A PRELIMINARY INVESTIGATION OF THE SOILS OF SIGNY ISLAND, SOUTH ORKNEY ISLANDS

By M. W. Holdgate,[*] S. E. Allen[†] *and* M. J. G. Chambers[‡]

Abstract. Signy Island is largely composed of quartz-mica-schists, with thin and local marble bands. About half the surface is snow-free in summer and exposed to the influence of a cold maritime climate. Much of the ground is covered by talus and glacial detritus. The mechanical break-down of rock by frost-action is proceeding rapidly and solifluction processes are influencing the upper layers of the ground on a large scale. Because of this, there is little vegetation cover and no clear soil stratification on many slopes. Stable areas support widespread cryptogamic vegetation and under some bryophyte communities there is considerable peat formation. Probably because of the lack of appropriate soil animals, there is little mixing of material between the upper organic and basal mineral layers, but under patches of grass and *Colobanthus crassifolius* there are more developed soils approximating to brown earths. Chemical analyses of a wide range of samples suggest that nutrients are not limiting for plant growth even in areas of the most severe leaching.

A scientific and meteorological station was established at Factory Cove, Signy Island, South Orkney Islands, in 1947, and since 1961 this has been the main centre for biological research by British Antarctic Survey personnel (Holdgate, 1965). The present paper describes the results of a study of 170 soil samples collected on Signy Island by M. W. Holdgate in February 1962 and transported in cold storage at about 2°C to the Nature Conservancy, Merlewood Research Station, where they were deep frozen prior to investigation by S. E. Allen. The laboratory methods used in the analyses are outlined in the Appendix. During the period 1961–64 M. J. G. Chambers studied solifluction and associated physical aspects of soil formation and movement on Signy Island (Chambers, 1966*a*, *b*).

Topography, Geology and Climate of Signy Island

Signy Island (lat. 60°43′S., long. 45°38′W.) is one of the smaller members of the South Orkney Islands. It is roughly triangular in outline, 8 km. long and 5 km. wide, with an area of about 18 km.^{2} and a maximum height of 280 m. The north point of the island lies only 1·5 km. south of the nearest part of Coronation Island, the largest of the South Orkney Islands group.

In contrast to Coronation and Laurie Islands, which are heavily glacierized, Signy Island has only a small ice cap and more than half its surface becomes snow-free in summer, revealing bare rock, talus, soil and cryptogamic vegetation. The snow-free areas lie largely along the indented western and eastern coasts, where there are strips of lowland which are markedly terraced on the west but have a mammillated topography on the north-east. Benching at 30–60 and 80–100 m. may mark old marine erosion surfaces. The cruciform upland area stands back from the coasts and is ice-capped in its southern part, where McLeod Glacier spills down to coastal ice cliffs (Fig. 1). Glacial erosion is evident in the landforms, which include numerous cirques, while substantial drift deposits mantle the lower ground.

Signy Island is composed of regionally metamorphosed sediments now largely quartz-mica-schists and amphibolites with local marbles. Outcrops of marble occur at many points on the lowland area between Stygian Cove and Borge Bay, on the western lowlands between Port Jebsen and Thulla Point, and more locally on the western flanks of the Robin Peak plateau. The marbles of Signy Island are of variable thickness, rarely exceeding 6 m. and often forming bands under 3 m. thick, but in these areas they form small, prominent knolls over which a local soil is developed by direct weathering. There is no doubt that the ice cover of Signy Island was formerly more extensive. Perched blocks are conspicuous in several places, and old moraines

---

[*] Now at: The Nature Conservancy, London.

[†] The Nature Conservancy, Merlewood Research Station, Grange-over-Sands, Lancashire.

[‡] Now at: Department of Geography, University of Calgary, Alberta, Canada.

Br. Antarct. Surv. Bull., No. 12, 1967, p. 53-71.

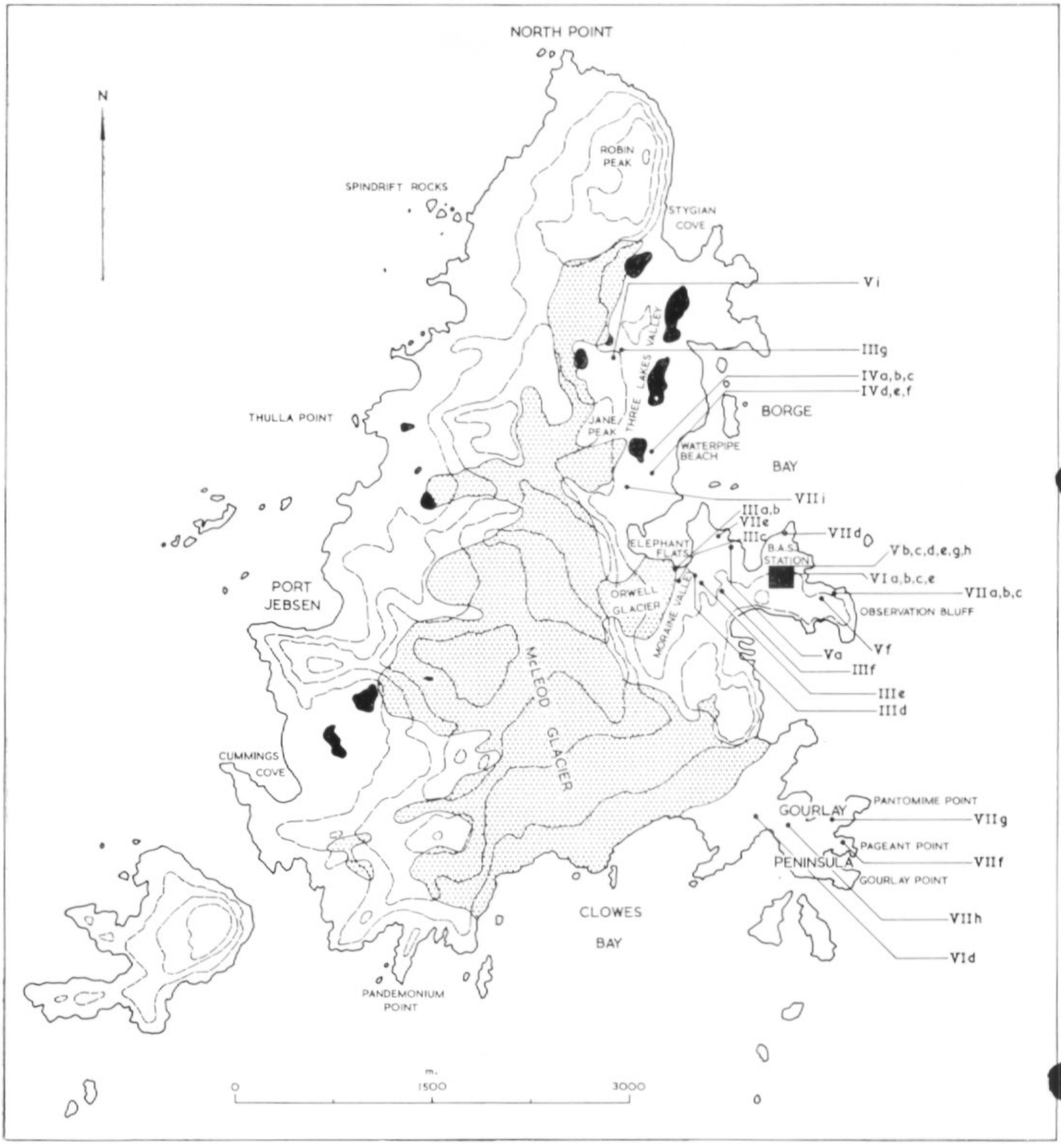

Fig. 1. Sketch map of Signy Island. The main areas of the ice cap are indicated by stipple. Collecting stations for soil samples are shown, the numbers referring to Tables III to VII.

are prominent in the amphitheatre east of Cummings Cove (where one dams a small tarn) and at two places beyond the snout of the present Orwell Glacier on the east coast. Elsewhere on the island such evidence of the later stages of glacial retreat are less conspicuous but amorphous debris covers most lowland regions. Fluvioglacial outwash fans are conspicuous locally.

Much of the drift is probably of local origin, although it is difficult to assess what proportion was derived from Signy Island itself since Coronation Island immediately to the north is composed of similar rocks, especially quartz-mica-schists. Marble fragments occur frequently in the drift, but at a low level of abundance. The intense modification and movement of the lowland drift mantle of the island under the present subaerial periglacial conditions has rendered all but the most recent moraines and fans a heterogeneous layer of unconsolidated waste.

Surface meteorological records have been kept at Signy Island since 1947, and those up to 1950 have been summarized and tabulated by Pepper (1954). Table I extends the information up to 1963. It is apparent that in terms of temperature the island has a relatively oceanic-type regime typical of the zone defined by Holdgate (1964) as the "maritime Antarctic". The relatively small temperature range confirms the moderating influence of the adjacent ocean, while the rapid change during the equinoctial months represents a transition between the contrasting air-mass sources of winter and summer. Thus, although strong westerly and north-westerly winds predominate throughout the year, together with heavy cloud and frequent precipitation, the seasonal variation in the origin of the air masses is sufficient to bring about the changes evident in Table I. The oceanic influence also accounts for the high mean cloudiness and lack of sunny days. Precipitation is also frequent (Table II), although the daily totals are often less than 0·05 mm. Even though absolute precipitation is low, because of the high cloudiness and humidity, and consequent low level of evaporation and transpiration, the net precipitation in the summer months is considerable. Because of the difficulty in accurately recording snowfall totals when high winds and drifting snow prevail, only summer figures are available for Signy Island. Some attempt at measuring total precipitation over the years has, however, been made at the Argentine station "Orcadas del Sur" on Laurie Island, only 70 km. from Signy Island, and the results are included in Table II (data from Van Rooy, 1957). Figures for the summer months of 1962–63 and 1963–64 from Signy Island agree well

TABLE I. TEMPERATURE, WIND SPEED AND CLOUDINESS AT SIGNY ISLAND. ALL DATA ARE FOR THE PERIOD 1947-63

(Cloudy days are defined as days on which the total amounts of cloud for the 12.00, 18.00 and midnight G.M.T. observations added together equal or exceed 20 oktas. Clear days are defined as those on which the cloud totals for these observations added together equal or are less than 4 oktas. On Signy Island these times represent 09.00, 15.00 and 21.00 hr. local time.)

	Mean temperature (°C)	*Mean highest maximum temperature* (°C)	*Mean lowest minimum temperature* (°C)	*Mean wind speed* (kt.)	*Mean daily sunshine* (hr.)	*Mean number of cloudy days*	*Mean number of clear days*
January	+0·7	+9	−2	11·7	2·4	25	0
February	+0·8	+9	−4	14·4	1·8	23	0
March	+0·1	+8	−7	15·0	1·2	25	0
April	−2·2	+6	−12	15·5	1·0	22	0
May	−6·4	+5	−21	13·8	0·7	20	1
June	−8·2	+4	−25	13·2	0·5	17	1
July	−10·5	+4	−29	13·0	0·9	17	2
August	−9·2	+4	−26	14·0	1·6	16	2
September	−5·2	+5	−21	17·0	1·9	20	1
October	−2·6	+6	−14	17·2	2·2	23	0
November	−1·4	+7	−9	15·3	2·3	24	0
December	−0·2	+7	−4	12·1	1·9	27	0
Year	−3·8	+6	−15	14·3	1·5	22	–

TABLE II. FREQUENCY OF PRECIPITATION (DAYS/MONTH) AT SIGNY ISLAND OVER THE TWO YEARS 1962 AND 1963, AND MEAN TOTAL MONTHLY PRECIPITATION AT LAURIE ISLAND OVER THE PERIOD 1903–54 (VAN ROOY, 1957). THE MEAN RELATIVE VARIABILITY OF THE LAURIE ISLAND MONTHLY TOTALS IS ABOUT 40 PER CENT

	Signy Island Precipitation frequency (days/month)		*Laurie Island Mean monthly total precipitation* (mm.)
	1962	1963	1903–54
January	26	29	35
February	25	27	39
March	30	30	49
April	27	29	42
May	25	28	33
June	30	29	25
July	29	24	32
August	27	30	31
September	28	30	30
October	28	29	28
November	30	26	32
December	29	28	26
TOTAL			402

with the Laurie Island data, so that it is reasonable to assume that the latter, as tabulated, provide a good indication of the total Signy Island precipitation.

