SVERIGES GEOLOGISKA UNDERSÖKNING

SER C NR 648 ÅRSBOK 64 NR 5

JAN LUNDQVIST

PROBLEMS OF THE SO-CALLED ROGEN MORAINE

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CONTENTS

Abstract 3

Introduction 4

Review of suggested origins 5

Description of the Rogen moraine 7

  Topographical aspects 7

  Morphological aspects 11

  Surface 18

  Interior of the ridges 19

Conclusions about the formation of Rogen moraine 24

Literature 31

Abstract. The ridge moraine landscapes, named after the Rogen area in Härjedalen, western Sweden (Fig. 1), have earlier been interpreted as having been formed subaërially or subglacially, at the ice margin or at some distance inside it, by active or stagnant ice. To find a compromise between the varying theories about the origin the author has examined the data available from many tracts with Rogen moraine, especially in the province of Jämtland. The discussion considers topographical and morphological aspects, the surface and interior structure of the ridges. It leads to the following theory of the origin of the ridge moraine. The morphology originated subglacially by tension of the basal till in the land ice when it moved over basins or other concave breaks in the terrain. When the movement stagnated and the ice wasted down ablation moraine could also be deposited on the ridges. The preservation of the ridges demands dead-ice deglaciation although they must have been formed already below the active ice.

INTRODUCTION

Ridged moraine of the type characterizing above all the area north of Lake Rogen, western Härjedalen in Central Sweden, has attracted a lot of interest among Swedish geologists and geographers. The type has often been called Rogen moraine after that region, a therm that can be appropriate to avoid longer descriptive terms, implying a more or less clearly expressed interpretation. A short review of earlier proposed theories about the formation of the Rogen moraine follows.

Characteristic for the Rogen moraine are the subparallel ridges, which are a most significant difference from ordinary dead-ice moraine, to which the Rogen moraine has been considered closely related. The ridges, making up practically the whole mass of the moraine, can be followed for several kilometers. Their height is mostly 10 to 20 m but can exceed 30 m. The width is generally

Fig. 1. Oblique air photograph from the type area at Lake Rogen. It is clearly seen that the long ridges are composed of shorter, crescent-shaped parts and that their ends are often curved towards the viewer, e.g., at the gap to the right of the centre of the picture. The ice movement was towards the viewer. – Photo J. Lundqvist 1963. Av försvarsstaben godkänd för publicering.

of the order of 100 m but can often be about twice that width. Sometimes the ridges can be rather regular and parallel, reminiscent of end moraines. In general, however, they are anastomozing and angular – ridges can even turn at about right angles – although the main trend all over a certain tract is the same. Fig. 1 from the type area gives an impression of these facts.

During field work in northern and central Sweden, especially for the reconnaissance map of the Quaternary deposits of the County of Jämtland, the author has made numerous observations that can contribute to a more complete interpretation of the Rogen moraine than has hitherto been possible. These observations have to some extent been published in the description to the map mentioned (J. Lundqvist 1969). It can nevertheless be appropriate to summarize them in a special article and to combine them with observations from other regions. Thus the genetical problem can be discussed more completely than is possible in a map description. A short synthesis of the author's views upon the problem is, however, already given in the description and has also been touched upon in lectures at the University of Stockholm. It should be emphasized that a detailed investigation of the type area at Lake Rogen is now being carried out by Dr. L. Wastenson at this university. This article is not intended to anticipate his results but rather to complement them on a more regional basis. Thus the present author has not even studied the type area in detail, although it is included in the investigation of the County of Jämtland. On the other hand, more aspects can be collected if more than one tract is studied, even if the study only deals with the outlines.

REVIEW OF SUGGESTED ORIGINS

Several divergent theories about the origin of the Rogen moraine have been presented. In earlier works dealing with the interior of northern Sweden (e. g. Högbom 1894, Tanner 1915) there are no good descriptions of this typ of moraine. In more vague terms areas with Rogen moraine are referred to either as hummocky moraine or, where the ridges are especially distinctly developed, as end moraines.

Later, when better topographic maps were available which clearly showed the very special morphology, the end moraine theory was accepted without much discussion (see Högbom 1920, Frödin 1913, 1925). The simple reason for this acceptance was the very clear ridge forms, reminiscent of true end moraines, and the elongation at right angles to the direction of the dominant ice-movements. In his later work, Frödin (1954) had been influenced by other interpretations of the Rogen moraine and referred to it in more general terms as moraine ridges. At least in some instances he certainly considered it a type of dead-ice moraine, whilst in other cases he retained the end moraine hypothesis. This especially applies to some tracts with longer ridges in Central Jämtland.

G. Lundqvist (1937, 1943, 1951) raised severe objections to the end moraine theory, emphasizing especially that these large ridges, much larger than common end moraines of the De Geer type, occur in the ice-divide zone, and even pass the ice divide. Also they occur together with unmistakable dead-ice moraine and on even lower levels. For these reasons above all G. Lundqvist also interpreted the Rogen moraine as a special type of dead-ice moraine. However, observations indicating that the moraine ridges had been subject to pressure by the ice made it necessary also to assume slight residual movements in the ice. G. Lundqvist (1937) even suggested a reactivation of the ice. The ridges should have been formed in crevasses in stagnant ice lobes, not far from the front, and during a later reactivation the pressure phenomena were formed. Such phenomena were also observed and interpreted in the same way by Lindkvist and Svensson (1957). Although it was not stated by these authors, the theory of a slight activity in the ice implies in reality an approach towards the subglacial hypothesis. In spite of this the accumulation of material in open crevasses seems to have been emphasized. This is also shown in G. Lundqvist's (1937) ranking of the depressions between the ridges in the same category as the kettle holes of glaciofluvial deposits. Perhaps also G. Lundqvist's (1963) later change of the designation dead-ice moraine to ablation moraine for the Rogen type is an expression of such an opinion. Also the present author (J. Lundqvist 1958, 1958 a) showed a stratigraphy of the Rogen moraine that clearly indicated formation in open crevasses in stagnant ice (cf. p. 23).

A more complex mode of formation of the Rogen moraine was suggested by Mannerfelt (1945 and others), implying accumulation both subglacially and in open crevasses. He considered dead-ice moraine in general as being formed by subglacial, supraglacial and marginal elements intimately mixed (Mannerfelt 1945, p. 155). It should be noticed that he, as well as G. Lundqvist, emphasized formation not far from the ice margin even if the end moraine theory was abandoned.

An entirely subglacial origin of the Rogen moraine was suggested by Granlund (1943, p. 46). According to this theory till was forced up into basal crevasses in the ice by the pressure of the ice. This subglacial theory was later developed especially by Hoppe (1952 and others). The orientation and dip of the boulders favoured this theory. Mainly because of the ground moraine character of the till in the ridges most other recent investigators have adopted the theory of a subglacial origin (e.g. Rasmusson & Tarras-Wahlberg 1951, Kujansuu 1967). A few more observations, closely related, are specially important in addition to the character. The present author (J. Lundqvist 1967, 1969) described several examples of the direct transition from Rogen moraine to drumlins. Wastenson (1969) described a striation of the ridges within the Rogen area in the direction of the ice movement, reminiscent of fluted-moraine surfaces. Both drumlins and fluted moraine are typical subglacial phenomena and the observations thus favour the theory of Granlund and Hoppe. Especially the drumlin transitions indicate formation below the ice sheet rather far from its margin. These phenomena are further discussed on p. 15.

Summarizing the opinions quoted we find the most contradictory conclusions about the genesis of the Rogen moraine. It has been supposed to be formed either in open ice crevasses (subaërially) or in basal crevasses (subglacially), either at the ice margin or at least at some distance inside it, and either by active or stagnant ice. Evidently each opinion finds its support. The purpose of this article is to critically examine the available data, old as well as new, and to find a compromise between the diverging theories of the origin.

