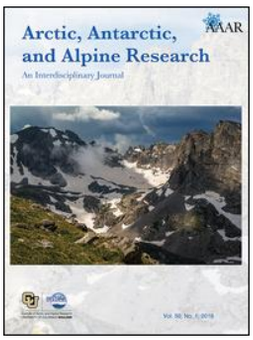

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THE FORMATION OF VERTICAL EDGES ON ANTARCTIC MOSS PEAT BANKS

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ABSTRACT

Moss peat banks, which can be up to 3 m deep, greater than 2500 m^2 in area, and up to 5000 yr old, occur in the Antarctic. Radiocarbon dates show that the peat accumulation rate has varied from 0.25 to 2.00 mm yr^{-1}. These peat banks have an abrupt vertical edge of exposed peat, which does not appear to be due to erosion of a once-larger peat bank. These edges seem to have arisen because, as peat accumulates and the moss banks become deeper, increased snow-lie prevents outward growth of the banks at their edges.

INTRODUCTION

The maritime Antarctic region, as defined by Holdgate (1977), is dominated by a wide range of cryptogamic communities with mosses predominating in the moister, more sheltered habitats and lichens in the more arid and windswept situations. There are only two native vascular plants (Longton, 1967; Gimingham and Smith, 1970). Peat "banks" formed by one or both of the tall turf-forming mosses *Chorisodontium aciphyllum* (Hook. f. et Wils.) Broth. and *Polytrichum alpestre* Hoppe are a unique feature of the vegetation (Smith, 1979). These banks average 1 to 2 m in depth, and the peat consists of the relatively uncompacted remains of the two moss species. The peat accumulates in aerobic nonwaterlogged conditions (there is little evidence of water flow through the peat); the current annual peat accumulation rate of actively growing banks (ca. 1 mm yr^{-1}) is about half the annual moss growth rate (ca. 2 mm yr^{-1}). There is about 50% loss in dry weight of the moss shoots before the peat becomes incorporated into the permafrost at ca. 20 to 30 cm depth (Fenton, 1980).

The surface of these banks often has a succession of phases ranging from continuous healthy actively growing moss, through areas of increasingly abundant epiphytic crustose and fruticose lichens, to a stage where wind erosion and cryoturbation kills and removes the living vegetation revealing a loose fibrous peat which may eventually become recolonized (Smith, 1972; Collins, 1976). These moss banks, some of which exceed 2500 m^2 in area, occur in several coastal localities of the northern maritime Antarctic and are especially common on Signy Island, South Orkney Islands (60°43'S, 45°38'W) (Fenton and Smith, 1981). About 40% of Signy Island (total area about 20 km^2) is covered with permanent ice and barely 5% of the snow-free ground supports closed vegetation. The physical characteristics of the island and its vegetation are described by Smith (1972) and Collins et al. (1975). There is intensive freeze-thaw activity in mineral soils (Chambers, 1966, 1967a, 1967b), and diurnal freeze-thaw cycles are frequent in moss banks throughout the summer but particularly at the time of the spring thaw and at the onset of winter (Walton, 1981).

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VERTICAL EDGE FORMATION

One of the most striking characteristics of the deeper *Chorisodontium*-dominated banks is their abrupt vertical edges of exposed peat (Figures 1, 2, 3). It has been suggested that these edges are caused by erosion (Smith, 1972; Collins, 1976), but a typical feature of vertical erosion surfaces is a sloping accumulation of debris below the face, the angle of which is characteristic of the material of which it is composed. On Signy Island there are about 25 moss banks with vertical edges, but these banks overhang the mineral substratum at their bases in all but one site, without a debris slope below the face (Figure 3a). This almost total absence of eroded living moss at the base of the banks suggests that their vertical edges are not erosion features, since it is improbable that all of the eroded moss could have been washed or blown away. Indeed, in the few cases where some fallen live moss turf does exist below the faces, all but the top 2 cm of the accumulation is permanently frozen and so would be slow to erode further.

Antarctic moss banks growing on slopes often have a complex internal structure because the active-layer peat tends to be moving downhill (Fenton, 1978). Banks with vertical edges generally do not occur on steep slopes, but some degree of downhill movement is probably responsible for the formation of these edges. The main characteristics of these vertical edges are summarized below:

(1) Edges are vertical with no moss debris below.

(2) All edges overhang the mineral substratum at their base.

(3) Moss shoots in the peat under the overhang are vertical but upside down.

(4) Edges have uniform south-facing orientation (Table 1).

(5) Vertical edges never occur on the uphill sides of moss banks.

