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From bedrock to biota: weathering, physico-chemical properties, protozoans and micrometazoans of some soils of East Antarctica

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Abstract

1. An analysis of bedrock and associated soils was conducted at a series of coastal localities in East Antarctica as well as further inland in the Prince Charles Mountains. Protozoans and micrometazoans were extracted from soil samples and an assessment made of their ecological relations with each other and with soil characteristics.

2. Mineral soils, regardless of topographic elevation and proximity to the coast, were characterised by large gravel fractions (fragments of underlying bedrock) and minimal clay fractions, implying that these soils were predominantly the products of physical weathering, with little chemical alteration. Only where humans, dogs or birds contributed organic matter were there elevated concentrations of nitrogen, phosphorus or organic matter.

3. Generally, mineral nitrogen did not seem to have resulted from microbial mineralisation, but at some sites there was evidence that atmospheric nitrate had been concentrated by sublimation of snow. Water-soluble and dilute acid-soluble phosphorus concentrations were surprisingly high for such organically poor soils. There was a sufficiently large labile pool of common macronutrients to sustain the autotrophic activity likely to occur within the bounds of prevailing temperatures and moisture; thus, nutrients are not likely to be limiting for these soil communities.

4. There was a limited fauna. Flagellates were rare and ciliates occurred only in the coastal areas sampled, whereas amoebae were found over a greater geographic and elevational span. Micrometazoans such as rotifers, tardigrades and nematodes were more common in coastal soils than in those further inland, but occurred in soils over most of the naturally occurring range of soil moistures, acidities, nutrient levels, electrolyte levels and organic contents. Exceptions were the exclusion of rotifers from alkaline soils with high nutrient levels, and the tendency of nematodes to be absent from soils with low pH. Tardigrades were found at almost all levels of all soil characteristics.

5. The occurrence of these metazoan phyla under such a range of environments probably resulted from their known capacity to alternate between endurance of inclement conditions in a state of deep dormancy (anhydrobiosis), and taking advantage of ephemeral favourable conditions by temporarily resuming metabolic activity. The conditions measured in soils containing micrometazoans may merely indicate those conditions these animals can survive while dormant, not those under which active animals can carry out vital processes.

6. In some localities there were positive associations between various taxon-pairs of metazoans and protozoans, whereas at others their occurrences seemed to be random with respect to each other.

1. Introduction

In their book on Antarctic soils, Campbell and Claridge (1987) concluded that (1) physical weathering is the dominant process of rock decay in Antarctica, and its various manifestations are important in the formation of regolith and subsequent soil formation; (2) chemical weathering, because of low prevailing temperatures and relative unavailability of water, occurs slowly and to a limited extent; and (3) while Antarctic soils are not completely devoid of life, the influence of the organic cycle, and of the organisms involved in it, have a nearly negligible influence on soil development. In general, the Antarctic environment is one in which pedogenic processes operate slowly.

There is variability in the nature of Antarctic soils and in the rates of soil-forming processes, depending on the kind of parent rock and on local climate. Inland localities tend to be drier and colder than coastal regions, and there are also regional differences in climate imposed by variations in topography and elevation. Microclimate may differ considerably from the macroclimate and it is the former that affects the soil and its biota. Aspect, slope and soil colour may influence temperature markedly through their modification of surface temperatures and hence availability of water in the liquid state.

Viewed from the ecological perspective, Antarctic soils constitute a harsh environment and their biotas are depauperate compared to those from more benign areas. In this context it is perhaps surprising that there are so many, rather than so few, inhabitants.

Janetschek (1963, 1967) identified two separate terrestrial ecosystems in continental Antarctica. The chalikosystem occurs where there is bare ground and consists of the soil and its contained organisms. Autotrophic bacteria and unicellular algae form the base of a food web that eventually leads to predators, either directly through grazers (e.g. some mites and some tardigrades), or more circuitously via organic detritus to heterotrophic bacteria and microfungi, in turn consumed by microbivorous invertebrates such as protozoans, rotifers and some nematodes. Top predators are some mites and at least one species of tardigrade. Nitrogen is fixed by some bacteria, especially the cyanobacteria.

The bryosystem is characterised by visible vegetation (chiefly mosses and lichens, but sometimes including a fleshy alga, *Prasiola crispa*) and its contained biota of micro-organisms and metazoans. The heterotrophic participants encompass the same taxa as occur in the chalikosystem – for example, bacteria, microfungi, protozoans, rotifers, tardigrades and nematodes.

To Janetschek's two systems a third can be added, the lithic system (Vincent 1988). It consists of those microalgae, cyanobacteria, fungi and heterotrophic bacteria living directly on exposed rock, or under or in translucent rock crystals.

The present report deals with a range of mineral and organic soils and examines changes occurring during weathering of bedrock and concomitant occupancy of the soil by organisms to form a dynamic soil ecosystem. It is a first step towards answering the question: How do physico-chemical and biotic factors interact in influencing the community structure of these soils?

2. Study areas

The Prince Charles Mountains consist of a series of nunataks and massifs rising above the ice sheet bordering the western edge of the Lambert Glacier, 300 km inland from Mawson station. Within the mountains, soil samples were collected at 12 localities of diverse elevations, topographies and soil types (Figures 1–3). Most of the region is devoid of vegetation although some sites have sparsely distributed lichens, and in some cases, mosses. The areas with the most bryophyte and lichen cover, and the mildest climate, are Jetty Peninsula and Else Platform. Miller and Heatwole (1996a) reported upon the tardigrade fauna inhabiting the mosses and lichens of the Prince Charles Mountains.

The majority of the soils considered in this paper directly overlie Precambrian crystalline basement rocks of the extensive East Antarctic Shield. In the region of present interest, this basement comprises repeatedly deformed granulites, gneisses and migmatites, variously intruded by charnockites, granites, pegmatites and mafic dykes (e.g. Tingey 1982; Sheraton 1982; Sheraton and Black 1983, 1988; James and Tingey 1983; Clarke 1988; Fitzsimons and Thost 1992). In contrast, two of the sample sites, Jetty Peninsula and Pagodroma Gorge, are located in the Beaver Lake graben, an area of downfaulted Permian to Early Triassic strata known as the Amery Group. These strata consist mainly of arkosic sandstones and subordinate conglomerates, siltstones, shales and coal seams (Mond 1972; McKelvey and Stephenson 1990). In places, the Precambrian basement and the Amery Group are overlain by Cenozoic Pagodroma Tillite (McKelvey and Stephenson 1990) or younger glacigene deposits. Additional description of the study areas is contained in the Appendix.

3. Materials and methods

3.1 LOGISTICS

The field work was conducted during the 1989 –1990 austral summer program of the Australian National Antarctic Research Expeditions (ANARE), of which two of the authors (H.H. and N.C.N.S.) were field expeditioners. The study took place in the Prince Charles Mountains with supplementary sampling at several locations near the coast of East Antarctica, including the permanent Australian station, Mawson, and its environs, and the Vestfold Hills near Davis station (Figure 1).

During the winter before field work was undertaken, a forward base (Dovers; lat. 70° 14' S, long. 65° 51' E) was set up using Hagglunds tracked vehicles. During the 1989 – 90 summer, scientists working on a variety of projects dispersed from this base by helicopter in groups of two, throughout the Prince Charles Mountains, where they camped in tents and were supplied and moved as required by helicopter. As part of a wider study of the structure of Antarctic biotic communities (Heatwole 1983), the senior author collected large numbers of soil samples for extraction of organisms and for measuring physico-chemical characteristics. He also took the opportunity to collect corresponding samples of parent rock.

3.2 SOIL SAMPLING

At each of 48 sampling sites (12 localities) in the Prince Charles Mountains, and at each of 16 sites at five coastal localities in East Antarctica, 1 – 20 replicate soil cores for biological analysis were taken with sterile screw-cap tubes (14 mm in diameter) and capped. A total of 559 cores were taken; 418 in mountains and 141 in coastal areas.

The depth of sampling varied, depending on soil depth and presence or absence of barriers to coring, but most cores were between 3 and 10 centimetres in length. A single tube of soil was also collected at each sampling site and sealed for later measurement of moisture content. Finally, at some sites and using a trowel, about 100 cm^3 of soil for analysis of physical and chemical properties was placed in either a glass jar or a plastic bag.

All samples were frozen in nearby snow or ice. These samples were transported by helicopter to Dovers and/or Mawson and kept frozen there. During transport to Australia they were stored in the ship's freezer. Replicates were sent by refrigerated truck to the various universities where they were stored in laboratory freezers until analysed.

The present paper treats the soil biota only at the level of high taxonomic categories. Detailed analysis at the species level will appear in a later series of publications, pending completion of specific identifications.

A detailed description of the sampling sites appears in the Appendix.

3.3 MAJOR-ELEMENT GEOCHEMISTRY OF BEDROCK AND SOIL

Samples of some of the common bedrock types of the Prince Charles Mountains and in the vicinity of Mawson station were collected and identified. Four types from the Prince Charles Mountains were subjected to detailed treatment and their chemical compositions were compared with those of associated soils. The four types selected were: (1) granitic gneiss and (2) amphibolite from Blustery Cliffs (samples B1 and B4 respectively), (3) quartz sandstone from Jetty Peninsula (J1), and (4) garnet pegmatite from Mt Woinarski (W3). Coarse (>2 mm) and fine (<2 mm) soil fractions were analysed separately on the assumption that any chemical modification is likely to be more evident in the finer fraction. The analyses were performed using conventional X-ray fluorescence methods for silicate rock analysis (e.g. Norrish and Chappell 1967) using fused beads. Corrections were made for matrix effects and calibrations were based on a wide range of international standards.

3.4 PHYSICAL ANALYSIS OF SOIL

Original aggregate samples were air-dried prior to dry-sieve analysis from 19.05 mm to 2.00 mm. Subsamples of the <2.00 mm fractions were used for analysis of particle size and subsamples of the clay suspensions were retained for X-ray diffraction (XRD) to determine mineralogy.

3.4.1 Water content

Samples of frozen soil were weighed and then thawed and dried to constant weight at 105°C and the soil water content calculated gravimetrically. Moisture content was also expressed as per cent by volume.

3.4.2 Soil particle-size

Samples of 10 g of thawed, air-dried soil (particle-size <2.00 mm) were ultrasonically dispersed for 6 minutes in 50 ML of a solution containing 20.45 g of sodium hexametaphosphate and 4.55 g of sodium carbonate per litre. The resulting suspensions were transferred to one-litre measuring cylinders and made up to volume with distilled water in a constant-temperature room at 23°C. The contents were stirred and at specified settling times, subsamples were withdrawn by pipette and the suspended solids determined by gravimetry to estimate clay and silt fractions. Coarse and fine sand were determined by washing, drying and dry-sieving the remaining sediment. Particle-size distribution of the soils was classified using the United States Department of Agriculture Texture Triangle (Brady 1974). The following designations of particle-size were used: coarse sand 0.2 – 2.0 mm; fine sand 20 – 200 μm; silt 2 – 20 μm; clay <2 μm.

3.4.3 Clay mineralogy

XRD analysis was carried out according to the methods of Thorez (1975, 1976) and Brindley and Brown (1980). Subsamples of suspended clay were retained and centrifuged to concentrate the clay prior to saturation with 0.5 M $MgCl_2$. These were washed free of chloride with 75% ethanol and applied to glass tiles. The specimens were dried and then solvated with ethylene glycol at 80°C for 4 hours, after which they were cooled to 25°C in a saturated atmosphere of ethylene glycol prior to XRD analysis using Co Ka radiation. The tiles were heated to 340°C overnight and allowed to cool in a desiccated atmosphere for further XRD analysis. The tiles were then heated to 550°C overnight and allowed to cool in a desiccated atmosphere for final XRD analysis.

The analysis was predominantly qualitative. Mineral concentrations were estimated from measurements of relative heights of major peaks in the preferentially oriented samples on the initial treatment, rounded to the nearest 5%, and verified from other treatments. Absolute values may vary slightly due to minor changes in crystallinity, orientation and specific mass absorption coefficients of the various minerals but relative trends are more consistent. Effort was made to prepare and measure samples under identical conditions to minimise such variations.

3.5 CHEMICAL ANALYSIS OF SOIL

Soil samples were thawed and air-dried at room temperature and dry-sieved to <2.00 mm. Subsamples of the <2.00 mm fraction were then dried for 16 hours at 105°C and the loss in weight determined. In all subsequent analyses, samples of air-dried material equivalent to the desired oven-dried weight were taken. Organic carbon was estimated by the loss of weight caused by ignition in a muffle furnace. pH was determined in 1:5 soil:water or soil:1 M KCl filtered extracts using a standard glass electrode assembly. Mixtures were shaken for 1 hour. Conductivity of the 1:5 soil:water filtered extracts was measured with a Radiometer CDM 83, all samples being brought to 25°C with a thermostat. Water-soluble phosphate was measured in 1:5 soil:water extracts using the modified Murphy and Riley procedure of Watanabe and Olsen (1965). Water-soluble potassium was measured in 1:5 soil:water extracts using flame photometry with lithium at 100 mg mL^{-1} in the aspirated, diluted samples. Exchangeable potassium was extracted with 1.0 M ammonium acetate at pH 7.0. Extract concentrations were then determined as before with a flame photometer. Dilute acid-extractable phosphate was determined by the HCl-H_2SO_4 procedure of Nelson et al. (1953), with colorimetric measurement by the Watanabe and Olsen (1965) method. Ammonium and nitrate nitrogen were extracted using 2 M KCl and then determined by the distillation procedure of Bremner and Keeney (1966). Total nitrogen was measured using the digestion and distillation procedures of Bremner (1965). The salicylic acid-thiosulphate modification of the semi-micro Kjeldahl procedure was applied to all samples in order to include any nitrate present.

Soil characteristics were individually analysed with StatView II software for correlation with each other and for their relation to elevation, employing the Spearman Rank Correlation test with a correction for tied values.

3.6 SOIL BIOTA

When multiple samples were taken, the seventh was reserved for extraction of protozoans and the others used for extraction of rotifers, tardigrades, and nematodes.

Protozoa were extracted using different methods for different taxa. For naked amoebae, small amounts of soil were added to wells cut in non-nutrient agar plates spread with *Escherichia coli* and replicates incubated at 20°C to 30°C and examined 5 – 14 days later. For ciliates, samples of 2 – 4 g of soil were rehydrated (not flooded) with distilled water and two cracked rice grains added to each culture. They were examined daily for three weeks and ciliates were harvested by micropipette, fixed and stained by protargol silver impregnation (cf. Foissner 1991). Flagellates were harvested from cultures and examined live in hanging drop preparations prior to fixation for electron microscopic examination.

For extraction of metazoans, frozen soil samples were defrosted at 1°C for 24 hours, then chilled water (about 5°C) was added to each vial and left for half an hour. Next, the sample was transferred to a 600 mL beaker, which was then filled with water while being stirred vigorously. Twelve seconds were allowed for soil particles to settle. The water was then decanted through two sieves of 1680 and 30 µm mesh aperture. After the initial extraction, the processes of adding water, stirring, decanting, and sieving were repeated twice and the specimens from the three extractions pooled for each sample. The contents of the 30 µm sieve were washed into a tall glass tube and left to settle for two hours or more. The supernatant was removed and the remaining extract transferred to a counting dish. Tardigrades were killed with boiling water and then fixed in 4% formalin. Nematodes were killed and fixed in hot FA 4:1. Rotifers were sent alive to Dr Russell Shiel, who videotaped them under a microscope for later identification.

For a few samples with high organic content (soil from a dog run at Mawson station), the technique was altered slightly. The supernatant was filtered through filter paper under suction by use of a Buchner funnel, and the residue was preserved in 5% buffered formalin and later examined for metazoans under a compound microscope.

Association among different invertebrate taxa was assessed by Chi-square analyses that compared the observed joint occurrences of each pair of taxa with their expected joint occurrences based on random association. When Chi-square values equalled or exceeded 3.841 the result was significant at the 95% confidence level. Significant values in which two taxa have a greater number of observed joint occurrences than expected indicate a positive association, whereas significantly fewer joint occurrences than expected suggest a negative or exclusionary relationship. When the expected number of joint occurrences was fewer than five, the sample was considered too small for adequate statistical testing.

In the present paper only the higher taxonomic categories of the invertebrate fauna are treated. Identification of the specimens is in progress and detailed taxonomic treatment and ecological studies at the specific level will appear in a later series of papers.

4. Results and Discussion

4.1 CHARACTERISTICS OF BEDROCK AND SOILS

The gravelly soils described here are associated with landforms and weathering and erosion processes typical of glacial and periglacial climates. Weathering is predominantly physical, with frost the major apparent factor. Thus, many flat and gently sloping surfaces are covered with a felsenmeer of locally derived rock fragments, and steeper slopes are commonly scree-covered. Rock debris and bedrock outcrops generally show little or no chemical weathering; surface discolouration is typically either absent or mild and confined to a veneer <2 mm thick. Even in the local deposits of gravelly soil described here, the coarser fragments (>2 mm) are only slightly friable and moderately discoloured, suggesting that they have experienced minimal chemical decomposition.

The identities of the bedrocks and their constituent minerals at the sample sites, where known, are listed in Table 1. In the Prince Charles Mountains, the most common bedrocks are granitic gneiss and pegmatite, both comprising quartz, plagioclase, K-feldspar and smaller amounts of either garnet or biotite, or both. Amphibolite (composed mainly of plagioclase and hornblende) and ultramafic granulite (mainly pyroxene) form the bedrock at only one site each. At all sites in the vicinity of Mawson, the bedrock is charnockite, comprising quartz, plagioclase, K-feldspar, pyroxene and biotite. In marked contrast, the soils of Jetty Peninsula and Pagodroma Gorge are underlain by clay-cemented, quartz-rich arkosic sandstones.

The sampled soils typically contain 20 – 80% gravel comprising fragments of the underlying bedrock only; foreign fragments are not visible. The soils are therefore interpreted as the products of predominantly *in situ* weathering, although some preferential removal or redistribution of the finer material by wind or meltwater may have occurred.

Geochemical comparisons between the soils and their parent bedrocks (Table 2) suggest that chemical differences are generally small (indeed largely within the probable limits of sampling precision), and that the fine soil fractions show few consistent differences from the corresponding coarse fractions. The only consistent trends are that the soils, especially the fine fractions, show (1) slightly increased oxidation of Fe (i.e. increased Fe_2O_3/FeO ratios), and (2) slightly higher H_2O contents relative to the parent bedrock samples. For the crystalline basement rocks (B1, B4, W3), there is no evidence of consistent preferential concentration or depletion of any major elements during weathering. There is, however, a large compositional contrast shown by the fine soil fraction compared with the parent bedrock and the coarse soil fraction for Jetty Peninsula, location J1.

Particle-size analyses (Tables 3 and 4) demonstrate that pedogenesis is at an early stage and suggest that weathering is very slow. Of the 52 samples analysed, 48 contain more than 20% gravel and 11 contain more than 50%. The clay fraction exceeds 5% of the <2 mm portions in only 14 samples, and it exceeds 20% in only two samples. Quartz was detected in the clay-sized fraction in only 11 samples, ranging from trace to 5% (Table 5), even though this mineral is a major component of most of the parent rocks. It is concluded, therefore, that soil formation in the Prince Charles Mountains and coastal East Antarctica is occurring very slowly, predominantly by physical, rather than by chemical, weathering. The mineralogical analyses of the clay component reveal strong correlation between samples within individual sampling regions (Table 5). In general, kaolinite is predominant in groups E, J and P, illite in groups B, LV, O, Q, R, S and W, montmorillonite in groups C, I, M, PH, U and X and vermiculite in F. Exceptions include W2 (chlorite dominant and kaolinite subdominant), W5 (vermiculite dominant; illite subdominant), M5 (vermiculite dominant; montmorillonite subdominant), M8 (illite dominant; chlorite subdominant), C2 (illite dominant; montmorillonite subdominant) and B4 (chlorite dominant; kaolinite subdominant). It should be noted, however, that sample W2 has parent rock of granite and chlorite compared with W1 and W3 where parent rocks are garnet pegmatite.

Thirty-nine of the samples contain interlayer material from trace level up to 35%. Sepiolite was detected in 26 samples, ranging from trace to 15%.

It is difficult to ascertain whether these very small clay fractions are the product of incipient chemical weathering, were transported by wind, or were derived directly from the parent rock during physical disintegration.

The soils developed on sandstone (i.e. J and P series samples) generally have slightly larger clay fractions (composed predominantly of kaolinite; see Table 5) than those on crystalline basement. Possible interpretations are that this might be the result of (1) more intense chemical weathering compared with other localities, or (2) physical disaggregation of the kaolinite-rich cement of the parent sandstone, or (3) local concentration of the clay fraction by the action of meltwater.

The possibility of faster chemical weathering at the Jetty Peninsula (J) and Pagodroma Gorge (P) sites is perhaps feasible in view of their location close to sea level, which results in a slightly less frigid climate and the presence of meltwater for longer periods, compared with locations at higher elevations in the Prince Charles Mountains. However, most of the other samples from sites close to sea level (Else Platform, Mawson, Field Rock) have clay fractions only slightly, if at all, larger than those from sites at elevations of 1000 – 2000 m. Therefore, there is no compelling evidence in the particle size data to suggest that climatic differences related to elevation have significantly affected chemical weathering rates. Instead, it is more likely that the higher clay content of soils of the sandstone-derived J and P series reflects the make-up of the parent rock.

The fine soil fraction of sample J1 from Jetty Peninsula is markedly enriched in Al_2O_3 and depleted in SiO_2 relative to the coarse fraction and the parent bedrock (Table 2), and this presumably reflects relative enrichment of kaolinite in the fine soil fraction.

