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THE ORIGIN OF PINGOS IN REGIONS OF THICK PERMAFROST, WESTERN CANADIAN ARCTIC

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ABSTRACT. The presence of pingos in regions of thick and continuous permafrost is often explained by the freezing of a talik previously developed beneath a standing water body, usually a lake. These pingos are generally referred to as "Mackenzie Delta" or closed system type pingos. A number of pingos studied in the islands of the Western Canadian Arctic indicate that the conditions for favourable closed system pingo growth are much more varied. For example, pingos situated on low terraces of the Thomsen River in north central Banks Island (73° N) probably developed following the lateral migration of the river and the freezing of a talik which had formed beneath the channel (Fig. 2). Two near parallel pingo-like ridges developed on the lower part of the gentler slope of an asymmetrical valley in southern Banks Island (71° N) are thought also to have formed by the freezing of sub-channel taliks at times when the stream migrated laterally to produce the valley asymmetry (Fig. 6). On Prince Patrick Island, elongate pingos located near the coast at Satellite Bay (77° N), formed following fluctuations of sea level and the inundation of river valleys (Fig. 7). Other pingos, located in the central parts of Prince Partic Island (76° N), appear related to the presence of deep faults in the underlying bedrock at a time when permafrost was aggrading (Fig. 9). Those pingos thought related to the evolution of streams often exhibit an elongate, ridge-like form.

Introduction

Two types of pingos are generally distinguished in the literature. These are the closed system ("Mackenzie") type, found in regions of continuous permafrost, and the open system ("Alaska") type, found in regions of thin and/or discontinuous permafrost. Their mechanisms of growth are widely accepted and frequently mentioned in textbooks (e.g. Washburn 1973, pp. 153–161; French 1976b, pp. 93–100). Pingos are regarded as classic features of permafrost terrain.

The "Mackenzie" type pingos are formed in a closed system resulting from the freezing of taliks formed beneath lakes (Mackay 1962, 1973). It is know that, even in periglacial environments of intense cold, lakes may exist which are too deep to freeze completely to their bottom in winter. However, if the depth of water decreases for any reason, permafrost may begin to develop on the floor of the lake. This may occur if, for example, the lake is suddenly drained, or if it infilled with sediments. As a result, a pocket of unfrozen sediment becomes enclosed by permanently frozen sediment. The expulsion of water shead of the advancing freezing plane and resulting build-up of pressure within the unfrozen zone leads to the migration of water towards the surface and the growth of a pingo.

The object of this paper is to suggest that the "Mackenzie" type environment of closed system pingo growth is not sufficient to explain all pingos actually found in regions of thick and continuous permafrost. Several groups of pingos, located on Banks

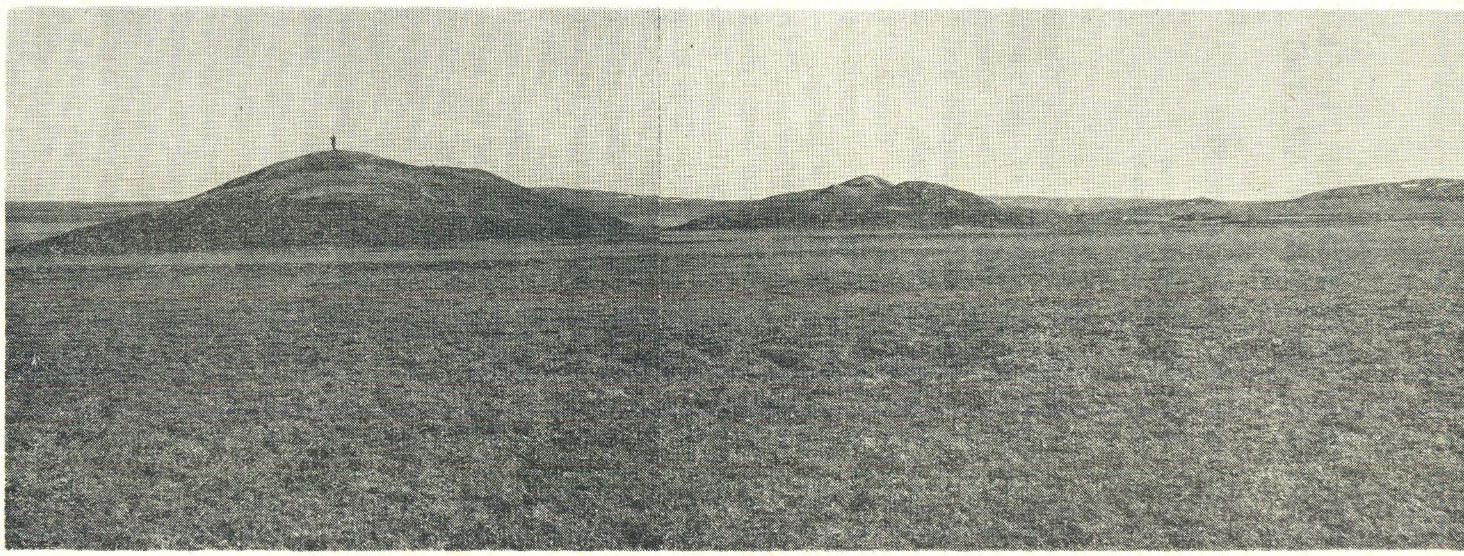

Fig. 1. Photo of two Thomsen River pingos

Island and Prince Patrick Island in the Western Canadian Arctic, illustrate the variety of geomorphic conditions which are thought possible for closed system pingos growth.

