Bulletin de la

Commission Géologique

de Finlande

N:o 232

On the deglaciation of western Finnish Lapland

by Raimo Kujansuu

Geologinen tutkimuslaitos · Otaniemi 1967

Bulletin de la Commission Géologique de Finlande N:o 232

ON THE DEGLACIATION OF WESTERN FINNISH LAPLAND

BY

RAIMO KUJANSUU

WITH 51 FIGURES IN TEXT AND TWO APPENDED MAPS

GEOLOGINEN TUTKIMUSLAITOS
OTANIEMI 1967

ABSTRACT

The interpretation of aerial photographs has been applied to the study of the glacial geology of western Finnish Lapland. The combined evidence of field data and aerial photographs leads to the conclusion that there were three stages in the movement of the ice over this region. The third stage was marked by a conspicuous deviation in the direction of the ice flow. Genetically and morphologically different late-glacial erosion and accumulation forms distinguish the morphological glacial zones. The extramarginal drainage channels enable the reconstruction of the successive positions of the receding ice margin. The data provided by the lateral meltwater channels indicate that the annual rate of thinning down of the ice sheet was three meters and its gradient averaged 2.3 m to each 100 m. It may therefore be estimated that the final recession of the ice from northeast to southwest took approximately 800 years in western Finnish Lapland.

Helsinki 1967. Valtion painatuskeskus

ACKNOWLEDGMENTS

While mapping Quaternary deposits in western Finnish Lapland since 1959, I have paid particular attention to the evidences of the retreat of the continental ice sheet and to late-glacial formations. In studying these phenomena, I have endeavored to take full advantage of aerial photographs. The interpretation of photographs has also played an important part in the mapping of Quaternary deposits, substantially reducing the amount of field work involved and otherwise expediting operations. The interpretation of photographs has proved an effective means of, among other things, determining the final directions of flow of the continental ice sheet as well as mapping and genetically classifying the channels eroded by meltwaters and the accumulations of material dating from the deglaciation stage. It was the late Dr. Seppo Penttilä, a splendid teacher and loyal comrade of mine both in the field and in indoor work, who inspired my interest in glacial geology and in the interpretation of aerial photographs. I shall always remember him with quite special gratitude.

I wish to acknowledge my debt to my teachers in the field of Quaternary geology at the University of Helsinki, Professor Emeritus Väinö Auer and his successor Professor Joakim Donner. I am grateful to the former for his fascinating lectures and his encouraging and stimulating attitude toward my research work in Lapland, and to the latter for his constructive suggestions and good counsel during the writing stage of my study.

I thank Professor Vladi Marmo, Director of the Geological Survey of Finland, for having authorized the publication of this paper in the Bulletin de la Commission géologique de Finlande.

Then, it gives me pleasure to express my appreciation to Professor Esa Hyyppä, head of the Department of Quaternary Deposits of Geological Survey, for our many fruitful discussions on glacial geology as well as for the valuable advice he has been able, as a veteran Lapland explorer, to give younger colleagues like myself. Thanks are further due to Dr. Kalevi Virkkala and Dr. Marjatta Okko, who during their conscientious reading of the manuscript made many useful suggestions.

The field assistants in the mapping operations carried out by the Geological Survey in western Lapland during the years 1961—66 were Messrs Erkki Arppe, Heikki Hirvas, Seppo Koho, Pertti Lahermo, Sakari Leskelä and Martti H. Salmi. In thanking them all at the same time for their excellent work, I wish to extend Mr. Salmi an extra handshake of appreciation for having been my closest co-worker for about two years and for also having participated in the compilation tasks involved in making certain maps. I remember with warm feelings my ever-helpful handy man and boatman, Sauli Valkama. Mr. Paul Sjöblom translated my Finnish manuscript into English, and the illustrations and maps reproduced in the following pages were copied for printing by Miss Satu Moberg and Mrs. Pirkko Oranne. My warmest thanks to them, too!

I am also deeply grateful for the two grants awarded me by the Emil Aaltonen Foundation to help finance my glaciogeological research work in Lapland.

Otaniemi, June 1967

Raimo Kujansuu

CONTENTS

INTRODUCTION

Earlier studies

The region of the investigation (Fig. 1), referred to as western Finnish Lapland in this paper, is situated in the northwesternmost part of Finland. In the west it is bounded by Sweden and in the north by Norway. The region consists of the communes of Enontekiö and Muonio as well as parts of the communes of Inari, Kittilä and Kolari. Its southern boundary is 67°13′30″ north latitude and its eastern boundary 25°30′ east longitude. The most western point, where the borders of Finland, Norway and Sweden meet, is situated at 20°36′ east longitude and the most northern, Haltitunturi *), at 69°18′ north latitude. The area of the region covered by the investigation is roughly 20 750 square kilometers.

The most prominent of the very early investigators of the glacial geology of western Finnish Lapland was Väinö Tanner, whose first study was published in 1907. It dealt with the ancient ice-dammed lake of Kilpisjärvi in the westernmost part of the region (Tanner 1907). In 1915 Tanner published his extensive study on the movements and the melting of the continental ice sheet as well as on the geological formations associated with these phenomena in northern Fennoscandia. Western Finnish Lapland is included in the territory studied by him. In addition to the foregoing, Tanner dealt with the region in several other works, which date, *e.g.*, from 1911, 1936, 1937 and 1938. The one listed last is very broad of scope and describes the physiography of Finland as a whole. The study dated 1937 also discusses a certain esker situated in the farthest northwestern corner of the region now under investigation, the so-called esker of Tälisvuompuoltsha. The elucidation of the genesis of

*) Haltitunturi = Mount Halti

In this initial connection, it might be useful to point out the difficulty of dealing with Finnish (and Lappish) place names in English translation because of the agglutinative nature of the Finno-Ugrian languages. Thus, H a l t i is the proper name and t u n t u r i, meaning fell, has been added organically, to become a postfix. Postfixes frequently occurring in the text to follow include:

joki (eno, eädnu, johka) = river
järvi (javri, jaure) = lake
kero (oaivi, tsohkka) = top of a fell
kuru (kurra) = gorge
tunturi (tuoddar) = fell, mountain
vaara (varri) = hill, (rarely) fell or mountain,
vuoma (vuobmi) = broad river valley

Examples: Muonionjoki = Muonio river, Ounasjärvi = Lake Ounas, Yllästunturi = Mount Ylläs, or Ylläs fell, Njamahoaivi = Njamah fell.

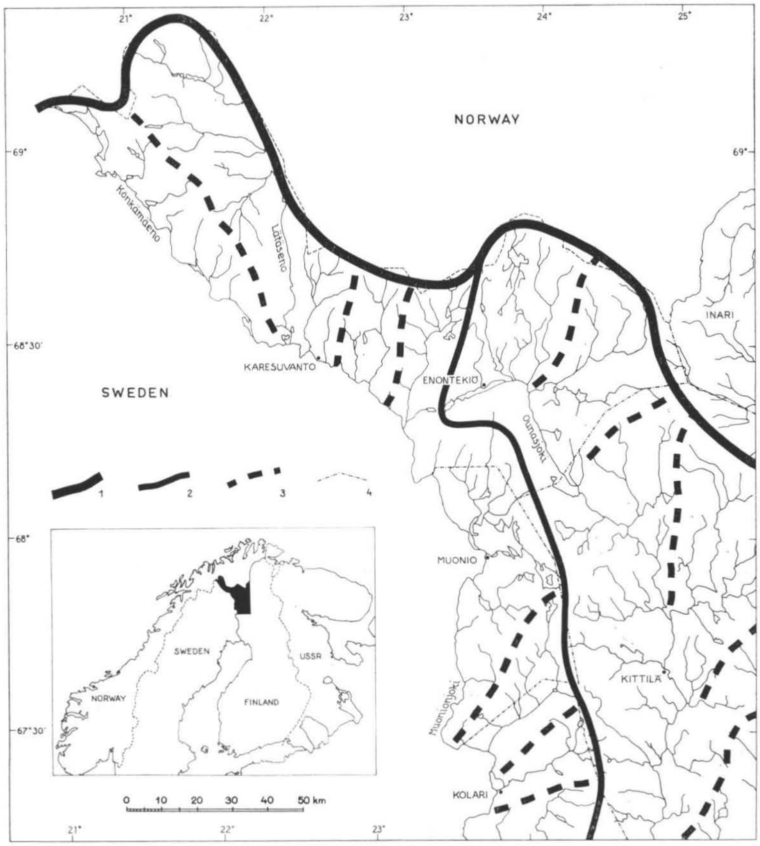


FIG. 1. Location of the region investigated in northern Europe (black); river systems and watersheds of western Finnish Lapland. 1) Main watershed, 2) watershed between the Muonionjoki and Ounasjoki drainage basins, 3) minor local (secondary) watersheds, 4) boundaries of the communes.

eskers was a particularly fruitful aspect of Tanner's research activity, for, besides the foregoing, he came out with papers on eskers in the years 1928, 1929, 1930 a, 1932 and 1934.

With regard to other parts of Finland's far North, mention should be made of Mikkola's (1932) study on the physiography and late-glacial formations. Virkkala (1955) and, especially, Penttilä (1963) investigated the erosion forms that were created in the marginal portions of the continental ice sheet. Penttilä drew far-reaching conclusions concerning the glaciological state of the glacier, its dynamic conditions and the process of wasting down in the light of the data supplied by these forms. Furthermore, Syrilä (1965) has studied the deglaciation and the glaciofluvial erosion forms in northernmost Finnish Lapland, and Mansikkaniemi (1965) the glacial and postglacial evolution of the Pulmanki Valley.

Glaciogeological research in the far North of Scandinavia began, just as in Finland, with the study of the history of the ice-dammed lakes. The most prominent of the Scandinavian researchers were Svenonius (1887 and 1898), Gavelin (1900 and 1910), Sjögren (1909), Högbom (1892 and 1910), Holmsen (1915), Enquist (1918) and Halden (1925) (see also Holdar 1952 and 1957). The deglaciation of supra-aquatic areas began to stir ever greater interest among Scandinavian geologists. Investigations began to be conducted with zeal into the mode of disappearance of the continental ice sheet and the formations created by the processes involved in melting of the ice (among others, Frödin 1915 and 1925, Geijer 1917, G. Lundqvist 1943). Mannerfelt (1945) has contributed a detailed description of glaciomorphological form elements, and Hoppe (*e.g.*, 1952, 1957 and 1959) has studied moraine forms and elucidated the subglacial origin of certain types of hummocky moraines.

The glaciological works of Ahlmann (*e.g.*, 1933, 1938, 1939 and 1944) have earned an almost classical reputation by now, and other representatives of this branch of research include Schytt (1958 and 1959), Liljequist (1956), Liestøl (1962 and 1963) and Østrem (1962).

The climate of late-glacial and postglacial times in Lapland has been described by Hyyppä (1936). His synthetic studies on the Baltic Sea (1963 and 1966) also touch upon the region dealt with in the present paper. The evolution of the local forests, the bogs and the paleobotany of the region have been investigated by, *inter alia*, Auer (1927), Aario (1940), Ruuhijärvi (1960, 1962 and 1963), Salmi (1963 and 1965) and Sorsa (1965).

Ohlson (1964) has done an extensive research on the frost and weathering phenomena of western Finnish Lapland. The data on the periglacial phenomena of the region have been supplemented by Seppälä's (1966) paper on frost wedges in the ground.

The following geological maps of the region are available: General geological map, pre-Quaternary rocks, 1: 400 000, sheet B 8, Enontekiö (Matisto 1959), sheet B 7, Muonio (Mikkola 1936), sheet C 7, Sodankylä (Mikkola 1937), and sheet C 8—9, Inari (Meriläinen 1965). The maps of Quaternary deposits have been published in accordance with the new General Index, and ready are sheets 27, Kittilä (Penttilä and Kujansuu 1964), 18, Kilpisjärvi (Kujansuu 1967) and 28, Enontekiö (Kujansuu 1965). The only explanatory text to have appeared so far is that prepared by Mikkola (1941) for sheets B 7—C 7—D 7 of the map of pre-Quaternary rocks.

The purpose and scope of the investigation

The study of the morphology of the formations created during the deglaciation stage of the continental ice sheet has much of significance to offer in areas where it is difficult to study the stratigraphy. The importance of morphology was emphasized as early as 1915 by Tanner (pp. 446, 557, 646; see also Penttilä 1960, p. 73, and 1963,

2 12883—67

p. 10). Morphological observations can best be made by examining aerial photographs with a stereoscope. An exaggerated three-dimensional effect gives the morphology a highly detailed picture to the extent, in fact, that certain features like fluted surfaces, which the field investigator often totally fails to see, are clearly visible in aerial photographs. Besides the sparse vegetation, the study of surface forms by means of aerial photographs is facilitated by the circumstance that in the supra-aquatic region comprising most of western Lapland the glacial morphology remains very nearly in the same condition as it was at the time the ice sheet melted away. The study and mapping of extensive areas would be quite impossible without aerial photographs, for, in addition, the situation with regard to maps has been very poor. An improvement in this situation may be expected, however, in the very near future.

For the present study, interpretations have been made of more than 2 000 aerial photographs, varying in scale between 1: 20 000 and 1: 60 000, the most prevalent being 1: 30 000. An effort has been made to determine the genetic type of the formations directly from the photographs; stratigraphic observations have been used in checking the results in the field, particularly in cases hard to interpret. The determinations of elevation have been made by levelling, with a barometer and, to some extent, also photogrammetrically. Accordingly, the accuracy of the measurements varies. Frequently, the result represents only an accuracy involving an error of some $\pm$ 5 meters.

To determine the direction of the ice movement, stone counts have been made, the orientation of the stones in the till has been determined, the striations have been examined, and the trends of fluting observed from aerial photographs. The utilization of the fluting to determine the last direction of the ice flow has proved exceedingly fruitful in remote areas and those covered with Quaternary deposits. The flutings have been checked by observing the orientation of till stones in type areas.

The terminal positions and mode of retreat of the ice sheet have been determined by means of the evidence left behind by the extramarginal streams of meltwater that flowed in front of the glacier. It has been possible to map them by consulting aerial photographs with a high degree of accuracy (*cf.*, Derbyshire 1958). The fact that these channels reflect the terminal positions of the ice sheet is due to the circumstance that in most of the region investigated the ice withdrew from higher elevations to lower ones and forced the meltwaters to flow in front of the glacier in directions deviating from the general gradients.

It has been possible to study the glaciological state of the vanishing ice sheet — notably the annual thinning of the ice — by examining the lateral drainage channels. Like the subglacial drainage channels, they can be easily identified and very accurately mapped from aerial photographs.

It has become evident in connection with the study that, for instance, systematic investigation of the petrographic composition of till does not always yield the desired information concerning the directions of ice flow over so widespread an area as that now involved. Because the pre-Quaternary bedrock is mostly hidden by the overlying Quaternary deposits, the local bedrock maps are inaccurate and in many cases have been drawn with reference to the topography, vegetation and boulders (Mikkola 1941, pp. 8, 15). Moreover, the distance between observation points is fairly great. Better results can be obtained by following the indicator fans formed from known exposures if no other rocks of the same kind occur in the region. In a zone representing an ice divide, age and trend differences in the directions of movement hamper the application of this method in tracing the retreat of the continental ice sheet. It is for this reason that no detailed results of the stone counts, nearly 200 of which have been made, are presented, except in a few special instances.

The names of places used here are in agreement with the general maps on a scale of 1: 400 000 and economic maps on a scale of 1: 100 000 published by the General Survey Office. The Finnish-language place names have been used on the whole, but in certain places only the original Lappish names have been available, and these in many cases are descriptive of the morphological type or material components of the formation in question.

The purpose of the present paper is to arrive at a synthesis on the basis of extensive material. Detailed investigations and descriptions are needed to produce a complete picture of the event of melting and, particularly, its duration, as Tanner (1915, p. 653) has pointed out. Moreover, emphasis is laid in this study on the importance of aerial photographs in investigations of the glacial morphology of Lapland.

PHYSIOGRAPHIC REVIEW

Relief

The northwesternmost part of the region investigated, called the Enontekiö uplands by Granö (1952, p. 427), has the highest elevations in Finland, and the relative differences in altitude are there also the greatest (see Figs. 2, 3 and Appendix I). The highest summits include Halti, 1329 meters above sea level, Ridnitsohkka 1 317 m, Kovddoskaisi 1 184 m, Kahperusvaarat 1 144 m, Marffevarri 1 060 m, Jollanoaivi and Saana 1 029 m. Among valley levels might be mentioned Lossujärvi, 808 meters above sea level, Pihtsosjärvi 739 m, Somasjärvi 737 m, Saarijärvi 684 m, Porojärvi 587 m and Kilpisjärvi 473 m. The relative differences in elevation in this region are thus between 300 and 500 meters. On the summits of these fells and in the broad valleys there are tracts where, in a smaller framework, the differences in elevation are quite small, or only five to ten meters. Such areas represent comparatively flat terrain, whereas, considered by an large, the region has been designated as high mountainous country (Granö 1952). Toward the east, the elevations of the felltops and valleys diminish: Ropi 940 m, Peeravaara 928 m, Virdninippa 918 m, Harroaivi 828 m, Tsaibma 785 m and Tarju 723 m. Among valley altitudes might be mentioned: Tierbmesjavri 613 m, Nierivuoma 442 m and Kelottijärvi 368 m. At the same time, the relative differences in elevation shrink to less than 200 meters.

The Lätäseno valley constitutes a natural boundary, on the eastern side of which begin lower-lying and more level landscapes. The level ground extends all the way to Palojoki. In the southern part, the differences in elevation are less than ten meters in the vicinity of Karesuvanto and Palojoensuu. In the northern parts one finds mountainous, hilly and hillocky areas, where the relative differences in altitude vary between ten and a hundred meters. Summits include Tarvantovaara, 590 meters above sea level, Kiellitunturi 589 m, and Itämävaara as well as Liejangi 484 m. The elevations of the low-lying lands diminish from the north toward the south and from the west toward the east: *e.g.*, Syväjärvi approx. 410 m, Palojärvi 345 m, Suonttajärvi 295 m and Muotkajärvi 289 m.

The central part of the commune of Enontekiö is mainly mountainous country, where the differences in elevation range from 50 to 200 meters. The highest summits in the area are Termisvaara 618 m, Olkovaara 590 m, Tsuvgesvarri 586 m and Raututunturi 563 m, while the general elevation at Pöyrisjärvi is approximately 400 m and at

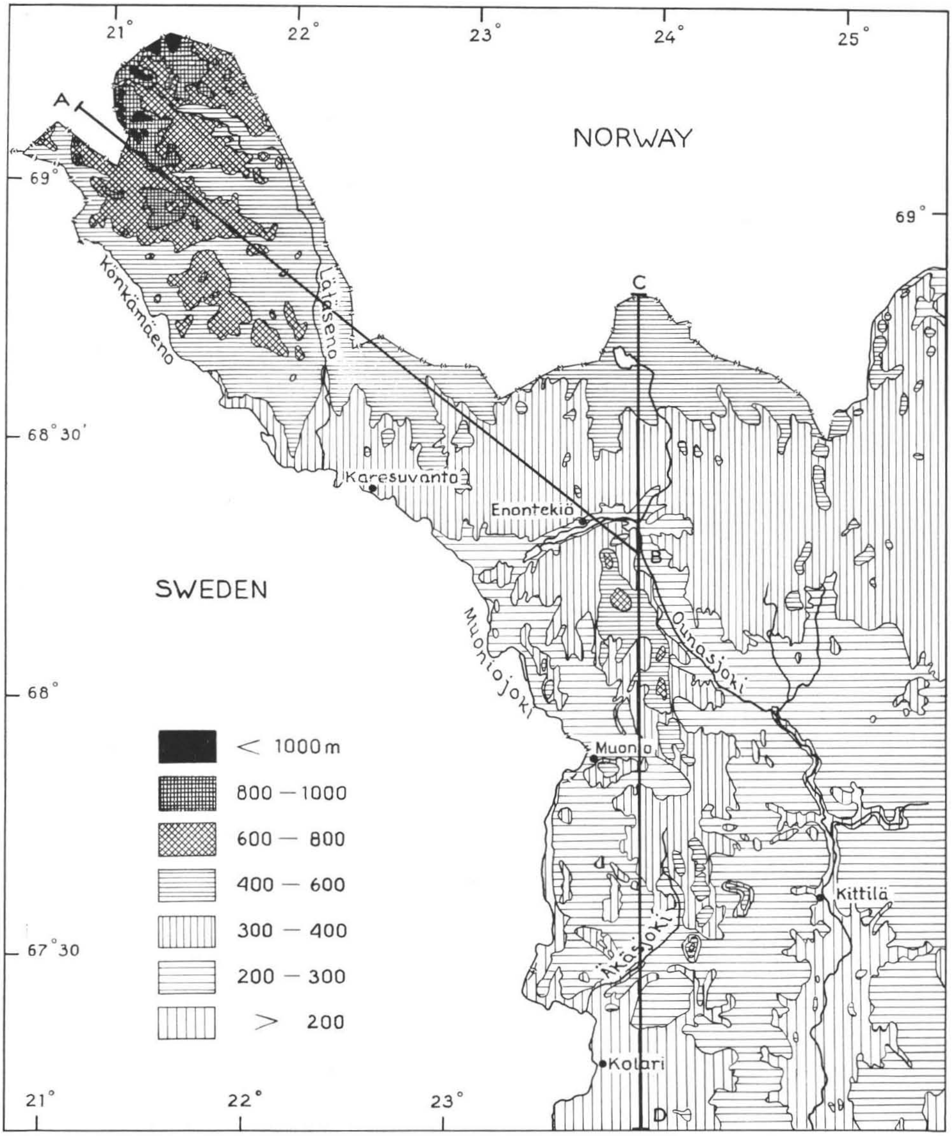


FIG. 2. Relief map of western Finnish Lapland. Lines A—B and C—D show the position of the profile in Fig. 3.

Seitalompolo 318 m. The main part of Muonio commune also consists of mountainous country, where the elevations of the summits are roughly between 400 and 500 meters: Sonkavaara 455 m, Mielmukkavaara 488 m, Olostunturi 524 m and Kiuaskero 443 m. The places on the lowest levels are Könkäsenjärvi 248 m, Utkujärvi 231 m, Kangosjärvi 218 m and Maunujärvi 158 m.

The Ounasselkä fell area *(cf.*, Granö 1931, p. 87; 1952, p. 427), comprising the Ounas—Pallas—Ylläs chain of fells, clearly represents an erosion remnant towering above the surrounding peneplain (see Fig. 3) There the relative differences in elevation exceed 200 meters. The height of the peneplain in the vicinity of the fell chain is approximately 200—300 meters: *e.g.*, Muotkajärvi 289 m, Pallasjärvi 266 m, Jerisjärvi 257 and Ylläsjärvi about 195 m. The summits rise to 600—700 m and even over 800 m: Outakka 738 m, Taivaskero 805 m, Keimötunturi 626 m, Lainiotunturi 635 m and Yllästunturi 718 m.

The eastern sections of Enontekiö and the northern part of Kittilä consist principally of hilly and hillocky country, where small flat stretches occur, too, and isolated heights, such as Puljutunturi, with its elevation of 482 m. From the central portion of Kittilä there extends a broad flat belt toward the southeast, being bounded by, *e.g.*, Levitunturi (532 m) and Aakenustunturi (575 m). The commune of Kolari boasts a corresponding flat area, the broad boggy tract of Teuravuoma. The southwestern and southern part of this district has a mountainous and hilly character. The highest of the summits are Iso Kelhu, 381 meters, and Karhujupukka, 326 m.

The biggest part of the area thus consists of a peneplain from which only a few erosion remnants and horst-like hills rise. They are situated mainly in the northern and northwestern parts of the area. The peneplain is situated in western Lapland in a position gradually sloping toward the south, though in the northwestern part the inclination is southeast, and the gradient amounts to about 1.3 m/km (*cf.*, Mikkola

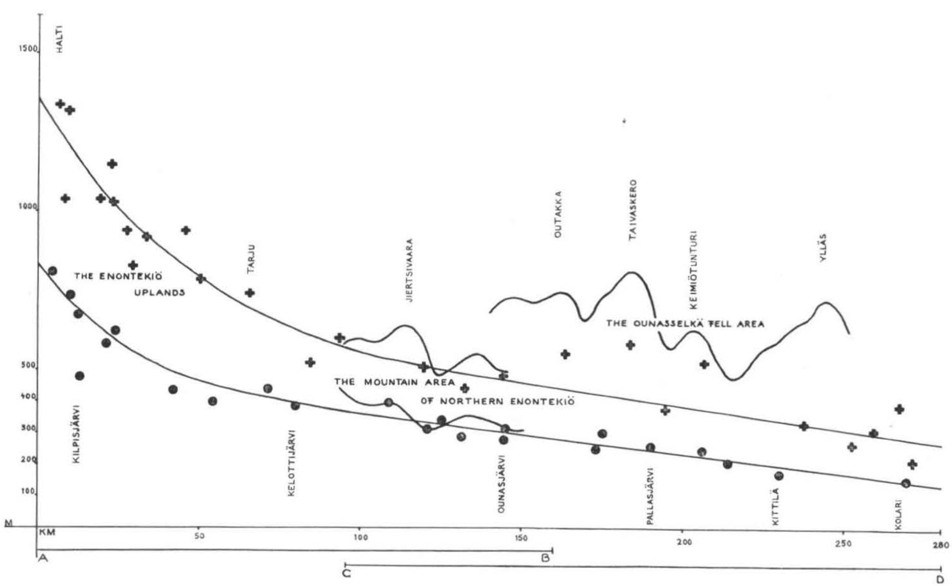


FIG. 3. Profile along lines A—B and C—D in Fig. 2, showing the elevations of summits (crosses) and valleys (dots). The profile also shows that the gradient of the peneplain is about 1.3 m/1 km in this region.

1932, p. 27). The gradient has been obtained from the profile in Fig. 3, which shows the elevations of the summits and valleys in the northwestern part from northwest to southeast and in the rest of the area from north to south. The southward inclination of the peneplain was of considerable significance in determining the forms created during the deglaciation, especially the erosion froms produced between the ice divide and the principal watershed (Fig. 1).

The bedrock and its influence on the relief

The bedrock of the region investigated (Fig. 4) is of Precambrian origin with the exception of the part at the extreme northwestern corner, where a Caledonian nappe is thrust across a breadth of 10 to 20 km over Cambrian sediments *(e.g.,* Tanner 1938, Hausen 1942). The nappe is in a position gently rising in an east-southeasterly direction. In this area there also occur Paleozoic ultramafic rocks, contained in a massive outcrop, known as the Halditjokko massif (Hausen 1941).

The most prominent of the rocks of the Precambrian bedrock comprise the greenstone area of Kittilä. This area is made up of metamorphosed, mostly spilitic rocks. Elsewhere the schists of central Lapland are structurally highly complicated and stratigraphically hard to explain. Among the metasediments, however, it has been possible to differentiate stratigraphically the Sirkka conglomerate and the greywackes associated with it as well as the conglomerate and quartzites and other schists of Kumputunturi. This so-called Kumpu—Oraniemi series (Mikkola 1941, p. 181) is deposited on top of the greenstone formation of Kittilä. The quartzites belonging to the series are coarsely clastic and often bluish red in color. They can readily be distinguished from the fine- and even-grained, usually sericite-bearing quartzites which are commonly met with in the area. The carbonaceous phyllite occurring in the Kittilä—Kolari area grades over into greywacke and into a schist type containing Al_2O_3-rich minerals — *e.g.*, the sillimanite-gneiss situated into the western parts of the area.