The 1,200 m. mountain barrier of Coronation Island, lying north and north-west of Signy Island and partly across the direction of the prevailing winds, certainly has a significant influence on the climate of the latter. Föhn effects are common, when the temperatures soar to 8°C or more, only to fall again when the wind loses its northerly component. Orographic cloud is frequent, and Signy Island often lies under a dense mass of stratocumulus on the lee side of Coronation Island while the sky is clear farther away from the mountains. There is reason to suppose that some precipitation caused by the high mountain barrier is blown south-eastwards over Signy Island, which thus receives more than it would were Coronation Island absent. Strong winds from all quarters also undoubtedly carry quantities of sea spray, especially in summer and, since all parts of Signy Island lie close to a coast, marine salts are deposited everywhere.

Soil formation on Signy Island thus proceeds under cold oceanic conditions, with high moisture and regular freeze-thaw activity. These features, especially in the absence of a thick vegetation cover, have a profound influence.

SOIL FORMATION AND PHYSICAL PROPERTIES

Derivation of the soils

Of the several different rock types occurring on Signy Island, the quartz-mica-schists are broken down the most rapidly by frost-action. During the summer months, when temperature fluctuations around freezing point are most frequent, the weather is generally cloudy with frequent drizzle. Hence the ground is constantly moist and the water available for penetration into the foliation of the bedrock is much greater than might be expected from the low monthly rainfall totals.

The most spectacular evidence of frost-shattering is the almost continuous cascade of rocks from high cliffs when temperatures rise well above freezing, especially on days of bright sunshine. However, this may not be the most significant aspect of mechanical break-down, since most ice-free surfaces are veneered by mineral soil and rock debris. On coarse talus slopes break-down is relatively slow. Although a large surface area of rock is exposed, drainage is good and the removal of shattered debris is less efficient than from sheer rock faces. The composite accumulations of mineral soil and rock fragments hold most moisture and they remain thoroughly soaked throughout the year. They are relatively insulated from shallow freeze-thaw cycles but at least once each year they undergo freezing.

Water frequently penetrates along the foliation of the schists, and on freezing it does not merely rive off small pieces but breaks the rock into a mass of platy fragments. In the course of soil excavation, examples of this phenomenon are frequently encountered. Although such rocks appear to be superficially intact, they disintegrate on touch. Frost-action on quartz-mica-schists results in the accumulation of small flakes and splinters set in a uniform, reddish brown mineral soil. The flaky or spicular form of these particles has an important influence on the mechanical properties of the soils they form. In contrast, the marbles of Signy Island weather to form rounded and pitted nodules (samples 91, 92, 93, 97), which accumulate as a pure deposit up to 10 cm. deep in some places. On ledges and in crannies these nodules become mixed with a finer material which could either be derived from further weathering or be added by wind transport. These nodules undoubtedly differ from the quartz-mica-schist flakes in their response to mechanical influences (such as solifluction), and also in the nature and degree of chemical weathering which affects them. Consequently they give rise to soils of different properties and compositions.

On Signy Island, as in most regions with cold climates, mechanical weathering through frost-action is especially important. Kelly and Zumberge (1961) considered that chemical weathering was unimportant at McMurdo Sound and Nichols (1964) believed that this might be the rule in the Antarctic generally. It is difficult on present evidence to assess the role of the two processes on Signy Island. Colour changes in the soil and the presence of secondary clay minerals suggest some active chemical weathering and it may be noted that both biotite and marble are susceptible to chemical action.

Soil-temperature regime

Because of the high mean annual wind speed, snow accumulation at Signy Island is relatively slight during the early winter months. The surface is therefore left open to the influence of falling air temperatures. As the Antarctic continental effect on the weather increases between late March and June, the air masses participating in cyclonic disturbances travelling eastwards into the southern Scotia Sea are of increasingly violent contrast. Cold fronts become sharply defined with a fall in temperature of 15°C or more within a few hours. Although heat loss from the warm and moist land surface is slow, the cyclonic fluctuations at this time of year (often lasting 3 or 4 days at a time) are sufficient to cool the upper 10–15 cm. to below freezing point. The mean air temperature decreases gradually, although it is still characterized by erratic fluctuations, and the average temperature for each winter month varies widely from one year to another. The minimum is usually reached in August, by which time sea ice surrounds Signy Island in most years. Snow accumulation is more likely when the sea ice is present, because snow drifts from the ice on to the island. However, the variable wind direction often causes large drifts formed in one lee to be blown away almost immediately the wind changes, leaving the surface exposed once more to the extremes of air temperature.

Precipitation in the late winter months is often associated with weak pressure troughs, and hence there is less tendency to drifting with the light winds. This results in a more even snow cover and a greater insulation of the ground surface, but usually this snow arrives too late and is too ephemeral to prevent deep frost penetration. Its greatest effect is to hinder thawing of the surface at the onset of warmer weather. The thaw is also extremely variable in its onset; whereas there are violent and warm north-westerlies in late September and October of some years, in others the winter pressure system remains dominant until the end of the year. Increased solar radiation with lengthening days and higher angle of the sun does not greatly influence the snow melt, since about 80 per cent of the direct and incident radiation is reflected by the snow surface. Warm air and especially rain are responsible for the most rapid disappearance of the snow cover, but even while the snow cover remains water seeps down to ground level and begins to transfer heat to the surface material. By the time the snow cover finally disappears the ground has already thawed to a depth of several centimetres and is completely saturated with water. The continuous flow of cold water over this surface hinders further melting and it is not until this has drained away that the thaw penetrates to any considerable depth. The large amount of energy necessary for ice to melt retards the thaw even further. This process is reversed as freezing takes place, and an equally large amount of latent heat is given out before water crystallizes into ice. As this change of state proceeds, there is a long period when the soil temperature does not change—a freezing boundary, which is usually slightly below 0°C because of impurities in the soil moisture.

The gradual penetration of heat to the surface rock debris and mineral soil proceeds steadily throughout the summer months, the depth of thaw varying according to local conditions. Ice can remain at 40 cm. beneath a waterlogged moss mat, while 2 m. or more of the surface can thaw on a well-drained coarse rock slope. The zone of perennially frozen ground is below the maximum depth of thaw and, although it is seldom very cold, it never receives sufficient heat to raise its temperature above freezing point. At the end of the summer its uppermost margin contains ice at melting point, and it remains in this critical state for several weeks while the material above gradually loses heat to the air and freezes from the surface downwards. Since the permafrost table is continually drawing away heat, the cessation of incoming atmospheric heat at this time causes the soil adjacent to the permafrost to re-freeze. The annual freezing plane finally joins the permafrost table as late as July or August, not long before thawing begins again at the surface. Hence the zone of material which is subjected to an annual freeze-thaw cycle (the active layer) is in a constant state of transition.

Whereas the base of the active layer only experiences one freeze-thaw cycle each year, its upper levels are subject to short-term fluctuations, and thus the regime of the layer can be summarized:

Depth (cm.)	*Temperature cycle*
1– 5	Diurnal
10–15	Cyclonic
50–200	Annual

There are numerous occasions during the summer when there is no diurnal frost cycle but there are cycles which are not apparent from the meteorological records. For instance, when the air temperature has remained constantly below –4°C, direct solar radiation has been observed to melt the soil surface to a depth of 3 or 4 cm., followed by rapid re-freezing at sunset.

Effects of ice and water in the soil

The drainage on Signy Island is generally poor and the climate is such that evaporation removes little water from the surface. Even at the end of the summer, sectioning down to permafrost level is often hindered by free-flowing water. Around March when the soil freezes, moisture content is critical, since it is the transformation of this water into ice that is associated with frost-heaving. The expansion resulting from this transformation plays only a minor part in heaving, because air spaces in the soil are usually sufficient to take up much of the volume increase. Most of the heaving seems to be caused by the partially unexplained phenomenon of ice segregation, the form of which depends on:

i. The rate of freezing.
ii. The structure and compaction of the soil.
iii. The soil moisture content.

In his study of frost-heaving, Higashi (1958) recognized three types of soil-ice formation:

i. Filament type (needle ice).
ii. Sirloin type (innumerable thin layers).
iii. Concrete type (a fine-grained crystal matrix with no visible segregation).

Filament ice results from slow freezing when there is a high moisture content within a zone of contrasting grain-size. On the whole it does not play an important part in the frost-action on Signy Island, and it is mainly confined to the movement of individual stones. Large ice lenses have been observed only in the bed of the Moraine Valley stream, where it appears there is a strong sub-surface flow of water far into the winter.

Sirloin ice has the most important influence on the active layer and it is this variety that usually forms during the cyclonic and diurnal freeze-thaw cycles. As many as 20 horizontal layers of ice may occur in a 1 cm. section of fine mineral soil, while occasional ice bands several millimetres thick have been found in the active layer. Expansion resulting from such formations can heave the surface up by 10 cm. or more within a few days (Fig. 2). There is some evidence to suggest that during the upward heave there is also a downward expansion immediately ahead of the freezing plane. The results of quantitative frost-heave experiments and surface-movement measurements are discussed in a separate paper by Chambers (1967).

Ice of concrete type does not cause large-scale heaving, since freezing takes place with a minimum of segregation. This ice form is characteristic of compacted clays but it also occurs in more varied soils when freezing has been exceptionally rapid or the moisture supply limited (Penner, 1959).

The effect of frost-heave on a uniform horizontal surface is slight, but on a sloping surface heave acts perpendicular to the slope and the return is vertical, causing the entire mass to move gradually down-hill. In reality the active layer is irregular and, since the thermal conductivity of large boulders differs from that of moist fines, uneven freezing takes place. Such uneven freezing also results where there is an irregular vegetation cover and insulation to the fluctuating air temperature is afforded to some areas and not to others (Williams, 1959).

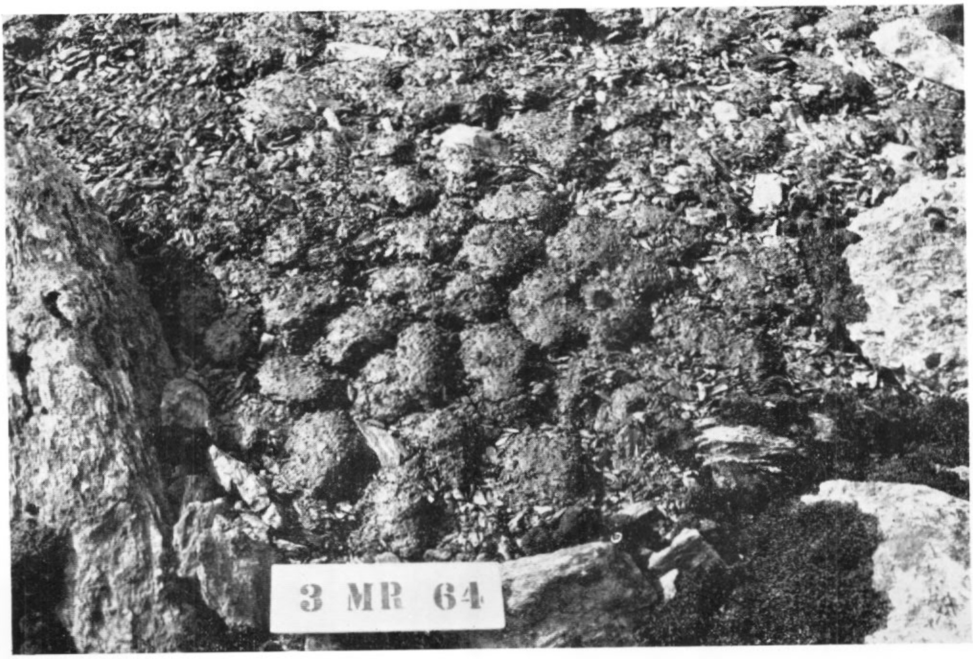

Fig. 2. Small frost-heave mounds dividing a large sorted circle; Cummings Cove. The date marker is 20 cm. long.

