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The Biota and Environment of Fumaroles on Mt Melbourne, Northern Victoria Land

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Summary. The aim of this investigation was to provide a general description of the biota and environment of fumarolic ground close to the summit (2733 m) of Mt Melbourne. Heat flow through the ground was examined and analyses made of the physico-chemical properties of the soil. Bryophyte vegetation comprised *Campylopus pyriformis* (K.F. Schultz) Brid. and *Cephaloziella exiliflora* (Tayl.) Steph. The former is a new antarctic record. These grew as scattered and confluent cushions where surface ground temperatures ranged between 14°–31 °C. Algae were epiphytic on bryophytes and formed crusts over most other areas of warm ground. Six species of cyanophytes and five unicellular chlorophytes are described. The majority were mesophilic but *Mastigocladus laminosus* showed a strong preference for soil temperatures > 30 °C. A loosely lichenised chlorophyte was also encountered. The only soil fauna was a testate amoeba, *Corythion dubium.* Heterotrophic microorganisms included thermotolerant fungi, actinomycetes and bacteria as well as typical mesophilic microflora. Nitrogen fixation, analysed using both C_2H_2 reduction and $^{15}N_2$ enrichment, occurred in bryophyte cushions and surface algal crusts containing *M. laminosus* and in sub-surface samples lacking cyanophytes. The biota are compared with those found at other thermal localities in Antarctica and the dispersal of propagules to these areas is discussed.

Introduction

Mt Melbourne (2733 m) in northern Victoria Land (Fig. 1; 74° 21′S, 164° 42′E) is a stratovolcano centred in a volcanic field formed by a large number of small, individual eruptive centres (personal communication L. Viereck and G. Wörner, Ruhr University, Bochum). It is located on a prominent fault zone separating the uplifted Transantarctic Mountains from the Ross Sea Basin. The volcanic field is young, probably about $2-3 \times 10^6$ years B. P. Mt Melbourne is composed mainly of trachytic, trachyandesitic and a few basaltic rocks, these being dated at 250000 years B. P. up to recent. The last eruption probably took place no more than a few hundred years ago at most (Adamson and Cavaney 1967; Nathan and Schulte 1967), and around the summit crater and on some upper parts of the mountain there are extensive areas of hot ground, fumaroles and ice-towers (Figs.

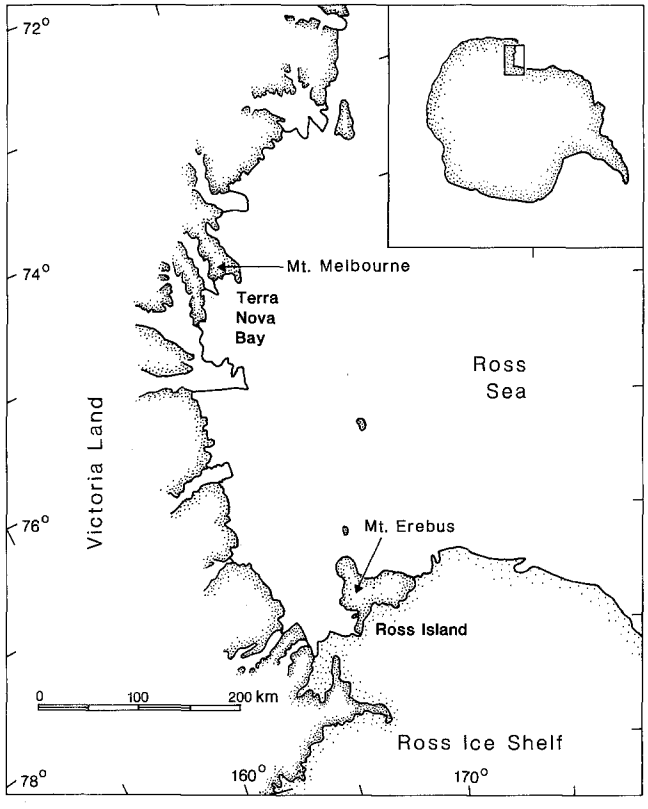


Fig. 1. Ross Sea and the coastal regions of Victoria Land showing the location of the two volcanoes, Mt Erebus and Mt Melbourne, where steam-warmed ground can be found. Inset shows the location of this region in relation to the whole continent

2–5). A brief description of some of these features and of the general geology is provided by Nathan and Schulte (1967) and Lyon and Giggenbach (1974).

Close to the summit of Mt Melbourne a remarkable community has been found which includes species of bryophytes and algae which must have been distributed to the mountain over long distances as they are not of local provenance. This hypothesis for the origin of exotic vegetation on warm ground elsewhere in Antarctica has been reviewed and discussed by Smith RIL (1984a, b). Moisture supply to this vegetation comes from the melting of snowfall and from the condensation of steam which is constantly emanating from the fumaroles.

Similar fumarolic soils to those on Mt Melbourne are found on Mt Erebus, Ross Island, southern Victoria Land and the vegetation there also has unique features (Broady 1984). A more diverse and luxuriant fumarolic vegetation has been described in the maritime Antarctic zone on Deception Island, South Shetland Islands (Collins 1969; Cameron and Benoit 1970; Young and Kläy 1971; Smith RIL 1984a, b), in the South Sandwich Islands (Longton and Holdgate 1979) and on Bouvetøya (Engelskjøn 1981). Elsewhere in Antarctica the only other areas of geothermal activity are on the continent in Marie Byrd Land (approximately 76°S 130°E; Le Masurier and Rex 1982) and at Seal Nunataks, Oscar Coast (64°S, 60° 03′W; pers. commun. RIL Smith, British Antarctic Survey) and in the sub-Antarctic on Heard Island (Quilty and Keage 1985) and Marion Island (Walton 1984). No biological investigations have been made of the geothermal features at these locations.

The field observations described here, and collections of samples for subsequent laboratory analysis, were made during a seven day camp during late November 1984 in the caldera close to the summit of the mountain. Previous expeditions by geologists (Nathan and Schulte 1967; Lyon and Giggenbach 1974) had commented briefly on the presence of vegetation on the fumarolic ground but this is the first detailed description of the biota and their environment.

Site Descriptions

Most fumaroles and warm ground are adjacent to the summit caldera of Mt Melbourne, although areas of surface activity extend downslope at least as low as 2400 m

Figs. 2–5. Features of geothermal ground on "Cryptogam Ridge" (site A, Fig. 6), Mt Melbourne. **2** The ridge with numerous ice-hummocks scattered along its length, a standing figure close to the middle of the ridge provides scale. The summit of the mountain is the high point across the caldera in the background. **3** A view along the length of the ridge showing snow-covered cool ground, snow-free ground and ice-hummocks covering other steam emissions. Warm ground (site B, Fig. 6) is also visible rising to the top of the slope in the centre background. **4** Close-up of exposed warm ground and associated small ice-hummocks. The soil here was covered by a red-brown crust of algae. **5** Miniature stone stripes approximately 10–15 cm wide at transect 5 (see Fig. 8). At *upper right* is a terracelet face with moss cushions

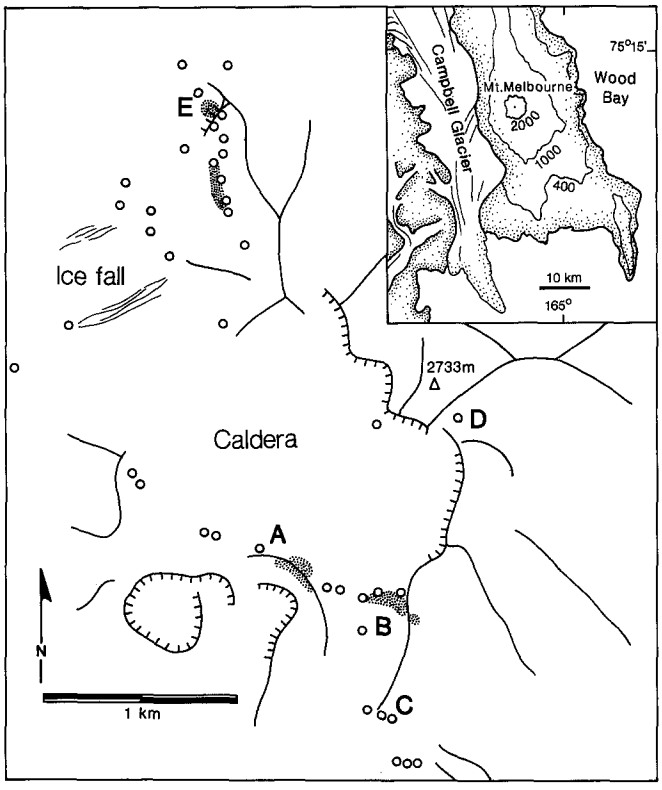


Fig. 6. Sketch map of the ridges (*lines*) and cliffs (*hatched lines*) in the caldera region at the summit of Mt Melbourne (based on Lyon and Giggenbach 1974) showing location of major areas of snow-free warm ground (*stipple*) and ice hummocks and towers (*circles*). Samples of soil and vegetation were removed from sites A–E. Site A was the main study site, unofficially named "Cryptogam Ridge" (see Fig. 3). Inset shows general topographical features in the vicinity of the volcano (based on "Mount Melbourne, Antarctica", 1:250000, SS 58–60/9, U.S. Geological Survey 1968) with contours in meters

on the northwest side of the mountain. The most extensive area of vegetation is found at "Cryptogam Ridge" (unofficial name, Fig. 6, site A) on the southern rim of the main crater. Most environmental studies were concentrated at this site. Here, warm ground extends along approximately 110 m of ridge, and up to 30 m to its south and about 20 m to its north (Fig. 7). The most extensive areas of warm ground were marked by snow-free areas at the time of our visit. On generally cooler ground where fumarolic zones were discontinuous, zones of geothermal activity were marked by ice and snow hummocks up to a metre in height.