Amphibolites and greenstones of volcanic origin are associated with the schist series as lenses and dikes of various descriptions, as are distinctly intrusive gabbros and granites, too, of which the last-mentioned occur extensively in the southeastern and nortern parts of the area. Mafic and ultramafic plutonic rocks are rather rare in the region investigated, and the ones that do occur are mostly pyroxene gabbros of medium coarseness. In the western parts of the region, there are both small and large bodies consisting of syenite, quartz diorite and granodiorite. The migmatites situated north of the Ounasselkä fell area in many instances grade over into the Hetta granite, which is unmistakably intrusive in character but also partly foliated. Also present in the region is a younger red microcline granite, which has been marked on the map in the same way as the Hetta granite.

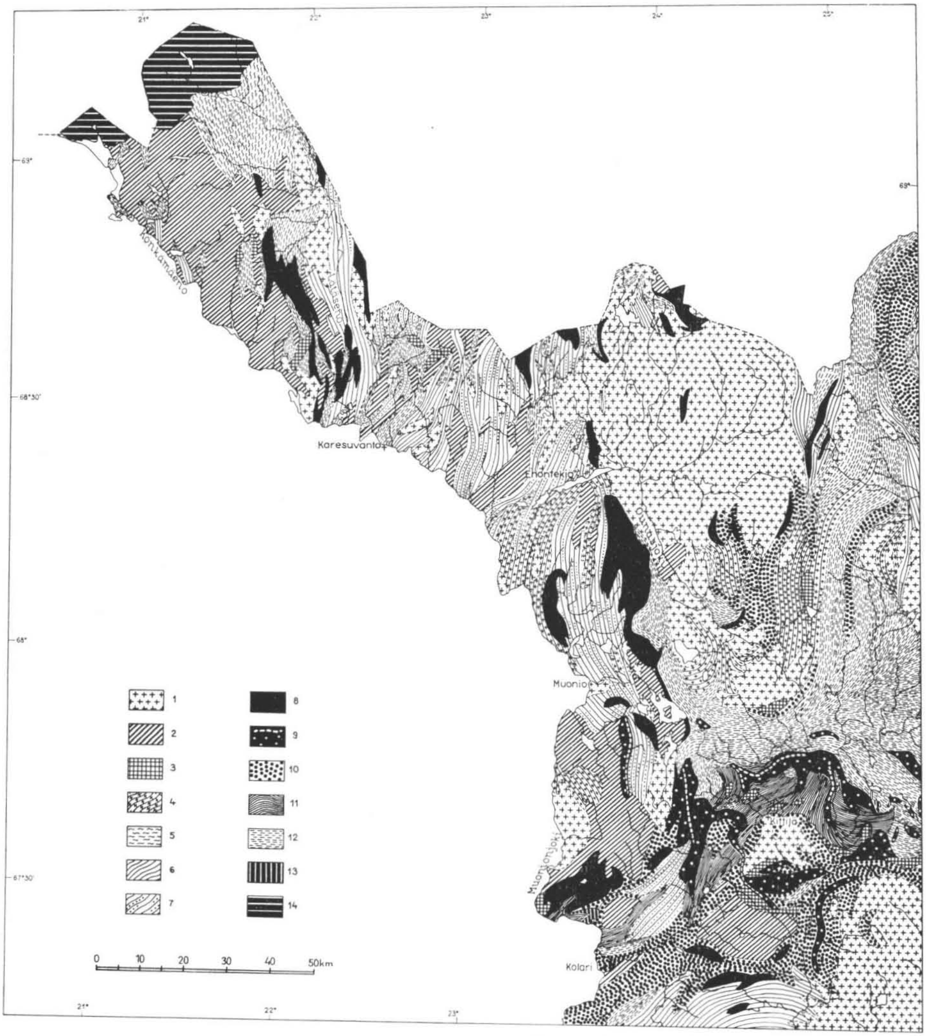


FIG. 4. Pre-Quaternary rocks in western Lapland according to Matisto (1959), Meriläinen (1965) and Mikkola (1936, 1937). 1) Granites, 2) quartz diorites and granodiorites, 3) diorites, gabbros and ultramafic rocks, 4) migmatites, 5) banded granite gneisses, 6) gneisses (and schists) of different kinds, 7) sillimanite gneiss, 8) quartzites, 9) quartzites and conglomerates of the Kumpu—Oraniemi series, 10) quartz feldspar schists, 11) phyllites, 12) greenstones and amphibolites, 13) carbonate rocks, 14) Paleozoic rocks.

Quite a special rock found in the region is a jasper quartzite, notably its red variety. Similarly present only in small areas are the carbonate rocks, of which the most noteworthy example is the limestone deposit situated at the mouth of Äkäsjoki. In addition, the region contains a number of dolomitic and calcitic carbonate rocks, in association with which quartzite often occurs as intercalations or as masses of indefinite form.

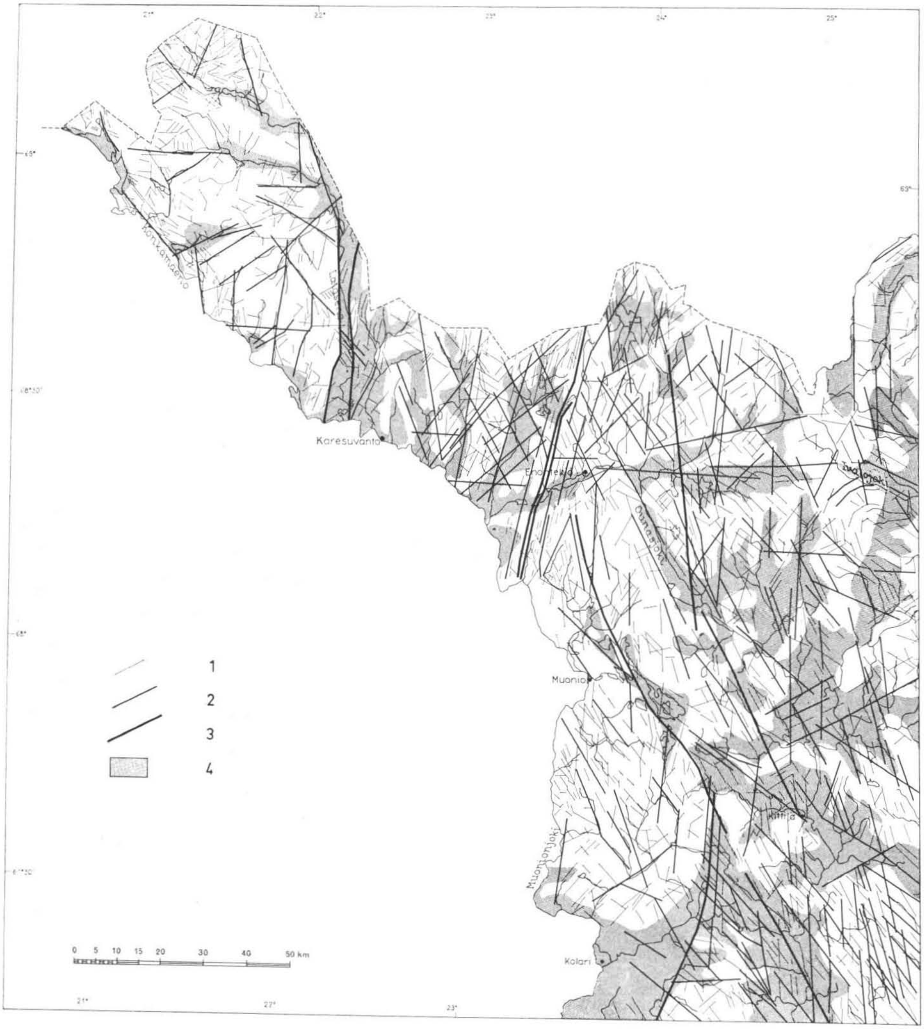


Fig. 5. Map of fracture tectonics. Lengths of the fractures: 1) < 10 km, 2) 10—40 km, 3) > 40 km. 4) The deep eroded and flat areas of bedrock.

The influence of the bedrock on the relief (Fig. 2) is so decisive that it might be said that all the major morphological features of the region are due to the bedrock topography. The influence of the bedrock stems from the varying resistance of the rocks to erosive action and/or from tectonic factors (Mikkola 1932, Tanner 1938, Niini 1964, 1967). Excellent examples of varying resistance are the quartzitic and amphibolitic fells, such as the fells of Ounasselkä. Extensive tracts of plutonic rocks likewise occur mostly in areas notable for their high relief, as, for instance, the mountainous country where the Hetta granite is situated. The flat and deeply eroded areas of the region are mainly situated on a base of mica schist and phyllite, as in the case of the lower course of Lätäseno and the vicinities of the parish centers of Kolari and Kittilä. The Kittilä greenstone area is also fairly flat and low-lying, though gently sloping hills do occur as exceptions to the rule.

The map of fracture tectonics of the region (Fig. 5), was drawn on a morphological basis and partly also from aerial photographs. It shows that in places the lowlands also border on distinct fractures or they occupy areas of conspicuously broken-up bedrock. In the high-relief area there occur fracture-tectonic systems divided into large blocks. Examples include the broad unbroken blocks of western Enontekiö (west of Lätäseno), which are bounded by Porovuoma—Rommavuoma, Rommavuoma—Suppivuoma and Suppivuoma—Könkämäeno—Lätäseno.

Quaternary deposits and the relief

In the greatest part of the region investigated, the bedrock is overlain by Quaternary deposits except in the far northwestern district, the Enontekiö uplands and in other areas of high relief. Elsewhere glaciofluvial erosion and to some extent, also river erosion exposed the bedrock in places.

Between one and five per cent of the area is covered with water, except in the eastern and northeastern parts, where the figure is less than one per cent, and in the vicinity of Muonio parish center, where it is from five to ten per cent (Granö 1931, p. 102). Lakes on the whole fill the tectonic depressions, like Jerisjärvi and Vuontisjärvi in the Muonio district. But some of the lakes and ponds, especially the small ones, have established their basins in places hollowed out by glaciofluvial erosion. This is true, for example, of the lakes associated with esker chains and extramarginal drainage channels.

The main features of the Quaternary deposits occurring in the region are indicated in Fig. 6. Talus formations and block fields resulting from mechanical weathering are typical of the Quaternary deposits in the Enontekiö uplands, though they are by no means the commonest. Block fields occur in greatest abundance in the northwesternmost part of the region — that is, the part where the bedrock is least covered — and in the Ounasselkä fell area. Some of the block fields originated by frost action.

Ground moraines, which consist mainly of fine sandy till (according to Atterberg's system) (see Fig. 7), occur as a moderately thin cover. The till blanket is thinnest on the tops of the fells, where it varies from 0 to 1½ meters in thickness, and thickest in the broad valleys and flats, where it is between two and seven meters. Hummocky moraines occur most abundantly in the central section of the region and their thickness is greater on the average than in the ground moraine tracts. The material in hummocky moraines varies in grain and is often rather coarse; in some cases, it is largely sorted.

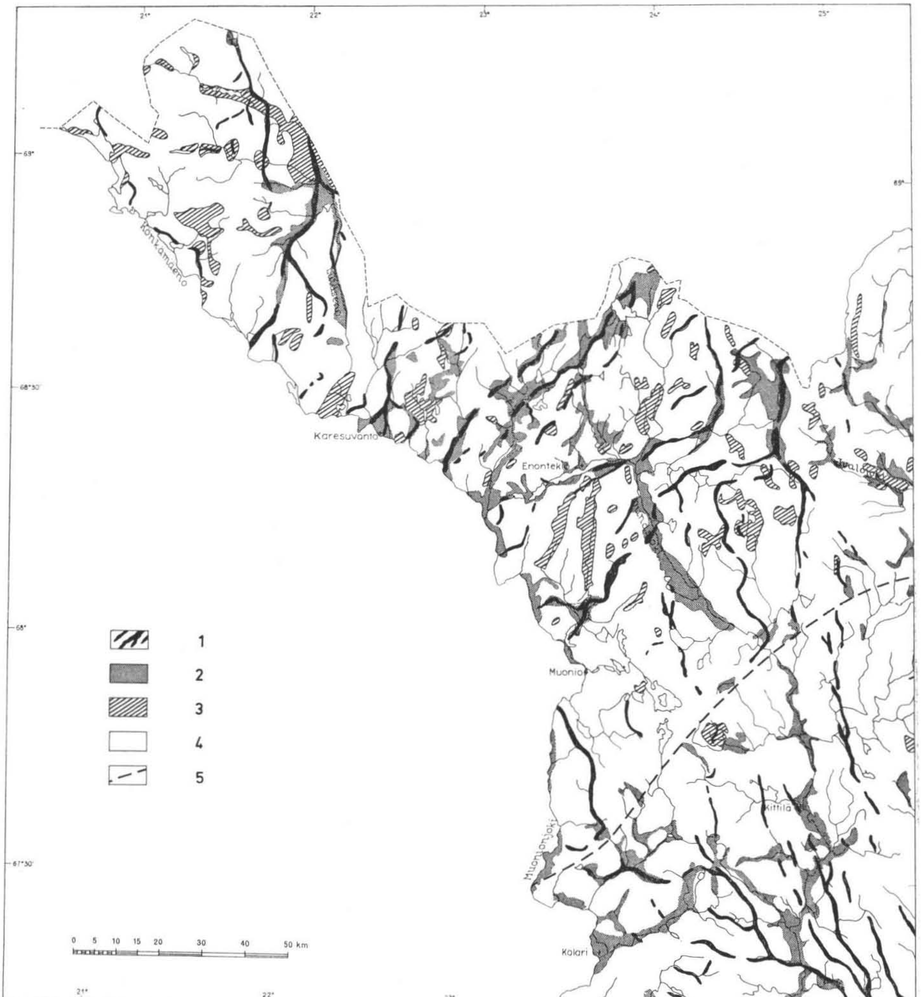


FIG. 6. Quaternary deposits in western Lapland. 1) Eskers, 2) other glaciofluvial deposits, 3) hummocky moraines, 4) mainly ground moraines and peatbogs, 5) esker divide.

The sorted material is principally of glaciofluvial origin and it occurs as eskers as well as deltas and sandurs. The material of the glaciofluvial deposits varies within broad limits from silty fine sand to gravel rich in cobbles (see Fig. 8). Eskers composed of fine-grained, sorted drift occur mostly in the central parts of the region, whereas in other parts they are built up of coarse sand and even coarser material in the main. The composition of the deltaic accumulations also varies appreciably, depending on their origin. The finest material, with a grain size ranging from

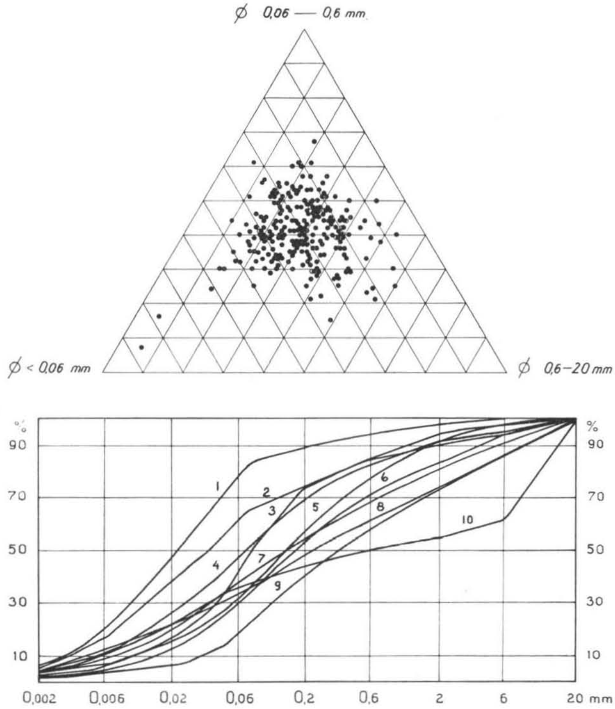


FIG. 7. Grain-size analyses of till presented by the triangular diagram. 1—10) Examples of the mechanical composition of till represented by cumulative curves.

0.06 mm to 2.0 mm, is found in the valleys of Ounasjoki and Muonionjoki. The accumulations consisting of coarser and poorly sorted drift are generally met with in high relief country.

Deposits produced by the present rivers are rather rare. The most extensive river deposits occur in places where there has been abundant glaciofluvial material, which the later action of a river has readily transported and redeposited. The material is in most cases fairly fine-grained.

Shore deposits are rather seldom met with in the region, for it lies for the most part above the uppermost marine limit. They were produced mainly by the littoral forces of ice-dammed lakes. These lakes, however, were generally small and often short-lived, so the shore formations left behind by them are not noteworthy (Fig. 49, p. 75). The grain sizes vary considerably, but generally the material is fairly coarse.

The accumulations of wind-blown sand are in most cases of glaciofluvial origin. The material has been sufficiently fine to be transported by the wind soon after the disappearence of the ice sheet, evidently after becoming fairly dry and during a windy period before plant life had had time to bind the sand to the ground. The dunes

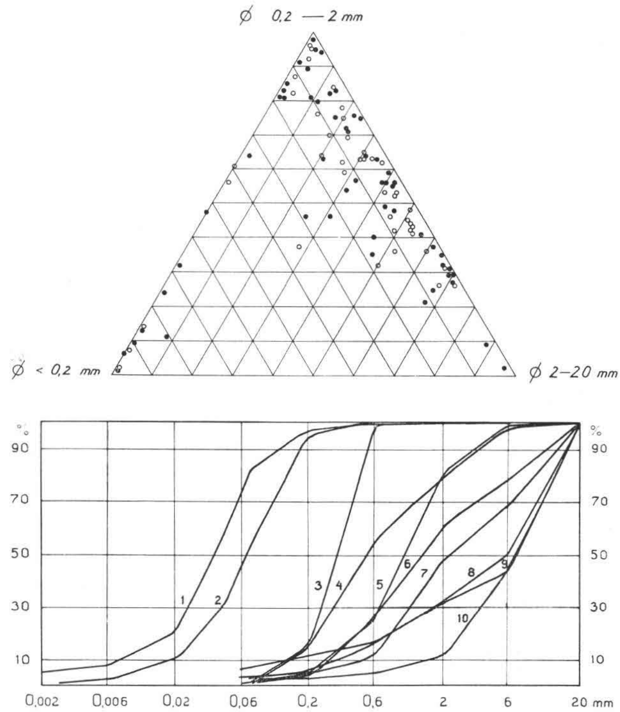


FIG. 8. Grain-size analyses of glaciofluvial material presented by the triangular diagram: circles, eskers; dots, other glaciofluvial formations. 1—10) Some typical cumulative curves of glaciofluvial material.

are for the most part fossilized, that is, they no longer shift position, with a few slight exceptions. The eolian sand is quite well sorted and there is little variation between the different deposits. The grain size ranges in the main from 0.06 mm to 0.2 mm (*cf.* Ohlson 1957, s. 134), though to a lesser extent the range is from 0.2 mm to 0.6 mm (see Fig. 9).

The finest material, glacial lake sediments and marine clays and silts are rare occurrences in the region of the investigation. Silty fine sands and silty clays occur in places in the broader river valleys, where ice-dammed lakes lasted for fair stretches of time. Marine clays and silts occur to some extent at the southern border of the region in the Ounasjoki and Muonionjoki valleys.

The peat deposits occur mainly in *Carex* bogs (*aapa*) and pine bogs, where the proportion of *Sphagnum* is slightly larger. In the northern section of the region the bogs are characterized by palsas or permanently frozen peat hummocks. The bogs are between one and four meters deep in the southern and central parts, but only about one or two meters in the northern parts. Bogs cover between 10 and 20 per cent of the area in the northwestern and northeastern sections as well as in the Ounas-

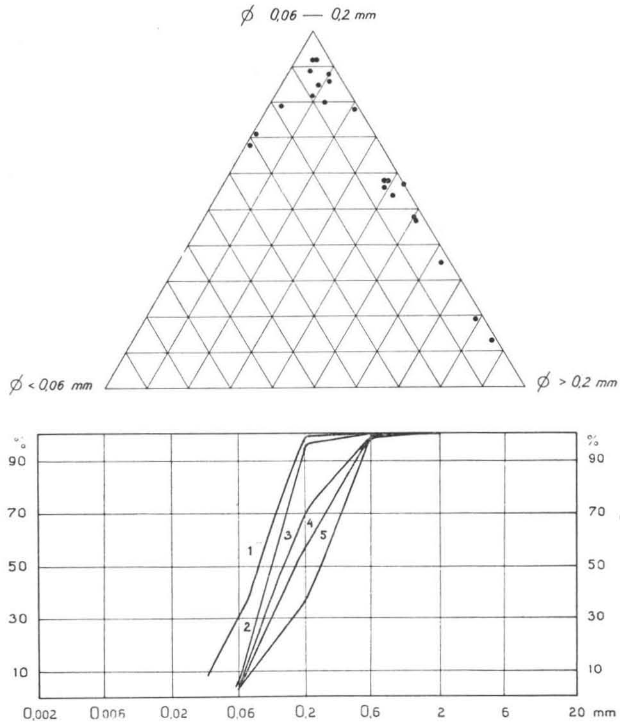


FIG. 9. Grain-size analyses of wind-blown sand in western Lapland.

selkä range of fells. The percentage rises to 30—40 in the eastern parts of Enontekiö, to 40—50 per cent in the stretch between Palojoki and Lätäseno, and to 50—60 per cent in the main part of the region (central and southern sections) (Atlas of Finland 1960, Sheet 11).

The influence of the Quaternary deposits on the land forms is rather small. To greatest extent, they contribute a levelling effect. Just as do the ground moraines, the broad glaciofluvial fields even out the low-relief features of the bedrock, often forming extensive flats through which streams have dug out steep-sloped channels. Although both areally and quantitatively inconsiderable, the finest-grained sediments along with the abundant peat beds contribute to the levelling effect, whereby the landscape is reduced to a more uniform level. The wind-blown sands, again, have created new forms, dunes, which are narrow, arching, asymmetric in cross-section and varying in height between two and ten meters. The most extensive dune tracts are from approximately two to ten square kilometers in area. Among the glacial accumulations, eskers are the long and sharp-ridged forms less than 50 m in height, and they run from one hill to another, mostly, however, following large valleys existing in the bedrock. Hummocky moraines account for the most extensive tracts affecting the relief. In the northern part of the region, in the commune of Enontekiö, there are broad areas where these hummocky moraines, in conjunction with small boggy hollows, give the landscape a network pattern. At the same time, the bogs soften the relief produced by the moraines. The relative differences in elevation are generally less than 20 m, though mostly only between two and eight meters. Since in the moraine tracts the overburden is of considerable thickness, the forms of the bedrock are also covered. Although the forms of the Quaternary cover are not particularly impressive in comparison with the configuration of the bedrock surface, they nevertheless do decisively enrich the landscape of these widespread far-northern wilds.

Weathering and erosion in preglacial times

Since remote geological times, the land surface of Finland has largely consisted of the same type of rather flat peneplain as prevails to this day (Tanner 1938). Erosion has recently been very weak. Exceptional in its relief is the westernmost part of Enontekiö. Even the Scandinavian mountain range was once reduced to the peneplain level, but in response to the remote influence of Tertiary (Alpine) orogeny this ancient chain of mountains began to rise up again. There no longer seem to be any clear signs of the Paleocene peneplain (Tanner 1938, p. 361) in western Finnish Lapland, although in the Caledonian sphere it does manifest itself as flat-topped fells. The uplift caused above all an intensification of the erosive processes, and this has had its effect on the surface forms in many ways, above all in the westernmost part of the region investigated. In the light of the level stretches at various elevations, Tanner (1938, p. 372) concluded that the uplift was rhythmic in character. This polycyclical relief is not so plain to see in Finland as in the mountain range area proper (see, *e.g.*, Wråk 1908, Evers 1941, Rudberg 1965).

The weakness of erosion in other sections of the region during preglacial times is revealed by the thick stratum of chemically weathered bedrock. This preglacial weathering is a phenomenon long familiar to observers in central Lapland, where it has been met with in places as a stratum nearly 100 meters thick (Virkkala 1955, p. 395). On the whole, the layer of weathered rock is substantially thinner. Observations of the same phenomenon have been made in the region dealt with in the present paper, but the thicknesses of the layers have not been measured. The weathered rock extends as a broad wedge from the east to the heart of the region, in the vicinity of the hamlet of Sirkka. Smaller weathered areas have been met with as far as the hamlet of Maunu, on the western side of Karesuvanto. The weathered rock does not occur as a uniform field but in many cases in the vicinity of higher places (Sirkka and Levitunturi) or in depressions, where it has evidently been best protected against glacial erosion. The partial preservation of the preglacial weathering crust in Lapland finds its most logical explanation in the circumstance that after the land surface had become very level, erosion and transportation of material did not take place to any substantial degree during the last geological eras. Also tectonic factors — the occurrence of weathered rock in depressed areas — helped preserve it. During glacial times, the erosive action of the ice was weak in the zone of the ice divide and in its immediate surroundings (Penttilä 1963, p. 16), although elsewhere it was exceedingly strong.

Taken as a whole, the preglacial weathering products were for the greatest part removed from the region of the investigation by glacial erosion, and the preglacial erosion forms merely changed character in response to glacial erosion. In the essential bulk, the surface forms remain the same as they had been in preglacial times.

EARLIER STAGES OF GLACIATION

Evidence of interglacial times

Direct evidence of interglacial times has not been met with in the region of the present investigation, but observations of interglacial deposits have been reported from nearby areas in Finland (Korpela 1962) and Sweden (Fromm 1960, G. Lundqvist 1960). Piirola's (1965, 1967) morphological analyses of valleys in northern Lapland gave indirect evidence of interglacial erosion. Penttilä (1963, p. 26) has contended that the channel of Rumakuru must have originated during some earlier deglaciation period, inasmuch as very little meltwater flowed through it in connection with the last stage of melting. There are two corresponding channels on Ounastunturi in western Lapland, and they indicate that melting of ice had taken place in a different direction from that of the final deglaciation stage. The position and trend of these channels were determined primarily by pre-existing tectonic fractures in the bedrock.

Interglacial or interstadial deglaciation in Finland is further evidenced by submorainal sorted material *(cf., eg.,* Brander 1943, Aurola 1949, Mölder 1949), at least all of which was probably not accumulated subglacially or covered with superglacial till as late as the melting stage, but rather bear witness to a new advance or oscillation of the ice sheet *(cf.* Hoppe 1959, p. 200).

Indirect evidence is further provided by a conglomerate met with just east of the border of the investigated region, on the southern slope of Haurespää, some 11 km to the north of the hamlet of Tepsa. Composed of both sorted drift and till, the conglomerate closely resembles postglacial *Ortstein* (iron-cemented B-horizon of podsol soil). The sorted material is presumably glaciofluvial gravel and sand, *i.e.*, an obvious product of the Ice Age. The cementing matter is a hydrous ferric oxide, limonite. The most natural explanation focusses on the interglacial period and the till accumulated in connection with the preceding glaciation as well as glaciofluvial material deposited as a result of melting of the glacier. The various constituents have become consolidated, with the cementing ferric matter apparently having at least indirectly derived from iron ores situated in the near vicinity. The possibility of a postglacial origin seems to be precluded by the glacial erosion forms, although indistinct, occurring on top of the formation and by the fact that on the southern side of Haurespää runs an esker surrounded by plain marks of erosion.