DESCRIPTION OF THE ROGEN MORAINE

TOPOGRAPHICAL ASPECTS

The regional distribution of the Rogen moraine comprises the inland of northern to central Sweden (Fig. 2). Well developed examples occur in northern Värmland (J. Lundqvist 1958) and northern Dalarna (G. Lundqvist 1951). In the provinces of Jämtland and Härjedalen (County of Jämtland) this moraine type is very widely distributed in the region between the mountain range in the west and the highest coastline in the east. Here is the type area at Lake Rogen, where the Rogen moraine reaches far into Norway (Holmsen 1935). Still larger areas occur in central Jämtland. To the north of this area landscapes of this type seem to be more rare. Very good examples are found even in northernmost Jämtland, but they occupy rather small areas. In the County of Västerbotten there are still a few such tracts (see Granlund 1943, Mannerfelt 1945). A very well developed tract is known from Lake Tärnasjön, north-east of Tärna. Farther north the conditions are less known. In and around the upper courses of the rivers L. Lule älv and Pite älv, where they pass the premontane region, the Rogen moraine seems to have a rather wide distribution. Map sheets 14 Kvikkjokk and 16 Tjåmotis, Luovos in the series published by the State Power Board (see Bergström 1961) show Rogen moraine in scattered areas around the lakes Saggat–Skalka in the river L. Lule älv, around Lake Karats to the south and in many adjacent tributary valleys. Farther south-westwards the type is known from the region south of Lake Rappen, north of Arjeplog. In many of these instances the type is less well developed although the ridges are clearly visible. From the whole interior of northernmost Sweden north of the rivers Lule älv no good examples are known. According to Hoppe's (1952 and others) studies the hummocky moraine there seems to belong to other types, characterized by hummocks or more irregularly oriented ridges (Veiki moraine). The present author is well acquainted with these regions but does not know one single good example of true Rogen moraine.

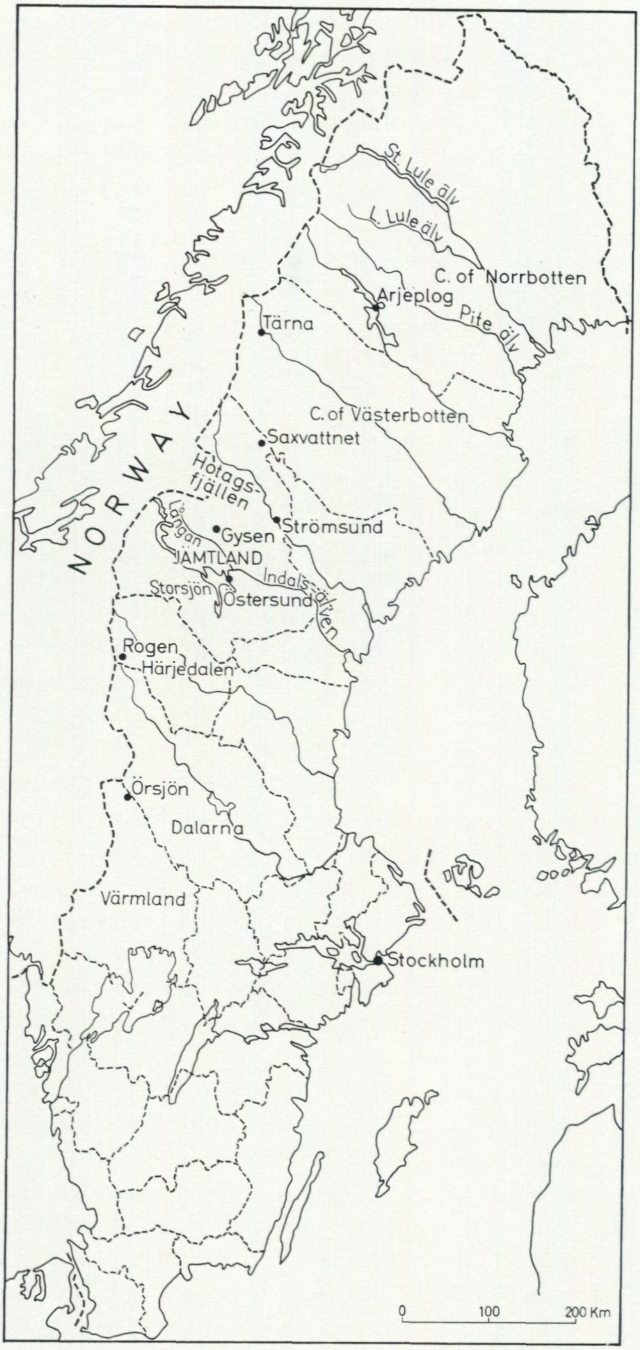

Fig. 2. Location map.

Farther east, that is, in the region around and below the highest coastline (the highest ancient position of the Baltic shore) there does not seem to be any ridged moraine of true Rogen type. However, ridges very similar to Rogen ridges are described from the coastal parts of the County of Norrbotten by Hoppe (1948) and Fromm (1965). These ridges are similar to Rogen moraine both in their morphology and interior but the name, Rogen moraine, has not been used for them. Also, their position below the highest coastline and in close connexion with end moraines is very different from the true Rogen moraine. Hoppe (1948) and Fromm (1965) interpreted them as special facies of marginal formations alternating with the end moraines. Because of the interior of mainly glacio-fluvial material Hoppe (1959), compared these ridges with the eskers of the region. According to this interpretation the ridges were formed by subglacial meltwater under the outermost parts of the ice still in motion. They "ought to be described as a type of subaquaeous thrust end moraines". These ridges will not be discussed in the following text, but they are sometimes referred to because they can also give some aspects of the origin of Rogen moraine.

Regarding position in relation to the ice divides, the Rogen moraine mainly belongs to the region around the main divides east of the mountains (cf. G. Lundqvist 1961, J. Lundqvist 1969). In these districts the ice mainly wasted away as dead ice. The last active ice was centered in the mountains (cf. Hoppe *et al.* 1959, J. Lundqvist 1969). In the region where the ice was possibly still active during the recession typical Rogen moraine is absent or rare. This also applies to those parts of Härjedalen and southern Jämtland where glacial morphology and striae indicate motion of the ice during the deglaciation. Where Rogen moraine is found in such regions it occurs in sheltered valleys and depressions where conditions favoured isolation of local dead-ice bodies.

From a more local point of view the Rogen moraine belongs to the lower part of the landscape, especially valleys and basins. Hoppe (1959) stated that it "appears generally in mountain valleys, although it occasionally also can extend over more non-dissected landscapes". The investigations in Jämtland have shown that the very large areas with Rogen moraine actually occur in rather flat regions. Central Jämtland west of Strömsund, NW of Hammerdal and SE of Lake Gysen are good examples. Also the Rogen area itself is rather flat although some mountains rise smoothly about 200 m or more above the high plateau where the moraine landscape occurs. In more dissected landscapes the valleys and basins are naturally smaller or narrower and consequently the Rogen moraine occupies smaller areas, although these can be frequent.

Towards the sides of a basin or valley the Rogen ridges disappear. Sometimes they gradually pass into the moraine cover of the adjacent slope, sometimes they end with a steep slope, facing the valley side, before they reach it. The disappearance of the ridges may be due to the general thinning of the till cover at higher levels. In areas where the till is generally thicker the ridges can reach rather high ground above the bottoms of the basins. This is the case towards the mountain Handskinnsvålen in the Rogen district and, still more pronounced, in the mountain plateau Bastunäsfjället at the Saxvattnet area, northern Jämtland.

Where the Rogen moraine occurs in valleys or elongated basins the ridges are generally extended at right angles to those. This, however, does not seem to be a necessary condition for its formation. The reason is simply that the valleys mostly run in the direction of the main drainage and the same courses, within the regions in question, were also followed by the main ice movements determining the orientation of the Rogen moraine. There are many examples of these ridges being extended at an oblique angle to the valley or even along it. The best examples are found in Central Jämtland north of Lake Näldsjön and in the Indal valley north of Östersund.

With reference to the local morphology of the landscape it is important that the Rogen moraine occurs in areas that have a concave profile along the direction of ice movement determining the moraine orientation. Where the profile is definitely convex the moraine becomes more drumlinoid in shape, that is, extended at right angles to the Rogen ridges. In a valley, e. g., the Rogen ridges occur in the basins mainly, that is, in those parts where there are often lakes and where the river has a deposition stretch. In the parts between, where there are stretches of erosion, the moraine shapes become either more indistinct or even extend at right angles to the Rogen moraine. These statements apply to the more dissected landscapes. Where the general morphology is flat it is much more difficult to see any certain trend in the distribution.

