivaceus* were found at the ice–soil interface when the 5–10 mm of overlying mineral material was removed. The extent of each patch was up to 20 cm^2. Where soil was sun-illuminated and moist, brushing it away from the ice at randomly chosen spots within a 1 ha area revealed green patches on about 33% of occasions. Such growths were not encountered at any other site, even at the Szabo Bluff moraines (site J) where the mineral veneer comprised granitic material visually identical to that at Price Bluff.

Direct microscopic examination revealed algae in 10 samples from soils lacking visible algal growths (n = 119). These comprised unidentified green unicells in six samples, *D.* cf. *olivaceus* in three, and *L. muticopsis, Gloeocapsa* cf. *ralfsiana* and *Phormidium autumnale* each in a single sample. However, cell-free mucilaginous sheaths of cf. *L. fragilis* and *G.* cf. *kuetzingiana* were seen in 55 of these samples. Cultures were more successful with 28 samples producing growths. However, only in five of these did any single alga form more than 10 colonies.

There are indications of different distribution patterns in soils (Table II). The strongest of these is the occurrence of *D.* cf. *olivaceus* at sites J and K where it was found in a total of eight samples. In contrast, cultures revealed *Chlamydomonas* sp. A at only site A, *Chlorococcum* cf. *elkhartiense* at sites A and B, and *Tetracystis* cf. *fissurata* at site B. However, >10 colonies were produced in only two of the four samples containing *Chlamydomonas* sp A and in none of the seven samples containing the latter two algae.

Pond algae and their habitat

We encountered a large number of ponds at sites A, B and K. Fifty were counted in an approximately 2 ha area of moraine at Price Bluff (site K) and over 600 were estimated within an approximately 10 ha area at site B (Fig. 3). Site A, and wide-expanses of other moraines in the vicinity of both sites A and B which were observed during travel, had a similar density of ponds to site B. Throughout La Gorce Mountains, ponds must number at least several thousands. Most were in the range of 2–15 m diameter but a particularly large example close to site B was over 30 m long. Each pond occupied a circular to elliptical depression in the ice-cored hummocky moraines. These depressions were mostly shallow, being no more than 1 m deep, but at site A their sloping sides were estimated to rise to as much as 8 m above the pond surface.

All ponds were ice-covered. The ice was generally very milky due to high densities of small bubbles and was free of morainic debris. Very slight melting around the periphery was occasionally observed but there were no ice-free moats. Evidence of previous periods of more vigorous melt were observed at site B. There were frozen melt flows between some ponds and a sinuous channel, several metres long and about 15 cm wide, cut through ice downslope from an area of moraine.

Descriptive data for ponds is given for site B (Table III). Ice depth was 25–34cm and water depth 15–35cm. In all ponds, water temperature was around 0°C with bottom waters slightly warmer than just below the ice. Conductivity was low, as were dissolved reactive phosphorus (DRP) and dissolved organic phosphorus (DOP) concentrations. However, there were high concentrations of NO_3-N.

Evidence of algal growth in ponds was seen at site A. Scattered fragments of grey-brown, freeze-dried mats were found over and below stones in a 5 m^2 area of moraine alongside each of two ponds. Mats were neither present on the surface of pond ice nor observed on sediments through the few windows of clear ice. At site B, samples taken through drill holes contained small fragments of living, thin, blue-green mat from four ponds, and microscopic algal populations in sediments from three others.

Microscopic examination of samples from site B showed them to be dominated by apparently healthy *P. autumnale*. Other algae were infrequent (Table II) and at lesser abundance. Algae failed to grow in culture. In contrast, the freeze-dried mat from site A was dominated by mucilaginous sheaths of cf. *L. fragilis* and *G.* cf. *kuetzingiana*. Small chains of pigmented cells were occasionally seen amongst the former and their viability was confirmed by growth in culture (Table II) along with *Chlamydomonas* sp. A and *C.* cf. *elkhartiense*.

