4 The Fossil Pingos of Wales and the Hautes Fagnes, Belgium

A. PISSART

EDITOR'S REVIEW

Although pingo collapse is not in itself indicative of climatic change (cf. Mackay 1979, 1987), possible pingo remnants in mid-latitude, non-permafrost regions have been used extensively as indicators of former glacial conditions and have remained the subject of considerable debate since the earliest reports of such features by Pissart (1956) and Frenzel (1959) in Europe. Since these early publications, ramparted depressions have been linked to former ground-ice conditions over wider areas of Europe (e.g. Frenzel 1967; Mitchell 1971; Watson 1971; Sparks et al. 1972; Cailleux 1976; Bryant & Carpenter 1987; Coxon & O'Callaghan 1987) as well as in North America (e.g. Bik 1969; Flemal et al. 1973). The interpretation of these features as former pingos has been re-assessed based upon long-term research on contemporary ground-ice forms (e.g. Mackay 1987, 1988). For example, the work of J.R. Mackay (1986) on the Ibyuk Pingo, Tuktoyaktuk Peninsula, arctic Canada, which is one of the largest of the world's pingos provides approximate dimensions for ancient pingos. After complete collapse, the central depression of Ibyuk Pingo will leave a pond no more than 16m deep and a rampart no higher than 5m.

Pissart was one of the few early authors to later re-assess his "pingos" based upon the increasing amount of data that was being collected on ground-ice forms. In 1956, Pissart was one of the first geomorphologists to document fossil pingos and the 1963 paper was the first attempt to map and make stratigraphic studies of the now widely referenced ramparted depressions of central Wales and the "viviers" of the Hautes Fagnes in Belgium. Due to their dissimilarity to modern pingos, the "viviers" were later explained by Pissart (1974, 1976) as features formed by segregated ice in a discontinuous permafrost zone. Pissart (1983) and Pissart & Juvigne (1980) later interpreted the "viviers" as mineral palsas.

Much has been written on the evidence of fossil pingos in Britain, Ireland and on the northwest European mainland. Pissart (1963) was one of the earliest publications on pingo remains in Europe and the first on pingos in Britain, the latter having since received considerable research interest both as geomorphic features (cf. Watson 1971; Watson & Watson 1972, 1974) and as palaeoclimatic indicators (cf. Watson 1972; Handa & Moore 1976). It is thus quite clearly a benchmark in the permafrost literature.

Some of the most important concepts in the paper include the references to the work of Fraser (1956), who documented the occurrence of pingos on slopes (typical settings for the Welsh and Belgian examples), and the work of Shumskii (1955) on the formation of Bulgannyakhs. Groundwater is invoked by Pissart to produce the elongate shape, especially in the case of the Belgian "pingos", as an alternative to the Shumskii closed system model. This type of pingo formation by an open system mechanism was originally suggested by

Les traces de pingos du Pays de Galles (Grande-Bretagne) et du plateau des Hautes Fagnes (Belgique). *Zeitschrift für Geomorphologie* 7: 119–135 (1963). Translated by A. Pissart, Université de Liège, Belgium, 1992

Muller (1959) and is now universally accepted. Pissart went on to study pingo-like landforms in permafrost regions and identified various features that could not be explained by the accepted pingo formation theory (e.g. Pisssart, 1967, 1975; Pissart & Gangloff 1984).

PREAMBLE

During a study visit to Wales in 1961, we discovered in the bottom of a valley near Llangurig, hollows very similar to those called "viviers" in the Hautes Fagnes (Belgium). They are circular hollows, full of peat and surrounded by ramparts. In a paper published in 1956, we proposed that these features were pingo remnants. The hollows of Wales are interpreted in the same way and allow us to confirm how these features have appeared. To establish the comparison with the "viviers", we have collected new observations in Belgium. We present here not only the description of the pingo remnants of Wales but also new observations on the "viviers" of the Hautes Fagnes.

THE PINGO REMNANTS OF WALES

Topographic Location

The pingo scars observed in Wales are located 35km east of Aberystwyth, on the bottom of a glacial valley which opens to the west on the Wye valley at Llangurig and to the east to the Afon Dulas valley, 5km south of its confluence with the Severn near Llanidloes. The geomorphological history of this valley is complex and is not the concern of this paper. To understand it, it would be necessary to consider the morphology of a large part of Wales.

This important valley (Figure 4.1), which is 400m wide and is similar to nearby valleys of the Wye and the Severn, cannot be explained by normal erosion. It does not appear to be developed along a soft structural zone, because its alignment is almost perpendicular to the steeply inclined stratification of the Silurian bedrock. Orientated east–west, the valley continues without any break in slope into the upper Wye valley and appears to be a glacial valley made by a glacier coming from Plynlimon. Today, this valley is a broad windgap with an ill-defined drainage pattern in its central part. The water flows in its eastern part to the Severn river and in the western part to the Wye river. In the central part of the valley, a small rivulet flowing from the southern slope and called "Nant Gynwyd" crosses the valley and flows immediately to the north through a narrow gap which, probably, was cut where a glacial diffluence existed.

After the melting of the glacier, this valley was partially filled with sediments, especially where two rivulets (the "Nant Gynwyd" and the "Nant Cae-garw") arrive in the valley from the south. These two rivulets have deposited in the broad valley an enormous amount of poorly washed gravelly sediment, which will be described later and which probably represents periglacial accumulations. These accumulations of unknown thickness (in one place more than 5m was observed) have closed up the middle part of the east–west valley and have increased the marshy character of the valley bottom between