On "Cryptogam Ridge" the warmer snow-free areas are mostly gently sloping (<10°) and consist of narrow terracelets approximately 50–150 cm wide, separated from those above and below by an abrupt rise of 8–12 cm. The surface consists of a pavement of compacted small stones and gravel in a matrix of sand and silt. At some points, terracelets are underlain by small boulders at only a few centimetres depth although usually these are encountered at depths in excess of 12–15 cm. The finest substratum is usually found along the toe and face of each terracelet. Miniature stone stripes are frequent on terracelets near the upper part of "Cryptogam Ridge". The stone stripes (Fig. 5) are oriented at right angles to the slope, are mostly 10–12 cm wide and consist of small stones 1–4 cm diameter. Frost-heave was observed on the margin of snow pack adjacent to terracelets with stone stripes. On cooler ground coarser stones and boulders predominate except under hummocks of ice and snow and adjacent to small steam vents, where the substratum usually contains a high fraction of sand and smaller particles.

At site B fumarolic ground is marked by crevasses and ice towers extending up the steep caldera rim. Above this, just below the ridge crest are small areas of sloping ground with small steam vents surrounded by snow-free patches several square metres in extent. Sporadic patches of moss occur here. Very limited stands of moss also occur at site E where a northwest to southeast trending line of ice-towers and small patches of bare ground mark the location of further geothermal activtiy. Here macroscopic plants are limited to the immediate vicinity of small steam vents.

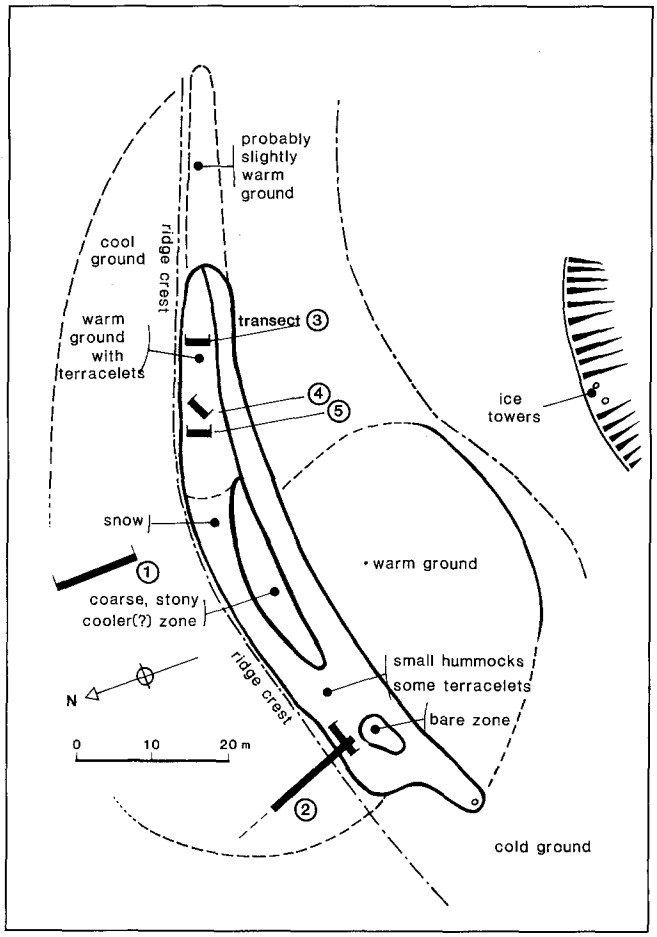


Fig. 7. Sketch map of "Cryptogam Ridge", Mt Melbourne (site A, see Fig. 6) showing the extent and type of geothermal activity and the positions of transects (1–5) used for measuring temperature/depth profiles (see Fig. 8 for details of transects 2, 3 and 5)

Materials and Methods

Ground Temperature Measurement

Ground temperatures, to a depth of 15 cm, were measured along six transects from 1.2 to 7 m in length using a Yellow Springs YSI 42SC telethermometer and 400 series probes that could be pushed firmly into the substratum. At selected sites temperatures were measured to 100 cm depth.

When removing samples for microscopic examination of the microbiota, the surface temperatures of soil and vegetation, and shade air temperatures (at 2 m height above the ground), were measured using tip-sensitive thermistor probes (Digitron Instrumentation Ltd., UK, model 1751K with hypodermic probes). Care was taken to insert the sensor no deeper than 2 mm when measuring surface temperatures.

Physico-Chemical Soil Properties

Ten soil cores (3 cm^2 in area) were randomly sampled from bryophyte vegetated areas at site A to 5 cm depth and kept frozen (0 to $-14\,°C$) until analysed. Moisture, pH, particle size analysis, bulk density, conductivity, and total nitrogen were determined on bulked 2 mm sieved soil samples according to the procedures given by Black (1965). Organic matter was determined by loss on ignition at 520 °C for 4 h. X-ray diffraction was employed to investigate clays in the clay-sized fraction derived from particle size analysis. Water soluble ions were determined in 1:5 soil:water extracts and free iron and aluminium oxides by dithionite (courtesy of Dr. G. Claridge, D. S. I. R. Soil Bureau, Wellington, NZ).

Assessment of Nitrogenase Activity

Acetylene (C_2H_2) reduction and $^{15}N_2$ assays were performed on samples from steam-warmed areas at site A. Details of replicates, sample depths and the presence of microbes, known from other studies to possess nitrogenase activity, are summarized in Table 2. Cores (1.2 cm^2 area) were incubated in situ at field moisture and temperature in 40 ml glass bottles fitted with rubber septa. The bottles were pushed into the ground at the positions from which cores were removed.

For C_2H_2 reduction a 1% C_2H_2 headspace was used and incubations lasted no longer than 6 h. Ethylene determinations were made using a portable gas chromatograph, as described by Davey (1982), in a tent in which the air temperature was maintained at 21°–26 °C using a primus stove. Controls to determine endogenous C_2H_4 production and to monitor background C_2H_4 levels were run.

For $^{15}N_2$ fixation samples previously incubated with C_2H_2 were flushed with air and incubated for 5 days in an atmosphere containing 25% by volume of 99% enriched $^{15}N_2$ gas. They were then frozen and returned to New Zealand for digestion (Kjeldahl). Enrichment of ^{15}N levels in these samples over the naturally occurring ^{15}N levels in steam-sterilized control samples incubated with $^{15}N_2$ gas were determined by Dr. E. Jottkandt (Bedford, UK) on a Neir isotope mass spectrometer.

Analysis of the Microbiota

Heterotrophic Microorganisms. Qualitative and quantitative analyses of bacteria, actinomycetes and filamentous fungi were performed on samples removed aseptically from areas adjacent to those used to determine nitrogenase activity. Microbial abundance was estimated by serial dilutions on yeast glucose agar (YGA, 5 g yeast extract (Difco), 10 g glucose l^{-1}), trypticase soy agar (TSA) and potato dextrose streptomycin (5 $\mu g\ ml^{-1}$) agar (PDA). Duplicate plates were incubated in the dark at 10, 20 and 50 °C for up to 14 days. Selected isolates on mesophilic and thermophilic YGA plates were pure cultured for identification later. In a few cases bacterial isolates were cultured for 4 days at 60 °C on YGA plates in moist chambers and cursorily examined using Gram stain, pigmentation and colony morphology.

Algae and Protozoa. A total of 71 samples, of no more than 1 cm^2 of surface vegetation and underlying soil to a depth of about 1 cm, were removed from sites A–E for microscopic examination and culture. Careful aseptic techniques were followed and the samples were transported and stored deep frozen at about $-14\,°C$ in sterile polythene bags. All samples were initially examined in the field within 24 h of collection using a field microscope (Nikon Hand Microscope Model H) and were re-examined later in the laboratory using an Olympus BH microscope. Illustrations were made using a *camera lucida* attachment to the latter.

Cultures were inoculated approximately 14 weeks after sample collection, the samples having remained in deep frozen storage. About 0.5 g of each sample was macerated in 10 ml of sterile Bold's basal medium (BBM; Nichols 1973). Each suspension was then streaked across the surface of 1.5% agarised BBM in each of two petri plates. Cultures were incubated at 18, 35 and 45 °C, illuminated by six 20 W, cool white fluorescent lamps on a 16:8 h light:dark cycle. Unialgal clonal cultures were isolated by the usual procedures of colony transfer and streak plating.

Results

Ground Temperatures

Temperature profiles were made across a variety of cool and warm, snow-covered and exposed, vegetated and bare ground (Fig. 8). Ambient air temperatures at a height of 0.5–1 m above the ground generally ranged from $-6\,°C$ to $-20\,°C$ with an extreme low of $-32\,°C$. In a typical transect across a series of terracelets, ground temperatures were relatively cool ($<0\,°C$ at surface) close to intact snow pack but increased across the bare terracelet surface to reach a maximum of up to 42 °C at the surface adjacent to where there is a change in slope of the terracelet face. It was generally here that largest moss cushions were found. Smaller ones were also associated with the toe and upper end of terracelets where ground temperatures of up to 30 °C at the surface were usual. Near the lower end of "Cryptogam Ridge" a transect across a small shallow pebbly channel showed that moss cushions and liverwort mats occurred where surface temperatures were greater than 20 °C. In contrast, distinct algal felts predominated where the temperature on the substratum surface was between 10–20 °C.

Forty measurements were made 5 mm below the surface of eight moss cushions. With an air temperature of $-6\,°C$ the moss temperatures were: mean 20.3 °C, range 14°–31 °C, S.D. 4.8 °C.

Across the terracelets a regular temperature depression of several degrees was encountered below the stone stripes, especially at the down-slope margin where there was a very sharp decrease. This suggests a heat flux difference through coarse and fine substrata. On cooler but snow-free ground where temperatures of about 0 °C appeared too low to support vegetation, geothermal activity was sometimes apparent lower down the profile with temperatures of up to 25 °C recorded at depths of 15 cm.

