SVERIGES GEOLOGISKA UNDERSÖKNING

SER. Ba ÖVERSIKTSKARTOR MED BESKRIVNINGAR NR 27

TORBJÖRN FAGERLIND

GLACIAL DEVELOPMENT IN THE PAJALA DISTRICT OF NORTHERN SWEDEN

WITH ONE PLATE

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1. ABSTRACT

The investigated region comprises the Pajala district in the north-eastern part of Norrbotten, the northernmost county of Sweden. The aim of the investigation was primarily to clarify different glacial movements and to make a survey of the distribution of those Quaternary deposits in the region which had not earlier been mapped typologically. Different ice movements have been shown in 117 localities of glacial striations, 171 till fabrics, 112 particle counts, and various, orientated, moraine ridges. The results of these investigations and contemporaneous studies of late-glacial drainage have been connected with the glacial development in the area. The oldest known ice movements in the region, from the north or north-west, are judged to have been older than the last interstadial, which is correlated to the interstadials of Jämtland and Perä-pohjola for 45 000—59 000 years BP (J. Lundqvist 1974). The ice movements in the latest glacial stage are, as regards the whole area, from the south or south-west, and regarding the southern parts, from the west in connection with the deglaciation phase. The evidence for the glacial development is based not only on the ice movements but also and primarily on 29 localities with more or less well-established two till beds and till-covered sediments. The different glacial stages have been relatively dated, chiefly by correlation with Finnish investigations, among others, that by Hirvas, Kujansuu and Tynni (1976b). A schematic picture of the deglaciation pattern has been constructed with the aid of the results of this investigation, taking into account especially the distribution of the Quaternary deposits, the ice movements and the late-glacial drainage. The retreat of the ice was in principle from north-east to south-west and from east to west in the south-eastern part of the area.

2. INTRODUCTION

The investigated region measures about 8 000 km² and is situated along the Swedish-Finnish border, 10 to 150 km north of the Arctic Circle in Norrbotten, the northernmost county of Sweden (Fig. 1). Morphologically, the landscape can be described as relatively flat; the highest hills are about 450 m above sea-level and the lowest parts of the valleys are about 80 m above sea-level. The flatness of the region is well illustrated by the frequent, large mires. In the southern part of the investigated area, the hills are often elongated north-west to south-east and can be described as large drumlin-like forms. The drainage pattern is dominated by the Torne, Muonio, Lainio, Tärendö, and Kalix Rivers. The lakes are in general rather small and shallow.



Fig. 1. Location map.

The predominant Quaternary deposits are till and peat (Fromm 1965, the map), but in the northern part vast areas are covered with ice-lake sediments, usually consisting of sand and silt. The glaciofluvial deposits consist of small

eskers and rather wide deltas and delta-like formations. The highest shoreline lies about 170 m above sea-level (Santesson 1927, G. Lundqvist 1961, p.101, Fromm 1965, p. 142). Areas below the highest shoreline are situated especially along the valleys of the Torne, Muonio and Kalix Rivers up to some 10 km north of Pajala.

The present work was started in 1973 when the Department of Mineral Preparations at the Royal Institute of Technology in Stockholm and the Geological Survey of Sweden (SGU) were commissioned to carry out a survey called "The complementary prospecting and mineral technical inventory".

The sponsors of the project were the Fund for Northern Sweden and the National Labour Market Board. The Quaternary part of the project was aimed at getting such information as would make it easier to investigate geochemical anomalies and mineral deposits. The Quaternary investigations took into consideration in the first place such circumstances as could lead to increased knowledge of different glacial movements but also the mapping of the distribution of the Quaternary deposits in the northern part of the Pajala district. This part of the project was carried out under the supervision of Dr Erik Fromm (SGU) and was led by the author with the assistance of Mr Kjell Moreborg. The preliminary results of this investigation have been reported earlier (Fagerlind 1975). The present publication is for the most part based on material collected during the above project. The further work on the collected material and the complementary studies, as well as the drawing of the figures, the writing and the other kinds of work connected with the publishing, have largely been carried out with help of the ordinary staff at the SGU. The manuscript has been linguistically corrected by Mr Neil Tomkinson and revised by Dr Per H. Lundegårdh.

The investigation was simplified by very good relationships with the authorities in Pajala village and the Pajala district, the Forest Service, the National Road Administration, and the Employment Office.

3. EARLIER INVESTIGATIONS

The works mentioned in this chapter do not constitute a complete outline of the geological investigations concerning the Pajala district, nor do they form the basis of this publication. Instead, an outline is given of the published material forming the basis of the planning and carrying out of this work and improving the development of assumptions and conclusions. In the publications mentioned below, references will be found to all the essential publications which contain both detailed investigations and surveys of all available information concerning the Quaternary geology of the northernmost parts of Sweden.

Ödman (1957) describes the bedrock in the county of Norrbotten, both the

distribution of the rock types and the rock stratigraphy, on a map and in a monograph. Nowadays, the distribution of the rock types and the rock stratigraphy outlined by Ödman are not fully accepted, and, because of the scale of the map, 1:400 000, it is often too generalized to permit detailed considerations. For some parts of the region, larger-scale (1:50 000) and more reliable bedrock maps have been published, namely, Lainio NW, NE, SW, SE (Witschard 1970), Tärendö NW, NE, SW, SE (Padget 1970) and Pajala NW, NE, SW, SE (Padget 1977). These maps have been produced with the aid of aeromagnetic maps.

"Quaternary deposits of the southern part of the Norrbotten county", a map and a copious monograph by Erik Fromm (1965), have been of great importance for this investigation. Fromm's work gives not only a survey and a description of the distribution of the Quaternary deposits and phenomena within the mapped area but also an excellent compilation of the works of other authors dealing with Quaternary geology in the northern part of Sweden. Fromm's observations and conclusions within the Pajala district agree for the most part with those of the present author. Fromm has, however, only tentatively discussed different alternative explanations for his observations, which can be connected with different stages in the glacial development before the last phase of glaciation. Of particular importance in such a discussion is the observations made by Fromm concerning changes of ice movements, the Kalix till (Beskow 1935, pp. 122—123), till-covered sediments, and the two till beds. Two till beds have been described mainly from two localities, Njalatj and Pajala. The latter locality is treated in more detail by Järnefors (1952).

Hoppe (1959) has given a general survey of the principles of the deglaciation and related phenomena in Norrbotten county. In a later work, "Case studies of deglaciation patterns" (1967), Hoppe penetrates these questions in greater detail as regards the southern part of the Pajala district. Hoppe's results are of great value, but, like Fromm (1965), he attributes different ice movements to the last glacial stage, which partly contradicts the results of this investigation.

Rudberg (1949) has written a very comprehensive work on kursu valleys (rock canyons) in Norrbotten county. The results of his investigations are of great importance for the understanding of deglaciation and the late-glacial drainage in the Pajala district.

Other surveys which are or have been of great importance for the understanding of the Quaternary geology of northern Scandinavia are Tanner's studies of the Quaternary System in the northern parts of Fennoskandia (1915), G. Lundqvist's map of the deglaciation and the highest shoreline in Sweden (1961) and the Finnish soil maps on a scale of 1:400 000 (Kujansuu 1965, 1966, 1967a, Pentillä and Kujansuu 1964, Hirvas and Kujansuu 1971). The now predominant research concerning glacial development in the north of Finland was initiated by the above-mentioned soil mapping which forms the basis of Kujansuu's thesis "On the deglaciation of western Finnish Lapland" (1967b). The deglacia-

tion research on northern Finland is being continued in the Geological Survey of Finland under the leadership of Kujansuu and forms part of the International Geological Correlation Programme (IGCP). Outlines of the results of the investigations in the north of Finland have been presented by Hirvas, Kujansuu and Tynni (1976b), Hirvas (1977a) and Hirvas *et al.* (1977). These results make it possible to correlate different stages of different ice movements in the glacial developments within vast areas in northern Scandinavia. Furthermore, Korpela's work in 1969 on the Peräpohjola Interstadial ought to be mentioned.

The discussion about the glacial development in northern Sweden has been presented by Ljungner (1949) and by J. Lundqvist (1967, 1969, 1971, and 1973). An excellent outline of different investigations and discussions in this respect has been given by J. Lundqvist in "Outlines of the Weichsel glacial in Sweden" (1974). Of special interest in this work are the correlations between the Peräpohjola Interstadial in Finland and the Jämtland Interstadial in Sweden.

4. METHODS

4.1. THE MAPPING OF QUATERNARY DEPOSITS

The northernmost part of the Pajala district, north of a line joining Aareavaara, Kangos and Kurkio, has been mapped in a broad way regarding the Quaternary deposits. The mapped area is a continuation of the map entitled "Quaternary deposits of the southern part of the Norrbotten county" (Fromm 1965). The mapped area measures c. 2 300 km^2 and the mapping was finished in about five months, if the calculation is based on the work of one person. In order to get acceptable results, taking into account the personnel and the time available, a simplified method of mapping was used as compared with the small-scale mapping done by the SGU (cf. J. Lundqvist 1969, pp. 7—14). The mapping of the different deposits was simplified as far as possible, details were eliminated, and topographical maps and aerial photographs were used to a large extent.

The Quaternary deposits have been divided in till (without subdivision), coarse sediments (sand and coarser fractions), fine-grained sediments (silt and finer fractions), and peat. Furthermore, morphologically distinguishable, glaciofluvial deposits, certain channels of late-glacial drainage and glacial striations have been reproduced on the map. The boundaries between the different geological elements have been determined mainly by mapping along the roads and during longer or shorter walks in the terrain, and with the aid of topographical maps and aerial photographs. The mapping depth has been about 0.5 m in general.

Because of the necessary generalizations, the map will not in all respects give a complete picture of the distribution of the Quaternary deposits. Outcrops have not been shown, owing to difficulties in delimiting them with the aid of the map material. The slight differences between the grey tones on the aerial photographs are often not sufficient to distinguish coarse sediments or coarse-grained till from outcrops. The consequence of this is that outcrops can be found within the different types of deposits in the map. The mapping depth may be less than 0.5 m in some parts, especially regarding the outer limits of the fine sediments. The peat deposits were mapped after the boundaries of the mires according to the topographical maps. This generalization ought to be satisfactory, however, judging from the experience gained in the field investigations. Smaller areas of till can be found within the sediment limits. Sediments have been discovered as spots in an area mostly consisting of till west of the Lainio River within the so-called "Lainio bow" (Fromm 1965, pp. 108—109), which shows an extremely complicated picture of Quaternary deposits and late-glacial drainage. The "Lainio bow" had to be mapped in detail, in order to get a correct picture of the distribution of the different kinds of deposits. Only a selection of late-glacial drainage channels is given. The mapped area is to a large extent characterized by the influence of drainage water in different forms, and a complete picture of the late-glacial drainage would have required mapping in greater detail than was possible.

It is judged, however, that most of the distribution of the loose deposits shown agrees well with the real facts. There are good conditions for generalizations in delimiting different types of deposits. At an early stage of the mapping work, it was shown that the boundaries between sediments and till are often on the same level. It was then supposed that the main part of the sediments was deposited in ice lakes. With the aid of the topographical maps, limits for ice lakes were constructed, after which these limits were checked at some places in the field. To a very large extent the theory agreed with the reality. Where our assumptions did not agree, more intense field work was done and new levels were often found, where the boundary between sediments and till could be drawn. This circumstance, and the modern topographical maps, were the main conditions that ensured that the mapping could be done with relative care in a short time. The map presented is judged to have a precision comparable with the map of the southern parts of Norrbotten county (Fromm 1965), which, however, is richer in details. Disagreements along the boundary between this and the earlier maps of Quaternary deposits are probably due to the fact that in the earlier mapping work there were difficulties in getting a complete picture of the distribution of the deposits, owing to difficulties of access to the border areas and the antiquated maps.

In principle, the agreement with the Quaternary map in the neighbouring areas in Finland (Penttilä and Kujansuu 1964) is good. Discrepancies can

usually be explained by different meanings of the designations of the types of deposits. The largest discrepancy is that the Finnish maps of the Quaternary deposits do not show the fine-grained sediments.

4.2. STRIAE OBSERVATIONS

In view of the comprehensive literature on Quaternary geology and the practical results of a large number of geological surveys, there cannot be any doubt that certain score-marks on rocks are erosional effects of the continental ice. Most of these score-marks were formed as glacial striations. The results of this investigation are to a large extent dependent on ice movements indicated by glacial striations, and a large part of the field work implied the location of distinct striae, as well as their evaluation and measuring.

According to Fromm (1965, p. 122), Ödman (1957), Padget (1970, 1977), and Witchard (1970), most of the bedrock in the Pajala district is easily weathered. Accordingly it is difficult to find glacial striations on naturally exposed rocks. The search for outcrops with glacial striations was therefore concentrated in places where the bedrock had been exposed artificially in recent time. Such outcrops are often less weathered than those which have been exposed since the deglaciation of the area. Rocks exposed by man are to be found mainly along the roads in ditch-cuttings and in gravel or till pits.

Good localities with glacial striations are characterized by many parallel striations in small spots. There one usually finds a microstriation, which in combination with the micromorphology is often of good help in judging the directions in which the striations have been impressed. Usually, the general sculpture of the rock, as well as marks such as crescentic (parabolic) cracks, crescentic gouges (G. Johnsson 1956, pp. 116—125) and the positions of the ordinary striae on the outcrops in relation to their morphology, help us to confirm the evaluation of the directions of the ice movements. It is often difficult to decide whether a single score-mark, especially on the weathered surface of a rock, derives from glacial erosion or not. Certain cracks or cuts made by man might be confused with glacial striations, particularly when one is looking for and wishing to find glacial striations. It is obvious that mistakes can be made, and the observation of striae by one single geologist involves a subjective judgement.

At many localities, glacial striations running in different directions have been found. In several cases, it was possible to decide the relative ages of these striations. The best evidence of relative ages is to be found when older glacial striae are situated on surfaces which have been protected from the erosive force of a younger ice in motion. It is more difficult to interpret the relative ages of glacial striations when the only evidence is that they cut each other. The younger striations must cut the older ones, but to decide if they really do so is often diffi-

cult and sometimes impossible. Here also, evaluations are subjective. In this project, the most important outcrops with glacial striae of different ages were checked by other geologists than the observer. It is important to realize that the relative ages of glacial striations only give information about the relative ages of different directions of ice movements and not, or only to a restricted extent, information about the capacity for material transport of different ice movements.

The greater part of the observations of glacial striations is judged to be of good quality, and some are of very good quality. A small number is uncertain, particularly in areas where few observations were made. In such areas, evidence of ice movements, although to some degree uncertain, is presented in this work.

4.3. MORAINE MORPHOLOGY

Morphological structures were mainly selected from the topographical maps but also to a certain extent from aerial photographs. Fromm's (1965, pp. 107—108 and the map) and Hoppe's (1967, p. 206) results have been very useful in evaluating the material and the genesis of different land forms. The scale of the aerial photographs used in this work was mostly about 1 : 60 000, and therefore it was difficult and sometimes impossible to find the smallest ridges. The contour lines on the topographical maps give a good picture of land forms, often even of small ones. Furthermore, small, elongated ridges can be contoured by means of the symbols of forest land in the mires. Particularly elongated moraine ridges were of interest in this work. Such ridges are assumed to have had a drumlin-like genesis and to reflect the directions of glacial movements (Hoppe 1951, 1957, 1959).

The purpose of this part of the investigation was to make a regional survey of the directions of the moraine ridges, which, in combination with other signs of glacial movements, visualize and confirm the glacial development in the area. The most serious objection to the method used is that the genesis of the mapped ridges is not completely clear, in spite of the good help obtained from Fromm's (1965) and Hoppe's (1967) works and from the experience gained during the field investigations. However, this kind of work seems to improve considerably regional investigations dealing with the discovery and interpretation of the movements of continental ice-sheets.

4.4. TILL-FABRIC ANALYSES

The till-fabric analyses made in this investigation imply a practical application of the preferred orientations of the long axes of stone particles in their relation to ice movements. The fabric analyses were simplified in comparison with those of many other investigators (Holmes 1941, H.G. Johansson, 1972, pp. 11—12,

Boulton 1971, Björnbom 1977, and others). It was necessary to simplify the methods for many reasons. First of all, the assistants who made the measurements in the field had no experience of this kind of work; secondly, a great many fabric analyses had to be made, due to the large area to be investigated; and, finally, the time available was restricted.

The intention behind the till-fabric analyses was to get information about ice movements, to make it possible to define different layers of till, and to get information about the transport capacities of different ice movements. These analyses are to be seen as a complement to other methods, particularly striae observations and particle counts, which also yield information about ice movements and the rock-material transport of the continental ice-sheet.

The analyses were made in till on a horizontal surface of measuring about one square metre. The long axes of the particles were to be at least twice the length of the axis at right-angles to the long axis. The particles were not allowed to dip too much (cf. H.G. Johansson 1972, p. 11). About 100 particles with a diameter of 2—20 cm were scraped and brushed up, and the long axes were measured with a compass. The dip directions of the long axes were noted in these analyses, which were made in the later part of the field investigation in 1974.

In most localities, two analyses were made, one at a depth of 0.5—0.7 m and the other 1.0—1.2 m beneath the ground level. Most of the fabric analyses were made in formations which can be classified as drumlinoids, drumlins or moraine without any particular morphology. The till in which the fabric analyses were made should mostly be classified as lodgement till.

The directions of the long axes of the different paticles have been tabulated in 5° or 10° classes, and the result of each analysis is shown in a rose diagram (G. Lundqvist 1948, p. 5). From this diagram, the main direction is interpreted, as well as the breadth of the interval that encloses the main direction, the secondary maximum (sub-direction) and the number of particles (in per cent) contained in the interval around the main direction. The factor selected is the quotient of the percentage of particles within the main interval divided by the number of degrees within the interval (%/°), and a subjective judgement is made of the value of the analyses as indicators of directions (good, fairly good, fairly bad, bad, unjudgeable). The main direction is either interpreted as the centre of the predominant direction interval or over a 10° interval if it has a marked maximum. The breadth of the main interval is interpreted with the help of the rose diagram. Distinct secondary maxima have been noted. The factor (%/°) should yield an objective value of the analyses as an indicator of glacial movements. As this factor does not always agree with the visual picture of the rose diagram, it is complemented with the subjective value. For instance, a wide interval with a relatively low percentage at every 10° interval gives a low value of the calculated factor, although the rose diagram gives a fairly good indication of the preferred orientation of the particles. A single maximum in a

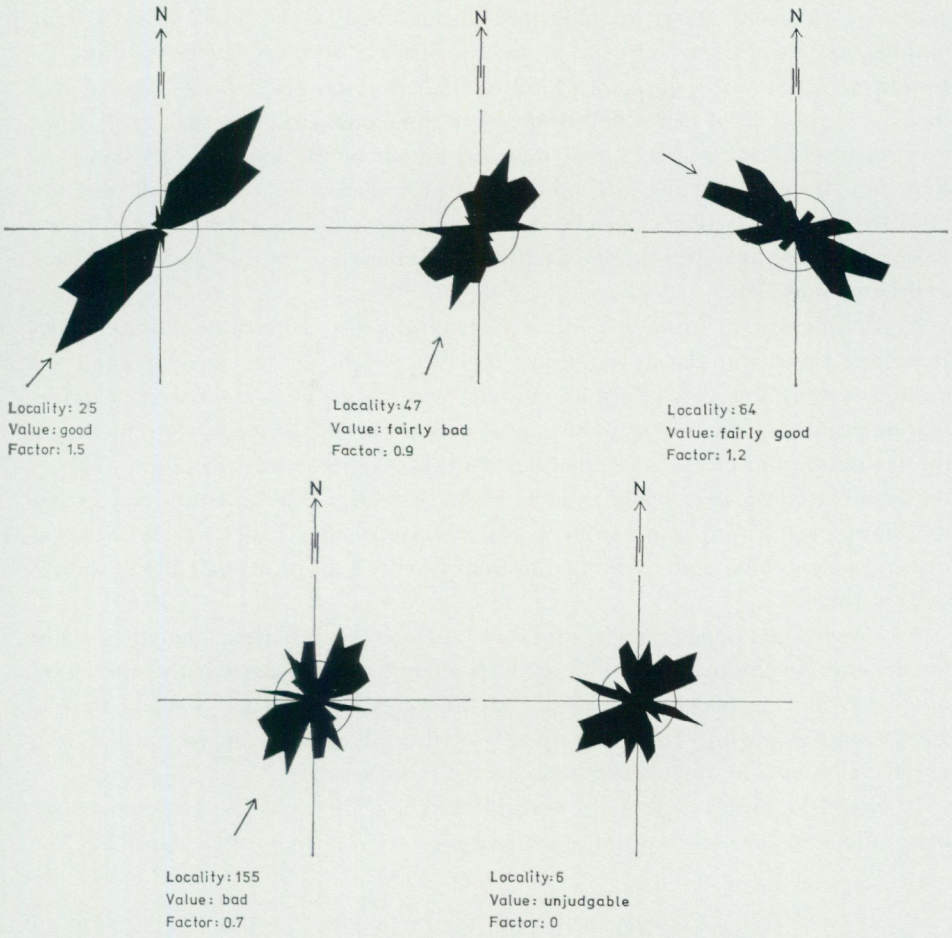


Fig. 2. Judgements of the till fabrics, examples. The arrows show the presumed direction of ice movement. The circles denote 6 %. For the value and the factor, see the text.

10° interval with a high percentage gives a high value of the factor, in spite of the fact that several sub-directions are to be found, and the visual picture of the rose diagram will not give a uniform indication of the preferred orientation. The factor and the subjective judgement will therefore complement each other, and both are necessary if the till fabrics are to be presented in tabular form in a proper manner (Appendix III). Fig. 2 shows rose diagrams which are as representative as possible of the different classes.

The method above can be criticized in many ways. However, it has been shown by many authors (G. Lundqvist 1948, p. 27, Järnefors 1952, p. 192, and others) that the long axes of stone particles in lodgment till will have a preferred orientation in the direction of ice movement. It is pointed out that one cannot draw

general conclusions about ice movement from single fabrics, but from a large number of observations one can draw conclusions of fairly good validity (G. Lundqvist 1948, p. 27, Järnefors 1952, p. 192, Boulton 1971, p. 69). Local factors, such as mode of deposition, bedrock morphology, landslides, etc., will, however, influence to a certain extent the orientations of the long axes of stones, so that they deviate from the directions of ice movements (Rudberg 1958, Boulton 1971, p. 69, Minell 1973). In places with two till beds, the particles may be reorientated in at least the upper part of the underlying till due to MacClintock and Dreimanis 1964.

It is important to work in materials permitting the ice movements to be determined. From the glacial striations and other signs of ice movement on the ground surface, one gets information about general ice movements but no information regarding the extent of the influence of the different ice movements on the transportation of the rock material. In this investigation, two fabric analyses on different levels were made at most of the localities. The intention was partly to obtain a significant result from the orientation of the particles from the locality and partly to be able to define different layers of till or at least to get indications of them.

As already mentioned, single till-fabric analyses do not yield enough support for general conclusions, and such analyses should be compared with other signs of glacial movements. In this work, the till fabrics will often be compared to glacial striations with ocular descriptions of the till material in the cuttings and to particle counts in the material used for the fabric analyses.

It should be observed that the term "fabric" in this work is restricted to the orientations of the long axes of stone particles (cf. Pettijohn 1957, pp. 72—73).

4.5. PARTICLE COUNTS

In connection with and at the same levels as the till-fabric analyses, the till was sifted and 150—300 particles with diameters of 1—3 cm were sampled. These particles were analysed, as regarded the rock material, at the SGU in Stockholm by K. Moreborg, who also to a large extent extrapolated the results of the analyses, in order to get the transport direction of the particles. The particle counts in this work will be restricted to analyses of the rock content in tills, determined only from particles with diameters of 1—3 cm (cf. Lindén 1975, pp. 15—17).

The results of the method practised in this investigation can be divided into three parts: the determination of the rock particles, how the rock content of tills can be connected with the ice movements and the length of transportation, and how determinations of the rock content of tills as compared with the results of other methods in this investigation, clarify the till stratigraphy.

Before classifying the rock fragments, the rock types in the investigated area were simplified and divided into as representative groups as possible by K. More-

borg most kindly assisted by H. Lindroos, who is mapping the rocks in some parts of the Pajala district. The rock types of the particles counted were finally classified in the following groups: granite, gneiss, syenite, greenstones (excl. gabbro), gabbro, porphyry, quartzite, granite poor in quartz, skarn, magnetite, and schist (see Appendix IV).

When the percentage distributions of particles of different rock types had been calculated, the relations between the data obtained and the solid bedrock could be investigated. This study made it possible to find out how long the particles had been transported, and sometimes also to determine the depth of deposits of material transported in different directions.

Several methodological difficulties arose in connection with the analysis of the particles and with the interpretations of the prepared particle counts. There is some difficulty in deciding, with certainty, the types of bedrock in the particles, since the particles are comparatively small. The bedrock maps to a large extent fail to give exact information (Ödman 1957, Witschard 1970, Padget 1970, 1977), in the main owing to the fact that outcrops are frequently very sparse. The various areas of rocks, for example migmatite and granite, are not homogeneous or unambiguously definable. Since several ice movements have occurred in the area, re-stratification of material in one ice movement may have taken place in another (Gillberg 1977). The spread and the distance of transportation of the rock fragments are dependent on the movement of the ice and its picking and depositing ability, which has been influenced by climatic and morphological factors (see G. Lundqvist 1940, pp. 36—40). These sources of error rendered it impossible to make a detailed evaluation of the petrographical analyses in the way in which they were planned for this investigation. The evaluation, that is, the interpretation of the transport directions and the transportation distance, has been made on the basis of the comparatively large relative differences in the rock content of the till and on the broad outline of the rock distribution.

For the above-mentioned reasons, the interpretations of the transport directions are reproduced by arrows, which show a supposed transport direction and a sector which roughly expresses the uncertainty in the judgement (see Fig. 17). The transport distance of the material has been reproduced as an interval (for example, 1—7 km), which includes the limits of the transport distance of a rock fragment which can be assigned to a source in the bedrock.

The relative differences of rock contents in samples from varying depths from the same locality may indicate two till beds. However, these relative differences are dependent on the number of counted particles. To be certain to obtain adequate basic statistical data permitting determinations of the actual differences of the rock content at different levels, more particles should be counted than have been counted in this investigation (Galehouse 1971, Melkerud 1977, pp. 38—39). However, the number of counted particles is so large that the relative differences are beginning to be established (J. Lundqvist 1952, pp. 11—12, Pers-

son 1973, pp. 5—6). If the results of the particle counts are compared with the results of the fabric analyses, the striae investigation and the description of the bed sequence at the localities, a good basis for a judgement will be available in the interpretation of the till stratigraphy.

4.6. TRACES OF LATE-GLACIAL DRAINAGE

The late-glacial drainage created a great many erosional formations, most of which can be described as dry channels and be classified by the nomenclature used (for instance, Fromm 1965, pp. 132—139). The local conditions during their development cannot, however, be explained without detailed studies and a fairly good knowledge of the deglaciation pattern. The aim of the compilation of the late-glacial, erosional forms in this work is to show parts of the deglaciation pattern with the aid of the late-glacial drainage. Because of the regional character of this work, it has not been possible to analyse complicated, local drainage systems in a detailed manner, nor to classify all the erosional forms in a correct, scientific way.

The erosional forms, mainly water-washed rocks, water-washed till, lateral drainage channels, overflow channels, glaciofluvial or rock canyons (kursu valleys), and extra-marginal channels were taken from the works of Fromm (1965, pp. 131—139), Rudberg (1949) and Hoppe (1967, p. 206) and were to a certain extent mapped in connection with the field work by means of topographical maps and aerial photographs.

5. THE DISTRIBUTION OF QUATERNARY DEPOSITS IN THE NORTHERN PART OF THE PAJALA DISTRICT

In general, this region is characterized by very extensive sediment and mire areas, mostly situated in the lower parts of the landscape. The till-covered area is small as compared with that prevailing in other parts of Sweden. The mire area is very but not exceptionally large in comparison with other parts of north-eastern Sweden and northern Finland. The Muonio River descends from *c.* 250 m above sea-level (a.s.l.) in the northern part of the mapped area to *c.* 160 m a.s.l. at the southern boundary of the map, a distance of *c.* 75 km. The altitude along the western boundary varies between 300 and 450 m a.s.l. The mountain tops in the area are situated between 300 and 450 m a.s.l. The highest shoreline lies at *c.*170 m a.s.l. (Fromm 1965, p. 102). It is only the valley of the Muonio River in the most southerly part of the mapped area which is situated below the highest shoreline.

The mapping of the Quaternary deposits (see the map enclosed in the pocket

on the cover) carried out in the northern part of the Pajala district is here described, with emphasis on the large features of the distribution of the Quaternary deposits and on certain elements that are important for the understanding of the late-glacial evolution in the region. As was mentioned in section 4.1 (p. 8), there is no basic material for detailed descriptions on a large scale or a classification of deposits richer in details. Some of the observations made in

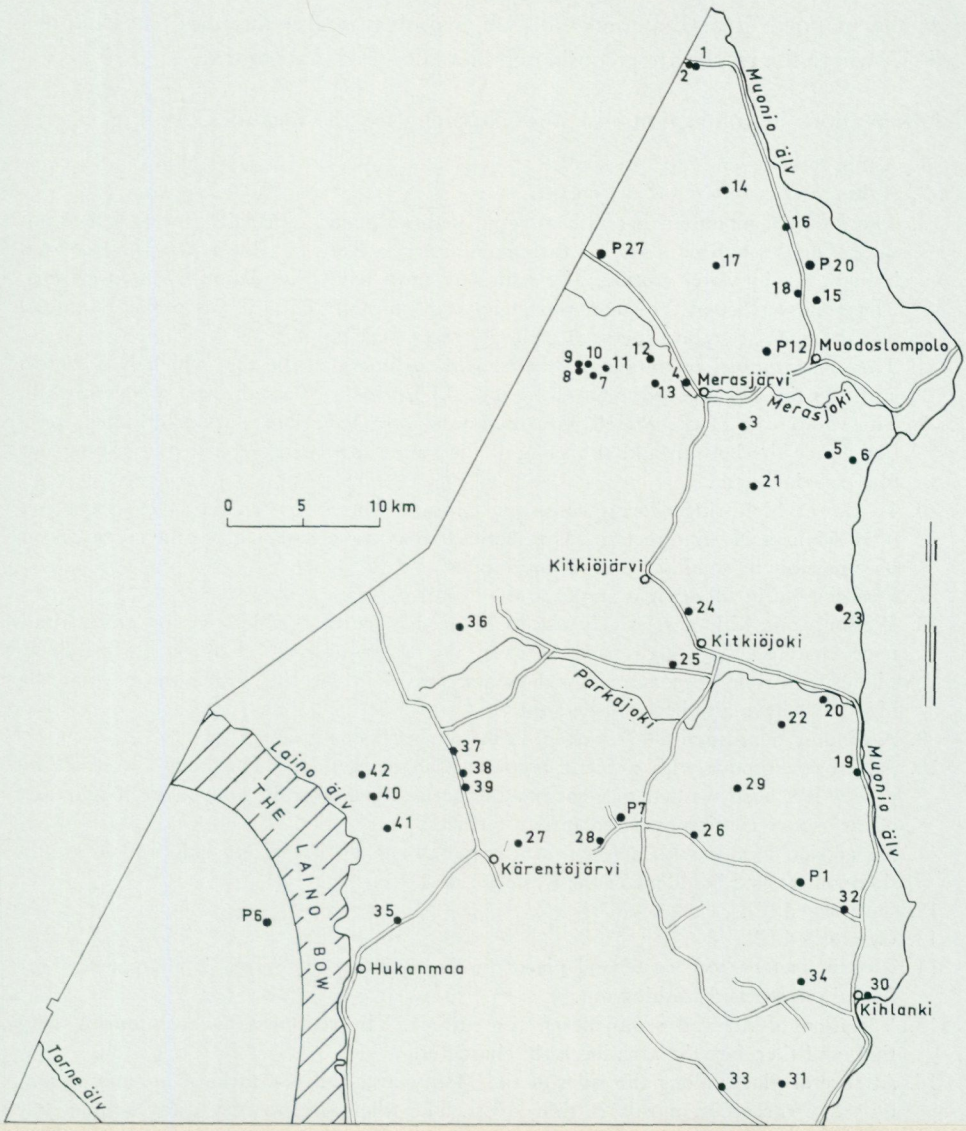


Fig. 3. Some observations made in connection with the soil-mapping. The numbered points refer to notes (see pp. 18—19). The points marked with the letter P refer to soil samples, which have been sifted in laboratories.

connection with the mapping are briefly recorded below and in Fig. 3. The main result of the mapping is that a rough picture of the distribution of Quaternary deposits has been obtained, and this information is accompanied by an increased understanding of the late Quaternary evolution. In addition, the map will be a good foundation for planning work that needs more details. The mapping methods used have functioned well, and therefore similar methods can probably be used in other areas with somewhat similar conditions, for example, north of the mapped area. Experience of soil mapping is also discussed in Chapters 6—7, where the results are reconsidered in a large regional context.

Observations in connection with the mapping (for the localities, see Fig. 3).

1. A thin sand cover (*c.* 0.2 m) on till.
2. A thin sand cover (*c.* 0.2 m) on silt.
3. The Paloluki mountain is totally covered with sediment, especially fine and medium sand. On the northern side of the mountain, relatively far down, the till has been brought out by water erosion. The sediments must have been deposited in an ice lake where the surface of the water was at least 280 m a.s.l. The till was probably eroded into the open at certain spots when the ice lakes were tapped.
4. The Aukeatunturi mountain is covered with sediment to the top, which is *c.* 295 m a.s.l. On the top, the sediment cover is *c.* 0.1 m thick. The sediment is covering till.
5. The valley east of the Metelivaara mountain must have had a water-draining function, since the bottom and the sides of the valley are characterized by washing out to a certain extent.
6. 1—1.5 m high ridge forms consisting of sand and stony gravel. The ridges are oriented in a N—S direction. The material may have had a glaciofluvial origin or may possibly be small ice-margin formations.
7. Washing out in till at right angles to the height curves.
8. Washing out with a relatively abundant occurrence of boulders in the water drainage channels. The high parts between the water-drainage channels are relatively plane, with a large content of stones and gravel in the till, which means that the high parts have also been washed out.
9. A winding depression 6—7 m deep. Probably an erosion groove.
10. An erosion groove with a plane bottom. Rich in boulders. The height west of the groove has been washed out, so that the surface is markedly stony. The height east of the groove consists of two planes of terraces.
11. An erosion groove with a steep, sandy, river bank on its eastern side and here and there outwashed boulders on the western side.
12. Outwashed till.
13. Outwashed till.
14. The till can be seen at several places in the sediment. The area is characterized by fluvial erosion and washing out.
15. Variation of till and sediment on the surface. The sediment cover is mostly very thin, and therefore the area has a till character.
16. At several places along the sides of the Mäntyvinsa and Kahtovaara mountains sandy sediments occur, mostly in thin layers. The till is silty to fine sandy, with a low content of boulders and stones and, because of this, has a sediment-like character. The sediment is considered to have been developed in an ice-lake and may have been wave-washed.