Fungi

Fungal colonies developed from cultures of only four of the 80 samples. Two samples, each from site B, yielded single colonies of *Penicillium chrysogenum* Thom. This displayed maximum growth at 25°C with reduced growth down to 5°C. There was no growth at 0°C. A second fungus occurred in a soil sample taken from near the lichen site at Mount Roland and in a soil sample containing visible *D.* cf. *olivaceus* from Price Bluff. This fungus has a colony morphology that is

Table III. Morphometric characteristics of, and physical and chemical analysis of water in, nine randomly chosen, typical ponds at site B, La Gorce Mountains. Chemical data are means of two samples taken from each pond. Water temperatures are from just below the lower surface of ice/just above sediments.

Pond	Surface area m^2	Ice depth cm	Water depth cm	Temp °C	TDN mg m^{-3}	NO_3-N mg m^{-3}	NH_4-N mg m^{-3}	DON mg m^{-3}	TDP mg m^{-3}	DRP mg m^{-3}	DOP mg m^{-3}	Conductivity mS cm^{-1}
1	16	33	28	-0.1/+0.1	934.5	858.6	26.5	59	7.2	6.0	1.1	65
2	3	25	15	+0.7/+1.8	1195.5	1129.5	23.8	42.5	3.6	2.8	1.0	75
3	15	32	26	-0.2/+0.2	1207.5	1183.3	10.0	14	2.7	1.5	1.4	72
4	13	26	22	-0.2/+0.1	731	690.1	6.6	34	1.6	1.1	<1	44
5	19	34	32	-0.2/+1.1	612	540.0	10.5	61.5	2.1	1.9	<1	47
6	46	32	34	nd	996	950.4	6.8	39	1.4	1.3	<1	69.5
7	13	28	24	nd	548.5	519.4	4.9	24	1.7	1.2	<1	27
8	13	33	22	nd	1937.5	1900.5	7.4	29.5	2.5	1.5	<1	75.5
9	56	29	35	nd	895	774.3	9.9	111	3.1	2.0	1.1	61
Mean	22	30	26	0.0/+0.7	1006.4	949.6	11.8	46.1	2.9	2.1	1.1	59.6
sd	17.4	3.3	6.5	0.4/0.8	418.6	425.8	7.8	28.8	1.8	1.5	0.1	16.7

nd = no data.

distinctly similar to a lichen mycobiont, i.e. slow-growing and crusty with a turban-shape and dark pigmentation. It appeared after eight weeks incubation in each of the triplicate cultures from the two soil samples, forming up to 10 colonies in each Petri plate. Its optimal growth temperature is 15°C and it grows at -4 and 25°C.

Discussion

Farthest south lichens

The Mount Roland lichens (sites G and H) are about 15 km farther south than the previous recorded southern limit of lichens (Claridge *et al.* 1971). Both epilithic lichens found at site G are widespread in continental Antarctica (D. Øvstedal, personal communication 1997). *Lecidea cancriformis* has been recorded at other sites around 86°S (Claridge *et al.* 1971, Kappen 1993) and, in the McMurdo Dry Valleys, is one of seven epilithic lichens occurring occasionally in protected niches on the surfaces of rocks colonized by cryptoendoliths (Nienow & Friedmann 1993). The sparse chasmoendolithic lichens at sites G and H have not been identified.

If it is assumed that suitable habitats will be colonized, then, at the La Gorce Mountains, these must be very rare. The identical geology of Szabo Bluff (site J) and Mount Roland and the very similar granites of all other nunataks north of Robison Glacier (Fig. 1; Stump *et al.* 1986) suggest that their distribution is not limited by unsuitable rock chemistry. Also, many rock surfaces lacking lichens appeared similarly weathered to those at the lichen sites. Although a high degree of weathering might be a prerequisite for colonization (Claridge *et al.* 1971) it could also outpace growth. Sufficient duration of moisture supply and adequate microclimate temperatures during summer are probably critical (Kappen 1993, Nienow & Friedmann 1993). The rock-face which supports lichens at site G is protected from prevailing katabatic winds blowing down the glaciers and might attain more favourable temperatures (Campbell & Claridge 1987, p. 59). Year-long records of microclimate at the lichen-occupied site and at adjacent uncolonized rock surfaces, as collected by Friedmann *et al.* (1987) at Linnaeus Terrace (77°35'S, 161°05'E), would provide a fascinating comparison.