Additional temperature measurements were made at depths between 15–100 cm although at several points the probe could not be inserted deeper than 50–60 cm. Below 15 cm temperatures at the warmest sites ranged from 44°–59.5 °C, usually with little increase with increasing depth. A typical range of temperatures on a level terracelet near the ridge crest was: 50 cm, 44°–53 °C; 60 cm, 53 °C; 70 cm, 49°–55 °C. Under different

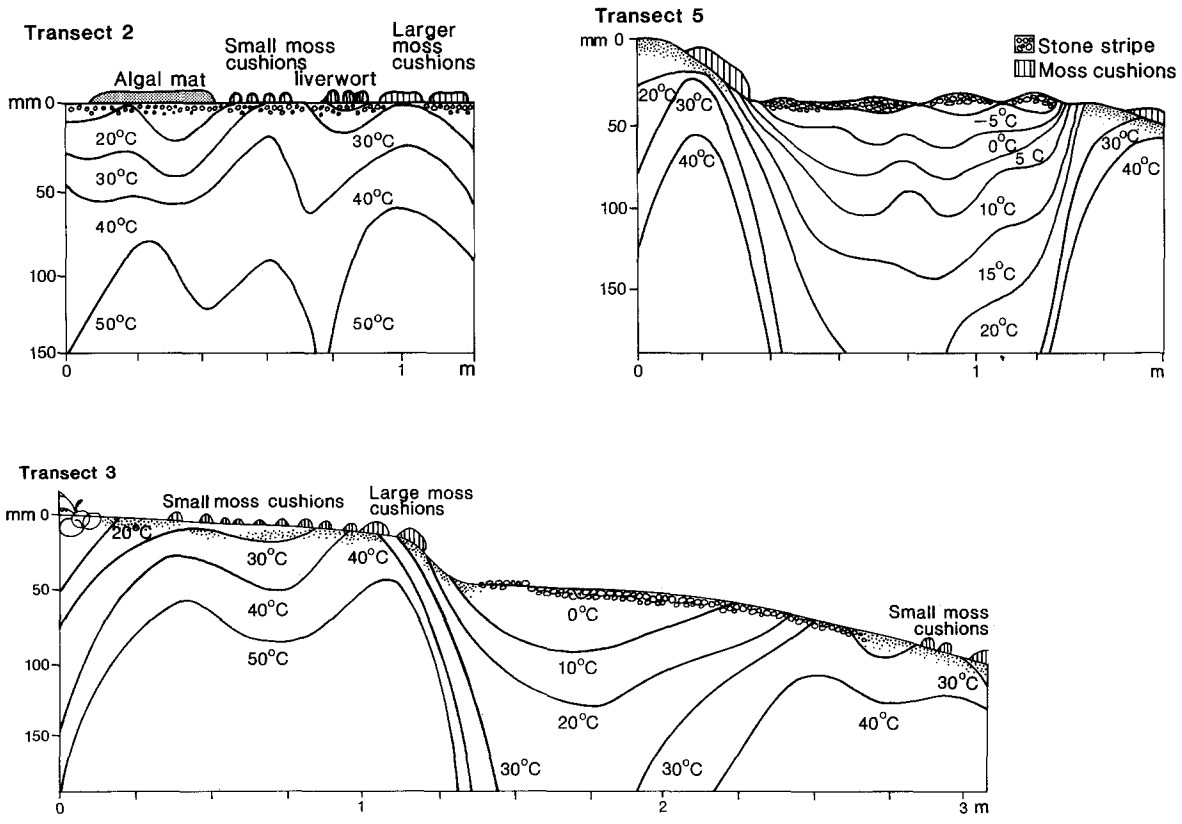


Fig. 8. Temperature/depth profiles along three transects on "Cryptogam Ridge" (site A in Fig. 6). The position of each transect is shown in Fig. 7. The section of transect 2 illustrated is the short portion at right angles to the main part of the transect

substrata the following temperatures were measured: fines 80 cm, 49 °C; 100 cm, 54°–55.5 °C; stone stripe 50 cm, 47 °C; depression with boulders 30 cm, 41°–42 °C; 50 cm, 51.5 °C. A smaller number of measurements indicated a similar but slightly cooler temperature regime at sites B and E. The highest surface temperature recorded at these sites was of 49.5 °C, at the opening of a small steam vent at site E.

Estimates of geothermal flux (based on Dawson 1964, see Given 1980, Table 1) suggest that on areas clear of snow but with no macro-plants (<20°–35 °C at 5 cm depth) heat flow is probably <10 cal m^{-2} s^{-1}. Where there are moss cushions and algal mats (20°–55 °C at 5 cm depth) heat flow is probably about or a little above 10 cal m^{-2} s^{-1}. All temperature measurements have been used to construct temperature/depth curves to show relative changes in temperature with depth under different levels of geothermal flux. Two sets of curves describe the data (Fig. 9). Type A is typical of warmer sites where the substratum is fine, but type B is more characteristic of slightly cooler sites and those where the substratum is coarser (e.g. under stone stripes). Below about 10 cm depth there was usually relatively little temperature increase. Extrapolation to greater depths, sug-

Table 1. Physical and chemical properties of colonized soil from Mt Melbourne[a]

pH	Conductivity (mmhos cm^{-1})	Moisture (%)[b]	Bulk density (g cm^{-3})	Particle analysis (%)			Organic matter (% loss on ignition)[b]
				Sand (50 μm)	Silt (50–2 μm)	Clay (2 μm)	
5.1	0.06	115	0.85	90	8	2	11

Extractable chemicals

Extractable chemicals (me 100 g^{-1})									(mg g^{-1})[b]		Total nitrogen
Na	K	Ca	Mg	Cl	HCO_3	SO_4	NH_4	NO_3	Fe_2O_3	Al_2O_3	(%)
0.015	0.06	0.005	0.007	0.33	0	trace	0	0.003	14.9	10.1	0.24

[a] Data are means of 10 subsamples (1–5 cm depth) collected beneath moss and liverwort (samples 1 and 2, Table 2)
[b] On a dry weight basis

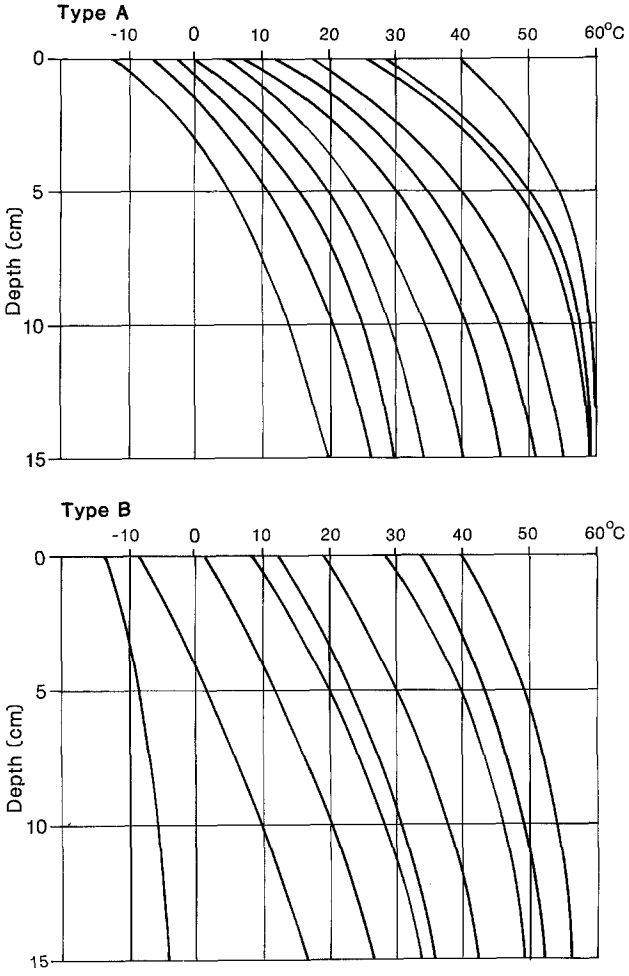


Fig. 9. Generalised temperature-depth relationships on geothermally active ground, Mount Melbourne. **Type A** typical of warmer sites with a fine substratum. **Type B** characteristic of slightly cooler sites and those with a coarser substratum

gests that the maximum temperature is unlikely to exceed about 60 °C, a conclusion supported by probing to depths of up to one metre. This differs markedly from curves constructed for Karapiti, New Zealand (Given 1980) where temperatures can exceed 100 °C at quite shallow depths.

A possible interpretation is that conduction is the principal form of heat transport rather than superheated groundwater circulating from greater depths. Possibly a considerable volume of substratum may be heated to approximately 60 °C with rapid cooling occurring near the surface. The profiles suggest that a regular system of convection cells (points of concentrated geothermal flux) may exist on "Cryptogam Ridge", similar to cells suggested by some profiles at Karapiti.

As well as these relatively large scale spatial differences in ground temperatures there was also quite considerable variation over small distances of the substratum surface as indicated by surface temperature readings made within two 15 cm square quadrats placed on vegetated areas of steaming ground. 60 measurements were made in one quadrat containing both moss cushions and a red-brown to green surface crust of algae and 40 in the second which enclosed an almost macroscopically homogeneous orange-brown algal crust (Fig. 10). In the former, on the moss surface the temperature range was 15°–32 °C and on the algae 15°–36 °C. In the latter the range was 15°–40 °C. There were no obvious zonation patterns with regard to temperature differences within either quadrat and neither were there any distinct patterns in vegetation which could be correlated with temperature. Samples removed from 12 positions in quadrat 1, and 8 in quadrat 2, showed that the dominant algae could vary over distances as short as 1 cm even where the surface crust was macroscopically homogeneous (Fig. 10).