In the normal valley or basin position the profile of the substratum of the moraine is, of course, always concave along the ridges. This, however, is not a condition for their formation, as clearly demonstrated by their occurrence in flat areas, or parallel to the valley.

In the normal position the ridges sometimes extend all over the depression, as in the case in the Rogen area. It is just as common that the ridges extend from the valley sides only some distance towards the centre of the depression, where there is a gap in the ridges. A good example has been shown from Värmland (J. Lundqvist 1958, Fig. 142). In that case the ridges rise above a basement, the contour of which is rather even towards the central gap, not showing the promontories typical of most lakes in comparable positions within a Rogen moraine.

In some instances eskers pass through Rogen moraine tracts. Hoppe (1952) described a few examples from the type area north of Lake Rogen. In these cases, as well as in the Gysen area in Jämtland (cf. Lindkvist and Svensson 1957), for example, the eskers occur in close contact with the till ridges. Hoppe (1952, p. 63) found that, as far as it was "possible to judge from the contacts, *the eskers are younger formations than the moraine ridges*". The eskers in question are of a type that is generally considered to be subglacially formed (Hoppe 1952, J. Lundqvist 1969). In these cases there are no gaps in the moraine ridges around the eskers. Also, it is remarkable that the eskers do not cross the ridges at right angles as one would expect, but obliquely although the main trend is that the eskers follow the direction of ice movement while the moraine ridges transverse it. In these cases the eskers are rather small and, as mentioned, formed in closed crevasses in or under the ice.

There are also instances where large eskers and valley trains cross Rogen moraine tracts. Perhaps the best examples are found along the rivers Öjån and Storån west of Strömsund, Jämtland. There the glaciofluvial deposits follow the present river courses crossing the low watershed between them. Thus their course is dependent mainly on the same large-scale morphology that determines the courses of the rivers. The orientation of the moraine ridges is therefore not exactly transverse to the somewhat winding course of the glaciofluvial deposits, only in outline. Around the glaciofluvial deposits – on the watershed also around erosion phenomena – there is a distinct gap in the moraine ridges. In some places these reach almost to the glaciofluvial deposits, in others the gap is broader, leaving a low basement of till between the gravel and the ridges.

From the foregoing the conclusion might easily be drawn that there are eskers or other glaciofluvial phenomena in all instances where there is a central gap through the moraine ridges. This, however, is not the case. In many basins where the gap is well developed, such as the Örsjö basin (J. Lundqvist 1958) and the lakes Saxaborga and Gysen in northern Jämtland, the glaciofluvial deposits are either almost or completely lacking (Saxaborga, Örsjön) or do not follow the gap (Gysen).

Concerning the general thickness of the drift in Rogen moraine tracts very little is known. A general impression from Central Jämtland is that the till between the ridges is rather thin, the ridges thus corresponding to most of the till cover. Similar indications were mentioned from Värmland and at least some part of the Rogen tract (J. Lundqvist 1958, pp. 66, 209).

MORPHOLOGICAL ASPECTS

The ridges of the Rogen moraine at the first glance may give a very confusing and irregular impression. A closer study will reveal a picture containing some very regular features.

The distance between the ridges is mostly of the same order as their width, i.e., a couple of hundred metres. Sometimes the ridges may give a more slender impression and seem to be more sparsely spread. This impression is mostly false, due to the fact that the depressions between the ridges are filled with water or are peat-covered, hiding the base of the ridge. Only in those cases where the Rogen moraine occurs in a region with generally thin till cover are the ridges really narrower and more incomplete. A good example of this is in Lake Fisklössjön, north-western Jämtland (J. Lundqvist 1969, p. 243). In other instances the ridges are situated much more closely, the depressions between them being very narrow and giving an impression of furrows in a more even till cover. The general situation and morphology immediately show that the furrows must be a primary feature and are not caused by erosion. Examples of this type are known from Särvsjö, northern Härjedalen, and Lake Flottringen, south-eastern Jämtland (J. Lundqvist 1969, pp. 63, 339).

The relationship between the dimensions of the ridges and depressions is mostly about the same within each certain tract and so is the size of the ridges. There can be great differences, however, even between adjacent tracts. A good example is found in the Gysen region, Central Jämtland. South-east of this lake the ridges as well as the depressions between them are about 50–100 m wide. This rather extensive tract of ridges is broken towards the west by a somewhat flatter moraine terrain. West of this, only about 1 km west of the ridge landscape, there is another tract of Rogen moraine following the river Gysån. This tract is situated at about 50 m lower altitude. It is characterized by broader ridges, 100–150 m wide, with rather flat upper surface. The width of the interjacent depressions is about the same.

As already stated, the ridges are somewhat winding and often anastomozing. The winding courses are partly due to changes of the general orientation, partly to smaller morphological features. The latter, which probably have a principal importance, are due to the fact that the ridges are composed of many small ridges, each one having a curved outline. In outline these small ridges are crescent-shaped with a concave lee-side and a convex side facing the ice movement. The combination of many such small ridges (in the following called crescent ridges) gives a long ridge of Rogen type (called a main ridge). The lee-side of this is characterized by smoothly curved concave parts and interjacent protruding parts with a sharper angle. On the opposite side of the main ridge the convex parts are smoothly curved whilst the concave parts are sharp-angled. Sometimes they are formed by two ridges meeting at almost right angles. All these features are mostly visible on vertically taken aerial photographs from Rogen moraine areas.

This description can be illustrated by some statistics from the Finnvattnet area, northern Jämtland (see Fig. 7). In a type area of about 7 km² the proximal sides of the ridges are characterized by protruding parts that have rounded contours (97 % of all cases). Only 3 % of these parts have an angular outline. The interjacent inlets were 23 % rounded while 77 % were angular. On the distal (lee) side of the ridges the protruding parts were rounded (57 %) or angular (43 %). The concave parts (inlets) were mostly rounded (76 %) while in 24 % the ridge parts met at a sharp angle. Between 80 and 130 cases were studied. A closer scrutiny showed that the rounded promontories facing the ice movement were the proximal ends of drumlinoid parts or parts of crescent

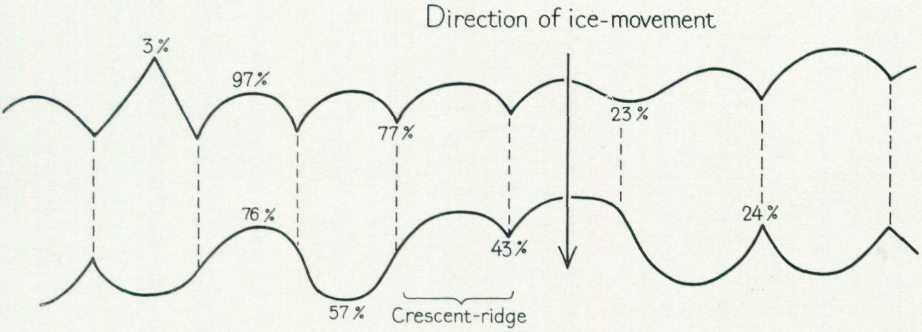

Fig. 3. Sketch illustrating the statistics mentioned in the text. The figures indicate the percentages of the form of the convex and concave parts on the distal and proximal sides of the ridges within a type area at Lake Finnvattnet.

ridges. The inlets between them were in most cases the abrupt change from one drumlinoid part to another. In some instances these limits were smoothened. On the lee-side the rounded promontories were the distal ends of drumlinoid parts. The angular ones corresponded to the distal ends of crescent-ridge parts, sometimes a combination of two adjacent such parts. The rounded interjacent inlets mostly corresponded to the lee-side of a part of a crescent ridge. The angular ones were often the abrupt limit between two adjacent drumlinoid parts. These different types are illustrated by Fig. 3.

On aerial photographs it is seen that the branching of the ridges is very often formed by one or two of the curved arms of a crescent ridge being elongated to meet the following main ridge. Sometimes the convex side of a crescent ridge is extended to meet the adjacent main ridge. If these extended parts are especially elongate even a type of transverse ridge is formed at approximately right angles to the Rogen moraine.