The parent sandstone consists of 0.5 – 2 mm grains of quartz (80 – 90%), feldspar (5 –10%) and muscovite (<1%), and a fine-grained matrix or cement (5 - 10%) composed mainly of kaolinite and quartz. The large enrichment in Al_2O_3 in the fine soil fraction cannot be solely the result of *in situ* kaolinization of the small amount of feldspar in the parent rock. It could, however, be largely the result of an approximate two-fold physical concentration of kaolinite liberated by disintegration of the parent rock, during which the fine-grained kaolinite-rich matrix might be expected to make a disproportionately larger contribution to the fine (<2 mm) soil fraction, relative to coarser quartz and feldspar. The coarser (>2 mm) soil fraction is correspondingly slightly depleted in kaolinite and Al_2O_3 (see Table 2) relative to the parent rock. Meltwater seepage may well be responsible for further local concentration of clay-size material (e.g. sample P7) and complementary depletion elsewhere (e.g. P6). It is therefore concluded that the larger kaolinite-rich clay fractions in the samples of the J and P series probably do not indicate significantly faster chemical weathering at the Jetty Peninsula and Pagodroma Gorge sites.

Among the soils developed on crystalline basement rocks, two samples (Q2 and M8) have anomalously large clay fractions (Table 4). Sample Q2 was collected from a local basin with no drainage outlet (see site description of Mt Jacklyn in the Appendix) (Figure 3d). Therefore, its larger clay fraction is possibly the result of local concentration of finer particles carried by inflowing meltwater, and is not an indication of more intense chemical weathering. Interpretation of the larger-than-usual clay fraction in M8 is more difficult. This soil was waterlogged at the time of sampling (see site description), which suggests either concentration of finer particles by meltwater seepage or enhanced chemical weathering.

Most of the soils are relatively dry (Table 6); 10 samples (23%) have water contents of less than 1% dry weight, 24 (55%) have water contents between 1% and 5%, three (7%) are in the range of 5 – 10% moisture content, and seven (16%) have moisture contents greater than 10% dry weight; the highest value is 34.3%. In some localities this water would not all be accessible to living organisms because it occurs as ice even near midday.

The analyses chosen to indicate general nutrient status of the soils are those that emphasise the degree to which organic accumulation has proceeded, and the relative availability of several critical macronutrients. Because field sampling encompassed a wide range of macro- and micro-habitats, and sites with and without input from man and other animals, the data (Table 7) allow some separation of the likely contributions of purely physical and chemical factors in the development of nutrient capital during pedogenesis. Accordingly, when possible, this separation between inorganic and organic contributions to the nutrient pool is highlighted.

Loss on ignition (LOI) would be expected to give a reasonable indication of the amount of organic matter but bear a much weaker relationship with the amount of clay present. In broad terms, this is shown by the data; those few samples most influenced by human activity (M6, M8) stand out, whilst for most of the remainder a closer relationship is apparent between clay content (see Table 3) and LOI. This holds at least within the range of 0 - 4% LOI and 0 - 10% clay (Figure 4).

Concentrations of total nitrogen are very weakly related to LOI within the range of 0 - 0.4% N and 0 - 4% LOI. Included in this grouping are samples from sites affected by animals or with lichens present, but they do not separate from those soils collected where these influences were not evident. Otherwise, samples with higher nitrogen concentrations all derive from samples from Mawson or Pagodroma Gorge. Included in these are soils ranging in N content from 0.06 to 1.18%.

Nitrogen present as NH_4^+- N ranges from 1800 $\mu g.g^{-1}$ to <0.1 $\mu g.g^{-1}$, with a distinct association between high values and bird or human influences. Overall, however, there is no clear relationship between NH_4^+- N and the total N pool, and all that can be said is that most of those soils obviously affected by humans or birds contain moderate concentrations of ammonium ion in association with the higher values of total N. However, there are notable exceptions, such as M1, E3 and W5, which have similar, moderate concentrations of NH_4^+- N despite greatly different total N contents. All those samples with NH_4^+- N below such moderate values (<9 $\mu g.g^{-1}$) have total N concentrations of <760 $\mu g.g^{-1}$.

NO_3^-- N presents a superficially similar picture to that for NH_4^+- N in that some samples affected by humans and birds (M6, M6t, P1) have moderately high NO_3^-- N concentrations. There are, however, similarly affected soils (M1, M2, M7, M8, P4) with low concentrations, and there is another group of samples (F1, P5, P7, Q2, W1, W2, W3, W5) with moderate to very high concentrations of nitrate for which there is no evidence of human or bird influence. This latter group stands out from all others in having high NO_3^-- N and low total N concentrations as well as NH_4^+- N concentrations less than 6 $\mu g.g^{-1}$.

pH readings in water range from strongly alkaline (8.76) to strongly acid (4.23) with most between 5.0 and 7.5. Exchange acidity, taken as the difference between pH measured in water and in KCl, is moderate in most samples, but this does not appear to relate either to organic matter (LOI) or to clay content. There is a tendency, however, for some soils from the Mawson and Pagodroma Gorge collections (M6, M6t, P1, P5, P8), and others from sites with seepages (P7, Q2), to have higher pH values (6 – 9 range) in association with high NO_3^-- N concentrations. Contrasting with these samples is a small group of soils (C1, W1, W2, W3, W5) in which high acidity (pH 4.23 – 5.14) is associated with high NO_3^-- N (52.0 – 220 $\mu g.g^{-1}$). Members of this latter group derive from upper plateau or ridge sites at Corry Massif or Mt Woinarski. The separation of the various soil groups is shown in figure 5.

Conductivities of 1:5 soil:water extracts are generally low, with eight samples above 200 $\mu S.cm^{-1}$ and only four of those above 1000 $\mu S.cm^{-1}$. For 34 of the 46 soils analysed, conductivities were less than 100 $\mu S.cm^{-1}$. Those with the highest values were collected from sites where the influence of birds was obvious (P1), from seepage accumulation points (P7, Q2), or from localities at high elevations (C2, F1, W1, W2, W3). No useful relationship is evident when either pH (water) or NO_3^-- N is plotted against conductivity.

Water soluble phosphate concentrations of the 46 soils range from 0.01 to 14.9 $\mu g.mL^{-1}$. However, the great majority (43) fall below 0.1 $\mu g.mL^{-1}$ and 18 of these are 0.05 or less. The three samples greater than 1.0 (M6, M8, P1) represent sites influenced by humans, dogs, or birds, with the highest concentration (P1, 14.9 $\mu g.mL^{-1}$) coming from material collected below the remains of a snow petrel.

Dilute acid-soluble phosphate, which supposedly gives a measure of all exchangeable plus more labile Fe and Al phosphates, also varies widely among samples, ranging from 7 to 344 $\mu g.g^{-1}$ (W2 to P1). Between these extremes there is a cluster of the Mawson and P1 and P4 samples towards the higher end. However, there is a considerable overlap of these soils with uncontaminated ones in the range of 100 – 140 $\mu g.g^{-1}$. When water-soluble and acid-soluble phosphate values are plotted against each other (Figure 6), the previously stated separations are clear. In particular, the plot shows that for those soils unaffected by humans or other animals there is no useful relationship between the separate measures of the more labile phosphorus fractions.

Water-soluble and exchangeable K measurements both display great variability, the former ranging from 2.7 to 527 $\mu g.g^{-1}$ and the latter from 0.06 to 2.24 $cmol.kg^{-1}$. Neither of these characteristics shows any clear relationship to conductivity. However, the data do indicate that the higher values of water-soluble K are associated, in the main, with bird and human influences, or with sites where seepage collection of salts was apparent or might be expected.

There are few general interrelationships amongst the soil chemical analyses noted above, but the data set as a whole has reasonable internal consistency in that the variability evident can be explained in most instances by reference to specific attributes of the sample sites and the influences of birds and humans (see descriptions of individual sampling sites).

The Mawson and Pagodroma soils are most notable in this regard since they include the majority of the higher values for LOI, total N, NH_4^+- N and water-soluble P, and demonstrate how relatively marked such influences can be when the general context is one of low background concentrations.

Figure 4 shows how additions of organic matter have raised a number of samples above the general trend represented by the cluster of points within the range of 0 – 4% LOI and 0 – 10% clay. P2, P3 and P5 extend the common trend for uncontaminated samples, but P1 and P4, and to a lesser extent P7, fall below, even though they come from sites influenced by snow petrels and have moderate clay contents.

Total N concentrations in the soils are very low except in four samples from Mawson station and one from Pagodroma Gorge. These man- and bird-influenced soils have concentrations that could sustain appreciable plant production were microclimatic conditions favourable. For the remainder of the set, however, the quantities are low and would compare unfavourably even with the poorest soils from hot deserts. Even so, in the context of Antarctic conditions the pool of potentially available N represented by the lower concentrations (about 100 – 300 $\mu g.g^{-1}$) should be sufficient to allow development of appreciable biomass if the organic N were mineralised to NH_4^+- N and NO_3^-- N. Assuming only 100 $\mu g.g^{-1}$ total N and a bulk density of 1.5 $g.cc^{-1}$ in a slice of soil 1 m x 1 m and 0.1 m deep, the total quantitiy of N contained (15 g) is, for the growth conditions operative, a sizeable reservoir. The higher concentrations of NH_4^+- N are associated with the higher total N values, but it is unlikely that this inorganic N was produced by microbial mineralisation following addition of organic N to the soils. For the majority of the soils, those with less than 9 $\mu g.g^{-1}$, it is more likely that the NH_4^+- N came from atmospheric additions. It is possible, too, that some may have been extracted by Kjeldahl digestion from fixed ammonium sources. In this respect, Greenfield (1991) has shown that some rocks and soils from Antarctica contain substantial quantities of fixed ammonium.

As noted already, NO_3^-- N concentrations range from high to very low. However, they are not related in a consistent manner to total N, nor to those inputs from humans and other animals that appear so influential in the cases of total N and total P. What is clear, however, is that the samples can be partitioned into three reasonably distinct sets according to their pH versus NO_3^-- N relationships (Figure 5). When shown in this way, the data separate into a group with high NO_3^-- N and low pH, another with moderate NO_3^-- N and relatively high pH, and a large group in which NO_3^-- N concentrations are all quite low and pH ranges from strongly acid to moderately alkaline. Most interesting amongst these is the group of Mt Woinarski soils together with one of the Corry Massif samples. In these, total N is comprised almost entirely of NO_3^-- N, so it cannot be argued that the mineral N was derived in the past from organic N by way of microbial mineralisation. Rather, because of the remoteness and high elevation of the sample sites, it seems more reasonable to attribute the NO_3^-- N accumulation to concentration of atmospheric accessions by sublimation of snow, as suggested by Claridge and Campbell (1968). The single Mt Woinarski sample that is not included in the group (W4) was collected from an outwash plain at lower elevation and its low NO_3^-- N status and higher pH are consistent with the characteristics of its site. Similarly, the C1 sample was collected on the upper plateau of Corry Massif and appears consistent in relation to the hypothesis. Other samples from undisturbed sites which have moderate NO_3^-- N are Q2 and F1. Both are alkaline, the former coming from a basin where salts had accumulated (see conductivity), and the latter from the upper plateau of Mt Forecast where some salts also had accumulated. The high NO_3^-- N of P7 can also be explained by reference to the nature of the collection site since the area is one where seepage accumulation of salts is evident and acidity from nitrate would be readily neutralised.

The other soil characteristic that requires further comment on its potential for influencing organisms is P. It has been noted already that humans, dogs and birds have been instrumental in raising the P status of some soils by large amounts, thereby increasing water-soluble P to concentrations that are more than adequate to meet any biological demand that could reasonably be expected (but note that P4 is anomalous in this regard). It is worth commenting, however, that in the majority of the low-concentration samples shown in Figure 6, the actual concentrations are quite sufficient for reasonable autotrophic production when viewed in the context of many unamended soils from temperate areas, and certainly in relation to the kinds of soluble reactive phosphate concentrations found in seawater.

Thirty of the 46 soils analysed had water-soluble P concentrations $<0.12\ \mu g.mL^{-1}$ together with dilute acid-soluble P of $<150\ \mu g.g^{-1}$ (Figure 6). If these are taken to be representative of soils unaffected by biological input, they suggest that Antarctic soils generally may be capable of providing adequate phosphate for life. Given the total P analyses for rocks and soils shown in Table 2, and provided there has been some degree of chemical weathering, it is likely that soluble reactive phosphate in liquid water would not be limiting for biological production.

This conclusion contrasts with that of Parker et al. (1982), who found that no free phosphate could be detected in any of the soils they collected from the Pensacola Mountains, West Antarctica. On the other hand, the data of Weand et al. (1977) for meltwater entering Lake Bonney, southern Victoria Land, show that orthophosphate concentrations ranged from $<1.0\ \mu g.L^{-1}$ to $>250\ \mu g.L^{-1}$ over a period of one week, with the highest concentrations occurring during the early flow period. These results imply that without flushing of available soil moisture, soluble P concentrations in equilibrium with their solid phase P reservoir may typically be similar to those obtained by us from a short-term soil:water equilibration.

4.2 FAUNA

No testate amoebae were recovered from any of the samples. Naked amoebae were recovered from all the localities studied in coastal East Antarctica, including a relatively high proportion of the individual samples from that area, on average 79% (Table 8). By contrast, only four of the 11 localities tested in the Prince Charles Mountains yielded this group and even at the positive sites the proportion of samples with amoebae was always low, 50% or less. Most of the positive samples in the Prince Charles Mountains were from low elevations. At the highest locality at which amoebae were found (Moore Pyramid, 1615 m) soils were frozen most of the day (see Appendix). The positive sample was from a slope facing in a north-easterly direction, and where the soil had thawed deeper than a few centimetres by late afternoon.

No ciliates or flagellates were found in any of the soil samples from the Prince Charles Mountains. However, ciliates were found in more than half of the soil samples from Mawson station and its vicinity and from the Vestfold Hills (Table 8). Only one sample contained flagellates; it was M6 from Mawson with a colonial flagellate.

Of the 12 localities in the Prince Charles Mountains from which samples were available for extraction of metazoans, seven (58%) yielded rotifers, six (50%) yielded tardigrades and six yielded nematodes; tardigrades and nematodes were both found at four localities (33%) and rotifers and nematodes at two (17%). All three taxa occurred at one (8%) locality.

Within a locality there was variation in the metazoans yielded by individual sampling sites. At eight of the 48 individual sampling sites (17%) rotifers and tardigrades occurred together, sometimes in the same replicate (see section on association below). At six sites (13%) both tardigrades and nematodes were present. Both rotifers and nematodes occurred jointly at two sites (4%). At only one site (2%) were all three taxa represented.

There was also variation among replicate samples at the same sampling site. Tardigrades and nematodes occurred in about the same proportion of the individual samples (16 and 17% respectively) and occupied about twice as many samples as rotifers (8%) (Table 9). Only 22 individual cores (6%) contained both tardigrades and rotifers, one (0.2%) contained both rotifers and nematodes, 18 (5%) contained tardigrades with nematodes, and no individual core contained all three taxa together.

The coastal areas were quite different, with all three metazoan taxa being much more common than in the inland region. All were found at all four localities (Table 9); rotifers occurred at 12 (80%) of the 15 sampling sites, tardigrades at 13 (87%) and nematodes at eight (53%).

At Mawson station and Field Rock, the localities closest to the sea, rotifers were present, on average, in about two-thirds (64 - 69%) of the replicates and tardigrades in about three-fourths (70 - 77%). Nematodes were somewhat less common (27 - 62% of the replicates), but still much more common than inland. Two, or even all three, of the major taxa were frequently found in a single sample. Forty-nine (62%) of the 79 samples from Mawson and Field Rock contained both rotifers and tardigrades, 22 (28%) contained tardigrades and nematodes together, and 18 (23%) had rotifers and nematodes. Included in the above statistics were 17 samples (22%) that had all three taxa together.

Moving even a short distance inland resulted in a decline in number of samples containing metazoans as exemplified by Rumdoodle and the Vestfold Hills, both of which had relatively few samples containing rotifers and tardigrades; also Rumdoodle had low numbers of nematodes, and in fact was poorer in metazoans than some of the localities in the Prince Charles Mountains. Rumdoodle protrudes above and is surrounded by the ice cap and lies at a higher elevation than do the coastal 'oases' of Mawson station, Field Rock and the Vestfold Hills. In these features it resembles many of the localities in the Prince Charles Mountains. Consequently, it is not surprising that Rumdoodle faunistically resembled the Prince Charles Mountains more than it did the coastal localities geographically closer to it.

Not only did taxa become less common inland, but the ratios of their relative occurrences changed. In the Prince Charles Mountains, nematodes had the highest percentage occurrence (17% of samples), followed by tardigrades (16%) and finally rotifers (8%). In coastal East Antarctica this ratio changed, with nematodes occurring least frequently (31%), tardigrades most often (50%), and rotifers intermediate (46%).

In an attempt to gain insight into factors potentially influencing occurrence of animals in samples, the moisture contents of those soil samples for which such data were available were plotted against the elevation of the locality from which the sample came, distinguishing between samples yielding animals of a particular taxon and those that did not (Figure 7). It is clear that all three taxa of metazoans occurred over a wide range of elevations, being consistently absent only from samples taken above about 1700 m. Rotifers and tardigrades spanned the entire range of soil moistures, and nematodes were missing only from samples at the extreme upper (water-logged) end of the spectrum, and that may have been by chance. Within the span occupied, there were no obvious elevational changes in frequency of occurrence for either tardigrades or rotifers; by contrast, nematodes tended to occur with greater frequency in samples from the lower elevations (clustering of dots in the lower portion of the lower graph in Figure 7).

Amoebae occurred in soils over the entire span of moisture conditions encountered, and ranged from sea level to over 1600 m (Figure 8). They were thus a more eurytopic group than the ciliates, which occurred only at low elevations and were absent from the wettest soils.

Discernment of the reason why some taxa were more common in lowland coastal localities than they were at higher elevations further inland is confounded by the number of environmental variables correlated with elevation. Seven of the soil characteristics shown in Table 7 were negatively correlated with elevation (Table 10). Thus, with increasing altitude, soils tended to be drier and more acidic and have less organic matter, soluble phosphorus and total nitrogen. These characteristics related to such vital biological needs as availability of water and nutrients and could affect, either singly or in combination, the suitability of soils for occupancy by protozoans and/or micrometazoans. The other soil attributes (conductivity, exchangeable K, water-soluble K, nitrates and ammonium-N) showed no significant correlation with elevation (P values 0.18 - 0.97).

A further problem is that many of the altitudinally related attributes showed correlation among themselves. All seven of those that showed a significant correlation with elevation (Table 10) were tested for correlation with each other. Of the 21 possible combinations, nine showed significant correlations. Some of these were merely different measures of similar phenomena: for example water-soluble P versus acid-soluble P ($P = 0.0052$), pH H_20 versus pH KCl ($P = 0.0001$). Other correlations reflect the importance of water in biological processes. Soil moisture was positively correlated with three features relating to the potential nutrition of the microfauna (organic matter, $P = 0.0005$; soluble phosphorus, $P = 0.0021$; total nitrogen, $P = 0.0014$) as well as to both measures of pH (H_2O, $P = 0.0048$; KCl, $P = 0.0194$). Finally, soluble phosphorus and total nitrogen ($P = 0.0074$) and amount of organic matter and total nitrogen were related ($P = 0.0001$), as would be expected. The remaining 11 pairs of attributes showed no significant correlations ($P = 0.09$ - 0.86).

Plots of the relationship of paired soil characteristics, separately by presence or absence of the metazoan groups, were prepared as a means of assessing the range of conditions suitable for a particular group (Figures 9 - 12). Data matching particular sampling sites with extraction of protozoans were too few for such an analysis.

Rotifers occurred in soils with a wide span of pH but were present only in those with relatively low organic content (Figure 9). Nematodes were just the opposite, occurring in soils over the entire range of organic matter content, but primarily in samples with high pH. Tardigrades were eurytopic in regard to both characteristics and occupied samples throughout the ranges of organic content and pH encountered.

Rotifers were not found in soils at the higher end of the range of nitrate-N occurring in the samples, but otherwise all metazoans were found in samples covering most of the range of both ammonium-N and nitrate-N (Figure10). Metazoans occurred over most of the range of exchangeable K and water-soluble P encountered in the samples, although rotifers, and perhaps nematodes, may have tended to cluster away from the very highest values (Figure 11). All three taxa occurred throughout the range of conductivities sampled, and over a wide range of total N (Figure 12).

Although content of organic matter, water-soluble P and total N correlated with elevation (Table 10), the former factors did not seem to restrict the distributions of metazoans within the ranges sampled, and consequently would not seem to be responsible for the observed elevational differences in metazoan occurrences. By contrast, the tendency for lower pH at the higher elevations could be a factor in the decrease of nematodes with elevation, but would not account for the similar reduction in occurrences of rotifers since the latter taxon seems to be favoured by low pH.

In summary, (1) tardigrades occurred throughout the range of almost all variables tested and therefore would not seem to be restricted by any naturally occurring levels, (2) rotifers may tend to be absent from alkaline soils and those with the highest levels of organic matter and nutrients, and (3) nematodes may be favoured by alkaline soils. These statements are based on presence/absence of taxa in samples over a spectrum of attributes, and are subject to sampling errors and synergistic effects. They should not be considered as conclusions, but rather as hypotheses for further testing.

In the analysis of biotic association, not all taxon-pairs met the minimum requirement of five expected joint occurrences, yet several patterns seem to emerge (Table 11). The taxon-pair of rotifers and tardigrades occurred together more frequently than expected in the soils of both the Prince Charles Mountains and the more coastal localities. Nematodes and amoebae appear to be associated in the Prince Charles Mountains, but not in the coastal regions.

Two taxon-pairs show positive association in coastal areas but not in the mountains: these are rotifers/amoebae and nematodes/ciliates. Other taxon-pairs did not exhibit significant tendency toward either association or mutual exclusion at any locality.

5. General discussion

Within the classification of Campbell and Claridge (1969), the present soils fall predominantly into the ultraxerous and xerous subdivisions of the frigic, zonal division. Several other soils are intrazonal in that either saline groundwaters are an important influence (e.g. Q2, basin, Mt Jacklyn) or additions of organic detritus have strongly affected the nature of the soil (several samples from Mawson and Pagodroma Gorge). Additionally, there were several samples of apparently recently deposited material that can be considered azonal. In the entire set, however, it is evident that biochemical activity has had a negligible influence on pedogenesis. Likewise, low temperature and scarcity of free water have restricted chemical weathering to some accumulation of salts and a small amount of oxidation. The materials collected are thus little more than the products of physical weathering and are shallow and of a coarse texture.