17. A system of sediment ridges consisting of sand on the surface. Dunes and eolian sand occur in the area.
18. Here and there, a very thin sediment cover, and therefore the boundary between sediment and till is difficult to delimit. Compare No. 15.
19. The boundary between fine and coarse sediments is at *c.* 205 m a.s.l. The coarse sediments occur on the lower levels.
20. The boundary between fine and coarse sediments is at *c.* 220 m a.s.l. The coarse sediments are found on the lower levels.
21. The boundary between fine and coarse sediments is at 250—255 m a.s.l. The fine sediments occur on the lower levels.
22. Sand layer *c.* 0.7 m thick under till.
23. Fluvial erosion.
24. Heavy washing out in till.
25. The Patovaara mountain (282.8 m a.s.l.) is covered with sediment. On the western side of the mountain, the sediments are supposed to be of glaciofluvial origin, that is, no ice-lake sediment, contrary to what is to be found in the rest of the area.
26. Heavy washing out and sediment accumulation.
27. Heavy washing out and sediment accumulation.
28. Channels of fluvial erosion.
29. Sediments consisting mainly of sand. The sediments are probably material accumulated in an ice-lake outlet where the speed of the water was moderate. The top of the sediment is situated at *c.* 245 m a.s.l.
30. 1—1.5 m till on sediment.
31. Drainage channel running N40°W—S40°E.
32. The fine-grained sediments are not level-bound in this area. The till occurs on lower levels than the sediments. The boundary between the till and the fine-grained sediments is suspected to be an ice-margin site.
33. Overflow of the Kursu valley.
34. Silty sediments occur in thin layers. The sediments are not level-bound. An ice-margin site is suspected. Compare No. 32.
35. Variation of till and silty sediments. The sediment cover is normally thin.
36. Till of coarse type (sandy). Probably washed out.
37. Washing out and sediment accumulations.
38. Coarse silt sediments cover the till here and there in thin layers. The height is *c.* 315 m a.s.l. Probably a small ice lake?
39. Washing out.
40. Washing out. Dry valley.
41. Variation of coarse silty and fine-sandy sediments, that is, the boundary between coarse and fine-grained sediments is not clearly defined.
42. Fine sandy sediments. The material becomes coarser to the north. The sediments are sandy to gravelly *c.* 2 km north of the marking.

5.1. EXPOSED OUTCROPS

The bedrock has been described by Ödman (1957) and in the south-western part of the mapped area by Witschard (1970). The predominant rock types are migmatized gneisses and granites. The outcrops have not been mapped (see section 4.1), because the mapping method caused difficulties in getting a represen-

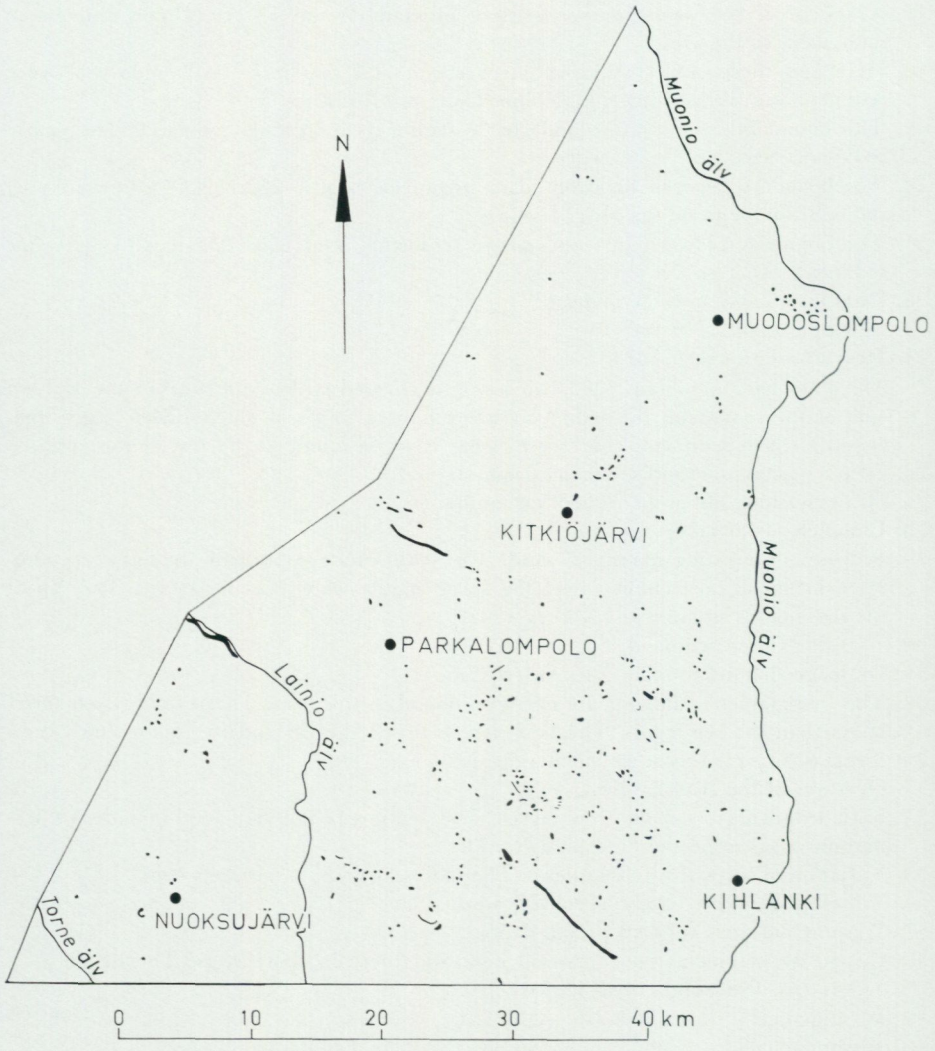


Fig. 4. Outcrops and local boulders (after Ödman 1957).

tative distribution of them. Within the different types of deposits shown in the map, outcrops of variable sizes are therefore to be found. A compilation of outcrops and local boulders will be seen in Fig. 4, which has been copied from the bedrock map (Ödman 1957). Only a rough picture of the outcrops can be given in this way, however. None the less, the figure shows that the area west of the Lainio River and the northern part of the mapped area are poor in outcrops. Experience gained during the mapping also shows that most of the outcrops are to be found in connection with erosional tracks of the late-glacial drainage. It is common to find outcrops also on the tops of mountains. The visual picture in Fig. 4 gives a somewhat wrong impression, as the outcrops and the extension of

the local boulders have been enlarged for technical reasons connected with the reproduction. The general impression is that the whole mapped area is very poor in outcrops.

5.2. TILL

With the mapping methods used, it was not possible to separate different types of till, such as till with large boulders, from till with a medium boulder content, or silty till from sandy till etc. The grain-size composition of the till is known from only a few till samples which have been sifted in the laboratory, and from ocular inspection of the grain size in connection with the work on till fabric (see Tables 1 and 2). The predominant impression of the tills is that they usually appear as sandy or silty to fine-sandy till with a comparatively low boulder content. Here and there within the mapped area, the till has a surface rich in stones and boulders and is mainly supposed to have been developed through the washing out of meltwater from the continental ice. This state of affairs is especially clear west of the "Lainio bow" (see Fig. 3), where the overflowing on a wide front is supposed to have occurred in an extramarginal position, that is, in front of the ice margin. Washing out of till or deep erosion in till occur frequently over the whole region (for example, notes 7—14, 24, 26, 27, 31, 36, and 39, p. 18, and Fig. 3). In the given examples, the washing out or erosion is supposed to have occurred very close to the ice margin, subglacially or extra-marginally.

The till fabric is often characterized by the occurrence of sandy and/or silty sediment veins, which show that the till was deposited under the influence of water (J. Lundqvist 1969, p. 57). Till of the "*Kalix pinnmo*" type (cf., among others, Fromm 1965, pp. 103—107) has not been observed within the mapped area. However, till-covered sediments have been seen at some localities (section 6.2.4 and Fig. 18, localities Nos. 156—157, 200 and 203, and Table 14). The stratigraphy of the till seems to be more "disturbed" in the southern parts of the investigated area and in the area south of the map than in the northern parts. "Disturbed" means that there are more frequent signs of two till beds and till-covered sediments. The till fabric, the rock contents and the stratigraphy of the till are further treated, together with the till-fabric analyses and the particle counts (in sections 6.2.2.—6.2.4). A frequent feature in the till is the fissilities (Fromm 1965, p. 102, J. Lundqvist 1969, p. 56), which appear as schistose structures parallel to the ground surfaces in the till material. The grain-size composition does not seem to have been locally changed by fissilities. In this form, fissilities are considered to be a function of the pressure and movement of active ice. It is astonishing in this context that fissilities should also appear in relatively loose, consolidated till, and therefore other origins for these structures should be looked for. A question which naturally arises is whether the frost can influence the structure of the till and cause similar phenomena to "fissilities".

TABLE 1. Till samples sifted in the laboratory. The grain-size content is given as a percentage (see Fig. 3).

Sample	*Gravel*		*Sand*			*Silt*			*Clay*	*Term*
No.	*Coarse*	*Fine*	*Coarse*	*Me-dium*	*Fine*	*Coarse*	*Me-dium*	*Fine*		
P 6	5	5	7	20	29	21	7	3	3	Sandy
P 7	3	5	12	18	24	26	8	1	3	Silty to fine sandy
P 20	6	7	17	27	22	15	4	1	2	Sandy
P 27	10	9	14	23	24	—	—	21	—	Sandy

The moraine morphology in the region can be divided into three categories: 1, irregular surface forms, 2, elongated forms or a tendency to elongated forms and, 3, hummocky moraine (Hoppe 1957, pp. 7—14, J. Lundqvist 1969, p. 65).

1. The most common morphology in the region is large irregular hills or mountains. They probably reflect most of the bedrock morphology. The irregularity is in obvious contrast with the conditions south-west of the mapped area. In the latter area, a clear orientation towards, approximately, NW—SE has been found, mostly among the large forms but also among the small forms, which, however, often also have the orientation S—SW to N—NE (section 6.2.1). The fact that the appearance of the surface forms has been markedly changed in this area may indicate different conditions for the ice movement and transportation of material as compared with those to the south and west of the area.

2. Moraine formations that are elongated or have a tendency to be elongated occur in small numbers in the southern part of the mapped area. The directions are NNW—NW to SSE—SE (see Fig. 14, p. 37). It seems doubtful whether all should be characterized as drumlinoids, that is, forms that have been developed by a continental ice in its direction of movement (Hoppe 1951, 1957, 1959). These surface forms may also reflect the general system of joints in the bedrock. The elongated formations probably appeared as a combination of the tectonics of the bedrock and the movements of the continental ice (cf. Rudberg 1954).

The two elongated (NE—SE) surface forms, *c.* 13 km north-west of Muodoslompolo (the Muosselkä and Kuusivaara-Laakopolo mountains), are most probably due to the morphology of the bedrock. On the topographical map, one can see that the south-western parts of the mountains have a smaller inclination than the north-eastern ones. A field examination of parts of the Muosselkä mountain showed that the north-eastern part of the ridge was to a large extent exposed bedrock, that this was roughly broken and that the north-eastern slope consisted to a large extent of talus. On the assumption that the ice movements were SW—NE, this is interpreted as meaning that the south-western side of the mountains is characterized by thrust-side erosion and the north-eastern side by lee-side erosion effected by the inland ice. The original form may possibly have been influenced during earlier glaciation periods.

3. An area west of and close to the Lainio River, the so-called Lainio bow

TABLE 2. Ocular estimation of the grain-size distribution of till in the field (see Fig. 16).

Locality No.	*Classification of till*	*Remarks*
99, 100	Sandy	Very firmly consolidated
147, 148	Sandy	Brownish-grey, sharp change in colours
154, 155	Silty to fine sandy	
156, 157	Sandy	Sand lenses, fissilities
160, 161	Silty to fine sandy	Greyish-brown, brown
164, 165	Sandy	Relatively loose
166, 167	Silty to fine sandy	
181, 182	Sandy	Fissilities
183, 184	Sandy	Brownish- to greenish-grey
185, 186	Silty to fine sandy	Fissilities
190, 191	Sandy	Covered with silt, sand
192	Sandy	Fissilities
194, 195	Silty to fine sandy	Fissilities
200	Silty to fine sandy	Fissilities, cover sediment
201	Sandy	
203	Sandy	Covered with *c.* 0.15 m of silt
204, 205	Sandy	With low boulder content, relatively loose
210, 211	Sandy	With low boulder content
212, 213	Sandy	
216	Silty to fine sandy	
218	Silty to fine sandy	
230	Sandy	
231	Sandy	Veins of sand
232	Sandy	Veins of sand

(Fredholm 1886, p. 32, Tanner 1915, Geijer 1917, pp. 34—36, 1948, pp. 578—582, G. Lundqvist 1943, pp. 44—48, Hoppe 1952, pp. 18—19, 1957, pp. 7—14, and Fromm 1965 pp. 108—109), is characterized as a hummocky moraine. The surface forms consist of irregular ridges, half-moon-shaped ridges, and elongated ridges with no common direction and depressions, often without an outlet. Several of these are probably dead-ice pits. The remarkable amount of rugged terrain in the Lainio bow is best seen on the topographical map and on aerial photographs (see Fig. 5). The necessary generalizations of the present map unfortunately give a somewhat wrong impression of the characteristic ruggedness. This area was difficult to map with the overview mapping method used. The whole area was classified as consisting of till on the surface, which is mainly true. However, when considered in detail, the area is more complicated regarding the distribution of loose deposits, and full justice can only be done to it by detailed mapping. The area is best described by Fromm (1965), on his special map of Kangos and in the text referring to this (pp. 108—109):

> The ground surface consists of till with a varying content of boulders, sometimes till extremely poor in boulders, and spots and areas with glacio-fluvial material, without any special morphological signs. In sections, glacio-fluvial material has been noticed below a surface layer of till. In spots, particularly in depressions on the plateaus within the edge ridges, there are often sediment layers on the surface, mostly silt.

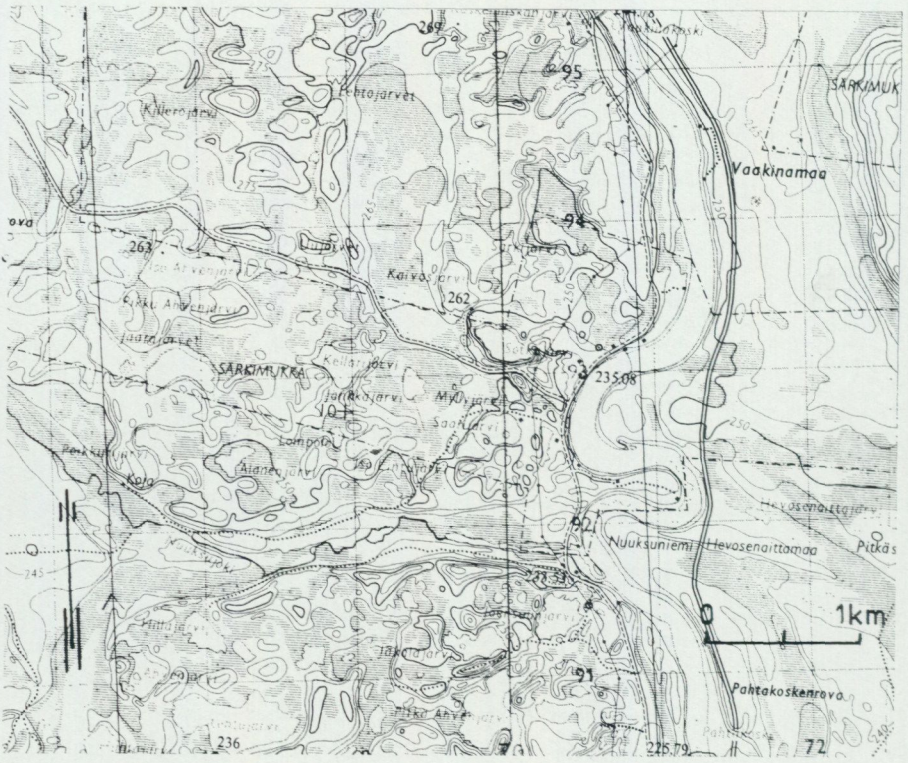


Fig. 5. A part of the topographical map 29L Lainio SE, about 5 km north of Kangosfors, showing a section of the morphologically irregular "Lainio bow".

Of more special interest in this work is not the distribution of the loose deposits within the Lainio bow, but what were the preconditions for the development of the hummocky moraine and why this moraine has such a marked boundary. The Lainio bow is a marked height ridge (see Fromm 1965, Fig. 5, pp. 16 and 108). Within the height ridge of the Lainio bow, exposed outcrops have not been found, and therefore the thickness of the till is expected to be considerable (Fromm 1965, p. 16). The Lainio bow seems in some periods to have had a damming effect on the glacier water flowing from the west. The glacial water, which flowed in the frequently occurring, probably extra-marginally developed drainage channels, found its way to two or three breakthrough points. Two of these points can clearly be seen on the topographical map, one *c.* 3 km south of Kangos and one *c.* 10 km east of Nuuksujärvi by the Lainio River (Fig. 5). The Tärendö River is probably another drainage channel from this area. Since the drainage took place only through two or three passages through the Lainio bow, this confirms the opinion that the drainage channels developed extra-marginally. Subglacial drainage or drainage in immediate connection with the ice margin, when it was in close contact with the height area of the Lainio bow,

would probably have produced more erosion furrows in the hummocky moraines. The specific moraine morphology shows that it is very probable that the forms developed through a stagnating ice (Hoppe 1952, pp. 9—19, 1957, pp. 7—14). Whether the sharply delimited Lainio bow marks a marginal position of the continental ice is discussed later in the light of all the results (see section 7.2).

5.3. GLACIOFLUVIAL AND OTHER SEDIMENTS

The sediments have been divided into two grain-size groups, coarse-grained sediment (fine sand and coarser) and fine-grained sediment (silt and clay).

The main parts of both the fine and the coarse sediments can genetically be classified as ice-lake sediments. The part of the sediments that consists of glaciofluvial deposits in the form of eskers is marked on the map accompanying this paper. Some deposits of glaciofluvial origin, kame deltas (J. Lundqvist 1969, p. 75), have also been marked in Fig. 25. Otherwise, it is difficult to draw a borderline in the coarse-grained sediments between what should be considered glaciofluvial deposits and what should be regarded as coarse-grain, ice-lake sediments. The difficulties in separating glaciofluvial sediments from postglacial sediments in the river valleys are clear. In the present investigation, this was not done, since such a delimitation would have applied to only a small area and would not have improved the investigation.

The eskers in the southern part of the accompanying map run from W—NW to E—SE and on the remaining parts of the map from SW to NE. In the area south of the mapped area, the eskers have, without exception, an orientation NW—SE. The eskers orientated SW—NE can be classified as subglacial formations, and most of them must have been formed sub-aquatically (J. Lundqvist 1969, p.74), due to the water levels of the ice lakes (see section 6.3.3). The eskers south-west of Parkajoki are, however, probably supraaquatic (J. Lundqvist 1969, p. 70). The eskers oriented in W—NW to E—SE in the southern part of the mapped area were developed mainly as marginal eskers (J. Lundqvist 1969, p. 75) judging from the late-glacial drainage pattern (see section 6.3). It may be noted that the water divide for the melt-water from the continental ice runs through the mapped area. The approximate site of this water divide may probably be located from Kihlanki WNW and further out.

Glaciofluvial deposits of special interest are Särkitievat and Mukkaharjut and their "feeding eskers". Both these deposits are characterized by having an extraordinarily hilly terrain. The surface material consists mostly of sand. The big, relative differences in height within the area are due to the frequent occurrence of kettle holes (see Fig. 6). The formations probably arose through the glacial river, which deposited the "feeding eskers", flowing out to the ice-margin or to a broken part of the ice-margin area and depositing sediments in which broken

pieces of ice were embedded. The deposit can be likened to a delta formation and be called a kame delta (J. Lundqvist 1969, p. 75). The plentiful kettle holes imply that the ice was comparatively unstable, so that ice boulders and small icebergs could to a large extent be broken loose. The ice boulders and the icebergs were stranded in the glaciofluvial deposits and were covered with new sediments. When the icebergs and ice boulders melted, this hilly surface arose. Further formations with a similar character to the above-mentioned can be found within the map area (see Fig. 25). It seems as if the line from *c.* 5 km south-west of Kitkiöjärvi-Mukkaharjut-Muodoslompolo to north-east of Naankijärvi and to the Finnish border constitutes one long continuous stretch of glacial rivers. A secondary esker to this stretch is the eastern "feeding esker" of Mukkaharjut, which can be traced towards SSE to *c.* 3 km south-west of Kitkiöjoki. These eskers and formations are situated within the areas with level-bound ice-lake sediments (see subsection 6.3.3).

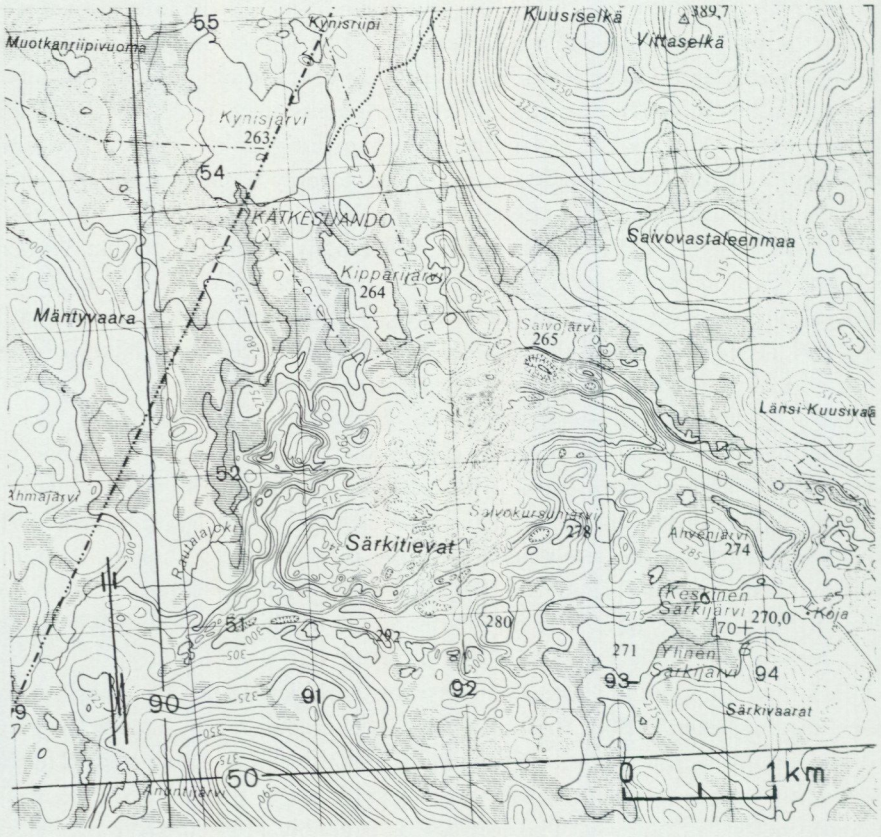


Fig. 6. A section from the topographical map 30M Muonionalusta SW, showing the kame delta of Särkitievat. Note the irregular morphology and the height of Särkitievat in comparison with the surroundings.

The glaciofluvial deposits occurring within the ice-lake areas show that the eskers were deposited before the ice-lake sediments were formed.

The level-bound sediments have in large areas a morphological surface, which probably reflects the moraine and/or bedrock morphology. Without digging sample pits, it may be difficult to decide whether an area consists of fine-grained sediment or till poor in boulders, since the typical till morphology and till vegetation mostly exist in areas of fine-grained sediment.

The thickness of the coarse-grained sediments seems to vary considerably between the central parts of the sediment areas and the marginal areas towards the till. At Östra Merasjärvi, the Merasjoki has eroded its way down into the coarse-grained sediment, where the thickness is estimated to 25—30 m. At several spots in the till-margin area, the thickness of the sediments is generally less than a metre.

The fine-grained sediments seem in general to be relatively thin, from less than a metre to an approximate maximum of 2—3 m. They are also in general considered to be mostly silty. Two samples have been analysed regarding the grain-size content (Table 3), one (P 12) taken *c.* 4 km north-west of Muodoslompolo in a silty layer in coarse sediment and the other (P 1) *c.* 4 km west of Kaarnevaara in a vast area of fine-grained sediment. Here and there, the fine-grained sediments give an indication of varved layers, but this has not been studied in any detail.

It seems probable that the vast area of sediments was deposited mostly in ice lakes, because of the level-boundedness shown by the sediments. Both coarse- and fine-grained sediments occur, and there are rare indications of shorelines. The morphology of the sediments reflects the surface of the bedrock and the moraine (cf. Hoppe 1957, pp. 14—17, Holdar 1957, pp. 345—355, J. Lundqvist 1959, p. 10, 1969, p. 156, 1972, Kujansuu 1967b, pp. 79—82).

TABLE 3. Fine-grained sediment samples sifted in the laboratory. The grain-size content is given as a percentage. For localities, see Fig. 3.

Sample No.	*Gravel*		*Sand*			*Silt*			*Clay*	*Term*
	Coarse	*Fine*	*Coarse*	*Medium*	*Fine*	*Coarse*	*Medium*	*Fine*		
P 1	—	—	—	—	12	42	37	5	4	Silt
P 12	—	—	—	2	9	30	42	11	6	Silt

5.4. ORGANIC DEPOSITS

The distribution and delimitation of the organic deposits are generalized according to the mires, as they occur on the topographical maps. They form a very good basis for such generalizations of what could have been evaluated from the field work. The types of peat have not been classified. According to Fromm (1965, pp. 172—186), most of the peat which occurs should be classified as mire complexes characterized by fen areas (mostly "poor fen") and restricted bog ve-

getation. For a more detailed description of the peat types, the above-mentioned work may be referred to. As can be seen on the map accompanying this paper, the organic deposits are spread over vast areas. In several cases the mires have elongated forms, which might indicate that they have grown up in the bottoms of valleys to be interpreted as tracks of late-glacial drainage, usually after extra-marginal drainage.

6. QUATERNARY GEOLOGY OF THE PAJALA DISTRICT

In this chapter, the results of the investigations of the whole Pajala district will be treated. Experience gained from the mapping of the loose deposits (Chapter 5) will be involved in the further treatment, and this will cause some repetitions. The further treatment is in several respects based on Fromm's (1965) investigations, especially his map of Quaternary deposits.

Geological occurrences will be pointed out, which, under the existing circumstances, should lead to an increased understanding of the regional aspects of the glacial development.

6.1. GLACIAL STRIAE

The results of the investigations of striae in the Pajala district can be seen in Fig. 7 and Appendix I. In order to systematize the observations, the striae directions are divided into rough intervals. The division is made, first of all, on the basis of the relative ages of the striae (Table 4) but also on the moraine morphology; see section 6.2.1 as well as Fromm's (1965), Hoppe's (1967) and Kujansuu's (1967) results and observations. The direction intervals are N—NW (= N—N 70°W), S—SW (= S—S 70°W) and W (= S 70°W—N 70°W). The given striae directions refer to the direction *from* which the continental ice moved. In 51 localities, two or more different striae directions can be traced. Of these, 31 localities with relative relationships in age between the striae have been determined (Table 4).

TABLE 4. Division of the relative ages of the striae.

Older direction	*Younger direction*	*Number of observations*	*Locality No.*
N—NW	S—SW	19 (53%)	T2, T4, T5, T10, T13, T17, T19, T20, T34, T35, T38, T44, T45, K2, K4, K7, K10, K11, and K44
N—NW	W	4 (11%)	T3, T6, T8, and T11
S—SW	W	5 (14%)	T2, T5, T41, K2, and K7
W	S—SW	3 (8%)	K31, K32, and K36
S	SW	4 (11%)	T2, T21, T22, and T51
N	NW	1 (3%)	T62

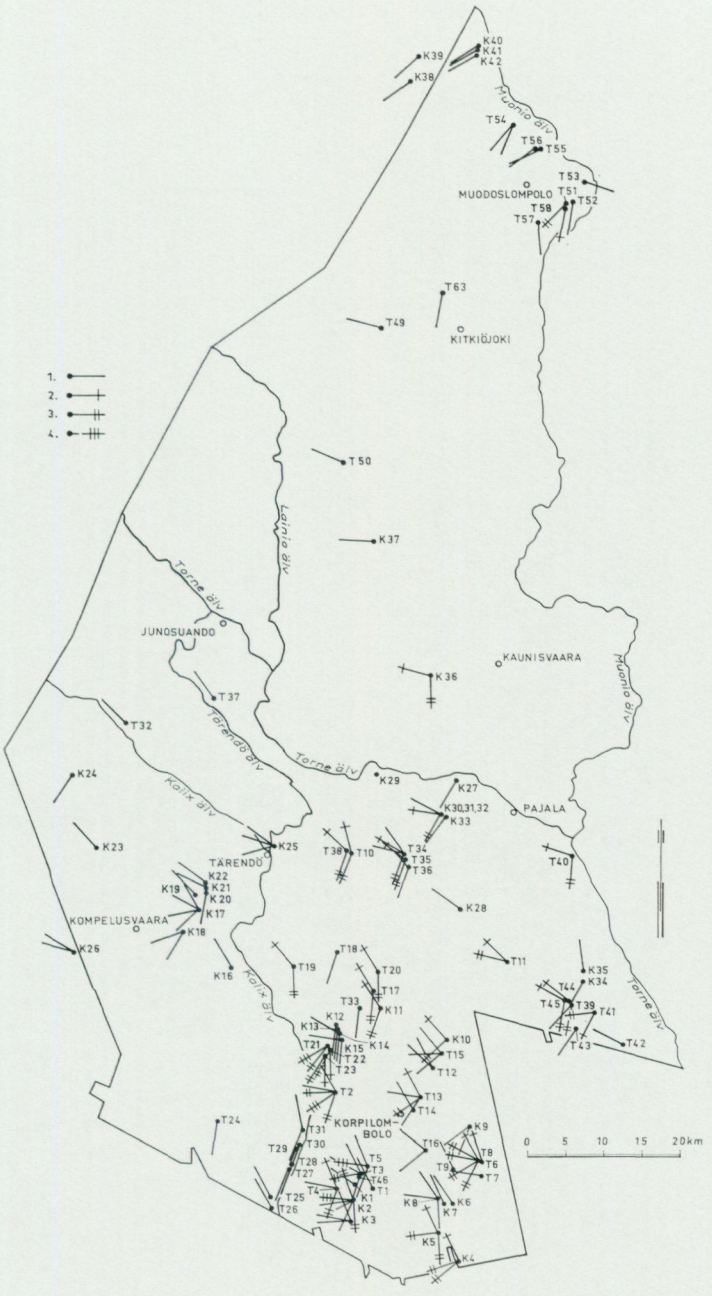


Fig. 7. A survey of localities with glacial striae and the directions and relative ages of the glacial striae. 1. No relative ages. 2. Older striae. 3. Younger striae. 4. Youngest striae.

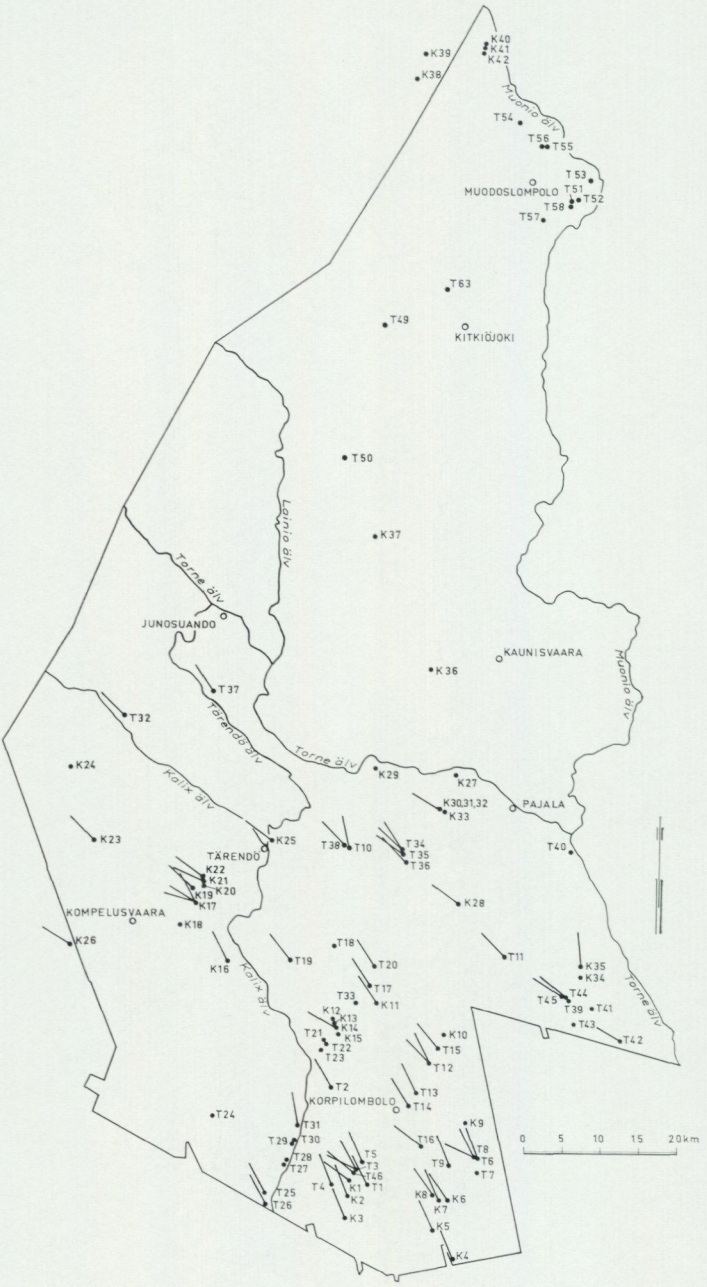


Fig. 8. Glacial striae from N—NW.

The older age of the N—NW direction as compared with the W and S—SW directions can be proved at several localities. Thus, for instance, T2 can be used as a key locality for making this judgement (see Appendix I). S—SW directions older in relation to W directions have been established at localities K2, T2, T5, and T41, and hints of this age division can also be found at localities K7 and T8. There are only three localities, K31, K32 (Fig. 12) and K36, where the W striae are older than the S—SW striae. The same age relations can, with some uncertainty, be interpreted at localities T3 and T11. The age division between S and SW striae shows that the straighter, southerly striae are older than the south-westerly.

Table 5 shows the division of the measured directions of the striae. The S—SW striae are predominant as compared with the N—NW and W ones. This is an astonishing result when compared with Fromm's work (1965, p. 120). The explanation is certainly the numerous fresh outcrops that have appeared mainly along the new and rather frequent forest roads.

TABLE 5. Division of measured striae directions from 117 localities.

Direction	*No.*	*%*
N—NW	66	37
S—SW	74	42
W	37	21

Figs. 8—10 show the regional division of the occurrences of the different striae directions. N—NW directions are represented only south of the Torne River. The S—SW direction is found mainly south of the Torne River and in the northernmost parts around Muodoslompolo. The westerly directions occur mainly in the south-eastern part of the area, and to some extent between Kaunisvaara and Kitkiöjoki. The striae locations are sparse north of the Torne River, mainly owing to the rare occurrence of new, fresh outcrops and the fact that the naturally exposed outcrops are often too weathered to be fit for striae observations. The accidental, regional division of striae localities makes it very difficult to correlate different striae directions in time (cf. J. Lundqvist 1969, p. 147).

