Permafrost related features in Holsteinsborg district, West Greenland

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Extensive areas of uplifted Holocene marine sediments are covered by permafrost mounds – domes and ridges up to 7 m high, and thermokarst lakes. The domes are related to both open system pingos and palsas but the ridges are of uncertain origin and not hitherto described. They all may be the result of an extension of permafrost in the late Neoglacial following a milder mid Holocene period.

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The coastal area of W. Greenland between 67° and 68° N lies in the zone of discontinuous permafrost, according to Weidick's (1975) compilation of scattered geotechnical and other observations. At Holsteinsborg the mean air temperature is −2.7°C (1961–1965) (Lysgaard, 1969), which can be compared with the limiting value proposed for continuous permafrost of −4°C for Greenland (Weidick, 1975).

However, although permafrost in the area is likely to be discontinuous and thin, morphologic features related to its presence, or its degradation, are common in certain environments – in particular ice cored mounds and associated thermokarst lakes.

Description of features

Mounds of two basic types occur widely on the extensive areas of uplifted fine grained marine sediments which occupy hollows and valley floors below 150 m: circular domes and straight ridges. Other more complex forms such as sinuous ridges and compound domes also occur but can be considered as varieties of these two basic types. All types may occur singly or as fields of one or more types. Their distribution is shown in Fig. 1.

Fig. 2 shows a typical example of a dome from the Nîsip kûa field, 5 m high and 25 m diameter, with characteristic flattened profile, steep sides and circular plan. Often they are surrounded by a low bench, here 0.5 m high by 2 m wide. Active degradation affects some domes, with slumping and flow of material from scars in their sides fed by the melt of the constituent ice. A final stage in this decay process is represented by the circular ponds with raised rims which occur together with the domes (Fig. 3). In the upper Nîsip kûa field

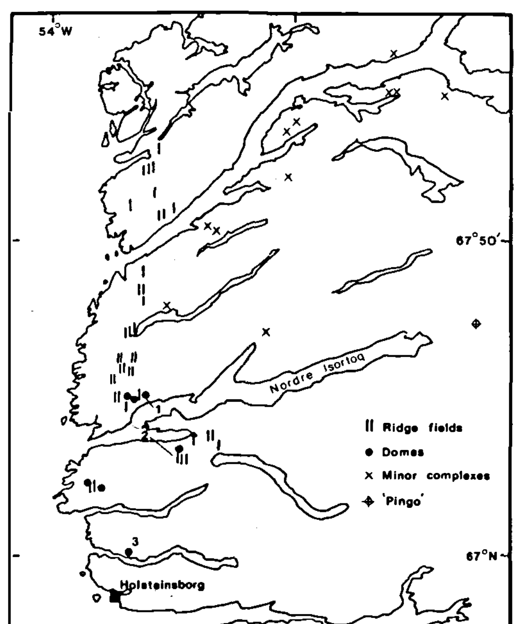

Fig. 1. Distribution of ice cored mounds. All localities also have thermokarst lakes. Location of 'pingo' from Weidick (1974). Locality 1 is Nîsip kûa and locality 2 Isortuarssuk, for 3 see fig. 4.

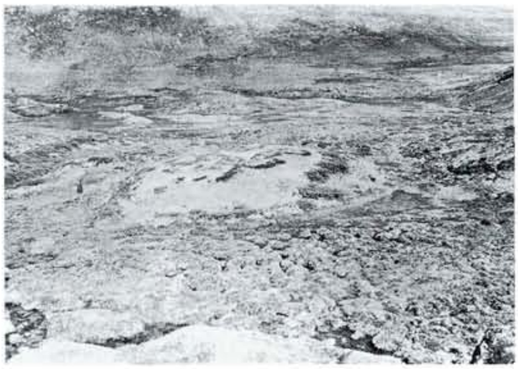

Fig. 2. Ice cored dome, Nîsip kûa (width of dome 25m).

simple domes occur together with complex domes, sinuous ridges and related thermokarst lakes, covering an area of ~ 1 km^2 (Fig. 3). Other similar fields occur lower down this valley.