The general climate of continental Antarctica is much more severe than that of the Antarctic Peninsula, the Antarctic maritime islands or the sub-antarctic islands (Holdgate 1977; Betts 1983). The three taxa of metazoans prevalent in our samples — tardigrades, rotifers and nematodes — are famous for their ability to repeatedly enter and arouse from a deep dormancy, known as cryptobiosis or anhydrobiosis (see review by Heatwole 1995), during which metabolism ceases entirely. Animals may remain in such suspended animation for extended periods, the longest recorded being 120 years (Franceschi 1948). While anhydrobiotic, organisms can tolerate extremes of temperature, nearly complete desiccation, noxious chemicals, anoxia, ultraviolet light, vacuums and even considerable ionising radiation (see Heatwole 1995). They regain viability when again subjected to favourable conditions. Anhydrobiosis may encompass adaptation to critical levels of several environmental parameters.

Unlike some Antarctic mites that are rather sensitive to moisture and tend to occur in the moister soils and near meltwater channels (Rounsevell 1981, Heatwole et al. 1989), the micrometazoans of the present study were present also in dry soils, probably by persisting there in the dormant state between periods of suitable moisture.

Similarly, the observed occurrence of micrometazoans at relatively high elevations in the Prince Charles Mountains may be related to deep dormancy. Soil temperatures at such sites often are very low. Indeed, Parker et al. (1982) reported only subzero values for soil temperature from the Pensacola Mountains in summer. However, as Gregorczuk (1980) pointed out, the exceptional transparency of the atmosphere over the Antarctic means that in good weather a non-reflective substrate (e.g. exposed soil or rock as opposed to ice) receives a relatively high intensity of solar radiation even in the mountains. Consequently, the effect of elevation on microclimate may not be as marked as expected from macroclimatic differences. In the present study, daily maximum air temperatures near sea level (e.g. Pagodroma Gorge) extended above freezing on some occasions but were as low as -25°C during inclement weather at higher elevations on some of the nunataks. However, even at elevations near 2 000 m on some of the isolated nunataks of the Prince Charles Mountains, soils exposed to direct sun on a favourable aspect thawed for at least a portion of cloudless days. This microclimatic characteristic is perhaps critical in determining the presence of animals in the soils occurring there. It is likely that topographic nuances become increasingly important at the higher elevations. Slight differences in aspect could determine whether a microsite remained frozen or thawed out sufficiently during the day to allow biological activities to proceed. At some of our montane localities, soil at some sites remained frozen all day whereas at others thawing took place to varying depths in the afternoon (see descriptions of sites). Even such ephemeral warming and thawing would probably allow dormant micrometazoans to become active briefly and to periodically carry out their vital processes.

Anhydrobiosis may be relevant also to survival during food shortages, and is perhaps another contributing reason for the persistence of micrometazoans in the present study over such a wide range of environmental conditions. During cessation of metabolism, tardigrades, nematodes and rotifers would have no nutritional requirements, and low densities of food would not have an impact upon them. The initiation of more benign conditions would not only favour their awakening from anhydrobiosis but also the multiplication of such food organisms as bacteria and soil algae. Thus, the populations of metazoans and their food might show similar responses.

The extraction process itself brings anhydrobiotic animals out of dormancy and the attributes of the soil at the time of sampling may not be those under which the animals thrive or are active, but rather those that are stressful to the animals and which they avoid through dormancy. Evaluation of the relationship of the levels of environmental variables to activity versus dormancy cannot be assessed until tuns (dormant stages) and active animals are extracted separately from samples.

A further significance of anhydrobiosis relates to dispersal. Habitable regions of the Antarctic resemble an archipelago with nunataks and coastal oases scattered as 'islands' in a sea of liquid and/or frozen water (Miller et al. 1988; Miller et al. 1994; Miller and Heatwole 1995, 1996a,b). Nematodes, tardigrades and rotifers would be most likely to reach such far-flung habitats by being caught up as dust and dispersed by wind. The conditions of such transport could be sustained more easily in an anhydrobiotic state than in an active state. Furthermore, upon arriving at an inhospitable site not immediately favourable for establishment, persistence in the anhydrobiotic state might retain viability until the return of conditions favourable for colonization.

Although anhydrobiosis is an important adaptation of Antarctic metazoan invertebrates, it is not strictly a polar phenomenon. Rather, it seems to be an adaptation to harsh or ephemeral habitats generally; it is an important adaptive strategy of some desert nematodes (Heatwole 1995).

Among the Protozoa, only naked amoebae occurred at elevated inland localities. The reasons for this are unclear although it suggests that they may withstand harsh environmental conditions better than do other taxa. Many free-living Protozoa (especially amoebae and ciliates) form resistant cysts that survive adverse conditions and facilitate dispersal. Encystment has been associated with desiccation, extreme temperatures (high and low), reduced oxygen levels, pH changes, accumulations of metabolites and depletion of food supplies (Laybourn-Parry 1984; Parker et al. 1984; Foissner 1987). Little comparative information is available on the survival of cysts of different protozoan taxa although cysts of individual species of amoebae are extremely hardy (Page 1976).

In contrast, testate amoebae were not detected in any soil samples. Testate amoebae are frequently encountered in aquatic habitats, moss beds and loose, highly organic soils as opposed to mineral soils (Foissner 1987). Numerous taxa have been detected in water and moss samples from the Arctic (e.g. Beyens et al. 1986) but they have yet to be recorded from Antarctica.

Several phytoflagellate species have been found in water samples from Antarctica (e.g. Burch 1988) but only one colonial species was detected (in one soil sample) in the present study. Free-living flagellates are essentially aquatic, being found in benthic and planktonic communities and semi-terrestrial habitats such as moss beds and water films around soil particles (Laybourn-Parry 1984). In the present study, the single soil sample containing flagellates was high in moisture and organic content, originating from a site heavily contaminated by dog excrement.

Ciliated Protozoa were detected at 19 sampling sites, all confined to lower coastal elevations (Table 8). Numerous species have been described previously from Antarctica and sub-Antarctic islands but almost exclusively from water, moss and lichens (e.g. Thompson 1972; Ryan et al. 1989). Elsewhere, ciliates occur in many different soil types and are particularly numerous in nutrient-rich soils even when their numbers may be limited by the phenomenon of 'ciliatostasis' (Foissner 1987). In the present study, they occurred in soils relatively rich in organic matter such as M6 (see Table 7), but also were found in poorer soils (e.g. M5, M7, LV, X1). All inland soils, even those with relatively high organic content, and located at low elevations (Else Platform, Jetty Peninsula, Pagodroma Gorge) lacked ciliates. It would appear that the coastal restriction of this group is not related to either elevation *per se*, or to amount of organic matter, and other explanations must be sought. It may be relevant that two of the inland areas at low elevation (Jetty Peninsula and Pagodroma Gorge) had soils derived from sandstone rather than from crystalline bedrock.

Biotic as well as physical factors may determine distributional patterns. In the present study, some taxa were positively associated at some sites, and no taxon-pairs showed significant negative association (exclusion). Most of these taxa probably are distributed by winds while in an anhydrobiotic or encysted state. Consequently, individuals exert no active influence on their destinations. Associations may arise from the fact that randomly distributed propagules of both groups share the same environmental requirements for resuming active life-processes and becoming established. In addition, some Antarctic species of tardigrades are predatory (Miller and Heatwole 1995) and their occurrence at a site may depend upon prior colonisation by prey species. Such a relationship would also contribute to positive association.

The taxa discussed in the present paper constitute only a part of the biotic community of Antarctic soils. The autotrophs of the chalikosystem are algae, moss protonema and cyanobacteria. In a study of soils from Wilkes Land, Heatwole et al. (1989) found that these organisms contributed measurable amounts of chlorophyll to some soils, and that in addition there were heterotrophic micro-organisms, including bacteria, yeasts and filamentous fungi, in numbers that varied widely among samples. Those kinds of organism, along with Protozoa, serve as the food base for most Antarctic soil nematodes, rotifers, and tardigrades, although there is at least one Antarctic species of predatory tardigrade, *Milnesium tardigradum*, that eats other tardigrades as well as rotifers and nematodes (Miller et al. 1994; Miller and Heatwole 1995).

Mites have been recorded from various localities in East Antarctica (Rounsevell and Horne 1986). In Wilkes Land, Heatwole et al. (1989) found mites only from soils of a particular texture and moisture content. Only a small proportion of their total samples contained mites, and then only from two sites. Rounsevell (1977, 1981) and Rounsevell and Horne (1986) noted that *Nanorchestes antarcticus*, one of the most common and widespread of Antarctic mites, is restricted to meltwater seepages overlain by flat rocks, and not found where slopes allow better drainage. Even at those localities, in summer the mites were usually beneath rocks on the surface, rather than in the soil proper. Another common mite, *Tydeus erebus*, is found mainly on slopes adjoining bird colonies or in areas of mosses and lichen growth. Thus, both of these common species are restricted to rather narrow habitats.

Rounsevell (1979) examined soil associated with botanical specimens from the Prince Charles Mountains and found eight species of arthropods, of which four species were almost certainly contaminants. However, he considered four species of mites genuinely to have originated from that locality. It is likely that mites occurred at some of the localities sampled in the present study, but were not detected because their restricted habitats were not sampled.

Collembolans have not been recorded from the present study areas (Greene et al. undated). However, Rounsevell and Horne (1986) predict that they will arrive there through the agency of human dispersal.

A species cannot exist indefinitely without a trophic base. However, persistence in a dormant state could prolong occupancy of an area even in the absence of food. The extent to which biotic interactions, as opposed to physical factors, influence the occurrence or abundance of particular taxa in the soils of East Antarctica is still poorly understood.

The metazoan fauna of the Antarctic bryosystem is much better known than is that of the chalikosystem. The question arises as to whether the metazoan assemblages of the

Antarctic chalikosystem are structured in the same way as those of the better studied bryosystem. The present data allow for a comparison to be made from one locality. Miller et al. (1988) collected 491 samples of mosses and lichens from the Vestfold Hills and extracted the metazoans. The mean frequency of representation by the various taxa were: rotifers in 78% of the samples, tardigrades in 25% and nematodes in 59%; a ratio of 3.1:1:2.4. Corresponding values for present soil samples from the Vestfold Hills were rotifers 10%, tardigrades 10% and nematodes 45% (ratio 1:1:4.5), suggesting that soil at this locality may be poorer in metazoans (especially rotifers and tardigrades) than are mosses and lichens, and that the proportions of these taxa vary considerably between the two systems. In moss samples, rotifers, nematodes and tardigrades were all positively associated (amoebae and ciliates were not recorded).

Association of various metazoan taxon-pairs also occurs in the bryosystem of other Antarctic localities. For example, in the Windmill Islands rotifers, nematodes and tardigrades tended to occur together more often than expected by chance in 242 samples of mosses, lichens and algae (Miller and Heatwole 1996b). On a finer scale, three of the six species of tardigrade tended to be positively associated. These associations may be related in part to certain kinds of plants being more suitable than others. All three metazoan taxa were found in mosses more often than expected by chance but less often in lichens and algae. Similarly, in the bryosystem of the Prince Charles Mountains, tardigrades were positively associated with mosses, but occurred in lichens less often than expected on the basis of random distribution among plant taxa (Miller and Heatwole 1996a). By contrast, at two other Antarctic localities, the Larsemann Hills (61 samples; Miller et al. 1994) and the Mawson Coast (26 samples; Miller and Heatwole 1995), distribution of tardigrades among mosses, lichens and algae followed expectations based on random assortment among plants.

Appendix
Description of the study areas and sampling sites

PRINCE CHARLES MOUNTAINS

Else Platform (70° 21' S, 68° 50' E), 28 January 1990 (Figure 2a).

Else Platform is a low-lying (0 – 180 m), essentially ice-free area of 140 km^2. It consists of rounded, felsenmeer-covered hills, 10 – 20 m in height, with scattered snowbanks and numerous frozen lakes in depressions. The rocks are predominantly quartz-feldspar-garnet-biotite granulites and gneisses, with minor mafic, calc-silicate and pelitic granulite units, all intruded by garnet-bearing granite and pegmatite, and by mafic and alkaline ultramafic dykes (Hand et al. 1994). These rocks have weathered *in situ* to form a veneer of rock debris and local patches of soil which commonly retain the white, red or black colour of the underlying parent rock. The veneer of rock debris commonly displays a polygonal pattern known as 'patterned ground' or 'frost polygons'. Individual polygons are a few metres in diameter and have coarser rock debris concentrated at the margins and finer debris in the centre. Where water seeps into valleys, or into ponds on the edge of the ice sheet, soils are alluviated as separate, sometimes-adjacent fans of fine particles, each fan of a different colour. All of the following samples were taken within 4 km of each other.

E1: At edge of ice. White, weathered rock on a north-eastern slope of about 30°. There are angular pebbles, cobbles and a few boulders. Soil exposed at surface in patches, light brown, appears moist, is 3 cm deep and then frozen and interstitial among rocks. No mosses or lichens apparent.

E2: Same except that the rocks are black and angular. Soil dark brown, frozen below 3 cm and interstitial, appears moist to wet. No mosses or lichens apparent.

E3: Same, but associated with angular red boulders, cobbles and pebbles. These rocks seem less weathered and may have originated further uphill. Soil appears moist to 3 cm and then frozen. No mosses or lichens apparent.

E4 to E6: Flat plateau. Black, red and white rocks weathered *in situ* by frost shattering (Figure 3a). Soil light brown (at all rock types) and 15 cm deep; appears dry in places, moist in others. Some black mosses present; no lichens apparent.

Jetty Peninsula (70° 47' S, 68° 35' E), 25 – 26 January 1990.

Jetty Peninsula is a low-lying (0 - 200 m), ice-free peninsula of quartz sandstone (Table 1) between Beaver Lake and the Lambert Glacier. The broken rock and soil form frost polygons. Soil develops in the mounds in the centres of the polygons and sometimes is quite deep. The furrows at the edges of the polygons are sheltered and contain fragments of rock encrusted with lichens; mosses grow at the edges of the furrows.

J1: Southern end of Jetty Peninsula. A low, flat area of quartz sandstone (Table 1). Soil uniformly textured, brown, up to 10 cm deep, in scattered bare patches or under small pieces of sandstone; soil appears moist except for top 1 cm. No mosses or lichens apparent.

J2: Flat plain. Same as J1 but mosses present.

J3: Old snow bank melted in a depression 10 m in diameter. Still some small patches of snow and small pool with some ice. No rocks larger than cobbles. Soil moisture sampled near edge of depression. Soil light brown and appears wet; 3 cm thick, resting on sandstone. No mosses or lichens apparent.

J4: Slight knoll with boulders sheltering soil. Rocks as in J1 and J2. Mosses and lichens present.

J5: Knoll with large quartz sandstone boulders (Table 1). A pocket (2 m by 4 m) of fine-textured, rose-red soil of the same colour as an adjacent boulder. Soil undifferentiated at least to 13 cm. Moisture content appeared to vary with microtopography.

Pagodroma Gorge (70° 50' S, 68° 04' E) and vicinity, 22 – 24 January 1990.

Pagodroma Gorge is a narrow, steep-sided gorge about 6 km long and 120 m deep that has been fluvially incised into the Permian Bainmedart Coal Measures (McKelvey and Stephenson 1990). It begins on the eastern side of Radok Lake, in Bainmedart Cove, and drains north-eastward into Beaver Lake. The eastern half of the gorge is now estuarine, having been flooded by the rising level of Beaver Lake. Occasional debris slides at the base of the cliffs and accumulations of sand occur in places along the gorge.

P1: Northern edge of Pagodroma Gorge. Remains (wings and bones) of a dead snow petrel (*Pagodroma nivea*) lying on sand at the edge of ice on the stream. Two samples of sterile cores taken beneath the bird. No mosses or lichens apparent. Elevation about sea level.

P2: Headland on southern side of mouth of Pagodroma Gorge at Beaver Lake. Slope about 20°, facing north. Top layer of soil with hard crust for about 1 mm, then a layer about 4 – 5 cm, light brown and dry in appearance; below, a dark, brown layer, appearing moist, going down to at least 30 cm. Cobbles on top of soil (not included in sampling) (Figure 3b). No mosses or lichens apparent. Elevation about sea level.

P3: Alluvial fan extending from weathered cliffs with coal seam interbedded with sandstone. North side of gorge, slope about 10°, facing south. Soil dark grey with chips of coal; appears moist except for top 1 cm which seems dry. Not zoned at least down to 25 cm. No mosses or lichens apparent. Elevation about 20 m.

P4: Sandstone scree slope, about 45°, facing south. Cavity under sandstone boulder containing old nest of snow petrel. Mummified chick in crevice. Soil on bottom of cavity with coal chips, guano and feathers. Accumulation of soil mixed with feathers; excavated to a depth of 15 cm and bottom not reached. Cavity 0.5 m wide and exiting from other side of rock (two entrances) about 1.5 m away. No mosses or lichens apparent. Elevation about sea level.

P5: Cul-de-sac of Glossopteris Gully. Slope 20°, facing south. Sandstone slabs highly weathered and mixed with other rocks accumulated at bottom of slope 10 m above a meltwater stream; no snow above but present on opposite side of stream. Soil between flat slabs of sandstone; at least 15 cm deep, not zoned. No mosses or lichens apparent. Elevation about 10 m.

P6: Eastern edge of Radok Lake. Slope 20°, facing north. Meltwater seepage at edge of snowbank. Soil wet, black and sandy; no zonation down to 15 cm where rock was encountered. No dry layer on top. Overlain by flat pieces of sandstone and cobbles. No mosses or lichens apparent. Elevation about sea level.

P7: North bank of Pagodroma Gorge where it enters Radok Lake. On level ground, with vertical exposure on top of bank about 4 m high. Soil is Pagodroma Tillite; appears dry on top. Second sampling on level ground at base of bank where soil is weathered and washed out of bank at edge of snow bank. No mosses or lichens apparent. Elevation about 5 m.

P8: Flagstone Bench, top of sandstone hill south of Pagodroma Gorge. Rotten, weathered quartz sandstone in flat slabs on surface plus smaller pieces. Soil tan, fine-textured, 5 cm deep, not zoned. No mosses or lichens. Elevation 215 m.

Blustery Cliffs (71° 25' S, 68° 00' E), 20 – 21 January 1990 (Figure 2b).

Blustery Cliffs consists of a south-easterly facing cliff topped by a plateau at an elevation of 1120 m and gradually slanting north-west.

B1: Plain of tumbled boulders, up to 1 m in diameter, protruding above field of shallow drift snow up to 50 cm deep. Occasional patches of bare soil between rocks surrounded by thin layers of clear ice protruding outward, leaving small air spaces between soil and ice. Soil patches temporarily exposed; on warm days snow melts and re-freezes. Soil grey-brown and moist; unstratified and up to 3 cm deep. No mosses or lichens apparent. Elevation 1120 m.

B2: Same plain as B1 but further north-east. Rock and soil type same as B1, but only occasional patches of snow, mainly bare boulders with cobbles and soil between. Soil as described for B1, but 10 cm deep at sampling site, and appears dry in the top 1 cm. No mosses or lichens.

B3: Base of eastern face of Blustery Cliffs. Rocks same as at B1 and B2. Soil same but in larger and deeper accumulations; interspersed with snowbanks. Moist soil up to 15 cm deep. Soil not zoned. No mosses or lichens. Elevation about 200 m.

B4: Hill south of south-eastern edge of Blustery Cliff Plateau. Jumble of angular black boulders on 30° slope, facing north. Soil in pockets of about 20 cm maximum diameter and up to 8 cm deep; appears moist throughout. Scattered snow patches; peak above slope snow-covered. Soil black; interspersed with angular chips of rock. No mosses or lichens apparent. Elevation about 1150 m.

Mt Woinarski (71° 13' S, 66° 29' E), 13 – 18 January 1990.

The summit of Mt Woinarski is at 1560 m. The summit and the ridge leading north-west from it are of bare, weathered rock, consisting of folded, banded gneisses intruded by dykes of granite and pegmatite. There is a scree slope down the south-western side of the ridge and a flat area north-east of the ridge leading over slopes to moraine at the edge of the icesheet. The flat part and north-eastern slopes are covered by ice and snow. The south-eastern scree slope has isolated patches of snow.

W1: On south-western scree slope of about 45°. Soil interspersed among thin scree of cobbles and boulders on basement of garnet pegmatite (Table 1). Soil fills interstices, lacks notable zonation; only to 10 cm thick. No mosses or lichens apparent. Elevation about 1500 m.

W2: Rocky peak at north-western end, beneath peak at western edge of ice where ridge abuts ice. Area flat, sheltered on north-west by partly overhanging granite (Table 1). Thin layer of soil accumulated among weathered rocks; not zoned and only 5 cm thick, light brown. Small snow patches present. No mosses or lichens evident. Elevation about 1530 m.

W3: South-east and below trig station on scree slope. Outcrop of garnet pegmatite (Table 1) weathering and contributing scree. On south-western-facing slope about 30°. Soil fills interstices of scree to an indeterminate depth, not zoned, light brown. Snow patches among scree. No mosses or lichens apparent. Elevation about 1500 m.

W4: Outwash plain or moraine at eastern foot of Mt Woinarski. A mixture of small boulders interspersed with smaller rocks and pockets of soil (Figure 3c). Soil with no apparent differences in texture to 12 cm depth except for pebbles in surface layers. Top 3 cm dry but moist from there down. Snow patches dispersed over plain. No mosses or lichens apparent. Elevation about 1100 m.

W5: On a saddle running at right angles (east) from the main ridge of Mt Woinarski. Soil interstitial to a jumble of angular boulders and cobbles, light brown, appeared dry. Soil 15 cm deep in places; no zonation except for pebbles and gravel near surface. No mosses or lichens evident. Elevation about 1400 m.

Mt Jacklyn (70° 16' S, 65° 49' E), 13 February 1990 (Figure 2c).

