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AGE DETERMINATION OF FOSSIL ICE-WEDGE POLYGONS IN NORDIC AREAS

Abstract

In the Nordic areas there are indications of fossil ice-wedge polygons in the ground surface, e.g. as: (1) a pattern of shallow furrows, (2) crop marks in cultivated areas. Where the original ground pattern has been destroyed, the existence of a former polygon pattern is indicated by ice-wedge casts which are observable in vertical sections, for instance in gravel pits.

The paper intends to give a survey of and to discuss applicable methods for dating the formation or fossilization of such ice-wedge polygons. The examples have been chosen from those areas in northern Norway which are included in the excursion program, but experiences from two other areas are also referred to, namely the Swedish west coast and Iceland.

Two aspects are treated in the chronological discussion: relative and absolute dating. For an absolute dating of polygons in coastal areas a reliable shoreline diagram is a very valuable tool. Moreover C-14 datings are a possible means of estimating the age of polygon furrows.

In Iceland, tephro-chronology offers a unique possibility for discussing geomorphological sequences; in this case, not only to determine the age, but also to analyse the material supplied and the structural details at the infilling of frost fissures.

Finally it is pointed out that an age determination of polygon patterns are not only of interest for producing a time scale of ice-wedge development or fossilization, but also to yield information on the climatic conditions prevailing in late-glacial time.

Résumé de l'auteur

Dans les régions septentrionales, la présence de coins de glace fossiles est décelée à la surface du sol par les indices suivants: (1) un réseau de sillons peu profonds, (2) des marques visibles sur photos aériennes dans les champs cultivés. Lorsque le réseau de sol original a été détruit, l'existence d'un réseau polygonal est indiqué par des pseudomorphoses de fentes de gel qui sont observables dans des sections verticales comme, par exemple, dans des gravières.

Le présent papier s'efforce de donner un inventaire et de discuter desméthodes applicables pour dater la formation ou la fossilisation de tels polygones de coins de glace. Les exemples ont été choisis dans ces régions de la Norvège septentrionale qui ont été parcourues par l'excursion mais, il sera question, en outre, de deux autres régions, à savoir la côte occidentale de Suède et l'Islande.

Deux aspects sont traités dans la discussion chronologique, à savoir la datation relative et absolue. Pour une datation absolue des polygones dans une région côtière, l'existence d'un diagramme de l'évolution des lignes de rivage est un outil de très grande valeur. En outre, des datations C-14 sont un autre moyen d'arriver à une estimation de leur âge.

En Islande, la tephrochronologie offre une possibilité unique pour discuter des séquences géomorphologiques; elle peut servir, non seulement à déterminer l'âge, mais aussi à analyser le matériel fourni et les détails structuraux du remplissage des fissures de gel.

Finalement, l'auteur souligne que la détermination de l'âge de réseaux polygonaux est non seulement intéressante pour donner une échelle de temps du développement des coins de glace ou de leur fossilisation, mais aussi qu'elle apporte une information sur les conditions climatiques ayant régné pendant le Tardiglaciaire.

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INTRODUCTION

At present northeasternmost Scandinavia has no glaciers, but its close proximity to the extensive Euro-Asiatic permafrost zone might have given rise to terrain forms belonging to the permafrost series which may now be observed as features under active development, or as fossil traces from earlier climatic periods when the boundaries of continuous permafrost extended westward and covered northern Scandinavia.

On this background it was, in 1961, considered of great interest to make systematic analyses of aerial photographs and search for indications of frozen ground morphology in northeastern Norway. The area proved to contain many interesting geomorphological problems, some of which will be discussed at the relevant places during the excursion.

In this paper attention will be focused on one of them, the fossil ice-wedge polygons and their chronology. Specifically, the problem is to be treated from a methodological viewpoint supported by some examples from Nordic areas other than northern Norway. All examples will be from areas which were glaciated during the Würm.

The age conditions of the ice-wedge polygons shall be treated under two aspects: the relative and the absolute age of their formation.

RELATIVE AGE OF FOSSIL ICE-WEDGE POLYGONS

In Nordic areas the polygon pattern may be visible in two ways: (1) as a micro-topography of furrows (such as found in northern areas) or (2) as crop marks (such as found in cultivated areas in southern Scandinavia).

Within the same area the polygons may differ as regards their geometrical pattern or dimensions of the corresponding wedge casts in vertical sections.

