# DISTRIBUTION, COMPOSITION AND GENERAL CHARACTERISTICS OF THE MOSS BANKS OF THE MARITIME ANTARCTIC

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ABSTRACT. This paper discusses the ecology of the tall turf-forming mosses *Chorisodontium aciphyllum* and *Polytrichum alpestre*, and the development and dynamics of the deep moss banks formed solely by these species within the maritime Antarctic botanical zone where these banks are a unique feature of the vegetation. Most of the research has been undertaken at Signy Island (lat. 60°43′S, long. 45°38′W), South Orkney Islands, but some comparative studies were also made on Galindez Island (lat. 65°15′S, long. 64°16′W), Argentine Islands. The distribution of moss-turf banks throughout the maritime Antarctic region is outlined and their floristic composition compared.

The distribution of moss banks on Signy Island has been mapped and their extent calculated as 34 ha, 1.7% of the total area of the island; the proportion of continuous and discontinuous, and permafrost and non-permafrost turf has also been determined. Five *Chorisodontium*-dominated banks and one *Polytrichum*-dominated bank on Signy Island, and one *Polytrichum* bank on Galindez Island were selected for detailed investigation, and they are presented as case studies. These banks have been mapped and from core samples taken along transects accurate profiles of some of the deeper banks are illustrated. The deepest recorded on Signy Island is 205 cm for a bank above the north-west coast, and a radiocarbon date of 4 801 ± 300 years B.P. has been obtained for a basal peat sample taken from a depth of 125 cm in the same bank; deeper samples proved to be of younger origin. This suggests that this area of Signy Island has been ice-free and available for plant colonization and moss-bank development for at least 4 500–5 000 years. The principal factors which permit or limit moss-bank development are discussed.

EXTENSIVE closed stands of vegetation dominated by bryophytes are not common in Antarctic regions. However, these are most frequent in the maritime Antarctic (Fig. 1), as defined by Holdgate (1964), where communities of carpet- and turf-forming mosses locally cover relatively large areas, i.e. exceeding 100 m$^2$ (Longton, 1967; Gimingham and Smith, 1970). Certain communities or sociations within the moss-turf sub-formation (see Gimingham and Smith, 1970) develop a unique feature in the vegetation of the Antarctic in the formation of comparatively deep banks of moss peat. This peat is composed almost entirely of two tall turf-forming mosses, *Chorisodontium aciphyllum* (Hook. f. et Wils.) Broth. and *Polytrichum alpestre* Hoppe. Banks composed of *Polytrichum* are more compact, stable and resistant to wind erosion due to the cohesion of the shoots, which are bound tightly together by the dense tomentum of rhizoids. *Chorisodontium*-dominated banks tend to be loose and easily damaged by trampling as the shoots are only sparsely covered with rhizoids.

Various aspects of the ecology of these moss banks and of the growth, production, population dynamics and decomposition of the component species have been recorded by Holdgate (1964), Longton (1967, 1970, 1972), Gimingham and Smith (1970), Baker (1972), Smith (1972) and Collins (1976*a*, *b*). This paper describes the development, structure and dynamics of the moss banks rather than of the individual species of which they are composed.

## GENERAL FEATURES OF THE MOSS BANKS

The term "moss-peat bank" is used here to describe the *Polytrichum alpestre–Chorisodontium aciphyllum* association in the moss-turf sub-formation (Gimingham and Smith, 1970; Smith, 1972). These two mosses, either individually or more commonly in association, accumulate organic matter frequently up to 1–2 m in depth. This accumulation differs from most peats for virtually no humification occurs; it also differs in its mode of formation because peat production normally requires some degree of waterlogging and de-oxygenation (Moore and Bellamy, 1973, p. 204). These Antarctic moss banks are neither saturated nor anaerobic and peat develops due to (i) the tall erect growth form of the component species (Gimingham and Smith, 1971); (ii) the low temperature and (iii) low pH (3.5–4.5) of the peat, both of which inhibit microbial activity and consequently the rate of decomposition is low (Baker,

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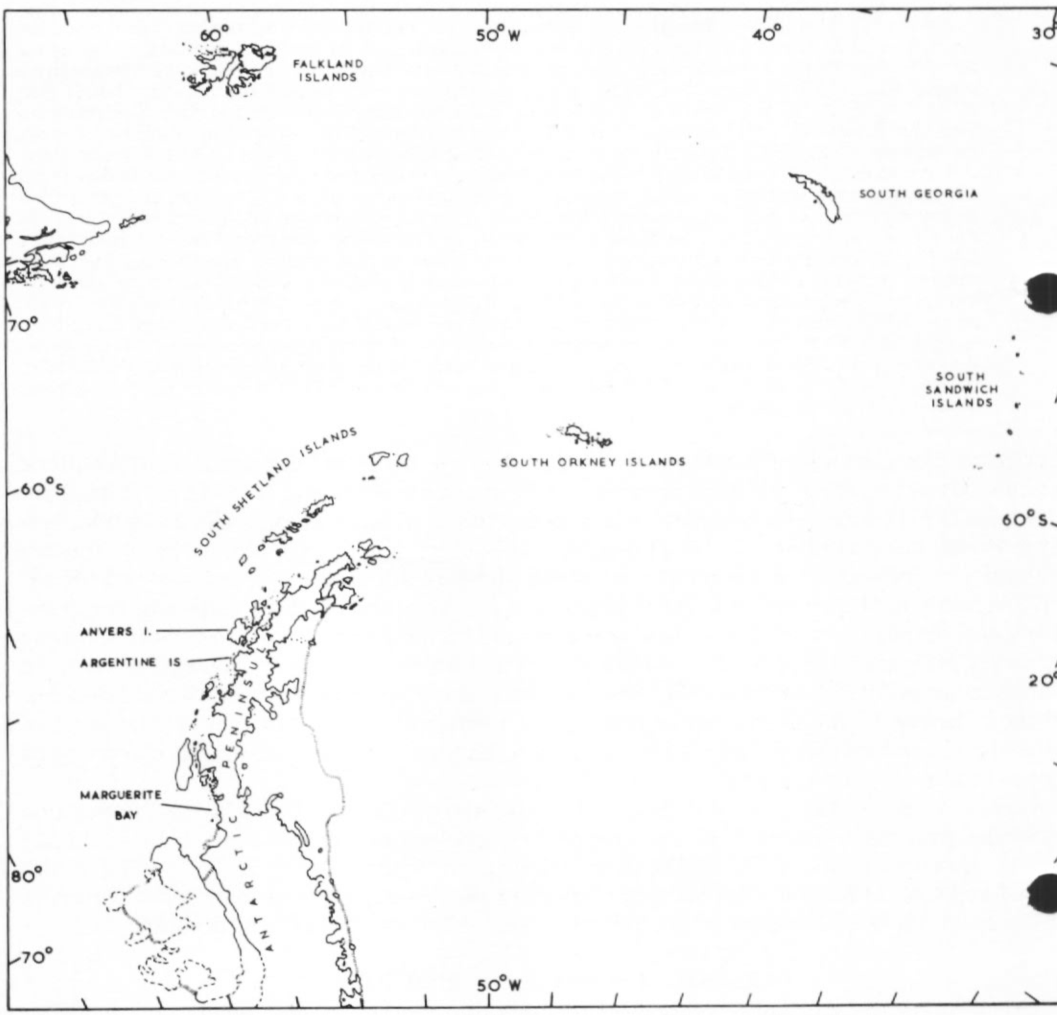


Fig. 1. Map of the Antarctic Peninsula and Scotia arc showing the localities mentioned in the text.

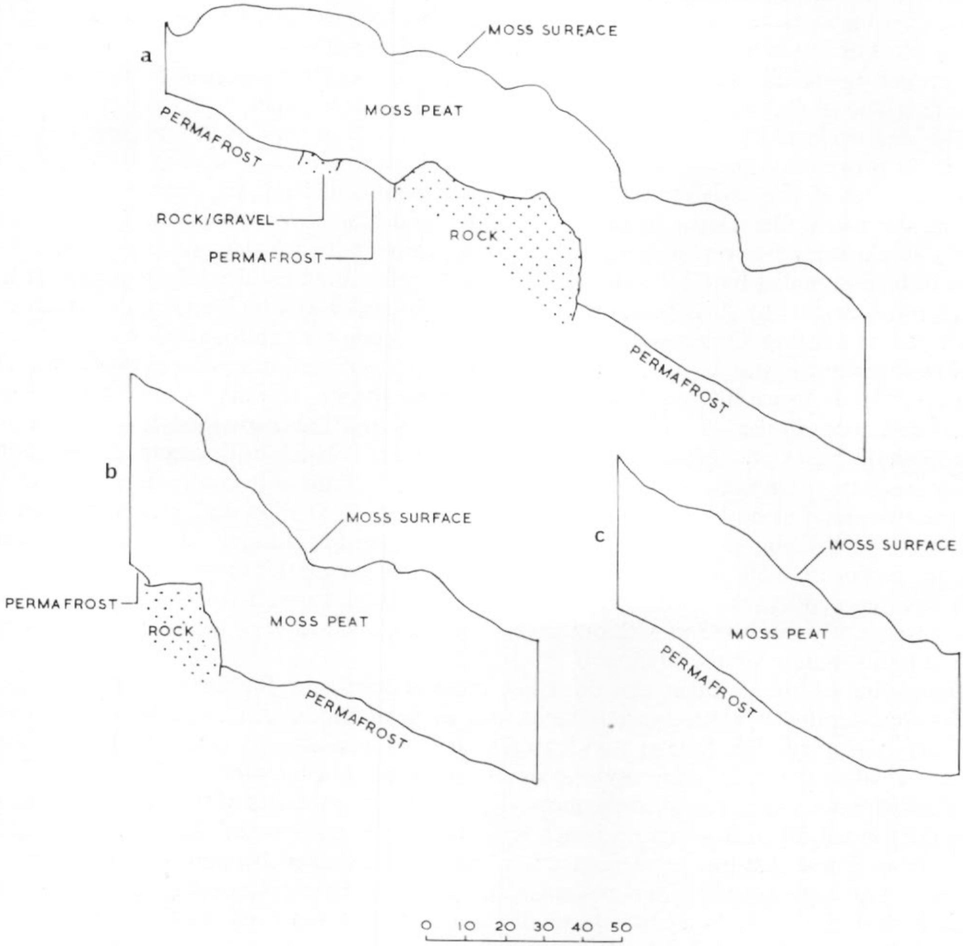


Fig. 2. Sections of *Polytrichum* banks showing the relation between surface topography and the permafrost surface.