A postulated explanation of the mode of formation of the vertical edges, illustrated diagrammatically in Figure 4, is now proposed. Edges with the characteristics of each stage illustrated have been observed in the field (see Fenton, 1978: Plates 3, 7-11).

FIGURE 1. A *Chorisodontium*-dominated moss bank at about 75-m altitude on Signy Island showing a characteristic vertical edge with permanent snow/ice below; scale markers are 1 m long.

FIGURE 2. A *Chorisodontium*-dominated moss bank at about 180-m altitude on Elephant Island, South Shetland Islands, showing a frozen vertical edge 3.4 m high; this is the deepest and one of the highest accumulations of peat known south of 56°S. (Photograph by 1976-77 Combined Services Expedition).

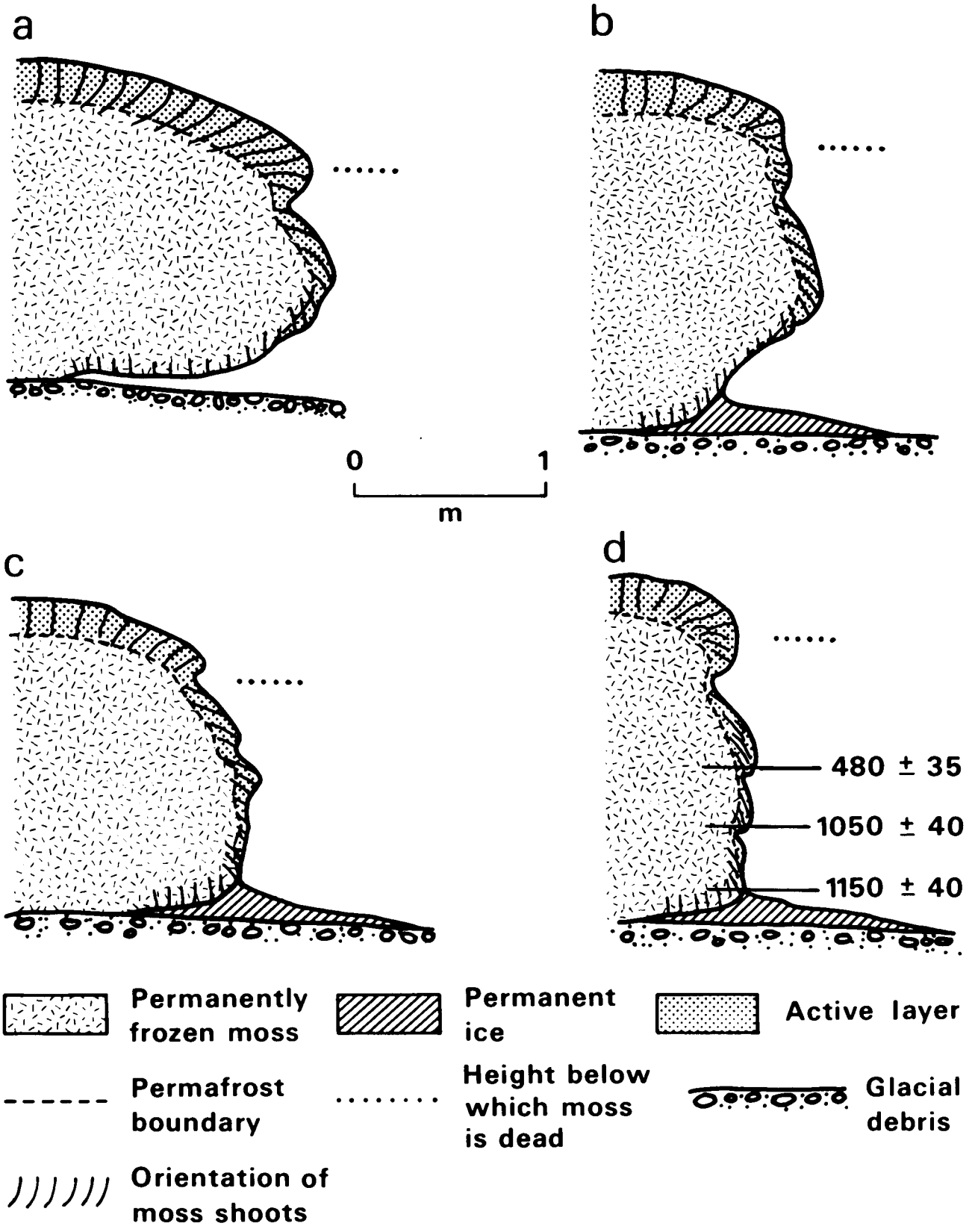

FIGURE 3. Cross-sections of the vertical edges of some Signy Island *Chorisodontium* moss banks. Radiocarbon dates (yr BP) given for d (N.E.R.C. Radiocarbon Laboratory samples, 1150 ± 40 [SRR-1091], 1050 ± 40 [SRR-1092], 480 ± 35 [SRR-1093]).

