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PEDOLOGY AND MICROBIOLOGY

Soil types and nutrients on Signy Island

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Although all the soils on Signy Island are at an early stage of development a number of contrasting types are present. In this report the influence of the various internal and external soil-forming factors described by Jenny (1941) and others on the chemistry of the Island's soils are considered.

Parent rock

The parent rock is largely quartz-mica schist but with subordinate amphibolites (hornblende) and marble. The mica schist dominates in the formation of mineral debris in contrast to the marble which is particularly resistant to weathering. In temperate latitudes schist weathers to a fragmentary soil which is often subject to drought and is rather low in mineral nutrients. On Signy Island frequent precipitation and high humidity maintain saturated conditions at most times. Under these conditions, and to freeze-thaw cycles in particular, the schist is vulnerable to weathering. In some places a grey, flakey, fragmentary material is produced which is further sorted out by solifluxion and drainage to give local concentrations of silt and clay.

Whenever the schist foliation is inclined towards the vertical the structural planes are exposed to maximum water penetration. This would facilitate the replacement of potassium in the schist planes by sodium ions which are abundant in the Island's water. Comparison of results obtained from soil clay with those from the parent rock (figure 6) show a higher extractable potassium and magnesium in the clay. In addition, the Al/Si ratio was found to decrease from 0·56 in the schist to 0·47 in the clay fraction. This suggests that, although physical weathering is dominant, chemical changes are also significant. Other evidence supporting this suggestion, although less conclusive, is the presence of free sesquioxides and the many instances of colour banding on the Island.

The physical/chemical breakdown of the schist is probably the main source of nutrient potassium and also provides some calcium, magnesium and trace mineral nutrients. It will be seen later that the semi-ombrogenous vegetation, without access to the schist potassium, is lower in this element. Clay (and peat) colloids provide a retention medium for these and other ions released from the parent materials. The extractable levels of principal nutrients in the mineral soils are shown in table 2. Other results from polygonal and stripe soils have no chemical significance apart from higher exchange capacity associated with redistribution of the clay fractions. The fragmentary material gave lower extractable results. The marble does not appear to influence the nature of the mineral soils apart from areas immediately around marble knolls.

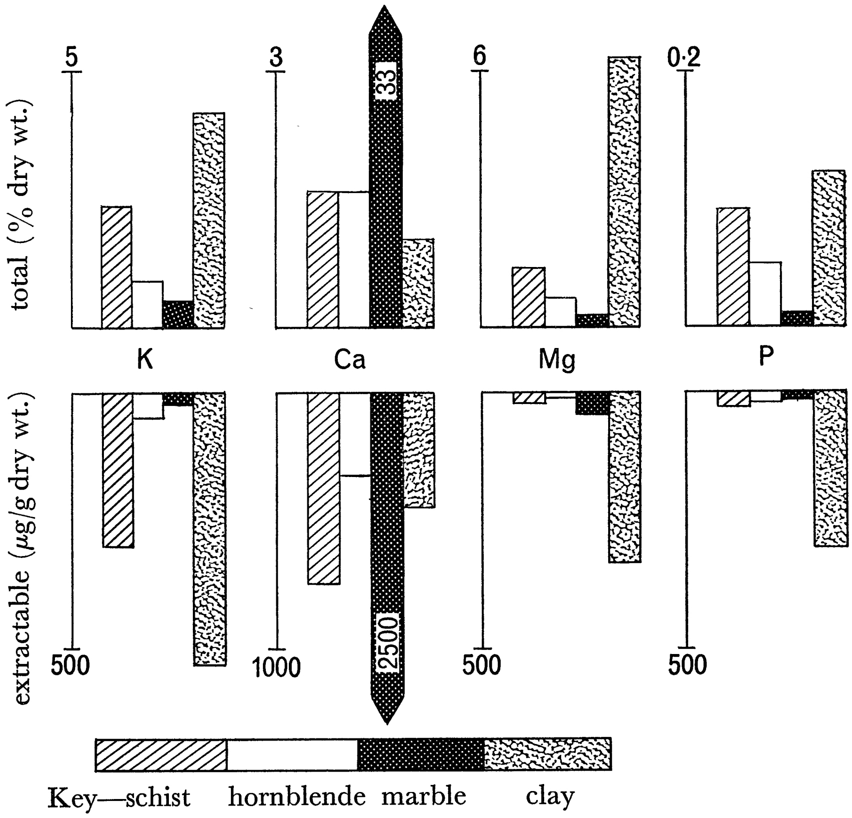

FIGURE 6. Potassium, calcium, magnesium and phosphorus content of parent rocks and of the clay fraction of Signy Island soils.