Therefore, a bare patch may experience several frost-heave cycles during a season, while the soil beneath the surrounding vegetation cover undergoes only one such cycle. Each time this happens the bare patch suffers upheaval relative to the unaffected vegetated area. When thawing occurs at the surface of the domed-up soil patch and water is rapidly released from segregated ice, fine silt flows radially down the gradient created by the differential heave. If this occurs where the local surface is slightly tilted, most of the flow is in one direction and the vegetation down-slope of the bare patch is over-run. Thus a patch becomes elongated and on steeper slopes stripes rather than patches develop.

One of the most significant geomorphological factors of a periglacial environment is the rapid release of water as thawing takes place. Frost-heave disturbs and loosens up the soil, whereas ice segregation concentrates available water which was distributed evenly throughout the entire mass prior to freezing. When ice segregations melt, sufficient water is released to allow the shear stress exerted by gravity to overcome the frictional and cohesive forces between the individual mineral grains. This fundamental process of solifluction occurs on Signy Island on such a vast scale that it is often difficult to realize what is happening. Whole slopes are in motion, and it is not until an obstacle is encountered which causes buckling of the surface material that the extent of the motion is apparent (Figs. 3 and 4). This large-scale down-slope movement occurs whenever sufficient thaw water is released to overcome the soil strength, which is controlled by the grain-size distribution. Above a certain limit the percentage of coarse material prohibits any movement, but below this limit the fines (particles <2 mm. in diameter) support the coarse fragments and carry them along. The abundant presence of mica flakes in the Signy Island soils renders them highly susceptible to solifluction, because the movement tends to align the flakes with their long axes parallel to the direction of movement. Once this has taken place, lateral movement between the flakes is facilitated and vertical penetration of water is hindered. Hence water tends to flow parallel to the orientation of the mica flakes, further improving the lubrication. Since an average sample in the size range 0·2 to 0·002 mm. from anywhere on Signy Island (except from the marble outcrops) contains up to 60 per cent mica, these factors could have considerable significance.

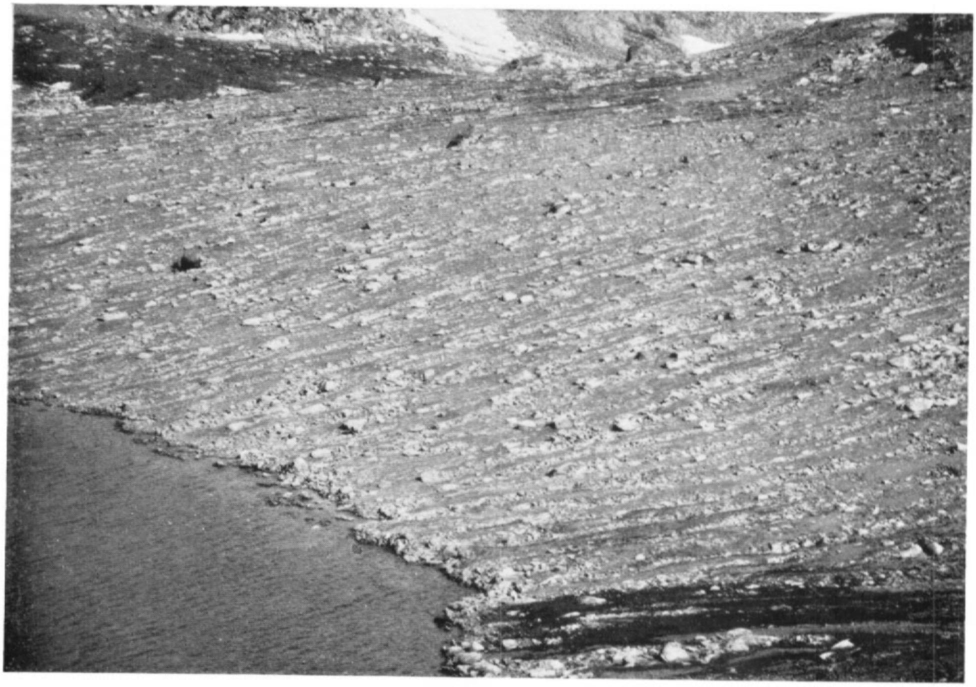

Fig. 3. Vegetation-free slope showing stream lines in very moist soil but with no distinct stripes; Cummings Cove.

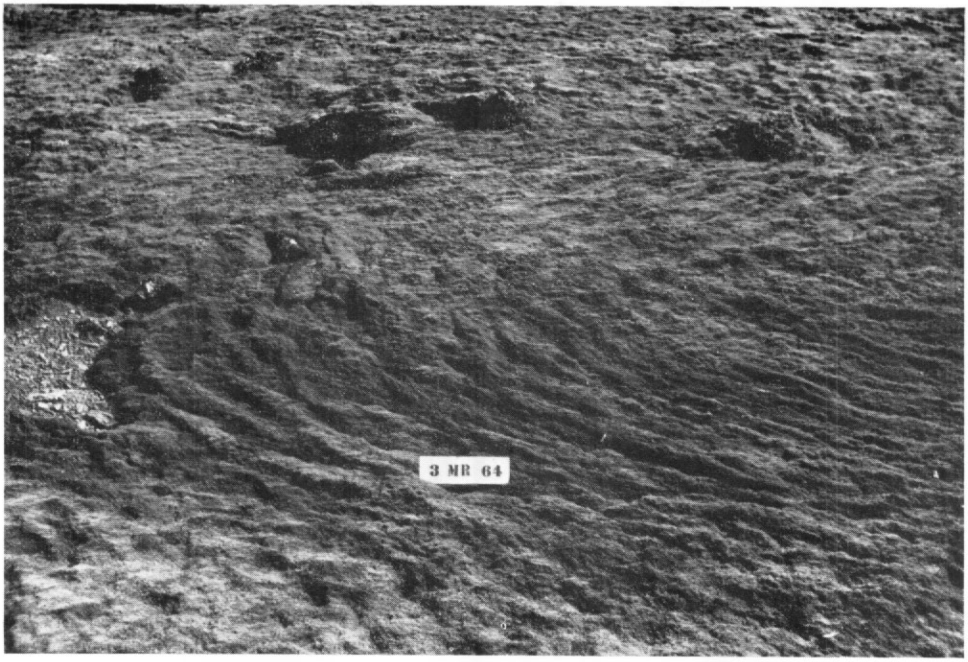

Fig. 4. Buckling of a moss mat by solifluction of the underlying mineral soil; Cummings Cove. The date marker is 20 cm. long.

Since solifluction reaches its maximum when melting releases segregated soil moisture, the descending level of thaw through the active layer during the summer means that the plane of movement increases in depth at the same rate. Theoretically, this process should continue until the thaw reaches its maximum depth at permafrost level. In fact, movement rarely occurs at such a depth, probably because thawing is so slow that normal drainage processes can cope with the water released. Preliminary results from Signy Island suggest that movement generally reaches its maximum between 10 and 15 cm. beneath the surface, although at some sites the maximum was at 0 to 5 cm. The actual amount of movement varies widely; while some rocky slopes appeared to be either stationary or moving so slowly that no movement could be detected over 2½ years of observation, other areas of finer and more moist composition showed surface movements up to 15 cm./yr.

The speed and nature of movement down a debris slope are determined by slope angle, moisture content and the ratio between coarse and fine material. Above a certain limit a preponderance of large stones prohibits mass movement, but below this level there are two categories of slope pattern resulting from movement:

i. Where fines predominate the relatively few stones are carried along without hindering flow; the entire slope cover moves as a unit and the coarse debris is distributed randomly over it. This is the most rapid and unstable form of solifluction, and such a slope always lacks vegetation (Fig. 3).

ii. When coarse debris is present in sufficient quantity to hinder movement but not to prevent it, differential solifluction across the surface results in fast and slow streams which perpetuate themselves and develop into alternating coarse and fine stripes (Fig. 5). The most rapid movement occurs along the centre lines of the fine stripes, so that stones pushed up by frost-heaving are slowly swept to either side. The widths of both coarse and fine sections of the stripes vary from 20 cm. to 3 m. or more, whilst their lengths and continuity appear to depend largely upon the local topography.

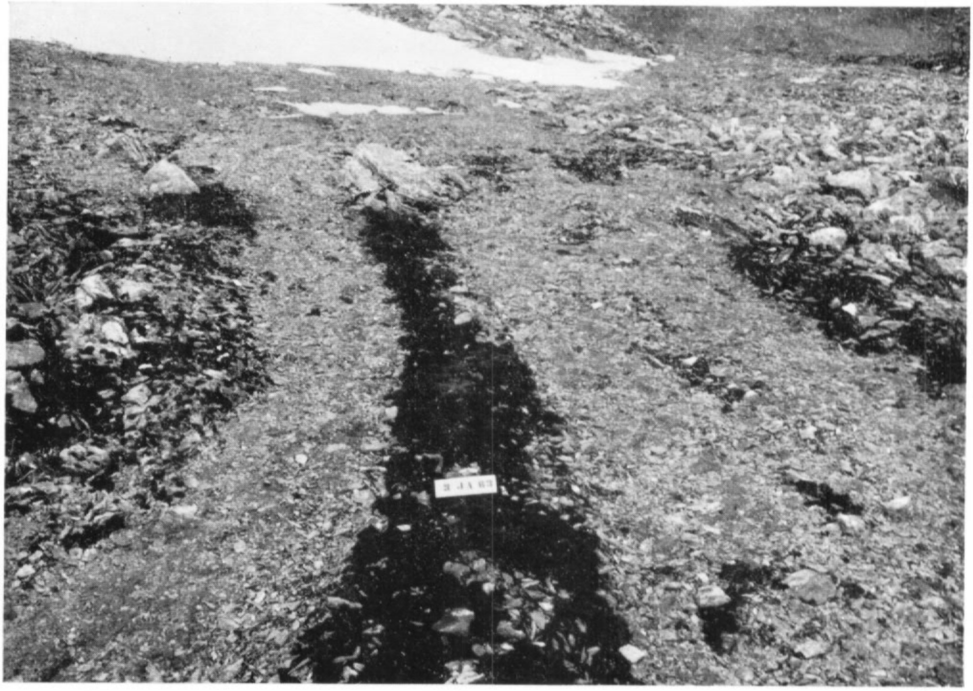

Fig. 5. Colonization of moss along a stable zone down-slope from a large boulder; south of Factory Cove. The date marker is 20 cm. long.

As long as movement continues, the coarse stripes are slowly augmented by material from the fines on either side, but before the final stage of a surface entirely covered by coarse debris is reached, the stripes stagnate and growth ceases. This stage had clearly been reached in several stripes from which measurements were taken, and it is suspected that some degree of sinking had taken place along the coarse stripes during extreme saturation of the underlying material, with the instability which this entails. The occurrence of a short mudflow from the middle of a 15° vegetation-free slope after a prolonged period of rain was an indication of such instability, and further proof of it was the quaking felt on walking across the surface. By concentrating coarse material at the surface, frost-heaving accentuates this instability. It is likely that the pressure exerted by this rock debris is sufficient to force the semi-liquid fines upward from below.

The vulnerability of these bare and unconsolidated slope deposits to rapid erosion was demonstrated by the effect of a heavy rainfall (32·1 mm.) on already saturated surfaces on 4 April 1963. There was more erosion in those few hours than in the whole of the previous year. Gullies 1 m. deep and over 2 m. wide were slashed through masses of slope debris as run-off flooded the inadequate melt-water courses. Yet, before the long-term significance of such storms can be assessed, their frequency must be determined. The meteorological records for Signy Island only go back as far as 1947 and these do not give a complete picture. Since the surface conditions at the time of rainfall are critical, the water content and depth of the thawed layer will affect the rate of run-off. What appears to be a storm comparable to that of 1963 occurred on 11 March 1954 under strikingly similar conditions. On this occasion 30·1 mm. of rain fell after a month of warm wet weather, so it is likely there was a similar effect on the landscape. However, no sign of this earlier storm remained in 1962, and thus the scars must have been erased within 8 years. In a few months the sharp contours of the latest gullies had been softened by slumping and rill wash, and it seems that they will soon vanish. Even if such storms occur only once every decade, their role in removing vegetation-free slope material is far greater than that of all the annual streams during the same period.

The melt-water streams flowing from the ice cap of Signy Island and snow banks have a totally different significance. The direct erosive and load-carrying capacity of the small and ephemeral streams is relatively slight, and their main influence is keeping soil moisture along their courses at saturation level throughout the summer months. This allows solifluction at the surface to continue as long as the streams run, whereas on drier slopes movement ceases as soon as the ground ice has melted and water has drained away. The presence of a break in slope immediately below a permanent snow patch illustrates the effect of this process.