In other words, the locality, including the conglomerate, appears to have been overlain by till and become exposed only during the last deglaciation stage as a result of erosive action. Mr. T. Mikkola [1]) also found peat consolidated by limonite near the conglomerate. It was interpreted by him as postglacial.

The thick layers of surficial deposits in the larger river valleys — in places measuring over forty meters in thickness, as in the parish center of Kittilä — are apt to contain till beds of different ages and even organic material, as at Permantokoski (Korpela 1962), where C^{14} dating yielded an age of over 35 000 years. However, so far no sizable cuts have been made through the deposits in Kittilä.

The trends of the last ice movements

The glacial times, including the last one, the Würm, evidently began with an abundant accumulation of snow in the Scandinavian mountain range. The first valley glaciers came into existence in the highest and rainiest fell areas (valley-glacier phase).

Ice tongues pushed out from the mountain country through the valleys both eastward and westward. This marked the piedmont-glacier phase. An eastward and east-southeastward flow is the oldest advance of the ice in western Finnish Lapland (see Figs. 10 and 11). Only few reliable observations substantiate this interpretation. Gradually the glaciers combined to form the continental ice sheet. At the same time as the glacier advanced eastward, the center of glaciation, or the ice divide, shifted ever farther in the same direction and from northern parts southward. At the main stage of glaciation a part of the ice divide was situated along the southern Muonio—northern Kittilä line. This was evidently also the most long-lasting stage. The ice movements at the time in question are indicated by the most conspicuous striation directions in the area (Fig. 10). The schematic illustrations in Fig. 11 show the trends of the glacier's advance in its main features.

The action of the ice sheet in the ice divide zone and its immediate vicinity was weak. This is evidenced by the preservation in places in the eastern and northeastern parts of Kittilä of the rather thick preglacial weathering crust. Moreover, the till blanket in this zone is fairly thin (Mikkola 1941, p. 14).

Determining the directions of ice movement in the central parts of the region is exceedingly difficult, for the ice divide shifted and at various times the ice left behind marks running in different directions. The map of eskers gives a picture of the directions of flow of the continental ice sheet at this time (Fig. 6). The striations observed outside the zone of the ice divide run very often in line with the eskers, or the direction of the most rapid ice movement (*cf.* von Klebelsberg 1948). The

[1]) T. Mikkola's report of 1967, in manuscript, is at the Institute of Geology and Paleontology of the University of Helsinki.

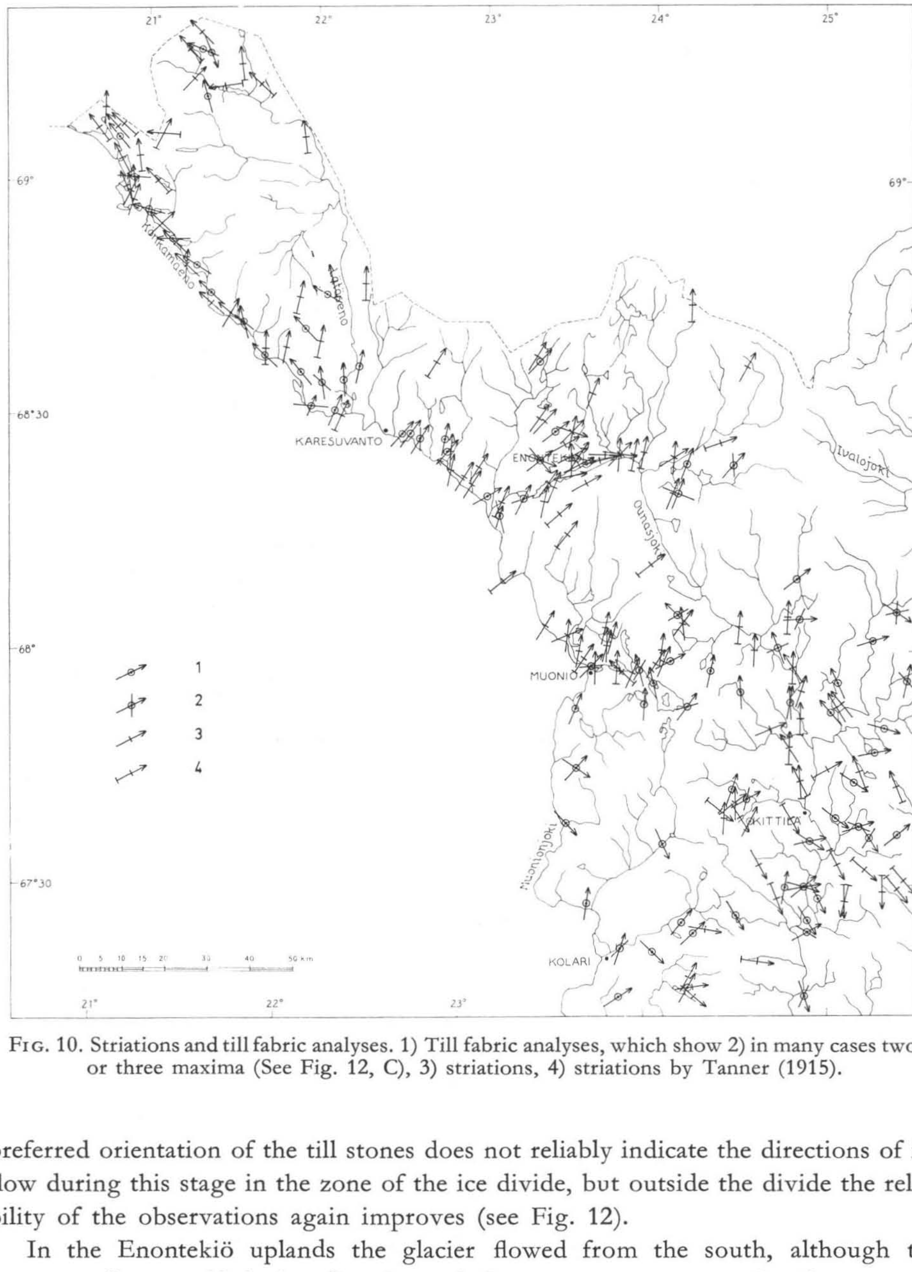


FIG. 10. Striations and till fabric analyses. 1) Till fabric analyses, which show 2) in many cases two or three maxima (See Fig. 12, C), 3) striations, 4) striations by Tanner (1915).

preferred orientation of the till stones does not reliably indicate the directions of ice flow during this stage in the zone of the ice divide, but outside the divide the reliability of the observations again improves (see Fig. 12).

In the Enontekiö uplands the glacier flowed from the south, although the largest valleys guided the direction of flow to some extent. On the summits of the fells the ice flowed from the south and south-southwest, while on lower levels the flow was from the southeast. A northward flow prevailed throughout western Enontekiö as far as the Lätäseno valley. East of Lätäseno the flow

FIG. 11. Schematic illustrations of the trends of the movements of the continental ice sheet during the stage of 1) initial advance, 2) main glaciation, and 3) deglaciation. Ruled area, ice divide.

turned toward the north-northeast and ever more toward the northeast farther in the east. Both the striations and the orientation of the till stones confirm this conclusion (see Fig. 10). In northern Muonio the movement took place nearly from the southwest, though a S—N trend also occurs. In northern Kittilä the ice flowed from the south. At the eastern edge of the region, a shift toward the northeast is again to be observed. On the southern side of the ice divide, the movement quite clearly took place from the northwest. Numerous till fabric analyses lead to the same conclusion, although in certain cases the stones appear to have become re-oriented in response to a later flow of the ice (*cf.* MacClintock and Dreimanis 1964). Nearly all the eskers in the southern district have a roughly northwest-southeast trend. This most conspicuous direction of flow is in places revealed by the striped appearance of landscape, clearly seen in aerial photographs, and it is met with especially in the granite area in the southeastern corner of the region. In the eastern parts of the ice divide zone at least two maxima regularly occur in the rose diagrams showing the orientation of stones in till. These indicate considerable variation in the directions of flow. The final result is glacial transport from the west (*cf.*, Fig. 18, p. 35) since there occur directions between northwest and southwest.

It is possible that the retreat of the continental ice sheet in Lapland was not a continuous process. Contradictory views have been expressed on this subject (Tanner 1938, p. 496, Hoppe 1948, p. 36). Apparently, following a rapid melting stage, the ice sheet re-advanced or underwent oscillation in Lapland. The extreme limits of the final ice movement cannot been determined reliably, but it may be assumed to have reached the Palojoensuu—Pulju belt. It is approximately in this belt that the observations end with regard to the forms of the stratified drift underlying the till blanket and the hummocky moraine tracts begin, which are a fundamental feature of all Enontekiö. Hummocky moraines are almost totally absent from the central and southern parts of the region covered by the present investigation (Fig. 6).

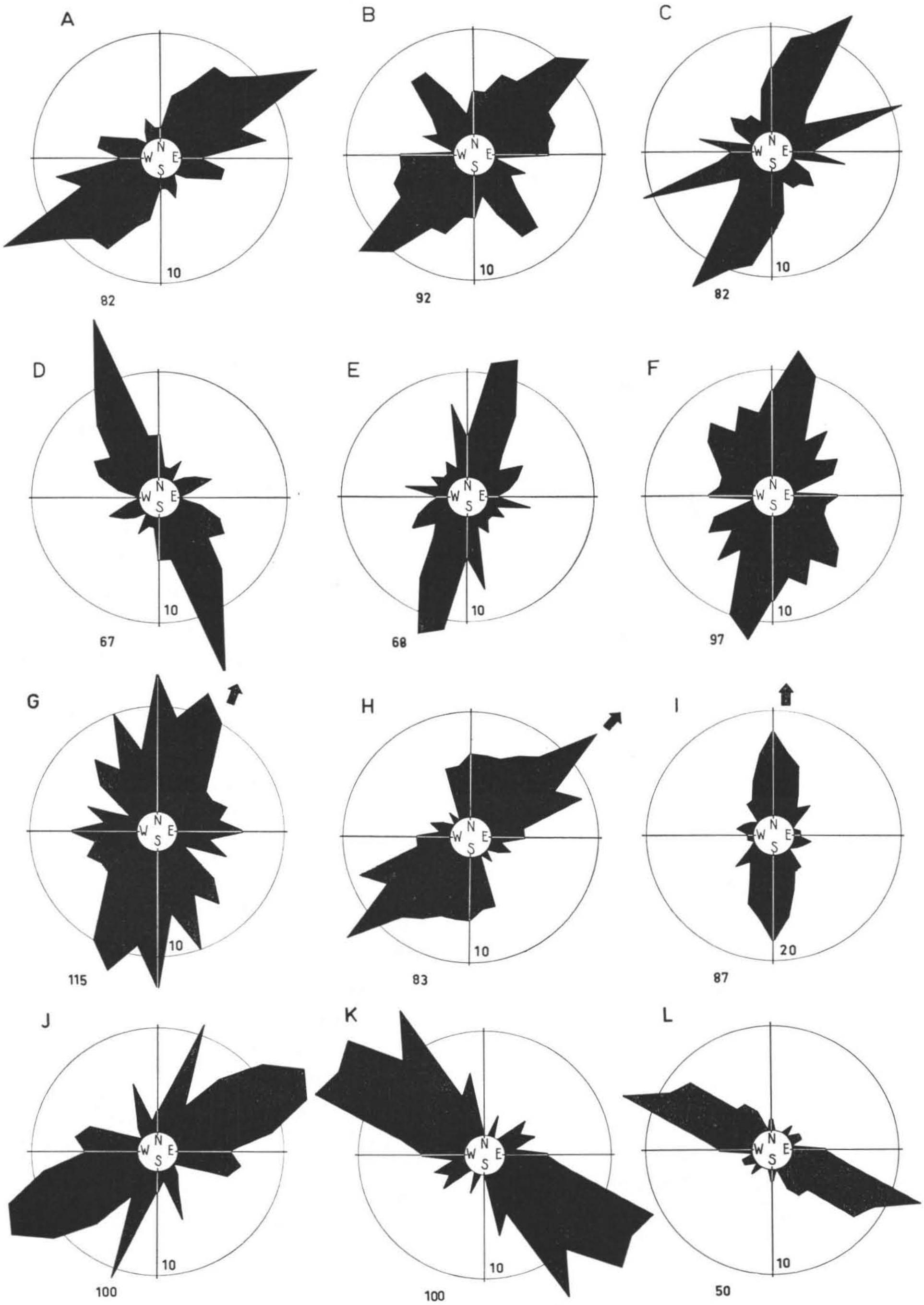


FIG. 12. Some rose diagrams showing the orientation of till stones. The figure outside the circel shows the number of the stones measured. A, B, C, typical ground moraines. D, E, F, so-called younger till covering glaciofluvial material. G, H, I, fluted surfaces. The arrow shows the direction of fluting. J, K, L orientation analyses from a cutting west of Hetta. J. 0.40 m deep, K, 0.80 m deep and L, 1.20 m deep. The till fabric analyses give evidence of two till beds in this site.

The signs interpreted as the last ice movements may have been caused by a local glaciation in territory already deglaciated through the heavy accumulation of snow and its conversion to ice beyond the margins of the continental ice sheet. The erosive action of the glacier would in that case have been slight, and this would explain the preservation of the eskers underneath the ice *(cf.* Virkkala 1951, p. 53). Another explanation might be that there had developed an extensive area of dead ice, which on account of a deterioration of climatic conditions once more turned into an actively flowing glacier *(cf.*, Virkkala 1952, p. 73). Conditions must nevertheless have changed to the extent that the accumulation area and the ice divide shifted some distance farther south than earlier. The thickness of the ice sheet must have exceeded 500 m, for signs of a last ice movement have been observed in, for example, the areas of Ylläs and Aakenus on the highest summits of the fells.

The study of the last stage in the ice movement has proved difficult because of the Quaternary deposits covering the bedrock and the weakness of the glacial abrasion. Measurable glaciogenic abrasion forms are met with in only few places. The exposed areas are often quite broken up on account of the intense mechanical weathering to which they were subjected after deglaciation. It may, indeed, be said that determining the directions of flow of the continental ice sheet in western Finnish Lapland as well as in the whole of central Lapland purely in the light of striae observations would lead to rather deficient results. This is particularly true of the direction of the last ice movement. The ice was incapable of leaving behind marks elsewhere than in the surficial deposits, either in the form of erosion or in that of deposited material. Tanner's (1915, Taf. V) early map of striations shows the most conspicuous striation trends in the region; but in many cases they reflect only the older directions of flow of the ice. The study of the preferred orientation of the stones in the till has cast additional light on the matter, notably in places where the youngest till can be clearly observed, *e.g.*, when it lies on top of sorted glacial drift (Fig. 13). In these places the stones are oriented parallel to the youngest movement (Fig. 17, p. 34).

FIG. 13. Till overlying glaciofluvial material (so-called younger till), 3 km north of Kurtakko, Kolari.

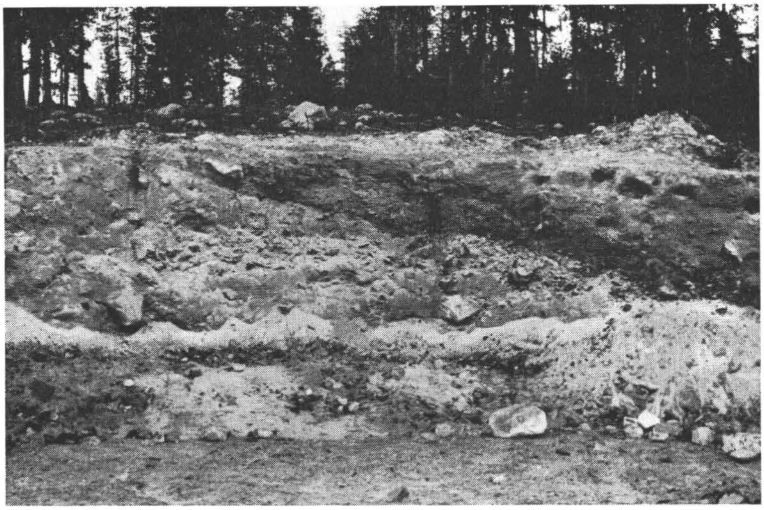


FIG. 14. Two till beds in Torassieppi, Muonio. The orientation of till stones is 170° in both beds. The striations in this area have nearly the same trend.

In certain spots it has been possible to differentiate separate till beds (Figs. 12 and 14) and the orientation of their stones is different in the two beds *(cf.*, Fromm 1965, p. 102; Järnefors 1952, p. 192). Nevertheless, there do exist areas completely lacking in signs of the last glacier flow.

The most fruitful procedure in determining the directions of the last ice movement has proved to be the interpretation of aerial photographs. Various streamline-molded forms or glacial flutings (see Gravenor and Meneley 1958, p. 715) bear more reliable witness to the directions of movement of the ice sheet than do, *e.g.*, the striations, because microtopography affects flutings less than it does striations.

Fluted moraine surfaces are a fairly commonly observed phenomenon in recently exposed terrain in front of present-day glaciers. The literature has made mention of this ever since the early years of our century (Gilbert 1904, p. 77; Grant and Higgins 1913, p. 66; Tarr and Martin 1914, p. 448). Flutings have been described as parallel ridges or grooves, depending on whether the investigator concerned has viewed them as products of erosion or deposition. They may also be the product of a combination of these two processes. In aerial photographs glacial fluting appears as a weaker or clearer parallel pattern, which is generally best developed on the lee slope of an elevated stretch of ground (Figs. 15 and 16). In many instances, a stronger deposition of till had started in such places.

Fluting also occurs as large forms, which make it easier to perceive the orientation. Present in the region are drumlin-like forms, too, with either steep or gentle slopes, the long axes of which quite accurately indicate the direction of the ice flow. The flutings represent the normal structural character of a moraine surface and simply

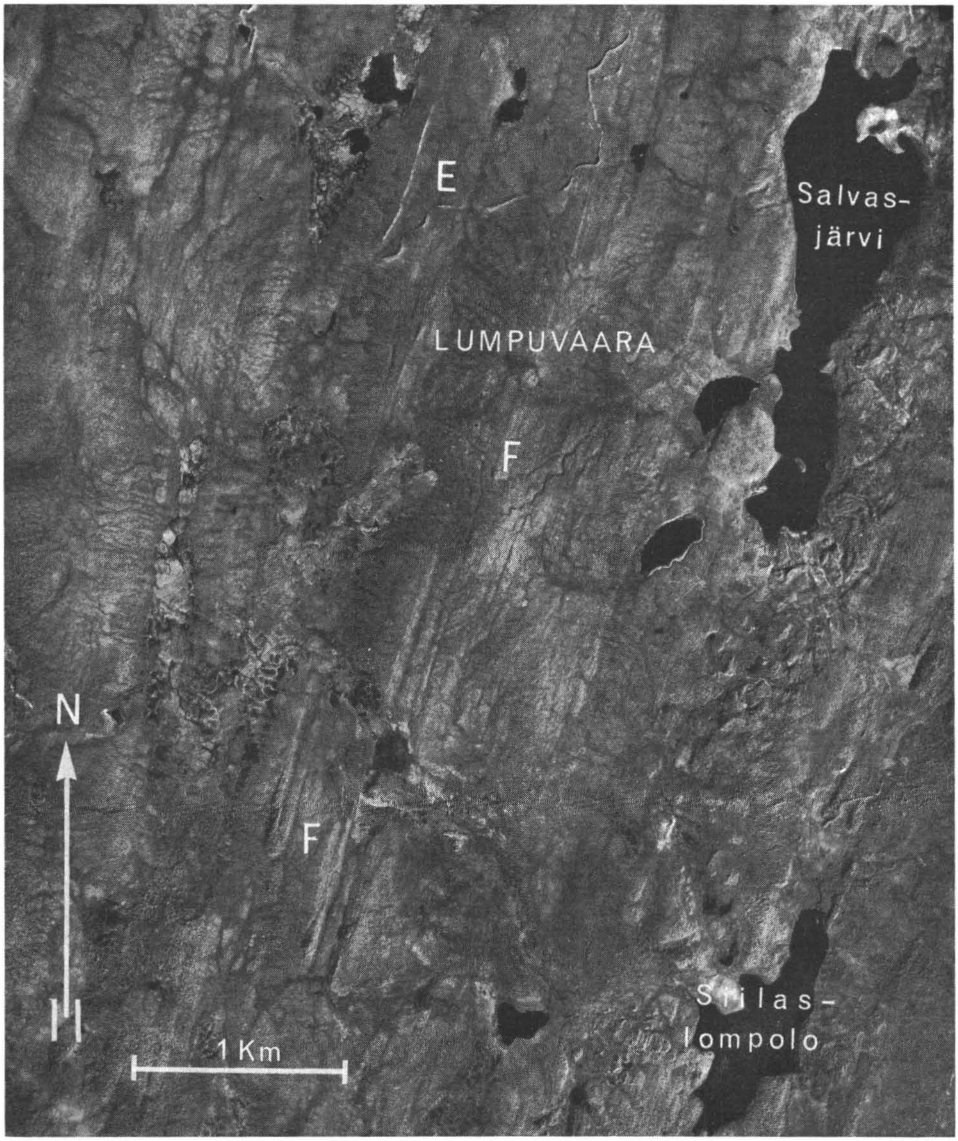


FIG. 15. Fluted surfaces on Lumpuvaara, northern Enontekiö. F) Drumlins and small-scale flutings, E) a small esker chain on which slight flutings are also visible. There are indications of actively flowing ice. By permission of the General Survey Office.

make it plain that the locality has been the scene of an actively flowing glacier. On the eastern side of Karesuvanto there is a good example of a form with gentle slopes, which is rather hard to detect in the field on account of its flatness. It is only 2—5 m high but between 50 and 200 m broad and 2.5 km long. In some instances, elongated

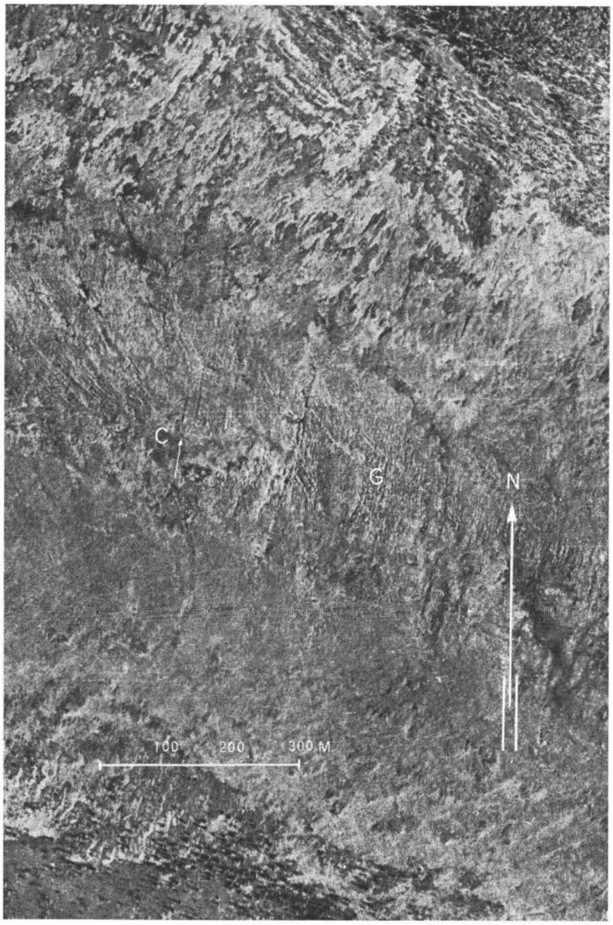


FIG. 16. Small crag and tail formations (C) and giant grooves (G) on Aakenustunturi, which show that the ice has flowed from the south in western Kittilä. By permission of General Survey Office.

moraine patches rising slightly above the bogs may have stretched in line with the ice flow; at least when forming a field of some appreciable extent, or »basket of eggs» (Charlesworth 1939, p. 260), their orientation is distinctly perceptible. On Aakenustunturi there are small crag-and-tail formations (Fig. 16), the height of which is one or two meters, the breadth two to five and the length thirty to fifty meters. They indicate the direction of ice flow without ambiguity: The ice flowed from south to north.

It is by means of the orientation elements on moraine surfaces that the trends of the last ice movement have been determined. When trends deviating from those described by Tanner (1915, Taf. V) were first detected in the southern and central parts

FIG. 17. Trends of the latest ice movement according to flutings. *Cf.* Figs. 10 and 11.

of the region of the present investigation, it was assumed that they merely represented local shifts in the direction of the glacier flow or, then, misinterpretation was suspected; but further investigations produced additional observations of the same kind. The new trend perforce had to be accepted as marking the direction of the advance of the last ice cap.

During the deglaciation stage the ice divide must have shifted position from the southern Muonio—northern Kittilä line, which represents the time of the main glaciation toward the south and west. From the new ice divide the movement proceeded in the southwestern section of the region from the southwest (see Fig. 17). The result

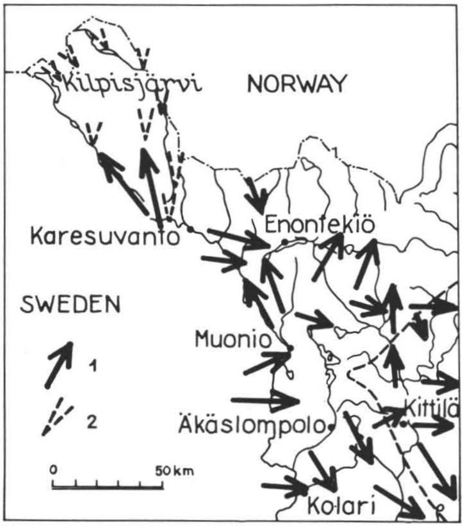


FIG. 18. Main trends of glacial transport (till) according to 1) stone counts, 2) Tanner's observations (1915).

agrees completely with observations of the behavior of the ice sheet in Sweden *(e.g.* G. Lundqvist 1943, p. 11; 1961, map; Fromm 1965, p. 121; Hoppe 1951, p. 160; 1959, p. 209; Järnefors 1952, p. 193) as well as with the trends of the final advance of the ice reported from the area of Pello—Ylitornio (Okko 1941, p. 629; Virkkala 1951, p. 53; Atlas of Finland 1960, Sheet 4). The movement from the southwest continued across the Kolari area into the eastern part of Kittilä and the southern part of Muonio. A flow from southwesterly direction is evidenced also farther north, as in the area of the Ounasselkä range of fells, which clearly guided the flow by acting as a topographic obstruction. The movement from the southwest had shifted on the western side of the fells to proceed from a south-southwesterly and, in many places, even from southerly direction. In Muonio the ice flow had thus taken place principally from the south, although pressure from the southwest had been exerted in valleys and in the close surroundings of the lower fells. At the southern Enontekiö, immediately past the northern tip of Ounastunturi, the direction of flow turned locally even toward the east. The pressure exerted by the fells had been discharged in this shift in the direction of flow, which may not be connected with the last ice movement observed in the southern and central parts of the region; rather, it may date from the time of the main deglaciation stage.

On the eastern side of the Ounasselkä range of fells, the glacier movement took place quite uniformly all the way from the center of Kittilä in a northward line (Fig. 17). On the northern side of the fells, the Muonio and Kittilä lobes of the last local ice movement merged after a slight bend eastward and then headed straight north.

In western Enontekiö the direction of the last ice movement (deglaciation stage) adheres so close to that of the older one (main glaciation stage) that differentiating between them is seldom possible. As the glacier thinned down, the ice flow merely tended to follow the directions of the valleys. In the valley of Lätäseno it flowed toward the north, and in the valley of Könkämäeno toward the northwest. Local variations occur.

