Tundra polygons.

Photographic interpretation and field studies in North-Norwegian polygon areas.

By

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Introduction.

When working with aerial photos, the interpreter very soon realizes that the vegetation adjusts itself very well to differences in the ground conditions, which is in this way registered in photography. This fact constituted one of the starting points when the author, with the help of aerial photos, began the search for large-scale patterned ground of the tundra polygon shape, which earlier had not been identified in Scandinavia.[1]

In Arctic regions, *recent* tundra polygons can be clearly distinguished on aerial photographs which is a well-known fact derived from numerous investigations (amongst others, Troll 1944, Washburn 1950, Black 1952, Andreev 1955, Hopkins, Karlstrom et al 1955). The fact that there are considerable changes in the soil caused by the frost (cf. Figs. 1, 2 and 3) supports the hypothesis that, if a polygonal pattern of the tundra type developed in an area and this, at a later date in a milder climate, came to lie outside the tundra zone, it should be possible to trace *fossil* polygons or fragments of such with the help of the adjustment of the vegetation to the ground conditions. This idea has been followed up in order to investigate the correctness of the hypothesis and in order to check the possibility of this method.

[1]) In vertical sections and gravel-pits, however, fossil periglacial formations have been observed and studied particularly in Denmark and Southern Sweden (Nörvang and Johnsson). As regards Swedish investigations of patterned ground reference is made to the surveys by Rapp and Rudberg (1960) and J. Lundqvist (1962).

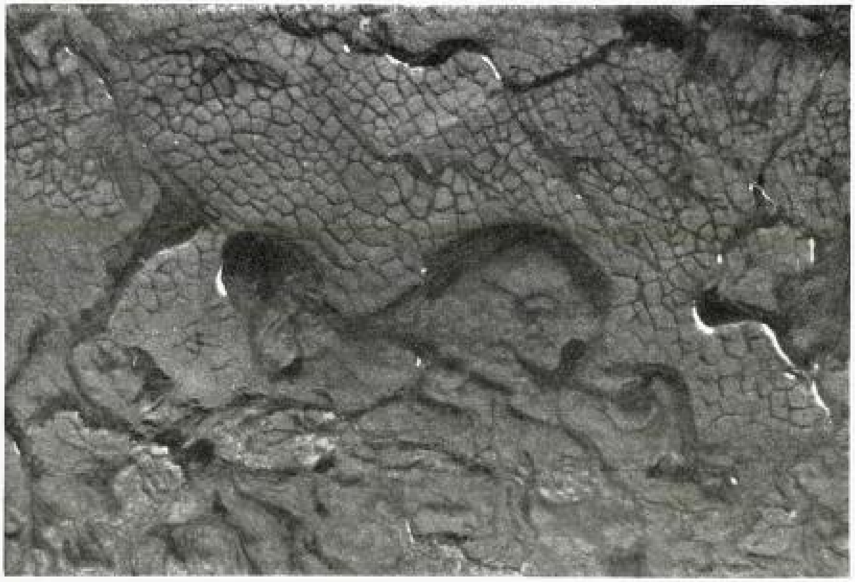

Fig. 1. High-centered polygons, Northern Greenland. Appr. scale 1 : 20 000 (enlargement from the original scale 1 : 50 000). Copyright The Geodetic Institute of Denmark.

Fig. 2. Low-centered polygons in fluvial deposits, Northern Greenland. Appr. scale 1 : 20 000 (enlargement from the original scale 1 : 50 000). Copyright The Geodetic Institute of Denmark

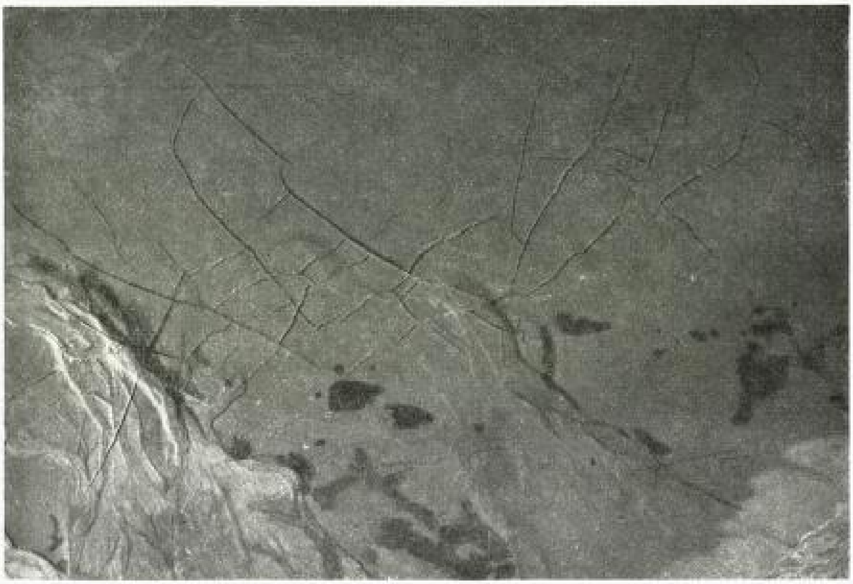

Fig. 3. Frost generated contraction cracks, Trail Island, Eastern Greenland. Appr. scale 1: 40 000 (enlargement from the original scale 1 : 50 000). Copyright The Geodetic Institute of Denmark.

To gain experience of the reproduction of the phenomenon in aerial photos of recent tundra areas, a great number of photos from Northern Greenland have been examined at the Geodetic Institute of Denmark, Copenhagen.

When the search for polygonal tundra ground was started, it seemed to be adequate to begin in the far north, in order to try, if possible, later on to follow the forms and their variation in other areas.

According to the general map on the extent of permafrost in the northern Hemisphere drawn up by Black (1954), neither the zone of continuous nor discontinuous permafrost touches upon the Scandinavian peninsula.

The zone of sporadic permafrost, on the other hand, penetrates to the north-western part of Scandinavia. The knowledge of the occurrence of recent permafrost in Scandinavia must still be regarded as insufficient (cf. J. Lundqvist 1962). For the most usual type of permafrost, palses (hummocks of frozen peat) G. Lundqvist (1951) has, however, prepared a map, comprising observations made in Sweden. Later J. Lundqvist completed this map (1962) in his survey of frost phenomena in Sweden.

The extreme northern areas of Scandinavia have so far been insufficiently photographed from the air. Parts of the coast of the Varanger Peninsula, which were recently photographed in a scale suitable for this purpose, were chosen as the first area. Here, almost immediately polygonal patterns in the ground were discovered (demonstrated on a higher seminar at the Department of Geography, University of Lund, in February 1962 and referred to in Geogr. Ann. H 3–4 1962). Polygonal ground in some additional areas were identified during the studies of aerial photographs in the archives of Norges geologiske undersøkelse and Geofysisk malmletning in Trondheim (December 1961) and in the archives of Widerøes flyveselskap (March 1962).

During field investigations in areas with polygon ground on the Varanger Peninsula in the summer of 1962, it was possible to study some polygon lines in cuttings showing distinct fossil ice-wedges (Svensson 1962b).

