ORIGIN OF POLYGONAL PEAT PLATEAUS UNDER CONDITIONS OF CONTINUOUS PERMAFROST, TRUELOVE LOWLAND, DEVON ISLAND, N.W.T.

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Abstract

Features identified as polygonal peat plateaus have formed under conditions of continuous permafrost in the Truelove Lowland, northeastern Devon Island, N.W.T. The features, ranging in size from 300 m^2 to 0.5 km^2 , have formed in sediments associated with shallow lakes. Permafrost aggradation into these lake sediments has been a consequence of glacio-isostatic uplift during the last 10 500 years and the progressive emergence of the Lowland from the sea. Coastal lakes which began as a series of marine lagoons have been successively isolated, flushed with fresh water and infilled with organic and inorganic sediments. As a result of the aggradation of permafrost into the saturated lacustrine sediments raised mounds have formed underlain by ground ice comprising both segregated and intrusive ice lenses. The development of epigenetic ice wedges has led, in turn, to the formation of a polygonal patterned ground delimiting the individual raised mounds. During the summer months the flow of surface water through the ice wedge depressions is eroding the sides of the raised polygonal mounds causing a degraded appearance.

Résumé

Des formes de relief, identifiées comme des plateaux palsiques à polygones, se sont formées sous des conditions de pergélisol continuel dans la plaine Truelove Lowland, Devon Island, Territoires du Nord-Ouest. Variant de 300 m^2 à 0.5 km², les formes se sont développées dans des sédiments associés à des lacs de faible profondeur. La glacio-isostasie des 10 500 dernières années et l'émersion progressive de la plaine ont eu pour conséquence l'accroissement du pergélisol dans les sédiments lacustres. Des lacs côtiers, qui ont débuté comme une série de lagunes marines, ont été successivement isolés, renouvelés en eau fraîche, et remplis de sédiments organiques et inorganiques. À cause de l'accroisement du pergélisol dans les sédiments lacustres saturés, des buttes se sont soulevées sous la poussée de glace de ségrégation et de glace intrusive. Le développement de coins de glace épigénétique a conduit, subséquemment, à la formation d'un sol structuré, délimitant les buttes individuelles. Pendant les mois d'été l'écoulement de l'eau dans les sillons des coins de glace érode les rebords des buttes à polygone, leurs donnant un air dégradé.

Introduction

The Truelove Lowland (75° 33'N, 84° 40'W) is one of a series of lowlands located on the northeastern coast of Devon Island, N.W.T. (fig. 1). Fields of large polygonal peat mounds cover extensive areas and are among the more distinctive features of the Lowland. The mound fields vary considerably in size, ranging from small, isolated areas roughly 300 m² in area, to large complexes over 0.5 km² in extent. The mounds range in diameter from 1.5 m to 8 m, with flat or raised centres, and separated by polygonal depressions, 10 cm to 2 m in width and roughly 1 m deep. Snow and water accumulate in the depressions. The edges of some of the larger mounds appear to be collapsing and organic material is slumping into the depressions.

Previous attempts to classify these features have used such terms as palsas (King, 1969; Washburn, 1983), peat bogs (Barr, 1971), peat mounds (Brown, 1973), and ice-centred polygons (Jankovska & Bliss, 1977). However, none of these terms has proved to be entirely satisfactory. A more appropriate term would appear to be polygonal peat plateau (Permafrost Subcommittee, 1988). However, such features, comprising a generally flat-topped expanse of peat, elevated above the general surface of a peatland, and containing segregated ice and ice-wedge polygons, are more typical of the boundary between the zones of continuous and discontinuous permafrost, rather than the High Arctic.

Obviously, given the present controversy about the appropriateness of the existing terminology (Washburn, 1983), there is a need for a more detailed and precise description of these features. Consequently, this paper examines the fields of polygonally-shaped peat mounds in the Truelove Lowland in terms of their morphologies, compositions and stratigraphy in an attempt to establish their likely mode of development and provide a suitable basis for their classification.

Study Area

During the postglacial isostatic uplift of the Lowland and its emergence from the sea over the last 10 000 years a series



Figure 1. Location of polygonal peat plateaus in the Truelove Lowland.

of coastal marine lagoons were isolated by emerging submarine bars that were preserved as a series of raised beaches. Although initially containing saltwater, these lakes have since been decanted and flushed with freshwater derived from snow and ice melt. Covering roughly 22% of the Lowland, they have a mean depth of 3 m and are slightly alkaline and oligotrophic. Progressive infilling with sediments of many of the lakes has resulted in much of the Lowland being covered by lake deposits. All the fields of polygonal mounds occur in topographic depressions subject to flooding and are located either adjacent to present lakes or occupy locations that were previously lakes. Often, they are found in the shallow depressions formed between the subparallel raised beaches, and some sites are dissected by streams or are situated at the base of the escarpment where water is seeping out of the base of the talus fans and talus slopes. In such instances streams have dissected the bogs thereby contributing to their degraded appearance.



