The Pingos of Prince Patrick Island (76 degrees N - 120 degrees W)

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PREFACE

This translation of a study of pingos in the Canadian Arctic Archipelago is of particular interest to the Division of Building Research in its investigations of the fundamental and engineering aspects of permafrost and the natural features associated with this phenomenon. Pingos are the most striking landforms in the permafrost region and their origin has long been the subject of much speculation. Two types of pingos were described in the book by F. Müller, "Observations on Pingos," which was issued in the National Research Council Technical Translations series in May 1963 (TT 1073). This present translation describes another type of pingo in very severe permafrost conditions in the Far North which, according to the author, has not been encountered elsewhere.

Field studies in North America of these unusual features are limited and scattered. Observations have been made in Siberia for some years but the resulting Russian publications have not been generally available. Dr. Pissart's observations have enabled him to propose suggestions as to their origin and history which contribute to a better understanding of some of the geological processes associated with permafrost in the High Arctic.

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N.B. Hutcheon,
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THE PINGOS OF PRINCE PATRICK ISLAND (76°N, 120°W)

by

A. Pissart*

ABSTRACT

More than 150 pingos have been observed on Prince Patrick Island. The majority of these domes of injected ice may be divided into two distinct groups:

The first group is made up of more than 100 pingos located on the surface of the island's summit at an altitude of about 100 metres. They are aligned in two parallel rows of domes, circular in ground plan, whose height and diameter do not exceed 13 metres and 250 metres respectively. Presenting no positive trace of present day evolution and showing no relationship with the topography, these forms exist in the valleys as well as on the summits. They are possibly related to some deep geological structure.

The second group of pingos is made up of mounds at an altitude close to sea level and situated at the head of two bays more than 90 km distant from each other. In this group particularly are elongated pingos resembling eskers as well as those with the characteristic circular shape. Observed cuts have shown the arrangement of layers in the sides of the pingos as well as the core of injected ice. They appear to have developed following a definite change of sea level which drowned the bay and resulted in the melting of the upper permafrost. The later re-establishment of the permafrost may have begun with the appearance of this injected ice.

Other pingos of a different type have also been recognized on the island.

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INTRODUCTION

In the course of the last decade, there has been a proliferation of research work on pingos. Of particular importance are the publications by F. Müller (1959), J. Ross MacKay (1962), W. Holmes, D. M. Hopkins, and H. L. Foster (1963), and C. Maarleveld.

The principal result of these works has been the recognition in the Arctic of two types of pingos, differing genetically from each other. This distinction, already proposed by Porsild in 1938, appears to be widely accepted today.

The first type of pingo is well represented in the Mackenzie Delta. It comprises forms located in shallow lakes, or lakes which have completely dried out, and their origin is linked to this particular situation. Beneath arctic lakes, whose depth exceeds the thickness of winter lake ice, the ground is not frozen, even if continuous deep permafrost exists in the area. If, as a result of infilling, or of a lowering of the lake level, the depth of the water body decreases, all the lake water will be completely frozen in winter, and the lake bed itself will begin to freeze. In this fashion, the encircling permafrost will advance, and will begin to encroach upon the zone located beneath the lake. This advance results in the encirclement of a pocket of water-saturated unfrozen sediments by impermeable frozen ground. The increase in volume resulting from the freezing of the water in this enclosed space produces very high pressures, which inject water from depth into the overlying beds, where it forms the ice core of a growing pingo.

This mechanism demands the presence of thick permafrost, with a correspondingly rigorous climate. The mean annual temperatures of the areas of North America where this type of pingo occurs vary, according to Holmes, Hopkins and Foster, between 12° and 20°F (-11° and -5.5°C).

The second type of pingo occurs in areas of well-marked relief. Slopes are essential to their development. Here the pressure required for the upward injection of water is supplied not by the action of freezing, but by a circulation of subterranean water occurring beneath a frozen layer, and nourished by surface water descending a slope. The injection of water into the overlying beds occurs at the foot of the slopes where the overlying frozen layer is less resistant.

The climatic conditions required for the production of this type of feature are much less rigorous than for the preceding type. The authors just cited mention mean annual air temperatures varying between 22° and 28°F (-5.5 and -2.2°C) with reference to the pingos of interior Alaska. However, pingos of the same type have been described from an area of Greenland by F. Müller, with more rigorous climatic conditions; there the mean annual temperature occasionally reaches -10°C.

It has been demonstrated in a recent article (Pissart, 1965) that traces of pingos exist in Belgium in topographic situations which exclude the two genetic hypotheses described above. These traces of pingos have in fact been found on the summit of a relatively narrow ridge, where the mechanisms observed above could not have operated.

Moreover, several earlier authors have thought that other types of pingos might exist: J. Ross MacKay (1962, p. 22) and F. Müller (1959) have described pingos which belong to neither of the two categories described above. The Prince Patrick Island pingos which I am about to present are again of a distinctly different category, and by virtue of this, they merit special attention.

GEOLOGY, HISTORY, RECENT GEOMORPHOLOGY AND CLIMATE OF PRINCE PATRICK ISLAND

Prince Patrick Island forms part of the Queen Elizabeth Islands, and stretches mainly between the 76th and 77th parallels, straddling the 120th meridian (Fig. 1).

The island is located on the shores of the Arctic Ocean, and two thirds of its surface has the appearance of a typical maritime plain, sloping gently towards the west, and drained by a characteristic dendritic drainage network. The substrate of the area is composed of subhorizontal beds of sands and gravels resting unconformably on Primary and Secondary formations, which outcrop in the east of the island. The majority of the pingos studied are located in these sand-and-gravel formations, known as the Beaufort Formation. Despite the fact that large numbers of pieces of wood are preserved within the Beaufort Formation, its age is unknown. Authors who have studied it (Tozer and Thorsteinsson, 1964, p. 167) have established that it is a deposit dating from the Tertiary or from the beginning of the Quaternary. To judge from the amount of erosion which has occurred since the time of deposition of these sediments, I prefer to think that these are Tertiary deposits.

The lower formations, partly Devonian, partly Secondary in age, generally display only gentle dips. However, they are cut by radial faults (Fig. 1), and as Tozer and Thorsteinsson (1964, p. 120) have observed, certain of these occurrences seem to have affected the Beaufort Formation. Indeed, these authors have observed on aerial photographs the presence of straight or slightly curved lines, over 50 km in length, which have no topographic expression, but which separate areas of slightly differing vegetation. Tozer and Thorsteinsson see in these lines the surface expression of the radial faults identified in the underlying beds.

The geomorphological history of the area is not well established. At least one major glaciation has covered the entire island, as witnessed by numerous erratics. Apart from some very infrequent striated rocks, and traces of numerous glacial meltwater drainage channels, there are few other signs of glaciation. Fyles (1965, p. 4) expresses the same opinion, when he writes that the distribution of erratics in the eastern part of the island suggests that the major glaciation which transported them there was prior to the last cold period.

The island does not appear to have experienced any significant glaciation during the Wisconsin. It is, however, likely that a thin local ice cap covered the island, but without leaving any clear traces in the topography.

The geomorphology of Prince Patrick Island is thus largely periglacial. The permafrost is certainly very thick, but thus far no boring has been carried out, and hence its actual thickness is unknown. It should be borne in mind, however, that a bore hole, 300 km to the south east, on Melville Island, showed the ground to be frozen to a depth of 515 m (Hamelin and Jacobsen, 1964, p. 15). There appear to be indications of the presence of raised beaches on the aerial photographs. No shells were found on the ground, however; the forms of marine erosion are indistinct; and on this subject too, knowledge is limited.

The present climate of Prince Patrick Island is extremely severe. Meteorological observations made at Mould Bay since 1948 indicate a mean annual temperature of -18.5°C (-1.5°F). The table of mean monthly temperatures given in the appendix shows that the monthly means exceed 0°C only in July and August, and that freezing is intense during nine months of the year. From the very low precipitation (annual mean 81 mm = 3.23 in.) it is understandable that no ice cap covers the whole island at present.

The table of monthly means combining comparable climatic parameters for both Prince Patrick Island and the areas of Greenland and the Mackenzie Delta where pingos have been observed, clearly indicates that the climate of the area studied here is by far the most severe.

THE PINGOS: DESCRIPTION AND GENETIC HYPOTHESES

Systematic study of the aerial photographs of Prince Patrick Island revealed the presence at several points on the island of more or less circular mounds, which appeared at first sight to be pingos. It was often impossible to decide whether these mounds were due, in fact, to the presence of intruded ice, or whether they were simply hills isolated by chance erosion. I shall not delay over a description of hypothetical forms but will describe only indisputable pingo forms. The majority of these can be divided into two groupings, totally distinct from the point of view of genesis, age and location factors. For these reasons, I shall consider them separately. The first of these groups of pingos is located 18 miles (29 km) northwest of Mould Bay, on the summit of the island (Point 1 on Fig. 1), while the second comprises forms developed at the sea coast, and which I observed near Satellite Bay and Intrepid Inlet (Points 2 and 3 on Fig. 1).

The Pingos Located on the Summit of the Island, Northwest of Mould Bay

These pingos were first recognized during the summer of 1964 by J. G. Fyles, Head of the Pleistocene Geology Section of the Department of Energy, Mines and Resources. He very kindly authorized me to study these forms, and was good enough to supply me with the photographs he had taken of them, prior to my departure for the field. I wish to thank him very cordially for his kindness.

Description of the Topography

The plateau on which the observed pingos are located lies 18 miles (29 km) northwest of the weather station at Mould Bay. It forms part of the summit surface of the island, and the rivers rising there diverge: some flow westward to the Arctic Ocean; others head towards the southwest in the direction of Walker Inlet; while still others make for the sea in the southeast, in Mould Bay.

The plateau lies at an altitude of about 100 m, and is cut by shallow, but very wide, valleys. The latter display some remarkable peculiarities; often they continue from one drainage basin to another without there being any true valley head. Because of this, it is completely impossible to trace the limits of the different basins on the aerial photographs. They are, moreover, misfit valleys - much too wide for the streams making use of them at the present day; finally, they occasionally cut each other at right angles. In fact, they are inexplicable in terms of simple normal erosion, and one can explain them only as glacial meltwater drainage channels. Along with a few erratics, which are in some cases quite massive, these channels are the most obvious traces of a former glaciation, whose great age is attested by the fact that the fluvial forms are blurred by solifluction. Fyles (1965, p. 4) also observed on Prince Patrick Island a topography for which a morainic origin is a possible explanation, and also hills resembling kames, and two gravel ridges which seem to be eskers.

Numerous ponds dot the upper parts of the valleys. Some are due to solifluction which carries down into the bottoms of the valleys great quantities of pebbles, which are too large to be washed away by the stream. Since they can not be carried away by the running water, they accumulate, and eventually produce local reverse slopes. Others result from the blocking of the valleys by pingos; and still others, in this case of a temporary nature, are occasioned by snowbanks. When the outflow from a small lake produced by the blocking of a valley by a snowbank occurs by way of an outlet not located across the snowbank, the latter obviously will not be incised markedly by the meltwater, and as long as the snow persists, such a small lake may no doubt persist for several years.

To complete the description, one should add that the plateau is developed on the sands and gravels of the Beaufort Formation. Frequently, a certain percentage of finer sediments is present in these sands, and it is this fine fraction which permits the development of the solifluction phenomena discussed above.