Mt Jacklyn comprises several connected peaks (up to 1120 m elevation) of garnet gneiss surrounding a central, elongate valley, with a glacier entering the south-western end. The valley gradually slopes upward to peaks on the north-east. There are many highly weathered, wind-scoured boulders scattered on the slopes. Fine soil up to several decimetres thick has accumulated in the deeper part of the valley towards the south-western end, but soil also is abundant on the slopes. It appears that the finer particles have washed downward into the valley, leaving coarser materials on the slopes.

Q1: Mountainside, slope 30°. Small rock outcrops and scattered boulders of garnet gneiss (Table 1). Mostly bare of snow. Soil light brown to reddish and appearing dry;

20 cm deep, then mostly rock. No mosses or lichens apparent at sampling site. Elevation about 1100 m.

Q2: Basin with glacier at south-western end causing internal drainage with no outlet. Vertical exposure, level. Large area of soil accumulated in the bottom of the basin (Figure 3d) to a depth of 15 cm, then frozen; yellowish-green, contrasting in colour with surface rocks. Soil appears dry. Surface cobbles. No mosses or lichens evident at sampling site. Elevation about 1080 m.

Q3: Northern slope of 20°, facing south. Large accumulations of reddish soil among boulders; appears dry, 10 cm deep, then frozen. No mosses or lichens evident at sampling site. Elevation about 1100 m.

Farley Massif (70° 14' S, 65° 47' E), 16 February 1990.

Farley Massif is located a few hundred metres north-west of the ANARE summer field base, Dovers. Like nearby Mt Jacklyn it is composed of garnet gneiss (Table 1).

R1: Mountainside of boulders of garnet gneiss (Table 1), interspersed with smaller stones. Slope of 20°, facing south. Soil 10 cm deep; appears dry. No mosses or lichens evident at sampling site. Elevation about 1060 m.

Moore Pyramid (70° 18' S, 65° 08' E), 3 – 4 February 1990 (Figure 2d).

Moore Pyramid is a nunatak at the edge of the smooth, blue icesheet of the Scylla Glacier. A moraine extends peripherally from the base of the mountain to the ice in which it becomes embedded. Occasional heaps of finer moraine, accompanied by soils, protrude above the ice.

O1: South-eastern end of Moore Pyramid. Topography flat, vertical exposure, site shaded by the mountain. The soil is mostly frozen. No mosses or lichens apparent. Elevation about 1400 m.

O2: Lateral moraine about 20 m high at north-western end. Slope 30° facing north. Boulders, cobbles and other stones in a heap. Few small areas of exposed soil; frozen below 1 - 3 cm. Snow covers much of moraine in a light powder. No mosses or lichens apparent. Elevation about 1420 m.

O3: Same moraine as O2 but closer to mountain and with a southern exposure. Slope 15°. Sample from lee of large salmon, black and white pegmatite rock (Table 1) which it resembles in colour. Soil mostly frozen. No mosses or lichens apparent. Elevation about 1420 m.

O4: Near summit of mountain; 20° slope, facing north-east. Garnet gneiss (Table 1) weathered into nearly vertical sheets with areas between sheets containing brown soil up to 4 cm deep, covered by irregular cobbles. Patches of snow frequent in area. Soil thawed at 1620 hrs. No mosses or lichens apparent. Elevation about 1615 m.

O5: Gully from near summit of Moore Pyramid, south-east toward the ice. North-eastern exposure on a 20° slope. Soil thawed at 1750 hrs. Weathered white pegmatite (Table 1). Soil overlain by angular chips of the pegmatite. Soil mostly brown; 4 cm deep before reaching rock or frozen soil. No mosses or lichens apparent. Elevation about 1680 m.

Mt Wishart (70° 19' S, 65° 16' E), 31 January to 1 February 1990 (Figure 2e).

Mt Wishart (elevation 1668 m) is a nunatak protruding above the Scylla Glacier. It has large snow banks on the lee side, and wind scours through lower areas. The windward side has snow cliffs near the base of the mountain, leading into deep 'valleys'. The peak of Mt Wishart is capped by weathered boulders of garnet gneiss and pegmatite. There is no soil on the southern (windward) or western sides of the mountain.

I1: Lee side of Mt Wishart, near summit; mostly snow-covered. Rock is pink gneissic garnet pegmatite (parent rock sample I1), weathered and cracked. Soil sample taken on boulder slope with some scree. Soil in small, exposed patches up to 1 m diameter; frozen below 1 - 3 cm depth. No mosses or lichens apparent. Elevation 1660 m.

I2: Scree slope at base of Mt Wishart on north-western side, at bottom of a large wind-scour about 100 m deep. Slope 30°. Rock is mylonitized granitic gneiss (parent rock sample I3) and white gneissic garnet pegmatite. Soil frozen below 2 cm. Light dusting of dry snowdrift over soil. No mosses or lichens apparent. Elevation about 1300 m.

Mt Starlight (70° 12' S, 64° 30' E), 6 February 1990.

Mt Starlight consists of a series of peaks, at elevations of about 2150 m, connected by ridges of rock and boulders, surrounded by snow and deep wind-scours.

S1: A west-facing ridge of about 20° slope. Boulders with cobbles and pebbles interspersed, and extensive patches of soil. Surface cobbles, under which soil mostly frozen. No mosses or lichens apparent. Elevation approximately 1800 m.

Corry Massif (70° 27' S, 64° 39' E), 10 – 11 February 1990 (Figure 2f).

Corry Massif is a large plateau (2065 m) surrounded by steep cliffs rising from the Scylla Glacier. There is a boulder moraine at the ice fringe.

C1: Upper plateau of white boulders, broken and weathered *in situ*. Slope level; vertical exposure. Soil up to 10 cm deep, appears dry; occurs in large patches distributed extensively over plateau. Small snow patches. No mosses or lichens apparent. Elevation 2060 m.

C2: North-western slope; 15° gradient. Parent rocks varied, ranging from white to pink to black. Some small boulders but mostly small stones and cobbles with extensive soil of varying colours, white to yellowish to light brown at sampling site. Soil appears dry to 10 cm depth, then frozen. Elevation 1990 m.

C3: On north-eastern edge of Corry Massif where it abuts on the Scylla Glacier. A large moraine of boulders of same type as mountain and slope, with ridges about 50 m high. Flat, vertical exposure. Same rock types as C2. Soil in pockets among boulders, seemingly dry to 3 cm, then frozen, finally overlying pure ice. No mosses or lichens apparent. Elevation 1690 m.

Mt Forecast (70° 40' S, 64° 20' E), 9 February 1990.

Mt Forecast consists of several large rocky peaks protruding a few hundred metres above the ice of the Charybdis Glacier. There is an upper plateau bounded by slopes with many boulders and outcrops of rust-coloured rock.

F1: Upper plateau; level, vertical exposure. In the centre of the plateau is a pinkish pegmatite and seams of black ultramafic granulite. Soil dark brown to black and up to 10 cm deep, then frozen. Soil dry on the surface; had it been wet it would have been frozen as temperatures were below -20°C. Scattered small patches of snow. No mosses or lichens apparent. Elevation approximately 2000 m.

COASTAL AREAS

Mawson station (67° 36' S, 62° 52' E), 6 - 7 January 1990 (Figure 2g).

Mawson station lies on a horseshoe-shaped rocky outcrop 1 km long and slightly more than 0.5 km wide, rising from sea level to an elevation of 33 m. The area is largely free of ice in summer although scattered snowbanks persist throughout summer and, together with the adjacent ice cap, provide sufficient run-off to form meltwater channels and seepages. The station has been inhabited since 1954 and has over 30 buildings (Betts 1981). The human population ranges from 25 - 30 in winter to about 90 in summer.

M1: Immediate environs of station. Human and dog influenced; penguins also present. On Mawson Charnockite (quartz, K-feldspar, plagioclase feldspar, pyroxene). Smooth and superficially stained. Small pockets of snow in sheltered places. General slope about 30°. Smooth rock covered by patches of gravel. South-western exposure. Rocks with grey crustose lichens of about 25% cover. At edge of crevices under big blocks of rock where smaller particles (sand and gravel) (soil up to 4 cm deep) accumulated are patches of moss covered by yellow lichens. The moss is mostly black (dead) and in small hummocks, but alive and green on edges. Seepage of water from cracks in rocks and from snow-melt. Bird feathers among moss clumps.

M2: Same but 4 m away. Moss covered by a grey lichen.

M3: Same but with orange crustose to foliose lichens.

M4: Western edge of Mawson station but north-easterly exposure. Same rock type as M1 and M2. Nearly flat. Sandy soil with gravel (pebbles, cobbles and boulders) on surface. Soil about 5 cm deep, waterlogged from meltwater seepage. Moss cover nearly complete, in mounds, 1 - 2 cm thick. No lichens seen on soil, but a few scattered grey crustose ones on rocks.

M5: Sheltered well-drained site on hill at south-western part of station. Surrounded by pipe conduits and buildings. Green moss cover, about 15%. Soil an accumulation of sand apparently washed from rocks above. Gravel (pebbles, cobbles and boulders) present; nearly continuous on surface (Figure 3e). Some *Prasiola crispa* at edges of patch. No snow above patch, but snowbank 1 m to the side. Soil not waterlogged, but wet.

M6: Run-off area from dog kennels. Soil sandy, up to 8 cm deep with gravel and pebbles accumulated on the surface on top of smooth rock. A lot of discarded coke fuel from old split bags accumulated with it. A heavily contaminated area. Soil wet, with seepage channel 1 m away. M6t is a subsample of only the top centimetre of a large sample of soil.

M7: South-western side of Mawson station. Flat area of Mawson Charnockite with some crevices and with large boulders on it. There is an accumulation of moist sand at least 20 cm thick to bedrock. Uniform texture and colour throughout except that there are some pebbles and gravel on the surface. The area is used by Adélie penguins and there are splatters of guano on the rocks and feathers on the soil. Ice cap is only 15 m away and there are meltwater pools at the edge of it.

M8: About 15 m from M7. Soil waterlogged from meltwater. Mud with sand and gravel at edge of meltwater pool beside snow. Soil up to 15 cm deep, of uniform texture except pebbles and gravel on top. There is a mat of decaying feathers of Adélie penguins on soil and some old penguin bones. There is a mat of *Prasiola crispa* about 25 cm in diameter.

M9: About 20 m north of M5; flat ground, northern exposure. Sheltered by boulders. No mosses or lichens evident. Soil moist. Sandy with pebbles and gravel on top. Snow bank about 4 m away but site not in meltwater seepage. M9t and M9b represent respectively the top half and bottom half of a replicate sample of soil.

M10: At edge of hut by path. Heavily trafficked area. Rubbish accumulated. Snow bank 1.5 m away. A few rocks. Soil of uniformly textured sand and mud, up to 3 cm deep, on bare rock.

Field Rock (67° 36' S, 62° 54' E), 17 February 1990.

Field Rock is located near sea level, about 1.9 km east of Mawson station but separated from the station by ice and not often visited. Soil and parent rock (Mawson Charnockite) is similar to that at Mawson. The area consists of a large boulder field interspersed with smaller rocks and soil. Mosses and lichens present (Figure 3f).

X1: Bare soil, not covered by moss or lichens.

X2: Black moss cushions; core sampled through cushion into soil.

X3: Yellow moss cushions; core sampled through cushion into soil.

Rumdoodle (67° 46' S, 62° 49' E), 18 February 1990 (Figure 2h).

Rumdoodle is a nunatak with sheer sides emerging from the ice and located 18 km south of Mawson station.

U1: Heavy scree soil with large patches of deep (10 cm) soil on a steep angle (45°) facing west.

U2: Base of cliff, deep (20 cm) soil, finely divided in a secluded spot, protected by erratic boulders. Influenced by skuas as bones of *Pagodroma* scattered over site and there are droppings.

Béchervaise Island (67° 35' S, 62° 49' E) 25 February 1990.

Béchervaise Island is an island of Mawson Charnockite, located in the bay offshore from Mawson station. It contains an Adélie penguin rookery.

Béch-1: North-eastern slope, 20°. Soil of finely divided organic matter (guano), 10 cm deep.

Vestfold Hills (68° 30' S, 78° 00' E), near Davis station, 2 March 1990 (Figure 2i).

The Vestfold Hills are rolling hills, largely snow-free and with numerous lakes.

LV: Lichen Valley, a flat-floored valley with boulders and erratic rocks. Soil 20 cm deep, dark brown, sandy, covered by gravel and pebbles. Slope of 5° facing north.

PH: Platcha Hut, located on a north-facing, 15° slope leading upward from Lichen Valley. Gravel on soil. Soil about 10 cm deep. Sandy, nearly black.

Tables

Table 1. Bedrock types and constituent minerals at various localities in the Prince Charles Mountains and in the vicinity of Mawson station.

M = major constituent (>10 vol %); m = minor constituent (1–10 vol %).

		CONSTITUENT MINERALS*							
SITE	BEDROCK TYPE	Qtz	Plag	K-f	Gt	Bi	Pyx	Hbe	Others
PRINCE CHARLES MOUNTAINS:									
Else Platform									
E1	Gneissic pegmatite	M	m	M	m	m			
E2, E3	Garnet gneiss	M	m	M	M	m			
E4, E6	Garnet gneiss	M	M	M	m	m			
E5	Pegmatite	M	M	M					
Jetty Peninsula									
J1, J5	Quartz sandstone	M	m	m					Clays (m)
J2 – J4	Quartz sandstone								
Pagodroma Gorge									
P8	Quartz sandstone								
Blustery Cliffs									
B1 – B3	Granitic gneiss	M	M	M		m		m	
B4	Amphibolite	m	M			m		M	
Mt Woinarski									
W1, W3	Garnet pegmatite	M	M	M	m				
W2	Granite + chlorite rock	M	M	M					Chlorite (M)
Mt Jacklyn									
Q1 – Q3	Garnet gneiss	M	M	M	m	m			
Farley Massif									
R1	Garnet gneiss								
Moore Pyramid									
O3	Pegmatite	M		M		M			
O4	Garnet gneiss	M	m	M	M	m			
O5	Pegmatite	M	M	m		M			

Table 1 continued

		CONSTITUENT MINERALS*							
SITE	BEDROCK TYPE	Qtz	Plag	K-f	Gt	Bi	Pyx	Hbe	Others
Mt Wishart									
I1	Gneissic garnet pegmatite	M	M	M	m	m			
I3	Mylonitised granitic gneiss	M	M	M	m	m			Calcite (m)
I5	Garnet gneiss	M	M	M	m	m			
Corry Massif									
C1	Garnet pegmatite	M	m	M	m				
C2A,B	Pegmatite	M	M	M					
C2C	Gneissic charnockite	M	M			m	M		
Mt Forecast									
F1A	Pegmatite	M	M	M		m			
F1B	Ultramafic granulite		m				M		
MAWSON STATION AND VICINITY:									
Mawson station									
M1 – M10	Charnockite	M	M	M		m	M		
Field Rock									
X1 – X3	Charnockite								
Rumdoodle									
U1, U2	Charnockite								
Béchervaise Island									
Béch 1	Gneissic charnockite	M	M	m		M	M		

*Mineral abbreviations: Qtz = quartz, Plag = plagioclase, K-f = K-feldspar, Gt = garnet, Bi = biotite. Pyx = pyroxene, Hbe = hornblende.

Table 2. Major element analyses of selected soils and their parent rocks. Coarse (>2 mm) and fine (<2 mm) soil fractions analysed separately.

ROCK TYPE (FIELD SAMPLE NUMBER)

	Granitic Gneiss (B1)			Amphibolite (B4)			Quartz Sandstone (J1)			Garnet Pegmatite (W3)		
Catalogue No.*	R68650	R68651	R68652	R68653	R68654	R68655	R68656	R68657	R68658	R68659	R68660	R68661
Material	Rock	Coarse Soil	Fine Soil	Rock	Coarse Soil	Fine Soil	Rock	Coarse Soil	Fine Soil	Rock	Coarse Soil	Fine Soil
SiO_2	67.97	68.05	66.28	52.67	53.81	55.14	93.21	94.30	80.13	73.83	71.13	68.30
TiO_2	0.51	0.28	0.24	0.83	0.79	0.82	0.14	0.17	0.35	0.08	0.40	0.54
Al_2O_3	15.01	16.69	16.79	17.44	16.88	16.08	3.96	3.06	9.64	14.39	13.79	13.65
Fe_2O_3	1.76	1.30	2.76	3.73	3.44	4.17	0.09	0.13	1.02	0.09	1.11	1.93
FeO	1.72	0.75	1.01	6.01	5.38	4.60	0.12	0.14	0.84	0.22	1.98	2.95
MnO	0.08	0.06	0.06	0.16	0.15	0.15	0.01	0.01	0.04	0.01	0.08	0.15
MgO	1.02	0.51	0.45	4.42	4.16	4.05	0.01	0.05	0.62	0.08	0.96	1.25
CaO	2.39	2.35	2.09	9.35	8.72	7.68	0.02	0.09	1.51	0.42	1.82	2.58
Na_2O	4.13	4.99	4.98	2.47	2.94	2.87	0.09	0.20	1.67	3.03	2.75	2.50
K_2O	3.59	3.70	3.84	0.92	1.19	1.22	0.44	0.23	1.49	7.08	4.73	3.73
P_2O_5	0.16	0.09	0.06	0.23	0.22	0.19	0.02	0.02	0.09	0.03	0.07	0.07
S	0.01	0.02	0.01	--	--	0.02	0.02	0.03	0.07	0.01	0.09	0.23
H_2O	1.35	1.15	1.22	1.84	1.84	2.80	1.61	1.21	2.20	0.64	0.81	1.86
Total	99.70	99.94	99.79	100.07	99.52	99.79	99.74	99.64	99.67	99.91	99.72	99.74
Fe_2O_3/FeO	1.02	1.73	2.73	0.62	0.64	0.91	0.75	0.93	1.21	0.41	0.56	0.65

* Catalogue of specimens in the Department of Geology and Geophysics, University of New England, Armidale.

Table 3. Particle size analysis of soil samples from the Prince Charles Mountains and coastal East Antarctica (%).

Sample	> 19.05	19.05– 11.13	11.13 – 9.60	9.60– 5.66	5.66– 4.76	4.76– 4.00	4.00– 2.80	2.80– 2.00	< 2.00
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
PRINCE CHARLES MOUNTAINS:									
Else Platform									
E1	0	7.18	2.82	10.00	2.36	3.31	5.57	5.61	63.16
E2	3.27	6.74	3.89	11.44	3.03	3.27	4.83	5.03	58.49
E3	0	4.76	4.72	11.58	3.10	3.60	5.12	4.73	62.39
E4	2.41	2.80	1.12	2.72	0.61	1.62	3.76	3.92	81.04
E5	0	10.29	4.50	15.22	3.46	3.54	5.68	4.79	52.52
E6	0	5.56	0.34	2.34	1.58	2.09	3.34	3.34	81.41
Jetty Peninsula									
J1	2.56	2.94	0.53	3.70	1.31	2.18	4.54	5.21	77.03
J3	0	2.81	0.68	4.15	0.81	2.00	4.99	6.42	78.15
Pagodroma Gorge									
P1	0	0.65	0	4.54	1.96	3.55	9.59	11.20	68.51
P2	0	1.02	1.33	3.21	0.81	0.86	1.97	2.67	88.14
P3	1.20	5.57	2.32	5.77	1.79	2.13	2.99	3.22	75.02
P5	5.77	7.67	1.66	6.48	2.13	2.15	4.16	5.29	64.69
P6	11.55	6.41	0.71	6.03	2.44	2.29	3.88	3.77	62.93
P7	1.31	4.22	3.63	9.40	3.51	2.82	7.48	8.64	58.98
P8	0	3.55	1.90	5.37	1.42	2.68	4.95	5.66	74.48

Table 3 continued

Sample	> 19.05	19.05– 11.13	11.13 – 9.60	9.60– 5.66	5.66– 4.76	4.76– 4.00	4.00– 2.80	2.80– 2.00	< 2.00
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
Blustery Cliffs									
B1	0	4.15	3.06	8.96	2.94	4.12	12.52	20.49	43.77
82	0	0.84	0.86	7.50	5.69	8.66	21.12	20.50	34.83
B3	0	1.61	1.74	6.00	2.81	4.66	10.64	14.93	57.60
B4	1.04	9.44	1.77	5.42	1.86	2.63	4.91	6.89	66.05
Mt Woinarski									
W1	1.16	7.63	3.31	9.58	4.07	5.08	8.35	8.68	52.14
W2	0	6.26	1.91	11.99	4.78	5.48	10.13	10.56	48.89
W3	0	3.31	2.69	10.75	5.14	5.10	8.44	8.34	56.24
W4	1.11	0.45	0.45	4.99	3.12	3.99	7.44	9.24	69.21
W5	0	5.37	2.41	8.22	3.86	5.85	10.54	11.04	52.71
Mt Jacklyn									
Q1	0	0.83	1.22	6.97	3.70	4.72	6.97	6.91	68.67
Q2	9.65	1.55	0.36	4.27	1.16	1.34	2.01	2.56	77.10
Q3	0	0.79	1.17	3.52	1.18	2.17	5.59	6.91	78.66
Farley Massif									
R1	0	14.07	5.99	18.16	5.88	5.97	8.17	6.87	34.90

Table 3 continued

Sample	> 19.05 (mm)	19.05– 11.13 (mm)	11.13 – 9.60 (mm)	9.60– 5.66 (mm)	5.66– 4.76 (mm)	4.76– 4.00 (mm)	4.00– 2.80 (mm)	2.80– 2.00 (mm)	< 2.00 (mm)
Moore Pyramid									
01	0	19.39	17.07	30.81	6.60	7.48	8.74	5.21	4.69
02	2.71	4.34	2.18	14.91	4.38	8.28	15.07	18.08	30.05
03	0	4.25	3.61	15.77	5.23	7.35	11.11	10.48	42.19
04	0	8.69	2.69	10.29	2.31	3.41	7.28	10.35	54.99
05	0	15.64	2.63	17.35	5.99	6.82	10.88	10.67	30.02
Mt Wishart									
I1	0	0	1.29	16.34	6.95	8.03	13.62	13.89	39.88
Mt Starlight									
S1	0	14.00	8.23	27.33	5.86	8.62	10.08	7.79	18.08
Corry Massif									
C1	0	6.09	2.57	8.83	3.59	4.51	7.36	7.04	60.01
C2	1.49	2.92	4.99	12.14	3.58	5.09	9.09	9.88	50.81
C3	0	1.40	0.51	1.39	0.78	2.52	5.25	8.57	79.58
Mt Forecast									
F1	1.32	5.47	1.69	7.94	3.33	3.46	7.41	9.67	59.70

Table 3 continued

Sample	> 19.05 (mm)	19.05– 11.13 (mm)	11.13 – 9.60 (mm)	9.60– 5.66 (mm)	5.66– 4.76 (mm)	4.76– 4.00 (mm)	4.00– 2.80 (mm)	2.80– 2.00 (mm)	< 2.00 (mm)
COASTAL EAST ANTARCTICA:									
Mawson station									
M1	0	0.31	0.35	4.87	1.55	2.90	7.68	9.34	73.00
M2	0	5.74	3.76	9.58	2.82	3.18	5.31	5.28	64.32
M5	2.55	0.58	0.51	5.05	1.64	2.30	4.20	6.10	77.07
M6	0	9.08	2.47	5.00	2.90	2.98	5.58	6.38	65.60
M6 t	0	3.58	0	1.65	2.04	3.47	7.29	7.53	74.45
M7	0	0	0	2.65	2.18	2.90	9.58	12.75	69.93
M8	0	3.77	5.65	9.42	2.25	2.27	3.08	0.16	73.41
M9 b	0	2.14	1.53	2.85	1.10	1.69	2.70	2.58	85.40
M9 t	2.26	9.54	2.71	7.25	2.51	2.79	4.39	5.72	62.83
Field Rock									
X1	4.27	0.72	1.68	4.00	1.62	2.89	5.24	6.19	73.40
Rumdoodle									
U1	1.22	8.90	2.17	10.76	3.89	4.14	9.62	11.65	47.66
Vestfold Hills									
LV	0	4.44	4.60	8.62	2.94	5.20	7.51	7.60	59.10
PH	4.29	6.86	0	6.00	2.24	3.31	6.17	7.39	63.75

Table 4. Textural analysis of soil samples from the Prince Charles Mountains and Coastal East Antarctica (%).