Without making a comparison with the results of other investigations, the following trends of the ice movements can be seen in the Pajala district, which can be divided into 1, the area north of Kitkiöjoki, 2, the area between Kitkiöjoki and the Torne River, 3, the area south of the Torne River.

Area 1: Within this area, the striae directions vary between *c.* S10°W and S65°W. In two locations, they diverge from this interval. At T57 there is a clear stria oriented S4—8°E and at T53 an uncertain observation oriented S70—80°E (N70—80°W). These diverging striae directions may possibly be a function of the influence of the topography during the melting period or may reflect an ice movement at right angles to the ice edge in the melting period. These observations will not be used separately for the interpretation of ice movements.

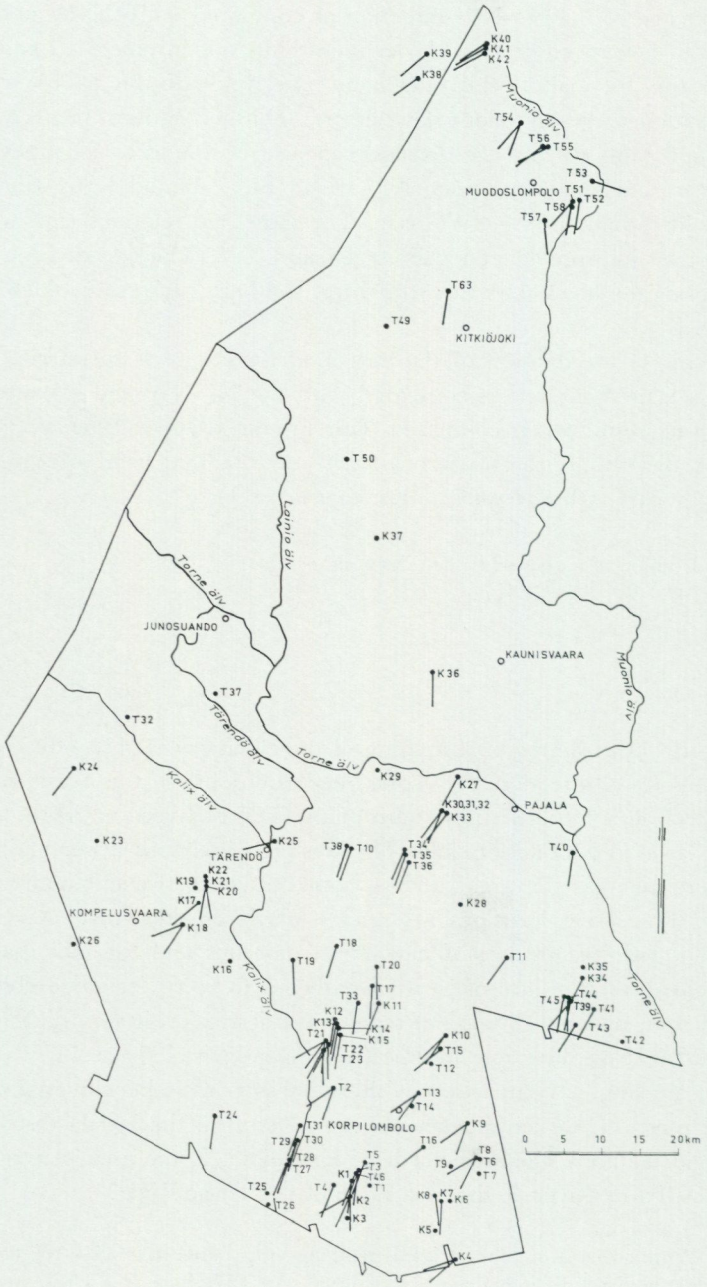


Fig. 9. Glacial striae from S—SW.

At only one locality (T51) the age relationship has been decided. It shows that striae from S10°W are older than striae from S45—50°W, that is, turning clockwise.

From the relative homogeneity of the striae directions in this area, it may be concluded that during the latest glaciation phase the ice movement was from the south or south-west. There is a faint indication that the straighter, southerly directions are older than the south-westerly, but otherwise there is no evidence of different phases during the glaciation.

Area 2: In the area between the Torne River and Kitkiöjoki, there are only four striae localities (K36, K37, T49, T50). T49 and T50 yield unclear, diffuse striations oriented N70—74°W. K37 is also a relatively poor striae location, where the direction of one stria is N86°W. K36 shows an older striation oriented N70—76°W and a younger one oriented S—N. North of this area, there are only S—SW striae and south of this area striae from S—SW, N—NW, and W. It is strange that there are no more directions and striae localities within this area. This may indicate diverging conditions for the ice activity as compared with the northern and southern areas.

In the area now studied, no conclusions based only on the striae picture can be drawn concerning the different phases of the glaciation. One suggestion, which cannot be confirmed by the striae material, however, is that the westerly directions may be correlated to the north-westerly in area 3, which may be implied by the striae in the above-mentioned locality K36.

Area 3: From what has been shown by the age relationships of the striae, the ice movements can be divided into at least three stages, A—C:

A. The oldest direction from the north or north-west. It is possible that the older, more westerly oriented striae directions may belong to this phase, or possibly they may constitute a stage between the N—NW and the S—SW directions.

B. A younger stage as compared with A, with S—SW ice-movement directions. The more southerly oriented directions within this interval are older than the south-westerly directions, which may belong to a later stage. This can possibly be correlated to or regarded as belonging to the same phase as stage C.

C. The youngest stage, with a westerly orientated ice-movement direction. This stage may be regarded as a deglaciation stage of an ice with little eroding ability. This statement is based solely on the fact that these striae occur mostly as thin scratches on the upper parts of the outcrops (Fig. 13).

One of the most important results of the striae investigation is that the S—SW ice-movement direction which Fromm (1965, p. 121, five striae observations and one locality with till fabrics) pointed out and which Hoppe (1967, pp. 206—207) further confirmed by studies of drumlins, must now be regarded as having a larger regional extension than was earlier thought. The S—SW ice movement was so strong that at several places it sculptured the outcrops (Fig. 11), and the extension is now known *c.* 10 km south of the border of the investigation area and also occurs west of the Kalix River (Fig. 9; cf. Hoppe 1967, p. 208). Judging from the character of the striae observations, it does not seem probable that the S—SW direction represents the local change of the ice movement in the finishing stage of the glaciation (cf. Fromm 1965, p. 127, Hoppe 1967, pp. 207—208, and Ljungner 1949, pp. 70—74).

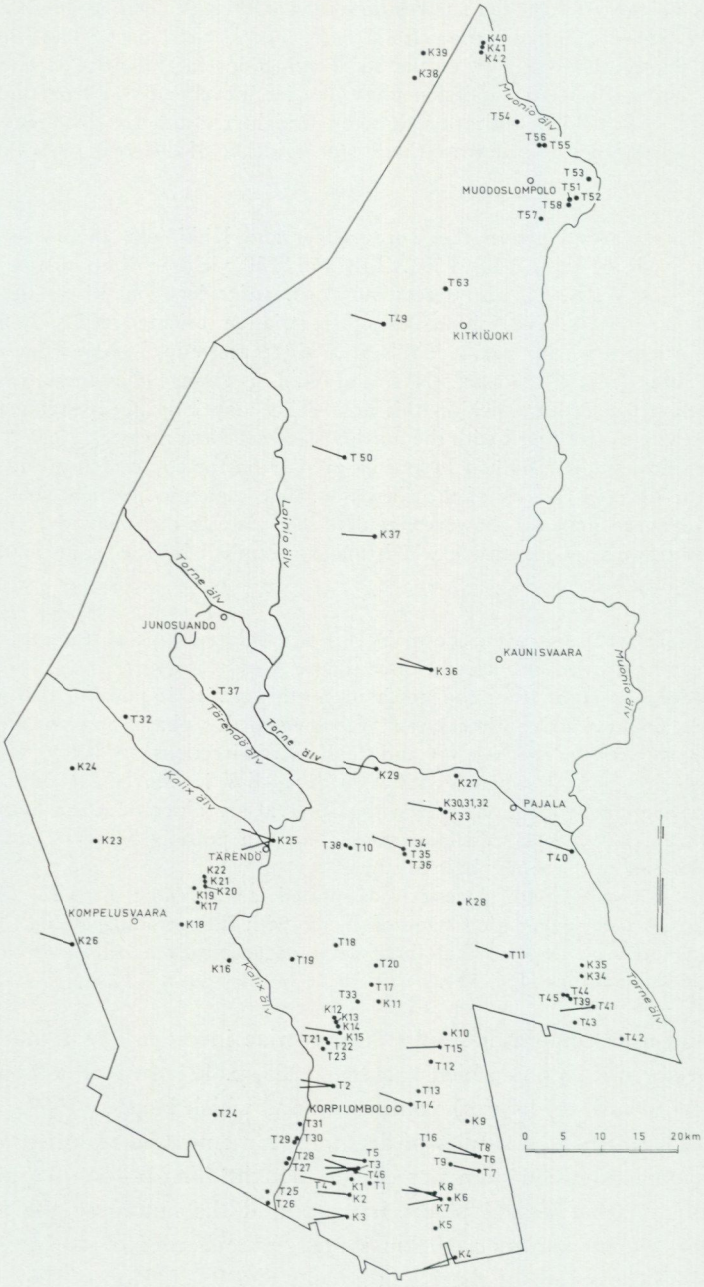


Fig. 10. Glacial striae from W.

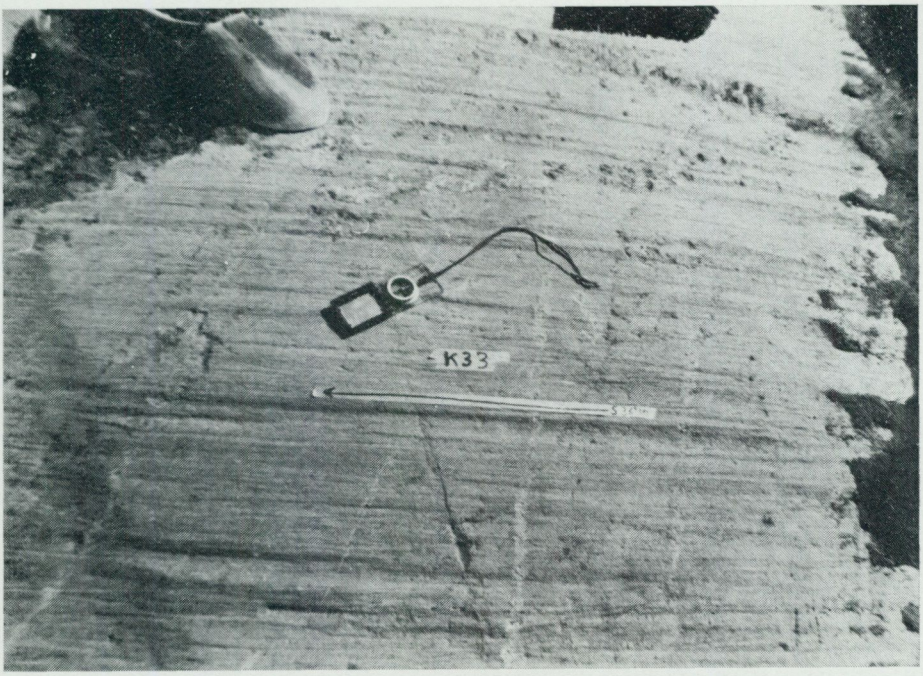


Fig. 11. Striae locality K 33 (see Appendix I and Fig. 7). An outcrop striated and sculptured from the south-west. Photograph: K. Moreborg.

In order to be able to discuss as a whole the different stages of the glaciation implied by the striae directions demonstrated, the interglacial and interstadial stages should also be taken into account and not only the conditions during the final stage of the glaciation. One cannot discuss the positions of one or more ice divides without observing the glacial developments at large. One can, however, state that the northern boundary for the N—NW directions lies *c.* 10 km north of the Torne River, judging from Swedish investigations (G. Lundqvist 1961, p. 39, Fromm 1965, p. 120). However, Kujansuu (1967b, p. 28) and Hirvas *et al.* (1976b, pp. 258—261) have shown that the ice-movement directions from the north or north-west have been found very far north in the adjoining areas of Finland. They also stated that different movements originated mainly from glaciation stages separated by interstadial or interglacial periods, and in that way every glaciation period has its own ice divides. These questions are further discussed in section 7.1.

6.2. TILL

6.2.1. MORAINE MORPHOLOGY

As can be seen in Fig. 14, the NW—SE-oriented surface forms dominate the topography of the area. The S—SW to N—NE ridge forms are, however, marked



Fig. 12. Striae locality K 32 (see Appendix I and Fig. 7). Yonger striae from S 32° W and older from N 80°W. Photograph: K. Moreborg.

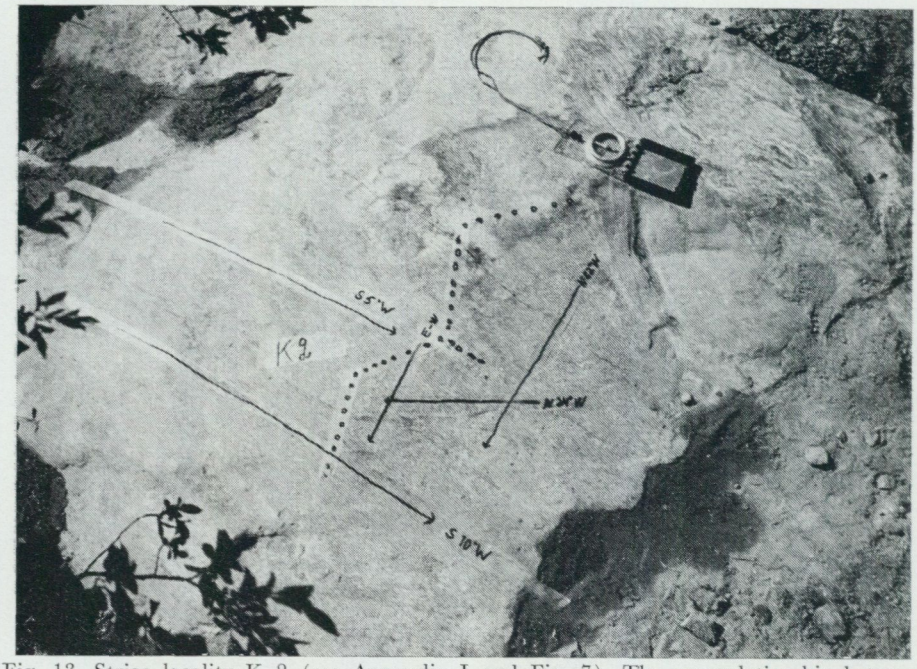


Fig. 13. Striae locality K 2 (see Appendix I and Fig. 7). The age relationship between the different striae is as follows: Oldest striae from N—NW, younger from S—SW and youngest from *c.* W.

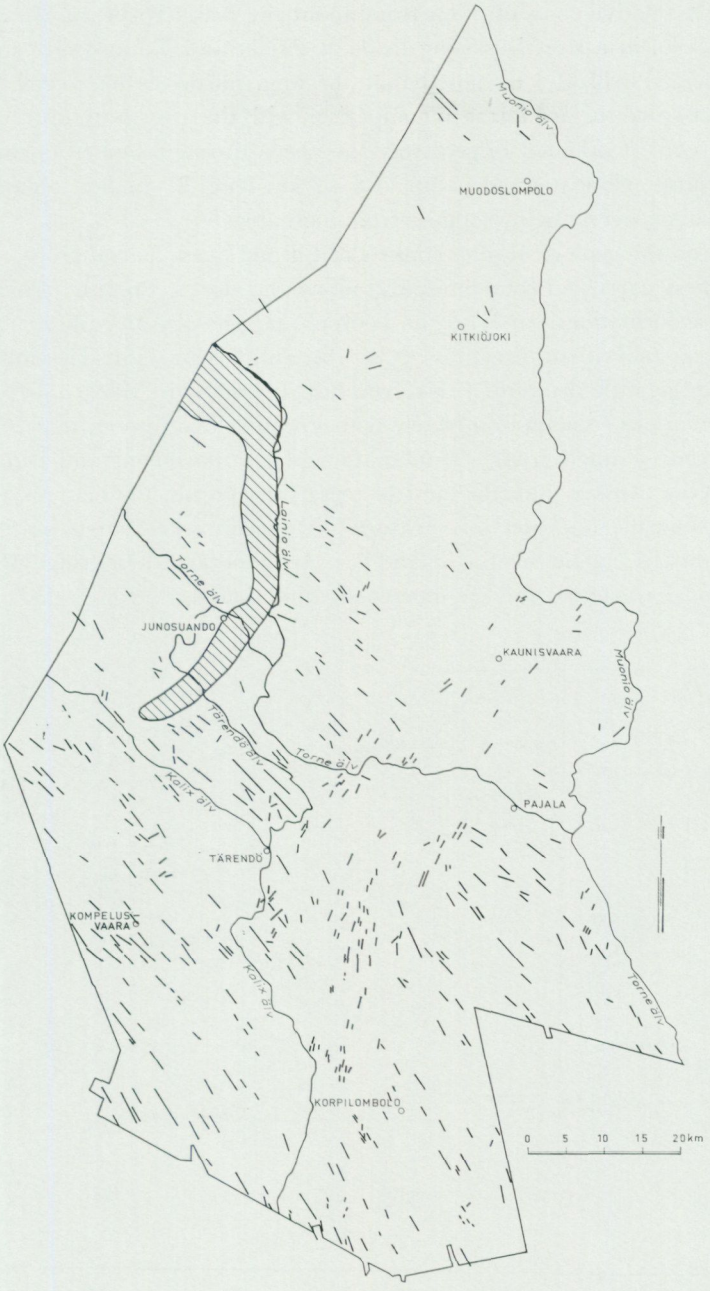


Fig. 14. Orientated surface forms. Most of them refer to moraine ridges, normally rock drumlins or drumlins. The marked area on the Lainio River indicates the hummocky moraine of the Lainio bow.

and show a relative concentration from about the Kalix River, at the latitude of Korpilombolo, in a stretch passing through Pajala and Kaunisvaara to the Finnish border. It will also be noted that the area north of the Torne River has very few oriented surface forms in comparison with the area south of it.

Three types of oriented ridge forms have been distinguished from the working maps: 1, large, elongated ridges up to 6—7 km long, 2, smaller, separate ridges and, 3, smaller, overhanging tongues from high areas.

Type 1 on the geological map consists of till and often has outcrops of bedrock in its highest parts and sometimes also along the slopes. Fromm (1965, p. 107) refers these formations partly to the bedrock morphology and partly to the predominant ice-movement directions: NW—SE and NNW—SSE. He calls (p. 107) these forms gigantic drumlins (rock drumlins, J. Lundqvist 1969, p. 61). My own field observations coincide completely with Fromm's description, that is, the large surface forms resulted from a combination of ice movement and bedrock morphology. One can say that, for most of these ridge forms, the bedrock morphology or possibly the main tectonic features have been accentuated by the erosion and depositions caused by the inland ice. In general, these ridge forms may be said to characterize the ice-movement direction during a period when the

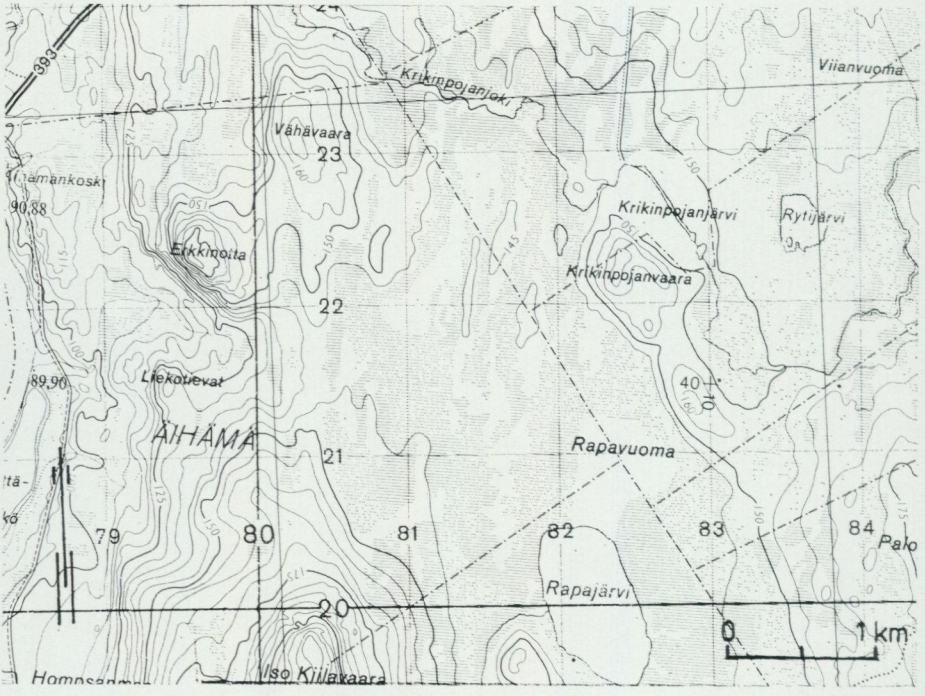


Fig. 15. A section from the topographical map 27M Korpilombolo NW, showing examples of drumlins formed during an ice movement from S—SW (cf. Hoppe 1967, pp. 205—206).

thickness of the ice was so great that the heights in the comparatively shallow area could not influence the ice-movement direction to any extent. It is also very probable that the NW—SE orientation of the ridge forms describes a main stage of the glaciation, an opinion which coincides with the ideas of Fromm (1965, pp. 122—130) and Kujansuu (1967b, pp. 26—36).

Types 2 and 3 are mainly to be found in the area where Hoppe (1967, p. 206) has shown drumlins with S—SW to N—NE directions. Most of the separate ridges as well as the ridges stretching out from larger and smaller heights were probably formed under similar conditions, that is, a drumlinoid-forming pattern indicating an ice movement from S—SW. One of the ridges situated *c.* 10 km north-west of Korpilombolo (see Fig. 15) can be described as an elongated, flat, moraine ridge with a low boulder content and sandy or silty to fine sandy till. The ridges are generally 0—1 km long and 2—5 m high. It may be presumed that these drumlins were formed during a later period of time than the north-westerly rock drumlins, judging from the juts and tongues of the large north-westerly formations and also by comparisons with the age relations of the striae. Considering the spread of these formations, from the Kalix River west of Korpilombolo to Kaunisvaara (Fig. 14), it seems that this glaciation phase was too extensive to be only a link-off in the ice movement during the deglaciation phase, as Hoppe (1967, p. 207) supposed.

The hummocky moraine of the Lainio bow has already been described in section 5.2 (p. 23). A comprehensive literature about the genesis of different kinds of hummocky moraines was reviewed in J. Lundqvist's (1969, pp. 61—66) work. The physiological factors which influenced the origin of the different kinds of ridges in the hummocky moraine have not been studied in this investigation. The discussion about the suggestion that the Lainio bow is a marginal formation (Geijer 1948, pp. 578—582) will be further treated in section 7.2 in the light of the discussion about the deglaciation of the area.

6.2.2. TILL FABRIC

171 till-fabric analyses have been made. Double analyses, that is, analyses on two levels in the same section, have been made at 74 localities (Appendix II and III and Fig. 16). At the remaining localities, only one analysis has been carried out. As was earlier mentioned in section 4.4, the till fabrics should be interpreted in comparison with other elements of direction. In this case, it seems to be most convenient to use the striae material as a starting-point for the description and the interpretation of the till fabric.

Most of the 171 analyses have given a reasonable indication of direction (see Table 6).

TABLE 6. A subjective evaluation of the direction indications of the till fabrics and the average direction factor of each class (see section 4.4).

Direction information	*No. %*	*Average direction factor*
Good	47	1.4
Fairly good	22	1.1
Fairly bad	14	1.0
Bad	5	0.9
Unjudgeable	13	—

For the further estimation of the direction indications, only the three best classes are used, which correspond to 83 % of the analyses performed. The "bad" is excluded, though there is a vague hint of a direction maximum, because of the uncertainty of the method as a whole.

On te same indications as for the striae observations (p. 28), the direction indications for till fabrics are divided into the intervals N—N70°W to S—S70°E, S—S70°W to N—N70°E and S70°W—N70°W to N70°E—S70°E. Moreover, preliminary directions in the intervals S10°W—S10°E to N10°E—N10°W as well as S70°W—N70°E and N70°W—S70°E could be distinguished, since there are difficulties in judging whether the ice movement had been from N—S or S—N and whether S70°W and N70°W should be classified as westerly or south-westerly or north-westerly intervals (Table 7). As for the striae directions, all directions from the east are excluded, and therefore the interval can be noted as N—NW, S—SW, and W. The given directions indicate *from where the ice has moved.*

TABLE 7. The directions of ice movements estimated from till fabrics.

No.	*Measured directions from*
26 (18%)	N—NW
62 (44%)	S—SW
12 (9%)	W
25 (18%)	N 10°W—N 10°E and S 10°W—S 10°E
4 (3%)	N 70°W
12 (9%)	S 70°W

If the N—S and S—N directions and the border-line cases S70°W and N70°W are estimated with the aid of existing striae orientations, and the direction of the main interval tendency in accordance with the upper or the lower analyses is determined, a direction division like that in Table 8 may be made.

TABLE 8. The ice-movement directions estimated from the till fabrics.

No.	*Measured directions from*
31 (22%)	N—NW
92 (65%)	S—SW
18 (13%)	W

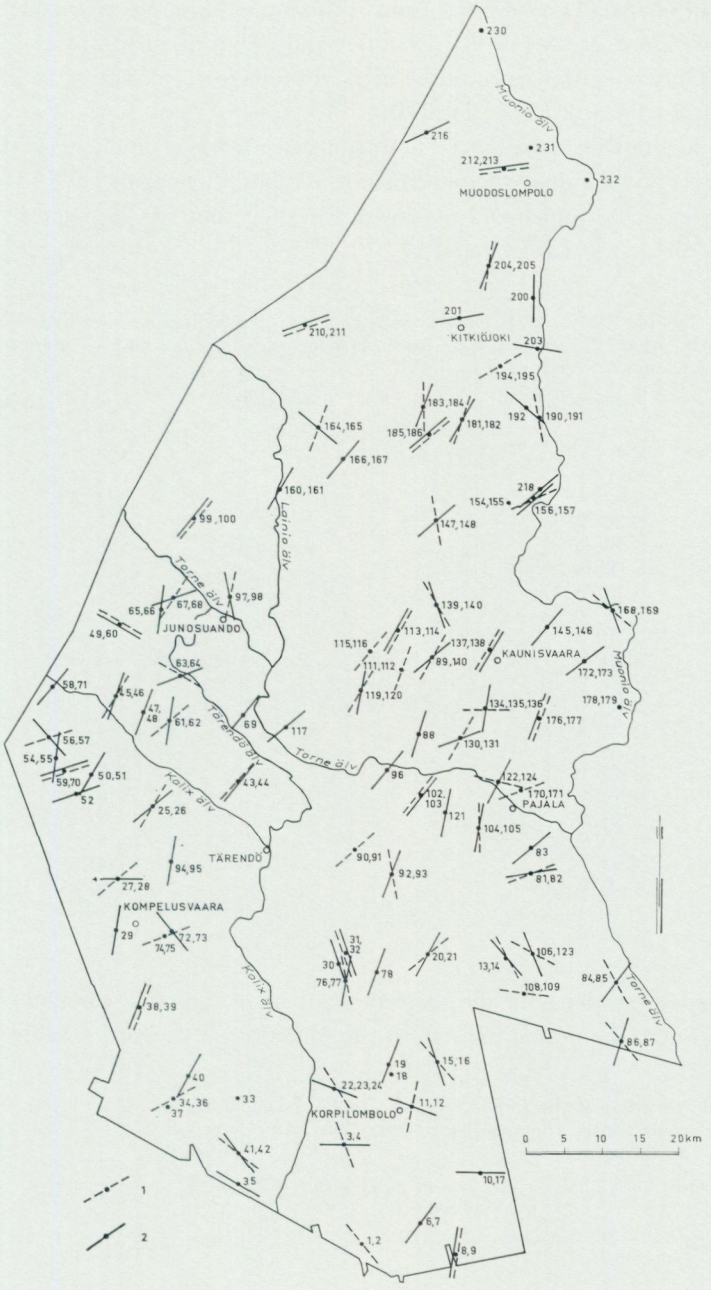


Fig. 16. Till fabric. 1 shows the direction of the preferred orientation of the particles in a lower section of the locality and 2 shows the preferred orientation of the particles in an upper section or represent a single till-fabric analysis in the locality.

In localities with two analyses from different levels more than one direction has been obtained at 13 (18 %) localities and only one direction at 36 (49 %) localities. Only one analysis could be used as indicator of direction at 22 (30 %) localities and none at 2 (3 %) localities.

If we add the directions from the upper and the lower analyses at those localities where only one analysis indicates the direction, we shall have a further 11 localities where the upper and the lower level together can be regarded as indicative of a direction (Tables 9 and 10).

TABLE 9. Double fabric analyses with only one analysis indicating the direction. × denotes that the analysis has an indication of direction and — denotes no indication of direction.

Locality No.	*Direction*	*Upper analyses*	*Lower analyses*	*Upper + lower analyses*
6/7	S 40°W	×	—	S 70°W
10/17	W	×	—	W
34/36	S 60°W	—	×	S 60°W
47/48	S 20°W	×	—	—
50/51	S 30°W	×	—	S 30°W
54/55	S 10°W	×	—	—
58/71	S 40°W	×	—	—
65/66	S 10°W	×	—	—
72/73	N 40°W	×	—	—
74/75	S 70°W	—	×	—
90/91	S 50°W	—	×	—
94/95	S 10°W	×	—	—
108/109	N 80°W	—	×	—
111/112	S 20°W	—	×	S 20°W
115/116	S 40°W	—	×	S 40°W
145/146	S 30°W	×	—	S 30°W
160/161	S 30°W	×	—	S 30°W
166/167	S 40°W	×	—	—
170/171	S 80°W	—	×	S 80°W
172/173	S 60°W	×	—	S 50°W
190/191	N 10°W	—	×	N 10°W
194/195	S 60°W	—	×	—

As regards localities with the same indications of direction for both the upper and the lower analyses, the division of the directions is shown in Table 10.

TABLE 10. Division of the indications of directions at localities where both analyses have given the same interval of direction.

Direction from	*No.*	*No. according to Table 9*	*Total %*
N—NW	9 (25%)	1	21
S—SW	25 (69%)	8	70
W	2 (6%)	2	9

It is of great interest to note the localities that have different indications of direction at different levels. The result of these analyses can be seen in Table 11. The upper analysis points to a later direction than the lower.

TABLE 11. Upper and lower analyses at the same locality with different directions.

Locality No.	*Direction*	*Direction in upper + lower analyses*
Younger S—SW/older N—NW		
63/64	S 70°W/N 60°W	—
84/85	S 50°W/N 30°W	—
86/87	S 10°W/N 40°W	S 10°W
147/148	S 50°W/N 10°W	—
Younger W/older N—NW		
3/4	W/N 20°W	—
22+23/24	N 70°W/N 30°W	N 70°W
Younger W/older S—SW		
11/12	N 70°W/S 10°W	—
27/28	W/S 50°W	S 60°W
67/68	S 70°W/S 40°W	S 70°W
164/165	N 70°W/S 20°W	S 10°W
Younger S—SW/older W		
124/122	S 30°W/N 80°W	—
134+136/135	(S—N)/W	—
Younger N—NW/older S—SW		
56/57	N 40°W/S 70°W	—

In view of the uncertainty of the method and the evaluation, too far-reaching conclusions should not be drawn from Table 11. The double directions are no evidence but may indicate two till beds. Localities 84/85, 147/148, 3/4, 22+23/24, 124/122, 134+136/135, and 56/57 also show ocular differences of the material at the different levels of analysis. The localities where both analyses together have given a useful indication of direction can be explained by the fact that one analysis had a predominant maximum or that the different directions were so close that together they gave an indication of direction or that the result of the analyses is not representative of the assumed connection. It is also remarkable that the N—NW direction at locality 56/57 is younger than that towards the S—SW. This relation finds no support in the present or earlier investigations. The explanation may possibly be that the N—NW direction lies close to the W interval and instead ought to be oriented towards W, or that secondary processes have influenced the orientation of the particles (G. Lundqvist 1948, p. 8, Rudberg 1958). This shows again the above-mentioned weaknesses in the method used. If there are two till beds, it also seems probable that the particles in the upper part of the lower till have been re-orientated (MacClintock and Dreimanis 1964). It is also probable that a re-orientation will yield the same indication of direction as in the upper till.

The measurements of the dip of the particles in relation to the direction of the ice movement are recorded in Table 12. The measurements were performed in connection with 39 analyses, of which only 32 have yielded useful indications of directions. In 14 (44 %) of the analyses, most of the particles dip against the direction of ice movement and in 17 (53 %) with the direction of ice movement. In one analysis (3 %), the same number of particles dips against as with the ice-

movement direction. When most of the particles dip against the ice-movement direction, the average percentage of particles dipping in this direction is 59 %. In the opposite case, the average percentage of particles dipping in the ice-movement direction is 65 %. To judge from the above material, there is a small predominance of particles dipping with the ice-movement direction. This investigation does not show any clear trend in either direction. The reasons for the absence of a positive result may be either that there is no connection between the dip of the particles and the ice-movement direction or that the measured particles had a small dip which entailed that the difference in dip in either direction was very small. Particles with a small dip have been judged to yield much better indications of direction for the ice movements than particles with a large dip (Johansson 1978, p. 11).

TABLE 12. Till fabrics. The dip of the particles within the direction maximum. The direction of the ice movement is considered to be found within the interval of the direction maximum.

Locality No.	*Interval*	*Particles dipping against the direction of ice movement, %*	*Particles dipping with the direction of ice movement, %*
135	S 48°W—N 68°W	54	46
136	S 12°W—S 12°E	52	48
139	N 18—32°W	39	61
140	N 3—72°W	36	64
145	S 18—52°W	54	46
147	S 38—57°W	29	71
148	N 3—12°W	46	54
160	S 28—37°W	29	71
164	N 48—72°W	58	42
165	S 13—32°W	32	68
166	S 23—52°W	29	71
168	N 8—37°W	35	65
169	N 28—67°W	34	66
181	S 8—52°W	29	71
182	S 3—27°W	27	73
183	S 8—62°W	75	25
184	S 3—32°W	76	24
185	S 38—72°W	33	67
186	S 38—62°W	44	56
191	N 22°W—N 22°E	60	40
192	N 38—62°W	56	44
195	S 48—62°W	50	50
200	S 12°W—S 12°E	53	47
201	S 68°W—N 68°W	58	42
203	N 58—90°W	69	31
204	S 3—32°W	37	63
205	S 3—17°W	54	46
210	S 23—72°W	52	48
211	S 53—82°W	43	57
212	S 73—87°W	42	58
213	S 73°W—N 78°W	35	65
216	S 38—72°W	54	46

83 per cent of the analyses performed have yielded maxima of the orientation of the long axis permitting interpretations to be made and conclusions to be drawn. The investigation has also shown the weaknesses in the material, which

indicates that we have to be careful about drawing general conclusions founded only on till fabrics. In using the till fabric as an indicator of direction, too narrow intervals should not be used, since the direction maximum is often situated within a rather broad sector (10—70°), which in itself is the best indicator of direction. As regards the wrong sources it is difficult to prove if the till fabric diverges from the ice-movement direction, and the till fabric should not be used in regional connections such as this, if no comparative material is available.