Figure 2 is drawn from aerial photographs, and shows the distribution of pingos I have identified in this area. From it, one can see that the mounds are very numerous, totalling over 130, and that they are grouped in two WSW-ENE alignments, over 15 km in length. These very clear alignments, separated by a zone over 2 km in width without a single pingo, are in no way related to the topography. They extend in a direction peculiar to them alone, without regard to the relief, and the pingos which constitute them are located randomly on the summits, in the valley bottoms, and on the slopes.

In 1965 I traversed this area for a week with W.S.B. Patterson of the Polar Continental Shelf Project; he assisted me enormously in carrying out these measurements, and together we sought at length for clues as to the origin of the forms. The average diameter of the seventy pingos we measured in the field is 59 m, and their average height is 3.3 m. These, then, are generally features of quite small dimensions; the smallest mounds studied are only one metre high and 20 m in diameter; the largest attains a diameter of 250 m, and a height of 13 m.

Generally, these mounds have an approximately circular plan view (Fig. 3); the few pingos whose outlines differ markedly from a circular shape are due to the coalescence of several distinguishable circular mounds.

The smallest formations frequently have a lens-shaped appearance, or that of a flattened dome (Fig. 4a). Sometimes a more pointed summit occurs at the top of this dome. The medium-size forms often have the appearance of a truncated cone (Fig. 4c and 4d). As for the largest mounds (Fig. 5 & 6), they generally present an irregularly mammillated appearance, for they are dotted with summits, whose arrangement, seen in profile, seems to indicate the presence of a central crater (Fig. 4e & 4f). Finally, the mounds produced by the juxtaposition of two, three or four individual circular forms, have a variable form, as a function of the arrangement of the units composing them (Fig. 4g).

On the ground, these different types of pingos are not generally scattered at random. On the contrary, they are most frequently grouped in categories, depending on their complexity.

Numerous pingos were examined in detail, with a view to studying signs of present-day evolution. They are always covered with sands and gravels. Frequently, pebbles form a type of surficial pavement, which, however, does not entirely obscure the underlying sands. The pebbles situated on these mounds are often covered by black lichens, an indication of a certain age, and of a certain stability. Elements displaying an eolian polish are rather rare; wind-facetted pebbles are completely absent. This appears to be generally the case on Prince Patrick Island, even where sands are abundant. Eolian effects appear to be weak because of the infrequency of strong winds (Pissart, 1966).

Slight trench-like forms with a depth of 10 to 20 cm form a network of polygons on these pingos; their diameter frequently reaches 20 m. The pebbles are most numerous in these trenches, piled on top of each other, as if their accompanying sand had disappeared downwards. Occasionally, smaller polygons of about 5 m in diameter fit within the previously-mentioned ones, and in their case, the demarcating fissures are shallow and less distinct. The persistence of these features on steep slopes, which occasionally reach 20°, and the absence of lichens on the edges of these polygons, where there appears to be a certain downwards movement towards the centres of the trenches, indicate that these structures are evolving at the present day. We shall see later, in the description of sections which were observed, that these are ice-fissure polygons, partly filled with ice, and partly with an entirely mineral fill.

As mentioned earlier, the form of the largest pingos is frequently irregular, since relatively sharp summits give them a mammillated appearance. Often, these forms are associated with small depressions, one to three metres in diameter, and reaching a depth of 50 cm. It appears that this association of forms is the result of the onset of the melting of an underlying ice mass, the central core of the pingo. While this interpretation appears self-evident in the case of the closed depressions, it requires some elaboration with regard to the sharp summits. Three arguments may be advanced in favour of this point of view:

(a) As already pointed out, these secondary summits are associated with the closed depressions.

(b) Identical mounds have been observed near Satellite Bay, on pingos which are indisputably undergoing melting (see Fig. 12).

(c) The few exposed sections appear to indicate that while a regular stratification parallel to the surface may be observed on the outer slopes of the pingo, this is frequently disrupted on the site of the irregularities present in its centre, as if it were the result of subsidence of this area.

The slopes of these pingos are generally less than 20°, and are thus in every case markedly less than the angle of repose for these materials. The gradients are steepest where late-lying snowbanks persist, and the steepness of the slopes here is clearly the result of nivation.

In conclusion, the appearance of the slopes of these pingos does not differ from that of the slopes of the neighbouring valleys; the same tundra polygons occur on them, and these slopes generally have an angle of less than 20°. The steeper slopes are the result of the effects of nivation. The melting, which has left traces in the landscape, does not appear to be occurring at present, or, at least, if it is, it is so slow that it is not apparent on the surface. In short, the current observations produced no clear signs of present-day evolution.

However, Fyles has indicated one pingo (No. 1 on Fig. 2), which appears to show traces of present-day development. Belonging to type B in Figure 4, it displays a fairly sharp summit above a general lens-shaped form. This summit is devoid of lichens, and this fact would suggest a recent evolution. The observation is not, however, entirely conclusive. The greatest slope on this pingo does not exceed 20°, and thus does not substantiate a more rapid evolution. The presence of a sharper summit, where snow cover is entirely absent during winter does not encourage the preservation of lichens. Finally, this pingo is isolated in the centre of a very level area, and makes an excellent vantage point. It was covered with numerous caribou tracks. These animals, by turning over pebbles with their hooves, certainly help to explain the scarcity of lichens on this summit. Altogether, these observations do not supply sufficient proof of present-day growth in these pingos.

Section Through a Pingo (Figure 7)

Between 16 and 23 July 1966, a section in pingo II (Figure 2), was excavated by means of a pump. This pingo, located on the summit of a hill, was chosen because it offered conditions favourable to the use of a pump, i.e. a sufficient gradient, and proximity to a small lake temporarily dammed by a snowbank.

The principal feature is the presence of a continuous mass of ice at a depth of between 1.2 and 3.0 m. This is generally pure transparent ice, composed of crystals 0.5 to 2.0 cm in length, without any preferred orientation. I believe this to be the actual ice core of the pingo.

This ice core has raised the sand-and-gravel beds of the Beaufort Formation, with slight accompanying deformation. These deposits, which are well stratified and which include much wood debris, appear to be in situ. At first sight, the ice mass appears to follow a bedding-plane. A more detailed examination shows that this is not the case; it truncates the overlying beds. In only two spots, and in each case for a length of not more than one metre, thin beds of clay, about 0.5 m thick, occur near the ice. Elsewhere, the sands and gravels lie directly upon the ice.

At the point marked 5 on Figure 7, the ice shows different characteristics. It presents the appearance of vertical stratification; inclusions are much more numerous, whence its white colour, and it is penetrated in its upper part by fine vertical lines of sand. This is an example of an ice wedge, which corresponds at the surface to one of the slight depressions which form the polygonal network described earlier. Next to this ice wedge, the beds are badly deformed and form a pinched-out syncline, no doubt related to the growth of this structure.

The outer slope, which in fact comprises the side slope of a valley, is composed of reworked sands and gravels which have moved down the slope. At point 3, a large block which I believe to be an erratic since it appears too large to be carried by the stream which might have transported the Beaufort Formation, seems to indicate that this slope deposit has a thickness of almost 1.5 m.

In the upper part of the section, several sand and gravel wedges occur. They do not exceed 1.2 m in depth, while their maximum width is 0.6 m. These structures are developed in the "active layer" of the soil, and do not include ice. These appear to be forms similar to Péwé's sand wedges (1959) or to the ground veins of the Russian authors (Dylik, 1966). There is very distinct sorting within these wedges. The smallest elements descend more rapidly into the fissures than the largest elements, the fissures appearing each year due to the thermal contraction of the soil. The presence and simultaneous development of both ice wedges in the permafrost, and sand and gravel wedges in the active layer, appear capable of explanation with reference to the difference in ice content, which would permit the overlying layer, as a result of its lesser cohesion, and lesser thickness, to open into a network of polygons of a smaller mesh than those separating the ice wedges (Pissart, 1967).

In another pingo (III in Figure 2), another section was excavated. It did not exceed a depth of 2 m, and did not reach the ice core of the pingo. Here too, wedges of sand and gravel transected the "active zone" in a similar fashion.

Interpretation, Genesis and Age of the Pingos

The following is a brief résumé of the principal points for which any explanation of the genesis and age of these pingos must account:

(a) Their arrangement in two parallel lines, related to neither topography, nor to hydrography, nor even to any structure visible on the surface.

(b) Their apparent present stability; apart from one dubious case, there appears to be no movement at present.

(c) Their often considerable volume: the largest of these pingos has raised a mass of more than 150,000 cubic metres (m^3) above the ground surface. If this mass is derived from the increase in volume resulting from the freezing of water in a closed system, the quantity of water which produced it, would have to be nine times greater, i.e. would have to approach 1,350,000 cubic metres (m^3).

(d) An age younger than the major glaciation which covered the island, for they are located in some cases, in the channels carved out by the melt-waters from that ice mass.

Quite indisputably, these pingos are not forms resulting from phenomena occurring wholly in the very uppermost part of the ground. The total absence of any relationship with surface features definitely establishes this. It is certain, moreover, that their alignments are due to some geological structure, but the latter must be at depth. It may involve either clay beds within the Beaufort Formation, or a deep geological structure located beneath that formation. The first hypothesis is unsupported, while, in contrast, the second one finds certain support in Tozer and Thorsteinsson's geological map. Indeed this map, which I have reproduced (Fig. 1), shows that the substratum has been affected by faulting. While almost all of these faults have a north-south alignment, which does not correspond to the orientation of the lines of identified pingos, there is, however, a further localized orientation of pingos near Landing Lake, which seems to be apparent in the continuation of the southern series of mounds. It would appear possible from this, that the two observed alignments delineate the lines of faults concealed beneath a thickness of almost 50 m of the sands and gravels of the Beaufort Formation.

If it is admitted that the pingos are related to faults affecting the bedrock, two hypotheses may be invoked to explain their evolution. The first involves the possibility that the faults have permitted access of water from depth; the second that the faults determined the presence of geological traps, holding captive in the sands of the Beaufort Formation a water mass, which, on freezing in a closed system, produced the observed intrusions.

The first of these hypotheses, the movement of water from depth through the permafrost by way of these faults, is a priori very acceptable. The thickness of the overlying Beaufort Formation makes it understandable why the alignment of the pingos should not be perfect.

Moreover the dimensions of the pingos I observed correspond very well to those of pingos resulting from the upwards movement of water from the lower part of the permafrost; according to Shumskii (1959) this type of form reaches 10 to 12 m and occasionally even 15-17 m in height. However, he emphasizes that this type of ice injection mound occurs only on the margins of the permafrost zone, where the permafrost is relatively thin. Now, when it is remembered that on nearby Melville Island, the permafrost is over 500 m thick, and that it is probably of equal thickness here, this hypothesis loses its appeal. It is extremely unlikely that the water could have made its way through such a thickness of frozen ground. It would, moreover, be completely unfounded to postulate that the permafrost might be thinner here, because there is nothing to lead one to think that the geothermal gradient might be steeper locally.

If it is accepted that the present thick permafrost indeed constitutes a barrier to the movement of water from depth, one is forced to the conclusion that these forms developed prior to the appearance of that barrier, perhaps at the beginning of the Wisconsin. There is indeed nothing to contradict the view that these pingos may be very ancient. It is possible that it may have been the development of the permafrost itself, as in the Mackenzie type of pingo, which controlled the appearance of closed cells, and which consequently provided the necessary pressure to impel the water towards the surface. In this case, the alignments would correspond to 'traps' in aquiferous beds, which might also be related to the presence of the faults discussed earlier.

