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Pingos: An Overview of the Present State of Knowledge

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ABSTRACT

The external and internal characteristics of pingos are described. A discussion of the genetic mechanisms leads to the classic distinction between closed-system (developing from cryostatic pressure) pingos and open-system pingos (developing from hydraulic pressure), both related to pressure exerted on underground water beneath a permafrost layer. A formal genetic definition of the term pingo is developed on the basis of a terminological discussion and consideration of related features.

RÉSUMÉ

Après avoir décrit les caractères externes et internes des pingos (forme, dimension, réseau de fractures), l'auteur rassemble ce qui connu sur leur structure interne et leur vitesse de croissance. Les mécanismes génétiques responsables des pingos sont classiquement de deux types: les pingos nés par pression cryostatique suite à l'apparition de systèmes fermés, et les formes dues à la pression hydraulique (système ouvert). Les premiers existent seulement dans la zone de pergélisol continu et sont toujours localisés dans des sédiments meubles; les seconds répartis dans la zone de pergélisol continu et discontinu soulèvent parfois des roches consolidées. La glace qui les constitue peut être de la glace d'injection ou de ségrégation mais elle est toujours apparue suite à la mise sous pression d'une nappe aquifère. Ce caractère distingue les pingos des palses qui se forment seulement par cryosuccion. Comme ce derniere mécanisme ne peut créer des buttes supérieures à plus de 10 m d'élévation, les buttes cryogéniques plus élevées sont incontestablement des pingos; les formes apparues dans des tourbieres a la limite du pergélisol discontinu sont des palses. Quand un des deux caractères que nous venons de citer ne peut être utilisée, une étude détaillée du mécanisme de formation des buttes est nécessaire pour déterminer s'il s'agit de pingos ou de palses.

ZUSAMMENFASSUNG

Nach Beschreibung der äußeren Merkmale (Form, Größe und Spaltennetz) der Pingos werden vom Autor weitere Hinweise über die innere Struktur und Wachstumsgeschwindigkeit gesammelt. Aufgrund der Bildungprozesse lassen sich die Pingos in zwei Gruppen unterteilen: die durch hineingepreßtes Wasser im geschlossenen System und die im offenen System gebildeten. Dabei lassen sich die der ersten Gruppe nur im kontinuierlichen Permafrostbodengebeit sowie im lockeren Material nachweisen, die der zweiten im diskontinuierlichen sowie kontinuierlichen Permafrostbodengebiet, wobei manchmal selbst Festgesteine zerstört werden. Das Eis kann hier entweder 'segregated ice' bzw 'injection ice' sein, wobei aber in beiden Fällen gespanntes Bodenwasser als Voraussetzung vorhanden sein muß. Dagegen werden die Palsa durch 'cryosuccion' gebildet, wobei Hügel von maximal 10 m Höhe gebildet werden können. Die periglazialen Hügel, die höher als 10 m sind, müssen Pingos sein. Formen, die am Rand des kontinuierlichen Permafrostbodengebietes erscheinen, sind Palsa. Eine detaillierte Untersuchung der Hügelformung ist manchmal nötig, um zu entscheiden, ob es sich um Pingos oder Palsa handelt.

12.1 INTRODUCTION

Knowledge of the controls of pingo appearance is of great interest and significance. These mounds provide information on permafrost distribution and on groundwater circulation, and in the context of these characteristics the Pleistocene remnants of pingos have a considerable palaeo-climatic significance.

The author was first concerned with these features when he described as pingo remnants hollows surrounded by rims in Belgium (Pissart, 1956) and in Wales (Pissart, 1961). This interpretation was hypothetical, since little was known about present day pingos at that time. For more than 25 years he has worked spasmodically on Belgian pingo pseudo-remnants, and also on the frost mounds of the Canadian Arctic. Both research programmes were intended to provide a better understanding of Pleistocene periglacial mounds, and to determine the palaeo-climatic conditions of their formation. Over the same period an extensive research literature on these topics has been published, and translations of Russian work have become available to geomorphologists.

As a consequence, the level of understanding of pingos has greatly increased, through some controversy remains. For example, the author remains convinced that the hollows he described in Belgium and Wales are remnants of periglacial frost mounds, but he now believes them to be 'mineral palsas' rather than pingos. No other possibility appears to account for the distribution, shape and genesis of these fossil features. The problems of palsas and of pingo scars are dealt with in Chapters 11 and 13 of this volume respectively, so the present chapter is restricted to present-day pingos.