Physico-Chemical Soil Properties

The physico-chemical properties of the bulked soil sample are presented in Table 1. The coarse texture, low pH, conductivity and salt content are fairly typical of other volcanic areas in Antarctica, e.g. Mt Erebus (Ugolini 1965) and Deception Island (Cameron and Benoit 1970; Smith RIL 1984a). Unlike Ugolini who detected illite and kaolinite in Mt Erebus soils no ordered clay minerals were detected in the present study. The clay-sized fraction consisted of high temperature feldspar and anorthoclase with smaller amounts of allophane and amorphous silica.

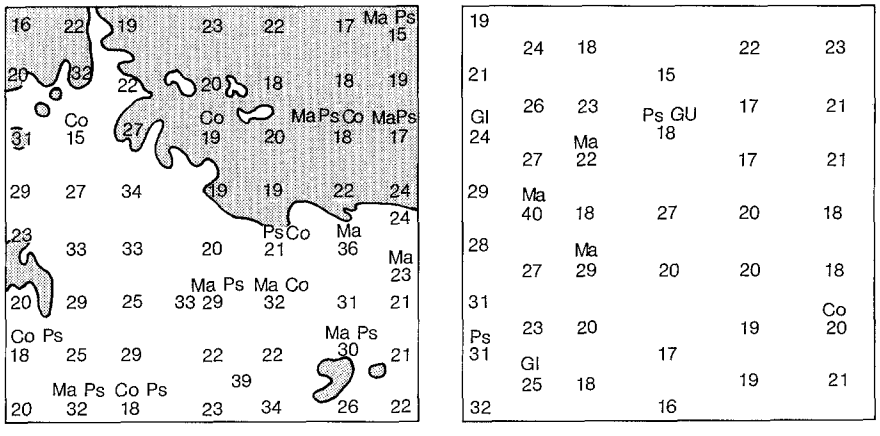


Fig. 10. Variation in surface (0–2 mm) temperatures (°C) of moss and algal crusts within two 15 cm square quadrats on steaming ground, site A (see Fig. 6). Moss cover is stippled. Algae recorded as "abundant" or "frequent" at each location sampled are indicated above the position of sampling. Gl = *Gloeocapsa magma*; Ma = *Mastigocladus laminosus;* Co = *Coenocystis oleifera*; PS = *Pseudococcomyxa simplex*; GU = unidentified green unicells

Table 2. Nitrogenase activity in soil and vegetation from Mt Melbourne

Sample material	Replicate cores	Depth (cm)	Nitrogenase activity (nmoles C_2H_4 g^{-1} dw d^{-1})		(nmoles $^{15}N_2$ g^{-1} dw d^{-1})		Microbes identified and known to be potential nitrogen fixers[a]
			Mean	Range	Mean	Range	
1. Moss, liverwort	6	0–1	47	43–53	11	7–13	*Mastigocladus laminosus*
2. Moss	6	0–1	56	51–59	11	5–12	*Mastigocladus laminosus*
3. Bare vent soil	6	0–2	21	10–24	8	4–9	*Mastigocladus laminosus, Bacillus* sp.
4. Soil below moss	6	2–5	72	36–87	8	7–16	*Bacillus* sp., *Klebsiella* sp.
5. Frozen moss	2	0–2	9	3–14	0		None
6. Moss rhizoids	2	0–1	41	37–44	0		*Mastigocladus laminosus*

[a] Cyanophyta detected by microscopic examination and bacteria by culture
dw = dry weight

Allophane was detected by Ugolini (1965) in Mt Erebus soils and is probably derived from weathering of volcanic ash by geothermic processes.

Assessment of Nitrogenase Activity

The results for both methods, corrected for controls, are given in Table 2. Unequivocal evidence for nitrogen fixation is provided by positive results for four samples incubated with C_2H_2 followed by $^{15}N_2$. Three of the samples contained the heterocystous cyanophyte *Mastigocladus laminosus.* Bacteria, in addition to cyanophytes, appear to be responsible for a proportion of the nitrogen fixed as indicated by the presence of *Bacillus* and *Klebsiella* spp. in the subsurface sample which lacked cyanophytes.

The Biota of Fumarolic Ground

Bryophytes

Campylopus pyriformis (K. F. Schultz) Brid.
Synonymy: *Campylopus pallidus* Hook. f. and Wils.
Campylopus torquatus Mitt.

This is the first record of this genus for continental Antarctica. A total of at least five species of the genus are reported from fumarolic ground in the maritime Antarctic, on Deception Island (Smith RIL 1984a) and in the South Shetland Islands (Longton and Holdgate 1979). There are no cold ground records from these localities.

This species is circum-polar on other southern continents and has also been recorded from Western Europe and the Azores (Corley and Frahm 1982). In southern Australia it is found on old stumps in forests and on tussocks in boggy ground (Scott et al. 1976). It is probably calciphobous (pers. commun. D. G. Catcheside).

Herbarium material has been deposited as MELU 7866.

Cephaloziella exiliflora (Tayl.) Steph.
Synonymy: *Cephaloziella varians* (Gott.) Steph.

C. exiliflora (Tayl.) Steph. has been recorded at sites on Budd Coast, Wilkes Land, and in the Larsemann Hills, Ingrid Christensen Coast, Princess Elizabeth Land (Seppelt 1984) and on fumarolic ground in the South Sandwich Islands (as *C. varians,* Longton and Holdgate 1979). A *Cephaloziella* tentatively assigned to *exiliflora* has been recorded as a post-eruption colonist on Deception Island (Smith RIL 1984b). The only other record of a hepatic for Victoria Land is of *C.* cf. *varians* collected from near Cape Hallett (Greene 1967).

Herbarium material has been deposited as MELU 7867.

Algae

Sample material consisted of felts and crusts of algae that coated small stones, gravel and finer substrata, especially in areas where steam was rising from the surface. These growths were readily visible to the unaided eye and covered most of the steaming ground, to a greater extent than the bryophyte vegetation. They were generally somewhat mucilaginous layers up to about 2 mm thick which consolidated the mineral substratum and varied in colour from green, dark blue-green and brown to red-brown and almost black. In addition, microscopic populations of algae were found coating the surfaces of bryophytes and occasionally the algal epiphytes were visible as dark crusts. No significant differences were noted between the algal community inhabiting the bryophyte cushions and that covering mineral substratum.

The majority of samples were removed from exposed areas of warm ground that were not covered by ice-hummocks. However, in areas B, D and E, 9 samples of gravel and sand were removed from the dimly illuminated interiors of large ice-hummocks which formed caves over warm ground. In all cases but one there was no vegetation visible but in the latter a thin green crust coated the small stones. Only six of the total 71 samples failed to reveal any algae and three of these were taken inside the caves. There was no evidence to suggest any difference in the algal flora of the five areas sampled. The distribution of algae in response to ground temperature, and a subjective estimate of their abundance in field material is shown in Fig. 11.

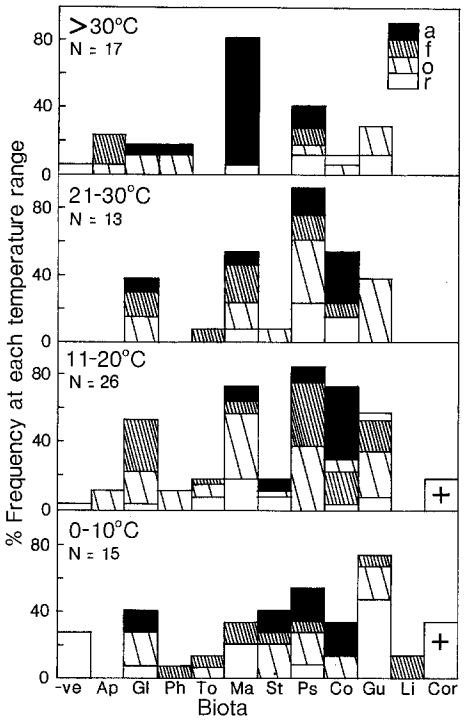


Fig. 11. The percentage frequency and abundance of algae, a lichenised alga and a protozoan at different soil surface temperatures, as identified by microscopic examination of field material. Within each temperature range the frequency of each organism is shown as a percentage of all samples within that particular temperature range. A subjective estimate of abundance is given on the scale: a = abundant; f = frequent; o = occasional; r = rare. Key: -ve = no vegetation detected; Ap = *Aphanocapsa elachista*; Gl = *Gloeocapsa magma*; Ph = *Phormidium fragile*; To = *Tolypothrix bouteillei*; Ma = *Mastigocladus laminosus*; St = *Stigonema ocellatum*; Ps = *Pseudococcomyxa simplex*; Co = *Coenocystis oleifera*; Gu = unidentified green unicells; Li = a lichenised alga; Cor = *Corythion dubium* (+ = presence/absence data only)

In addition to field observations, some indication of the temperature range required for growth of the different species was obtained from cultures. No algal growth was obtained at 45 °C in culture. This corresponded well with the maximum temperature of 44 °C at which living algal cells were observed in field material, and the sample with the highest recorded field temperature of 47 °C containing only rare, apparently dead cells. At 35 °C in culture only two algae grew; *Mastigocladus laminosus* and *Phormidium fragile*. The former displayed a strong preference for temperatures greater than 30 °C in the field (Fig. 11) although it was also found in decreasing abundance and with decreasing frequency at temperatures down to 1 °C. The latter showed no strong preference in the field. A culture temperature of 25 °C produced the widest range of species, including five species of unicellular Chlorophyta, as well as *P. fragile* and *M. laminosus*. The remaining four cyanophytes did not develop in the culture conditions provided. In field material (Fig. 11) maximum recovery of Chlorophyta was between 1°–30 °C although there were still significant populations in some samples where the temperature was greater than 30 °C. Only two of the Chlorophyta obtained in culture, *Pseudococcomyxa simplex* and *Coenocystis oleifera*, were regularly recognised during microscopic examination of field material. The remainder were probably the dominant constituents of the category "unidentified green unicells" which could not be confidently identified using the latter technique. These were rarely a dominant component of field communities but were often observed at lower levels of abundance, particularly at temperatures below 20 °C.