It is in this context of violent local contrasts, between coarse and fine, wet and dry, stationary and mobile, that the soils and vegetation patterns of Signy Island must be considered.

VEGETATION AND SOILS

*The vegetation**

A preliminary account of the vegetation of Signy Island has been given by Holdgate (1964), and more detailed descriptions are in preparation. Five main types occur, each characteristic of a distinct kind of habitat:

i. A lichen-moss sub-formation dominated by *Usnea*, *Himantormia* and *Andreaea* species, typical of exposed, rocky, montane ground.
ii. A moss turf sub-formation dominated by *Dicranum aciphyllum* and *Polytrichum strictum*, with local lichen encrustations, characteristic of moderate or steep, well-drained, often north-facing slopes well exposed to the sun.
iii. A moss mat sub-formation dominated by *Brachythecium*, *Acrocladium*, *Pohlia* and *Drepanocladus* species, typical of wet soakways, runnels, snow patches and other ill-drained situations.
iv. A biotically induced sub-formation around bird colonies and seal wallow grounds, largely bare of plants apart from some crustose lichens and green alga (*Prasiola*).
v. A vascular plant sub-formation, very local in distribution dominated by *Deschampsia antarctica* (Gramineae) and *Colobanthus crassifolius* (Caryophyllaceae).

The presumed inter-relationships of these communities, and their response to gradients of exposure, moisture and stability will be discussed elsewhere. In the following sections the soils sampled in each main vegetation type are discussed in turn.

Soils of moraines and raw glacial detritus (*Table III*)

Much of the Signy Island soil material originated from moraine, and it has variously been re-worked by solifluction and outwash. The sites sampled in 1961–62 were therefore located on the recent moraines of Orwell Glacier, above Elephant Flats (Fig. 1). This terminal moraine, which rises some 15 m. from the sea, is double and the inner and outer ramparts are evidently different in age.

The inner, younger moraine consists of raw glacial debris which is still subject to considerable frost movement. The material varies widely in particle size and shows no layering. The surface is almost devoid of plants, supporting only a few tufts of moss (*Pohlia cruda*, *Tortula* spp., *Dicranoweisia*), with small patches of crustose lichen on the larger rocks. Samples (1, 2; site a; Table III) of the finer material were very alkaline in reaction (pH approximately 9) and had a high level of extractable calcium; both features are probably due to the presence of marble fragments. Although the inorganic carbon determinations indicate that the total amount of marble in the moraine is small, there is no organic material to buffer to a lower pH. All the extractable constituents tend to be higher in the inner moraine samples probably because of the abundance of the clay fraction which reduces the water percolation and enhances the absorption capacity.

The outer, older moraine is much more stable, and the samples collected (3, 4; site b; Table III) are of coarser material. The stability of the surface has allowed plant colonization and up to 60 per cent cover in places. *Drepanocladus* and *Tortula* spp. dominate the mosses (the latter genus is calcicole on Signy Island), and there are various lichens on the rocks. The soil

---

* The plant names used in this paper are provisional only, pending taxonomic revisions now in progress.

pH is lower than on the younger moraine (about 6 per cent). The increase in plant cover provides organic matter for incorporation in the soil but nevertheless the nutrient status is low compared with other island sites. Even though the vegetation has probably been established for several decades its influence on the soil material has not been very great.

A section of glacial detritus was sampled in Moraine Valley nearby. The section (samples 7–12; site c; Table III) showed considerable colour banding with shades ranging from grey (with iron nodules) through yellow and red to a silvery grey lowermost layer of schist bedrock decomposing *in situ* with ice above. The coloured banding suggests intermittent drainage or frost-action causing chemical action, probably through oxidation and reduction. The extractable constituents near the surface are low, probably because of the considerable downwash, but the levels increase near the bedrock. The values for pH and extractable calcium show some increase with depth, although the influence of marble fragments is not evident. The apparent increase in organic content which is not supported by the carbon results is probably due to moisture retention in the schistose structure.

These samples taken together provide a useful example of development from glacial detritus which may be compared with the *in situ* development over different rock materials.

Soil development in areas of marked solifluction and low vegetation (*Table III, sites d, e, f, g*)

A series of samples (13–18) was collected along a single stone stripe on a slope above Elephant Flats. The stripe contained central bands of compacted gravel flanked by zones of small schistose fragments, and it was about 75 cm. wide. There is little vegetation in this unstable area. *Andreaea* was found on some stones and a few small patches of *Drepanocladus* and *Acrocladium* occurred on wetter parts.

The top of the slope (site f), containing the least modified parent material, is the most alkaline and has the least development of organic matter (samples 17, 18). There is a regular gradation in pH and organic matter down the slope to the compacted ground at the lower altitude (site d). From the signs of elephant seal activity on the compacted ground, it is probable that they are responsible for the local increase in nitrogen and phosphorus, especially since there is virtually no vegetation. No differences of any significance were apparent in the cation results from the samples taken along the stripe.

A series of soil patterns was examined on the nearly level surface of the col north of Jane Peak (Table III; samples 77–79; site g). These have a near circular form, with central zones of fine material and boundary circles of coarse debris. The central material appears to have been heaved through material more like that towards the periphery and had, as might be expected, a higher clay fraction.

Although the area is now without vegetation cover, the results for carbon, nitrogen and phosphorus, which are moderately high compared with the solifluction material on the elongate stripe, suggested past vegetation. This would account for the depression of pH.

Taken as a whole, the results in Table III do provide a reasonable illustration of the composition of mineral detritus on Signy Island, variously derived from glacial action and variously modified by solifluction. It would appear that in general this material is alkaline to circum-neutral in reaction, rather base-rich, and (as might be expected) lacking in organic carbon and with a low total nitrogen content. There is little clear development of horizons in the profile, perhaps because of immaturity and continuing mechanical re-arrangement.

Soil development over stable schist outcrops (*Table IV*)

Ridges of quartz-mica-schist, which compose much of the upland of Signy Island, have in general rugged surfaces on which rock outcrops alternate with block scree and finer debris. On stable rocky ground, the highest and most exposed levels are covered by lichens, crustose species and the large branched *Usnea antarctica* predominating. In situations with slightly more shelter, a similarly large, blackish, branched lichen, *Himantormia lugubris*, is typical. Finally, in hollows, often above small stones, gravel and a mineral soil, there are mats of blackish mosses of the genus *Andreaea*. Locally, some of these are colonized by *Polytrichum strictum* and other mosses, with consequent transition to other communities.

The soils of these upland vegetation types were sampled on the ridge west of Observation

Table III. Analytical data for samples collected from moraine and mineral debris, Signy Island

(All results except pH expressed on dry basis)

	Sample site	*Sample number*	*pH*	*Loss on ignition* (550°C) (per cent)	*Extractable* (N ammonium acetate pH 7·0) (mg./100 g.)				*Total* (per cent)				*Extractable* (0·002N H_2SO_4 at pH 3)	*Total*	*Total*	*Extractable* (mg./100 g.)		*Inorganic carbon* (per cent)	*Organic carbon* (per cent)	*Mechanical analysis* (*on soil < 2 mm.*) (per cent)	
					Na	K	Ca	Mg	Na	K	Ca	Mg	P (mg./100 g,)	P (per cent)	N (per cent)	Aqueous NO_3' —N	6 per cent NaCl NH_4^+ —N			*Clay*	*Silt*
	Old moraine of Orwell Glacier (12 February 1962)																				
Site a	Old moraine with mixed plant cover	1	6·2	2·0	13	9	49	13	—	—	—	—	7	0·17	0·06	0·5	0·5	—	0·5	7	16
	Old moraine with mixed plant cover	2	5·8	1·9	9	7	32	11	—	—	—	—	6	0·16	0·07	0·3	0·3	—	0·5	8	20
Site b	New moraine almost bare of plants	3	9·5	1·0	26	9	165	10	—	—	—	—	15	0·09	0·02	0·07	0·3	0·1	0·1	14	17
	New moraine almost bare of plants	4	8·9	1·0	29	11	175	12	—	—	—	—	16	0·09	0·03	0·06	0·2	0·1	0·1	14	18
	Bank of stream draining Moraine Valley (12 February 1962)																				
Site c	Grey-brown material (1–5 cm.)	7	5·7	2·3	4	4	6	7	—	—	—	—	8	0·15	0·07	0·01	0·2	—	0·6	8	18
	Yellow band (ca. 30 cm.)	8	5·3	3·2	4	4	11	9	—	—	—	—	4	0·12	0·04	<0·01	0·1	—	0·4	10	13
	Grey clay with iron nodules (ca. 60 cm.)	9	6·0	3·1	7	5	22	25	—	—	—	—	8	0·10	0·04	0·02	0·1	—	0·3	15	16
	Reddish decomposed rock (ca. 90 cm.)	10	6·1	3·7	5	6	30	17	—	—	—	—	10	0·10	0·04	0·02	0·1	—	0·5	—	—
	Soft yellowish grey wet material (ca. 120 cm.)	11	7·4	2·0	5	6	56	26	—	—	—	—	9	0·07	0·03	0·03	0·2	—	0·4	6	20
	Decomposing bedrock with permafrost ice (ca. 140 cm.)	12	7·8	3·7	4	6	69	25	—	—	—	—	6	0·08	0·03	0·03	0·1	0·5	0·7	5	10
	South slope above Elephant Flats (12 February 1962)																				
Site d	Compacted gravel; no vegetation (altitude 3 m.)	13	6·5	4·4	14	9	55	20	—	—	—	—	10	0·17	0·15	0·04	0·5	—	0·9	8	19
	Compacted gravel; no vegetation (altitude 3 m.)	14	6·7	2·8	12	9	39	14	—	—	—	—	12	0·12	0·11	0·06	0·3	—	0·5	10	18
Site e	Mid slope; a few *Andreaea* tufts (altitude 15 m.)	15	7·0	2·4	15	7	64	20	—	—	—	—	12	0·09	0·06	0·10	0·2	—	0·5	7	19
	Mid slope; a few *Andreaea* tufts (altitude 15 m.)	16	7·0	2·7	11	5	64	18	—	—	—	—	9	0·10	0·08	0·3	0·2	—	0·6	5	20
Site f	Top of slope; no vegetation (altitude 45 m.)	17	7·4	0·7	18	6	56	16	—	—	—	—	14	0·09	0·04	<0·01	0·1	—	0·4	6	16
	Top of slope; no vegetation (altitude 45 m.)	18	7·6	0·4	14	6	62	16	—	—	—	—	17	0·10	0·06	0·02	0·1	<0·1	0·4	9	18
	North end of Jane Peak shoulder above col; solifluxion patch at 75 m. (20 February 1962)																				
Site g	Yellow stony soil (30–50 cm.); centre of zone	77	5·5	3·3	4	5	18	9	—	—	—	—	13	0·18	0·07	0·01	0·1	—	0·7	17	11
	Brownish stony soil (30–50 cm.); outside of zone	78	5·3	7·2	5	7	11	5	—	—	—	—	3	0·17	0·18	0·8	0·1	—	2·8	5	11
	Centre of "stone circle"; yellow stony soil (30–50 cm.)	79	5·6	4·0	6	7	12	4	—	—	—	—	4	0·15	0·11	<0·01	<0·1	—	1·0	7	19

Analyses by Chemical Section, The Nature Conservancy, Merlewood Research Station (August 1962).

