Observations of Open System Pingos in a Marsh Environment, Mellemfjord, Disko, Central West Greenland

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The purpose of this note is to draw attention to the special topographic setting of some pingos observed in Mellemfjord (Greenlandic: Akugdlît), Disko Island, Central West Greenland. The geomorphology of the area is presented as an important base for the development of the pingos, as they are not typical open system pingos. Using evidence on sea level and general climatic change, the pingos are tentatively dated to have been developed during the Little Ice Age cold climate period.

Keywords: *Marsh initiated pingos, Greenland, Disko, periglacial phenomena*

The investigated small hills positioned in a braided river environment in Mellemfjord have previously been described as "mud volcanoes" (Nielsen, 1980) formed by rising gases of methane seeping up from coal layers below. The name is derived from the fact that the form of the hills is like small volcanoes, reminding of the volcanic origin of the Tertiary basalt mountains of Disko (Nielsen, 1980). Previously Noe-Nygaard & Rosenkrantz (1950) have described the occurrence of these mud volcanoes (Danish: dyndvulkaner) in West Greenland on the peninsulas of Svartenhuk and Nugssuaq and on the Disko Island and explained their genesis as Nielsen (1980) did. Generally the mud volcanoes on Disko Island are known to exist in the bottom of large fluvially dominated flat valleys (Noe-Nygaard & Rosenkrantz,1950).

Generally two types of pingos are accepted: 1) the closed system pingo and 2) the open system pingo (French,1976). One of the latest definitions of pingos given by Pissart (1988) defines a pingo as a multiannual icecored 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. Müller (1959) generally interprets pingos in West Greenland as being of the same type as the East Greenland (open system) pingos.

The aim of this paper is to draw attention to the special character and position of the mud volcanoes in Mellemfjord obtained by combining geomorphological observations.

Environmental Setting

The observed small hills are positioned in Mellemfjord, a 25 km long fjord on the central west coast of the Disko

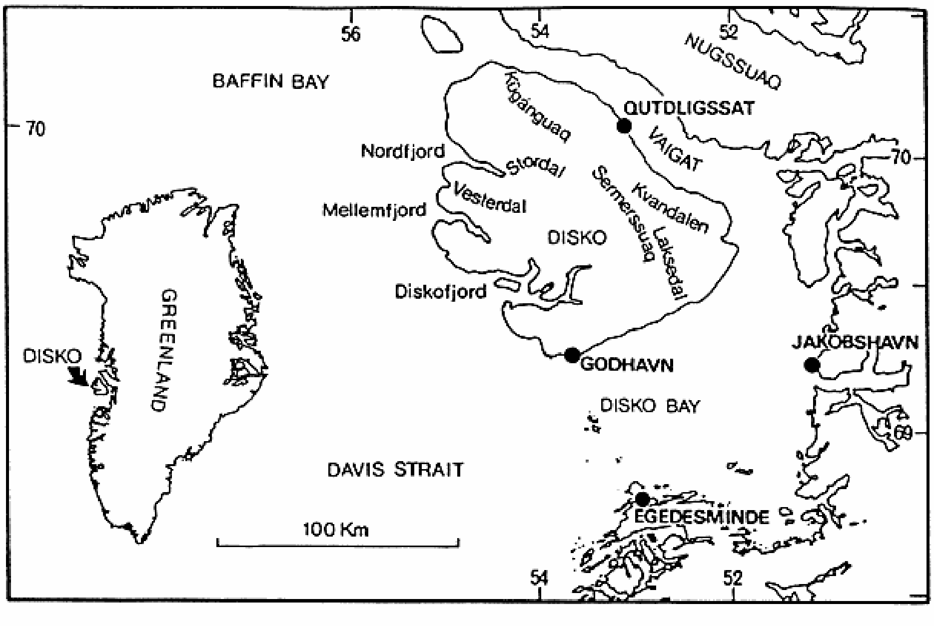

Figure 1: Mellemfjord on Disko in Central West Greenland.