Several previous authors have reviewed the existing information on pingos. For example, Barr and Syroteuk (1973) summarize the contemporary knowledge of these features in the important study area around Tuktoyaktuk, Canada, while both Washburn (1973, 1979) and French (1979) present syntheses on pingos within their books on periglacial geomorphology. Nevertheless, significant advances have been made more recently (notably by Mackay, 1979), so that it is appropriate now to attempt a further overview of the facts and hypotheses concerning pingos.

12.2 PINGO SHAPE, SIZE AND EXTERNAL APPEARANCE

Pingos usually have a conical shape. The largest ones may reach about 50 m in elevation, as is the case with the 48 m high Ibyuk pingo near Tuktoyaktuk in the Mackenzie Delta, probably the highest so far recorded (Figure 12.1). Mackay (1979) notes that in the Tuktoyaktuk Peninsula, where the Ibyuk pingo is still growing, 85 per cent of pingos are less than 20 m in elevation. It can be argued that a minimum height is not necessary for a mound to be called a pingo, since Mackay gives this name to small features which are less than 1 m in height. The diameters of normal pingos range between 30 m and 600 m (Mackay, 1978b). There is a relationship between the elevation and diameter such that when a pingo is very extensive it is generally not very high, while the greatest heights correspond to features with small diameters (Mackay, 1978b).

FIGURE 12.1 The Ibyuk pingo near Tuktoyaktuk in the Mackenzie Delta, N.W.T., Canada. With its 48 m elevation, this is one of the highest pingos in the world

Some pingos appear as very elongated mounds (Müller, 1959; Mackay, 1963; Pissart, 1967; Tarnocai and Netteville, 1976; Pissart and French, 1976; Rotnicki and Babinski, 1977; Liestol, 1977). Sometimes, indeed, they may be so long and narrow as to resemble eskers. Pissart (1967) describes from Prince Patrick Island a mound 1300 m long but having a maximum of 8.75 m elevation. Unlike palsas, pingos retain the same diameter throughout the period of their evolution, with the consequence that the steepness of the pingo slopes increases progressively as they grow. Barr and Syroteuk (1973) and Mackay (1978b) indicate that these slopes rarely exceed 45° inclination.

Two kinds of cracks are found on the surfaces of pingos. The first displays a radial distribution in plan, converging on the summit of the mound. They result from stretching of the sediments covering the ice core during mound growth. When these cracks become large enough, they include melting of the ice core to produce an enlarging hollow at the summit through thermokarst processes. In this state, complete with a summit depression, the pingo resembles a small volcano. The second type of crack, less conspicuous than the first, shows a concentric pattern which has been described by several authors (Müller, 1959; Mackay and Stager, 1966; Rampton and Mackay, 1971; Washburn, 1973). Mackay (1973) compares these cracks with those which appear when some volcanic laccoliths are updoming the ground, and (as is discussed further below) he shows that they are active when the pingos are pulsating.

12.3 THE INTERNAL STRUCTURE OF PINGOS

A massive ice core is characteristic of pingos (Figure 12.2) but is not found in all such features (Figure 12.3). When a large body of ice is present, it is the

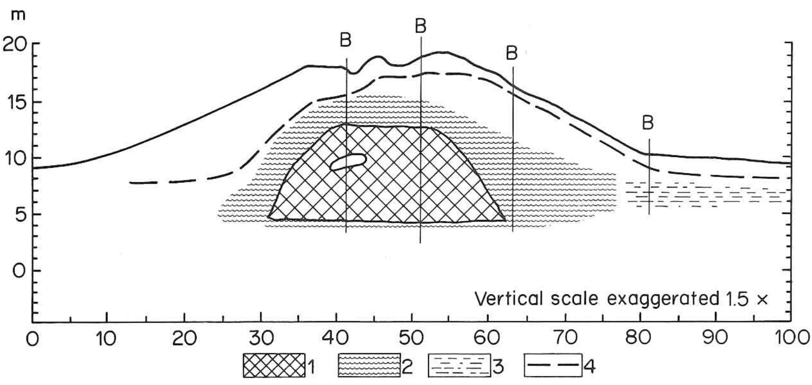

FIGURE 12.2 Distribution of ice inside a large pingo near Yakutsk (USSR). The ground is upheaved by a core of injection ice and lenses of segrated ice. (Key: 1. Core of pure ice; 2. Ice lenses . . . 40–70 per cent by weight; 3. Ice lenses . . . 25–40 per cent by weight; 4. Permafrost table; B. Borings.) (After Soloviev, 1952)