Figure 2. Phalarope polygonal peat plateau (scale bar is 40 m).

The present soils and vegetation in the Lowland comprise a complex mosaic of cushion plant-lichen and cushion plant-moss communities (Bliss, 1977) underlain by Cryosols. The polygonal mound fields are characterized by a cushion plant-moss community dominated by *Dryas integrifolia*, *Salix arctica* and *Alopecurus alpinus* (Muc & Bliss, 1977) underlain by Glacic Fibric Organo Cryosols (Walker & Peters, 1977). Depth to the permafrost table ranges from roughly 0.5 m on the peat mounds to 10 cm in the depressions.

Methods

Roughly 24 sites with large peaty polygonally-shaped mounds and associated depressions occur within the Lowland (fig. 1). During the 1988 and 1989 field seasons all mound fields in the Lowland were mapped with the aid of air photographs, supplemented with detailed topographic surveys. Three of the sites were selected for more detailed examination and cored. The stratigraphy of the features was examined using a modified 7.62 cm diameter CRREL icecoring auger with a Stihl power head. During both field seasons a total of 63 full length cores were obtained at the three sites. The centres of polygonal mounds were cored, together with the intervening depressions. The cores were extruded in the field, sampled and weighed and then ovendried at 105 °C and reweighed for moisture content. Ice content (expressed on a volume basis) and bulk density were determined and the Loss on Ignition measured following ignition at 550 °C for two hours.

Results

The area covered by polygonal mounds and intervening depressions on the northwest side of Phalarope Lake is the largest individual polygonal mound field in the Lowland, being roughly 400 m in diameter, with a distinctive shape (fig. 2). Located on a low-lying interfluve, the site appears to have been an extension of Phalarope Lake at one time. Individual polygonal mounds in the feature range in height from 0.20 to 2.5 m, with diameters as large as 8 m. The tops of the mounds are vegetated with a cushion plant-moss community (Muc & Bliss, 1977) and often covered by turf hummocks. The edges of many of the mounds are collapsing and slumping into the depressions which range in width from 2 cm to 3 m. Water in the depressions is often coloured brown by humic substances and water flow is channelled by the polygonal network.

Coring revealed that the depressions are underlain by vertically foliated wedge ice to a maximum depth of 2.13 m. Coring of the centres of several of the mounds revealed a shallow active layer to a depth of 15 cm comprising plant fragments and black organic matter (fig. 3). This is underlain by a composite layer 72 cm thick of frozen black organic material. Underlying this are several layers of green algal material with a total thickness of 46 cm. Within these sediments are found small, randomly spaced, vertically oriented ice veins. At a depth of 1.33 m lies a 22 cm thick horizontal ice lens with round bubbles 1-2 mm in diameter. Occasional large bubbles, roughly 4 mm long, are elongated with a vertical orientation. Underlying this is a 25 cm thick layer of green algal material and abundant Carex fragments. Coring terminated at a beach deposit comprising boulders and large pebbles in a grey inorganic matrix at a depth of 180 cm.

The polygonal mound field located due east of Little Beschel Lake (fig. 1) is composed of several rectilinear mounds oriented in a north-south direction and parallel to the escarpment. Individual mounds are separated by depressions up to 4 m in width that are underlain by vertically foliated wedge ice to a depth of 2.15 m. A small stream originating above the site has dissected the feature, taking advantage of the integrated network of depressions. The generally flattopped and sparsely vegetated mounds range in size from 3 to 6 m in diameter and have a maximum height of 1 m.

Coring of one of the mounds (fig. 4) revealed a stratigraphy consisting of 21 cm of unfrozen brown peaty sediments underlain by 21 cm of unfrozen interdigitated brown and black organic sediments. This, in turn, is underlain by 6 cm of frozen brown sediments and a 1.39 m thick lens of vesicular ice with vertically oriented organic layers and vertical bubble trains. Beneath this are found convoluted and frozen laminations of grey, brown and black inorganic sediments to a depth of 2.19 m — the maximum depth reached by the corer.

The third polygonal mound field investigated is adjacent to Lower Beschel Lake (fig. 1). Covering an area of roughly 84 000 m², the feature comprises several discrete mound subfields, some of which have been dissected by the stream draining the Beschel Lake system, whereas others have formed in different parts of the catchment of Lower Beschel Lake. The flat-topped polygonal mounds comprising the feature have a maximum height of 1 m and are between 2 and 8 m in diameter. The mounds are well vegetated and covered with many smaller hummocks. The edges of many of the mounds are slumping into the intervening depressions which range in width from a few centimetres to 1 m and are water-filled during the snow-melt period.