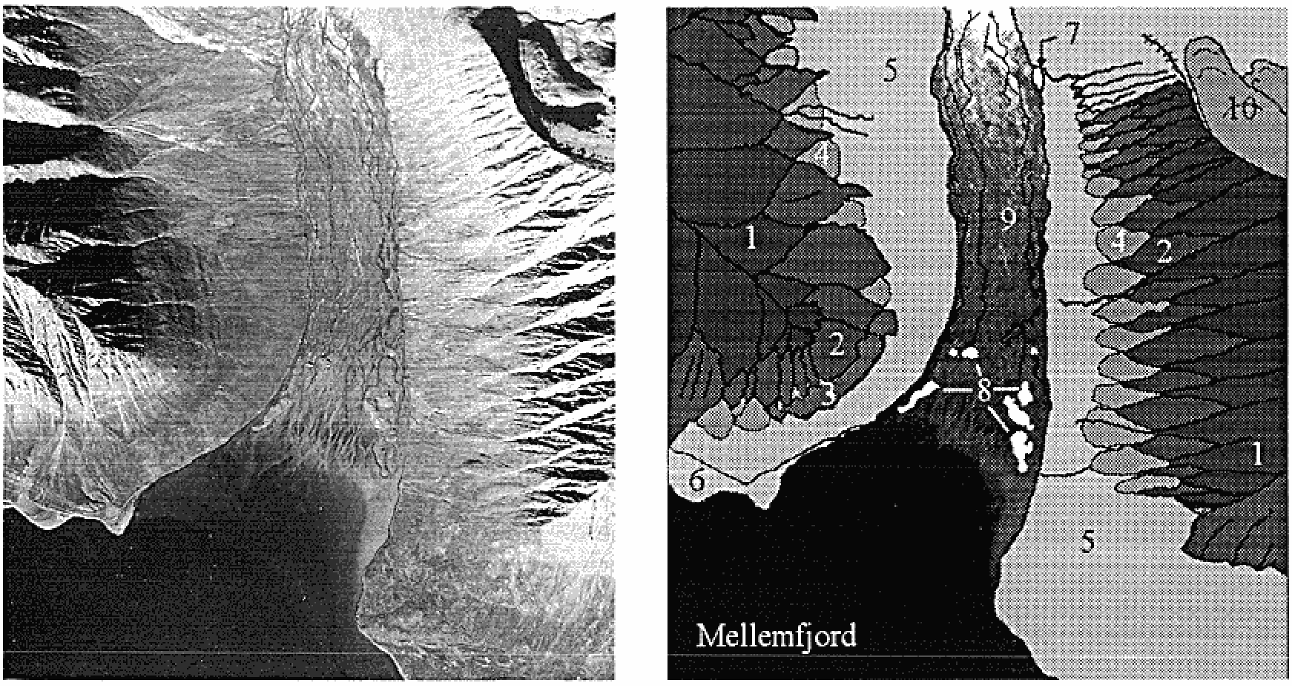

***Figure 2:** Aerial photograph (27.08.1964) and geomorphological map of the Iterdlagssûp kûgssua valley area. North is upwards. The valley is approximately 600 m wide at the mouth where the pingos are situated. The Iterdlagssûp kûgssua valley is surrounded by 1 ravines, 2 basalt valley side, 3 solifluction lobes, 4 talus cones, 5 lower valley side with solifluction, soil creep and sheet flows and 6 raised marine terraces. An icing 7 and marsh flats 8, where the pingo remnants occur, are present in the valley bottom 9. A glacier-derived rock glacier 10 leads to the upper parts of the valley.*

Island (Figure 1). The fjord is a large estuary running in an NW-SE direction. Along the sides of the fjord Tertiary plateau basalt mountains reach 1000 m asl. The landscape is alpine and characterised by cirques and U-shaped valleys, some of which are partly filled by glaciers. Several active talus-derived and glacier-derived rock glaciers (Humlum,1988) characterise the slopes of the southern side of Mellemfjord.

The mean annual air temperature in the inner part of Mellemfjord is -7.8° C (1993-1994), measured at a meteorological station positioned close to the investigated small hills (Humlum et al.,1995).

This means that the area is located in the zone of continuous permafrost. In Mellemfjord the precipitation is not measured, but in Godhavn the annual precipitation is around 400 mm (Humlum et al.,1995).

During the maximum Wisconsin glaciation, called the Godhavn Stage (Ingolfsson et al.,1990), Mellemfjord was filled by an extensive valley glacier (Donner,1978). The deglaciation of the inner part of the Mellemfjord area took place about 8,000 BP (Donner,1978), while the outer coast was deglaciated prior to 9,100 BP (Ingolfsson et al.,1990). Sea level was highest between 9,250 and 9,000 BP forming the highest marine limit at about 55 m asl. at Enoks Havn in the Mellemfjord area (Ingolfsson et al.,1990).