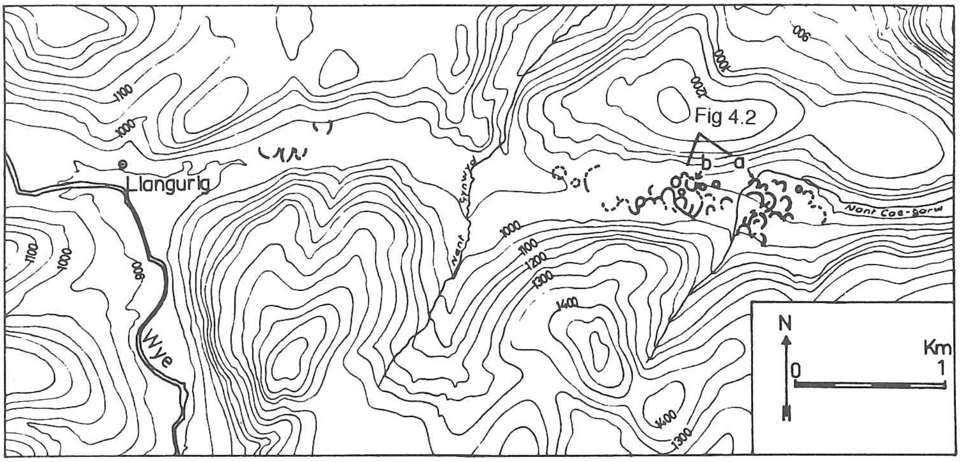

Figure 4.1 Map of the distribution of pingo remnants near Llangurig (Wales). The thick lines represent the walls around the hollows. Below one of these ramparts labelled "a" (visible also on Figure 4.2) I have observed the profile given on Figure 4.4. For "b", the two characteristic circular hollows are visible in the foreground of Figure 4.2. The contour interval is 50 feet

the two rivulets where an important peat has accumulated. It is on these periglacial deposits and in the marshy part of the valley between the two rivulets that the pingos have grown.

Description of the Pingo Remnants

Figure 4.2 clearly shows the features that we are discussing: ramparts encircle swampy hollows filled with peat. These features sometimes are isolated, but very often, as is visible on the map, are joined side by side or seem to overlap.

However, in many cases the hollows do not appear so clearly and it is often difficult to identify the ramparts for the larger features. Mapping of the parts of the ramparts which are visible often allows identification of the circular morphology. Sometimes the central hollows are not clear because there is no peat infilling. In several places, especially in the periglacial deposits of the Nant Cae-garw, the depressions are filled up with sediments. It is however clear that these features have the same genesis to the hollows filled up with peat.

The distribution map of these ramparts (Figure 4.1) shows more than 40 more or less well preserved circular walls. On the slopes, their morphology generally is semi-circular with a broad opening oriented to the upper part of the slope. Their density is very irregular in the valley; they are numerous in the eastern part, near the rivulet Nant Cae-garw. They may also exist in great numbers in the middle part of the valley, but here the peat covers everything and only dubious forms exist; on the western side of the valley, 1km from Llangurig, four nice ramparts have been preserved. The building of the railway has however destroyed their northern parts.

Figure 4.1 also shows the relative position of the ramparts. Not only do we find that isolated and contiguous features exist, but in several places the ramparts are overlapped.

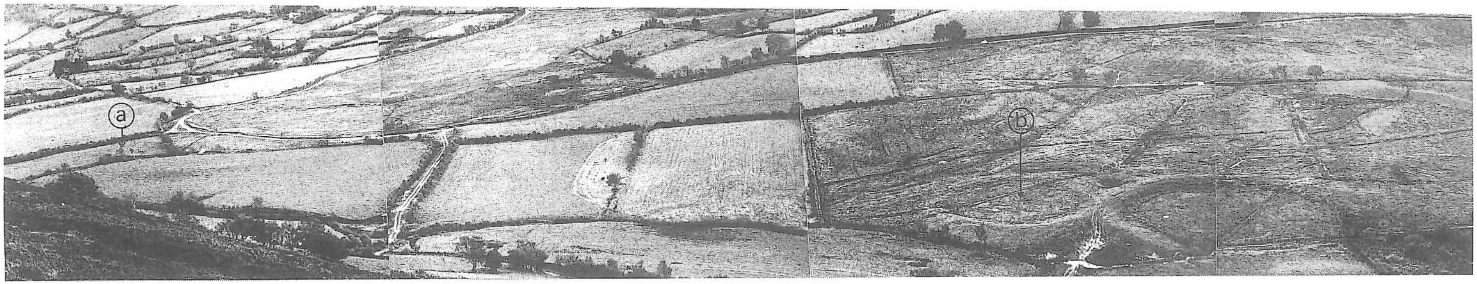

Figure 4.2 Pingo remnants near Llangurig (Wales). View to the southeast. The letter ''a'' indicates the place where the section on Figure 4.4 was observed. The letter ''b'' is the circular hollow from which the profile given in Figure 4.3 originates

This morphology indicates their successive growth, the more recent features having destroyed the older ones.

The internal diameter of these hollows is between 42m and more than 120m, this last value being the diameter of hollows not completely closed. The measurements of the ramparts are not easy because their width and elevation are connected with the peat infilling. For the two features clearly visible on Figure 4.2, we have measured for the smaller one (42m in diameter) a rampart of 15m width and 0.70m of elevation above the surface of the peat infilling; the larger hollow (75m in diameter) has a rampart of 23m width and an internal elevation of 1.60m. The profiles of the edges of the rampart usually show a convex shape on the outside, but a more rectilinear shape on the inside.

Borings made through the peat which fills the smaller circular hollow visible on the left of Figure 4.2, provide the N–S profile of Figure 4.3. This profile shows the great depth (6.5m) of the hollow and the steep slope of the mineral/peat contact slope which is as high as 20°. The hollow is a little asymmetrical but its profile is not very far from the shape of a reversed cone.

We also had the opportunity to observe a section through the semi-circular rampart which is indicated by the letter "a" on Figure 4.1. This place is also visible on Figure 4.2. The diameter of this feature, if the rampart is continued in a regular circle, is 74m. Its central part is not peaty because it is filled by washed sediments. Although vegetation obscures a part of the section, what we have observed here is of great interest. It shows that the upper part of the rampart corresponds with an anticline structure in the deposit below (Figure 4.4). The section comprises three different sedimentary units that we shall present from the bottom to the top of the axis of the anticline structure:

I. A well-washed openwork gravel of non-rounded phyllitic stones which are clearly imbricated. The visible thickness is 1m. Inside this unit, it is possible to recognize several different layers: (a) a clayey brown lens with a thickness from 3 to 5cm; (b) a coarse gravel (maximum length of stones = 10cm) which is strongly cemented by Fe and Mn deposits; (c) immediately above this gravel, a sand lens with a thickness varying between 1 and 4.5cm.

