Antarctic Science 8 (2): 121–126 (1996)

Preliminary investigation of the thermal biosystem of Mount Rittmann fumaroles (northern Victoria Land, Antarctica)

R. BARGAGLI[1], P.A. BROADY[2] and D.W.H. WALTON[3]

[1]Department of Environmental Biology, University of Siena, Via delle Cerchia 3, 53100 Siena, Italy
[2]Department of Plant and Microbial Sciences, University of Canterbury, Private Bag 4800, Christchurch, New Zealand
[3]British Antarctic Survey, Natural Environmental Research Council, High Cross, Madingley Road, Cambridge CB3 OET, UK

Abstract: The biota and environment of fumarolic ground recently discovered near Mount Rittmann are described. Three patches (about 1 m^2 each) of the moss *Pohlia nutans* were found in a minor caldera rim. Cyanophytes, chlorophytes, protozoa and bacteria were isolated from the moss and warm ground (30–50°C). The results are compared with those of previous studies on Antarctic volcanoes. The origin of the geothermal flora is discussed in terms of long-distance transport of propagules to the continent.

Received 10 November 1995, accepted 1 February 1996

Key words: colonization, continental Antarctica, geothermal ground, physico-chemical properties

Introduction

The McMurdo Volcanic Group in the Ross Sea and Victoria Land is one of the most extensive alkali volcanic provinces in the world (Harrington 1958). On the basis of volcanic distribution and tectonic setting it was subdivided by Kyle & Cole (1974) into four informal provinces: Balleny, Hallett, Melbourne, and Erebus.

Although several expeditions into northern Victoria Land have recognized the general distribution of volcanic centres and many detailed studies have been made on their geology, chronology, petrology, and geochemistry in the last 30 years (Wörner *et al.* 1989, Kyle 1989), a new volcano was discovered in the Melbourne Province, during the 4th Italian Expedition (1988/89). The name Mount Rittmann has been proposed (Armienti & Tripodo 1991). The volcano is located in the Mountaineer Range (2600 m; 73°27'S; 165°30'E) on the left side of the Aviator Glacier, between the Pilot Glacier and the head of the Icebreaker Glacier (Fig. 1). The base of the volcano outcrops on the almost vertical cliffs of the Pilot Glacier. A ring of smooth hills and outcrops of volcanic breccia, containing xenoliths and juvenile pumices, outlines the rim of the main caldera. Mount Rittmann lavas are of an age (4 Ma) and alkalinity intermediate between Mount Overlord and Mount Melbourne products (Fig. 1, Armienti & Tripodo 1991). During the 6th Italian Antarctic Expedition (1990/91) fumaroles and grounds heated by geothermal activity were discovered in a minor calderic structure of Mount Rittmann (73°28.28'S, 165°36.93'E; Bonaccorso *et al.* 1991).

In Victoria Land, similar warm ground occurs on the summit of Mount Melbourne and on Mount Erebus, sheltering vegetation communities with unique features (Broady 1984, Broady *et al.* 1987). Mosses, algae and liverworts transported over long distances to newly exposed fumarolic grounds have also been found in the maritime Antarctic zones at Deception Island, South Shetland Islands (Young & Kläy 1971, Smith 1984) and the South Sandwich Islands (Longton & Holdgate 1979). The transport of propagules from circumpolar continents to Antarctica is also corroborated by the common occurrence of pollen grains in moss cushions from northern Victoria Land (Linskens *et al.* 1993). Despite the isolation and the altitude of the areas of warm ground (2733 m Mount Melbourne and 3794 m Mount Erebus) these environments provide vegetation communities with constant free water (both from the condensation of steam and melting of snow), suitable temperatures, and shelter (under ice and snow hummocks).

The aim of this paper is to give a preliminary description of the biota and environment of the thermal biosystem at Mount Rittmann. The results of this study emphasize the fragility of these biological communities, the risk of introducing new organisms by human vectors and the need for adequate protective measures for the minor caldera of Mount Rittmann.