Only geophysical research, aimed at establishing any relationship between the structures at depth and the observed alignments, appears likely to disclose new clues which might result in furthering knowledge of the genesis of these pingos.

It must be acknowledged, moreover, that an explanation involving the development of such forms as the result of the initial cooling of the climate, has already been proposed by Leffingwell (1919, p. 154) for pingos in Alaska.

In all respects, the location of these pingos on the summit of the island, far from any lake, means that quite indisputably, they belong neither to the Greenland, nor to the Mackenzie type.

THE PINGOS SITUATED CLOSE TO SEA LEVEL NEAR SATELLITE BAY AND INTREPID INLET

Pingos of an entirely different type were observed near two bays, located at points 2 and 3 on Figure 1, and situated one in the northwest of the island at the head of Satellite Bay, the other in a secondary inlet off Intrepid Inlet. In both cases, these pingos have developed at an altitude very close to the present sea level, and surrounded by alluvial deposits. Their genesis is related to their position. It is thus necessary to describe the geomorphological complexes in which they are located.

Satellite Bay

As can be seen from Figure 8, which illustrates part of the feature, an extensive "glacis" stretches eastward from Satellite Bay for an average distance of two kilometres. Its length has been traced from the northern extremity of the bay for a distance of more than 10 km; it thus continues for almost a further 5 km beyond the limits of Figure 8. We are thus dealing with an outwash plain, slightly concave in profile, which is continued uphill by wide dry valleys. Its gradient generally varies from 0.6° at the top to 0.3° at the bottom. This decrease in gradient is accompanied by a decrease in the dimensions of the pebbles covering the surface. The maximum length of the coarse elements decreases progressively from 20 cm at Y on Figure 8, to only 8 cm at X on the same figure, only 1.5 km downhill. Similarly between V and W, the maximum dimensions of pebbles decreases progressively, and the median of five measurements of centile undertaken on the surface every 200 m, produced the following results: 12.5 cm, 12.5 cm, 11.5 cm, 11 cm, 10 cm, 8.5 cm, 6 cm, 7.5 cm, 4.5 cm. Elsewhere on this glacial outwash plain, too, this general decrease in the size of the coarsest elements occurs, but it is much less regular, in that the contributing effects of the slopes result in the disruption of the pattern. Moreover, local interlockings of different surface levels occur, as for example, in the case of area T, which lies at a lower level, with respect to the surfaces located on either side.

Moreover, the "glacis" assumes the general aspect of a low-angle cone at the mouths of the upstream valleys; this appearance is emphasized by the tundra polygons. The latter produce a quadrangular effect, in that their sides follow two directions: one group is aligned in accordance with the line of maximum gradient, and thus assumes a radial pattern; the others more or less follow the contours, and thus outline segments of a circle, centred on the mouth of the valley.

This large "glacis" is inexplicable in terms of normal erosion. The catchment area of the valleys debouching upon it is extremely small, their length upstream generally not exceeding 2 km. Moreover, the watershed of the island is quite close, approximately 4 km to the east, and due to this fact, no river capture or drainage change can be envisaged to explain the large volumes of water of which evidence is found here.

For these reasons, it is contended that this large "glacis" is a glacial outwash plain, produced by a major glaciation from the east, which brought numerous erratics to Prince Patrick Island. This glaciation must date from an early period, however, for the outwash plain is deeply incised by the courses of numerous streams, often of quite a small volume.

The surface of this fluvioglacial deposit continues downstream right to the present coastline. At this point, it ends at about 12 m above sea level in characteristic deltaic deposits, in which foreset beds are well displayed. The heights of 10.7 m, 13.8 m and 12.0 m correspond to the crests of the seaward extremities of the "glacis" where foreset beds are displayed, at points A, B, and C on Figure 8. It was impossible to establish whether these variations were the result of a sea level change during the development of the fluvioglacial deposit.

These observations of deltaic deposits, repeated at four locations, spaced along a 4-km stretch of the bay, clearly establish that the sea level must have stood at a level close to +12m, at the time of glacier retreat. Two lakes, each several hundred metres in length, occur on this "glacis"; one is visible on Figure 8, and both appear to be quite deep. Their explanation is a difficult matter. They cannot be explained in terms of later erosion, and they must be due either to blocks of dead ice, or more simply, to areas which were not entirely overwhelmed by the formation of the fluvioglacial deposit.

A lower series of deltas occurs at about 3.5 m above sea-level; they were observed at six points, of which three are indicated on Figure 8, at heights between 3.25 and 4 m. A certain number of low terraces occur in the lower part of the valley where the pingos to be discussed next are located; these correspond to one or several sea levels between 2.5 and 3.5 m. The surface of these terraces is irregular; it is disrupted by ice wedge polygons to such an extent that it was difficult to decide with any certainty, whether they all corresponded to the deltas located at a height of 3.5 m, which have just been mentioned. Since such a relationship is very probable, however, both the deltas, and the terraces at 3.5 m, have been represented in an identical manner on Figure 8.

Description of the Pingos

The pingos located at the head of Satellite Bay are relatively few in number. Differences in their appearance, visible in Figure 8, allow them to be grouped into 3 categories: round, oval, and very long pingos may be distinguished according to their plan. There also occur remnants of pingos which have completely, or almost completely thawed; their original form is sometimes difficult to reconstruct.

Only one pingo presents a completely classic conical form, with a depression in its summit, which from its position, resembles a volcanic crater. Its dimensions are quite limited, however, since this mound is only 50 m in diameter, and only 3 m high (Fig. 9).

Two slightly higher mounds (6 to 7 m), which display comparable depressions in their summits, are oval in plan. They constitute a transition to the very elongated pingos which are the most important forms which were identified. The largest of these forms has the appearance of a long ridge comparable to an esker (Fig. 10). It attains a length of 1300 m, while its width is variable, but generally lies between 40 and 70 m, and its height does not exceed 8.75 m. It differs in external appearance from an esker, in that its central portion is occupied by a depression, aligned along the major axis of the mound (Fig. 11). It was this axial depression, an indisputable sign of thawing, which permitted the recognition of this form on the aerial photos as a type of pingo; this interpretation was confirmed, as described later, by the exposure at two separate spots of the ice core. Locally, this thawing pingo displays not only a central depression, but also mammillated relief (Fig. 12), which resembles that of the large pingos on the summit of the island (Fig. 5).

Apart from these signs of melting, this long pingo is incised by transverse valleys which cut this ridge at right angles to its major axis (Fig. 10). They are the work of water flowing down from the nearby terrace. There is no evidence to indicate whether this erosion occurred simultaneously with or after the appearance of the pingo.

Near these melting forms, and still conspicuous in the surrounding topography, there occur pingos in a much later stage of evolution; only a few traces of these remain. They are concentrated on the left bank, and their common identity with the other structures can be established largely from the very steep, almost vertical appearance of the stratification on either side of an almost imperceptible central hollow. The part of the ice core situated beneath ground level is situated in the permafrost, and has not yet melted probably because of this fact. From this is derived the difference in appearance between these forms and the relict pingo traces known from Europe.

Location of the Pingos in the Topography

All the observed pingos are located beneath the level of the presumed glacial outwash plain. They occur either on the lower terraces described previously, or else perhaps in the present alluvial plain. The circular, volcano-like pingo rises from a terrace lying at 3.1 m above the river, while the very long pingo, for the major part of its length, is in immediate contact with the present alluvial plain. At several points, moreover, it is being vigorously eroded by the river.

From all observations, it is impossible to determine whether some of these forms developed in the present alluvial plain, or whether they were all formed on the low terraces. The topographic forms do not permit a statement as to whether there are two generations of forms developed at different levels, or simply a single group of pingos, all of the same age. The assembled facts would suggest, however, that two distinct assemblages exist, one comprising well preserved forms, located close to the present river, the other comprising almost completely melted structures, which are distributed mainly on the left-bank terraces

Observed Sections

Numerous sections were observed in these pingos. Many of these were exposed by digging (here the assistance of Leif Lundgard in 1965, and of Raymond Richard in 1966 is acknowledged); these showed only the upper 60 cm of the soil, the depth of the thawed layer at the time of the visit to the area, at the beginning of August, 1965. Two more important cuts have been excavated by the outflow from lakes located on the summits of pingos. The flow was increased artificially by digging a small channel, allowing flow to begin. Two further larger cuts were produced by means of a pump in 1966. These sections exposed the injected ice, and confirmed that the dip of the beds is extremely steep on the slopes of the pingos. This inclination of the strata on the flanks is quite widespread. It was verified at numerous spots, because the steeply dipping beds outcrop on the crests bounding the central depressions produced by thawing. Thus it is possible to follow the upright beds, and to identify the structure of the pingo. This structure is not always simple. Indeed, sometimes the pingo is constituted not by a lens of ice of simple form, but by a mass of ice displaying apophyses, as indicated in Figure 13.

The best of all the sections examined was the result of lateral erosion by the river. Figure 14 illustrates the profile observed in 1965, and located on Figures 8, 10 and 11 by the letter M. This section revealed the structure of half of the longest pingo, for it extended transversely from the outside of the mound to its medial depression. In 1966, a section was also excavated in the other half of the pingo, and thus exposed the complete transverse profile of this structure, presented in Figure 15.

The Ice Core

Preliminary observations showed that the central depression corresponds to an ice mass. This is composed of crystals attaining a length of 2 cm; these are clearly visible to the naked eye, by virtue of the different orientation of gaseous intrusions, which are particularly numerous. These crystals present exactly the same appearance as the crystals in the intruded ice which Fritz Müller (1959, Fig. 15b) observed in a pingo in Greenland. Because of the multiple gaseous inclusions, the ice is generally whitish in colour; locally, however, the ice contains fewer inclusions, and hence is much more transparent. The external portions of the ice mass, in contact with the bounding vertical beds, displays, for a width of 1.5 m on one side, and 3.0 m on the other, a stratification parallel to those beds (Fig. 16). Proceeding from the outside towards the centre, this stratification is due, for the first 50 cm, to generally very fine sandy layers, and further in, to a reddish coloration of the ice, produced by deposits of iron oxides. These iron oxides are particularly abundant in the upper part of the ice core at the contact between the ice and the overlying deposits, where they appear to be accumulating as melting proceeds. Elsewhere, they are easily explained by the precipitation of the oxides contained in the water at the point of freezing (Cailleux, 1964; Ek and Pissart, 1965). This stratified appearance is a local appearance and has not been found elsewhere. It testifies to the slow growth of the ice core early in its formation by the advent of successive small quantities of water.

A thin vein of markedly different ice, in which the crystals are oriented perpendicularly to the stratification, detaches itself from the left extremity of the main ice mass, and penetrates obliquely into the surrounding clay. This is probably an example of ice segregation.

On the right, the ice mass includes two beds of sand disposed parallel to the stratification of the uplifted formations and appearing to form part of them.

As noted previously, an ice core identical to the one described above was observed right in the centre of each of the mounds studied, wherever a sufficiently deep section could be excavated, i.e. in five different spots. These observations prove without a shadow of doubt that the central depressions of the mounds examined are due to the melting of the ice core.

Material Surrounding the Ice Core

The stratified material pushed up by the ice core consists principally of sands and gravels. However, the closer to the ice core itself, the finer the sediment, to the point where it is quite distinctly clayey at the actual contact. It should be borne in mind that P.A. Shoumsky (1955, p. 121) has indicated that injection ice normally appears at the contact between permable and impermeable beds, as is the case here. Variations in colour accompany the grain size changes, for with the appearance of the fine fraction, the beds become increasingly dark, with a very dark bluish tinge replacing the yellow colour of the sands.