To judge by the results of the stone counts, till was transported during the various stages of ice movement. The till appears to have been carried with the greatest power during the main glaciation stage. The most conspicuous exceptions are central Enontekiö, and northern Kittilä where the strongest transportation seems to have occurred as early as the initial advance of the ice sheet, and in central Kittilä, where till can be observed to have been transported also by the ice of the last ice cap. Elsewhere the last ice transported till only slightly. Contrary observations notwithstanding (see Penttilä 1963, p. 19), the transportation distances appear to have been considerable, generally between five and fifteen kilometers; but distances of as much as 30 km must be taken into consideration in the light of stone counts. On the other hand, the local bedrock is also well represented in the stone counts. In places it is possible to differentiate between the long-distance till and the younger, overlying till, which in many cases contains only local material. The results of stone counts are schematically presented in Fig. 18.

DEGLACIATION

Accumulation forms

Eskers and kames

There is quite an abundance of eskers in western Finnish Lapland. They vary considerably in their orientation: N → S, W → E, S → N and even almost directly E → W. The directions in which the eskers run are determined principally by the position of the ice divide, but also by the morphology prevailing in the areas dominated by the Ounas—Pallas—Ylläs chain of fells and the high fells of the northwesternmost part. To replace the concept of the ice divide, one might, in considering the eskers, speak of an esker divide, or the glacier's watershed, which has determined the direction of flow of the glacial streams that deposited the esker material (Fig. 6). The esker divide, which by and large also constitutes a zone, merges almost completely into the zone of the ice divide (Fig. 12), determined by the most conspicuously developed directions of the striations.

The orientation of the esker chains in the northwestern section of Finnish Lapland varies between 150° and 180° (upstream direction) and in the area of Karesuvanto—Hetta between 185° and 225°. In the middle of the commune of Enontekiö, there is a sharp bend in the eskers: first the trend is 180°, then it turns 60°—75°, and between Hetta and Peltovuoma is 240°—255°. The esker of Hietatievat is joined from the south by the Pulju esker, the trend of which at this point is 150° and farther south, in the vicinity of Pulju hamlet, 180°. This turn in the eskers in the middle of Enontekiö is probably not due simply to the trends of the valleys, although the eskers do generally run parallel to them, but it represents the influence of Ounastunturi on the directions of the ice flow and on the ice sheet as a whole (p. 35). In the northern part of Muonio the trend of the eskers is 210°, but in northern Kittilä it varies between 150° and 180°. This difference likewise probably reflects the influence of the Ounasselkä range of fells. In the central and southern parts of the commune of Kittilä and in the commune of Muonio, the trend is distinctly different, namely, 330°—345°, while in the commune of Kolari it is 270°—300°. The trend of the eskers is seen in the map shown in Fig. 6.

Comparing the trends of the esker chains with the map of striations (Fig. 10), one will observe that they are fairly closely in line with the most prominently developed striations. There occur, of course, deviating directions as well, owing to advances and local oscillations of the ice at different times. On the other hand, the eskers

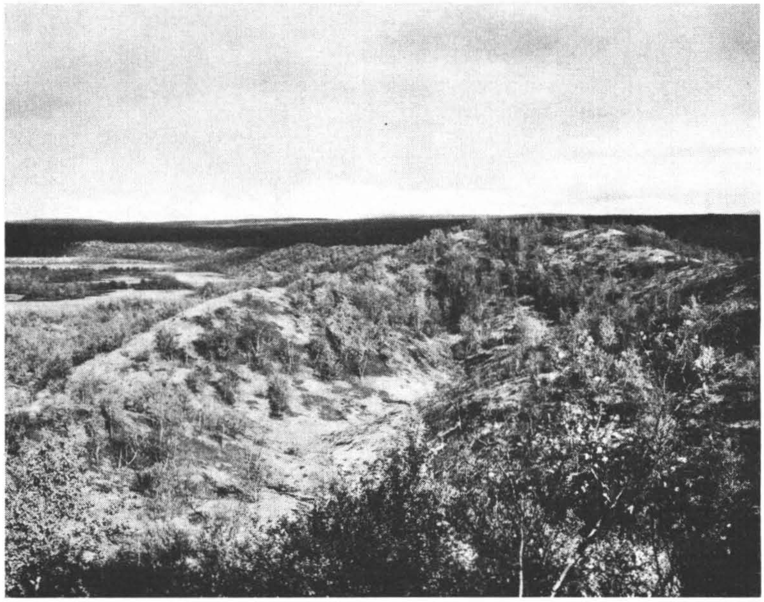


FIG. 19. The Raastajoki esker near Palojärvi in northern Enontekiö. It has a very sharp crest and steep slopes and follows quite a straight course. In the picture the esker is seen as two parallel ridges which join in the background (*cf.*, Fig. 24).

do not appear in the central and southern parts of the region to run parallel to the last retreat of the continental ice sheet (see map on p. 86, Fig. 51). Checked against the map of fracture tectonics in the region (Fig. 5), many of the esker chains will be seen to run parallel to the fractures. This can be construed to mean simply that the esker chains follow the valleys, *i.e.*, the major fractures. It is a different matter, however, whether the waters underneath the ice sheet have sought this lowest level or whether the fractures (= valleys) produced in the ice zones of weakness toward which the meltwaters flowed or whether a dislocation of an old fracture line in the bedrock underlying the ice is the responsible factor (*cf.*, Hyyppä 1954, p. 45). Dislocations also seem to have taken place in late-glacial times (Kujansuu 1964).

The eskers thus are closely associated with the valleys, running in line either with their bottoms or their slopes, or snaking a course from one slope to another. The watershed eskers generally cross over the lowest level, but this is by no means the rule.

The eskers vary considerably in morphology and in the grain size of the sorted drift they are built of. They may be divided into different types:

1) Flattened out or level-topped, with material mostly fine of grain (Figs. 20 and 23);

2) sharp-crested, steep-sloped and straight-lined, built of coarse-grained material (Figs. 19, 22 and 24);

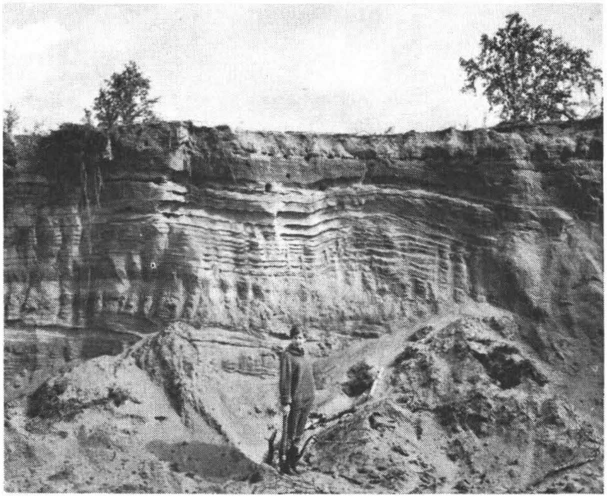


FIG. 20. The Pättikkä esker in western Enontekiö. The material is very fine of grain and well sorted. The material and stratification give evidence of peaceful deposition in water.

3) round-shaped, in many cases till-covered, meandering and segmented, with coarse-grained material (Fig. 21);

4) highly fragmentary (Appendix II);

5) small, »embryonic» eskers (Fig. 15, *cf.* Penttilä 1963, p. 53);

6) »till eskers» (Fig. 25).

This classification is arbitrary insofar as there occur all conceivable intermediate types; carried farther, the classes might be broken down endlessly. Furthermore, the different types are apt to occur in the same esker. This suggests that the different types merely represent different stages of esker development or reflect slight changes in the conditions prevailing during the deposition of the eskers. Type 1 probably represents the crevice or tunnel esker, which evolved in standing water. Type 6, again, represents the most primitive esker, composed primarily of till. Type 4 is characterized by large erosion zones. Types 2 and 5 are englacial or subglacial in origin and Type 3 represents on esker that originally belonged to another type but after deposition was caught under the ice.

The different stages of development might be described as follows: Till is pressed up into a zone of weakness under the ice sheet *(cf.* Woldstedt 1954, p. 127) (6), where metlwaters also collect (5). If there is only a small amount of material, a segmentary chain forms (4), whereas if there is an abudance of material, a coarse core of esker forms (2). If a glaciofluvial stream is discharged into a glacial lake or the sea through a tunnel or a crevice, the ice-contact material (stratified drift) is apt to be covered with delta sediments *(cf.* Eriksson 1960, p. 115). The crest of the esker is

FIG. 21. Till overlying the Sotkaselkä esker near Nilivaara, in eastern Kittilä. The esker is not a ridge on this site, but only a few hundred meters northward there is no till cover and the esker forms a sharp ridge.

FIG. 22. Coarse, poorly stratified and poorly sorted ice-contact material in the Aakenus esker, western Kittilä.

abraded through wave action when drying up, and the esker material may become re-sorted and partly transported by the wind (1). Depending on the amount of drift carried by supraglacial meltwater streams, an esker could end up as either Type 2 or Type 4.

An excellent example of an esker of Type 1 is the Hietatievat—Piippotievat—Utkujärvi chain, of which Fig. 23 shows the part around Piippotievat, on the immediate eastern side of Ounastunturi. The area of the watershed has been washed bare across a zone between one and two kilometers broad. Two deep gullies, Hannukuru

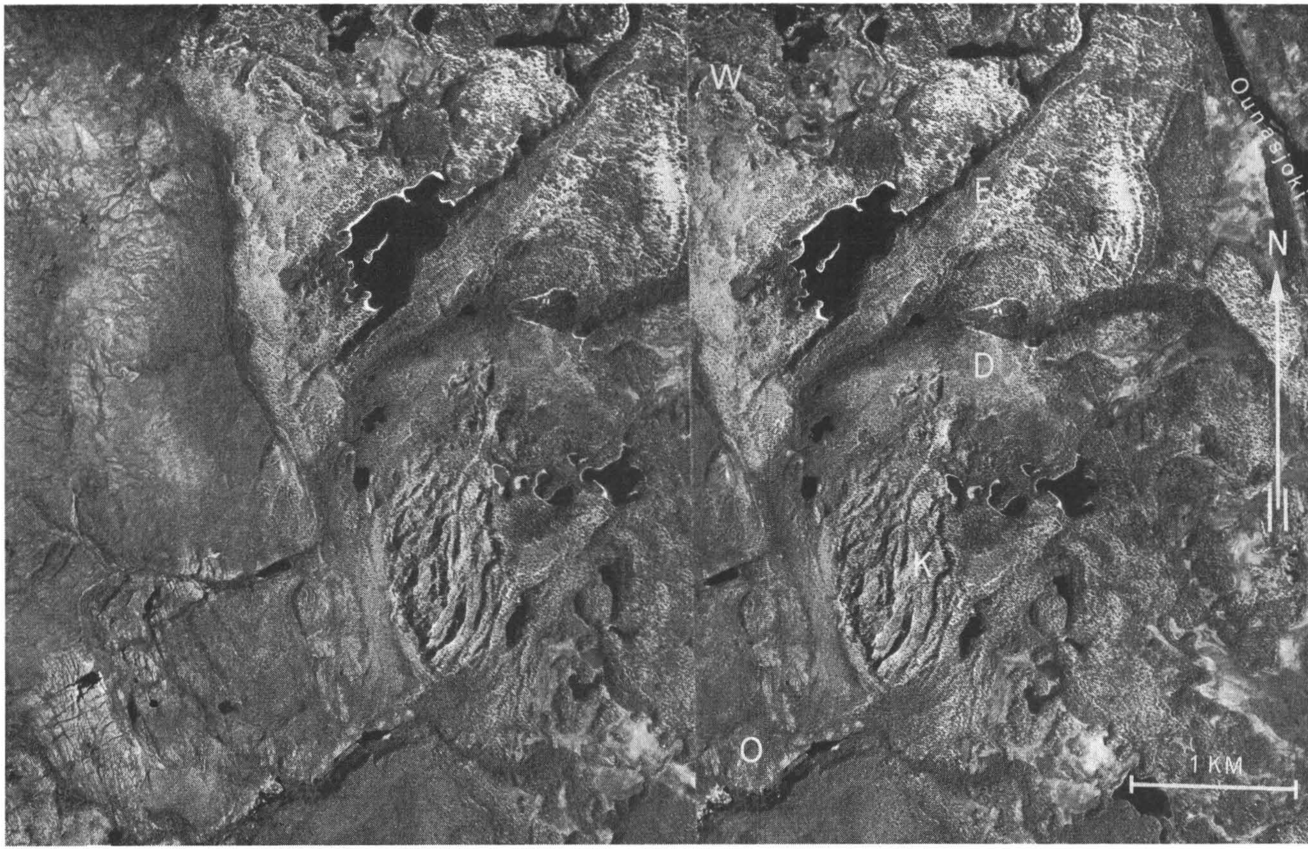


FIG. 23. Stereopair showing the Piippotievat glaciofluvial accumulations immediately on the eastern side of the Ounasselkä fell chain. E) Esker, D) deltaic part of formation, K) kames, O) outcrop of bedrock (eroded by glacial meltwaters), W) wind-blown sand. See text. By permission of General Survey Office.

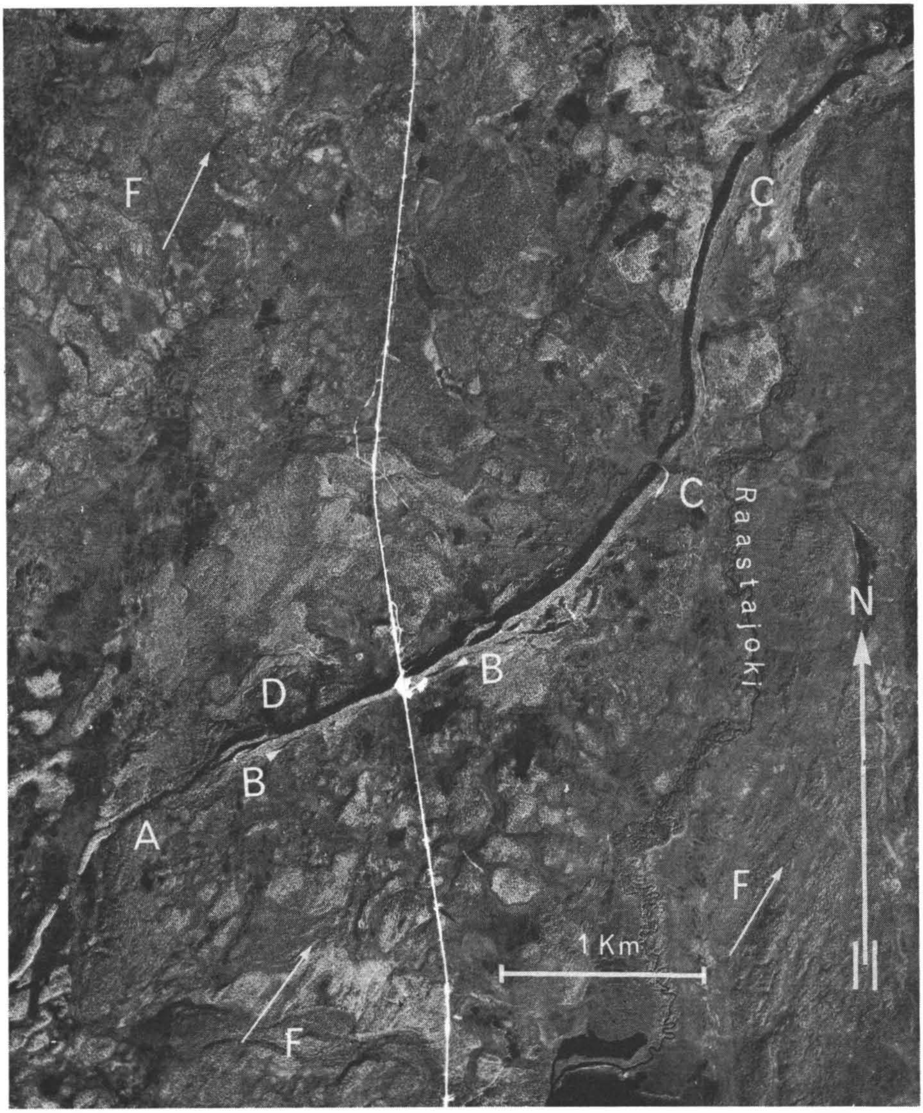


FIG. 24. Aerial photograph showing the course of the Raastajoki esker in northern Enontekiö. A) Glaciofluvial erosion zone in the esker chain, B) parallel ridges, C) esker cut by creek erosion, D) small deltas deposited by ice and esker-dammed lake, F) fluted surfaces. By permission of General Survey Office.

and Ruotakuru, have been cut into the rock and they were guided by the local tectonics. On the western side of the watershed, an abundance of fine-grained material was deposited to form a broad field, in the center of which runs the ridge of the esker proper. Behind the fell, that is, on its eastern side, the process of glaciofluvial deposition started normally either in a tunnel or in an open crevice. This stage is repre-

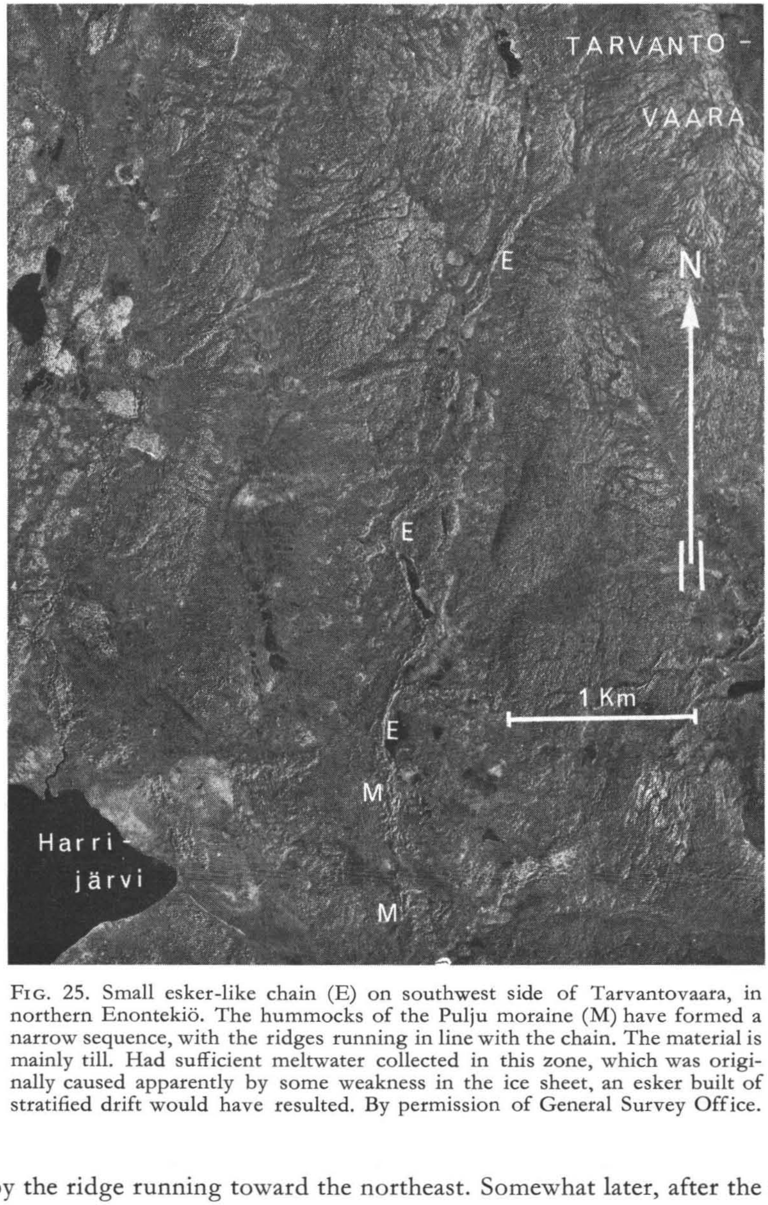


FIG. 25. Small esker-like chain (E) on southwest side of Tarvantovaara, in northern Enontekiö. The hummocks of the Pulju moraine (M) have formed a narrow sequence, with the ridges running in line with the chain. The material is mainly till. Had sufficient meltwater collected in this zone, which was originally caused apparently by some weakness in the ice sheet, an esker built of stratified drift would have resulted. By permission of General Survey Office.

sented by the ridge running toward the northeast. Somewhat later, after the ice sheet had thinned down to expose the summits of the fells as nunataks, glacial drift was deposited also on top of ice lying on the eastern side of the fell. As the ice thinned further, the deposited material was evened out at the 325-meter level, which marks the formation of the delta-like section. The ice buried under the drift melted, resulting in the creation of a kames area. Some kettles developed also in the delta-like section, as the levelling-out process took place even before the complete melting of the ice.

Type 2 shows up best in the Raastajoki esker (Figs. 19 and 24), north of Leppäjärvi. It is either straight or gently arching, and the crest is quite sharp. The ridge has small humps at approximately 200-meter intervals. At these points the ridge reaches heights of 25 or 30 meters above the surrounding ground. The material is coarse, to the extent, in fact, that in places along the slopes there occur block fields. In certain places the esker is represented by erosion belts (Fig. 24, A), or it has split up into parallel ridges (Fig. 24, B). At frequent intervals, low lateral ridges pay the esker company.

Type 3 is represented by the esker of Hanhimaa—Sotkaselkä (Fig. 21), which in the place shown in the picture lacks any special form and lies under a thick blanket of till. The extensions of the esker at Hanhimaa represent Type 3 at its best.

Segmented eskers, Type 4, occur in connection with subglacial channels (Fig. 47 and Appendix II).

Small embryonic eskers (5) occur abundantly in various parts of the region, notably in the northern parts, as, for instance, at Lumpuvaara, where (Fig. 15) the same kind of fluting appears on their surfaces as on the ground moraine in the middle of the picture.

The pressing-up of the till into a subglacial esker-like sequence (6) appears distinctly in Fig. 25. The moraine tract consisting of small hillocks and ridges stretches as a band several kilometers long. Had sufficient meltwater collected in this system, it would probably have developed into an esker.

The region investigated might be divided into three parts according to the dominating esker types: I) The western section, or western Enontekiö, II) the northern section, consisting of the rest of Enontekiö and III) Muonio, Kittilä and Kolari, constituting the central and southern section of the region. Area I is characterized by Types 2 and 4, Area II by Types 1, 2, 5 (6), and Area III by Types 1 and 3. The situation of Type 3 almost exclusively in Area III has been referred to (p. 28) in connection with discussion of the directions of the ice movements. Evidently, the last ice cap advanced in this particular area subsequent to the deposition of the eskers.

The accumulation of the material was not even in the esker sequences; rather, in the area of the watershed, for instance, was erosion at work instead of the deposition of glacial drift (Fig. 23). In some places, the accumulation was prominent uphill, in other places downhill or both ways, as in the esker of Piippotievat. On the other hand, the evidence indicates that the eskers deposited uphill contain material of a finer grain than the ones that evelved downhill, to an extent, indeed, that on the average the eskers formed on the main watershed are of finer-grained composition than the ones oriented toward the south and southeast. Thus, the esker at Kalkkoaivi, which is very fine of grain in the basin of Kelottijärvi but exceedingly coarse of grain at Kalkkoaivi (downhill deposition), while in the surroundings of Melajärvi, as the formation once more works uphill, the material turns finer.

In a number of eskers, especially those trending northward, erosion marks left by the meltwater river that deposited the drift can be clearly seen. Some of the eskers are partially covered by somewhat younger deltaic accumulations (*cf.*, Eriksson 1960, p. 115). Examples are Leppäjärvi and Munnikurkkio. And in such cases, no other evidence of the meltwater river responsible for the deposition of the drift can frequently be seen than elongated kettles formed by the melting of the lower parts of the walls of the ice tunnels or crevices (*cf.*, Hoppe 1959, p. 207). Also elsewhere the kettles are apt to occur as hollows situated between small parallel ridges and the esker proper.

In association with the eskers there also occur deltas or sandurs, as at Kivitievat, in the northern part of the commune of Kittilä, and at Syväjärvi, in the northern part of Enontekiö (Fig. 29, p. 49). Evidently, what happened was a slight pause in the retreat of the ice sheet, during which the drift carried by the meltwater stream formed a delta or sandur in front of the glacier, depending on whether the material was deposited into an ice-dammed lake or on dry ground. In the case of Kivitievat, the deposition appears to have taken place in a crevice opening up northward, as indicated by the ice-contact features observable on the sides of the delta.

The eskers in the southern part of western Finnish Lapland also include enlargements, on the proximal side of which is a prominent ice-contact bank. Such enlargements likewise occur to the south of the area, being represented by, *e.g.*, the accumulations of Orajärvi, Naalastentievat and Pasmajärvi. Noteworthy as occurring in the region under investigation are the accumulations of Venejärvi and Ampiaispalo as well as of Tiukupuljut and Kuusanjärvi. At the southern end of the area, that is, in a subaquatic district, esker enlargements they exhibit delta-like features, whereas in the supra-aquatic part of the region there occur fields of mounds and hollows, *i.e.*, kames areas associated with an esker sequence. The formation of Tiukupuljut—Kuusanjärvi represents a somewhat different type.

The eskers generally consist of a single ridge, though in many instances there occur parallel ridges, whether shorter or longer (Figs. 19 and 24), and kettles (Figs. 23 and 26). The main eskers occur as long chains, which frequently are broken up into segements. In many cases, they branch out, like rivers with their tributaries, which the eskers actually do strongly resemble viewed according to their basic pattern. Eskers show clearly the subglacial hydrography of the meltwaters.

Examined along their total length, it appears as if the eskers had sooner started to form underneath the ice than at the glacier margin. Furthermore, it seems that the process of deposition and the whole glaciofluvial action had taken place far from the glacier's edge, under the ice. For example, in the fell country the action of the large subglacial streams was impossible during the final stage, since dead ice continued to fill the valleys after the upper slopes of the fells had become exposed. The subglacial channel systems often crossed the fells (Fig. 47, p. 70), as does the esker of Ahkoaivi—Tälisvuompuoltsha. The stagnated tongues of ice and evidently the entire marginal portion of the ice sheet had a different system to accomodate the flow of waters, including the small subglacial streams.

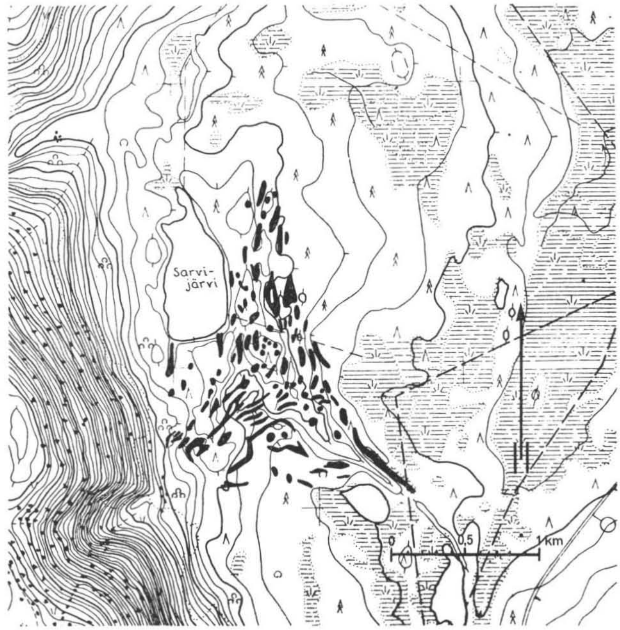


FIG. 26. Orientations of the kettle holes (black) in the supraglacial delta, Sarvijärventievat, east of Pallastunturi.