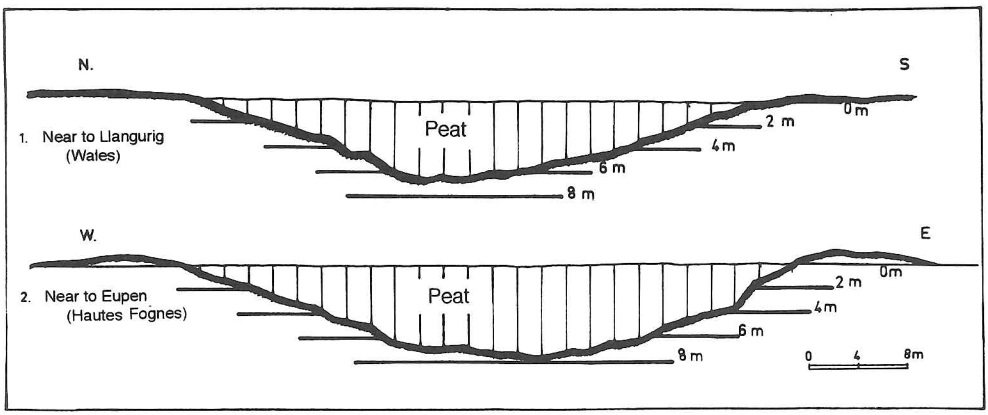

Figure 4.3 Profiles produced from borings through the peat, with an interval of 1.5m, and showing the shape of the bottom of a hollow in Wales and a "vivier" in the Hautes Fagnes (scale of height not exaggerated)

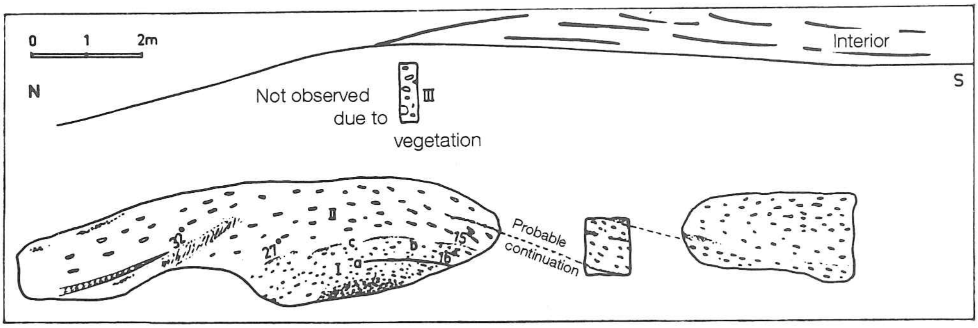

Figure 4.4 Vertical section showing the fluvial stratified deposits which are deformed in an anticline (see description in the text. Scale of height not exaggerated)

II. A poorly washed gravel, coarser than the gravel below (maximum length of stones = 15cm), in which some lenses of thinner material appear. Locally Mn and Fe deposits cement the material. The stratification in the pebbles is largely inclined to the south. This deposit has a thickness of more than 1.10m. Its upper limit is obscured by vegetation.

III. A 1m thick deposit which is clearly different and on which no action of flowing water appears. Blocks of several sizes (amongst which the biggest is 75cm and most are larger than those seen below) occur in a yellow clayey matrix. It seems to be a solifluction deposit.

The sedimentary units I and II are clearly river deposits and are similar to the horizontally stratified deposits in nearby sections. The granulometry of the samples taken in this profile and in the horizontal layers a few hundred metres away are similar (Figure 4.5). Their origin is not related to the occurrence of a rampart but they are the only periglacial gravels which were deposited by the "Nant Cae-garw" in the main valley. The individual position of the pebbles indicates deposition by a river flowing from the south to the north. These characteristics are clear on both sides of the anticline and indicate that the deformation occurred after the deposition of the sediments. This anticline results from the deformation of horizontal stratification which has undergone an uplift in the north side and a downward movement on the south side. The observations verify this interpretation: on the south side, very thin sand lenses show a slope of 15° in the opposite direction of flowage, and in one case a very thin layer shows a slope of 27° which is very steep for such a deposit.

The results of palynological analyses of samples takes in the large hollow visible on Figure 4.2 were provided by Miss D. Trotmann who agreed to do the study. On the basis of these analyses, the bottom of the peat was probably deposited during the preboreal period. This result has been confirmed in the Nuclear Physics Laboratory of the Liège University by the measurement of the ^{14}C content of a sample from the base of the peat. This sample did not contain enough ^{14}C to give a precise date; however, the analyses have shown that it is older than 5000 years.

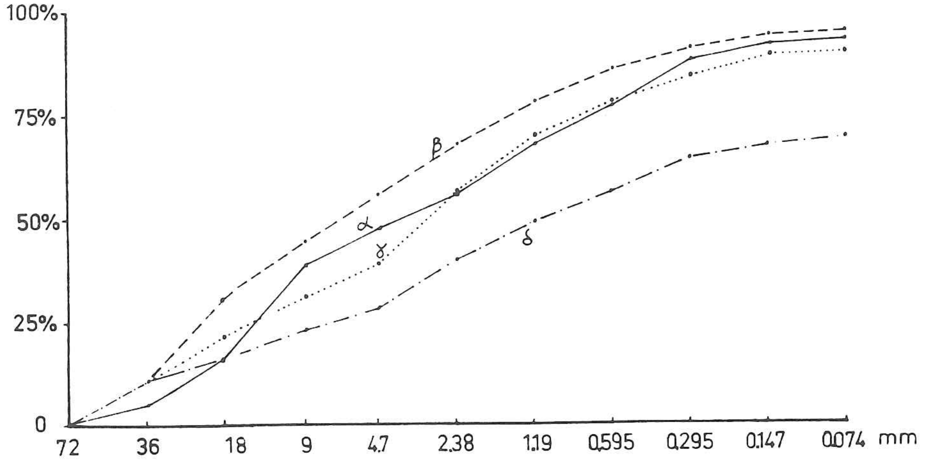

Figure 4.5 Granulometric curves of the material displaced by the "pingos" of Wales. The samples α and δ are from the arched structure shown on Figure 4.4. The samples β and γ are from undeformed layers, taken 200m from the other samples. Sorting index (Q of ϕ of Krumbein) $\alpha = 2.1$; $\beta = 1.97$; $\gamma = 4.3$

THE HOLLOWS CALLED "VIVIERS" IN THE HAUTES FAGNES

Topographic Location

While the observed features described in Wales are all in the bottom of a valley, the similar hollows known in Belgium are on the higher plateaux of the country. As a matter of fact, they are distributed in some parts of the Hautes Fagnes Plateau (40km ESE from Liège; Figure 4.6) and of the "Baraque Fraiture" Plateau (50km SSE from Liège), at more than 500m a.s.l.