In Norway the fossil polygon patterns occur mainly in late-glacial deltas or on terraces, raised during the isostatic uplift after the deglaciation.

Plate 1 shows such a raised area in the inner part of Laksefjord with a polygonal net showing as dark lines. An analysis of the picture reveals that there is a difference between the northern and the southern part of the area. In the first, the polygon sides are longer and more rectilinear. The lines are also more weakly marked, and the polygons are of larger dimensions than those found in the southern part of the picture.

For both parts of the area, there is no decisive difference in material which might explain why the polygons are not alike. A fact is, however, that the northern polygon surface lies 8—10 m lower than the southernmost one, a difference in level which is topographically marked by the existence of terraces.

The difference in levels is the result of a difference in age between the two surfaces. When the lowermost one was elevated above sea level, the higher one had already for some time been exposed to an arctic climate causing polygon formation which could now also start in the lower-lying surface. Here the polygon pattern is of a more tentative character.

What now appears as a geometrical difference in the fossil polygon patterns can be explained as a relative difference in age. In the upper surface the polygons developed earlier and have been active for longer periods than in the lower-lying surface.

The elevation conditions for plains with polygonal networks may also give rise to a discussion of their absolute age. This will be discussed specifically later in this paper.

In vertical sections of gravel pits one often finds wedge casts of different dimensions, mostly as regards their width. Narrow wedges may sometimes be considered younger fissures which have later divided larger polygons into minor units, or have been active for only a short period. A relative age ratio is difficult to state in this case, however, when not supported by a surface pattern of polygons.

As regards the length of the period of fissure development it can rather safely be stated that, in a given area, a wide wedge cast in all probability corresponds to a longer period of repeated frost cracking than a narrow wedge cast. The reservation must be made, however, that the deformation of matrix which has taken place during fossilization may have varied from wedge to wedge — not least due to difference in material.

Based on BLACK's information in the growth rate of active ice wedges, MAACK (1967) made an experiment to calculate the time lapse of formation of an ice wedge which is now visible as a wedge cast in the Kunes area (Laksefjord). His result was that the wedge had presumably been growing by cracking during 1,250 winters.

ABSOLUTE DATING OF FOSSIL POLYGON NETS

By the registration of polygon sites that was made in the northeastern coastal districts of Norway (SVENSSON, 1963, 1964, 1971) it was found that for several areas polygon patterns are absent below a certain critical level. This is especially conspicuous in raised marine surfaces where the polygons can be followed from the highest shoreline and farther downward until, at a certain level, they suddenly disappear (pl. 2). For such localities it is of direct interest to try to determine the age of the shorelines corresponding to the critical levels. These vary according to position in relation to isobases of land uplift.

When the survey started at the beginning of the 1960s, a shoreline chronology for the area existed in TANNER's regional work from 1930. For the Bussesund locality at the easternmost part of the Varanger peninsula, where the ice-wedge polygons were first identified (SVENSSON, 1962), the pattern is found within the interval 81—64 m a.s.l. and most distinctly in the upper part of the interval. When using TANNER's diagram, the i-line falls in the 68-m level of the actual locality. Since the i-line, according to TANNER, corresponds to a climatic cooling in late-glacial time (Younger Dryas period, c. 8000—9000 B.C.) a climatic-morphological relationship seems to be obvious.

However, against TANNER's chronology, Norwegian Quaternary geologists have put forward some objections. More recent investigations are underway, and I therefore wish to await a possible revision of TANNER's concept before making a final dating of the collected material of polygon sites. MARTHINUSSEN has kindly informed me (written communication, 1965) that a shoreline (the main line S_0), dated by him to the later part of the Younger Dryas, at Svartnes, which is quite near the actual locality, lies 38 m above present sea level.

In general, the fossil ice-wedge polygons in northeastern Norway are not found at levels raised above sea level after the Younger Dryas (SVENSSON, 1971). This conclusion has been agreed upon by SOLLID, *et al.* (1973)[1].

When attempting to establish an absolute chronology of geomorphological features, it is natural first to try a C-14 dating of organic material. For this purpose driftwood from the terraces and organic material in the wedge casts have been sought for, but in vain. The polygon furrows are, however, partly filled witht peat which can reach a thickness of 20—25 cm. Four 0.5 cm thick samples from the very bottom part of polygon furrows at the Bussesund locality have been dated (one in 1964 at the Laboratory for Radiologic Dating in Trondheim, Norway, and three in 1967 at the Laboratory for Radio-Carbon Dating in Lund, Sweden). The result was as follows:

Sample	DF 149, T441	4890 ± 70 years B.P.
,,	Lu-5	4350 ± 100 ,,
,,	Lu-116	4840 ± 100 ,,
,,	Lu-116A	4890 ± 100 ,,

It is evident that there might be some sources of error in dating material of this type. Thus the sample was taken in a relatively thin and superficial peat mass where there might be a risk of contamination with e.g. young roots.