Within another part of Scandinavia, viz. the inner Scandes (Padjelanta). K. Gustafsson and P. Jobs made an interesting observation on remaining "tjäle" (late summer 1962) in terraces of former ice dammed lakes. After studying the aerial photos taken over that area, Rapp identified areas of probable tundra polygons on the terraces (Rapp, Gustafsson and Jobs 1962). Such frozen ground phenomena had not been observed earlier within that part of Scandinavia. In this case, the aerial photos were used to verify the indications from field studies.

Polygonal patterns have also been noticed with the help of aerial photos from more Southern areas of Norden and later studied on the ground (in Halland, Svensson 1962 c and in Jutland, Svensson 1963).

The purpose of this article is to deal with the interpretation of the aerial photos and with field control of some of the areas observed in the northernmost parts of Norway. Taking into account the limited knowledge as regards the occurrence of polygons of large-scale patterned ground in Scandinavia, it was thought appropriate to reserve a large portion of this article for illustrations comprising both, aerial and ground photos. The map (Fig. 4) has been drawn up with the purpose of indicating the position of the observations made as referred to in the text or the figures.[1]

[1]) In order to avoid misunderstandings it should be pointed out that the map does not include every occurrence of large-scale patterned ground. To the extent aerial photographs is recorded in an appropriate scale and become accessible for civilian studies, it is very probable that an additional large number of polygonal areas will be discovered. Furthermore, not all aerial photographs available from inland of Finnmark have been used in this study.

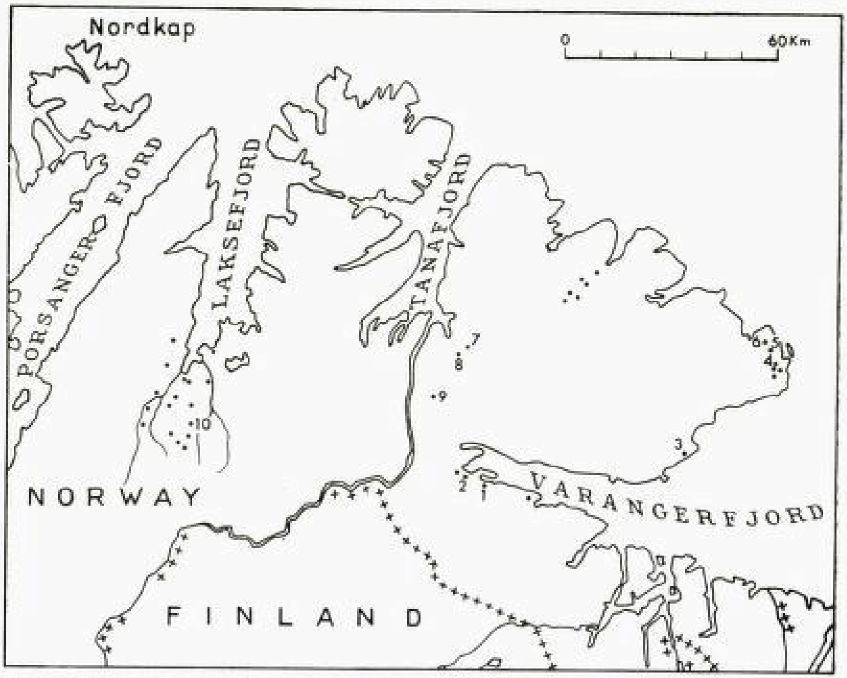

Fig. 4. Observations of large-scale polygon ground in the extreme north of Norway. The numbers refer to observations mentioned in the text or contained in pictures. Observations which are not commented on have been marked only by dots.

The Manifestation of the Pattern in the Ground. Type of Terrain.

As mentioned above, it has been assumed that the vegetation could register the differences of the ground caused by the formation of polygons. In analysing the aerial photos, indications were soon forthcoming which supported this hypothesis, viz. the pattern of denser vegetation which the polygon sides indicated in photography and which contrasted greatly with the areas lacking vegetation. However, during field studies it was shown that the polygon margins (-sides) often had a morphological manifestation, as they were in the form of trenches or furrows in which vegetation, in the otherwise level and wind-eroded surface, could get a better hold and thus was able to form a denser growth (see Fig. 2, Svensson 1962 b).

As a rule, the trenches are relatively narrow and shallow and give no

Fig. 5. A network in the ground on a low mountain (Olafjeld 487 m a.s.) in Finnmark, Northern Norway (top. map sheet Alta). Appr. scale 1 : 6 000 (enlargement from the original scale 1 : 20 000). Photo Wideroes Flyveselskap, Oslo.

relief impression in stereoscopic viewing of the aerial photos. On the other hand, remaining snow can sometimes emphasize the pattern (Fig. 5).

A division of types according to form or position is not aimed at in this report. When studying a great number of photographs it has, however, been found that large-scale polygon ground mostly occurs and can best be identified in terraces or deltas at the highest shore line. Fluvial deposits have also in a number of cases been found to be a type of terrain that has received a polygonal pattern (Fig. 6). Finally, it would seem that flat surfaces in the inner parts of the mountains can constitute suitable terrain for the occurrence of polygon grounds (Fig. 5).

In the following, a division of the observations made will be effected, without paying attention to genesis or systematics, into coastal areas on the one hand and deposits in upland areas on the other hand. In the first case the areas are comprised of raised terraces, beaches and deltas, and in the latter of more indifferentiated types of terrain without connection with the coast.

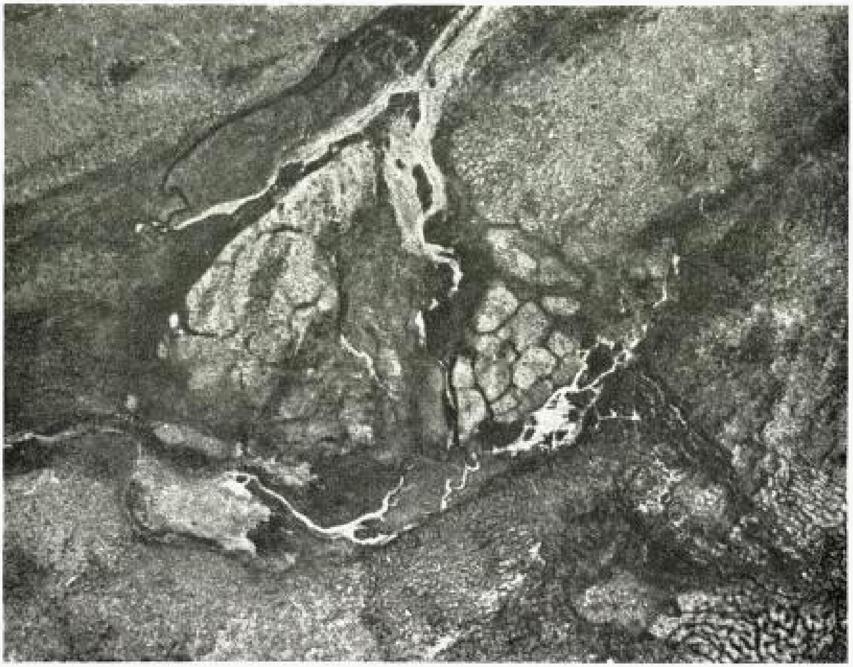

Fig. 6. Polygons in a delta of a local accumulation basin, locality no. 10 on the map fig. 4. Appr. scale 1 : 4 000 (enlargement from the original scale 1 : 20 000. Photo Widerøes flyveselskap, Oslo.