These plateaux have an impervious Palaeozoic bedrock, made of phyllites and quartzites. They are covered with clay resulting from very old weathering of the bedrock, which is mixed with some aeolian silt. Quartzite stones, which are very resistant to the chemical weathering, are included in this fine material. The few hollows observed on the "Baraque Fraiture" Plateau are generally circular and not very close to each other. Ninety-five per cent of the observed features are on the Hautes Fagnes Plateau which is aligned SW to NE and stretches 35km, from the Malchamps crest (5km south of Spa) up to Germany near Montjoie. There are more than a thousand hollows which cover almost continuously some parts of the plateau surface (probably more or less than 2500ha). These areas always correspond with gentle slopes and sometimes with horizontal summits. In most cases the hollows are on the northern side, but they are also present in some parts of the southern slope of the plateau.

The "viviers" in Belgium show a greater variety of aspects than the hollows we have described in Wales. Keeping in mind that all intermediary features exist, we may distinguish:

1. Closed hollows, completely surrounded with a rampart and whose shape on a map may be: (a) regular (circular or oval), 150m maximum diameter, 250m maximum internal length; or (b) irregular.

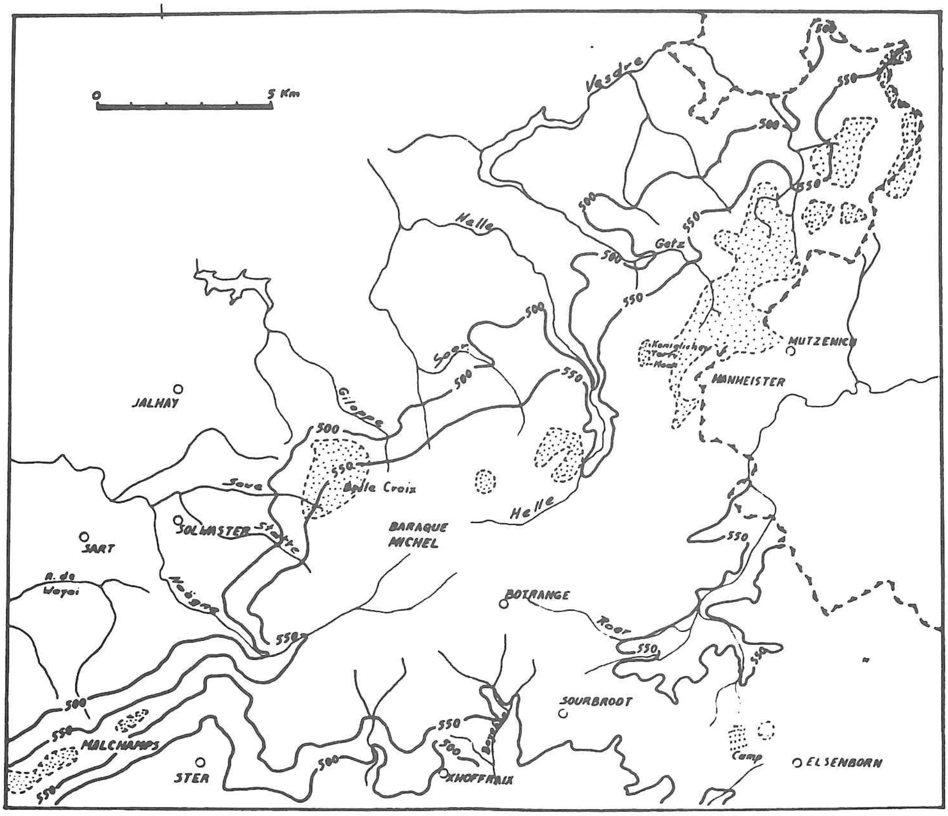

Figure 4.6 Topographic map giving a view of the distribution of the "viviers" on the Hautes Fagnes Plateau. Heights in metres

2. Opened hollows without a closed rampart on the upper part of the slope. On a map, they may appear as: (a) slightly elongated where the ramparts have the shape of a horseshoe (maximum diameter 100m); or (b) very elongated. In the most extreme cases, the feature appears as long walls parallel to the slope (maximum observed length of 800m).

Figure 4.7 provides some sample maps from the Hautes Fagnes Plateau and from the Baraque Fraiture Plateau showing the rampart signatures of these features on aerial photographs. On Figure 4.7a, the hollows are circular, with a simple shape. Figure 4.7b shows features which are usually closed, sometimes circular but more often oval or complex. Figures 4.7c and 4.7d show features open to the upper part of the slope but very different; on Figure 4.7c, the original circular shape and the individuality of each rampart is obvious, while on Figure 4.7d, the walls are elongated along the slope and appear as parallel walls between which it is difficult to see any relationships.

On the other hand, the uniformity of the characteristics in the different parts of the plateau is remarkable. In some places, all or almost all ramparts are elongated; in others, all or almost all depressions are circular. Although this homogeneity is not exclusive, it is however extremely clear.