72); (iv) the existence of a permafrost which usually develops once the moss depth exceeds 20–35 cm; (v) the invertebrate biomass (Nematoda, Collembola and Acari) being an order of magnitude lower than in most other communities on Signy Island (Collins and others, 1975).

Accounts of the suspected sequence of development of these moss banks from the initial colonization of a suitable substratum to the eventual formation of a moss-peat bank have been given by Smith (1972) and in greater detail by Collins (1976*a*). In most peat-forming ecosystems, the component species are usually hydrophiles occupying wet habitats on poorly drained ground or in wet depressions, leading ultimately to the development of blanket or raised bogs and deep accumulations of peat. However, the moss banks of the maritime Antarctic are formed by mesophilic species usually on sloping, stony, relatively well-drained ground. Initial colonization is generally by invasion of *Drepanocladus uncinatus* or *Calliergon sarmentosum* carpets on moist seepage slopes, or of mixed stands of *Andreaea* spp. and fruticose lichens on drier ground, by small dome-shaped turves of *Chorisodontium aciphyllum* with subsequent establishment of *Polytrichum alpestre* among the latter moss. Unlike peat "bogs" in temperate and other tundra regions, including the sub-Antarctic, the *Polytrichum–Chorisodontium* banks develop as raised mounds of loose fibrous frozen moss peat capped by the living moss and associated cryptogamic epiphytes, often with high vertical faces, especially on the deeper down-hill edge. Evidence that resistance to decomposition is, in fact, an inherent characteristic of *Polytrichum alpestre* will be given in a later paper.

The *Polytrichum–Chorisodontium* peat banks of the maritime Antarctic are regarded as "semi-ombrogenous", deriving moisture from precipitation but also relying to some degree on ground water in the early stages of their development and from the thawing of permafrost during summer in the deeper frozen banks (Allen and Northover, 1967; Holdgate and others, 1967). Banks occurring on level or gently sloping ground with a regular supply of ground water tend to be dominated by *Chorisodontium*, probably reflecting the initial colonization of hydrophilic moss carpets by this species rather than by *Polytrichum* which appears to require drier substrata or existing *Chorisodontium* turf for it to become established. Consequently, *Polytrichum*-dominated stands tend to occur mainly on steep well-drained rocky slopes. This is contrary to its apparent requirements in northern tundra regions, where it is frequently associated with species of *Sphagnum* in moist areas and late snow-bed habitats. However, intermediate banks are perhaps the commonest feature in which both species are present with either assuming dominance locally throughout the bank. Banks (generally those co-dominated by the two mosses) developed on level ground tend to be shallow and seldom exceed about 40 cm in depth. Similarly, those on steep slopes (generally dominated by *Polytrichum*) are seldom deeper than 50–70 cm. However, banks formed on gentle stony slopes attain considerably greater depths, particularly those dominated by or formed solely by *Chorisodontium*. These frequently reach 1–2 m with one exceptional bank of 3 m deep being known on Elephant Island (Allison and Smith, 1973).

Depending on the gradient and on which moss is dominant, the surface micro-topography varies considerably. *Chorisodontium* banks may be gently undulating, relatively hummocky or extensively rippled. The former two features result almost entirely from the growth form of the moss, while the small-scale ripple systems are probably generated by the strong prevailing wind which affects the growth of the moss. The most exposed parts of the banks are frequently subjected to wind and frost action which leads to surface erosion and the removal of all living vegetation. These features have been described and illustrated by Smith (1972) and Collins (1976*a*). Although healthy *Chorisodontium* turf tends to have a smooth or gently undulating surface, healthy *Polytrichum* turf is generally hummocky, comprising small hummocks of more vigorously growing moss 2–5 (–10) cm in diameter and 3–4 cm in height. Otherwise, *Polytrichum* forms a relatively even compact surface on level or gentle slopes but, as with *Chorisodontium* on steeper slopes, solifluction over the permafrost within the bank frequently causes the surface layer of moss to slip and form steps which may lead to erosion by frost splitting and desiccation of the peat. Erosion of these banks can also be enhanced by burrowing petrels, particularly dove prions (*Pachyptila desolata*), or the nesting activities of brown skuas (*Catharacta skua*).

The relationship between surface topography and the permafrost surface is shown in Fig. 2; the latter reflects the former to only a small extent for, because of the thermal properties of ice, the permafrost surface is always smooth. In this paper the term "permafrost" refers to permanently frozen moss, for even what has been described here as a "non-permafrost moss bank" will have a permafrost in the mineral substratum beneath (Chambers, 1966).

## Floristic Composition and Distribution

Unlike similar peat-mound structures in the Arctic, e.g. palsas, in which vascular plants, particularly dwarf shrubs and graminoid species, are important components, the Antarctic counterparts have no phanerogamic associates. Floristically, the banks of the maritime Antarctic are very simple, comprising the two tall turf-forming mosses, occasional scattered

TABLE I. COMPOSITE LIST OF SPECIES ON *Polytrichum alpestre–Chorisodontium aciphyllum* BANKS IN THREE REGIONS OF THE MARITIME ANTARCTIC

| *Species* | *South Orkney Islands* | *Elephant Island* | *Arthur Harbour–Argentine Islands region* |
|---|---|---|---|
| *Polytrichum alpestre* | a | a | a |
| *Chorisodontium aciphyllum* | a | a | o–lf |
| *Drepanocladus uncinatus* | r | r | r |
| *Pohlia nutans* | o–f | o | f |
| | | | |
| *Barbilophozia hatcheri* | f | f | o |
| *Cephaloziella varians* | f | f | f |
| | | | |
| *Alectoria chalybeiformis* | f | f | – |
| *A. nigricans* | f | – | – |
| *A. pubescens* | r | f | – |
| *Cladonia carneola* | o | o | o |
| *C. furcata* | f | f | f |
| *C. metacorallifera* | f | f | f |
| *C. rangiferina* | r | r | – |
| *Cornicularia aculeata* | o | r | r |
| *C. epiphorella* | r | – | r |
| *Ochrolechia frigida* | f | f | f–a |
| *Psoroma hypnorum* | r | r | r |
| *Sphaerophorus globosus* | f | f | f–la |
| *Stereocaulon alpinum* | o | r | r |
| *Usnea antarctica* | f–a | f–a | r |
| *Himantormia lugubris* | r | – | – |
| Crustose species (mainly *Buellia, Lecidea, Rinodina*)+blue-green algae | f | f | f |
| | | | |
| *Omphalina* spp. | o | ? | r |

Cover assessment: a. Abundant (affording >50% cover in stand); f. Frequent (affording 5–50% cover in stand); o. Occasional (affording 1–5% cover in stand); r. Rare (affording <1% cover in stand); Prefix l. Locally, e.g. la, locally abundant (i.e. contagious distribution within stand).

shoots of a few other bryophytes and commonly a variety of epiphytic crustose and fruticose lichens, especially in the more wind-swept parts of the banks.

Table I indicates the general species composition of typical moss banks in the South Orkney Islands, Elephant Island, the easternmost of the South Shetland Islands, and the Arthur Harbour–Argentine Islands area. While the overall composition is similar, there is a noticeable decline in the number and abundance of fruticose lichens while *Chorisodontium* becomes much more restricted farther south. Banks in the more northerly localities are commonly overgrown with dense growths of *Alectoria* spp., *Cladonia* spp., *Sphaerophorus globosus* and *Usnea antarctica*, while more exposed parts are often encrusted extensively by *Ochrolechia frigida* and species of *Buellia*, *Lecidea*, *Rinodina* and sterile *Cladonias* as well as blue-green algae. With the exception of *Sphaerophorus*, the fruticose species are generally scarce on the more southerly banks and crustose species, especially *Ochrolechia frigida*, predominate where the moss has been killed by wind and frost action. *Chorisodontium* reaches its southernmost locality on the islands in Collins Bay, south-east of the Argentine Islands (Smith and Corner, 1973), but *Polytrichum alpestre* has occasional outlying stations as far south as the Léonie Islands and Jenny Island (lat. 67°44′S) in northern Marguerite Bay, where it forms small stands of shallow turf (Bertram, 1938; Longton, 1967; Greene and others, 1970). Almost identical moss-peat banks occur on the sub-Antarctic island of South Georgia (lat. 54°S), but here they barely become raised above the level of the surrounding topography. Small hummock-shaped mounds of *Chorisodontium* up to about 50 cm deep are common amongst tussock grass (*Poa flabellata*) on moist coastal hillsides, usually with *Polytrichum alpinum*, liverworts and species of *Cladonia* associated. Drier sites support locally extensive *Polytrichum alpestre*-dominated banks with various species of *Cladonia* and flowering plants (*Juncus scheuchzerioides*, *Festuca contracta* and *Poa flabellata*) often present. Some of these banks are up to 2 m deep and appear to be the climax stage of a hydrosere, the initial phase of which was a floating mat of hydrophytic mosses in shallow lakes. However, it is possible that part of these deep peat deposits were formed by tussock grass which may have dominated the site during one of the seral stages of development. Both *Polytrichum* and *Chorisodontium* occur as a closed understorey in bogs dominated by the rush *Rostkovia magellanica* in damp rock basins with an efficient drainage system. Here, moss and rush peat often accumulates to over 1 m in depth.