Study area

Ice and snow hummocks, fumaroles and ground heated by geothermal activity (Fig. 2a) are evidence of near-surface cooling magma and suggest that the caldera is much younger than lava outcropping in the Pilot Glacier, at the base of Mount Rittmann (about 4 Ma; Armienti & Tripodo 1991). Fumaroles and warm ground occur on a rough and unstable sub-vertical slope (*c.* 200 m wide and 80 m high). The ground consists of pyroclastic rocks and volcanic debris in a sandy matrix. The fumarolic vents are only a few centimeters wide and at 10 cm depth the temperature ranges from 50–63°C. Around the vents the substratum is covered by whitish efflorescences (i.e. small hydrothermal alteration zones of volcanic materials, with probable formation of clayey minerals

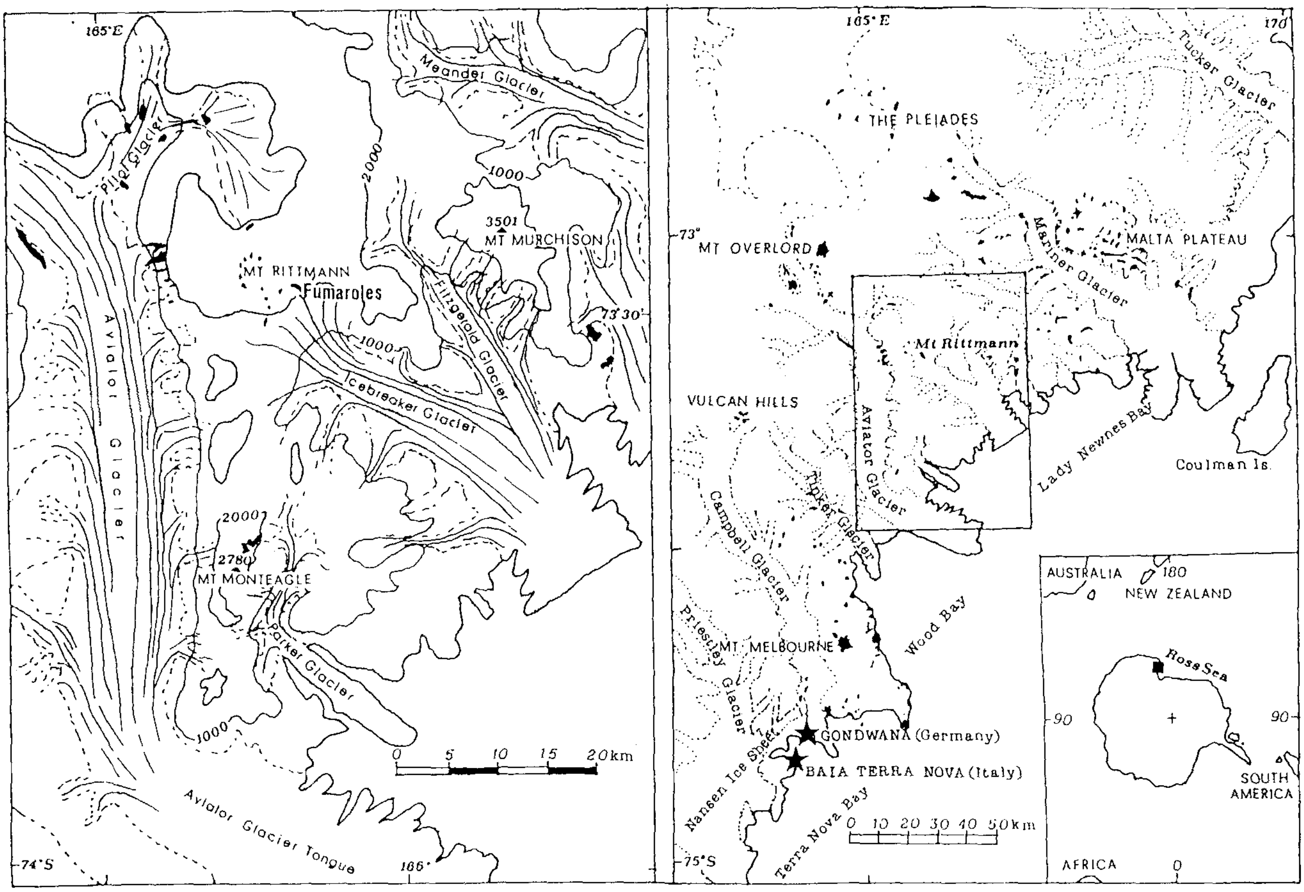

Fig. 1. Major volcanic centres in the Melbourne volcanic province and outcrops of fumaroles on Mount Rittmann.

and amorphous silica). The gases have little sulphurous smell and CO_2 is presumably the predominant fumarole gas.