1. *Polygons in Coastal Areas.*

During the course of deglaciation, late glacial deltas have developed at several points on the southern side of the Varanger Fjord (cf. Holtedahl-Andersen: Glacial map of Norway/Holtedahl 1960/). The distal parts of these deltas are very often changed through a later marine erosion, as well as through the formation of beach ridges. Due to land elevation, the delta surfaces are now situated above the present sea level.

Figure 7, locality 1,[1] shows parts of such a delta, in the inner parts of which the fluvial pattern can still be distinguished. Nowadays, the delta formation which is deposited in front of a low mountain range and around mountain hills is connected with nothing but a minor stream. The aerial photo indicates on the delta surface (about 87 m above sea

[1]) The numbering of the localities refers to the symbols on the map.

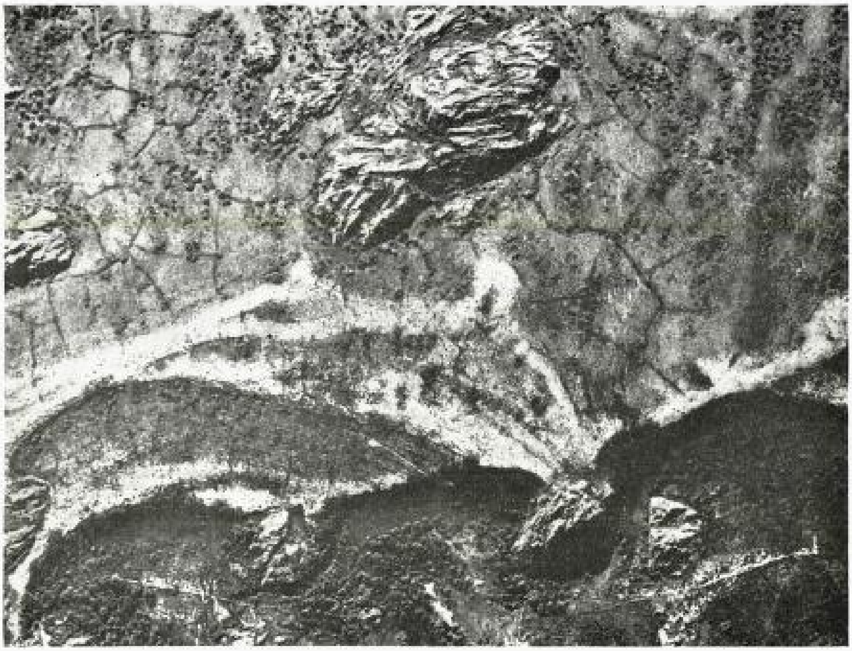

Fig. 7. Polygons in a wave-cut delta south of Veinesbugten (top. map sheet Nesseby). Locality no. 1 on the map fig. 4. Appr. scale 1 : 6 000 (enlargement from the original scale 1 : 10 000). Photo Wideroes flyveselskap, Oslo.

level)[1] the occurrence of a polygonal[2] pattern which can be observed with differing clearness in the various parts of the delta, but which is lacking entirely in the proximate part.

As can be seen on the photo (Fig. 7), the size of the sides varies considerably in the polygon pattern. The greatest side amounts to 65 m, and the smallest to 7–8 m (the measurements have been effected on closed polygons only). The sides are not always rectilinear, but sometimes slightly bent in their contour. The shape of the polygons varies with the non-uniform size of the sides and the number of corners. The majority are, however, tetragons. In a somewhat lower lying part between the delta

[1] The measurements of the heights are effected according to the barometer principle.

[2] As is customary the term "polygon" is used as a descriptive collective term for closed figures with four or more corners and not always having a rectilinear delimitation or even surface. This meaning partly deviates from the geometrical definition but the term with this meaning is applied in investigations on surface patterns.

Fig. 8. Horizontal view of part of the delta surface, fig. 7. A polygon furrow is seen running parallel to the bottom side of the picture.

surface and a beach ridge appears a diffuse pattern of almost orthogonal tetragons.

In the ground, the pattern is constituted by linearly extending depressions which perhaps could best be described as furrows, even if, in cross-profile, they are not emphasized by any marked break, but more gradually merge into the even polygon surface. The difference in height between the central parts of the polygon level and the bottom of the furrows varies, but can, on the average, be regarded as between 20–30 cm (maximum 50–60 cm). In the majority of cases, these furrows contain peat and are then more or less overgrown by denser vegetation.

Sometimes stones can be observed in the bottom of the marginal trenches of the polygons. In certain parts, there are very much stones in the polygon surface (Fig. 8).

It cannot be determined if this accumulation of stones in certain parts of the delta is of mainly primary origin as a consequence of fluvial and marine processes, or a secondary result of frost action. The frost pattern in the stone surface clearly indicates, however, later frost action, so that in any case it may be presumed that the frost accentuated the occurrence of stone. During digging (9th July 1962) in one of the furrows,

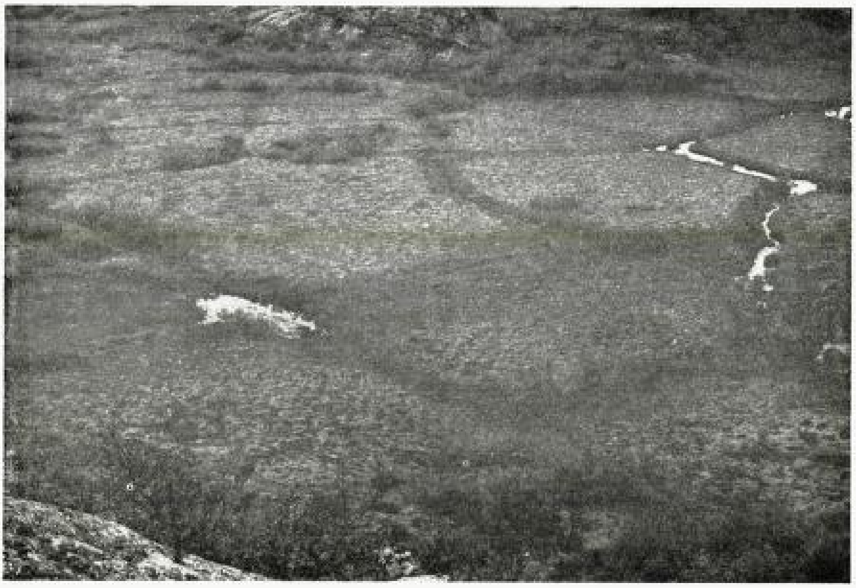

Fig. 9. View from a mountain slope over the eastern polygons of locality no. 1 (outside the picture fig. 7).

"tjäle" was reached after 25 cm, as corresponding to 80 cm under the polygon level.