In the inner part of the fjord a tributary valley, Iterdlagssûp kûgssua, coming from the north, ends in Mellemfjord. This valley is the largest leading to Mellemfjord. It has a flat bottom with a braided glaciofluvial river system (Figure 2) draining several glaciers in the upper part of the valley. A delta of approximately 1 km² is built into Mellemfjord south of the valley and this place is called Iterdlagssuaq. The deltaic tidal area, which is covered by fine grained sediments, is nearly flat with an inclination of only a few ‰ and ends with a steep delta front sloping towards the bottom of Mellemfjord.

Close to the front of the delta the tidewater range is maximally around 2.5 m, which makes the estuary microtidal, probably with a saltwedge, as there is a relatively large inflow of river water (Pethick,1984).

When the Iterdlagssûp kûgssua valley was first exposed during the deglaciation of the inner part of Mellemfjord around 8,000 BP, the valley was a fjord that ended further up in the valley as sedimentation in the valley had just started. At the same time sea level was approximately 50 m higher than the present according to the emergence curve presented by Ingolfsson et al. (1990).

By glaciofluvial sedimentation going on since deglaciation, the inner parts of Mellemfjord have been converted to the Iterdlagssûp kûgssua valley, moving the deltafront to its present maximal position towards the south. In the same period sea level dropped because of isostatic rebound and probably reached its lowest position below the present sea level. According to a ^{14}C dating of a whalebone found at the Enoks Havn area in the outer part of Mellemfjord, the sea level was roughly 2 m below the present sea level at about 2,750 ± 180 years BP (Bojsen & Jacobsen,1979).

The Iterdlagssûp Kûgssua Pingos

At the interface between the inner part of the delta and the glaciofluvially dominated part of the valley, one circular dome and several remnants of domes rising approximately 5 to 10 m asl. can be seen (Figure 2). The diameter of the hills varies from about 20 to 50 m. Most of them display fluvially eroded slopes, leaving only parts of earlier larger forms. As digging in the hills demonstrated the existence of solid ice cores beneath updomed fluvial sand, these forms are considered as pingo remnants.

In the 600 m wide flat-bottomed Iterdlagssûp kûgssua valley the pingo remnants are found on the highest parts of marsh flats (Figure 3), which are sparsely covered by salt-tolerant vegetation. On the marsh flats some fossil dry shallow channels that drained the mudflats during their deposition can be seen (Figure 4).

Fluvial dissection of the pingos is causing slumping of their sides (Figure 5). At the slump scars massive and segregated ice was found about 0.5 m below the surfaces of the pingos. The covering material of the pingos was predominantly fluvial sand deposited by the glaciofluvial rivers of the Iterdlagssûp kûgssua valley.

In one particular pingo a central depression, partly filled with a lake, likewise had a core of massive ice 0.5 m below the slumping inner side. The salinity of the water in the lake in the central depression was measured to be 0.12 ‰, while the value for the glaciofluvial river was 0.05 ‰. In Mellemfjord the salinity of the water was measured to be 29 ‰, which is normal for sea water in the Arctic during the summer (Kiilerich,1965).

Figure 3: Pingo remnants in the Iterdlagssûp kûgssua valley bottom located on the highest marsh flats. The valley bottom is approximately 600 m wide. Seen towards the east. 21.08.93.

Figure 4: Channel on marsh flat, which was active earlier as the marsh plain was accumulating. Today the channel is covered by vegetation. Seen towards the east. 21.08.93.