Unlike in January 1991, when almost all the area was covered with hummocks and ice, in January 1994, more extensive warm ground was ice-free. The hummocks (one more than two metres high) were situated mostly on the western side of the caldera rim and on its boundary. Eastward, the cliff was ice-free and fairly accessible. These favourable conditions allowed us to discover three patches of moss (*c.* 0.7–1.0 m^2 each) close to the rim of the caldera. The bryophyte vegetated soil was sandy, moist and warm (air temperature, 1 m above the ground: –13.4°C, soil and vegetation surface temperature ranged from 41.5–43.4°C). The lower slope was surveyed in January 1996 and other patches of the same moss were found.

Materials and methods

Physico-chemical substratum properties

Two samples of vegetated soil (each 5 cm^2 in area) were collected randomly from each patch with new pairs of disposable plastic gloves, and placed in sterile polyethylene bags. The water content and pH of samples was determined immediately on return to the base at Terra Nova Bay. The mossy soil samples were then stored frozen until being oven dried (50°C), prior to analyses in Italy.

Concentrations of inorganic nutrients were measured in soil extracts (soil:deionized water, 1:5, w:w) and in moss and soil subsamples digested with concentrated HNO_3 in a Teflon bomb at 120°C for 8 h. Elements were determined by a combination of analytical techniques, including inductively coupled plasma-atomic emission spectrometry (ICP-AES), atomic absorption spectrometry (AAS) and electrothermal atomic absorption spectrometry with Zeeman background correction (ZETAAS). Data quality was checked by analysis of Standard Reference Materials (SRM 1572 "citrus leaves" and SRM 1646 "estuarine sediment"; NIST, Gaithersburg, USA).

Total organic C and N were determined in bulked soil subsamples (powdered and sieved at 0.125 mm)according to the procedure outlined by Gaudette *et al.* (1974) and the Kjeldahl method, respectively. Total carbonates were determined by reacting 100 mg of powdered subsample with HCl and titrating the excess HCl with NaOH (AOAC 1975). Grain size analysis was also carried out in a bulked soil