In the easternmost parts of the delta, which is situated between mountain hills, the polygons are best defined (Fig. 9) and give here an almost "fresh" impression. Here, the surface of the ground is covered only to a smaller degree by vegetation. The polygon surface is visibly free from stone. Lichens and weathered soil make considerably lighter the impression which the polygon ground here conveys. Towards the polygon furrows, the vegetation increases and thus emphasizes the cellular pattern.

In these eastern parts the polygons are connected with two small lakes. On account of the high groundwater level, parts of the polygon lines are swamped and are, in some cases, filled with shallow pools particularly accentuated in the polygon corners. In many parts of the elongated pools occur accumulations of stones at the bottom.

In several parts of the polygon surface, sections of minerogenic soil can be observed which were brought to the surface by frost action and here clearly contrast with the rest of the ground which is covered by lichen and weathered soil. In the beginning of July, "tjäle" was found at varying depths in the polygon surface. In the majority of test holes it

Fig. 10. Tetragonal pattern in an area of raised beaches at the streamlet Falkelven (top map sheet Kiberg). No. 3 on the map fig. 4. Appr. scale 1 : 4 000 (enlargement from the original scale 1 : 10 000). Photo Widerøes flyveselskap, Oslo.

occurred at a depth of 30 or 35 cm. During digging in the polygon furrows, groundwater was found at a depth of 30 cm under the lowest point of the furrow.[1]

Locality 2. Horizontal changes, such as fissures in the ground, were not observed in the polygon area described above. On the extensive gravel plateau south of the inner Varanger Fjord (top. map sheet Nesseby) fissures were, however, observed at various places. In the outer parts of the plateau there is a polygonal pattern which can be slightly observed on aerial photos. The pattern consists of narrow furrows, partly filled with peat. In this peat layer open fissures of the samme type as on Fig. 23, run rather continuously over several metres in the direction of the furrow. The fissures cannot, however, be distinguished in the subsoil and it is doubtful whether it has any vertical continuation at all or if it is only to

[1] When digging in these polygons a year later (July 1963) no "tjäle" was observed At the depth of 70 cm the ground water soaked in and made further digging impossible.

Fig. 11. Horizontal view of part of the tetragonal-patterned area in fig. 10.

be regarded as fissures originated by the drying of the peat layer. Test holes of a metre were dug (10th July, 1962), but no "tjäle" could be observed.

Locality 3. Amongst the areas of patterned ground observed on aerial photos none has, from a geometrical point of view, a more regular shape than the Falkelven area (Fig. 10). In an area of beach ridges a four-sided cellular pattern can be noticed. The tetragons are almost orthogonal and the size of the sides is of remarkable uniformity in one and the same square. In those cases where a larger tetragon seems to have been secondarily divided into a number of smaller ones, these also have a square character.

In some parts of the area, the sides have a parallel or orthogonal orientation in relation to the raised beach ridges. Where these bend slightly, the lines cut the very flat ridges at an oblique angle, so that the main directions in the pattern are maintained. Prior to visiting this area, the possibility was considered that the square pattern could reflect a regular tectonic pattern in the underlying rock, which showed through a thin soil layer. Even though this possibility could not be entirely excluded, it now seems less probable.

When studying the pattern in the terrain, it does not appear equally clearly, which is mainly due to the fact that it is impossible to obtain a good view on the slight slope. However, with the help of the aerial photos it is easy to identify the various squares in the ground which are delimited by shallow trenches (Fig. 11).

To a large extent, the ground is composed of stones of slate and sandstone in a soil of silt and clay. The very low content of stones in the surface layer itself is remarkable. During the digging, a clear difference could be observed between the position of the stones in the polygons and in the borderlines. In the first case, the stones and blocks have an almost horizontal or flat orientation, and in the latter an arbitrary orientation with a not inconsiderable slope or vertical position towards the longitudinal axis of the furrow, apparently caused by sliding or slipping during the filling-in of the fissure.

Still further out on the Varanger peninsula, considerable number of polygon areas (see map. Fig. 4) of varying clearness are found, only a few of which will be dealt with. The locality No. 4, Bussesund, (top. map sheet Vardø) is the place where tundra polygons were first identified on the Varanger Peninsula. In this locality, there is a gravel pit which is cut through the polygon trenches. Here, the three-dimensional character is emphasized through the fossil ice-wedges which are clearly marked in the vertical section and which constitute a direct continuation of the polygon lines on the ground surface. The locality has been mentioned in earlier reports (Svensson 1962 a and b).

At Bussesund there also occur at various places smaller areas with a polygonal ground pattern or with localities with occasional polygons. These areas may comprise parts of previously larger, continuous polygon areas, where erosional processes have removed the pattern.

Localities 5 and 6. On aerial photographs from the peninsula between Bussesund and Persfjord, (top. map sheet Vardø), two interesting localities with polygon ground can be observed south-west and west of Lake Barvikvand. These, as well as the foregoing areas, belong to the upper part of the glaciomarine deposits.

In the frontal protruding part of the terrace formation in locality 5 (Fig. 12), the ground pattern has a very complicated character without any marked similarity in shape between the polygons. Within the irregular pattern as well as in the northern parts of the area on Fig. 12, there appears a more uniform tetragonal mesh.

Some of the polygon lines in this locality show a secondary change through erosion. This is, in the first place, true of the lines which cut

Fig. 12. Fracture-like pattern in a marine terrace west of Lake Barvikvand. No. 5 on the map fig. 4. Appr. scale 1 : 6 000 (enlargement from the original scale 1 : 10 000). Photo Widerøes flyveselskap, Oslo.

across the beach ridge system and extend towards the terrace slope. Here, the lines were attacked by erosion, whereby valleys were formed, a kind of "fissure valleys" in loose material. These short valley forms give the terrace slope a cut-up appearance (Fig. 13 a).

The connection with an original polygon line clearly appears on the upper parts of the short valleys where they merge into such a line (Fig. 13 b). Here, the furrow is well protected against erosion by a dense and low growth of Betula nana.

In the front parts the "larger" valleys reach a depth of 5 m under the terrace surface. Here, the bottom is rather level (Fig. 13 c). That mass-movement is still an active process in material transport can be seen from the consistency and structure of the material at the mouth of the valleys. Remaining snow obviously prepares the soil for solifluction.

As regards quantity, the accumulation of material at the mouth of the "fissure valleys" hardly corresponds to the obvious result of erosion, if

Fig. 13. a. *Top*: Marine terrace west of Lake Barvikvand with eroded polygon lines.
b. *Bottom left*: Rear part of eroded polygon line in the terrace.
c. *Bottom right*: Front part of do.

these valleys are judged as ordinary ravine formations. These polygon lines have, however, to a large extent contained ice-wedges, with the disappearance of which the volume was reduced. Even if this fact is taken into account, there seems nevertheless to exist a disproportion between the erosion result and the accumulated material immediately at the mouth. In this connection, a further transport e. g, through solifluction must be presumed.

The above-mentioned melting of the ice in the wedges may have contributed to this valley formation. The water which became free during melting probably caused solifluction when escaping on the slope of the terrace. It is also possible that the filled out ice-wedges directed the movements of the groundwater whereby solifluction was initiated on the emergence on the terrace slope. In any case, it is quite clear that the valleys with their position in a beach terrace in the majority of cases cannot have constituted properly functioning drainage systems.