Pingos of the Thomsen Valley, North Central Banks Islands *(A. Pissart and H. French)*

A group of seven pingos situated on low terraces of the Thomsen River (73° 45′*N*; 119°50′W), were examined in 1974 (French 1975, Pissart 1975). Sections excavated across several of the features revealed massive ice bodies within their centres (Pissart and French 1976). The sediments enclosing the ice cores were fluvial sand and gravel. These were tilted upwards on both sides of the ice cores, indicating that the mounds had been upheaved by the growth of the ice bodies.

The mounds vary in height between 5 and 14 m (Fig. 1). In plan, the majority are elongate with their long axes approximately parallel to the valley alignment. A further characteristic is their distribution in a rough linear fashion downvalley.

The growth of these pingos required the presence of a talik. However, Banks Island is located in the zone of continuous permafrost (Brown 1972) and drilling indicates that permafrost extends to a depth of 430 m in the western lowlands (Judge 1973). Thus, a closed rather than an open system hypothesis has to be considered. Since no lake sediments or other evidence for the former existence of a lake have been found at the locality of these pingos, a simple "Mackenzie" type explanation is inapplicable. Instead, bearing in mind the elongate form of the pingos, their alignment approximately parallel to the present river, and their location on low terraces, it is hypothesised that the pingos developed following the lateral movement of the Thomsen River and the freezing of localised sub-river taliks (Fig. 2). The Thomsen River is a sizable river, being over 170 km long, and it is possible that some of the deeper sections of the main channel do not freeze to their bottom during winter. A similar mechanism has been suggested by Mackay (1963, pp. 88–94) for the various hillocks and pingo ridges which occur in the modern Mackenzie Delta.

Although it can be objected that the lateral movement of a river is usually a slow process and, as such, could occur without producing a closed talik, it is also possible that the rapid abandonment of a channel or an abrupt change of course could result in the temporary development of a closed talik. The presence of several terraces in the Thomsen Valley in the vicinity suggests a history of migration and subsequent downcutting of the main channels of the Thomsen River, probably in association with decreasing discharges.

Pingo-like ridges, Upper Sachs River, Southern Banks Island *(H. French)*

An isolated pingo with a summit crater and lake exists near the junction of two small stream valleys in southern Banks Island (71°45′N; 123°12′W). The streams currently drain into Raddi Lake and the Sachs River. Field investigation in 1975 however (French 1976a), was focussed upon two irregular and elongate ridges which extended upvalley from the pingo for a distance of over 2 km (Fig. 3). The ridges are approximately parallel to each other, varying from 50 to 200 m apart, and are located towards the foot of the northwest facing slope. The valley is strongly asymmetrical with the present stream undercutting the foot of the steeper southwest facing slope. Neither of the ridges exceed 10 m in height, and they