Sample	2.00 mm– 212 µm	212 µm– 20 µm	20 µm – 2 µm	< 2 µm	USDA Texture Class
PRINCE CHARLES MOUNTAINS:					
Else Platform					
E1	38.63	41.57	13.62	6.18	Loamy Sand
E2	43.41	39.64	9.28	7.67	Loamy Sand
E3	47.36	39.44	8.17	5.03	Loamy Sand
E4	62.72	32.94	2.46	1.88	Sand
E5	57.68	35.83	2.79	3.70	Sand
E6	47.94	42.98	4.79	4.29	Sand
Jetty Peninsula					
J1	51.90	33.76	8.01	6.33	Loamy Sand
J3	45.90	44.22	4.13	5.75	Sand
Pagodroma Gorge					
P1	36.78	29.30	16.98	16.94	Sandy Loam
P2	53.39	24.00	7.69	14.92	Sandy Loam
P3	49.74	28.22	11.63	10.41	Sandy Loam
P5	46.83	29.26	11.45	12.46	Sandy Loam
P6	56.48	30.15	6.98	6.39	Loamy Sand
P7	23.12	16.04	21.93	38.91	Clay Loam
P8	62.31	17.87	11.45	8.37	Loamy Sand

Table 4 continued

Sample	2.00 mm– 212 µm	212 µm– 20 µm	20 µm – 2 µm	< 2 µm	USDA Texture Class
Blustery Cliffs					
B1	91.38	6.83	1.21	0.58	Sand
B2	81.18	16.71	1.12	0.99	Sand
B3	80.80	16.59	0.94	1.67	Sand
B4	58.80	29.94	8.42	2.84	Sand
Mt Woinarski					
W1	76.34	15.98	3.98	3.70	Sand
W2	72.24	17.08	7.27	3.41	Sand
W3	83.16	12.27	3.11	1.46	Sand
W4	90.61	6.70	0.64	2.05	Sand
W5	84.05	11.95	2.84	1.16	Sand
Mt Jacklyn					
Q1	72.22	22.04	4.10	1.64	Sand
Q2	24.06	30.51	15.77	29.66	Sandy Clay Loam
Q3	72.35	25.50	1.87	0.28	Sand
Farley Massif					
R1	80.46	17.91	0.92	0.71	Sand

Table 4 continued

Sample	2.00 mm– 212 µm	212 µm– 20 µm	20 µm – 2 µm	< 2 µm	USDA Texture Class

Moore Pyramid

01	N/A	N/A	N/A	N/A	N/A
02	96.97	1.95	1.07	0.01	Sand
03	86.70	12.22	0.81	0.27	Sand
04	82.57	16.50	0.00	0.93	Sand
05	N/A	N/A	N/A	N/A	N/A

Mt Wishart

W1	83.98	14.39	0.66	0.97	Sand

Mt Starlight

S1	85.23	10.53	1.77	2.47	Sand

Corry Massif

C1	76.62	17.58	3.54	2.26	Sand
C2	89.17	8.69	1.58	0.56	Sand
C3	85.02	13.26	1.33	0.39	Sand

Mt Forecast

F1	77.33	19.31	2.48	0.88	Sand

Table 4 continued

Sample	2.00 mm– 212 µm	212 µm– 20 µm	20 µm – 2 µm	< 2 µm	USDA Texture Class
COASTAL EAST ANTARCTICA:					
Mawson station					
M1	42.15	49.40	4.99	3.46	Sand
M2	46.31	47.42	3.19	3.08	Sand
M5	74.02	21.00	2.86	2.12	Sand
M6	52.23	38.89	5.30	3.58	Sand
M6 t	58.07	37.15	2.69	2.09	Sand
M7	84.40	13.86	1.44	0.30	Sand
M8	58.61	24.99	5.26	11.14	Loamy Sand
M9 b	43.07	40.81	14.98	1.14	Loamy Sand
M9 t	70.73	25.60	2.66	1.01	Sand
Field Rock					
X1	56.85	40.17	1.70	1.08	Sand
Rumdoodle					
U1	97.94	2.05	0.00	0.01	Sand
Vestfold Hills					
LV	72.52	23.54	2.10	1.84	Sand
PH	62.87	30.09	5.50	1.54	Sand

Table 5. Clay mineralogy of soil samples from the Prince Charles Mountains and coastal East Antarctica (%).

T = trace amounts

Sample	Mont.	Verm.	Chlor.	Illite	Kaol.	Quartz	Int. K:I	Sepiol.	Int. M:I	Int. I:C	Int. M:C
PRINCE CHARLES MOUNTAINS:											
Else Platform											
E1	5	0	5	10	80	0	0	0	0	0	0
E2	20	0	5	5	70	0	0	0	0	0	0
E3	15	0	10	10	65	0	0	0	0	0	0
E4	10	0	5	20	60	0	0	0	5	0	0
E5	10	0	5	15	65	0	T	0	0	0	5
E6	5	0	10	10	75	0	0	0	0	0	0
Jetty Peninsula											
J1	0	0	10	10	80	0	T	T	T	0	0
J3	5	5	5	10	65	0	5	5	0	0	0
Pagodroma Gorge											
P1	5	0	5	15	55	0	0	5	15	0	0
P2	5	0	5	10	75	0	0	0	5	0	0
P3	5	0	5	15	70	0	T	T	5	0	0
P5	0	0	5	10	80	0	5	0	0	0	0
P6	5	0	5	10	70	0	5	0	5	0	0
P7	5	0	10	20	55	0	5	0	5	0	0
P8	5	0	T	15	75	0	5	0	0	0	0

Table 5 continued

Sample	Mont.	Verm.	Chlor.	Illite	Kaol.	Quartz	Int. K:I	Sepiol.	Int. M:I	Int. I:C	Int. M:C
Blustery Cliffs											
B1	30	20	10	30	5	0	5	0	0	0	0
B2	25	15	5	35	10	0	5	0	5	0	0
B3	10	10	10	45	15	0	10	0	0	0	0
B4	15	0	45	10	25	0	5	0	0	0	0
Mt Woinarski											
W1	5	30	5	35	15	0	0	5	5	0	0
W2	5	T	35	20	30	0	5	5	0	0	0
W3	10	40	T	40	5	0	T	T	5	0	0
W4	5	5	25	40	25	0	0	0	0	0	0
W5	5	60	0	30	T	0	0	T	5	0	0
Mt Jacklyn											
Q1	15	20	T	25	0	T	5	10	25	0	0
Q2	10	5	T	55	0	T	T	10	20	0	0
Q3	10	20	T	60	0	0	0	5	5	0	0
Farley Massif											
R1	20	20	T	35	5	0	T	10	10	0	0

Table 5 continued

Sample	Mont.	Verm.	Chlor.	Illite	Kaol.	Quartz	Int. K:I	Sepiol.	Int. M:I	Int. I:C	Int. M:C
Moore Pyramid											
01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
02	15	20	5	25	15	0	10	10	0	0	0
03	10	15	5	50	5	0	5	10	0	0	0
04	10	10	5	15	15	0	5	15	25	0	0
05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mt Wishart											
I1	40	15	10	25	10	0	T	0	0	0	0
Mt Starlight											
S1	10	10	T	40	0	5	T	10	25	0	0
Corry Massif											
C1	40	10	T	20	0	0	0	0	10	20	0
C2	20	5	10	45	0	0	0	15	0	0	5
C3	40	10	5	25	10	0	5	0	0	5	0
Mt Forecast											
F1	5	65	5	0	5	5	T	15	0	0	0

Table 5 continued

Sample	Mont.	Verm.	Chlor.	Illite	Kaol.	Quartz	Int. K:I	Sepiol.	Int. M:I	Int. I:C	Int. M:C
COASTAL EAST ANTARCTICA:											
Mawson station											
M1	75	0	5	15	5	T	0	T	0	0	0
M2	75	0	5	10	10	T	0	T	0	0	0
M5	20	60	5	15	T	T	0	0	0	0	0
M6	55	0	5	15	10	0	5	10	0	0	0
M6 t	60	0	5	15	10	T	5	5	0	0	0
M7	60	0	T	20	5	T	T	0	15	0	0
M8	5	10	10	30	5	0	0	5	35	0	0
M9 b	95	0	T	5	T	T	0	T	0	0	0
M9 t	70	0	5	10	5	T	5	5	0	0	0
Field Rock											
X1	75	5	5	10	5	0	0	0	0	0	0
Rumdoodle											
U1	85	0	T	10	0	0	0	5	0	0	0
Vestfold Hills											
LV	30	0	5	50	10	0	5	0	0	0	0
PH	45	0	5	35	10	0	5	0	0	0	0

Table 6. Water content of soil samples from the Prince Charles Mountains and coastal East Antarctica.

	MOISTURE CONTENT	
SAMPLE CODE	PERCENT DRY WEIGHT	PERCENT VOLUME
PRINCE CHARLES MOUNTAINS:		
Else Platform		
E1	5.43	7.06
E2	11.50	19.13
E3	2.87	4.21
E4	4.60	6.34
E5	4.79	---
E6	8.63	11.86
Jetty Peninsula		
J1	4.83	6.85
J3	16.95	26.40
J5	0.79	1.07
Pagodroma Gorge		
P1	4.14	5.66
P2	12.14	15.28
P3	7.72	9.78
P4	3.90	2.90
P5	2.86	3.76
P6	15.48	22.04
P7 (1st cm)	1.35	1.42
P7 (deeper soil)	11.40	16.21
P8	4.01	5.29

Table 6 continued

	MOISTURE CONTENT	
SAMPLE CODE	PERCENT DRY WEIGHT	PERCENT VOLUME
Blustery Cliffs		
B1	3.92	5.03
B2 (1st cm)	0.12	0.16
B2 (2nd cm)	2.97	3.85
B3	3.55	4.68
B4	11.30	19.63
Mt Woinarski		
W1	2.00	---
W2	1.36	---
W3	0.64	---
W4	1.75	2.35
W5	1.79*	2.39*
Mt Jacklyn		
Q1	0.15	0.24
Q2	1.63	2.19
Q3	0.20	0.32
Farley Massif		
R1	0.25	0.36
Moore Pyramid		
01	34.29	44.79
02	2.96	3.90
03	3.04*	3.81*
04	2.56	3.59
05	4.20	---
Mt Wishart		
I1	3.39	4.60
Mt Starlight		
S1	2.09	3.25

Table 6 continued

	MOISTURE CONTENT	
SAMPLE CODE	PERCENT DRY WEIGHT	PERCENT VOLUME
Corry Massif		
C1	0.38	0.62
C2	0.20	0.32
C3	0.19	0.31
Mt Forecast		
F1	0.21	0.32
COASTAL EAST ANTARCTICA:		
Mawson station		
M1	14.42	---
M2	1.85	---
M5	14.37	---
M6	19.03	---
M6 t	12.70	---
M7	1.43	---
M8	66.68	---
M9 b	6.86	---
M9 t	4.91	---
Field Rock		
X1	0.29	---
Rumdoodle		
U1	0.28	---
Vestfold Hills		
LV	4.13	5.80
PH	3.86	---

* Tube with cracked lid – sample probably dried to some extent.

Table 7. Physico-chemical properties of some soils from the Prince Charles Mountains and coastal East Antarctica.

SAMPLE NO.	pH KCl (1:5)	pH H_2O (1:5)	µS cm^{-1} (1:5)	WATER-Sol. P (1:5) (µg mL^{-1})	WATER-Sol. K (1:5) (µg mL^{-1})	WATER-Sol. K (1:5) (µg g^{-1})	EXCH. + Sol. K (cmol.kg^{-1})	COLOUR (MUNSELL)	TOTAL N (µg g^{-1})	MIN. N (KCl) NH_4-N (µg g^{-1})	MIN. N (KCl) NO_3-N (µg g^{-1})	DILUTE ACID-Sol. P (µg g^{-1})	LOSS ON IGNITION (%)
B2	6.83	6.81	12.2	0.11	0.6	6.3	0.33	7.5YR 5/4 Brown	161	4.1	0.2	42	0.6
B3	6.36	7.02	7.7	0.08	0.5	4.9	0.21	10YR 5/3 Brown	102	4.4	<0.1	61	0.3
B4	7.44	8.28	19.5	0.08	0.6	5.8	0.25	10YR 5/2 Grey brown	102	3.0	0.5	122	1.2
C1	4.81	5.14	2.0	0.05	3.1	31.2	0.24	10YR 5/3 Brown	245	1.3	220	45	0.7
C2	4.44	4.68	269	0.04	2.2	21.6	0.22	5YR 4/6 Yellowish red	<5	<0.1	3.3	29	0.7
C3	6.65	6.64	68.3	0.06	1.2	11.5	0.30	7.5YR 5/4 Brown	<5	0.3	3.3	55	0.2
E1	6.52	7.38	13.8	0.06	1.1	10.6	0.22	10YR 6/3 Pale brown	171	1.8	0.5	113	1.4
E2	6.38	7.35	15.8	0.07	1.4	14.1	0.27	10YR 6/2 Lt brown grey	166	2.1	<0.1	49	2.3
E3	6.29	7.00	10.6	0.06	0.9	8.5	0.24	10YR 6/3 Pale brown	171	15.3	0.9	92	1.4
E4	6.52	7.04	14.8	0.08	0.6	6.1	0.19	10YR 6/3 Pale brown	166	<0.1	0.6	63	0.8
E6	6.75	7.49	10.9	0.07	0.6	5.7	0.43	10YR 6/3 Pale brown	187	0.4	0.3	80	1.4
F1	8.25	7.93	237	0.04	9.3	93.1	0.59	2.5Y 5/4 Reddish brown	32	1.9	18.0	27	0.2
F5	6.74	6.37	19.0	0.05	1.0	10.1	0.30	10YR 6/4 Lt yellow brown	380	5.8	0.7	64	1.2
J1	4.68	4.98	20.2	0.05	0.9	9.2	0.16	2.5Y 7/2 Lt grey	230	1.5	0.3	91	1.4
J3	5.01	5.89	17.0	0.12	0.9	9.1	0.18	10YR 7/2 Lt grey	214	1.9	0.7	64	1.1
LV	8.14	7.93	81.3	0.19	1.5	15.4	0.23	2.5Y 5/2 Grey brown	321	6.1	3.9	125	0.3

Table 7 continued

SAMPLE NO.	pH KCl (1:5)	pH H$_2$O (1:5)	µS cm^{-1} (1:5)	WATER-Sol. P (1:5) (µg mL^{-1})	WATER-Sol. K (1:5) (µg mL^{-1})	WATER-Sol. K (1:5) (µg g^{-1})	EXCH. + Sol. K (cmol.kg^{-1})	COLOUR (MUNSELL)	TOTAL N (µg g^{-1})	MIN. N (KCl) NH$_4$-N (µg g^{-1})	MIN. N (KCl) NO$_3$-N (µg g^{-1})	DILUTE ACID-Sol. P (µg g^{-1})	LOSS ON IGNITION (%)
M1	4.06	4.94	11.9	0.23	0.6	6.0	0.10	10YR 6/2 Lt brown grey	1382	10.7	7.1	104	2.0
M2	4.95	6.87	18.7	0.39	0.3	2.7	0.10	10YR 5/3 Brown	1892	244	2.2	86	2.1
M5	5.85	7.14	12.1	0.22	0.6	5.7	0.14	10YR 5/2 Grey brown	145	2.2	1.8	102	0.4
M6	5.99	6.27	96.2	1.39	3.4	34.2	0.31	10YR 4/2 Dk grey brown	1756	38.0	64.4	152	8.0
M6 t	6.02	6.80	29.8	0.85	1.1	10.8	0.22	10YR 5/3 Brown	755	63.8	16.5	127	1.1
M7	4.99	6.33	8.4	0.23	0.6	5.7	0.15	10YR 5/2 Grey brown	203	4.5	1.0	126	0.3
M8	4.90	5.07	61.3	1.09	3.8	37.6	0.35	10YR 4/2 Dk grey brown	6431	82.1	2.9	168	13.2
M9 t	6.89	7.84	26.2	0.22	0.5	4.9	0.24	2.5Y 7/2 Lt grey	161	0.7	0.9	120	0.2
M9 b	5.53	6.74	22.5	0.06	1.7	16.6	0.14	10YR 7/2 Lt grey	43	2.1	1.5	224	0.3
03	4.67	5.25	18.1	0.08	0.9	8.8	0.24	10YR 6/2 Lt brown grey	96	3.6	2.8	76	0.5
04	4.81	5.36	9.3	0.06	0.4	4.4	0.11	10YR 6/4 Lt yellow brown	386	6.8	1.1	14	0.5
P1	7.17	7.21	1860	14.9	31.0	310	1.62	10YR 5/1 Grey	11802	1800	36.7	344	2.0
P2	7.65	8.19	10.3	0.04	0.4	4.2	0.38	10YR 6/2 Lt brown grey	375	1.2	0.7	55	3.4
P3	7.81	8.06	47.0	0.05	2.2	22.3	0.18	10YR 5/1 Grey	557	2.6	0.6	38	4.4
P4	6.93	7.30	188	0.03	3.0	29.7	0.32	10YR 5/2 Grey brown	43	<0.1	1.0	229	0.3
P5	7.55	7.76	139	0.71	2.4	23.7	0.31	10YR 5/2 Grey brown	557	2.2	18.2	45	4.5
P6	7.14	7.42	17.4	0.09	1.2	11.6	0.09	10YR 5/2 Grey brown	760	0.7	0.3	23	6.4

Table 7 continued

SAMPLE NO.	pH KCl (1:5)	pH H_2O (1:5)	µS cm^{-1} (1:5)	WATER-Sol. P (1:5) (µg mL^{-1})	WATER-Sol. K (1:5) (µg mL^{-1})	WATER-Sol. K (1:5) (µg g^{-1})	EXCH. + Sol. K (cmol.kg^{-1})	COLOUR (MUNSELL)	TOTAL N (µg g^{-1})	MIN. N (KCl) NH_4-N (µg g^{-1})	MIN. N (KCl) NO_3-N (µg g^{-1})	DILUTE ACID-Sol. P (µg g^{-1})	LOSS ON IGNITION (%)
P7	7.72	7.75	2180	0.02	1.5	146	1.02	10YR 4/2 Dk grey brown	380	5.7	198.1	88	6.7
P8	8.64	8.76	174	0.06	6.6	66.4	0.51	10YR 7/3 V pale brown	209	3.0	12.2	22	3.1
Q1	4.16	4.88	21.5	0.04	0.9	8.6	0.11	7.5YR 5/6 Str brown	134	0.5	<0.1	108	0.5
Q2	7.72	8.15	4610	0.02	53.0	527	3.59	2.5Y 5/4 Lt olive brown	273	5.1	56.7	69	2.1
Q3	3.50	4.39	48.0	0.02	1.5	14.5	0.18	7.5YR 5/6 Str brown	91	1.5	1.4	132	0.5
R1	3.89	4.25	25.0	0.02	0.8	8.3	0.12	7.5YR 5/6 Str brown	155	<0.1	2.2	75	0.4
U1	3.72	4.85	7.7	0.17	0.3	3.2	0.30	2.5Y 6/2 Lt brown grey	316	3.9	3.1	103	0.5
W1	3.84	4.23	909	0.02	1.9	19.2	0.28	10YR 5/4 Yellow brown	190	2.7	174.6	16	1.2
W2	4.39	4.57	773	0.01	1.6	16.2	0.36	10YR 5/3 Brown	184	2.1	163.1	7	2.6
W3	3.67	4.26	1097	0.01	2.8	27.5	0.33	10YR 6/3 Pale brown	143	3.0	120.2	14	1.0
W4	5.29	6.06	9.0	0.04	0.7	7.4	0.21	10YR 6/3 Pale brown	145	3.1	0.9	27	0.5
W5	4.06	4.35	123.5	0.02	2.4	24.4	0.36	10YR 5/3 Brown	96	9.3	52.0	74	0.5
X1	5.05	5.92	6.6	0.07	0.3	3.2	0.12	10YR 6/2 Lt brown grey	96	3.9	0.3	130	0.4

Table 8. Occurrence of protozoans in samples of soils from the Prince Charles Mountains and the Mawson Coast, Antarctica.