Eskers are often found linked with kames, as in the accumulations of Piippotievat and Ampiaispalo. A further example is the broad kames field in the esker of Sarvijärvi (Fig. 26). The distinct orientation of the kettles is probably due to the directions of meltwater flow and the trend of cracks and crevices in the ice sheet. The same kind of formation also occurs on the southwestern end of Somasjärvi and it is connected with the esker of Valtijoki, in the Enontekiö uplands. It is only natural that ice should have been buried under glaciofluvial material, especially in areas marked by strong relief, where deposition of drift could easily have taken place even directly on the surface of the ice. Unmelted dead ice had to remain a fairly long time, for, *e.g.*, at Piippotievat the kames area was levelled out by the action of streaming waters to some extent at the present elevation of 325 meters before the kettles evolved (Fig. 23). The drift with dead ice, which together formed the kames field proper, however, resisted the levelling force of the meltwaters. In the kames area situated at the edge of Siilasvuoma, there occur distinct kame-terrace features. They are rather extensive, level stretches of ground without kettles. More examples of this type are described in the next chapter. The material composing the kames is on the average slightly finer of grain than that found in the main body of the esker.

Deltas and sandurs

The meltwaters streaming in front of the continental ice sheet eroded and transported mineral matter in abundance. Erosion was strongest at the present watersheds because the gradient of the channels was steepest there: in many cases, rather than flowing in peaceful streams, the meltwaters formed glaciofluvial rapids. The glacial drift transported by the waters was deposited as the rate of flow slowed down, either on the sides of valleys or into a glacial lake occupying a valley. In the former instance, a sandur evolved, in the latter, a delta.

Deltas are typical of the northern and central parts of the region under investigation in particular. On the other hand, although their origin can be inferred from their outward form and relations to shore features and spillways, the elucidation of their internal structure is impossible since excavations have been made into these accumulations in only two or three places. One cannot draw sufficient conclusions regarding the genesis of structural features on the basis of only scanty observations, especially if there are discrepancies.

Deltas can be classified in western Finnish Lapland as follows on morphological grounds:

1) Extramarginal deltas, which formed through the deposition of glacial drift by streams of meltwater beyond the edge of the ice sheet (Figs. 27 and 28);
2) esker deltas (Fig. 29);
3) marginal deltas, representing deposition into small icemarginal lakes (Fig. 30);
4) supraglacial deltas (Fig. 26);
5) marine or fluvial deltas;
6) deltas or sandurs deposited on dry land (Fig. 33).

Tanner (1915) has described the extramarginal deltas that formed in the ice-dammed lake of Könkämäeno (see Fig. 27). A corresponding sequence of events took place as the waters continued to stream onward to the ice-dammed lake of Lätäseno. The flow started in, for instance, the area of the delta of Saitsijoki (Fig. 28)

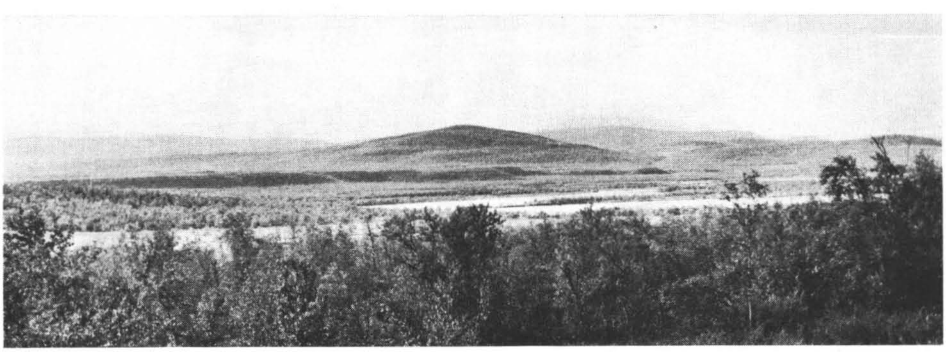


FIG. 27. Distal part of the extramarginal delta, deposited in the ice-dammed lake of Könkämäeno, at Siikavuopio.

FIG. 28. Block field on the Saitsijoki delta, 25 km northwest of Karesuvanto. The material in extramarginal deltas are often quite coarse and not well sorted.

while there was still ice at the bottom of the Lätäseno valley north of the mouth of Saitsijoki. This is indicated by the northerly orientation of the channels on the surface of the delta, as likewise by the hollows formed by dead ice in the northern portions of the formation, where it tends to resemble a kame terrace. The deposition of material took place during the final stage at the 450-meter level. The southern part of the Saitsijoki delta is cut by a sizable channel, through which nowadays flows the Saitsijoki. The surface is by and large flat but it is criss-crossed by a number of larger or smaller channels, which cause unevenness in minor features, as do a few hollows left by dead ice in distal parts. They also provide evidence of the proximity of the ice sheet during the period of deposition.

The material composing the Saitsijoki delta is quite coarse, at least in the surface portions, to the extent, in fact, that in places block fields occur (Fig. 28). Beyond the delta, on the other hand, the material is so fine that the wind has blown it into dunes. There is a similar formation fifteen kilometers farther north, in the vicinity of the Munnikurkkio rapids; but it fills the entire bottom of the valley, signifying that the ice had disappeared totally from the area at the time it developed. Later river erosion dug a channel through it. On the southern side of Saitsijoki, some eleven kilometers away, there is a smaller delta at the southern end of Ruossakero. The history of its origin is the same as that of the ones described in the foregoing, but in this case the deposition took place at the 410-meter level, a height at which shore features evidencing an ice-dammed lake stage can also be observed. In the valleys of Tarvantojoki and Palojoki, there are numerous deltas, as the map of Quaternary deposits shows (Fig. 6).

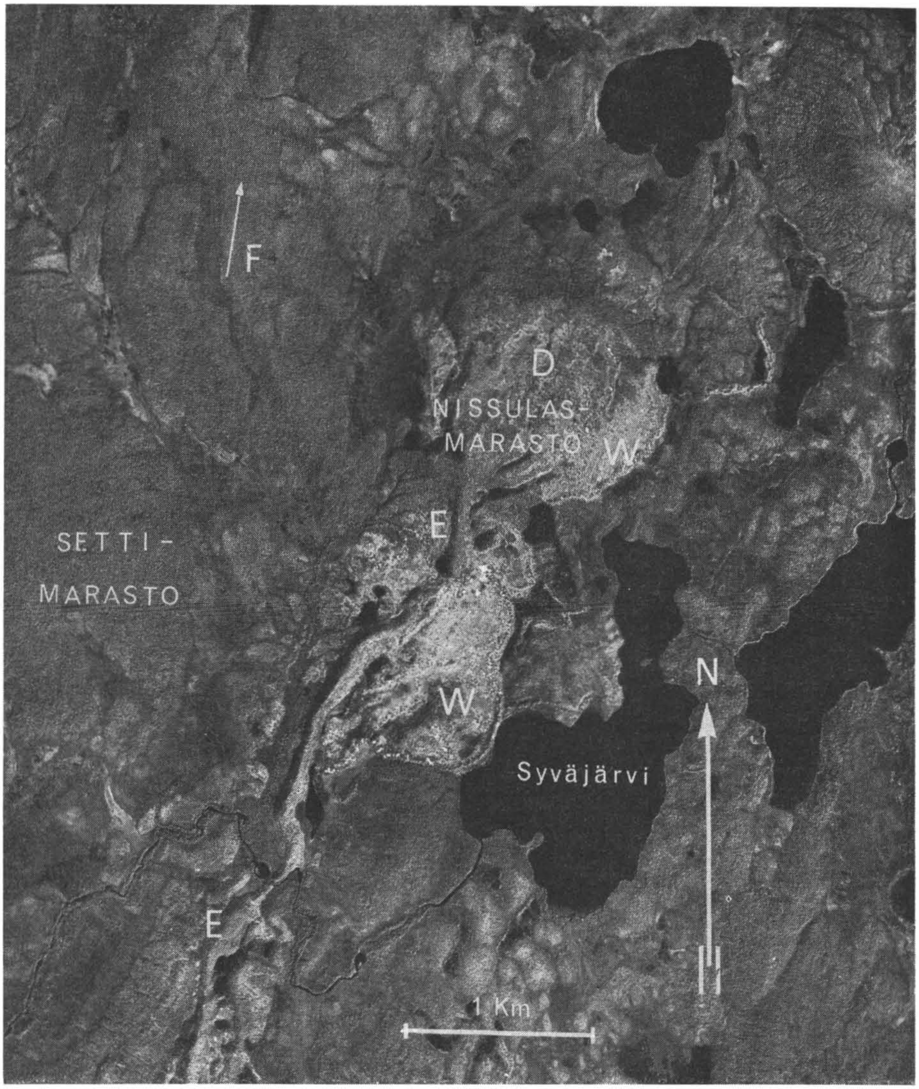


FIG. 29. Aerial photograph showing a deltaic enlargement of the Syväjärvi esker, 20 km north of Karesuvanto. E) Esker, D) deltaic part of the esker, W) wind-blown sand, F) fluted surfaces. The delta was obviously created by a halt in the retreat of the ice sheet. The glacial stream deposited material longer than earlier in the same place. By permission of General Survey Office.

Esker deltas (Type 2), which are enlargements of esker chains, are less common than extramarginal deltas. There are no more than two distinct examples of this type to be found in the entire region. The one situated on the northern side of Syväjärvi (Fig. 29) has been mentioned previously in conjunction with the discussion on eskers. Possibly it evolved during the same stage of the ice-dammed lake of Lätäseno as did the

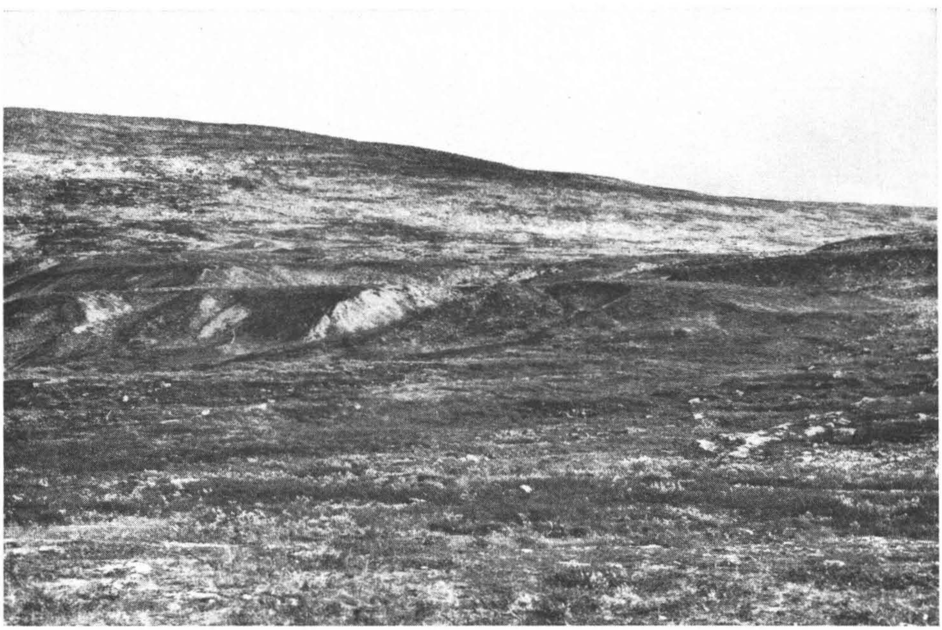


FIG. 30. Small hanging delta on the northern slope of Meekonvaara, indicating the occurrence in the valley of an ice marginal lake. Photo M. Saarnisto.

delta of Saitsijoki. The material composing the esker deltas are generally the same as that of the esker proper. Hietatievat and possibly a few other enlargements of esker chains formed under supra-aquatic conditions in front of the ice sheet to produce sandurs.

Glaciofluvial deltas also formed in small ice-marginal lakes at the end of overflow channels (Type 3). Tanner has described one (1915, pp. 503—505) situated in the Enontekiö uplands (Fig. 30). The occurrence of numerous levels of deposition indicates a swift sinking of the waterline during the accumulation of drift. This is only natural, for the ice thinned down the whole time. Penttilä (1963, pp. 23 and 57) described deltas that formed under corresponding conditions in the Laanila area.

In certain situations, deltas formed in part on top of the margin of the ice sheet. As the ice melted away, such a delta would evolve into a kames field, which is likely to be difficult to differentiate from the forms of other kames topography. Portions of Piippotievat (Fig. 23) and Sarvijärventievat (Fig. 26), where the orientation of the kettles is clear, may be designated as deformed supraglacial deltas. Evidently, in the last-mentioned place the meltwater stream that delivered the material composing the esker came to the surface of the dead ice at this point and transported drift there for quite a long time. The meltwaters streaming from the side, from Pyhäkuru, contributed to the accumulation of material in this locality. The kettles are oriented in line with the two aforementioned meltwater streams. At Piippotievat the kettles all trend the same way, that is, parallel to the direction of flow of the meltwaters.

FIG. 31. Deltaic formation of Palovaara in western Enontekiö, with coarse and poorly sorted material, which was deposited during a powerful discharge of waters from the ice-dammed lake of Könkämäeno. Photo S. Penttilä

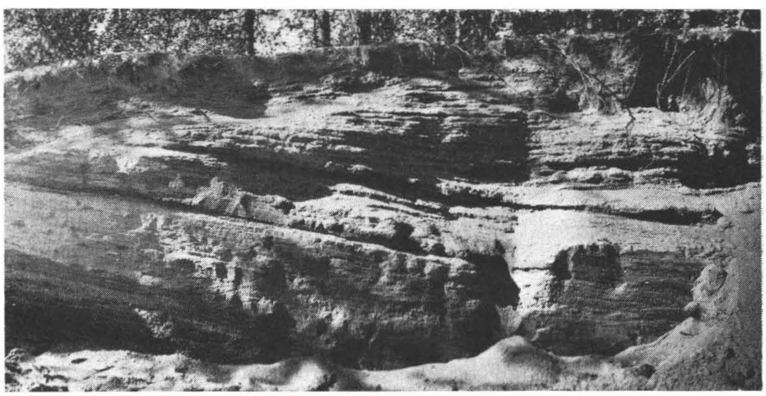


FIG. 32. Material and inner structure of the Pöntsö delta.

The meltwater streams finally discharged into the sea, where at the final stage the coarser drift was deposited to form deltas. The finer-grained material was transported even farther by the waters and finally ended up as varved sediments in the sea. In the Ounasjoki valley there are two deltas, one at Kittilä on the 180-meter and the other at Helppi on the 171-meter level. In both one has observed delta bedding, in the latter, to be sure, only in the surface portions. At the proximal end of the Kittilä

FIG. 33. This aerial photograph presents an excellent illustration of the Repojoki sandur, in western Inari. The fan-like form and braided channel pattern are clearly visible. By permission of General Survey Office.

delta, at the mouth of Aakenusjoki, there occurs horizontal bedding in the coarse, not fully sizesorted glaciofluvial material. This delta represents some kind of alteration from extramarginal to marine or fluvial delta.

In the few excavations, some of which extend no farther than the surface layers, both topset beds intercalated with current-bedded strata and delta bedding can be observed (Fig. 31). Delta bedding occurs, *e.g.*, in the small deltas situated south of Pöntsö (Fig. 32). Topset beds intercalated with current-bedded strata occur, on the other hand, in the formation situated in the Kulkujoki valley. Although the structure bears signs of deposition in supra-aquatic conditions, certain other circumstances may be interpreted to mean deposition of material in water.

Along the upper course of Repojoki, there exists an accumulation whose morphology clearly suggests a sandur (Fig. 33). Its surface is covered with a dense network of small stream beds, which spread fanlike; and the surface appears to slope more than in the deltas. The inclination has not, however, been measured. Furthermore, the formation lacks the distal slope of deltas. The sandur of Repojoki formed while meltwaters streamed across the ridge of Repovaara through a narrow gorge. As the waters reached low-lying ground south of Repojänkä, the rate of flow slowed down and the glacial drift was deposited to form the fanlike structure. A strong current wore a channel through the formation and today it is the bed of the Repojoki.

Whichever the mode of origin of individual deltas, they are important to explaining the deglaciation process. The elucidation of the internal structure must, however, await the appearance of new cuts through these formations.

End moraines

During the dissipation stage of the continental ice sheet, its margin in the mountainous part of western Enontekiö consisted of numerous tongues filling the local valleys. Although these ice tongues were nearly stagnant, great lateral moraines formed along their margins in a number of places as evidence of their periodic or local oscillation. These moraines are steep-sloped and sharp-ridged and asymmetric in cross-section. They may be several kilometers long, like the moraine on the southern flank of Lammasoaivi which has a length of some five kilometers. For a distance of about two kilometers it has quite a distinct shape, being as much as 15 meters high. Another one is situated on the northern side of Peerajärvi with an E—W trend, and a third, running in the same direction, on the southern flank of the Sinettä fell. The largest lateral moraines are associated with the valley of Könkämäeno and its subsidiary valleys. Elsewhere in the region only a few scattered examples have been found: *e.g.*, on the northern side of Toskaljärvi, in the valley of Vuomakasjoki and on the southern slope of Ailakkavaara. It is not always easy to determine whether the formation is a lateral or a terminal moraine.

Unmistakable end moraines are a rarity in the region and most of them are situated in valleys of the Enontekiö uplands (Fig. 34) and in the central part of the same commune, as described by Tanner (1915). The most prominent of them is the end moraine of Härmäpori (Tanner 1915, p. 215), which is several kilometers long and in places nearly 20 m high. The area also contains an abundance of small end moraines. Ridges interpreted by Tanner (1915, p. 190) as end moraines occur on the northwestern side of Peltovuoma in central Enontekiö, where there are numerous ridges one to three meters high running roughly in E—W direction. In these moraines the long axes of the stones are oriented at right angles to the long axis of the ridge (Fig. 42).

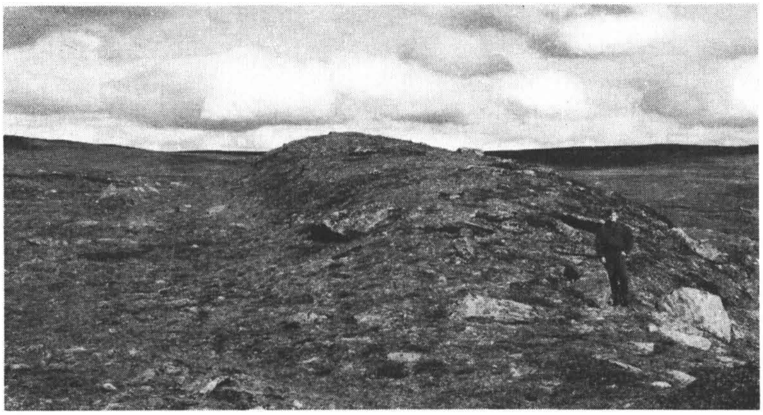


FIG. 34. Southernmost end moraine of the late-glacial Halti valley glacier. The ice stood to the left of the moraine. Photo M. Saarnisto.

In the valley of Lätäseno there are substantially larger end moraines of a different type. They run parallel to the glacier margin and the trend of the stones is likewise perpendicular to the long axis of the ridges. Some of them are fairly flat, with the ice-contact side nevertheless having a slighter slope than the distal side; they are, in fact, more or less only swellings on the body of the ground moraine similar to those described by Chamberlin (1894). On their surfaces one can observe fluting, which in places spreads out in a fanlike manner and thereby indicates slight radiating movement at the glacier's edge or the oozing out of glacial drift underneath the ice into radiating crevices.

The symmetrical moraine ridges in the vicinity of Kelottijärvi are situated partly in line with the movement of the ice sheet, partly at right angles to it. The orientation of the stones is weak, yet perpendicular to the longitudinal direction of the formation. In the basin of Kilpisjärvi there are numerous end moraine ridges *(cf.*, Tanner 1915, p. 198), as on the south side of the Iso-Malla fell, between Salmivaara and Tsahkajavri, and on the eastern shore of Ala-Kilpisjärvi. A few of them are distinctly ridgelike and large boulders have accumulated in them or in their extensions, whereas in other cases they are broader and flatter. The distal side in these ridges, too, is steeper than the proximal side, which seems to signify that the till was not pushed forward by the ice sheet but trickled out from underneath it, or, then, that it is only a swelling on the ground moraine accumulation produced during a standstill stage of the glacier. A bed structure conforming to the surface has been noted in these formations as an indication of this. The till fabric is not plainly perpendicular to the long axis of the ridges although such an orientation does occur as a minor feature. The hummocks and ridges have also been interpreted as representing ablation moraines (Lagercrantz 1951, p. 125).

Large end moraines of the Salpausselkä type have also been met with in western Finnish Lapland. The deltaic and sanduric enlargements of eskers in the central and southern sections of the region have been described on p. 45. Along the same line on the eastern side of Kittilä is the Nunospuljut end moraine, which is situated to its greatest extent east of the region investigated. It consists of moraine ridges pressed together, trending approximately north—south and containing an abundance of sorted material mixed in with till. The entire belt measures roughly one kilometer in breadth and between two and three kilometers in length. The highest of the ridges rise about 20 m above the surrounding terrain.

On the western side of Kumputunturi, at the southeastern end of Jeesiöjärvi, there runs a marginal formation trending SW—NE, which has been cut into several segments by extramarginal streams. The material in the surficial portions consists in many spots of sand and gravel rich in cobbles. This has apparently prompted Tanner (1915, p. 395) to interpret the formation as an esker. Yet, on its northwestern side one can observe in it an unmistakable ice-contact slope. The ridges of the Kuusanjärvi—Tiukupulju belt are composed of both sorted drift and till. The belt runs approximately at right angles to the eskers crossing it. It belongs in the same zone as the aforementioned formations.

The sparse occurrence of end moraines in the region and, particularly, the lack of washboard moraines — which are a typical feature of subaquatic tracts (Mawdsley 1936) — cast light on the state of the glacier and the conditions prevailing during the period of deglaciation. The melting process was so rapid that not even during the winters did any appreciable movements occur, which might have created end moraines. Their concentrated occurrence, first of all, in the Enontekiö uplands indicates that the ice margin was more active there, being due to the close proximity of the accumulation area. Their further concentration, in the second place, in the central part of Enontekiö probably reflects the separation of the glacier on the lee of Ounastunturi by the fell into two lobes *(cf.,* Tanner 1915, pp. 659—660). The marginal formations in the southern part of the region indicate a certain marginal position of the ice sheet which came about when the retreat of the ice margin halted (Fig. 51).

Hummocky moraines

In the commune of Enontekiö the landscape in many places is dominated by hummocky moraines. Even a superficial acquaintance with these moraines indicates that they are of several different types, viewed both morphologically and genetically (Fig. 35).

On the western flank of Ounastunturi there rests a moraine accumulation consisting of quite densely situated hummocks varying in height between about 5 and 15 meters. It evidently evolved out of ablation till during the melting of the buried ice.

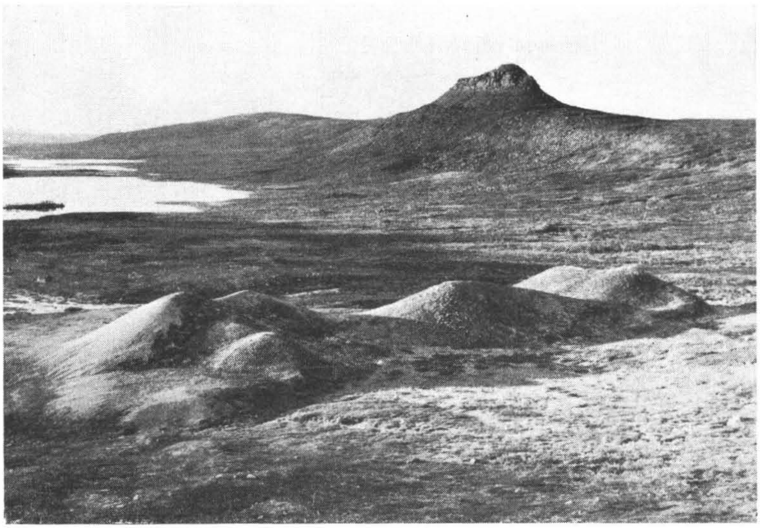


FIG. 35. Hummocks of glacial drift 12—15 m high, which have been interpreted as esker knolls by Tanner (1915, p. 241) and ablation moraine hummocks by Ohlsson (1964, p. 19). Photo M. Saarnisto.

The hummocks are lined up in somewhat irregular rows running parallel to the margin of the ice sheet, and many of the hummocks have a longitudinal axis weakly oriented in line with the movement of the glacier. Such ablation moraines are clearly outnumbered by other forms in the region under investigation. Some ablation moraines occur in the central part of Enontekiö and in the valleys of the western uplands.

In northern Kittilä, approximately at the latitude of the hamlet of Pulju, there begins a stretch of ground representing a type of hummocky moraine very little dealt with in the literature. Penttilä (1963, p. 46) mentions the occurrence in the Laanila area of what seems to be such a moraine, which he surmises to be a small-scale example of Veiki moraine described by Hoppe (1952, p. 5). It seems, however, that this moraine is quite an independent type, which will be called Pulju moraine in this paper. It consists of small hummocks, often only from one to five meters high, or of ridges of the same height and between 50 and 300 meters long, which are situated helter-skelter or in thick clusters running either parallel to the movement or margin of the ice sheet or crossvalleywise. In many spots one also meets with ring ridges, measuring no more than 50 to 150 meters in diameter. The slopes are gentle and the hollows between the ridges are mostly filled with peat. Pulju moraines are quite common in low-lying places in northern Kittilä as well as southern and central Enontekiö (Fig. 36). Also at Ounastunturi there occur accumulations of the Pulju moraine type. There the forms are slightly sharper, in addition to which there are fairly long ridges.

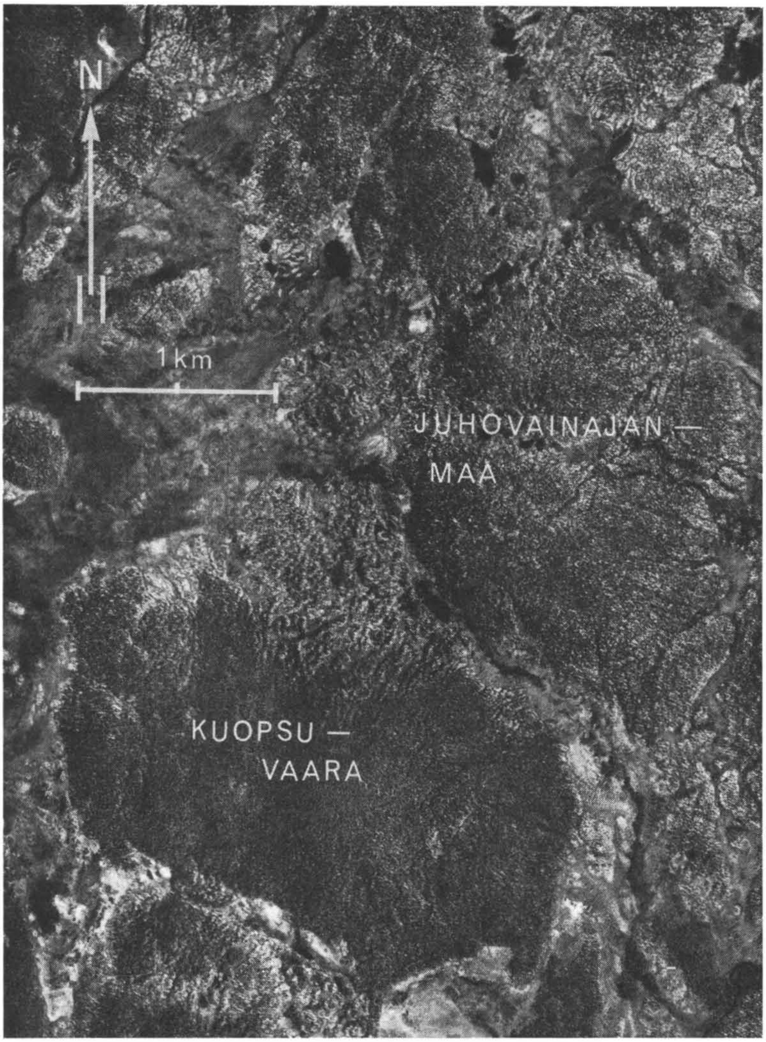


FIG. 36. Aerial photograph of the Pulju moraine area in northern Kittilä. It consists of small hummocks and ridges and ring ridges (2—8 m high). The author has interpreted them as having accumulated subglacially (submarginally). By permission of General Survey Office.