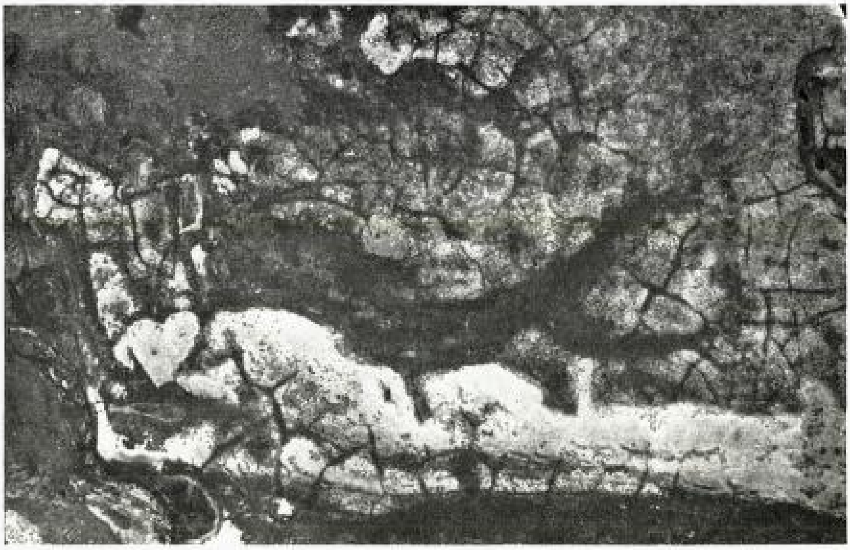

Fig. 14. Polygon pattern at the small river from the mountain ridge Grøhøgda–Mellemfjeld No. 6 on the map fig. 4. Appr. scale 1 : 6 000 (enlargement from the original scale 1 : 10 000). Photo Widerøes flyveselskap, Oslo.

Leffingwell's observations of recent ice-wedges in Alaska (Leffingwell 1915) which became the foundation for the theories on ice-wedge polygons, were made in wave cut banks, where the ice-wedges occur in vertical exposures. In some of the illustrations in Leffingwell's paper it is clearly seen how the ice-wedges act as zones of weaknesses, where erosion dissects the bank in a manner that can be relevant to the small valley forms of locality 5.

Locality 6 (Fig. 14), is situated west of Lake Barvikvand at the river running from the mountain range Grøhøgda–Mellemfjeld. In the outer parts of a delta (terrace) formation, a partly diffuse polygonal pattern can be observed which looses in clearness and disappears in the locally higher parts of the delta. Here, the flat surfaces have been subjected to deflation whereby parts of the pattern were probably destroyed.

Divided by a branched fossil drainage system, the pattern occurs anew inside the top of the terrace. Within a horseshoe-shaped part there can thus be observed on aerial photos a section of concentrically bent polygon lines with transverse furrows, to a certain extent radially arranged.

The polygon pattern has an extension clearly marked in the terrain by

Fig. 15. Part of the gravel-pit at the lower course of the river Julelven. (No. 7 on the map, fig. 4). A fossil ice-wedge appears at the spade.

furrows in many places half a metre deep (calculated from the polygon surface) and particularly accentuated in the junctions.

The inner parts of the "horseshoe" lie somewhat lower than its bent edge. The maximum difference in level amounts to 1,5–2 m.

The drainage system mentioned contributes to accentuate the horseshoe shape. The concentric polygon lines, however, belong to the opposite leg.

The arrangement of the polygon lines indicates that the fissure formation may have occurred not only under the influence of forces working horizontally. A force in the interior of the ground working vertically may also have been active. The lower lying inside part also supports such an interpretation. Thus it seems possible that this may have been formed through the shrinking of a low, dome-shaped elevation caused by frost action in the ground.

Locality 7. The occurrence of ice wedges in vertical cuttings through a polygon pattern has been confirmed at Bussesund (locality 4), as mentioned on page 310. The ice-wedges observed form the immediate con-

Fig. 16. From the right-hand bottom corner, a polygon furrow runs towards the centre of the picture where it is interrupted by another, continuous line.

tinuation of the polygon furrow down into the ground. On passing a gravel-pit by the lower course of the river Julelven (top. map sheet Tana), three similar fissure fillings of ice-wedge type were observed. The gravel-pit is situated in a wide, wooded terrace surface (Fig.15). In the high cutting the ice-wedges protrude somewhat from the otherwise even wall. The ice-wedges contain rather fine fractions which give greater consistency.

The stone material nearest the ice-wedges shows a more arbitrary direction than the otherwise quite regularly arranged beach terrace material. Thus a number of stones are tipped or placed on edge. Some of the strata are also inclined towards the ice-wedge.

Bearing in mind the close connection between the ice-wedges and the polygon lines noted in the above-mentioned locality at Bussesund, it was interesting to examine the terrace surface, especially above the ice-wedges. It was shown that furrows leading to the edge of the gravel-pit just above the ice-wedges could be traced in the dense ground vegetation. Such a furrow appears in Fig. 15 as a slight depression in the surface.

The furrow in question can be followed for some ten metres or more into the birch forest, until it is orthogonally interrupted by another furrow (Fig. 16), which in its turn is cut by another similar line. The furrows form a system which it is, however, difficult to survey in this case because of the ground vegetation. The surface form within the wooded terrace around the gravel-pit is undoubtedly identical with the polygon areas described earlier.

II. *Polygons in upland areas.*

The Norwegian areas by the Arctic Ocean, from which aerial photos are available, are mainly tracts where human activity has required aerial photography, especially low lying areas. Thus large mountain areas do not occur in aerial photographs available for civil use. On that account it is still too early to get a general idea of the occurrence of large-scale polygon ground within many of the upland areas. A number of polygon regions have, however, been identified by the photo interpretation and some examples will be cited here.

Locality 8. The mountain plateau at Herrekløftfjeld (top. map sheet Tana) contains within a very limited area a ground pattern of the polygon character (Fig. 17). In this locality the polygons lie on a slight, somewhat uneven slope and are divided, as in earlier cases, by shallow trenches. At the bottom of these is a 5–10 cm thick layer of peat. In general these polygons are less clearly marked in the ground than those previously described.

It is not easy to determine to what extent recent frost action contributes towards making the contours indistinct. It is, however, clear that recent frost has a great effect on the formation of the ground surface on the mountain plateau. Thus within the polygons appears a pattern of small surfaces without vegetation, consisting of soil of the mud circle type (J. Lundquist 1962). These clearly show frost action. Fresh, unweathered material has been brought up to the surface; frost boils spread; stones without a covering of lichen lie on the surface, and other stones are turned with the lichen-covered side downwards. When these mud circles occur in somewhat sloping ground, they get a terrace-like form. The mud circles often contain small stone rings.

Locality 9. The mountain range of Lievlamfjeldet – Brandfjeldet east of the lower Tana River is in many respects an interesting area (top. map sheet Tana).