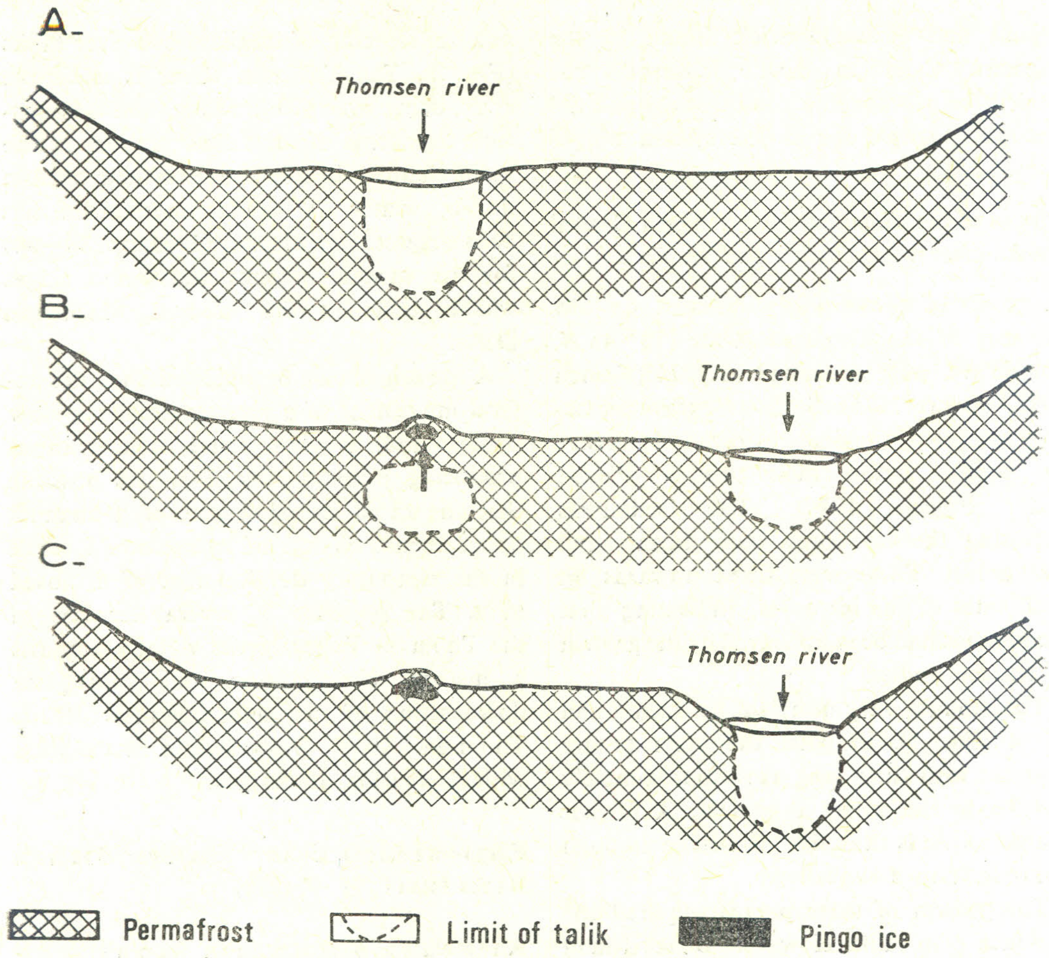

Fig. 2. Suggested origin of the pingos of the Thomsen River, Banks Island

vary from 20–100 m in width. A characteristic of both ridges is the number of shallow elongate or enclosed depressions aligned along the ridge axes (Fig. 4).

At the surface the ridges are composed of coarse sand and gravel, and possess a hummocky sinuous appearance. A section cut through one of the features revealed massive ice bodies to exist beneath the depressions (Fig. 5). The overlying gravels and sands were virtually structureless but relatively well sorted, none of the boulders being in excess of 30 cm in diameter.

The elongate form of the ridges, and their composition of coarse sand and gravel, are facts in favour of their interpretation as eskers. However, their location towards the bottom of a sharp, asymmetrical valley, the linear depressions aligned along their axes with ice bodies beneath, and the absence of other evidence for recent glacial activity within the valley, or on the surrounding terrain, suggest that these features are of a different origin.

In all probability, these features are linked to the evolution of the valley in which

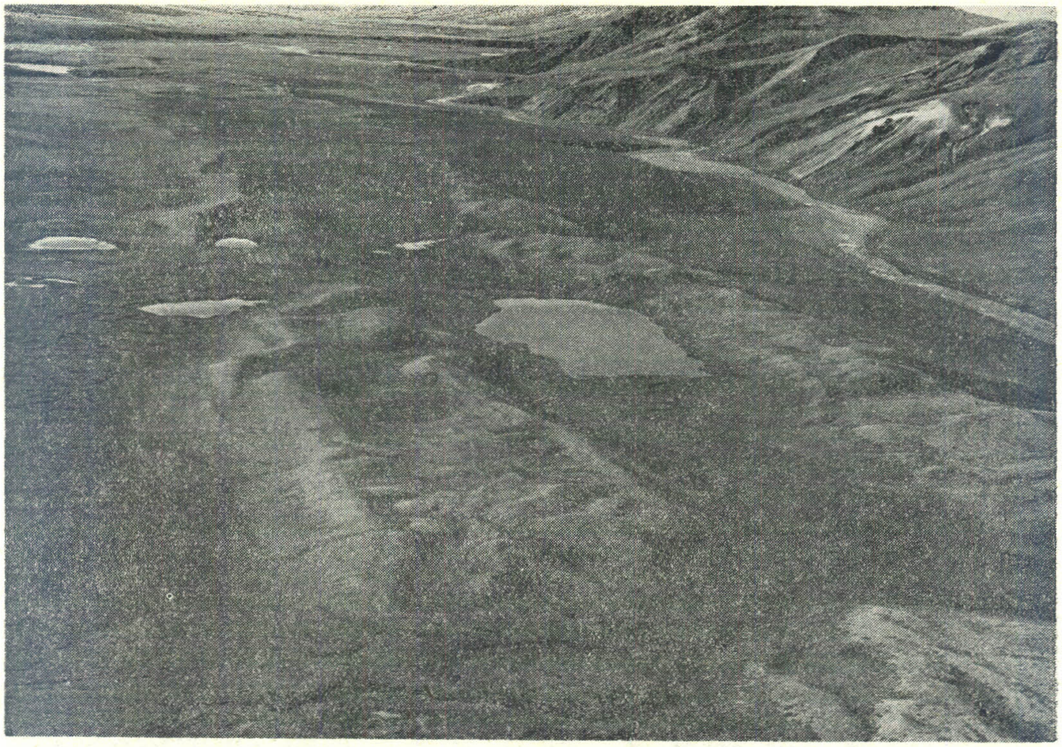

Fig. 3. Oblique air view of pingo-like ridges, Upper Sachs River, Banks Island, showing their central depressions, the parallel alignment of the rigdes, and their location within an asymmetrical valley

