Biological survey of Robertskollen, western Dronning Maud Land: area description and preliminary species lists

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Robertskollen, a group of nunataks fringing an ice-rise in the northern Ahlmannryggen, western Dronning Maud Land, Antarctica, has been proposed as a potential site for a biological research programme planned to focus on the structure and functioning of nunatak ecosystems. A preliminary biological survey of the area was conducted during the summer of 1987-88. All nunataks in the group were visited, their topography described, and their fauna and flora sampled. Here, we describe the Robertskollen area and give preliminary lists of taxa for a number of plant and animal groups.

Approximately 600 pairs of snow petrels Pagodroma nivea *breed at three of the five large nunatak complexes, where they apparently have a considerable influence on the distribution and abundance of other organisms. Preliminary examinations of plant collections indicate that at least four species of mosses, 20 lichen taxa and 17 algal taxa occur at Robertskollen. Several plant associations are identified, essentially similar to those reported from mountain ranges farther east in Dronning Maud Land. Three species of mites (Acari) were collected at Robertskollen, but no springtails (Collembola) were found. The most abundant mite is the oribatid* Maudheimia wilsoni *which is endemic to western Dronning Maud Land. Extractions from soil and vegetation samples contained various tardigrades, nematodes, rotifers, protozoans and fungi; species lists for some of these taxa are presented. Concentrations of several plant nutrients were greater in lithosols close to bird colonies than in those distant from colonies.*

Robertskollen, 'n groep nunatakke wat 'n yshoogte in die noordelike Ahlmannryggen, westelike Dronning-Maudland, Antarktika, omsoom, is voorgestel as 'n terrein met potensiaal vir 'n biologiese navorsingsprogram wat sal konsentreer op die struktuur en funksionering van nunatak-ekosisteme. 'n Voorlopige biologiese opname van die gebied is gedurende die somer van 1987-1988 uitgevoer. Al die nunatakke in die groep is besoek, topografie is beskryf, en die plant- en diergemeenskappe is bemonster. Hier beskryf ons die Robertskollen-gebied en gee voorlopige lyste van die taksa van 'n aantal plant- en dieregroepe.

Ongeveer 600 pare Witstormvoëls Pagodroma nivea *broei op drie uit vyf van die groot nunatak-komplekse, waar hulle skynbaar 'n aansienlike invloed op die voorkoms en verspreiding van ander organismes uitoefen. Voorlopige plantondersoeke toon dat minstens vier soorte mosse, 20 korsmosse, en 17 wiere op Robertskollen voorkom. Verskeie plant-assosiasies is uitgeken, grootliks soortgelyk aan dié wat bekend is vir bergreekse verder oos in Dronning-Maudland. Drie myt-spesies (Acari) is op Robertskollen versamel, maar geen springsterte (Collembola) is gevind nie. Die volopste myt is die oribatied* Maudheimia wilsoni *wat endemies aan westelike Dronning-Maudland is. Uittreksels uit grond- en plantegroeimonsters het allerlei traaglopers, rondewurms, wieldiere, protosoë, en swamme bevat; spesielyste word vir sommige taksa ingesluit. Konsentrasies van verskeie plantvoedingstowwe was hoër in monsters na aan voëlkolonies, as dié wat verder daarvandaan geneem is.*

Introduction

South African research at the ice-free areas of continental Antarctica has focused to date on earth sciences (e.g. Wolmarans & Kent 1982). The only biological studies have been incidental observations by members of geological field parties on the birds in the mountains polewards of SANAE, the South African station on the Fimbul Ice-shelf, western Dronning Maud Land (Fig. 1) (La Grange 1962, Krynauw *et al.* 1983). Nothing is known of the types or species of terrestrial organisms or of their distribution patterns.

However, a preliminary biological survey was undertaken during the summer of 1987-88. The aim of this reconnaissance survey was to collect information for a proposed research programme on the biology of the inland mountain ranges. Because of logistical constraints from ongoing commitments to the geological and geophysical research programmes, it was possible only to examine a single locality. Robertskollen (71°28'S, 3°15'W) was selected for two reasons: breeding colonies of birds had been recorded on some nunataks, while others are devoid of birds (La Grange 1962, Krynauw *et al.* 1983). Robertskollen is also conveniently situated close to the oversnow supply route between SANAE and Sarie Marais field station at Grunehogna (72°28'S, 2°22'W).

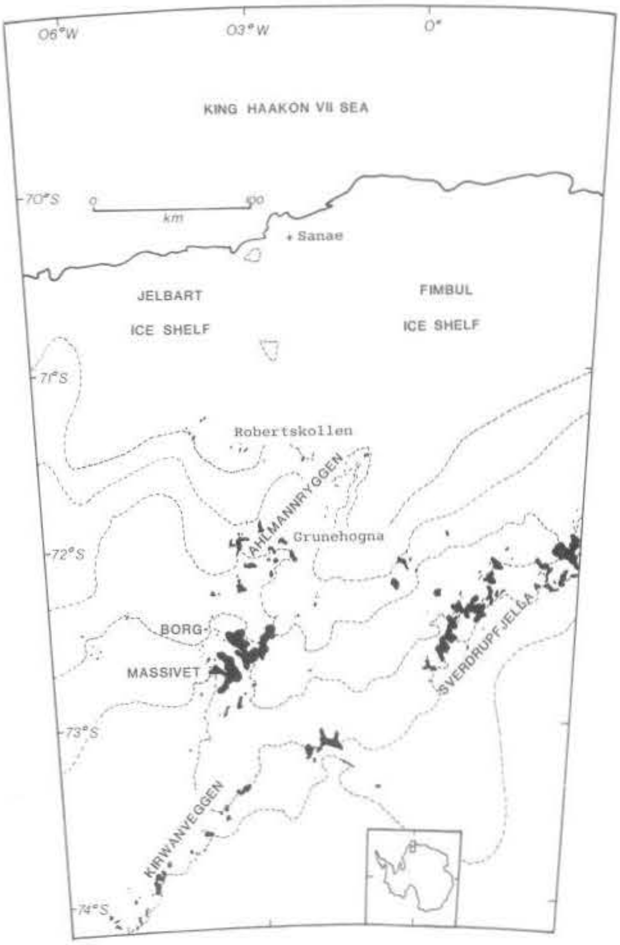

Fig. 1. The mountain ranges and nunataks of western Dronning Maud Land, showing the position of Robertskollen in relation to local bases. Contour interval is 200m

Methods

PGR and BPW visited Robertskollen between 22 December 1987 and 27 January 1988. Camp was established on an ice ridge approximately one-third of the way between 'Ice Axe Peak' and 'Peaceful Hill' (Fig. 2). To reduce contamination of the area, we recommend that future camps are established away from the Robertskollen ice-rise (e.g. on the flats south of the present camp-site).