In the aerial photos of the south-eastern parts of the elevation, point 390, there can be observed a small oval area which shows plainly in the

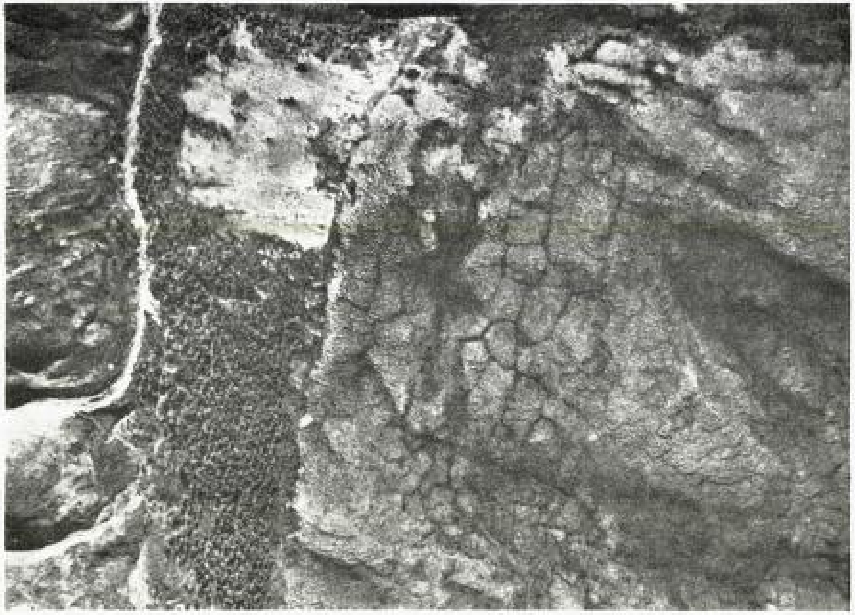

Fig. 17. Polygons on Herrekloftfjeld about 325 m a.s.l. No. 8 on the map fig. 4. Appr. scale 1 : 6000 (enlargement from the original scale 1 : 20 000).
Photo Widerøes flyveselskap, Oslo.

photos owing to its light gray tone and clearly defined contour (Fig. 18). On examining the aerial photo in more detail, a network is observed on the ground inside the curved contour. After the identification of the pattern in this section, it appears that it can be traced within a considerably larger area of which the light section is thus only a part.

The oval field is an enclosed area used by the Lapps for separating the reindeer. The light gray tone in which the ground inside the enclosed area is represented is caused by the fact that the ground has been trampled by the animals feet and the vegetation largely destroyed. The polygon pattern, on the other hand, still remains.

When this area was studied in the field (July 1962), the vegetation in the reindeer enclosure consisted largely of feeble shoots of Betula nana and Vaccinium myrtillus. The ground was partly covered by a thin layer of peat, containing a large amount of dead roots and twigs. Within the polygon lines the layer of peat and not yet decayed plants were thicker. In spite of this accumulation, the lines still occur as decimeter-deep furrows in the ground (Fig. 19).

The pattern within the area is composed as a rule of tetragons (cf.

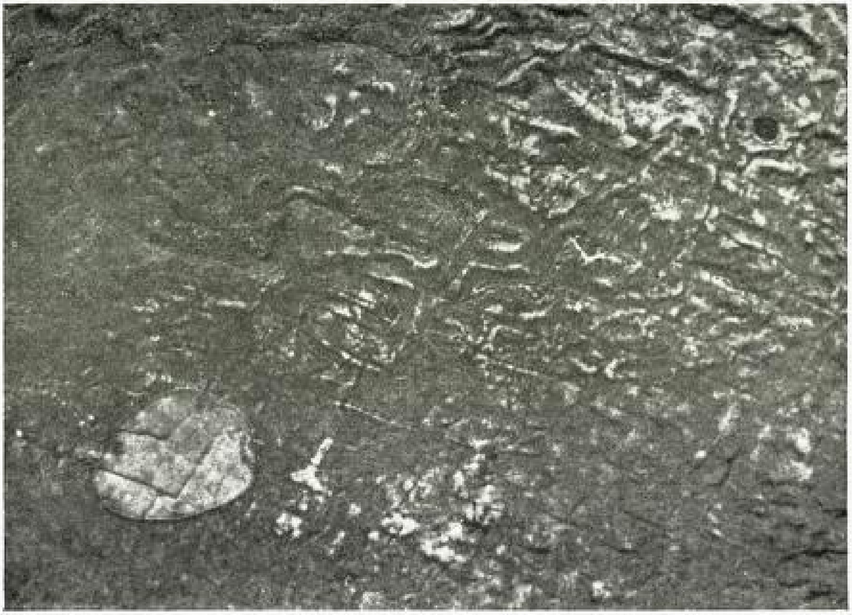

Fig. 18. Tetragonal pattern on the eastern slope of the mountain ridge Lievlamfjeldet-Brandfjeldet about 225 m a.s.l. No. 9 on the map fig. 4. Appr. scale 1 : 6 000 (enlargement from the original scale 1 : 20 000). Photo Widerøes flyveselskap, Oslo.

Fig. 18). Regarding the geometrical qualities of the pattern in general, the orthogonal character is also apparent. On the gentle slope on which the tetragons occur, the sides are largely arranged parallel with or orthogonally to the contours of the slope. The lines of the former, parallel, direction usually run unbrokenly through several rows of tetragons, while the lines in the direction of the slope are more often interrupted. Thus the squares are largely found in bonds.

The patterned area largely corresponds in extent to a glaciofluvial deposit on the mountain side. From the morphological point of view this accumulation has the character of a complicated system of low eskers. In some parts small, relatively shallow pools of water occur, situated in kettles. The reindeer enclosure lies in the lower, flatter parts of the area.

As regards its direction and form, the tetragonal pattern does not appear to be influenced to any extent by the contour of the system of low eskers, but keeps its regular character over large parts of the mountain slope.

The system of ridges, hills and kettles in the area cannot altogether be

Fig. 19. Part of the tetragonal pattern inside the reindeer enclosure.

said to have a normal glaciofluvial character. The question arises if not certain forms can be traced back to frost action, not only as regards the tetragonal fissure formation and the changes resulting from this, but also other relief features in the pattern.

Two interesting forms, to judge from their outward appearance, of similar character but difficult to interpret, occur in the upper parts of the mountain range, without visible connection with the above mentioned polygonal area.

The forms are low, which means that they escape attention in the horizontal perspective. On the aerial photos they are mainly noticed on account of their contours. Under the stereoscope they show up clearly owing to the exaggerated stereoscopic effect obtained, which gives to the forms a more crater-like character than they actually have.

The formations have a circular to oval shape (Fig. 20), with a lower central part. The highest of the forms, which is situated in a slight depression, has a diameter of 40 m. Its inner circular depression is 10 to 12 m wide. The form stands out most clearly from its environment to north and south. Here the edge lies 1½–2 m higher than the surrounding ground.

Fig. 20. Oval forms with a depressed centre on Lievlamfjeldet–Brandfjeldet. Appr. scale 1 : 5 000 (enlargement from the original scale 1 : 20 000). Photo Widerøes flyveselskap, Oslo.