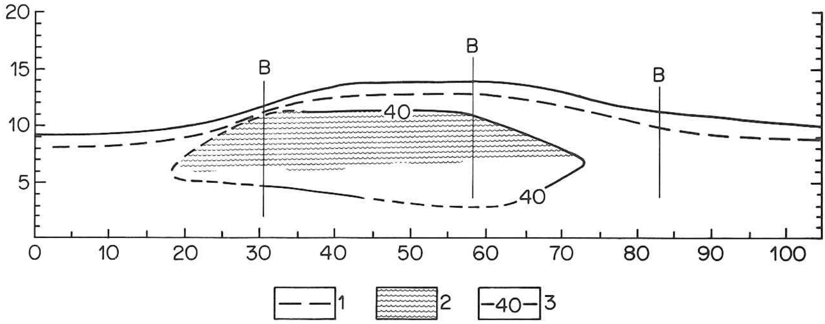

FIGURE 12.3 Distribution of ice inside a flat pingo in central Yakutia (USSR). (Key: 1. Ice lenses . . . 40–140 per cent by weight; 2. Permafrost table; B. Borings.) (After Soloviev, 1952)

result of the freezing of water that has been injected through the ground (injection ice). To produce such injection, the water in the ground must be under a pressure high enough to upheave the frozen ground and form a lens of water. On several occasions such lenses of free water have been located by boring (Mackay, 1978a). Previously, Mackay (1977) had demonstrated by precise levelling that some pingos rise or fall by a few centimetres in a period of a few months or even days. The explanation that he gives for this phenomenon is short-term variation in the thickness of the water lenses, and he classifies these mounds as 'pulsating pingos'. Mackay (1971, 1973, 1978b) emphasizes the fact that 'segregation ice' may also be present in large quantities, and this matter is discussed further below. Such segregation ice forms lenses in the ground as a result of displacement of water by capillary forces. During the freezing period, water migrates through the soil and accumulates as ice lenses.

The materials upheaved during pingo growth are usually loose sediments such as gravels, sands or clays, but it has been observed several times that pingo ice can appear in solid rocks such as sandstones (Müller, 1959; Åhman, 1973) and shales (Balkwill *et al.*, 1974). A layer of clay along the contact with the ice is described by Soloviev (1952), Pissart (1967), and Pissart and French (1976). The thickness of the upheaved layers is necessarily greater than that of the active layer (otherwise it would simply lead to the production of seasonal mounds), but it is very different from one pingo to another. The greatest thickness so far described is probably the 14 m for the Ibyuk pingo near Tuktoyaktuk (Müller, 1959), which is a contender for being the highest in the world.

12.4 RATE OF GROWTH

Indications of the rate of pingo growth have occasionally been published. Schumskii (1959) suggests a range from very low values up to 0.5 m yr^{-1}. After almost 10 years of precise levelling in the Mackenzie Delta, Mackay (1973, 1976, 1979, 1983) has demonstrated a maximum ground upheaval of 1.5 m yr^{-1} during the first two years of mound growth. Subsequently, the rate of growth decreased as the square root of the elapsed time (Mackay and Black, 1973). The 48 m high Ibyuk pingo was shown to be still growing by a total amount of 2.8 cm during the two years 1973–75. The greatest rates of upheaval are probably the result of injection of water, since it is impossible to achieve such rates simply through the freezing of water already present beneath the mound. A mean upheaval rate of 34 cm yr^{-1} for a pingo 12 m in height during the period 1973 to 1978 was the most rapid increase recorded by Mackay (1979) for a mature feature.

12.5 PROCESSES OF PINGO GENESIS

Two kinds of genesis are traditionally claimed for pingos, both offering explanations for the pressurization of water in the ground. The first uses a closed-system explanation for the type of pingo found in the Mackenzie Delta, while the second takes an open-system view and is generally applied to the pingos of Alaska and Greenland.

12.5.1 The closed-system explanation

The pingos of the Mackenzie Delta and of Central Yakutia belong to this type. They occur in regions with thick permafrost, and usually grow on the locations of former lakes (Figure 12.4). The thermal conditions beneath these lakes play a leading role in pingo formation, as was first shown by Porsild (1938). Provided that the water is deep enough, an open talik (non-frozen ground surrounded by permafrost below and on the sides) will exist beneath the lakes of the permafrost zone. This ground remains unfrozen because during winter the lake water offers thermal insulation and does not freeze to the bottom, while in summer the heat transmission may be greater through the water than through the surrounding dry sediments. The mean annual temperature at the lake bed is thus higher than the ground surface temperature in the vicinity.