N = number of samples from which extractions were made.

		NUMBER (%) OF SAMPLES CONTAINING:	
LOCALITY/SITE	N	AMOEBAE	CILIATES
PRINCE CHARLES MOUNTAINS:			
Jetty Peninsula	4	2 (50)	0
Pagodroma Gorge	7, 5	2 (29)	0
Blustery Cliffs	3	1 (33)	0
Mt Woinarski	7	0	0
Mt Jacklyn	3	0	0
Farley Massif	1	0	0
Moore Pyramid	6	1 (17)	0
Mt Wishart	1	0	0
Mt Starlight	1	0	0
Corry Massif	3	0	0
Mt Forecast	1	0	0
TOTAL	37, 35	6 (16)	0 (0)
COASTAL EAST ANTARCTICA:			
Mawson station	19	18 (95)	13 (68)
Field Rock	7	2 (29)	3 (43)
Rumdoodle	2	1 (50)	0
Vestfold Hills	5	5 (100)	3 (60)
TOTAL	33	26 (79)	19 (58)

Table 9. Summary of occurrences of metazoans in soil samples from the Prince Charles Mountains (PCM) and coastal East Antarctica (CEA).

N = number of replicate samples examined from a particular sampling site.

		NUMBER (%) OF SAMPLES CONTAINING:		
LOCALITY/SITE	N	ROTIFERS	TARDIGRADES	NEMATODES
PRINCE CHARLES MOUNTAINS:				
Else Platform				
E1	5	0	0	2 (40)
E2	5	0	1 (20)	3 (60)
E3	5	0	0	3 (60)
E4	5	0	0	4 (80)
E5	6	0	0	5 (83)
E6	5	0	0	2 (40)
Total	31	0	1 (3)	19 (61)
Jetty Peninsula				
J1	7	1 (14)	3 (43)	0
J2	5	4 (80)	4 (80)	0
J3	10	2 (20)	2 (20)	0
J4	1	0	1 (100)	0
J5	10	1 (10)	4 (40)	0
J6	1	0	0	0
J8	1	0	0	0
J9	1	0	0	0
J10	1	0	0	0
Total	37	8 (22)	14 (38)	0

Table 9 continued

		NUMBER (%) OF SAMPLES CONTAINING:		
LOCALITY/SITE	N	ROTIFERS	TARDIGRADES	NEMATODES
Pagodroma Gorge				
P1	2	0	0	0
P2	20	0	0	5 (25)
P3	8	0	0	0
P4	9	0	0	0
P5	9	0	0	3 (33)
P6	9	0	0	3 (33)
P7	19	0	2 (11)	3 (16)
P8	9	0	0	3 (33)
Total	85	0	2 (2)	17 (20)
Blustery Cliffs				
B1	9	1 (11)	4 (44)	1 (11)
B2	9	0	6 (67)	6 (67)
B3	9	0	8 (89)	8 (89)
B4	8	0	5 (63)	6 (75)
Total	35	1 (3)	23 (66)	21 (60)
Mt Woinarski				
W1	9	0	0	0
W2	9	0	0	0
W3	9	0	0	0
W4	17	3 (18)	0	0
W5	17	0	0	0
Total	61	3 (5)	0	0
Mt Jacklyn				
Q1	9	3 (33)	0	0
Q2	9	0	0	0
Q3	9	1 (11)	0	1 (11)
Total	27	4 (15)	0	1 (4)

Table 9 continued

		NUMBER (%) OF SAMPLES CONTAINING:		
LOCALITY/SITE	N	ROTIFERS	TARDIGRADES	NEMATODES
Farley Massif				
R1	9	1 (11)	1 (11)	0
Moore Pyramid				
O1	9	0	2 (22)	0
O2	7	0	1 (14)	0
O3	9	0	0	0
O4	9	9 (100)	9 (100)	0
O5	8	5 (63)	8 (100)	0
Total	42	14 (33)	20 (48)	0
Mt Wishart				
I1	8	0	0	2 (25)
I2	5	0	0	0
Total	13	0	0	2 (15)
Mt Starlight				
S1	10	0	0	0
Corry Massif				
C1	9	0	0	0
C2	9	0	0	0
C3	6	0	0	4 (17)
Total	24	0	0	4 (7)
Mt Forecast				
F1	9	1 (11)	0	0
GRAND TOTAL				
(PCM)	383	32 (8)	61 (16)	64 (17)

Table 9 continued

		NUMBER (%) OF SAMPLES CONTAINING:		
LOCALITY/SITE	N	ROTIFERS	TARDIGRADES	NEMATODES
COASTAL EAST ANTARCTICA:				
Mawson station				
M1	2	2 (100)	2 (100)	0
M4	3	1 (33)	3 (100)	1 (33)
M5	12	8 (67)	11 (92)	10 (83)
M6	11	11 (100)	11 (100)	2 (18)
M7	9	2 (22)	2 (22)	0
M8	11	11 (100)	11 (100)	0
M9	9	6 (67)	5 (56)	5 (56)
M10	9	1 (11)	1 (11)	0
Total	66	42 (64)	46 (70)	18 (27)
Field Rock				
X1	9	7 (78)	7 (78)	7 (78)
X2	2	0	1 (50)	1 (50)
X3	2	2 (100)	2 (100)	0
Total	13	9 (69)	10 (77)	8 (62)
Rumdoodle				
U1	9	0	0	1 (11)
U2	10	1 (10)	1 (10)	0
Total	19	1 (5)	1 (5)	1 (5)
Vestfold Hills				
LV	11	2 (18)	2 (18)	9 (82)
PH	9	0	0	0
Total	20	2 (10)	2 (10)	9 (45)
GRAND TOTAL				
(CEA)	118	54 (46)	59 (50)	36 (31)

Table 10. Correlation of soil characteristics with elevation and partial correlation among soil properties, as tested by the Spearman Rank Correlation test.

* = significant; ** = highly significant.

VARIABLES	RHO	P
CORRELATION WITH ELEVATION:		
Soil Moisture	0.57	0.0001**
Organic Matter (LOI)	0.39	0.0117*
Water soluble P	0.49	0.0019**
Acid soluble P	0.51	0.0009**
Total N	0.48	0.0018**
pH (Water)	0.44	0.004**
pH (KCl)	0.37	0.0187*
NO CORRELATION WITH ELEVATION:		
Conductivity	0.08	0.6161
Exchangeable K	0.02	0.8864
Water-soluble K (wt.)	-0.007	0.9622
Water-soluble K (vol.)	0.006	0.9691
Nitrate N	0.21	0.182
Ammonia N	-0.15	0.3294
CORRELATIONS OF:		
Soil Moisture & Organic Matter	0.53	0.0005**
Soil Moisture & Soluble P	0.47	0.0021**
Soil Moisture & Acid-soluble P	0.22	0.1542
Soil Moisture & Total N	0.49	0.0014**
Soil Moisture & pH (Water)	0.43	0.0048**
Soil Moisture & pH (KCl)	0.36	0.0194*
Organic Matter & Soluble P	0.65	0.5111
Organic Matter & Acid-soluble P	0.92	0.3581
Organic Matter & Total N	0.71	0.0001**
Organic Matter & pH (Water)	0.26	0.0917
Organic Matter and pH (KCl)	0.22	0.1528
Soluble P & Acid-soluble P	0.43	0.0052**

Table 10 continued

VARIABLES	RHO	P
CORRELATIONS OF:		
Soluble P & Total N	0.41	0.0074**
Soluble P & pH (Water)	0.25	0.1071
Soluble P & pH (KCl)	0.17	0.2841
Acid-soluble P & Total N	0.03	0.862
Acid-soluble P & pH (Water)	0.05	0.7266
Acid-soluble P & pH (KCl)	-0.07	0.6391
Total N & pH (Water)	0.18	0.2286
Total N & pH (KCl)	0.21	0.1665
pH (Water) & pH (KCl)	0.94	0.0001**

Table 11. Association between various micro-invertebrate taxa in soils from the Prince Charles Mountains (PCM) and coastal localities.

χ^2 = Chi-square value.

Shaded values are statistically significant.

ASSOCIATION			PCM				COASTAL			
			Observed	Expected	χ^2	+/–	Observed	Expected	χ^2	+/–
Rotifer	x	Tardigrade	7	3.67	**5.90**	+	12	10.40	**9.23**	+
Rotifer	x	Nematode	3	4.35	0.90	–	6	4.80	2.50	+
Nematode	x	Tardigrade	6	6.33	0.04	–	7	6.07	2.02	+
Tardigrade	x	Amoeba	4	2.36	2.28	+	12	11.27	2.68	+
Nematode	x	Amoeba	4	1.82	4.59	+	7	6.07	2.02	+
Rotifer	x	Amoeba	3	2.00	0.92	+	11	9.60	5.10	+
Ciliate	x	Amoeba	0	0	0		7	6.93	0.01	+
Tardigrade	x	Ciliate	0	0	0		8	6.93	2.64	+
Nematode	x	Ciliate	0	0	0		6	3.74	**5.53**	+
Rotifer	x	Ciliate	0	0	0		7	6.40	0.60	+

Figures

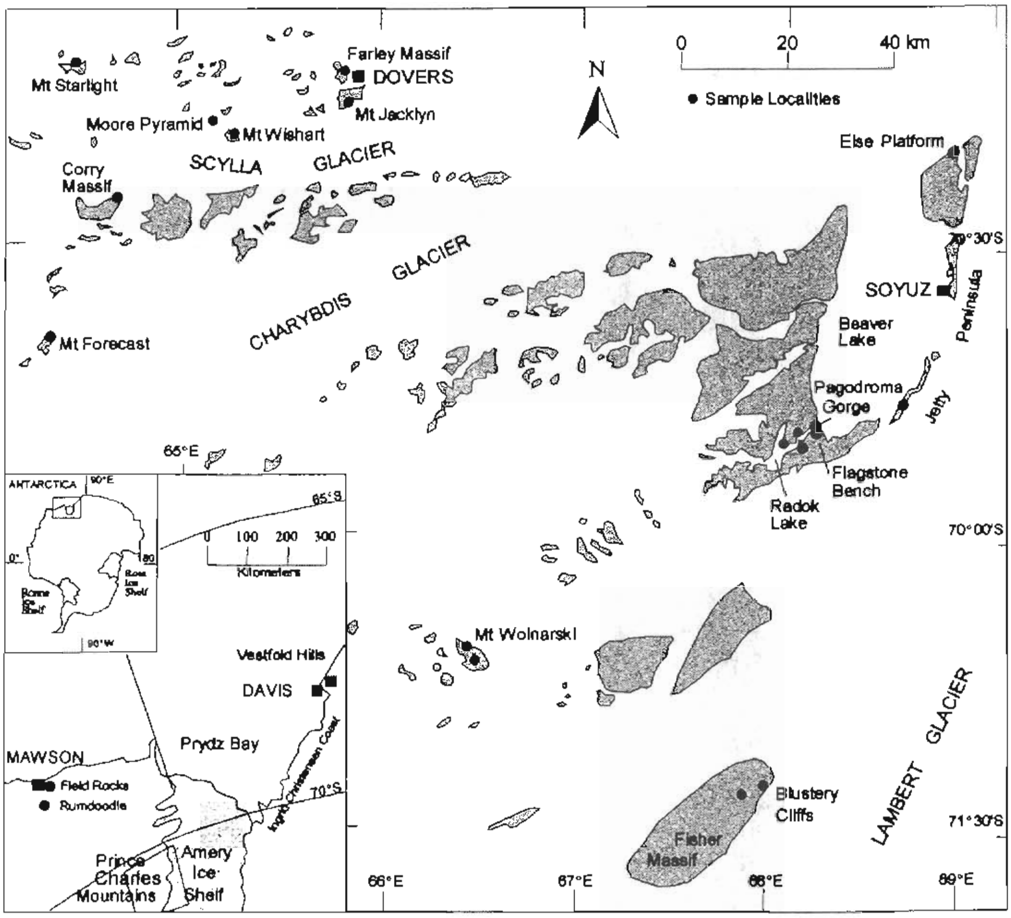

Figure 1. Map of the northern Prince Charles Mountains with an inset of the East Antarctic coast, showing sampling localities. Smaller inset of Antarctica shows location of a portion of the East Antarctic coast shown in larger inset.

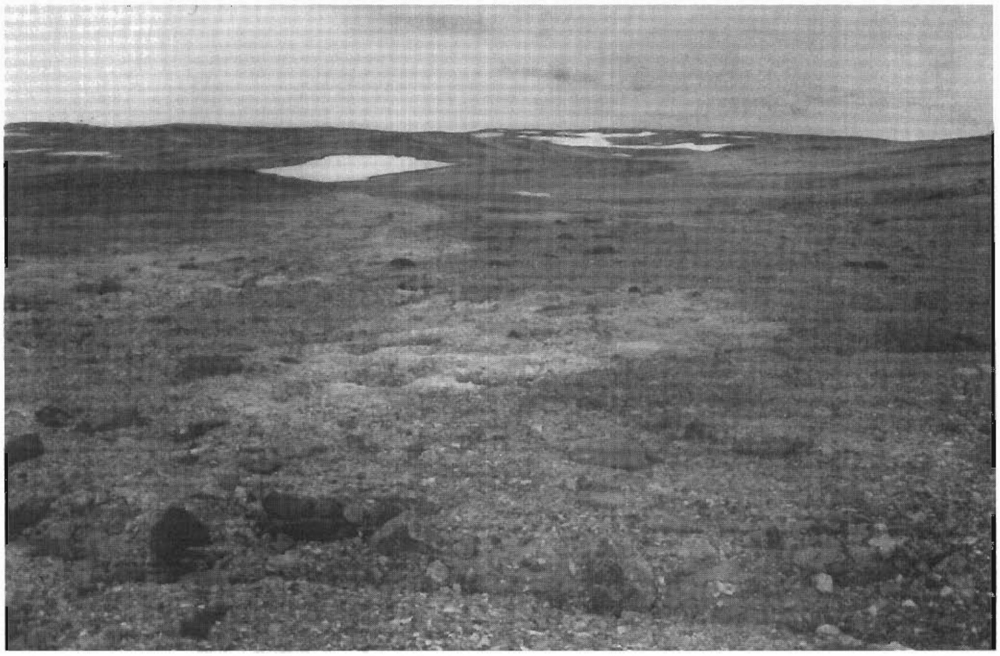

Figure 2. Panoramas of the study sites: a. Else Platform.

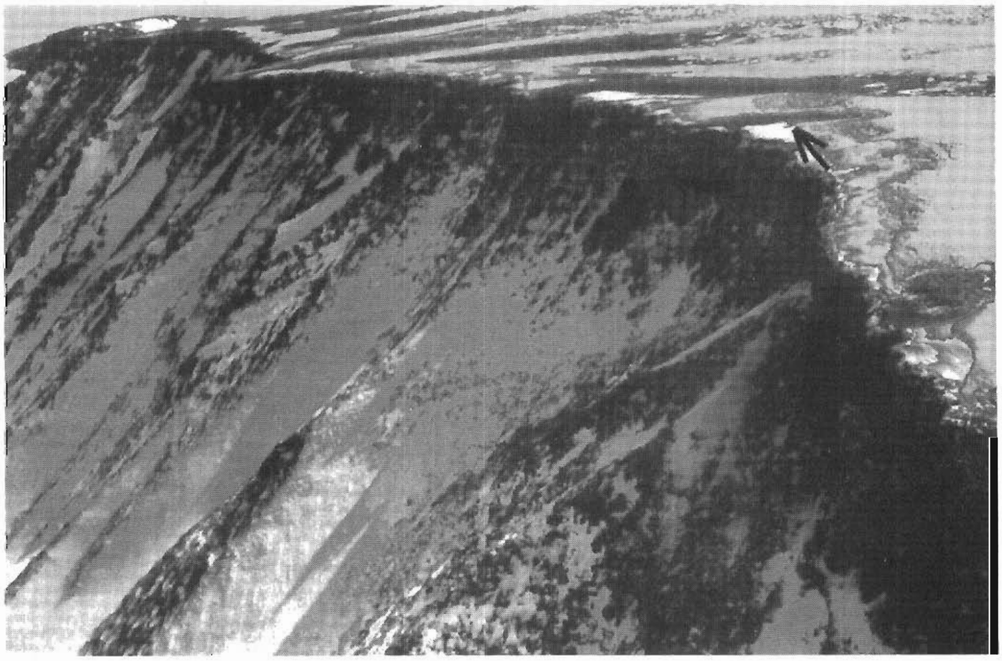

Figure 2b. Blustery Cliffs; arrow points to helicopter for scale.

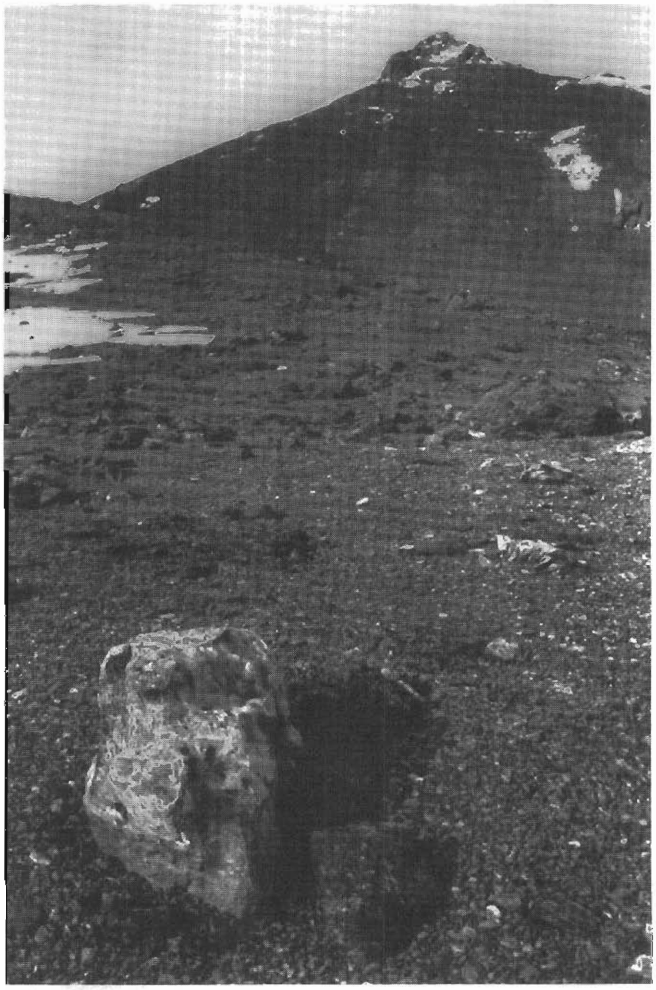

Figure 2c. Mt Jacklyn.

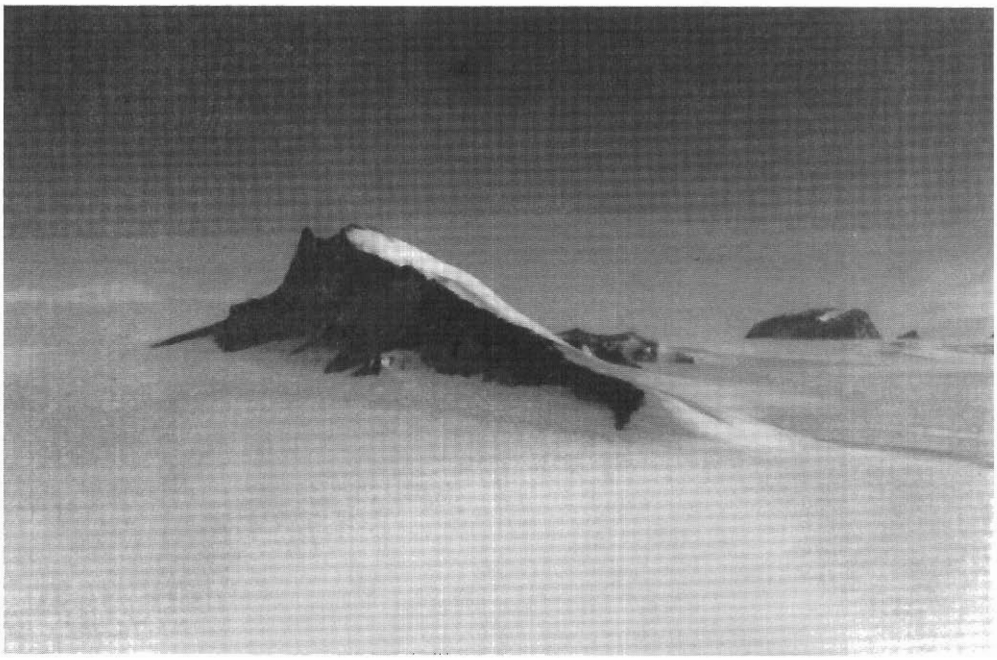

Figure 2d. Moore Pyramid.

Figure 2e. Mt Wishart.

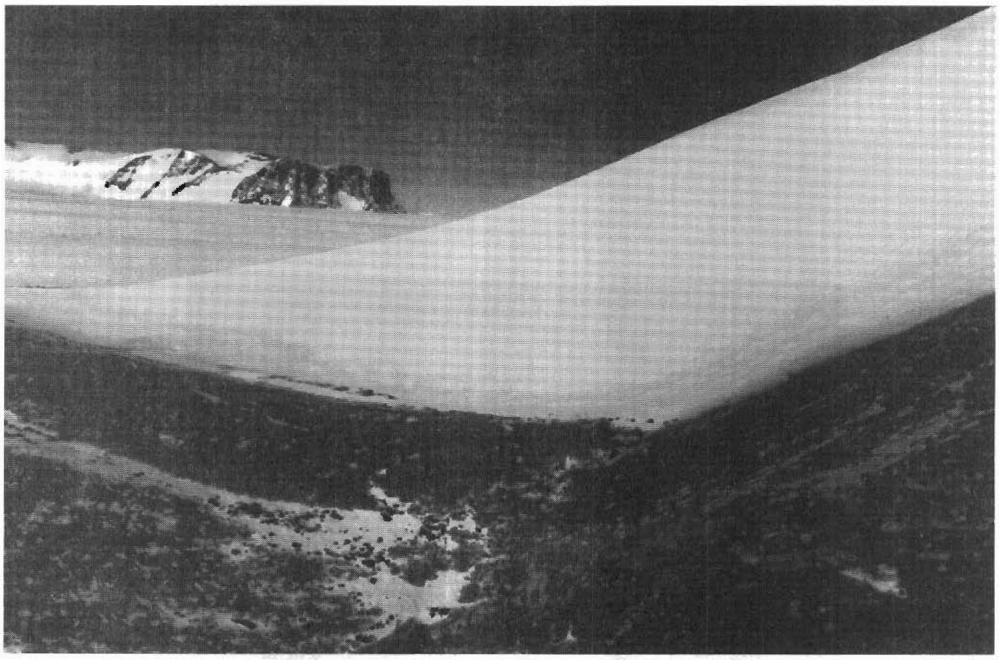

Figure 2f. Corry Massif.