The existence of a furrow is a qualification for an effective accumulation of organic material, and during the fossilization of the polygon net (e.g. the melting out of ice wedges) fairly well developed furrows were formed. From present-day polygon areas it is, however, known that already during the active stage of ice-wedge formation organic material can gather in fresh polygon lines. A chronologic determination of polygon fossilization by C-14 dating of peat samples must therefore be considered fairly uncertain, but it can be stated that the values obtained here are in good accordance with each other.

Concerning the chronological aspect of the fossilization of ice-wedge polygons it should be pointed out that with an amelioration of climate, ice wedges may exist for a long time in the ground as inactive ice wedges. It means that there can be a considerable interval between the climatic event and the final formation of polygon furrows adequate for accumulation of organic material. In that case the C-14 datings give no information about the time for the climatic change, but only a minimum age of the formation of the furrow.

[1] The polygons in the innermost part of Karlebotn, by SOLLID (1973, p. 298) stated to be an exception, are not fossil ice-wedge polygons (*cf.* SVENSSON, 1969, p. 395), as will be seen during the excursion (5^{th} September).

Photo Fjellanger-Widerøe A/S, Oslo

Pl. 1. Raised delta surface in the inner part of Laksefjord with patterns of fossil ice--wedge polygons. The nets are outlined by a low vegetation in shallow furrows. Approx. scale 1 : 12 500

