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by Risto Aario, Lars Forsström and Pertti Lahermo

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GLACIAL LANDFORMS WITH SPECIAL REFERENCE TO DRUMLINS AND FLUTING IN KOILLISMAA, FINLAND

BY

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WITH 16 FIGURES AND ONE APPENDIX

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Glacial landforms in Koillismaa, north-eastern Finland, were mapped from false-colour and black and white aerial photographs, with subsequent field control. The area is characterized in particular by different kinds of glacial stream-line forms, erosional and depositional, and their transitions into forms devoid of linear elements. It seems as if the streamlined landscape with drumlins and fluting was formed predominantly during the final retreat phase of the continental ice sheet at its marginal zone where the ice was still active, but had already begun to stagnate in depressions and in front of obstructions, where hummocky moraine was being formed.

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INTRODUCTION

The bedrock, surficial geology and geophysical characteristics of the Koillismaa area, north-eastern Finland (Fig. 1), have recently been surveyed with the intention of collecting detailed information and of developing methods of prospecting.

The present paper reports on the main glaciogenic elements of the area, which is characterised by drumlins and fluting. Additional detailed work is in progress regarding the forms, composition, structure and genesis of the various glacial landforms of the area as well as other problems of local glacial geology. The results will be published later.

The surficial geology of Koillismaa has been previously described by Hänninen (1915) and Tanner (1938), and more recently by Glückert (1974). The glacial geology of the Suomussalmi area, south of the present area, has been thoroughly investigated by Virkkala (1951).

GENERAL SETTING

The bedrock and its effect on relief

In the southern part of the study area the bedrock belongs to the Pre-Karelian basement complex as shown on the geological map, 1: 400 000 (Matisto 1958). The basement complex consists of various gneisses and younger quartzose and granodioritic rocks. The youngest rock encountered in the granitegneiss complex is microcline-granite both existing as separate massives and migmatizing other rocks. In the eastern parts of the area there are the ultrabasic massive of Näränkävaara and the alkaline massive of Iivaara. Diabase dikes of different ages are frequent.

In the northern part, north of the parish of Kuusamo the rocks of the Karelidic schist belt are dominant with combined extrusive and intrusive rocks. The schists are mainly various quartzites and mica-schists with which dolomites are also associated (Silvennoinen 1972). The volcanics and diabases which occur with the schists are often of a spilitic nature (Piispanen 1972).

In the western part of the area basic layered intrusions belonging to the

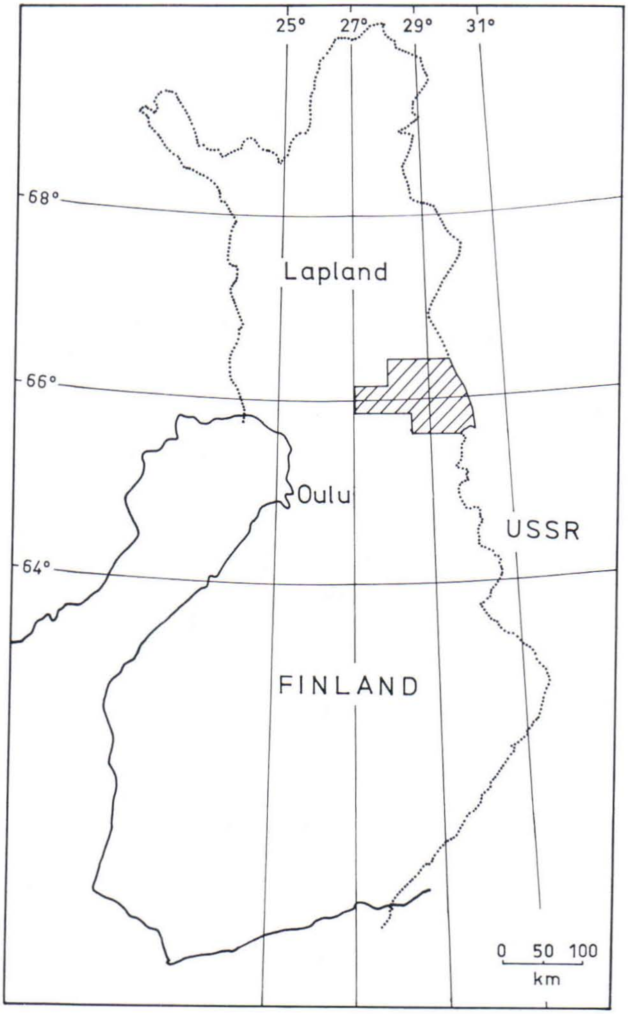


FIG. 1. The study area, Koillismaa, North-Eastern Finland. The area covers a total of about 8500 square kilometers in the communes of Kuusamo, Taivalkoski, Pudasjärvi, Ranua, Posio and Salla.

Karelidic schist belt are found while further to the west there are younger microcline-granites (Piirainen *et al.* 1974).

The absolute and relative variations in altitude seem to depend to some extent on the rock types. Näränkävaara and Iivaara are considered to be residual hills composed of rocks more resistant than the surrounding (Aario 1966, p. 59). In many cases quartzite rocks have remained higher than the surrounding land. Some of the highest peaks are quartzite (e.g. Valtavaara 490 m and Riisitunturi 462 m). Some other areas with a particular type of relief seem to correlate with petrologic units, although tectonic events undoubtedly also contributed to the variation in topography (Granö 1952, p. 93). Accordingly, some parts of the area were divided into morphologic-geologic units on the basis of the size, frequency, orientation and relative altitude of the relief (Talvitie and Luoma-aho 1972).

The predominant orientation of the lakes, between W-E and NW-SE, is mainly controlled by fracture lines. In addition to tectonic factors, erosion caused by running water has contributed to the roughness of the relief, particularly in the NE part of the area where deep, narrow river valleys dissect the hills (Aario 1966, p. 262). Drumlins, and occasionally eskers, also influence the orientation of the lakes.

The surficial deposits and their effect on relief

The general aspects of the landscape are controlled by the topography of the bedrock. The Quaternary deposits on the hills are thin, as is shown by the frequent exposures of bedrock on the slopes. Moreover, in the gently undulating areas the surficial deposits often conform to the topography of the bedrock, smoothing and levelling it. However, fluting and drumlins parallel to the direction of ice movement and more or less independent of the structure of the underlying bedrock dominate the landscape over most of the area. The effect of esker trains and hummocky moraine on the topography is more local and restricted to low areas, often in fracture zones.

METHODS OF INVESTIGATION

Interpretation of aerial photographs

The current study on the surficial geology of the Koillismaa area began with a stereo interpretation of aerial photographs, using mainly infrared diapositive films at a scale of 1: 60 000 (Kodak Infrared Aero Film, type 8443) (p. 24). The flights for the project were made in the summers of 1971—1972. The north-western corner of the study area was not, however, covered by these flights and, hence the interpretation there is based on black and white diapositive photographs of the same scale. For detailed field studies 1: 30 000 black and white paper prints were used. Mosaics of a scale of 1: 100 000, constructed from both the infrared and black and white photographs were employed for a large scale survey.

The drumlins and fluting as well as the various glaciofluvial features, whether erosional or depositional, were first mapped from the aerial photos. In general, the till areas covered by forest are violet in colour. Drumlins with spruce growing on them are rather dark, whereas those which support pine and deciduous trees are more reddish in colour. Low-lying areas, the lower slopes of drumlins and the valleys between ridges, for example, also appear reddish due to the dwarf-shrub and sedge vegetation on the damp ground. Within the area, there are numerous clear-felled areas whose barren drumlins appear bluish. The blue colour is also characteristic of glaciofluvial deposits.

The outlines of the drumlins are usually clearly visible on the infrared photos. On the steep slopes, in particular, the colour changes more distinctly than on the gentle slopes, where the bog vegetation grades into vegetation of the drier till areas. The surrounding peatlands often show up as yellow, red or bluish areas.

A characteristic of the Koillismaa area is, that it contains a whole gradational series of streamline forms from the ideal half-ellipsoidal drumlins to narrow, parallel ridges. These forms also grade imperceptibly into a relief more or less devoid of linear elements, such as the various forms of hummocky moraine, low relief morainic plains and till veneered bedrock topography. Further, there is a transition: streamline forms composed of till — rock core forms — crag and tails — roches moutonnées — rather irregular bedrock forms (see also Flint 1957, pp. 68—69).

In the photo interpretation only those forms in which the topography of the bedrock is not a predominant factor are marked as drumlins. Here the longitudinal bedrock forms often owe their orientation to tectonics, having been only slightly affected by the abrasive action of the glacier. Further, the streamlined forms must have a sharply pointed upstream end and a more or less definite downstream end to be mapped as a drumlin. Fluting has been considered as a member of this gradational series of forms, which consists of narrow, straight, parallel ridges and grooves, erosional or depositional, and is composed of till or bedrock. Usually they have no definite ends. Drumlins were marked on the map (Appendix 1) as individuals, and fluting as the existence of a fluted surface. Often the drumlins themselves were also fluted. For practical reasons, the drumlins alone were marked in that case. Only forms with a minimum length of around 400 m were mapped.