However, if the lake water should decrease sufficiently in depth (for example, in relation to lake sedimentation or to lake drainage by erosional lowering of the outlet stream), then a point is reached when the lake is able to freeze down to its bed during winter. At this stage a completely enclosed pocket of unfrozen sediment will be produced (Figure 12.5), and if freezing continues then the volumetric increase of the trapped water gives a pressure (cryostatic pressure) which may cause an injection of water towards the surface. If this water arrives at the surface during winter, it gives an icing (Schumskii, 1959; Mackay, 1977). If gas is contained within the water, its ejection through the overlying frozen sediment may be truly explosive with an outburst of water and mud several

FIGURE 12.4 A pingo in a closed thermokarst depression in Central Yakutia (USSR). (Photo A. Pissart, unpublished)

metres high (Schumskii, 1959). However, more usually the water does not actually reach the surface, but remains trapped in the ground under an upheaved layer of sediments a few metres thick. This pocket of water is later frozen to give injection ice; that is, ice from the freezing of injected water in the ground.

This mechanism is now well established. It is supported not only by direct observations of the appearance of pingos (e.g. Mackay, 1979) on aerial photographs taken since 1935, but also by borings through taliks under lakes (Johnston and Brown, 1961) and through pockets of water under pressure below the pingo ice (Mackay 1977, 1978, 1979). Mackay has emphasized that we lack detailed knowledge of the limits of the pocket under pressure: it may be a talik bounded in all directions by permafrost, or a pocket with boundaries of permafrost on the sides but an impervious layer at the base.

Some pingos with essentially the same origin have been described in other situations. The lateral displacement of rivers sometimes induces talik development which produces a closed system within the ground. Pingos initiated in this way are described in Canada by Mackay (1963), Pissart and French (1976), French and Dutkiewicz (1976); in Mongolia by Rotnicki and Babinski (1977); in China by Wang Shaoling and Yao Heqing (1981); and in Antarctica by Corte (1983).

A rather similar process is described on Prince Patrick Island by Pissart (1967). Here, the fluctuation of sea level in a ria would have melted the coastal

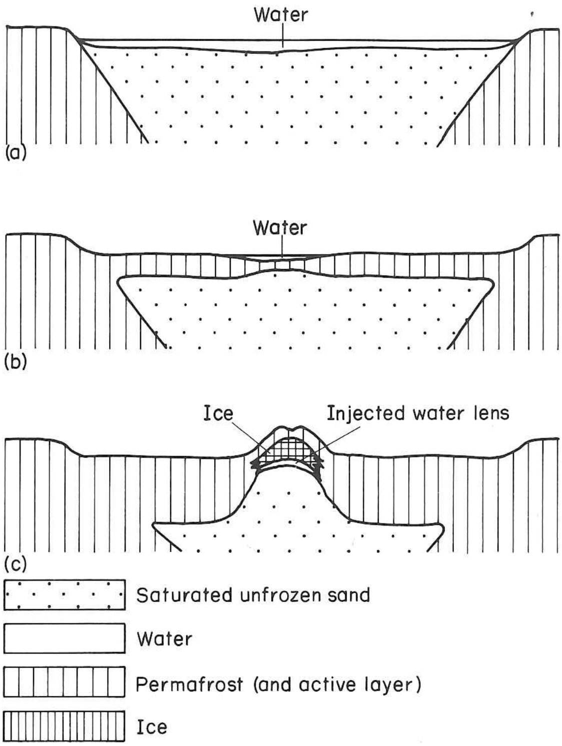

FIGURE 12.5 Genesis of a closed system pingo by cryostatic pressure. (After Mackay, 1979)

permafrost. Later, a closed system was formed by the infilling of the ria by fluvial sediments, and as a consequence groundwater injection has occurred to give pingos (Pissart and French, 1977). As has already been noted, a few of these features are very elongated because the injections have followed the bed of the river. The same type of origin is claimed by Åhman (1973), who explains a pingo described in Spitzbergen by Svensson (1971) as being the result of the freezing of young sediments after post-glacial rebound of the island.

12.5.2 The open-system explanation

Pingos of this type are less well known. Their morphology is identical to that of the closed-system features, the highest so far reported being the 42 m mound described by Liestol (1977) in Spitzbergen. Mounds 30 m in height were studied by Müller (1959) in Greenland, and similar features by Holmes *et al.* (1968) in Alaska. Once again, the basic mechanism is the development of high water pressure in the ground. The pressure is here explained by a hydraulic system—