Below are presented short descriptions of the algae as observed by direct observation of field material, and when possible in culture, together with brief ecological observations. Notes are provided regarding records from fumarolic ground on Mt Erebus (Broady 1984) as well as from other antarctic localities. It is recognised that the species concept in the Cyanophyta is in a state of flux. Identifications provided here are based on field specimens and follow the classical approach as exemplified by Geitler (1932).

Cyanophyta

Aphanocapsa elachista West and West 1894. Fig. 12-2. [Geitler 1932, p 156, Fig. 69b]

Field Specimens. Colonies small, irregular, containing up to about 30 cells scattered throughout colourless, non-stratified mucilage. Cells spherical, pale blue-green, 1–2 µm diameter.

This alga was observed only in 7 samples and may have been overlooked during direct observation because of its small size and pale colour. It never dominated the community in any sample and there was no clear indication of a temperature preference.

An identical alga was recovered from fumarolic ground on Mt Erebus.

Gloeocapsa magma (Breb.) Hollerbach 1924. Fig. 12-1. [Geitler 1932, p 198, Fig. 93]

Field Specimens. Colonies containing up to about 30 cells, generally arranged in regular groups of two, four and eight, as a result of cell division in three planes; mucilage dark red-brown, distinctly stratified throughout. Cells blue-green, 4–12.5 µm diameter. Mucilage sheath up to 5 µm thick around individual cells.

G. magma was occasionally a dominant member of the algal communities both on mineral substrata and as an epiphyte on bryophytes. There is a single previous record of this alga from Antarctica in a freshwater stream, Dronning Maud Land (Hirano 1979).

Phormidium fragile Gom. 1892. Fig. 12-3. [Geitler 1932, 999, Fig. 636c, d]

Culture. Trichomes 1–2 µm wide. Sheath colourless, up to 0.5 µm thick. Cells 1–2.5 µm long. Terminal cell rounded, slightly longer than intercalary cells.

Field Specimens. Identical to culture material except for a larger range in cell length of 1.5–7.5 µm.

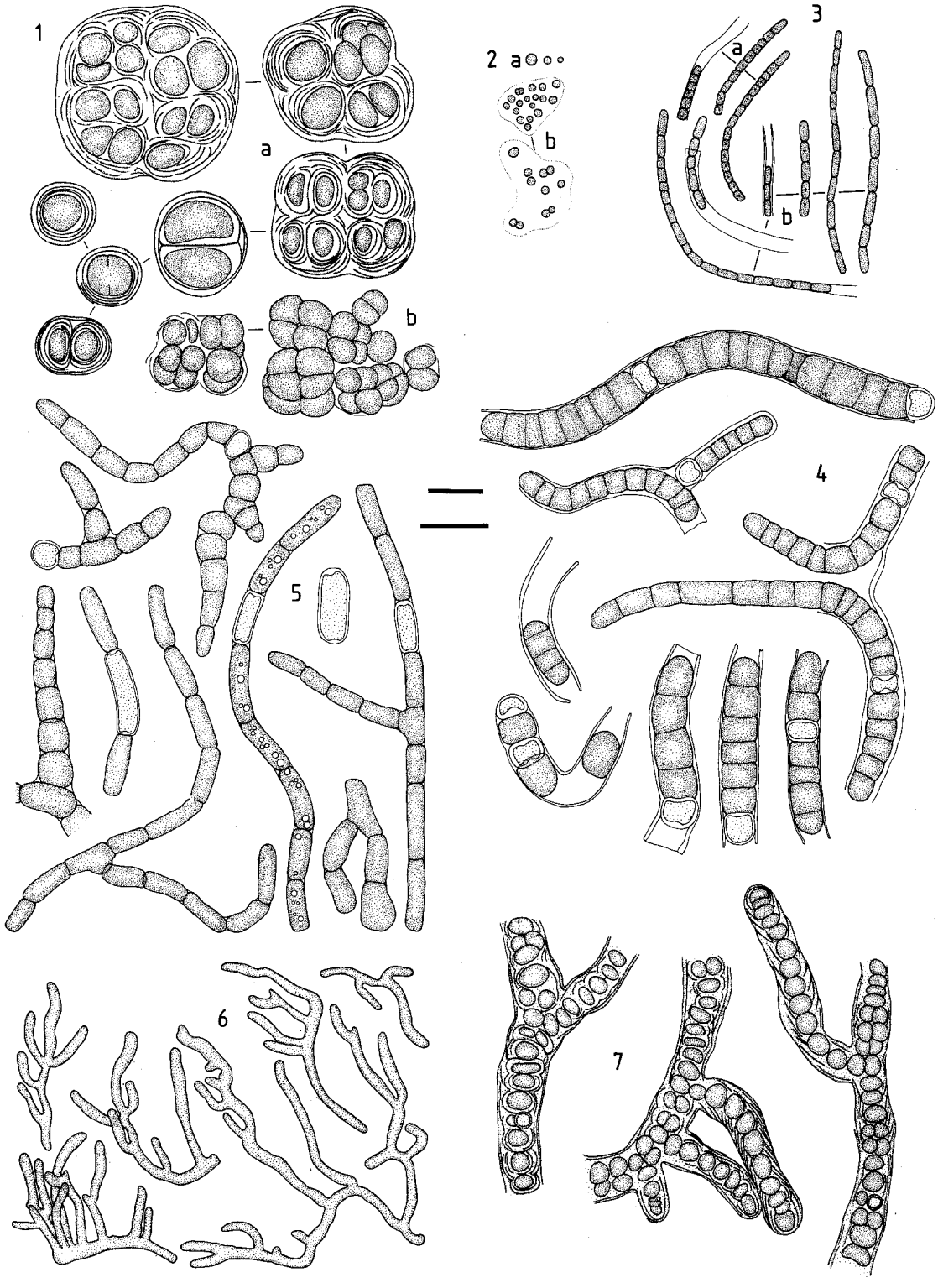


Fig. 12. Algae from geothermally heated ground. 1: *Gloeocapsa magma*; a = typical colonies with stratified mucilage; b = colonies with poorly developed mucilage. 2: *Aphanocapsa elachista*; a = range in cell size; b = small mucilaginous colonies. 3: *Phormidium fragile*; a = specimens from culture; b = field material. 4: *Tolypothrix bouteillei*; typical short filaments with few displaying false-branching. 5: *Mastigocladus laminosus*, heterocystous filaments and non-heterocystous fragments from field material. 6, 7: *Stigonema ocellatum*; 6 = richly and irregularly branching filaments; 7 = detail of the predominantly uniseriate trichomes and the stratified sheath. Scale lines equivalent to: *upper* 10 µm in nos. *1–5*; lower 120 µm in no. *6* and 30 µm in no. *7*

The abundance of this alga on Mt Melbourne was substantially less than that observed on Mt Erebus where it dominated felts at temperatures mostly between 30°–40 °C. In this investigation it occurred in a low proportion of samples over a wide temperature range. There are several previous antarctic records (Prescott 1979).

Tolypothrix bouteillei (Breb. and Desm.) Lemm. 1910. Fig. 12-4. [Geitler 1932, 724, Fig. 464]

Field Specimens. Filaments 4.5–8 μm wide, mostly occurring as short unbranched lengths of up to 20 cells, occasionally showing single and double false-branches. Trichomes 3–7.5 μm wide. Cells 2–9 μm long, mostly approximately as long as wide. Heterocysts both intercalary and at the base of false branches. Sheath thin, colourless.

The material is not so richly branched as that illustrated by Geitler (1932).

The alga was only occasionally encountered and never dominated the community in any sample. There are indications that it does not grow at temperatures greater than 30 °C.

There are few records of species of *Tolypothrix* from the Antarctic continent (Prescott 1979); however, this species has been observed once in soil from Dronning Maud Land (Akiyama 1968).

Mastigocladus laminosus Cohn 1863. Fig. 12-5. [Geitler 1932, 558, Figs. 350–352]

Field Specimens. Filaments branching abundantly. Trichomes 3–6.5 μm wide. Cells 3.5–14 μm long. Heterocysts subspherical to cylindrical.

This is clearly one of the major constituents of the microflora, growing over a wide range of temperatures in the field but showing a distinct preference for those greater than 30 °C.

It was found on Mt Erebus where its distribution was restricted to certain areas of fumarolic ground, perhaps where soil conditions were supportive of growth. There was no evidence of such a disjunct distribution at Mt Melbourne. The only other record of a possibly similar alga in Antarctica is of a "*Mastigocladus*-like" species from a lake on Anvers Island (Parker et al. 1972). Elsewhere it is well known as a ubiquitous inhabitant of thermal areas (Castenholz 1973).

Stigonema ocellatum Thuret 1875. Fig. 12-6, 12-7. [Geitler 1932, 504–509, Figs. 305–307]

Field Specimens. Filaments branching abundantly, 24–37 μm wide. Sheath thick, golden-brown and distinctly stratified. Trichomes mostly uniseriate, occasionally biseriate. Cells 10–21 μm diam.

Dimensions of this material are on the whole slightly less than those given by Geitler (1932) but other features are in close agreement.

This alga occasionally dominated dark brown felts over the mineral substratum at temperatures below 20 °C.

Stigonema has rarely been observed in Antarctica; two species are recorded from a stream in Dronning Maud Land (Hirano 1979) and one from soil in Princess Elizabeth Land (P. Broady, unpublished observation). *S. ocellatum* was the tentative identification for the dominant component of algal felts on wet mires on the sub-Antarctic Marion Island (Croome 1973).