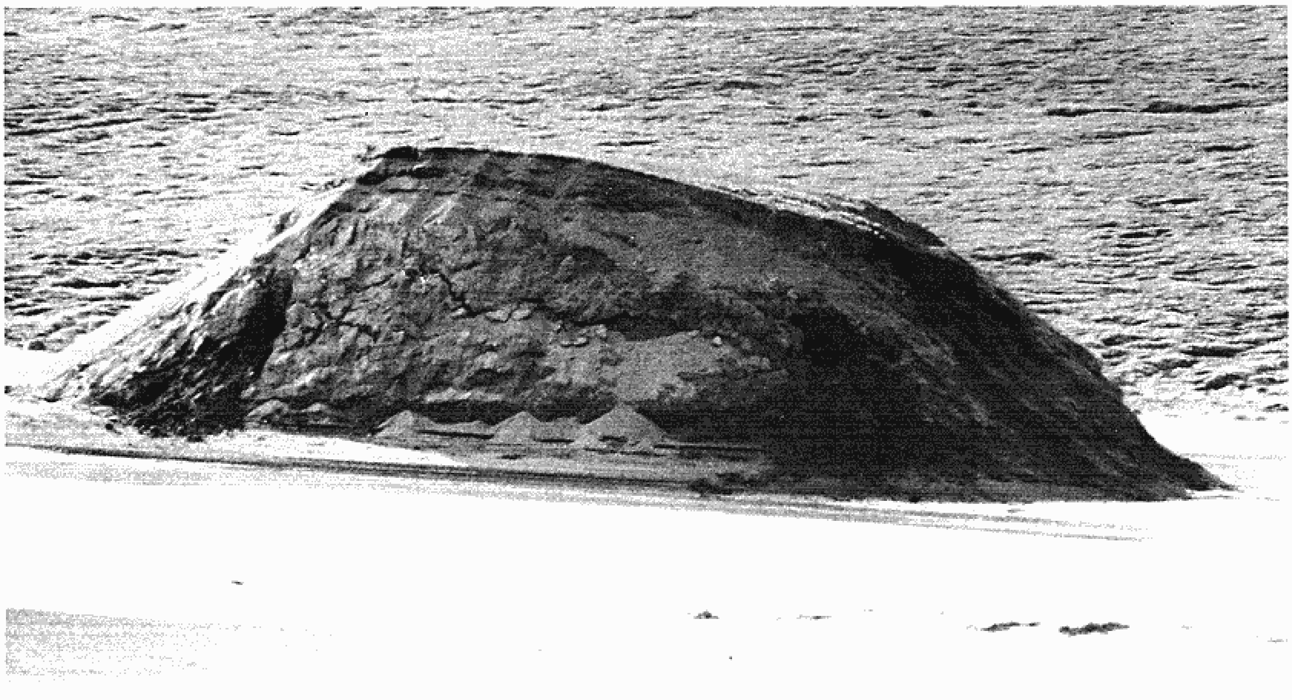

Figure 5: Fluvially eroded pingo remnant with a fluvial channel below the active slumping side. The pingo remnant is about 5 m high. 21.08.93.

According to these observations the massive ice bodies of the described hills in the Iterdlagssûp kûgssua valley mouth are clearly pingo ice as defined by Pissart (1988).

Genesis of the Pingos

The number of pingos in the Iterdlagssûp kûgssua valley mouth is considerable compared to other locations in West Greenland where normally only one or two pingos are found. Recently Yoshikawa (1991) has described two pingos from the Sarqaq Valley, 100 km to the east of the study area, on the Nûgssuaq Peninsula, but he did, however, not discuss their genesis in detail.

If the investigated pingos were "mud volcanoes", one could expect their positions to be more casual and scattered in the valley and not confined to a specific area across the valley on the interface between the deltaic and fluvial parts.

The pingos are probably not of the closed system type as their position and evolution are not controlled by the presence of former lakes. In the Iterdlagssûp kûgssua valley bottom the permafrost is not suspected to be very thick opposed to what is generally described for closed system pingos (Pissart,1988).

Most of the Greenlandic pingos are characterised as being of the open system type (Müller, 1959). The Iterdlagssûp kûgssua valley pingos, however, cannot be characterised as typical for the open system type as they are not found in the lower part of the valley plain, but actually on the highest parts of the marsh flats. Their location some distance away from the valley sides shows that they are not dependent on water coming from the sides, but obviously on water coming from the valley. Finally the observed pingos are not seasonal frost mounds because of their size and their long existence in the valley. They can be seen in the valley on old aerial photographs from 1964 clearly stressing their perennial existence.

The pingos of the Iterdlagssûp kûgssua valley occur only on the slightly higher marsh flats and this position gives crucial clues as to their genesis. The marsh formation probably started when the bars were raised by fluvial sedimentation just above the mean daily high-water level and became mudflats. On the most elevated and well-drained parts of the marsh flats, frost penetration must have been more pronounced and lasted for longer periods than was the case for the surrounding lower and more water-soaked areas. Each year this must especially have been the case during the early autumn, when the surrounding fluvial surface was still unfrozen, while the higher parts of the marsh flats must have been frozen relatively early.