TABLE 2. SOME CHEMICAL CHARACTERISTICS OF SIGNY ISLAND MINERAL SOILS

The data for the Alaskan brown soil are from Drew & Tedrow (1957).

	pH	organic matter (%)	exchangeable cations (mg/100 g) K	Ca	Mg	P (%)	N (%)	C/N
Signy material								
schist gravel	6·1	2·0	3	13	5	0·16	0·04	30
schist clay	6·3	2·5	8	30	10	0·14	0·06	25
marble debris	8·4	2·2	3	660	15	0·15	0·05	26
brown soil	5·4	11·8	18	76	40	0·28	0·57	12
Arctic material								
Alaskan brown soil	4·3	11·5	8	21	9	—	0·38	18

Results on dry weight basis

ORGANISMS

Under this heading the contribution by all the main groups of plants and animals on the Island to the chemical status of the soils will be considered. Vegetation is examined first.

The dominant macroscopic plants of Signy Island are bryophytes and for this study they can be divided into three groups:

(1) The semi-ombrogenous forms (*Polytrichum–Dicranum*) which occur on their own flush beds of peat.

(2) The soligenous type of vegetation (*Brachythecium–Drepanocladus*) found on peats which are permeated with ground water. Peat development in association with these mosses is moderate.

(3) The *Andreaea–Grimmia–Tortula* group of bryophytes which are associated with rocky surfaces (*Andreaea* with the schist and *Grimmia* with marble). Organic matter accumulation beneath them is minimal and they appear to depend upon direct contact with rock for much of their mineral ions.

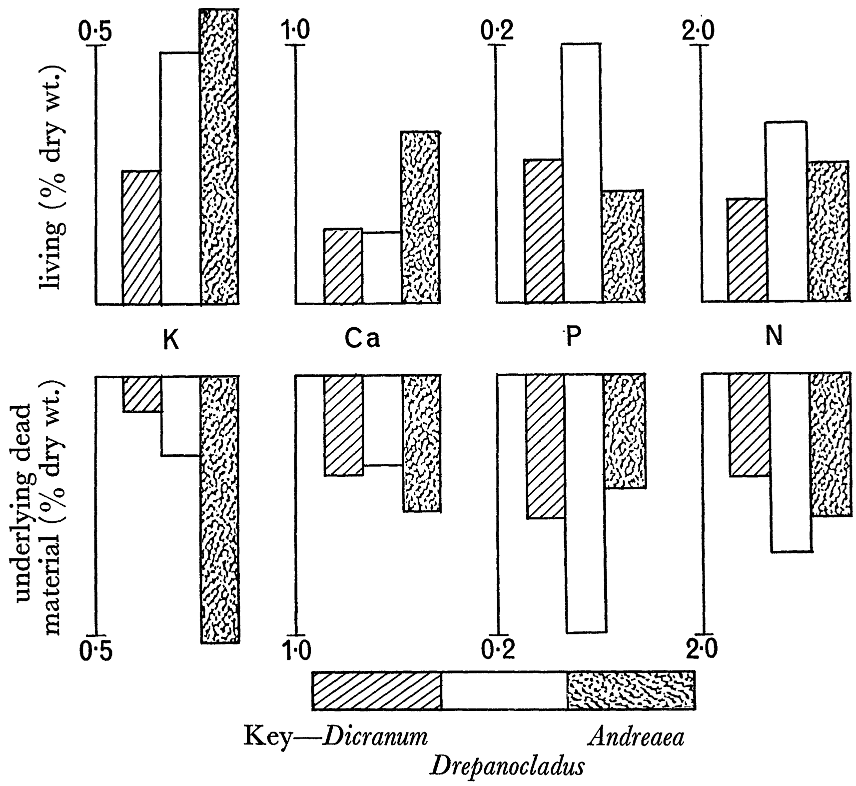

FIGURE 7. The potassium, calcium, phosphorus and nitrogen content of some bryophyte species and of their underlying dead tissue.

