Polarforschung 64 (3): 109–113, 1994 (erschienen 1996

Growth and Collapse History of Pingos, Kuganguaq, Disko Island, Greenland

By Kenji Yoshikawa[1], Toshio Nakamura[2] and Yaeko Igarashi[3]

Abstract: The growth and collapse history of two pingos located approximately 18 m a.s.l. and 35 m a.s.l. in Kuganguaq, Disko Island, west-central Greenland were examined. The pingos of this area were formed on Tertiary basalt rocks. One of the pingos is located in the middle of an alluvial fan, the other is on a river bed. Both have already collapsed.

The pingo on the river bed had already collapsed at least 3545±60 year BP (^{14}C dating from base of the pond sediments in the pingo crater). Both pingos formed after the sea's retreat as permafrost developed in the newly exposed delta bottom.

Zusammenfassung: Bildung und Zerfall zweier Pingos, ungefähr 18 m bzw. 35 m über dem Meeresspiegel in Kuganguaq, Disko Island, westliches Mittelgrönland werden beschrieben Die Pingos von Disko Island bildeten sich über tertiären Vulkaniten. Einer der Pingos liegt auf einem alluvialen Sedimentfächer, der andere liegt in einem Flußbett; beide sind bereits seit langem zerfallen. Der Zerfall des Fluß-Pingo erfolgte vor mindestens 3540+60 Jahren (^{14}C-Datierung der Seesedimente im Pingokrater). Beide Pingos bildeten sich nach dem Absinken des Meeresspiegels als sich Permafrost-Bedingungen in dem aufgetauchten Deltabereich bildeten.

INTRODUCTION

Pingos are ice-cored hills that grow in permafrost regions. PORSILD (1938) suggested that the word serves as a generic term for the ice-cored hill in permafrost regions. They are either a closed or hydrostatic-system type (where the water source is from porewater expulsion), or an open or hydraulic-system type (where the water source is from a hydraulic head). The pingos in West Greenland are of the open-system type. ROSENKRANTZ (1940, 1942) described pingos in West Greenland as "Mud volcanoes".

Pingos predominate on Disko Island and in the Nugssuaq Peninsula area,West Greenland, and in the Scoresby land area, East Greenland. Both areas are dominated by continuous permafrost (WEIDICK 1975). Almost all pingos are common in areas underlain by Tertiary volcanic rocks in West Geenland.

In East Greenland, pingos are the most striking relief features at the bottom of its valleys. These pingos have been investigated since the 1950s (MÜLLER 1959, CRUICKSHANK & COLHOUN 1965, WASHBURN 1969, O'BRIEN 1971 etc.). A thorough investigation was made of two typical pingo types in the Mackenzie Delta and in East Greenland and a morphogenetic explanation of these pingos were given in a report by MÜLLER (1959).

LIESTØL (1977) described the origin of the open-system pingo in Spitsbergen as resulting from the warm based local glacier water through the underground moving towards the coast through the sub-permafrost layer. The glaciers in Spitsbergen exhibit surging behavior, where a lot of water exists at the bottom of the glacier. There is surging behavior of some of the glaciers in the Tertiary bed rock region of Disko Island. Pingos in Disko Island were possibly from a similar origin as the Spitsbergen's pingos.

The Disko Bay area became ice-free at a relatively early stage, around 10,000 years BP. Glaciers retreated from large fjords of Nordfjord, Mellemfjord and Diskofjord at 8,000 years BP (DONNER 1978). However, there are local glaciers in this area. The period when local glaciers retreated and the sea transgressed to the marine limit was between 9,250-9,000 years BP in the coastal area of northwest Disko Island (INGOLFSSON et al. 1990). The northern part of Disko Bay has not been influenced by glacial re-advancement compared to the southern part since the Fjord stage (about 9,000 years BP) from a geomorphologic feature. The topography is distinctly non-glacial, small valleys possessing a characteristic V-shaped cross profile, and there is a marine terrace in Kuganguaq in the northern part of Disko Island, that was reported to be 60 m above mean sea level (INGOLFSSON et al. 1990).

The purpose of this paper is to discuss pingo growth conditions and the age for pingo growth and collapse in the Kuganguaq. The observations recorded in this report were made during the summers of 1992,1993 and 1995. Field work was carried out by boat from Sarqaq village. The two pingos studied were the Delta and Fan pingos, which are located in the Kuganguaq delta area (Fig. 1).