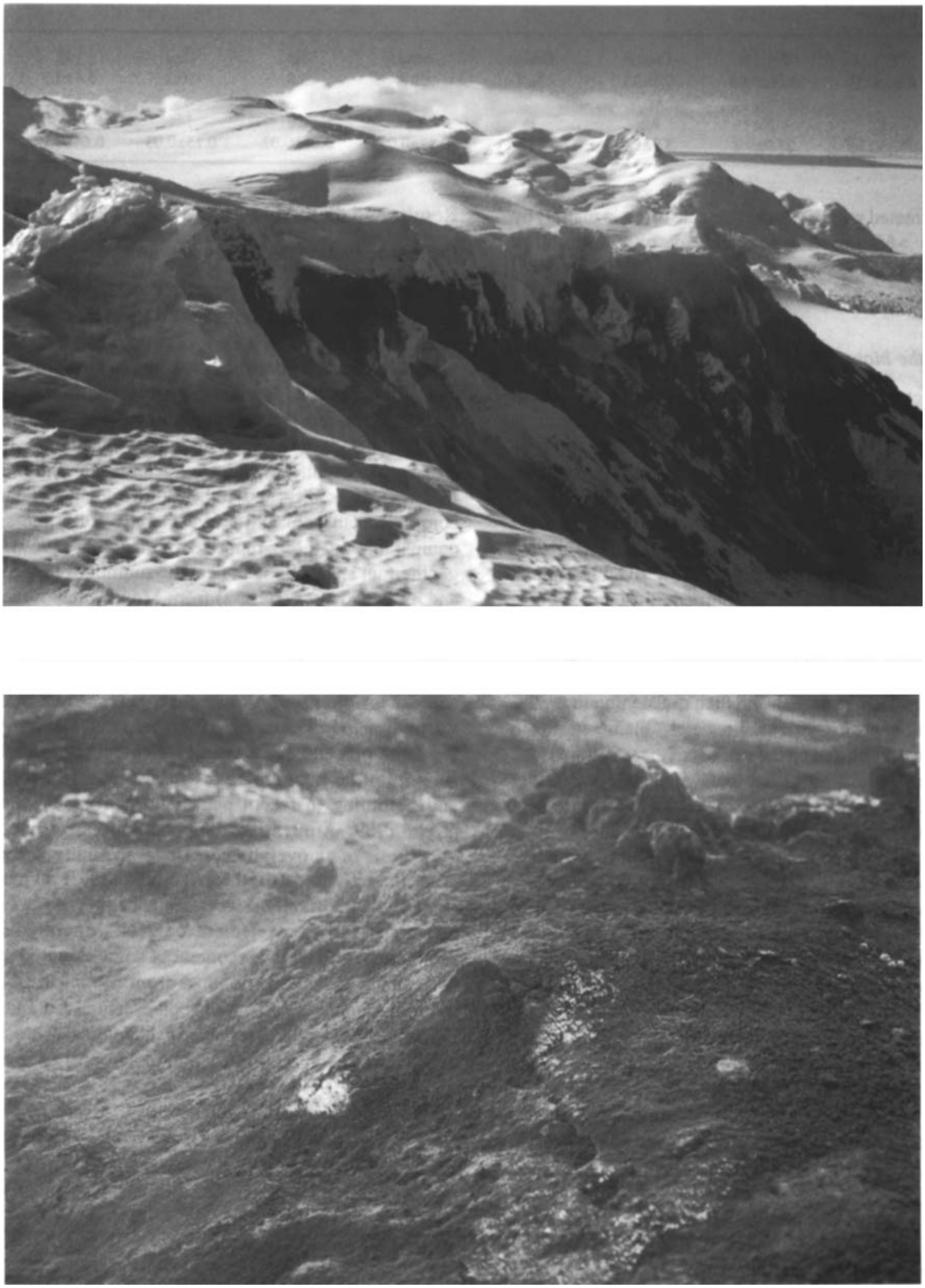

Fig. 2. a. The slope of Mount Rittman with fumaroles and warm ground (January 1994, looking eastward to Lady Newnes Bay); **b.** a patch of *Pohlia* on the caldera rim.

https://doi.org/10.1017/S0954102096000181 Published online by Cambridge University Press

Table I. Physico-chemical properties of vegetated soil and inorganic (water-extractable) nutrients (mean±SD of six samples; physical properties as %, nutrients as $\mu g\ g^{-1}$ dw).

Water	TOC	Total N	CaCO³	Gravel	Sand	Silt	Clay	pH	C/N
18.2±2.3	0.84±0.15	0.11±0.03	0.5±0.1	21.7	61.3	6.8	10.2	5.4±0.2	7.5±0.1
Ca	**K**	**Na**	**Mg**	**P**	**Zn**	**Cu**	**Mn**	**Fe**	**Mo**
8.2±2.9	35.7±12.4	27.9±9.8	5.9±1.4	3.8±1.1	0.12±0.07	0.08±0.02	0.15±0.03	0.64±0.12	< 0.01

sample (pretreated with H_2O_2 to eliminate organic matter) by sieving the >63 μm fraction and by photoextinction sedimentometry of the silty-clayey fraction (Baldi & Bargagli 1984).