There is little difference in the general feature of the banks throughout their range in the maritime Antarctic (Fig. 1). South of lat. 60°S the *Polytrichum–Chorisodontium* banks are most extensive (occasionally exceeding 2 000 m$^2$) and widespread in the western South Orkney Islands (notably the south side of Coronation Island, Robertson Islands, Signy and Moe Islands). Few stands occur on Laurie Island where the largest also appear to occur on the southern side of the island, notably at Cape Dundas. Others have eroded to such a degree that they possess no living surface but stand as raised mounds of frozen peat on dry stony slopes (Smith, 1972).

The relatively dry porous volcanic substrata of most of the South Sandwich and South Shetland Islands do not possess stands of *Polytrichum alpestre* or *Chorisodontium aciphyllum* and both species are scarce (Longton, 1967; Lindsay, 1971; Longton and Holdgate, 1979). Here, the *Polytrichum–Chorisodontium* association is replaced by small stands of the *P. alpinum–C. aciphyllum* association, which rarely develops peat exceeding about 30 cm deep. On Elephant Island, however, banks similar to those found in the South Orkney Islands are not uncommon, presumably a reflection of the geological similarity between the two island groups (Allison and Smith, 1973).

On the western seaboard of the Antarctic Peninsula and offshore islands, *C. aciphyllum* appears to have a restricted distribution which is probably correlated with the increasingly drier climatic conditions towards the south. Thus, most of the moss-turf banks in this area are dominated by *P. alpestre*. At Hope Bay, in the extreme north, the climate is intermediate between that of the maritime Antarctic typical of the western side of the Antarctic Peninsula and the sub-continental climate of the eastern side of the Antarctic Peninsula. Here, the weather is much drier and colder than the northern part of the western Antarctic Peninsula, and *P. alpestre*, in the absence of *C. aciphyllum*, forms shallow discontinuous turves up to 10 cm deep. Along the west side of the Antarctic Peninsula, *Polytrichum* banks occur sporadically, reaching their maximum development in the area bordered by Arthur Harbour, Anvers Island, in the north and the Argentine Islands archipelago and islands in Collins Bay in the south, together with the adjoining mainland of the Graham Coast. Within this area, *Polytrichum*-dominated banks are common and occasionally exceed 500 m$^2$ in area and 1 m in depth (Smith and Corner, 1973). In Arthur Harbour, large banks occur on Litchfield Island and to a lesser extent on Laggard and Hermit Islands and on Norsel Point, with small banks on some of the neighbouring islands and promontories. Although *Chorisodontium* is dominant in some banks, it is the sole peat-bank component on the largest of the Joubin Islands, about 12 km west of Arthur Harbour. Small *Polytrichum* banks, rarely exceeding 50 cm in depth, occur in several localities along the Danco Coast (e.g. Paradise Harbour) and on offshore islands (e.g. Bryde Island), east of Anvers Island. Comparatively deep *Polytrichum* banks with associated *Chorisodontium* form quite large stands on the north side of Hovgaard and Petermann Islands with smaller banks on some of the smaller islands and headlands in Penola Strait. In the Argentine Islands, several large deep banks occur on the easternmost islands with *Chorisodontium* generally a scarce associate. Locally extensive stands of the *Polytrichum–Chorisodontium* association are frequent on the Berthelot Islands and Somerville and Darboux Islands in Collins Bay, while localities on the Graham Coast, notably Edge Hill, Rasmussen

Island and the adjoining mainland, and Capes Tuxen and Pérez, possess extensive *Polytrichum* banks on steep rocky slopes.

From the present knowledge of the occurrence of moss banks in the maritime Antarctic, they would appear to have a rather disjunct distribution. Their major development is in the South Orkney Islands and easternmost of the South Shetland Islands where the climate is much more oceanic, with frequent summer rain, than the Arthur Harbour–Argentine Islands area about 4–5° of latitude farther south. The latter area has a much higher incidence of sunshine and lower precipitation during summer which appears to favour the development of *Polytrichum*-dominated banks at the expense of *Chorisodontium*. Furthermore, the more southerly sites have probably been snow-free for a shorter time than those in the South Orkney and South Shetland Islands and consequently the development of moss banks is a more recent feature of the vegetation of the region.

## Distribution of Moss Banks on Signy Island

Fig. 3 shows the distribution of the moss banks on Signy Island and Table II indicates their area in relation to the island as a whole. The total area of continuous moss turf is about 27 ha, although this does not include discontinuous turf, i.e. turves with a ground cover of less than about 50%. There are 15 ha of this category, giving a ground cover of about 7 ha; this gives a total area of 34 ha of *Polytrichum–Chorisodontium* turf. *Chorisodontium* is the dominant species on Signy Island and the *Polytrichum*-dominated banks characteristic of steep slopes, although occasionally extensive, comprise only 4% of the total area of moss banks.

To illustrate the distribution of moss banks more clearly, the island has been subdivided into sections and Table III shows the extent of continuous moss turf in each section; although the average cover of moss turf is 2.3% of the snow-free ground, locally it can be as high as 14%, as in area 1a where most of the deep steep-edged moss banks occur.

The volume of moss peat has been calculated (Table IV). The average depth listed for each type of moss bank is only an approximation, based on field observations, so the final result gives only the order of magnitude; the total volume of *Polytrichum* and *Chorisodontium* peat has thus been determined as about 90 000 m$^3$.

Table II. Area of permanently snow-covered and snow-free ground and of the moss-turf stands on Signy and Moe Islands

| | *Area* (km$^2$) | | *Area as percentage total area* | |
|---|---|---|---|---|
| | Signy Island | Moe Island | Signy Island | Moe Island |
| Terrain | | | | |
| Ice cap and permanent snow | 7.51 | 0.15 | 38.3 | 12.1 |
| Lakes | 0.21 | 0 | 1.1 | 0 |
| Snow-free ground | 11.86 | 1.09 | 60.6 | 87.9 |
| Total | 19.58 | 1.24 | 100.0 | 100.0 |
| Moss turf | | | | |
| Continuous turf | 0.27 | *c.* 0.03 | 1.4 | 2.4 |
| Discontinuous turf | 0.13 | *c.* 0.05 | 0.7 | 4.0 |
| Discontinuous turf allowing for 50% cover | 0.07 | *c.* 0 03 | 0.3 | 2.4 |
| Total | 0.34 | *c.* 0.06 | 1.7 | 4.8 |

TABLE III. AREA OF CONTINUOUS MOSS TURF IN VARIOUS SUB-DIVISIONS OF SIGNY ISLAND

| | *Area* | | | |
|---|---|---|---|---|
| | km² | *As percentage of sub-area* | *As percentage of total snow-free ground* | *As percentage of total area of moss turf* |
| Total area of moss turf | 0.27 | | 2.3 | |
| Non-permafrost turf | 0.18 | | | 66 |
| Permafrost turf | 0.09 | | | 33 |
| *Polytrichum*-dominated turf on steep slopes (with permafrost) | 0.01 | | | 4 |
| Area 1 (including area 1a) | 2.40 | | 20.2 | |
| Total area of moss turf | 0.07 | 2.8 | | 24 |
| Non-permafrost | 0.03 | 1.1 | | |
| Permafrost | 0.04 | 1.7 | | |
| Area 1a | 0.38 | | 3.2 | |
| Total area of moss turf | 0.05 | 13.9 | | 18 |
| Non-permafrost | 0.02 | 4.1 | | |
| Permafrost | 0.04 | 9.8 | | |
| Area 2 | 2.52 | | 21.2 | |
| Total area of moss turf | 0.04 | 1.7 | | 15 |
| Non-permafrost | 0.03 | 1.3 | | |
| Permafrost | 0.01 | 0.4 | | |
| Area 3 | 2.53 | | 21.3 | |
| Total area of moss turf | 0.02 | 1.0 | | 9 |
| Non-permafrost | 0.02 | 0.6 | | |
| Permafrost | 0.01 | 0.4 | | |
| Area 4 | 2.01 | | 16.9 | |
| Total area of moss turf (all non-permafrost) | 0.02 | 0.9 | | 7 |
| Area 5 | 1.47 | | 12.4 | |
| Total area of moss turf | 0.07 | 4.4 | | 24 |
| Non-permafrost | 0.04 | 2.7 | | |
| Permafrost | 0.03 | 1.7 | | |
| Area 6 | 0.80 | | 6.8 | |
| Total area of moss turf (all non-permafrost) | 0.06 | 7.0 | | 21 |

TABLE IV. DEPTH AND VOLUME OF THE DIFFERENT CATEGORIES OF MOSS TURF ON SIGNY ISLAND

| *Type of moss bank* | *Area* (km²) | *Depth* (cm) | *Volume* (m³) |
|---|---|---|---|
| Discontinuous: non-permafrost | 0.07 | 10 | 7 000 |
| Continuous: non-permafrost | 0.18 | 20 | 36 000 |
| permafrost | 0.09 | 50 | 45 000 |

## ANALYSIS OF SELECTED MOSS BANKS

*Signy Island, South Orkney Islands*

*Polytrichum alpestre-dominated bank*. The first moss bank considered is an extensive stand dominated by *Polytrichum alpestre* and typical of steep north-facing slopes on Signy Island. The site, on the north side of Observation Bluff, has an average slope of 30° (Fig. 4). The species composition is given in Table V and it will be noted that this bank has few epiphytic

Fig. 4. The extensive *Polytrichum*-dominated bank on the north side of Observation Bluff, Signy Island (site A).