The above concept of the terms *drumlin* and *fluting* is not compatible with the classification of drumlins recently suggested by Glückert (1971, 1973 and 1974). He uses the term *drumlin* in a very broad sense, and it seems to cover a large group of forms from the streamlined ones mainly composed of till to roches moutonnées and different kinds of bedrock hills, often irregular in shape and only slightly sculptured by the glacier. Moreover, very high bedrock hills, even fjelds, for example Pyhätunturi 455 m, Kuntivaara 481 m, Iivaara 469 m, Penikkavaara 435 m, Näränkävaara 370 m and Naatikkavaara 430 m, have been termed drumlins in his classification (Glückert 1974).

Field analyses

Firstly, the map constructed on the basis of the aerial photo interpretation was checked in the field. The main part of the field work, however, was concentrated on the study of the form, composition, internal structure and origin of drumlins and other glaciogenic deposits. For this purpose test pits were dug in representative drumlins and morainic hummocks. Stone counts and orientation analyses were carried out at depths of 1 and 2 metres and, if necessary, at other significant horizons. Two hundred stones were taken for the orientation analyses and stone counts, the latter being performed afterwards in the laboratory.

Observations on striations were also made in the study area (Appendix 1), without, however, embarking on systematic mapping.

DRUMLINS AND FLUTING

Distribution

Drumlins and fluting are neither evenly distributed nor do they form a coherent field in the study area. Hence, the question as to the size of the field is fairly meaningless. However, according to Hänninen (1915, p. 9), the drumlin field in Kuusamo (Koillismaa) including the extention in the USSR is about 90 km long in a S—N direction and at least as wide in a W—E direction.

The map showing the distribution of drumlins and fluting in Koillismaa (Appendix 1) differs from the one recently drawn by Glückert (1974). This is due predominantly to the difference in concept of the terms *drumlin* and *fluting* (p. 8). It also comes partially from the differences in the mapping methods used. The present map is based on aerial photos with field control. Glückert (1973, p. 6, 1974, p. 37) has preferred topographic maps and it seems that from them it has not always been easy to distinguish drumlins from forms which owe their existence mainly to tectonics.

It is not easy to subdivide the study area because the drumlins do not occur as separate clearly defined fields. However, to simplify the discussion the following sub-areas were established (Appendix 1).

The *Korouoma sub-area* (1) comprises the drumlin and fluting field in the west, which extends from west of the Korouoma valley to the western end of lake Ylikitka. The strike of the schistosity and the fracture lines in this fairly flat gneissose bedrock area are more or less transverse to the direction of ice movement and, consequently, also transverse to the directions of the drumlins and fluting. The most prominent fracture valley, Korouoma, is about 100 m deep and at an angle of roughly 30° to the drumlins. Its influence on the orientation of the drumlins seems to have been negligible. Drumlins occur on the leeward side of the hills as extensions of fluting or together with it. Many of the drumlins are fairly large and well developed.

The *Suolijärvi sub-area* (2) in the NW includes the region around the lake Suolijärvi and the northern part of the lake Posionjärvi. The morainic hummocks in the lake valleys distinguish this sub-area from the others. The drumlins and fluting are similar to those in the other sub-areas. In places, however, the drumlin relief is subdued by the morainic hummocks which overlie them.

The *Kitkajärvi sub-area* (3) comprises the vicinity of the lakes Kitkajärvi. Drumlins occur close to the lakes often forming elongated promontories and islands. In the elevated areas with high relief fluting predominates.

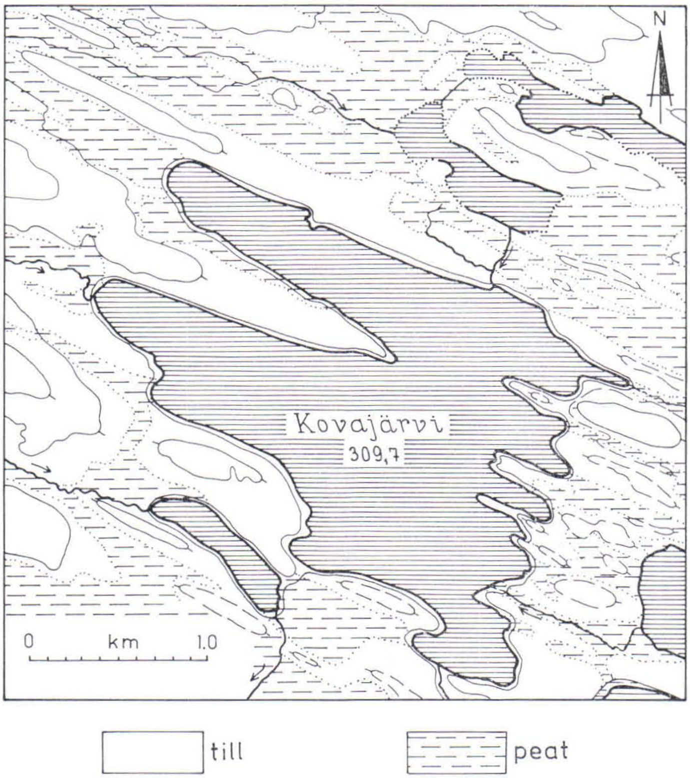


FIG. 2. Stream-lined drumlin landscape at Kovajärvi, Kuusamo. The small promontories in the south-eastern side of the lake are drumlins, the biggest one in the north-western side is mainly composed of bedrock. The drawing is based on a 1: 20 000 topographic map (4522/07, 08) with 10 m contour intervals.

In the *Kovajärvi sub-area* (4) the veneer of surficial deposits is fairly thin and the structure of the bedrock is easily recognizable on the aerial photos. The large fractures in the bedrock run approximately parallel to the elongation of the drumlins and fluting. Well-developed drumlins are rare and many of them probably have a rock core. Some drumlins extend into Kovajärvi as promontories (Fig. 2).

The largest *sub-area* is *east of Kuusamo* (5). It has a dense swarm of drumlins in its southern half. They diminish in number northwards where they occur as sporadic groups, with transitional forms into fluting dominating.

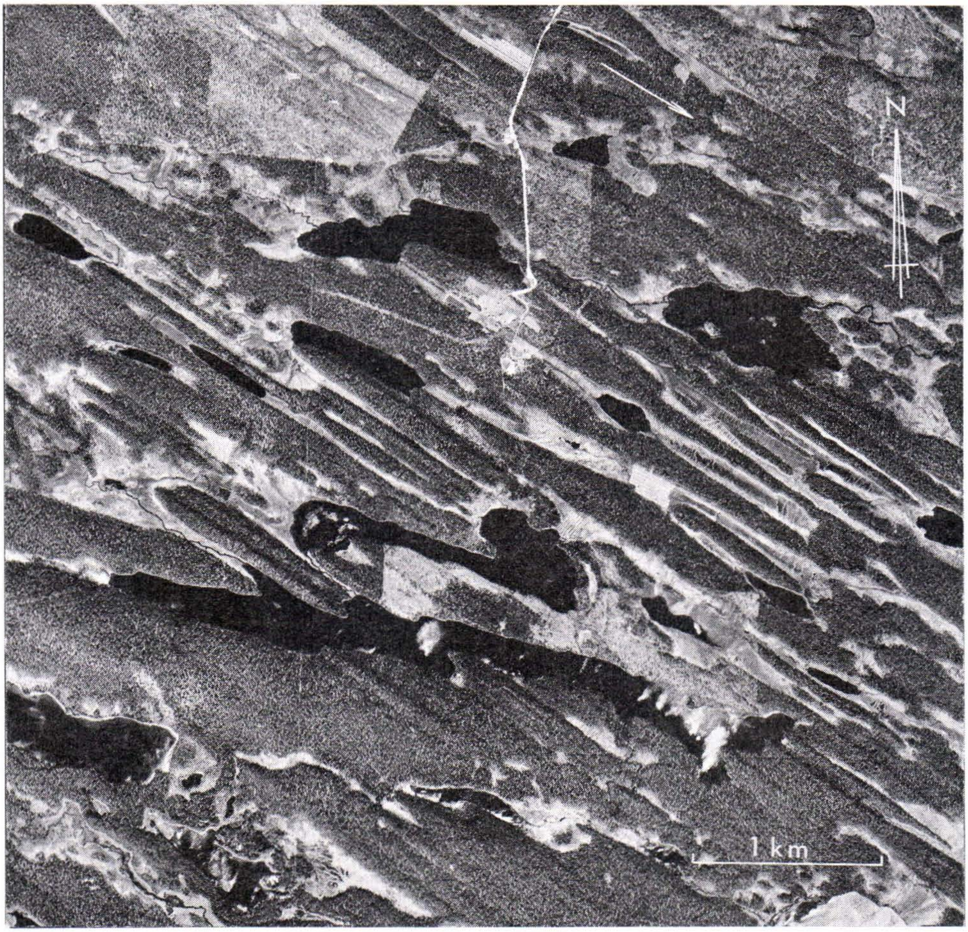


FIG. 3. The long, narrow drumlins typical of the south-eastern part of the area (aerial photo 6337/129). This orientation cuts across the local tectonic orientation, which here is shown by the trend of the numerous lakes. The arrow shows the direction of ice flow. By courtesy of Topografikunta (The Army Map Service).

Outside the Kuusamo sub-area, in the northern part of the area, fluting disappears.

South and south-east of Iivaara the drumlins are often very narrow and long and grade into fluting. Their orientation is NW—SE and deviates distinctly from the orientation of the large fracture lines, which are reflected by the elongation of the lakes (Fig. 3). The best-developed drumlins are encountered in the Iijärvi, Kuusamojärvi, Muojärvi and Joukamojärvi regions, where they often occur as numerous promontories, islands and isthmuses.