Analysis of the biota

Surface vegetation and underlying soil subsamples (about 2–3 cm^2 wide and 1.5 cm thick), were examined for moss (Cambridge, UK) and algae (Christchurch, NZ). A single deep-frozen sample of moss and underlying soil was used for the microalgae. Strict aseptic precautions were followed throughout. Sample material was examined under a light microscope before treatment. Cultures were then established on Bold's basal medium (Nichols 1973), BG-11 (Rippka *et al.* 1979) and BG-11-N (combined nitrogen sources omitted). Approximately 0.25 g fragments of sample material were inoculated into liquid and scattered over agarized media. Enrichment cultures were established by spreading sample material in a petri dish and then moistening to *c.* 80% water-holding capacity with sterile water. Flame-sterilized coverglasses were placed on the surface of these cultures. All cultures were incubated at 15–20°C and at 40°C under continuous illumination supplied by cool white fluorescent lamps at *c.* 100 $\mu Em^{-2}s^{-1}$. All cultures were examined by light microscopy at magnifications up to 1000 x after two and five weeks incubation.

Some samples were immediately incubated at the base on yeast extract and basal salt solution, at different temperatures and pH 4.0 and 6.0 for bacterial identification. The reaction flasks were subsequently stored at 4°C and strains isolated by repeated serial dilution technique in the Naples laboratory. Investigation of certain morphological and physiological parameters of the isolates are still in progress.

Results and discussion

Fumarolic ground and moss composition

The physico-chemical properties of the substratum are summarized in Table I as mean and standard deviation of the six soil samples. The bulk soil sample had a rather coarse texture (grain-size frequency distribution median = 0.85 mm), and can be classified as a fine gravelly medium sand (Doeglas 1968). Thus, most of soil particles have a grain-size and a specific surface area which do not favour the adsorption of labile organic matter or water extractable inorganic elements. In terms of acidity and rather high moisture content (in comparison to cold and arid Antarctic soils) the soils are comparable to those reported by Ugolini (1967) from a geothermal area at 3600 m near the summit of Mount Erebus and by Broady *et al.* (1987) from Mount Melbourne.

Table II compares concentrations of macro- and trace elements in mossy soil and in moss *Pohlia nutans* from Mount Rittmann fumaroles were compared with those of soil and *Campylopus pyriformis* collected on Mount Melbourne warm ground in December 1990 (prepared and analysed by the same procedures). Average element concentrations in soils from the two fumarolic areas were fairly comparable and according to recent petrologic and geochemical data (Kyle 1989, Armienti & Tripodo 1991) corroborate the hypothesis of an overall decrease in alkalinity in the recent volcanic activity of the Mount Melbourne Province. The most evident differences between substrata of the two sites concerned the trace element content: Mount Melbourne samples showed a higher content of some essential nutrients such as Cu and Zn, while those from Mount Rittmann had rather high concentrations of non-essential Cd and Pb.

The two moss species reflected geochemical characteristics of the substrata, both in the high cation exchange capacity

Table II. Comparison of elemental concentrations in acid digested vegetated soil and moss samples from Mount Rittmann and Mount Melbourne (mean ±SD of three samples).

	Ca	K	Mg	Na	Al	Fe	Cd	Cu	Hg	Mn	Pb	Zn
			%						μg/g			
Soil												
Mount Rittmann	0.64±0.18	0.49±0.14	0.37±0.15	0.31±0.15	2.90±1.50	1.10±0.60	0.56±0.06	6.60±2.2	0.05±0.02	795±214	12.2±3.6	96±6
Mount Melbourne	0.76±0.21	0.48±0.13	0.67±0.24	0.22±0.11	2.40±1.20	1.30±0.70	0.11±0.04	14.0±5.8	0.02±0.02	940±319	4.90±2.7	122±18
Moss												
[1]*P. nutans*	0.09±0.03	0.22±0.07	0.14±0.04	0.05±0.01	0.41±0.15	0.37±0.13	0.46±0.19	4.20±1.1	0.08±0.02	498±234	3.60±1.9	73±9
[2]*C.pyriformis*	0.11±0.04	0.19±0.05	0.21±0.05	0.03±0.01	0.57±0.17	0.44±0.16	0.08±0.02	4.90±1.3	1.12±0.34	368±211	1.30±0.7	43±12

[1]from Mount Rittmann [2]from Mount Melbourne.

typical of bryophytes (Brown & Bates 1990) and the large number of soil particles trapped in the samples (demonstrated by the very high content of lithophilic elements such as Al, Fe and Mn). The high content of Hg in *C. pyriformis* may be evidence of emission of gaseous mercury from the Mount Melbourne fumaroles and corroborates the results of previous Hg biomonitoring along the coast of northern Victoria Land (Bargagli *et al.* 1993).