TABLE V. MEAN PERCENTAGE COVER AND FREQUENCY OF OCCURRENCE OF PRINCIPAL SPECIES IN THE *Polytrichum alpestre*-DOMINATED BANK ON OBSERVATION BLUFF, SIGNY ISLAND

| *Species* | *Cover* (%) | (Range) | *Frequency* (%) |
|---|---|---|---|
| *Polytrichum alpestre*: living | 62 | 20–95 | 100 |
| dead | 12 | 0–45 | 97 |
| total | 74 | | |
| *Chorisodontium aciphyllum* | 16 | 0–60 | 99 |
| Epiphytic lichens (including *Alectoria* spp., *Cladonia* spp., *Sphaerophorus globosus*, *Usnea antarctica*, *Ochrolechia frigida*, *Buellia* sp., *Lecidea* sp., *Rinodina* sp.) | 10 | 0–50 | 97 |

Data are means of 77 20 cm by 20 cm quadrats.

crustose and fruticose lichens, and is relatively healthy and actively growing throughout its area. Its location on Signy Island is indicated in Fig. 3 (site A) and Fig. 5 illustrates the moss bank, showing orientation, slope and distribution of the permafrost. Table VI provides the areas of the various permafrost and non-permafrost zones, their depth and volume. The depth was measured on 1 March 1976 and measurements made the previous summer indicated that no significant thawing of the permafrost occurs after this time. Coring through the permafrost revealed that the maximum depth of this bank is 90 cm. The moss is growing over coarse scree which explains the range in depth and the existence of the many protruding rocks; the moss bank is still expanding in size but only in the centre (the continuous permafrost zone) has there been enough accumulation of peat to mask the underlying topography. The range

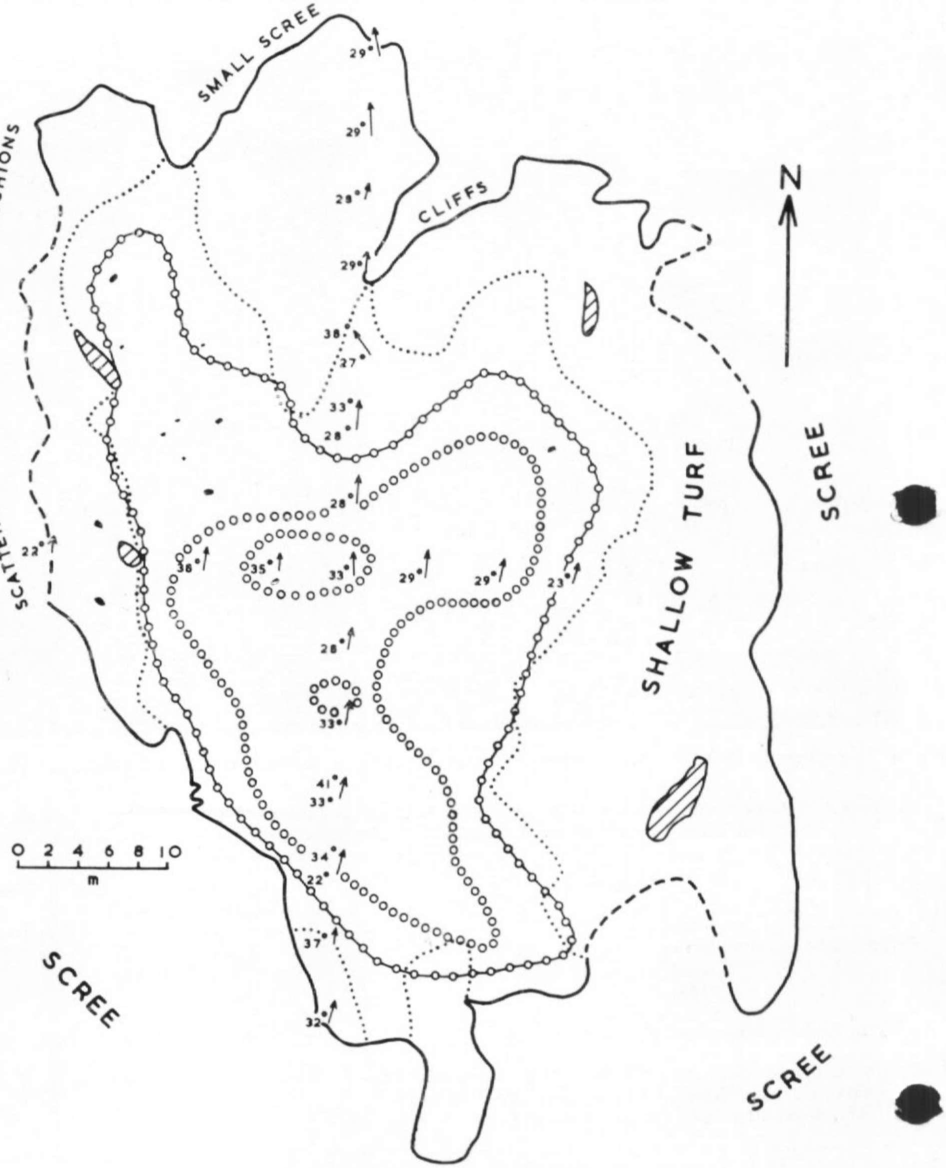


Fig. 5. Map of the *Polytrichum*-dominated bank on the north side of Observation Bluff, Signy Island (site A) For key to symbols see Appendix.

in depth of the active layer is least in the continuous permafrost zone, any variation tending to reflect the surface topography of the bank. In the discontinuous zone, the depth to the permafrost, where it occurs, is slightly greater, caused by differential thermal conductivities of rock and peat. The increased range in this zone is explained by the micro-topography of the substratum, namely scree with air spaces amongst the rocks which will influence the thermal regime, as will the differential thermal conductivities mentioned above. The total volume of moss is 821 $m^3$, 25% of which is permanently frozen, although frozen moss underlies only 16% of the area (these figures do not include any frozen moss occurring in the discontinuous permafrost zone).

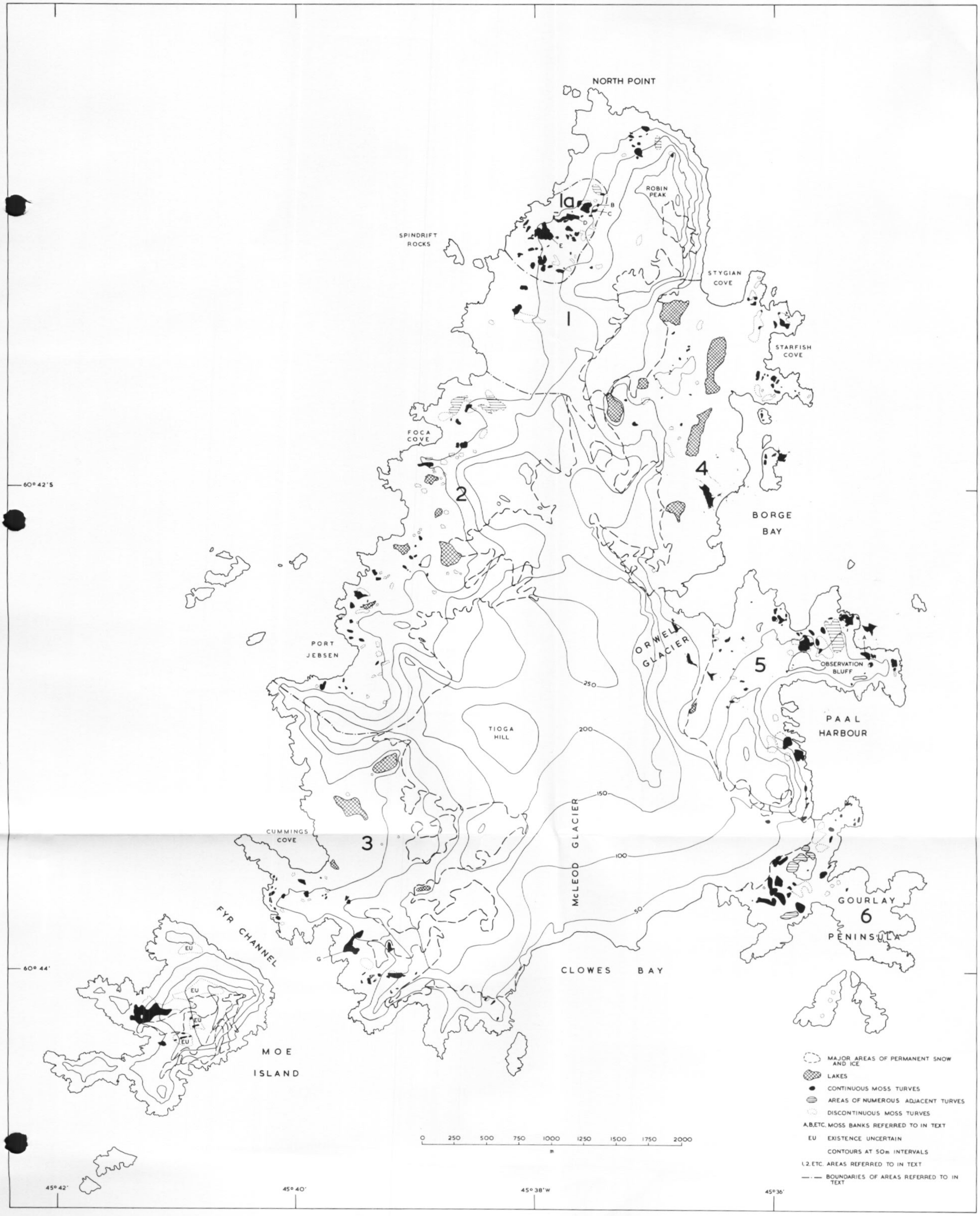


Fig. 3. Map of Signy Island showing the location of all *Polytrichum–Chorisodontium* moss turves.