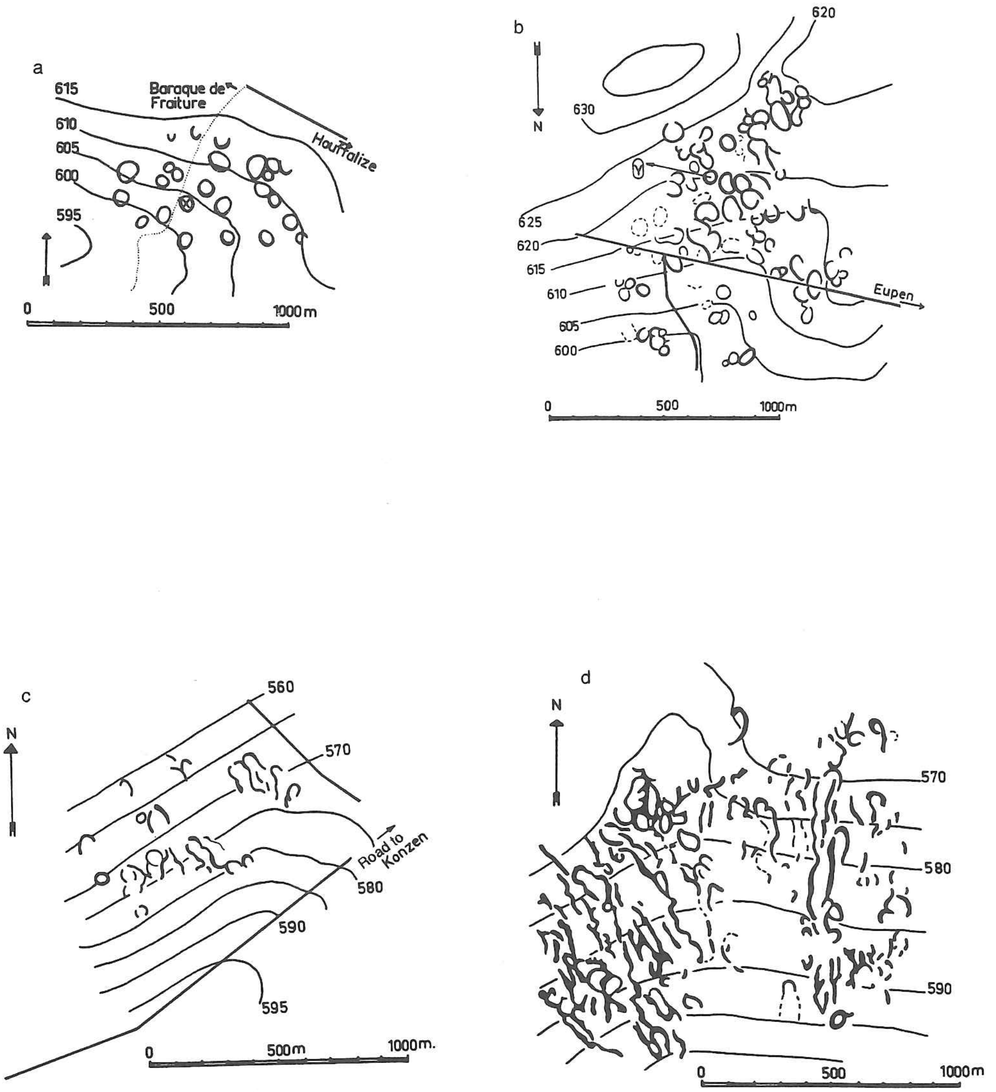

Figure 4.7 Parts of the topographic map of the Hautes Fagnes Plateau and from the Baraque Fraiture Plateau showing the different types of pingo remnants. The walls are drawn from aerial photographs and the contour intervals (in m) are from the topographic maps. On Figure 4.7a, the "vivier" X was palynologically studied by Professor Mullenders. The profile of the "vivier" Y on Figure 4.7b is given on Figure 4.3

Surely the slope is the most important factor in explaining these different morphologies. Its role appears clearly on Figure 4.7d on which we see, on the one hand, that the rims are always parallel to the slope and, on the other hand, that the elongated features take the place of closed features as soon as the slope becomes steeper. However, Table 4.1, indicating the values of the steepest slopes on which the closed "viviers" and the long

Table 4.1 Steepest and most gentle slopes where different forms of hollows are found

	Steepest slope	Most gentle slope
Very elongated forms (opened long walls)	4%	2.4%
Closed forms	5%	0%

walls are distributed, shows that this influence is not the only one which was active when the features appeared. Some closed hollows sometimes exist on slopes where there are long walls and indeed these closed hollows are present on steeper slopes (5%) where the elongated walls do not exist. We do not know the reason for this observation but it is possible that the long walls are located only on slopes of a great length.

Two last observations must be presented about the slope: the "viviers" are present on slopes lower than 5% and this value seems to have a real meaning. On the slopes of the Stelingberg and on the slopes below the summit located at the place named Hoscheit, there is also a clear limit for the appearance of the features we are studying and this limit corresponds to a sudden decrease of the slope.

We have only a little information on the morphology of the base of the peat accumulation and on the thickness of the accumulated peat. A profile drawn after borings every 1.50m has shown that for a "vivier" with 45m of internal diameter (this feature is visible on Figure 4.8), the thickness of the peat is 7.50m. This hollow is very similar to the hollow observed in Wales (Figure 4.3). On the other hand, the "viviers" opened at their upper side, do not show an important peat thickness, especially in the features from the "fagnes de Bellecroix". The hollows are partially filled with slopewash deposits coming from the upper slope.

Some sections in the walls of these features were observed. They have provided the observations given below:

1. The walls are built with unsorted material (sorting index of Cailleux between 7.9 and 6.4), specifically clay and silt with numerous blocks of quartzite exceeding 50cm in length. A part of the granulometric curve is given on Figure 4.9. The samples B and E are from places several kilometres distant from the places where the samples C and D were taken but nevertheless the granulometric curves are similar.
2. Sometimes, the external part of the wall shows a reddish brown material with less pebbles (granulometric curve A on Figure 4.9) which may be aeolian loess. The limit between these two deposits is approximately parallel to the external slope of the rampart (Figure 4.10). This may be due to the accumulation of the upper part of the soil coming from the top of the mound.
3. The individual position of the pebbles is very often characteristic in the central part of the rampart. The pebbles are in a vertical position. This fabric may be the result of a lateral pushing on the deposits.

The age of the "viviers" has not been precisely determined. The very good state of preservation indicates that they are relatively recent. The palynological studies made since 1937 by Professor R. Bouillenne and his collaborators have shown that

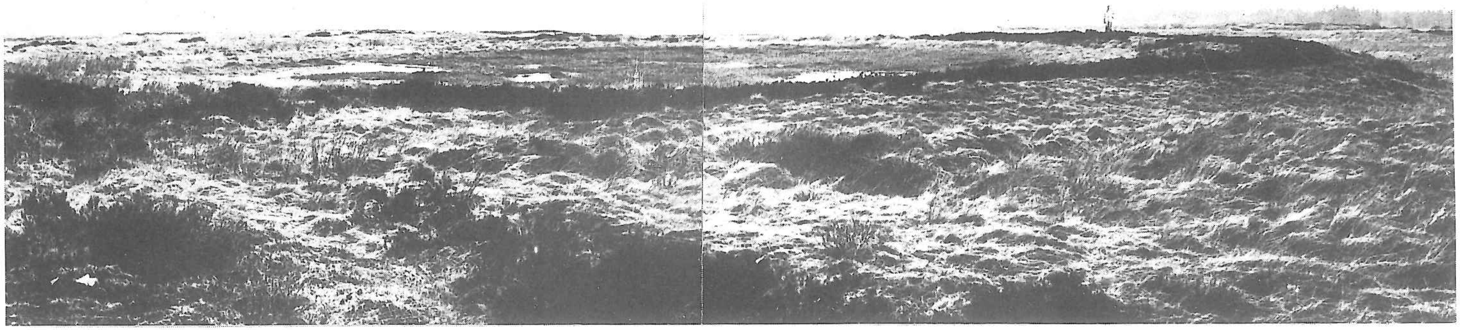

Figure 4.8 Picture of a "vivier" in the Hautes Fagnes. Its profile obtained after borings is given on Figure 4.3. This "vivier" is marked Y on Figure 4.7b. Location: source of the Getz-Bach