All nunataks in the group were visited and their topography was described. Estimates of the areas of exposed rock were made from large-scale aerial photographs of the area taken in January 1984 (Institut für Angewandte Geodäsie, Frankfurt) and a map drawn from the photographs by the South African Chief Directorate: Surveys and Mapping (1988).

A census of breeding snow petrels *Pagodroma nivea* by counting nest sites, and an investigation of snow petrel breeding biology was undertaken. The distributions of other biota were related to three different habitat types, identified *a priori* along a bird-influence gradient; these were, in order of decreasing bird influence, 1) within bird colonies, 2) beyond the influence of birds at nunataks with colonies, and 3) at nunataks lacking colonies of breeding birds. The abundance and distribution of macrophytes and mites were determined from 38 transects analysed at randomly-selected sites within these habitat types (see Ryan & Watkins in press a). Mite densities were estimated from direct counts on the underside of ten rocks (each approximately 25 cm²) at each transect site. Rocks were subjectively selected with the aim of recording the largest number of mites.

Representative examples of mosses, lichens, algae and mites were collected for subsequent identification by experts. Unless otherwise specified, plant and soil samples were dried under ambient field conditions, then refrigerated at 4 °C en route to South Africa where they were analysed. Mites were preserved in 70 per cent ethanol, although some live *Maudheimia wilsoni* were kept frozen, and were readily resuscitated by thawing after storage for six months.

Macrophytes were identified by RILS. Twelve vegetation, soil and other samples were examined for algae by light microscopy only; culturing techniques were not used. Fungi were isolated by AE from four soil samples and the nest contents and regurgitations of snow petrels. Two plating methods were used: a dilution technique with peptone-glucose-rose bengal-streptomycin agar, diluting the samples 1:100, 1:1 000 and 1:10 000, and a plating technique whereby samples were transferred aseptically into petri dishes and submerged with saline Czapek Dox agar at 0,3 and 10 per cent NaCl. Each specimen was incubated at 5, 15, 26 and 37 °C, and cultures isolated were stored at 5, 15 and 26 °C on potato-dextrose agar.

Twelve samples each of mosses (HH & WRM) and lichens (HD) were examined for tardigrades and other micro-organisms. Dried plant samples were placed individually in small glass dishes with water, then covered and allowed to stand for 24 hours. The mosses were then teased apart and the water collected in a centrifuge tube after filtering and rinsing through a plastic screen. The tubes were gently centrifuged for five minutes and the supernatant (drawn off by syringe) replaced by an equal volume of four per cent sucrose solution (to relax the specimens). After standing for two to three hours, an equal volume of five per cent buffered formalin was added to the tubes. The supernatant was removed after the samples were allowed to settle for 12 hours, and tardigrades were mounted in Hoyer's medium.

Nematodes were isolated using the Baermann tray technique (Southey 1970) from samples of mosses (n = 7), soil (4) and

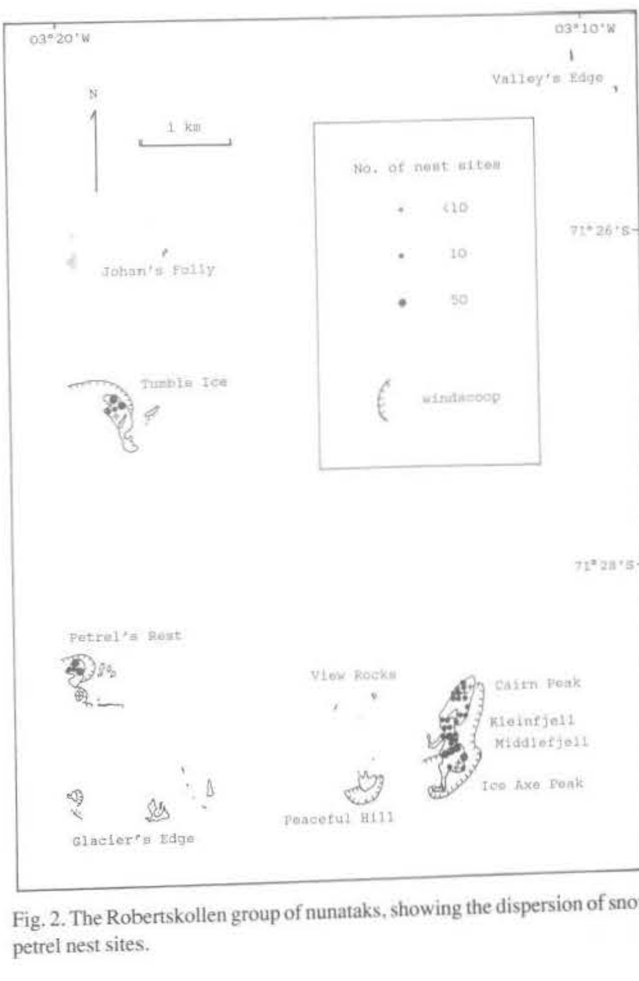

Fig. 2. The Robertskollen group of nunataks, showing the dispersion of snow petrel nest sites.

Prasiola crispa (1). Ciliated protozoans were extracted by WF from three moss samples, two soil samples from snow petrel nests and one *Prasiola crispa* sample, using the non-flooded petri-dish method (Foissner 1987). Cultures were sampled four times over 26 days and determinations were confirmed using silver impregnation.

Fourteen soil samples devoid of macrophytic vegetation were collected to determine the concentrations of soluble nutrients and trace elements. All samples were collected from similar ice-free, exposed, level hollows amongst mafic rocks. Seven sites close to bird breeding colonies (< 100 m) and six sites distant from colonies (i.e. at nunataks lacking colonies or in areas with mean nest densities less than 15 nests per hectare) were sampled, and were compared with soil collected from within snow petrel nest scrapes. Soil samples were kept frozen until analysed by GT. Total carbon was determined by ashing (where carbon content was large) or by the Walkley-Black method. Total nitrogen content was measured using Kjeldahl analysis. All other elements were determined from extractions in a one per cent solution of citric acid similar to the Bray Number 2 extraction technique. Concentrations of elements were measured simultaneously in a direct current emission spectrometer.

Description of the Robertskollen area

Location

Robertskollen is a group of nunataks in the northwest of the Ahlmannryggen, western Dronning Maud Land. It was named after Brian B. Roberts, Secretary of the United Kingdom Antarctic Place-Names Committee (Alberts 1981), after being mapped by Norwegian cartographers from oblique aerial photographs taken during December 1951-January 1952 by the Norwegian-British-Swedish Antarctic Expedition (Giaever & Schytt 1963). However, the first known ground visit was in November 1960 during the first South African National Antarctic Expedition (La Grange 1962, Krynauw *et al.* 1983).