The variation in absolute altitude from one region to another is small in the Koillismaa area; hence, its influence on the occurrence of drumlins must

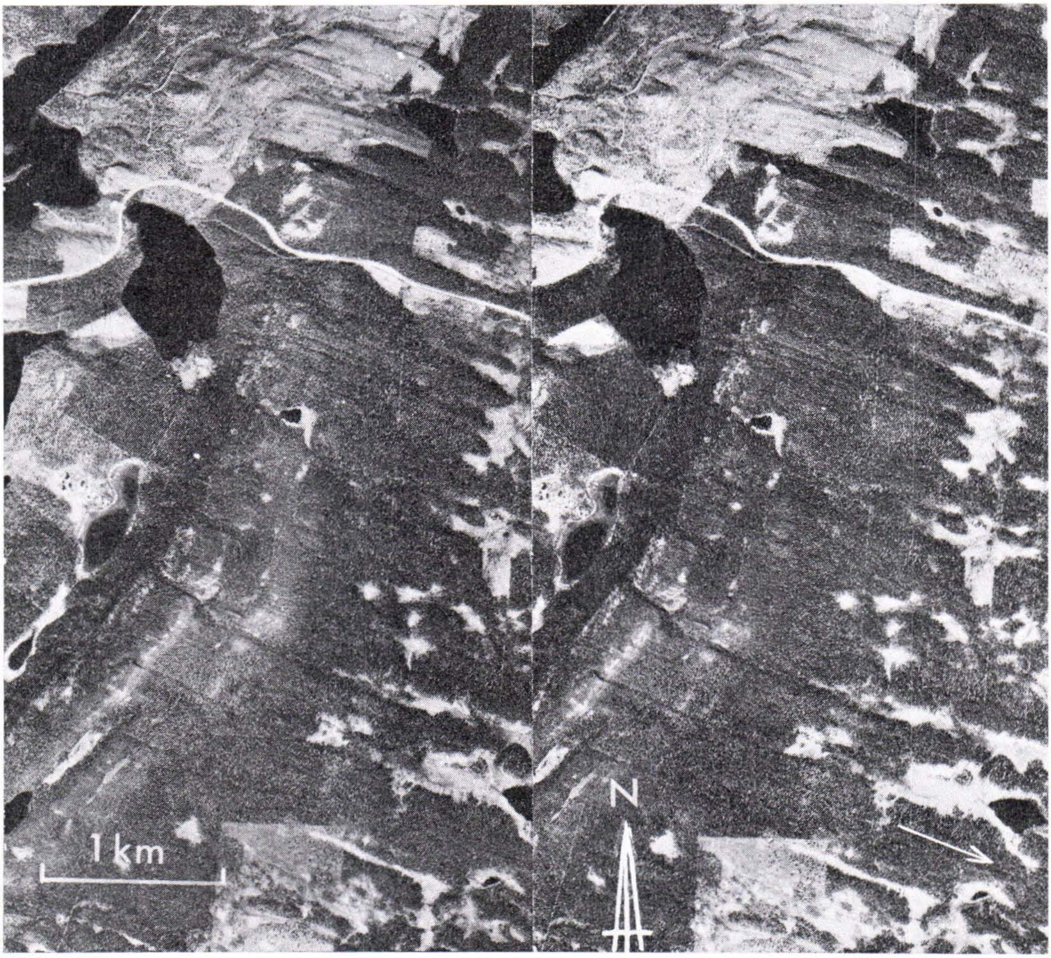


FIG. 4. The fluted surface of Valtavaara (aerial photos 6910/18, 19). Unlike drumlins, fluting commonly occurs even in areas of high relief. The arrow shows the direction of ice flow. By countesy of Topografikunta (The army Map Service).

have been insignificant. Differences in relative altitude within a local region have had a definite effect in that the frequency of drumlins is highest in the areas of rather low relief (see Högbom 1905; Virkkala 1948, p. 26; Hoppe 1951, p. 164; Aartolahti 1968, p. 26; see also Fig. 15, p. 24). In the study area these areas are mainly composed of granitegneiss. The abundance of drumlins could also be due to the small protuberances of the bedrock, which encourage sedimentation. The quartzite areas are characterized by a higher variation in altitude with the consequence that drumlins are less common. In Koillismaa the system of fracture lines is, in places, approximately parallel to the direction of the movement of the ice. According to Penttilä (1961, p. 76), this facilitates the formation of drumlins. The present study, however, does not provide conclusive evidence either for or against this concept.

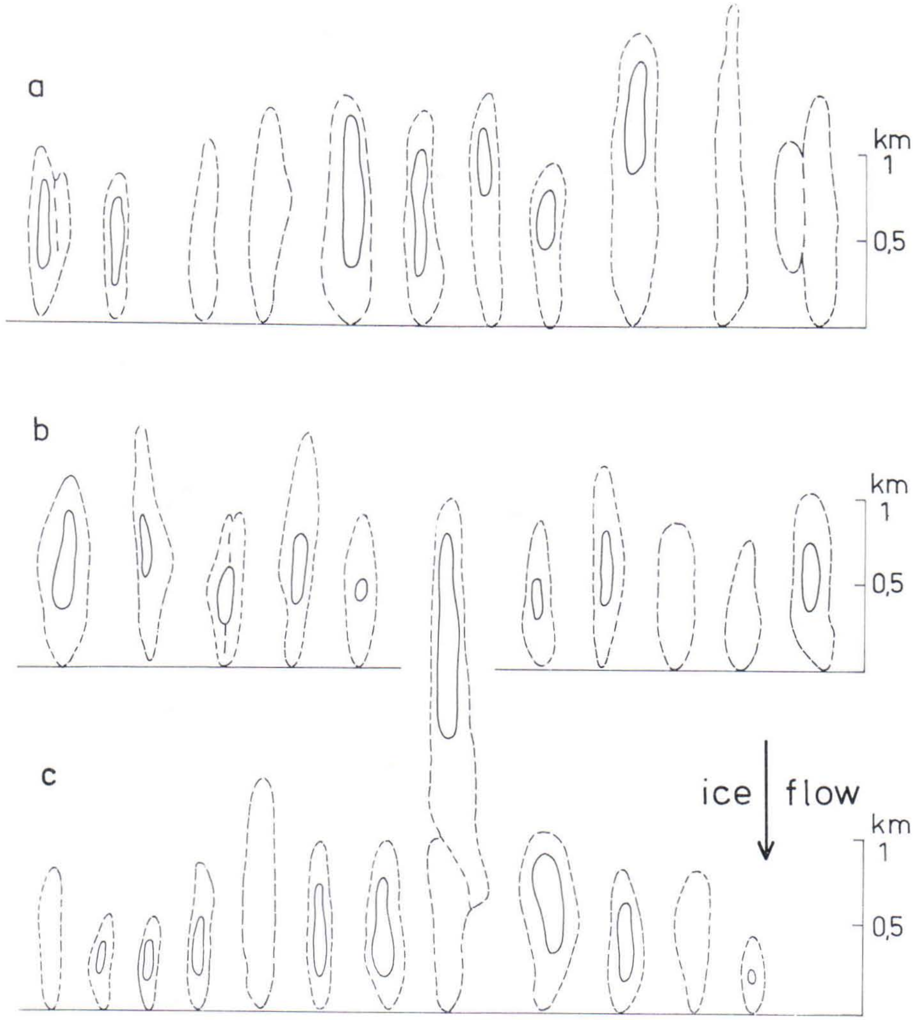
Unlike drumlins, fluting even occurs on the top of high hills. The summits of Iivaara and Valtavaara, which are among the highest hills in the area, are distinctly fluted (Fig. 4). On the steep stoss-slopes and low-lying depressions there is no fluting (see Gravenor and Meneley 1958, p. 718; Aronow 1959).

Forms, composition and structure

Drumlins have been classified into numerous types (e.g. Chamberlin 1894, pp. 522—523) on the basis of their shape. According to Tanner (1938, p. 489), the drumlins in Finland are mainly of the elongated ridge type of the Chamberlin classification. Hänninen (1915, pp. 12—14) has described elongated ridges, elliptical hills and mamillary hills as real drumlins in the Koillismaa area. Outside this group he has further described drumlin-shaped bedrock forms; i.e. rock drumlins (drumlinvaarat), and drumlin shields, the rather high ridges with groups of smaller stream-lined bodies side-by-side on top of them. A closely similar division of the drumlins in Koillismaa, but with a different notion of the term *drumlin* has recently been suggested by Glückert (1974) (see, however, p. 8 in this paper).

As mentioned before, a whole gradational set of streamline forms as well as a transition into non-linear elements are present (p. 8). Accordingly, the forms described as examples below are only certain members of this gradational series. On the map (Appendix 1), only those forms are marked as drumlins in which the topography of the bedrock is not a dominant factor. Fluting is mapped as a group of forms, both erosional and depositional, consisting of long elongated ridges and troughs. These occur on till and bedrock and exhibit considerable variation in size. In one particular sub-area the distance between separate flutes is approximately constant.

The length of the drumlins in the Koillismaa area varies from 100 m to 2—3 km. However, those over 2 km in length are rather rare. Their height varies from a few metres to about 20 m, but commonly they are lower than



15 m. The shape of drumlins is rather variable; often they are symmetrical, sometimes the proximal end is broader and steeper than the distal end, however, the reverse is also common. The highest point is generally somewhat closer to the proximal than the distal end. Drumlins which are very close together often coalesce. Some examples of drumlin forms are presented in figs. 5, 6, 7 and 8.