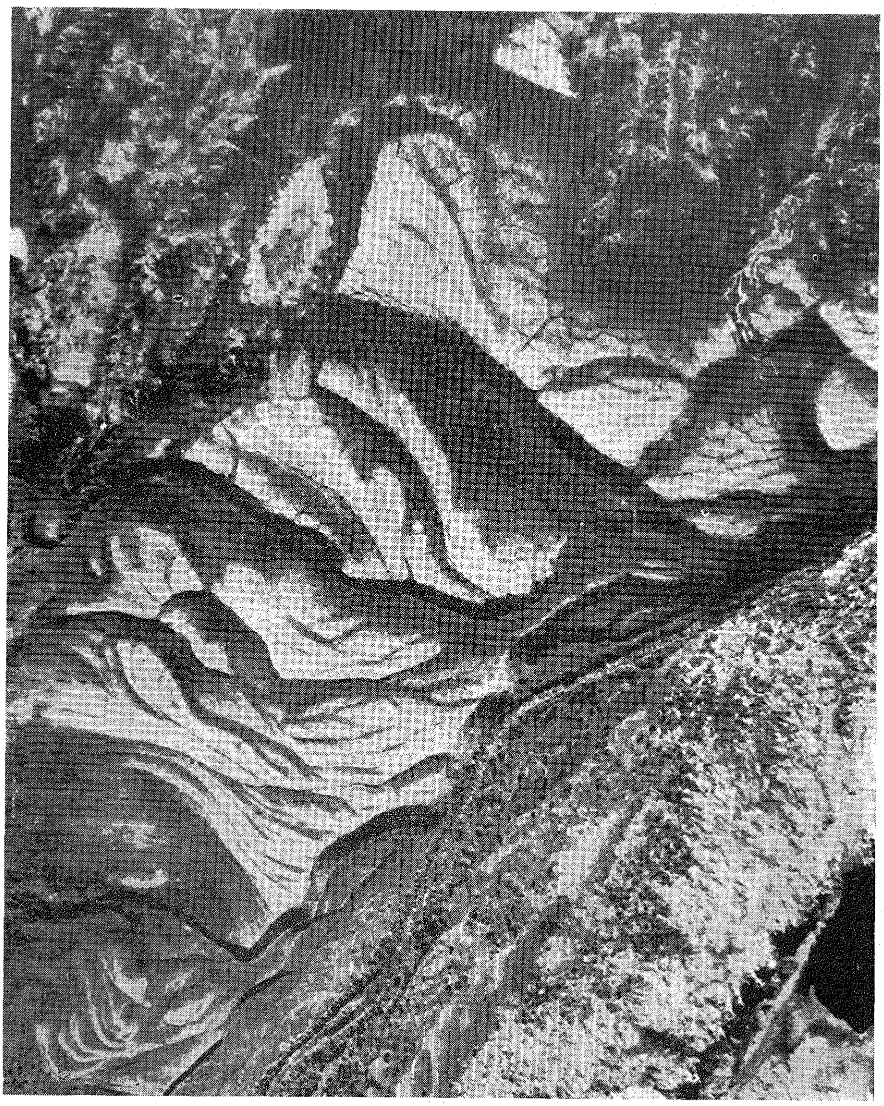

Photo Fjellanger-Wideröe A/S, Oslo

Pl. 2. A staircase of marine terraces formed in fluvioglacial delta deposits in the inner part of Risfjord. In the upper terraces polygon patterns occur. Approx. scale 1 : 6000

Based on air photos and reconnaissance flights, a survey of fossil polygon patterns has been carried out in southern Sweden (SVENSSON, 1974). In dry periods they can be observed as vegetational networks, especially in some areas along the Swedish west coast in former marine surfaces.

Unlike northern Norway, there was no recent shoreline chronology here at first, but with MÖRNER's work in 1969 it became possible to determine the age of the raised marine surfaces in which polygons occur. Hereafter, the efforts have been concentrated on finding the lowest-lying indications of polygons.

In figure 1 some of the observations have been plotted on part of MÖRNER's shoreline diagram. The lowest, most westerly observations fall fairly well within

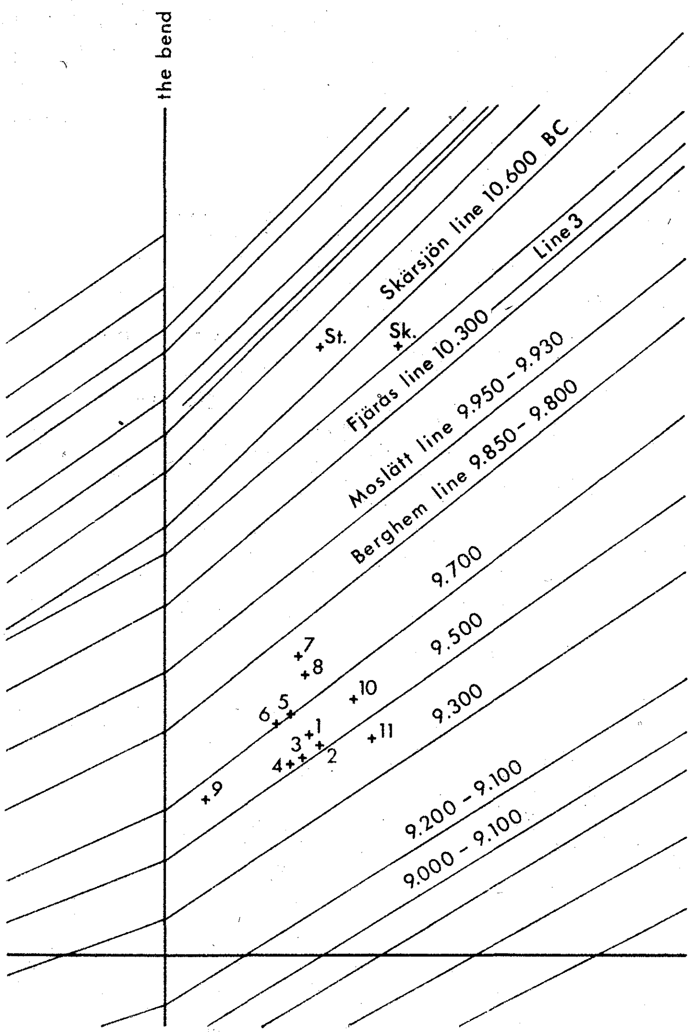

Fig. 1. Low lying polygon sites (1—11) from the Swedish west coast inserted in a distance diagram of Late-Glacial shorelines (MÖRNER, 1969)

the interval 9800—9400 B.C., i.e. at levels which were not elevated above sea level until the Allerød period.

Thus the youngest polygons cannot have developed before the Allerød period. During the following period, Younger Dryas (9000—8050 B.C.) [2], these virgin surfaces became exposed to an arctic climate. That the Younger Dryas was a period of climatic cooling is above all visualized in stagnation of the receding Scandinavian ice sheet causing an acumulation of the Central Swedish end moraines (part of the Fennoscandian end moraines known in Finland as „Salpausselkä" and Norway as „Raer").