The initial stage is the development of the downhill edge of a shallow turf growing on a mineral substratum (Figure 4, Ia). On a north-facing slope growth of the moss shoots results in an increase in thickness of the turf, while the turf is at the same time expanding downhill by moss growth and possibly also by downslope movement. After a certain depth is reached (20 to 30 cm) the lower layers become permanently frozen (Figure 4, Ib); the turf continues to grow, with the peat mass as a whole being supported by the solid core of permafrost (Figure 4, Ic, Id). This results in a low rounded edge, all of it consisting of green, actively growing moss.

On south-facing slopes, although the beginning of the process is the same (Figure 4, IIa), the process of development of the downhill edge soon alters. These edges have snowdrifts persisting in their lee for longer periods than those on north-facing slopes; these drifts either kill the moss shoots or result in a slower moss growth rate (Figure 4, IIb). There is then a feedback mechanism: as a moss bank becomes deeper, more snow persists in the lee of it; indeed, the taller edges often have permanent snow (ice) below them (Figures 1, 3b, c, d). The fact that most vertical edges are orientated 135 to 225° (Table 1) suggests that the prevailing wind direction (225 to 315°) is not a major factor in their formation, although it may be significant that the eroding vertical face is parallel to the wind direction.

Thus persistent snow lie will result in cessation or retardation of moss growth at the base of the edge; the faster growth at the top of the edge, possibly combined with downhill movement, will result in development of an overhang (Figure 4, IIb). When the turf is deep enough, permafrost forms in the lower layer which supports the peat mass, so that the overhang can become significant (Figure 4, IIc, d), especially as the upper layers of the turf may be moving downhill. Movement downslope of the active layer cannot be greater than the rate of moss growth, ca. 2 mm yr^{-1}, because shoots in the active layer are connected to those in the permafrost (see Figure 1 in Fenton, 1980). An overhang of up to 120 cm has been observed (Figure 3a). Under the overhangs the permafrost is near or at the surface, and the moss shoots in the peat are orientated vertically but upside down. Sometimes an overhang is obscured by a fall of moss or more commonly by permanent snow (ice) (e.g., Figure 3b, c, d). Similar overhangs can occur at the base of arctic turf-banked solifluction lobes and terraces; these are caused by the slower downhill movement of the basal material (Warren Wilson, 1952; Jahn, 1975: 152).

TABLE 1
Orientation of vertical edges on Signy Island moss peat banks

Mean orientation of vertical edge	Number of moss banks
0- 45°	0
45- 90°	0
90-135°	1
135-180°	10
180-225°	11
225-270°	4
270-315°	0
315-360°	0