A thorough comparison will often reveal that the branching and winding of the ridges give adjacent ridges outlines corresponding to each other, so that promontories in one ridge correspond to inlets in the adjacent. The total impression may even be that of a giant jig-saw puzzle.

When there is a central gap in the ridges it is rather common that the inner ends of the main ridges are curved towards the distal side along the gap, thus getting an orientation at more or less right angles to the general ridge direction. An example of this is the Örsjö area in Värmland (J. Lundqvist 1958, Fig. 142). The effect is an exception to the general rule that the main ridges are as a whole often slightly curved with the convex side facing the ice movement. This feature can be seen when the ridges traverse a limited basin but is less evident when they extend over a broader area.

Occasionally the subdivision into crescent ridges becomes more pronounced, the crescents being more regular and gradually separated. Examples of this type

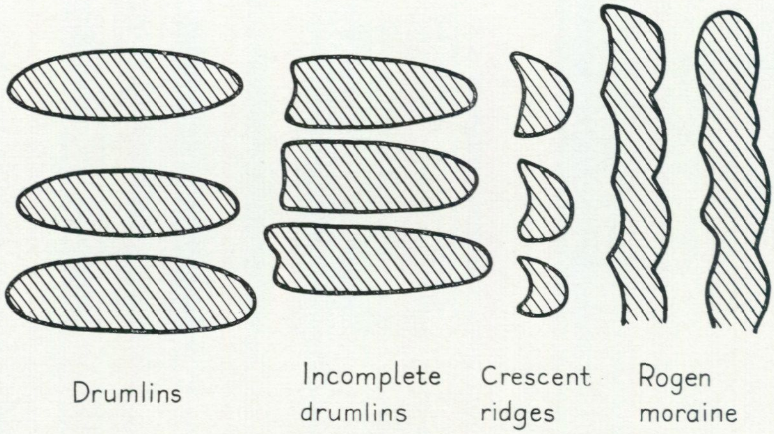

Fig. 4. Sketch showing the main morphological elements making up the gradual transition from drumlins to Rogen moraine.

Fig. 5. Oblique air photograph from a drumlin cluster in the transition zone between drumlins and Rogen moraine (Fig. 4). From the Hotagsfjällen mountains, Jämtland. – Photo J. Lundqvist 1966. Av försvarsstaben godkänd för publicering.

are known in some flat highlands in Jämtland, e.g., S. Borgafjällen, Hotagsfjällen and the plateau north of Lake Landösjön–Långan. The mountain plateau Hotagsfjällen can serve as type area. It has been described earlier as an area where drumlins gradually pass into Rogen moraine (J. Lundqvist 1967, 1969). The plateau is vaulted, convex in the direction of ice movement. This is a topographical situation typical for drumlins in Jämtland. They occur especially where the plateau begins to slope in the direction of ice flow. Where there are depressions in the plateau the drumlins become incomplete, their distal end being first more abrupt, then even concave. The drumlins in this way become shorter and gradually change into ridges at right angles to the drumlin orientation (see Figs. 4 and 5). These ridges are very similar to the crescent ridges described above. Also, these incomplete drumlins towards the lower part of the depressions combine to form ridges at right angles to the direction of ice movement, which, if they become a little more irregular, are identical with the Rogen moraine. We have a continuous transition from drumlins in the terrain with convex profile to Rogen moraine in the concave position typical for this morphology.

In those instances where there are transitions to drumlins the whole moraine surface, Rogen ridges as well as isolated crescent ridges and incomplete drumlins, often shows a distinct striation, more or less well-developed fluted moraine. This fluting is clearly visible in Fig. 5. The structure partly corresponds to the depressions between the drumlins that can be followed even over the transverse Rogen ridges. Partly it is a finer striation of lower order, seen even on the highest parts of the moraine hummocks and ridges.

In ordinary Rogen moraine tracts without transitions to drumlins the striation is in many instances less clearly visible. Only a close scrutiny will reveal a faint structure. Wastenson (1969, Tonell & Wastenson 1969), as mentioned above, has described such striation in, among other places, the type area at Lake Rogen. An almost necessary condition for discovering the fluting is that the ground is not hidden by too dense a forest vegetation.

All that has been said here about variations within the long main ridges of the Rogen moraine applies to areas where they occur in limited basins or in valleys transverse to the ridge direction. In the more rare instances where the ridges run along the valleys or large land forms they seem to be more straight. They are less winding and the partition into crescent-shaped parts is less pronounced. This may help to explain why Frödin (1954, p. 72) interpreted such ridges as frontal moraines.

In other instances where the ridges are more straight and regular than usual there is a close conformity between the ridges and the strike of the bedrock. Small outcrops and a generally thin till cover make it clear that in these cases the moraine forms are caused by the structure of the substratum. They should not be considered a type of Rogen moraine. Examples are known from the Ankarvattnet region, northern Jämtland, and south of Lake Hotagen, Central Jämtland.

From the foregoing it follows that there are some variations in height within the Rogen ridges. Some parts, corresponding to the centres of the crescent ridges, are higher than the interjacent. The more obliterated the drumlin or crescent-ridge structure becomes, the more even is the height of the main Rogen ridge. Within a certain, limited tract of ridges there is often a consistent height, all ridges reaching approximately the same maximum height. This height, which can reach about 30 m, is greatest in the centre of a basin. Towards its sides the ridges are often somewhat lower, although still distinct until they suddenly disappear against the bordering slope. Sometimes the ridges end with an abrupt slope just before they reach the adjacent higher ground. In detail the ridges can appear rather hummocky but seen as a whole in relation to the total height and the total thickness of the till cover the consistency in height of the tops is rather conspicuous. It is especially striking when the ridges are situated close together, their crests together forming a slightly undulating moraine surface broken only by the narrow interspaces between the ridges. At least, even where the consistency is less pronounced, the upper surface formed by the crests is not rougher than an ordinary moraine surface in a corresponding position. The contour map of the Örsjö tract (J. Lundqvist 1958, Fig. 142) gives some impression of this. Most ridges there reach a maximum height of about 6 m above the lake surface. Only a few small hillocks reach above this limit.

The cross-section of the Rogen ridges is often almost symmetrical (cf. G. Lundqvist 1937, Fig. 15). This is the case where the drumlinoid forms are invisible or where the drumlinoid parts are completely developed with smoothly rounded distal ends. Where there are crescent ridges, and sometimes also where drumlinoid contours are lacking, the proximal slope is often more gentle, and the distal slope steeper. Parts of the ridges may even have a profile of a roche moutonné. Observations of similar profiles have been mentioned by Hoppe (1959).

In the foregoing the gradual transition between drumlinoid forms and Rogen moraines has been emphasized. On the other hand, there are also transitions to quite irregular hummocky forms, typical for dead-ice moraine. Small dead-ice forms, such as small rounded hills and hollows, are quite common in most Rogen moraine tracts but it seems to be more rare that whole moraine tracts show transition forms. Generally either ridges or irregular hummocks dominate completely, making the classification easy. There are, however, instances where scattered ridges of Rogen type occur in dead-ice moraine. Such morphology can be seen in depressions in the mountains, e.g. in northernmost Jämtland. In other instances a distinct parallel structure can be observed over a whole tract, but small hummocks as well as hummocky morphology within the ridges are very common. Fig. 6 shows an example of the latter type from the Gysen re-

Fig. 6. The area with Rogen moraine in the Gysen region shows a somewhat hummocky morphology. It represents a transition type to dead-ice moraine. Lake Gysen is visible in the background. – Photo J. Lundqvist 1958. Av försvarsstaben godkänd för publicering.

gion. Some of the long ridges seem to consist of series of mounds, lacking drumlinoid shape.

A special type of ridge pattern, which can be interpreted either as a transition to irregular dead-ice moraine or as two crossing ridge systems, has been described by Frödin (1954, Fig. 18) and J. Lundqvist (1969, p. 282) from the Storsjö region, Central Jämtland. The region is rich in hummocky dead-ice moraine but Frödin interpreted the type as a ridge moraine influenced by two ice movements, the younger one being the result of a so-called "Epiglacial" ice advance. This advance most probably never took place (J. Lundqvist 1969) but nevertheless the ridges run approximately transverse to two different directions of striae.