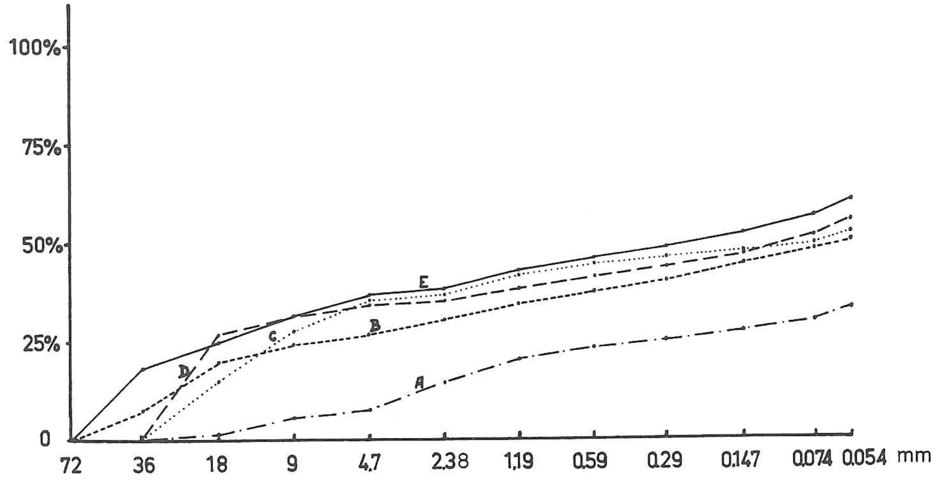

Figure 4.9 Granulometric curves of material from the walls of pingo remnants in the Hautes Fagnes. See text for more details

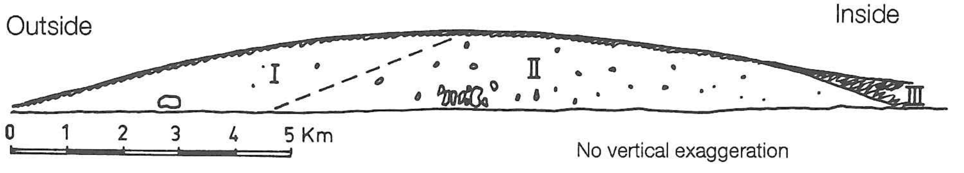

Figure 4.10 Profile through the wall of a "vivier" on the Haute Fagnes Plateau. (Scale of height not exaggerated)

these hollows were formed before the preboreal time. Recent studies have confirmed this age.

The "viviers" have been studied for the first time by the research team of Professor R. Bouilenne working in the Scientific Station of the University of Liège in the Hautes Fagnes. They were the first to make a map of these hollows in the Ardennes with the use not only of the relief but also of the distribution of vegetation; the vegetation on the walls is very different from the rest. They have made several sections in the peat accumulated inside two "viviers" and have made observations in numerous others. This research has shown that inside the peat there are broken tree trunks which have been set out as floors built on piles. These piles are parts of trunks with their rough tips embedded in the mineral ground of the bottom. They were fixed with stones accumulated around them. The buried part of the trunks are burnt.

The presence of human work seems absolutely clear here and is confirmed by the discovery of some flints in the area. First considered as Mousterian and later regarded as Campinian, the conclusion was that a certain number of the "viviers" were inhabited by prehistoric man.

CONCLUSION: INTERPRETATION OF THE HOLLOWS

The Problems Related to these Features

The hollows I have described from Llangurig, Wales, and the "viviers" of the Hautes Fagnes in Belgium are definitely similar in shape and size. They are certainly formed by the same process. I am also certain that the elongated walls of Belgium are due to an associated process, because all the transitions from the rectilinear walls to the circular ones are found (Figure 4.7).

On the other hand, the description I have given in the present paper proves definitely the natural genesis of these features: the arched stratification of a rampart in Wales is an unquestionable trace of a natural action. In 1956, when we proposed for the first time a periglacial origin for the "viviers", we did not have an undisputable argument to reject a human genesis. Furthermore we had only the lack of proportion between the enormous work to excavate the "viviers" and the level of technology of the Stone Age as an argument.

The natural processes which have formed the hollows described include the appearance, the growing and the melting of ice in the ground. Figure 4.11 gives a present-day example of one of these ice lenses observed by J.R. Mackay in Canada. After the melting of

Figure 4.11 Pingo eroded by the sea (height 15 feet). Picture taken by J.R. Mackay (Geographical Branch, Mines and Technical Survey, August 1955, near Point Atkinson, NWT, Canada)