Chlorophyta

Chlorella emersonii Shihira and Kraus 1965. Fig. 13-1. [Komárek and Fott, 1983, 593, plate 167, Fig. 4]

Culture. Cells spherical and broadly ellipsoidal, up to 18 μm diameter. Chloroplast covering most of cell wall, perforated. Pyrenoid surrounded by a thin, apparently entire, starch sheath. Irregular rupture of the sporangium wall releases 2–8 spores. Sporangium wall fragments persist.

The same species was recovered from Mt Erebus soils but there are no other antarctic records.

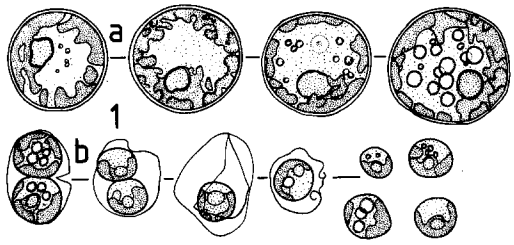
Chlorella cf. *reniformis* Watanabe 1977. Fig. 13-2, 13-3. [Watanabe 1977, 173, Fig. VIII, 1–9]

Culture. Cells subspherical and broadly ellipsoidal, up to 13 μm diameter. Chloroplast parietal, extensive, broadly lobed into two or a small number of broad lobes, with occasional perforations. Reproduction by release of small numbers of spores by irregular rupture of sporangium wall, remains of which persist. Spores often reniform, or cylindrical and ellipsoidal, from 6 by 3 μm.

Field Specimens. Identical to material in culture except that cell aggregates occur in which spores appear to be held together, and develop, within ruptured remains of the sporangium wall. Observed only in a single sample.

Of the five *Chlorella* species lacking pyrenoids (Fott and Nováková 1969; Watanabe 1977) this isolate approaches only *C. zofingensis* Doenz and *C. reniformis*. The broad, deep lobing of the chloroplast and the

Fig. 13. Algae, a lichenized alga and a protozoan from geothermally heated ground. *1*: *Chlorella emersonii*; a = adult cells; b = autospore release and young cells. *2, 3*: *Chlorella* cf. *reniformis*; 2 = specimens from culture; a = adult cells showing the chloroplast in surface view and optical section; b = young cells; c = sporangia; d = recently released, mostly reniform spores; *3*:field material; a = adult cells, single and remaining in aggregates within the remains of the sporangium wall; b = sporangia. *4*: *Coccomyxa gloeobotrydiformis*; a = cells irregularly distributed in mucilage; b = adult cells; c = young cells and sporangia. *5*: *Pseudococcomyxa simplex*; a = specimens from culture showing adult cells, young cells and spore formation and release; b = field material. *6, 7*: *Coenocystis oleifera*; 6 = specimens from culture, a = cells somewhat regularly distributed throughout mucilage; b = detail of part of colony showing adult cells and spore release; *7*: field material; a = occasional specimens lacking distinct stratifications; b = the usual appearance of the distinctly stratified mucilage. *8*: field material of an unidentified, unicellular, green alga with a stratified mucilaginous envelope. *9*: a loosely lichenised alga; a = surface view of and optical section through a cluster of algal cells surrounded by a dense, thin sheath of melanised, septate fungal hyphae; b = clusters of fungal-sheathed algae connected by hyphae. *10*: *Corythion dubium,* a variety of tests, one containing an encysted cell. Scale line equivalent to 10 μm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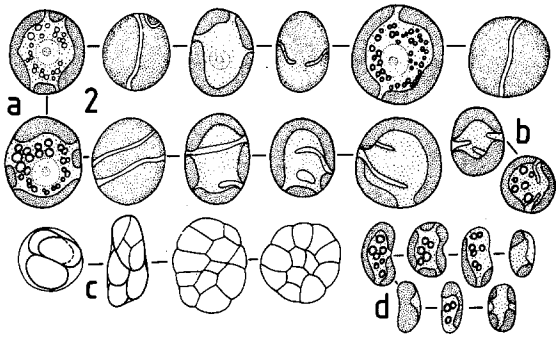
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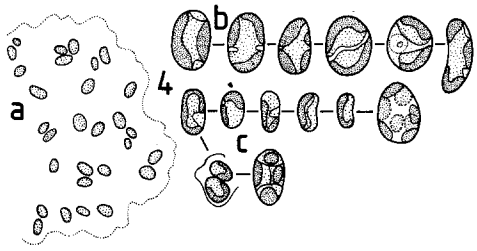
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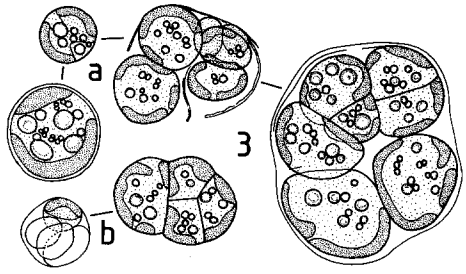
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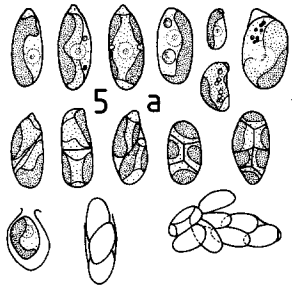
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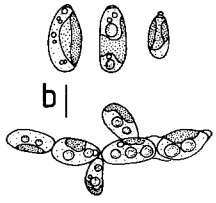
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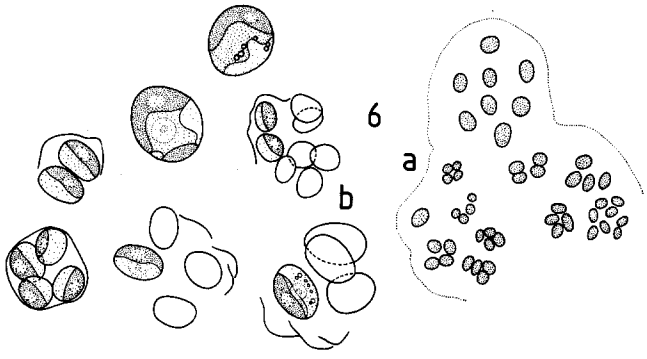
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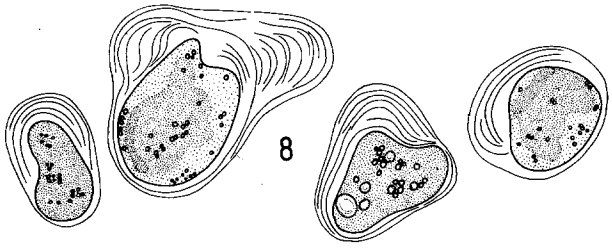
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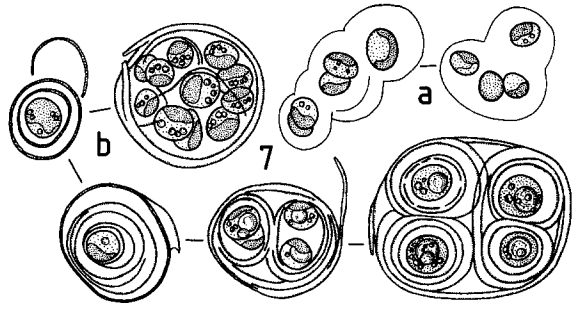
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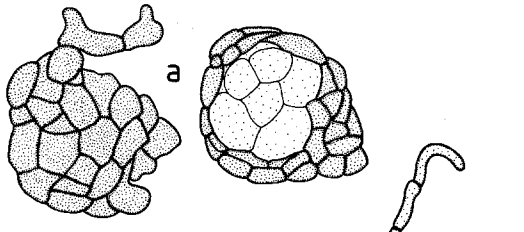
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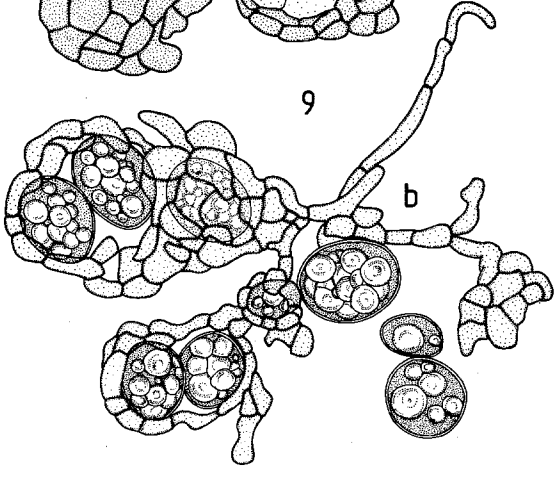
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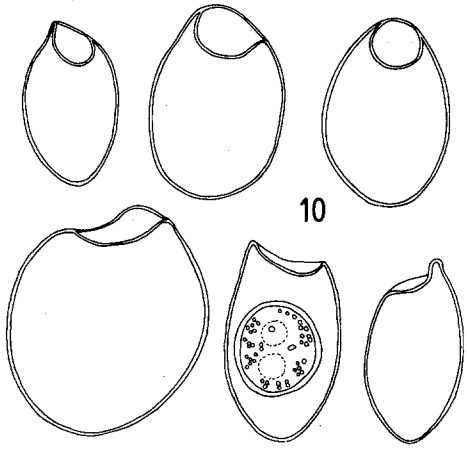
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reniform spores are close to the latter although the two adult cell types described by Watanabe (1977) were not observed. It is also close to *Lobosphaera tirolensis* Reisigl but that has spherical cells and a usually bi-lobed chloroplast. A similar isolate from Mt Erebus (Broady 1984), identified as *C. protothecoides* Krueger, also lacks a pyrenoid but differs in having spherical adult cells. There are no previous antarctic records of *C. reniformis.*

Coccomyxa gloeobotrydiformis Reisigl 1969. Fig. 13-4. [Komárek and Fott 1983, 418, plate 126, Fig. 4]

Culture. Colonies containing numerous cells, densely and irregularly arranged throughout soft, homogeneous mucilage. Adult cells narrowly to broadly ellipsoidal, rarely reniform, up to 9.5 μm long by 5 μm wide. Chloroplast parietal, extensive, broadly lobed. Reproduction by release of 2, 4 and 8 often reniform autospores by rupture of the sporangium wall, faint remains of which persist.