METHODS

Offshore, onshore and land permafrost conditions were monitored at the mouth of Sarqaq dalen and Vaigat (Fig. 1). In Sarqaq Dalen, there is another pingo in the delta of Sarqaq dalen. The mean annual temperature of the ground (tundra) at the valley floor was measured to be -6.7 °C (1.5 m above sea level), which is just beside the mouth of Sarqaq dalen, 20 m from shore line. The sub sea ground temperature was at -2.7 °C (1 m below sea level) 30 m from the shore (1992-1993) by data-logger (Hakusan Corporation DM-3000; Fig. 2). Delta permafrost is thought to be of similar condition between Kuganguaq and Sar-

[1] Kenji Yoshikawa, Graduate School of Environmental Science, Hokkaido University, Sapporo 060 Japan.
[2] Toshio Nakamura, Dating and Materials Research Center, Nagoya University, Nagoya 442 Japan.
[3] Yaeko Igarashi, Earth Science Hokkaido University, Sapporo 060 Japan.
Manuscript received 13 June 1996; accepted 14 August 1996.

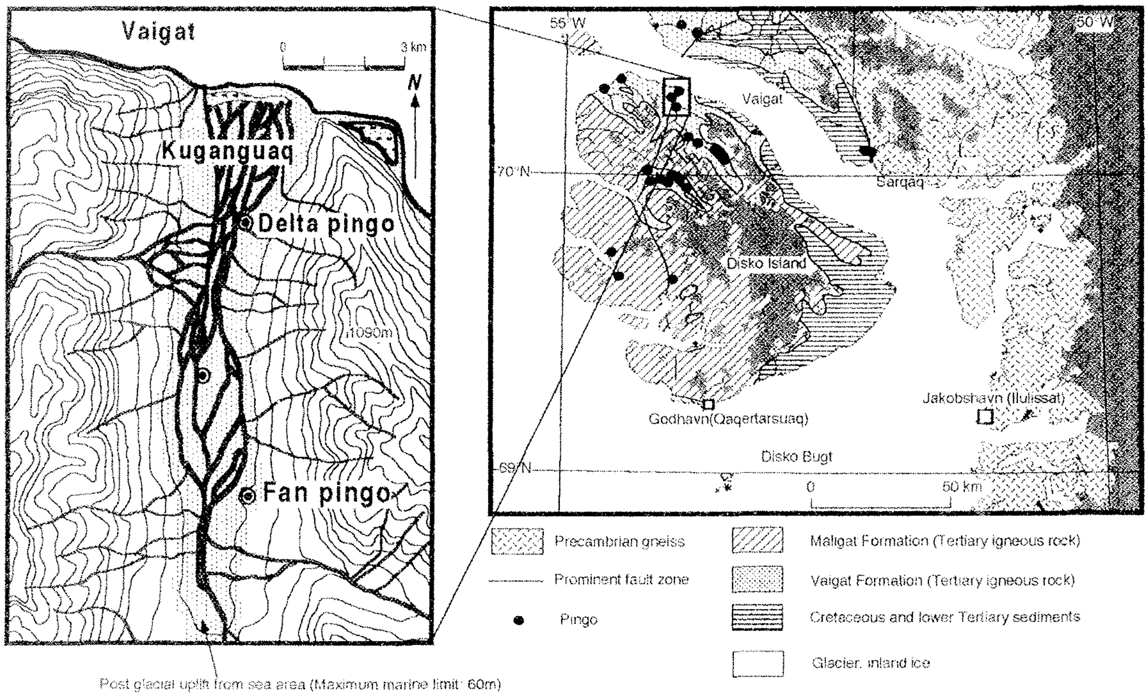

Fig. 1: Location map of study area and setting of investigated pingos (Geology after PEDERSEN 1985).

Abb. 1: Arbeitsgebiet und Lage der untersuchten Pingos (Geologie nach PEDERSEN 1985).

qaq in the same Vaigat area. Since the ground temperature is lower than the delta bottom temperature. As the sea level changes and retreats, new permafrost is formed in the area which was once the delta bottom.