A restricted algal flora

Previous investigations of algae at far south locations (Claridge *et al.* 1971, Cameron 1972a, Parker *et al.* 1982a) reported between three and seven species. The 17 taxa found by this study demonstrates the need for extensive sampling before conclusions can be drawn regarding algal diversity at remote locations.

We cannot confirm Cameron's (1972a) findings of *Neochloris aquatica* Starr and *Porphyrosiphon notarisii* (Menegh.) Kuetz. However, his *Schizothrix calcicola* (Ag.) Gom. is probably identical to our cf. *L. fragilis*. Cameron (1972a) noted that algal growths in liquid cultures at 20°C appeared only after eight months incubation. In our cultures readily visible colonies had developed by seven weeks at 8°C and all isolates grow at 15°C. Whether algae from La Gorce Mountains prefer low incubation temperatures requires investigation. If their response is similar to isolates from other polar regions (Seaburg *et al.* 1981, Tang *et al.* 1997) most would be expected to be psychrotrophic, eurythermal mesophiles.

The 17 species is a small fraction of the total of 700 non-marine taxa estimated to occur in Antarctica (Pankow *et al.* 1991). It is fewer than found farther north by comparable investigations in one region using similar methodology and intensity of sampling (Table IV). The use of culture techniques at Edward VII Peninsula and northern Victoria Land would probably have revealed an even wider diversity of chlorophytes and xanthophytes (Broady 1996).

Taxonomic problems and lack of detailed descriptions for many Antarctic algae make it difficult to confidently compare taxa with those recorded at other locations. Of the chlorophyte genera, only cf. *Gloeotila* is unusual and all others have been recorded elsewhere. The single diatom recorded in the present study, *L. muticopsis* (syn. *Navicula muticopsis* v. Heurck) is widespread in Antarctica (Prescott 1979). *Hammatoidea normanni* is the only cyanobacterium which is not well-known, but the La Gorce specimens might be an ecomorph of *Homoeothrix* sp. which was recorded as an epilithic alga at Vestfold Hills (Broady 1981) and at Edward VII Peninsula (Broady 1989).

Xanthophytes in general and the cyanobacterium *Nostoc*, although amongst the many algae which are widespread in

Table IV. Numbers of algal taxa at La Gorce Mountains compared with those at three more northerly Antarctic locations.

Location	Lat/long.	Total taxa	Cyano	Chloro	Xantho	Bacill	Methods used	Habitats examined	Reference
La Gorce Mountains	86°30'S, 147°W	17	6	10	0	1	DME, CU	TE, AQ	This study
Edward VII Peninsula	78°S, 153°W	30	19	10	1	0	DME	TE, AQ	Broady 1989
Northern Victoria Land	74°30'S, 164°E	52	20	17	3	12	DME	TE, AQ	Broady 1987
Vestfold Hills	68°38',S, 78°12'E	82	34	36	8	8	DME, CU	TE	Broady 1986

Taxa are: Cyanobacteria, Chlorophyta, Xanthophyceae, Bacillariophyceae (diatoms). Methods are: DME, direct microscopic examination; CU, cultures. Habitats are: TE, terrestrial, non-aquatic habitats; AQ, aquatic habitats.

Antarctica, are notable for their absence at La Gorce Mountains. The diversity of diatoms is also greatly restricted, for instance compared with the 27 species found by Seaburg *et al.* (1979) in southern Victoria Land.

An inability to survive dispersal might prevent diatoms from colonizing favourable habitats on nunataks of Edward VII Peninsula (Broady 1989). Likewise, this could be the reason for their paucity at La Gorce Mountains and their absence from ponds close to Darwin Glacier (79°50'S, 160°E; Vincent & Howard-Williams 1994). The occurrence of *Nostoc commune* Vauch. in thawed ponds and lakes about 50 km north of La Gorce Mountains in Moraine Canyon (86°09'S, 157°30'W; Cameron 1972a) and the culture of two species of the xanthophyte *Heterococcus* from soils sampled at lower altitudes (1010 and 610m) and farther north (86°02'S and 85°35'S) along Scott Glacier (Claridge *et al.* 1971) indicates an ability of these algae to disperse to, and grow in, these somewhat milder environments.