Exposures in domes in three areas showed a similar basic stratigraphy of peat, up to 2 m thick, on marine silts, with only occasional additional minor components of sand between the peat and silt and/or gyttja layers in the peat (Fig. 4). Ice is present as interstitial ice in the fibrous peat and as frequent thin lenses up to 1 cm thick in the silts.

Straight ridges cover wide areas of marine sediments as sub-parallel ridges, of variable height and spacing, orientated perpendicular to the axis of the main surface drainage system. Figs. 5 & 6 show the field south of Isortuarssuk with ridges up to 5 m high with furrows and ridges up to 60 m wide and 700 m long, covering an area of ~ 3 km^2. The furrows may be either closed or open and utilised by surface drainage. Typically, as here a marginal depression equal to the relief of the ridges separates the mound field from the adjacent hillslope (Fig. 6). This apparently coincides with a change in sediment lithology from silts and sands to till, with the till having a wave washed surface up to the level of the marine limit. A deep exposure at the north end of the field showed 6 m of sands and silts on 24 m of compact clayey silts.

The sinuous ridges (Fig. 3) appear to be a var-

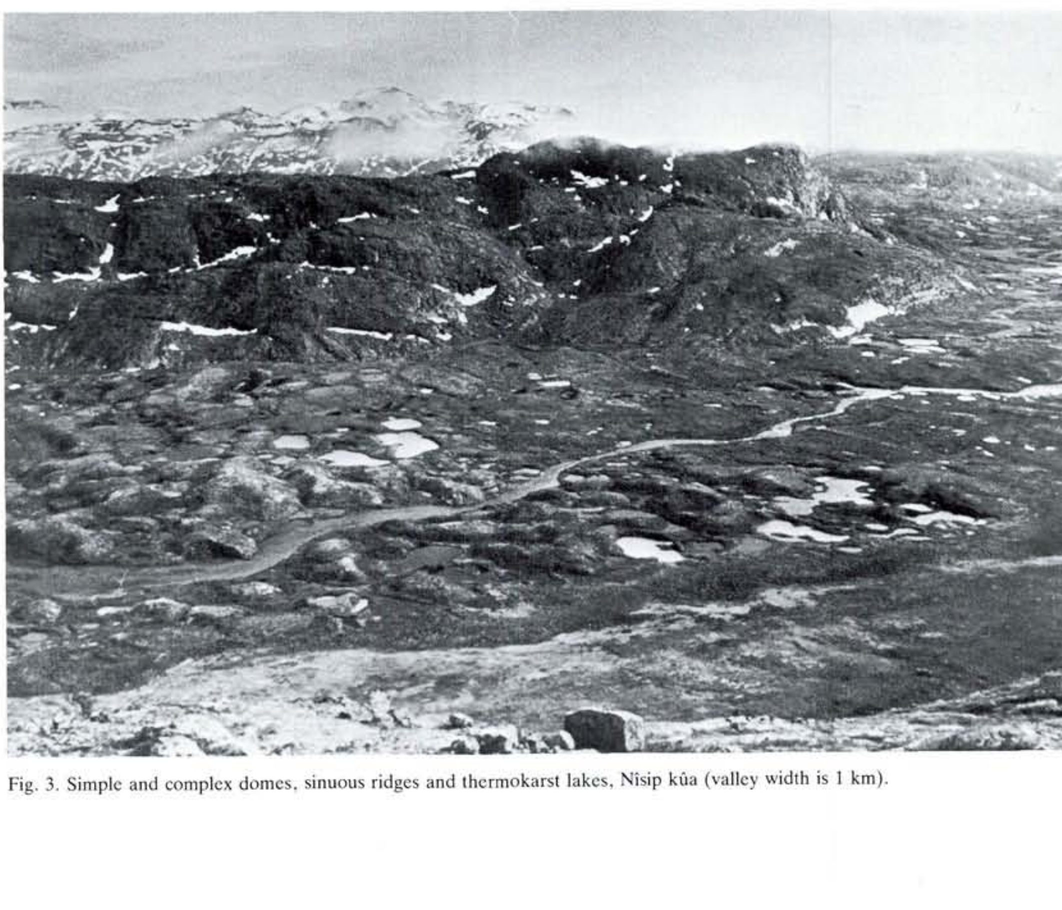

Fig. 3. Simple and complex domes, sinuous ridges and thermokarst lakes, Nîsip kûa (valley width is 1 km).