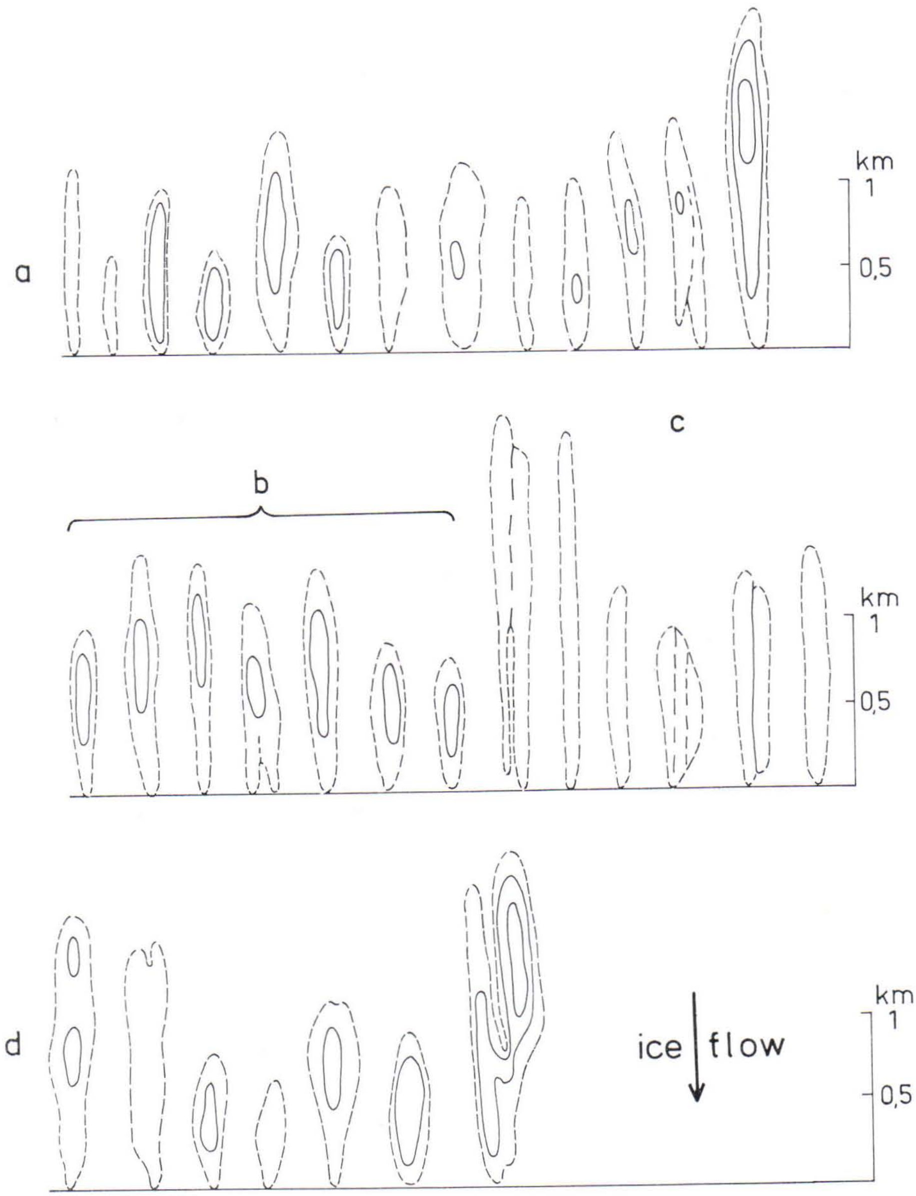


FIG. 5. and FIG. 6. Shapes of drumlins in the drumlin field of Koillismaa. The outer line of each drumlin has been drawn on the basis of aerial photographs, the inner lines are contour lines from topographic maps (10 m intervals). The order of the drumlins follows approximately that within a drumlin field, moving from the edge to the center. They are grouped so that 5a represents drumlins from the Korouoma sub-area, 5b from the Kitkajärvi sub-area, 5c from the Kovajärvi sub-area, 6a, 6b and 6c from the sub-area east of Kuusamo, and 6d from outside the sub-areas distinguished here. The shape of drumlins is variable. In the south-eastern part, narrow drumlins prevail (6c). At the borders of the drumlin field the drumlins change into more irregular forms (6d) and further outside the field they pass into non-oriented morainic forms.

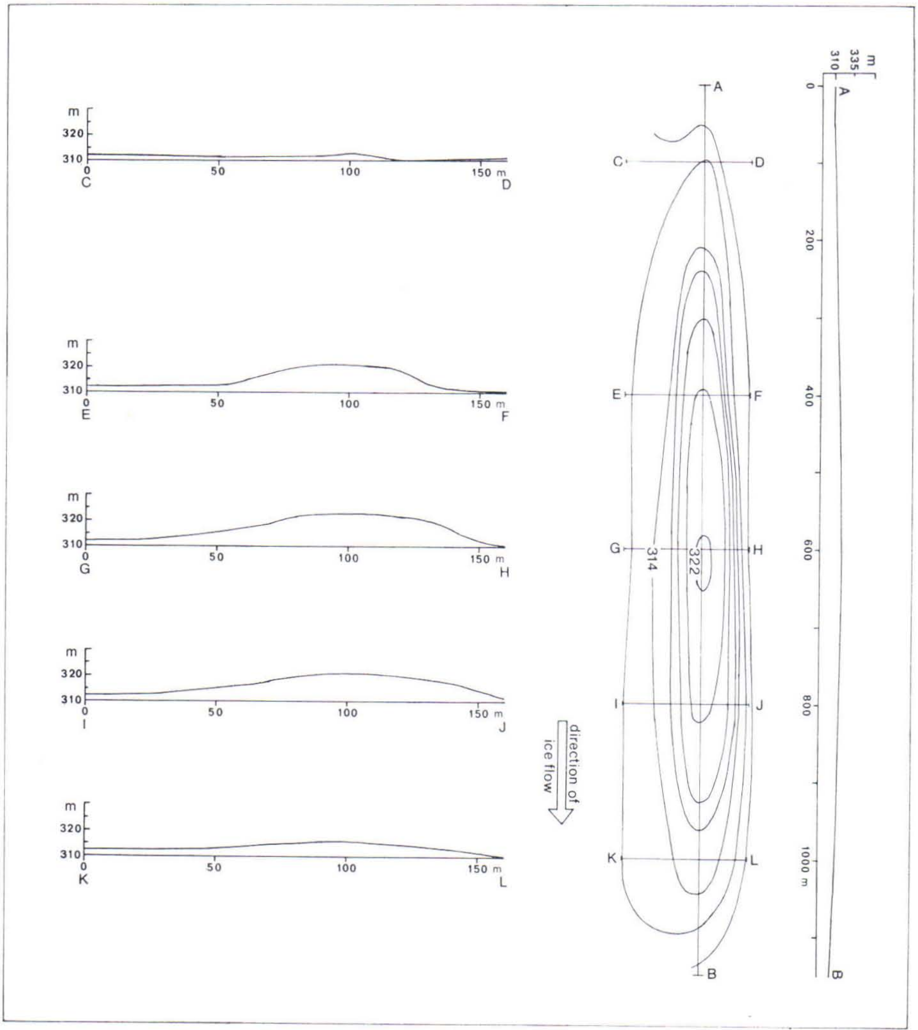


FIG. 7. A diagrammatic sketch of a drumlin at Kovajärvi. Its rather narrow, symmetrical form is common for the whole study area.

The regional differences in size and shape are small. However, in the SE of the area the drumlins differ from the others owing to their characteristic narrow forms (Figs. 3 and 6 c), which is approaching that of fluting.

Adjacent drumlins often resemble each other. In a coherent field, the forms of the drumlins change from the margin to the centre; a change is also observed parallel to the movement of the ice (see Charlesworth 1957, p. 390). At the margins, the drumlins are commonly less well developed (Fig. 6 d).

In Koillismaa the drumlins are generally straight. Nevertheless, those to the east of Kuusamo exhibit a slight bending due to the curvilinear motion of the ice (Fig. 6 a). Some forked drumlins also occur, the forks pointing in slightly different directions. Wright (1937, p. 34) suggests that the forked drumlins were formed as a result of a minute change in the direction of ice movement.