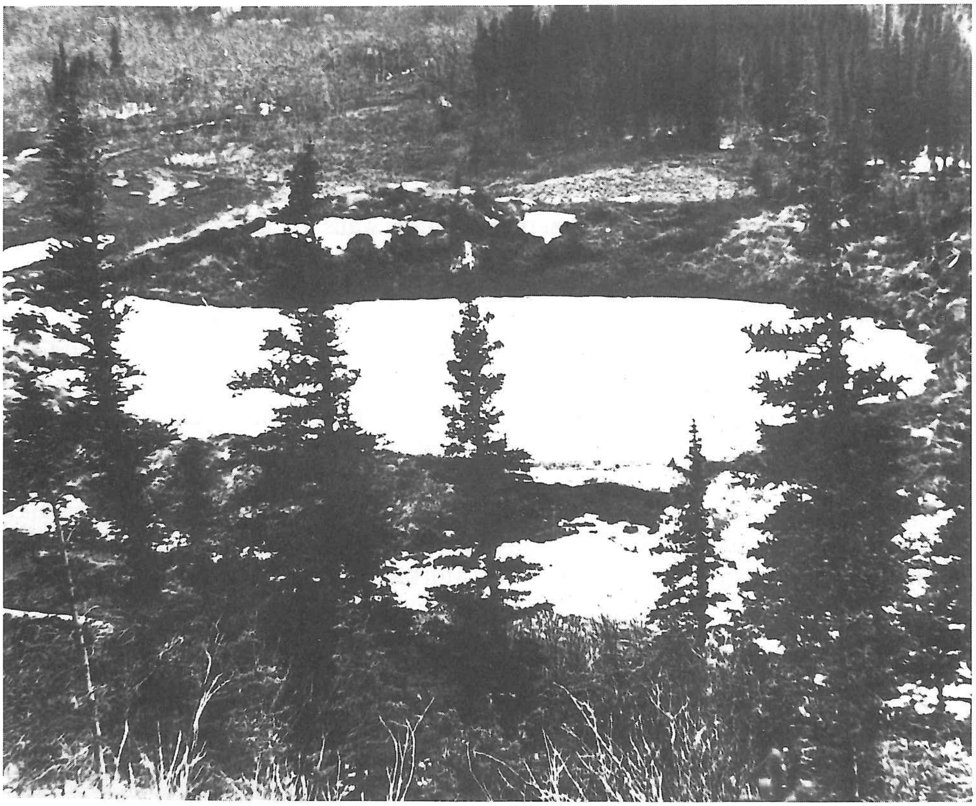

Figure 4.12 Circular hollow with a rim after the melting of a pingo (Black Mountain, Mackenzie Delta, NWT, Canada; Picture J.K. Fraser, National Research Council of Canada)

the ice a circular hollow surrounded by a rim remains. Some similar hollows are known in the arctic countries. We would like to mention the paper of J.K. Fraser (1956) who, with the use of photos reproduced here as Figures 4.12 and 4.13, has described some features comparable to those that we have described in Europe, from the Northwest Territories (Canada). Fraser has interpreted these depressions as pingo remnants and his interpretation is supported by the proximity of several conical mounds with a crater on the top, as shown on Figure 4.14. These mounds seem to be pingos. It is interesting to note that these pingos are outside the coastal plain. They are located on the complex morphology of a landslide in the Richardson Mountains which are 900m higher than the Mackenzie Delta. The majority of present-day pingos are described from coastal or fluvial plains. Fraser's paper describing pingos located on a complex morphology shows that these features also appear on slopes.

The pingos located on the Mackenzie Delta have been studied on aerial photographs by J.K. Stager (1956). After seeing 1380 pingos this author has given statistics about their shape, their size and their location. On a map, 71% are round, 20% ovals and 9% irregular. If we consider the scars in the Hautes Fagnes, the percentages of these categories were different. The round forms are only a minority here, while the irregular forms are certainly more numerous. However this difference appears easy to explain

Figure 4.13 Wall of a pingo remnant (Black Mountain, Mackenzie Delta, NWT, Canada; Picture J.K. Fraser, National Research Council of Canada)

because it must be the slope factor which does not affect the flat surface of the Mackenzie Delta. If, on the Hautes Fagnes Plateau, we considered only the "viviers" located on horizontal surfaces, the percentage of rounded forms would also be very high. Among the irregular forms of Stager, there are not only triangular forms and very irregular forms, but also long elongated hills. This last type of pingo is probably comparable to those which have produced the elongated walls in the Hautes Fagnes.

Because the present-day pingos are only found in countries with a very cold climate, they are not yet well known. For this reason it is interesting to underline the observations we have made in Belgium and in Wales about the depth of the hollows. This depth must be very great and we have, for example, a value of 8m for an internal diameter of 45m. This observation is not in agreement with the paper of J. Corbel (1961) who suggests that, after the melting, a crater exists only under the walls and does not go below the original surface. This opinion is surprising because it seems clear that the materials accumulated in the walls are coming from the places where the mound was growing and that a deficit in material must exist there.

On the other hand, the sections through the ramparts that we had the opportunity to see, are of great interest. They give information on the growth of the ice core and

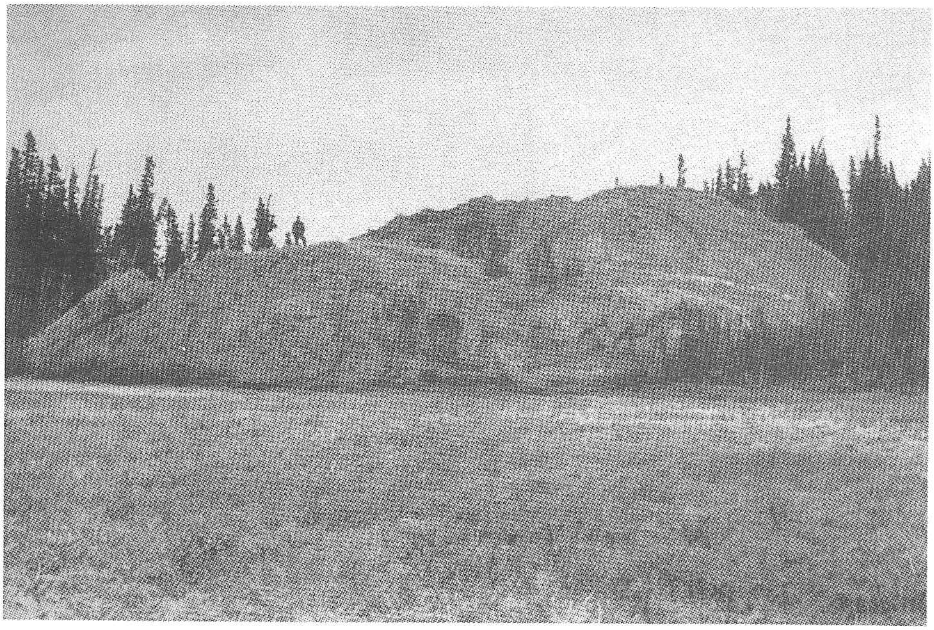

Figure 4.14 A present-day pingo in the country where Figures 4.11, 4.12 and 4.13 were taken. (Picture J.K. Fraser, National Research Council of Canada)

on the genesis of the rampart. The arched shape of the stratification (Figure 4.4) which was observed near Llangurig may be explained only by the collapse of beds following the melting of sediments which have been laterally pushed during the growth of the pingo (Figure 4.15). In Wales, the sediments displaced by the ice were not observed; on the Hautes Fagnes Plateau, the occurrence of numerous vertical stones in the central part of the walls seems to represent this compressed zone (Figure 4.10).