Lindkvist and Svensson (1957, p. 211) described how the Rogen ridges in the Gysen area are sometimes eroded and sharpened towards the central gap by meltwater erosion. Such features can be observed where extramarginal meltwater streams have come into contact with the ridges. Examples occur in the Storå region east of Laxsjö, Central Jämtland, at the river Låddan, Central Härjedalen, and in many other places where outwash plains extend into the depressions of a Rogen moraine. However, the effect of the erosion generally seems to be small. Aerial photographs clearly show how the contours of the

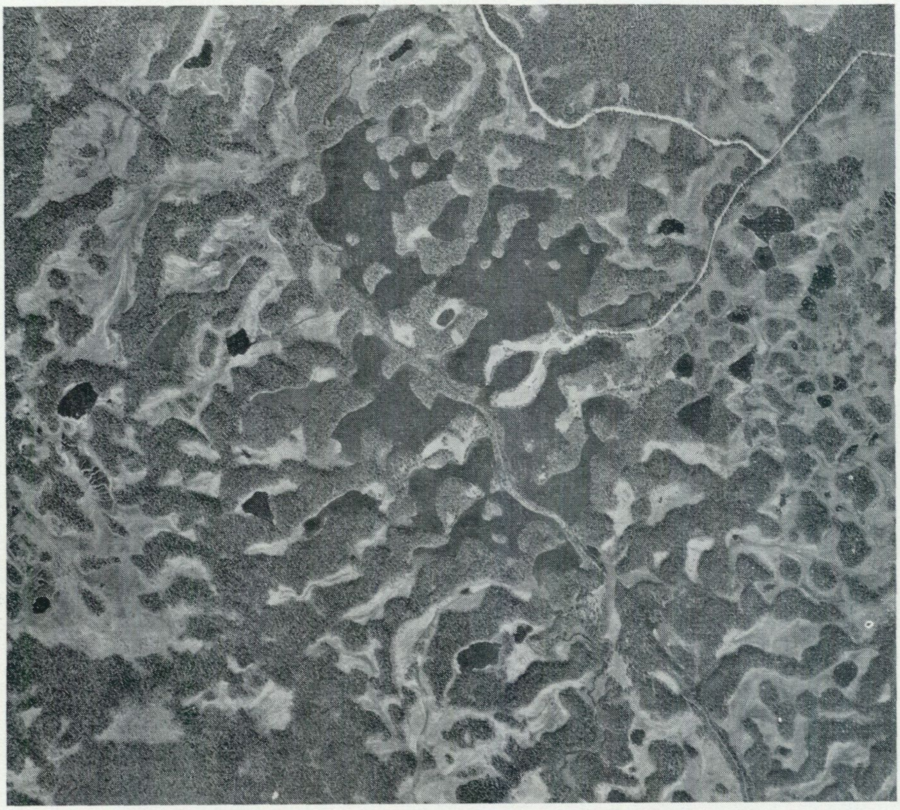

Fig. 7. Vertical air photograph from the Finnvattnet tract, Jämtland. The striation of the ridges at right angles to their extension is clearly visible, and so are the different types of the convex and concave parts of the ridges (cf. Fig. 3). An esker traverses the moraine tract. It should be observed that it does not exactly follow the central gaps in the ridges. The light fields between the moraine ridges are fens. The statistic study, represented by Fig. 3, was made in this region. – Photo by Rikets allmänna kartverk 1965. Godkänd för reproduktion och spridning av rikets allmänna kartverk den 21.10.1969.

ridges are of the same type as where no erosion has taken place. Also where an esker passes through a Rogen moraine tract the erosion along the esker seems to have been insignificant. The ridges either end smoothly towards the esker or join it without a gap. The Finnvattnet area offers good examples of these features (Fig. 7). Therefore it can be concluded that erosion has played an insignificant role in the formation of the ridges.

SURFACE

The surface of the Rogen moraine ridges is to a great extent dependent on the general type of the till in the region. Because the Rogen moraine belongs to the lower parts of the terrain the content of boulders is often somewhat higher than in the surroundings, following the general rules for the variations of the till in the interior of Sweden (cf. G. Lundqvist 1943). Generally, however, the boulder content is determined by the rock types forming the till. In the type area at Lake Rogen the bedrock consists of sparagmites that often give a higher boulder frequency. As a consequence of this and of the situation in a basin the till surface is extremely rich in large boulders. Enormous boulders are piled upon each other and often soil cannot even be seen between them. In Central Jämtland the bedrock consists of less resistant shales, greywackes and limestones that give a till with very low boulder frequency. Consequently, the Rogen moraine also has a surface with very few boulders, so that even such areas can be used for agriculture.

A rather common feature is a concentration of boulders at the foot of the ridges. This is especially pronounced in the relatively cold areas in or close to the mountain range where the boulder frequency is high. Most probably, however, this is a secondary feature caused by frost action (G. Lundqvist 1937). In the mountains the boulders and stones are in this way transported by frost heaving and solifluxion downwards and concentrated at the base of steep slopes, small scarps and hills.

In the most boulder-rich tracts, such as the Rogen and Örsjö areas, the boulders often lie very superficially, even piled upon each other. The surface is that of an ablation moraine. Where the frequency is lower, and also sometimes where it is high, the boulders are more firmly rooted in the till. They seem to be pressed into the ground by, e.g., ice pressure. G. Lundqvist (1937) considered this fact to be evidence of a certain reactivation of the stagnant ice sheet in which the moraine landscape had been formed.

The striation of the ridges, transverse to their direction, was treated above among the morphological aspects. It should be emphasized that this structure is visible only from the air, especially in aerial photographs from high altitude. On the ground it has not been possible to notice this faint structure. On the other hand, in aerial photographs the striation is often as clear in the extremely boulder-rich terrain, e.g., in the Rogen district as in areas with lower boulder frequency.

INTERIOR OF THE RIDGES

In spite of the very wide distribution of the Rogen moraine, large excavations showing the interior structure and material are rather rare. Large excavations are almost necessary to give sufficient information. Small pits, made for sampling the till, are completely insufficient. The information available indicates, however, that there are great variations in the interior structure and bedding.

The most common material of the ridges seems to be ordinary basal till, similar to the surroundings of the Rogen moraine areas (Fig. 8). It shows the same regional variations as the till in general, that is, coarse-grained and rich in boul-

Fig. 8. Cut in a moraine ridge in the type area northeast of Lake Rogen. It shows an ordinary basal till. – Photo J. Lundqvist 1963.

ders and stones where the rocks are resistant, and fine-grained with low frequency of boulders and stones in regions with loose rocks.

Like the boulder frequency at the surface, the interior shows the ordinary variations with topographical situation, that is, the Rogen moraine in depressions is often more stony and coarse-grained than the till on surrounding higher ground. This is probably the real cause why the Rogen moraine in general has been described as coarse-grained, permeable and rich in boulders (G. Lundqvist 1937, Hoppe 1952, Bergström 1961). This must not be applied generally to all Rogen moraine. There are also indications that there may be, at least in some instances, differences between the material of the ridges and of the till immediately adjacent to them. In the Mårdsjö region, eastern Jämtland, the till in the ridges has a sandy matrix, while at their base and surroundings the till is much more clayey. Also in the Gysen–Föllinge region, Central Jämtland, the compact basal till in the ridges seems to have a higher boulder frequency than the ordinary till of the area. Boulders and stones are abundant in a clayey to silty matrix.

In the same area, around Lillholmsjö, Lindkvist and Svensson (1957) also observed that boulders were abundant in the interior of the ridges. The lower frequency on the ridges was explained by them to be caused by human action, people in old days having used the superficial flat boulders of schists and shales for building purposes. In the till of the ridges these authors found a frequent fissility, slightly dipping northwards, that is, towards the last ice movement. Although they interpreted the ridges as crevasse fillings close to the ice margin they considered the fissility as indication of a slight activity of the ice.