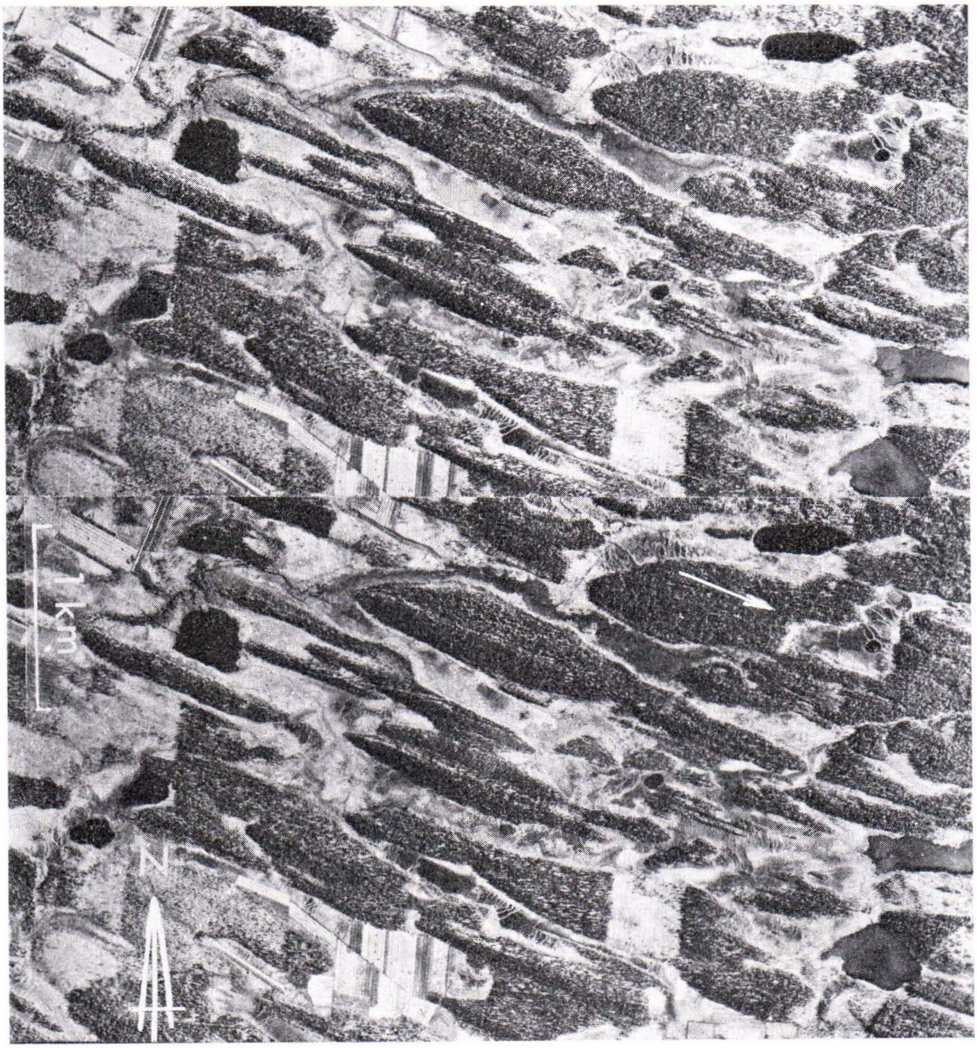


FIG. 8. Well-developed drumlins from an area 13 km north of the parish of Kuusamo (aerial photos 6336/136, 138). The arrow shows the direction of ice flow. By courtesy of Topografikunta (The Army Map Service).

As mentioned previously (p. 8), there is a transition from drumlins composed entirely of till to forms composed entirely of bedrock. However, on the basis of the external shape alone it is difficult to estimate which of the drumlins have a rock core (see Virkkala 1961, p. 226). In the Tammela area, southwestern Finland, studied by Aartolahti (1968, p. 25) drumlins seem frequently to have a rock core.

The internal structure and composition of the drumlins was also examined from numerous test holes and pre-existing cuts. It was found that the frequency of stones and boulders on the surface of the drumlins was slightly higher than in the interior. Sorted material was not common. However, pockets of sand occurred fairly regularly under the stones, and in places there were even larger sand layers. The studies carried out so far have not allowed separate till sheets to be distinguished.

No significant variation in grain size was observed in relation to depth. Close to the surface within the B soil horizon the material was occasionally coarser, probably as a result of cementation caused by iron compounds. In general the material was a sandy till, differences between separate drumlins being slight (Fig. 9). The lithology of the stones suggested that the major part of the material originated from the local bedrock.

So far, only tentative orientation analyses of the stones within drumlins have been made. Many of the well-formed, high relief drumlins show no orientation maxima, whereas numerous low relief drumlins in almost level morainic areas have clear orientation maxima (Fig. 10) (see Lundqvist 1948; Virkkala 1960 a). Orientation appears to be independent of depth.

Indication of directions of ice movement

The direction of the last major ice movement is manifested in the orientation of the drumlins and fluting (Appendix 1). Over the area as a whole the direction was fairly uniformly from NW to SE or from WNW to ESE, except in the eastern part where the directions spread out to form a fan-shaped pattern. This is an indication of the lobate character of ice during the formation of the drumlins (Alden 1911, p. 733; Gravenor and Meneley 1958, p. 718).

Virkkala has suggested that the youngest ice movement, south of the present study area in Suomussalmi, was from the north (Virkkala 1951). However, in Koillismaa this direction was not encountered. The drumlins, which are oriented NW—SE, are not deformed and there is no indication that the ice has advanced over them.

The till stratigraphy is currently under study. It is, however, already evident that there are several older ice movement directions differing from those of the drumlins and fluting, although the differences are not very great. For the time being, these directions cannot be connected with the directions suggested by Korpela (1969) for the till sheets overlying and underlying the Peräpohjola Interstadial beds.

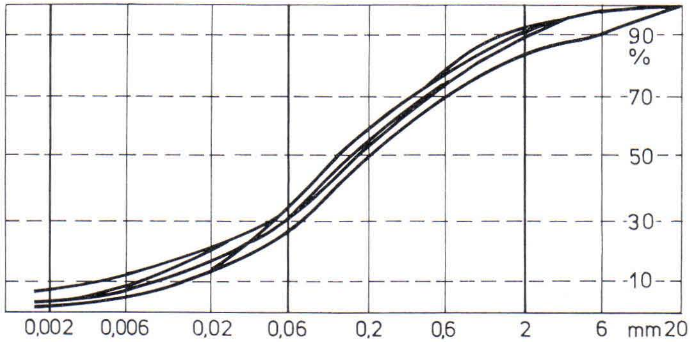


FIG. 9. Grain size distribution within 6 drumlins, sampled at a depth of 1 m. The grain size was not found to vary in relation to depth.

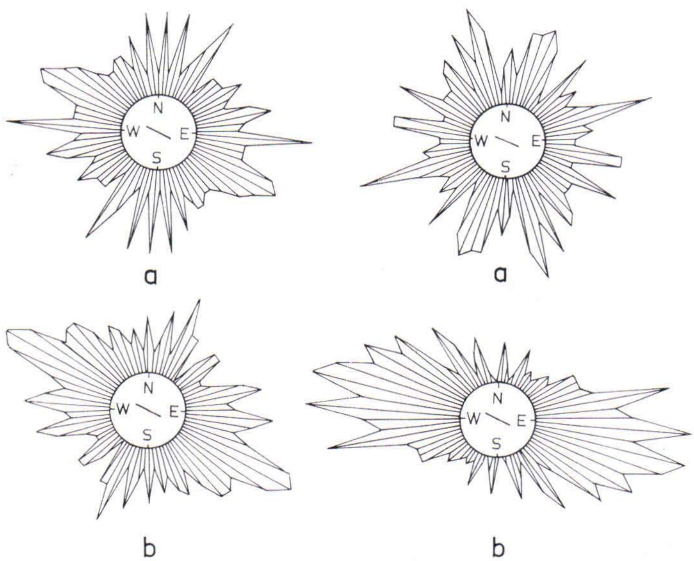


FIG. 10. Examples of stone orientation diagrams from 10 a: well-developed high relief drumlins, 10 b: low relief drumlins. The material in the high drumlins often has no preferred orientation, the orientation maxima are commonly better in the low-relief forms. The line in the middle indicates the ridge direction.

Relation to other glaciogenic forms

Glacial deposits and features

In addition to drumlins and fluting, till also occurs as a veneer which closely follows the relief of the bedrock, as hummocky moraine and, rarely, as end moraine.

The till veneer which conforms to the bedrock relief and occurs especially in the SW part of the area, consists in places of separate till sheets. Their stra'igraphic rank, however, is still unresolved. In the south-east the contact of the till veneered area with drumlin areas is fairly sharp, elsewhere it is generally gradational. The well-developed flutes and drumlins decrease in

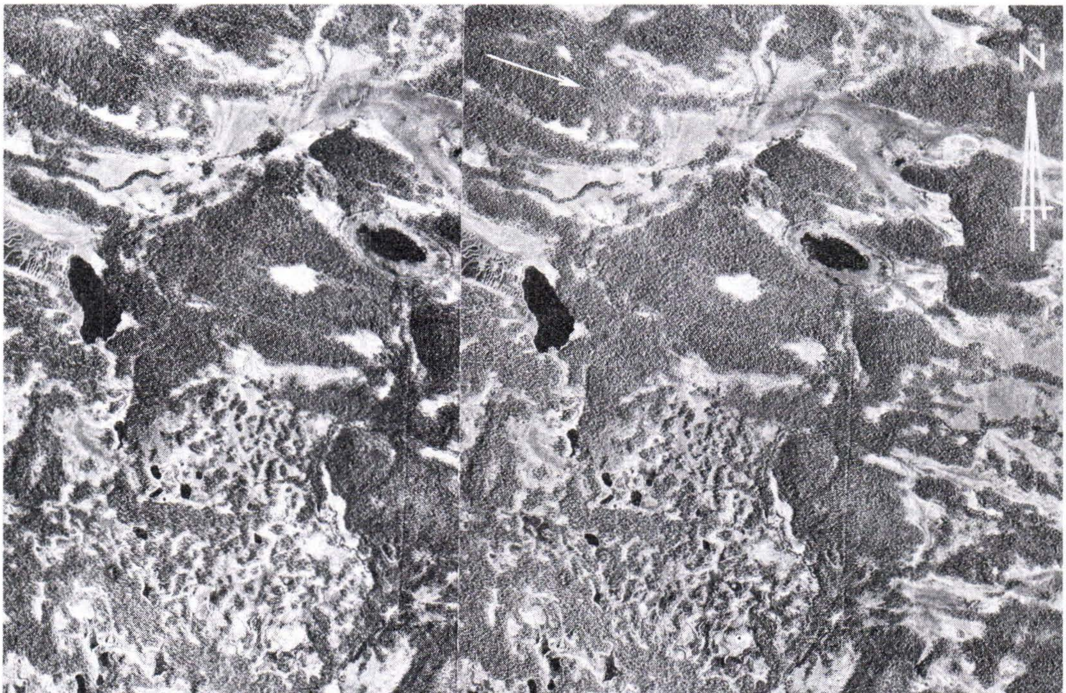


FIG. 11. Glacial landscape near Korouoma (aerial photos 6340/257, 259). Ice came from west-north-west. At the front of obstructions hummocky moraine was formed. By courtesy of Topografikunta (The Army Map Service).