Some moss species are cosmopolitan or circumpolar and can be used as an effective global monitoring medium or to establish reference levels of air pollutants that are already globally distributed (Wiersma *et al.* 1986). The results of analytical determinations on mosses from Mount Melbourne and Mount Rittmann fumaroles show that on assessing baseline concentrations of heavy metals and the extent of global atmospheric pollution in the Southern Hemisphere, emissions from active volcanoes and pollution from human activities in Antarctica itself (Boutron & Wolff 1989) cannot be disregarded.

The biota of Mount Rittmann fumaroles

Bryophytes. The bryophyte material was not fruiting and the stems were short and delicate. It was provisionally identified as *Pohlia nutans* (Hedw.) Lindb. This is a cosmopolitan species known from Europe, Asia, Africa and Australasia. It is widely distributed on all the subantarctic islands, maritime Antarctic islands and the Antarctic Peninsula (Greene *et al.* 1970). It has also been found at various localities in East Antarctica (Savich-Lyubitskaya & Smirnova 1973). Most recent collections show it to be present on the Hallett Peninsula, Thurston Island and the Eights Coast in the Ross Sea. Its normal Antarctic habitat is damp depressions and moist cracks but it is found around fumaroles on the South Sandwich Islands where it is apparently a colonizer of cold and warm ash and scoria (Longton & Holdgate 1979). It produces both spores and vegetative propagules at continental sites.

Algae. Microalgae observed are listed in Table III. Direct microscopic examination of the original sample revealed only occasional algae. Dominant were short fragments of *Mastigocladus laminosus*. Trichomes of *Phormidium* cf. *fragile* were rare and there were occasional cells of *Pseudococcomyxa* cf. *simplex* and unidentified spherical green unicells.

At 40°C only *Phormidium* cf. *fragile* and cf. *Lyngbya* sp. grew successfully. *M. laminosus* was present as unhealthy growths at two weeks but was absent at five weeks incubation. All algae developed at 20°C and most successfully on agarized media. Identification of unicellular and colonial chlorophytes is based on discrete colonies removed from agar surfaces. Species identifications are tentative as isolates were not established for more detailed study.

Whilst examining cultures for microalgae, two protozoa were encountered. One was a small cyst-forming naked rhizopod and the other a flagellate resembling *Bodo* sp. No testate amoebae were seen either in original sample material or in cultures.

Bacteria. A thermophilic bacterium was isolated from Mount Rittman soil. The isolate is thermo-acidophilic with maximum growth at 65°C and at pH 3.5–4.0; however, it did grow up to 70°C. Physiological and chemical tests are in progress in order to prove if it is related to *Alicyclobacillus*.

There are two possible explanations for differences in microflora and fauna between communities at the three volcanoes in the Ross Sea region. The environment at each location could be selecting for the growth of different assemblages of species. Alternatively, dispersal of viable propagules to these isolated, small areas of warm ground could be a rare event resulting in the colonization of the soils by the few species that manage to reach the site. It seems likely that the high frequency of chlorophytes and the occurrence of thermophilic cyanobacteria are a result of environmental selection due to acidic and hot soils respectively. Other differences could be due to stochastic factors, although more detailed characterization of the microenvironments inhabited by particular species could identify selective factors.

Conclusions

The community of microalgae is very similar to those described from both Mount Erebus (Broady 1984) and Mount Melbourne (Broady *et al.* 1987). Only two Mount Rittmann taxa have not been found at the latter two sites, cf. *Lyngbya* sp. and *Nostoc* sp. At Mount Erebus and Mount Rittmann

Table III. Algae associated with moss on fumarolic ground at Mount Rittmann with an indication of occurrence of similar taxa at Mount Erebus (E; Broady, 1984)and Mount Melbourne (M; Broady *et al.* 1987).