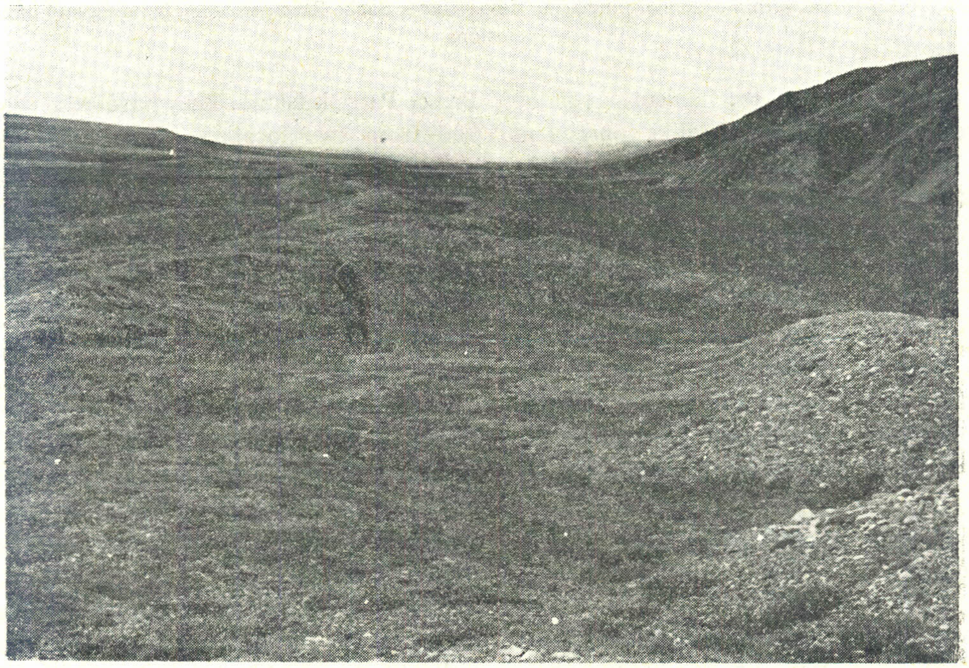

Fig. 4. Shallow linear depression developed along the axis of one of the pingo-like ridges, Upper Sachs River

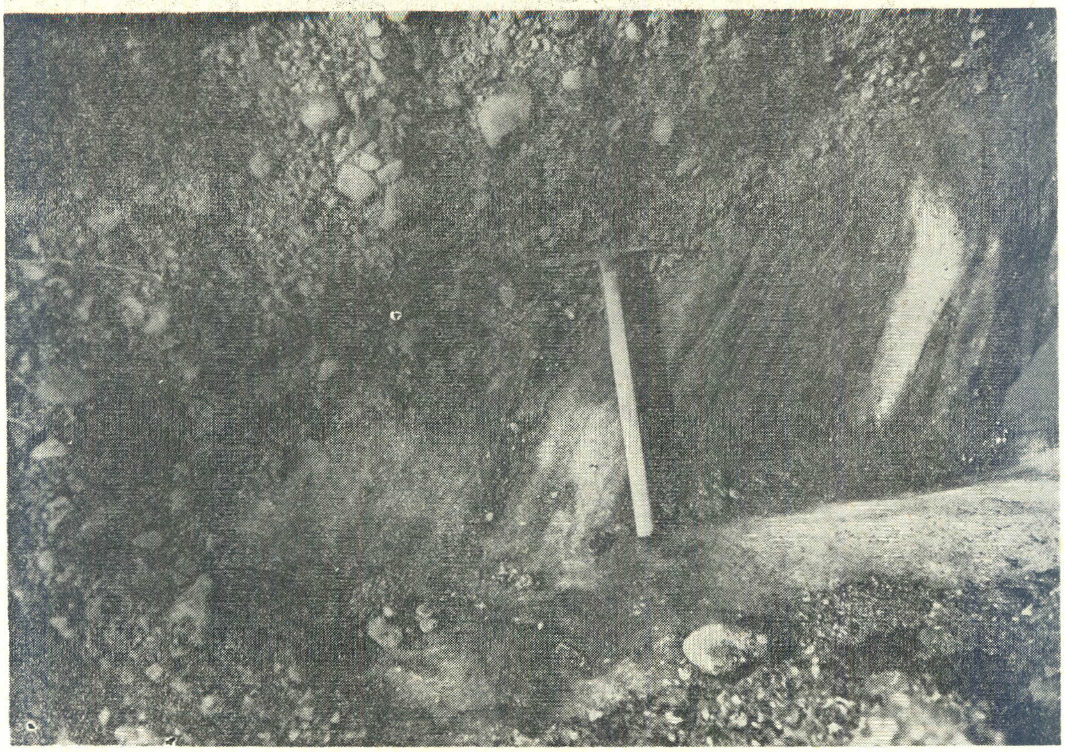

Fig. 5. Ice body found within center of pingo-like ridge, Upper Sachs River, showing banding and mineral inclusions

they are located. A mechanism involving the freezing of sub-channel taliks consequent upon the lateral migration of the stream seems most logical (French and Dutkiewicz 1976). An elongate, near-continuous talik might have developed in the permeable gravel infill of the valley bottom. The dual nature of the ridges on the gentler slope could then be explained in terms of two successive positions of the stream channel as it migrated to its present position at the foot of the southwest facing slope (Fig. 6).