The measurements of pingo water salinity show that the ice that constitutes the frozen core of the pingos is fresh. Therefore the water must have been coming from the glaciofluvially interjacent channels or from the glaciofluvial sediment now positioned over the pingos.

In the late autumn and early winter the valley bottom is covered by a growing icing. During a 1993 summer visit rests of an icing were still present in the valley and rests of an icing can also be seen on aerial photographs showing the area in different previous years, one shown in Figure 2. As the embryonic pingos grew high enough to protrude the icing during the winter and the spring, the wind must have been sweeping the pingos free of snow, improving frost penetration, which had a positive feedback effect on the pingo growth.

The relatively high level of the marsh flats is thus considered as the main control on the initiation and maintenance of the special sort of pingos found in the Iterdlagssûp kûgssua valley mouth. Therefore, the mud volcanoes could be termed marsh initiated pingos, a special kind of open system pingos.

The Influence of the Local Topography on the Formation of the Pingos

In the Mellemfjord area several other U-shaped valleys have been filled partly by glaciofluvial material and therefore they likewise have a flat fluvially dominated bottom leading to the fjord. Only one other pingo has been recognized from aerial photographs in the innermost valley called Kildedalen or Akugdlît itivnerat. This pingo is located in the valley mouth in a position equal to that of the pingos in the Iterdlagssûp kûgssua valley mouth. In the other valleys leading to Mellemfjord no pingos or remnants of pingos have been found on aerial photographs. In the main valley in the innermost part of Mellemfjord (Kildedalen), several pingos have been described by Donner (1978), the largest being 50 m in diameter and 10 m high. These pingos are indirectly given a maximum age of 5,000 BP by Donner (1978) based on his reconstruction of the sea level curve.

The number of pingos in the Iterdlagssûp kûgssua valley demonstrates that the conditions for the development of marsh flats in this particular valley are more favourable than in any of the other valleys ending in Mellemfjord. There are several controlling conditions on marsh and pingo formation in the Iterdlagssûp kûgssua valley mouth and on the distribution of the pingos in the Mellemfjord area:

1. In the Iterdlagssûp kûgssua valley the delta plain is in a much more protected and sheltered position further inside the valley mouth than in any of the other valleys ending in Mellemfjord, which have recent deltafronts exposed along the Mellemfjord coastline. This gives a wide and more flat delta plain with much better conditions for mudflats and marsh flats to form, just as the marsh flats are well protected against icebergs.

2. The southerly exposure of the Iterdlagssûp kûgssua valley mouth must be crucial for the ability of the mudflats to be vegetated and thereby raised above the mean highwater level to become marsh flats. As the mountains surrounding Mellemfjord are rather high, about 1000 m asl., the Iterdlagssûp kûgssua valley mouth is the only protected valley mouth that is not situated in shadow for longer parts of the day during summer. This gives good conditions for plant immigration and growth on the mudflats, making the transition to marsh flats possible.

3. The Iterdlagssûp kûgssua valley is the largest valley ending in Mellemfjord and has in its upper part several northerly exposed valleys with glaciers ending in the central valley. During the winter large amounts of cold air are flowing from these high tributary valleys through the main valley enhancing frost penetration of the ground at the exposed marsh flats, where the pingos are found.

4. As the Iterdlagssûp kûgssua valley is relatively long with a large area draining to the valley, much sediment is transported to the delta area enabling the establishment of the marsh flats and a large delta plain.

Dating the Pingo Growth

The development of the pingos in the Iterdlagssûp kûgssua valley is closely linked to the geomorphological development of the valley bottom.

Today the pingos are located just above the mean highwater level, meaning that spring tide high-water can still reach the marsh flats surrounding the pingos. This position shows that the pingos must be relatively young, as they have been formed after sea level reached its present position sometime after 2,700 BP.

According to Mackay (1979) the maximum growing rate for a pingo through 5 years is measured to be 0.34 m/yr for a mature pingo. As the pingo grows higher, the growth decreases by the square root of the age (Mackay & Black, 1973). Therefore the Iterdlagssûp kûgssua valley pingos can easily have developed during a rather short time span. The Little Ice Age (1400 to 1900 AD) would probably have offered good conditions for frost penetration enabling the development of the pingos. The pingos from the Iterdlagssûp kûgssua valley are tentatively dated to this period.