It is of methodological interest to note that the assistants who made the till-fabric analyses made a new measurement of Järnefors' (1952) locality with two till beds. His results show a fairly good agreement with the results obtained by the assistants. His locality is the same as locality 124/122 (Fig. 16), which shows an upper till with a particle orientation of *c.* S30°W (depth of analysis 0.6 m below ground level) and a lower till with a particle orientation of *c.* N80°W (depth of analysis *c.* 2.0 m below ground level). In the upper till, the direction maximum varies (depth of analysis *c.* 0.5 m below ground level) in Järnefors' report between *c.* S—N and SW. In the lower till (depth of analysis *c.* 1.5 m below ground level), the maximum, according to Järnefors' interpretation, is at *c.* NW but a more westerly sub-direction can clearly be seen (Järnefors 1952, pp. 192—193). The fairly good agreement between this and Järnefors' investigations emphasizes to a certain extent the value of the analysis in the present paper.

In the report of the results summarized below and the interpretation of the till-fabric analysis performed, it is presumed that the predominant orientation of the long axis of the particles largely indicates the ice-movement direction (see section 4.4).

Since 65 % of the interpretable analyses have shown an orientation towards S—SW, it may be concluded that the till was to a large extent influenced by the S—SW ice movement, as is also clearly shown by the striae investigation. As shown by Tables 7, 8 and perhaps also 11, as well as the relative age relations of the striae, material transported from the S—SW predominates in the upper part of the till layer within the whole investigated area. It seems, however, that material transported from both the W and N—NW occurs here and there on the surface. The material transported from the N— NW must be regarded as the oldest material and seems to come up close to the ground surface as a "window". How large these "windows" are cannot be estimated. As regards the till fabrics, the influence of the westerly direction on the material transport cannot be generally explained. However, these fabrics provide supporting evidence of a westerly direction of ice movement. Fairly strong indications of two till beds can be seen at six localities (see p. 43). The regional picture of the ice-movement directions derived from the till-fabric analyses (Fig. 16) agrees very well with the ice-movement directions obtained from the striae investigations (section 6.1).

The origin of two till beds and the thickness of different till layers are treated in more detail in sections 6.2.4 and 7.1.

6.2.3. PARTICLE COUNTS

In all, 112 samples have been counted from 72 different localities. The petrographical contents of the till samples are described in Appendix IV and the till localities in Appendix II. It proved to be very difficult to relate the petrographical content of the till samples to the bedrock on the basis of the bedrock maps (Ödman 1957, Padget 1970, 1977, Witschard 1970). The most important result of the petrographical analyses is the relative differences in the bedrock material revealed in samples on different levels from the same locality. At 12 localities, relative differences in the petrographical composition have been shown (localities 3/4, 6/7, 8/9, 10/17, 22/23/24, 25/26, 43/44, 45/46, 56/57, 106/123, 134/135/136, and 147/148). The differences vary in clarity, but they have been tentatively assessed. It cannot be denied that the method is subjective, a fact which could not possibly be avoided in this material. At 27 localities it was judged that there were no noticeable differences, and at 32 localities only one sample was counted.

In spite of the above-mentioned difficulties in relating the petrographical content of the till samples to the surrounding bedrock (see section 4.5), attempts have none the less been made to interpret them thus (see Fig. 17 and Table 13).

TABLE 13. The ice-movement directions interpreted with the aid of the petrographical content of the till sample.

Ice-movement direction	*Locality No.*	*Geographically separated localities*
SW	6 , 8, 10, 84, 85, 230, 232	6
W	99, 100, 135, 148	3
N	96	1
NW	7, 9, 17, 18, 19, 25, 26, 27, 28, 56, 57, 78, 120, 123, 138, 147	13

If it can be shown that the result in Table 13 has a statistical value, there will be a clear predominance of localities showing a N—NW ice-movement direction, which is a different result in relation to the striae observations and the till fabrics. This seems to be a logical result, since the N—NW ice-movement direction is the oldest met with in the area and one may assume that till material transported during later periods to a large extent originated from a till deposited earlier.

The geographical division of the different directions seems to coincide rather well with the division of the striae directions, especially the westerly ice-movement directions north of the Torne River. North-westerly directions occur mostly south of the Torne River, and in the far north there are only indications of ice-movement directions towards SW.

At localities with relative differences in the petrographical contents of the material on different levels, the given directions do not quite coincide with the remaining result (Table 14).

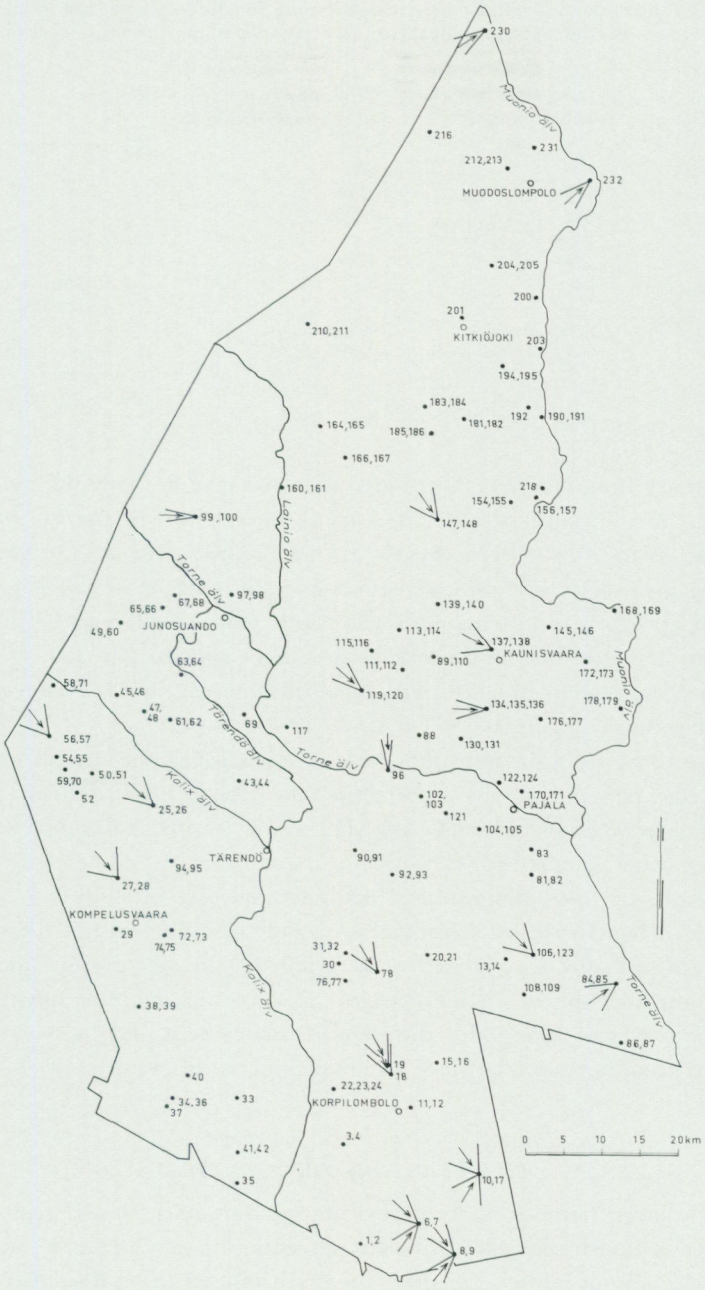


Fig. 17. Direction of transport of till material based on particle counts. The arrow shows the probable direction of transportation and the sector shows the areas from which the rock material may have come.

TABLE 14. Interpreted ice-movement direction at localities where the relative differences in the petrographical composition occur at different levels in the material.

Sample No.	*Direction, upper analysis*	*Direction, lower analysis*	*Remark*
3/4	—	—	No indication of direction
6/7	NW	SW	
8/9	SW	NW	
10/17	SW	NW	
22/23/24	—	—	No indication of direction
25/26	NW	NW	
43/44	—	—	No indication of direction
45/46	—	—	No indication of direction
56/57	NW	NW	
106/123	—	NW	In 106 no indication of direction
134/135/136	—	W	134+136, not analysed
147/148	NW	W	

At localities 8/9 and 10/17, the results seem to coincide with the general trend of the age relationships between the striae, though the results do not coincide with those of the till-fabric analyses (S—SW/S—SW and W/? respectively).

The north-westerly and westerly directions also seem reasonable if we assume that a redeposition of till material has taken place (Gillberg 1977). However, this material should not be used by itself but in comparison with other indications of ice movements and stratigraphical differences. Such a conclusion will be drawn from the results in section 6.2.4.

Attempts have been made to judge the distance for which the till material was transported when indications of direction have been given. The transport distances vary between 0 and *c.* 25 km. The usual transport distance seems to be only one or a few kilometres.

The results of the petrographical analysis are very difficult to interpret and have been of benefit to the investigation to only a limited extent. Petrographical analyses are probably a good way of studying the till stratigraphy and the transport distances of the till, if it is possible to carry out more frequent sampling, mainly in traverses along the different ice-movement directions (cf. Lindén 1975) and sampling can take place systematically on different levels.

6.2.4. TWO TILL BEDS AND TILL-COVERED SEDIMENT

At a fairly large number of localities, the sections have shown relatively large differences in the stratigraphy by ocular inspection, particle counts and till-fabric analyses. At some localities, the differences are judged to be due to two till beds of the same type as Järnefors (1952) describes, and in others they have been caused by till-covered sediments. A fairly short time was spent at each locality, and most of the work was carried out by non-geologists (see Chapter 2). Because the results of the analyses came afterwards, the investigations concerning

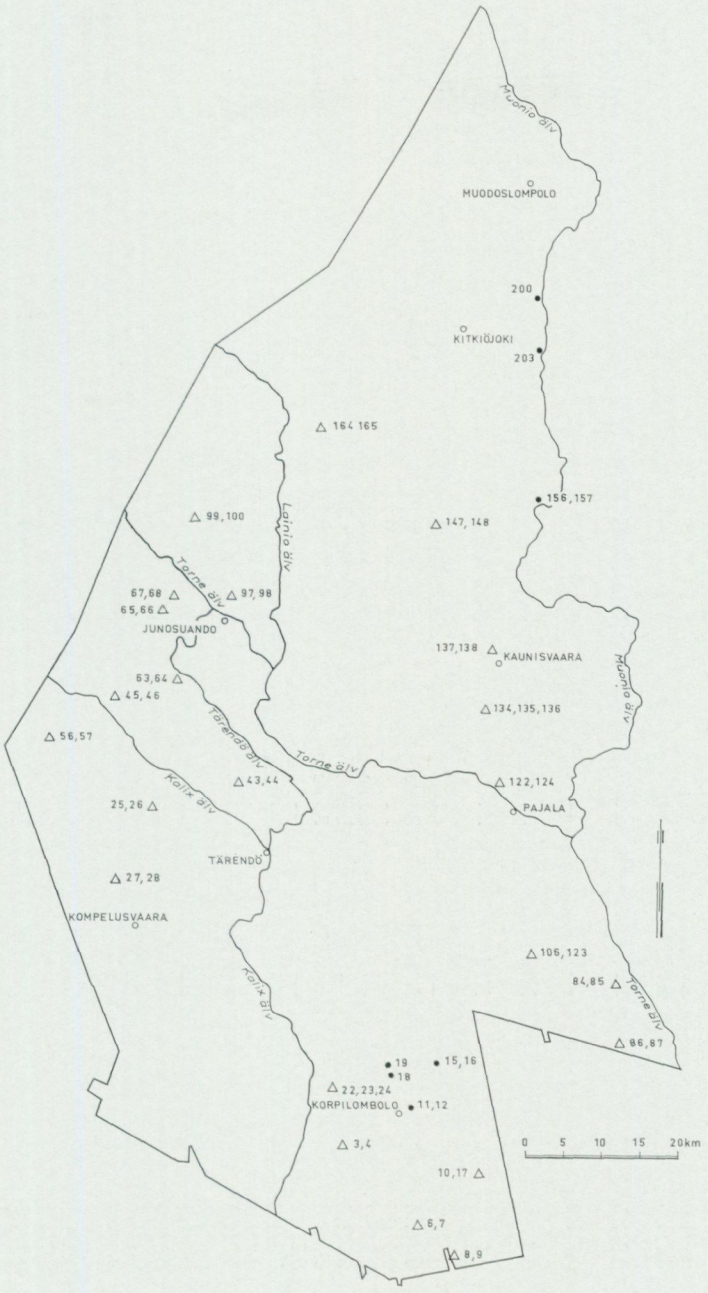


Fig. 18. Localities with indications of two till beds and till-covered sediments. The triangles mark the two till beds and the dots the till-covered sediments. Compare with Table 15.

TABLE 15. Indications on stratigraphically different levels in Quaternary deposits. The results were obtained by till-fabric analyses, particle counts and ocular inspections. The notation 3/4 indicates that analyses were carried out on two levels at the same locality (locations: Fig. 18).

Locality No.	*Depth of the analyses below ground level, m*	*Particle counts*		*Till-fabric analyses, direction*	*Ocular difference of the material in the section*	*Remarks*
		Interpreted direction	*Relative difference in the bedrock composition*			
3/4	1.0/2.0	—	Some	W/N 20°W	Yes	
7/6	0.3/1.2	NW/SW	Yes	S 40°W/—	—	
8/9	0.5/1.0	SW/NW	Yes	S 10°W/S 10°W	Some	
10/17	0.7/1.5	SW/NW	Yes	W/—	Yes	See striae locality T7
11/12	0.6/1.5	—	—	N 70°W/S 10°W	Yes	Till-covered sediment
15/16	0.7/1.2	—	—	N 20°W/N 40°W	Yes	Till-covered sediment
18	0.7	NW	—	—	Yes	Till-covered sediment
19	0.7	NW	—	S 20°W	Yes	Till-covered sediment
22+23/24	0.4/0.9/1.3	—	Some	N 70°W/N 30°W	Yes	
25/26	0.5/1.0	NW/NW	Some	S 50°W/S 30°W	Yes	
27/28	0.5/1.0	NW/NW	—	W/S 50°W	—	
43/44	0.7/1.2	—	Some	S 40°W/S 40°W	Yes	
45/46	0.7/1.2	—	Some	S 20°W/S 30°W	Yes	
56/57	0.5/1.0	NW/NW	Some	N 40°W/S 70°W	Yes	Sediment in till
63/64	0.7/1.2	—	—	S 70°W/N 60°W	—	
65/66	0.7/1.2	—	—	S 10°W/—	Yes	
67/68	0.7/1.5	—	—	S 70°W/S 40°W	—	
84/85	0.7/1.2	SW/SW	—	S 50°W/N 30°W	Yes	
86/87	0.6/1.2	—	—	S 10°W/N 40°W	—	
97/98	0.5/1.2	—	—	N 10°W/S 10°W	Yes	
99/100	0.5/1.0	W/W	—	S 40°W/S 30°W	Yes	
106/123	0.7/1.2	—/NW	Some	N 10°W/N 60°W	—	
124/122	0.6/2.0	—	—	S 30°W/N 80°W	Yes	Järnefors' (1952) two till beds
134+136/135	0.5/1.2	—/W	Yes	S—N/W	Yes	
137/138	0.7/1.2	—/NW	—	S 20°W/S 30°W	Some	
147/148	0.7/1.2	NW/W	Yes	S 50°W/N 10°W	Yes	
156/157	0.7/1.2	—	—	S 40°W/S 70°W	Yes	Till-covered sediment
164/165	0.7/1.2	—	—	N 70°W/S 20°W	—	
200	0.7	—	—	S—N	Yes	Till-covered sediment
203	0.7	—	—	N 80°W	Yes	Sediment in till

the stratigraphical relations were not carried out in an optimal way. The increasing consciousness of the frequently complex stratigraphy makes one give more attention to the meaning of the differences afterwards than was given during the field work. This increased consciousness was due to a certain extent to an excursion which the author made in the summer of 1977 to the northernmost parts of Sweden and Finland. The Finnish works and experience (among others, Kujansuu 1967b, 1972, 1975, Niemelä *et al.* 1975, Hirvas *et al.* 1976a,b, and Hirvas 1977a,b,) may have given the indications in different stratigraphical units an increased significance.

Table 15 and Fig. 18 show the best indications on two till beds or till-covered sediments from various localities. It is most important to find out if the material shows ocular variations, changes of particle orientation and relative differences in bedrock composition from one level to another. However, less weight should be placed on the interpreted ice-movement direction (see subsection 6.2.3) derived from the particle counts.

All localities with supposed two till beds can be seen in Fig. 18.

Locality 3/4 shows both petrographical and ocular differences and the fabric in the upper till coincides with the youngest striae direction for the area (W—E) and with the oldest striae direction in the lower till (NW—SE). The upper till is light brown, sandy and *c.* 1.3 m in thickness, the lower is dark grey and sandy and has fissilities (see Appendix II).



Fig. 19. Till fabric analyses and particle counts made in close connection with a glacially striated boulder. The striae on the top of the boulder are suspected to have been cut without moving the boulder. Photograph: T. Fagerlind.

Locality 10/17 shows clear petrographical and ocular differences in different layers. The fabric in the upper till is westerly and the lower shows an unclear maximum to the north-west. The upper till is brown and sandy, has fissilities and is *c.* 1 m thick, the lower is dark grey and sandy and has fissilities. A large boulder, *c.* 2 x 1.5 m at the top and more than 1.7 m deep, is situated in the section (see Fig. 19). The boulder is well polished on the surface and the sides. There are striae in the direction N80°W in the upper surface of the boulder. It may be assumed that the striae were scored without moving it. The direction indications of the petrographical composition coincide well with the youngest and the oldest striae in the area.

Localities 22+23/24 show an ocular difference and a certain petrographical difference in the analysed levels. The upper till is brownish-grey and sandy, has fissilities and is *c.* 1.2 m thick. The fabric shows a maximum at *c.* N70°W, which is interpreted to be closest to the westerly ice movement when compared with the nearby striae locality T2. The lower till is dark grey and sandy and has fissilities. The particle orientation (N30°W) coincides well with the oldest striae directions.

Locality 84/85 shows an ocular difference of the material in the section wall, further an upper particle orientation at S50°W and a lower at N30°W. The petrographical analyses show no marked differences in the section but a weak indication of the material transport from the south-west. The upper till is light-brown, sandy, *c.* 1 m deep and has fissilities. The lower till is grey, sandy and has fissilities. The indications of direction at the different stratigraphical levels coincide well with the age relationships of the striae in the area.

Locality 124/122 is the same as Järnefors' (1952) locality. The upper till has indications of directions in the S—SW and the lower in the WNW. The more westerly orientation of the lower till coincides with the oldest striae directions for the area. It is therefore quite reasonable to correlate this direction with older N—NW directions in the areas south and west of this locality. The younger till has a S—SW orientation, which can also be correlated to younger striae. The difference in material is mainly displayed by the brown colour of the upper bed contrary to the grey colour of the lower bed.

Localities 134 and 136/135. The upper till (0.6 m) is a brown, sandy till with fissilities and the lower a firmly consolidated sandy till. The material shows petrographical differences where the composition of the lower till material gives a weak indication of a westerly transport direction. The fabric also indicates a westerly ice-movement direction in the lower till. This may be correlated with the lower till in locality 124/122. The direction of transport in the upper till is judged to be S—N.

Locality 147/148. The upper till is *c.* 1 m thick, brown and sandy. The colour transition towards the lower, grey, sandy till is sharp (see Fig. 20). There is a difference in the petrographical composition between the upper and the lower till. The material in the upper till is assumed to have had its origin north-west of the locality and the material in the lower till west of the locality. The fabric analysis yields a direction in the SW for the upper and N—S (S—N?) for the lower till. There are few striae observations in this area, but what there are have westerly, south-westerly and southerly directions. As regards the striae, the younger till may be interpreted as SW and the older (lower) as S.

The above-described localities and the remainder, which are listed in Table 15, give indications of two till beds. The large spread of the localities contradicts the hypothesis of small oscillations of the ice. Together with the striae observa-



Fig. 20. Till locality 147/148. The till beds show a sharp difference in colour. Photograph: K. Moreborg.

tions, the till localities in Table 15 would seem to clearly indicate traces of different glacial stages within the investigated area. The results also indicate interstadial or interglacial periods. It seems important that more detailed till-stratigraphical investigations should be made within the investigation area.

Further and perhaps more important indications of the big variations during the glaciation are given in all localities containing till-covered sediment.

In localities 11/12, 18 and 19, a 1—2 m thick, light-brown, sandy till covers (see Appendix II) generally sandy but also gravelly sediments. The sediments are stated to be several metres thick in localities 18 and 19 (see Figs. 21 and 22). All three localities are situated in a NW—SE stretch of sand and gravel deposits. At localities 18 and 19, the sand and gravel deposits form a ridge-shaped esker. It is obvious that these sand and gravel deposits are the remains of eskers, which have partly been eroded and partly covered with till (cf. Fromm 1965, pp. 20, 131—132). If this assumption is correct, the sand and gravel deposits were most probably deposited during an interstadial or interglacial period. The till fabric in locality 19 indicates a S—SW direction of the movement, in locality 18 there are no indications of direction and in locality 11/12 — not in close connection with the sand and gravel deposits — there are double directions in the till, the upper from the W—NW and the lower from the south.

Locality 15/16 at Ohtanojärvi shows a very complex and interesting stratigraphy (Fig. 23). The locality is situated in a gravel pit, where the overlying till has been scraped off, according to the owner. In the described section, however, the original ground surface is under the scraped-off material. On the top of the profile, there is 0.3—0.6 m of



Fig. 21. Locality 18. Till-covered, glaciofluvial sediments. Photograph: T. Fagerlind.

Fig. 22. Locality 19. Till-covered, glaciofluvial sediments. The till has clearly developed fissilities. Photograph: T. Fagerlind.





Fig. 23. Locality 15/16. Till-covered, coarse sediments. As regards the stratigraphy, see the text. Photograph: T. Olsson.

filling, after that comes 0.4—0.8 m of brown till that contains small lenses (*c.* 0.05 m long and 0.01 m thick) of silty to fine-sandy, white material. These lenses are judged to be the remains of a leached-out layer, that is, remains of an older ground level. The brown till turns into a grey till (0.4—0.6 m thick) with lots of sediment veins. The grey and brown tills are separated by a stone horizon. Below the grey till, there is firmly consolidated sand 0.5—1.0 m thick and, below that, a stony, sandy gravel. The till-fabric analysis was performed before the section was exposed, according to the description above, at another spot in the gravel pit. An upper, *c.* 1 m thick, light-brown, silty to fine sandy till and a lower, grey, firmly consolidated till with fissilities were found. In both tills, the particle orientations indicate an ice movement from the N—NW. It was difficult to investigate the locality because of the large number of inhabited swallows' nests. Further analyses, primarily diatom and pollen analyses, are planned. If there is further evidence of two till beds, with an older ground horizon in the upper, the stratigraphy must represent one interstadial and one interglacial stage, or possibly two interstadial stages.

In locality 156/157, near Kihlanki, there are sandy and gravelly sediments below a grey, *c.* 1 m thick, sandy, till cover (see Fig. 24). The spread of the sediments is difficult to see in the locality. They seem, however, to be of relatively great thickness. The fabric shows an upper direction of S40°W and a lower direction of S70°W.

At locality 200, sandy sediments occur under *c.* 1.2 m of mainly brown, sandy till with a predominance of particle orientations *c.* S—N. The thickness of the sediments and the spread could not be judged.

Locality 203 has a complex structure, with till and sediment. It may be till with an abundant occurrence of sediment veins or possibly a till-covered sediment deposit. The work in the locality was difficult because of landslides. The particle orientation in the till is approximately westerly.

The Quaternary stratigraphy within the area indicates several stages of the glaciation. The till-covered sediment and also the two till beds strongly indicate an interstadial period in the last glaciation. These relationships seem to be very important in interpreting the Quaternary development of the area (see section 7.1). Differences in the directions and ages of the striae are reflected by the Quaternary stratigraphy. The final evidence of interstadial or interglacial stratigraphy



Fig. 24. Locality 156/157. Till-covered, sandy and gravelly sediments. Photograph: H. Överby.

can only be given when datable material has been analysed (cf. Fromm 1965, p. 93). This can to a certain extent be weighed against comparisons and correlations (see section 7.1) with the above-mentioned, extensive, Finnish material (Hirvas *et al.* 1976b, among others).

It should be observed that differences between various sorts of tills are often very characteristic. Generally, the upper till is brown or greyish-brown and the lower till is grey (Fig. 20), a contrast that also recurs on the Finnish side (Hirvas *et al.* 1976b).

6.3. LATE-GLACIAL HYDROGRAPHY

6.3.1. GLACIOFLUVIAL DEPOSITS

In the northernmost part of the Pajala district, stretches of ice river occur in the SW—NE and WNW—ESE directions. The deposits are judged to have been subglacially and marginally developed (see section 5.3).

The SW—NE stretches of glacial river are three in number. The first is the ridge-shaped esker that joins the kame delta at Särkitievat. The second is the stretch that begins *c.* 6 km south-west of Kitkiöjärvi, passing by Kitkiöjärvi to Mukkaharjut and up to the Muonio River at Naankijärvi. This stretch is marked by ridge-shaped eskers, kame deltas and fluvial erosion. The third stretch is situated south-west of the mouth of Parkajoki, and the material has to a large extent been deposited as a ridge-shaped esker and has probably developed supraaquatically. This has, however, not been closely studied. The kame deltas (see Fig. 25) were probably formed at or close to the ice margin. In the glaciofluvial material, ice boulders and icebergs were embedded, which, when they melted, gave rise to large kettle holes. The "feeding eskers", which are connected from the south-west with these kame deltas, are presumed to have mostly been formed subglacially and subaquatically up to the levels of the ice lakes, owing to the facts that the ridges consist of rather coarse material and that parts of the stretches show clear signs of fluvial erosion in the form of clean-washed outcrops etc.

The development of the kame deltas may be explained by saying that the water pressure in the ice disappeared at the broken parts of the ice margin and that the material was stored up to a level which corresponded to approximately that of the existing ice lake. The highest part at Särkitievat is situated at 340—345 m a.s.l. In the kame deltas at Mukkaharjut, the highest parts are situated at a level of 300—305 m a.s.l. The kame deltas rise much above the ice-lake sediments (see Fig. 25). This can only be explained by saying that the "delta formations" were deposited when the hydrostatic pressure at the ice margin was comparatively higher than when the ice-lake sediments were deposited. It also means that the feeding eskers were subaquatically developed. The above described glaciofluvial

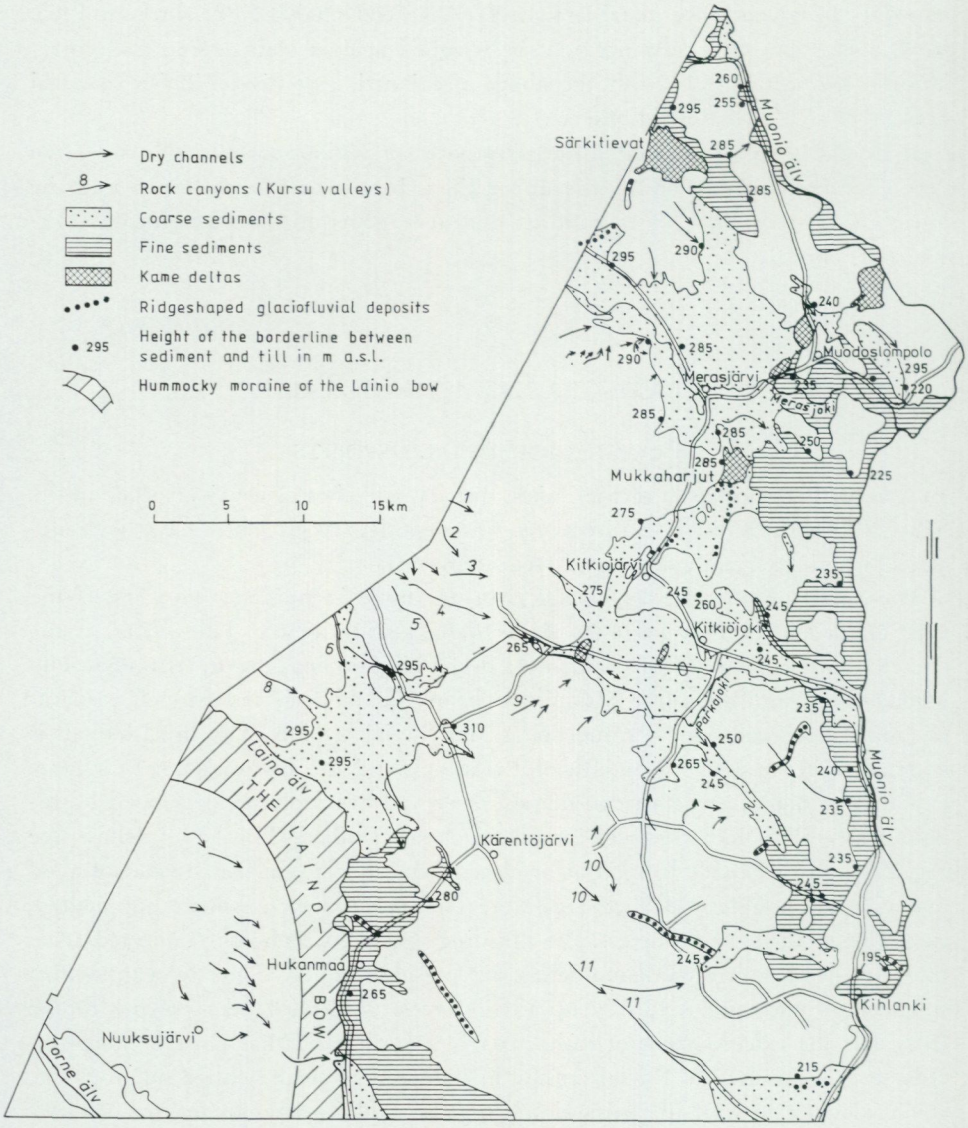


Fig. 25. Glaciofluvial and ice-lake sediments and tracks of late-glacial drainage.

stretches should also indicate the direction of the ice retardation in the area, that is, from NE to SW.

The WNW—ESE, glaciofluvial deposits in the southern parts of the present map of loose deposits (Fig. 25) are judged to be a function of a marginal, glacier-water flow. The ridge-shaped sediment deposits are so-called marginal eskers, developed in water flowing either along the ice edge or in ice cracks or tunnels in a stagnant ice. This assumption is mainly founded on the conditions

for the development of kursu valleys (see subsection 6.3.2). This is especially clearly shown in the sediment area west of Kihlanki and at the mouth of Aareakursu. The water drainage along the Aareakursu was on two occasions forced to take north-easterly and easterly directions respectively over areas situated higher in relation to the normal drainage direction of the kursu. These relationship provided an ice margin stretching approximately E—W and a retardation of the ice towards the south or south-west.

In the part of the Pajala district covered by Fromm's (1965) map of Quaternary deposits there are glaciofluvial deposits which are divided into eskers, gravel plains and sand plains. The gravel and sand plains are mostly delta formations deposited at the highest shoreline (Fromm 1965, pp. 130—132). The eskers generally have a NNW—SSE orientation. They are usually believed to have been formed subglacially in stagnant ice, where the glacier water could cut a way forward in the normal direction of drainage. Their directions do not reflect the retardation of the ice. Wholly or partly till-covered eskers are also rather common. They have been interpreted by Fromm (1965, p. 131) as subglacially deposited comparatively far away from the ice margin. Though I have not made any thorough field observations of my own, the glaciofluvial deposits have been interpreted as deposited in mainly three ways.

1. As subglacially developed in a stagnant ice (Fromm 1965).

2. As marginally developed (marginal eskers), according to what is described above for the northern areas.

3. As probably subglacially developed in an early interstadial period. The reasons for this are dealt with in section 7.1 (p. 71).

No definite evidence of how the ice retreated over this part of the Pajala district can be obtained on the basis of only the glaciofluvial accumulation forms. There are, however, no relations that quite contradict the general trend of the retardation of the ice to the south or south-west.

6.3.2. EROSION BY LATE-GLACIAL DRAINAGE

In the northern part of the Pajala district, the large amount of sediments indicates an extensive, late-glacial flow of water. In addition to the forms of accumulation, this late-glacial flow has left many traces, mostly in the form of dry valleys (Fig. 25). Dry valleys which can be classified as extra-marginal drainage channels, kursu valleys and overflow channels have been observed. Also erosion forms such as washed-out till, clean-washed outcrops and channels in till have been noted — developments which have not been studied in any detail. In that part of the investigation area which is on Fromm's (1965) map, many erosion forms such as clean-washed outcrops, lateral drainage channels, overflow chan-

nels, extra-marginal drainage channels, and kursu valleys (rock canyons) have been observed. However, the late-glacial drainage has influenced the landscape to a smaller extent in the southern part of the investigation area as compared with the northern.

The above-mentioned forms of erosion have only been studied generally (cf. section 4.6). The erosion forms of the late-glacial drainage are of great importance for the mapping of the course of the deglaciation. Below, such observations and conclusions are reported as seem to be important for the understanding of the course of the deglaciation.

Extra-marginal drainage channels. The most common form of extra-marginal drainage channel is the flat-bottomed, mire-covered, elongated low valley. These valleys generally have a small gradient in the stream direction, and the material in the valley slopes is often remarkably little influenced by erosion. In some places, the water has, however, cut furrows in the till of the slopes. Often an erosion groove ends in a large mire, which in its turn has a drain-like, mire-covered groove. One gets a very vivid picture of this ancient water drainage in these mire formations. The width of these late-glacial water channels varies a great deal but is generally 50—100 m. It is difficult to draw a borderline between what may be indicative of an extra-marginal drainage channel and an extra-marginal lake. Plentiful examples of drainage channels of extra marginal type can be found in the whole mapped area and in adjacent areas in Finland (Kujansuu 1967b, pp. 71—73). Especially clear and beautifully shaped, extra-marginal drainage channels can be found west of the Lainio bow and north of Nuuksujärvi (see Fig. 26). The origin and the abundant occurrence of extra-marginal drainage channels, which can be regarded as characteristic of this type of terrain, must be due to the mostly flat landscape and the fact that the landscape was first deglaciated in higher-lying areas. The latter fact means that the water from deglaciated areas and from the ice and ice lakes was forced to find occasional drainage channels until the whole area had been deglaciated.