Terrestrial algae and their habitats

The great difficulty in finding visible growths of algae despite intensive search suggests that favourable microhabitats for growth are very uncommon. Sufficient duration of microclimate temperatures high enough to supply meltwater is probably critical. It has been convincingly argued (Kennedy 1993) that water availability plays a primary role in limiting distribution of terrestrial organisms in Antarctica. Cameron *et al.* (1971) recorded soil surface temperatures no greater than -3°C during 30 December 1970–4 January 1971 at Mount Howe. This nunatak is 90 km farther south and about 1000 m higher than the La Gorce sites. The latter may be at a critical location where suitable microclimate temperatures are marginally possible.

The visible growths at sites G and K were supplied with meltwater at the time of sampling. However, many other moraine soils were moist when sampled but either had no algae (46 samples) or had very low numbers (seven samples). It is possible that in these soils, water was available for insufficient time due to shading, e.g. by adjacent boulders, when temperatures would drop rapidly. Alternatively, some soils could be toxic, as demonstrated for soil samples from Mount Howe (Cameron *et al.* 1971).

Different soil algae are well known to have preferences for substrata of a particular chemistry (Hoffmann 1989). The difference in parental rock could explain the occurrence of eight soil algae at sites A and B (Table II) where greywacke-shale and silicic porphyry rocks predominate, and their absence at otherwise similar sites with granitic rocks (sites G, J and K; Stump *et al.* 1986). However, the presence of all these in only a low frequency of samples and then at low abundance suggests that favourable growth conditions are lacking.

Desmococcus olivaceus has been termed "the commonest green alga in the world" and is seen worldwide on rock and tree trunk surfaces (Laundon 1985). It is also common in Antarctica (Broady & Ingerfeld 1993) as an epilithic, chasmoendolithic and soil alga. However, the soil–ice interface microhabitat in which it occurs at Price Bluff (site K) is unlike those elsewhere. Incident light striking the soil surface will be greatly reduced below a few millimetres, perhaps to 0.01–1.0% of incident as found by Ellis-Evans (1997) at 2.5–3.0 mm depth where algal biomass peaked in an Antarctic lithosol. At Price Bluff, the deeper soil–ice interface, at *c.* 5–10 mm depth where algae occurred, could also receive light by backscattering of radiation penetrating adjacent ice which is free from surface mineral material. Water is supplied by ice melt due to solar heating of the thin veneer of soil. Absence of this alga from the soil–ice interface at sites A and B could be due to different chemistry of parental rock or its inability to transmit sufficient light.

Pond algae and their habitat

The ponds at La Gorce Mountains are the farthest south recorded. None was noted at Mount Howe by Cameron *et al.* (1971) but they are common farther north and at lower altitudes (Cameron 1972a, Vincent & Howard-Williams 1994). The duration of water below the ice cover can only be speculated. At this latitude there is 24 h of sunlight from about 2 October–12 March, i.e. about 23 weeks, and a further five weeks when the sun appears above the horizon. At midsummer the sun reaches no higher than 27° above the horizon. The glancing angle of the sun, the bubble-filled structure of the ice, and shading by surrounding mountain ridges suggest that penetration of sunlight through the ice and warming of dark, bottom sediments must be slight. The cold air temperatures, even at midsummer, and windy conditions must further reduce the period of positive heat balance in the ponds. However, the duration of water availability is obviously sufficient for production of thin microbial mats.

Freeze-dried mats on moraine adjacent to two ponds at site A were clearly derived from the ponds. Although cells were occasionally observed during microscopic examination, and their viability was confirmed by growth of algae in culture, most material consisted of empty mucilaginous sheaths of cf. *L. fragilis*. The specimens were greatly fragmented and did not form mats attached to the soil surface as do terrestrial algae growing *in situ* (Broady 1996). Freeze-dried mats are also common on McMurdo Ice Shelf (78°S, 166°E) where ponds can drain due to cracking and melting down of pond walls (Howard-Williams *et al.* 1990). Also, pond mats might be exposed as ponds shift position due to thermoerosional and ablation processes (Pickard 1983, Campbell & Claridge 1987, p. 120). The mats were not observed to derive from material dislodged from pond sediments, followed by melting through the overlying ice until emerging on the surface, a process which is common in ponds and lakes at lower Antarctic latitudes (Parker *et al.* 1982b).