number from the drumlin field towards the area of till veneer. They are replaced by discontinuous ridges until they too disappear and the surface morphology becomes irregular. Finally, the topography is almost entirely controlled by the bedrock. The direction of the movement of the ice, which in the south is WNW is, however, still visible on the aerial photos. This orientation manifests itself both in the bedrock and in the surficial deposits. However, the orientation seems mainly to reflect the underlying ice-sculptured bedrock. Whether or not this orientation represents an older glacial phase than the strongly developed drumlin field east of Kuusamo remains to be seen.

Hummocky moraine occurs in depressions and at the front of the steep stoss-slopes (Fig. 11 and 15). Thus, they often follow the fracture valleys.

The contact of the drumlin and fluting areas with the hummocky moraine areas is transitional with all gradations. From the drumlin area towards the hummocky moraine area the drumlins change into discontinuous ridges, then into aligned knobs, and finally into separate, more or less irregular morainic hummocks (Fig. 12). This gradation suggests that the drumlins and the hummocky moraine were probably formed during the same depositional phase. From Central Sweden a transition of drumlins into the Rogen moraine and irregular hummocky forms has been described by J. Lundqvist (1967, 1969 a, b). The abundance of morainic hummocks is especially characteristic of the northern part of Posionjärvi and the surroundings of the Suolijärvi lakes in the NW of the area. The hummocks vary in size and shape. They grade from tiny, roundish hillocks a few tens of metres in diameter, to sinuous rows of hills up to a kilometre in length and locally 300 m in width and 15 m in height. The ridges are partially joined together and are often perpendicular to the direction of the ice flow and the distance between separate ridges is fairly constant. To a certain extent a resemblance to the Rogen moraine type can be seen. The morainic hummocks are strewn with large boulders, the biggest of which are visible even on the aerial photos. However, some of the islands and promontories of Suolijärvi are drumlins or groups of drumlins sometimes supporting morainic hummocks and ridges. In these cases the hummocks and ridges evidently date from the final stagnation phase of the ice sheet.

Several test pits were dug in the hummocks in various parts of the study area. Stones and boulders were found to be frequent in the surface horizons while, in a couple of pits, the surficial layer was composed of stratified sand. Deeper down in the hummocks the sorted layers alternate with non-sorted drift. Even finely laminated silts and clays were encountered. The amounts of sorted and non-sorted drift varied from one pit to another. In one the sorted material might predominate and in another the non-sorted (Fig. 13).

As a consequence, the grain size distribution varies within much wider limits in morainic hummocks than in drumlins. An abundance of stratified drift indicates considerable glaciofluvial activity during the formation of hummocks. This is further suggested by their occurrence together with eskers in the same low-lying areas. The orientation analyses of the long-axes of stones within the morainic hummocks only shows, with some exceptions, poorly developed maxima (Fig. 14). The results of lithological analyses did not differ significantly from those obtained from nearby drumlins.

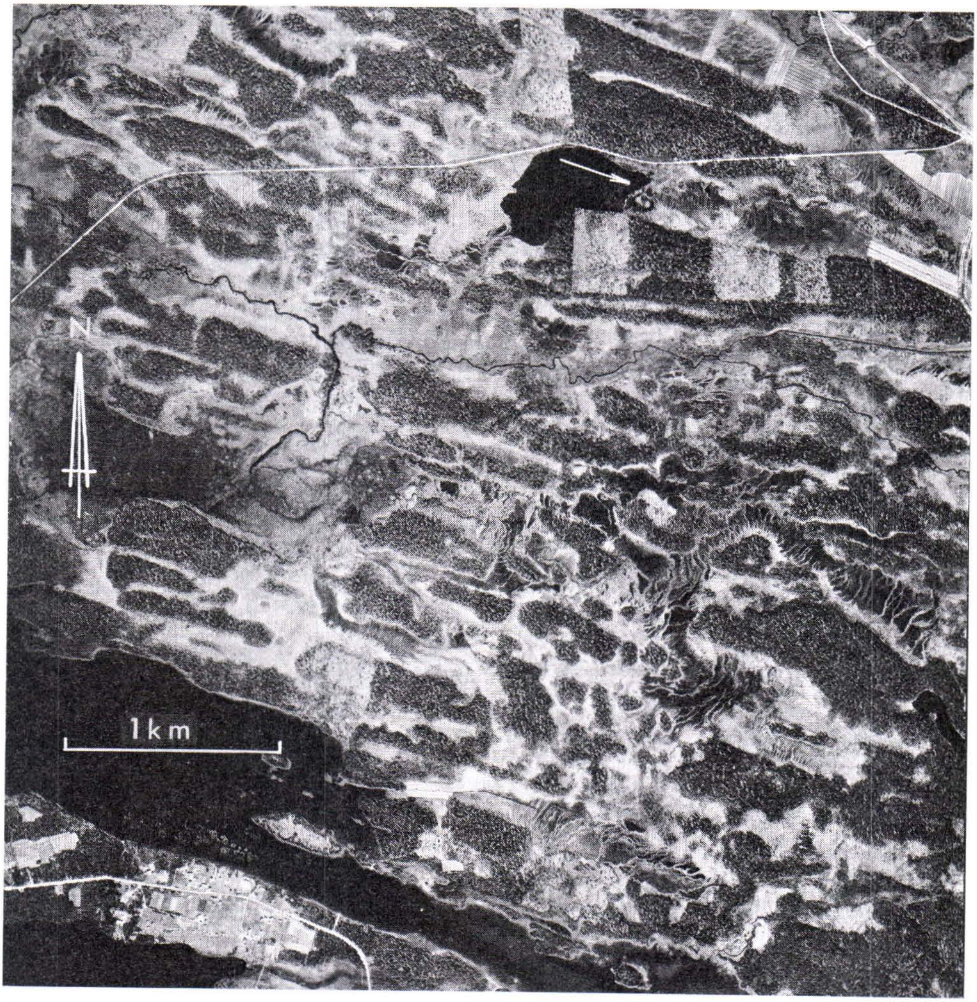


FIG. 12. Transitional forms from drumlins to morainic hummocks north of Käsmäjärvi (aerial photo 6337/142). In Koillismaa it is possible to find the full gradation of forms from typical drumlins through poorly-developed forms and aligned knobs to a more or less irregular hummocky relief. The arrow shows the direction of ice flow. By courtesy of Topografikunta (The Army Map Service).

Only a few end moraines have been recognized with certainty in the study area, and these in the SE part. They are ridges up to 1 km in length, less than 10 m in height, and evidently younger than the adjacent drumlins.

Some observations of striation were carried out along the roads. The striae are almost exactly parallel to the direction of the drumlins and fluting (Appendix 1). Some cross-striae were encountered in the western part of the

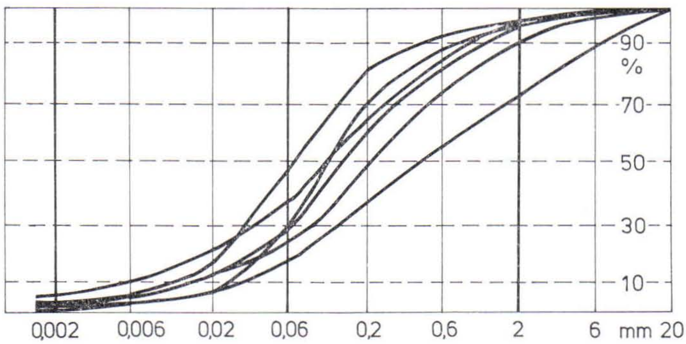


FIG. 13. Grain size distribution of 6 morainic hummocks, sampled at 1 m depth. The material varies within much wider limits than in the adjacent drumlins.