The bottom of the centre of the form lies 1 metre below the south-eastern boundary. The centre is largely covered with earth hummocks.

The contour is influenced by recent frost and solifluction which also leave traces on the surface layer and its stone accumulation. In the neighbourhood the watered pattern of mud circles can be observed in the aerial photos. On the whole the photo analysis gives the impression of very strong and recent frost action in the area.

In digging the middle part of the formation, "tjäle" was found at a depth of 45 cm. Some metres away no "tjäle" was observed, in spite of the fact that the test holes were made some dm deeper. At the latter place, however, there was no surface layer of peat, whereas there was a distinct layer some 10–15 cm thick at the first test hole. (The peat layer, of course, very much delays the thawing of the ground through its insulating effect, which is known inter alia from the pals formation). Under the surface the clay-silt material is obviously free from stones.

A number of similar forms from different parts of Northern Scandinavia have been observed during the analysis of aerial photographs.

Fig. 21. Polygonal pattern on the plateau of Finnmarksvidda (Grønåsen–Bjørnhaugene, top map sheet Alta) Appr. scale 1 : 6 000 (enlargement from the original scale 1 : 20 000). Photo Widerøes flyveselskap, Oslo.

A common feature is that they very often occur in connection with large-scale polygons of the tundra type or adjacent to such ground forms. In spite of the difference in shape, it can therefore be justified to mention the group in this connection.

On aerial photos from the interior of Finnmark with its extensive mountain plateaux, large-scale network can be observed in many places (Fig. 21). The polygon surfaces often show recent frost action in the form of small-scale frozen ground types such as mud circles, stone rings etc.

The delimitation of the pattern is in many cases considerably less rectilinear than in the polygon ground of the coastal areas. As in these districts, the lines are morphologically reproduced in the terrain. That is to say, the contours of the pattern consist of furrows (Fig. 22) which are partly filled with organic material.

Owing to the frequently curved lines one is sometimes faced with the question to what extent running water may have contributed to the forma-

Fig. 22. Polygon furrows in the area of fig. 21.

tion of the furrows. On account of the slope, possible lateral drainage or some other disturbances in the consequent drainage, it is clear that the pattern has no fluvial traits and from a genetic point of view cannot be referred to fluvial processes.

The localities visited do not show any fluvial influence on the furrows. The peat layer was intact and showed no erosion. In local depressions in the furrows and in some of the corners which often form depressions water has, however, stood, which is shown by the absence of vegetation or belated vegetation.

A detail that arrests attention is the fact that at the bottom of the furrows there is often an irregular but quite clear fissure in the peat layer (Fig. 23) of the same nature as that mentioned in locality 2 (p. 308). When the peat layer was removed from the furrow, a rather superficial concentration of stone was revealed. After that followed unsorted material, mainly consisting of sand and gravel. No continuity in the open fissure in a vertical direction could be observed. A test hole was dug to a depth of 75 cm without "tjäle" being traced. The fissure must probably be regarded merely as a formation caused by drying of the surface layer of the furrow.

Fig. 23. Open zigzagged fissure in the peat layer of a polygon furrow.

In this paper mainly large-scale polygon patterns have been dealt with and the serviceability of aerial photos for tracing this type of ground has been emphasized. In the course of the work the knowledge has been gained that also frozen ground phenomena such as stone pits, stone streams, stripe hummocks and mud circles can very often be identified on aerial photos in scales of 1:20.000 (occasionally on still smaller scales). Such pictures are therefore very useful for reconnaissance purposes. Naturally with a larger scale the possibility of identifying these smaller ground forms increases, especially on viewing and magnifying in the stereoscope. With scales around 1:10.000, for example, the polygonal division that sometimes occurs in the peat layer of palses can be observed, and on the large-scale pictures, Fig. 24, a large part of the forms of patterned ground in mountain areas can be identified.

To start with, the hypothesis was put forward that the changed properties of the ground, due to frost action would be reflected in vegetation. Fossil forms of frozen ground could in that way be registered in the photograph. This has been a good working hypothesis in that a large

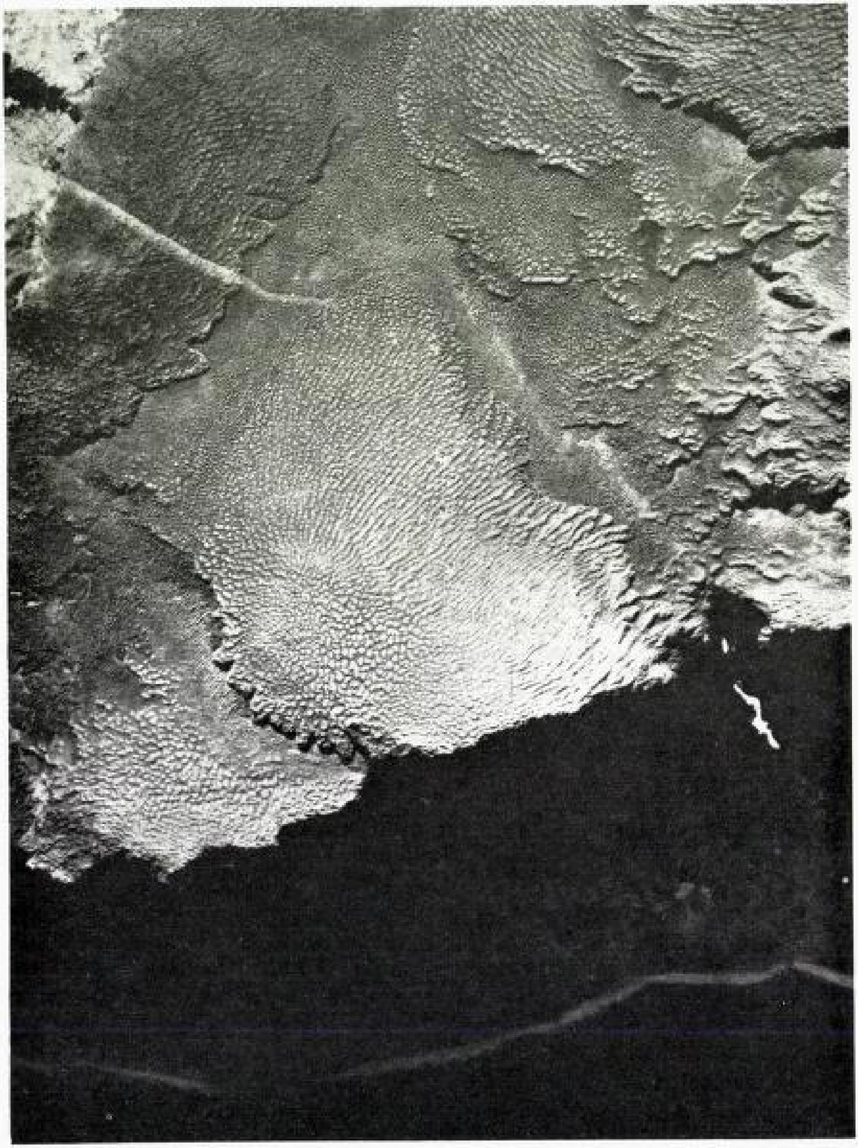

Fig. 24. Large-scale aerial photograph with patterned ground on the plateau of Magerøy (the island of Nordkap, fig. 4). Appr. scale 1 : 4 300 (The original scale is appr. 1 : 4 000). Photo Widerøes flyveselskap, Oslo.

number of polygon areas were discovered because of the arrangement of the vegetaion on polygon lines. The dependence on these lines that the ground vegetation gets, is, however, in the first place the protection offered by the polygon furrows under the ruling climatic conditions. Whether differences in quality decisive for the vegetation really exist in the ground could therefore not be decided and in that respect the hypothesis was incomplete.