These general variations in grain size and colour, readily apparent when the entire section is considered, are not visible when only a part of it is examined. Indeed, in detail, the lighter and darker beds alternate without any apparent order. It should be added that the dark-bluish beds become brown on exposure to the air, and that this dark colour was thus only observed as a result of excavation into the permafrost. Microscopic study of a prepared section from these sediments showed that the dark colour of the deposit is due to the presence of organic substances which are frequently identifiable (pollen, moss fragments, etc), which since the time of deposition have been completely protected from oxidation or alteration. The clay beds overlying the ice include outer shells of marine foraminifera very similar to those existing at present in the Arctic. The species observed (Bucella Frigida, Spiroplectammina Biformis, Elphidium Incertum, E. Orbiculare, Asterellina Pulchella) are typical coastal forms from shallow water environments. The study of the foraminifera contained in my samples was very kindly undertaken by G. Vilko of the Bedford Oceanographic Institute (Dartmouth, Nova Scotia).

Wood debris also often occurs within the sandy beds. This material has been reworked from the Beaufort Formation, which contains large amounts of wood. It provides no indication as to the age of the enclosing sediments. These deposits of sand, gravelly sand, and clay are very well bedded. Locally, they present a characteristic intersecting stratification. As these beds have been deformed, however, it is difficult to reconstruct their original appearance. The beds at present display a dip varying from 80° to 40°.

Ice wedge cracks occur at both extremities of the section. On the left, an ice wedge 50 cm in length, gives a false impression of widening in its lower part, as a result of the warping of the profile. On the right, several ice wedge cracks filled with sand and ice were observed. Above these structures, the appearance of the material is very complex. Assorted masses of sands and gravels appear to have reached their present position there by downward movement of overlying material. This phenomenon no doubt was produced when, following erosion of the pingo, the upper parts of these ice wedges came within the active zone and melted. At the heart of this material, 1.5 mm (sic) from the present surface, organic debris was found, which has been radio carbon dated at the Geological Survey of Canada laboratory (Sample No. GSC 854). Its age is 7090 ± 150 years. In view of their position, these organic remains appear to be very much younger than the pingo itself.

Finally, slope deposits with poorly defined bedding occur on the outer parts of the pingo; on the right, these cover the confused mass in which the dated organic debris was found.

Interpretation

On this description, the following general interpretations can be based:

(a) The uptilted strata represent a continuum of originally horizontal marine and fluvial deposits. These do not represent the substrate, i.e. the Beaufort Formation, but are sediments laid down by the river.

(b) These beds were pushed up after their deposition, and a simple geometrical reconstruction permits the observation that the oldest beds were originally deposited at a depth at least 10 m beneath the present river bed.

(c) The oldest beds of the series, i.e. those now located closest to the ice core, are composed of fine sediments, deposited in calm water, and are of a marine origin, as testified by the study of the foraminifera.

As already indicated, the very elongated form of the main pingo is unusual. Few authors have described pingos of this type. The earliest known article mentioning similar forms, is that of Porsild, who in 1938 spoke of very long pingos, elongated parallel to the line of maximum slope in the Seward Peninsula of Alaska. Stager (1956, p. 15) and J. Ross Mackay (1962) have also indicated the occurrence of pingos similar to eskers in the Mackenzie Delta. Finally Lewis (1962) has recently described a small elongated pingo developed in the alluvial plain of a river in Alaska, in the journal "Arctic."

The elongated form of these pingos has not been explained until now, and nothing in the literature could possibly account directly for the Prince Patrick Island forms. Several hypotheses are plausible, but none is absolutely certain. At first sight, it seems probable that this long pingo might correspond to a former course of the river. The present observations, however, do not permit a complete elucidation of the circumstances which gave rise to the pingos just described. Two separate hypotheses could be defended; they are proposed below.

The first lies in the interpretation of the beds uplifted by the pingos as fluvial and marine formations deposited prior to the development of the glacial outwash plain, which levelled off the area where the pingos are located at a height of approximately 12 m above present sea level. These formations are definitely not glacial outwash plain deposits, for the centile is much smaller, and is comparable to that of the present alluvial material in the stream. In this case, these formations, segregated from the fluvioglacial deposits just mentioned, were simply uplifted by the growth of ice injection mounds, and supply no evidence as to the conditions which preceded the appearance of these forms. The genesis of the pingos would thus be as follows: following the lowering of sea level, the valley, the terraces and the present alluvial plain would have been formed. Warmer climatic conditions, and greater nourishment of the stream would have permitted superficial thawing of the permafrost beneath the bed of the river to a depth of several tens of metres. With a drop in temperature once again, the permafrost would reinvade the thawed zone and imprison a closed cell of saturated sands within the frozen ground. This would give rise to the injection of the water towards the surface, by the same mechanism as that in the Mackenzie Delta pingos.

This first hypothesis seems implausible. The stream at present flows for scarcely more than a few weeks per year, and is completely incapable of thawing the permafrost. A major climatic amelioration would have been necessary before the flow of this little stream could last long enough each year to permit such a thawing of the ground. This thawing, moreover, would have had to extend to a depth of several tens of metres, to account for the volume of saturated sand, which on freezing, has produced the mass of the pingos.

The second hypothesis appears more feasible although it is recognized that the objections formulated are insufficient to definitively invalidate the first hypothesis. The second hypothesis is as follows. It involves the recognition in the beds uplifted by the pingos of deposits which filled an inlet of the sea, or more exactly, a ria, the invasion of which by sea water had previously resulted in the thawing of the permafrost. Subsequent to the fashioning of the glacial outwash plain, which had levelled everything off at a height of 12 m, erosion would not only have continued down to the level of the present alluvial plain, but would also have excavated a valley to greater depth, related to a sea level lower than at present. The uplifted formations would correspond to the infilling of the inlet, which had been produced by a subsequent positive movement of sea level. Beneath this ria the permafrost would obviously have thawed completely or at least partially thawed.

In other words, this hypothesis involves the following stages:

(a) The fashioning of a glacial outwash plain, levelling the area where the pingos occur to a height in excess of 12 m.

(b) Lowering of sea level by about 10 m to beneath the present sea level, and dissection of this outwash plain with reference to this base level.

(c) A later rise in sea level, bringing it to its present position, and creating a ria. The penetration of sea water into the lower part of the valley would result in the thawing of the permafrost there, or at least partial thawing.

(d) Infilling of the ria and the re-establishment of frozen ground. The progress of the latter controls the imprisoning of a mass of water-saturated sands between the thick permafrost and the surficial frozen ground.

(e) The freezing of these saturated sands resulting in the injection of water under pressure towards the surface by the same mechanism as that which produced the Mackenzie pingos.

This hypothesis would explain the grain size variations observed in the formations in the upper part of the pingo. It also appears to derive considerable support from the limited extent (see Fig. 7) of deltas at present debouching into Satellite Bay. Indeed it is surprising to note that the downcutting of more than 10 m by all the rivers of the glacial outwash plain, should, in this almost tideless bay, have produced deltas which, even in the case of the main rivers, reach only a few hundreds of metres in size. There is a discrepancy between the volume removed and the mass deposited, which would appear capable of resolution only by postulating the existence beneath present sea level of more extensive submerged deltas.

This hypothesis is supported further by the occurrence of identical pingos near Intrepid Inlet, some 100 km away. They appear capable of explanation only in terms of a similar development.

INTREPID INLET

Ninety-five kilometres southwest of Satellite Bay, in a bay opening off Intrepid Inlet (point 3 in Fig. 1), there occurs a further complex of pingos, which present great similarities to those just described. The similarities include the location of the pingos in the midst of a terrace complex situated at the mouth of a stream, and also the fact that these pingos have appeared at the level of the present alluvial plain, i.e. at an altitude very close to sea level.

Figure 17 illustrates better than a long description the location of these forms and stresses particularly the occurrence of an elongated pingo similar to those found near Satellite Bay; it has a complex form, and is being undercut by lateral erosion by the river, which has completely destroyed it in some places.

The sections excavated proved that this elongated mound was indeed a pingo for, as indicated in Fig. 18, here also an ice core occurs beneath fine, blackish sandy deposits, comparable to those found near Satellite Bay. These deposits testify to sedimentation in calm water, either in a lake or in the sea. Just as near Satellite Bay, these fine deposits are blackish in the permafrost, but become brown when they are exposed to the atmosphere. Here there occurs a 30-cm layer of sands and gravels between the ice and the fine material. No foraminifera tests were observed in these blackish beds, however. The sand/gravel deposits covering these fine beds are indisputably fluvial in origin.

The disposition of the strata is in general identical to that observed in the surveyed profiles near Intrepid Inlet; the stratification is almost vertical near the ice core. The syncline observed in the section illustrated in Fig. 18 is a unique occurrence, which has not been found elsewhere. At the summit of the highest part of the pingo, there are outcrops of debris from the Mesozoic substrate, reddish blocks of sands and fossiliferous sandstones, whose presence among the fluvial sands can be explained only by assuming that the pingo developed in the underlying secondary rock, and has raised part of the bedrock.

It would appear from these observations that there is here, just as near Satellite Bay, a large pingo which has grown up almost at the level of the present alluvial plain, and concurrent with infilling which followed a period of sedimentation in calm water.

The similarities existing between this pingo and those observed 95 km to the north constitute a weighty argument in favour of the hypothesis that they were produced as the result of sea level fluctuations which affected all the coasts of the island. The terraces lying at more than 10 m indicate the occurrence of a primary phase, during which sea level was higher than at present. Subsequently, a drop in sea level to below the present zero altitude resulted in the incision of the rivers into these terraces. A final eustatic fluctuation, or a final movement of the land, transformed this cove into a ria, and provoked the thawing of the permafrost. The infilling of this ria by the deposition of the fluvial beds which have been elevated in the pingo, allowed the re-encroachment of the permafrost, and the development of a closed system, giving rise to the pingo.

The elongated form of this ice injection mound may very well correspond to the depression which the river would have excavated prior to the rise of sea level. The fact that the pingo does not extend right to the shore could be explained as follows: at the downstream end the ground waters, submitted to increasing pressure, might have been able to escape to the sea through impermeable beds. The pingo thus would not have started to form until this outlet had been closed by the encroachment of the permafrost; alternatively, the occurrence of impermeable beds may in itself have determined the formation of a closed cell, right from the start of the freezing process.

OTHER PINGOS ON PRINCE PATRICK ISLAND

A. — On the other side of the bay from Mould Bay weather station, and 23 km to the southwest of it (point 4 on Fig. 1), there occurs a pingo whose outward appearance permits no doubt as to its identity. This pingo is in a state of thawing and appears as an elongated mound, with a discontinuous longitudinal depression along its main axis. Its morphology is thus identical to those already described from the Satellite Bay and Intrepid Inlet areas. However, its topographic location is different, as can be seen from Figures 19 and 20. It is in fact situated at the foot of an abrupt slope, 150 m in height, on a talus cone. The gradient of this cone lies between 6° and 3°. This pingo is composed of talus of Devonian sandstones and schists, derived from the local bedrock, and is the only one observed which was not composed of sands and gravels. The surface of the mound in fact displays nothing but pebbles and blocks, exceeding 1 m in length in some cases, embedded in a muddy matrix.