The material composing the ridges is the same fine sandy till as elsewhere, and the long axes of the stones are clearly oriented with the movement of the ice. In certain cases, as east of Karesuvanto, the terrain is weakly fluted. In this instance, an advance of the ice appears to have taken place in the western part of the hummocky moraine terrain, whereas in the eastern part such signs are not to be seen, although the till fabric there shows an identical orientation. Evidently, in the eastern part the advance of the ice sheet was to some extent obstructed by a

Fig. 37. Aerial photograph of hummocky moraines (M) around the Tälisvuompuoltsha esker (E) in northwestern Enontekiö. The ridges are mostly situated in the direction of the glacier margin, but they are not end moraines. They have often been interpreted as being subglacial by origin. By permission of General Survey Office.

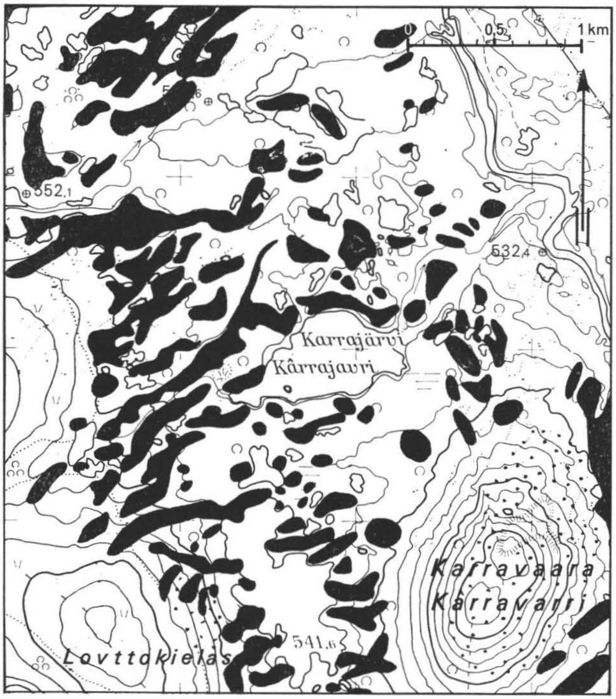


FIG. 38. Hummocky moraines in the Karravaara area (black).

hill in front of the glacier. In the light of the foregoing, it would seem logical that the hummocky moraine terrain evolved under a stagnant — or semistagnant — marginal portion of the glacier *(cf.* Tanner 1915, p. 222), where water-saturated drift had become pressed up into cracks and cavities in the basal ice *(cf.*, Hoppe 1952, pp. 8 and 55). A probable precondition for the development of the Pulju moraine was the existence of a sufficiently thick bed of basal till. It was in the moraine tract on the eastern side of Karesuvanto, at least, that the maximum thickness of till measured in the region under investigation was discovered by drilling. The thickness of more than 16.5 meters was reached in precisely this area, and even then bedrock was not hit.

The valley of Lätäseno forms a natural boundary between different types of hummocky moraine, for where the fell country proper begins the hummocky moraines undergo a complete change of character. Instead of Pulju moraines, there occur numerous fields consisting of ridges resembling end moraines. Similar features have been described abundantly from the fells of Swedish Lapland *(e.g.*, Holmsen 1935, G. Lundqvist 1937, Mannerfelt 1945, Hoppe 1952, 1957). The ridges and hummocks are fairly large, as much as 10 to 20 meters high, 50 to 150 meters wide, and between hundreds and thousands of meters long. By and large, the ridges are not continuous but are

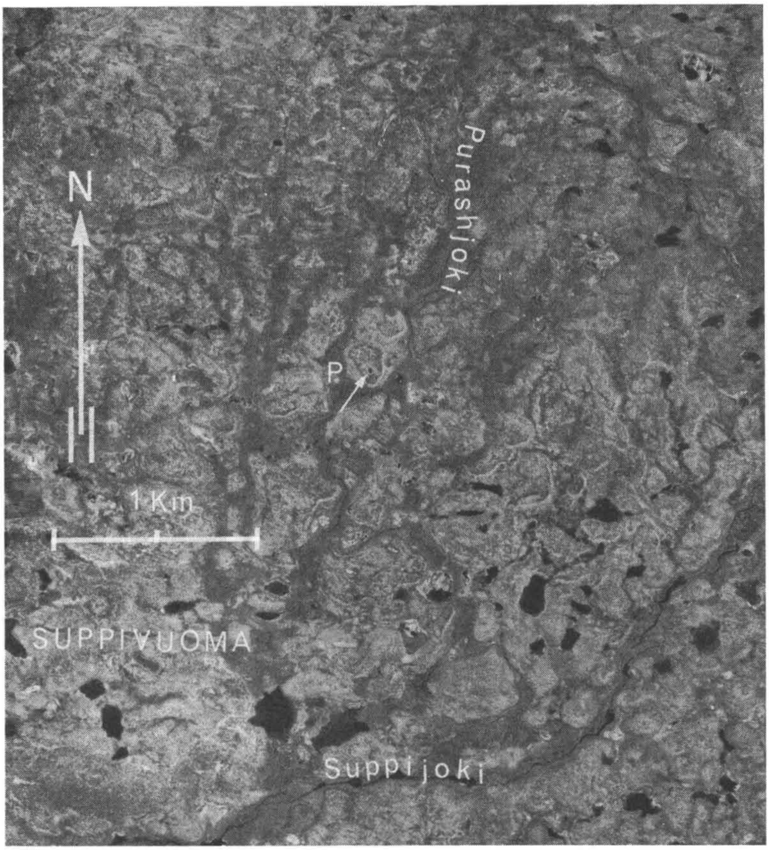


FIG. 39. A fine illustration of the hummocky moraines in Suppivuoma, western Enontekiö. A typical moraine plateau (P), on which there is a little pool showing the existence of a rim ridge. The slopes of the plateaus and ridges are often very steep (ice-contact slope; *cf.* Fig. 41). Similar moraine hummocks have been interpreted by Hoppe as being subglacial or submarginal by origin. By permission of General Survey Office.

broken into segments and branch out as well as joining neighboring ridges (Figs. 37 and 38). Characteristic of them, however, is the fact that they generally run across valleys and often form arches reminiscent of end moraines. The distances between ridges vary between 70 and 200 meters. The stretches between the ridges consist mostly of the same till as the ridges do, though in places there also occur block fields, outcrops of bedrock or they are covered with peat. At its most typical such a moraine landscape is to be observed on the western side of Karravaara (Fig. 38) and in the vicinity of the esker of Tälisvuompuoltsha, in the valley of Poroeno (Fig. 37). The last-mentioned formation has been described by Tanner (1915, p. 174) as a variety of ablation moraine (Swedish: *avsmältningsmoräner)*, but the present

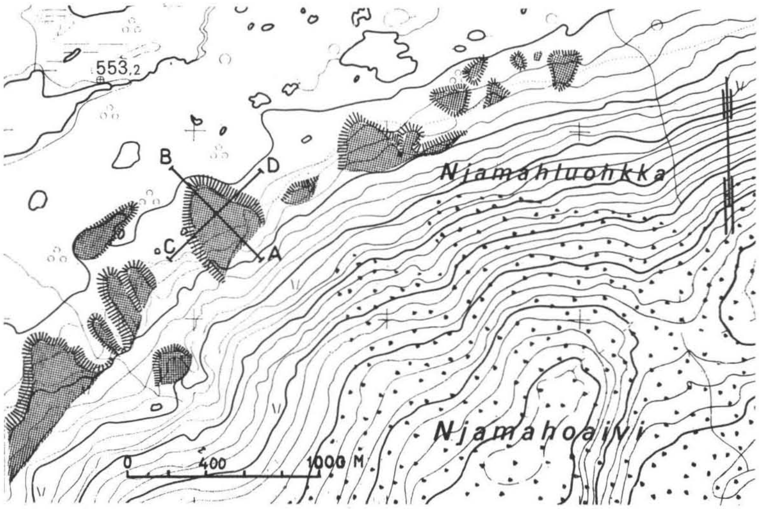


FIG. 40. Moraine hummocks (grey) on southeastern slope of Suppivuoma valley in western Enontekiö. The line A—B and C—D show the directions of profiles in Fig. 41.

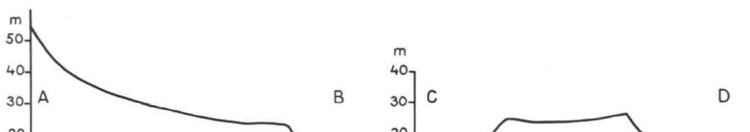


FIG. 41. Schematic illustrations of the profiles along the lines A—B and C—D in Fig. 40. The profiles indicate that these hummocks are similar to one shown in Fig. 39. Only the topographic situation is different.

author joins Hoppe (1952) in the view that these moraines (so-called Rogen moraines) are of subglacial origin. The till fabric analyses yield a result corresponding to that of Hoppe's (1952, p. 65) from the Rogen region. The orientation of the till stones is in most cases perpendicular to the ridges (Fig. 42).

At Suppivuoma there occur plateau-like moraine hills measuring some 500 meters in diameter and ten meters in height, which are slightly hollow at the center — to the extent, in fact, that in some cases the hollow contains a pool (Fig. 39). The slopes, on the other hand, are steep, signifying an obvious glacial contact form. The hummocky moraine shown in the picture is nearly identical in form with the moraine from Veiki described by Hoppe (1952, p. 6). The foregoing example, in which moraine ridges occur among the plateaus, is situated at the northern margin of Suppivuoma. At the southeastern margin, on the lower flank of Njamahoaivi,

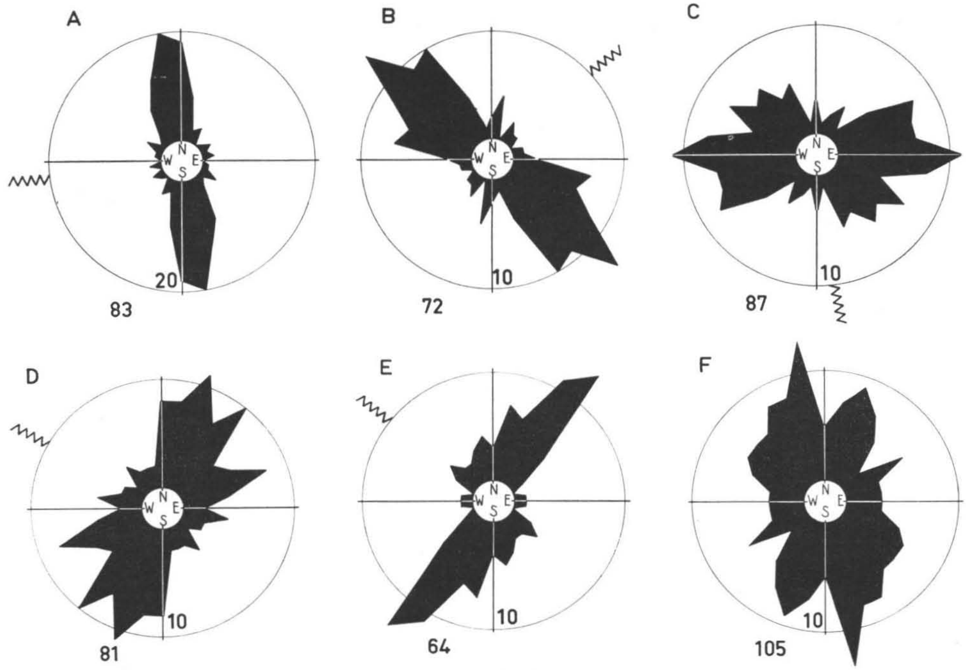


FIG. 42 Rose diagrams showing the orientation of till stones in end moraine (A, B, C) and hummocky moraines (D, E, F). The Zig—Zag line beside the circle indicates the ridge direction.

there are moraine plateaus that extent out of the fellside without any steep slopes, whereas on the lower side the slopes are quite conspicuous (see Figs. 40 and 41). The ground pattern of plateau-like moraine hills is often triangular, with the base upslope; the cross-section is indicated by Fig. 41. The surface of these formations is also concave, *i.e.*, the edge of the plateau consists of a low rim. Hoppe (1952, pp. 6, 11, 13) has remarked that the orientation of the stones is perpendicular to the rim, or the movement (= pressure). The trickling of drift took place toward the rim. Besides possibility of a subglacial origin, there is another: ice might have remained only in the stretch of ground between the mounds, and changes of temperature might have caused expansion and contraction of the ice and the generation of sufficient pressure to orient the stones and to raise the bank along the rim of the plateau (G. Lundqvist 1937, p. 16; 1943, p. 37).

Hummocky moraine tracts occur in the northern parts of the region, whereas they are almost totally lacking in the southern parts. At the northern end of the region, in the district of Finnmarks vidda in Norway, the moraine forms are once again mainly of the drumlin and fluting type (Holtedahl, 1960, p. 431). It is obvious that these circumstances likewise reflect the state of the ice sheet and climatic conditions during the period of deglaciation.

Glaciofluvial erosion forms

Overflow drainage channels

In each locality the oldest of the glaciofluvial erosion features are the col gullies (*cf.* Mannerfelt 1945, p. 33), or overflow channels, which occur at the highest levels on the fells and hills. In western Lapland, however, they are not so typical of the landscape as at Laanila (Penttilä 1963, p. 21). The circumstances of origin of the overflow channels vary greatly (Rudberg 1949, p. 491). A general characteristic is that they could not have evolved where they are under the conditions now prevailing, but there must have been ice and an abundance of meltwaters at the time of their formation. The meltwater stream that wore down any given channel might have flowed under, inside, on top of or in front of the glacier; or the channel could have formed along the edge of the ice damming a lake, where, as the water streamed over the lowest point, normal erosion took place. The overflow channels are on the whole fairly short, but deep and with steep slopes. In most instances the meltwaters have sought the fracture line in the bedrock and then completely cleared it of the weathered or broken material. Overflow channels are also to be found in places where no streaming of waters took place during the final period of melting. On Ounastunturi there are two such, distinctly V-shaped channels, in which no appreciable flow occurred during the last stage of deglaciation (p. 25). Their trend does not conform to other data on the state of the glacier during this stage. On the other hand, it was unmistakably during the final stage of deglaciation that a typical col gully developed between Lumikero and Suastunturi from the discharge channel of the ice-dammed lake at Kerässieppi. The elevation of its threshold is about 365 meters.

Among col gullies associated with subglacial systems should be mentioned the ones occurring at Pissivaara (504 m), on the southeastern side of Kilpisjärvi, on the northwestern flank of Laassavaara (615 m), as well as between Mukkavaara and Peeravaara (617, 613 and 605 m). The first two mentioned are associated with the same subglacial system, the younger of them at Pissivaara, to be sure, more than 100 m lower down. Evidently, at least this lower gully was dug out subglacially rather than at a time when the ice margin had reached the spot, for at the same elevations (507 m) there are shore features of a glacial lake and the channel would have had to terminate in water. The subglacial tunnel had probably ceased to function by that time and the valley been filled with the last remnants of dead ice, where large channels could no longer function there being no continuity of hydrostatic pressure. The aforementioned channels are not situated along fracture lines in the bedrock and for that reason are not distinctly V-shaped, although the erosive forces have been strong (see Fig. 43). An example of a gully that had formed under subglacial conditions is also to be seen in Appendix II from the south side of Pallastunturi.

Among col gullies guided by the tectonics might be mentioned the ones crossing Aakenustunturi (*cf.*, Tanner 1915, p. 628) which has the shape of an arch opening toward the southwest. They have formed in joints cutting the arch, but they are

FIG. 43. Small overflow channel in the Siilasvuoma esker chain in westernmost Enontekiö.

fairly small in size (depth < 10 m). As the summit of the fell became exposed as a nunatak, meltwaters collected behind the arch to form a small ice-dammed lake; and it is the water rushing down the discharge channel that eroded the gullies. The threshold altitudes of the gullies are 485 m, 465 m and 377 m, which indicate the descent of the point of discharge as the melting glacier thinned down. At the final melting stage the meltwaters flowed along strictly lateral drainage channels.

Had the general gradient relations in the region been contrarywise (see Fig. 3), the significance of the overflow channels to the study of the deglaciation conditions would have been exceedingly great. Now the extramarginal channels, which in a sense also represent overflow channels, cross the local watershed and, together with the lateral drainage channels, most clearly represent the conditions prevailing in the marginal parts of the continental ice sheet.

Lateral drainage channels

The lateral drainage channels that formed along the contact between, the melting glacier ice and the fells vary quite considerably in size and shape. In many cases the channel starts in a depression terrace or stony bank hard to notice in the terrain;

FIG. 44. Lateral drainage channel on Pälkevaara in northwestern Kittilä. Photo S. Penttilä.

it is likely to be detected only by virtue of the slightly more luxuriant vegetation there. The channel widens and deepens, and it may be either one- or two-sided and worn out of till, weathered bedrock or, in some instances, sorted material. The channels wide at their mouths and in front of them, on the lower mountain slopes, sorted drift has sometimes been deposited to form a thin bed (Fig. 49, p. 75). The sides of the channels vary in steepness, being steeper in the deep ones than in the shallow ones (Fig. 44).

The lateral drainage channels came into existence during spring floods, when the melting of the snow was at its height. As the glacier melted later on, during the summer, the ice turned brittle and the meltwaters generally found their way under the marginal portion through cracks and crevices. During the winter these sublateral channels filled up and froze over. The channel that formed the following spring took shape a bit lower down and once more followed the line of the ice margin (Fig. 45). Thus the lateral drainage channels form a nearly parallel series, which is cut by sublateral channels. The gradient of the latter is noticeably steeper than that of the lateral channels. Together they create a network pattern. In certain cases a channel may have traced its course beneath a lobe of the glacier in the same place several years in succession, thereby forming a sublateral collector channel. A good example is to be seen in the aerial photograph taken on the northern side of the highest point of Pyhätunturi (Fig. 46). The sublateral collector channel runs nearly perpendicular to the contour lines on the map. There are instances where sublateral gullies have run together from an extensive area to form a subglacial collector channel at a valley bottom. The lateral meltwaters gathered in proglacial channels in front of the ice sheet and flowed in line with the general gradient or, when so forced by the ice

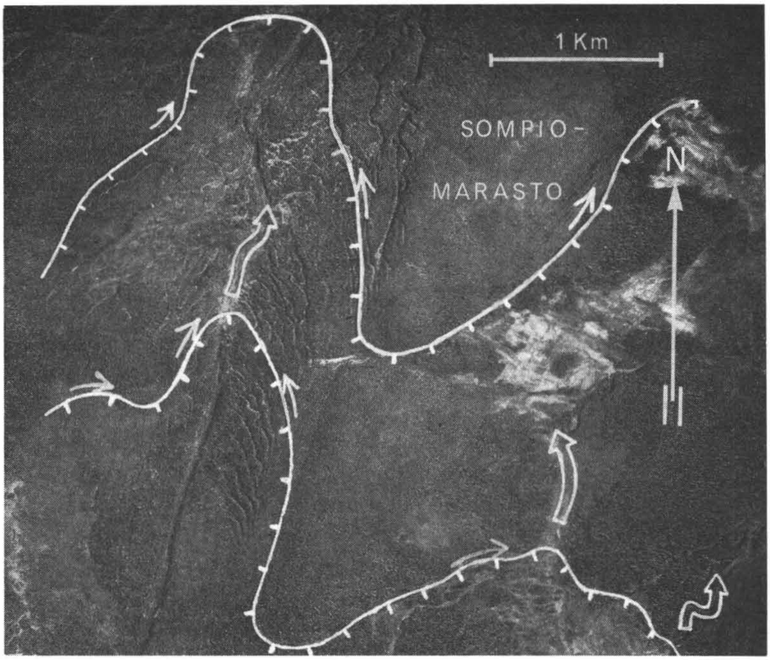


FIG. 45. Lateral drainage channels on Sompiomarasto, northern Kittilä. The channels give evidence of a south-southwestward trend in the retreat of the ice sheet. In the aerial photograph the hatched line indicates the positions of the ice terminus and the arrows the directions of flow of meltwater streams. By permission of General Survey Office.

margin, extramarginally. In many places both the lateral and the sublateral channels tend to follow the jointing of the bedrock (*cf.*, Virkkala 1955), as, for example, on the northwest flank of Pyhätunturi (Fig. 46) and the northern flank of Suppivuoma. At Suppivuoma approximately one out of every five channels is situated in a tectonic fissure, into such a natural hollow or fracture line the meltwaters have run for several years in a row. Accordingly, such a channel is distinctly larger than the ones on either side, which apparently represent only a single season's erosion.

A further noteworthy feature of lateral drainage channels is that they are generally smaller near the summits of the fells than on lower levels, while the distance between them, as vertically measured, increases somewhat downhill. This is probably due to the fact that the gradient is steeper in the frontal portions of a glacier than farther back and the rate of melting more rapid; similarly, the volume and rate of flow of the meltwaters are greater; and together these factors directly contribute to increased erosion. The best series of channels have generally formed on slopes that were situated at right angles to the edge of the melting ice sheet. It is in such places, moreover, that the gradient of the ice was steepest in relation to the slope of the ground. It is only natural that channels should have appeared most easily in these

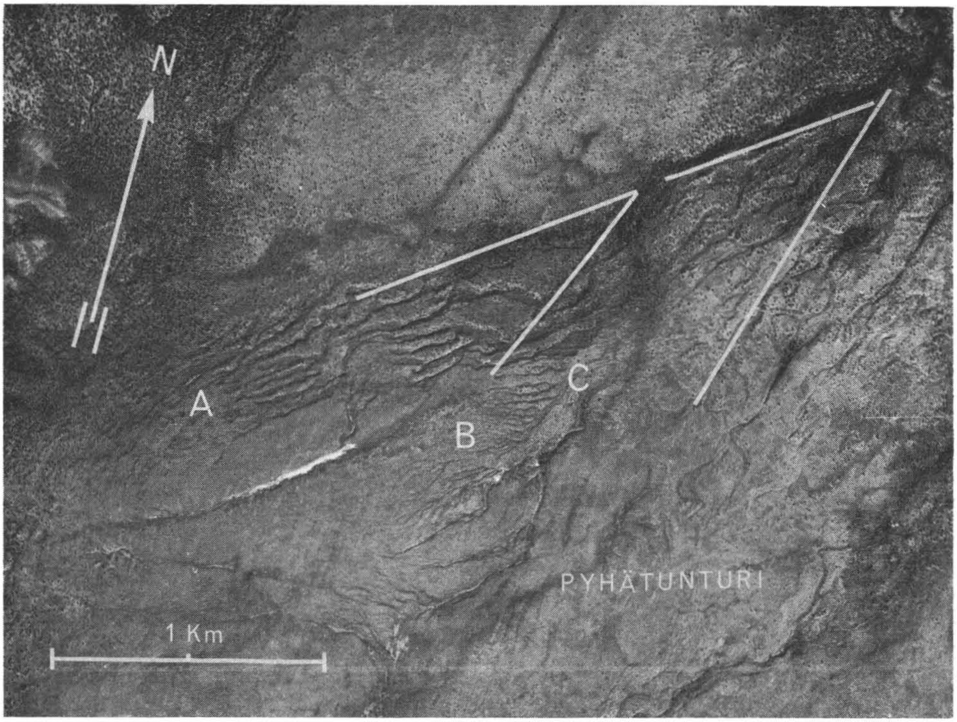


FIG. 46. Lateral and sublateral drainage channels on Pyhätunturi, near the western boundary of Kittilä. Lines: most prominent tectonic trends in the bedrock, which the lateral and sublateral channels in most cases follow. A) Large channels, which evidently functioned for several years. B) Small, annual channels, often with forks near head or with short, through-shaped gullies situated between them. C) Sublateral, fracture-guided channel through which meltwaters had flowed under ice sheet. By permission of General Survey Office.

places, where the gradient of the channels has been found to be 2.3—2.7 m to each 100 meters. Corresponding observations have been reported from other parts of Finnish Lapland. For example: Tanner (1915) reports 2—4 m to each 100 meters, Virkkala (1955, p. 411) 2/100, and Penttilä (1963, p. 36) 1—4/100. On mountainsides that had faced the ice margin, the channels are shorter and their gradient is steeper — *i.e.*, they were lateral for only a short distance, after which they had run underneath the ice. The same phenomenon is to be observed also on the opposite slope. This is due to the slighter gradient of the contact between the glacier and the mountainside, with the consequent slower rate of flow of the waters. What happened was that the water very quickly flowed under the ice margin. The gradient measured for these sublateral channels exceeds 10 m to each 100 meters and in some places reaches 25/100. On the other hand, on the lee of, for instance, Aakenustunturi a channel gradient of only 0.5/100 was measured. Previously Penttilä (1963, p. 36) ascertained it to be altogether possible. The trend of the channel on the northern side of Aakenustunturi makes only a rather small angle with edge of the retreating ice sheet, and the gradient of the lateral channel is no longer nearly at its steepest. The position of this channel, too, indicates a tendency toward sublateral flow.

There have been differences of opinion regarding the annual rhythm of the channels. Opponents of the view have included Mikkola (1932) and Holdar (1957). Protagonists after Tarr (1908, 1909) have been, *e.g.*, Tanner (1915), Virkkala (1955) and Penttilä (1963). The evidence is that annual channels could form only in suitable places and under suitable conditions. A gentle slope and a moderately but not too soft ground are fundamental requirements. In addition, certain properties are also required of the glacier *(cf.*, Penttilä 1963, p. 65). Neither must the bedrock be very much broken up, for fracture lines collect water and influence the direction of flow. On steep slopes a channel may have functioned for several years. In such cases, the channels are often forked at their upper end. Also channels assumed to be of the annual variety are apt to have weak branches toward their starting point or short through-like forms between them, representing some exceptional phase in the development of the channels. In places the meltwaters have washed the slope bare.

In western Lapland the best series of lateral drainage channels are to be found in the area of Yllästunturi. On Lainiotunturi there are as many as about 120 channels, of which especially the uppermost ones, situated at a height of between 500 and 600 meters, are splendid examples from standpoint of measurements. Starting from the top, the mean values of groups of ten channel intervals are as follows: 1.1 m, 1.5 m, 1.9 m, 1.7 m, 2.0 m and 1.9 m. At the lower end the distance between channels approaches three meters. The mean value obtained for the entire series of channels is 2.0 m (247 m and 121 channels). This series plainly reveals the tendency of the distances between lateral drainage channels to increase toward the lower slopes. The gradient of the channels on Lainiotunturi has been measured to be 2.5—5 m to each 100 meters. On the western flank of Yllästunturi the mean channel interval values vary between 3.0 and 3.7 m and the gradients between 1.6/100 and 3/100. On Pyhätunturi the distance between channels is three meters and on Äkäskero the gradient is between 3/100 and 7/100. On Aakenustunturi there are also a few good series of channels. The mean values of groups of ten channel intervals obtained from different parts of the mountain are: 1.9 m, 2.6 m, 3.2 m and 2.5 m, or very nearly of the same magnitude as on Yllästunturi. The gradient likewise agrees well: 1.7—3.2 m to each 100 meters.