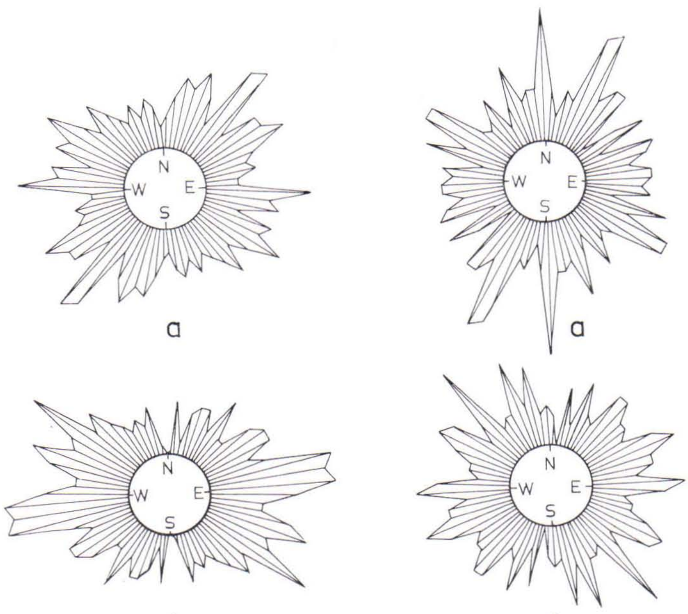


FIG. 14. Examples of stone orientation diagrams from two morainic hummocks, a from 1 m, b from 2 m depth. The orientation is usually poorly developed with no distinct maxima.

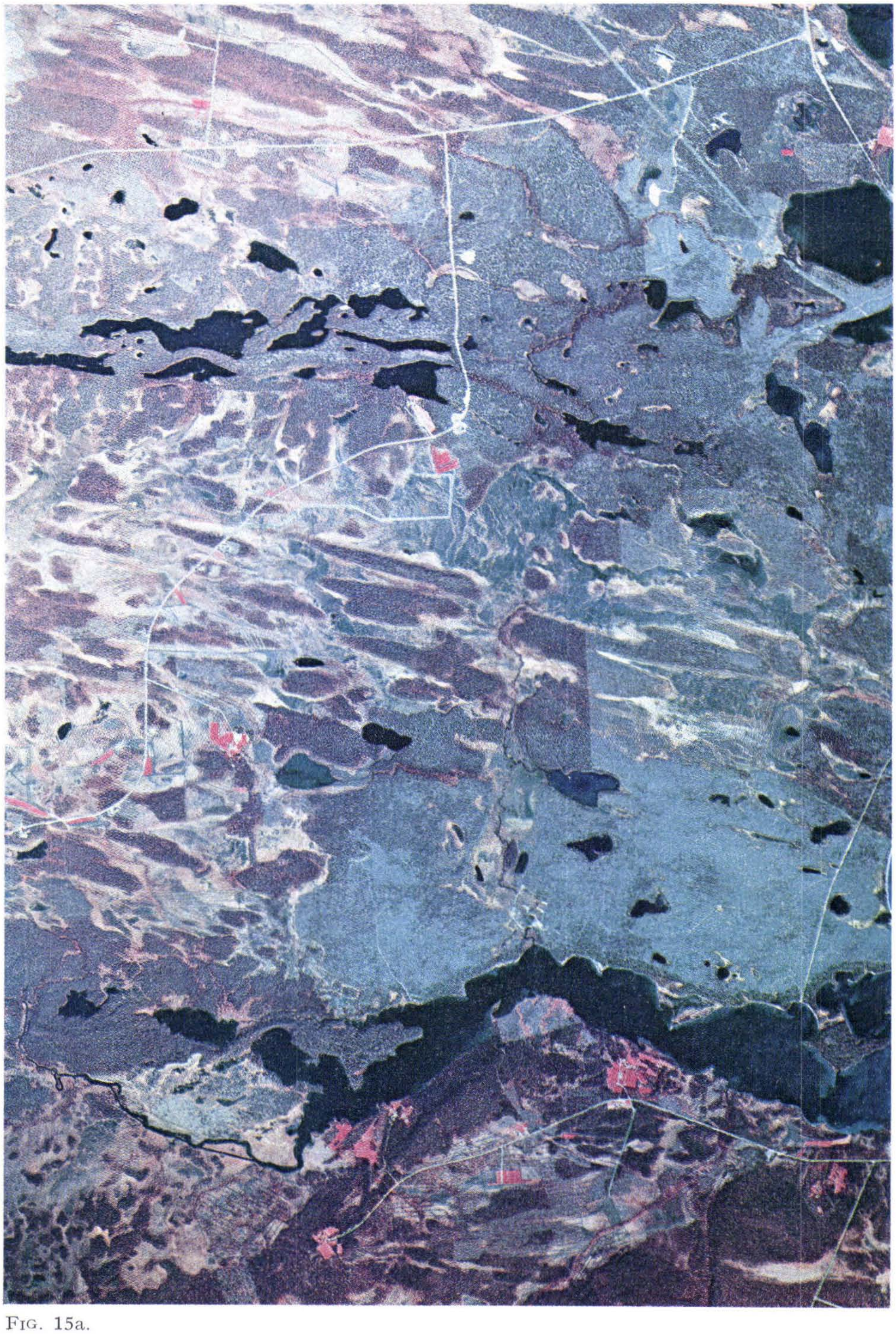


FIG. 15a.

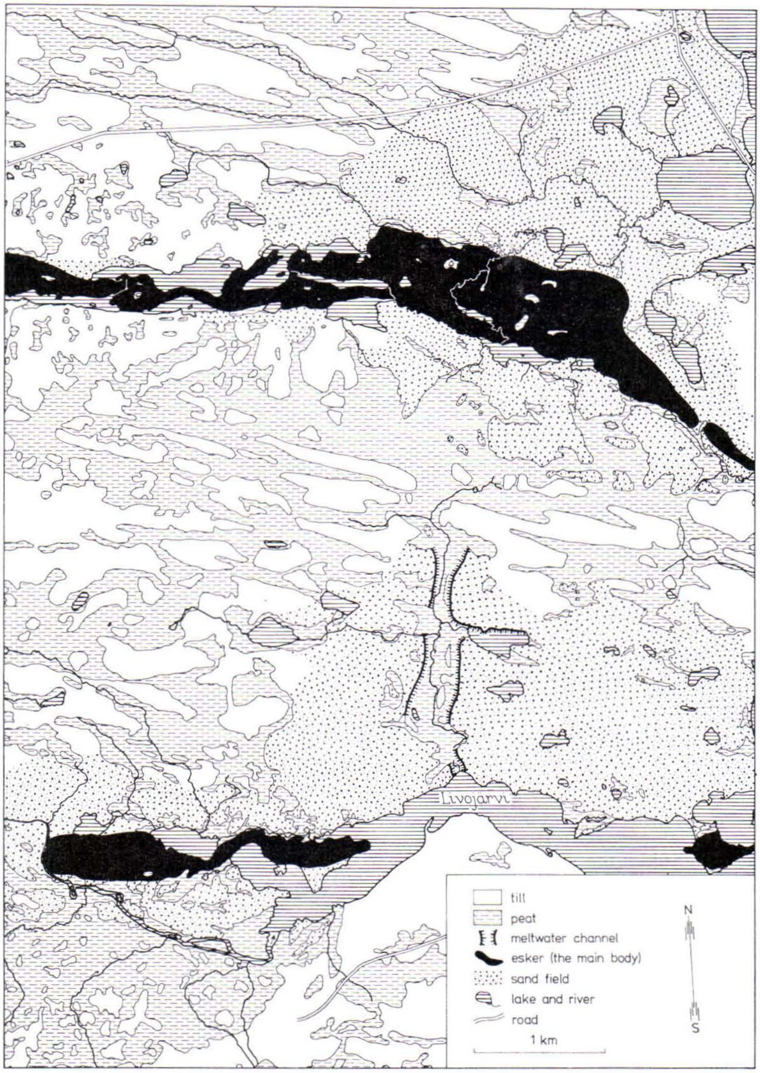


FIG. 15b. Surficial geology shown on aerial photo V 7128 08 (Fig. 15a).

FIG. 15a. An infrared aerial photograph (V 7128 08) from an area south of the parish of Posio showing many of the features characteristic for the whole Koillismaa area. Till appears violet, glaciofluvial material is blue. Hummocky moraine exists in the depressions. It is often veneered by glaciofluvial sand belonging to the esker train which also tends to follow low lying areas, commonly fracture zones. Drumlins occur in the low-relief areas with higher altitudes between. A meltwater channel runs across the drumlin area in the middle of the photograph and terminates in a delta in the south. By courtesy of Topografikunta (The Army Map Service) area. When it was possible to establish age relations, the direction of the youngest striations coincided with the orientation of the drumlins, the oldest striations were approximately from west to east. In the NE several directions were also encountered. Since the variation in altitude is considerable in this area the differences may also be due to local topography.

Glaciofluvial deposits and features

The esker trains exhibit an orientation approximately parallel to the direction of the ice flow (Appendix 1). The eskers vary in shape. Many of them are sinuous, sharp crested ridges with steep sides, which stretch for several kilometres or they might consist of successions of mounds often linked by low ridges. Fairly often several ridges occur parallel to each other or larger mound fields are formed with abundant kettle holes. In places the glaciofluvial material spreads outside the main body to form extensive delta-like sand plains (Fig. 15). In Kuusamo and south of Livojärvi, adjacent to the eskers are large sand fields that were probably deposited into an ice lake and were subsequently levelled by littoral forces (see also Hyyppä 1966). In several places they are now covered by parabolic dunes, often irregular in shape.

Like morainic hummocks, the eskers are greatly controlled by local topography, both generally existing in valleys. Evidently they date from the final disintegration stages of the glacier. Drumlins and fluting were formed at an earlier stage when the movement of the ice was still strong and to a great extent independent of the local topography. The difference in age is further shown by the fact that glaciofluvial material has, in places, been deposited on drumlins and flutings (Fig. 15). Virkkala (1951, p. 37; 1954, pp. 21—28; 1960 b, p. 20) has reported drumlins grading into eskers in the Suomussalmi area, but this has not been encountered in the Kuusamo area.