Cyanobacteria	
Oscillatoriales	
cf. *Phormidium fragile* Gom. (trichomes 2–3 μm wide)	EM
cf. *Lyngbya* (trichomes 1 μm wide)	
Nostocales	
Nostoc sp.	
Stigonematales	
Mastigocladus laminosus Cohn	EM
Chlorophyta	
Chlorococcales	
Chlorella cf. *protothecoides* Krueger	E
Chlorella cf. *reniformis* Watanabe	M
Coccomyxa cf. *gloeobotrydiformis* Reisigl	EM
Coenocystis cf. *oleifera* (Broady) Hindak	EM
cf. *Oocystis minuta* Guillard, Bold & MacEntee	E
Pseudococcomyxa cf. *simplex* (Mainx) Fott	EM
Scotiellopsis cf. *terrestris* (Reisigl) Punkocharova & Kalina	E

chlorococcalean taxa are most diverse. It has been postulated that this is a consequence of the somewhat acid reaction of the soils. However, at Mount Melbourne similar soils contain a greater diversity of cyanobacteria. Five species of cyanobacteria and seven species of coccoid and colonial chlorophytes are absent from Mount Rittmann but present at one or both of the other two volcanoes. Their absence from Mount Rittmann can only be confirmed following more extensive sampling as the present list of taxa is based on just one sample. In particular, a search should be made for the unusual thermophilic, non-heterocystous form of *M. laminosus* described from Mount Erebus (Melick *et al.* 1991) especially on hot ground at temperatures up to 55°C. The flora at all Ross Sea region fumarolic sites differs markedly from that at low altitude sites on maritime Antarctic volcanoes (Broady 1993), possibly due to a more saline and nutrient-rich environment at the latter.

Protozoa occurrences are contrasting at all three Ross Sea region volcanoes. None were observed at Mount Erebus (Broady 1984) whilst at Mount Melbourne a single testate rhizopod, *Corythion dubium*, was recorded (Broady *et al.* 1987). The Mount Rittmann microfauna is also exceedingly limited but the naked rhizopod and the flagellate are new records for continental Antarctic fumarolic ground.

The single species of moss, *Pohlia nutans*, could be derived from local sources in northern Victoria Land and thus its occurrence is less remarkable than disjunct bryophyte records from other Antarctic geothermal areas.

Acknowledgements

This work was undertaken within the Italian National Programme for Antarctic Research (PNRA). D.W.H. Walton is grateful for the invitation to visit and work at Terra Nova Bay. We are grateful to Dr A. Gambacorta (Istituto per la Chimica di Molecole di Interesse Biologico) and E. Esposito (CNRS, Naples) for assistance with the bacterial isolate, to Dr M.E. Newton for bryophyte identification and Dr H. Peat for assistance with species distributions.

References

A.O.A.C. 1975. *Official methods of analysis of the Association of Official Analytical Chemists*. 12th ed. Washington DC: AOAC, 1094pp.

Armienti, P. & Tripodo, A. 1991. Petrography and chemistry of lavas and comagmatic xenoliths of Mount Rittmann, a volcano discovered during the IV Italian expedition in northern Victoria Land (Antarctica). *Memorie della Società Geologica Italiana*, **46**, 427-451.

Baldi, F. & Bargagli, R. 1984. Mercury pollution in marine sediments near a chlor-alkali plant: distribution and availability of the metal. *Science of the Total Environment*, **39**, 15-26.

Bargagli, R., Battisti, E., Focardi, S. & Formichi, P. 1993. Preliminary data on environmental distribution of mercury in northern Victoria Land, Antarctica. *Antarctic Science*, **5**, 3-8.

Bonaccorso, A., Maione, M., Pertusati, P.C., Privitera, E. & Ricci, C.A. 1991. Fumarolic activity at Mount Rittmann volcano (northern Victoria Land, Antarctica). *Memorie della Società Geologica Italiana*, **46**, 453-456.

Boutron, C.F. & Wolff, E.W. 1989. Heavy metal and sulphur emissions to the atmosphere from human activities in Antarctica. *Atmospheric Environment*, **23**, 1669-1675.