The steep gradients of the edges of the central depression, locally attaining 42°, testify to the fact that the melting of the centre of the pingo is either very recent or still in progress. However, there appears to be neither flow nor percolation of meltwater from this mound. On the basis of its location at the bottom of a valley, at the foot of a slope exceeding 150 m in height, this pingo may have been derived from the injection of water under a hydraulic head from the neighbouring relief, and may thus constitute an example of a pingo of the Greenland type. In that case, since it is very unlikely that such a mechanism could develop under the present conditions of very thick permafrost, it seems probable that the development of this mound may be a very ancient phenomenon.

B. — Two pingos, similarly elongated, were observed to the east of the pingos described in the first part of this article, and located 23 km northwest of Mould Bay.

The first one, located at point 5 on Figure 1, stretches along the axis of the valley for several hundred metres; its origin is clearly indicated by the occurrence of a more or less continuous depression along its summit. Its maximum height reaches 10.5 m. The genesis of this pingo, situated as it is along the axis of a major valley probably sculpted by glacial meltwaters, and stretching for several hundred metres, has not been elucidated.

The second pingo is located near the outlet of Landing Lake, 16 km north of Mould Bay. The pingo is about 100 m in length and attains a maximum width of 32 m. Since the ice which created it has almost completely melted, it presents the appearance of a rim, with a maximum height of 3 m, surrounding a central depression.

C. — Finally, several tens of small mounds, resulting from ice injection, occur 60 km north of the Mould Bay weather station (point 6 on Fig. 1), on the crest of the island. To this extent, their location is identical to that of the pingos described at the beginning of this article. These mounds are scattered across the horizontal plateau, which is composed of sands and gravels of the Beaufort Formation, in the zone of indistinct relief where the watershed of the island is located.

These mounds are generally circular; their diameter varies between 30 and 70 m, and their height is always very low; the maximum observed altitude reached only 2.1 m. These mounds are frequently dissected by tundra polygons, and appear on the aerial photos as dark, almost black, patches, due to the fact that lichens are more numerous on them, and cover practically all the pebbles on their surfaces.

The origin of these forms is unknown. No relation to topography was observed, and no alignment could be determined. These mounds occur only in this restricted area of the Beaufort Formation. Their small dimensions make them comparable to "Bugors"*, and one should not exclude the possibility that their origin may be due to the growth of lenses of segregation ice in the occasionally silty beds of this very gentle plateau, where drainage is difficult.

CONCLUSION

This piece of research establishes the existence of at least two distinct types of pingo on Prince Patrick Island, i.e. far north of the Arctic Circle. They belong to

* Ed. Note: Russian word for "mound" as in peat "mound."

neither the Greenland nor the Mackenzie type , and show that the possible varieties of pingos are more numerous than previously acknowledged. This study emphasizes, moreover, that independent of any climatic fluctuation, sea level fluctuations may promote ice injection mounds.

It has not been possible to resolve all the problems posed by these pingos. The main one is that of their age. It may one day be established by radio carbon dating of the organic remains which occasionally occur in the fine beds overlying the ice core.

Finally, this study of pingos has drawn attention to the complexity of sea level fluctuations in this western part of the Queen Elizabeth Islands. The sea was initially at a level higher than at present, since old deltas occur at a height close to 10 m. These deltas accumulated at a time when a large ice sheet covered at least part of the island since, near Satellite Bay, they grade into a glacial outwash plain. If the present interpretation is correct, the sea then dropped to below the present level, then underwent a sharp rise to reach its present level. The latest sea level movement in Prince Patrick Island was thus a positive one, i.e. opposite in direction to that which is occurring in the remainder of the Queen Elizabeth Islands, where the raised beaches are extremely conspicuous. The absence of isostatic uplift seems to indicate that no large Wisconsin ice cap extended over Prince Patrick Island during the course of this final cold period.

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* Shoumsky and Shumskii are different spellings of the same name; the first is a transliteration into French, the second into English.

APPENDIX I.

Mean monthly and mean annual temperatures (in degrees C.) and precipitation at Myggbukta (East Greenland), Tuktoyaktuk (Mackenzie Delta, Canada) and Mould Bay (Prince Patrick Island).

The data for Myggbukta and Tuktoyaktuk were taken from F. Müller (1959); the values for Mould Bay were calculated from the weather station records there.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Precip.(mm).
Myggbukta (Greenland), 73° 30'N., 21° 30'W; (2 m above sea level); 1922-1937.													
-20.0	-20.0	-21.6	-16.2	-6.0	1.4	3.9	-3.1	-1.2	-10.4	-14.6	-17.9	-10.0	220
Tuktoyaktuk (Mackenzie) Northwest Territories, 69° 27' N, 133° 2'W; 1948-1955.													
-28.0	-31.2	-24.7	-17.2	-5.7	3.6	10.5	10.4	3.6	-6.9	-17.1	-26.1	-10.7	185
Mould Bay, Northwest Territories (Prince Patrick Island), 76° 15'N, 119° 21'W; 1948-1965.													
-33.9	-36.0	-33.2	-23.8	-11.4	-0.2	3.3	1.4	-6.9	-17.3	-26.8	-31.4	-18.0	81.

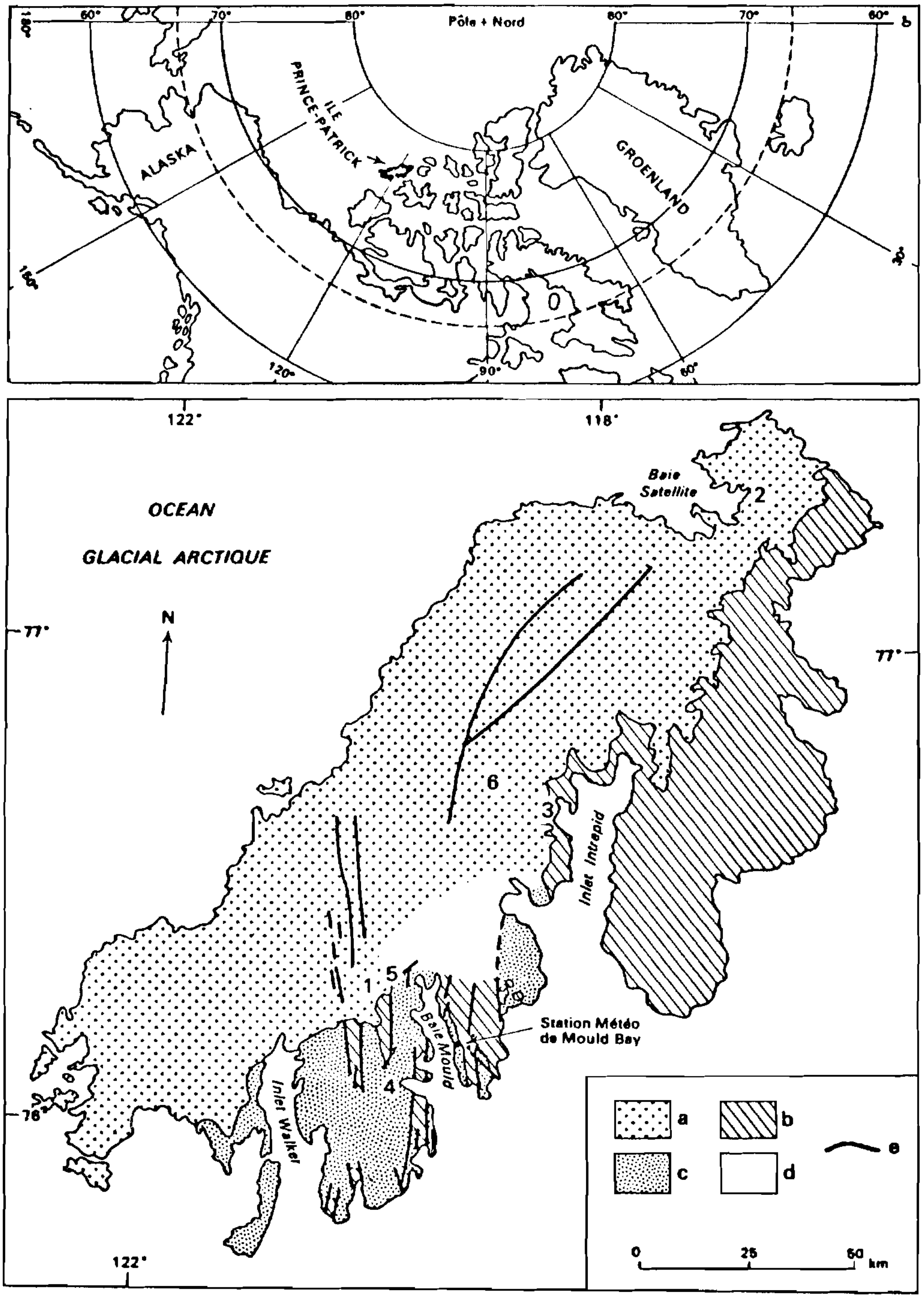

Fig. 1

Major features of the geology of Prince Patrick Island, according to Tozer and Thorsteinsson (1964, Fig. 12)

a) Beaufort Formation (Tertiary or Pleistocene)
b) Pennsylvanian, Permian, Mesozoic and Tertiary
c) Ordovician, Siluruan and Devonian
d) Unknown
e) Faults
1 to 6: Locations of pingos studied