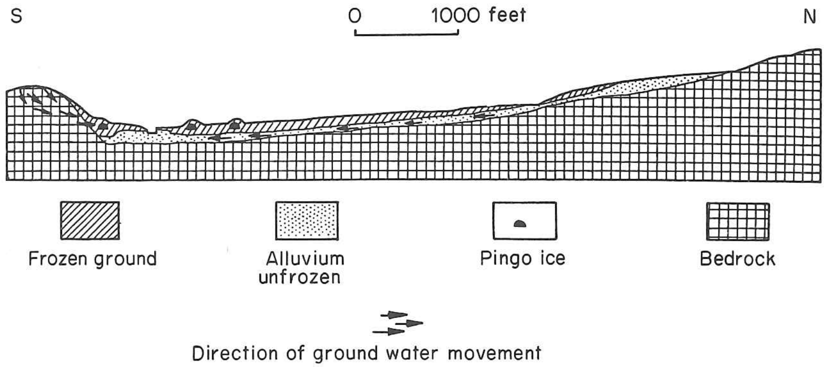

FIGURE 12.6 Genesis of an open system pingo by hydraulic pressure, (After Holmes, *et al.*, 1968)

in other words, it is attributed to a head of water resulting from differences in altitude (Figure 12.6). For this reason, such pingos are restricted to the low-lying parts of areas with sufficient local relief to generate the necessary water head. Pingos of this type occur in discontinuous permafrost as well as in the continuous permafrost zone.

12.5.3 Pingo genesis in the discontinuous permafrost zone

Open-system pingos in the discontinuous permafrost zone are described by Schumskii (1959) in Siberia; by Holmes, *et al.* (1968) in Alaska; and by Hughes (1969) in the Yukon, Canada. In such cases the water mainly moves under the permafrost, which is not very thick. Water reaches this subpermafrost position by entering through parts of the ground surface that are free of permafrost. In Alaska and the Yukon, the open-system pingos are preferentially located on south and southeast-facing slopes, this pattern being attributed by Péwé (1975) to the fact that water more easily finds an access through the permafrost on these slopes.

A location at the base of gentle slopes (2–26° in Yukon; Hughes, 1969) not far from the bottom of the valley is usual for this sort of pingo. All those reported in the literature are formed in slope or aeolian deposits; none has been described in bedrock. It is often the case that the pingo is associated with the position of bedrock fractures which probably influence ground permeability differences (Hughes, 1969). Holmes, *et al.* (1968) suggest that subsurface water movement would be easier in such locations.

These pingos are very scattered. Their density in Alaska is only 38 per 1000 km^2, and they are rare in parts of Alaska that have been ice-covered within the last 25,000 years (Péwé, 1975). Hughes (1969) observed the same spatial restriction in the Yukon, and explained it as the result of either glacial removal of the slope deposits, or the characteristics and limited formation of permafrost in recently glaciated areas.

12.5.4 Pingo genesis in the continuous permafrost zone

In Spitzbergen, Greenland and the Brooks Range (Alaska), some open-system pingos have been described where continuous permafrost occurs—though it is sometimes difficult to demonstrate the continuous character of the permafrost. Liestol (1977) in Spitzbergen near Svalbard, shows that the permafrost thickness fluctuates from 75–450 m in a region where he describes seventy pingos. In northeast Greenland, where they have studied five pingos, Cruickshank and Colhoun (1965) mention variations of permafrost thickness from 80–220 m. Müller (1959) also considered that the east Greenland pingos were in a continuous permafrost zone. More recently, Hamilton and Curtis (1982) have described more than fifty typical open-system pingos in continuous alpine permafrost in the Brooks Range (Alaska).

Unlike the situation in discontinuous permafrost, pingos upheaving solid rock have been found in continuous permafrost in Greenland (Müller, 1959; Cruickshank and Colhoun, 1965), Spitzbergen (Åhman, 1973), Siberia (Schumskii, 1959) and Alaska (Hamilton and Curtis, 1982). However, this is unusual, and the majority of the pingos are in loose sediments such as slope, fluvial and marine deposits.

12.5.5 Water associated with open-system pingos and the development of heaving pressures

In both the continuous and discontinuous permafrost zones perennial springs have often been seen very close to, or sometimes inside, more or less degraded pingos (e.g. Müller, 1959; Holmes *et al.* 1968). In winter these springs form naledi (icings) which are well described in Spitzbergen by Liestol (1977) and Åkerman (1980). Clusters of pingos are reported in relation to such springs. It appears that when the spring is closed by development of a pingo, the water emerges nearby thus producing neighbouring mounds—a phenomenon well illustrated by Müller (1959).

It is shown by Cui Zhijiu (1980) in China that water beneath an actively growing 18 m high open-system pingo on the Quinghai Xizang plateau is still under pressure. A boring through 14 m of ice released a 22 m high outburst of water, gas and mud. Unfortunately, few details of this study are available, though the author mentioned that the pingos are at the site where bedrock faults intersect, at an altitude of 4650 m and some 500 m below the nearest summits. The same influence of the fracture pattern was noted in the Brooks Range by Hamilton and Curtis (1982), who see no influence of glaciation on the distribution of the pingos.