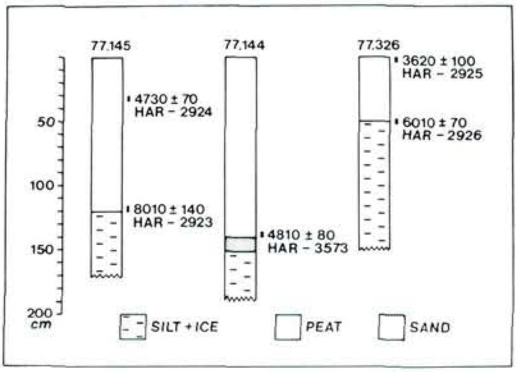

Fig. 4. Radiocarbon dated profiles in ice cored domes. Sites 77, 144 & 145 are from locality 1 and 77 326 from locality 3 (fig. 1).

iant on the straight ridges, although they grade also into other forms which resemble compound domes.

Lakes are a consistent feature of all the mound and ridge fields, including the rimmed circular ponds referred to above, linear ponds between ridges and larger more complex shaped lakes. Their occurrence in marine deposits and their relationship to the domes and ridges suggest that all are thermokarst features formed by the degradation of permafrost. No information is available about their depths.

Origin

On the basis of their scale and stratigraphy the Holsteinsborg ice cored domes appear to belong to a category of features intermediate between pingos and palsas, according to the diagnostic characteristics for these outlined, respectively, by Mackay (1978) and Svensson (1976). Thus they resemble both the minerogenic palsas and minerogenic cored peat palsas of northern Scan-

Fig. 5. Vertical aerial photograph of ice cored ridge field, Isortuarssuk (scale is 1 km). (Section of Geodætisk Institut's aerial photograph 264/S/280. Reproduced with permission (A. 51/81) of Geodætisk Institut, Denmark.)

Fig. 6. Ice cored ridges with marginal depressed zone in the foreground, Isortuarssuk. The ridge is 5 m high.

dinavia (Åhman, 1976; Svensson, 1976) and the smaller, and more common, of the closed system pingos of Northwest Territories, Canada (Mackay, 1979). Since classic palsas occur in subarctic areas with sporadic permafrost, and pingos in arctic thick permafrost regions, the occurrence of transitional types in the discontinuous permafrost zone is not surprising.

The domes may have originated entirely from the formation of the segregated ice lenses seen in the exposures, but could also contain massive segregated or injection ice as in the majority of pingos. Whatever the nature of the ice core it does not seem necessary to invoke an external hydraulic force to aid their growth as in open system pingos, and thus they are closed system, or in Mackay's (1979) terminology, hydrostatic types.

Their relationship with the rimmed ponds suggests that, as with palsas, a cyclical growth and decay of the features is currently occurring. However the radiocarbon dated peat sections suggest that at least some points have seen continuous peat accumulation for over 3,000 years in the mid-Holocene and that development of both the domes and circular ponds is post 3500–4000 B. P. This is not precisely datable, however, because the tops of the sequences are either eroded or contaminated with rootlets.

These small closed system transitional pingos differ from the generally larger pingos already described from Greenland, which are probably all open system types. Thus open system pingos are described from East Greenland by Muller (1959) and O'Brien (1971), whilst in West Greenland Weidick (1974) has mapped 23 pingos in the alluvial valleys of the basalt bedrock areas between 69° and 71° N, which from their situation are also likely to be open system ones. Two other isolated pingos he shows, from the alluvial Nordre Isortoq valley in the eastern part of the Holsteinsborg District, are of uncertain origin.

The ice cored ridges, at least in their frequency, appear to be a much more novel feature than the domes. Isolated palsa ridges (Åhman, 1976) and pingo ridges (Pissart & French, 1977) have been described before but none have the organisation and frequency of the Holsteinsborg examples. No other explanation of their origin than a permafrost related one seems tenable. For example glacio-tectonics can be discounted because of lack of structural and lithologic evidence for it.