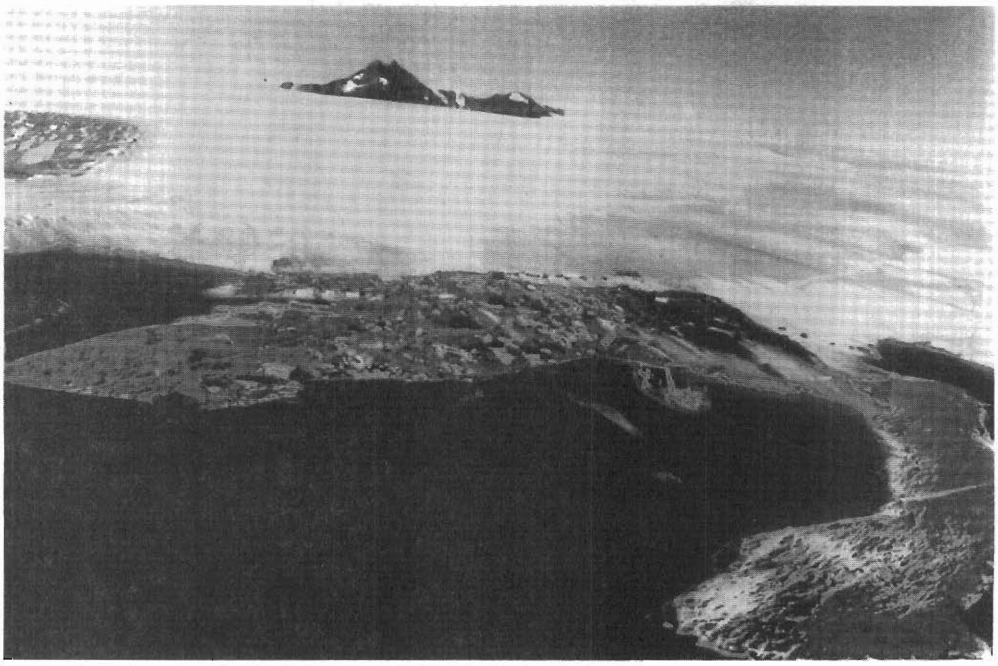

Figure 2g. Mawson station; note buildings and ship for scale and Mt Henderson in the background.

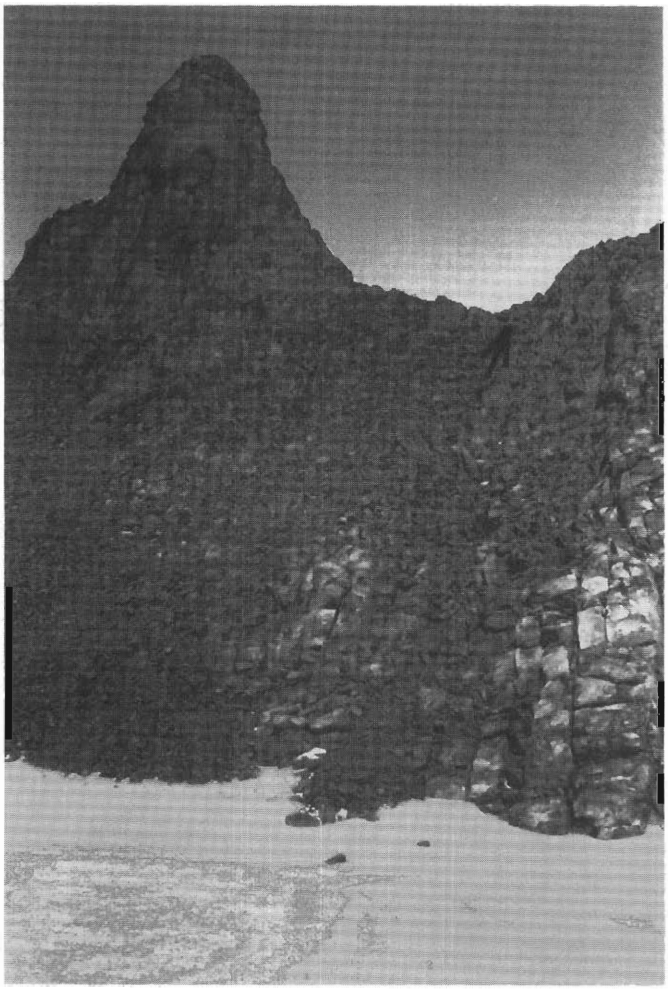

Figure 2h. Rumdoodle; arrow points to person for scale.

Figure 2i. Lichen Valley in the Vestfold Hills.

Figure 3. Antarctic sampling sites: a. Else Platform, site E6; note Swiss army knife for scale.

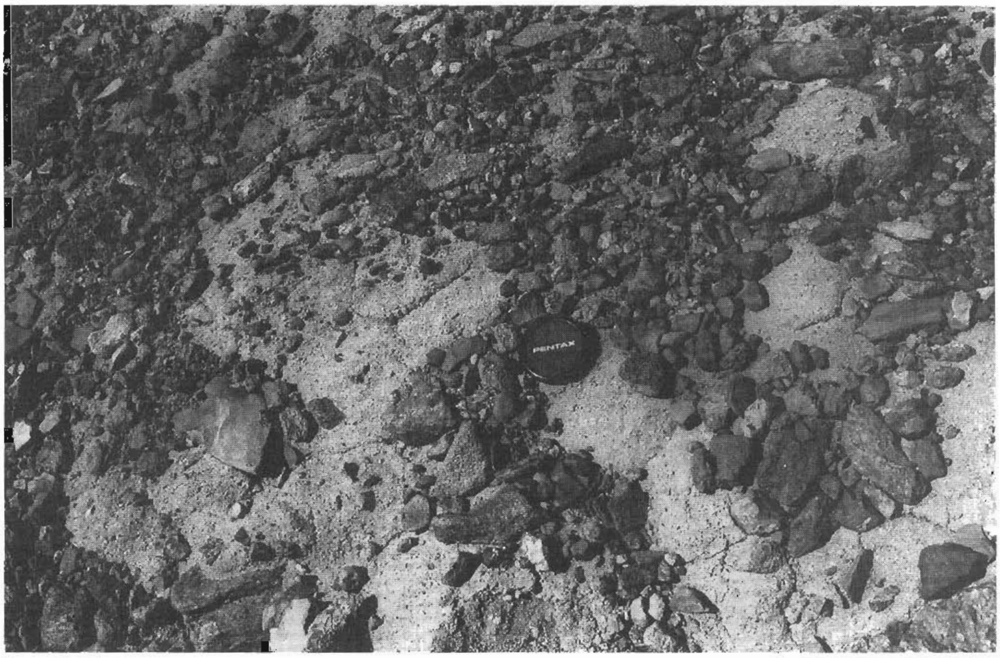

Figure 3b. Pagodroma Gorge, site P2; note lens cover for scale.

Figure 3c. Mt Woinarski, site W4; note lens cover for scale.

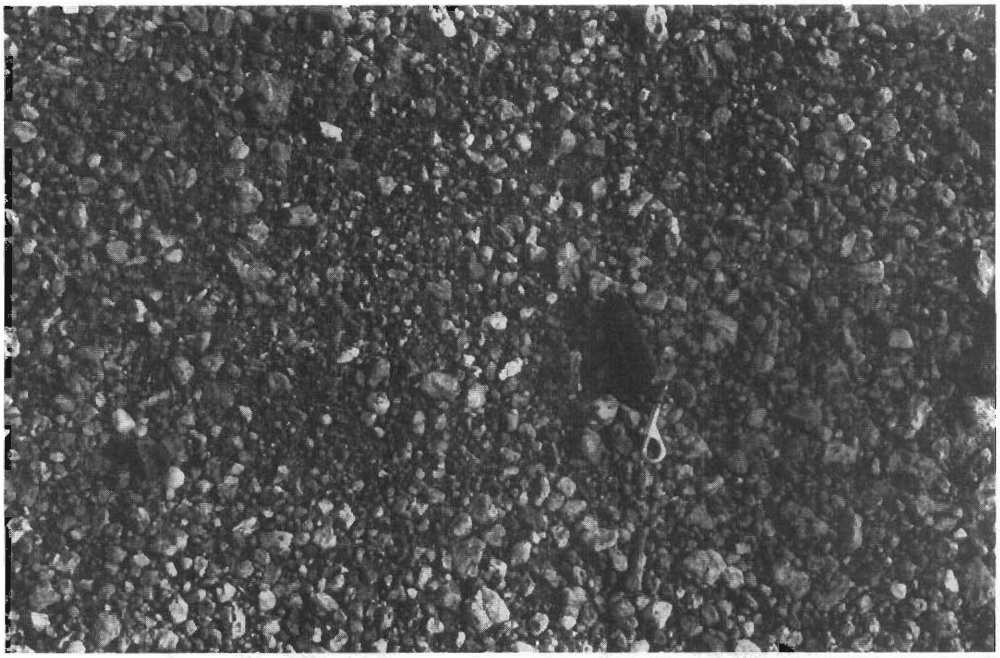

Figure 3d. Mt Jacklyn, site Q2; note Swiss army knife for scale.

Figure 3e. Mawson station, site M5; note cushions of moss.

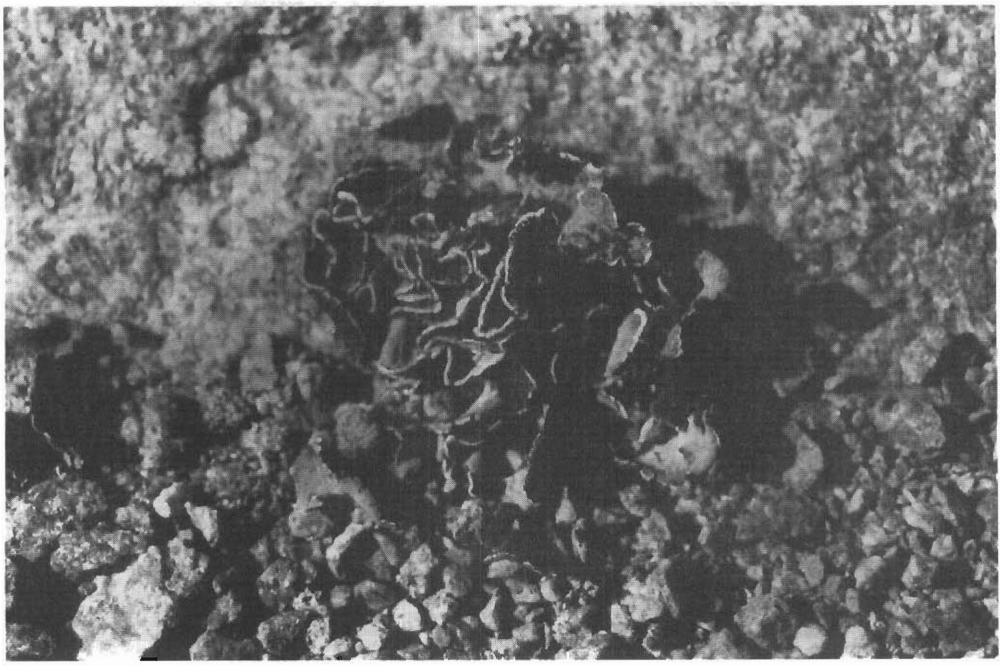

Figure 3f. Field Rock, note rosette-like lichen.

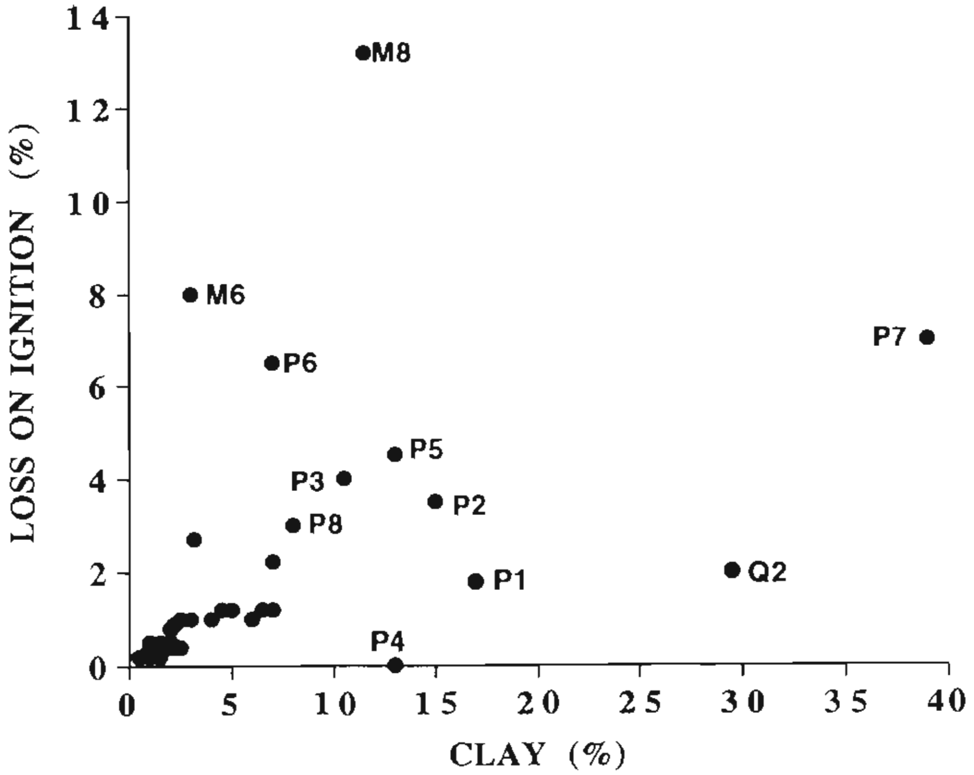

Figure 4. Relationship between percent weight loss on ignition (LOI) and clay content for some Antarctic soils. See site descriptions and Table 7 for sample designations.

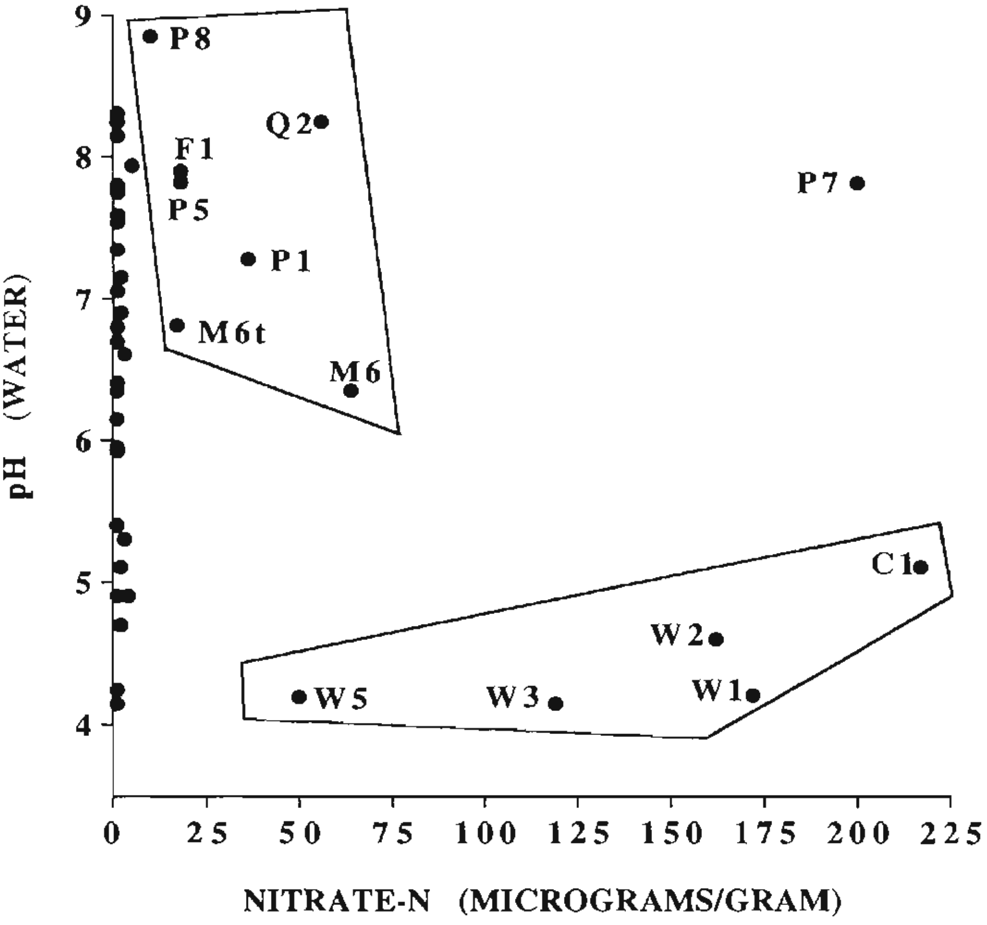

Figure 5. Relationship between pH and nitrate nitrogen for some Antarctic soils; sample designations as in site descriptions and Table 7.

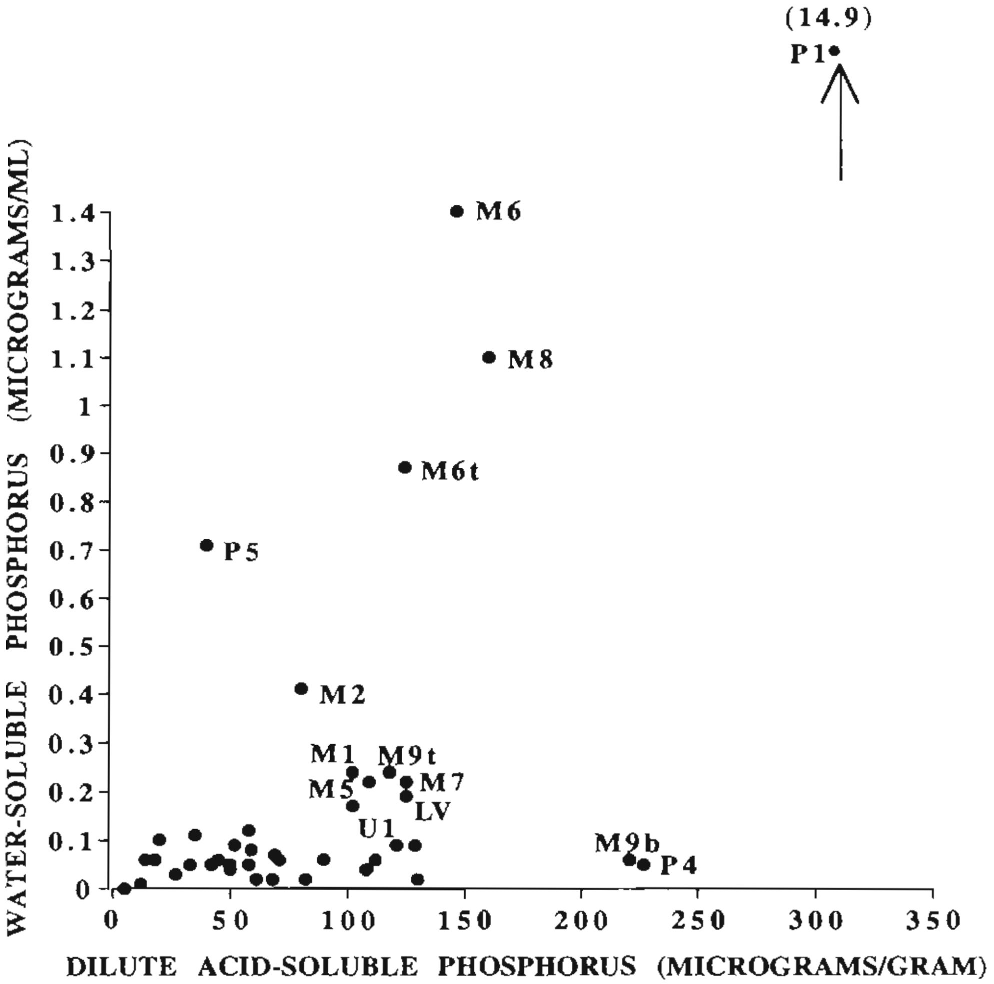

Figure 6. Water soluble phosphorus concentrations in relation to dilute acid-extractable phosphorus present in some Antarctic soils; sample designations as in site descriptions and Table 7.