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TABLE VI. AREA, DEPTH AND VOLUME OF DIFFERENT ZONES OF THE *Polytrichum alpestre*-DOMINATED MOSS BANK ON OBSERVATION BLUFF, SIGNY ISLAND

| | *Area* ($m^2$) | *Area* (as percentage of entire bank) | *Mean depth with range* (cm) | *Volume* ($m^3$) |
|---|---|---|---|---|
| Non-permafrost turf | 1 526 | 63 | | 323 |
| Moss turf with surface rocks visible | 1 171 | 48 | 20 (5–42) | 234 |
| Moss turf with no surface rocks visible | 355 | 15 | 25 (13–40) | 89 |
| Discontinuous permafrost turf | 521 | 21 | 32<br>30 (16–37)*<br>35 (29–42)† | 167 |
| Permafrost turf | | | | |
| Active layer | 403 | 16 | 32 (27–36) | 129 |
| Frozen moss | 403 | 16 | 50 (27–58) | 202 |
| TOTAL | 2 450 | | | 821 |

* Depth to rock (39 % of the area).
† Depth to permafrost (61 % of the area).

*Chorisodontium aciphyllum-dominated banks*. The area between Spindrift Rocks and North Point on the north-west coast of Signy Island contains the deepest and most extensive moss banks (area 1a on Fig. 3); the moss banks discussed below, i.e. sites B, C, D and E are also indicated on Fig. 3 and illustrated in Figs 6–10. These are situated from about 25 to 100 m a.s.l. and are all *Chorisodontium*-dominated, with a maximum cover afforded by *Polytrichum* of 6 %, although in some instances the latter species is absent. For example, at site C, which contained no *Polytrichum*, the cover of living *Chorisodontium* averaged 59 % (the mean of 42

Fig. 6. Two *Chorisodontium* banks on the west coast of Signy Island, near Spindrift Rocks; site B is to the right and site C is in the centre and left. Coronation Island is in the background.

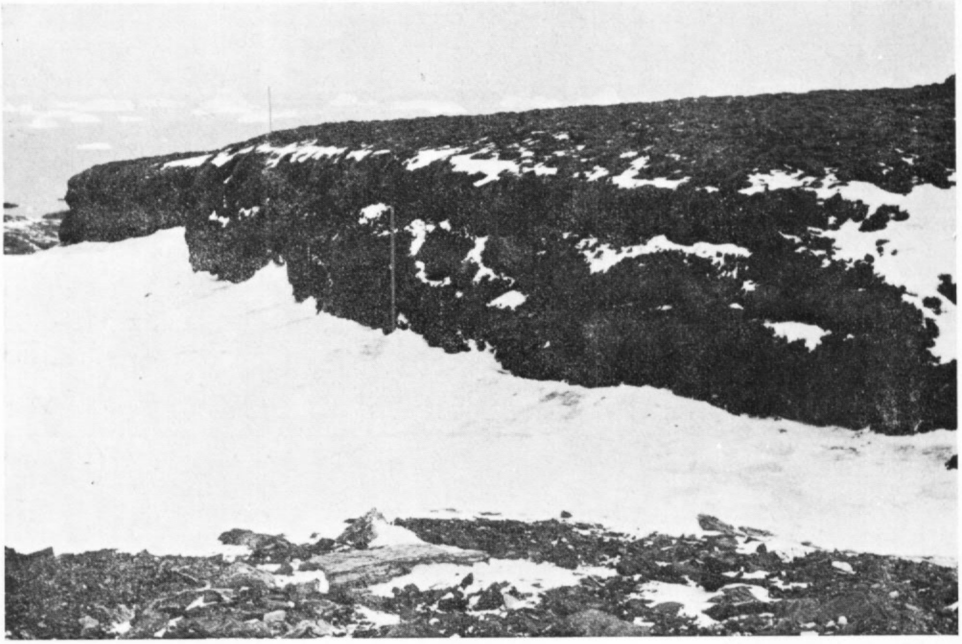

Fig. 7. The vertical edge of site C, below which lies a small permanent snowdrift. Scale markers are 1 m long.

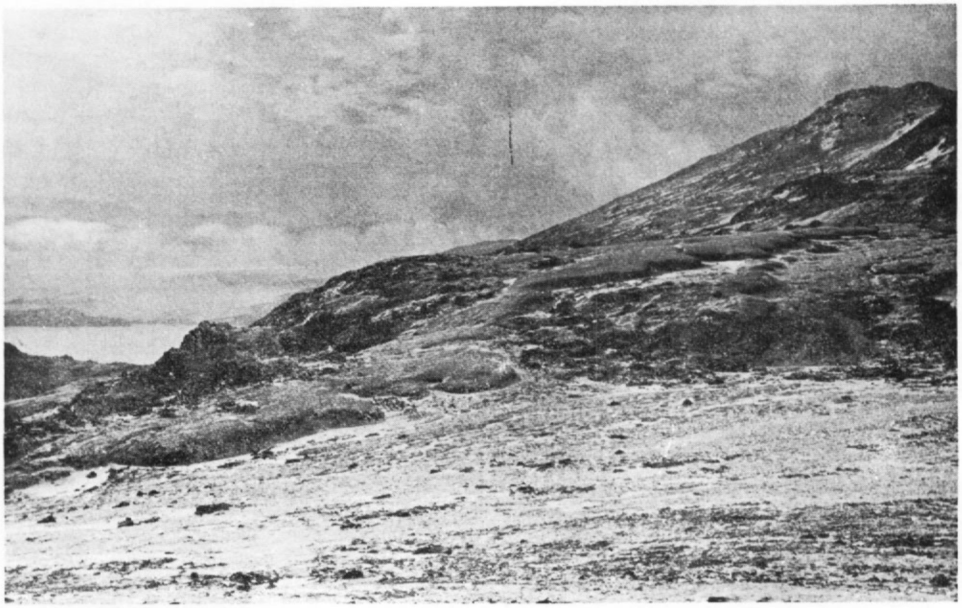

Fig. 8. Site D, looking north, on the west coast of Signy Island, with the full length (about 200 m) of the vertical edge on the south side of the moss bank visible.

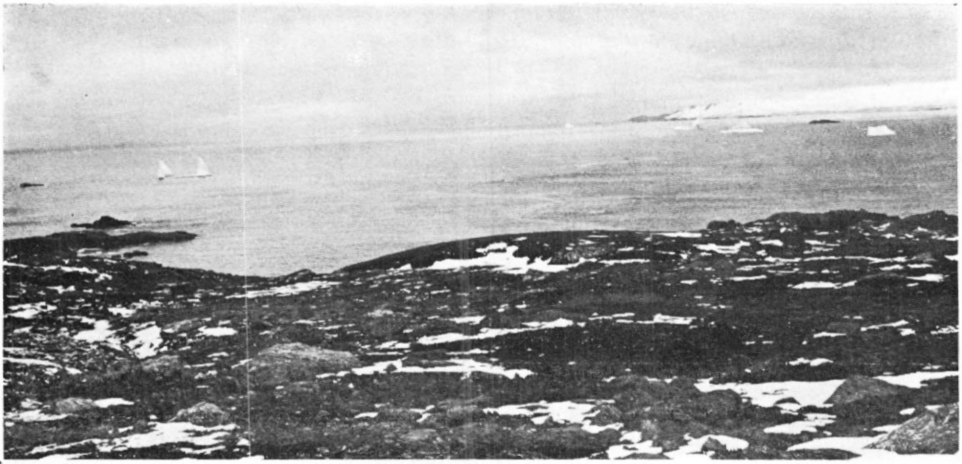

Fig. 9. Site D, looking west, showing the domed outline; the bank is shallow to the right with the vertical edge on the left side.

20 cm by 20 cm quadrats); the remaining 41 % cover consisted of dead *Chorisodontium* and/or epiphytic lichens (see Smith, 1972). Two of the moss banks studied have areas of wind-eroded peat (see Smith, 1972) and all the banks described below are underlain by an almost continuous permafrost. Figs 11–13 are maps of sites C, D and F, respectively, and Table VII quantifies their various zones.

The average depth to the permafrost (mean of 57 cores) at site C was 20.5 cm, with a range of 17–24 cm; again, this range probably reflects the surface topography of the bank for, as mentioned above, the permafrost surface tends to be smooth. These active-layer depths were measured on 11 March 1976 but measurements made the previous summer confirmed that by this date the active layer is at its maximum depth.