Chemical compositions of these three vegetational types and their underlying dead tissue are given in figure 7. The semi-ombrogenous vegetation has the lowest mineral content and was also found to have the lowest pH, whereas the reverse is the case with the rock species. The soligenous group is intermediate in character. The recirculation of potassium in the plant, assessed by the comparison of the vegetation with the underlying dead material, is more evident with the *Polytrichum–Dicranum* communities. Tests were carried out to examine the capacity of all the mosses to retain nutrients from synthetic rain solutions. It was found that most of the mosses were able to take up nutrients in this way, although surprisingly the *Andreaea* and *Grimmia* showed the highest retention capacity.

Peats that develop under mosses in the Arctic regions rarely pass the dense compact fibrous stage and reach the hydrolytic gelatinous humification stage shown by blanket bog peats of the British Isles. The Signy peats show the structural features associated with Arctic peats but the pH is higher and they generally have a higher nutrient content

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(table 3). Results for the Arctic peat included in the table are typical of much of the Russian and Alaskan data. Neither these peats nor the Signy material were as acid or as low in nutrients as the British moss peats. Very little mixing occurs between the peat on Signy and underlying mineral soils, although slight penetration of the rock by humic acids is shown by staining and may contribute to rock disintegration.

TABLE 3. SOME CHEMICAL CHARACTERISTICS OF PEATS FROM SIGNY ISLAND, GREAT BRITAIN AND RUSSIA

The data for the Russian Arctic peat are from Vilenskii (1957).

		pH	Na/K	total bases (Ca + Mg)	% dry wt P	% dry wt N
Polytrichum–Dicranum peat (Signy Island)	2 cm	5·0	8	0·57	0·08	1·4
Polytrichum–Dicranum peat (Signy Island)	10 cm	5·2	8	0·53	0·12	2·0
Upland *Sphagnum* peat (Great Britain)	2 cm	3·2	0·3	0·19	0·03	1·5
Arctic peat (Russia)	—	3·9	0·9	0·55	0·04	1·0

The only vascular plants on the Island (*Deschampsia antarctica* and *Colobanthus crassifolius*) are found on north-facing slopes. These slopes are effective radiation traps and also appear to be subject to snow drifting which affords protection during the winter. These plants appear to be able to produce sufficient litter for incorporation into a brown earth type soil which has some similarity to the shallow brown soils of Tedrow, Drew, Hill & Douglas (1958). The chemical composition of this soil may be compared with the raw mineral soils by reference to table 2. It can be seen that the incorporated organic matter is higher and has the relatively low C/N ratio of 11 to 13 frequently shown by active 'flush' soils in upland and Arctic regions. On this evidence it is the only soil likely to have an active microbial population.

This leads to a consideration of the role of micro-organisms which for the purpose of this discussion fall under the general heading of organisms. Apart from those in the brown soils they do not appear to be active in chemical fixation or nutrient circulation. The high C/N ratios of the peat and conditions of waterlogging would favour a mainly anaerobic population that is not particularly active in decomposition. Incubation tests with various peat samples did not lead to any significant increase in inorganic nitrogen, but the brown soils when similarly tested showed a slight increase. The composition, population and activity of the micro-organisms in these soils is discussed by Heal, Bailey & Latter in another paper presented at this Discussion, p. 191.

The third group of organisms to be considered are the large breeding colonies of vertebrates, principally penguins, seabirds and seals. The high results obtained for calcium, phosphorus and nitrogen from the breeding sites are shown in figure 8. Such large amounts are toxic to vegetation in the immediate area, but even away from the rookeries and wallow grounds the effect of this chemical reservoir is very important. Analyses of all the soils showed higher values for phosphorus and inorganic nitrogen than are found in similar type soils of other parts of the world. A few of the samples taken at a considerable distance from the contaminated areas had abnormally high levels of phosphorus that could only be explained as a result of droppings in the immediate area. The down-wash by snow meltwater would help in the distribution of nutrients from these random droppings. The relative importance of the different ways of distribution from the contaminated area is not yet clear. Rainwater was found to contain large amounts of inorganic nitrogen but not the non-volatile phosphates. Wind movement of fine particulate matter and aerosols, drainage, and periodical movement of nesting areas, must all be taken into account.