TABLE IV. ANALYTICAL DATA FOR SAMPLES COLLECTED FROM MARBLE AND MONTANE SCHIST, SIGNY ISLAND

(All results except pH expressed on dry basis)

	Sample site	*Sample number*	*pH*	*Loss on ignition* (550°C) (per cent)	*Extractable* (N ammonium acetate pH 7·0) (mg./100 g.)				*Total* (per cent)				*Extractable* (0·002N H_2SO_4 at pH 3) P (mg./100 g.)	*Total* P (per cent)	*Total* N (per cent)	*Extractable* (mg./100 g.)		*Inorganic carbon* (per cent)	*Organic carbon* (per cent)	*Mechanical analysis* (*on soil 2 < mm.*) (per cent)	
					Na	K	Ca	Mg	Na	K	Ca	Mg				Aqueous NO_3' —N	6 per cent NaCl NH_4^+ —N			*Clay*	*Silt*
	Marble knolls by southern lake in Three Lakes Valley (20 February 1962)																				
Site a	Coarse decomposing nodular marble; no vegetation (0–5 cm.)	91	8·5	1·6	18	2	631	8	—	—	—	—	1	0·15	0·06	<0·01	0·1	9·3	<0·1	3	1
	Finer material on nearby slope; no vegetation (1–5 cm.)	92	8·4	2·1	23	2	720	10	—	—	—	—	4	0·18	0·08	0·3	0·2	6·7	<0·1	2	6
	Pockets of dark soil and decomposing marble (3–8 cm.)	93	8·4	2·1	23	2	667	6	—	—	—	—	1	0·15	0·08	0·4	0·2	5·4	<0·1	1	7
	Thin peat below shallow *Drepanocladus-Pohlia* mat (2–3 cm.)	96	6·9	37·4	71	16	1,160	71	0·17	0·49	5·61	0·61	6	0·20	1·90	4·3	0·2	—	21·3	—	—
	Nodular marble soil almost bare of vegetation	97	8·2	4·0	25	2	727	10	—	—	—	—	7	0·14	0·23	0·4	0·2	7·3	0·8	1	7
Site b	Surface *Andreaea* mat from area of schist debris	100																			
	Surface; green		—	63·8	—	—	—	—	0·14	0·50	0·66	0·70	—	0·08	1·11	—	—	—	38·4	—	—
	Underlying; brown		6·0	71·4	—	—	—	—	0·13	0·55	0·27	0·66	—	0·10	1·01	<0·01	0·5	—	38·6	—	—
	Dry gravelly soil below sample 100 plant mat (1–6 cm.)	101	6·2	7·3	16	12	79	42	—	—	—	—	2	0·20	0·34	0·4	0·5	<0·1	3·2	1	9
Site c	Surface *Grimmia* mat from area with marble debris Surface; green	102	—	85·1	—	—	—	—	0·09	0·30	1·10	0·43	—	0·12	1·22	—	—	—	41·6	—	—
	Gravelly and clayey soil below sample 102 mat (1–6 cm.)	103	6·8	7·8	15	10	182	30	—	—	—	—	13	0·24	0·37	0·4	0·6	<0·1	2·8	4	15
Site d	Surface *Tortula* mat from marble knoll	104																			
	Surface; green		—	72·7	—	—	—	—	0·08	0·50	1·74	0·51	—	0·18	1·66	—	—	—	36·6	—	—
	Underlying; brown		7·1	43·7	—	—	—	—	0·10	0·80	2·98	0·69	—	0·18	1·38	<0·01	1·1	—	22·1	—	—
	Peaty soil below sample 104 with some marble debris (3–6 cm.)	105	7·3	15·5	40	10	650	38	—	—	—	—	22	0·21	0·72	>2	0·7	0·2	7·9	1	6
Site e	Thin peaty layer below a "plumose *Drepanocladus*" mat with schist and marble debris (2–4 cm.)	106	7·1	29·2	87	22	1,220	66	0·09	0·01	1·86	0·84	14	0·21	1·16	3·9	0·4	—	17·1	—	—
	Dark brown mineral soil below sample 106 peat (5–10 cm.)	107	7·7	6·4	33	3	420	21	—	—	—	—	21	0·13	0·36	0·2	0·2	<0·1	2·1	1	2
	Yellow clay lower down section (10–20 cm.)	108	8·2	2·3	14	6	225	10	—	—	—	—	29	0·32	0·11	<0·01	0·2	<0·1	0·4	10	20
Site f	Peat below *Drepanocladus-Andreaea* mat on flank of schist knoll (3–4 cm.)	109	5·5	34·4	40	22	185	68	0·11	0·99	0·74	0·57	6	0·32	1·42	3·3	0·3	—	15·5	—	—
	Stony mineral soil lower down section	110	7·0	6·2	18	5	261	24	—	—	—	—	7	0·26	0·45	0·13	0·7	<0·1	2·1	<1	<1
	Col between Observation Bluff and Factory Cove bluffs; areas of schist with mountain-top moss and lichen community (altitude 60 m.) (22 February 1962)																				
Site g	Soil of decomposing schist on edge of snow patch (5–10 cm.)	155	5·5	6·9	6	6	29	13	—	—	—	—	2	0·12	0·31	0·1	0·1	—	3·1	1	2
	Similar soil of adjacent stone stripe (0–5 cm.)	156	6·0	4·0	20	6	88	55	—	—	—	—	5	0·16	0·08	0·2	0·2	—	0·7	3	10
Site h	Dead *Andreaea* mat on edge of snow patch (0–5 cm.)	157	5·5	63·6	57	22	93	94	0·08	0·80	0·27	0·44	2	0·20	1·78	<0·01	1·3	—	31·7	—	—
	Pockets of gritty clay below this dead moss (5–10 cm.)	158	5·3	6·9	5	5	18	5	—	—	—	—	6	0·14	0·19	0·1	0·4	—	2·6	3	4
Site i	Surface mat of *Polytrichum* (0–6 cm.)	166																			
	Surface; green		—	91·7	—	—	—	—	0·15	0·29	0·24	0·38	—	0·07	0·69	—	—	—	43·7	—	—
	Underlying; brown		4·6	89·7	—	—	—	—	0·17	0·17	0·36	0·41	—	0·08	0·83	<0·01	<0·4	—	42·9	—	—
	Main peat layer of mat (2–6 cm.)	167	5·2	88·8	133	28	93	245	0·12	0·27	0·39	0·29	<1	0·08	1·08	<0·01	<0·4	—	41·3	—	—
	Peaty soil below main moss mat (6–8 cm.)	168	5·2	26·3	30	10	55	56	0·09	0·10	0·35	0·38	3	0·21	1·14	1·0	0·2	—	17·7	—	—
	Gravelly dark soil over rock (8–10 cm.)	169	5·1	11·4	8	5	24	7	—	—	—	—	7	0·19	0·45	0·04	<0·1	—	5·4	1	5
Site j	Loose mineral soil among lichens in ledges of boulders (0–1 cm.)	170	5·2	9·6	12	10	14	13	—	—	—	—	6	0·20	0·35	>2	0·4	—	3·9	1	16

Analyses by Chemical Section, The Nature Conservancy, Merlewood Research Station.

Bluff (Fig. 1). Samples 155 and 156 (Table IV; site g) are representative of the coarse, unstratified mineral debris derived from decomposing schist on the edge of a semi-permanent snow patch where vegetation was lacking. Sample 170 (site j), from pockets in a rock outcrop, probably contains some wind-blown material. Samples 157 and 158 (Table IV; site h) are representative of *Andreaea* mats and the underlying gritty clay in the same area, and samples 166–69 of a more complex, layered profile below a small patch colonized by *Polytrichum strictum* (Table IV; site i). In this series, the nutrient content of the soils can be closely correlated with the amount of organic matter present. The material associated with the decomposing schist around the snow patches and below the moss mats contains very small amounts of the extractable ions, nitrogen and phosphorus. The figures are very similar to those obtained from a skeletal schist soil in Scotland:

	Loss on ignition (per cent)	*Extractable* (mg./100 g. dry) Na	K	Ca	Mg	P	N
Scottish sample (Perthshire)	7·0	6	5	18	10	0·3	0·2
Signy Island (sample 155)	6·9	6	6	29	13	0·12	0·31

The pockets of gritty clay do not show any strong absorption characteristics and the soil solution appears to be largely derived from rain water. These samples have a broadly similar pH (6·0–5·2), a moderate loss on ignition (4·0–0·6 per cent), and low organic carbon and nitrogen, and in general resemble the soils of the stone stripe areas already discussed. The development of *Andreaea* mats over material of this kind appears to have relatively little influence, probably because these mosses do not form deep peat.

When, however, the montane *Andreaea* mats are in turn colonized by *Polytrichum strictum* and other species, and peat accumulates, there are marked changes, and the soils immediately below the moss carpets, with their much higher organic content, provide a striking contrast. Their retention capacity for nutrient ions is very high. A comparison of a sphagnum moss peat from a montane site in south-west Scotland and from a similar depth on Signy Island is interesting.

	pH	*Loss on ignition* (per cent)	*Extractable* (mg./100 g. dry) Na	K	Ca	Mg	P	N
Scottish peat (Kircudbrightshire)	4·5	94	15	18	110	60	0·03	1·5
Signy Island peat (sample 167)	5·2	89	133	28	93	245	1	1·1

The nutrients contained by the moss mats are retained by the underlying peat (comparison of samples 166 and 167) and the mineral material below is little modified (cf. samples 167, 168 and 169). The large amount of sodium and magnesium in the peat (compared with the Scottish peat) illustrates the importance of rainfall income. The sites may be described as rainfall flushes, where the moss and peat traps the incoming nutrients, enabling the vegetation to develop independently of the underlying rock debris. The contribution of the organic acids from the peat to rock decay is probably negligible compared with mechanical break-down.

The phosphorus levels, when compared with the Scottish data, appear very high and this seems to be a feature of all the Signy Island peat soils. The cause will be discussed later (p. 67).

Soil development over stable marble outcrops (*Table IV*)

In the area of the southernmost lake in Three Lakes Valley, and between it and Waterpipe

Beach, there is a series of prominent marble knolls over which soil formation is proceeding *in situ* by decomposition of the rock to form nodular debris and then fine mineral material. Samples 91, 92, 93 and 97 typify such material (Table IV; site a). In this vicinity three types of plant community are developed. Over the most exposed and rocky crests *Grimmia* sp. forms shallow carpets physiognomically very like the *Andreaea* patches over quartz-mica-schist, and there are crustose lichens on the rocks. Where the soil is deeper and moister and where exposure is less, *Tortula* spp. and *Drepanocladus* spp. dominate more continuous vegetation. Samples 102 and 103 (site c; Table IV) typify the *Grimmia* community, while samples 96 and 104–08 represent other vegetation types (sites d and e). Because the marble bands are narrow, there is a close juxtaposition of these calcicole communities with *Andreaea* carpets and other types developed on the adjacent schists. Samples 100 and 101 (site b; Table IV), from an *Andreaea* patch, may be compared with montane samples considered in the preceding section. As in the montane schist areas, the mats of *Andreaea* and *Grimmia* grow rather directly above a coarse basal mineral soil, to which they contribute little or no peaty material. More complex, layered profiles are apparent below the peat-forming *Tortula* and *Drepanocladus* vegetation, although the organic bands are usually only 2–3 cm. thick.

Samples collected from this area might be expected to contain large amounts of extractable calcium but the recorded figures are probably inflated, because of the slight solubility of calcium carbonate in the extractant. Sodium and magnesium are also moderately high compared with the schist areas but this is possibly due to differences in maritime influence. However, it is probably the high calcium availability and its effect on pH that influence the nature of the vegetation. The effect of the underlying rock on the nutrient composition of the peat in this area contrasts with the situation in the montane vegetation over schist.

The high absorption values together with the high pH of these peats may be responsible for some stimulation of activity by micro-organisms. The low C/N ratios for this site support this possibility and such activity might account for the high nitrate results.

A comparison of the results obtained from the marble areas on Signy Island with corresponding data from calcareous sites with similar organic content in Britain is of interest.

	pH	*Loss on ignition* (per cent)	*Extractable* (mg./100 g. dry)					
			Na	K	Ca	Mg	P	N
Signy Island (sample 107)	7·7	6	33	3	420	21	21	0·4
Signy Island (sample 96)	6·9	37	71	16	1,160	71	6	1·9
Limestone: north Lancashire	6·6	8	11	10	160	18	0·6	0·2
Calcareous: Rhum	7·0	28	40	47	700	200	1·0	0·9

On this set of figures the high phosphorus results for Signy Island soils are also apparent. The very low extractable/total phosphorus ratio may be due to greater phosphorus fixation by calcium and iron. The results for the Rhum soils bear the closest resemblance to the Signy Island samples—Rhum is also a small island site subject to a maritime depression system.