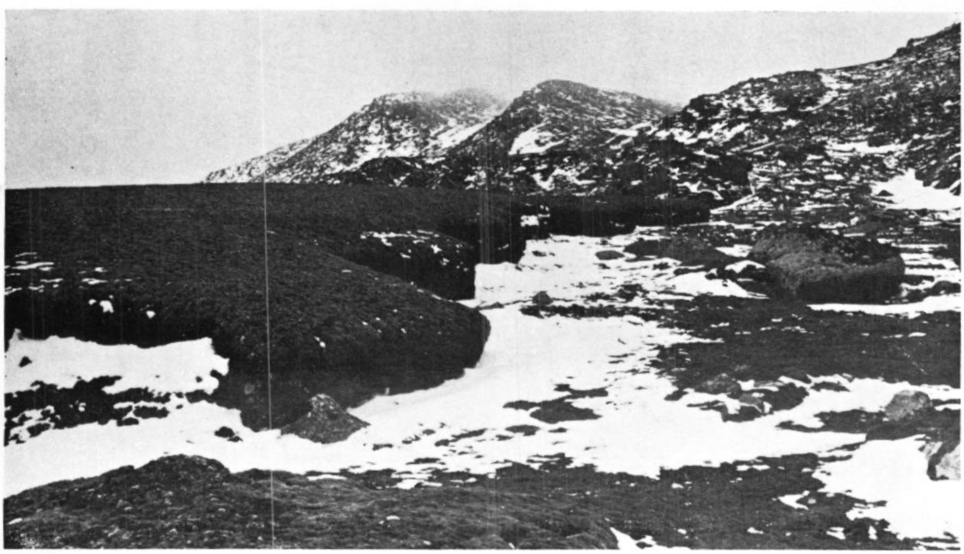

Fig. 10. The vertical edge of site D, looking east; about 50 m is visible.

The depth to the permafrost under the black wind-eroded peat was 15 cm (range 13.5–16.5 cm). Similarly, at site D the permafrost was 14 cm under the black peat and 20 cm nearby under the green healthy moss; this is the shallowest active layer at the time of maximum thaw encountered on Signy Island. The explanation for this difference is not immediately clear; it is possible that the thermal conductivity of the black peat is less because the moss shoots tend to be horizontally orientated, whereas the top 10–20 cm of healthy moss is vertically orientated. In such a cloudy regime as Signy Island, difference in colour may not be important; certainly, thermistor readings taken (by R.I.L.S.) on the surface and 1 cm below the surface of different coloured saxicolous cushion-forming mosses (e.g. species of *Andreaea*, *Grimmia*, *Dicranoweisia* and *Tortula*) during periods of sunshine and overcast weather showed virtually no difference

TABLE VII. AREAS OF DIFFERENT ZONES OF THREE *Chorisodontium aciphyllum* MOSS BANKS ON THE NORTH-WEST OF SIGNY ISLAND

| *Type of moss-bank surface* | *Bank C* | | *Bank D* | | *Bank F* |
|---|---|---|---|---|---|
| | *Area* ($m^2$) | *Area* (as percentage of entire bank) | *Area* ($m^2$) | *Area* (as percentage of entire bank) | *Area* ($m^2$) |
| Wind-eroded peat | 55 | 9 | 190 | 9 | 0 |
| Moss killed by influence of adjacent giant petrel colony | 17 | 3 | 0 | 0 | 0 |
| Moss turf with surface rocks visible | 52 | 9 | 234 | 10 | 0 |
| Moss turf with no rocks visible | 468 | 79 | 1 813 | 81 | 821 |
| TOTAL | 592 | | 2 237 | | 821 |

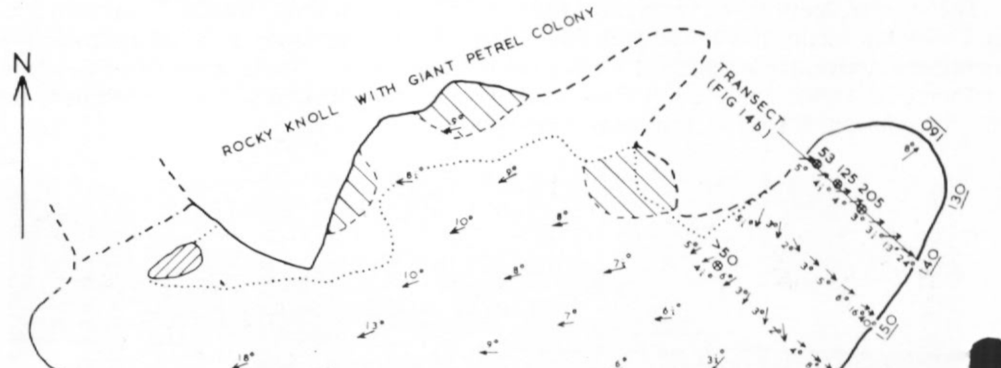


Fig. 11. Map of a *Chorisodontium* bank on the north-west of Signy Island (site C). For key to symbols see Appendix.

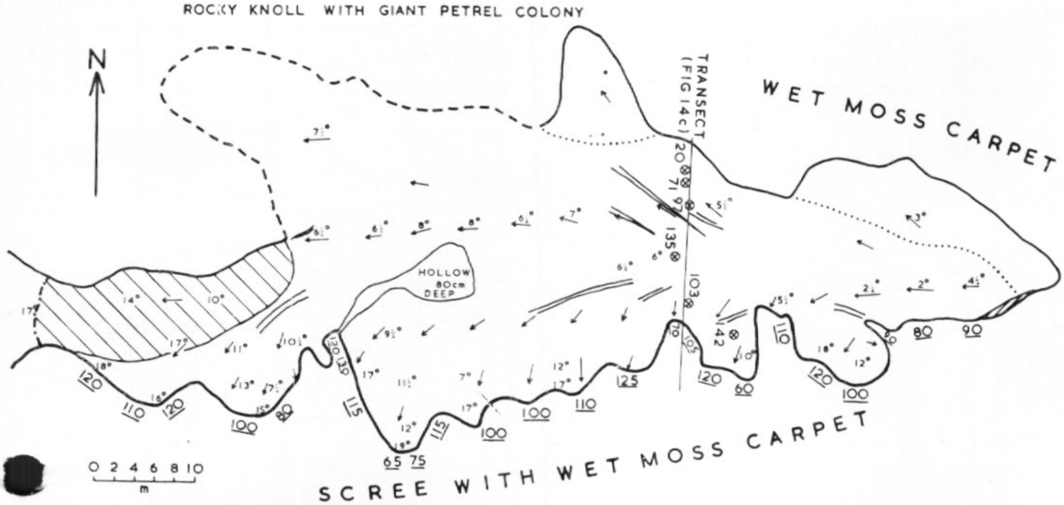


Fig. 12. Map of a *Chorisodontium* bank on the north-west of Signy Island (site D). For key to symbols see Appendix.

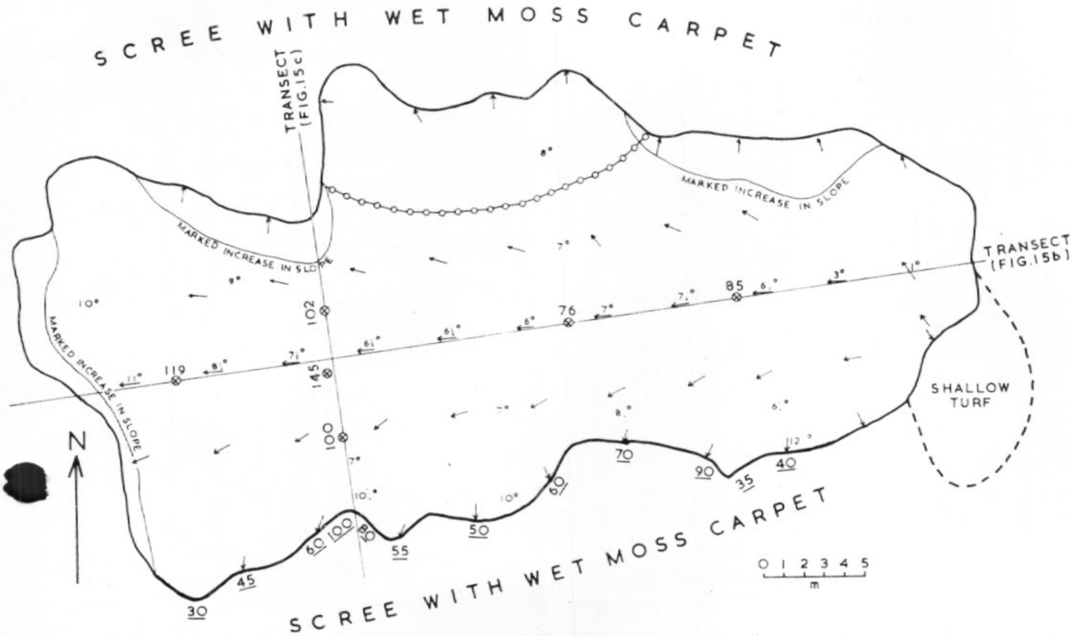


Fig. 13. Map of a *Chorisodontium* bank on the north-west of Signy Island (site F). For key to symbols see Appendix.

in temperature between species/colours under the same weather conditions. It is interesting to note that site G (Fig. 3), a south-facing *Chorisodontium* bank above Fyr Channel at the south-west corner of the island, has an average active-layer depth of 21 cm at the end of the summer.