Other observations of ordinary basal till in the ridges have been made during the mapping, especially in the Gysen–Föllinge and Laxsjö regions and in Central Jämtland north to east of Lake Storsjön. Several large excavations have been studied and they all have given the same impression of basal till without irregularities, such as sorted material, lenses etc. (Fig. 8). Still other observations have been published from the Saxvattnet tract, northern Jämtland, by Rasmusson and Tarras–Wahlberg (1951). They emphasized that the till was very hard-packed. The same statement was made by Hoppe (1952, p. 66) about the eastern outskirts of the Rogen area, south of Brändåsen. Here he also observed that the sandy matrix of the till often contained sediment veins, making it similar to Kalix till (see p. 22).

In the Rogen area Hoppe (1952, Fig. 36) found that the long axes of the boulders in the ridges are mostly oriented transverse to the ridges. The same orientation had been found also by G. Lundqvist (1948) in "ridged dead-ice moraine". This applies, naturally enough, to instances where the ridges run transverse to the direction of ice flow, the boulders generally being oriented in this direction. It also applies to other instances where the ridges run at an oblique angle to the direction of ice flow. In a distinct ridge at Brevåg, Central Jämtland, the orientation was found to be strictly transverse to the ridge. It coincides with a rather old ice movement, not with the younger ones. Some exceptions, where the boulders are oriented along the ridges, were mentioned by G. Lundqvist (1948) but it is uncertain if these observations refer to true Rogen moraine. Other such observations from the well-developed Rogen moraine at Lake Gysen were, however, published by Lindkvist and Svensson (1957). In the Örsjö tract the orientation is rather variable, either transverse to or parallel with the ridges (J. Lundqvist 1958, Fig. 48). A common feature in all the examples mentioned here is that the orientation is evidently more dependent on the direction of the ridge than on the direction of ice movement. This is especially clear in the Örsjö tract where in several instances the direction of ice flow falls between two orientation maxima.

In some instances observations indicate that other material than the ordinary basal till makes up the ridges. In the Örsjö tract in Värmland (J. Lundqvist 1958) the material in those ridges that allowed observations at depth seemed to be a loose ablation till with high frequency of boulders and stones. There

Fig. 9. In some instances the Rogen ridges consist of sorted, bedded material of fine sand, Kalix till. The picture shows an example from Lake Tisjön, Dalarna. In this case the material is fine sand of the type seen in the upper part of the picture down to about 8 m depth. There, rounded stones become abundant, as seen in the lower part of the picture. – Photo J. Lundqvist 1960.

could be a central part of basal till (cf. p. 23) but the sections available showed only loose ablation till.

Kalix till (Fig. 9) is a type of basal till consisting entirely of water-deposited, sorted sediments with very irregular, slightly folded bedding, covered with a thin mantle of more ordinary, often boulder-rich till. It is nowadays considered to be formed by subglacial sedimentation. J. Lundqvist (1969, p. 57) pointed out that it often occurs in depressions in the inland, which were occupied by dead ice at the deglaciation, and that it can be regarded as a transition form between dead-ice moraine and ice-lake sediments. Thus the topographic position coincides, at least to some extent, with that of the Rogen moraine.

Consequently, it is only natural that several observations of Kalix till in Rogen moraine ridges have been made. It was mentioned above that Hoppe observed sorted material, reminiscent of Kalix till, east of the Rogen tract. More pronounced examples are known from the Örsjö basin and the adjacent Hånå

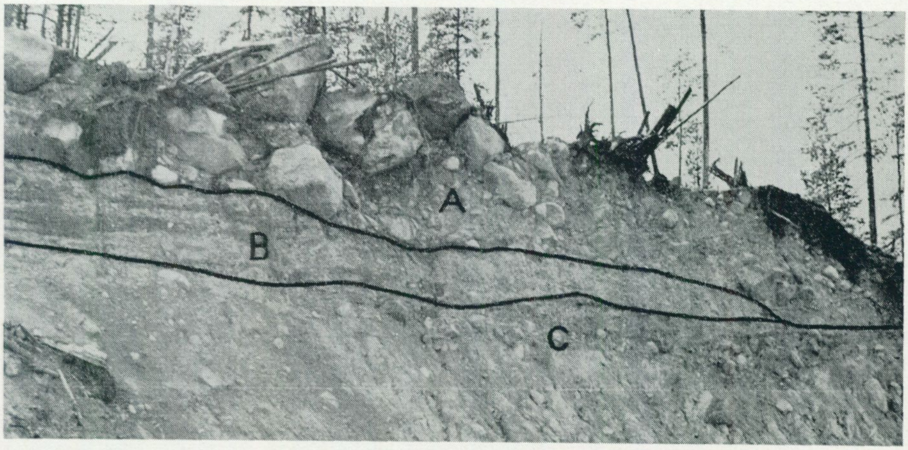

Fig. 10. The section at Lake Örsjön, described in the text. Bed A = loose ablation moraine with large boulders. B = glaciofluvial, sandy gravel. C = basal till. – Photo J. Lundqvist 1953.

valley in Värmland (J. Lundqvist 1958). Also the ridges similar to Rogen moraine mentioned on p. 9 (Hoppe 1948, Fromm 1965) generally consist of Kalix till. Fromm (1965, p. 118) also mentioned that Kalix till is common in other ridges of the same region, which are more closely related to true Rogen moraine.

Another example (Fig. 9) has been observed at Lake Tisjön, Dalarna, east of the Örsjö region. The morphology there is not typical Rogen moraine but consists of high hummocks that sometimes have a ridge-like appearance. It can be considered a less well-developed Rogen moraine. A large section showed a very thin mantle of ordinary basal till with abundant large boulders and beneath it typical Kalix till. The sandy to silty sorted material extended down to a depth of about 8 m where rounded stones became abundant. The sand was in this way replaced by a stony sediment of glaciofluvial type with the same structure as the ordinary Kalix till.

In the Tisjö tract there have been ice-lake dammings, as shown by ordinary ice-lake deposits south of the area with Rogen-like moraine. In the Örsjö and Hånå valleys no such sediments are known, but the topographic position is that of ice-dammed lakes. This applies especially to the Hånå valley, which is drained northwards towards the receding ice.

At the southern end of Lake Örsjön a special stratigraphy was measured (Fig. 10; J. Lundqvist 1958, p. 68). In a moraine hummock, not extended to a distinct ridge but closely related to the Rogen ridges, a large excavation showed the following section: A (at the surface)/1.5 m of ablation moraine with abundant large boulders, B/1–1.5 m of gravel of glaciofluvial type with horizontal undisturbed bedding, C/> 5 m of basal till with low boulder frequency.

CONCLUSIONS ABOUT THE FORMATION OF ROGEN MORAINE

The general impression of the field observations described is that some evidence speaks against, other evidence in favour of the theories of formation briefly reviewed on p. 5.

1. Concerning the question marginal or inframarginal (subglacial) formation the following can be concluded. As pointed out already by G. Lundqvist (1937) the position in the ice-divide zone clearly contradicts a marginal formation, that is, the Rogen moraine being considered end moraines. The ice sheet in most of these central regions was, according to other indications, most probably stagnant when and if there were ice margins developed. Even if, as in Härjedalen, the ice was somewhat active during deglaciation (J. Lundqvist 1969), the ice bodies remaining in the depressions where Rogen moraine is found must have been completely stagnant. G. Lundqvist (1937) supposed that there had been a faint reactivation of the ice but, as Mannerfelt (1945) pointed out, there are no general signs of such a reactivation. Especially at the late stage, when there should have been ice margins traversing the basins, a general reactivation seems to be out of question. The regional distribution, as well as the larger size of the Rogen ridges compared with ordinary end moraines in Sweden, favours the theory of subglacial formation.

The pattern of the Rogen moraine, with the ridges extending from each side of the basin and often having a bend towards the distal side in the centre of the basin, does not agree with the smoothly convex front of an ice lobe. Each half of a ridge is rather concave on the distal side, even if the main course of an entire ridge can be somewhat convex. The pattern does not suggest a marginal formation.

The drumlinoid and fluted features transverse to the ridges clearly favour the opinion of a subglacial origin. These features must necessarily have been formed below active ice. They do not themselves give any information about the distance from the ice margin but the fact the ice movement stagnated at a rather early stage indicates a formation far from the margin.