In a survey of methods to determine the age of formation or fossilization of polygon patterns in the Nordic countries, THORARINSSON's tephrochronology ought also to be mentioned (THORARINSSON, 1944 with later revisions).

Recent frost fissures occur in many areas of the interior of Iceland. Also distinct patterns of furrows very similar to ice-wedge polygons are found in some areas (SVENSSON, 1977, fig. 6). These polygons have, however, no connection

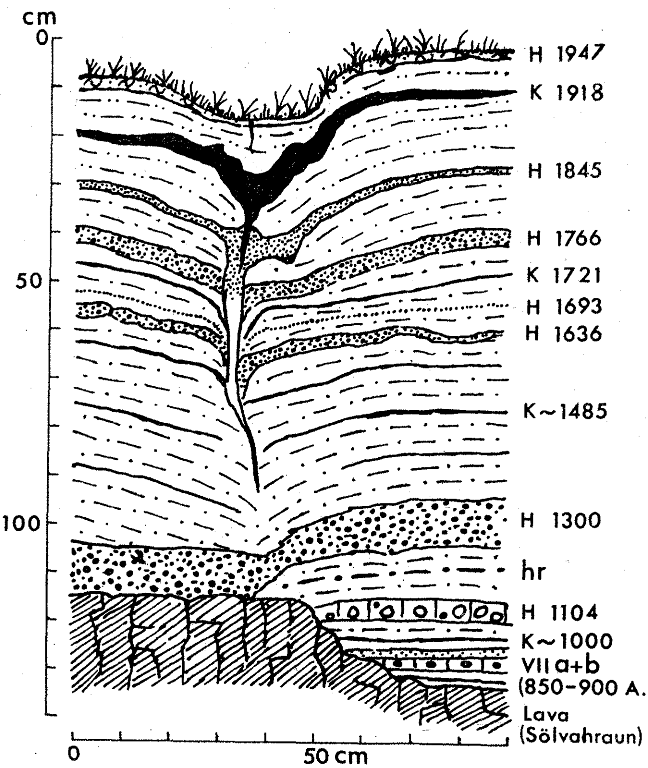

Fig. 2. Section below a frost-fissured polygon furrow west on Valafell, Iceland, with dated tephra layers from eruptions of Hekla (H) and Katla (K)

The drawing is made by C. E. Johansson

[2] This time interval is indicated by MÖRNER (1969). In his revision of the deglaciation chronology BERGLUND (1979) suggests 10 900—10 200 B.P. for the Younger Dryas.

with recent permafrost, but show in vertical sections thin, wedge-like infillings of eolian material or volcanic ashes, tephra.

This type of wedge will not be discussed here (*cf.* FRIEDMAN, *et. al*, 1971), only attention called to the fact that wedges often cut tephra layers which might be used for detailed studies of the infillings. As many of the tephra layers are dated (by THORARINSSON), the infillings and their relation to earlier ground surfaces can be considered from a chronological point of view. Thus, in section (Fig. 2) there can be observed a locally increased thickness in the H 1845 layer that may indicate the existence of a polygon furrow in the ground surface at the time of the Hekla eruption in 1845. In same section the existence of another polygon furrow is still more evident from the time when the ground was covered by ashes from the Katla 1918-eruption, and in the polygon furrow in the present ground surface a fresh frost fissure has opened through the Hekla 1947 tephra layer.

CONCLUSIONS

From the methodological point of view there seems to exist some different possibilities to consider the chronological problems of polygon patterns. Besides the methods advanced here, there must also be a biostratigraphical approach. Because of the lack of reference diagrams when the study started, no material has been collected for trying this method.

Some of the attempts might be considered just experiments, and many questions still need to be disscused; for instance the bearing of radiocarbon dating of organic material in connection with fossil ice-wedge polygons.

So far, the apparently most promising method for determining the age of polygon patterns is based on dated levels in shoreline diagrams. Moreover, it seems possible to construct a relative chronology for polygon patterns in erosional terraces of the staircase model.

Finally, it ought to be stressed that from a paleoclimatic point of view it is of great interest to reach chronological datings of polygon formation. Thus it is of great paleogeographical importance to find that during the Younger Dryas period there existed such hard arctic conditions at the Swedish west coast that ice-wedge polygons could form in this marine environment so far from the receding ice margin.

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