Some erosional grooves in till. In the northern part of the investigated area, drainage channels occur in till, often more than 5 m deep, with sharp sides and with erosion remains in the form of boulders and stony till. The channels occur relatively far down the slopes of high land and are usually at a right angle to the contour lines of the topographical maps. These forms occur especially frequently in an area *c.* 7 km WNW of Merasjärvi, where the glacier water flowed towards the large ice-lake area (Fig. 25). Some drainage channels emerge, that is, flatten out, at the edge of the ice-lake sediments. Others emerge in mires, which probably functioned as extra-marginal drainage channels. Since the erosion grooves occur relatively far down the slopes, there should be no erosion forms like overflow channels. A probable explanation of the origin of the erosion

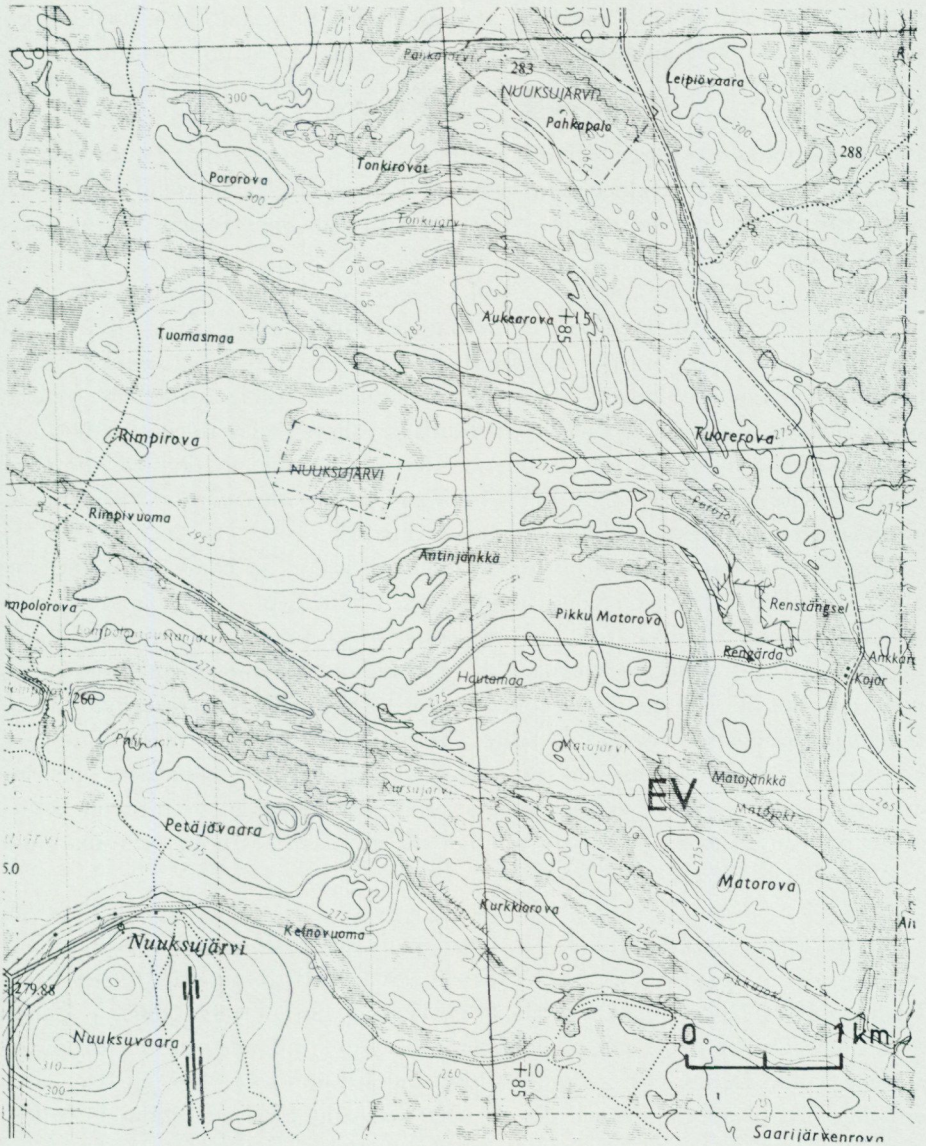


Fig. 26. A part of the topographical map 29L Lainio SE, showing mire-covered, extra-marginal, drainage channels.

forms is that small ice rivers eroded the till either a little bit into the ice (sub-glacial) or in a crack in the ice margin. There may also have been extra marginal erosion, where the morphology provided conditions for rather deep erosion. They can, however, probably mostly be classified as sub-glacial chutes (cf. J. Lundqvist 1969, p. 81).

Overflow channels and lateral drainage channels often assume a damming ice

margin, which can only be regarded as representing local and occasional marginal positions. I made an attempt to systematize these ice margins within the Pajala area (Fagerlind 1974, p. 12) on the basis of material from Fromm (1965), Hoppe (1967) and observations of my own. This showed that 65 % of the ice-margin positions (43 pieces) had a southerly, 16 % a westerly, 5 % an easterly and 6 % a northerly deglaciation direction. That is, a general trend for the ice to retreat towards the south can be seen, even though there is only a weak indication of this.

Washed-out till. "Washed-out till" implies a broad drainage over till areas, so that the till surface is washed out from the finer material. This seems to have happened mainly in connection with extra-marginal drainage, when the glacier water flooded over comparatively flat drainage valleys and washed out the finer material of the till on its way to other, better morphologically defined, drainage channels. Clear examples of this can be found in the area with extra marginal drainage channels west of "the Lainio bow" (Fig. 25).

The washing out of till on a broad front also occurs in connection with the above-described erosion channels in till. Daniel (1975, p. 103) points out that the drainage on a broad front may be either extra-marginal or subglacial and that it is difficult to decide which. When washing-out has only affected the upper surface of the till, it seems to me that the erosion has been extra-marginal. When the till generally shows signs of water erosion through sediment veins and/or has a very coarse composition and has a washed-out, upper surface, one can assume that the erosion has been subglacial. It will, however, be difficult, without careful investigation, to verify whether the drainage has been extra-marginal or subglacial.

Kursu valleys (rock canyons). There are many descriptions and interpretations of the origin of kursu valleys (A.G. Högbom 1901, B. Högbom 1916, Geijer 1917, Rudberg 1949, Hoppe 1950, Virkala 1955, Pentillä 1963, Fromm 1965, J. Lundqvist 1969, Daniel 1975, and others). Several factors influence the formation of a kursu valley. Daniel (1975, pp. 93—100) and J. Lundqvist (1969, p. 81) point out that first of all, one should decide what were the local conditions for different phenomena. There are, however, many outward similarities in the different kursu valleys. These are often valleys cut deep in the bedrock and have remarkably straight extensions. The creeks have frequently sharp angles. A common feature of the kursu valleys is that large volumes of water have flowed through them. It has also in many cases been assumed that they are located in zones of tectonic weakness in the bedrock. Their canyon-like forms make it improbable that glacial erosion caused their formation. Indeed, a combination of water erosion and tectonic zones in the bedrock is the most probable condition for their formation. The main discussion has mostly dealt with the form of the

water flow that caused the erosion. Possible types may be glaciofluvial subglacial erosion, glaciofluvial lateral erosion, and extra-marginal erosion in connection with catastrophic tappings of ice lakes. It has been pointed out that the kursu valleys may have been drainage channels during earlier glaciations, that is, the latest glaciation may only have scoured up loose deposits and to a lesser extent eroded the valley. The most important questions in this work are the following. 1. Did the water flow have a subglacial, lateral, extra-marginal or catastrophic course? 2. Are combinations of these forms possible? 3. To what extent did the kursu valleys act as transportation routes for the glacier water? These questions are considered to be important, since they are intimately connected with the course of the deglaciation. Rudberg (1949) described the kursu valleys in the Pajala district in considerable detail, but, because of the lack of visual maps, was not able to get the same general view of the ancient water flow as is to a large extent described by the topographical maps (for descriptions of details, cf. Rudberg 1949). As regards Isokursu, Kursujärvi, a kursu valley at Kolkonjoki and Kursunpalo, reference may be made to Fromm's (1965, pp. 134—136) description.

Below the kursu valleys are described with emphasis on the drainage function in the light of the distribution of the Quaternary deposits, drainage directions and morphological elements at the beginnings and at the ends of the valleys. The interpretations are made mainly with the help of the topographical map, the soil map and to some extent the experience gained in the field. For the numbering, see Fig. 25.

1. *Juomukursu*. The *c.* 25 m deep, *c.* 2 km long valley is situated between two small mountains. Its upper part begins at *c.* 380 m a.s.l. and the valley flattens out at *c.* 350 m a.s.l., that is, there is a fall of *c.* 30 m. West of the valley, a rather flat mire area occurs, to which drainage channels of extra marginal type seem to lead. If this has connections with the fluvial erosion in the kursu valley, the water must have been diverted by an ice margin *c.* E—W. In the mouth of the kursu valley no sediment has been found. It does not seem unreasonable to assume that a continuation of the water-flow could have taken place in an extra-marginal form through what is now an irregular mire area down to the area with ice-lake sediments. It seems probable that this valley was formed as a type of overflow channel.

2. *Haapakursu* is *c.* 3 km long and *c.* 20 m deep in its upper part and *c.* 10 m deep in its lower part. Its upper part begins at *c.* 370 m a.s.l. and its lower part flattens out at *c.* 320 m a.s.l., that is, there is a fall of *c.* 50 m. The valley winds probably due to the bedrock and till morphology. Otherwise, its formation must have resembled that of Juomukursu.

3. *Liivakursu* (see Fig. 27). The main kursu valley is 1.5—2.0 km long and *c.* 15 m deep. The outlet is connected with that of Haapakursu at *c.* 300 m a.s.l. Its upper part is situated at *c.* 330 m a.s.l., that is, there is a fall of *c.* 30 m.

South and west of the upper part of Liivakursu, drainage channels of extra marginal type and erosion traces in the form of small valleys occur. The extra marginal drainage

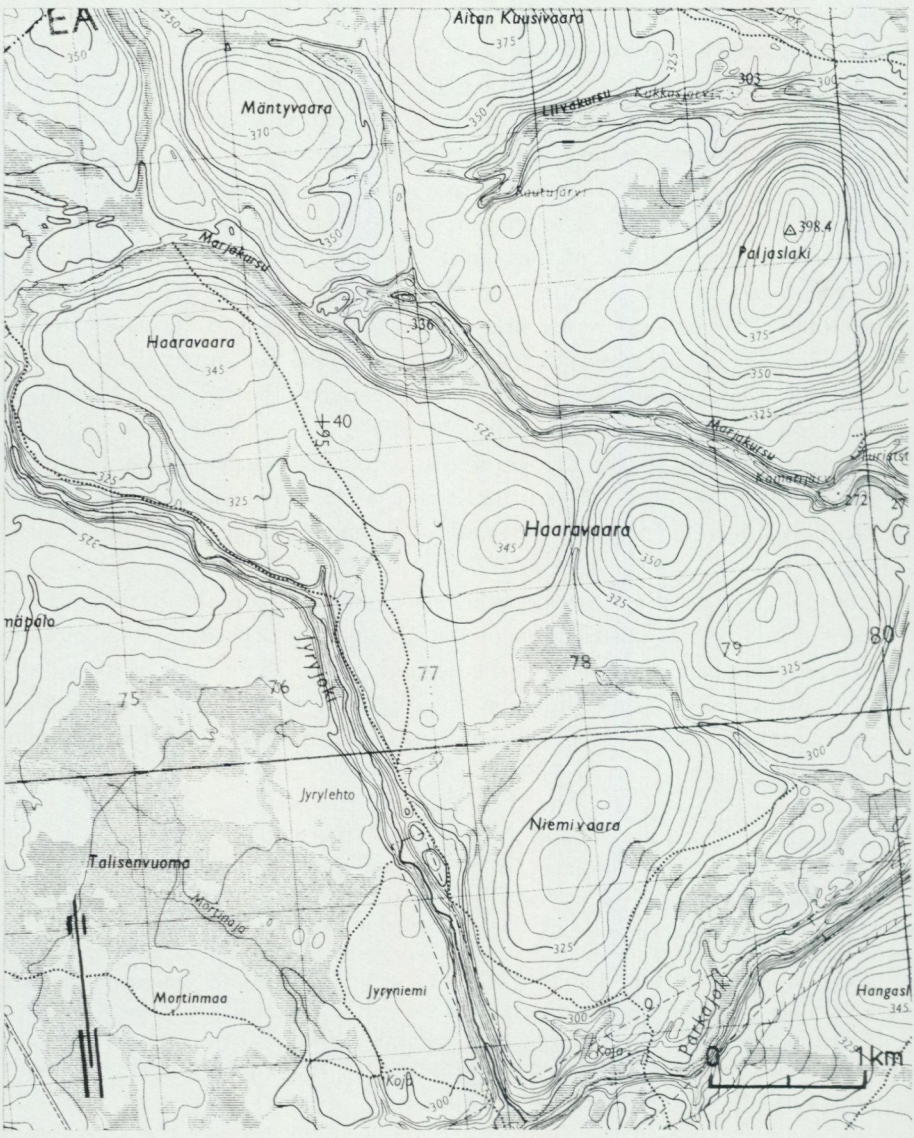


Fig. 27. A section of the topographical map 29L Lainio NE, showing examples of kursu valleys (rock canyons).

is completely governed by the topography, that is, the grooves turn gently around the high parts. The smaller valleys seem to have been formed by a comparatively violent course of events. Liivakursu's drainage system may be finished when Marjakursu's drainage system takes over the water drainage. The ancient water drainage is very clear on the topographical map and presumes a damming ice-margin *c.* E—W. The erosion took place under circumstances partly of overflow type, partly of marginal type and to some extent of extra-marginal type, and the morphology has the appearance of being able to

drain large masses of water. The different drainage forms make it improbable that the erosion forms appeared through subglacial drainage.

4. *Marjakursu* (Fig. 27) is 6—7 km long and nearly 40 m deep. Its upper part is situated at *c.* 320 m a.s.l. and its lower part at *c.* 270 m a.s.l., *i. e.*, there is a fall of *c.* 50 m. Its lower part is connected with the Parkajoki valley, where the sediment accumulations are deposited in what is assumed to have been the surroundings of an ice lake. It appears as if also the beginning of Marjakursu has a connection with extra-marginal drainage. Marjakursu has a somewhat winding course that in certain parts shows sharp and in other parts softer creeks. Their situation in the country can probably be assigned partly to the morphology in general and partly to an ice-damming. The depth of the cut-down valley and the partly straight and partly sharply angled course indicate that erosion has been facilitated by tectonic zones of weakness in the bedrock. If one considers only the situation of Marjakursu, a subglacial, glaciofluvial erosion cannot be excluded, but, compared with Liivakursu and the drainage forms in the north-west, a marginal or to some extent an extra-marginal water flow seems to have been the cause of the fluvial erosion.

5. *The valley of Jyryjoki* (Fig. 27). From 1.5 km south-east the border of the investigated area down to Parkajoki, the depression of Jyryjoki has a kursu-like appearance. The kursu is *c.* 7 km long, nearly 30 m deep in some parts and falls from a level of *c.* 305 m a.s.l. to *c.* 270 m a.s.l., that is, 35 m. Also the beginning of this valley seems to have a flow of extra-marginal type. Jyryjoki has a winding course similar to that of Marjakursu, and the way in which it was formed must have resembled that of Marjakursu. The very distinct cut-down valley at the mouth finished abruptly at the Parkajoki River, and this valley also has a kursu-like appearance.

The Parkajoki River flows between a wide area with ice-lake sediments at Parkalompolo and the large area with ice-lake sediments at Kitkiöjärvi and Kitkiöjoki. South of Parkajoki, in the extension of Jyryjoki, is a valley with an uncertain topography, which may be due to the eroding effects of glacier water. Further away in the same direction, sediments occur in a different manner from that in the large sediment area. These sediments are situated at a higher level than the rest of the sediments in the area and do not occur as an even cover (see Fig. 3, notes 37—39, pp. 19). However, further investigations are needed to make these relations clear.

6. *The valley of Olosjoki.* West of and in the Pajala district, the Olosjoki depression has a kursu-like appearance. The conditions for its formation must have been similar to those in the earlier described kursu valleys. On the soil map, Olosjoki has a comparatively sharp, marked depression for *c.* 1.5 km of its upper part, and this part falls into a sediment area. Where the cut-down part ends, a mire-covered, *c.* 150 m wide and 4 km long channel appears, which is assumed to have been initiated as a marginal drainage channel. This led late-glacial water from the Olosjoki water system to that of Parkajoki. This also indicates that Olosjoki must have been blocked by either dead ice or an ice front running approximately east-west. The remaining part of the Olosjoki valley has a meandering course in sediments down to the Lainio River.

7. *The valley of Parkajoki.* (Fig. 27.) The depression of Parkajoki between the mouths of Jyryjoki and Marjakursu has on its southern side steep slopes 25—30 m high, which to a large extent consist of bedrock. The northern side is flatter but shows clear signs of fluvial erosion up to *c.* 300 m a.s.l., a level that is largely the same as that of the upper part of the southern side. Parkajoki probably transported much larger amounts of water in late-glacial times than it does now. The picture on the map gives reason to

assume that the ice lake, which is marked by the sediment areas around the valley of Olosjoki, was probably released at an early period by Parkajoki. A fact that confirms this statement is that Olosjoki, from what can be seen, was dammed and the water was led to the drainage system of Parkajoki.

The fluvial erosion in the upper depression of Parkajoki must have been marginal or extra-marginal. The later alternative argues that there were natural morphological conditions for this. However, the initial reason for drainage by Parkajoki must originally have been marginal. The drainage later changed over and became extra-marginal.

8. *Suolakursu.* The kursu valley has its longest and most marked part north-west of the investigated region. The kursu is *c.* 6 km long, *c.* 30 m deep and its bottom falls from *c.* 300 m a.s.l. to *c.* 290 m a.s.l., that is, *c.* 10 m. The upper part connects with an extra-marginal drainage system and the kursu valley falls into the large sediment area. This kursu was probably formed in a similar way to the remaining kursu valleys, that is, marginally or in part possibly extra marginally. The ice margin must have stretched approximately east-west.

9. *Kylmänkursu* is *c.* 1 km long, *c.* 15 m deep and falls from *c.* 340 m a.s.l. to *c.* 320 m a.s.l., *i.e.* 20 m. The kursu begins in a mire area with no special signs of ancient water flow. In the extension of the kursu valley, clear erosion remains occur in the form of small depressions and cavities, which fall into ice-lake sediment areas at Kitkiöjoki. The origin of this kursu valley is very difficult to explain under present conditions. We may, however, suspect an origin of overflow type, since the mountain north of the valley shows signs of small erosion channels. It may also be connected with the ice-lake sediments at Parkalompolo, that is, this kursu may have functioned as an ice-lake drainage. If this is correct, the mentioned kursu valley may have had a marginal or extra-marginal origin. However, subglacial, fluvial erosion cannot be excluded, although this cannot be proved with the present basic data.

10. *Manalaisenkursu and Kihlankikursu.* These two kursu valleys have more diffuse shapes as compared with the ones earlier described. The steep slopes are not so sharp, although the valleys on the whole are rather deep. Manalaisenkursu, however, occasionally has sharp slopes *c.* 20 m high. The special characteristic of both these valleys is the very rough topography surrounding them. They are situated between relatively high mountains, and the steep slopes show many signs of erosion in the form of drainage channels. In front of the mouths of both valleys and in their extension there is an esker formation. The drainage channels on the mountain sides must have been developed either as sub-glacial chutes or as overflow channels.

The comparatively high mountain tops may have emerged as nunatakks, and nunatakk ice lakes may have been formed. The possible tapping of these ice lakes may have developed the above-mentioned small erosion forms, which in that case should be called sub-glacial chutes (J. Lundqvist 1969, p. 81). This would also have meant that the subglacial erosion took place very close to the marginal zone in broken ice. Presumably the ice was "dead". The glacio-fluvial deposits seem to be a marginal esker. The probability of such a conception is increased to some extent by the drainage channel of Aareakursu (see below).

11. *Aareakursu.* This kursu valley has been carefully described by Rudberg (1949, pp. 445—451) in a work to which the reader is referred regarding the morphological formation of the valley. The beginning of Aareakursu may be traced up to the sediment area at Parkalompolo. The feeding streams seem to be of marginal and/or extra-marginal type. Close to the sediment area there are mire-covered, gently winding, rather shal-

low channels. Closer to the kursu valley, there are two elongated lakes, Kärentöjärvi and Kukasjärvi, which were in all probability feeding streams for Aareakursu. The upper part of Aareakursu, called Rauturimpivaara on the topographical map, exhibits signs of strong fluvial erosion. An ice margin in this area running approximately east-west and a copious feeding stream from the north-west seem to have been preconditions for the formation of these morphological elements. This also means that the flowing water must have been linked off to the east or to the north-east from the depression of Aareakursu. In these directions, it does not seem improbable that water transport could have taken place to the sediment area situated west of Kihlanki. The link-off of the water would in that case have been marginal and the continued flow marginal or extra-marginal. In accordance with this, the water flow in Aareakursu must have been either sub-glacial or marginal. The sediment deposit at the mouth of the kursu valley resembles, however, an out-washed plain, which indicates that the deposit was made in a deglaciated area. However, the flow-out of sediment in a straight easterly direction indicates that also here the water flow was linked off by a damming ice margin running approximately east-west. The sediment deposition could thus have taken place in the form of an alluvial fan only after the ice had melted away, implying that the esker formation in this area should be interpreted as a marginal esker.

The conclusion from the above descriptions is that the origin of the kursu valleys may in general be assigned to a water flow along an ice margin. Some kursu valleys have been developed by overflow effects. It is more doubtful if a subglacial, glaciofluvial erosion caused the kursu formations. If that occurred, the water must have found its way under an almost dead ice. The volumes of water came partly from deglaciated areas where the water made its way forward in extra-marginal drainage channels to a damming and/or a linking off ice edge, and partly from glacier water from the inland ice. These two water-supplying areas should explain the very large volumes of water which have presumably passed through the kursu valleys, a theory supported, *inter alia*, by the conditions necessary for the formation of the large ice lake and the large sediment areas. The conception is also supported by the direction of the ice movement emerging from the striae studies. This explanation of the origin of the kursu valleys coincides in principle with the conclusions of Högbom (1916), Rudberg (1949) and Fromm (1965).

Further evidence for these interpretations requires a more detailed inventory of the drainage courses, the erosion effects and the classification of loose deposits.

6.3.3. DEVELOPMENT OF THE ICE-LAKES

The rough features of the local extension of different ice-lake stages are illustrated by the large sediment areas in Fig. 25. The given damming levels are assigned to places where the sediments going out towards the till have been mapped. The real surfaces of the ice lakes must have been situated at a greater height, approximately 0—5 m higher. However, in the further treatment, the concepts of damming level and sediment level will be assigned to the boundary between se-

diment and till. The levels have not been determined but are taken directly from the topographical map. With regard to the uncertainty in the mapping as to where the boundary between sediment and till is to be set, one has to allow for a margin of error of at least ± 5 m on the given levels.

Within the area of the present map of loose deposits, there are three larger, ice-lake areas (Fig. 25), the first along the depression of Merasjoki and the Muonio River in the Muoduslompolo district, the second along the depression of Parkajoki and the Muonio River at Kitkiöjoki, the third along the depression of Olosjoki and the Lainio River. The development of the three ice-lake areas shows that the deglaciation must have taken place roughly from north-east to south-west, that is, the ice lakes were formed between a damming ice margin in the south and higher areas in the north. The inflow of water came from melting ice and from brooks and rivers in already deglaciated areas. Within all these areas, there are both coarse-grained and fine-grained sediments. From the, at least in part, thick, coarse-grained deposits and the fine-grained sediments we may assume that the ice-lake periods within at least parts of these areas were relatively long. Further conditions for the development of the ice lakes are that the natural drainage ways of first the Muonio River and then the Lainio River must have been dammed by ice. There must have been damming masses of ice in the southern parts of the valleys of the Lainio and Muonio Rivers when the areas north of them were mainly deglaciated. The highest damming levels can be found in the west of the investigated region, and they decrease gradually towards the east. A decrease of the damming levels towards the south will also be quite evident if we look at the sediment areas in general. In more limited perspectives, a gradual decrease from north to south does not seem so clear. From Särkitievat to the western part of the sediment area at Muodoslompolo, the level decreases only from 290—295 m a.s.l. to 285—290 m a.s.l. From the western part of the sediment area at Kitkiöjoki to the south—south-western part of the sediment complex, the damming level decreases from *c.* 275 m a.s.l. to *c.* 265 m a.s.l. However, the levels decrease from 290—295 m a.s.l. to *c.* 265 m a.s.l. (*c.* 30 m) if we consider them in a wider perspective. In the sediment area at Olosjoki, the damming levels decrease from *c.* 295 m a.s.l. in the north to *c.* 265 m a.s.l. in the south. For the sediment area at Muodoslompolo the decreasing levels from east to west are 290—295, 285, 245—255, 235, and 220 m a.s.l. The corresponding figures for the area at Kitkiöjärvi-Parkajoki are 275, 265, 250, 245, and 235 m a.s.l.

On the basis of Kujansuu's (1967b, pp 79—81) work, the main features of the drainage in the ice lakes can be explained. The tapping of the ice lakes took place eastward to the ice-lake areas in the drainage system of Ounasjoki in Finland, which in turn are drained to other water systems further to the east.

The drainage of the ice lakes within the area at Muodoslompolo seems to have taken place via extra-marginal drainage channels to the dammed basin of the Muonio River, which in turn was tapped into the Ounasjoki ice-lake basin.

The water of ice-lake stages corresponding to the sediment levels at 295—290 m a.s.l. can be assumed to have escaped towards Ounasjoki, partly via Moutkajärvi (295 m a.s.l.), *c.* 50 km north-east of Muodoslompolo, and at Kulkujärvi (293 m a.s.l.), *c.* 40 km east of Muodoslompolo (Kujansuu 1967b, p. 79). The ice-lake stage corresponding to the sediment level of 285 m was probably tapped further south, between Mustakero and Kolvakero (278—273 m a.s.l.). At Äkesjärvi, *c.* 40 km SSE of Muodoslompolo, tappings took place at the levels 250—270 m a.s.l., which may be compared to the stages with corresponding sediment levels of 245—255 m a.s.l. The lowest pass mentioned by Kujansuu is at 215 m and is situated between Kesänkitunturi and Yllästunturi, *c.* 60 km SSE of Muodoslompolo. The pass thresholds in Finland between 215 and 250 m may be correlated with the sediment levels between 220 and 235 m a.s.l. Within this ice-lake stage, assumed ice-lake shore-lines have also been noted *c.* 3 km north of Muodoslompolo with a level of *c.* 240—245 m a.s.l. The outgoings of the sediments towards the till are remarkably constant over large areas, primarily regarding the sediment layers at 290 and 285—245 m a.s.l., as well as the level at 235 m of the sediment in the depression of the Muonio River. This shows that there were ice lakes with rather large areas of open water. The passes permitting the water of the ice lakes to escape probably developed gradually when the ice margin moved. This also confirms the assumption that at least certain stages in the ice-lake development were of relatively long duration. However, there are also irregularities in the levels of the sediment within the area, which can surely in many cases be explained by ice remaining within the ice-lake basin.

West of the ice-lake area at Kitkiöjoki, rather extensive drainage seems to have taken place extra-marginally towards the ice-lake area at Muodoslompolo. When the areas below 275 m a.s.l. were deglaciated, the extra-marginal drainage could take place eastward at the western margin of the ice-lake area at Kitkiöjoki, which was drained north-eastward to the depression of the Muonio River. This north-easterly drainage must have remained during the ice-lake periods, which correspond to the sediment levels of 275 and 265 m a.s.l. and probably 250 m a.s.l. During the later period, it seems as if extra-marginal drainage-ways may have been opened to the east. The sediment levels of 245—235—195 m a.s.l. should have been formed when the depression of the Muonio River was ice-dammed south of this ice-lake area. The damming of the Muonio River must gradually have been moved to the south, probably some 10 km south of Kihlanki, before the depression of the Muonio acted as a drainage channel down to the Torne River. The drainage of the ice-lake area at the Muonio River took place further east to the Ounasjoki depression, in accordance with what has been described above. Also some stages in this ice-lake complex seem to have lasted for rather long periods of time, to judge from the spread of both the fine- and the coarse-grained sediments, primarily the stages corresponding to the sediment levels at 250—245 and 235 m a.s.l.

The drainage of the ice-lake area at Olosjoki and the Lainio River must have taken place in three directions, north-east, east and south-east. The north-east drainage took place mainly along the westernmost part of Parkajoki (see subsection 6.3.2, p. 65) and further to the north-east, partly in extra-marginal drainage channels and partly via the ice-lake complex at Kitkiöjoki. When the areas east of Olosjoki and the Lainio River were deglaciated, the drainage also took place in this direction.

The main drainage channel to the east and east-south-east is Kihlankikursu and the stretch to Kihlanki (see p. 66), further via Keräntöjärvi and Kukasjärvi to Aareakursu. This water is led towards the Muonio River. Before the Lainio River and the Torne River acted as drainage channels, the drainage must have taken place to the east or to the south-east. Traces of such a drainage are to a large extent hidden by the widespread mires (among others, Kukkovuoma and Terravuoma) in this part of the Pajala district. Traces of the drainage in question may, however, be seen partly in the glaciofluvial stretch from the vicinity of Hukanmaa south-east to the kursu-like depression along Kolkonjoki (Fromm 1965, p. 136), partly along Kursujärvi, partly along shallower drainage channels at Lombolojoki—Muotkamaa (4 km south of Käymäjärvi) and along the partly kursu-like channels 2—5 km north of Antis (Fromm 1965, p. 136). Fromm also reports traces of ice-lake sediments down to the surroundings of Junosuando, which also show that a drainage must have taken place east of the Lainio River and north of the Torne River during the late-glacial period.

Persistent sediment levels have been found in the ice-lake area at Olosjoki and the Lainio River at 295, 280 and 265 m a.s.l. which leads to the conclusion that all water from this place was led to the Muonio River and further east to the Ounasjoki drainage system in Finland (Kujansuu 1967b, pp. 79—81) during long periods until the area around the Torne River became deglaciated.

The damming and the drainage of the ice-lakes indicate that the ice had retired mainly from north-east to south-west. Since the deglaciation took place from higher to lower areas, it also seems natural that the ice-margin should have been broken up and that remnants of dead ice could remain in front of the living ice.

This means that it is difficult to interpret dammings and damming channels as a function of an active ice margin and that such a relation would make it difficult or perhaps impossible to co-ordinate the presumed ice-margin sites chronologically.

7. SUMMARIZING DISCUSSIONS AND CONCLUSIONS

7.1. THE GLACIAL DEVELOPMENT OF THE PAJALA DISTRICT

Several authors (among others, G. Lundqvist 1961, Fromm 1965, and Kujansuu

1967b) have already observed various ice-movement directions in the Pajala district and its surroundings. The different causal connections that made these different directions possible in the Swedish Torne River valley have been very little discussed, however. The separate directions were interpreted by Fromm (1965) as having arisen during the deglaciation period. Hoppe (1967) also assumed that the recorded changes took place in the deglaciation phase and were due to the different recession directions in the Kalix River and the Torne River depressions respectively, and to differences in the activity of the ice and recession over and under the highest shore-line. Hirvas *et al.* (1976b) assigned the different ice movements in adjacent areas in Finland to five different, glacial stages, separated by four interstadial or interglacial periods. The results of the present work are to a large extent connected with the results of the extensive Finnish works, *i. e.* changes in the ice movement directions might to some extent be explained by different stages in the glaciation, with intervening interstadial and/or interglacial periods. The most important indications of such a development in the Pajala district are the striae observations, the till-covered sediments, and the two till beds.

The S—SW ice movement in the southern part of the area has been clarified by the present work. The indications of the S—SW movement are spread over the whole of the Pajala district, including its southern and western parts. The age relationships of the S—SW striae are such that there is a great deal of evidence that they belong to the same generation phases in the southern parts of the district. It has also been shown that the S—SW ice movement was of such an intensity that, in spite of the clear striae, it sculptured outcrops at different places in the region, deposited a till bed at least here and there, and created original surface forms of its own, mainly drumlins (Hoppe 1967, p. 206). The relations mentioned show that this ice movement had a regional extension of such a magnitude that it would be difficult to explain it by local changes in the movement during the deglaciation phase (cf. Hoppe 1967, p. 207).

The till-covered sediments in the southern parts of the district, together with the remaining results, indicate that the region was deglaciated before the younger S—SW and W ice movements became predominant there. This applies primarily to locations 11/12, 18 and 19 (subsection 6.2.4.). As regards locality 15/16 at Ohtanojärvi, similar correlations are difficult to make without closer investigations, but the relationship suggests an interstadial or interglacial bed sequence. The glaciofluvial deposits that can be found on the map of Quaternary deposits by Fromm (1965) within the southern parts of the region, east of the Kalix River, are often small, with either a diffuse extension or a NW—SE orientation. This orientation seems remarkable in relation to the latest ice-movement directions of S—SW or W, which contradict the general opinion as to the orientation of the glaciofluvial stretches in relation to the ice-movement direction. The absence of glaciofluvial deposits in large parts of this area seems remarkable

in view of the large amounts of sediments occurring west and north-west of the area. These relations can be hypothetically explained by saying that the NW-oriented, glaciofluvial deposits were deposited during the phase of glaciation when the north-westerly ice melted and the area was deglaciated during an interstadial period. When the area was glaciated again and the ice movement became S—SW and W, the glaciofluvial material was removed by erosion or covered with till. To judge from the S—SW striae and the moraine morphology (see Figs. 9 and 14), the S—SW ice seems to have had a maximum velocity just within the area where the glaciofluvial deposits are absent. The till-covered sediments can be seen at the edge of the area of the large glacial activity of the S—SW ice. The fact that the glaciofluvial deposits, or parts of them, have been retained from an early interstadial period might be explained by saying that a strong, local growth of ice took place before any ice movement to speak of was developed during the latest glaciation phase. Evidence that this was the case within parts of northern Scandinavia includes the fact that the deeply weathered rock at Vuotso in the northeasternmost part of Finland could be retained, and also the till-covered eskers in northern Finland (Niemelä *et al.* 1975, Kujansuu 1975). The last glaciation phase did not begin with valley glaciers pushing forward from areas at higher levels, or with a portion of inland ice being pushed forward over the area and "planing" the bottom layer. On the contrary, the ice is judged to have grown locally in a tundra climate (J. Lundqvist 1974, p. 331).

In the light of the experience gained during the present investigation, the assumption by Fromm (1965, p. 106) that the so-called "Kalix pinnmo" might be interpreted as retransported, glaciofluvial deposits could be accepted, at least regarding deposits of this kind in the Pajala district.

Very few Swedish localities with assumed interstadial or interglacial bed sequences (J. Lundqvist 1978, p. 27) have been described from the northernmost part of Sweden. J. Lundqvist (1971) interpreted a bed sequence in the Leveäniemi mine *c.* 100 km north-west of Pajala as consisting of interglacial, organic sediments of Eemian age. The locality at Leveäniemi shows a lower till, which was deposited during a nice movement from the north-west and is overlain by glaciofluvial or glaciolacustrine sediments. These sediments are correlated to the Jämtland interstadial (45—59 000 years BP). The sediment is overlain by an upper till which is judged to have been deposited during an ice movement from the south or south-west.

New observations of organic material or deposits with radiocarbon ages between *c.* 30 000 and 41 000 BP indicate another interstadial period later than the Jämtland Interstadial (J. Lundqvist 1978, pp. 7—11).

As I mentioned earlier, there is an extensive Finnish material on the glacial evolution of northern Finland. It is mainly the investigations led by Raimo Kujansuu that form the basis of the latest estimations. The stratigraphy of 1 228 localities was investigated (Hirvas 1977a, p. 128), and for these localities more

than 2 000 till-fabric analyses and *c.* 1 300 petrographical analyses were made and more than 11 000 samples were taken for different studies in the laboratory. Five glaciation stages were established, several divided by sediments. Datable, organic material, and the microfossil contents of the sediment and the till, show that the bed sequences contain interglacial sediment more than 50 000 years old. These sediments are correlated to the interglacial deposits at Leveäniemi (J. Lundqvist 1971). Interstadial deposits (Kujansuu 1972, Hirvas *et al.* 1976b, pp. 266—272, Korpela 1969) are related to the Peräpohjola Interstadial, which is correlated to the Jämtland Interstadial (J. Lundqvist 1967).