This isolate is very close to that described by Reisigl (1969) from high altitude soils in the Himalaya Mountains except that he did not record the production of 8 spores and adult cells are slightly smaller.

This species was present on Mt Erebus and has also been recovered in culture from Princess Elizabeth Land (Broady 1982).

Coenocystis oleifera (Broady) Hindak 1984. Figs. 13-6, 13-7.
Synonymy: *Sphaerocystis oleifera* Broady 1976, 397, Fig. 5.

Culture. Colonies containing numerous cells distributed throughout colourless homogeneous mucilage; cells often in groups of 4 and 8, less frequently in pairs. Cells broadly ellipsoidal, up to 10 μm, rarely 13 μm long by 9 μm wide. Chloroplast parietal, more or less cup-shaped, and broadly lobed; containing an indistinct pyrenoid which may be surrounded by a few small starch grains. Reproduction by 4 and 8, less frequently 2, narrowly ellipsoidal autospores, released by rupture of sporangium wall which persists.

Field Specimens. Differs from material in culture in having smaller cells up to 6 μm diam., and most markedly due to the distinct concentric lamellations in the mucilage surrounding cells and cell groups. Large oil globules are frequently found in the cells.

At temperatures below 30 °C this alga was often a dominant component of reddish-brown mucilaginous felts covering the mineral substratum and of the epiphytic communities on bryophytes. Its overall abundance was greater than that at Mt Erebus where it was not recognised during direct microscopic examination of sample material, but only in culture, presumably because it was present in relatively low numbers. This species has also been recorded from Mac.Robertson Land (Broady 1982) and the South Orkney Islands (Broady 1976).

Pseudococcomyxa simplex (Mainx) Fott 1981. Fig. 13-5. [Komárek and Fott 1983, 612, plate 171, Fig. 1]

Culture. Cells pyriform to narrowly ellipsoidal, up to 11 μm long by 6 μm wide, with a small mucilage pad at one apex. Chloroplast parietal, covering about half of wall. Reproduction by apical release of 2–8 autospores from ruptured sporangium.

Field Specimens. Identical to the alga in culture except that cells adhere to soil particles and to one another by the apical mucilage pad.

Together with *M. laminosus* this was the most frequently observed of all algae. It was often a co-dominant in samples and occurred over a wide range of temperatures but with a preference for those below 30 °C. This alga was also recognised as a major component of the Mt Erebus vegetation during microscopic examination of field material. It is probably an ubiquitous antarctic soil alga (Broady 1987) and has been recorded from Mac. Robertson Land and other soils in Victoria Land.

Unidentified Green Unicell. Fig. 13-8

Field Specimens. Cells irregularly shaped, 13–20 μm long by 8–14 μm wide, each surrounded by a firm, distinctly lamellated, mucilaginous envelope of varying width. Cell contents very granular and shape of green chloroplast impossible to determine.

This alga was observed as occasional cells in a single sample.

Lichenised Alga. Fig. 13-9.

Field Specimens. Globular and more irregular clusters of green algal cells surrounded by tight, dense sheaths of fungal hyphae, with loose wefts of hyphae interconnecting the clusters. Algal cells mostly broadly ellipsoidal, 8–13 μm long by 5.5–9 μm wide, containing a green chloroplast, the shape and position of which could not be determined due to the presence of numerous oil globules. Fungal hyphae melanised and septate. No penetration of the algal cells by hyphae was observed.

These loosely lichenised algae were frequent in two samples; a dry, dark brown surface crust over gravel and as an epiphyte on a tightly woven mat of moss protonema and rhizoids. Both materials were recorded at a low field temperature of 2 °C.

Protozoa

Corythion dubium Taranek. Fig. 13-10. [Smith HG 1978, 47, Fig. 48, no. 30]

Field Specimens. Observed as empty tests and, on one occasion, as a test containing an apparently encysted cell. Tests 21–31 μm long by 12–25 μm wide; plates not resolved using light microscopy. Terminal aperture approximately circular, 6–12 μm diam.

Occasional tests were observed at temperatures below 20 °C in both mineral substratum and amongst bryophytes.

Table 3. Abundance of heterotrophic microorganisms in Mt Melbourne soils as detected by serial dilution plates[a]

Sample[b]	10 °C[c]			20 °C			50 °C		
	YGA[d]	TSA	SPDA	YGA	TSA	SPDA	YGA	TSA	SPDA
1	3	1	0	600	400	0.8	0	0	0
2	1	2	0.004	500	200	0.2	0	0	0
3	2	8	0.1	900	40	3	7	0.04	0.005
4	160	13	0.02	62000	33000	2	4	0.01	0.01

[a] Results are expressed as colony forming units g^{-1} dw soil $\times 10^{-3}$ and include all bacteria, actinomycetes and fungi
[b] See Table 2 for brief description of sample material
[c] Incubation temperature
[d] Media: YGA, yeast glucose agar; TSA, trypticase soy agar; SPDA, streptomycin potato dextrose agar

This protozoan is the most abundant and frequently occurring testate rhizopod in the antarctic biome (pers. commun. H. G. Smith, Lanchester Polytech, Coventry, UK). It is a member of a diverse community of flagellates, rhizopods and ciliates common to sub-Antarctica and maritime Antarctic vegetated habitats and shows a preference for acid soils and peats supporting moss vegetation (Smith HG 1978). It was recovered from tephra on Deception Island 12 years following eruptions (Smith HG 1985). There are two records from continental Antarctica (Sudzuki 1964; Decloitre 1960).

Heterotrophic Microorganisms

The results of dilution plate counts are presented in Table 3 and identification of microbes in Table 4. YGA generally favoured higher microbial numbers and was particularly successful for thermotolerant/thermophilic organisms such as *Thermomonospora* sp., *Chaetomium* sp., *Malbranchea pulchella* var. *sulfurea, Myceliophthora thermophile* and *Streptomyces coelicolor.* Additionally, several unidentified Gram positive bacteria were capable of growth at 60 °C and are likely to be true thermophiles.

Discussion

There are distinct differences in the bryoflora of each of the four fumarolic areas so far examined in Antarctica. The greatest diversity has been found in the maritime region in the South Sandwich Islands (Longton and Holdgate 1979) where 16 species of bryophytes are restricted to warm ground, out of a total bryoflora for the islands of 43 species. At Deception Island, only 11 years after catastrophic eruptions, four species were found to be restricted to warm ground out of a total flora of about 39 species (Smith RIL 1984a). On the Victoria Land volcanoes only one bryophyte and one hepatic occur on Mt Melbourne and protonemata of an unidentified moss have been reported on Mt Erebus (Broady 1984). The two species, *Campylopus pyriformis* and *Cephaloziella exiliflora,* on Mt Melbourne are from genera which are well known as primary colonists of volcanic substrata elsewhere. Species of both genera occur on warm ground at Deception Island and the South Sandwich Islands (Longton and Holdgate 1979; Smith RIL 1984b). There are several possible reasons for the low diversity of Victoria Land warm ground bryophytes compared with those from maritime Antarctica.

Maritime Antarctica is closer to a rich source of propagules from more temperate regions to the north and west, i.e. South Amercia and South Georgia and, being in the circumpolar westerly airstream, could receive propagules from as far afield as New Zealand. In contrast, the areas of warm ground on Mt Melbourne and Mt Erebus are a considerably greater distance from rich propagule sources and well south of the westerly airstream. In maritime Antarctica recolonisation of new substrata on Deception Island was rapid. Two species of bryophytes were observed after only nine months (Young and Kläy 1971), and 11 years after the next eruption over nine species had recolonised fumaroles (Smith RIL 1984a). In Victoria Land, it would be expected that a longer period

Table 4. Heterotrophic microorganisms from Mt Melbourne soils growing on yeast glucose agar plates[a]

Microorganisms	Incubation temperature (°C)		
	10	20	50
Fungi			
Aspergillus		3[b]	
Chaetomium		3, 4	4
Cryptococcus	1		
Malbranchea pulchella var. *sulfurea*		3, 4	3, 4
Mucor		1	
Myceliophthora thermophile			3
Paecilomyces		3	
Penicillium	1, 2, 4	1, 3, 4	
Actinomycetes			
Streptomyces coelicolor		4	3, 4
Thermomonospora			3, 4
Bacteria			
Bacillus	1, 3, 4	4	
Klebsiella		4	
Micrococcus		4	

[a] Two replicate plates at each temperature
[b] Numbers refer to the sample in which the microbes were detected (see Table 2 for a brief description of sample material)

would be required for a similar diversity of propagules to arrive. Also, there is evidence that both Mt Erebus and Mt Melbourne have been vigorously active within the last few hundred years (Ross 1847 cited in Giggenbach et al. 1973; Nathan and Schulte 1967) and propagules of possible colonists may not yet have reached these potentially favourable habitats.

The local cold ground bryoflora of maritime Antarctica is also a richer, more diverse source than cold ground bryoflora in Victoria Land. Maritime Antarctica has about 75 species of bryophytes (Smith RIL 1984c) whereas in Victoria Land only seven species have been recorded (Longton 1973; Kappen 1985). This is reflected in the presence of 21 species of cold ground bryophytes being associated with fumaroles in the South Sandwich Islands (Longton and Holdgate 1979) and more than five on Deception Island (Smith RIL 1984a). It is interesting that none of the Victoria Land species have colonised either of the two volcanoes as dispersal problems would appear not to be great. In the immediate vicinity of Mt Melbourne they are represented by at least three species. We have found two *Bryum* spp. 12 km east of Mt Melbourne at coastal Edmondson Pt, and *Sarconeurum glaciale* (C. Muell.) Card. et Bryhn 67 km southwest at Inexpressible Is. This suggests that the environment of fumaroles may be usuitable for the establishment of the local cold ground species, possibly because of a different soil chemistry.