Soil development below Polytrichum-Dicranum carpets (*Table V*)

Dicranum aciphyllum dominates many gently sloping, fairly sheltered and moderately moist areas of Signy Island, often with *Polytrichum strictum* as an associate. With increasing gradient, or on stony and particularly well-drained slopes, the latter species becomes increasingly prominent until it comes to dominate the association. At higher levels in communities of either moss, lichens encrust the surface of the community, forming a third vegetation type.

Dicranum-Polytrichum communities are the most significant peat formers on Signy Island.

On gentle slopes, as above Spindrift Rocks on the west coast (Fig. 1), high banks covered by this vegetation stand as island masses 1 or 2 m. above the adjacent ground surface. These banks have a core of frozen peat, the permafrost in summer being only about 30–40 cm. below the surface; the base of one bank, 190 cm. below the present surface, has been dated at A.D. 147±, indicating an overall accumulation rate of about 1 mm. per annum (Godwin and Switsur, 1966). The surface of these banks is often rippled and hummocked, and lichens encrust the highest parts; such encrusted areas are sometimes foci of erosion which may expose the peat over several square metres. On sloping surfaces the peat layer is generally shallower and may suffer cracking and slumping due to frost-action. It may also have ramps and ridges on its surface, and these similarly become colonized by lichens and are equally liable to erosion.

Samples from *Polytrichum-Dicranum* vegetation were collected on the slope south of the British Antarctic Survey station (Table V; sites b, c, e, g, h), on the ridge running out to Observation Bluff (site f) and below Jane Peak (site i). At most of these sites the stratigraphy was the same. An upper layer of living moss about 8 cm. thick overlay peat, in which the moss stems were distinct, of some 5–10 cm. in thickness. Below this layer was a basal, almost structureless and more mineral brown soil, overlying rocky or stony debris. This basal layer was often, but not always, frozen. The broad stratigraphy was the same where the peat was thicker, and sample 19 (Table V; site a), from the base of a bank 1 m. deep above Mooring Point, is representative.

Chemically, these samples proved similar to those obtained from shallow *Polytrichum* carpets in montane sites. The nutrient concentration is highest just below the living vegetation, and falls away down the peat profile to relatively low levels in the basal material overlying the rock. This distribution is similar to that found in peat profiles that form on summit bogs on British mountains. The moss and underlying peat are similar in nutrient composition, assuming that most of the total nutrients are there in the extractable form. The peat layers build up a reservoir of nitrogen and phosphorus exceeding that in the plant layer at the surface, suggesting some surplus. The main peat layers are slightly more acid than the basal soils over the rock (pH about 4·5–4·75 compared with 4·7–5·4). The inorganic nitrogen levels in the peat are higher than average for the Signy Island samples, although under these more acid conditions ammonium-nitrogen predominated.

These peats, like the thin montane *Polytrichum* peat discussed earlier, can be considered as basically ombrogenous since much of their water content is derived from precipitation.

Soil development in Brachythecium-Acrocladium-Drepanocladus vegetation (*Table VI*)

If the *Polytrichum-Dicranum* vegetation is to be regarded as a semi-ombrogenous formation deriving its moisture from precipitation, conversely, the *Brachythecium-Acrocladium-Drepanocladus* series of communities have something of the soligenous mire, since most of them are permeated by drainage water. At one end of the sequence come the *Pohlia-Brachythecium* cp. *antarcticum*-hepatic mats on level ground with considerable waterlogging and late snow cover. The peat soils here (Table VI; sites c, e) are broadly similar in their general composition to those below *Polytrichum* and *Dicranum* carpets. Stratigraphically, the layers are thinner, the vegetation capping seldom exceeding 5 cm. in thickness, the main peat 3–5 cm. and the lower dark "soil" 5–8 cm. Some of the yellowish basal layers smelt of H_2S in the field and consequently were noted as reducing.

Outwards from the centres of snow patches and seepage zones the vegetation changes to communities of *Drepanocladus* and *Acrocladium*, while *Brachythecium* cp. *sarmentosum* flanks rapid streamlets on steeper slopes. Samples from these communities (Table VI; sites a, b, d) show no apparent difference from the other peat types. As in the central zones of snow patches, some peat below *Drepanocladus* on the boggy ground above Clowes Bay was yellowish and smelt of H_2S in the field. As a whole, the peats from these wet-ground communities were slightly less acid than those under *Polytrichum-Dicranum* carpets, but this may be due to the influence of the basal soil on the shallow organic layers. There are certainly insufficient data to separate the peat types in support of the subjective distinction between their "ombrogenous" and "soligenous" water relationships.

Soils of grass patches (*Table VII*)

The two vascular plants of Signy Island, the grass *Deschampsia antarctica* and the "pink" *Colobanthus crassifolius*, grow in the coastal zone in flushed sites exposed to the north and sheltered from the south, and hence effective radiation traps. Most sites are subject to heavy sea-bird influence. In the field it was noted that the grass clumps grew over a loamy, often dark, but never peaty soil in contrast to the highly organic layers beneath the moss mats. This integration of the organic matter into the soil suggests intense biological activity encouraged by the favourable micro-climate, flush conditions and soil oxidation.

Samples were obtained at five different sites (Table VII; sites a, b, c, d, e), all in the general neighbourhood of the British Antarctic Survey station. The soils varied greatly in depth, from as little as 5 cm. over rocks near Mooring Point (samples 135, 136) to well over 15 cm. below Observation Bluff (samples 131, 132). In general composition and structure the soils closely resemble the brown earth soils of temperate zones.

Detailed accounts of the ecology and general biology of these vascular plants will be published elsewhere by S. W. Greene, A. Holtom, A. D. Bailey, R. Corner, M. W. Holdgate and others.

Soils of areas contaminated by birds and seals (*Table VII*)

Samples were collected from an area near Pageant Point, heavily contaminated by birds (53–63; sites f, g; Table VII) and from elephant seal wallow grounds in the same area and north of Elephant Flats (Table VII; site h). Vegetation in these areas was almost totally absent.

The samples from within the penguin colony, consisting largely of black reducing mud, were alkaline in reaction (pH 7–8) and contained large amounts of all the extractable constituents. In particular, the potassium and phosphorus were high compared with sites free from contamination. The total concentrations of phosphorus and nitrogen were also high. The reducing conditions caused by the bird droppings resulted in very high levels of ammonium-nitrogen. Dilution of the drainage from the penguin colonies in the surrounding area reduced the cations to the Signy Island average but the phosphorus and nitrogen figures remained high. Exposure to oxidation increased the ratio of nitrate to ammonium-nitrogen.

The elephant seal wallow grounds are typified by black compacted reducing muds which are agitated by movement of the animals and directly contaminated by faeces and hair. The general level of extractable ions and nitrogen in the samples from this area were again increased, and the ammonium-nitrogen results were particularly high. The phosphorus, although moderately high, did not approach the excessive levels from the penguin colonies.

The detailed examination of these areas, although of no interest to the study of soil development *in situ*, indicates the potential influence of birds and animals on the soils of a small island.

DISCUSSION

From the preceding descriptive account, it is evident that a considerable diversity of mineral material occurs on Signy Island, but that there is no completed development of mature soils. Such mineral material is alkaline to weakly acid in reaction, of reasonably high base status, and considerably disturbed by down-wash and solifluction. This is a gleyed-textured material over a permafrost parent layer, capped locally by coarse solifluction debris or by a peat band of variable thickness. Such gleyed conditions are common in tundra regions.

The development of moss mats of the montane *Andreaea* or *Grimmia* type leads to little modification of this material and to no formation of peat. However, considerable organic accumulation occurs beneath *Polytrichum-Dicranum* mats and those of the *Brachythecium-Pohlia-Bryum-Drepanocladus* series. Such peat, in its upper levels consists of recognizable moss stems, which are, in the *Polytrichum-Dicranum* series, packed out by permafrost ice crystals to form a tough material superficially resembling "Tufnol". This peat is acid in reaction but it may contain surprisingly high levels of extractable cations. Below moss peat layers there is generally a transitional horizon of amorphous peaty material, sometimes vesicular in structure, and then various types of mineral material. The basal mineral soils clearly resemble those

Table V. Analytical data for samples collected from *Polytrichum* and *Dicranum* carpets on Signy Island

(All results except pH expressed on dry basis)

	Sample site	*Sample number*	*pH*	*Loss on ignition* (550°C) (per cent)	*Extractable* (N ammonium acetate pH 7·0) (mg./100 g.)				*Total* (per cent)				*Extractable* (0·002N H_2SO_4 at pH 3) P (mg./100 g.)	*Total* P (per cent)	*Total* N (per cent)	*Extractable* (mg./100 g.)		*Inorganic carbon* (per cent)	*Organic carbon* (per cent)	*Mechanical analysis* (*on soil < 2 mm.*) (per cent)	
					Na	K	Ca	Mg	Na	K	Ca	Mg				Aqueous NO'_3 —N	6 per cent NaCl NH_4^+ —N			*Clay*	*Silt*
Site a	Valley above Mooring Point; moss peat (1 m. depth) (12 February 1962)	19	5·3	27·6	18	13	122	55	0·13	0·89	0·73	0·58	13	0·54	0·99	>10	4·3	—	14·5	—	—
	Steep bank above station dominated by *Polytrichum* and *Dicranum* (13 February 1962)																				
Site b	Under Factory Cove bluffs (altitude 30 m.). Just below moss mat (5–8 cm.)	20	4·7	85·4	146	22	246	221	0·15	0·10	0·45	0·22	2	0·23	1·87	>10	3·4	—	41·8	—	—
	Over rock (10–15 cm.)	21	5·3	58·0	62	10	200	136	0·09	0·27	0·50	0·23	13	0·34	1·93	8	7·2	—	31·6	—	—
	Main peat layer (5–10 cm.) (adjoining Sample 20)	22	4·7	84·7	121	18	294	220	0·13	0·09	0·50	0·27	6	0·19	2·12	>10	4·9	—	43·2	—	—
	Base permafrost material over rock (15–20 cm.)	23	5·4	52·4	40	9	149	85	0·08	0·41	0·64	0·36	21	0·40	2·06	>10	14·5	—	28·5	—	—
Site c	Under Factory Cove bluffs (altitude 30 m.). Surface vegetation mats	24																			
	Surface; green		—	89·0	—	—	—	—	0·11	0·30	0·28	0·28	—	0·16	1·39	—	—	—	44·1	—	—
	Underlying; brown		4·7	94·0	—	—	—	—	0·16	0·04	0·35	0·28	—	0·15	1·46	<0·01	3·1	—	46·0	—	—
	Surface; green	25	—	92·0	—	—	—	—	0·15	0·21	0·30	0·32	—	0·18	1·10	—	—	—	45·2	—	—
	Underlying; brown		4·4	94·8	—	—	—	—	0·12	0·07	0·42	0·29	—	0·11	1·16	<0·01	0·3	—	43·8	—	—
Site e	Under Factory Cove bluffs (altitude 45 m.). Surface vegetation (0–8 cm.)	26																			
	Surface; green		—	97·1	—	—	—	—	0·09	0·23	0·12	0·20	—	0·13	1·28	—	—	—	48·1	—	—
	Underlying; brown		4·5	97·3	—	—	—	—	0·11	0·05	0·24	0·22	—	0·07	1·08	<0·01	1·1	—	47·2	—	—
	Middle peat layer (5–10 cm.)	27	4·3	97·0	128	11	204	195	0·14	0·04	0·29	0·20	1	0·09	1·30	>10	1·3	—	46·7	—	—
	Basal frozen soil; over rock (15 cm.)	28	4·7	81·9	114	11	431	224	0·12	0·06	0·59	0·23	1	0·12	1·56	>10	6·7	—	46·4	—	—
Site f	Observation Bluff (altitude 90 m.). Surface vegetation (0–8 cm.)	29																			
	Surface; green		—	95·9	—	—	—	—	0·10	0·28	0·22	0·23	—	0·08	0·69	—	—	—	46·0	—	—
	Underlying; brown		4·7	84·7	—	—	—	—	0·13	0·09	0·38	0·34	—	0·13	1·06	<0·01	<0·4	—	40·0	—	—
	Peaty layer (7–15 cm.)	30	4·6	77·2	96	27	221	177	0·11	0·11	0·44	0·20	1	0·23	1·79	<0·01	<0·01	—	38·3	—	—
	Basal soil; not frozen (20–25 cm.)	31	4·7	35·2	36	5	78	49	0·11	0·38	0·81	0·43	5	0·32	1·25	0·2	0·2	—	24·0	—	—
	Slope above station dominated by *Dicranum* on moist slopes (13 February 1962)																				
Site g	Altitude 15 m. Surface vegetation (0–8 cm.)	32																			
	Surface; green		—	97·2	—	—	—	—	0·12	0·35	0·26	0·34	—	0·07	0·53	—	—	—	45·9	—	—
	Underlying; brown		4·9	94·6	—	—	—	—	0·09	0·14	0·37	0·28	—	0·08	0·70	<0·01	<0·4	—	44·5	—	—
	Basal organic matter (8–10 cm.)	33	5·0	37·4	6	12	50	45	—	—	—	—	11	0·46	1·62	0·2	0·7	—	19·1	12	15
Site h	Altitude 30 m. Surface vegetation (0–8 cm.)	36																			
	Surface; green		—	96·8	—	—	—	—	0·15	0·33	0·31	0·32	—	0·07	0·60	—	—	—	46·7	—	—
	Underlying; brown		4·9	92·6	—	—	—	—	0·11	0·18	0·32	0·37	—	0·10	0·77	<0·01	<0·4	—	42·5	—	—
	Basal peat (ca. 10 cm.)	37	4·9	46·3	37	13	79	38	0·11	1·08	0·31	0·85	7	0·32	1·71	1·5	0·5	—	23·5	—	—
	Below Jane Peak (20 February 1962)																				
Site i	Lichen-encrusted *Polytrichum* mat (0–10 cm.)	82																			
	Surface; green		—	91·2	—	—	—	—	0·16	0·19	0·32	0·34	—	0·10	1·16	—	—	—	44·1	—	—
	Underlying; brown		4·7	95·2	—	—	—	—	0·16	0·06	0·40	0·35	—	0·09	1·27	<0·01	<0·4	—	45·3	—	—
	Peat below above mat (10–12 cm.)	83	5·2	80·6	61	11	134	192	0·09	0·33	0·28	0·16	2	0·20	2·24	0·09	0·1	—	41·9	—	—
	Fine gravel below above extending to 30 cm.	84	5·8	5·9	3	3	12	5	—	—	—	—	6	0·12	0·30	<0·01	0·1	—	4·1	—	—