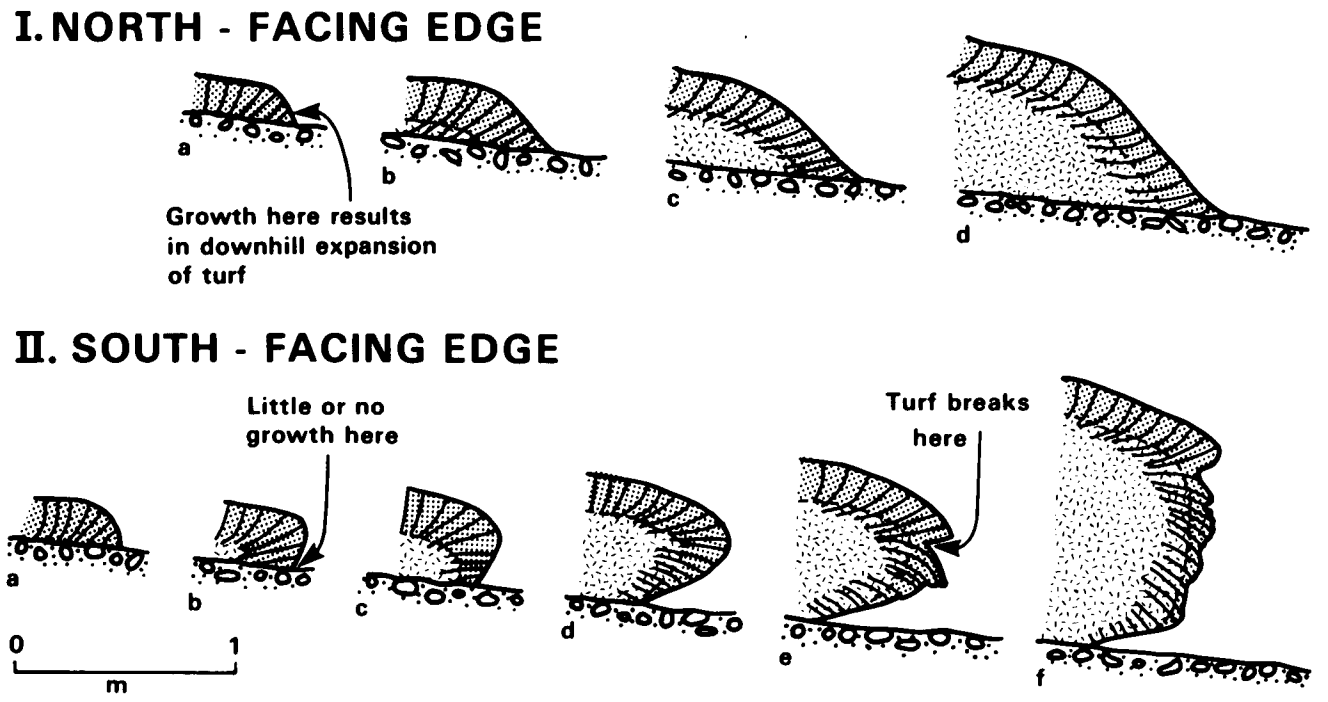

FIGURE 4. Schematic diagram showing postulated mode of formation of the steep edges of *Chorisodontium* moss banks. Key as for Figure 3.

Once there is a significant overhang, a line of weakness tends to develop in the turf above, caused by the unsupported mass of shoots being greater than their lateral cohesion. The turf then splits, and a segment of moss becomes detached (Figure 4, IIe). (Ruptures can occur in similar positions in arctic turf-banked solifluction terraces [Warren Wilson, 1952].) This segment does not normally reach the ground, because it is supported by shoots still anchored in the permafrost. The shoots in the detached section thus becomes orientated down the face, and they have retained enough strength not to break, because decomposition is so slow (Baker, 1972; Fenton, 1980).

As the surface layer continues to move downhill (in this model it is only essential that the surface layers *near the edge* of the moss bank are moving downhill) it now invariably breaks at the same place, i.e., at the top of the edge, and no moss ever reaches the ground; eventually a vertical edge is built up (Figure 4, IIf). Once the turf begins to break and the vertical edge forms, downslope extension of the moss bank as a whole will stop. The permafrost, which is very near the surface of the edge (Figure 2), supports and prevents the downhill movement of the whole structure.

Sometimes the whole surface layer tends to break over the edge at the same time, so that the edge becomes built up by distinct layers (Figures 1, 3d); this perhaps occurs when the vertical edge is exactly at right angles to the slope. It should be stressed that these steep edges never occur on the uphill sides of moss banks, where the gradient of the moss is normally relatively level with the mineral substratum. On west-facing slopes of Signy Island an intermediate type of edge occasionally forms: the slope of the edge is relatively gentle, ca. 45°, but consists of exposed peat. These edges thus form because, while peat accumulation results in the moss bank becoming deeper, increased snow-lie prevents downslope growth of the bank at its edge.

MOSS BANK DEVELOPMENT

Samples for radiocarbon dating were taken from one bank (Figure 5) on the northwest coast of Signy Island in order to elucidate its development sequence. The dates indicate that the deepest part of this bank is not the oldest and the base of the vertical edge is relatively young. It is difficult to postulate a development sequence for this bank, but an attempt has been made in Figure 4. This developmental sequence would require the rate of growth on the uphill edge of the bank to have been much slower than that on the downhill side. This could be explained by the presence of giant petrel (*Macronectes giganteus*) nesting sites immediately above the moss bank; moss on the downhill side of such a colony is often killed by excreta and trampling by the giant petrels.