Several authors have calculated the pressures needed to upheave the ground. For example, Müller (1959) estimates this value to lie between 2.5 and 1.8 atmospheres; while Holmes *et al.* (1968) suggest a pressure between 6 and 22 atmospheres. As the local topographic relief sometimes appears inadequate to produce such artesian pressures, they ask whether cryostatic pressure might occasionally be added to hydraulic pressure to initiate the pingos under study.

12.5.6 The genesis of the ice in pingos

While the broad two-fold hypothesis of open- and closed-system pingo formation is widely accepted, the detailed mechanism of core ice formation sometimes remains undecided. The ice in open-system pingos has rarely been described. O'Brien (1971) is the only author who has observed in this type of pingo the large ice crystals which he regarded as typical of injection ice. In the Mackenzie delta, in contrast, observations on closed-system pingos are more numerous and form the basis of the discussion below. It should be noted that open- and closed-system pingos grow in essentially the same way (that is, through the action of water under pressure in the ground), so that the overall problem of ice genesis is the same in all types of pingo.

Mackay (1978) quotes more than twenty-five references which describe segregation ice inside pingos in the USSR or North America. He adds that his own observations on the ice cores of seventeen pingos in the Tuktoyaktuk Peninsula (Mackenzie Delta) have shown that two had only mineral material with a high percentage of ice, five were formed of segregation ice and mineral matter, four were formed of both segregation and injection ice, and six of injection ice only. The description of the first two cores gives no basis for explaining how these pingos could have developed. Part of the problem may result from the fact that it is actually very difficult to determine reliably the genesis of ground ice. Gell (1978) undertook a meticulous study of ice samples from three different Mackenzie delta pingos, but after detailed examination with a polarizing microscope he was unable to specify the origin of the ice.

The equivocal nature of the present position can be further illustrated. For several years, Mackay (1971, 1973, 1978b) has emphasized the importance of segregation ice, and has shown how this kind of ice can develop within pingos. More recently, his field studies have demonstrated for some pingos a fundamental role for the injection of water. It now appears certain that both types of ice occur in pingos. In this context it is relevant to note that Soloviev (1952), who has studied pingos both through boreholes and through open wells, describes two distinct types of boulgouniakhs. The first is high with steep slopes and a core of pure ice (Figure 12.2); the second is flat with gentle slopes and only lenses of ice (Figure 12.3).

Mackay (1971, 1973, 1978b) has shown how it is possible for segregation ice lenses to grow under a thickness of more than 10 m of sediments if the water in the soil is under pressure. The equation that he used shows, however, that it is necessary to achieve a very delicate balance between the water which freezes beneath the pingo and the amount of water required to provide the increase in pressure which keeps segregation lenses growing. Such an equilibrium state seems unlikely to be maintained for long periods. Nevertheless, it can be helped if water from the same talik is periodically injected into a neighbouring pingo. Another alternative is to accept the possibility that a very thin layer of the upheaved material beneath the pingo was unfrozen and thus permitted the development of ice lenses from a pocket of injected water. Further detailed work will be necessary to confirm these interpretations.

12.6 SUBMARINE PINGOS

Mounds similar to the Mackenzie Delta pingos have been discovered on the floor of the Beaufort Sea 120 km north of the Tuktoyaktuk Peninsula. Within an area of 5000 km^2, seventy-eight such mounds were observed at depths of less than 65 m by Shearer *et al.* (1971). The mean basal diameter of these features is 400 m, and they have a 30 m mean height. Other mounds were noted beyond the limits of the 5000 km^2 study area, and it is likely that they are more numerous on the continental shelf of the Beaufort Sea than is currently recognized.

The genesis of these mounds is still problematic. It is likely that they are pingos, but it is not known whether they have grown on the seabed or if they are submerged terrestrial forms. Both hypotheses confront objections. It is difficult to explain how terrestrial pingos could withstand erosion during the period of the marine transgression, but at the same time it is equally difficult to argue how pingos could develop actively on the seabed when the basal sea water temperature is rarely much less than -1 °C.

12.7 REMNANTS OF THAWED PINGOS

Despite its great importance for fossil periglacial studies, the remnant morphology of thawed pingos has been the subject of relatively few studies. This may result partly from the fact that scientists concerned with present-day processes are more interested in the genesis of mounds than in their decay, but it also reflects the fact that in currently periglacial areas it is impossible to predict exactly what remnants will remain after complete thawing of the ground.