Robertskollen is one of the most northerly outcrops in the region, approximately 130 km from the sea (the ice-shelf front) and 145 km south of SANAE (Fig. 1). The nunataks are situated around the periphery of an ice-rise and range in altitude between 200 and 500 m above sea level. To the west is Schyttbreen, a large glacier, and to the east is Båkenesdokka (the Bakenes Depression), along which runs the SANAE-Grunehogna oversnow supply route. There are five large nunatak complexes (Ice Axe Peak, Tumble Ice, Petrel's Rest, Peaceful Hill and Glacier's Edge) and several smaller nunataks (Fig. 2). The nunataks range in area between 100 m^2 to 12,5 ha. More detailed descriptions of the nunataks are given below. Place names within the Robertskollen group have not been officially ratified.

Geology

The intrusive Robertskollen complex underlies the entire group, and comprises a lower, rhythmically layered ultramafic unit, overlain by a mafic unit (Von Brunn 1963, 1964, Krynauw 1986). The ultramafic unit is exposed in the lower parts of Ice Axe Peak, Tumble Ice and Petrel's Rest. Most of the ultra-mafic rocks consist of mela-olivine gabbronorite. The mafic unit is the predominant rock-type in the group, being found at all nunataks, and consists of gabbronorite and gabbro. Dolerite dykes occur at Ice Axe Peak and Tumble Ice. Lithosols are found throughout, usually in small, isolated patches in sheltered areas between rocks, but also more extensively in flat areas on top of Tumble Ice and Petrel's Rest.

Climate

There are no detailed meteorological data for Robertskollen, but the climate during summer is comparatively mild because of the low altitude. During the study period air temperatures at the camp varied between 1 and -6 °C. Rock surface temperatures of up to 25 °C were recorded during sunny days, and meltwater streams were abundant. Even during blizzards, exposed rock surfaces were above 0 °C at midday. Relative humidity generally was low (20-30 %), but increased during blizzards. Winds blew predominantly from the northeast, and less frequently from the east and southeast. North and west winds were rare and seldom strong.

Detailed topography

Ice Axe Peak (480 m altitude; 12,5 ha).

This is the largest nunatak in the group, with four discrete peaks; from north to south, Cairn Peak (Fig. 3), Kleinfjell, Middlefjell and Ice Axe Peak. Cairn Peak is divided into northern and southern sections by a deep cleft, The Gap. The name Ice Axe derives from an old ice axe placed at the summit of the southern peak during November 1960 by Prof. V. von Brunn in memory of his stepfather,

Fig. 3. Cairn Peak, the northern section of the Ice Axe Peak complex, viewed from the camp. The summit is the highest point at Robertskollen. Kleinfjell is on the extreme right. Note the ice-covered lake to the left of Cairn Peak.

Baron Gaston Radio von Radiis, the original owner of the axe (J.R. Krynauw in litt. to P.R. Condy). The axe is still present, although the inscription on the brass plate on the handle is becoming illegible. Cairn Peak was named after the rock cairn erected at its summit, apparently by a South African geological party that visited the area during January 1982. Kleinfjell and Middlefjell are descriptive names, denoting their size and position in the nunatak complex respectively.

The eastern side of most of the complex comprises high cliffs with steep narrow scree slopes between the four main peaks. Fairly steep boulder slopes occur in places where there are ledges on the cliffs. Below the eastern face is a large, subdivided windscoop (deflation hollow) with several ice-covered lakes. Meltwater streams run down the scree slopes (and cliffs) during warm weather. The tops and western side of the complex are more gently sloping, typically with stable, large boulder slopes, although unstable scree slopes occur in places. Bedrock is exposed in places, particularly along ridges. There is a series of five ice-covered lakes below the western side, situated in shallow deflation hollows that mostly lack the steep slopes and overhangs typical of windscoops. An ice ridge leads almost to the top of the complex between Middlefjell and Ice Axe Peak, and there are areas of apparently permanent ice on the southwestern corner of Cairn Peak and in the northeast of Ice Axe Peak. Several meltwater lakes form in depressions around the latter ice patch during warm weather, and there is a small rock pool at the southern tip of Ice Axe Peak.

Tumble Ice (358 m; 5,4 ha).

This is the second largest nunatak in the Robertskollen group, and consists of a large west-facing spur that juts out over Schyttbreen. It was named after the blocks of ice that had tumbled into its

Fig. 4. The northern face of Tumble Ice, with the isolated eastern cliff on the left.

windscoop (J.R. Krynauw in litt. to P.R. Condy). There are two separate areas of exposed rock: the main nunatak and a section of northwest-facing cliff to the east, separated from the main nunatak by an ice stream (Fig. 4).

The main section has cliffs bordering its western edge, with windscoops where these meet the glacier ice. The windscoop in the north is large and there is an extensive area of boulder and scree slopes below the north-facing cliff. A small ice-covered lake is fed by a substantial stream in this region. Elsewhere the cliffs descend directly into glacier ice. The top of the main nunatak is relatively flat, with coarse gravel and sand flats disrupted by isolated boulder hillocks. There is a large area of exposed bedrock at the raised western point. To the east, the top is almost level with the glacier ice and drift snow is blown onto the rock during blizzards. This results in a moisture gradient running from east to west on top of the main nunatak. There is a large area of apparently permanent ice on the top in the lee of the easternmost row of hillocks.

Petrel's Rest (326 m; 3,5 ha).

This nunatak complex, comprising a number of areas of exposed rock, is a spur overlooking the Schyttbreen. It was named after the corpse of a snow petrel found frozen into a windscoop (J.R. Krynauw in litt. to P.R. Condy). There are two main nunataks, a large one to the north and a small one to the south, separated by a steep ice stream. East of these two nunataks are a number of small, low-lying outcrops, only those on the northern flank of the spur being more than 1 000 m^2 in extent.

The large northern nunatak has two subsections: a cliff-edged massif in the north, separated from the glacier ice to the east by a large windscoop, and a lower, southern section that is invaded by drift snow during blizzards as described for Tumble Ice. The top of this latter section is flat, with coarse gravel and sands predominating. The north- and east-facing cliffs of the northern massif have boulder and scree slopes below them, whereas the west-facing cliffs end in glacier ice. The top of the northern massif consists primarily of boulder slopes and exposed bedrock. The smaller southern nunatak is edged by cliffs on all sides, being separated from the glacier ice to the east by a windscoop. Its summit is similar to that of the northern massif.

Peaceful Hill (c. 460 m; 2,2 ha).