Analyses by Chemical Section, The Nature Conservancy, Merlewood Research Station.

Table VI. Analytical data for samples collected from wet-ground vegetation on Signy Island

(All results except pH expressed on dry basis)

	Sample site	*Sample number*	*pH*	*Loss on ignition* (550°C) (per cent)	*Extractable* (N ammonium acetate pH 7·0) Na (mg./100 g.)	K	Ca	Mg	*Total* Na (per cent)	K	Ca	Mg	*Extractable* (0·002N H_2SO_4 at pH 3) P (mg./100 g.)	*Total* P (per cent)	*Total* N (per cent)	*Extractable* Aqueous NO_3' —N (mg./100 g.)	6 per cent NaCl NH_4^+ —N	*Inorganic carbon* (per cent)	*Organic carbon* (per cent)	*Mechanical analysis* (*on soil < 2 mm.*) *Clay* (per cent)	*Silt*
	Slope above station; samples from mats of *Drepanocladus*, *Acrocladium* and *Brachythecium antarcticum* (15 February 1962)																				
Site a	*Drepanocladus* mat (to 5 cm.) (altitude 45 m.)	43																			
	Surface; green		—	55·5	—	—	—	—	0·12	1·80	0·13	0·57	—	0·20	1·01	—	—	—	26·4	—	—
	Underlying; brown		5·6	50·4	—	—	—	—	0·09	1·70	0·12	0·62	—	0·22	0·89	<0·01	0·9	—	24·0	—	—
	Peaty layer (5–7·5 cm.)	44	5·2	22·8	13	13	30	16	0·11	2·50	0·26	0·66	11	0·30	0·80	1·2	0·2	—	10·6	—	—
	Soil of fine gravel and organic sediment (to 25 cm.)	45	5·3	5·3	4	5	7	6	—	—	—	—	11	0·27	0·18	0·11	0·1	—	2·1	6	20
Site b	Thin *Drepanocladus* mat (0–3 cm.) (altitude 60 m.)	46																			
	Surface; green		—	87·7	—	—	—	—	0·14	0·50	0·28	0·33	—	0·20	1·40	—	—	—	46·1	—	—
	Underlying; brown		5·3	89·1	—	—	—	—	0·10	0·17	0·35	0·21	—	0·25	1·59	<0·01	0·7	—	43·2	—	—
	Peat band (3–5 cm.)	47	4·8	71·9	40	19	70	44	0·07	0·27	0·39	0·26	9	0·43	2·98	2·8	0·2	—	32·4	—	—
	Dark organic soil (5–9 cm.)	48	5·0	24·2	14	7	23	18	0·10	1·04	—	0·25	8	0·28	0·67	0·08	0·2	—	12·0	—	—
	Yellow soil with gravel (9–20 cm.)	49	4·9	6·8	8	5	18	13	—	—	—	—	11	0·29	0·17	>10	0·2	—	2·6	1	13
Site c	*Brachythecium antarcticum* mat (0–5 cm.) (altitude 45 m.)	50																			
	Surface; green		—	88·0	—	—	—	—	0·16	0·80	0·15	0·24	—	0·30	1·50	—	—	—	43·0	—	—
	Underlying; brown		4·4	83·3	—	—	—	—	0·04	0·35	0·26	0·25	—	0·37	1·77	<0·01	0·8	—	41·9	—	—
	Vesicular peat (5–8 cm.)	51	4·8	66·[illegible]	54	13	99	43	0·09	0·62	0·25	0·23	31	0·52	2·00	4	3·7	—	33·3	—	—
	Yellow and black lower peat (8–15 cm.) with mineral nodules over rock	52	4·7	33·5	25	6	45	17	0·04	0·84	0·36	0·22	19	0·56	1·18	0·9	0·6	—	19·5	—	—
	Gourlay Peninsula and Clowes Bay (16 February 1962)																				
Site d	Peat below *Drepanocladus* mat; sloping to bay south of Rethval Point (2–6 cm.)	64	4·5	78·5	82	23	138	56	0·09	0·24	0·20	0·06	55	0·62	2·43	9	4·7	—	40·4	—	—
	Deeper peat below above (6–8 cm.); directly over stones	65	4·2	45·8	32	24	57	29	0·13	0·60	0·21	0·14	27	1·17	2·04	4·5	1·3	—	21·7	—	—
	Slope above station; *Brachythecium antarcticum* (17 February 1962)																				
Site e	Vegetation layer (0–3 cm.)	71																			
	Surface; green		—	88·8	—	—	—	—	0·10	0·40	0·21	0·21	—	0·45	2·20	—	—	—	42·4	—	—
	Underlying; brown		5·3	74·4	—	—	—	—	0·07	0·55	0·17	0·31	—	0·55	1·96	9	56·1	—	37·1	—	—
	Vesicular peat (3–6 cm.)	72	4·7	49·5	36	12	58	24	0·09	0·97	0·28	0·23	27	0·78	1·82	1·9	1·0	—	24·7	—	—
	Amorphous brown soil (6–10 cm.)	73	4·8	35·1	16	7	42	18	—	—	—	—	20	4·95	1·32	0·6	0·6	—	16·0	—	—
	Wet yellowy gravelly soil at base (10–15 cm.)	74	4·8	4·4	4	3	17	5	—	—	—	—	13	0·31	0·15	<0·01	0·2	—	1·9	3	10

Analyses by Chemical Section, The Nature Conservancy, Merlewood Research Station.

Table VII. Analytical data for samples collected from grassland and contaminated areas, Signy Island

(All results except pH expressed on dry basis)

	Sample site	*Sample number*	*pH*	*Loss on ignition* (550°C) (per cent)	*Extractable* (N ammonium acetate pH 7·0) (mg./100 g.) Na	K	Ca	Mg	*Total* (per cent) Na	K	Ca	Mg	*Extractable* (0·002N H_2SO_4 at pH 3) P (mg./100 g.)	*Total* P (per cent)	*Total* N (per cent)	*Extractable* (mg./100 g.) Aqueous NO_3-N	6 per cent NaCl NH_4^+-N	*Inorganic carbon* (per cent)	*Organic carbon* (per cent)	*Mechanical analysis* (*on soil < 2 mm.*) (per cent) *Clay*	*Silt*
	Samples from grass patches (*Deschampsia antarctica*) (21 February 1962)																				
Site a	Uppermost patch, north of Polynesia Point (altitude 45 m.)	119																			
	Surface; green		—	81·3	—	—	—	—	0·14	0·40	0·36	0·44	—	0·25	1·85	—	—	—	43·0	—	—
	Underlying; brown		4·9	58·8	—	—	—	—	0·09	0·40	0·69	0·44	—	0·35	2·61	0·01	1·1	—	32·6	—	—
	Peat and roots below sample 119 (depth 3–8 cm.)	120	4·8	40·5	46	19	80	71	0·08	0·99	0·32	0·25	4	0·47	1·53	2·7	0·2	—	23·3	—	—
Site b	Grass patch lower down same slope (altitude 30 m.)	121																			
	Surface; green		—	58·3	—	—	—	—	0·10	0·55	0·58	0·63	—	0·32	2·14	—	—	—	32·6	—	—
	Underlying; brown		4·8	63·5	—	—	—	—	0·15	0·45	0·66	0·68	—	0·34	1·31	1·3	6·0	—	17·6	—	—
	Uneven fibrous peaty soil below sample 121 (depth 3–8 cm.)	122	4·8	41·6	50	17	68	51	0·16	0·47	0·95	0·54	6	0·36	1·35	2·0	1·1	—	22·3	—	—
	Gravelly dark loam (6–15 cm.)	123	7·6	16·2	17	10	43	25	—	—	—	—	12	0·33	0·62	—	0·3	—	7·5	—	—
Site c	Large patch of grass and *Colobanthus* on flushed slope at 25 m. Surface vegetation	131A	—	37·4	—	—	—	—	0·19	1·05	0·42	0·83	—	0·27	1·57	—	—	—	16·3	—	—
	Mineral soil (0–10 cm.)	131B	5·6	13·9	56	24	150	83	—	—	—	—	4	0·23	0·45	>2	2·0	—	5·6	4	6
	Deep loamy soil extending from 5–15 cm. and deeper	132	5·4	13·5	57	19	172	99	—	—	—	—	5	0·27	0·60	>2	0·3	—	6·5	11	13
Site d	Berntsen Point, by emergency hut, at 5 m. Peat from bare ground (1–5 cm.)	133	4·8	50·4	77	13	55	48	0·14	0·71	0·33	0·26	13	0·80	2·23	1·1	0·2	—	26·7	—	—
	Dark peaty soil over boulders (5–10 cm.)	134	4·6	30·5	34	10	34	21	—	—	—	—	13	1·00	1·23	0·2	0·1	—	16·0	—	—
Site e	Gully at Mooring Point (altitude 7·5 m.); patch of dead grass (0–2 cm.)	135																			
	Surface; green		—	75·1	—	—	—	—	0·10	0·50	0·46	0·46	—	0·29	2·66	—	—	—	39·7	—	—
	Underlying; brown		4·8	43·2	—	—	—	—	0·08	0·90	0·44	0·49	—	0·31	1·96	4·0	5·5	—	23·0	—	—
	Thin brown peaty layer over stones (2–5 cm.)	136	5·0	28·0	[illegible]40	2[illegible]	147	79	0·08	1·20	0·47	0·37	3	0·30	1·27	3·5	0·4	—	12·0	—	—
	Pageant Point; area of rookeries and nesting ledges exposed to sea spray (16 February 1962)																				
Site f (*sites away from penguins*)	Soil below surface layer of alga *Prasiola* (1–5 cm.); with rapid run-off	53	3·7	25·3	18	10	17	14	—	—	—	—	14	0·16	1·74	>10	1·4	—	11·7	3	4
	Yellow gravelly soil on cliff slope; no vegetation (0–5 cm.)	54	4·7	15·4	21	37	69	21	—	—	—	—	35	3·04	1·31	>10	5·6	—	6·9	11	21
	Pantomime Point; soil in lichen area (1–5 cm.)	56	4·8	27·8	43	20	80	49	—	—	—	—	91	0·84	1·80	>10	0·9	—	13·0	5	3
Site g (*sites with penguins*)	Bare gravelly mud in penguin rookery (0–5 cm.)	55	7·1	13·2	45	87	63	26	—	—	—	—	620	5·04	1·32	>10	48·7	—	5·5	6	6
	Pantomime Point; penguin rookery; organic mud (0–5 cm.)	58	8·2	30·9	170	157	341	108	0·49	0·68	7·84	1·88	1,110	5·83	2·63	>5	678	—	13·9	—	—
	Pantomime Point; black reducing mud; rookery drainage (0–5 cm.)	61	7·9	20·1	118	128	63	191	—	—	—	—	920	5·40	2·06	>10	86·8	0·1	8·7	—	—
Site h (*sites with elephant seals*)	Black organic reducing material from elephant seal wallow grounds; Gourlay Peninsula	62	5·8	67·8	95	22	272	140	0·13	0·45	0·77	0·26	78	0·93	4·42	0·6	79·4	—	31·5	—	—
	Black organic reducing material; from elephant seal wallow grounds; Gourlay Peninsula	63	8·3	73·2	448	240	307	224	0·45	0·48	0·63	0·33	89	0·54	3·89	>10	>900	—	36·1	—	—
	Elephant Flats area																				
Site i	Bare peaty humus in vegetation-free wallow area (0–5 cm.)	117	5·9	45·7	53	37	81	37	0·11	0·82	1·57	0·47	30	—	2·43	2·4	2·3	—	22·5	—	—
	Grey clay without organic matter (10–15 cm.); below sample 117	118	7·6	2·6	9	19	182	6	—	—	—	—	48	0·21	0·15	>2	4·3	<0·1	0·4	12	18