Coring revealed that beneath the depressions vertically foliated wedge ice extends to a depth of 2.40 m. This ice is underlain by grey/green inorganic sediments. Coring of the centre of one of the mounds (fig. 5) revealed the presence of 16 cm of unfrozen brown fibrous peat underlain by 6 cm of unfrozen grey inorganic material which is, in turn, underlain by 15 cm of black fibrous peaty material, the lower 10 cm of which is frozen and ice-rich. Beneath this is a 19 cm thick horizontal ice lens containing vertically oriented bubble trains and organic material which grades into frozen black peaty material at a depth of 89 cm. At this depth a second horizontal ice lens exists, 1.51 m thick and composed of vesicular ice with bubbles 1-3 mm in diameter in vertical trains and small amounts of vertically oriented lenses of organic material. The basal material in the core comprises grey/green silty sediments high in ice content and extending to a depth of 2.70 m.

Discussion

Coring indicated that, in general, the raised centres of the mounds contain a horizontally bedded sequence of sediments comprising basal greyish inorganic sediments, overlain by well humified algal material, and finally by a relatively thin veneer of poorly decomposed fibrous peat at the surface. In most instances the accumulation of the organic material has occurred in a lacustrine environment. Recent coring of the larger lakes in the Lowland has revealed the presence of relatively thick $(\pm 1 \text{ m})$ deposits of algal gyttja in the lake sediments. In a previous discussion of the paleobotanic record preserved in the Phalarope Feature, Jankovska & Bliss (1977) speculated on the role played in the development of the polygonal hummocks by partially decomposed masses of the blue-green algae Nostoc commune being washed ashore and incorporated in moss peat. Unusually thick accumulations of algal material could occur when free-floating algal mats are blown ashore during one of the episodic southeasterly Föhn wind events during late summer when the lakes are ice-free. This may explain the unusual thickness of peat at this site. It is also noteworthy that interbedded within the present nearshore algal sediments of this lake are layers of Carex fragments that have presumably been deposited by the wind and that similar deposits were found in the Phalarope polygonal mound field.

In the polygonal mounds the depth to the permafrost table is generally less than 30 cm, but the active layer is deeper when the organic content is lower, as in the Little Beschel polygonal mound field. Interspersed within the sediments in the mounds are horizontally oriented discontinuous ice lenses up to 1.5 m in thickness and vertical ice veins. Some of the ice lenses comprise clear, clean ice, while others contained varying amounts of organic material and gas vesicles. The mounds in the Phalarope polygonal mound field are unusual in that most of the ground ice appeared in the form of pore ice. In contrast to the mounds, coring of the depressions revealed the presence of a thin (< 10 cm) active layer underlain by vertically foliated wedge ice to a maximum depth of 2.40 m.



Figure 3. Sediment stratigraphy, ice content, bulk density and loss on ignition diagram for Phalarope polygonal peat plateau.



Figure 4. Sediment stratigraphy, ice content, bulk density and loss on ignition diagram for the the Little Beschel polygonal peat plateau.



Figure 5. Sediment stratigraphy, ice content, bulk density and loss on ignition diagram for the Lower Beschel polygonal peat plateau.

It is clear that the polygonal mounds contain a range of ground ice conditions, including both horizontal ice lenses and foliated wedge ice. The high degree of vesicularity in much of the basal lens ice and the wedge ice often caused the ice cores to shatter during the coring process. This suggests that the original freezing process was very rapid and that the basal lens ice in many of the mounds is intrusive ice.

Previous radiometric dating of basal organic samples from two of the features, i.e., the polygonal mound fields at Phalarope Lake and at Lower Beschel Lake, has yielded dates of 2,450 \pm 90 years B.P. (I-3231; Barr, 1971) and 4,300 \pm 95 years B.P. (S-430; Barr, 1971), respectively. The differences in ages can be interpreted as largely representing the effects of the glacio-isostatically controlled emergence of the Lowland.

Conclusions

The origin of these features is complex. The features are associated with former lake beds in which lacustrine sediments comprising algal gyttja and inorganic detritus have been deposited. The age of the features has been controlled both by the rate of glacio-isostatic uplift and by the history of lake development in the Lowland. As the lakes have drained, permafrost aggradation into the saturated lake sediments has led to the formation of epigenetic ice, in the form of both segregated ice and intrusive ice. Vertical heaving of the organic-rich deposits consequent to the development of the ground ice has been accompanied by the creation of fissures caused by thermal contraction and/or dilation and the subsequent formation of wedge ice. Desiccation of the originally saturated algal material may also have contributed to the formation of polygonal cracks in the surface material. In places, the flow of surface water through the network of polygonal depressions during the summer months is eroding the sides of the raised polygonal mounds, causing a degraded appearance.

The only features described in the literature that appear to share the same morphological and ground ice characteristics as the fields of flat-topped polygonal mounds in the Truelove Lowland are polygonal peat plateaus (Permafrost Subcommittee, 1988). However, as previously suggested, these features are more typical of the boundary between the zones of continuous and discontinuous permafrost. On the other hand, Truelove Lowland, in common with the other lowlands along the northeastern coast of Devon Island, has climatic and vegetational characteristics more typical of the Low Arctic (Bliss, 1977). The possibility exists that the polygonal peat plateaus of Truelove Lowland have formed in response to the unusual environmental conditions of this polar "oasis".

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