This nunatak, situated adjacent to Ice Axe Peak, faces south from the Robertskollen ice-rise, with a large south-facing cliff looking out over the mountains of the southern Ahlmannryggen. The nunatak was named after the peaceful times spent appreciating this view (J.R. Krynauw in litt. to P.R. Condy). Below the cliff is a windscoop containing an ice-covered lake. To the north, glacier ice invades depressions in the rock, leaving two ridges as isolated outcrops. Much of the top is undulating boulder and scree slopes, although there are some areas of exposed bedrock. The central depression fills with drift snow during blizzards and contains a meltwater lake (140 m^2, max. depth 1,5 m) in warm weather.

Glacier's Edge (449 m; 2,6 ha).

This is a group of nunataks in the southwestern corner of the Robertskollen ice-rise. The nunataks are on a ridge that overlooks Schyttbreen, hence the name (J.R. Krynauw in litt. to P.R. Condy). There are six outcrops grouped together in the east, with some exposed rock on the south-facing ice slope, and two nunataks in the west overlooking Schyttbreen. The eastern outcrops comprise mainly ridges of jointed bedrock that protrude from the glacier ice. Gravel hollows in the ridges accumulate drift snow during blizzards and contain meltwater pools (up to 6 m^2) in warm weather. There are no windscoops. The western-most outcrop is the largest nunatak and has a south-facing cliff and a small area of scree slope.

The more northerly of the two western nunataks is edged by cliffs, and is separated from the glacier ice to the east by a windscoop. It is raised above the level of the glacier ice more than the other Glacier's Edge outcrops, and is structurally similar to the southern nunatak at Cave Peak, but has a scree slope below the western cliffs. To the south of the main nunatak is a smaller, low-lying outcrop of jointed bedrock.

Other nunataks.

There are several small, isolated outcrops of essentially similar nature, composed predominantly of jointed bedrock. In many regards they are similar to the low-lying eastern outcrops of Glacier's Edge. Johan's Folly (195 m; 0,1 ha) is a single outcrop low down at the edge of Schyttbreen north of Petrel's Rest. It was named after the confusion caused by Johan Krynauw's sketchmap of Robertskollen which led to a wild-goose chase in search of "Tumble Ice". Valley's Edge (*c.* 320 m; 0,1 ha) is the most northerly and most isolated outcrop in the Robertskollen group. It consists of two low ridges overlooking the Båkenesdokka, hence the name (J.R. Krynauw in litt. to P.R. Condy). View Rocks (0,1 ha) is a group of three outcrops north of Peaceful Hill in the ice valley west of Cairn Peak. The largest outcrop has a small deflation hollow on its southern side with an ice-covered lake. The group was named after the excellent view that the largest outcrop affords of the Ice Axe Peak complex.

Results

Birds

Four species of birds were recorded at Robertskollen: Antarctic petrels *Thalassoica antarctica*, snow petrels, Wilson's storm petrels *Oceanites oceanicus* and south polar skuas *Catharacta maccormicki* (Ryan & Watkins 1988). The snow petrel is the only

Fig. 5. Analysing the floristic composition along a transect on jointed bedrock and boulder scree at Glacier's Edge.

Table 1
Approximate exposed rock areas of nunataks in the Robertskollen group (from aerial photographs) and the numbers and densities of snow petrel nests (occupancy standardized to late December, see Ryan & Watkins in press b)

Nunatak	Area (ha)	Nest sites Density (no.ha-1)	Nest sites no.	Breeding pairs Density (no.ha-1)	Breeding pairs no.
Ice Axe Peak complex					
Cairn Peak north	2,0	28,5	57	17,0	34
Cairn Peak south	3,5	24,9	87	17,1	60
Kleinfjell	0,8	23,8	19	12,5	10
Middlefjell	1,8	51,1	92	35,6	64
Ice Axe	4,4	58,2	256	38,6	170
Tumble Ice complex					
Northern cliff	1,5	66,0	99	48,0	72
Main summit	3,3	7,9	26	3,9	13
Eastern cliff	0,6		0		0
Petrel's Rest Complex					
Northern nunatak	2,4	51,7	124	35,0	84
Southern nunatak	0,4	7,5	3	5,0	2
Eastern outcrops	0,6		0		0
Peaceful Hill					
Main nunatak	2,0		0		0
Northern outcrops (2)	0,1		0		0
Glacier's Edge					
Eastern outcrops (6)	1,9		0		0
Western nunataks (2)	0,7		0		0
Johan's Folly	0,1		0		0
Valley's Edge (2)	0,1		0		0
View Rocks (3)	0,1		0		0
Total	26,3		763		509

proven breeding species, with an estimated population of 600 breeding pairs (Ryan & Watkins in press b). Wilson's storm petrels may also breed on the northern cliffs at Tumble Ice (not Petrel's Rest as indicated in Ryan & Watkins 1988 due to earlier confusion of nunatak names), where individuals were sighted on both occasions when the area was visited and their behaviour suggested that they were breeding. However, numbers are small; only eight Wilson's storm petrels were sighted during five weeks at Robertskollen. No evidence was found of breeding by Antarctic petrels or south polar skuas, and it is unlikely that these conspicuous, open-nesting species breed at Robertskollen (Ryan & Watkins 1988).

Snow petrels breed at three of the five main nunatak complexes, involving four discrete nunataks, the Ice Axe Peak complex, Tumble Ice and Petrel's Rest north and south (Table 1, Fig. 2). Most nests occur in fairly discrete subcolonies (generally 5 to 15 nests, maximum 46), although there are some isolated nests. Nest occupancy varied considerably between subcolonies, ranging between 10 per cent (1/10) and 89 per cent (8/9). The density of nest sites varied between different regions of the nunataks, with the greatest density at the north-facing cliff of Tumble Ice and the lowest densities on the summit of Tumble Ice and the small, southern Petrel's Rest nunatak (Table 1).

Nunatak topography appears to be the major determinant of colony dispersion (Ryan & Watkins in press b). Nest sites typically are in hollows between or under boulders, or in cliff crevices; open nest sites are scarce. Accumulations of snow petrel regurgitations ('mumiyo', Wisnes 1969) at nest entrances were up to 150 mm deep and weighed up to 3 kg.

Snow petrels were incubating at the start of the observation period (22 December). The first eggs hatched on 15 January, suggesting that egg-laying commenced around 2-4 December (given an incubation period of 43-45 days, Brown 1966, Mougin 1968, Isenmann 1970). During blizzards most nest sites became completely buried by snow, although adult birds dug themselves out after the blizzards stopped (Fig. 6). Capture to mark and measure adult birds resulted in at least 44 per cent of incubating birds handled deserting. This is a problem that future studies on the breeding snow petrels will have to address. Birds not withdrawn from their nests but marked on the head with a black marker pen on a stick (to identify individuals) did not desert. Additional data on the breeding biology of snow petrels at Robertskollen are detailed in Ryan & Watkins (in press b). All but one individual examined fell within the size range of the small nominate race (n = 54, Ryan & Watkins in press b).