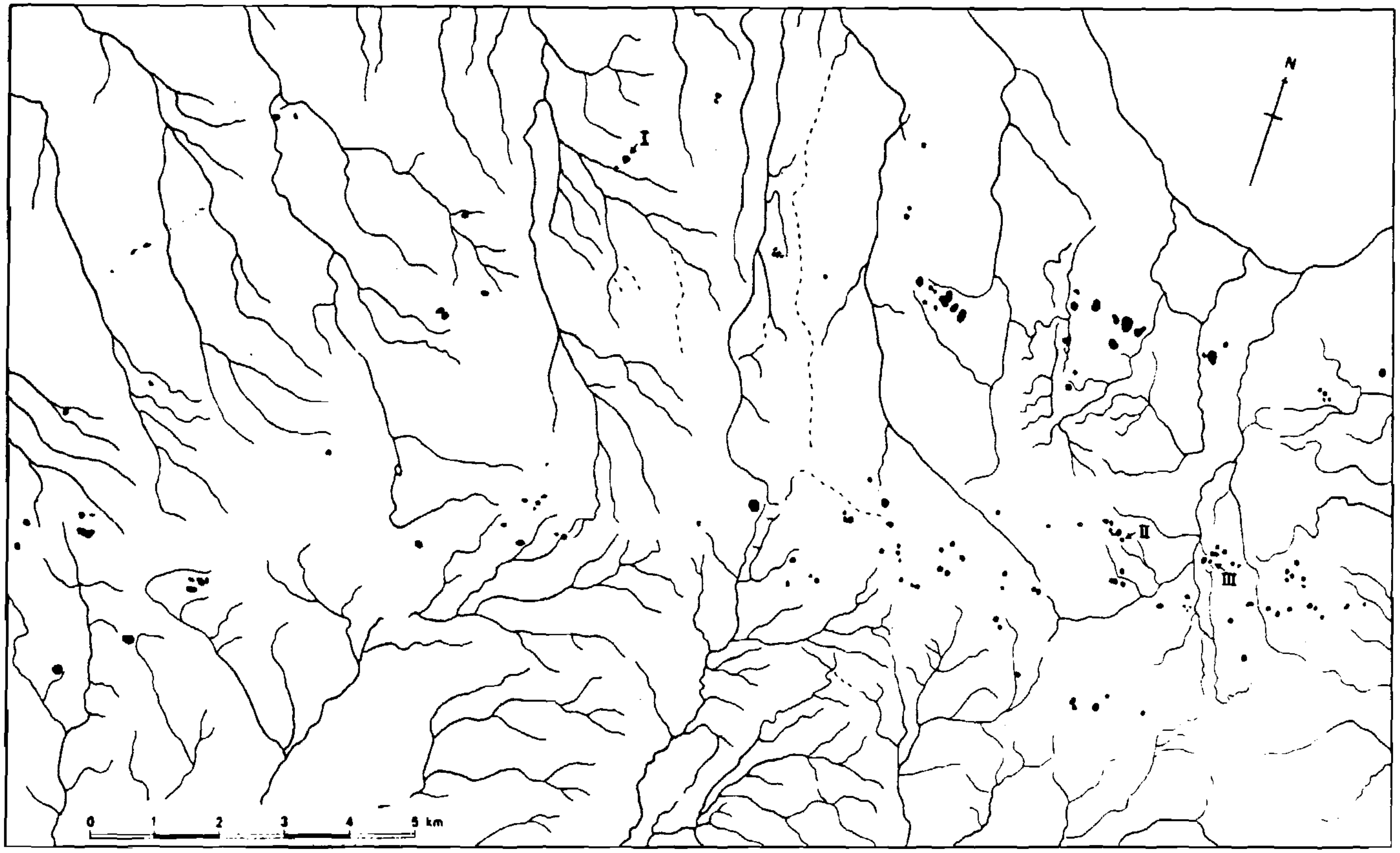

Fig. 2

Pingos identified on the summit surface of Prince Patrick Island, 18 miles (29 km) northwest of Mould Bay. Note their alignments. Map drawn from aerial photographs.

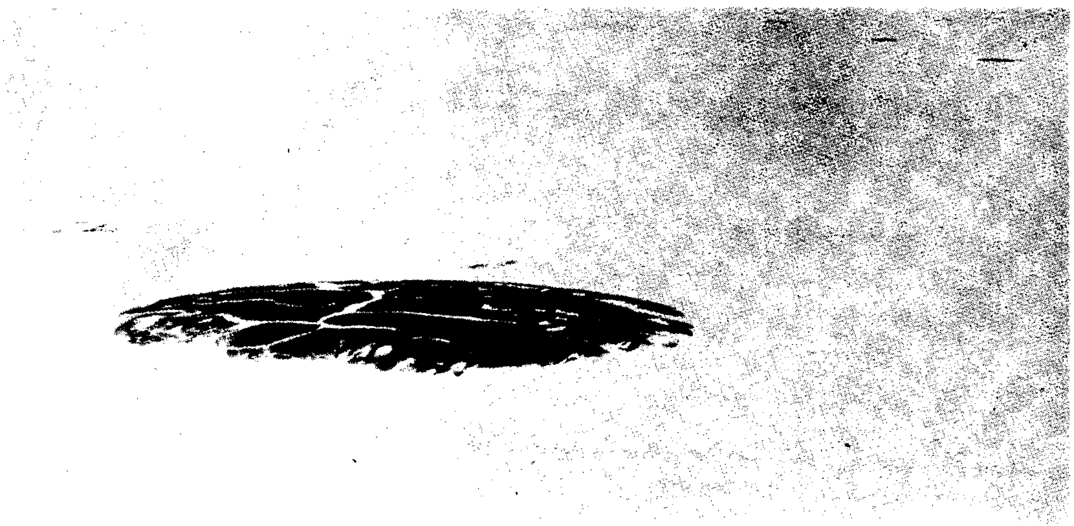

Fig. 3

A characteristic pingo: a circular lens rising slightly (2 m) above the plateau, and standing out clearly at the beginning of June 1965 because it has been completely blown clear of snow by eolian deflation

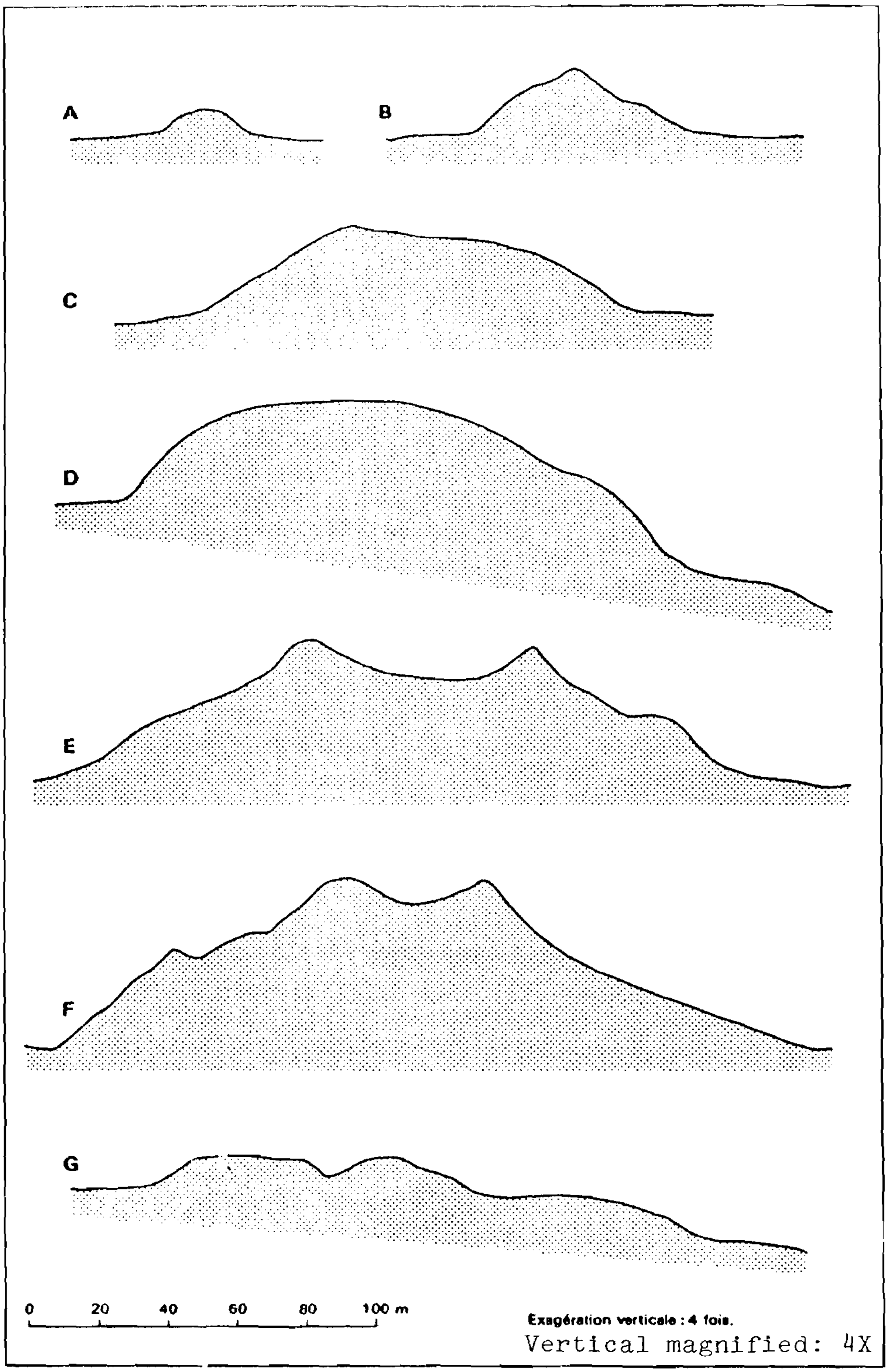

Fig. 4

Profiles of different types of pingos identified on the summit of the island 18 miles (29 km) northwest of Mould Bay. These profiles were surveyed in the field using an Abney level and a metric tape

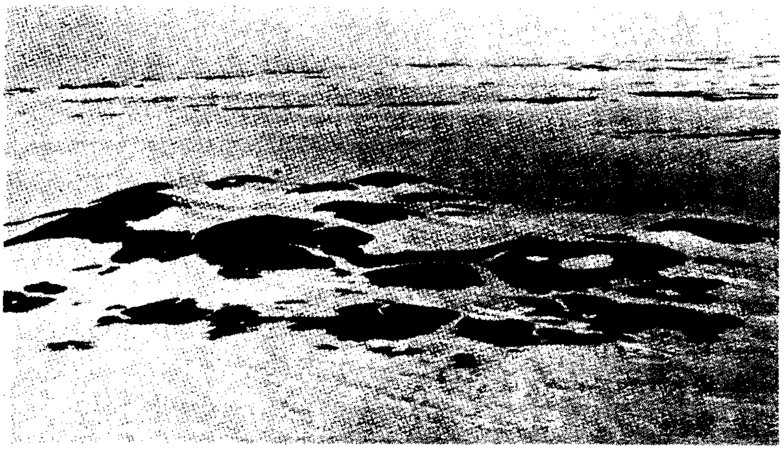

Fig. 5

A large thawing pingo located on the summit of the island, 15 miles northwest of Mould Bay. Maximum height: 11 m; diameter 210 m

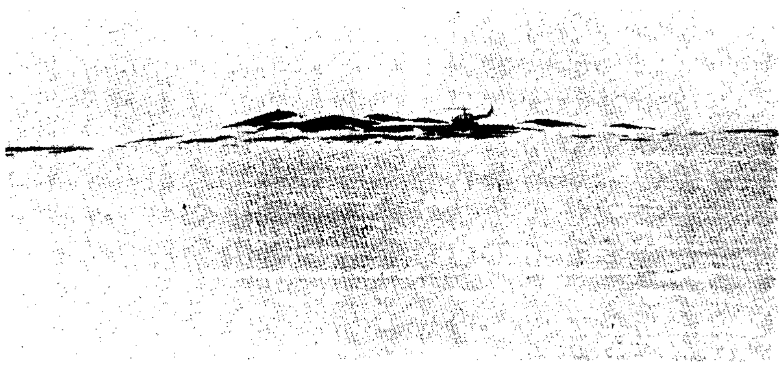

Fig. 6

The same pingo viewed from the air

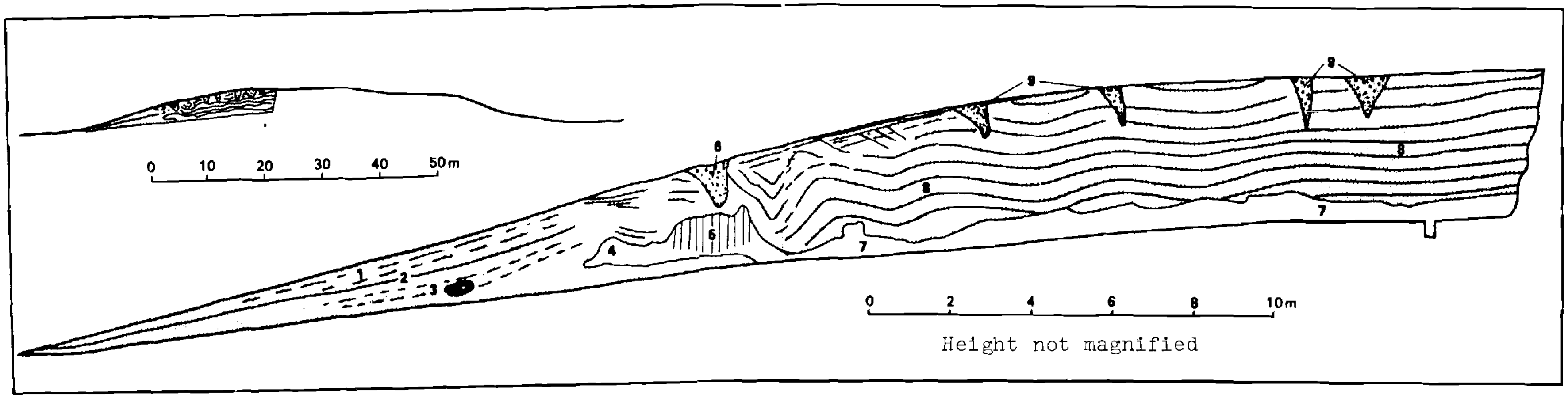

Fig. 7

Section excavated in the pingo marked II in Figure 2

1. Sands and small gravel displaying poorly defined bedding; slope deposits;
2. Indistinct contact with coarser sands and gravels;
3. Boulder, 0.7 by 0.5 by 0.3 m; probably an erratic;
4. Probably injection ice; length of largest crystals: 2 cm;
5. Ice wedge, vertically stratified;
6. Wedge in the active layer corresponding to the underlying ice wedge,
7. Injection ice; dimensions of the crystals: 0.2 by 1 cm;
8. Well stratified and slightly undulating beds of sands and gravels; Beaufort Formation probably in situ;
9. Frost polygon structures filled with mineral material