Coastal pingos, Prince Patrick Island
(*A. Pissart*)

Mounds similar to the pingo-like ridges described from southern Banks Island in the previous section also occur on adjacent Prince Patrick Island. They have been described from two localities, each being river valley locations near the coast (Pissart 1967). With one exception, all the mounds are elongate esker-like ridges several hundred meters in length (Fig. 7). Sections excavated across several of the ridges have demonstrated the existence of ice bodies in their centers.

In the Satellite Bay region of the northern Prince Patrick Island (77°20′N; 116°40′W) geomorphological mapping and the reconstruction of the geomorphological history suggest how some of these pingos may have formed (Fig. 8).

There, in the vicinity of the present coast, an extensive fluvial terrace grades into a well developed deltaic surface (Fig. 8a). This deltaic surface indicates a marine level approximately 12 m higher than present. The terrace is of a glacio-fluvial origin since it can be traced inland into the upper reaches of the Satellite Bay drainage basin where it is even more widely developed. In all probability, it formed as a glacial outwash plain produced by a major glaciation from the east.

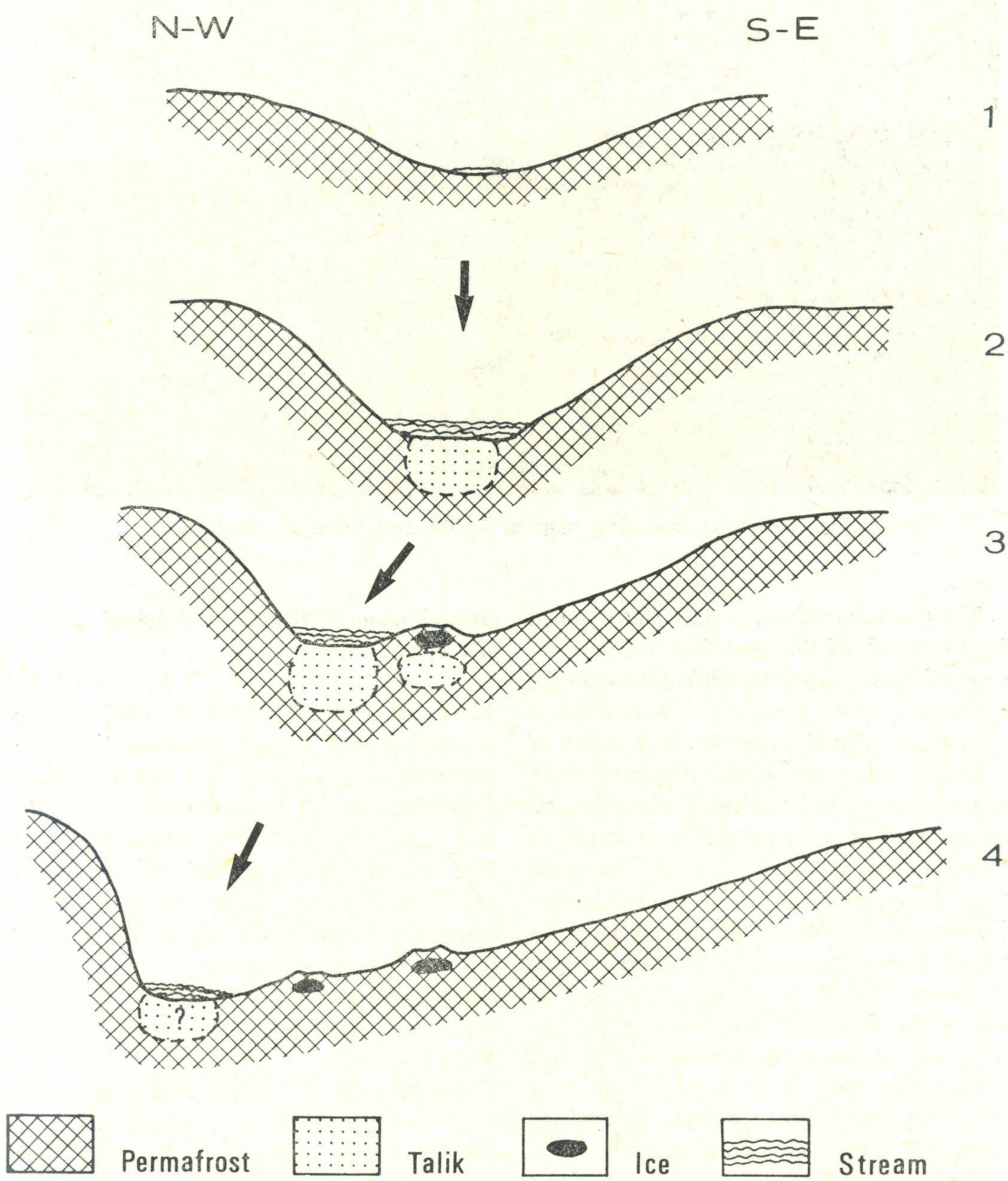

Fig. 6. Possible sequence of events leading to growth of pingo-like ridges, Upper Sachs River, Banks Island