Plants

Vegetation at Robertskollen is relatively luxuriant for an inland continental Antarctic locality (*sensu* Lewis Smith 1984), with locally abundant plant cover. More than 40 plant taxa have been identified from samples collected during the survey, and more species are likely to be found by a dedicated botanical survey. The major vegetation types are discussed below, loosely following the system proposed by Engelskjøn (1985, 1986) for plant associations in the Gjelsvikfjella and Mühlig-Hofmannfjella.

Mosses

Four moss species were identified from material collected at Ice Axe Peak. *Ceratodon purpureus*, *Bryum pseudotriquetrum* and *Bryoerythrophyllum recurvirostre* occur in sheltered, fairly well irrigated sites, often within or adjacent to bird colonies. They

Fig. 6. Snow petrel on nest, having opened the nest entrance after a blizzard

Fig. 7. Moss stand of coalesced short turves on a sheltered, west-facing cliff ledge at Cairn Peak, Robertskollen. Lens cap is 52mm diameter.

typically grow on fine substrata (lithosols or gravels) in crevices or on cliff ledges (Fig. 7), although they also occur on fairly exposed, open areas. In some particularly favourable localities, such as the north-facing cliff at Tumble Ice, there are coalesced turves of up to 5 m^2 in area and up to 70 mm in depth. Dead moss shoots lie beneath such turves, and there is little accumulation of other organic matter. *Sarconeurum glaciale* was recorded from the base of an east-facing cliff at Ice Axe Peak, where it was growing in a pool of water fed by meltwater running down the cliff. *Grimmia lawiana* was not recorded from Robertskollen, although it was collected at Grunehogna and is the most widespread species in the Gjelsvikfjella and Mühlig-Hofmannfjella to the east (Engelskjøn 1986). It is likely that this species occurs at at least some of the more exposed sites at Robertskollen. None of the mosses encountered possessed sporophytes.

Apart from mosses growing in the most favourable, sheltered and moist localities, the turves and cushions typically have necrotic centres, encrusted with several lichens and cyanobacteria. The orange, yellow and white crustose lichens *Xanthoria candelaria, Candelariella antarctica, Caloplaca citrina, Lepraria* sp. and *Lecanora* cf. *expectans* are frequent epiphytes on the mosses *C. purpureus, B. pseudotriquetrum and B. recurvirostre*. Several algae and cyanobacteria (dominated by the thallose cyanonbacterium *Nostoc commune*) were epiphytic on *Sarconeurum glaciale*. The fruticose lichen *Usnea antarctica* was occasionally epiphytic on moss cushions.

Lichens

Two species of *Usnea, U. antarctica* and *U. sphacelata* are the major fruticose lichens at Robertskollen. Both occurred immediately below a snow petrel colony. They are abundant, particularly adjacent to bird colonies, where large stands occur in sheltered depressions and in crevices amongst stable scree slopes. They are also abundant away from bird colonies in shallow depressions that frequently accumulate drift snow during blizzards (e.g. the small outcrop north of Peaceful Hill and the eastern edges of Tumble Ice and Petrel's Rest north). Both species typically grow on rocks, but also occur on pebbles and gravels, although seldom on the finer lithosols. Individuals of *U. antarctica* in sheltered, well-watered microhabitats are greyish-green, whereas *U. sphacelata* is pale yellow. However, in more exposed habitats at least *U. sphacelata* thalli are blackened (the 'light' and 'shade' forms of Kappen 1983). During blizzards, the erect branches trap drift snow, assuring a supply of meltwater (Kappen 1985). However, after blizzards thalli of *Usnea* may be blown off the nunataks and are not infrequent on the adjacent glacier ice.

The *Usnea* spp. typically occur together with the foliose lichen *Umbilicaria decussata*, and rarely, in wetter situations, with *U. aprina*. There is generally an understorey of crustose lichens, predominantly *Buellia* spp. and *Lecidea* sp., and also the foliose lichen *Physcia caesia*. In deep, damp crevices there is occasionally an algal understorey. *Candelariella antarctica*, a yellow crustose lichen, is occasionally epiphytic on upper branches of *Usnea* spp. in very sheltered localities.

Pseudephebe minuscula, a black, wiry mat-forming fruticose lichen, also occurs at Robertskollen, growing on fairly sheltered rocks, almost exclusively at sites distant from the influence of bird colonies. It is seldom abundant, and typically is associated with *Umbilicaria decussata* and various crustose lichens such as *Buellia* spp. and *Lecidea* sp. At some localities it forms an understorey to *Usnea sphacelata*.

The foliose lichen *Umbilicaria decussata* is the most abundant lichen, occurring on all but the most exposed rocks, although it is

Table 2
Provisional list of lichens recorded from Robertskollen (sequence after Poelt 1973)

Ascomycetes	
Lecanorales	
Lecanorinae	
Lecideaceae	*Lecidea* sp. *Rhizocarpon ?flavum*
Lecanoraceae	*?Lecanora* cf. *expectans* *Rhizoplaca melanophthalma* (formerly *L. melanophthalma*)
Usneaceae	*Usnea antarctica* *U. sphacelata* (formerly *U. sulphurea* *Pseudephebe minuscula* (formerly *Alectoria minuscula*)
Umbilicariineae	
Umbilicariaceae	*Umbilicaria aprina* *U. decussata*
Acarosporineae	
Acarosporaceae	*Acarospora gwynni* *A. chlorophana* (formerly *Biatorella antarctica*, *B. cerebriformis*, see Øvstedal 1983b, Engelskjøn 1986)
Buelliineae	
Candelariaceae	*Candelariella antarctica* (= *C. hallettensis*, see Øvstedal 1983b)
Teloschistaceae	*Caloplaca citrina* *Xanthoria elegans* *X. candelaria*
Physciaceae	*?Buellia* cf. *frigida* *?Buellia* cf. *soredians* *Physcia caesia* *?Rinodina* sp.
Fungi Imperfecti	*?Lepraria* sp.

rare on vertical cliffs. At moist, sheltered sites it is largely replaced by *U. aprina*. *U. decussata* thalli attain diameters of at least 60 mm, whereas those of *U. aprina* can reach more than 100 mm. Both species typically are associated with various crustose lichens such as *Buellia* spp. and *Lecidea* sp., and *U. decussata* is often associated with fruticose lichens such as *P. minuscula* and *Usnea* spp.