Pond waters at La Gorce Mountains are similar to those reported by Vincent & Howard-Williams (1994) from close to the Darwin Glacier (79°50'S, 159°00'E). At both localities, concentrations of NO_3 were very high, dissolved organic nitrogen (DON) was relatively high but associated with low DOP and there was a strong positive correlation between NO_3 and conductivity (for La Gorce Mountains; df = 7, $r^2 = 0.764$, $P<0.001$). However, several ponds at Darwin Glacier had NO_3 and conductivity levels greatly exceeding those at La Gorce Mountains. Detailed discussion of the origin of these features is provided elsewhere (Vincent & Howard-Williams 1994, Timperley 1997) but long-range transport and precipitation seem likely sources of high NO_3 and possibly of DON.

At La Gorce Mountains, additional water samples are required to test for inter- and intra-site variation in pond chemistry and their possible effects on species composition of algal mats. The greater depth of depressions containing ponds at site A suggests a greater age for these ponds. Here, salts could be concentrated by ablation of pond surface ice and the longer period available for salt release from moraine due to weathering. At site B, where there was evidence for melt flow from pond to pond, variation in chemistry amongst ponds could occur due to those downslope receiving salts from those upstream, as postulated for ponds close to Darwin Glacier (Timperley 1997).

Local dispersal of algae

At the McMurdo Ice Shelf it has been noted that exposed dried mats are readily dispersed by wind (Howard-Williams *et al.* 1990) and large fragments of mat were collected in traps (Hawes 1991). Similarly, at La Gorce Mountains, local dispersal of algae-sized particles seems to occur readily as 45% of soil samples at site B contained cyanobacterial sheath material, very rarely with recognisable cells within, assumed to be derived from dried mats of cf. *L. fragilis* (Table II). As this alga was absent from living specimens in pond sediments at site B (Table II), it is unlikely that the sheath material came from ponds at this site. It is possibly blown from areas such as site A, where this alga does occur in ponds.

However, retention of viability of dispersed propagules could be very limited. Viable algae were detected by cultures in only 32 of the 124 soils sampled. Certainly pond mat algae survive poorly outside the pond environment as the rare culture of cf. *L. fragilis* from soil samples attests (Table II). Also, *D.* cf. *olivaceus*, although visible as small patches or seen during microscopic examination at sites J and K, and able to grow abundantly in culture (Tables I and II), did not appear in cultures of samples derived from any other sites. Thus, here is an alga with a rich local propagule source but which appears unable to survive or establish at sites to which it could reasonably be expected to disperse, especially site G which is downwind from site K. Also noteworthy is the failure to detect algae in seven dry soil samples at site G (Table II) despite their proximity to an algae-rich micro-site. At Signy Island, in the maritime Antarctic, Marshall & Chalmers (1997) were able to culture a range of chlorophytes and filamentous cyanobacteria captured by aerobiological samplers. However, propagule sources are abundant there and survival during dispersal is more likely in the humid climate. Comparable studies are required in harsh environments, such as La Gorce Mountains, in order to confirm the circumstantial evidence presented here for poor survival during or following dispersal.

Fungi

It is always difficult to establish the indigenous nature of heterotrophs in remote environments since they might be aerial propagules lying dormant in the soil. However, the isolate resembling a lichen fungus could reasonably be assumed to be active in soils of La Gorce Mountains as it has the ability to grow at typical soil temperatures, e.g. 5 and 10°C. Its occurrence in a collection taken close to lichens and its lichen mycobiont morphology suggests that it is the mycobiont of the local lichen. However, the only other sample from which it was cultured contained abundant free-living algae which could be a source of nutrition for the independent fungus. This is the southernmost occurrence of a mycelial fungus, exceeding the unidentified specimens cultured by Claridge *et al.* (1971) from soils collected farther north along Scott Glacier.