According to the current opinion, the Kalix till in the interior of some ridges (J. Lundqvist 1969, p. 57) indicates subglacial formation. According to the old opinion (Beskow 1935, p. 123, G. Lundqvist 1943, p. 126) the ridges should rather be considered marginal phenomena. Also according to Hoppe's (1948, p. 70) and Fromm's (1965, p. 107) opinion the ridges must be considered subglacially formed, although close to the ice margin. Thus the Kalix till, as also the ordinary basal till, does not give a conclusive answer to the question of marginal or inframarginal, although current opinion seems to favour the second alternative.

The ablation moraine and the section with glaciofluvial gravel (p. 23) in the

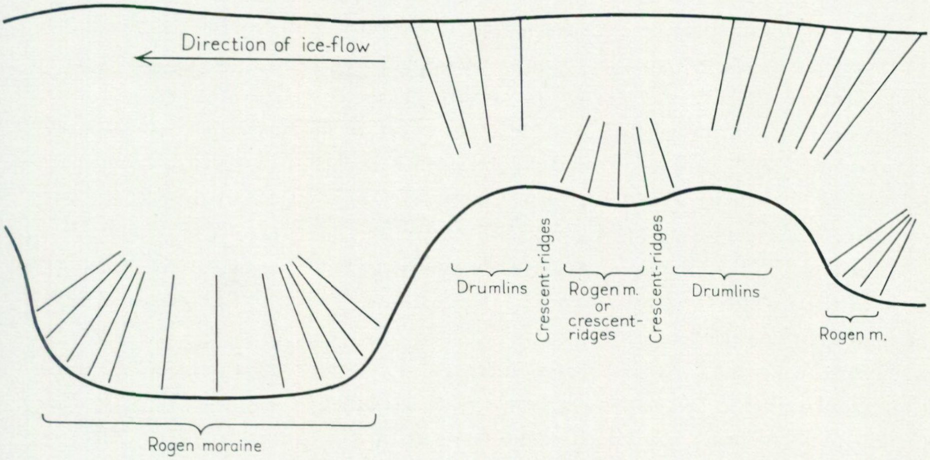

Fig. 11. Sketch showing roughly where tension occurs within an ice sheet moving over an undulating substratum. The tension is marked with thin lines in positions where a cracking could theoretically arise. The markings showing where Rogen moraine and drumlins occur correspond to the conditions observed in the field.

Örsjö tract are less compatible with a subglacial origin. Such material is more likely to be deposited in open crevasses etc. at or close to the ice margin. This material to some extent favours the end moraine theory, although not conclusively. The evidence is weak.

The even height of the ridges does not agree well with the end moraine theory. In true end moraine tracts the variations in height are usually great, high and large ridges alternating with insignificant ones.

2. Provided the ridges were formed in crevasses within the ice and not at its front, the question is if these extended upwards from the base of the ice or were open crevasses extending down from the surface. The observed facts give the following indications.

The general occurrence of the Rogen moraine in basins, that is, tracts that are concave in the direction of ice movement, clearly favours the theory of basal crevasses (cf. Fig. 11). In this position the lower parts of the ice have to move a longer distance than the upper parts. This, together with the general configuration of the substratum, will result in tension of the basal ice. The tension favours crevasse formation at the base of the ice, not at the surface (cf. Hoppe 1952, Fig. 30).

The basal till of the ridges is an evidence of formation in basal crevasses, and so is especially the regular orientation of its stones. Material which slipped down into open crevasses would probably rather resemble ablation moraine and get a more irregular stone orientation.

The Kalix till is more indifferent. It can be interpreted as formed subglacially in basal crevasses but the same structures can probably also arise in sediments deposited in open, surficial crevasses. The disturbances in the bedding could be caused either by movements during the disappearance of the surrounding ice or by the outflow of excess water from the sediment.

The loose ablation moraine and the Örsjö section (p. 23) do not favour a subglacial origin. Such coarse-grained material with abundant large boulders could not possibly be plastically forced up into basal crevasses according to the process described by Hoppe (1952, Fig. 30) for, e.g., rim ridges (cf. Hoppe 1952, J. Lundqvist 1958). Also, it is rather improbable that the undisturbed, well-sorted sediment in the Örsjö section was deposited subglacially. Deposition in an open crevasse is much more likely.

The drumlinoid forms and fluted surfaces of Rogen ridges necessarily imply subglacial origin. In this they clearly speak in favour of basal crevasses. Formation in open crevasses must be considered out of question. However, they rise a new question: Were there any crevasses at all or was the morphology developed directly under solid ice? The drumlin elements in the ridges make the concentration in crevasses highly improbable. On the other hand, it is difficult to explain the transverse morphology without assuming some kind of crevasses. The morphology rather favours a modified theory implying that the tension of the basal ice is sufficient to account for the ridge structure and that no crevasses were opened.

In agreement with what was stated above (p. 24) the pattern of the ridges does not favour the assumption of surficial crevasses.

3. Concerning the problem of whether the Rogen moraine was formed by active or stagnant ice, the material in the ridges does not give much information. Basal till and Kalix till can be deposited both by active and stagnant ice. Ablation moraine is more common in dead-ice terrain but also on a moving glacier there is some ablation, making deposition of ablation moraine in, e.g., crevasses possible.

The geographical distribution to some extent favours the opinion of Rogen moraine being a type of dead-ice moraine. The Rogen moraine is almost entirely confined to the regions where the last ice remnants were situated, wasting away as dead ice. However, in these regions also many moraine forms were developed at an earlier stage when the ice was still active.

The occurrence of Rogen moraine especially in basins provides additional evidence in favour of the dead-ice hypothesis. In such positions there were mostly ice bodies isolated during the deglaciation, which wasted down while remaining completely stagnant. The type area at Lake Rogen is a good example of all the geographical and topographical aspects of this question. The region is a combination of all the three types of area where, according to Ahlmann (1938) dead ice was developed: 1) in marginal zones isolated from the receding active ice, 2) in lee-side positions in relation to the active ice, and 3) in the central area of glaciation where the last remnants of the entire ice sheet were situated. The Rogen area is as a whole an example of type 2, it is situated in position of type 3, and the ice-recession towards the area from three directions (J. Lundqvist 1969) favoured isolation of type 1. However, even if the general conditions show that the ice was probably stagnant during the deglaciation of the Rogen moraine tracts, nothing contradicts the opinion that moraine forms also developed by active ice are relics within such areas. Mannerfelt (1945, p. 216) pointed out that "dead-ice moraine" is a complex of elements formed under quite different conditions.

The orientation of the stones in the ridges indicates that the till itself was deposited by active ice. But because there can be a great deviation between stone orientation and direction of ice movement, either something must have changed the position of the till after it was formed, or the orientation was developed by other movements within the till than the general ice movements (cf. Hoppe 1952).

The summary of the different aspects of the Rogen moraine gives somewhat contradictory evidence of its formation. The following tentative synthesis of the evidence available can be taken as the author's present opinion of the genesis of this problematic moraine morphology.

The formation of the ridge pattern was initiated when the active, moving, ice passed over a concave break in the landscape. Generally this occurred when a certain part of the ice entered a basin. The basal ice moved down the slope into the basin and where the bottom flattened out a tension arose (cf. Fig. 11). A corresponding tension effect could also originate at the foot of a steep slope rising against the moving ice. The Rogen moraine tracts at Lunndörren and Falkvålstjärnarna at the southern edge of the large mountain area in southwestern Jämtland offer good examples. In the latter case the tension at the base of the ice ceased and was replaced by compressing forces when the ice passed over the following terrain convexity. In a basin the tension forces were retained as long as the ice passed over the concavity, the basin. Successively new embryonic crevasses were formed where the basin began. Not until the ice had passed the whole basin and reached a following convex terrain did the arising compressive forces tend to obliterate the embryonic crevasse. Thus, in this case a possible morphological effect will be traced all over the basin, while in the case of rising heights only a narrow zone along the slope would be affected.

It is possible that the tension effect described could be increased by the load of till in the basal ice. This material made the ice less mobile. There was thus a combined effect of three factors: 1) the lower mobility of the till-loaded basal ice than of the upper ice, 2) the fact that the basal ice had to move a slightly longer distance than the surface, and 3) the concave form of the substratum. These factors together caused a considerable tension in the basal ice.