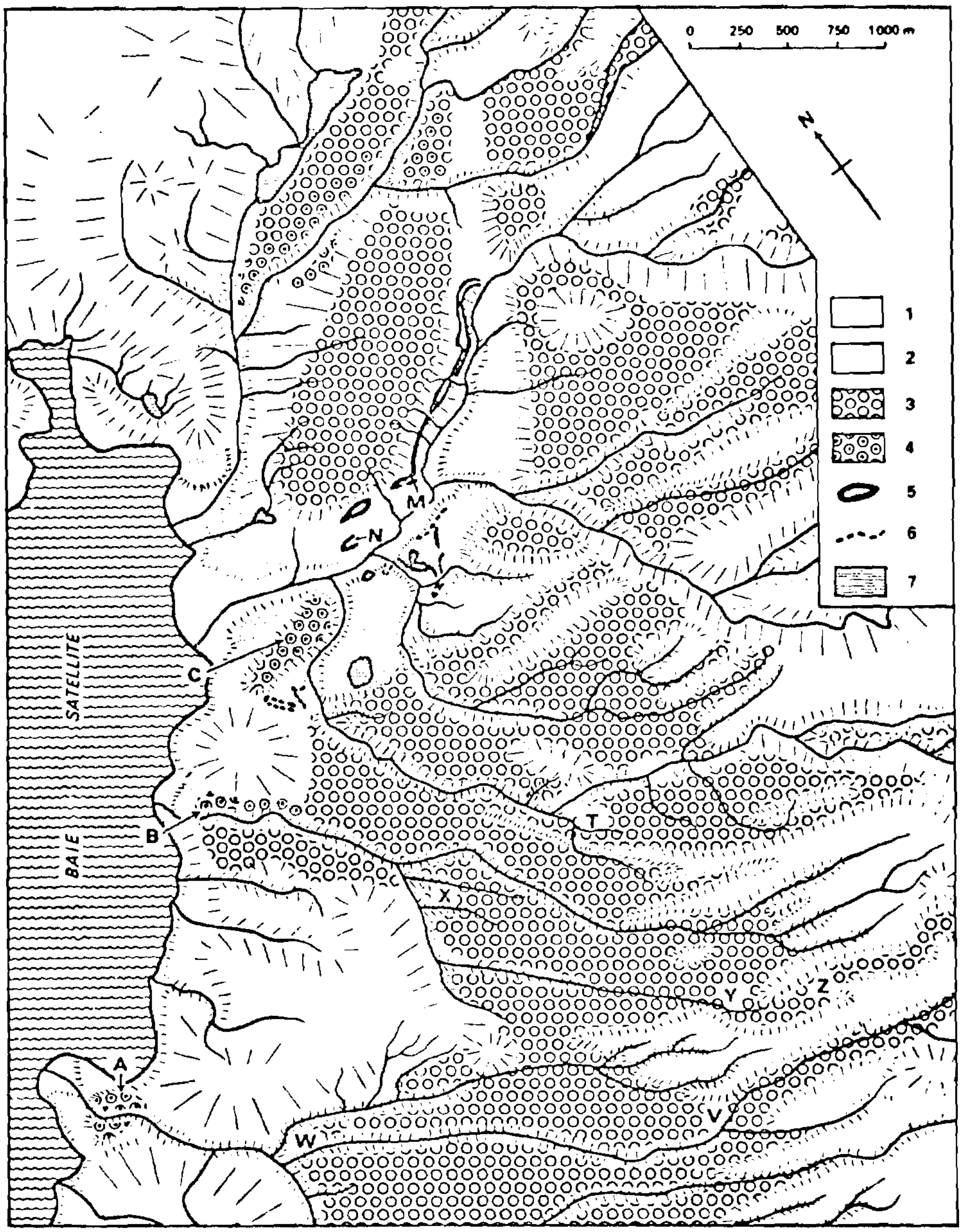

Fig. 8

Geomorphological sketch of the northwest shore of Satellite Bay, where the pingos studied are located. This map was drawn from aerial photographs.

1. Major river flats;
2. Deltas and terraces situated at about 3.5 m above sea level and above the river flats;
3. Glacial outwash plain;
4. Deltaic deposits (with foreset beds) related to the glacial outwash plain, and whose summits lie at 10.7 m above present sea level at A, 13.8 m at B, and 12 m at C;
5. Present-day pingo, in process of melting, as indicated by the white centre, representing the central hollow;
6. Traces of a pingo, indicated only by the deformation of the fluvial beds;
7. Lake

Fig. 9

Satellite Bay; 18th June 1965

1. Pingo in the form of a volcano (diamter 50 m, height 3 m)
2. Pingo N in Figure 8; truncated by lateral erosion by the river (height 7 m)

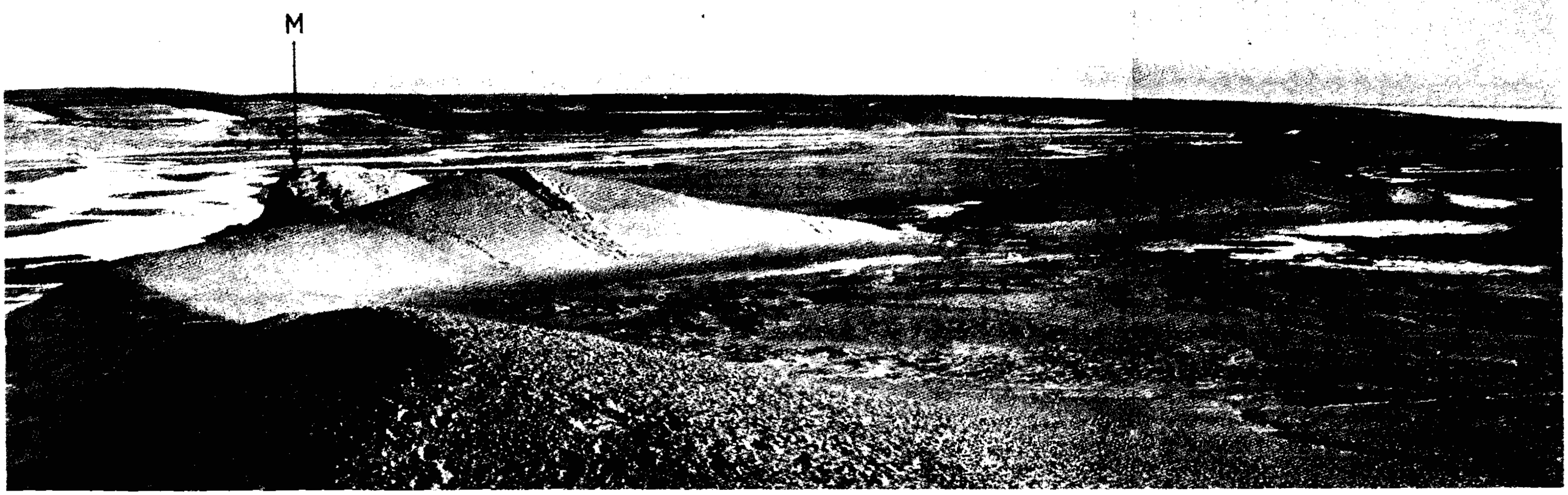

Fig. 10

The western end of the long pingo at Satellite Bay. Here the pingo is fragmented by small streams. The section illustrated in Figures 14 and 15, and marked M on Figure 8, is indicated by an arrow

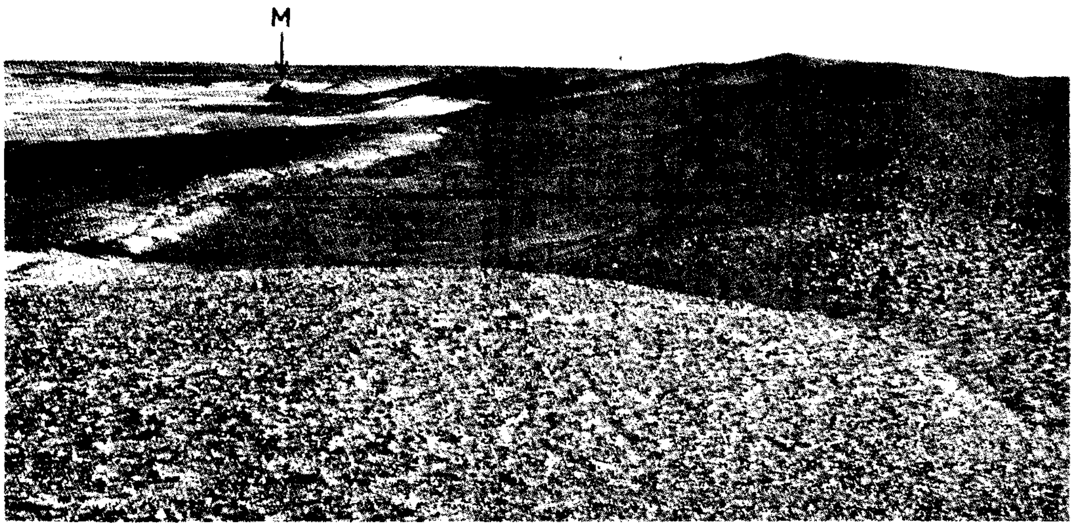

Fig. 11

The same pingo at Satellite Bay; viewed from the central depression (D), which follows the axis of the pingo. The section illustrated in Figures 14 and 15 is indicated by the letter M

Fig. 12

A pingo at Satellite Bay; mamillated appearance reulting from the irregular melting of the ice core, and reminiscent of that of certain pingos observed on the summit of the island (see Fig. 5)