Vertical cliffs typically support the reddish-orange folio-crustose lichen *Xanthoria elegans*, as well as *Buellia* spp., with the yellow-green *Acarospora gwynnii* in wetter situations. Extensive stands of *X. elegans* and associated lichens occur on some sheltered cliffs. However, all three taxa also occur away from cliffs. *X. elegans* occurs as a squamose growth form epiphytic on or adjacent to beds of the green alga *Prasiola crispa*.

There are some floristic differences between localities within or adjacent to bird colonies and localities distant from bird colonies. The sulphur-yellow *Acarospora chlorophana*, the mottled green and black *Rhizocarpon ?flavum* and the dull yellow-green *Rhizoplaca melanophthalma* grow at sites where birds have little influence, chiefly on nunataks that lack bird-breeding colonies. By comparison, *Acarospora gwynnii*, *Xanthoria elegans*, *Physcia caesia*, and some epiphytic lichens including *?Rinodina* sp. and *Candelariella antarctica* are most abundant at sites close to bird colonies.

Table 3
Provisional list of algae recorded from three habitats at Robertskollen

Taxon	Habitat type: Hollows under rocks – bird nests	Habitat type: Hollows under rocks – other	Habitat type: East-facing cliff
Cyanobacteria			
Chroococcales			
Gloeocapsa sp.	-	-	+
Synechococcus aeruginosus	-	-	+
Pleurocapsales			
cf. *Chroococcidiopsis* sp.	-	-	+
Nostocales			
Oscillatoriaceae			
cf. *Phormidium autumnale*	+	+	+
cf. *P. fragile*	-	+	-
cf. *P. laminosum*	-	-	+
cf. *Lyngbya murrayi*	-	-	+
Nostocaceae			
Nostoc commune	-	-	+
Scytonemataceae			
Scytonema sp.	-	-	+
Chrysophyta			
Bacillariophyceae			
Cymbella sp.	+	-	-
Hantzschia amphioxys	-	-	+
Navicula muticopsis	-	-	+
Pinnularia borealis	-	-	+
Chlorophyta			
Chlorococcales			
cf. *Chlorella* sp.	+	+	-
unidentified unicells	-	+	-
Ulotrichales			
Stichococcus sp.	+	+	+
Chaetophorales			
cf. *Coccobotrys* sp.	+	+	+
Prasiolales			
Prasiola crispa	+	+	+

+ = present, - = absent

Macro-algae and cyanobacteria

The most prominent alga is the foliose chlorophycean *Prasiola crispa* which typically is associated with bird colonies. Sheets of this alga occur in moist, sheltered hollows, usually shaded by overhanging rocks, below snow petrel nests. Away from the immediate influence of snow petrel nests, extensive stands were found only in the meltwater stream between Ice Axe Peak and Middlefjell. However, this stream probably also receives run-off from the adjacent bird colonies. Stands of up to 30 mm deep occur on both rock and mud substrata, often with some associated algae (*Phormidium* spp., *Cymbella* sp., cf. *Chlorella* sp., *Stichococcus* sp.

Table 4
Provisional list of fungi isolated from five habitats at Robertskollen

Taxon	Peaceful Hill soil	Ice Axe streambed	Snow petrel associated: colony soil	Snow petrel associated: nest soil	Snow petrel associated: mumiyo
Deuteromycotina					
Alternaria alternata (Fr.) Keissler 1912	-	+	-	-	-
Chyrsosporium pannorum (Link) Hughes 1958	-	+	+	-	-
C. merdarium (Link ex Grev.) Carm. 1962	-	-	+	-	-
Cladosporium cladosporioides (Fres.) de Vries 1952	-	+	-	-	-
C. sphaerospermum Penz. 1882	-	-	+	-	-
Epicoccum purpurascens Ehrenb. ex Schlecht. 1824	-	-	-	+	-
Fusarium oxysporum Schlecht. 1824 emend. Sny & Hans. 1940 pro maxima parte	-	-	-	+	-
Penicillium citrinum Thom 1910	-	-	-	+	-
P. frequentans Westling 1911	-	-	-	+	-
Phoma sorghina (Sacc) Boerema, Doornbosch & van Kesteren	-	-	+	-	-
Trichoderma harzianum Rifai 1969	-	+	+	+	-
Ascomycotina					
Thelebolus microsporus (Berk. & Br.) Kimbr. 1967	-	-	+	+	+

+ = present, - = absent

and cf. *Coccobotrys* sp.). In addition, some of the more exposed *Prasiola* stands support the epiphytic lichens *Candelariella antarctica* and *Xanthoria candelaria*.

Most algae occur in very wet, shaded microhabitats, either under the cover of other rocks (six species recorded, Table 3) or where there are meltwater streams on south and east-facing cliffs (13 species recorded, Table 3). The latter habitat typically has a blackish algal film over the wet cliff-face (composed chiefly of *Gloeocapsa* sp., *Phormidium* spp., *Nostoc commune* and various diatoms), with these and other algae in wet gravel hollows and epiphytic on the moss *Sarconeurum glaciale*.

Micro-algae and fungi

Endolithic algae (those growing within fissures or interstitial spaces in rock) appeared to be very scarce at Robertskollen, presumably because the rock structure is unsuitable. Chasmoendolithic growths of lichen gonidia with an associated unicellular green alga were found only in some highly fractured and layered rocks exposed on the northern cliff at Tumble Ice. Macroscopically visible green snow algae were found only in the northern windscoop at Tumble Ice. Four species of diatoms and two unicellular green algae were found in association with thallose algae (see Table 3).

Fungi were isolated from all soil samples except one from Peaceful Hill, a nunatak lacking breeding birds (Table 4). The greatest number of species were recorded in soil samples from snow petrel colonies and from the soil and bird remains from snow petrel nest scrapes. No fungi were isolated from the dried corpses of snow petrel chicks and only one species was found in mumiyo, the solidified regurgitations of snow petrels that accumulate at the entrances to nest crevices.

Mites (Acari)

Three species of mites were found at Robertskollen: *Maudheimia wilsoni*, an oribatid mite endemic to the mountain ranges of western Dronning Maud Land (Dalenius & Wilson 1958, Sømme 1986a), and two prostigmatid mites, *Eupodes angardi* and *Nanorchestes antarcticus*. *M. wilsoni* is readily recognized by its very slow, ponderous gait, its translucent tan coloration and its relatively large size (mean adult body length $\pm$ SD is 0,62 $\pm$ 0,03 mm; n = 100). It occurs at all but the smallest and most isolated outcrops (e.g. Valley's Edge and the smaller outcrops in the View Rocks group). The species occurs most frequently in dense aggregations in shallow depressions and crevices on the underside of rocks, where macrophytes are absent. However, a few are found on the sides of rocks on which there are some lichens, and they are very occasionally seen among *Usnea* or on moss cushions. Adults, nymphs and eggs were all found during the survey, but adults and nymphs were most numerous. The species is extremely abundant, attaining densities of up to approximately 40 000 individuals m^{-2}.