The most plausible effect of the tension would be a division of the less mobile, as a whole less plastic, till-loaded basal ice along fracture lines transverse to the movement. The gaps arising between the till-loaded parts would immediately be filled with till-free ice moving in from above. This hypothesis does not necessitate the assumption of subglacial open crevasses and of unfrozen, mobile till beneath the ice sheet. An assumption of open crevasses being filled by till requires an unfrozen substratum and a process comparable with the one described by Hoppe (1952, Fig. 30) for the rim ridges of the Veiki moraine. However, the existence of unfrozen till beneath an active ice sheet is unproved, although not unlikely. According to the process outlined the ridges of the Rogen moraine should be considered as parts of the divided regional cover of basal till. The interspaces correspond to purer ice.

The relatively broad ridges in some tracts (p. 12) as well as the constant height of the ridges (p. 16) could be regarded as direct evidence of this hypothesis. Neither of these facts agrees with the assumption of till being pressed upwards into crevasses from an unfrozen substratum of till. Also the drumlin forms give the theory some support although not conclusively. Hoppe's (1952, p. 62) observation of a cavity several dm long encountered below the surface of a ridge could also be taken as evidence of the same theory.

The central gap between the ridges in many tracts (p. 10) can be regarded as supporting the same hypothesis. When the moving ice passes into a basin that is also strongly concave transverse to the direction of movement there will be a tension in that direction also. There is a difference, however. In the direction of movement the tension will result in a repeated generation of fracture lines as long as the ice moves. Transverse to the direction of movement, on the contrary, one or at least very few fracture lines, originating as soon as tension begins, will be maintained more or less unchanged throughout the process of movement. According to the theory proposed above the effect would be one longitudinal zone of clear ice in the till-loaded basal ice resulting, after wastage of the ice, in a till-free zone across the basin in the direction of movement. Evidently the supposed effect correlates well with the central gap. Also Lindkvist and Svensson (1957, p. 217) considered the central gap to be comparable with a dead-ice hollow. If, on the contrary, there were crevasses in the basal ice being filled with till from below, the result would be a central ridge, a kind of radial moraine, instead of a gap.

In the fracture zone represented by the central gap meltwater streams could find their courses. This, however, by no means always occurred, the formation and existence of a central gap having in principle little correlation with the drainage within the last ice remnants.

The interpretation of the ridges as parts of a broken basal till sheet agrees well with the – at least in some cases – thin till between the ridges (cf. J. Lundqvist 1958, p. 66). On the other hand, the fracture lines do not necessarily have to extend down to the substratum of the basal ice. They might as well begin at

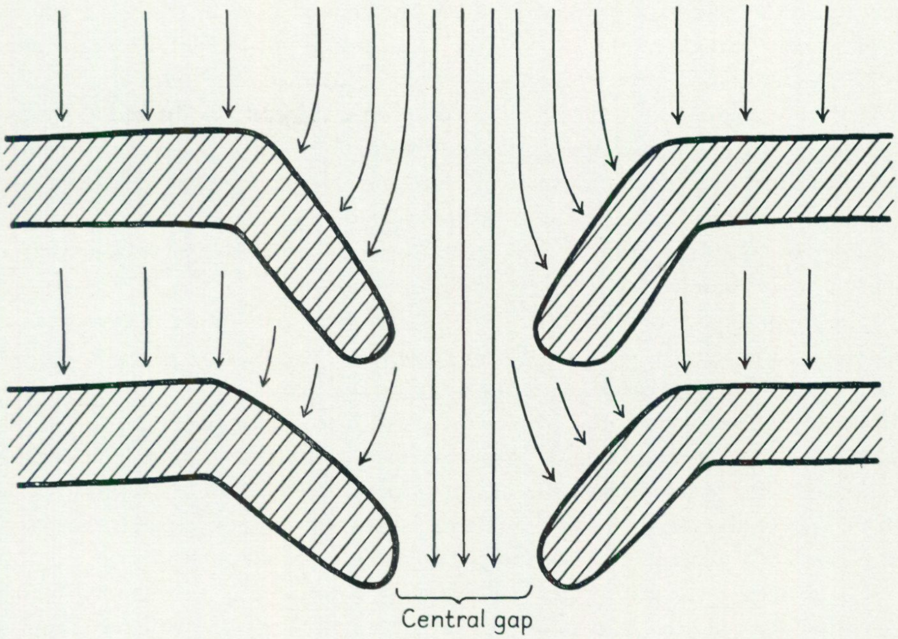

Fig. 12. Sketch map showing the differential ice movements at the base of an ice sheet moving through a Rogen moraine tract. The clear ice in the central gap moves faster than the surrounding till-loaded ice (cf. text, p. 28). This results in a sideward pressure from the central gap, forcing the till ridges slightly aside.

more or less well-defined shear planes in the basal ice below which a – more stagnant – till-loaded ice is left more coherent. In such a case there can also be a thicker till between the ridges.

The orientation of the stones in the ridges in most cases also agrees well with the interpretation suggested. A slight dip of the stones towards the sides of the ridges will probably always be due partly to settling of the material after the disappearance of the ice, partly to the pressure of the ice coming from above between the ridges under formation. It is perhaps more difficult to explain the divergence between stone orientation and ice movement in those cases where the ridges do not run strictly transverse to the ice movement. It can be explained, however, if we consider the greater mobility of the pure ice than of the till-loaded ice. The pressure of faster moving ice could probably cause a displacement of entire parts of the basal ice, even without influencing their interior fabric. Such differential movements in the basal parts of the ice sheet can account for irregularities in the direction of the ridges not referable to their division into drumlinoid parts.

A special case of such irregularities is the bend of the ridges towards the distal side in the central part of a basin, especially adjacent to the central gap (p. 13). The bend can as well serve as an illustration of a higher velocity of the clear ice along the fracture zone representing the central gap. In this zone the ice, moving with a higher velocity than the surrounding till-loaded ice, will exert a pressure upon the latter, tending to force it towards the sides (cf. Fig. 12). Whether one prefers to consider the embryonic ridges to be forced aside as a whole, or with some sideward motion also in their interior, such a diverging pressure from the central gap will explain the stone orientation as well as the bend of the ridges. At least some explanation of a similar type is necessary to account for the curvature of the ridges, chiefly inverse to the sinuous pattern within an ice lobe (p. 24).

The theory suggested thus does not assume the existence of open crevasses. However, the tension in general also favours the generation of open hollows etc. beneath the ice, in which some subglacial sedimentation can take place. Therefore, the observations of Kalix till are in close agreement with the theory. The more the ice melts during the deglaciation, the more favourable are the conditions for some formation of water-deposited sediments within the ice sheet. Especially in the most pronounced basins, the Rogen moraine can therefore contain a considerable amount of sediments similar to Kalix till.

The process outlined implies that the Rogen moraine is a subglacial feature generated by active ice. However, the rather fragile structure probably requires dead-ice wastage to be preserved. If the margin of an active ice sheet recedes across a tract where Rogen moraine was earlier initiated, the ridge structure will probably be more or less destroyed. As soon as the ice front reaches a basin the tensional forces in the basal part of the ice will be more or less replaced by compression forces, the front itself offering some resistance to the ice movement. The process within the ice will to some extent be reversed, and even if not so, an active front moving across the slender ridges will smoothen the forms or, at least, conceal them among marginal forms.

The fact that the ice in a Rogen moraine tract wastes away through ablation only will have the effect that dead-ice forms can be impressed upon the subglacial morphology. For instance, the fracture lines representing zones of weakness are likely to determine the pattern of open crevasses in the disintegrating dead-ice body. In such crevasses, filling with ablation moraine and deposition of sediments can occur. This simple fact can account for the diverging types of the interior of the ridges. In some tracts, like the Örsjö basin, the dead-ice deposits can make up a considerable part of the overburden but generally the subglacial deposits dominate.

In brief summary: The Rogen moraine should be considered a subglacial deposit of active ice, the preservation of which demands dead-ice deglaciation, and the situation of which is topographically determined.

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