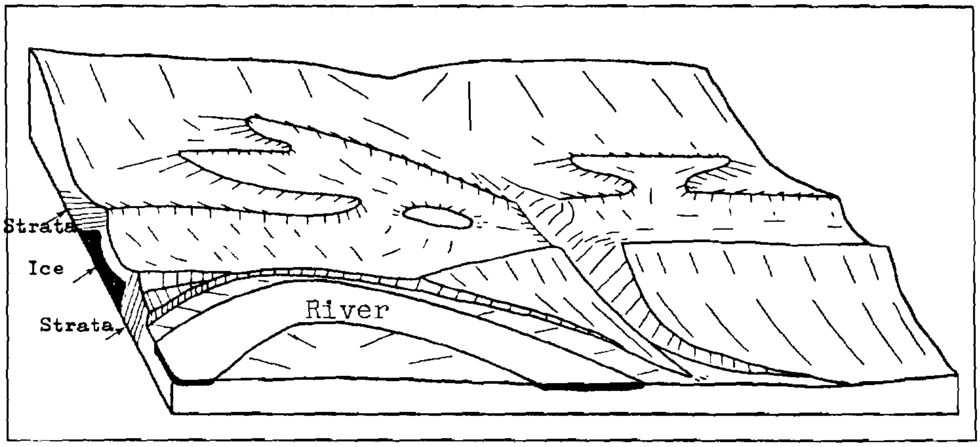

Fig. 13

Sketch showing the complex structure presented in places by the long pingo at Satellite Bay. On either side of the ice core, the originally horizontal sand/gravel beds have been turned up on end

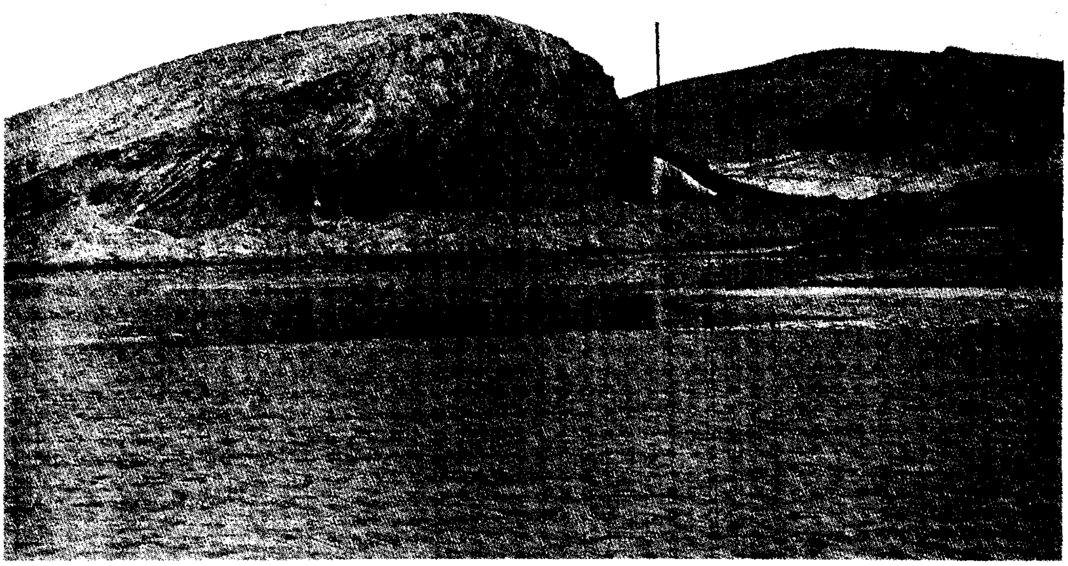

Fig. 14

Transverse section in the long pingo at Satellite Bay (point M on Fig. 8). This section is described in Figure 15. The ice core, at present in the process of melting, is indicated by an arrow

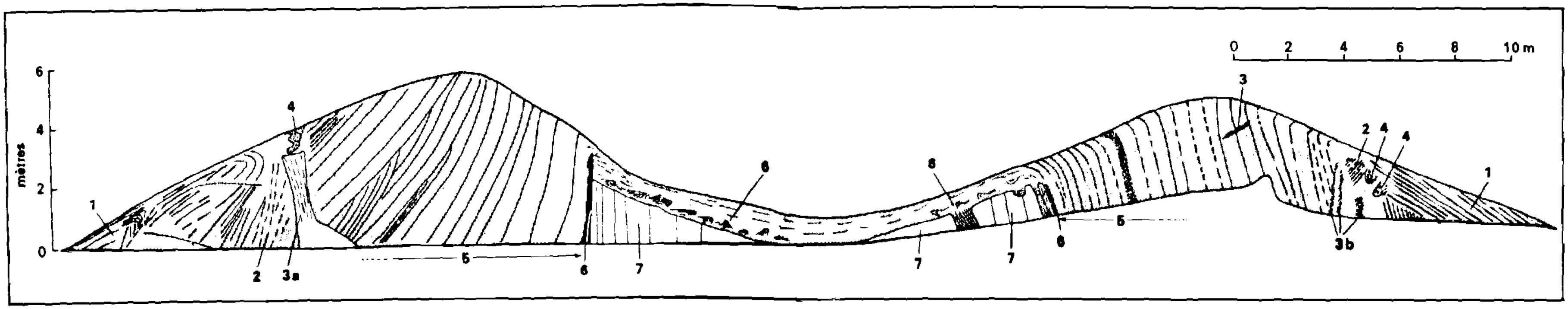

Fig. 15

Section through the long pingo at Satellite Bay (see figs. 14 and 16)

1. Sands and pebbles displaying poorly defined bedding; slope deposits;
2. Indistinct vertical beds;
3. a) Ice wedge; polygonal frost-crack feature,
   b) Ice and sand wedge; polygonal frost-crack feature;
4. Gravel wedges in the active layer corresponding to the ice wedge strucutres;
5. Beds of sands and gravels, whose particle size decreases in the direction of the arrow;
6. Black silt including marine foraminifera;
7. Injection ice of the pingo;
8. Slope deposits

Fig. 16

Detail of Figure 14, showing the core of injection ice in the long melting pingo. Note the generally stratified aspect of the ice, due on the left, to mineral particles, and on the right, to reddish iron oxides

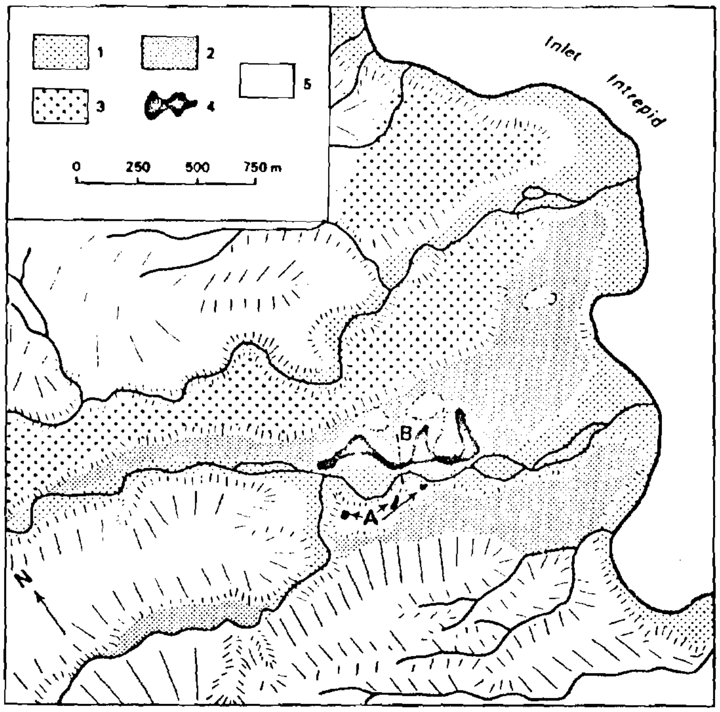

Fig. 17

Geomorphological sketch, drawn from aerial photographs, showing the location of the pingos observed near Intrepid Inlet

1. Present alluvial plain
2. Low terrace
3. Terrace at a height of more than 10 m above sea level
4. Pingo
5. Lake

B indicates the location of the section illustrated in Figure 18

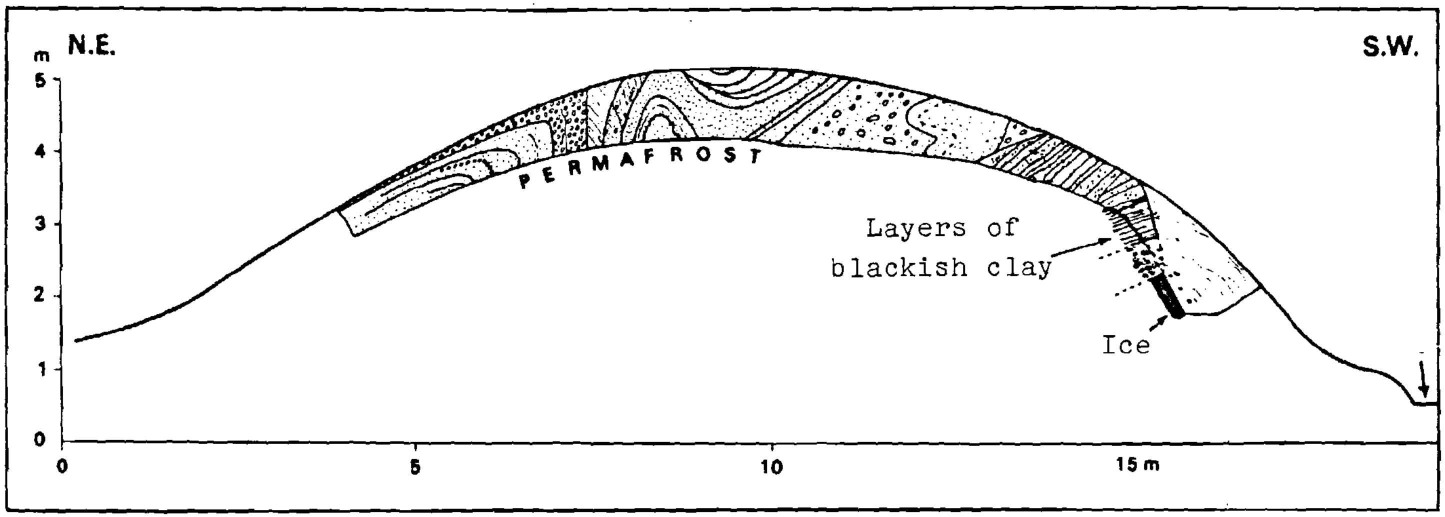

Fig. 18

Section through the elongated pingo at Intrepid Inlet at point B in Figure 17, showing the sequence of beds, their disposition, and the core of injection ice. This section shows only half of the pingo, the other half having been destroyed by river erosion

Fig. 19

Photograph of the thawing pingo, whose plan view is illustrated in Figure 20

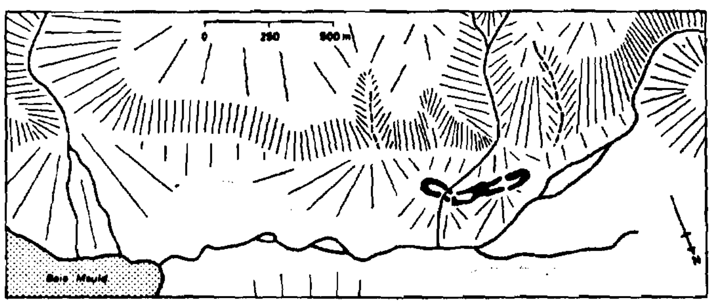

Fig. 20

Sketch drawn from aerial photographs and field surveys showing the form and location in the topography of an elongated melting pingo situated 23 km southwest of the Mould Bay weather station