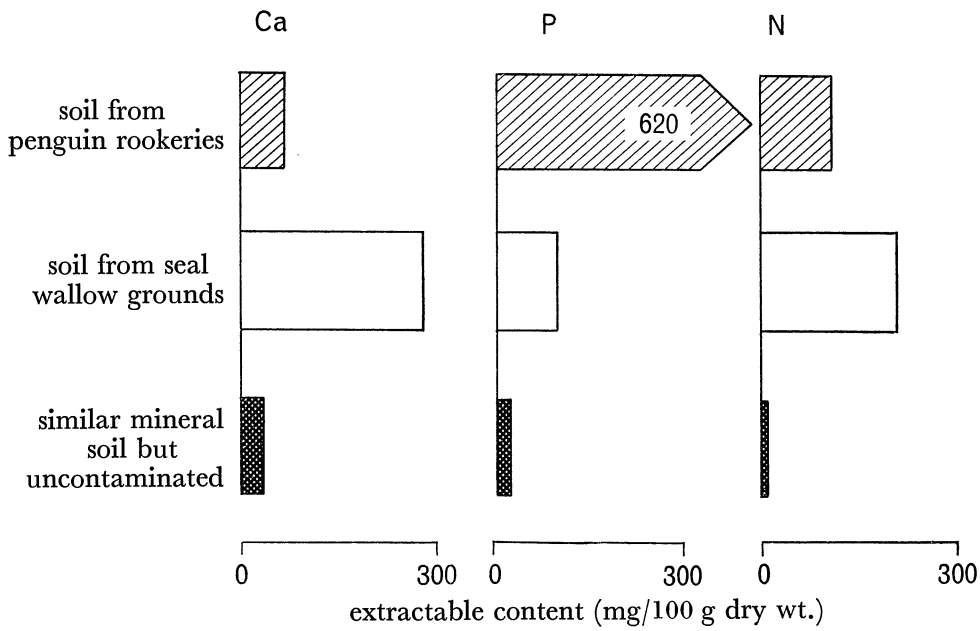

FIGURE 8. Comparison of extractable calcium, phosphorus and nitrogen in penguin and seal contaminated material and in uncontaminated soils. The composition of the contaminated material varies greatly and the data in this figure are only intended as an approximate measure.

Relief

The surface topography has considerable effect on drainage, micro-climate, and other factors which are responsible for secondary chemical effects. Most of these have been, or will be, discussed elsewhere.

Climate

Climate is considered in two aspects. First, rain precipitation and sea spray have an important role in the supply of nutrients, particularly to *Polytrichum–Dicranum* areas. The chemical content of the precipitation is strongly influenced by sea spray and by solution of gaseous inorganic nitrogen emanating from the fauna areas (figure 9). The higher pH of the moss peats, high base saturation, and the magnesium and sodium content can be partly ascribed to the rain and spray income. In addition, the high rates of drainage and leaching losses result in a rapid movement of nutrients through the ecosystem.

The effect of temperature on soil formation includes, in the widest sense, a consideration of freeze-thaw action with associated soil heave, instability and physical disintegration of the rocks. This has already been mentioned, and some aspects are examined in detail by Chambers (1966) and others. The release of extractable phosphorus and nitrogen in the soils as a result of repeated freezing is discussed in the following paper by Northover & Allen. The low temperature limits much chemical action, but the critical factor in chemical and physical weathering appears to be the frequency of freeze-thaw rather than extremes of temperature.