Subsequent to the supposed evolution of the pingos during the Little Ice Age, they have been reduced in size by fluvial and thermal erosion. However, as the area is situated in the zone of continuous permafrost, the pingos have been preserved as pingo remnants since the Little Ice Age. If the recent fluvial erosion continues in the Iterdlagssûp kûgssua valley mouth or if sea level rises, the pingos might disappear entirely.

Conclusion

A new term "marsh initated pingos" has been suggested for a special kind of open system pingos located on the highest parts of former mudflats probably developed during the Little Ice Age. Many of the so-called "mud-volcanoes" on Disko Island and in West Greenland might be marsh initiated open system pingos, as their geomorphic setting in the landscape is similar to those described in this paper. If this is true, a new and very sensitive tool for obtaining further knowledge on sea-level change is found, especially if absolute dating of the pingos by the luminescence technique or relative dating by the ^{14}C method can be performed. Simultaneously the position of this sort of pingos can yield further information on the influence of the local topography on pingo growth. Finally the appearance of the pingos in Mellemfjord shows that permafrost is present even in the valley bottom, close to sea level.

Acknowledgements

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References

Bojsen, T. & Jacobsen, P. (1979): ^{14}C datering af hvalknogle. Unpublished report cf. Engraf, A., Nielsen, N., Nielsen, J. & Humlum, O. (eds.) (1980): Arktisk Geomorfologi Enoks Havn, Disko 1978. Københavns Univsersitets Geografiske Centralinstitut, GEO - Noter, Nr. 5.

Donner, J. (1978): Holocene History of the West Coast of Disko, Central West Greenland. Geografiska Annaler 60(A) 1-2, 63-72.

French, H. (1976): The Periglacial Environment. Longman Group Limited London.

Humlum, O (1988): Rock Glacier Appearance Level and Rock Glacier Initiation Line Altitude: A Methodological Approach to the Study of Rock Glaciers. Arctic and Alpine Research, Vol. 20, No. 2, 160-178.

Humlum, O., Jacobsen, B.H., Christiansen, H.H., Rasch, M., Nielsen, N., Hansen, B.U. & Hasholt, B. (1995): Holocene landscape evolution in the Mellemfjord area, Disko Island, Central West Greenland: Preliminary Results. Geografisk Tidsskrift, 95: 28-41.

Ingolfsson, O; Frich, P., Funder, S. & Humlum, O. (1990): Paleoclimatic implications of an early Holocene glacier advance on Disko Island, West Greenland. Boreas, Vol. 19, 297-311.

Kiilerich, A. (1965): Oceanografi. Gjellerup, Copenhagen.

Mackay J.R. (1979): Pingos of the Tuktoyaktuk peninsula area, Northwest Territories. Géographie Physique et Quaternaîre, Vol. 33, No. 1, 3-61.

Mackay, J.R. & Black R.F. (1973): Origin, composition and structure of perennially frozen ground and ground ice: a review, North American Contribution. Second International Conference on Permafrost, National Academy of Science, 185-192.

Müller, F. (1959): Beobachtungen über Pingos. Meddelelser om Grønland, Vol. 154, No. 3, 1-127.

Nielsen, N. (1980): Landskabets storformer i Mellemfjord. In Engraf, A., Nielsen, N., Nielsen, J. & Humlum, O.(eds.) (1980): Arktisk Geomorfologi Enoks Havn, Disko 1978. Københavns Universitets Geografiske Centralinstitut, GEO - Noter, Nr. 5, 14-19.

Noe-Nygaard, A. & Rosenkrantz, A. (1950): Grønlandsbogen. Birket-Smith, K. et al. (eds.), J.H.Schultz forlag, Copenhagen, 85-116.

Pethick, J (1984): An Introduction to Coastal Geomorphology. Edward Arnold, London.

Pissart, A (1988): Pingos: An Overview of the Present State of Knowledge. In Clark, M.J. (ed.) Advances in Periglacial Geomorphology. John Wiley and Sons, New York, 279-297.

Yoshikawa, K. (1991): Age of Growth of Two Pingos, Sarqaq Dalen, West Central Greenland. Permafrost and Periglacial Processes, Vol. 2, 245-252.

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