The thickness of permafrost was reported to be about 150- 200 m at Disko Bay area near Jakobshavn (Ilulissat) (IRMEN-CHRISTENSEN & MAI 1988). However, the depth of permafrost was 14.5 m by electrical resistivity sounding at one of the marshes of Jakobshavn (Ilulissat) near the southern cemetery. Permafrost thickness varies with the location. Especially in the river bed permafrost is thin. From electrical sounding, three different layers of ground resistivity were obtained by numerical calculations. The first layer, 220 ohm-m and 0.45 m, corresponded to an active layer which was measured by digging down to 0.45 m (September 29, 1995). The second layer had a resistivity value 5700 ohm-m. At the third layer, resistivity was low again (500 ohm-m). The soil structure was not different between the second and third layers, but the resistivity measurements at depths of 14.5 m dropped again because of the temperature differences in the frozen and unfrozen ground.

Water sampling was carried out from both pingo ponds for the $\partial^{18}O$, electric conductivity, pH and chemical analyses on July 28, 1993. The water samples were brought back to Japan and analyzed at the laboratory. $\partial^{18}O$ analyses were done by the National Institute of Polar Research, Tokyo. Other examinations were done by the Institute of Low Temperature Science, Hokkai-

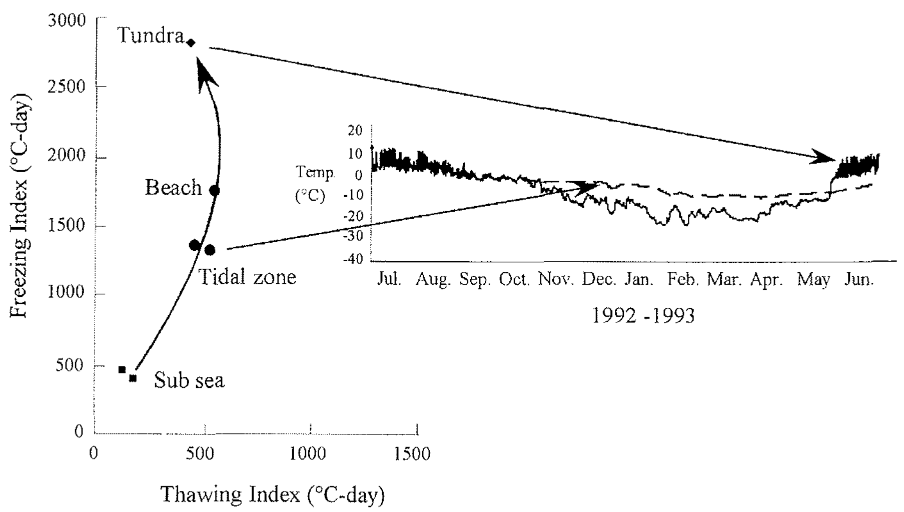

Fig. 2: Ground temperature (-5 cm) variation at the mouth of Sarqaq Dalen and freezing versus thawing index relationship with sea level.

Abb. 2: Variation der Tiefentemperatur an der Mündung des Sarqaq Dalen und Frost- versus Tauindex in Beziehung zum Meeresspiegel.

do University. Carbon dating samples were collected from base of the pond deposits and pingo slope of the Delta pingo. Carbon dating was done by the Dating and Materials research Center, Nagoya University.

FIELD SITES

28 pingos or pingo-like mounds are reported in West Greenland, 20 of these are located on Disko Island. Most pingos are located in major river beds and along the coast line on Tertiary rock. Precambrian Gneiss is extensively common in West Greenland.Tertiary volcanic rocks, unconformably overlying the Precambrian Gneiss formation, occur west of Sarqaq Dalen (Nugssuaq peninsula and Disko Island). Pingos are not associated with the Precambrian Gneiss area except of two pingos or pingo-like mounds at the delta and middle of the Isortoqelven. Many of West Greenland's pingos are located on top of Tertiary sedimentary or volcanic rocks. The groundwater table is thought to be high in these areas. Pingos are strongly related to bedrock type, but may as well be influenced by faults. Some pingos are associated with underlying fault zones, like the middle of the Sarqaq Dalen, where the Nugsuaq Peninsula Fault crosses north to south.