In the gravel-pits where polygon ground could be studied in vertical sections there was no "tjäle" on the occasion when the examination was made. According to oral information from workers, perennial frost has not been observed. Official road authorithies in this part of Norway (Statens Vegvesen, Finnmarks fylke) have also supplied information that permafrost is not encountered in road construction except in peat bogs (palses). It therefore appears justifiable to regard the observed tundra polygons as fossil.

As previously mentioned, the Varanger peninsula lies, according to Black's map of the spread of permafrost in the northern hemisphere (Black 1954), outside the zones of both continuous and discontinuous permafrost. This map is, however, a general one and naturally not exhaustive as regards particular details.[1]

In some cases, as mentioned, "tjäle" was encountered in test digging in polygon ground, but without the possibility of deciding on its depth or extent. It is quite clear that sporadic permafrost occurs on the Varanger peninsula. It is also possible that greater areas of permafrost occur (apart from the pals areas). Observations are, however, still insufficient for drawing conclusions on this question.

The occurrence of peat in the polygon furrows in several of the areas examined shows that a not inconsiderable time has passed since the polygon pattern was formed in the ground. This shows aspects of both chronological and climatological character. As regards the question of age, perhaps certain hopes can be placed on radio carbon-dating of the organic material of the furrows and in coastal areas also on comparisons of polygon patterned beaches with shore-line diagrams.

Within several polygon regions scattered forms of minerogenic mate-

1) According to Bogdanov et al. (quoted from Black 1954) in the northern hemisphere the southern limit of permafrost has moved north under the influence of the improvement in climate taking place at present. One result of this amongst others is that the permafrost can be divided and appear in isolated spots.

rial with what appears to be a sunken upper part have been observed (cf. pp. 319 – 321). The form can vary from merely an insignificantly elevated part of the ground to a low dome-shaped form. In the central "sunken" part layers of peat often occur. The forms are very fascinating and give associations of the palses and pingos of the recent frozen ground areas.

It is interesting that Rapp and Rudberg (1960) suspected that pingo forms occur in an area of the inner Scandes. G. Lundqvist (1953) also describes from these tracts the recent formation of dome-shaped forms in minerogenic material which can be connected with the pals formation.

A surveying of the occurence of tundra polygons in connection with field studies of its surface and vertical forms and their affinity is justified owing to the fact that the distribution of this ground form in Scandivavia is unknown. It would probably also bring to light new aspects of the status of the areas in question in past ages, not only from a climatic point of view, but also from a general geographical one. Finally, an investigation of this kind can provide data which are usable for comparative studies in areas where tundra once has occurred but the surface form of the polygon pattern has been obliterated, so that now the phenomenon is only accessible in its vertical form in scattered cuttings.

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Literature.

Andreev, W. N. 1955: Die Bestimmung der verschiedenen Tundratypen auf Grund von Luftbildaufnahmen und ihre von den auftretenden Frostspalten abgeleitete aerovisuelle Charakterisierung. (In Russian).

Benninghoff, W. S. 1953: Use of aerial photographs for terrain interpretation based on field mapping. Photogram. Engineer. 19.

Black, R. F. 1952: Polygonal patterns and ground conditions from aerial photographs. Photogram. Engineer. 18.
— 1954: Permafrost. A review. Bull. Geol. Soc. Amer. 65:2.
Frödin, J. 1914: Geografiska studier i St. Lule älvs källområde. Sveriges Geol. Unders. Ser. C, No. 257.
Holtedahl, O. 1960: Geology of Norway. N.G.U. Nr. 208.
Hopkins, D. M., Karlstrom, T. N. V. et al. 1955: Permafrost and ground water in Alaska. U. S. Geol. Surv. Prof. Papers 264 F.
Johnsson, G. 1956: Glacialmorfologiska studier i södra Sverige. Medd. fr. Lunds Univ. Geogr. Inst. Ser. Avh. nr. 30.
— 1959: True and false ice-wedges in Southern Sweden. Geogr. Ann. 41.
— 1962: Periglacial phenomena in Southern Sweden. Geogr. Ann. 44.
Lachenbruch, A. H. 1962: Mechanics of thermal contraction cracks and ice-wedge polygons in permafrost. Geol. Soc. Amer. Spec. Papers No. 70.
Leffingwell, E. de K. 1915: Ground-ice wedges. The dominant form of ground-ice on the north coast of Alaska. Journ. of Geol. 23.
Lundqvist, G. 1951: En palsmyr sydost om Kebnekaise. Geol. Fören. i Sthlm. Förh. 73.
— 1953: Tillägg till palsfrågan. Geol. Fören. i Sthlm. Förh. 75.
Lundqvist, J. 1962: Patterned ground and related frost phenomena in Sweden. Sveriges Geol. Unders. Ser. C, No. 583.
Mackay, J. R. 1957: Field observations of patterned ground. Canad. Alp. Journ.
— 1962: Pingos of the pleistocene Mackenzie delta area. Geogr. Bull. No. 18.
Marthinussen, M. 1960: Coast- and fjord area of Finnmark. Norges Geol. Unders. nr. 208.
Müller, F. 1959: Beobachtungen über Pingos. Medd. om Grönl. Bd. 153. No. 3.
Nørvang, A. 1939: Stenringe og frostspalter i Danmark. Naturhist. Tidende 3 Aarg. 7.
— 1942: Frostspalter i Jylland. Medd. fr. Dansk Geol. Foren. B. 10.
Rapp, A. och Rudberg, S. 1960: Recent periglacial phenomena in Sweden. Biulet. Perygl. No. 8.
Rapp, A., Gustafsson, K. och Jobs, P. 1962: Iskilar i Padjelanta? Ymer 1962.
Svensson, H. 1962 a: Note on a type of patterned ground on the Varanger peninsula Norway. Geogr. Ann. 44.
— 1962 b: Ice-wedges in fossil tundra polygons on the Varanger peninsula. Svensk Geogr. Årsb. 38.
— 1962 c: Ett mönster i marken. Svensk Geogr. Årsb. 38.
— 1963: Some observations in West-Jutland of a polygonal pattern in the ground. Geogr. Tidsskr. 62.
Troll, C. 1944: Strukturböden, Solifluction und Frostklimate der Erde. Geol. Rundsch. 34.
Washburn, A. L. 1950: Patterned ground. Rev. Canad. de Geogr. Vol. 4.
— 1956: Classification of patterned ground and review of suggested origin. Bull. Geol. Soc. Amer. 67.