Although the above explanation is plausible, according to the theory of vertical edge formation proposed, growth should be slower on the extreme downhill edge of the bank because of excessive snow-lie there. If the developmental sequence of Figure 4, II were followed, it can be seen from Figure 5 that the vertical edge did not form until after the first 3000 yr of moss bank growth had elapsed; in fact growth on the downhill edge was relatively fast in this period. Thus either a slight change in climate resulting in increased summer snow precipitation (or less summer melt) or the changing configuration of the moss bank itself caused increased snow-lie against the downhill edge, slowing growth and causing a vertical edge to develop after 3000 yr. Previous to this the snow that may have accumulated there could even have enhanced moss growth by increasing the water supply, assuming it melted during summer. Today moss growth immediately above the vertical edges is often faster than elsewhere on the bank because of shelter from the prevailing wind or increased water supply from temporary summer snowdrifts. Thus peat accumulation above the edge can be relatively fast so that the vertical edge develops rapidly. It would appear, therefore, that, as in certain shallow moss turves adjacent to semipermanent snowdrifts (Fenton, 1981), small changes in the period of snow-lie will determine whether its effect is beneficial or harmful to moss growth. Once a segment of moss has broken off to hang down above the overhang (Figure 4, IIe) and vertical edge formation is initiated, the edge will continue to develop *vertically* whatever the subsequent moss growth rate and in spite of the fact that a slow growth rate was necessary on the extreme downhill edge for it to develop initially; this is because the forces causing the segment to break over the edge remain the same.

Figure 3d, which illustrates the edge 12 m southeast of the transect shown in Figure 4, gives radiocarbon dates for the different layers visible in Figure 1 and shows that

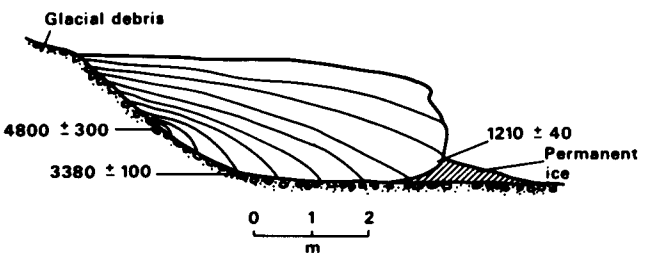

FIGURE 5. Cross-section of moss bank illustrated in Figure 1 with radiocarbon dates (yr BP) (N.E.R.C. Radiocarbon Laboratory samples 3380 ± 100 [SRR-1088], 4800 ± 300 [SRR-1089], 1210 ± 40 [SRR-1090]), and showing hypothetical moss bank surfaces at 500-yr intervals. Broken lines represent projected boundaries.

here the rate of peat growth at the edge has not been constant: approximately 1.8 mm yr^{-1} for the last 500 yr based on a radiocarbon date of 480 ± 35 yr BP (SRR-1093), 0.6 mm yr^{-1} for the previous 500 yr based on a radiocarbon date of 1050 ± 40 yr BP (SRR-1092), and 2.0 mm yr^{-1} for the first 150 yr based on a radiocarbon date of 1150 ± 40 yr BP (SRR-1091).

The oldest date obtained for this bank, 4800 ± 300 yr BP (SRR-1089) comes from a depth of 125 cm (Figure 5), which suggests that the average rate of peat accumulation for this part of the bank has been 0.25 mm yr^{-1}. The deepest part of the bank, 205 cm, has been dated at 3380 ± 100 yr BP (SRR-1088), giving an average rate of peat accumulation here ca. 0.6 mm yr^{-1}. Material at the frozen peat–permanent ice interface at almost the same depth below the vertical edge was dated at 1210 ± 40 yr BP (SRR-1090), indicating a mean rate of peat accumulation of ca. 1.6 mm yr^{-1}. This corresponds to the 1150 ± 40 yr BP sample taken elsewhere in the face of the same bank (see Figure 3d) which had an overall rate of growth of ca. 1.5 mm yr^{-1}. Thus the radiocarbon dates imply that the rate of peat accumulation at this site has ranged from 0.25 to 2.0 mm yr^{-1}, the variation perhaps being accounted for by minor climatic changes (see Fenton, 1981). This is similar to the calculated present-day peat accumulation rate of 0.9 mm yr^{-1} for a similar *Chorisodontium* bank on Signy Island (Fenton, 1980).

Thus it appears that the interrelationships of a low decomposition rate, downhill movement, permafrost depth, orientation, minor climatic changes, biotic factors, and changing configuration result in these banks having a complex developmental sequence. Indeed complexity of origin appears to be a characteristic of solifluction/permafrost phenomena in periglacial regions, for example, patterned ground, palsas, and pingos. It is possible that the precise conditions necessary for the formation of the vertical edges described here occur only in the maritime Antarctic, as such moss banks do not appear to exist in other tundra or temperate biomes.

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