Altogether 17 of these mounds are located in the Vaigat Formation area, which consists of early Tertiary volcanic rocks (Fig 1). The forrnation is divided into six members, which were formed by two major igneous events. The maximum thickness of each member is between 10- 800 m (PEDERSEN 1985). The Kuganguaq is located in the northern part of Disko Island (70° 15' N, 53° 55' W, Fig.l).

The Delta pingo is located in the Kuganguaq alluvial plain, which is 2.9 km from the shore. The pingo is about 140 m long, 100 m wide, and 15m high, approximately 18 m above sea level. The Delta pingo has a small deep crater, which is 3 m deep and approximately 15 m in diameter (Fig. 3). A spring or gas vent was not observed from the pingo. The rim part of the Delta pingo crater contains sediment composed of clay with sandy silt (delta material) and pebble with sand (fluvial deposit).

The Delta pingo was formed subsequent to exposure of the land from sea and permafrost formation. Sedimentation continued long after the delta material was deposited. The amount of vegetation in this area is scarce compared with other valleys. The base of the sediment from the pond bottom contains *Potamogetonon pusillu.s,* which has an age of 3280±60 years BP (NUTA-3916) at 2 m below pond bottom and 3540±60 years BP (NUTA-3915) at 1.2 m below pond bottom.

Fan pingo, situated in the middle of the alluvial fan in Harald Moltke Dal, is 100m across, 10 m high, approximately 35 m above sea level, and 6.6 km from the shore. There is a marine terrace and fan around the Fan pingo. Growth of the pingo occured at the same time as the landscape was formed. The pingo is composed of pebble containing fine gravel (alluvial fan deposit). It has no vegetation cover except in the pond. The Fan pingo has a small shallow crater, which is less than 0.5 m deep and approximately 10 m in diameter.

GEOCHEMISTRY AND STABLE ISOTOPE

Water samples were collected from Delta and Fan pingo crater ponds (July 28, 1993) and analyzed for their chemical, pH, and oxygen-isotope compositions (Tab. 1). They show low values of electric conductivity and ions. This suggests that water came from snow and rain, and ions from the atmosphere accumulated over a log period with melt water from the more actively decaying ice core of the pingo. Spring water from sub-permafrost layers, which has high electrical conductivity and ions,

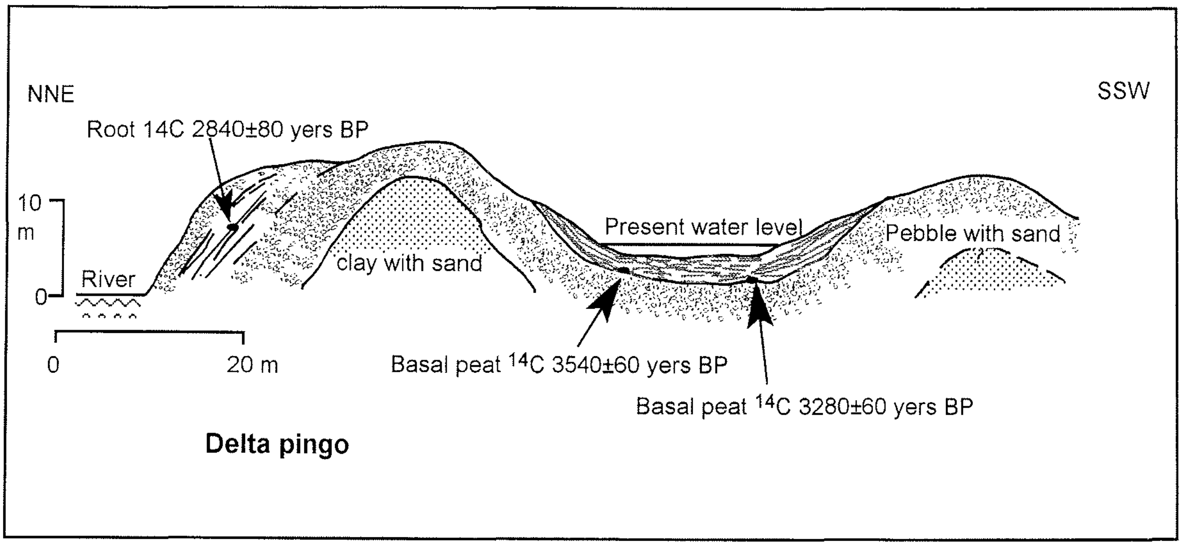

Fig. 3: Profiles of Delta pingo showing sampling locations.