Numerous pictures (e.g. Figure 12.7) show that the thawing of pingos begins on their summits, and that lakes which appear there are progressively widened by thermokarst processes, and evolve until they produce a broad hollow surrounded by a low rim. On the other hand, many authors have described tilted stratification on the sides of pingos, and also mass movements on their side-slopes (Figure 12.8). It seems clear in relation to such observations, that the

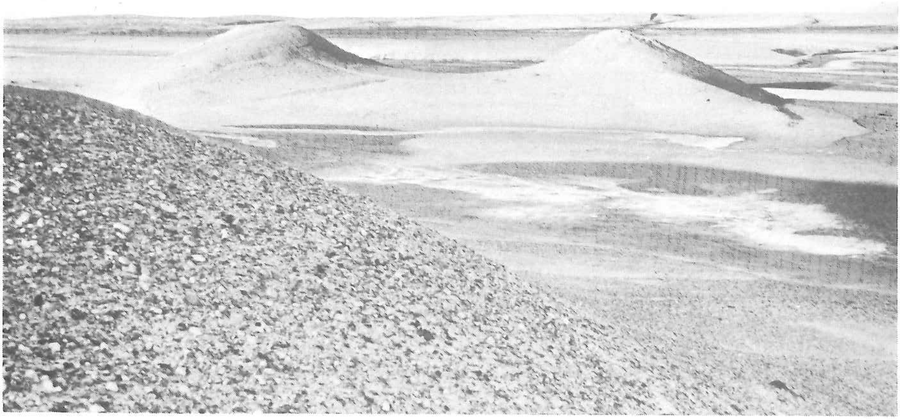

FIGURE 12.7 A melting pingo on Prince Patrick Island. It has been attacked on both sides by fluvial erosion

rim of a remnant pingo is formed in its outer parts of slope deposits accumulated against tilted sediments (Figure 12.9). Because these characteristics are not fundamentally different to those which remain after the thawing of other types of periglacial mound (for example, a mineral palsa), it is necessary to examine the environment and reconstruct the genesis of the mound before it can confidently be identified as a fossil pingo.

12.8 FUTURE PROSPECTS FOR PINGO RESEARCH

During the last decade, the major advance in the knowledge on pingos has derived from the work of J. R. Mackay. This material was synthesized in Mackay (1979), which attracted the Kirk Bryan Award of the Geological Society of America, thus clearly demonstrating the importance of Mackay's contribution. His precise levelling of pingos over several years has resolved an important dilemma concerning their mechanism of formation, and his programme of boring has permitted confirmation of hypotheses on subsurface phenomena.

Nevertheless, it is clear that there are still substantial gaps in knowledge, especially about open-system pingos. External description provides important information, but is merely an introduction and there remains a need for a greater mastery of present day evolution. Repeated levelling such as that employed by Mackay is a powerful means of elucidating present activity, but is not in itself