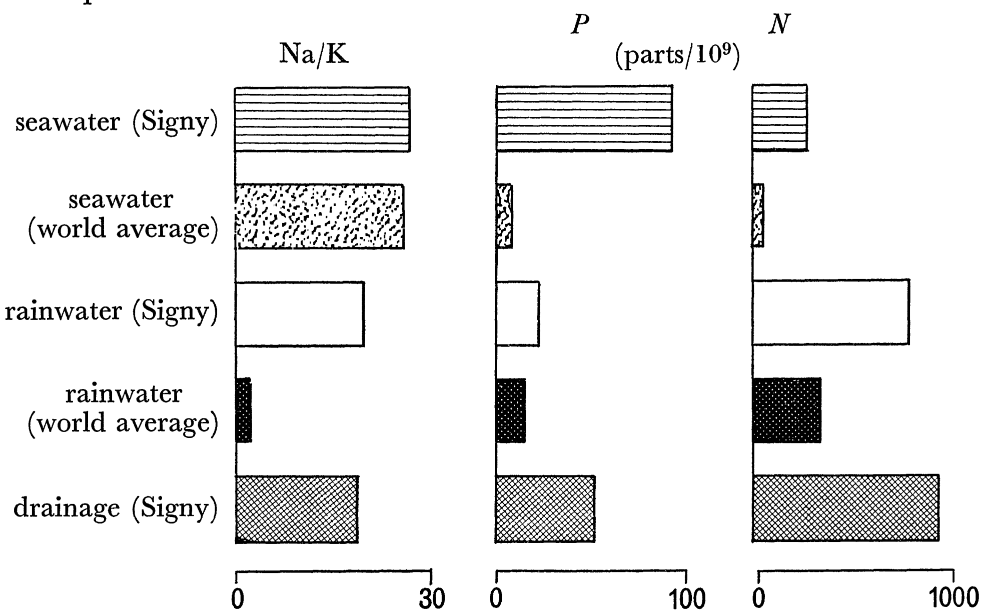

Figure 9. Sodium/potassium ratio, phosphorus and nitrogen in seawater, rainwater and Signy Island drainage water. The 'world average' data have been compiled from Angström & Hügberg (1952), Eriksson (1955), Gorham (1961), Spector (1956), Sugawara (1965), Wilson (1959) and also from unpublished information of Allen & Carlisle, Merlewood Research Station, Grange-over-Sands, Lancashire, Great Britain.

Time

Over-riding all the other soil-forming processes and their effect on the chemistry of the soil is the time factor. Under Signy conditions the time scale is naturally very long. It has been shown by radiocarbon dating that the accumulation of some of the mosses and peats has taken over 2000 years (Godwin & Switsur 1966). Chemical nutrient requirement at any one time must be very low indeed.

Summary

Chemical results indicate that soil-forming processes such as chemical weathering and activity by micro-organisms exist and that under the most favourable conditions relatively mature soils develop. It was found that the supply of all the principal nutrients was well in excess of the requirements of the Island's flora and fauna. It is suggested that a similar range of soil types and a similar regime in the circulation of chemical nutrients (summarized in figure 10) will be found on other islands in the Maritime Antarctic region.

The authors wish to thank the British Antarctic Survey for allowing them the opportunity to carry out this work, and they are also grateful to members of the Survey and Nature Conservancy staff who helped in various ways.

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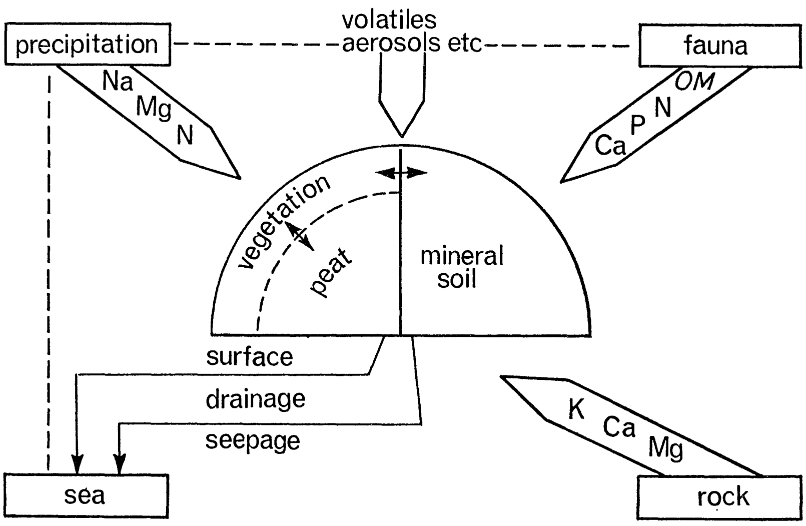

FIGURE 10. Supply and circulation of the principal chemical nutrients and organic matter (*OM*) on Signy Island.

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