The results of this examination of the stratigraphical investigations show great similarities to those of the Finnish investigations (Hirvas 1977a) on the particle orientation in till as well as the specific appearance of the tills and the till-covered sediments.

Unfortunately, in the Pajala district no datable material has been discovered which could facilitate and give a definite correlation to the Finnish material. The correlations have therefore been based on comparisons of ice movements in different stages of glaciation. Comparisons have been made between the works of Hirvas (1977a), J. Lundqvist (1971, 1974), Hoppe (1967), Fromm (1965) and the results of the assigned material. It seems to be too early to correlate the ice-movements to the whole of northern Norrland, since comparable material is lacking for large parts of the area west of the Pajala district. An investigation at present being performed by R. Lagerbäck at the SGU will probably make further comparisons possible.

Older Quaternary deposits. (See Table 16.) It has not been possible to prove the presence of any interglacial deposits within the Pajala district. In northern Finland (Hirvas *et al.* 1976b), relatively good evidence has been found for a fairly large number of interglacial localities of Eemian age, and in northernmost Sweden a locality at Leveäniemi has already been mentioned (J. Lundqvist 1971). It does not, however, seem unreasonable to suppose that interglacial deposits may be met with in the Pajala district.

In northern Finland there are also traces of two older, glacial stages, "flow stages IV and V" (Hirvas 1977a, pp. 130—131). These stages must belong to the Saale glaciations. There are, however, no possibilities at present of making more accurate decisions regarding the ages of these stages. In northern Sweden, no traces of glacial stages older than the Weichselian have been found.

The initial stage of the latest glaciation (glacial stage 3). The whole of northern Finland, except perhaps its northernmost part, had a north-westerly ice movement (Hirvas 1977a). This ice movement (see subsection 6.2.4, Fig. 8 and Fig. 28) can be traced in the Pajala district up to some 10 km north of the Torne River. Farther to the north, there are only indications of ice movements

TABLE 16. Correlations of the glacial development for the northernmost parts of Sweden and northern Finland. Compiled from Hirvas *et al.* 1976b and J. Lundqvist 1971, 1974.

Lithostratigraphy *Stratigraphical units* *Pajala district*	*Leveäniemi*	*Northern Finland*	*Chronostratigraphy* *Stages* *Pajala district*	*Leveäniemi*	*Northern Finland*	*Correlation*
W—SW till	Upper till (SW)	Till bed I	Glacial stage 1	Second glacial stage	Glacial stage I	Weichsel III ?
S—SW till	Upper till (SW)	Till bed II	Glacial stage 2	Second glacial stage	Glacial stage II	Weichsel II
Till-covered sand and gravel deposits	Glaciofluvial, glaciolacustrine sediments	Sand, silt, organic material	Interstadial	Interstadial	Interstadial	Peräpohjola, Jämtland
N—NW (W ?) till	Lower till (NW)	Till bed III	Glacial stage 3	First glacial stage	Glacial stage III	Weichsel I
—	Organic material	Sand, silt, organic material	—	Interglacial	Interglacial	Eem
—	—	Till bed IV	—	—	Glacial stage IV	Saale ?
—	—	Sand, silt	—	—	Interglacial/? Interstadial ?	?
—	—	Till bed V	—	—	Glacial stage V	?
—	—	Sand, silt	—	—	Interglacial/? Interstadial ?	?

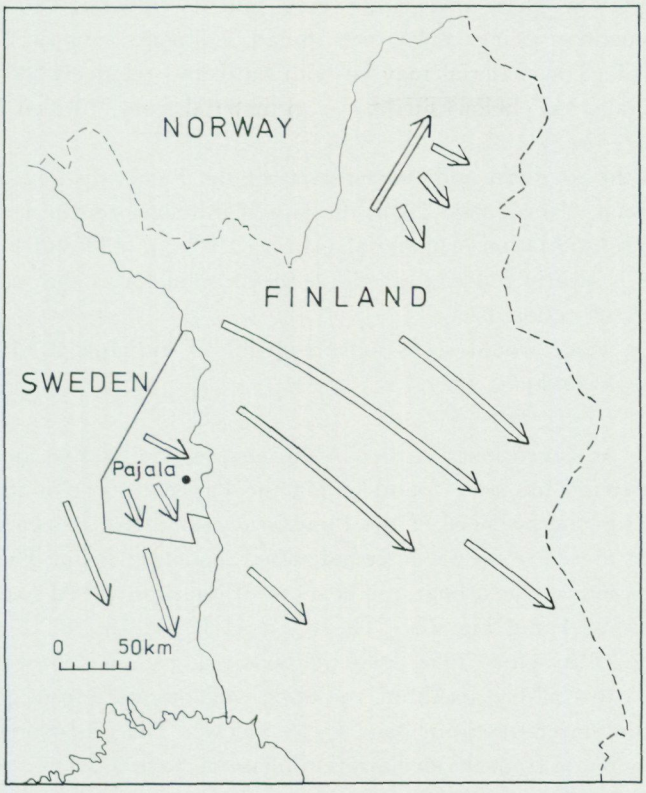


Fig. 28. Glacial stage 3. The direction of glacial flow during the initial phase of the last glaciation, Weichsel I (partly after Hirvas 1977a and Fromm 1965).

from the south and south-west. The W—NW striae at localities K 37, T 49 and T 50 (Fig. 10) may possibly belong to this stage. On the basis of this and earlier investigations (among others, G. Lundqvist 1961), it seems natural to assume that an ice divide was situated within the northern part of the Pajala district. However, this suggestion is contradicted by the ice-movement picture for "flow stage III" in Finland (Hirvas 1977a). Hirvas says (p. 130) that the till deposited during "flow stage II" (see Table 16) has considerable thickness in the north-western part of Finnish Lapland and that very few traces of ice movements dating from "flow stage III" are to be found within this area, which means that during glacial stage 2 and "flow stage II" the intensity in the activity of the ice was so great in these parts of northernmost Sweden and Finland that the traces of earlier ice movements were to a large extent wiped out or hidden under thick till. An ice divide during glacial stage 3 would then have been situated north of the Pajala district in higher-lying areas along the Finnish-Norwegian-Swedish borders in the Scandinavian mountain chain, which agrees with Ljungner's (1949, pp. 70—71) and Hirvas's (1977a, p. 130) hypotheses. Till deposited dur-

ing this glaciation phase is generally grey, and its colour is described by the author as sometimes being olive-green. Small sediment veins occur here and there in the till. The material may be both hard and relatively loosely packed. This till generally has obvious similarities to material from "till bed III" in Finland (Hirvas 1977a, p. 132).

As regards the southern and central parts of the Pajala district, and most of northern Finland, glacial stage 3 had the largest influence on the landscape picture and the transportation of material (Hirvas 1977a, p. 130 and Fromm 1965, p. 129). This is clearly reflected by the large drumlin forms that can be found in these areas (subsection 6.2.1).

In time this stage would seem to correspond to Weichsel I (Hirvas *et al.* 1976b, p. 272, J. Lundqvist 1974).

Interstadial. As I mentioned earlier in this chapter, no datable, interstadial or interglacial material has been found within the Pajala district or its immediate surroundings. On the evidence of the Finnish investigations, it seems reasonable to assume that there are several interstadial-bed sequences in the Pajala district. The localities yielding the strongest indications of interstadial-bed sequences were (see subsection 6.2.4 and Fig. 18) 3/4, 10/17, 11/12, 15/16, 18, 19, 22+23/24, 84/85, 124/122 (Järnefors 1952, two till beds), 134+136/135, 156/157, and 200. In several two-till-bed localities, the upper tills originate from glacial stages 1 and 2 and the lower tills from stage 3 (see below). The till-covered sediments must have originated from the deglaciation phase of stage 3, which took place in an early interstadial time (Table 16). The period between glacial stages 2 and 3 is correlated to the Jämtland and Peräpohjola Interstadials. These interstadials are older than 40 000 years and are judged to have occurred between 45 and 59 000 years BP (Hirvas *et al.* 1976b, pp. 266—272, J. Lundqvist 1974, pp. 331—332, and Korpela 1969, p. 100).

It is not possible at present to correlate stratigraphical units of the Pajala district with the interstadial period between 30 000 and 40 000 BP discussed by J. Lundqvist (1978). However, this interstadial period may have been developed in the investigated area, and traces of it can here be judged to belong to the Jämtland Interstadial.

The main stage of the latest glaciation phases (glacial stage 2) was characterized by the fact that the whole Pajala district and the northernmost part of Finland had an ice movement in a S—SW direction (Fig. 29). The central and southern parts of Finnish Lapland and the southern Torne valley had ice movements mainly in a westerly direction. The till deposits during this period corresponded in northern Finland to till bed II (flow stage II, Hirvas 1977a, Table 16) and on the Swedish side to till with S—SW particle orientations (see Fig. 16). The upper till in the Njalatj section, *c.* 80 km west of Övertorneå (Fromm

1965, p. 54), may well belong to this stage. The particle orientation in the upper Njalatj till has a more westerly direction. The colours of the tills are generally described as brown to brownish-grey, and the observed thickness is between 1 and 7 m in northern Finland (Hirvas 1977a) and between 0.5 m and 2 m in the Pajala district. Drumlins with S—SW orientations seem also to derive from this stage (Hoppe 1967).

An ice-divide zone runs through the central part of Finnish Lapland and separates at some distance south of the Pajala district the S—SW ice movement from the one coming from W (Hirvas 1977a, p. 129). The ice divide on the Swedish side had a W—E or possibly a SW—NE direction. The ice divide presented by G. Lundqvist (1961) should apparently have been moved 100—110 km to the south, according to the striae material produced in the present investigation. This also emphasizes the importance of the further investigations of the ice-movement directions and stratigraphy west and south-west of the Pajala district. The mentioned stage corresponds to Weichsel II (Hirvas *et al.* 1976b, p. 272, J. Lundqvist 1974).

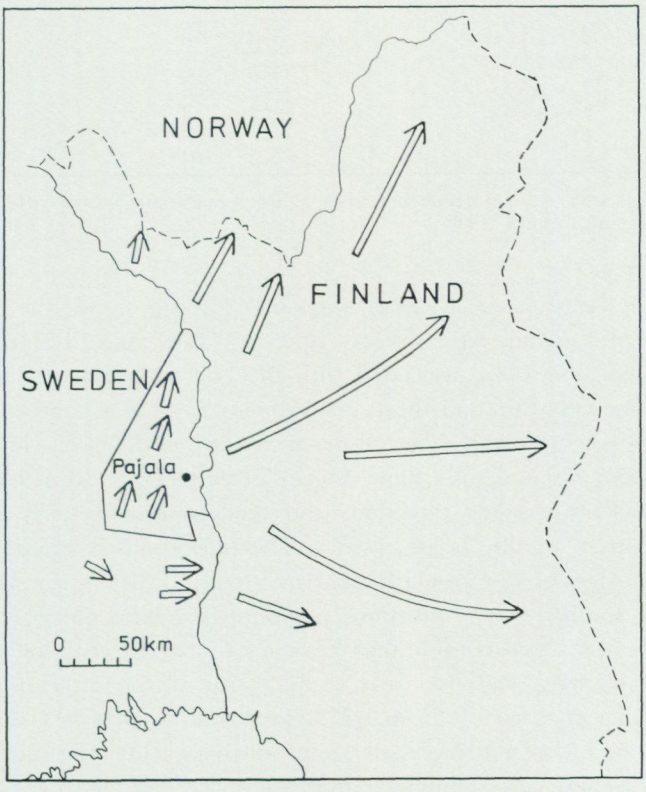


Fig. 29. Glacial stage 2. The main direction of the glacial flow during the last glaciation phase, Weichsel II (partly after Hirvas 1977a and Fromm 1965).



Fig. 30. Glacial stage 1. Youngest directions of ice movements (partly after Hirvas *et al.* 1976b and Fromm 1965).

Youngest ice movements (glacial stage 1). Fig. 30 shows the youngest ice movements. In Finland, these are described as "flow stage I" (Hirvas 1977a, Table 16) and have been associated with the late deglaciation stage when the ice had become very thin and the ice movements were to a large extent influenced by the local morphology. The till material (till bed I) often consists of ablation till but also of basal till. "Flow stage I" (see section 7.2) is comparable to the youngest south-westerly directions and the youngest westerly directions in the southern parts of the Pajala district. The indications of westerly directions in the central part of the Pajala district may possibly belong to this stage, but probably the south-westerly directions predominated here during the deglaciation phase. It also seems possible that Fromm's youngest directions in the Pajala district (W and SW) and the areas to the south as far as Haparanda (W) may belong to this stage (1965, p. 138). It should be observed that this stage was affected by an ice retiring partly from north to south and partly from east to west (see section 7.2). The closer the eastern ice margin comes, the stronger the western ice movement becomes. However, a gradual transition between the

closest older stage (stage 2) and stage 1 seems to have existed. If the ice movements in stage 1 were mainly affected by the ice margin and the local morphology, it seems irrelevant to assume a regional ice divide at this stage. On the other hand, the centre of the glaciation should be located south-west or possibly west of the Pajala district.

7.2. THE DEGLACIATION OF THE PAJALA DISTRICT

The principles of the glacial development described in the previous chapter have also partly changed the grounds for the earlier opinions about the deglaciation primarily described by Fromm (1965, pp. 122—130) and Hoppe (1967, pp. 204—208). Fromm declared that the change of ice movements was a result of the deglaciation. But he also expressed some doubts about the ages of different ice movements mainly related to the two till beds in Pajala and Njalatj. Fromm, however, lacked the evidence or correlation data necessary for a discussion of ice movements in greater detail, in relation to interstadial or interglacial periods. Hoppe also described the changes of the ice movements as a function of the deglaciation. The transition from an ice movement in a N—NW to S—SE direction to a movement in a S—SW to N—NE direction is explained by a link-off of the ice-margin around the Torne River during the deglaciation of the ice.

With the present basic data, the changes of the ice movements in the main phase of the Weichsel glaciation (N—NW ice movements) to the ice movements of later periods (S—SW or W) can be explained by stating that these periods were separated by an interstadial period. The earlier period had a centre for the glaciation north-west of the investigated region and the later period a centre south-west of this region.

The later period, that is, the glaciation period after the last interstadial, produced a S—SW ice movement over the whole Pajala district during its main stage. The till deposits from this stage have comparatively small thicknesses in the southern parts of the investigation area but significant thicknesses in its northern parts (Hirvas 1977a, p. 130), which shows that this glacial stage was not as extensive as the main stage of the glaciation.

During the deglaciation period, the ice movement was still S—SW, with a tendency to turn from a straight southerly to a south-westerly direction in the northern parts of the region. In the southern and, mainly, in the south-eastern parts of the region, a turning from south—south-west to west took place in the final stage of the glaciation. South of the investigated area it seems possible to correlate a westerly direction to the main and deglaciation periods of the last glaciation, if comparisons are made with Fromm's conclusions (1965, pp. 121—130). This relation also shows that an ice margin in an approximately N—S direction must have existed in the south-eastern parts of the Pajala district. It is estima-

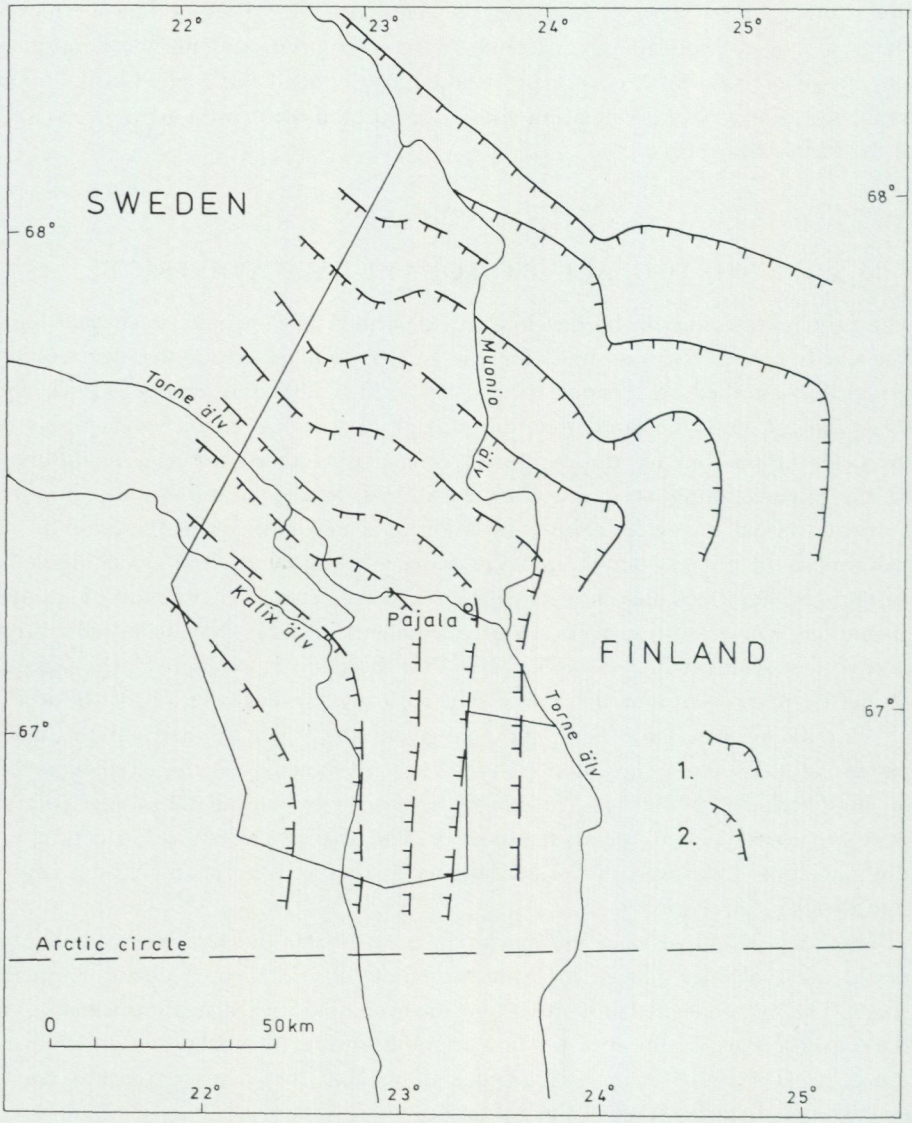


Fig. 31. A schematic picture of the deglaciation of the Pajala district. 1. Successive marginal positions of the glacier in western Finnish Lapland (after Kujansuu 1967b). 2. Hypothetical ice-recession lines in the Pajala district.

ted that, in the neighbourhood of Pajala and further south, the deglaciation took place from east to west, and north of Pajala mainly from north-east to south-west. The conclusions above can to a large extent be drawn from the knowledge of ice-movement directions which has been derived with the aid of striae (section 6.1), till fabric (subsection 6.2.2) and drumlins (subsection 6.2.1). Strong support for this deglaciation development is also given by the erosion and

accumulation forms (section 6.3) produced by the late-glacial melting water. The subglacially developed eskers in the northern parts of the investigated area show a retardation of the ice towards the south-west. The glaciofluvial marginal formations in the neighbourhood of Kihlanki indicate an ice margin in an approximately W—E direction and an ice retardation to the south-west. In the Pajala district observations in the area mapped by Fromm (1965) raise some doubts about the kind of glaciofluvial accumulations representing the last deglaciation periods (see section 6.3.1). The glaciofluvial accumulation forms in this part of the investigated area give, on the basis of what is known, only a diffuse picture of the retardation of the ice, but there are no relations that directly contradict the suggestion that the ice may have melted towards the south or south-west.

The formation and development of the ice lakes (subsection 6.3.3) assume an ice margin over the northern part of the Pajala district with a roughly E—W direction and a retardation towards the south. Large areas of ice-lake sediments have been observed as far as the neighbourhood of Junosuando (Fromm 1965, p. 135), which shows that the drainage channel of the Torne River was dammed by the ice retiring towards the south.

The erosion forms of the late-glacial water drainage (subsection 6.3.2), primarily the extra-marginal drainage channels, kursu valleys and to some extent also the gush channels and overflow channels, unambiguously show a deglaciation course in which the ice retired towards the south or south-west over most of the Pajala district.

Ice lakes, glaciofluvial marginal formations and some late-glacial drainage channels indicate ice margins here and there. However, it is very difficult to decide whether these ice margins originated from an active ice or are the remains of dead ice. It is also difficult to present detailed marginal sites of the retiring active ice from the existing material. For the same reasons, it seems more uncertain to compare chronologically different, ice-margin sites. For these reasons, the deglaciation course can only be schematically illustrated (Fig. 31).

The deglaciation course for western Finnish Lapland is described by Kujansuu (1967b, pp. 83—89). The main features of this work coincide well with the principal picture of the deglaciation course on the Swedish side. All the same it seems possible to correlate the ice movements for the latest glaciation phase in northern Finland to the corresponding relations in Sweden (Hirvas 1977a, p. 129, and section 7.1).

Fig. 31 shows schematically the deglaciation course for the Pajala district on the basis of the results in the present investigation, in Fromm (1965), and for the western part of Finnish Lapland on the basis of Kujansuu's results (1967b). The large ice-lake areas seem to indicate bends in the ice margin. This seems to be the case in the ice-lake areas at Muodoslompolo and Kitkiöjoki, and in the depression of the Lainio River, to judge from the late-glacial drainage chan-

nels. The sharp delimitation of the hummocky moraine, the so-called Lainio bow, west of the Lainio River, may be explained by stating that its eastern part must have been in contact with the ice-lake area along the Lainio River. The specific form of the Lainio bow (Fig. 25) should not be assigned to a marginal site of active ice but rather to the effect of the amount of glacier water that has been available in this area. In the light of the schematic deglaciation pattern, the Lainio bow cannot be described as a marginal formation of an active ice.

In the northern parts of Finland, the annual retreat of the ice was judged by Kujansuu (1967b, pp. 87—88) to have been 160—180 m a year and by others (Hoppe 1948, p. 85, Möller 1962, p. 141, and Fromm 1965, p. 113) to have been up to 300—400 m a year in the coastal region of Norrbotten. The present investigation cannot give any further information concerning the problem, but it seems reasonable that there should have been a slower retreat in the northern inland areas as compared to the coastal regions. With a mean retreat over the investigated region of 200 m a year, the Pajala district should have been deglaciated in about 700 years. In agreement with G. Lundqvist (1961, pp. 125—128), Fromm (1949, 1962, pp. 56—58, 1965, p. 209) and Kujansuu (1967b, p. 93), the deglaciation of the Pajala district started in Subarctic time (about 10 000 years BP) and ended in early Boreal time (about 9 000 years BP).

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APPENDIX I

DESCRIPTION OF THE GLACIAL-STRIAE LOCALITIES

The location is given by using the notation of the topographical map (for example, Korpilombolo NW), together with the x and y co-ordinates in the national grid system (for example, x:74256, y:18119).

K. 1. Location: Korpilomobolo NW, x:74256, y:18119. Depth: *c.* 0.2m. The outcrops have an indistinct and weathered striation running N 56°W. On the ridge, one can see a finer striation from S 7°W.

K 2. Location: Korpilombolo SW, x:74237, y:18121. Depth: 0—0.2 m. A large number of striae occur on different exposed outcrops. The striae directions are S—N (the direction which predominates), S 10—14°W, S 28°W, S 63—85°W, N 17—24°W, and N 78—86°W. Northerly and north-westerly striae occur only on the northern slopes. The south—south-westerly striae decrease on the northern ridges but continue and become thinner some centimetres on the northern side. On northern slopes, striae from the west occur. On a western slope, the westerly striae cross the southerly. The oldest striae are those from north or north-west, while the youngest seem to be from the west.

K 3. Location: Korpilombolo SW, x:74220, y:18116. Depth: 0—0.7 m. In the northern part of the outcrops, a 0.1 m long stria can be seen from N 22°W and some 0.01 m. long cuts from N 80°W. Over a large part of the outcrop, striae from S 87°W occur.

K 4. Location: Korpilombolo SE, x:74170, y:18271. Depth: 0.3—0.4 m. In the southern part of the outcrop, there are several striae from S 70°W. On a northern part of the outcrops also striae from S 70°W occur. Weak striae from N 24°W can also be seen. The N 24°W striae are probably older than those from S 50°W and S 70°W.

K 5. Location: Korpilombolo SW, x:74212, y:18237. Depth: 0—0.1 m. A weathered and rough surface which has striae only from N 24°W.

K 6. Location: Korpilombolo SE, x:74247, y:18254. Depth: *c.* 0.5 m. Only one direction, from N 35°W, occurs.

K 7. Location: Korpilombolo SW, x:74248, y:18238. Depth: 0.5—0.6 m. On the outcrop surface, striae from N 24°W can be seen. On the southern part, short cuts from S 4°E occur. On a surface declining towards the west, there are short cuts from N 71°W and a stria from S 82°W. The striae from N 24°W are probably the oldest and the S 82°W stria probably the youngest.

K 8. Location: Korpilombolo NW, x:74255, y:18234. Depth: *c.* 0.5 m. The predominant direction of the striae is from N 34°W. In the southern part of the outcrop, there are a few striae from S 4°E. In the western part, there are short striae from N 85°W.

K 9. Location: Korpilombolo NE, x:74355, y:18260. Depth: 0.2 m. On the outcrop surface, there are many weathered striae from S 55°W. On a southern slope, a marked stria from S 20°W can be observed.

K 10. Location: Korpilombolo NW, x:74461, y:18220. Depth: 0—0.4 m. Striae occur within the interval N 37—50°W, with the predominant direction from N 40°W. On a ridge, a weak microstriation running S 48°W can be seen crossing the striae from the north-west. On an outcrop 50 m from the previous one, striae occur from S 40°W. These are rough and about 0.1 m long. The oldest direction is N 40°W and the youngest *c.* S 40°W.

K 11. Location: Korpilombolo NW, x:74487, y:18131. Depth: 0.5 m. Striae from N 33°W occur on the outcrop. In a vein of harder material, striae from S 22°W can be seen. A clear facet has developed between the directions N 33°W and S 22°W where the S 22°W striae disappear towards the slope facing north. Older striae: N 33°W. Younger striae: S 22°W.

K 12. Location: Korpilombolo NW, x:74461, y:18070. Depth: 0—0.1 m. Striae from S 10°W occur all over the outcrop.

K 13. Location: Korpilombolo NW, x:74456, y:18071. Depth: 0—0.1 m. On an outcrop facing south, striae from S 10°W occur.

K 14. Location: Korpilombolo NW, x:74451, y:18073. Depth: 0—0.2 m. The outcrop is dominated by striae from S 4—10°W. Very indistinct striae from N 60°W can also be seen. It is, however, from the southerly direction that the outcrop surfaces have been formed.

K 15. Location: Korpilombolo NW, x:74443, y:18078. Depth: 0.2—0.3 m. On the outcrop, striae from S 8—10°W occur. An indistinct striation from N 80°W can also be seen.

K 16. Location: Tärendö SE, x:74516, y:17924. Depth: 0.2 m. An outcrop surface facing north-west has a striation from N 30°W.

K 17. Location: Tärendö SE, x:74588, y:17879. Depth: 0—0.2 m. On an outcrop facing west, a striation from S 78°W occurs. On another surface, striations from N 58—68°W predominate. It is also possible, with some hesitation, to distinguish striations from S 50°W and N 30°W.

K 18. Location: Tärendö SE, x:74562, y:17859. Depth: 0—0.1 m. Weathered but clear striae from S 32°W. On certain ridges, fine, thin striae from S 70°W can be found.

K 19. Location: Tärendö SE, x:74609, y:17871. Depth: 0.1—0.2 m. Striae from N 47°W have been found.

K 20. Location: Tärendö SE, x:74616, y:17881. Depth: 0.3—0.4 m. Striae can be found within the interval S 10°E to S 10°W.

K 21. Location: Tärendö SE, x:74622, y:17883. Depth: 0.3 m. The striae are from N 66°W.

K 22. Location: Tärendö SE, x:74637, y:17880. Depth: 0.3 m. Striae occur only from N 55°W.

K 23. Location: Tärendö SW, x:74661, y:17734. Depth: 0 m. Striation from N 44°W.

K 24. Location: Tärendö SW, x:74747, y:17699. Depth: 0—0.1 m. Striation from S 36°W.

K 25. Location: Tärendö SE, x:74690, y:17962. Depth: 0—0.5 m. On an outcrop surface exposed to the north, striae can be seen from N 54°W and N 70°W. On the ridge of an other part of the outcrop, striae occur at S 74°W.

K 26. Location: Tärendö SW, x:74525, y:17721. Depth: 0—0.3 m. On the eastern part of the outcrop, there is a good striation at N 73°W. On the western part of the same outcrop, there is a striation from N 58°W.

K 27. Location: Pajala NW, x:74797, y:18186. Depth: 0 m. On the rough surface certain elevations have been finely ground. On these, striae are to be found in the interval S 27—34°W.

K 28. Location. Pajala SW, x:74627, y:18210. Depth: 0.2 m. On the thrust side to the north-west, striae occur at N 54°W.

K 29. Location: Pajala NW, x:74802, y:18086. Depth: 1.5 m. On the outcrop, one can distinguish a clear striation from N 80°W.

K 30. Location: Pajala NW, x:74760, y:18169. Depth: 0 m. Striae 0.01 m wide with

a N 60°W direction sweep over the outcrop. This observation must be considered as rather uncertain.

K 31. Location: Pajala NW, x:74757, y:18170. Depth: 0.5 m. On a weathered surface, an unclear striation from N 80°W occurs. Twentyfive metres to the west, there are striae at S 25°W and N 80°W. The older are from N 80°W and the younger from S 25°W.

On another outcrop, there are younger striae from S 36°W and older from N 80°W.

K 32. Location: Pajala NW, x:74755, y:18173. Depth: 0.5 m. On an outcrop surface, there are fine striae from S 32°W. Fifteen metres to the west, a younger striation from S 32°W occurs and on the lee side towards the west, there is an older striation from N 80°W. On another outcrop surface, there is a clearly recorded relationship in age between the younger S 32°W and the older N 80°W striae.

K 33. Location: Pajala NW, x:74753, y:18183. Depth: 0.5 m. The outcrop has a well-turned, thrust side towards the south and clearly marked striae from S 34—36°W.

K 34. Location: Pajala SE, x:74557, y:18390. Depth: 0.5 m. The outcrop was shaped from the south-west and there is a clear striation from S 30°W.

K 35. Location: Pajala SE, x:74569, y:18380. Depth: 0.5 m. On an outcrop that declines towards the north, there are striae from N 5°W.

K 36. Location: Pajala NW, x:74936, y:18145. Depth: 0.5 m. Two directions occur. On the northern slopes of the outcrop, there are some preserved striae from N 70—76°W. On the ridges, the striae run S—N. Most probably the striae from N 70—76°W are older than those from S—N.

K 37. Location: Huuki SW, x:75095, y:18048. Depth: 0.3 m. Only one stria can be distinguished. This is *c.* 0.2 m long and its direction is N 86°W.

K 38. Location: Muonionalusta SW, x:75700, y:18025. Depth: 0—0.3 m. On an outcrop surface, there are some fine scratches from S 54°W.

K 39. Location: Muonionalusta SW, x:75737, y:18033. Depth: 0—0.4 m. Clear striae from S 49°W.

K 40. Location: Muonionalusta NW, x:75754, y:18110. Depth: *c.* 0.5 m. Several surfaces with clear striations on the thrust side. All the striae are in the S 58°W direction.

K 41. Location: Muonionalusta SW, x:75747, y:18109. Depth: 0.5 m. The outcrop is nicely polished and has a clear striation at S 61°W.

K 42. Location: Muonionalusta SW, x:75742, y:18110. Depth: 0.5 m. Several outcrop surfaces, all with clear striae at S 60°W.

K 43. Location: Korpilombolo SE, x:74078, y:18331. Depth: 0.3 m. A clear striation from N 64°W occurs.

— This locality and the following ones designated as K 44 — K54 are situated to the south of the investigated area.

K 44. Location: Korpilombolo SE, x:74107, y:18337. Depth: 0.5 m. On the outcrop, there are two striae systems with a clear relationship as regards age. The older system consists of the N 49°W striae, which cover the greater part of the outcrop. The younger system is the striae at S 8°W, which are visible on the ridges towards the south and may also be noted as short cuts on the surface dominated by north-western striae.

K 45. Location: Korpilombolo SE, x:74099, y:18340. Depth: 0—0.2 m. A predominant striation at N 58°W. On one of the surfaces, there is striation at N 28°W.

K 46. Location: Korpilombolo SE, x:74114, y:18377. Depth: 0.5— 1 m. A clear and abundant striation from N 60°W. On one of the surfaces, a weak scratch from S 20°W can be distinguished.

K 47. Location: Korpilombolo SE, x:74140, y:18359. Depth: 0—0.5 m. The outcrop surface is well ground and has a predominant striation at N 60°W. On a developed facet, there is visible on the south-facing part a fine striation at S 30°W.

K 48. Location: Korpilombolo SE, x:74168, y:18352. Depth: 0—0.5 m. On a few outcrop surfaces, there are striae from N 74°W.

K 49. Location: Korpilombolo SE, x:74143, y:18385. Depth: 0—0.3 m. On an outcrop surface, unclear striae can be seen at N 60°W.

K 50. Location: Korpilombolo SE, x:74199, y:18374. Depth: 0.3 m. On one surface, striae are clearly visible at N 86°W.

K 51. Location: Korpilombolo SE, x:74032, y:18397. Depth: 0.6 m. On the outcrops, there are striae from N 75°W.

K 52. Location: Korpilombolo SE, x:74031, y:18405. Depth: 0.3 m. Striae in only one direction at N 55°W.

K 53. Location: Korpilombolo SE, x:74068, y:18416. Depth 0—0.1 m. There are striae from N 47°W on the outcrop surfaces.

K 54. Location: Korpilombolo NW, x:74071, y:18415. Depth: 0—0.5 m. The outcrop has striae from N 54°W.

T 1. Location: Korpilombolo NW, x:74256, y:18195. Depth: 0 m. The outcrop surface is weathered and rough but a few striae from N 78°W can be distinguished.

T 2. Location: Korpilombolo NW, x:74357, y:18083. Depth: 0.5 m. On the richly striated outcrop, the following directions have been measured: N 25—38°W, S 18—30°W, S 56—84°W, W—E, and N 78—83°W. N 25—38°W must be the oldest direction, since these striae have been ground away on ridges and southerly declining surfaces. Traces of S 20°W striae can also be seen on the north-western slopes. On the ridges, thinner striations from W—E, S 56—84°W, and N 78—83°W appear. The oldest direction is N 30°W, and the next oldest S 20°W, while the youngest directions are from the W, S 56—84°W, and N 78—83°W.

T 3. Location: Korpilombolo NW, x:74273, y:18123. Depth: 0—0.1 m. Several outcrops appear. The measured directions of the striae are N 28—38°W, S 10—21°W and S 80—86°W. The north-westerly directions are older than the westerly.