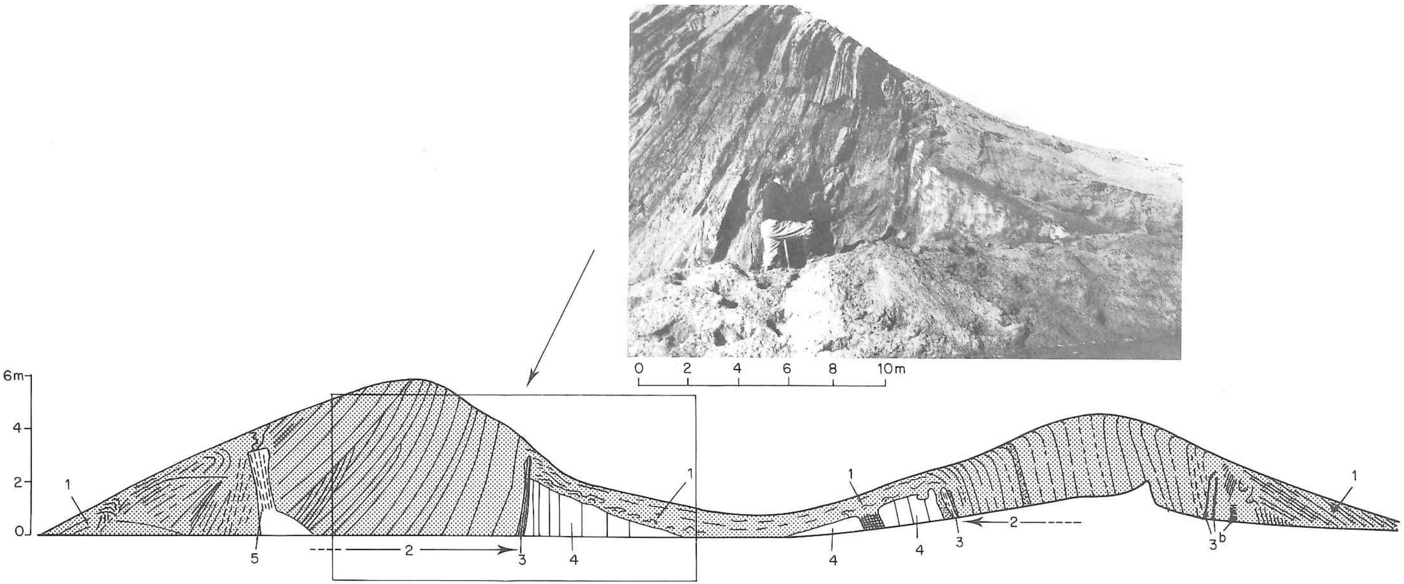

FIGURE 12.8 Section through a melting pingo on Prince Patrick Island. (Key: 1. Slope deposits; 2. Tilted layers of sand and gravel; 3. Clay; 4. Injection Ice; 5. Ice wedge. No vertical exaggeration.) (After Pissart, 1967)

FIGURE 12.9 An elongate pingo evolving by thaw in the Thomsen River, Banks Island, N.W.T., Canada. (After Pissart and French, 1975)

sufficient. More information is required on internal structures and ground ice characteristics, and these observations can only be collected by boring or sectioning the mounds. In addition, dating is important. Here, too, samples must be collected from sections if their structural and stratigraphic relationships are to be appreciated.

Such research is logistically demanding. It is possible only for scientists who can monitor the same sites for several years, and often requires bulky equipment in the field. Given the location of the features concerned, such exhaustive research becomes difficult and expensive. By contrast, research on palsas takes place in the zone of seasonal ground freezing, and is thus somewhat less of a logistic challenge. Nevertheless, the importance of this kind of research is beyond question, since it is only through a thorough understanding of present day periglacial frost mounds that we can hope to achieve a rigorous interpretation of fossil features.

12.9 CONCLUSIONS: THE DEFINITION OF THE TERM PINGO

The most important characteristic of pingo genesis is that these features appear when water is put under pressure in the ground. This pressure is absolutely necessary in order to permit growth of injection and segregation ice at depths of several metres beneath the ground surface. It remains difficult, however, to establish a clear terminological distinction between pingos and palsas, or between pingos and frost blisters which appear in the active layer.

It is suggested that the best differentiation between pingos and palsas is that proposed by Wramner (1972): the name 'pingo' should be given to mounds which grow when water is under pressure in the ground, while the name 'palsa' should be reserved for mounds which are associated with cryosuction (however defined). Such a genetic definition would allow us to regard as palsas the cryogenic mounds without a surface layer of peat which are described in northern Quebec by Pissart and Gangloff (1984). The main disadvantage of such a definition is that it precludes the immediate identification of an observed mound. Only after research on genesis will it be possible to select the correct name: in the meantime, non-specific terms such as ice-cored mounds, periglacial mounds or buttes cryogenes must be used.

Another related problem concerns the distinction between pingos and frost blisters. Several papers (Schumskii, 1959; van Everdingen, 1982; Brown *et al.*, 1983; Pollard and French, 1983; Washburn, 1983) have shown that ice-cored mounds may appear in the active layer by injection of water under cryostatic or hydrostatic pressure. In most cases, these mounds begin to melt during the following summer, and they tend to disappear within a few years. The names seasonal ice mound, seasonal pingo and frost blister (van Everdingen, 1982) have been used in the literature, and this temporary characteristic of such mounds is sufficient to separate them from true pingos.

Complications arise when the ice mounds do not melt immediately. Some of these ice-cored mounds may remain for several years because the upheaval of the ground has changed the local ground thermal regime. For example, the relative lack of snow on the top of the mound may induce an aggradation of the permafrost and the conservation of the frost mound. To maintain the significance of the term 'pingo' as closely as possible to its common usage, it is wise to exclude the frost mounds here discussed and to limit the meaning of pingo to those mounds which appear in or below permafrost rather than in the active layer.

Since so much confusion can arise when a classification is built solely on morphological description, it is argued here that the terminology must have genetic support. On this basis a pingo should be defined as a multiannual ice-cored mound produced when ice has grown in or below permafrost as a result of water pressure in the ground—this water pressure being either cryostatically (closed-system) or hydraulically (open-system) induced.

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