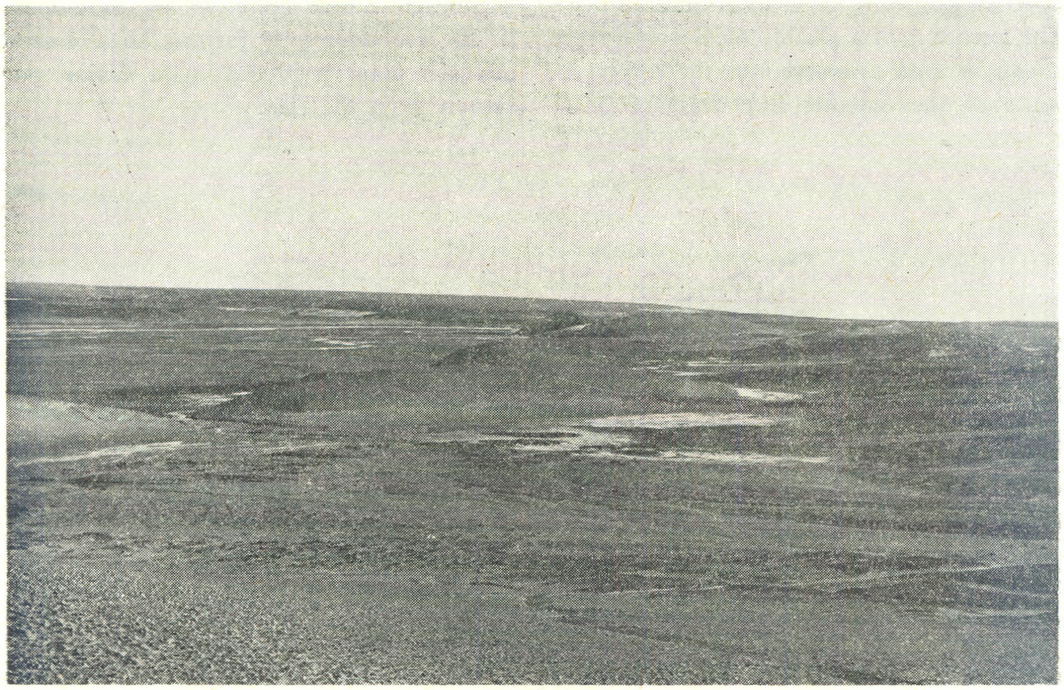

Fig. 7. Photo of an elongate pingo of Satellite Bay, Prince Patrick Island

The dissection of this surface was initiated by the uplift of the land following the retreat of the ice sheet (Fig. 8b). Subsequently, a rise in sea level flooded the incised valleys to produce a "ria" coastline. This influx of marine waters permitted the localised melting of permafrost along the length of the flooded estuaries. Because these rias were narrower closer to the sea than upvalley, the taliks were shallower nearer to the coast (Fig. 8c). Finally the infilling of the rias by new fluviatile sediments enabled the redevelopment of permafrost on the valley bottoms. This led to the formation of closed taliks and the growth of injection phenomena (Fig. 8d).

As in the case of the Banks Island features, it would appear that the shape of the water body, and the talik existing beneath, determined the location and elongate form of the pingos.

Summit pingos, Prince Patrick Island
(*A. Pissart*)

More than 140 circular or semi-circular mounds (Fig. 9) are located along the mjoar north-south divide of Prince Patrick Island, approximately 29 km northwest of Mould Bay (76°15'N; 110°25'W), (Pissart 1967). The average diameters of these features measured 58 m, with a mean height of 3.3 m. Generally speaking therefore, they are of only moderate dimensions; the smallest mound is 1 m high and 20 m in diameter while the largest is 250 m in diameter and 13 m in height.

The mounds are formed within sand and gravel of the Beaufort Formation. These sediments vary in thickness up to 500 m and rest discordantly upon Palaeozoic rocks. Sections excavated through several of these