T 4. Location: Korpilombolo NW, x:74252, y:18098. Depth: 0—0.1 m. The outcrops are dominated by older striae from N 20—30°W. These are crossed by striae from S 10—20°W, which appear especially on ridges and southern slopes. Further striae directions at N 8°W and N 38°W have been observed.

T 5. Location: Korpilombolo NW, x:74285, y:18133. Depth: 0 m. Striae from S 10—23°W (S 20°W is the predominant direction) N 74—82°W (N 82°W is the predominant direction) and N 20—22°W. The north-westerly striations occur especially on the north-western slope of the outcrop. On the western slope, one can clearly see how a stria from N 82°W cuts off several striae from S 20°W. The striae from N 20°W are probably the oldest, the ones from S 20°W the next oldest and the ones from N 82°W the youngest.

T 6. Location: Korpilombolo NE, x:74310, y:18283. See the description of the soil map (Fromm 1965, glacial-striae locality No. 5, p. 123). Older striae at N 15—23°W and younger at N 67—73°W.

T 7. Location: Korpilombolo NE, x:74239, y:18288. Depth: 0.5—1.0 m. One large boulder with a surface area of 2 x 1.5 m and a depth of more than 1.7 m is situated in a ditch. The boulder is well polished on the surface and also on the sides, with the exception of a small part on the eastern side, which is broken. The boulder has fine striae from N 80—84°W. It is not unlikely that the striae were scored without moving

the boulder, if comparisons are made with the till fabrics at the same locality (locality 10/17, Appendix II).

T 8. Location: Korpilombolo NE, x:74312, y:18280. Depth: 0—0.1 m. The N 20—30°W striae are the oldest, since they are found in depressions and in some cases striae from N 80°W cross them. It is also possible that striae from S 28°W are next oldest and those from N 80°W the youngest. The striae directions from N 65°W and S 60°W are more diffuse.

T 9. Location: Korpilombolo NW, x:74298, y:18249. Depth: 1—2 m. The outcrop was excavated on the thrust side of a 100 m long, 1—2 m high and about 20 m broad drumlin, oriented NNW—SSE. On the outcrop, there are striae from N 22°W.

T 10. Location: Pajala SW, x:74686, y:18013. Depth: 0.5 m. A fine system of striae from S 18—25°W. (S 22°W is the predominant direction) can be found on all surfaces. On the southern lee sides, there are fine striae running N—S and N 12°W. These are older than the southern striae.

T 11. Location: Pajala SE, x:74576, y:18283. Depth: 1.5—2.5 m. The striae on the rock surfaces that are 1.5 m below ground have a predominant direction from N 45°W. On a part sloping towards the south-west, there are 0.1 m long, indistinct striae at S 37°W and a very fuzzy striation at N 82°W. The striae from S 37°W cut down into those from N 45°W and constitute a younger generation. On another rock surface, 2—2.5 m below the ground, clear and predominant striations appear at N 70—75°W and N 80°W, crossing striae from N 45—50°W. The direction of the oldest striae is N 45°W. The direction of the younger striae is N 70—75°W and that of possibly the youngest S 37°W.

T 12. Location: Korpilombolo NW, x:74431, y:18203. Depth: 0 m. On the weathered outcrop, there are striae at N 28°W. On the ridge, a coarse stria from N 44°W occurs.

T 13. Location: Korpilombolo NW, x:74387, y:18188. Depth: 0 m. On an outcrop surface, a well-marked system of striae at N 26°W can be seen, crossed by striae from S 56°W. On another outcrop surface, there are clear striae at N 18°W. On a smaller ridge, there is a finer striation at N 82°W. Diffuse striae from S 35°W can also be traced. The oldest striae are probably those from the north-west, while those from S 56°W and S 35°W are younger.

T 14. Location: Korpilombolo NW, x:74365, y:18184. Depth: 1—2 m. The outcrop has been covered with glaciofluvial material. A weak, coarser striation at N 30—33°W can be distinguished.

T 15. Location: Korpilombolo NW, x:74443, y:18215. Depth: 0—0.5 m. Clear striae from N 35—52°W occur over the whole outcrop. More diffuse striations have been observed at S 48°W and S 88°W.

T 16. Location: Korpilombolo NW, x:74317, y:18209. Depth: 0 m. On the outcrop surface, there are unclear striations at N 52°W and S 52°W.

T 17. Location: Pajala SW, x:74515, y:18112. Depth: 0—0.5 m. On an outcrop surface sloping towards the west, single very coarse, older striae at N 32°W can be seen, covered with a pattern of coarse and fine striae from S 4°W—(S—N).

T 18. Location: Pajala SW, x:74557, y:18059. Depth: 0 m. On the weathered surface, a few very uncertain striae from S 18°W are to be seen.

T 19. Location: Pajala SW, x:74531, y:18006. Depth: 0—0.5 m. On a section of pegmatite, there are coarse striae at N 38°W. On the ridge and on a southern slope, there is a system of finer striae at S 2°E — S 10°E. Oldest striae: N 38°W. Youngest striae: S 2°E.

T 20. Location: Pajala SW, x:74537, y:18119. Depth: 0—0.5 m. The outcrop is dominated by striae running from S to N. On the northern part, there are a couple of coarse, older striae from N 32°W, which are situated on the lee side of the (S—N) striae.

T 21. Location: Korpilombolo NW, x:74434, y:18066. Depth: 1 m. Very coarse, older striae from S 10°W are crossed by a finer striation from S 40°W. On the ridge, a faintly outlined striation from S 60°W can be seen.

T 22. Location: Korpilombolo NW, x:74432, y:18069. Depth: 0—0.5 m. The outcrop that has its thrust side facing south is dominated by striae running from S to N. A younger striation from S 28°W can also be distinguished.

T 23. Location: Korpilombolo NW, x:74425, y:18060. Depth: 0—0.5 m. On the outcrop, indistinct striations occur running south to north and at S 30°W.

T 24. Location: Lansjärv NE, x:74321, y:17942. Depth: 0—0.5 m. The outcrop is very weathered. In a quartz vein on a slight slope towards the south, there is a microstriation at S 8°W.

T 25. Location: Korpilombolo SW, x:74227, y:18011. Depth: 0—0.5 m. Striae from N 28°W predominate and these turn to N 60°W in some cases. On a smaller surface, a finer, somewhat diffuse system of striae at N 5—10°W was measured.

T 26. Location: Korpilombolo SW, x:74217, y:18018. Depth: 0—0.5 m. The outcrop has a clear striation at N 28°W.

T 27. Location: Korpilombolo NW, x:74268, y:18035. Depth: 0 m. On several surfaces sloping towards the south, there are clear striations at S 20°W.

T 28. Location: Korpilombolo NW, x:74273, y:18037. Depth: 0 m. On the outcrop, striae occur at S 20°W.

T 29. Location: Korpilombolo NW, x:74297, y:18044. Depth: 0—0.5 m. The outcrop has striae from S 5—10°W.

T 30. Location: Korpilombolo NW, x:74302, y:18044. Depth: 0—0.5 m. Striae from S 20°W occur on thrust sides facing south.

T 31. Location: Korpilombolo NW, x:74323, y:18047. Depth: 0—0.5 m. The outcrop has striae from S 20°W on several surfaces. In the northern part, there is weak and indistinct striation at N 10°W.

T 32. Location: Tärendö NW, x:74827, y:17746. Depth: 0.5—1.0 m. Striae occur from N 45—50°W.

T 33. Location: Korpilombolo NW, x:74485, y:18096. Depth: 0—0.5 m. On a surface sloping towards the south, there is a fine striation at S 8°W.

T 34. Location: Pajala SW, x:74687, y:18128. Depth: 0—0.5 m. On the outcrop surface, there are plentifull striations at N 60°W and striations occur from S 18—20°W. The oldest striae are at N 60°W since these occur mostly on lee sides for the S 20°W striae. On an outcrop *c.* 100 m to the south, there is an older striation from N 45—50°W and a younger one from S 20°W.

T 35. Location: Pajala SW, x:74680, y:18127. Depth: 0.5 m. The outcrop is dominated by older, rough striae from N 50—57°W. On the ridges and on a slope towards the south, there is a younger, finer striation from S 20°W.

T 36. Location: Pajala SW, x:74669, y:18130. Depth: 1 m. There are striae at N 44°W and S 20°W, but they have no definable age relationship.

T 37. Location: Tärendö NE, x:74872, y:17870. Depth: 0.5 m. Striae occur at N 35°W.

T 38. Location: Pajala SW, x:74689, y:18058. Depth: 0—0.5 m. The outcrop is dominated by striae from N 45—50°W. On ridges and on slopes to the south, there are

clear and plentiful striations from S 20°W. The oldest striae are at N 45—50°W and the youngest at S 20°W.

T 39. Location: Pajala SE, x:74529, y:18365. Depth: 0.5 m. On one outcrop surface, striae can be seen from S 10°W. On another, there are striae from S 34—40°W and on yet another striae from S 20—30°W.

T 40. Location: Pajala SE, x:74719, y:18352. Depth: 0 m. On outcrop surfaces to the south, plentiful striations occur at S 8°W. On lee sides, there are indistinct striations from N 72°W.

T 41. Location: Pajala SE, x:74528, y:18405. Depth: 0.5 m. On the western slopes, plentiful, fine striations occur at S 83°W. On the lee sides, there are striae at S 30°W, which can be interpreted as an older direction.

T 42. Location: Korpilombolo NE, x:74487, y:18442. Depth: 1.5 m. Striae occur from N 60°W.

T 43. Location: Pajala SE, x:74504, y:18383. Depth: 0.5 m. Plenty of well-marked striae occur at S 34°W.

T 44. Location: Pajala SE, x:74536, y:18363. Depth: 0.5—1.0 m. On the outcrop, there are striae from S 4—10°W which disappear towards the north-sloping parts. Instead, older striae from N 52°W appear.

T 45. Location: Pajala SE, x:74539, y:18358. Depth: 0.5—1.0 m. The outcrop is dominated by striae from N 60°W. A finer, indistinct striation from S 4—14°W also occurs. Older striae: N 60°W. Younger striae: S 4—14°W.

T 46. Location: Korpilombolo NW, x:74269, y:18122. Depth: 0.4 m. On the outcrop there are striae at S 18°W. A somewhat diffuse striation at N 64—72°W also occurs on ridges as a microstriation and seems to have developed a facet, on the eastern side of which striae with a southerly direction occur plentifully. This may mean that the striae from N 64—72°W are younger than those from S 18°W.

T 47. Location: Lainio SW, x:75188, y:17525. Depth: 0 m. On outcrop surfaces towards the south-west, a plentiful striation at S 70°W occurs.

T 48. Location: Lainio SW, x:75201, y:17615. Depth: 0 m. Striae can be seen from S 50°W.

T 49. Location: Huuki NW, x:74374, y:18029. Depth: 0—0.1 m. One fine striation at N 74°W can be seen in a certain feldspar area. (Uncertain observation).

T 50. Location: Huuki SW, x:74189, y:18012. Depth: 0 m. Clear striae from N 70°W.

T 51. Location: Muonionalusta SW, x:75567, y:18243. Depth: 1—1.5 m. The outcrop has two systems with southern striae, S 10°W and S 45—50°W. The S 10°W striae are coarse and unclear and can be found within the interval S—N to S 20°W. The predominant direction is S 8°W.

T 52. Location: Muonionalusta SE, x:75570, y:18256. Depth: 0 m. The outcrop has been sculptured from the south. The striae are coarse and clear and have directions from S—N to S 20°W. The predominant direction is S 8°W.

T 53. Location: Muonionalusta SE, x:75602, y:18269. Depth: 1.5 m. The outcrop seems to have striae from S 70—80°E (N 70—80°W?). The striae occur most distinctly on south-eastern slopes. The estimation of the direction is somewhat doubtful.

T 54. Location: Muonionalusta SW, x:75652, y:18170. Depth: 0 m. Indistinct striations at S 20°W and S 40°W have been noted.

T 55. Location: Muonionalusta SW, x:75626, y:18205. Depth: 0.2—0.5 m. A striation at S 64°W has been noted.

T 56. Location: Muonionalusta SW, x:75625, y:18198. Depth: 0—0.5 m. An indistinct striation occurs at S 55°W.

T 57. Location: Muonionalusta SW, x:75537, y:18209. Depth: 0.5 m. On the southern sides of the outcrops, there are clear striations at S 4—8°E.

T 58. Location: Muonionalusta SW, x:75559, y:18244. Depth: 0 m. On the outcrop, which has been sculptured from the south, there is a coarse and distinct striation from S 10°W.

T 60. Location: Korpilombolo NE, x:74348, y:18398. Plentiful striations occur at N 50°W on the outcrop.

— The striae localities T 60—62 and T 64—66 are situated south of the investigation area.

T 61. Location: Korpilombolo NE, x:74267, y:18367. There is a coarse striation running from west to east.

T 62. Location: Korpilombolo SE, x:74198, y:18490. On the outcrop, a plentiful striation occurs at N 60—70°W. On the lee sides, there is a vague striation at N 10°W which is older.

T 63. Location: Huuki NW, x:75430, y:18101. Depth: 0 m. On the outcrop, there is a fine striation at S 10°W.

T 64. Location: Korpilombolo SW, x:74119, y:18053. On the outcrop, a clear striation occurs at N 24—34°W.

T 65. Location: Korpilombolo SW, x:74115, y:18050. Striae occur within the interval N 4° E to N 10° W. The predominant direction is N 4° W.

T 66. Location: Lansjärv SE, x:74183, y:17902. On the smooth outcrop surface, striae occur within the interval N 25—30°W.

APPENDIX II

DESCRIPTION OF THE TILL-FABRIC AND PARTICLE-COUNT LOCALITIES

The location is given by using the notation of the topographical map (for example, Korpilombolo SW), together with the x and y coordinates in the national grid system (for example, x:74179, y:18138).

1. Korpilombolo SW, x:74179, y:18138. A till section in an old pit. The section is 1.8 m high and 1.5 m wide.

0—1.0 m	Wave-washed till
1—1.8 m	Greyish-brown till, silty to fine sandy, with a high content of stones, with fissilities. In the till, lenses of sand occur

2. Korpilombolo SW, x:74177, y:18137. The fabric is from a newly-dug ditch. The section is 0.8 m deep and 1.5 m wide.

0—0.1 m	Brownish, wave-washed till
0.1—0.7 m	Brownish till, silty to fine sandy
0.7—0.8 m	Greyish till, silty to fine sandy

3, 4. Korpilombolo NW, x:74307, y:18104. A section in an old till pit. The whole formation gives the impression of having been deposited in plenty of glacial drainage water.

0—0.3 m	Gravelly sand
0.3—1.3 m	Light-brownish till, sandy, with lenses of sand and fine sand
1.3—2.0 m	Grey to greyish-green till, sandy with fissilities. At 1.7 m,

a fine-sandy lens with a width of *c.* 0.2 m which extends over the section

6, 7. Korpilombolo SW, x:74220, y:18218. An old till pit. The till is light, brownish-grey, sandy and softly consolidated.

8, 9. Korpilombolo SE, x:74173, y:18270.

0—0.05 m	Brownish, wave-washed till
0.05—0.8 m	Brownish-grey, sandy till
0.8—1.1 m	Greyish-brown till with weak fissilities

10, 17. Korpilombolo NE, x:74239, y:18288. In a ditch *c.* 1 m north-west of a large striated boulder. (Concerning the striae on the boulder see Appendix I, T 7.)

0—1.0 m	Brownish, sandy till with a low content of stones. It is rather firmly consolidated and has weak fissilities
1.1—1.5 m	Sandy till, dark grey. It has marked fissilities

11, 12. Korpilombolo NW, x:74365, y:18183. Section in a till pit.

0—0.3 m	Wave-washed sand
0.3—2.0 m	Sandy till, brownish-grey. At 2.0 m, there is a lens of sand and gravel

Till-covered, glaciofluvial material occurs in the section. The glaciofluvial material was to a large extent excavated.

13, 14. Pajala SE, x:74576, y:18283. A road section in a drumlin-like, flat, moraine ridge orientated SSW—NNE. At a depth of 0.4 m, the till is grey to greyish-green, sandy and rather loose. At a depth of 1.5 m, it is dark grey, sandy and firmly consolidated.

15, 16. Korpilombolo NW, x:74431, y:18202. A section in the south-western part of a till pit. The north-western part consists of glaciofluvial material. The till in which the analyses were made lies on the edge of the glaciofluvial deposit and one can clearly see the contact between them.

0—0.15 m	A light layer of silt, at the bottom a horizon with charcoal layers
0.15—0.5 m	Light, rust-brown, silty to fine sandy till with a developed soil profile
0.5—1.0 m	A rather loose, light-brown to grey till, sandy to fine silty
1.0—1.4 m	Greyish-brown, sandy to fine silty till, firmly consolidated and with fissilities

The till-covered sediments, which were discovered after the fabric analyses had been made, are described in the text (sub section 6.2.4.).

18. Korpilombolo NW, x:74403, y:18150. A large gravel pit with till on glaciofluvial matrial. The contact is clear. The ridge is orientated in a NW—SE direction. The place where the analysis was made is situated on the north-eastern side of the gravel pit.

0—0.2 m	Wave-washed sand and silt
0.2—c. 1.7 m	Light-brown, sandy till, rich in stones
c. 1.7—	Glaciofluvial material, sand and gravel

19. Korpilombolo NW, x:74415, y:18145. A gravel pit north-west of locality 18 in the same glaciofluvial deposit. In the eastern part of the gravel pit, the glaciofluvial material reaches the surface; in the western part, it is covered with till.

0—0.2 m	Wave-washed till
0.2—1.0 m	Light, brownish-grey till, sandy and with fissilities
1.0—	Glaciofluvial material, sand

20, 21. Pajala SW, x:74559, y:18185. An old till pit with sloping walls. The section was *c.* 5 m deep. The formation can be described as a large drumlin orientated NW—SE.

0—0.5 m	Light, rust-coloured, sandy till
0.5—1.2 m	Light-brown till, sandy, firmly consolidated with fissilities

22, 23, 24. Korpilombolo NW, x:74355, y:18084. A section in a ditch.

0—0.2 m	Rust-coloured, sandy till
0.2—0.4 m	Sandy till, greyish-brown
0.4—1.2 m	Sandy till, brownish-grey
1.2—1.3 m	Sandy till, brownish-grey, with fissilities
1.3—1.4 m	Greyish, silty to fine sandy till with fissilities
1.4—	Outcrop

The till is poor in boulders and stones.

25, 26. Tärendö SE, x:74715, y:17800. An old till pit.

0—0.6 m	Light-brown, sandy to fine silty till
0.6—1.0 m	Grey, rather firmly consolidated, silty to fine sandy till

27, 28. Tärendö SE, x:74612, y:17768. An old till pit.

0—0.2 m	Light-brown, silty to fine sandy till
0.2—0.4 m	Greyish-brown, silty to fine sandy till
0.4—1.2 m	Grey, sandy till

At 0.9 m, there is a vein of sand. The till is poor in boulders.

29. Tärendö SE, x:74548, y:17772. An old till pit in a moraine ridge orientated NNW—SSE.

0—0.2 m	Rust-brown, silty to fine sandy till
0.2—0.5 m	Light-brown, silty to fine sandy till
0.5—0.7 m	A grey to light-brown, silty to fine sandy till
0.7—1 m	Light-brown, silty to fine sandy till

The analysis was made at a depth of 0.5 m.

30. Pajala SW, x:74536, y:18067. A large till pit. The section was 50 m wide and 5 m high.

0—0.4 m	Brown, wave-washed till
0.4—5 m	Grey, silty to fine sandy till with fissilities

31, 32. Pajala SW, x:74556, y:18070. A section was dug from the ground level in a drumlin-like formation, orientated N—S.

0—0.3 m	Rust-brown, wave-washed till
0.3—1.0 m	Grey to greyish-brown, sandy till
1.0—1.1 m	Grey to greyish-brown, sandy till, firmly consolidated

34, 36. Lansjärv NE, x:74339, y:17873. A small till pit.

0—0.6 m	Loose, rust-brown, sandy till
0.6—1.2 m	Greyish-brown, sandy till

35. Lansjärv SE, x:74235, y:17968. A large, drumlin-like formation orientated NW—SE.

0—0.4 m	Rust-brown silt
0.4—1.2 m	Loose, grey, sandy till

The material has been greatly affected by water.

37. Lansjärv NE, x:74325, y:17868. A small till pit in a large, drumlin-like formation orientated NW—SE.

0—0.4 m	Rust-brown, sandy till
0.4—1.0 m	Grey, relatively firmly consolidated, sandy till

38, 39. Lansjärv NE, x:74453, y:17816. Till pit on the southern edge of an irregular hill of moraine.

0—0.2 m	Rust-brown, sandy till
0.2—1.5 m	Grey, sandy till

40. Lansjärv NE, x:74370, y:17887. In a large, drumlin-like formation orientated NW—SE.

0—0.4 m	Rust-brown, silty to fine sandy till
0.4—0.8 m	Grey, firmly consolidated, sandy till

41, 42. Lansjärv NE, x:74280, y:17980.

0—0.5 m	Loose, light-rust-brown, silty to fine sandy till
0.5—1.2 m	Grey, firmly consolidated, sandy till

43, 44. Tärendö NE, x:74767, y:17895.

0—0.3 m	Rust-brown, sandy till
0.3—1.0 m	Light-brown, stony, sandy till with fissilities
1.0—1.3 m	Grey to greyish-green, sandy till, relatively firmly consolidated

45, 46. Tärendö NW, x:74853, y:17735. On the proximal side of a large drumlin formation orientated NW—SE.

0—0.5 m	Rust-brown, sandy till
0.5—1.0 m	Light-brown, relatively loose, sandy till
1.0—1.3 m	Relatively firmly consolidated, grey, sandy till with fissilities

47, 48. Tärendö NE, x:74832, y:17769. A large section of till in an irregular hill of moraine.

0—0.3 m	Rust-brown, sandy till
0.3—1.7 m	Grey to greyish-green, sandy till

49, 60. Tärendö NW, x:74942, y:17728.

0—0.3 m	Rust-brown, sandy till
0.3—1.0 m	Grey, sandy till with fissilities, relatively loose
1.0—2.0 m	Firmly consolidated, grey, sandy till

50, 51. Tärendö SW, x:74746, y:17721. An old till pit with a *c.* 3 m high section.

0—0.25 m	Rust-red, silty to fine sandy till
0.25—0.75 m	Greyish-brown, sandy till
0.75—1.2 m	Sandy till, grey with rust-red features

The till is loose, with enclosed sand lenses.

52. Tärendö SW, x:74721, y:17706. An old till pit.

0—0.3 m	Rust-brown, sandy till
0.3—1.5 m	Grey, stony, sandy till

54, 55. Tärendö NW, x:74759, y:17671. An old till pit, situated on a ridge orientated in NW—SE.

0—0.3 m	Rust-brown, sandy till
0.3—1.2 m	Grey, sandy till with rust-red features

The till is loose. From *c.* 0.9 m, a rough outline of fissilities can be seen.

56, 57. Tärendö NW, x:74785, y:17644. An old till pit.

0—0.2 m	Light-brown, sandy till
0.2—0.7 m	Greyish, light-brown, sandy till
0.7—1.2 m	Grey, sandy till

The till is loose and has a remarkably high content of sand and silt, which also appears as veins.

58, 71. Tärendö NW, x:74829, y:17646. An old till pit.

0—0.2 m	Rust-brown, sandy till
0.2—1.2 m	Sandy till, grey with brown features

59, 70. Tärendö SW, x:74743, y:17688. An old till pit in a moraine ridge orientated N—S.

0—0.2 m	Rust-brown, sandy till
0.2—1.2 m	Grey, sandy till

61, 62. Tärendö NE, x:74830, y:17813. The site is situated in a ditch.

0—1.4 m	A light-brown, stony, sandy till

63, 64. Tärendö NE, x:74891, y:17810. The location is situated on the edge of the Lainio bow in a formation elongated west-east.

0—0.3 m	Rust-brown, sandy till
0.3—1.5 m	Grey, sandy till with fissilities

65, 66. Tärendö NE, x:74971, y:17775.

0—0.3 m	Rust-brown, silty to fine sandy till
0.3—1.0 m	Grey, silty to fine sandy till, loose and poor in stones
1.0—1.4 m	Grey, sandy till with a relatively high content of stones. Firmly consolidated

67, 68. Tärendö NE, x:74989, y:17795.

0—0.3 m	Rust-brown, silty to fine sandy till
0.3—1.7 m	Loose, grey, sandy till

69. Tärendö NE, x:74850, y:17900. Flat, elongated, moraine ridge orientated NW—SE.

0—0.3 m	Rust-brown, sandy till
0.3—1.1 m	Sandy till, grey, relatively firmly consolidated with fissilities

72, 73. Tärendö SE, x:74553, y:17843. A road section *c.* 4 m high in a moraine ridge with a NW—SE orientation.

0—0.2 m	Rust-brown, sandy till
0.2—0.3 m	Light-brown, sandy till
0.3—1.3 m	Grey, sandy till with lenses of sand

74, 75. Tärendö SE, x:74548, y:17833. A *c.* 2 m high road section in a NW—SE-orientated, moraine ridge.

0—0.25 m	Rust-red, silty to fine sandy till
0.25—1.1 m	Grey, sandy till

76, 77. Pajala SW, x:74515, y:18078. A road section in a moraine ridge orientated SSE—NNE.

0—0.1 m	Rust-red, silty to fine sandy till
0.1—1.1 m	Stony, sandy till, brownish-grey

78. Pajala SW, x:74533, y:18118.

0—0.15 m	Rust-red, sandy silt
0.15—0.30 m	Light-brown, sandy till
0.3—0.7 m	Grey, sandy till

81, 82. Pajala SE, x:74684, y:18307. A small moraine ridge orientated NW—SE.

0—0.2 m	Rust-brown, sandy till
0.2—0.7 m	Light-brown, sandy till
0.7—1.5 m	Greyish-brown, sandy till

83. Pajala SE, x:74718, y:18306.

0—0.6 m	Light-brown, sandy till with fissilities
0.7—1.0 m	Grey, sandy till with fissilities

84, 85. Pajala SE, x:74560, y:18433.

0—0.5 m	Loose, rust-brown, silty to fine sandy till
0.5—1.0 m	Light-brown, sandy till with clear fissilities
1.0—1.3 m	Grey, sandy till with fissilities

86, 87. Korpolombolo NE, x:74486, y:18443.

0—0.2 m	Rust-brown, sandy till
0.2—1.4 m	Grey, sandy till, loose but with fissilities

88. Pajala NW, x:74852, y:18134. A ridge formation orientated E—W.

0—0.4 m	Rust-brown, sandy till
0.4—0.8 m	Light-brown, sandy till

89, 110. Pajala NW, x:74959, y:18143. A ridge formation orientated NW—SE.

0—0.5 m	Light-brown, gravelly, sandy till
0.5—1.3 m	Light-brown to grey, sandy till with fissilities. In the upper part, veins of sand occur.

90, 91. Pajala SW, x:74681, y:18066. A ridge formation orientated SW—NE.

0—0.4 m	Brown silt with parts containing sand and gravel
0.4—1.1 m	Grey, sandy till with weak fissilities

92, 93. Pajala SW, x:74654, y:18113. A ridge formation running SSW—NNE.

0—0.3 m	Brownish-red, silty to fine sandy till
0.3—0.7 m	Grey, sandy till
0.7—1.1 m	Brownish-red, sandy till with sand lenses

94, 95. Tärendö SE, x:74651, y:17826. An old till pit.

0—0.1 m	Rust-red silt
0.1—0.3 m	Light-brown, silty to fine sandy till
0.3—0.7 m	Brownish-grey, sandy till
0.7—1.2 m	Firmly consolidated, grey, sandy till

96. Pajala NW, x:74803, y:18096. An old till pit in a ridge orientated SW—NE.

0—1.0 m	Greyish-brown, sandy till with fissilities

97, 98. Tärendö NE, x:74997, y:17868. An old till pit.

0—0.3 m	Rust-red, sandy till
0.3—0.6 m	Brown, sandy till
0.6—1.3 m	Grey, firmly consolidated, sandy till

99, 100. Lainio SE, x:75092, y:17815. A section in a till pit.

0—0.2 m	Rust-brown, sandy till

0.2—0.9 m	Light-greyish, brown, sandy till
0.9—1.2 m	Grey, very firmly consolidated, sandy till

102, 103. Pajala NW, x:74771, y:18148.

0—0.2 m	Light-brown, sandy till
0.2—2.2 m	Light-brownish-grey, sandy till with lenses of sand

104, 105. Pajala SW, x:74736, y:18228. A road section in a NW—SE-orientated, ridge formation.

0—0.1 m	Rust-red, silty to fine sandy till
0.1—1.6 m	Light-brownish-grey, silty till

106, 123. Pajala SE, x:74581, y:18317. Section in a till pit.

0—0.1 m	Rust-red, silty to fine sandy till
0.1—1.3 m	Light-brownish-grey, silty to fine sandy till

108, 109. Pajala SE, x:74531, y:18311. An elongated, moraine ridge running from N 10°W to S 10°E.

0—0.3 m	Rust-red, sandy till
0.3—0.55 m	Light-brown, sandy till
0.55—1.3 m	Grey, sandy till

111, 112. Pajala NW, x:74929, y:18106.

0—0.4 m	Loose, light-brown, silty to fine sandy till
0.4—1.5 m	Greyish-brown, sandy till, relatively loose and with fissilities

113, 114. Pajala NW, x:74981, y:18091.

0—0.4 m	Rust-brown, loose, silty to fine sandy till
0.4—0.8 m	Rust-brown, sandy till with fissilities
0.8—1.3 m	Grey, sandy till with fissilities

115, 116. Pajala NW, x:74952, y:18061.

0—0.6 m	Light-rust-brown, sandy till
0.6—1.3 m	Light-grey, sandy till with fissilities

117, 118. Tärendö NE, x:74880, y:17963.

0—1.2 m	Brown, sandy till

119, 120. Pajala NW, x:74896, y:18047.

0—0.1 m	Brown, sandy till, poor in stones
0.1—1.2 m	Grey to greyish-green, sandy till

121. Pajala NW, x:74754, y:18181. A section of ditch alongside a small newly made road.

0—0.3 m	Rusty, sandy till
0.3—1.3 m	Brownish-grey, sandy till, firmly consolidated
1.3—	Outcrop

122, 124. Pajala NW, x:74799, y:18247. Two till beds, according to Järnefors (1952). The moraine morphology is irregular.

0—0.7 m	Light-brown, sandy till with fissilities
0.7—2.5 m	Light-grey, sandy till

130, 131. Pajala NW, x:74853, y:18176.

0—0.2 m	Brown, sandy till
0.2—1.2 m	Grey to greyish-green, silty to fine sandy till

134, 135, 136. Pajala NW, x:74893, y:18221.

0—0.6 m	Brown, sandy till, less firmly consolidated than the underlying layers. Fissilities
0.6—4.0 m	Grey, sandy till. Firmly consolidated

137, 138. Pajala NW, x:74965, y:18217. The section is situated in a large till pit. Under the till, the schist bedrock can be seen.

0—0.2 m	Sand and gravel
0.2—0.5 m	Brown, sandy till, with a *c.* 0.15 m thick vein of gravel towards the underlying till
0.5—1.3 m	Greyish-brown, sandy till with fissilities
1.3—5.0 m	Grey, sandy till

139, 140. Huuki SW, x:75014, y:18145. Section in a large till pit.

0—0.4 m	Brown, sandy till with sediment lenses
0.4—1.5 m	Grey, sandy till with fissilities

145, 146. Huuki SE, x:75012, y:18291.

0—0.2 m	Rust-brown, sandy till with fissilities
0.2—1.2 m	Grey to brownish-grey, sandy till, rather firmly consolidated

147, 148. Huuki SW, x:75125, y:18129.

0—1.1 m	Brown sandy till
1.1—	Grey, sandy till. The transition in colour is sharp

154, 155. Huuki SW, x:75167, y:18207.

0—0.3 m	Reddish-brown, silty to fine sandy till
0.3—1.2 m	Grey, silty to fine sandy till

156, 157. Huuki SE, x:75170, y:18256.

0—0.3 m	Brown, sandy till
0.3—0.7 m	Grey, sandy till with sand lenses
0.7—1.0 m	Grey, sandy till with fissilities
1.—2.0 m	Sandy and gravelly sediments

Till-covered sediments occur in the section, which is built up in a complex way, with a large content of sorted material.

160, 161. Lainio SE, x:75141, y:17920.

0—0.1 m	Light-grey, silty to fine sandy till
0.1—0.3 m	Reddish-brown, silty to fine sandy till
0.3—0.7 m	Greyish-brown, silty to fine sandy till
0.7—1.2 m	Brown, sandy till

164, 165. Lainio SE, x:75227, y:17963.

0—0.2 m	Brown, sandy till
0.2—1.5 m	Brownish-grey, sandy till, loose

166, 167. Huuki SW, x:75184, y:18009.

0—0.4 m	Brown, silty to fine sandy till
0.4—1.2 m	Brownish-grey, silty to fine sandy till

168, 169. Huuki SE, x:75040, y:18372.

0—0.1 m	Rust-brown, sandy till
0.1—1.0 m	Greyish-brown, sandy till
1.0—1.2 m	Grey, sandy till

170, 171. Pajala NE, x:74795, y:18281.

0—0.3 m	Brown, sandy till
0.3—1.2 m	Grey, sandy till

172, 173. Pajala NE, x:74965, y:18340.

0—.0.2 m	Rust-brown, silty to fine sandy till
0.2—0.3 m	A stone horizon in the till
0.3—1.2 m	Grey, sandy till with sand lenses

In the eastern part of the till pit, the stone horizon is missing and firmly consolidated lenses of sand occur.

176, 177. Pajala NE, x:74895, y:18295.

0—0.2 m	Rust-red, sandy till
0.2—1.2 m	Grey to brownish-grey, sandy till

178, 179. Pajala NE, x:74913, y:18393.

0—0.2 m	Brown, sandy till
0.2—1.2 m	Grey to brownish-grey, sandy till with fissilities

181,182. Huuki NW, x:75256, y:18145.

0—0.3 m	Brown, sandy till
0.3—0.4 m	Greenish-grey, sandy till
0.4—	Greenish-grey, sandy till with fissilities

183, 184. Huuki NW, x:75272, y:18101.

0—0.2 m	Brown, sandy till, stone enrichment
0.2—0.4 m	Brown, sandy till
0.4—1.2 m	Greenish-grey, sandy till

185, 186. Huuki SW, x:75239, y:18109.

0—0.3 m	Reddish-brown, silty to fine sandy till
0.3—1.0 m	Grey, silty to fine sandy till, with fissilities

190, 191. Huuki NE, x:75281, y:18253.

0—0.4 m	Light-brown silt with features of sand
0.4—1.5 m	Brown, sandy till

192, 193. Huuki NW, x:75284, y:18218.

0—0.3 m	Rust-brown, sandy till, firmly consolidated with fissilities
0.3—0.6 m	Greyish-brown, sandy till with fissilities
0.6—1.3 m	Grey, sandy till

194, 195. Huuki NW, x:75341, y:18194.