Abb. 3: Schnitt durch den Delta-Pingo und Lage der Probenpunkte.

	Delta pingo	Fan pingo	Fan pingo/Delta pingo
$\delta^{18}O$(‰)	-11.4	-8.0	
pH	7.66	8.51	
EC (μs/cm)	110	266	2.42
HCO_3^-(mg/l)	50.9	129.9	2.55
Cl^-(mg/l)	3.0	14.1	4.70
SO_4^{--}(mg/l)	0.6	0.2	0.33
Na^+(mg/l)	7.0	11.4	1.63
K^+(mg/l)	0.2	1.0	5.00
Ca^+(mg/l)	11.2	12.5	1.12
Mg^+(mg/l)	4.2	30.1	7.17
Na^+/K^+	35.0	11.4	
SO_4^{--}/Cl^-	0.2	0.014	
Sample date	15:00,7/28/93	13:50,7/28/93	

Tab. 1: Results of chemical and isotope analyses.

Tab. 1: Ergebnisse der chemischen und isotopischen Analyse.

should not be connected to pond water. Thus, the pond water conductivity is lower than that of sub-permafrost water. The conductivity and ions of the Fan pingo were higher than the Delta pingo except for SO_4^{2-}.

Measurements of $\partial^{18}O$ in both ponds' water are characteristic of evaporational conditions (Tab. 1). The values of $\partial^{18}O$ are between meteoric water and SMOW (Standard Mean Ocean Water) values. Fan pingo water (-8 ‰) is heavier than Delta pingo water (-11.4 ‰).

DISCUSSION

The Delta pingo started growing later than the Fan pingo and is closer to the present shoreline and approximately 17 m lower than the Fan pingo. The base of the pond sediments contain the remains of the *Potamogeton pusillus*. The carbon dating of these remains was 3540±60 years BP (NUTA-3915). The Delta pingo had already enough water for *Potamogeton pusillus* to grow at 3540±60 years BP. Therefore, pingos must have started to collapse at least 4,000 years ago (Fig.5).

Near shore pingos are reported from Spitsbergen which is an area of glacial rebound (YOSHIKAWA & HARADA 1995). Greenland and Spitsbergen were covered with ice during the last glaciation. Retreat of the valley glaciers, accompanied by subsequent isostatic rebound caused a local sea-level retreat during a time of global sea-level rise. Low-lying and near shore areas covered by recent marine sediments are areas of post-glacial isostatic uplift. These areas now show the youngest permafrost, as they were covered by the sea before isostatic rebound started. The new permafrost layer formed a blocking layer for deeper ground water and created artesian conditions.

Much of the water is believed to originate from the bottom of the glacier. Water circulated through Tertiary bed rocks during a period when local glaciers stopped recessing and re-advancing. This was a good time for pingo formation. Open-system pingos required ground water from the sub-permafrost, which came from meltwater from glaciers or snow. This caused a relatively high groundwater pressure particularly in coastal areas and valley bottoms.

The main factors which influence growth of these pingos are (i) a geological setting with aquifers, (ii) transgression time to form permafrost and (iii) water supply from local glaciers. These pingos formed quickly after the sea's retreat as permafrost developed in the newly exposed delta bottom approximately at 6000-5000 years BP. The Delta pingo then collapsed at least 4000 years BP.

Fig. 4: Northern rim of the Delta pingo (photo K. Yoshikawa, July 23, 1993).

Abb. 4: Nordflanke des Delta-Pingo (K. Yoshikawa, July 23, 1993).