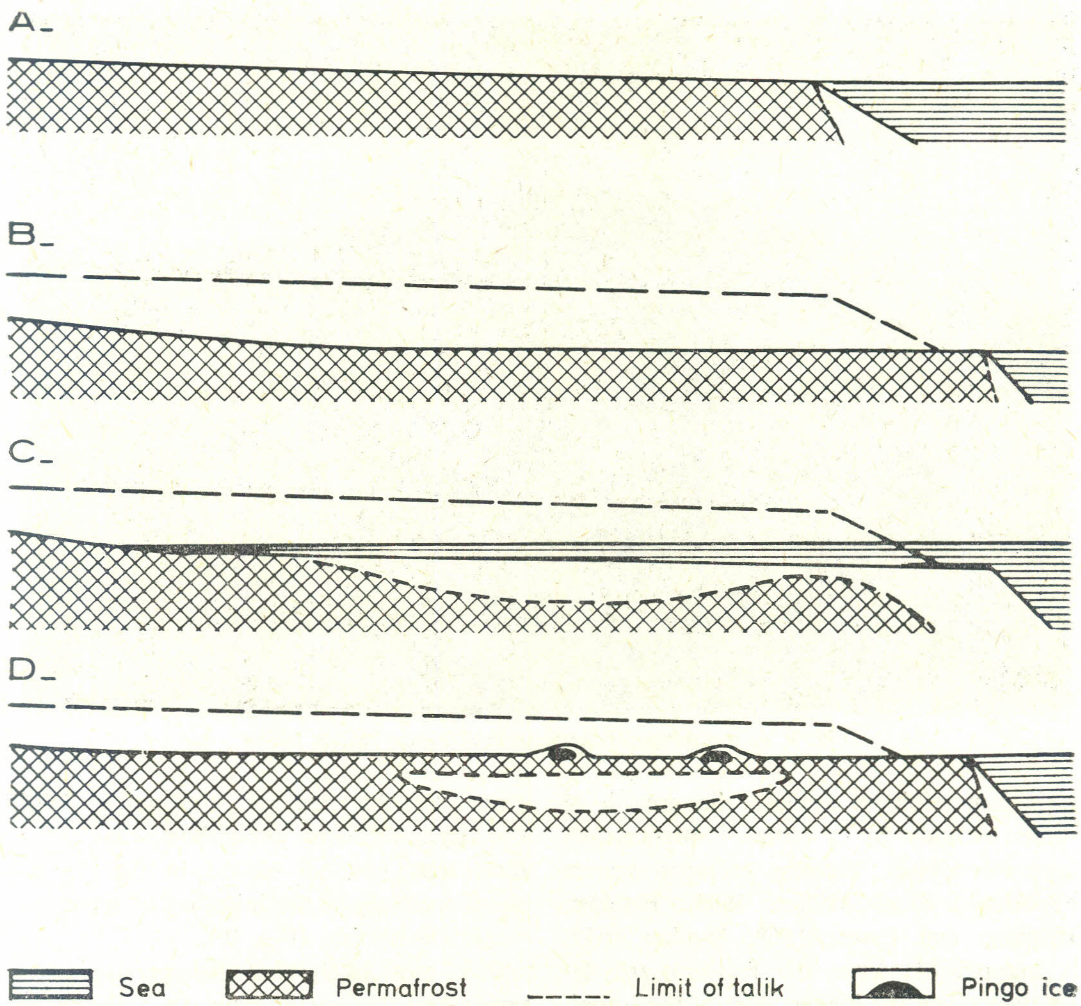

Fig. 8. Suggested evolution of linear pingos, Satellite Bay region, Prince Patrick Island

mounds showed the existence of ice bodies located at depth varying between 1.2 and 3.0 m below the surface.

The mounds occur in two broadly parallel lines, oriented west-south-west to east-north-east, over a distance of more than 15 km. They are separated from each other by a zone, more than 2 km in width, in which no mounds or other irregularities of relief are found.

The actual location of the mounds appears unrelated to the general topography of the surrounding area. Some are located in the bottom of valleys while others lay either on interfluve summits or valley side slopes. A number are located on the floor of meltwater channels which cut through the drainage divide. The location of the latter indicate they developed subsequent to the last glacial period on Prince Patric Island.

Since lakes would not have existed along summit of the island and certainly not at the exact localities of some of the features,