The glaciofluvial erosion channels are most abundant in the east. The water ran eastwards along the fracture lines and in between the drumlins. In places the drumlins were cut through by meltwater (Fig. 16). This happened especially when the drumlins occurred in the fracture zones or extensions of them, where meltwater concentrated. The position of the channels on the slopes of some drumlins shows that the valleys between the drumlins were sometimes still filled with ice when the channels were formed. Figure 15 illustrates an erosion channel formed partially or completely outside the margin of the ice.

Meltwater channels are a characteristic of supra-aquatic areas (Hoppe 1948, p. 98). Because the terminal levels of the channels in the study area often coincide with the present water levels, they have hardly changed at all since their formation.

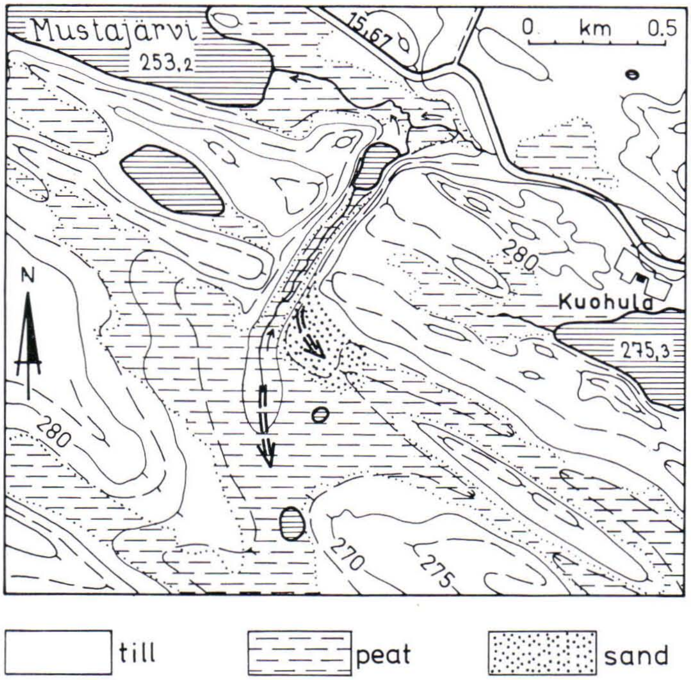


FIG. 16. A meltwater channel cutting across drumlins about 20 km south-east of the parish of Kuusamo (topographic map 4253/06). The arrow shows the direction of meltwater flow.

SUMMARY AND CONCLUSIONS

The present study was focused specifically on drumlins and fluting as well as on their relationship with other glaciogenic elements in Koillismaa. The drumlins are not evenly distributed. They abound on the areas of fairly flat relief tending to be absent in the areas with a relatively high relief. Instead, fluting is common both in association with drumlins and also on the top of some high hills and on their lee-slopes.

A long and relatively narrow drumlin type is characteristic for Koillismaa. Well-developed drumlins occur in the center of drumlin swarms. In the marginal parts they are often poorly developed and grade into morainic hummocks or a till veneer which conforms with the topography of the bedrock.

The drumlins are composed mainly of sandy till. The material is fairly homogenous between different depths within one drumlin and between different drumlins. Several well-developed, high-relief drumlins do not exhibit a distinct orientation of stones, whereas some low-relief drumlins in flatter morainic areas show clear maxima. The degree of orientation does not vary much in relation to depth. The material seems to derive mainly from the local bedrock.

The orientation of the drumlins and fluting is frequently NW-SE. However, in the south-eastern part of the area, the directions show a fan-like pattern indicating the lobate character of the moving ice.

Opinions differ as to when the drumlins were formed beneath the ice sheet (e.g. Alden 1911; Ebers 1937; Hoppe 1951; Virkkala 1951; Gravenor 1953; Kupsch 1955; Charlesworth 1957; Flint 1957; Lemke 1958; Vernon 1966; Smalley and Unwin 1968). The orientation of the drumlins and fluting in Koillismaa has not been controlled by local topography, an indication of the considerable thickness of the overriding ice sheet. Further the frequent elongated forms with transitions into fluting might suggest powerful ice flow (e.g. Chorley 1959). On the other hand the lobate character of the contemporary glacier must be taken into consideration in addition to the fact that transition series into morainic hummocks exist, whose composition frequently implies glaciofluvial activity. It seems as if at least most of the drumlins in Koillismaa were formed during the retreat phase of the ice sheet, in the marginal zone which was still active (see Smalley and Unwin 1968) but which had already stagnated in depressions and in front of obstructions, where hummocky moraine was being formed (see also J. Lundqvist 1969 a, b).

Glückert has suggested that the drumlins of the study area formed during the advance phase of the glacier, with only the esker-like drumlins possibly having been slightly re-shaped during deglaciation (Glückert 1974, p. 42). However, the basis for his conclusion, which is at variance with the one suggested here, is not clear from the evidence he presents.

In some cases it has been observed that morainic hummocks have also been deposited on the drumlins. These hummocks evidently date from the final stagnation of the continental ice in this area. That the ice finally disappeared by large-scale stagnation is suggested by the almost complete absence of end moraines and the rather frequent occurrence of hummocky moraine.

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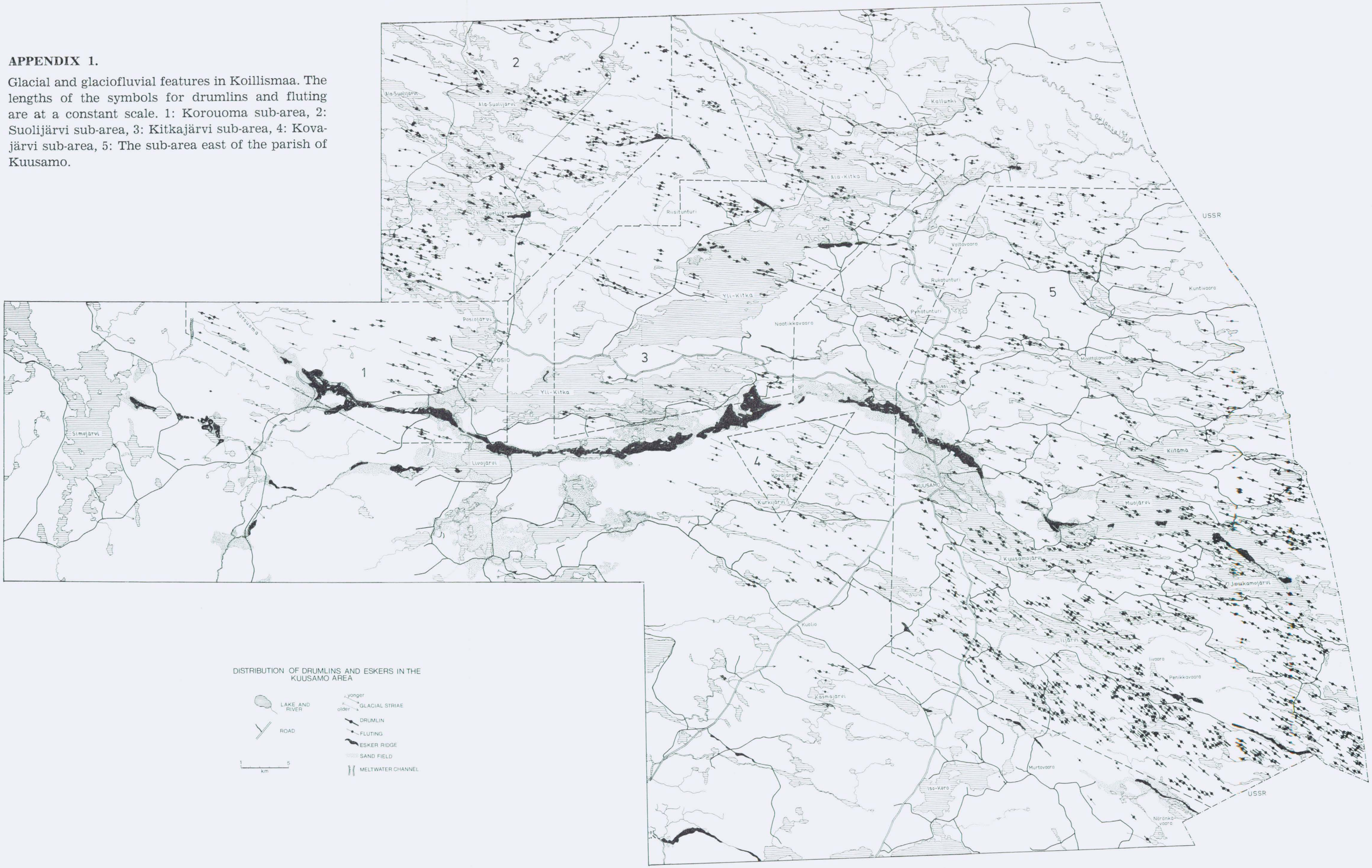
APPENDIX 1.

Glacial and glaciofluvial features in Koillismaa. The lengths of the symbols for drumlins and fluting are at a constant scale. 1: Korouoma sub-area, 2: Suolijärvi sub-area, 3: Kitkajärvi sub-area, 4: Kovajärvi sub-area, 5: The sub-area east of the parish of Kuusamo.



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