From this observation, we may conclude:

1. The ice lenses grow not only at the base of the mound but also from its sides.
2. The walls of the pingo remnants result only partly from the flowing of the ground which was above the ice. The importance of each of these processes (lateral pushing at depth and superficial movement) is surely not the same for all the features.

Let us see if these observations are in agreement with the descriptions given by scientists who have studied the present-day phenomena. The best descriptions are those found in the book of Shumskii (1955). Because this Russian work is not yet well known, we will give here some excerpts related to the present study:

> The ice injections are formed under pressure along layers of impervious rocks. The pressure of the water which displaces the sediments may have two origins. Sometimes the freezing reduces the flowing of deep waters and builds barriers of impervious frozen layers. In this case, the freezing has only passive action and the origin of the pressure is the hydraulic pressure of the flow of water. In other situations, the freezing gives a closed system, whereby a certain volume of pervious rock which contains water is surrounded with impervious material; if the empty voids are not sufficient to absorb

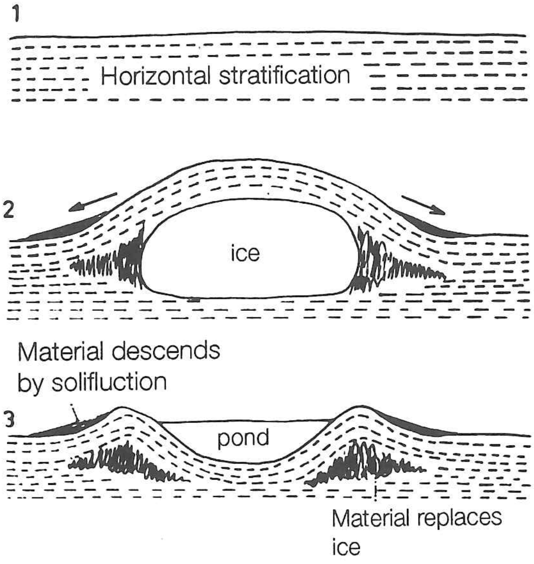

Figure 4.15 Sketch showing the probable double origin (surface solifluction and lateral pushing at depth) of the walls which remain after the melting of the ice

> the growing in volume of the water becoming ice, a great pressure results from the freezing itself. The water under a growing pressure flows in the direction of the lowest resistance; this is to say, to the direction where the thickness of the upper layer is thinner. The water under pressure pulls up the frozen substratum from the unfrozen one, building a lens of water which will later be frozen. If the upper layer is very rigid, or if it is not strongly connected with the bedrock below, a flat intrusive layer will appear. On the contrary, the upheaved roof will be bent strongly and a mound with a convex ice core giving the formation of a laccolith, will appear. It is the relation between the rigidity of the frozen ground and its anchorage at the base, and also the amount of existing water which will determine if intrusive layers of ice, or lenses with a marked convexity (cores of laccolith), or intermediary shapes of ice lenses, will appear. If the flow of water is too important, the roof will be broken and, on the top of the mound, some fissures will appear from which water will flow onto the surface: the laccolith then becomes a hydrovolcano or a mud volcano . . .

Shumskii studies later injections of ice which are growing in the active layer. He shows that there is no agreement about the mechanisms of genesis and that some authors believe that the injections appear through closed systems, while for others they appear as a result of the freezing of surface water. For him, both these systems exist . . .

> The multiannual injection of ice, resulting from the freezing of unfrozen ground under dried lakes are the biggest . . . The mounds of this kind are known under the yakutsk name of "boulgouniakh" which has the same meaning as the eskimo name of "pingo". Pingos grow gradually in frozen lacustrine hollows over long periods of time. They grow with a speed which may be very low or may reach a maximum of 10.5m a year. Usually their height is between a few metres and 20 or 25m. In the Arctic, their height may reach 40 or 70m. In some alluvial plains, the big pingos are higher than the highest summits of the neighbourhood. In diameter, they may reach

> several hundreds of metres. The mineral cover of the ice has a thickness between 2 and 8m; the bottom of the ice core ordinarily lies between 5 and 10m below the surrounding surface of the ground. Usually they appear in alluvial deposits and the injection ice of their core is between the clayey/sandy deposits of the valley and the sands and pebbles which lie below. The displacement of the waters which produces the pingo usually occurs almost entirely in the pervious deposits of the river . . .
> The growing mounds are held up by the aquiferous non-frozen rocks. Usually the water is under pressure . . .

All this information is easily applied to the features that I have described in Wales. The depth of the hollows, the fluvial material with pervious and impervious layers in superposition, the possibility of catching a relatively large amount of water in the openwork material, all correspond to the description of Shumskii. However, the situation is not the same for the "viviers" of Hautes Fagnes where the soft cover is usually impervious. Here it is difficult to understand from where the water came. It is not possible that these features have developed quickly during a sudden cooling, because the amount of water which was in the ground was not sufficient to build them. On the other hand, the intricate pattern of the walls in several places indicates the successive growing of the mounds. It is consequently necessary to envisage ice lens growth from superficial waters penetrating the ground during seasonal thawing. E. Muckenhausen (1960) shares the same opinion when he states that the elongated pingos are produced by the feeding of the upper part (up slope) of the ice core, giving a development of the mound in this direction. I also believe in this mechanism, without being able to explain in detail how it has worked. This theory does not only necessitate a feeding similar to the one which gives the seasonal mounds but also a multiannual process of injection to give the extremely large features of which we now see the remnants. It seems clear that we have here a formation process which does not correspond to Shumskii's description given above.

The palaeoclimatic implications of these pingo remnants were underlined by J. Corbel in 1961. These features appear under very cold climatic conditions. According to Corbel the present-day pingos are located in places where the mean temperature of the coldest month is below −20°C, where the mean annual temperature is between −10 and −15°C and where the annual mean precipitation is around 200mm. Furthermore, Corbel writes that the growing of pingos in the western part of Europe is not possible, because it would mean that the mean annual temperature change was as great as 22°C, that is to say a climatic change without comparison in the geological history. This shows the importance of the features I have described here. They have the characteristics of typical pingo remnants, which, according to J. Corbel himself, are circular rims and a stratification in these rims (Wales). I must add in conclusion that the cold climate which is necessary for the growing of these features had to be present at the end of the Würm time, as is demonstrated by the youth of the morphology and the palynological studies of Professor Mullenders and Miss Trotmann.