0—1.2 m	Brown, silty to fine sandy till with fissilities

200. Huuki NW, x:75429, y:18221.

0—0.9 m	Brown, sandy till with fissilities
0.9—1.2 m	Grey, silty to fine sandy till
1.2—	Sandy sediments

201. Huuki NW, x:75395, y:18127.

0—0.1 m	Rust-red, sandy till
0.1—0.5 m	Light-brown, sandy till
0.5—	Outcrop

203. Huuki NW, x:75319, y:18236.

0—0.15 m	Silty sediments

0.15—6.0 m Grey, sandy till

Part of the till section is built up in a complex way with features of sediment. A good deal is hidden by large amounts of slide material.

204, 205. Huuki NW, x:75474, y:18157.
0—0.3 m Sandy till
0.3—1.5 m Loose, grey, sandy till

210, 211. Lainio NE, x:75357, y:17930.
0—1.5 m Light-brown, sandy till, poor in stones

212, 213. Muonionalusta SW, x:75600, y:18160.
0—1.5 m Brown (downwards greyish-brown), sandy till

216. Muonionalusta SW, x:75629, y:18058.
0—1.5 m Greyish-brown, silty to fine sandy till

218. Huuki SE, x:75184, y:18259.
0—0.7 m Light-brown, silty to fine sandy till

230. Muonionalusta NW, x:75775, y:18112.
0—1.0 m Sandy till

231. Muonionalusta SW, x:75625, y:18191.
0—0.7 m Sandy till with veins of sand

232. Muonionalusta SE, x:75601, y:18268.
0—0.8 m Sandy till

Appendices continued on p. 104 ff.

APPENDIX III

TILL FABRICS

The positions of the localities are shown in connection with the description of the localities in Appendix II and in Fig. 16. The factor (% /°) is the ratio of the percentage of the particles in an interval to the breadth of the interval. Subjective evaluation of the fabric: good, fairly good (F. good), fairly bad (F. bad), bad and unjudgeable (Unjudg.).

Locality no.	Main dir., degrees	Breadth of interval, degrees	Sub.dir., degrees	Depth below ground level, m	Upper, middle, lower, single analysis	Other fabric in same locality	Evaluation of fabric	Factor % / °
1	N40W	N40-60W	-	1.2	Single	-	Good	1.2
2	N70W	N50W-(E-W)	-	0.5	Single	-	Bad	0.8
3	W-E	N80W-(W-E)	-	1.0	Upper	4	Good	1.7
4	N20W	N20W	-	2.0	Lower	3	Good	1.4
3/4	-	-	-	1.0-2.0	Upper+lower	-	Unjudg.	-
6	-	-	-	1.2	Lower	7	Unjudg.	0
7	S40W	S30-70W	-	0.3	Upper	6	Good	1.0
6/7	S70W	S70W-S40E	-	0.3-1.2	Upper+lower	-	F.good	1.0
8	S10W	S10E-S30W	-	0.5	Upper	9	Good	1.1
9	S10W	S10-30W	-	1.0	Lower	8	Good	1.7
8/9	S70W	S10-30W	N10W	0.5-1.0	Upper+lower	-	Good	1.4
10	W-E	N80W-S80W	-	0.7	Upper	17	Good	1.3
11	N70W	N50-70W	-	0.6	Upper	12	Good	1.1
12	S10W	S10W	S30W	1.5	Lower	11	Good	1.7
11/12	-	-	-	0.6-1.5	Upper+lower	-	Unjudg.	0
13	N30W	N30-60W	N10W	1.5	Lower	14	Good	1.2
14	N40W	N30-80W	-	1.1	Upper	13	F.good	1.0
13/14	N30W	N30-60W	-	1.1-1.5	Upper+lower	-	Good	1.1
15	N20W	N10-50W	-	0.7	Upper	16	Good	1.6
16	N40W	N20-70W	-	1.2	Lower	15	Good	1.4

15/16	N40W	N10-N60W	-	0.7-1.2	Upper+lower	-	Good	1.3
17	-	-	-	1.5	Lower	10	Unjudg.	0
10/17	E-W	N80W-80E	-	0.7-1.5	Upper+lower	-	F.good	1.0
18	-	-	-	0.7	Single	-	Unjudg.	0
19	S20W	S20E-S40W	-	0.7	Single	-	F.good	0.9
20	S30W	S30-50W	S-N	0.7	Upper	21	Good	1.4
21	S50W	S40-60W	-	1.2	Lower	10	Good	1.4
20/21	S50W	S30-60W	-	0.7-1.2	Upper+lower	-	Good	1.3
22	N70W	N60-80W	-	0.4	Upper	23/24	Good	2.0
23	N70W	N70W-(E-W)	N20W	0.9	Middle	22/24	Good	1.4
24	N30W	N10-40W	-	1.3	Lower	22/23	Good	1.4
22/23/24	N70W	N60-(E-W)	S40W	0.4-1.3	Upper+lower	-	F.good	1.1
25	S50W	S30-70W	-	0.5	Upper	26	Good	1.5
26	S30W	S10-40W	-	1.0	Lower	25	Good	2.0
25/26	S30W	S10-60W	-	0.5-1.0	Upper-lower	-	Good	1.4
27	W-E	S60W-N80W	-	0.5	Upper	28	Good	1.3
28	S50W	S40-70W	-	1.0	Lower	27	Good	1.2
27/28	S60W	S50-70W	E-W	0.5-1.0	Upper+lower	-	F.good	1.1
29	S10W	S10E-S30W	-	0.5	Single	-	Good	1.3
30	N20W	N10-30W	N50W	1.0	Single	-	Good	1.4
31	N20W	N10-30W	S10W	0.7	Upper	32	Good	2.0
32	N20W	N10-30W	S10-20W	1.0	Lower	31	Good	1.7
31/32	N10W	N10-30W	S10-20W	0.7-1.0	Upper+lower	-	Good	1.9
34	-	-	-	0.8	Upper	36	Unjudg.	0
35	N60W	N60-80W	-	0.8	Single	-	Good	2.3
36	S60W	S30-80W	-	1.2	Lower	34	Good	1.1
34/36	S60W	S60-40W	-	0.8-1.2	Upper+lower	-	F.bad	1.0
37	-	-	-	1.0	Single	-	Unjudg.	0

Appendix III (continued)

Locality no.	Main dir., degrees	Breadth of interval, degrees	Sub.dir., degrees	Depth below ground level, m	Upper, middle, lower, single analysis	Other fabric in same locality	Evaluation of fabric	Factor % / o
38	S20W	S10-40W	-	1.0	Upper	39	Good	1.8
39	S20W	(S-N)-S40W	-	1.5	Lower	38	F.good	1.1
38/39	S20W	S10-40W	-	1.0-1.5	Upper+lower	-	Good	1.5
40	S30W	S20-30W	-	0.7	Single	–	F.bad	1.2
41	N40W	N40-70W	-	0.5	Upper	42	Good	1.4
42	N50W	N50-70W	-	1.0	Lower	41	Good	1.8
41/42	N50W	N30-70W	-	0.5-1.0	Upper+lower	-	Good	1.4
43	S40W	S30-60W	-	0.7	Upper	44	Good	1.2
44	S40W	S10-70W	-	1.2	Lower	43	F.bad	1.0
43/44	S30W	S30-50W	-	0.7-1.2	Upper+lower	-	F.good	1.2
45	S20W	S10-60W	S80W	0.7	Upper	46	F.good	1.0
46	S30W	S10-40W	N20W	1.2	Lower	45	F.good	1.2
45/46	S30W	S10-40W	-	0.7-1.2	Upper+lower	-	F.good	1.1
47	S20W	S20-60W	-	0.9	Upper	48	F.bad	0.9
48	-	-	-	1.4	Lower	47	Unjudg.	0
47/48	-	-	-	0.9-1.4	Upper+lower	-	Unjudg.	0
49	N60W	N30-80W	-	0.7	Upper	60	F.good	1.1
50	S30W	S10-50W	-	0.5	Upper	51	Good	1.2
51	S50W	S50W	N50W	1.0	Lower	50	Bad	1.1
50/51	S30W	S30-50W	-	0.5-1.0	Upper+lower	-	F.bad	1.0
52	S70W	S40-80W	-	0.5	Single	–	Good	1.6
54	S10W	S10W	-	0.5	Upper	55	F.bad	1.2
55	-	-	-	1.0	Lower	54	Unjudg.	0

54/55	-	-	-	0.5-1.0	Upper+lower	-	Unjudg.	0
56	N40W	N40-60W	-	0.5	Upper	57	Good	1.2
57	S70W	S60-70W	-	1.0	Lower	56	F.good	1.1
56/57	-	-	-	0.5-1.0	Upper+lower	-	Unjudg.	0
58	S40W	S20-40W	-	0.5	Upper	71	Good	1.1
59	S70W	S40-80W	-	0.5	Upper	70	Good	1.3
60	N60W	N40-80W	-	2.0	Lower	49	Good	1.3
49/60	N60W	N40-80W	-	0.7-2.0	Upper+lower	-	Good	1.2
61	S10W	S10-40W	-	0.8	Upper	62	Good	1.3
62	S50W	S30-80W	-	1.3	Lower	61	F.good	1.2
61/62	S30W	S10-70W	-	0.8-1.3	Upper+lower	-	F.good	1.0
63	S70W	S70-80W	S10-40W	0.7	Upper	64	F.good	1.2
64	N60W	N40-70W	-	1.2	Lower	63	F.good	1.2
63/64	S70W	S70-80W	N60W	0.7-1.2	Upper+lower	-	Bad	0.9
65	S10W	S10-30W	S70W	0.7	Upper	66	F.bad	1.1
66	-	-	-	1.2	Lower	65	Unjudg.	0
65/66	-	-	-	0.7-1.2	Upper+lower	-	Unjudg.	0
67	S70W	S70-80W	-	0.7	Upper	68	F.good	1.2
68	S40W	S40-80W	0	1.5	Lower	67	F.bad	0.9
67/68	S70W	S70-80W	-	0.7-1.5	Upper+lower	-	F.bad	1.0
69	S40W	S30-50W	-	1.0	Single	-	F.good	1.1
70	S70W	S70-80W	-	1.0	Lower	59	F.bad	1.1
59/70	S70W	S40-80W	-	0.5-1.0	Upper+lower	-	F.good	1.1
71	-	-	-	1.0	Lower	58	Unjudg.	0
58/71	-	-	-	0.5-1.0	Upper+lower	-	Unjudg.	0
72	N40W	N40W	-	0.5	Upper	73	F.bad	1.2
73	-	-	-	1.0	Lower	72	Unjudg.	0

Appendix III (continued)

Locality no.	Main dir., degrees	Breadth of interval, degrees	Sub.dir., degrees	Depth below ground level m	Upper, middle, lower, single analysis	Other fabric in same locality	Evaluation of fabric	Factor % / o
72/73	-	-	-	0.5-1.0	Upper+lower	-	Unjudg.	0
74	-	-	-	0.5	Upper	75	Unjudg.	0
75	S70W	S50-80W	-	1.0	Lower	74	F.good	1.0
74/75	S60W	S60W	-	0.5-1.0	Upper+lower	-	Bad	1.0
76	S10W	S10W	S40W	0.5	Upper	77	Good	1.8
77	N10W	N10E-N10W	-	1.0	Lower	76	Good	1.5
76/77	N10W	N10E-N10W	-	0.5-1.0	Upper+lower	-	Good	1.3
78	S20W	S20W	-	0.5	Single	-	F.good	1.4
81	S70W	S60-80W	N70W	0.6	Upper	82	F.bad	1.0
82	S80W	S50-80W	-	1.2	Lower	81	Good	1.7
81/82	S80W	S50-80W	-	0.6-1.2	Upper+lower	-	Good	1.3
83	S50W	S30-70W	-	0.7	Single	-	Good	1.5
84	S50W	S30-70W	-	0.7	Upper	85	Good	1.1
85	N30W	N10-50W	-	1.2	Lower	84	Good	1.1
84/85	-	-	-	0.7-1.2	Upper+lower	-	Unjudg.	0
86	S10W	S10-40W	-	0.6	Upper	87	Good	1.5
87	N40W	N10-40W	-	1.2	Lower	86	F.good	1.1
86/87	S10W	S10W-S10E	-	0.6-1.2	Upper+lower	-	F.good	1.1
88	S20W	S10-60W	-	0.7	Single	-	F.good	1.2
89	S50W	S40-70W	-	0.6	Upper	110	F.good	1.1
90	-	-	-	0.6	Upper	91	Unjudg.	0
91	S50W	S50W	S10W	1.1	Lower	90	Good	1.6
90/91	-	-	-	0.6-1.1	Upper+lower	-	Unjudg.	0

92	S10W	S10E-S40W	-	0.5	Upper	93	Good	1.3
93	N10W	(N-S)-N30W	-	1.0	Lower	92	Good	1.1
92/93	S10W	S40W-S10E	-	0.5-1.0	Upper+lower	-	F.good	1.0
94	S10W	S10-30W	-	0.5	Upper	95	F.bad	1.0
95	-	-	-	1.0	Lower	94	Unjudg.	0
94/95	-	-	-	0.5-1.0	Upper+lower	-	Unjudg.	0
96	S40W	S40W	-	0.7	Single	-	Good	1.8
97	N10W	N10-30W	-	0.5	Upper	98	Good	1.6
98	S10W	S10E-S20W	-	1.2	Lower	97	Good	1.5
97/98	N10W	N20W-N10W	-	0.5-1.2	Upper+lower	-	Good	1.4
99	S40W	S30-70W	-	0.5	Upper	100	Good	1.2
100	S30W	S20-80W	-	1.0	Lower	99	Good	1.2
99/100	S40W	S20-70W	-	0.5-1.0	Upper+lower	-	Good	1.2
102	S40W	S30-40W	N60W	0.5	Upper	103	F.bad	1.1
103	S40W	S10-50W	-	2.0	Lower	102	Good	1.5
102/103	S40W	S20-50W	-	0.5-2.0	Upper+lower	-	Good	1.3
104	S10W	S10-30W	N10-40W	0.5	Upper	105	F.bad	1.3
105	S-N	N10E-S30W	-	1.5	Lower	104	F.good	1.2
104/105	S10W	S30W-S20E	-	0.5-1.5	Upper+lower	-	F.good	1.1
106	N10W	N30W-N10E	-	0.7	Upper	123	Good	1.5
108	-	-	-	0.5	Upper	109	Unjudg.	0
109	N80W	N50-80W	-	1.2	Lower	108	F.good	1.0
108/109	N50W	N20-80W	-	0.5-1.2	Upper+lower	-	Bad	0.8
110	S30W	S10-40W	-	1.2	Lower	89	Good	1.5
89/110	S40W	S10-50E	-	0.6-1.2	Upper+lower	-	F.good	1.1
111	S80W	S60-80W	-	0.7	Upper	112	Bad	1.0
112	S20W	(S-N)-S30W	-	1.2	Lower	111	Good	1.3
111/112	S20W	(N-S)-S30W	S70W	0.7-1.2	Upper+lower	-	F.good	1.0

Appendix III (continued)

Locality no.	Main dir., degrees	Breadth of interval, degrees	Sub.dir., degrees	Depth below ground level, m	Upper, middle, lower, single analysis	Other fabric in same locality	Evaluation of fabric	Factor % /o
113	S30W	(S-N)-S40W	S60-70W	0.7	Upper	119	F.good	1.1
114	S30W	S10-50W	-	1.2	Lower	113	F.good	1.1
113/114	S40W	S20-40W	-	0.7-1.2	Upper+lower	-	F.good	1.1
115	S40W	S40W	N60W	0.7	Upper	116	Bad	1.3
116	S40W	S10-50W	-	1.2	Lower	115	Good	1.6
115/116	S40W	S10-50W	-	0.7-1.2	Upper+lower	-	Good	1.2
117	S40W	S30-50W	-	0.7	Single	—	Good	1.5
119	S20W	(S-N)-S40W	-	0.7	Upper	120	Good	1.4
120	S30W	S30-50W	N-S	1.2	Lower	119	F.good	1.0
119/120	S20W	(S-N)-S40W	-	0.7-1.2	Upper+lower	-	Good	1.3
121	S10W	S10-40W	-	0.5	Single	—	Good	1.8
122	N80W	N50W-(E-W)	-	2.0	Lower	124	F.good	1.0
123	N60W	N60W	-	1.2	Lower	106	F.good	1.6
106/123	N20W	N10-20W	-	0.7-1.2	Upper+lower	-	Good	1.4
124	S30W	S10-40W	-	0.6	Upper	122	Good	1.3
122/124	S20W	S10-40W	-	0.6-2.0	Upper+lower	-	Bad	0.8
130	S70W	S30-80W	-	0.7	Upper	131	F.good	1.0
131	S30W	S20-70W	-	1.2	Lower	130	Good	1.3
130/131	S40W	S20-70W	-	0.7-1.2	Upper+lower	-	Good	1.1
134	N60W	N40-70W	S70W	0.5	Upper	135/136	Bad	0.8
135	W-E	S50W-N70W	-	1.2	Lower	134/136	F.bad	0.8
136	S-N	N20W-N20E	-	0.5	Upper	134/135	Good	1.2
134/136	S-N	S10W-S10E	-	0.5	Upper+lower	-	F.good	1.0

134/135/136	-	-	-	0.5-1.2	Upper+lower	-	Unjudg.	0
137	S20W	(S-N)-S20W	S60W	0.7	Upper	138	F.bad	0.8
138	S30W	S30W-S10E	-	1.2	Lower	137	F.good	1.0
137/138	S20W	(S-N)-S20W	-	0.7-1.2	Upper+lower	-	F.bad	0.9
139	N30W	N20-30W	-	0.7	Upper	140	F.bad	1.0
140	N10W	N10-30W	-	1.2	Lower	139	F.good	0.9
139/140	N30W	N30-10W	-	0.7-1.2	Upper+lower	-	F.good	1.0
145	S30W	S20-50W	-	0.7	Upper	146	Good	1.3
146	-	-	-	1.2	Lower	145	Unjudg.	0
145/146	S30W	S10-40W	-	0.7-1.2	Upper+lower	-	F.good	1.0
147	S50W	S40-50W	N20W	0.7	Upper	148	F.good	1.4
148	N10W	N40W-N10E	-	1.2	Lower	147	F.good	0.8
147/148	-	-	-	0.7-1.2	Upper+lower	-	Unjudg.	0
154	-	-	-	0.7	Upper	155	Unjudg.	0
155	S30W	S20-40W	-	1.2	Lower	154	Bad	0.7
154/155	-	-	-	0.7-1.2	Upper+lower	-	Unjudg.	0
156	S40W	S20-80W	-	0.7	Upper	157	F.good	1.0
157	S70W	S60-70W	-	1.2	Lower	156	F.bad	1.1
156/157	S70W	S60-70W	S20W	0.7-1.2	Upper+lower	-	F.good	1.3
160	S30W	S20-30W	-	0.7	Upper	161	F.good	1.2
161	-	-	-	1.2	Lower	160	Unjudg.	0
160/161	S30W	S20-30W	-	0.7-1.2	Upper+lower	-	F.bad	1.0
164	N70W	N70-30W	-	0.7	Upper	165	F.bad	0.8
165	S20W	S30W-S10E	N40W	1.2	Lower	164	F.good	1.0
164/165	S10W	(S-N)-S10W	-	0.7-1.2	Upper+lower	-	F.bad	0.8
166	S40W	S20-50W	-	0.7	Upper	167	F.good	1.0
167	-	-	-	1.2	Lower	166	Unjudg.	0
166/167	S50W	S20-80W	-	0.7-1.2	Upper+lower	-	Bad	0.7

Appendix III (continued)

Locality no.	Main dir., degrees	Breadth of interval, degrees	Sub.dir., degrees	Depth below ground level, m	Upper, middle, lower, single analysis	Other fabric in same locality	Evaluation of fabric	Factor % / o
168	N20W	N10-40W	-	0.7	Upper	169	Good	1.3
169	N50W	N30-80W	-	1.2	Lower	168	Good	1.3
168/169	N40W	N20-60W	-	0.7-1.2	Upper+lower	-	Good	1.2
170	-	-	-	0.7	Upper	171	Unjudg.	0
171	S80W	S70-80W	S10W	1.2	Lower	170	F.bad	1.1
170/171	S80W	S80W	S20W	0.7-1.2	Upper+lower	-	F.bad	1.3
172	S60W	S30-80W	-	0.7	Upper	173	F.bad	0.8
173	-	-	-	1.2	Lower	172	Unjudg.	0
172/173	S50W	S40-50W	-	0.7-1.2	Upper+lower	-	F.bad	0.9
176	S-N	S30W-S20E	-	0.7	Upper	177	Good	1.0
177	S20W	S20-40W	N10W	1.2	Lower	176	F.good	1.0
176/177	S10W	S40W-S10E	-	0.7-1.2	Upper+lower	-	F.good	0,9
178	-	-	-	0.7	Upper	179	Unjudg.	0
179	-	-	-	1.2	Lower	178	Unjudg.	0
178/179	S20W	S20-60W	N70W	0.7-1.2	Upper+lower	-	F.bad	0.8
181	S30W	S10E-S50W	N10W	0.7	Upper	182	Good	1.0
182	S20W	S40W-S20E	-	1.2	Lower	181	Good	1.0
181/182	S20W	S50W-S10E	-	0.7-1.2	Upper+lower	-	Good	1.0
183	S10W	S10-40W	N80W	0.7	Upper	184	F.good	1.1
184	S-N	(S-N)-S10W	N20W	1.2	Lower	183	F.good	1.2
183/184	S10W	(S-N)-S30W	-	0.7-1.2	Upper+lower	-	Good	1.0
185	S40W	S40-70W	-	0.7	Upper	186	Good	1.3
186	S50W	S40-60W	-	1.2	Lower	185	Good	1.5

185/186	S50W	S40-70W	-	0.7-1.2	Upper+lower	-	Good	1.3
190	N40W	N40W	N10W	0.7	Upper	191	Bad	1.1
191	N10W	N20W-N20E	-	1.2	Lower	190	Good	1.0
190/191	N10W	(N-S)-N20W	-	0.7-1.2	Upper+lower	-	Good	1.0
192	N60W	(W-E)-N40W	-	0.7	Single	-	Good	1.3
194	S10W	S10W-S10E	S50W	0.7	Upper	195	Bad	0.8
195	S60W	S50-60W	N10W	1.2	Lower	194	F.bad	1.3
194/195	S50W	S50-70W	N10W	0.7-1.2	Upper+lower		Bad	0.9
200	S-N	S40E-S20W	-	0.7	Single	-	F.bad	0.8
201	S80W	S70W-N80W	S40W	0.7	Single	-	F.bad	0.8
203	N80W	(W-E)-N60W	-	0.7	Single	-	Good	1.4
204	S20W	S10W-S20E	S80W	0.7	Upper	205	F.bad	0.8
205	S-N	S10W-S10E	-	1.2	Lower	204	Good	1.2
204/205	S-N	S30W-S20E	-	0.7-1.2	Upper+lower	-	F.good	0.9
210	S70W	S40W-S70W	S20W	0.7	Upper	211	F.good	1.0
211	S70W	S50W-S70W	-	1.2	Lower	210	Good	1.1
210/211	S70W	S50W-S70W	-	0.7-1.2	Upper+lower	-	Good	1.1
212	S80W	(W-E)-S70W	-	0.7	Upper	213	Good	1.5
213	S80W	(W-E)-S70W	-	1.2	Lower	212	Good	1.5
212/213	S80W	(W-E)-S70W	-	0.7-1.2	Upper+lower	-	Good	1.5
216	S50W	S40-70W	S20W	0.7	Single	-	F.good	0.8
218	S50W	S30W-S50W	N10W	0.7	Single	-	Good	1.2

APPENDIX IV

PARTICLE COUNTS

The distribution of rock types as percentages of the different particles.

Locality no.	Granite	Gneiss	Syenite	Green-stones	Gabbro	Porphyry	Quartzite	Granite poor in quartz	Skarn	Magnetite	Schist	Not ident. part.	No. of counted part.
1	21.0	5.7	9.8	6.2	37.1	8.7		3.1	6.7	0.5		1.0	194
2	19.2	30.8	6.8	3.6	5.9	8.8	1.2	2.4	21.9				169
3	30.6	22.3	5.6	4.8	7.9	4	3.2	11.9	7.2	0.8			126
4	22	21.3	15.3	2.8	14.6	4.4	1.2	13.4	3.2	0.4		1.6	254
6	25.5	31.5	15.5	10.5	5	1.5		9.5				1.0	200
7	33.9	13	8.3	7.3	24.4	3.6		4.7				3.6	192
8	20	31.3	32.5	1.3	4.4			3.8				4.4	160
9	8.6	19	26.4	3.7	22.7	1.2		15.3				0.6	163
10	46.1	15.1	14.8	3.4	3.8	4.2	2.4	6.2	3	1.0			291
11	19.4	25.9	17.5	3.2	11.6	4.6	1.9	8.4	6.1			0.6	155
12	15.6	27.3	13.7	5.5	7.7	5	0.9	16.4	4.6	0.5		0.5	219
15	55.3	23.2	1.8	3.6	4.8		0.6	4.8				3	168
16	52.3	22.7	2.3	6.3	3.9	0.8						0.8	128
17	21.4	26	11.7	6.2	9.6	1.2	2.5	18.7	1.6			1.3	239
18	46.2	35.5	5.3	4.7	9.0			4.2					189
19	39.1	40.1	4.5	2.0	4.5	2		4.0					197
20	23.2	22.2	13.4	11.4	6.5	3.9	2.3	6.1	8	1.9		0.4	262
21	14	24.4	10.5	12.9	10	5.5	2.5	6.5	12.5	0.6		1.0	201
22	40	28	6.4	10.2	5.6	2.3	3.0		3.8			0.8	265
23	34.7	19.7	14.2	5.4	6.4	4.9	2.0	2.5	7.8	1.0		1.8	204
24	32.6	22	17.8	12.8	8.5	3.5	0.5		1.4			0.7	141

25	35.9	37.8	5.1	13.9	3.1	0.5	2.1	1.5	1.0		2.1	195
26	27.3	29.6	7.4	3.4	5.1	5.1	2.8	9.1	6.9	1.7	1.7	176
27	50.2	23.6	4.4	2.9	3.4	3.9	1.0		6.7	1.0	2.9	207
28	39.9	29.8	5	4.4	5.5	3.9	2.8	3.9	3.9		1.1	181
30	26	18	18.0	10	11.3		0.7	10.0			1.3	150
31	38.9	15.3	11.5	10.5	9.4	0.5	2.1	9.4			1.1	190
32	38.8	24.7	8.8	7.1	12.3	1.2		4.1			1.2	170
34	67.8	13.4	5.2	1.6	4.1	1.5	1.0		1.5	1.0	2.6	193
36	65.2	16.3	5	3.4	2.2	2.3	1.1		3.9		0.6	178
43	33	13	9.3	20	10	6.9	2.3				3.1	130
44	32.4	16.9	21.2	9.1	14.8	3.5	0.7	6.3			1.4	142
45	21.8	24.3	10.9	4.5	12.4	2.1	2.1	14.0	2.6	4.7	0.5	193
46	18.8	40.6	8.4	4.1	10.9	5.2	2.6	4.2	4.7	0.5		192
47	17.4	20.2	14.1	3.3	10.8	8	4.2	12.7	2.3	3.8	2.8	213
48	30.1	12	13.8	5.6	11.2	8.8	4.2	7.8	2.3	2.3	1.9	216
50	32.4	28.3	6.1	6.1	7.2	5.1	1.0	8.8	2	2.6	1.0	194
51	35.3	29.7	6.7	9.1	2.4	7.4	1.8		3	3	1.2	164
56	32.8	35.6	5.5	6.5	9.8		1.0	1.0	2.7	0.5	3.3	183
57	40.3	35	3	7.1	1.8	2.4	1.2	0.6	2.4	4.7	1.8	169
58	32.8	14.5	10.6	7.3	6.7	5.5	4.4	11.6	6.1	0.6		180
61	3.5	82.0	2	2	1.5		2	0.5	1.5	0.5	4.5	200
62	6.8	82.6	1.9	2.4	3.4	0.5	0.5				1.9	207
63	21.5	14.9	15	10.5	13	0.5	1.0	11.5	2	1	5.5	200
64	23.9	13.6	10.4	14.5	6.2	2	3.6	16.6	6.7	1.6	0.5	192
71	53.2	17.3	1.4	7.3	7.3	6.7	1.4		4.4	0.5	0.5	207
72	43.6	15.6	7.6	2.3	7.1	1.9	3.8	13.2	2.8	2.4		211
73	50	16.1	8.1	2.8	3.8	3.8	0.5	8.6	5.2	1.9	1.4	219
76	44.7	10.5	5	5	11.6	3.3	1.7	11	4.4	1.1	1.7	181

Appendix IV (continued)

Locality no.	Granite	Gneiss	Syenite	Green-stones	Gabbro	Porphyry	Quartzite	Granite poor in quartz	Skarn	Magnetite	Schist	Not ident. part.	No. of counted part.
77	48.4	15.3	4.9	4.5	3.6	1.3	1.3	14.8	3.1	0.9		1.8	223
78	41.9	26.5	1.7	16.3	8.5	0.9		1.7				1.7	117
84	65.5	18.3	2.0	2	1	1	1.5	2.5	4	1		1	197
85	53.1	25.7	0.9	3.5	2.7	0.4	1.3	6.6	4.9	0.4		0.4	226
86	51.7	25.8	2	5.4	6.3			3.4	2	0.5		2.9	205
87	51.4	25.9	1.9	4.1	8.3	2.8		1	4.6	0.5			216
89	30.9	23.4	21.3	15.5	3.2			4.8				2.1	188
90	31.5	16.4	4.2	19.4	5.4	2.4	2.4	6.6	4.8	4.2		2.4	165
91	18.6	15.3	10.2	15.8	6.8	6.8	1.1	10.7	10.1	1.7		2.8	177
92	27.5	13.7	13.2	9.9	6.6	4.8	2.4	10	9.5	1.4		0.9	211
93	24.4	16	13.3	9.1	10.6	5.8	2.1	5.9	6.4	5.9		0.5	188
94	58.2	13.5	4.7	5.3	3.5	1.8	0.6	4.1	5.3	0.6		2.4	170
95	51.8	15.6	5.4	4.2	4.2	4.8		7.8	3	1.2		1.2	166
96	72.3	13.4	8.1	0.4	2.4			2.4					246
99	57.3	25	2.7	2.7	10.7			0.7				0.7	150
100	53.9	23	1	5.7	8	0.5		0.9					213
106	38.2	29.1	6.5	2.5	3	2	1	8.5	5.5	0.5		2.0	199
110	23.6	27.6	14.1	13.5	4.5	1.5		12				1.0	199
117	73.1	8		10.4	2.8				1.9				212
120	61.5	15		7.8	8.8	1.3			2.2		0.4	2.7	226
123	44.2	18.6	5.0	7.7	10	0.7	0.7	5.7	4.3			2.9	140
131	50.3	33.3		7.6	3	0.8	0.8		1.9		0.4	1.9	264
134	39.2	21.3		28.4	5	1.1	1.1		0.4			3.6	278

135	67.8	18.6	8.8	2					2.9	205
136	34	20.4	31.5	6.2			1.2	0.8	5.0	241
138	72.3	15.7	5.6	2.2		0.3	1.6	0.3	1.9	318
140	84.9	12.3	0.6	1.2			0.6		0.6	172
146	60.4	23.2	9.5	1.1	0.4	0.8	1.5	1.1	1.9	263
147	70.4	22	4.1	1.6		0.8	1.2			246
148	88	8	3.2						0.9	218
154	96.2	3.7								242
155	86.7	12	0.4	0.4	0.4					233
157	64	27.3	4.7	1.9	0.5				0.9	214
161	88.4	9.2	4.8				0.4		0.4	250
164	88.5	8.3	1.3			0.4			6.3	231
165	94.2	2.2	1.9	0.4		0.4	0.4		0.4	261
166	86.3	6.6	2.5			2.9	0.4		0.4	239
167	91.7	3.2	1.8	0.7		1.8	0.4		0.7	277
168	65.3	22.1	6.5	1.2		1.8	1.2	0.9	1.2	340
169	61.8	28.6	3.3	0.6		0.9	0.9	1.8	1.8	325
170	45.9	35.7	12	1.3	0.4	0.4	1.7	1.3	1.3	233
172	58.3	18.9	9.9	4.1		2.7	1.7	1.4	3.1	290
173	59.1	23	12.2	0.6	0.6	1.5	0.6	0.6	1.8	335
177	58	19.6	13.1		2	1.5	2	2.5	2	198
178	52.2	32.9	8.6	0.3		1.7	1.7	0.3	2.4	288
179	55.7	27.4	8.4	1.2	0.4	1.6	2		3.2	248
182	76.3	14.5	4.3	0.3	0.3	1	2	0.7	0.7	304
184	79.1	9.1	3.4	0.7	0.3	2.8	1	0.7	2.8	287
186	80.3	11.9	2.3	1.5		1.2			2.7	260
190	70	11.7	9.4	5	0.6	1.1	0.6		1.7	180
191	63.5	17.7	6.7	7.4		2.2			1.5	271

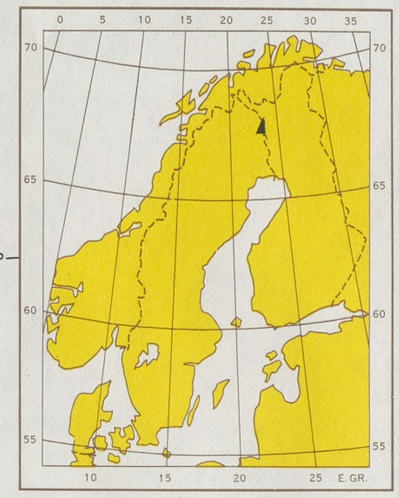
Appendix IV (continued)

Locality no.	Granite	Gneiss	Syenite	Green-stones	Gabbro	Porphyry	Quartzite	Granite poor in quartz	Skarn	Magnetite	Schist	Not ident. part.	No. of counted part.
192	75.1	5.9		4.7	4.7		6.3				0.4	2.8	254
195	94.6	1.8		2.5	1.1								276
200	66.6	25.8		2	4.4		0.4				0.4	1.6	252
201	94.5	2.8		2.8									254
203	63.2	24.5		2.9	4.1		1.2		1.7			2.5	242
205	40.2	42.7		4.4	8.9	0.4	0.7		0.4		0.7	1.8	281
211	96.2	1.6		0.4	0.8						0.4	0.4	237
213	53.8	37.4		2.1	3.3		1.1					2.2	182
216	69.9	17.3		2.4	5.3		2		0.3		0.7	2.3	302
230	52	35.5		2.7	6.6		1.6				0.5	0.5	183
231	57.9	32.2		3.3	2.2		1.1		0.5			2.7	183
232	57.2	37.3		1.7	3.4							0.4	236

QUATERNARY DEPOSITS OF THE NORTHERN PART OF PAJALA DISTRICT

JORDARTSKARTA ÖVER NORRA DELEN AV PAJALA KOMMUN

By Torbjörn Fagerlind



Peat deposits
Torv

Fine sediments (clay and silt)
Lera, mjäla och finmo

Coarse sediments (sand and gravel)
Grovmo, sand och grus

Ridgeshaped deposit
Ryggformad avlagring

Till with scattered outcrops of Precambrian rocks
Morän med enstaka urbergshällar

Late glacial drainage channel
Torrdal

Glacial striae
Räfflor

Godkänd ur sekretessynpunkt för spridning. Statens lantmäteriverk 1978–09–28

Scale 1:200 000

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