Eupodes angardi is a fast-moving species that occurs in two colour morphs: a dark morph with a dark-brown to black body and contrasting bright red legs and a central dorsal red stripe, and a pale morph with the entire body and legs red-tan. The dark morph occurs at all but the smallest nunataks, whereas the pale morph occurs only at nunataks with bird colonies. *E. angardi* are frequently found on the undersides of rocks in depressions, but during warm weather they emerge and run rapidly over the exposed rock surface, often pausing to investigate small crevices or lichens. Numbers varied greatly between localities, with a mean density of approximately 250 individuals m^{-2}.

Nanorchestes antarcticus is a very small, slow-moving mite with a mauve body and coral pink legs. It occurs at all outcrops at Robertskollen, typically in damp gravels and lithosols, as well as on the underside of rocks. It usually occurs deeper in the substratum than do *M. wilsoni* or *E. angardi*, occurring to at least 30 mm below the surface. Numbers are greatest within bird colonies, where the mean density is approximately 320 individuals m^{-2}. Elswhere the density is approximately 60 individuals m^{-2}.

Other fauna

No springtails (Collembola) were found, despite intensive searches of suitable substrata including sheets of *Prasiola crispa*, mosses and the underside of rocks. Their apparent absence is surprising considering the relative abundance of springtails at adjacent sites (Sømme 1986a, b). However, eight individuals, probably *Cryptopygus* sp., were observed in mosses at nunatak 1285, Grunehogna, a nunatak approximately 80 km south of Robertskollen.

Two tardigrade taxa were found in the lichen and moss samples. A previously undescribed species, *Macrobiotus* sp. nov., was isolated from three lichen samples from Ice Axe Peak, and *Diphascon (Hipsibius) puniceum* (Jennings 1976) subsp. nov. occurred together with *Macrobiotus* in one lichen sample. An unidentified species of *Macrobiotus* (possibly the same as the new species listed above) was found in four moss samples from Ice Axe Peak, and *Diphascon (Hipsibius) puniceum* was present in two of these samples.

Tardigrades were not found in moss samples from Tumble Ice (n = 2) or Petrel's Rest (n = 1), and were patchily distributed at Ice Axe Peak, being absent from two samples collected on Middlefjell and one collected on the east-facing cliffs. The abundance of tardigrades also varied considerably between samples, ranging from 0 to 141 adults in five samples from a small area of Ice Axe Peak. There was a greater diversity of tardigrades in two moss samples collected at nunatak 1285, Grunehogna, where four taxa were recorded: *Hypsibus chilenensis*, *H.oberhaeuseri*, *Macrobiotus harmsworthi* and *Macrobiotus* sp. (the unidentified species listed above).

Rotifers and nematodes extracted from moss and soil samples await identification. Nematodes were present in all twelve moss samples examined for tardigrades from Robertskollen, but were absent from two samples collected at nunatak 1285, Grunehogna. Rotifers were present in only two moss samples from Robertskollen, whereas they were found in both samples from Grunehogna. Ten ciliate taxa were identified, with the greatest diversity found in mosses (Table 5).

Soil Nutrients

Table 6 summarizes the concentrations of various elements in lithosol samples. Concentrations of most elements were very large in soil from snow petrel nest scrapes, and several elements were present in significantly greater concentrations in soils collected close to bird colonies than in soils from areas distant from colonies. Notable in this regard were raised concentrations of the major plant nutrients, nitrogen, phosphorus and potassium, in the areas around bird colonies.

Discussion

The snow petrel colonies at Robertskollen are of similar size to colonies recorded at adjacent mountain ranges (e.g. Sømme 1977, Mehlum *et al.* 1988). The breeding phenology of snow petrels is typical of the smaller, nominate race (see Ryan & Watkins in press b). Based on the size of the agglomerations of oil regurgitations found at nest sites, the colonies at Robertskollen probably have been occupied for approximately the last 10 000 years (cf. Hiller *et al.* 1988). Radiocarbon ages are being determined for mumiyo deposits collected at Robertskollen.

The vegetation at Robertskollen is relatively diverse and abundant for an inland site in continental Antarctica. This is probably related to the relatively mild climate associated with the low

Table 5
Provisional list of ciliates recorded from four habitats atRobertskollen

Taxon	Habitat type			
	Snow petrel nest soil	*Prasiola crispa*	*Sarconeurum glaciale*	Other mosses*
Colpoda inflata (Stokes 1885) Kahl 1931	-	-	+	+
Holosticha tetracirrata Buitkamp & Wilbert 1974	-	-	+	-
Homalogastra setosa Kahl 1926	-	-	-	+
Lamtostyla perisincirra (Hemberger 1985) Berger & Foissner 1987	-	-	+	-
Leptopharynx costatus Mermod 1914	-	-	-	+
Mycterothrix sp. nov.?	-	-	-	+
Opercularia arboricola (Biegel 1954) Foissner 1981	-	-	-	+
Opercularia sp. (coarctata?)	-	+	-	-
Pseudocohnilembus pusillus (Quennerstedt 1869) Foissner & Wilbert 1981	+	-	-	-
Pseudoplatyophyra nana (Kahl 1926) Foissner 1980	-	-	+	-

* *Ceratodon purpureus, Bryum pseudotriqetrum and Bryoerythrophyllum recurvirostre*

+ = present, - = absent

elevation of Robertskollen. The composition of the lichen flora is similar to that recorded from adjacent mountain ranges of Dronning Maud Land, e.g. Sverdrupfjella (Øvstedal 1983a), Tottanfjella (Lindsay 1971), Vestfjella (Lindsay 1972, Øvstedal 1983b), Heimefrontfjella (Bowra *et al.* 1966), Gjelsvikfjella and Mühlig-Hofmannfjella (Engelskjøn 1986) and Sør-Rondane (Dodge 1962). The algae are typical of continental Antarctic sites (e.g. Hirano 1983, Broady 1987). More species of algae would almost certainly be found, given more intensive collections and detailed analysis using culturing techniques (cf. Broady 1979).

There is a greater diversity of mosses at Robertskollen than at nunataks at a higher elevation farther east (Engelskjøn 1986), possibly associated with the less severe climate. Dalenius & Wilson (1958) mention that five species of moss were found at Passat and Boreas nunataks (71°18'S, 3°55'W), northwest of Robertskollen, but only *Sarconeurum glaciale* is named. This species and a species of *Grimmia* were reported from sites in the Heimefrontfjella (Bowra *et al.* 1966), while *S. glaciale* and *G. lawiana* were the only mosses reported from the Gjelsvikfjella and Mühlig-Hofmannfjella region (Engelskjøn 1986). Plant associations at Robertskollen are similar to those recorded in the nearby mountain ranges to the east (Engelskjøn 1986).