The transects of moss banks (Figs 14 and 15) are based on cores through the permafrost; it is possible to calculate the ratio of frozen: unfrozen moss across these, and data based on this are used in the calculations of volume given in Table VIII (these calculations will not therefore be as accurate as those given above for the *Polytrichum* moss bank); in this table the depth of the active layer is taken as 21 cm. The maximum depth encountered in a Signy Island moss bank is 205 cm at site C, where the bank is only 6 m wide (Fig. 14b); the base of this bank at a point where the depth was only 125 cm has been radiocarbon dated at 4 801 ±300 years

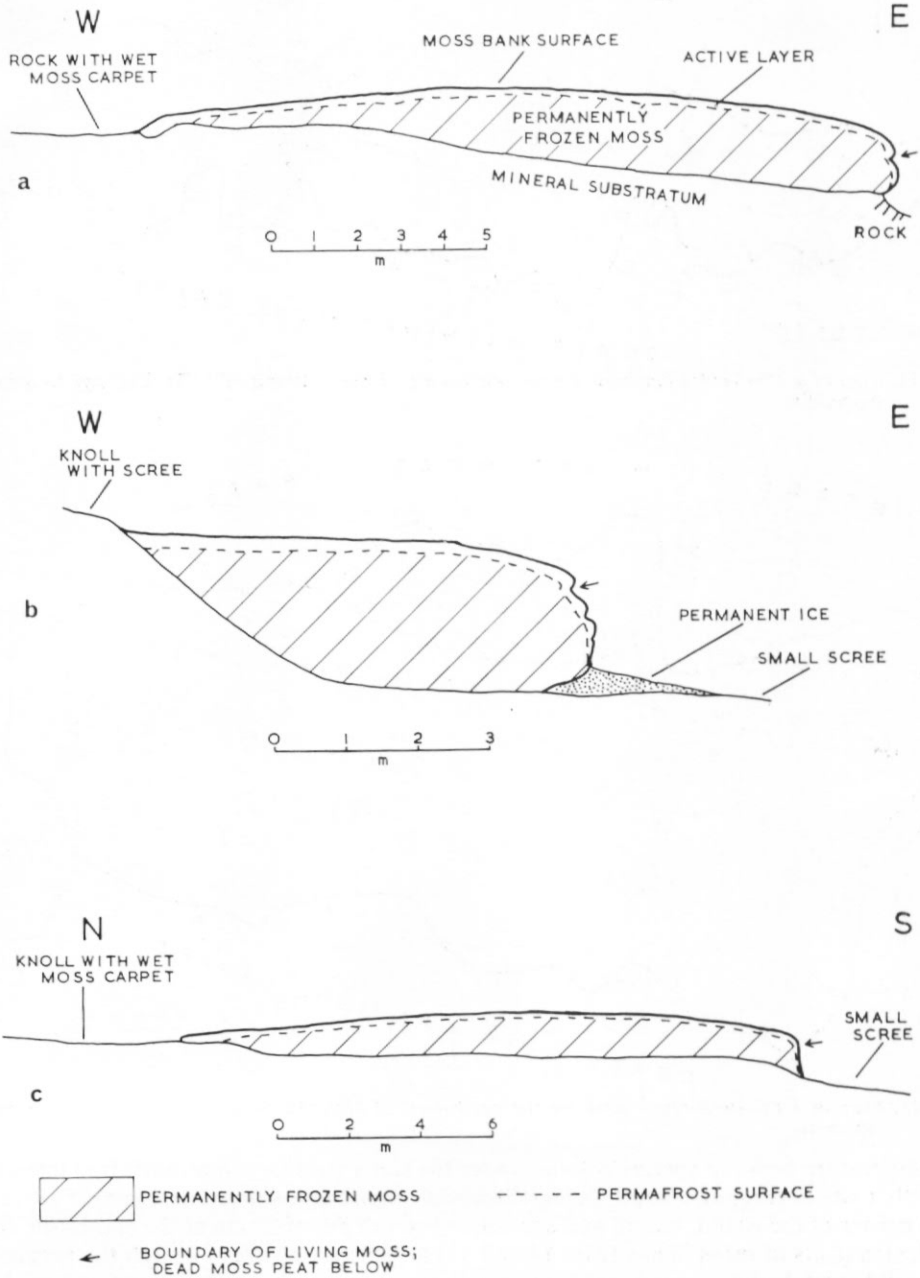


Fig. 14. Transects across *Chorisodontium* banks on the north-west of Signy Island. a. site B; b. site C; c. site D.

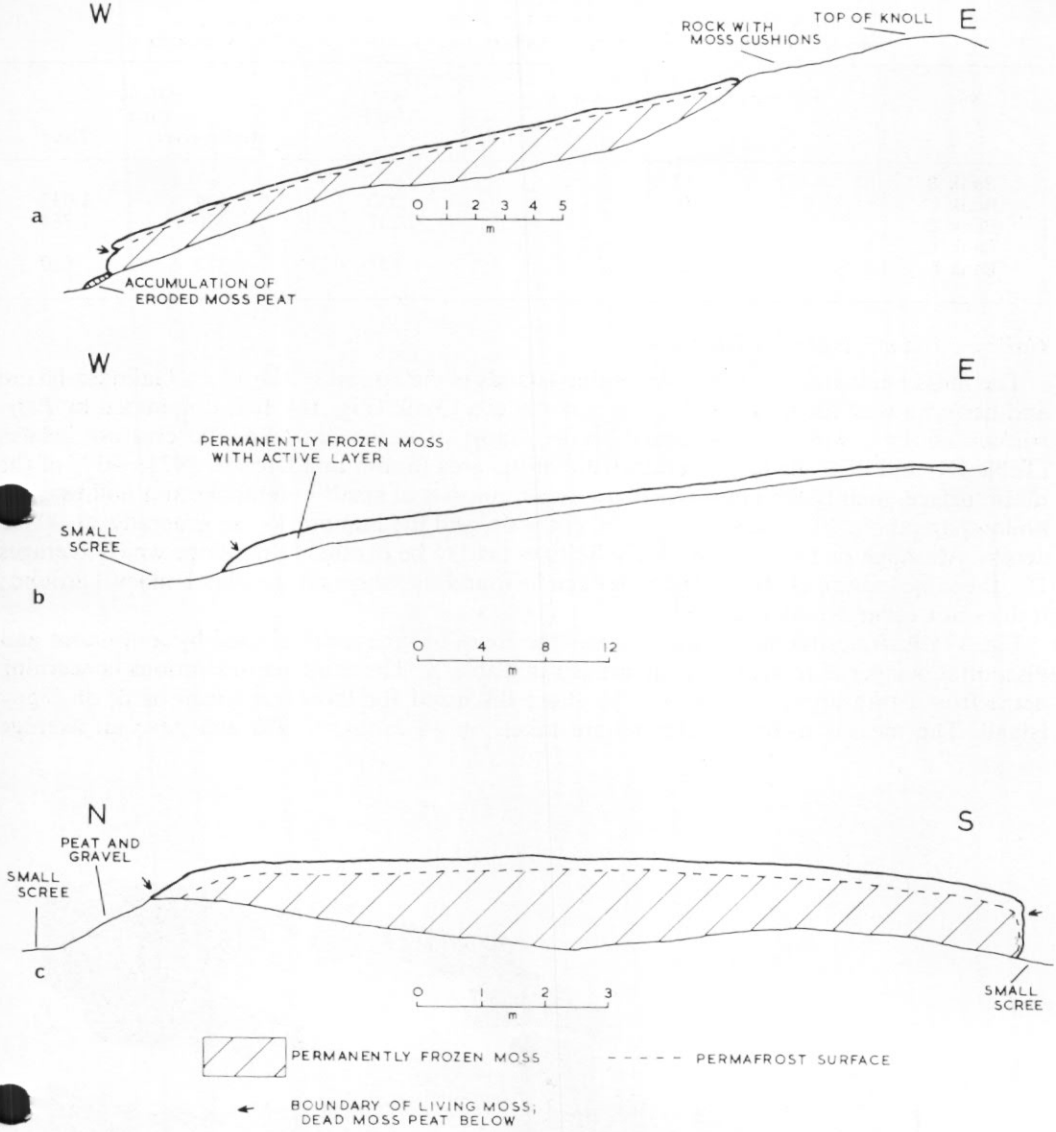


Fig. 15. Transects across *Chorisodontium* banks on the north-west of Signy Island. a. site E; b. site F, east–west; c. site F, north–south.

B.P., more than double the age of the previously oldest date obtained for a similar bank on Signy Island (Godwin and Switsur, 1966). Samples taken from deeper parts of the transect proved to be of younger origin. The reasons for this will be explained in a later paper.

The percentage of frozen moss is similar in all these moss banks, suggesting that they are all of the same age. The transects also show that these moss banks all have a similar structure; they are generally situated on the sides of knolls with the moss turf growing level with the substratum or gently sloping on the up-hill side, whereas the down-hill side has a steep or sometimes vertical or overhung edge. Again, the explanation of this will be provided in a later paper.

TABLE VIII. AREA AND VOLUME OF THE ACTIVE LAYER AND PERMAFROST OF *Chorisodontium aciphyllum* MOSS BANKS ON THE NORTH-WEST OF SIGNY ISLAND

| *Site* | *Volume of moss in permafrost* (%) | *Area* ($m^2$) | *Volume* ($m^3$) *Active layer* | *Total* |
|---|---|---|---|---|
| Bank B | 82 | – | – | – |
| Bank C | 88 | 592 | 124 | 1 033 |
| Bank D | 83 | 2 237 | 470 | 2 764 |
| Bank E | 82 | – | – | – |
| Bank F | 80 | 821 | 172 | 860 |

*Galindez Island, Argentine Islands*

The moss bank studied on the Argentine Islands is the largest of the 16 on Galindez Island and lies on a west-facing slope 4–11 m above Stella Creek (Fig. 16). It is dominated by *Polytrichum alpestre*, with few associated species, most of which are epiphytic crustose lichens (Table IX) and is of the type characteristic of the area (Smith and Corner, 1973). 40% of the moss surface, mainly the non-permafrost areas, consists of small hummocks and hollows; the hollows are about 20 cm deep and 10–30 cm wide, and the hummocks are generally 30–40 cm across. Although on this moss bank the hollows tend to be parallel to the slope which averages 17°, the same hummock–hollow complex can be found elsewhere on the island on level ground; it does not occur on Signy Island.