The growth optimum of 25°C suggests that *Penicillium chrysogenum* is unlikely to be indigneous. In Antarctica, *Penicillium* spp. are well-known both as airborne propagules and in soils from areas of human activity (Cameron 1972b). There is a slight possibility that the La Gorce Mountains isolate originated from an episode of *Penicillium* contamination which occurred at Mount Howe in 1971 (Cameron 1972b).

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References

BROADY, P.A. 1981. Ecological and taxonomic observations on subaerial epilithic algae from Princess Elizabeth Land and Mac. Robertson Land, Antarctica. *British Phycological Journal*, **16**, 257-266.

BROADY, P.A. 1986. Ecology and taxonomy of the terrestrial algae. *In* PICKARD, J., *ed., Antarctic oasis: terrestrial environments and history of the Vestfold Hills.* Sydney: Academic Press, 165-202.

BROADY, P.A. 1987. A floristic survey of algae at four locations in northern Victoria Land. *New Zealand Antarctic Record*, **7**, 8-19.

BROADY, P.A. 1989. Survey of algae and other terrestrial biota at Edward VII Peninsula, Marie Byrd Land. *Antarctic Science*, **1**, 215-224.

BROADY, P.A. 1996. Diversity, distribution and dispersal of Antarctic terrestrial algae. *Biodiversity and Conservation*, **5**, 1307-1335.

BROADY, P.A. & INGERFELD, M. 1993. Three new species and a new record of chaetophoracean (Chlorophyta) algae from terrestrial habitats in Antarctica. *European Journal of Phycology*, **28**, 25-31.

CAMERON, R.E. 1972a. Farthest south algae and associated bacteria. *Phycologia*, **11**, 133-139.

CAMERON, R.E. 1972b. Pollution and conservation of the Antarctic terrestrial ecosystem. *In* PARKER, B.C., *ed. Proceedings of the colloquium on conservation problems in Antarctica.* Lawrence, Kansas: Allen Press, 267-306.

CAMERON, R.E., LACY, G.H., MORELLI, F.A. & MARSH, J.B. 1971. Farthest south soil microbial and ecological investigations. *Antarctic Journal of the United States*, **6**(4), 105-106.

CAMPBELL, I.B. & CLARIDGE, G.G.C. 1987. *Antarctica: soils, weathering processes and environment.* Amsterdam: Elsevier, 368 pp.

CLARIDGE, G.G.C., CAMPBELL, I.B., STOUT, J.D., DUTCH, M.E. & FLINT, E.A. 1971. The occurrence of soil organisms in the Scott Glacier region, Queen Maud Range, Antarctica. *New Zealand Journal of Science*, **14**, 306-312.

ELLIS-EVANS, J.C. 1997. Micro-scale distribution of photoautotrophic micro-organisms in relation to light, temperature and moisture in Antarctic lithosols. *In* LYONS, W.B., HOWARD-WILLIAMS, C. & HAWES, I., *eds. Ecosystem processes in Antarctic ice-free landscapes.* Rotterdam: Balkema, 89-101.

FRIEDMANN, E.I., MCKAY, C.P. & NIENOW, J.A. 1987. The cryptoendolithic microbial environment in the Ross Desert of Antarctica: satellite-transmitted continuous microclimate data, 1984 to 1986. *Polar Biology*, **7**, 273-287.

HAWES, I. 1991. Airborne propagule sampling on the McMurdo Ice Shelf, 1990/91 – a comparison of samplers. *BIOTAS Newsletter*, **6**, 7-10.

HOFFMANN, L. 1989. Algae of terrestrial habitats. *The Botanical Review*, **55**, 77-105.

HOWARD-WILLIAMS, C., VINCENT, C.L., BROADY, P.A. & VINCENT, W.F. 1986. Antarctic stream ecosystems: variability in environmental properties and algal community structure. *Internationale Revue gesamten Hydrobiologie*, **71**, 511-544.

HOWARD-WILLIAMS, C., PRIDMORE, R.D., BROADY, P.A. & VINCENT, W.F. 1990. Environmental and biological variability in the McMurdo Ice Shelf ecosystem. *In* KERRY, K.R. & HEMPEL, G., *eds. Antarctic ecosystems: ecological change and conservation.* Berlin: Springer-Verlag, 23-31.