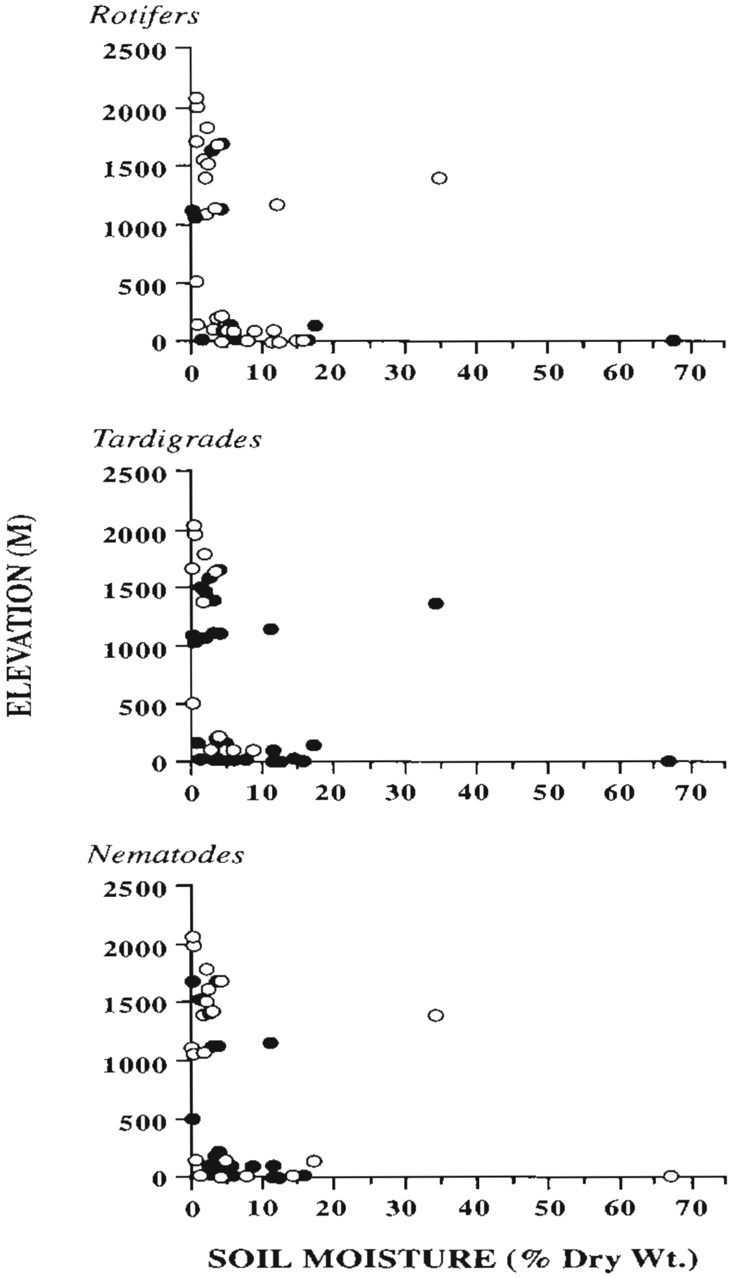

Figure 7. Occurrence of microscopic metazoans in Antarctic soils in relation to soil moisture and elevation. Dots indicate samples which contained the taxon designated. Circles indicate samples that did not contain the taxon designated.

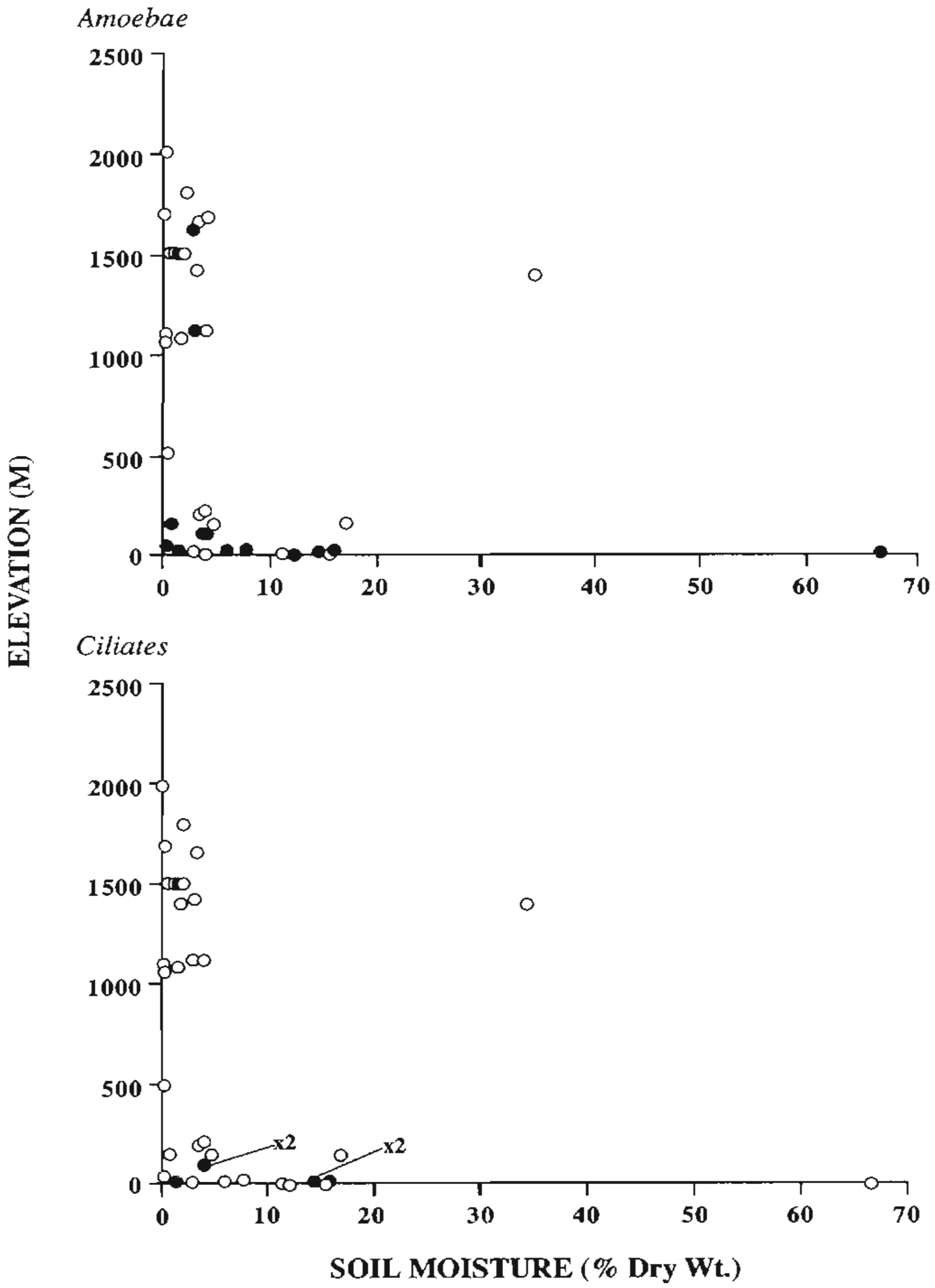

Figure 8. Occurrence of amoebae and ciliated protozoa in Antarctic soils in relation to soil moisture and elevation. Dots indicate samples which contained protozoans. Circles indicate samples that did not contain them.

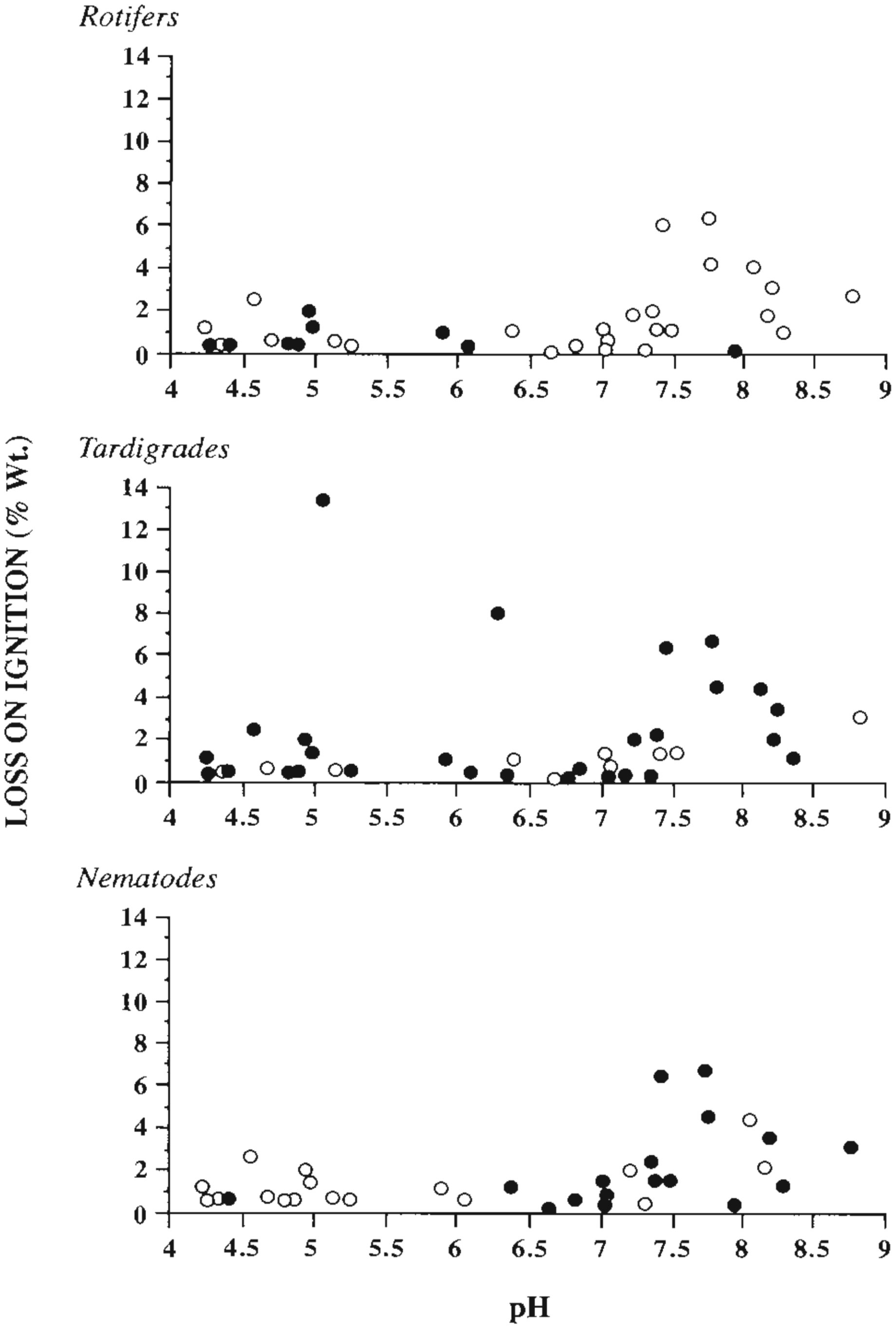

Figure 9. Occurrence of metazoans in soil samples of differing organic matter content and pH. Dots indicate samples which contained the taxon designated. Circles indicate samples that did not contain the taxon designated.

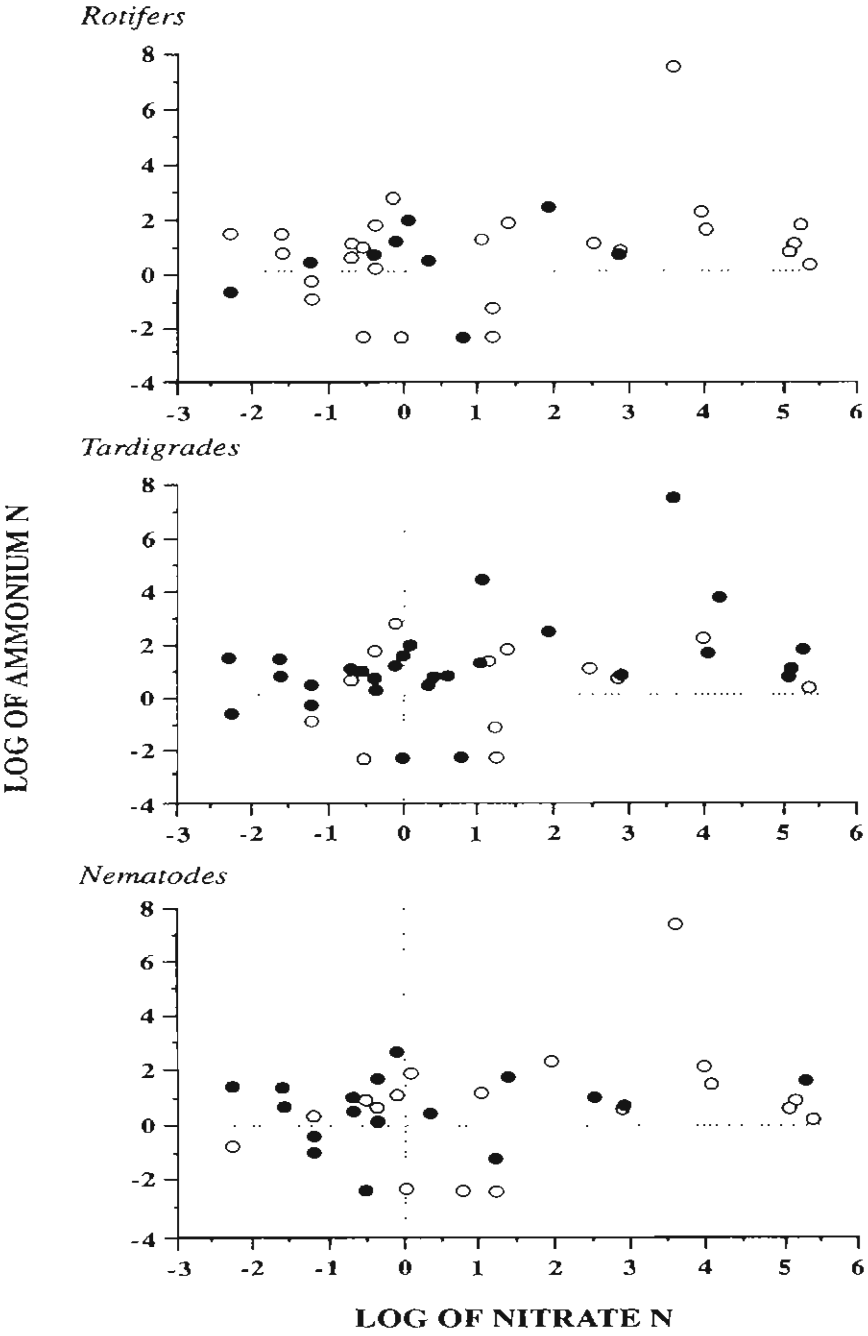

Figure 10. Occurrence of metazoans in soil samples of differing ammonium-N content (μg g^{-1}) and nitrate-N content (μg g^{-1}). Dots indicate samples which contained the taxon designated. Circles indicate samples that did not contain the taxon designated.

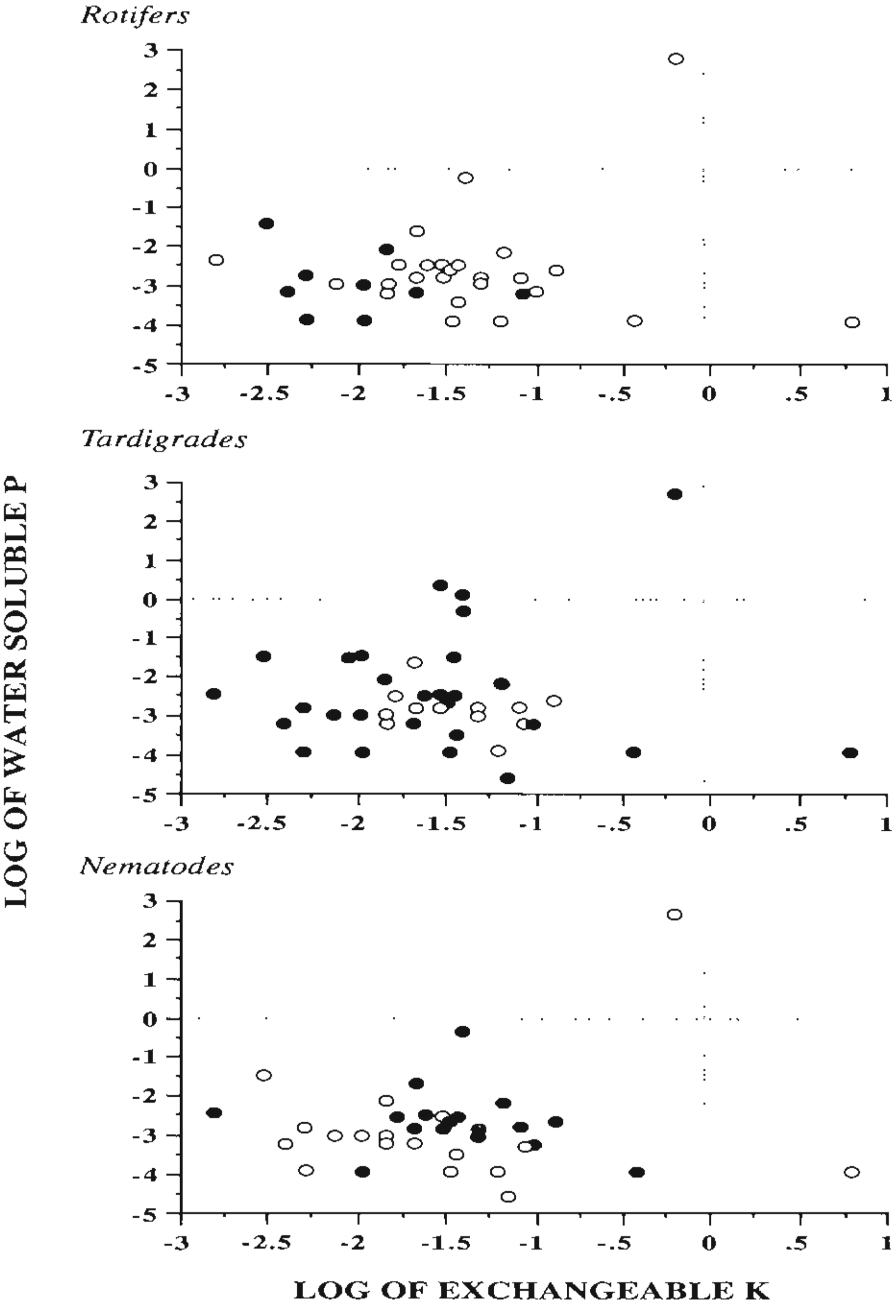

Figure 11. Occurrence of metazoans in soil samples of differing content of water-soluble P (µg mL^{-1}) and exchangeable K (cmol. kg^{-1}). Dots indicate samples which contained the taxon designated. Circles indicate samples that did not contain the taxon designated.

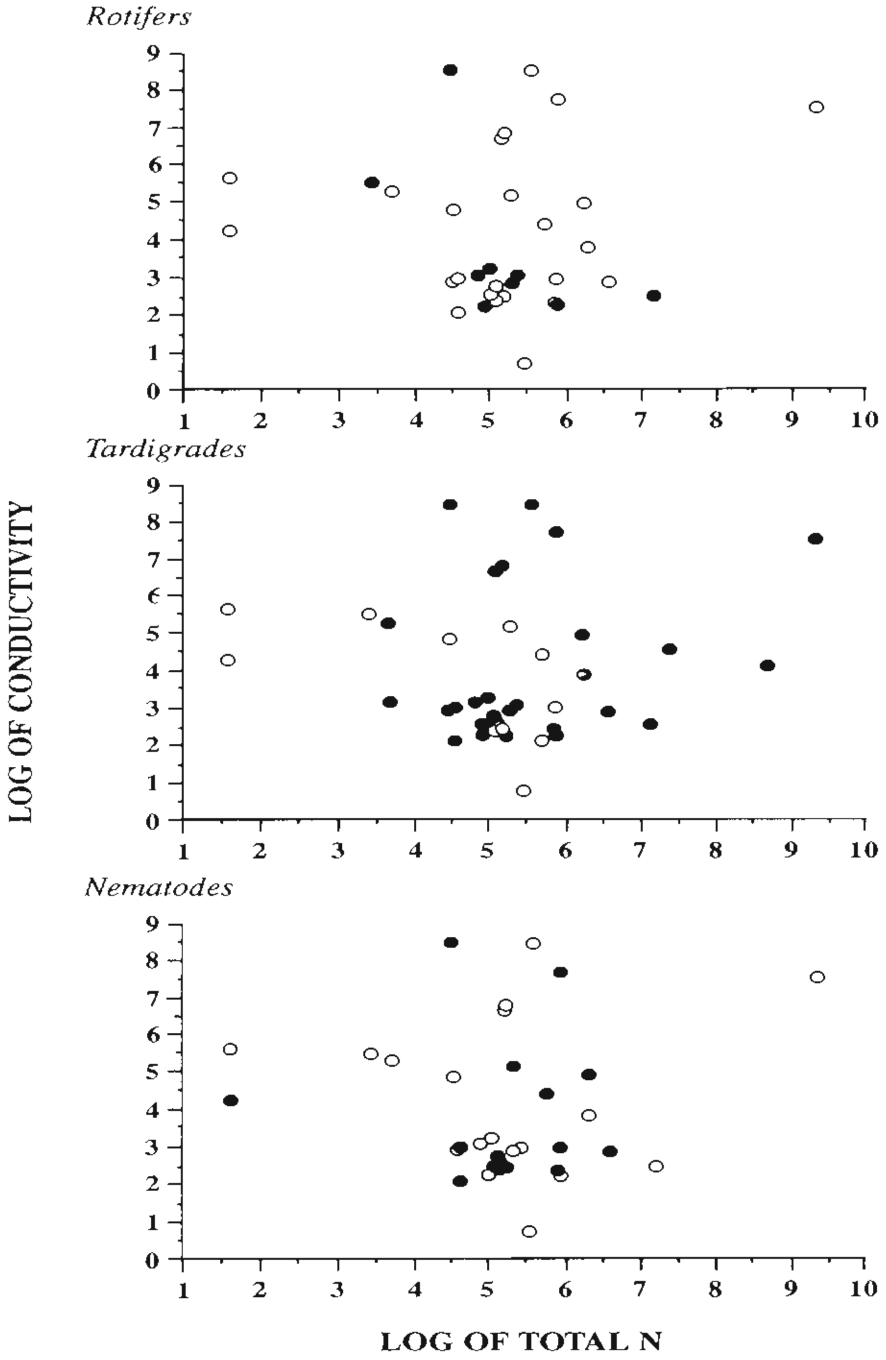

Figure 12. Occurrence of metazoans in soil samples of differing conductivity (μS cm^{-1}) and total N (μg g^{-1}). Dots indicate samples which contained the taxon designated. Circles indicate samples that did not contain the taxon designated.

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