Fig. 17 illustrates the bank and indicates the zones of moss peat affected by continuous and discontinuous permafrost; this is quantified in Table X. The same considerations concerning permafrost depth apply to this bank as those discussed for the *Polytrichum* bank on Signy Island. The measurements of depth were taken on 14 January 1976 and gave an average

Fig. 16. The *Polytrichum* bank, looking east, on Galindez Island, Argentine Islands. Mount Peary, on the mainland, is visible in the background.

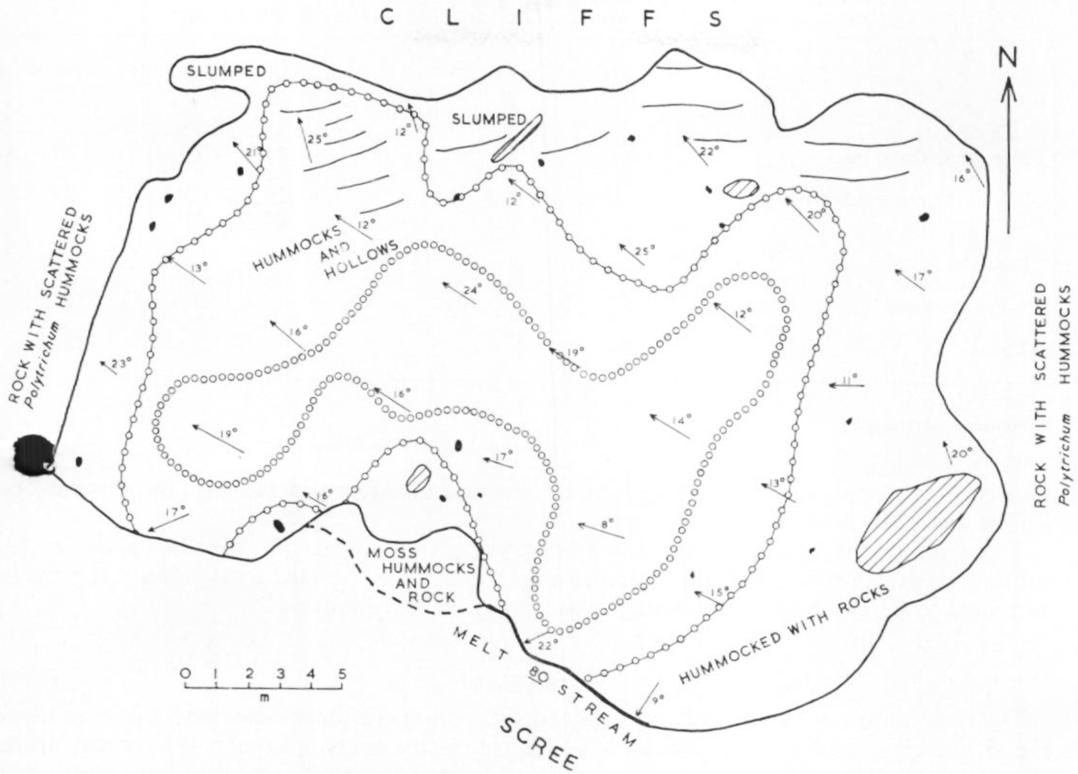


Fig. 17. Map of the *Polytrichum* bank above Stella Creek, Galindez Island, Argentine Islands. For key to symbols see Appendix.

TABLE IX. MEAN PERCENTAGE COVER AND FREQUENCY OF OCCURRENCE OF PRINCIPAL SPECIES IN THE *Polytrichum alpestre*-DOMINATED BANK ABOVE STELLA CREEK ON GALINDEZ ISLAND, ARGENTINE ISLANDS

| *Species* | *Cover* | | *Frequency* |
|---|---|---|---|
| | *Percentage* | *Range* | (%) |
| *Polytrichum alpestre:* alive | 47 | 20–95 | 100 |
| dead | 15 | 0–50 | 79 |
| total | 62 | | |
| *Chorisodontium aciphyllum* | 2 | 0–45 | 26 |
| *Pohlia nutans** | 4 | 0–50 | 50 |
| Black encrusting lichens (mainly *Lecidea* sp.) and blue-green algae | 12 | 0–95 | 76 |
| Other epiphytic lichens (mainly *Ochrolechia frigida*, *Sphaerophorus globosus* and *Cladonia* spp.) | 20 | 0–65 | 91 |

* Mainly in hollows.
Data are mean of 33 20 cm by 20 cm quadrats.

depth to continuous permafrost of 28 cm; measurements had also been made previously on 1 January 1976 and gave a mean depth to permafrost of 23 cm. Thus 5 cm of frozen peat had thawed in the first fortnight of January. Measurements made in moss banks on Signy Island

TABLE X. AREA, DEPTH AND VOLUME OF DIFFERENT ZONES OF THE *Polytrichum alpestre* MOSS BANK ABOVE STELLA CREEK ON GALINDEZ ISLAND, ARGENTINE ISLANDS

| | *Area* (m$^2$) | *Area* (as percentage of entire bank) | *Mean depth with range* (cm) | *Volume* (m$^3$) |
|---|---|---|---|---|
| Non-permafrost turf | 216 | 46 | 24 (5–37) | 52 |
| Discontinuous permafrost turf | 91 | 19 | 26 (20–33)*<br>29 (25–38)† | 26 |
| Permafrost turf | | | | |
| Active layer | 162 | 35 | 28 (25–30) | 45 |
| Frozen moss | 162 | 35 | 19 (12–22) | 31 |
| TOTAL | 469 | | | 154 |

* Depth to rock.
† Depth to permafrost.

showed that little significant thawing of permafrost occurs after mid-January, but this subject will be discussed further in a later paper.

Three cores were taken through the permafrost, giving a mean moss-bank depth, in the continuous permafrost zone, of 47 cm, and a maximum of 50 cm; the total volume of moss is setimated to be 154 m$^3$, 20% of which is still frozen in mid-January.

## DISCUSSION

The distribution of moss banks on Signy Island requires further discussion; it is clear from Fig. 3 that most occur on the coastal low-lying snow-free areas, although some occur up to 200 m altitude. The following factors are involved in determining the extent of moss banks in a particular locality:

i. a. Length of time the ground is snow-free in summer.
   b. Length of time the area has been free from permanent snow in the past.

ii. Stability of the substratum; moss banks cannot form where intense soil movement occurs.

iii. Biotic disturbance, especially by seals and penguins.

iv. Harshness of the environment; wind is the critical factor here and obviously related to altitude.

v. Nutrient status of the substratum; most of Signy Island is composed of acidic schist and soil derived from this rock which are favourable for *Polytrichum* and *Chorisodontium*, though there are areas of marble and amphibolite where these species canno- grow. Excessive nitrogen and phosphorus levels probably exclude their growth near penguin rookeries or seal wallows. Nowhere on the island are nutrients likely to be limiting for these species (Allen and Northover, 1967).

vi. Water supply; *Polytrichum* and *Chorisodontium* do not grow in areas of waterlogging or immediately adjacent to permanent melt streams. Because of almost daily summer precipitation, water is nowhere limiting for these species.

vii. Slope; there is a maximum slope on which these species can grow, i.e. when gravitational slumping is greater than the moss growth rate.

Aspect is not necessarily a limiting factor, for *Chorisodontium* moss banks occur on some south-facing slopes; this is probably due to the prevailing cloudiness of Signy Island. On the other hand, *Polytrichum*-dominated moss banks tend to occur on north-facing slopes.

Thus, areas of Signy Island where these factors are all favourable would be expected to support the largest stands of these tall turf mosses, as in area 1a; the radiocarbon date mentioned above indicates that this area must have been snow-free for at least 4 500–5 000 years. Factors i, ii and iii are the most important in determining the differences in moss extent between the different areas; for example, areas 4 and 6, which are low-lying, probably support no deep moss banks because of the influence of birds and seals. Since about 1975 some shallow moss banks in these areas have been rapidly destroyed by large numbers of fur seals (*Arctocephalus gazella*), which have been steadily increasing in recent years, and by elephant seals (*Mirounga leonina*), which have considerably increased their range inland during recent summers. Cummings Cove in area 3 has few moss stands because of soil instability associated with melt water from the ice cap and surrounding snow patches, which may have varied in size over the past few hundred years (Collins, 1976*a*).

The same factors will influence moss-bank distribution elsewhere in the maritime Antarctic, although the relative importance of each will alter; farther south, water supply becomes more limiting and is probably the most important criterion. Similarly, the absence of deep soil, especially on slopes, prevents the occurrence of solifluction throughout much of the Antarctic Peninsula compared with the South Orkney Islands, and on many of the South Shetland and South Sandwich Islands the substratum of the freely drained volcanic ash is not suitable for moss-bank development. Farther north, on South Georgia, extensive stands of vascular plants provide an additional restriction to the habitats available for moss-turf development.


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## APPENDIX

EXPLANATION OF SYMBOLS USED IN FIGS, 5, 11, 12, 13 AND 17