KAPPEN, L. 1993. Lichens in the Antarctic region. *In* FRIEDMANN, E.I., *ed. Antarctic microbiology.* New York: Wiley-Liss, 433-490.

KENNEDY, A.D. 1993. Water as a limiting factor in the Antarctic terrestrial environment: a biogeographical synthesis. *Arctic and Alpine Research*, **25**, 308-315.

LAUNDON, J.R. 1985. *Desmococcus olivaceus* – the name of the common subaerial green alga. *Taxon*, **34**, 671-672.

MARSHALL, W.A. & CHALMERS, M.O. 1997. Airborne dispersal of Antarctic terrestrial algae and cyanobacteria. *Ecography*, **20**, 585-594.

NIENOW, J.A. & FRIEDMANN, E.I. 1993. Terrestrial lithophytic (rock) communities. *In* FRIEDMANN, E.I., *ed. Antarctic microbiology.* New York: Wiley-Liss, 343-412.

PANKOW, H., HAENDEL, D. & RICHTER, W. 1991. Die Algenflora der Schirmacheroase (Ostantarktika). *Beihefte zur Nova Hedwigia*, **103**, 197 pp.

PARKER, B.C., BOYER, S., ALLNUTT, F.C.T., SEABURG, K.G., WHARTON JR, R.A. & SIMMONS JR, G.M. 1982a. Soils from the Pensacola Mountains, Antarctica: physical, chemical and biological characteristics. *Soil Biology and Biochemistry*, **14**, 265-271.

PARKER, B.C., SIMMONS JR, G.M., WHARTON JR, R.A., SEABURG, K.G. & LOVE, F.G. 1982b. Removal of organic and inorganic matter from Antarctic lakes by aerial escape of blue-green algal mats. *Journal of Phycology*, **18**, 72-78.

PICKARD, J. 1983. Surface lowering of ice-cored moraine by wandering lakes. *Journal of Glaciology*, **29**, 338-342.

PICKARD, J. & SEPPELT, R.D. 1984. Phytogeography of Antarctica. *Journal of Biogeography*, **11**, 83-102.

PRESCOTT, G.W. 1979. A contribution to a bibliography of Antarctic and subantarctic algae. *Bibliotheca Phycologica*, **45**, 312 pp.

RIPPKA, R., DERUELLES, J., WATERBURY, J.B., HERDMAN, M. & STANIER, R.Y. 1979. Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *Journal of General Microbiology*, **111**, 1-61.

SEABURG, K.G., PARKER, B.C., PRESCOTT, G.W. & WHITFORD, L.A. 1979 The algae of southern Victoria Land, Antarctica. A taxonomic and distributional study. *Bibliotheca Phycologica*, **46**, 169 pp.

SEABURG, K.G., PARKER, B.C., WHARTON JR, R.A. & SIMMONS JR, G.M. 1981. Temperature-growth responses of algal isolates from Antarctic oases. *Journal of Phycology*, **17**, 353-360.

STUMP, E., SMIT, J.H. & SELF, S. 1986. Timing of events during the late Proterozoic Beardmore Orogeny, Antarctica: geological evidence from the La Gorce Mountains. *Geological Society of America Bulletin*, **97**, 953-965.

TANG, E.P.Y., TREMBLAY, R. & VINCENT, W.F. 1997. Cyanobacterial dominance of polar freshwater ecosystems: are high-latitude mat-formers adapted to low temperature? *Journal of Phycology*, **33**, 171-181.

TIMPERLEY, M.H. 1997. A simple temperature-based model for the chemistry of melt-water ponds in the Darwin Glacier area, 80°S. *In* LYONS, W.B., HOWARD-WILLIAMS, C. & HAWES, I., *eds. Ecosystem processes in Antarctic ice-free landscapes.* Rotterdam: Balkema, 197-206.

VINCENT, W.F. & HOWARD-WILLIAMS, C. 1994. Nitrate-rich inland waters of the Ross Ice Shelf region, Antarctica. *Antarctic Science*, **6**, 339-346.

WISE, K.A.J. & GRESSITT, J.L. 1965. Far southern animals and plants. *Nature*, **207**, 101-102.