Broady, P.A. 1984. Taxonomic and ecological investigations of algae on steam-warmed soil on Mount Erebus, Ross Island, Antarctica. *Phycologia*, **23**, 257-271.

Broady, P.A. 1993. Soils heated by volcanism. *In* Friedmann, E.I., *ed. Antarctic microbiology*. New York: Wiley-Liss, 413–432.

Broady, P.A., Given, D., Greenfield, L.G. & Thompson, K. 1987. The biota and environment of fumaroles on Mount Melbourne, northern Victoria Land. *Polar Biology*, **7**, 97-113.

Brown, D.H. & Bates, J.W. 1990. Bryophytes and nutrient cycling. *Botanical Journal of the Linnean Society*, **104**, 129-147.

Doeglas, D.J. 1968. Grain-size indices, classification and environment. *Sedimentology*, **10**, 83-100.

Gaudette, H.E., Flight, W.R., Toner, L. & Folger, D.W. 1974. An inexpensive titration method for the determination of organic carbon in recent sediments. *Journal of Sedimentary Petrology*, 44, 249-253.

Greene, S.W., Greene, D.M., Brown, P.D. & Pacey, J.M. 1970. Antarctic moss flora. I. The genera *Andreaea, Pohlia, Poytrichum, Psilopilum*, and *Sarconeuron*. *British Antarctic Survey Scientific Reports*, No.64, 1–118.

Harrington, J.H. 1958. Nomenclature of rock units in the Ross Sea region, Antarctica. *Nature*, **182**, 290-291.

Kyle, P.R. 1989. Mc Murdo Volcanic Group, western Ross Embayement. *Antarctic Research Series*, **48**, 19-145.

Kyle, P.R. & Cole, J.W. 1974. Structural control of volcanism in the McMurdo Volcanic Group, Antarctica. *Bulletin of Vulcanology*, **38**, 16-25.

Linskens, H.F., Bargagli, R., Cresti, M. & Focardi, S. 1993. Entrapment of long-distance transported pollen grains by various moss species in coastal Victoria Land, Antarctica. *Polar Biology*, **13**, 8187.

Longton, R.E. & Holdgate, M.V. 1979. The South Sandwich Islands: IV. Botany. *British Antarctic Survey Scientific Reports*, No. 94, 53 pp.

Melick, D.R., Broady, P.A. & Rowan, K.S. 1991. Morphological and physiological characteristics of a non-hetrocystous strain of the cyanobacterium *Mastigocladus lamonosus* Cohn from fumarolic soil on Mount Erebus, Antarctica. *Polar Biology*, **11**, 81–89.

Nichols, H.W. 1973. Growth media-freshwater. *In* Stein, J R., *ed. Handbook of phycological methods. Culture methods and growth measurements*. Cambridge: Cambridge University Press, 7–24.

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.

Savich-Lyubitska, L.I. & Smirnova, Z.N. 1973. The moss *Pohlia nutans* (Hedw.) Lindb. in East Antarctica. *Soviet Antarctic Information Bulletin*, **8**, 222–224.

Smith, R.I.L. 1984. Colonization and recovery by cryptogams following recent volcanic activity on Deception Island, South Shetland Islands. *British Antarctic Survey Bulletin*, No. 62, 25-51.

Ugolini, F.C. 1967. Soils of Mount Erebus, Antarctica. *New Zealand Journal of Geology and Geophysics*, **10**, 431-442.

Wiersma, G.B., Franklin, J.F., Kohler, A., Croze, H. & Boelcke, C. 1986. Integrated global monitoring network. *In* Schweitzer, G.E. & Phillips, A.S., eds., *Monitoring and managing environmental impact: American and Soviet perspectives*. Washington DC: National Academy Press, 246-265.

Worner, G., Viereck, L., Hertogen, J. & Niephaus, H. 1989. The Mount Melbourne volcanic field (Victoria Land, Antarctica). II. Geochemistry and magma genesis. *Geologie Jahrbuch*, **38**, 395-433.

Young, S.B. & Klay, Y.R. 1971. Bryophytes in the 1969 crater of Deception Island, Antarctica: an apparent case of rapid long distance dispersal. *Ohio Journal of Science*, **71**, 358-362.