Analyses by Chemical Section, The Nature Conservancy, Merlewood Research Station.

water lakes on both east and west coasts of the island confirm that a considerable amount of sodium and chloride, probably of marine origin, occurs in such situations.

It is clear from this detailed study of the Signy Island soils that, with possible local exceptions, most principal nutrient elements are not limiting for plant growth even in areas of most intensive leaching. The maritime precipitation, high bird population, and widespread distribution of marble and hornblende fragments through glacial action together provide an adequate supply of most nutrient elements. The comparisons with a range of temperate soils from Britain with similar parent materials illustrate the ample reserve of nutrients in the Signy Island soils.

The only element that may be limiting at various stages is nitrogen in the available form. It is possible that because of the slow growth of lichens and mosses the atmospheric precipitation (with a contribution from bird droppings) provides an adequate supply. However, it is known that lichens (and some mosses) have the ability to fix nitrogen direct from the atmosphere, and this fixation rate may be dependent upon temperature. The rate of mineralization of organic nitrogen in the peat vegetation complex may be of importance. The presence of considerable inorganic nitrogen independent of bird contamination was detected but in other cases the high level of nitrogen in peat compared with surface vegetation suggests an accumulation. More work is required to clarify the factors controlling nitrogen uptake.

ACKNOWLEDGEMENTS

We are indebted to Sir Vivian Fuchs for support and encouragement, and to members of the British Antarctic Survey, especially those on Signy Island, for help in the field. Dr. R. J. Adie has given valuable advice on the presentation of this paper. We also wish to thank Mr. J. B. Cragg, Director of the Merlewood Research Station from 1961 until 1966, and Dr. O. W. Heal of its staff, for much stimulating discussion.

MS. received 16 December 1965

REFERENCES

CHAMBERS, M. J. G. 1966*a*. Investigations of patterned ground at Signy Island, South Orkney Islands: I. Interpretation of mechanical analyses. *British Antarctic Survey Bulletin*, No. 9, 21–40.

————. 1966*b*. Investigations of patterned ground at Signy Island, South Orkney Islands: II. Temperature regimes in the active layer. *British Antarctic Survey Bulletin*, No. 10, 71–83.

————. 1967. Investigations of patterned ground at Signy Island, South Orkney Islands: III. Miniature patterns, frost heaving and general conclusions. *British Antarctic Survey Bulletin*, No. 12, 1–22.

GODWIN, H. *and* V. R. SWITSUR. 1966. Cambridge University natural radiocarbon measurements VIII. *Radiocarbon*, **8**, 390–400.

HEAL, O. W. 1965. Observations on testate Amoebae (Protozoa : Rhizopoda) from Signy Island, South Orkney Islands. *British Antarctic Survey Bulletin*, No. 6, 43–47.

HIGASHI, A. 1958. Experimental study of frost-heaving. *Res. Rep. Snow Ice Permafrost Res. Establ.*, No. 45, 20 pp.

HOLDGATE, M. W. 1964. Terrestrial ecology in the maritime Antarctic. (*In* CARRICK, R., HOLDGATE, M. *and* J. PRÉVOST, *ed. Biologie antarctique*. Paris, Hermann, 181–94.)

————. 1965. Biological research by the British Antarctic Survey. *Polar Rec.*, **12**, No. 80, 553–73.

KELLY, W. C. *and* J. H. ZUMBERGE. 1961. Weathering of a quartz diorite at Marble Point, McMurdo Sound, Antarctica. *J. Geol.*, **69**, No. 4, 433–46.

NICHOLS, R. L. 1964. Present status of Antarctic glacial geology. (*In* ADIE, R. J., *ed. Antarctic geology*. Amsterdam, North-Holland Publishing Company, 123–35.)

PENNER, E. 1959. The mechanism of frost heaving in soils. *Bull. natn. Res. Coun. Can., Highw. Res. Bd.*, No. 225, 22 pp.

PEPPER, J. 1954. *The meteorology of the Falkland Islands and Dependencies, 1944–1950*. London, Falkland Islands and Dependencies Meteorological Service.

ROOY, M. P. VAN, *ed.* 1957. *Meteorology of the Antarctic*. Pretoria, Weather Bureau.

TICKELL, W. L. N. 1962. The dove prion, *Pachyptila desolata* Gmelin. *Falkland Islands Dependencies Survey Scientific Reports*, No. 33, 55 pp.

WILLIAMS, P. J. 1959. The development and significance of stony earth circles. *Skr. norske Vidensk-Akad.*, No. 3, 3–14.

exposed elsewhere on the island but they may, in their upper layers, be modified by the incorporation of organic material.

While the few centimetres of mineral soil immediately beneath bryophyte mats and their underlying peats thus show the influence of the surface vegetation, and percolation of peat-stained melt water causes discoloration in gravels and coarser rocks, the vegetation cover does not give rise to any sort of true "A" horizon. There are several factors which contribute to this small degree of interaction between the vegetation, peat and basal soil layers. First of all, decomposition of organic matter is slow, the thick peats beneath the larger moss banks indeed being permanently frozen. Secondly, the vegetation as a whole lacks root systems which penetrate the soil. The only exception to this generalization is found in the small areas supporting grass (*Deschampsia antarctica*) and the cushion plant *Colobanthus crassifolius*, both of which have substantial roots penetrating many centimetres. These patches, in their flushed gullies, overlie well-mixed loamy soil which is not recognizably peaty and not purely organic, although it has a high organic content. It may be highly significant that such moist and reasonably rich materials approach "brown earths" more than most soils on the island, and may be more developed than other substrata there. Such grass soils have also been shown to support a much greater diversity and abundance of testate Rhizopoda than marble soils or *Polytrichum-Dicranum* peats (Heal, 1965). Chemically, the grassland soils may be compared with northern British woodland brown earths, and it is hence striking that Heal found comparable numbers of Testacea in Signy Island grassland samples and in northern temperate materials; from the available information, the other sites on Signy Island will probably prove distinctly poorer in their micro-fauna.

In general, on Signy Island, there is a total absence of those invertebrate animals which in temperate regions contribute especially to soil mixing (earthworms and myriapods); the enchytraeid oligochaetes of the island are few in number and are largely restricted to the coastal zone. Collembola, mites and nematodes, which are abundant, are concentrated in the upper organic layers. Collembola are locally abundant in talus and lichen-covered rock areas and may there perhaps add some organic material to the soil in the form of faecal pellets and dead organisms, but their influence is likely to be much less important than in continental Antarctica. Soil bacteria, Protozoa (Heal, 1965) and Fungi are abundant and probably contribute to the soil directly and via invertebrates which feed on them. The overall influence of these organisms is, however, likely to be small and largely confined to the superficial layers. Over much of the island, therefore, unless vegetation mats are over-ridden by viscous mud in the process of solifluxion, little mixing of mineral soil and plant material takes place. Only locally, around penguin colonies, elephant seal wallows, colonies of burrowing petrels (especially *Pachyptila desolata*) (Tickell, 1962), and gull, skua and other sea-bird nesting sites, does a substantial mechanical disturbance of the soil occur through animal agency.

The influence of animals may none-the-less be of major significance. Signy Island has very large populations of breeding birds and around their colonies, and about seal wallow grounds, the substratum is heavily contaminated and has very high nitrogen levels. Away from the main colonies the barren marginal ground is acid, but in areas of high penguin density the soil is alkaline to circum-neutral and rich in extractable cations. Even well away from the main breeding areas the influence of birds is considerable, and there is no part of the surface which is not liable to receive droppings. Feathers and guano splashes are commonly seen in many of the lowland areas which, being near the coast, are also near bird breeding grounds. Grass patches are often conspicuously marked in this way. Over the whole island, moreover, a strong smell of penguins may be noted in the breeding season when the wind blows inland from one of the main colonies at Gourlay Peninsula, North Point, Pandemonium Point or Spindrift Rocks. It is most probable that organic and inorganic particles may be distributed from these areas by the frequent gales and have a significant chemical influence on soils all over the island. The high phosphate levels in Signy Island peats may be derived from this source.

Since there is no part of Signy Island more than about 1·5 km. from the sea, it is equally probable that spray is deposited in some quantity everywhere, especially during summer storms, and this influx of mineral salts must be important as a source of plant nutrients. Quantitative measurements have yet to be made, but analyses of rain, snow, melt-water streams and fresh-

APPENDIX

ANALYTICAL METHODS USED FOR DETERMINATION OF CHEMICAL COMPOSITION

Initial tests

pH: Determined on the fresh material with minimum wetting using a glass electrode and pH meter.

Loss on ignition: Ground material ignited in muffle furnace at 550°C until no further weight loss.

Mechanical analysis: Determined using the standard hydrometer method.

Solution preparation

Mineral and organic soil extracts: N ammonium acetate was used to extract soil cations and Truog's solution (0·002 N H_2SO_4 buffered at pH 3) was used to extract for phosphorus. Fresh samples were used for the organic soil extractions but the mineral soils were first air dried at 45°C. These extractions were carried out on a rotary shaker. Water was used as the extractant for nitrate and 6 per cent sodium chloride was used to extract ammonium ions. In all cases appropriate aliquots were taken for analysis.

Organic materials: The organic material was destroyed by digesting with a mixture of perchloric, nitric and sulphuric acids. The resultant digest was filtered and aliquots taken for analysis.

Individual constituents

Sodium and potassium: Determined with a flame spectrophotometer.

Calcium: Determined on a flame spectrophotometer after addition of lanthanum chloride to suppress interferences.

Phosphorus: Analysed by a colorimetric procedure based on development of the molybdenum-blue colour. Stannous chloride in hydrochloric acid was used as reducing agent and the colour intensity was read exactly 30 min. after development.

Nitrogen: A digestion based on the Kjeldahl procedure, using mercuric oxide as catalyst, was used to destroy the organic matter. The ammonia was then distilled in a semi-micro distillation unit, trapped in boric acid and titrated.

Nitrate-nitrogen: Determined on the polarograph using uranyl chloride as the electrolyte carrier. When necessary, colour was removed in advance by flocculation.

Ammonium-nitrogen: The semi-micro distillation procedure was used with magnesium oxide to liberate the ammonia which was then collected as for nitrogen.

Inorganic carbon: Dilute hydrochloric acid was used to generate carbon dioxide which was then trapped in soda-lime and determined gravimetrically.

Organic carbon: The organic matter was destroyed using the Van Slyke-Folch reagent (sulphuric acid, phosphoric acid and potassium dichromate). The carbon dioxide generated was carried over and determined gravimetrically as with inorganic carbon.