That the ridges are ice cored is deduced from the general elevation of the surface of the marine sediment outcrop relative to the depressed marginal zone, as described above. The furrows between the ridges, however, may have two explanations. Either they were created by the elevation of successive ridges, which is implied when considering the latter as types of pingos or palsas; or they are thermokarst features formed by the melting of linear zones in the permafrost of the sediments. The latter would be comparable to the thaw gullies associated with the formation of baydjarakhs in Siberian river terraces (Czudek & Demek, 1970) except that these are due to the melting of ice wedges and ultimately lead to a reticulate relief from the polygonal arrangement of the ice wedges. The occurrence of lakes in furrows could be explained by either mechanism since surface drainage accumulating in the furrows in the summer could eventually lead to the development of talik under them, leading to the accentuation of the relief. This might also be achieved in open furrows on a slope from their utilisation as surface drainage or seepage lines leading to downward erosion of the furrow by creep or wash. Mass movement of the sides of the furrow does take place, which could ultimately lead to the degrading of the ridge.

Whilst there is some evidence of a transition from straight ridges via sinuous over to complex domes which clearly originate as positive structures, the full understanding of the ridges requires further work.

Palaeoclimatic significance

The implication of the radiocarbon dated profiles is that peat accumulated in two of the basins for over 3,000 years in the mid-Holocene and that in these, and at the third dated locality, ice cored domes developed after c. 3500–4500 B.P. If it is legitimate to generalise from this sparse data then the development of both the domes and circular ponds can be seen to be a late Holocene phenomena, suggesting that aggradation of permafrost occurred in the area during the general climatic deterioration of the Neoglacial which began about 3000 – 3500 B.P. (Kelly, 1980).

The permafrost degradation associated with the decay of the domes and pond formation may be an inherent part of a cyclicity in the dome development or it may be related to growing instability in the system due to the climatic warming of this century, put at about 2°C for West Greenland (Weidick, 1975).

Whether this history applies also to the development of the ridges is not known. Certainly the sharpness of their forms implies recent activity, though the climatic significance of that depends upon whether the ridges or the furrows are the active elements.

The mid Holocene climate is considered from the occurrence of thermophilous marine molluscs to have been warmer than at present (Kelly, 1980), at least between 5000 and 6500 B.P. It is likely, therefore, that permafrost then was at best very sporadic in occurrence. However, in the early Holocene after deglaciation of the area at about 10,000 B.P. conditions must have been at least as cold as at present, implying the presence of discontinuous permafrost. Thus in the highest areas of marine sediments, such as Isortuarssuk, Nîsip kûa etc., which were exposed above sea level around 9000 B.P. (Kelly, 1979) permafrost and related surface features should have developed then. It is possible that the ridge fields are inherited from this episode, after which could follow degradation in the mid Holocene and renaissance in the Neoglacial. Surfaces, however, below about 50 m and not exposed before 7000 B.P. would only experience a single episode of permafrost development.

Conclusion

A characteristic suite of permafrost mounds and thermokarst lakes, developed in raised Holocene marine silts and sands, occurs in this part of the discontinuous permafrost zone in West Greenland. The dome shaped mounds are related in form and origin to both palsas and closed system pingos whereas the parallel ridge mounds are of uncertain origin and do not appear to have been described from other areas. In contrast the pingos which have been described previously from Greenland, all of which occur in the continuous permafrost zone, are thought to be open system types. The current Holsteinsborg features are thought to originate from an extension of permafrost in the Neoglacial following the milder mid Holocene when the area was probably only in the sporadic permafrost zone. There may have been an earlier phase of development of such features at the end of the last glaciation.

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Dansk sammendrag

Udstrakte områder i Holsteinsborg området består af hævede holocæne marine sedimenter, der er udformet som permafrost strukturer såsom domer og rygge op til 7 meters højde og thermokarst søer. Domerne er forbundet med pingoer i åbne systemer såvel som med palsaer, mens ryggene er af usikker oprindelse og har ikke tidligere været beskrevet. De kan muligvis skyldes en udstrækning af permafrostområdet i sen neoglacial tid følgende en mildere mellem holocæn periode.

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