At Paartoselkä the channel distance averages 2.0 m, at Rovalaki 2.2—2.8 m, on the western slope of Outakka 1.6—2.5 m (few channels), at Suppivuoma 2.8 m, and on the south flank of Anuntivaara 2.7 m. The gradient can be determined fairly reliably from the east slope of Adjahoaivi, where there are three large channels (situated roughly 15 m apart) which measure 2.4 km, 2.8 km and 3.2 km in length. The corresponding altitude differences between the heads of the channels and their gradients are: 54 m and 2.5/100, 66 m and 2.4/100, and 70 m and 2.2/100. Approximately the same result has been obtained from Kalkkoaivi, 2.7/100, and from Rahpesoaikielas, 1.9/100.

In the view of the present author, the significance of the lateral channels to the chronology of the deglaciation stage in the supra-aquatic areas is roughly the same as that of varved sediments in the subaquatic areas, although the lateral drainage channels cannot be directly bound to any absolute chronology as can varved clays. But they nevertheless give a fairly reliable idea of the rate of deglaciation in the region of investigation.

Subglacial drainage channels

The erosion forms most difficult to explain in the light of field observations alone are the subglacial drainage channels. The significance of aerial photographs in this case is in the broad panorama they afford, making it possible to connect larger and more widespread details than any field observer can.

Among the erosion forms created by waters streaming underneath the ice, mention has already been made of the sublateral forms, or those that originated under the glacier margin and were associated with the lateral drainage channels. A sublateral channel may be of the type known as a collector channel (see Fig. 46), where waters gathered for long periods of time. Underneath glacier lobes there formed subglacial collector channels that led the meltwaters out from under the ice. The extramarginal drainage channels, which will come under later discussion, may also have in certain instances functioned subglacially.

A special type apart is represented by the channels worn by mighty subglacial streams, which invariably are associated with esker-like subglacial accumulations of material. The amount of accumulation varies from one extreme to another: in certain channel systems the amount is very little (< 10 per cent of accumulation forms in long profile), in other systems very large (> 90 per cent). The accumulation forms are either continuous esker ridges, esker hummocks or only slight terrace-like structures along a channel. In cross-section such a channel is the same as an extra-marginal channel, but the forms are softer. A segmentary course having little or no regard for the topography is a prominent characteristic of the subglacial drainage channel.

A subglacial channel accompanied by only slight accumulations occurs in the area of Pallastunturi (Appendix II). This channel can be traced all the way from the eastern flank of Pallaskero, where it is represented by esker-like, N—S-trending ridge. Between Pallaskero and Välivaara the course of the channel turns nearly from east to west. At Välivaara the lowest point in the channel is at an altitude of about 365 meters, but only a kilometer away toward the west the bottom of the channel has dropped to approximately 320 m. Continuing to Lehtirova, the channel has again risen to an elevation of roughly 375 m. From there its course shifts to the southwest, after which, on the southwestern side of Lehtirova, it can no longer be traced. The system includes accumulations to some extent, the most noteworthy of them

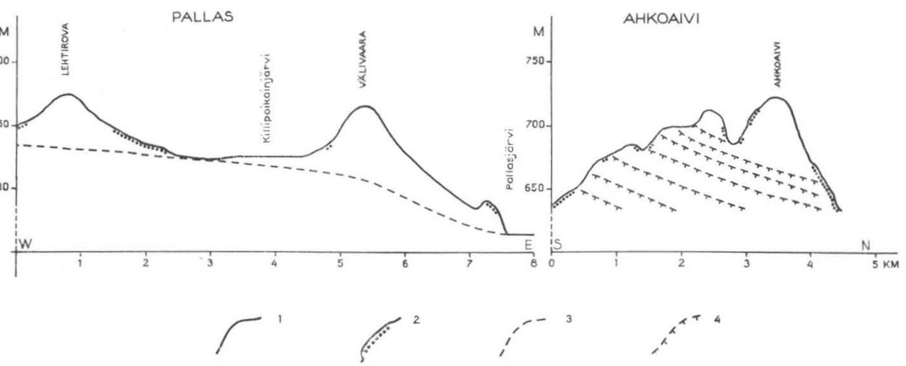


FIG. 47. Long profiles of subglacial channels *(cf.,* Appendix II). 1) Subglacial channel, 2) subglacial accumulation, 3) extramarginal channel cutting across subglacial channel, 4) lateral channel which intersects subglacial channel.

being situated on the northeastern side of Lehtirova and the eastern side of Pallaskero. The erosion had been most effective at the highest points (Lehtirova, Välivaara), where in addition to the surficial deposits the water had also worn down the broken surface of the bedrock. From Välivaara westward the erosive action had likewise been strong and Killipoikoinjärvi, for example, is situated in this channel. The breadth of the channel is at its maximum at this point (> 300 m). The course of the channel is independent of the relief, inasmuch as it does not follow the lowest level of the valley. The situation is made even clearer by the fact that also extramarginally streaming waters crossed the fell range from the same valley, and the channel worn down by these waters runs along the lowest level of the valley and cuts across the subglacial channel (see Fig. 47 and Appendix II).

Another example of subglacial drainage channel can be produced from northwestern Enontekiö. Across nearly the highest point on the summit of Ahkoaivi there runs a subglacial channel (Fig. 47), the material transported through this channel was deposited as the esker of Tälisvuompuoltsha (Tanner 1937) some 20 to 30 kilometers north of Ahkoaivi. In the area of Ahkoaivi the system includes very little in the way of accumulations. Running upslope the channel meanders, but downslope it generally runs straight. A similar channel joins the esker of Kuttanen from the northeast (Vittaselkä) near the Muonio river. As for the distribution of erosion and accumulation in the relief nothing for sure can be said except that erosion forms always prevail in high places and that accumulations occur with both downhill and uphill trends, with the latter nevertheless being more common. In low-lying areas erosive and accumulative actions appear to have prevailed alternately without any regularity.

The eskers are often associated with slight erosion zones. One example is the esker of Raastajoki (Fig. 24). Deposition had been a dominant feature in the creation of these formations, however, and the eskers have already figured in connection with the discussion of accumulation forms.

Extramarginal drainage channels

The very circumstance, frequently pointed out, that the continental ice sheet receded from the main watershed toward the south and the southwest approximately in line with the secondary water divides (Figs. 1 and 51) gives the extramarginal drainage channels (Appendix II) a special significance. The meltwater streams as well as the rivers that had appeared in the deglaciated area tended to flow in conformity with the general gradients toward the southeast and the south (see Fig. 3). But the portions of the glacier that filled the valleys prevented this, turning the flow over the water divides roughly in line with the ice margin. Since the meltwaters and the normal rivers functioning in the deglaciated area collected from far and wide in front of the glacier, the volume of water flowing in these extramarginal streams was considerably greater than that of the rivers existing in the region investigated at the present day. Furthermore, their geological activity was far stronger than that of present-day rivers, one reason also being in many instances the steep gradient of the channels. The melting of the margin of the ice sheet prevented the individual channels from functioning very long — in maximal cases at most between 100 and 200 years, most often only a few years, for on ground emerging into open air there always appeared new channels at a lower level.

The channels vary somewhat in form, depending on the morphological and topographical surroundings. In the northwestern part of Enontekiö the channels are generally steep-sloped and flat-bottomed in cross section. The bottom is roundish or sharp if the channel has cut into a fracture line in the bedrock, as in the case of Autsasenkuru, in the watershed between Könkämäeno and Lätäseno.

A good example of a channel system formed under the conditions prevailing in fell country is the one that was produced at the lower end of the Lätäseno valley (see Appendix I). Elsewhere in the region the channels came into existence mostly in low country, with the exception of the cases in which the waters flowed across the northern part of the Ounasselkä chain of fells.

In low-lying lands the channels are broader, stretching from 200 to 1 000 meters in width, and shallower, measuring between two and twenty meters in depth, as well as flat-bottomed. The bottom has in most instances become boggy or small lakes have formed there (cf. *Rinnenseen)*. The washing action has frequently extended down to bedrock. Dense forking and a braided pattern are also characteristic, as, for example, in the stretch of ground between Tarvantojoki and Palojoki and in the northeastern area of the main watershed (see Appendix I). In the far north the channels mostly run along the line of (270—)300°, in the central part of Enontekiö 300—360° and in the eastern part 270°. On the eastern side of the Ounasselkä range of fells, the trend is also principally from west to east, in the Muonio area it is 300° and in the southern part of the region 330°.

Evidently, these channels are not always wholly extramarginal but in certain places water began to flow underneath the dead ice, which in the end lost contact completely with the glacier. A channel might have originally formed in a place where it could not be situated without assuming the presence of ice walls. On the eastern side of Harrijärvi, northeast of Karesuvanto, in the watershed between Maljasjoki and Tarvantojoki, the formation of the channel had started subglacially, for its development in its particular topographic position presupposes the existence of glacier walls. The threshold elevation of the channel situated on the northern side of Tarvantovaara is 448 m. Strong washing action had started on the eastern side of Harrijärvi at the 445-meter level. At the following stage the waters had flowed north and northeast along the hillside and finally ended up in front of the glacier. The channel had clearly originated underneath the ice. At the next stage the waters had further turned toward the northeast (at the elevation of 418 m), guided by the glacier, but after the locality had become deglaciated the waters had flowed from the lowest level of the valley (412 m) straight east.

The extramarginal drainage channels in western Finnish Lapland can be divided into certain stages according to where the meltwaters ultimately emptied. According to the main watershed, two stages emerge: the Arctic Ocean stage and the Gulf of Bothnia stage. The meltwaters flowed into the Arctic Ocean from several points. The smallest volume of flow were in the western and northern drainage channels. From the valley of Kilpisjärvi, the waters crossed the watershed into both the Skibotnelva and Storfjordelva valleys. The meltwaters flowed north from Tenomuotka into Reisaelva and from Nierivuoma into Kautokeinoelva. In the northeastern section there are numerous crossing places over the main watershed. Noteworthy among them are Kietsimäjoki and the drainage channels leading into the Vaskojoki, Repojoki and Ivalojoki valleys, the last-mentioned of which guided the waters into the Arctic Ocean, which at the time extended into the basin of Lake Inari.

The stages marking a flow on the southern side of the main watershed, that is, into the Gulf of Bothnia, may be classified according to the principal rivers — namely, the Kitinen, Ounasjoki and Muonionjoki stages. The Kitinen river functioned longest as a channel for the flow of meltwaters. The most prominent of the channels crossing the watershed between the Kitinen and Ounasjoki rivers are the channel of Latvajärvi and those — situated beyond the investigated region — of Paanosenoja, Jalkajoki, Penikkajärvi, Seurujärvi and Pitslomajärvi.

In the southeastern corner of the region there is a series of channels through which waters flow into Kieringinjoki, a tributary of the Ounasjoki.

Waters crossed the watershed between Muonionjoki and Ounasjoki over the low-lying lands of the Muotkajärvi—Ounasjärvi area in central Enontekiö. There is no distinct channel in this locality, although water streamed over this route for a rather long time; the next channel crossing the watershed is in the area of Pallastunturi (see Appendix II). On the northern side of this channel there are two gullies crossing the watershed, Hannukuru and Suaskuru, both of which are situated at a fairly high elevation. Their threshold elevations are approximately 412 m and

365 m. Through Hannukuru over the watershed flowed the waters of the glacial stream that deposited the esker of Piippotievat (see Fig. 23), and Suaskuru, which belongs to the same series, was a discharge channel of the local glacial lake of Kerässieppi.

A typical extramarginal drainage channel crossing this watershed is the one running from Jerisjärvi to Kulkujoki, the threshold altitude of which is about 295 m. Slightly lower down, at the 273-m level, there is a channel running in the valley between Kolvakero and Linkukero. The next one toward the south runs from Äkäslompolo east via the valley between Kesänkitunturi and Yllästunturi. The slight gradient of this channel (1.6 m to each 1 000 meters) probably also explains the access to the Äkäsjoki of *Pallasea quadrispinosa*, the glacio-marine relict identified by Segerstråle (1956, p. 12). As the ice sheet receded toward the west-southwest, a route opened up for the waters to stream directly into the Muonionjoki valley, instead of the Ounasjoki, via the east side of Teuravuoma. This stage is connected with the Muonionjoki stage. Among the extramarginal channels of this stage should further be mentioned the one running via Luosujärvi as well as the several smaller ones in the areas of Paloselkä and Ristimella, which have a southward trend.

In the southern part of Muonio there are a few channels with a south-southeastward trend that have cut their way across the water divide between Muonionjoki and Äkäsjoki. The most noteworthy of them are the channels of Vittajoki, Särkijoki, Salmijoki and Valkeajoki. At the northern boundary of Kolari commune there is likewise a channel with a southeastward trend in the vicinity of Tapojärvi.

Considering the erosion and transport of material generally caused by extramarginal channels, it must be noted that on account of a heavy flow of water and variations in the amounts of it the effects were conspicuous. On the other hand, the glaciofluvial action varied in strength and was principally concentrated on glacial deposits. The flow of waters caused banks to form at various levels, eroded gullies outside the main channel, and transported previously deposited drift once more to lower levels. Only in certain instances did the water get at zones of weakness in the bedrock and wear them clean. At the present day, the action of the rivers in the biggest part of the region is very weak; therefore the erosive effects of the extramarginal channels on the landscape are equally significant.

In the river valleys of today the signs of glaciofluvial erosion have in most cases remained quite visible, and the present action of the rivers has not been capable of effacing them to any appreciable extent. In the large channels there often runs only a small brook. A great disparity thus prevails between channel and brook.

Even if one takes into account the recurrent nature of the deglaciation stages (*cf.*, Penttilä 1963, p. 42), the significance of the glaciofluvial erosion remains in the end slight in relation to the surface forms existing today. But in any attempt to explain the event of deglaciation, it is quite considerable.

10 12883—67

Ice-dammed lakes

In western Finnish Lapland, where the continental ice sheet receded from high to low elevations and, in general, in line with the valleys, meltwaters became dammed up in the valleys, forming ice-dammed lakes, which, to be sure, in most cases were quite small in area. The waters flowed through the lowest pass into the deglaciated valley below. Water collected also into valleys on higher levels and then likewise found a way to lower ground. Thus, there formed in front of the ice sheet a drainage system composed of glacial lakes and connecting drainage channels, which ultimately ran into the sea (see Appendix I). Most of the water came from the melting ice sheet, but also the rivers flowing in deglaciated areas coursed down to the ice margin according to the prevailing gradient. There the flow turned in response to the damming effect of the ice wall.

To judge by the shore marks (Figs. 48 and 49) and bottom sediments, large glacial lakes existed only in the major river valleys, notably those of the Könkämäeno, Lätäseno, Käkkälöjoki, Muonionjoki and Ounasjoki. Distinct shore marks left by the smaller glacial lakes, of which some were only widened or quiet stretches of water in an extramarginal channel or lateral bodies of water dammed up along the edge of a lobe of ice, are uncommon, because these lakes were short-lived and their water levels changed. In many instances, their existence is indicated solely by the deltaic formations deposited in them and by various stream terraces and spillways *(cf., eg.,* Gavelin 1910, p. 17).

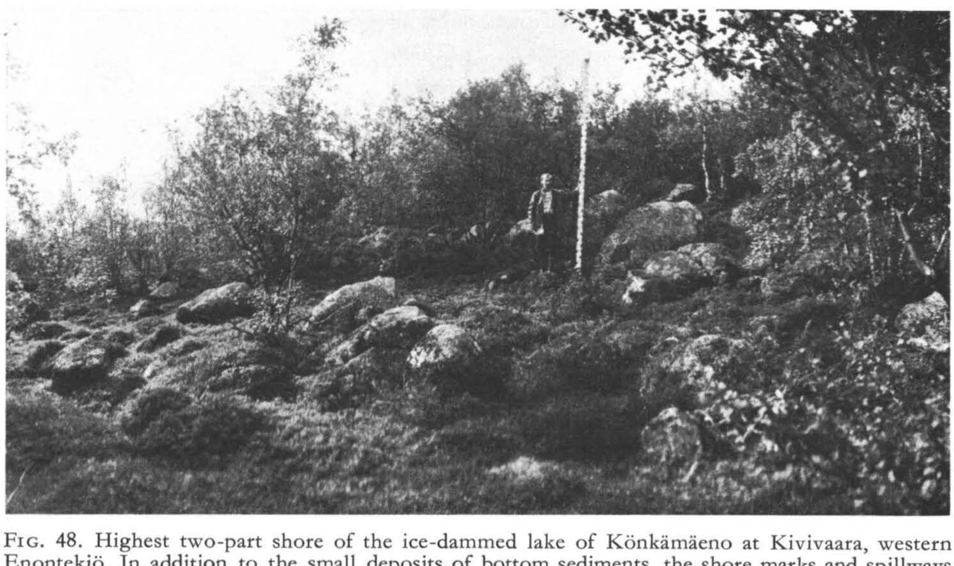


FIG. 48. Highest two-part shore of the ice-dammed lake of Könkämäeno at Kivivaara, western Enontekiö. In addition to the small deposits of bottom sediments, the shore marks and spillways provide evidence of the existence of ice-dammed lakes in western Finnish Lapland. The recession of the continental ice sheet along the line of the local water divides from high altitudes to lower ground favored their formation (by the damming up of the waters). Photo S. Penttilä

FIG. 49. Shore deposits of the ice-dammed lake on the north flank of Pälkevaara. Large drainage channels, which transported material into the lake dammed up by the margin of the ice sheet, contributed substantially to the abundant accumulation (*cf.*, Fig. 44).

Certain glacial lakes were created mainly out of water discharged into valleys by meltwater streams. Their history thus combines with the origin of the eskers. Glacial lakes of this type existed, for example, on the southwestern side of the Tarju fell, in the Valtijoki valley, on the southern side of Njargavarri, on the northern side of Syväjärvi, in the vicinity of the upper course of the Käkkälöjoki, on the northern side of Kerässieppi as well as at Pulju. In the case of Njargavarri, the subglacial channel that had deposited the material of the esker did not run through the lowest pass in the area across the watershed but directly north. When the subglacial phase had ended, the meltwaters followed the normal gradient and soon new channels were worn down to lower levels. The first threshold of the glacial lake was 625 m above sea level at the point where the subglacial channel was situated. About two kilometers to the south a new discharge channel opened up on the northern side of Anuntivaara at a elevation of 615 m. Here the direction followed by the 2-km long and in places nearly 20-m deep channel is WSW—ENE, and it terminated at the margin of the ice sheet on a lower level, where it built an accumulation resembling a kame terrace on the northeast side of Anuntivaara. The final discharge of the ice-dammed lake occurred via the south side of Anuntivaara at an elevation of 575—545 m.

The evolutionary history of the small ice-dammed lake on the western side of the Tarju fell differs somewhat from that described in the foregoing. At its initial stage the lake discharged northward, where the esker, too, is situated, then westward via the southern side of Tammukkaoaivi. The threshold height at Tammukkaoaivi was about 597 m and the waters flowed, partly in already deglaciated territory and partly in contact with the ice sheet as well as on top of it, toward the north, terminating at last in the lateral lake situated at the margin of the ice lobe on the northwestern side of Tammukkaoaivi. This phase may have been in, for example, subglacial connection with the contemporaneous ice-dammed lake of Kilpisjärvi.

Slightly later, with the retreat of the ice sheet, a new discharge channel of the ice-dammed lake of Tarju opened, but now toward the east, via the southern side of fell, at an elevation of approximately 594 m. The melting of the glacier let the waters flow to ever lower levels. Discharge channels registering different stages may be differentiated at elevations of 575 m, 565 m and 545 m. As the ice sheet thinned to a sufficient extent, the ice-dammed lake of Tarju joined that of the broader glacial lake of Könkämäeno at the lower level of 515 meters.

In the Valtijoki valley the receding glacier lobe was pursued by an ice-dammed lake which was exceptional in that deltas formed in it out of material transported by the Valtijoki river. Plenty of glacial stratified drift was available, inasmuch as an esker had accumulated in the valley slightly earlier. To judge by the heights of the deltas, shore marks and the elevations of the drainage channels, the ice-dammed lakes in the valleys had been situated approximately 760 m, 715 m, 650 m, 625 m and 610 m above present sea level.

Tanner (1907) had difficulties with ice-dammed lakes situated at different elevations because he could not find any suitable spillways. Consequently, he was obliged to assume the existence in the zone of the water divide between Stordalelva and Kilpisjärvi, among other places, of either *Steineis* or valley glaciers (Tanner 1907, p. 19) as well as the existence in the east of subglacial drainage channels. Evidently, his assumptions were mostly correct: the last remnants of the ice sheet filling the valley bottom and the active valley glaciers in the region could have blocked off many of the valleys trending west in such a way that not much water flowed in that direction. By and large the continental ice sheet receded in the region toward the southwest, which caused the waters to flow eastward, at first perhaps in part underneath the marginal zone of the ice or over it; but the discharge of the waters in the basin took place via the east through numerous channels situated on different levels (see Appendix I). At its maximum extent, the ice-dammed lake of Kilpisjärvi, which at this point might be referred to as the glacial lake of Könkämäeno, was apparently situated in the vicinity of Kivijärvi. There are quite distinct shore marks on both sides of the valley at elevations of 527m, 511 m and 502 m (Fig. 48).

At its final stage the Könkämäeno glacial lake seems to have formed a large body of water partly filled with dead ice in which many deltas were deposited on the Swedish side (Fig. 27), as Tanner (1915, p. 511, Fig. 95) has depicted. Regarding the drainage channels of different phases that crossed the water divide between Könkämäeno and Lätäseno, Tanner had, on the other hand, no knowledge. The present threshold levels of these drainage channels are 515 m, 500 m, 452 m, 428 m and 413 m above present sea level; and considering that some of the channels have been eroded 30 m deep, ice-dammed lake shores are likely to be met with at any level whatsoever. That only a portion of the deltas on the Swedish side are clearly associated with the principal phases determined by the drainage channels is due to the fact that they may represent only an incidental feature of the history of this glacial lake. The deltas are associated with the outflow of an ice-dammed lake on a higher level and need in no way be linked to the stages of the glacial lake situated on a lower level.

The ice-dammed lake of Lätäseno wandered from the upper course of Poroeno down to the lower levels and the waters of the ice-dammed lakes of the Könkämäeno valley eventually found their way into it. The shores, deltas and drainage channels corresponding to every stage met with below the Munnikurkkio rapids have been traced. The mighty drainage channel of the Könkämäeno glacial lake running through the valley of Saitsijoki terminated at the 450-m level of the lake in the Lätäseno valley. At the initial stage, there was still an extensive but thin tongue of dead ice in the valley, one that extended all the way to the watershed in the north. The material that was carried along with a powerful, discharge-like flow of water was deposited along the edge of the ice tongue and, during the first phase, partly on top of it to form a kame terrace, which subsequently, as the ice melted away, took on morphological features resembling deltas. On the western slope of Lohiselkä there are shore marks of this stage at the 450-m level. On the western slope of Settimarasto the shore appears in two parts, the upper one being at an elevation of 450 m and the lower one at 446 m. On the southeastern shore of Kaurajärvi there are similarly two ancient shorelines, one at 450 m and the other at 447 m. The drainage channel of this glacial lake stage starts from the southern end of Kaurajärvi as two forks running northeastward, the threshold levels (= present bog surface) of which are situated 449 m and 448 m above sea level. The channel turns via the north toward the southeast to the upper course of Tarvantojoki. The extension of the Syväjärvi esker, known as Nissulasmarasto, on the northern side of Syväjärvi (Fig. 29) may be regarded as a delta deposited into the aforementioned Lätäseno ice-dammed lake. Its main portion is situated 440—450 meters above present sea level. In the beginning it may have been distinctly deltaic in form, but as the glacier wasted down its ice-contact side collapsed to some extent, in addition to which wave action and post-glacial winds have deformed it.

The water level of the ice-dammed lake was determined by the lowest passes across the water divides between Hietajoki and Tarvantojoki as well as between Maljasjoki and Pahtajoki. As the ice sheet receded toward the south—southwest, the following channel opened up some seven kilometers to the south of the preceding one. There had still been ice in the area at that time, for the channel is situated in such a topographic position as to preclude its development there without bordering walls of ice (see p. 72). With regard to the ice-dammed lake of the Lätäseno valley, all the intermediate stages in the development of the channel are non-essential, for it was not until the 410-m level had been reached that a long-lasting stage occurred. And this elevation was determined by the drainage channel crossing the watershed between Pahtajoki and Maljasjoki, which channel came into existence in the proximity of Harrijärvi. The present threshold (= surface of the bog) of the channel lies 409 m above sea level.

A delta also formed on the northeastern side of Palkisvaara in the ice-dammed lake of Lätäseno, situated at the 410-m level. Its water level did correspond fairly exactly to the present altitude of 410 meters above sea level. Shore features representing this stage exist on the eastern flank of Ruossakero as well as on the western flanks of Lohiselkä and Settimarasto. On the slopes of Settimarasto shore marks may be detected between the heights of 415 and 409 meters, which is only natural in view of the evolution of the drainage channel.

The drainage channel of the following stage is not quite so clear, for the ice sheet had receded to the southern side of Lavivaara, whence the waters had streamed into Harrijärvi, which is connected to the drainage basin of Tarvantojoki. The drainage channel of the preceding stage ran along the same course, and the threshold was then at the 409-m level on the western side of Harrijärvi, while on the eastern side it was as low as 398 m above present sea level. Evidently, this was a somewhat longer lasting phase, seeing that shores evolved once more. Shore marks on the eastern side of Kuolbanoaivi at the 397-m level and on the same side of Palkisvaara at the 395-m level. Shore marks can also be observed on the slope of Settimarasto at this level. The brevity of this phase is indicated by the small size of the delta that was deposited on the northeastern flank of Kuolbanoaivi.

The reason why more levels are not to be distinguished in the deltas is probably that their deposition took place during the initial phase of discharge, representing the creation of the drainage channels, after which the waters flowed through washed out channels.

The last remnants of the ice-dammed lake of Lätäseno found their drainage channel on the northern flank of Jatuninselät, the threshold of the northernmost part being at the 373-m level and the southernmost part at the 367-m level. In the southeastern corner of Palovaara there is poorly sorted glaciofluvial material below the 367-m level (see Fig. 31). This material became deposited when the ice-dammed lake of Könkämäeno finally emptied via the southern side of the hill. On the southern slopes of Nunas, Kuolbanoaivi and Palkisvaara, shore marks representing the 367-m stage are to be found. The ice-dammed lake of Lätäseno emptied out via the southern side of Jatuninselät from an elevation of 338 m, and the waters in the end sought their outlet at this point in the existing channel.

The majority of the glacial lakes situated in river valleys functioned in the same way; for example, in the Tarvantojoki valley there was situated quite a corresponding, downward trending lake, the accumulations marking the height of the channel of which can always, generally speaking, be found. There are fewer shoremarks, however, for the reason that the size of the glacial lake or the free surface of water there was much smaller than in the ice-dammed lake of Lätäseno.