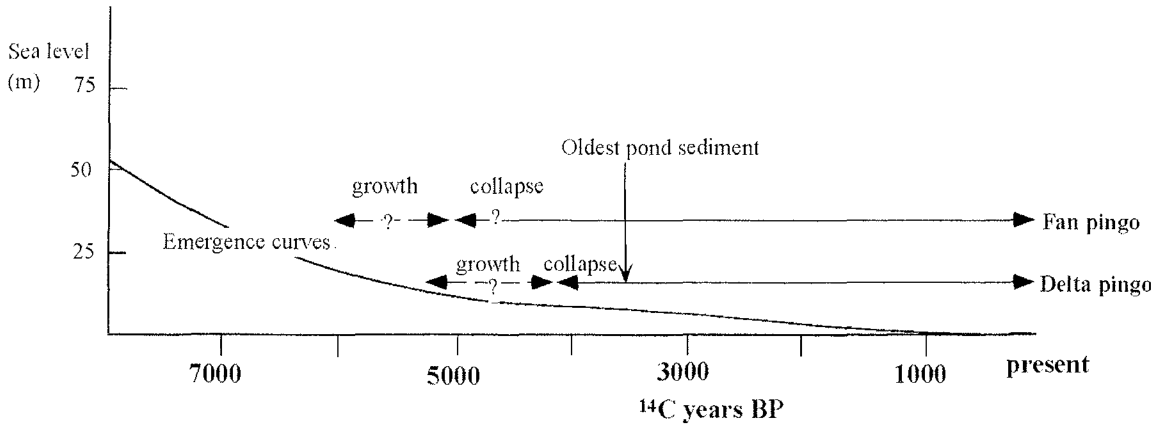

Fig. 5: Evolution of pingos in the Kuganguaq (emergence curve after Ingolfssen et al . 1990).

Abb. 5: Schematische Abfolge der Pingoentwicklung in Kuganguaq (Meeresspiegelkurve nach Ingolfssen et al. 1990).

ACKNOWLEDGMENTS

The authors are very grateful to Professor A. Weidick (Greenland Geological Survey) for his valuable suggestions, and the Greenland Geological Survey for supporting previous studies in this area. We thank Omron Corporation for financial support, and Proffessor Y. Ono, and Mr. K Harada for their advice. Professors O. Watanabe, Y. Fujii and H. Motoyama (National Institute of Polar Research of Japan) for providing $\partial^{18}O$ data. Ms. A. McCord and Dr. A.Chiu helped with editing and revisions.

References

Cruickshank, G.J. & Colhoun, A.E. (1965): Observations on pingos and other landforms in Schuchert dal, Northeast Greenland.- Geogr. Ann. 47A: 224-236.

*Donner, J. (*1978): Holocene history of the west coast of Disko, Central West Greenland.- Geogr. Ann. 60A: 63-72.

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

Irmen-Christensen, M. & Mai, H. (1988): Subsurface temperature predictions for hydropower developments.- Applied Hydrology in the Development of Northern Basins, 7th Northern Research Basins Symposium, Ilulissat, Greenland, pp. 25-34.

Liestøl, O. (1977): Pingos, springs, and permafrost in Spitsbergen.- Norsk Polarinsitutt Årbok 1977: 7-29.

Lysgaard, L. (1969): Grønlands klima.- Danske Meteorol. Inst. Medd. 21: 21 - 33.

Müller, F. (1959): Beobachtungen über Pingos.- Medd. Grønland 153/3: 1-127.

O'Brien, R. (1971): Observations on pingos and permafrost hydrology in Schuchert Dal, N.E. Greenland.- Medd. Grønland, 195/1:1-20.

Pedersen, K.A. (1985): Lithostratigraphy of the Tertiary Vaigat Formation on Disko, central West Greenland.- Report Geol. Surv. Greenland 124.

Porsild, A.E. (1938): Earth mounds in unglaciated arctic northwestern America.- Geogr. Rev. 28: 46-58.

Rosenkrantz, A. (1940): Dan danske Nugssuaq expedition 1939.- Medd. Dansk. Geol. Foren. 9: 653-663.

Rosenkrantz, A. (1942): A geological reconnaissance of the Southern part of the Svartenhuk Peninsula, West Greenland.- Medd. Grønland 135/3: 40-42.

Washburn, A.L. (1969): Weathering, frost action, and patterned ground in the Mesters Vig district, Northeast Greenland.- Medd. Grønland 176/4: 1-303.

Weidick, A. (1975): A review of Quaternary investigations in Greenland.- Ohio State Univ. Inst. Polar Studies Rept. 55 pp. 98-101, pp. 108-109.

Yoshikawa, K. & Harada, K. (1995): Observations on nearshore pingo growth, Adventdalen, Spitsbergen.- Permafrost Periglac. Proc. 6: 361-372.