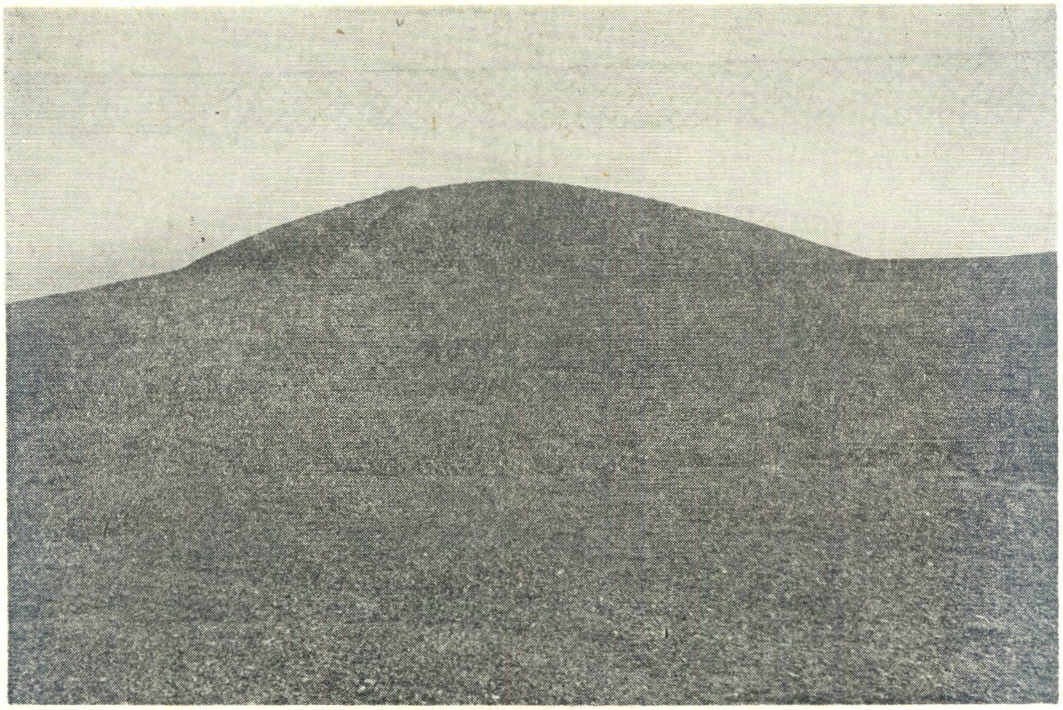

Fig. 9. View of pingo of the summit of Prince Patrick Island

it is impossible to explain the growth of these mounds by a simple "Mackenzie" type mechanism. Equally, an open system hypothesis (e.g. Müller 1963, Holmes, Hopkins and Foster 1968, Hughes 1969) is inapplicable since the features are developed along the highest part of the island. It is evident therefore, that other mechanisms are responsible. In this respect, one feature of the mounds which may be significant is their alignment in two parallel lines. One of these alignments appears to coincide with a fault line though to occur at depth in the underlying Palaeozoic rocks (Tozer and Thorsteinsson 1964). It may be therefore, that faults in the underlying impermeable rocks resulted in the formation of a number of structurally controlled depressions in the bedrock topography which acted as collecting areas for groundwater moving through the permeable sand and gravel of the Beaufort Formation. With the aggradation of permafrost, closed systems may have developed in the depressions resulting in the injection of water towards the surface (Fig. 10).

It is most likely that the aggradation of permafrost occurred after the disappearance of the ice sheet which once covered the island. When in existence, the ice sheet would have protected the underlying terrain from the extremes of cold experienced in proglacial suations and permafrost might either have been absent or not as thick as it is today.

Conclusions

The pingos described above are thought to illustrate situations where closed system pingo growth has occurred in different geomorphic settings to that of the classic "Mackenzie" type. Almost certainly, there

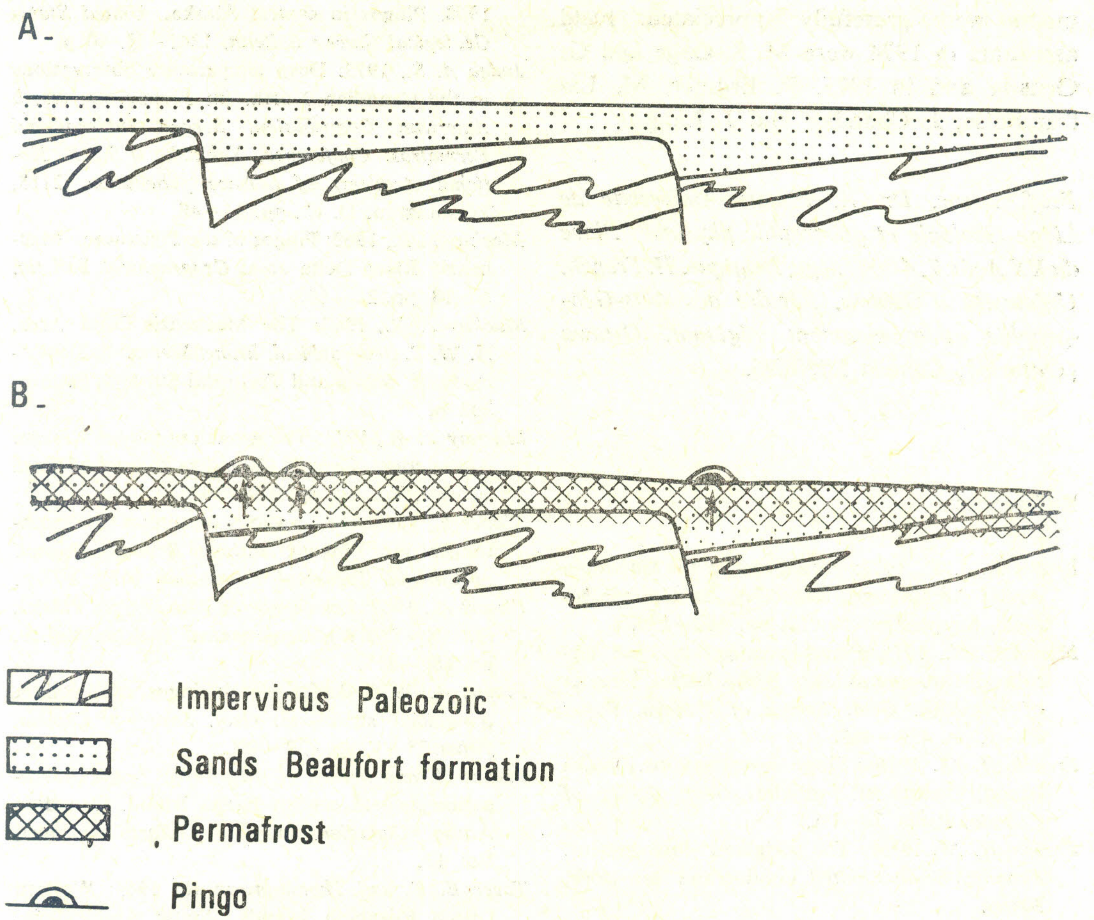

Fig. 10. Suggested evolution of a pingo along the summit of Prince Patrick Island

are others which have yet to be recognised. These examples also emphasise the necessity to consider the temporary existence of ground water movement and taliks in regions of thick permafrost, and the variety of pingo and pingo-like forms which may exist. In particular, the linear nature of certain pingos appears related to the evolution of the drainage network.

Acknowledgements

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