In reaching the Victoria Land volcanoes, propagules would probably experience far harsher conditions than they would in reaching maritime Antarctica. Considerably lower temperatures, intense desiccation and high levels of possibly harmful ultraviolet radiation would be encountered before arrival at the high altitude sites (2600–3500 m) of Victoria Land compared with conditions experienced in reaching the relatively low altitude sites (<550 m; Smith RIL 1984a, Longton and Holdgate 1979) in the moister, milder climate of maritime Antarctica. This could result in reduction, or possibly complete loss, of viability of diaspora of some species.

Even with the unlikely possibility of both regions receiving a similar diversity and abundance of viable propagules, environmental conditions on the Victoria Land volcanoes may prevent growth. Although physical conditions in fumarolic sites, for example soil moisture and temperature, may be similar at all four sites, the light regime at high altitude in Victoria Land is significantly different. Being at high latitudes the two volcanoes both experience a long period of constant darkness over midwinter, Mt Erebus for 15 weeks, and Mt Melbourne for 13 weeks. The maritime Antarctic sites are both well north of the Antarctic Circle and do not experience loss of the sun. Perhaps a proportion of potential colonists are unable to survive long periods of darkness whilst on warm ground which probably does not freeze over winter even if snow-covered, although it is difficult to see why *Campylopus pyriformis* and *Cephaloziella exiliflora* alone should have this ability. Evidence that the latter do survive each winter, and that each summer's growth is not the result of a fresh inoculum of propagules, is provided by the occurrence of sporadic 5–10 cm deep peat deposits below living bryophytes. These accumulations have presumably resulted from many successive summers' growth.

Table 5. A comparison of the biota of geothermal areas of two volcanoes in Victoria Land; Mt Melbourne and Mt Erebus

Biota	Mt Melbourne	Mt Erebus	Common to both areas
Moss	*Campylopus pyriformis*[a]	Unidentified protonema[a]	
Liverwort	*Cephaloziella exiliflora*		
Algae	*Gloeocapsa magma*[b]	cf. *Lyngbya* sp.[a]	*Aphanocapsa elachista*[a]
	Tolypothrix bouteillei[b]	*Bracteacoccus* cf. *minor*	*Phormidium fragile*
	Stigonema ocellatum[a]	*Chlorella protothecoides*[a]	*Mastigocladus laminosus*[a]
	Chlorella cf. *reniformis*[a]	*Chlorella reisiglii*[b]	*Chlorella emersonii*[a]
		Chlorella saccharophila[a]	*Coccomyxa gloeobotrydiformis*[b]
		Coccomyxa curvata[b]	*Pseudococcomyxa simplex*
		Oocystis minuta[b]	*Coenocystis oleifera*[b]
		Scotiellopsis terrestris[a]	
Lichenized alga	Unidentified		
Actinomycetes[c]			*Streptomyces coelicolor*[a]
			Thermomonospora sp.[a]
Protozoa	*Corythion dubium*[b]		

[a] No other Antarctic records
[b] No other records from Victoria Land
[c] Fungi and bacteria have not been included as determinations of the Mt Erebus microflora have not been made

As well as the marked difference in the bryoflora on Mt Erebus and Mt Melbourne there are also notable differences in the algal flora (Table 5). Of the 19 species recorded on the two volcanoes, seven are common to both, four are restricted to Mt Melbourne and eight are restricted to Mt Erebus. This would suggest that viable propagules of the 12 species that are not found on both volcanoes have not reached both sites. Alternatively, it is possible that viable propagules deposited on warm ground already supporting abundant algal populations may not be able to compete with the resident flora.

In the case of the thermophilic cyanophyte, cf. *Lyngbya* sp. edaphic factors could be responsible for restricting its occurrence to Mt Erebus. Temperatures suitable for its growth (up to 59 °C, Broady 1984) exist on both Mt Melbourne and Mt Erebus. However, on Mt Erebus it was noted that on the major area of heated ground cf. *Lyngbya* sp. dominated the soil flora at the higher temperatures and *Mastigocladus laminosus* was absent. Conversely, in other areas, again where temperatures were adequate for its growth, no cf. *Lyngbya* sp. was recovered but here *M. laminosus* was frequently observed. It was suggested that differences in soil chemistry were possibly responsible for this pattern. The presence of abundant *M. laminosus* on Mt Melbourne might indicate that soil conditions there are also unsuitable for the growth of cf. *Lyngbya* sp.

Unfortunately, no detailed comparison can be made with the algae of fumarolic zones in maritime Antarctica as full analyses have not been made and data are sparse (Cameron and Benoit 1970; Longton and Holdgate 1979; Smith RIL 1984a, c). However, it is interesting to note that of the 10 species found on fumarolic ground in the South Sandwich Islands (Longton and Holdgate 1979) only two, *Lyngbya* sp. and *Phormidium* sp., belong to genera found on the Victoria Land volcanoes, although in the absence of culture studies many micro-algae were probably overlooked. Of the 10 species recorded, four are present on cold ground in Victoria Land; *Calothrix* sp., *Navicula muticopsis, Prasiococcus calcarius* and *Prasiola* cf. *crispa.* Their absence, together with the absence of most other cold ground algae of the region (Seaburg et al. 1979; Broady, unpublished observations) suggests that edaphic factors, such as the acidity of the fumarolic soils compared with the generally alkaline to neutral reaction of cold ground soils of Victoria Land, could prevent their colonisation of the Mt Melbourne soils.

The occurrence of eight species of algae that are not known in Antarctica outside the fumarolic ground of Victoria Land, but that do occur elsewhere in the world, suggests that algae, as well as bryophytes, are being dispersed from temperate regions. Long distance airborne dispersal has been discussed as a source of inoculum on Mt Erebus (Broady 1984). In particular *Mastigocladus laminosus* is well known as a cosmopolitan inhabitant of hot springs and would appear to be ideally suited for long range dispersal to Victoria Land thermal ground because of its resistance to both desiccation and deep-freezing (Castenholz 1973). It has also been found to survive storage at 14°–15 °C in the dark for over a year (Castenholz 1973) which suggests that it could readily survive mid-winter darkness on the warm soils. It was an early colonist of the volcanic island Surtsey, off the coast of Iceland, being found just three years following eruptions (Castenholz 1972). However, in that case the source of propagules could have been as close as 50–90 km away, in warm springs on mainland Iceland.

M. laminosus displays nitrogenase activity in Mt Melbourne soils (Table 2) with a probable additional contribution from heterotrophic bacteria (Table 2, sample 4). The nitrogenase levels are within the ranges reported for other antarctic and arctic sites (Davey 1983; Smith and Russell 1982) although mean values are slightly lower than those reported here.

The occurrence of the protozoan *Corythion dubium* on Mt Melbourne is additional evidence that dispersal factors are no barrier to organisms with microscopic propagules. This species has a bipolar distribution and is the most common antarctic testate rhizopod (Smith HG 1978). However, as with a number of the algae and the bryophytes there are difficulties in explaining why it does not also occur at Mt Erebus. Although Janetschek (1963) recorded rhizopod Protozoa, as well as a rotifer and possibly a tardigrade in Mt Erebus fumarolic soils, these records are open to doubt as one of us (P. Broady, unpublished observations) saw no evidence of any microfauna during microscopic examination of 78 samples. It is considered that empty tests of *C. dubium* would have been found if they were present, as they were readily visible during examination of an almost equal number of Mt Melbourne samples. It is also considered that if microfauna, other that the protozoan, occurred on Mt Melbourne the animals would have been observed during microscopic examination of samples.

The culture counts of heterotrophic microorganisms indicate that active populations are present on Mount Melbourne. Our preliminary identifications suggest that this community also comprises cosmopolitan species. The fungi *Malbranchea pulchella* and *Sporotrichum thermophile* (= *Myceliophthora thermophile*) are widespread in thermal environments on other continents (Tansey and Brock 1978). In continental Antarctica thermotolerant isolates of *Aspergillus, Chaetomium* and *Myceliophthora thermophile* have been obtained from "cold" soils (Ellis 1980). At volcanic sites, mesophilic strains of *Penicillium* and *Cryptococcus* were isolated from recently formed cinder cones on Deception Island (Cameron and Benoit 1970) and soil from an active fumarole on Mt Erebus contained *Penicillium* and *Aspergillus* species (Ugolini and Starkey 1966). The thermotolerant actinomycetes *Streptomyces coelicolor* and *Thermomonospora* sp. have also been isolated from Mt Erebus fumarolic soils (Greenfield, unpublished results) and are widespread in hot muds in New Zealand (P. Stevens, University of Canterbury, pers. commun.). Ther-

motolerant bacteria have been isolated from Deception Island soils (Cameron and Benoit 1970).

In conclusion, a comparison of the four biologically investigated fumarolic regions in Antarctica reveals both similarities and differences in the nature of their biota. This reflects the situation in thermal biosystems worldwide for which Castenholz (1973) noted that "few, if any, identical assemblages of microorganisms can be found on a global scale even when the physico-chemical environment appears to be the same". The evidence suggests that airborne dispersal has the potential to distribute a wide range of microscopic propagules to many antarctic sites. Whether individual species retain their viability during dispersal and would be capable of growth when deposited on each area of fumarolic ground requires detailed study of the survival properties and growth requirements of each potential colonist and a more detailed analysis of the environment at each site.

In view of the small area of fumarolic ground supporting this unique and fragile community, we consider that it is vital that its importance is recognised and that adequate protective measures are taken in order to minimise the risks of disturbance and of the introduction of new organisms by human vector.

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