The mite community at Robertskollen is dominated numerically by the oribatid *Maudheimia wilsoni*, although the prostigmatid *Nanorchestes antarcticus* occurs at a wider range of nunataks. Like most continental Antarctic ecosystems, there is apparently no predator, and mite populations presumably are regulated by physical factors, although competition may occur.

Eupodes angardi previously has been recorded from the H.U. Sverdrupfjella, Gjelsvikfjella and Mühlig-Hofmannfjella farther east in Dronning Maud Land (Sømme 1986a). The Robertskollen records extend the known range westward, and are the first records for the area west of the Jutulstraumen. *Nanorchestes antarcticus* occurs throughout much of continental Antarctica (Strandtmann 1967), although the closely related *N. bifurcatus* occurs in the Heimefrontfjella, Dronning Maud Land, to the west of Robertskollen (Bowra *et al.* 1966, Strandtmann 1967).

Virtually nothing is known of the biology of *M. wilsoni* (Dalenius & Wilson 1958, Wallwork 1967, Sømme 1986a). It occurs in similar habitats to those occupied by *M. petronia* in northern Victoria Land, but does not occur commonly at the bases of *Usnea* spp., as has been reported for *M. petronia* (Gressitt & Shoup 1967). The habitat use of *M. wilsoni* is also similar to that of *Alaskozetes*

Table 6
Concentrations (± 1 SD, and range) of elements in lithosols from sites close to and distant from snow petrel colonies. Concentrations in soil from snow petrel nests are presented for comparison. Significance of differences tested using Mann-Whitney U-tests, NS = not significant

Nutrient	Nest soil (n = 1)	Colony soils (n = 7)	Non-colony soils (n = 6)	P
C (%)	22.9	1.09 ± .78 *(0.25-2.09)*	.55 ± .58 *(0.13-1.41)*	NS
N (%)	1.4	.175 ± .187 *(0.03-0.55)*	.016± .005 *(.012-.017)*	<0.002
P ($mg.kg^{-1}$)	6060.0	1560. ±1427. *(234-4110)*	182.9 ± 119. *(37-360)*	<0.01
K ($mg.kg^{-1}$)	1060.0	200.4 ± 44.5 *(145-263)*	122.5 ± 15.8 *(93-138)*	<0.002
Na ($mg.kg^{-1}$)	87.0	167.4 ± 181. *(51-552)*	68.7 ± 29.7 *(37-122)*	NS
Ca (ce%*)	41.7	2.36 ± 1.03 *(1.38-3.8)*	1.54 ± 0.49 *(0.91-2.0)*	NS
Mg (ce%)	12.6	0.73 ± 0.25 *(0.33-1.04)*	0.88 ± 0.71 *(0.20-2.0)*	NS
Cu (ce%)	6.5	5.04 ± 1.32 *(3.8-7.3)*	2.44 ± 0.77 *(1.5-3.6)*	<0.002
Zn (ce%)	47.2	1.79 ± 1.61 *(0.35-4.20)*	2.71 + 4.02 *(0.04-9.8)* +	NS
Mn (ce%)	18.8	9.7 ± 3.28 *(6.0-15.2)*	9.05 ± 5.57 *(2.8-18.3)*	NS
Fe (ce%)	1560.0	1033. ± 506. *(290-1830)*	252. ± 50. *(186-331)*	<0.005
Al (ce%)	750.0	896. ± 245. *(679-1333)*	488. ± 173. *(196-649)*	<0.002
B (ce%)	5.9	1.16 ± 0.37 *(0.53-1.61)*	.43 ± 0.21 *(0.20-0.80)*	<0.005

* ce% = centimoles.kg^{-1}

\+ one sample, value 51.5, omitted

antarctica, an oribatid mite from the Antarctic Peninsula and many continental localities (Gressitt 1967, Strong 1967). It is interesting that *M. wilsoni* occurs in loose to dense aggregations throughout the mid-summer period, because this behaviour is typical of overwintering oribatid mites farther north (Dalenius & Wilson 1958, Strong 1967). This observation supports Sømme's (1986a) contention that the range of *M. wilsoni* is limited to relatively low altitudes by physical conditions.

Only limited sampling for micro-organisms was undertaken during the current survey at Robertskollen. Most samples were collected at nunataks with bird colonies, were vegetation is more abundant than at nunataks lacking bird colonies (see below). More complete sampling will no doubt reveal a greater diversity of micro-organisms. However, some interesting patterns have already emerged, notably the apparent absence of collembolans and the relatively low diversity of tardigrades at Robertskollen. The extremely patchy distribution of tardigrades at Robertskollen also warrants verifying.

There have been few reliable studies of the Antarctic ciliate protozoan fauna (Smith 1978). The diversity found at Robertskollen is low compared to lower latitudes (Foissner 1987). All the taxa found at Robertskollen have a world-wide distribution (Foissner 1987, unpubl. data), but, with the exception of *Leptopharynx costatus*, all are new records for continental Antarctica (cf. Smith 1978). The presence of *Colpoda inflata* in the three moss species sampled, a genus previously unrecorded from Antarctica (Smith 1973), suggests that this genus has been overlooked because of inappropriate extraction and culturing methods.

Antarctic nunataks are among the most isolated ecosystems in the world. Apart from limited inputs by aerosols and other aeolian deposits, birds are the only vector for importing nutrients into the ecosystem. In spite of this unique characteristic, observations on the effects of ornithogenic products on the flora and fauna of inland nunataks are few (Siple 1938, Perkins 1945, Dalenius & Wilson 1958). It is generally accepted that plant abundance is greater at nunataks with bird-breeding colonies than at those lacking colonies, and that birds are an important source of nitrogen for plants in Antarctica (Lewis Smith 1985), but there has been no attempt to demonstrate a causal relationship between nutrient enrichment by ornithogenic products and increased plant (and animal) abundance. The floristic and faunistic differences noted along a bird-influence gradient at Robertskollen, together with the raised nutrient levels in soils around bird colonies, indicate the importance of ornithogenic products as determinants of plant assemblages at nunataks. This topic, together with the influence of physical factors on macrophyte assemblages, is discussed quantitatively in Ryan & Watkins (in press a). The significantly greater concentration of copper (and perhaps other trace metals) in soils close to snow petrel colonies presumably is related to the very high concentration of copper within the chitin of Antarctic krill *Euphausia superba* (Neugebauer *et al.* 1986), the main prey of snow petrels (Obst 1985).

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