In considering the evolution of the ice-dammed lakes in a broad perspective, it will be observed that the waters of the lakes in western Enontekiö crossed the watershed between the Muonionjoki and Ounasjoki, after Muotkajärvi (295 m), in four places, as has been described in the discussion extramarginal channels (p. 73). Corresponding ice-dammed lake stages also existed, to judge by the shore marks. On the northern side of Liepimäjärvi with a substantially faster rate of land uplift than that at Muotkajärvi, shores can be traced at the 325-m level (Tanner 1915, p. 523). The next lower channel runs via Kulkujärvi (293 m). The corresponding shores and plateaus are in the northern section of Muonio. The shores situated about 20 meters lower belong to the drainage channel between Mustakero and Kolvakero, at an elevation of 278—273 meters. At the final stage, the waters crossed the watershed from the valley between Kesänkitunturi and Yllästunturi at an altitude of 215 meters. The more significant threshold level, however, was the southern end of Äkäsjärvi, at 250—270 meters, which produced glacial lakes at this elevation in the Muonio area.

The down-shifting ice-dammed lake of the Ounasjoki valley was notably more complicated; and explaining it has proved to be the most difficult of all. Apparently, the picture of the ice-dammed lakes of the Ounasjoki valley will remain deficient, perhaps even erroneous, for any analysis of ice-dammed lakes cannot be successful purely on the evidence of the shore observations. The present author has not had the opportunity so far of determining the heights of the drainage channels crossing the watershed between the Ounasjoki and Kitinen rivers, and no previous data that can be relied upon are available either. The estimates of their elevations must therefore depend upon shore observations and conjecture.

Many smaller extensions or quite separate lakes were connected with the broader ice-dammed lake system of Ounasjoki. Two examples warrant brief presentation. At Pulju, in the northern part of Kittilä, there was an ice-dammed lake which first drained northward into the upper course of the Ivalo river and from there into Arctic Ocean, which extended into the Inari basin. In the light of the shore observations, the elevation of this ice-dammed lake was 325 meters. As the ice sheet receded southward, two new channels opened up in the east in the territory between Almunavaara and Sapakkovaara and joined at the site of Pyhäjärvi. The threshold levels of the channels are approximately 298 m and 295 m, and roughly at the same elevation shore marks can be seen also in the Pulju area. It was about this time, too, that the ice-dammed lake of Pulju merged into the broader ice-dammed lake of Ounasjoki. The next lower shore levels in the area occur at Salankijärvi at the elevations of 250 m and 280 m.

The second example of small, separate ice-dammed lake is that of Pöntsö, which existed as a bay of the glacial lake of Ounasjoki but functioned independently for a short time when the level of the waters of the lake of Ounasjoki sank below the 250-m level. The story of the glacial lake begins with a massive discharge of waters from the Muonionjoki system, as a result of which a great discharge channel and a delta appeared in the valley of Kulkujoki. At the initial stage the water level had been at an altitude of 274 m but rapidly sank to the 268-m and, further, 264-m levels, which produced, *e.g.*, the shore situated at the site of the hamlet of Pöntsö. The rapid sinking of the water level continued and the next stage, with its delta (Fig. 30), was at the height of 253 meters above present sea level; and at the same time the basin accomodated a separate ice-dammed lake up to the time the glacier disappeared in the south and allowed the basins to join together. The drainage channel of the Pöntsö lake was situated on the northern side of the hamlet to the east of Lohijärvi at an elevation of 247 meters. The lake joined the ice-dammed lake of Ounasjoki via the south at the 225-m level.

Most of the stages of the ice-dammed lake of Ounasjoki were of short duration. This conclusion is based on the large number of drainage channels. The stages of longest duration left behind distinct shore marks. On the land uplift isobase running through the hamlet of Tepasto, such marks occur at the 290—280-m, 268-m, 258-m, 250-m, and 238-m levels. Farther south, at Sirkka, noticeably lower stages are met with: *e.g.*, 220 m, 212 m, 209 m and 198 m. Not all the shores of the two groups occur in the same place. The most conspicuous of them, the signs of washing action in the belt between 290 m and 280 m, can be witnessed most frequently. The different stages have nevertheless been presented most clearly according to their drainage channels, although in the present connection it is still necessary to resort only to estimates of their elevations. It should be noted that in certain cases the level of the ice-dammed lake of Ounasjoki was regulated also by water divides other than the one between the Kitinen and Ounasjoki. A corresponding situation prevailed also in the ice-dammed lake of Lätäseno (p. 78). This introduces further difficulties.

The northernmost drainage channels of the ice-dammed lake of Ounasjoki, which are associated with the Pulju glacial lake stage, are at elevations of 320 m, 298 m and 295 m. Tanner (1915, p. 620) mentions the channels running toward Latvajärvi (307 m) and Piernakkaoja (309 m). The following channels are situated outside the boundaries of the region investigated. Channels run into Paanosenoja from the directions of both Ristijärvi and Sammaloja, and they are situated at an estimated elevation of 290—280 m. The Jalkajoki flows in the great discharge channel, into which the waters had first come via Ristijärvi and later from the upper course of the Nuutijoki. The elevations may be estimated at 275 m. The channel running from Seurujärvi to Hannukanoja lies at a level of 265 meters. The ones at the next lower level, Syväoja (260 m) and Iivarinkuru (255 m) are also likely to have served as outlets for small local ice-dammed lakes. It is fairly certain that the elevation of the channel running via Pitslomajärvi is 250 m, and that of Kiuasautonoja hard by it 240 m. The next drainage channels in the succession are again within the bounds of the region investigated. The elevation of the ice-dammed lake on the western end of Jeesiöjärvi was 207 m, and the evidence left behind by the streaming waters indicates that the channel was in use a fairly long time and that the volume of water running through it had been substantial. A few kilometers toward the south there is a smaller channel at the 204-m level which functioned only a short time, for slightly to the southwest from the former there opened up on the 205-m level a new channel, which guided the waters down to about the 202-m level. This possible ice-dammed lake was connected by a broad sound with lake Kelontekemä across the watershed. The next glacial lake stage of the extensive Kelontekemä—Kuusanjärvi—Kittilä bog tract was on the 195-m level. Retreating west and southwestward the ice sheet dammed the waters into this flat valley opening toward the west. On the northern side of Nilipää there is the drainage channel marking this stage, which channel possibly started to function subglacially. Channels may be found at even lower levels, as in the area of Särestövaara, where they are situated at elevations of 192 and 188 m. Immediately after these stages, the ice disappeared also from the valley of Ounasjoki, and the sea held sway over the same territory previously covered by an ice-dammed lake.

The existence of large ice-dammed lakes has been questioned in recent years (among others, Hoppe 1957, pp. 14—17; Holdar 1952, p. 80; 1957, pp. 345—355; J. Lundqvist 1959, p. 10) and in a number of regions their size and significance has perhaps been exaggerated. The absence of sediments has been attributed to the circumstance that dead ice filled nearly the entire basin, with room only on the sides for water. The lack of sediments and their coarseness when present is probably due, however, to the fact, at least in part, that the ice-dammed lakes had principally served as basins for the passage of flowing waters and in many cases had been of such brief duration that finegrained sediments failed to be deposited in them, except in a few scattered places where conditions favored sedimentation or where material had been plentifully available, as, *e.g.*, in front of deltas. In the Könkämäeno valley there are extensive tracts of silty fine sand in the proximity of the deltas on the Swedish side, which indicates that no ice remained in the valley in that particular area at the time of origin of the deltas. These sediments are in many cases varved and measure between 0.5 m and 2 m in thickness. In the Ounasjoki valley, where there had apparently been rather broad ice-dammed lakes, there occur stretches of silty fine sand and even silty clay in places to testify to the existence of ice-dammed lakes. Similar observations have been made in the vicinity of the Kittilä parish center and many other localities. It is excessive to require the occurrence of sediments in every locality where there had once existed an ice-dammed lake, in view of the fact that sediments do not occur everywhere even in the marine regions of the present day.

The prevalence of shore marks may also be held up as proof of the existence of ice-dammed lakes. Well-developed shore marks occur in the Kivijärvi area of the Könkämäeno valley (Fig. 49), along the lower course of Lätäseno and in the central and northern sections of Muonio as well as in the Ounasjoki valley around the vicinity of Tepasto. The drainage channels only go to show that there had been water in abun-

11 12883—67

dance, which is only natural, inasmuch as through the channel of Jeesiöjärvi, for example, there flowed the waters of the Muonionjoki and Ounasjoki river systems in addition to the meltwaters of the continental ice sheet. This helps us to understand the size of the channels and the amounts and composition of the material transported through them. That is why the deltas appear to be the most prevalent of the sediments of the ice-dammed lakes.

Marine stages

The region of the present investigation consists mostly of supra-marire territory, for it is only into the largest river valleys that the sea followed the melting margin of the continental ice sheet as narrow bays.

The shore marks of the marine stages are scarce in the region of the investigation, but the fluvial deltas deposited in the sea (p. 51) and the termination of the lateral drainage channels at a particular elevation further indicate the uppermost marine limit *(cf.*, Hyyppä 1966, pp. 162—163; Fromm 1965, p. 142, G. Lundqvist 1961, appended map). In the Ounasjoki valley there are two broad deltas, the upper one, at an elevation of 180 meters, being at the village of Kittilä, and the lower one, at 171 meters, at the very southernmost edge of the area, on the northern side of the hamlet of Helppi. A description was given of the area east of Kittilä in connection with the ice-dammed lakes. The glacial lake stages were caused by the ice in the Ounasjoki valley, and it was only after it had melted away that the sea worked itself into the same places — and even to approximately the same elevations. Evidencing the glacial lake stages are their drainage channels, while the marine stages are indicated by deltas. In Hyyppä's (1966, Fig. 13) system of shore line displacement, in the Baltic sphere, the highest shore is situated slightly above his Yoldia III (Y III) and the lower one fairly exactly meets his Y IV. At Kalkkarovuoma explored by Salmi (1963), on the eastern side of the village of Kittilä at the 193-m level, *i.e.*, slightly above the delta level, no marine stage could be observed, although Salmi does assume it to have been close by in the light of botanical evidence.

In the Muonionjoki valley, in the vicinity of Kolari, the marine stage was preceded by ice-dammed lakes. The oldest marine stage reached a level of about 168 meters on the northwestern side of the mouth of Äkäsjoki. The same stage is represented on the east flank of Pohjasenvaara, on the southern side of Kolari, by the termination of the lateral drainage channels at about the 180-m level. About 20 meters lower down a delta occurs in the vicinity of the mouth of Ylläsjoki at an elevation of 156 meters. The former is situated in Hyyppä's system (1966, Fig. 13) distinctly below Y III and the lowest between Y IV and Ancylus I (A I) when the ice sheet had totally disappeared from the region.

Aerial photographs covering the southeastern part of the region investigated reveal weak but fairly regular, shore-like, nearly horizontal terraces. In the surroundings of Lake Kelontekemä these marks are situated at an elevation of 200—203 meters and in the southern part of the region at 215—220 meters above sea level. In Hyyppä's system (1966, Fig. 13) they would represent Y II and the gradient of the terraces is likewise in conformity, being approximately 60—70 cm/1 km. The occurrence of *Stratiotes aloides* (Kotilainen 1956) at the same general level indicates a marine stage. On the other hand, the situation of the lateral and extramarginal channels at an appreciably lower level is in conflict with the foregoing. A number of explanations can be put forward: 1) The shores do not represent any marine stage. 2) At the edge of the glacier the ice was so broken up that the sea extended its influence as far as the stagnant marginal portion of the ice sheet via bays, and it was at this stage that these marks of the water level were created, while the marks of glaciofluvial erosion and, possibly, the ice-dammed lake stages were made after the sinking of the sea level. 3) The ice sheet had re-advanced over the shores already formed and during the final melting stage the sea no longer extended to this elevation. The activity of the glacier must have been weak, for shore features can still be detected in aerial photographs. The last of the various alternatives strikes the present author as the most plausible one.

Marine silts and silty clays occur to some extent in the southern and eastern sections of Kolari, notably as the bottommost stratum of the broad boggy tract of Teuravuoma. Similarly, the fine sediments in the Ounasjoki valley do not occur generally until the southern end of Helppi is passed, which means outside the bounds of the region investigated. The highest marine stages had thus been of fairly short duration and the conditions of deposition such that fine-grained sediments do not appear to any great extent above the levels of the places mentioned in the foregoing.

The disappearance of the continental ice sheet

Determining the mode and rate of disappearance of continental ice sheet in any given region is possible only if there exists a substantial body of observations on the local formations dating back to the melting stage. From the standpoint of the rate of the downwasting process, the most illuminating data are provided by the lateral drainage channels. The mode of deglaciation and the glaciological state of the ice sheet are best reflected, in addition to lateral drainage channels, by the evidences of subglacial activity, that is, both deposition and erosion. The deposition involves the formations accumulated by glacial streams and the subglacially deposited hummocky moraines, and the erosive action only, in the main, the sublateral and subglacial channels. The lateral channels reflect conditions in the marginal part of the melting ice sheet. It was aspired in the previous chapters to describe the fundamental aspects of all these factors. In contemplating the disappearance of the continental ice sheet, it should further be taken into account that interglacial and interstadial stages of melting occurred. But in the present connection, only the last retreat and melting away of the ice sheet have been studied.

12 12883—67

The relief of the fell country influenced greatly ice margin. In the valleys between the fells there formed giant tongues of ice or even completely separate bodies of dead ice. Large lobes of ice had existed at, for instance, Suppivuoma and in the valley of Lätäseno, and there had been areas of dead ice at Porovuoma and Rommavuoma as well as in many smaller valleys. This is proved by the extensive hummocky moraines now in these places.

The systems of lateral drainage channels in western Enontekiö indicate that the ice sheet had been fairly uniform in some areas and the surface had had a sufficient slope (averaging 2.3/100) to cause at least a slight movement toward the margin. Accordingly, the stagnation phase must have been limited to the masses of ice of rather modest dimensions that had lain on the floors of the valleys.

In the Enontekiö uplands there had evidently still been ice in the valleys when it had disappeared from the vicinities of, for example, Karesuvanto and Palojoensuu. The lingering of the ice sheet in the fells of the watershed is evidenced by the valley glaciers that, having been cut off main ice during the deglaciation stage, had functioned independently. At Mount Halti a tongue of ice four or five kilometers long had worked itself southward down the Kovdajohka valley and set up arching end moraines (Fig. 34; *cf.*, Tanner 1915, p. 200). It is conceivable that there had existed small, separate snowbank glaciers elsewhere, too, but their accumulation areas must have been so small that they had been unable to function to the same extent as the valley glacier of Halti. Such places include, *e.g.*, the cirque-like basins of Ridnijärvi and Ruodnajärvi on the eastern side of Ridnitsohkka as well as the small cirque on the northern flank of the Kovddoskaisi fell (Fig. 50). Comparing the end moraines of Halti with, for example, the 18th century moraines in Norway, which represent the greatest expansion of the glaciers during the postglacial time, one will observe that the moraine arches of Halti are considerably older and in all likelihood date back to the late-glacial stage.

A good idea of the deglaciation that took place in the fell country may be derived from the map drawn by Holdar of the Lake Tornio area (G. Lundqvist 1961, p. 70), which is less than 100 km to the southwest from Kilpisjärvi. The same series of geological events occurred in the Enontekiö uplands.

The disappearance of the ice sheet from the rest of the region investigated took place fairly uniformly compared to what happened in the fell country. The subglacial form elements, notably the accumulations of till, change character toward the east past the valley of Lätäseno. The Rogen- and Veiki-type moraines are replaced by Pulju moraines, which appear to form a continuous zone across Enontekiö all the way to the eastern boundary of the region investigated. In this area the glaciofluvial accumulations also contain material in abundance. To all appearances the melting process had been rapid and the ice stagnant. This is further suggested by the scarcity of lateral drainage channels, which occur most numerously along the eastern margin of the region and at the northern tip of Ounastunturi. The ice had melted fast under rather favorable conditions. The thermal conditions prevailing in the ice sheet had evidently been temperate.

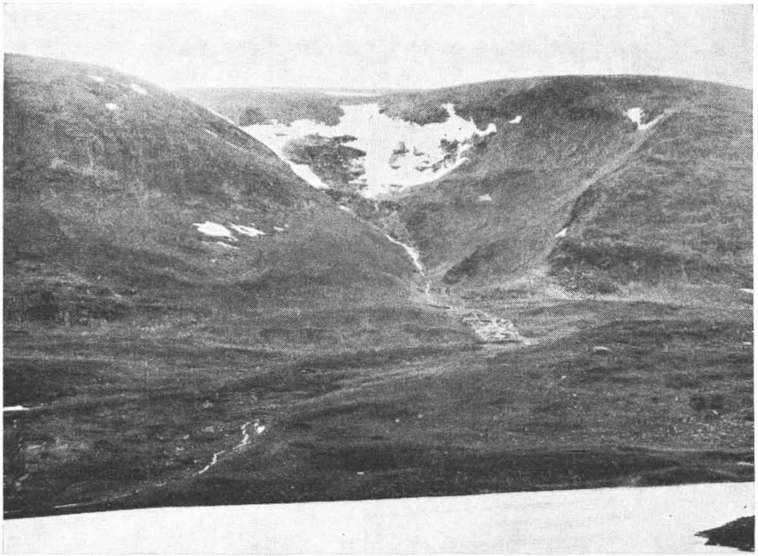


FIG. 50. A small cirque on the north slope of the Kovddoskaisi fell, in the northwesternmost part of Enontekiö. A small snowbank glacier evidently remained during the deglaciation stage in the cirque, which opens toward the north, as in the Kovdajohka valley, 5 km to the north-northeast. Originally the cirque, however, dated back to the initial stages of glaciation. Photo H. Hirvas.

With a few minor exceptions, the hummocky moraines end south of the Palojoensuu—Pulju line practically altogether. Moreover, the character of the eskers changes. They turn coarser of grain and on the average become smaller, in addition to which they are in many instances covered with till. Erosion marks also occur as evidence of the flow of subglacial streams, whereas in the area of Enontekiö subglacial meltwater streams produced accumulations nearly exclusively. This may be due to a scarcity of drift in the ice sheet. Signs of lateral erosion begin to occur in the Ounasselkä range of fells, and they increase strongly in frequency toward the south. Distinct fluting surfaces appear in the Ounasjoki valley, likewise on the fells of Aakenus, Lainio and Pyhätunturi. There is no mistaking the evidence of deteriorating climatic conditions and of activation of the ice flow. The solidity of the glacier and its subpolar thermal state are further indicated by the dense system of lateral channels (*cf.*, Ahlmann 1933. p. 211).

The rate of deglaciation (Fig. 51) can be estimated if the statistical data on the lateral drainage channels are sufficiently extensive. There are altogether too few satisfactory series of lateral drainage channels in the region of investigation to ensure accurate results, and the best series are overly concentrated in the same areas. A gratifying situation prevails in the central and southern parts of the region, where there are channels in considerable numbers, as has already been remarked. In the greater

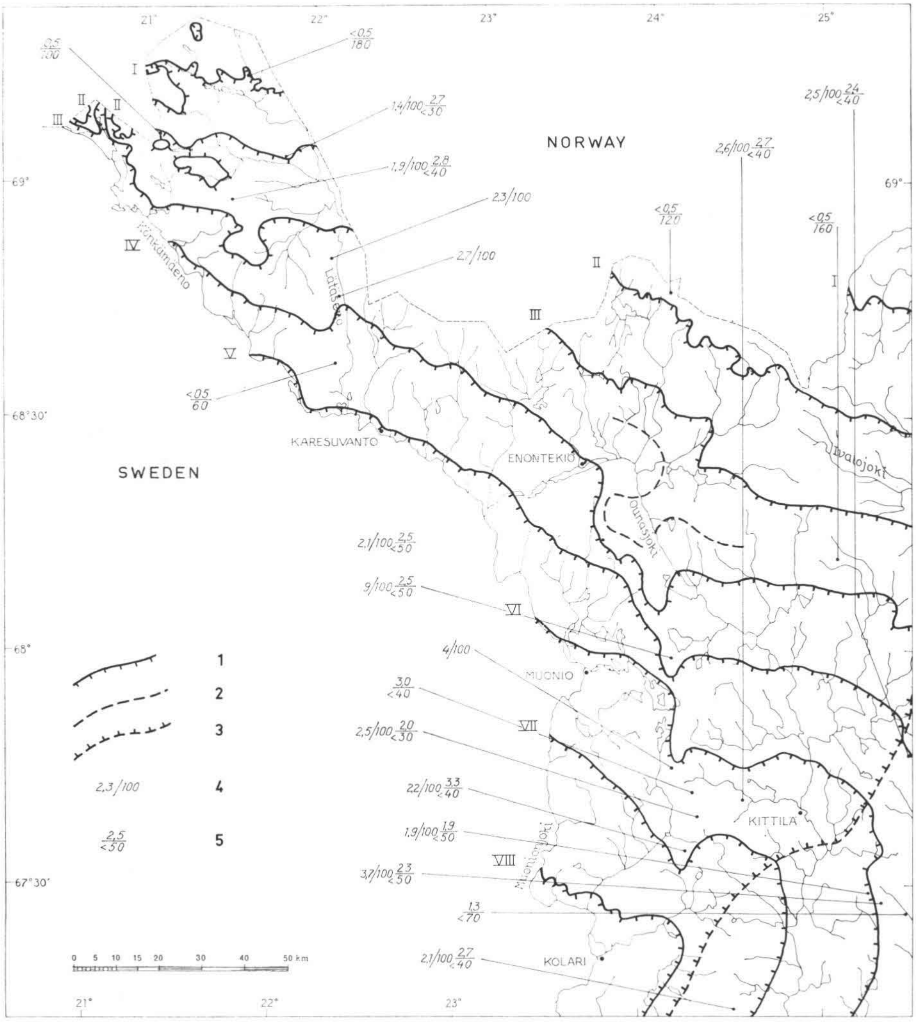


FIG. 51. Deglaciation of western Finnish Lapland. 1) Successive marginal positions of the glacier, 2) the stage of division of the ice sheet on the northeastern side of Ounastunturi, 3) the marginal formation of Venejärvi—Kuusanjärvi—Nunospuljut, 4) the gradient of the surface of the ice sheet, 5) the annual rate of deglaciation: above, vertical component; below, horizontal component.

part of Enontekiö, specifically in the area of hummocky moraines, the situation is by contrast quite bad. In the fell country of western Enontekiö, where channels do occur to some extent, difficulties are involved because of the existence of two types of channels (p. 66). Evidently, however, the small channels situated between the bigger ones are of more value in estimating the rate of deglaciation. Judged on this basis, the annual thinning down of the ice sheet amounted to from 2.5 m to 3 m. The larger channels indicate a rate three to five times more rapid, which is probably excessive. The gradient of the ice sheet in the marginal parts arrived at in many measurements is 1.7—2.7 m to each 100 meters. Converted to a process occurring on a horizontal plane, and also taking into account the horizontal distance between the channels, the annual retreat of the glacier's edge had been approximately 170 meters. A corresponding figure (180 m) has been obtained from the marginal positions of the ice sheet on the flank of the Valtijoki esker, which probably quite accurately indicate the annual recession of the glacier.

In central Enontekiö there is not a single measurable series of channels, and the author has had no opportunity to measure the channels in the northeastern part of the region investigated. Estimated by the eye, the distance between channels in a few of the series the author has seen exceeded three meters.

The distance between channels would seem to grow from 2.5 m to 3 m as one moves from the central part of the region to the southern part. The highest values obtained from the most reliable series yielded an average figure of 3.3 meters. The gradient of the surface of the ice sheet in the central and southern sections is 2.5 m to each 100 meters. Converted to a horizontal plane, this gradient represents an annual rate of retreat of 160 m if 40 m is taken as the horizontal component of the distance between channels and 3 m as the vertical component. The figures arrived at depend in the highest degree on the magnitude of the gradient. Here the measured averages obtained from the areas in question have been used.

The results recorded for Lainiotunturi suggest, however, that the rate of downwasting of the glacier depends greatly on the elevation. At the summit of the mountain the average obtained for a group of ten channel intervals is only 1.1—1.5 m whereas the interval is about 3 m on the lower slope; the average for whole series is 2 m. The small channel intervals occur at an elevation of 550—600 m, or between 350 and 400 m above the surrounding level country. It would appear as if the rate of thinning had been considerably faster along the margins than farther back in the mass of the ice sheet. The lessening of the gradient farther up on the glacier also contributes to the same circumstance.

If the influence of the elevation on the distances between channels had been as great as results indicate, the rate of melting must have been somewhat more rapid in western Enontekiö than in the southern part of the region investigated, for the channel intervals obtained from there represent fairly high altitudes as measured from the valley floors. It was not possible within the scope of the present study — nor do channel series suitable for the purpose exist — to determine the influence of the elevation, and consequently all the measured channel series have been treated as of the same value.

Excepting the central part of Enontekiö, the recession and dissipation of the ice sheet appear to have proceeded very much the same way throughout the region the whole time. According to Tanner's (1915, p. 647) observations, considerable local variation occurred in the rate of deglaciation, and this is, of course, only natural.

However, if it is assumed the average annual rate of the retreat of the ice had been 170 m, then about 800 years may be estimated to have been consumed in the disappearance of the ice sheet in the region (the direction of retreat having been NE—SW). The rate of retreat and downwasting would thus be double that reported from the Laanila area (Penttilä 1963, p. 37). On the Swedish side of the border, the distance between drainage channels is still wider *(cf., e.g.,* Mannerfelt 1945, pp. 51, 52, 68, 72; Hoppe 1950, pp. 43, 54), which only shows that the rate of deglaciation became accelerated as the climate grew warmer. At the same time as the continental ice sheet dimished in size, its influence on the local climate lessened in the immediate proximity of the glacier margin.

In the light of all the foregoing, it may be judged that the first area to emerge out of the ice was the fell country in the northeastern part of the region. About the same time, the highest summits of the northwestern fells began to break through into the open air. Obviously, the marginal portion of the glacier in the fell country consisted of lobes, or tongues, separated from each other by nunataks. Such tongues of ice were easily cut off from the main body of the glacier and formed separate areas of dead ice or lead an independent life for a short time in the mountains, as in the vicinity of Mount Halti. As the continental ice sheet continued to recede toward the southwest, new nunataks emerged in the northwestern section and the ice lobes gradually melted away *in situ*. In the northeastern and northern sections the retreat proceeded on considerably more level ground, and there the marginal portion of the ice was more uniform. In the fell country of central Enontekiö, the glacier margin consisted of small tongues; but to the same extent as in the northwest, areas of dead ice did not develop separately, for the entire margin was fairly stagnant. Dead ice appears to have remained in the northwest valleys even after the margin of the main body of the ice sheet had withdrawn to southern Enontekiö. At the same time, the ice sheet was divided into two extensive lobes separated by Ounastunturi. The marginal position shown on the map on page 86 (Fig. 51) by means of a broken line depicts the separation phase. The smaller and larger end moraines occurring on both sides of the Piippotievat—Hietatievat esker chain bear witness to the imbalance of the ice sheet during this separation phase (p. 55). Simultaneously, the margin of the ice sheet was receding also in the southern parts of the region approximately northwestward. It was during this stage of deglaciation the eskers were deposited in all western Finnish Lapland.

An apparent deterioration of the climate caused a halt in the recession of the glacier margin on the Venejärvi—Kuusanjärvi line (Fig. 51) and the creation of the marginal formation. This climatic change seems to have induced a new advance of the ice sheet. Signs of a re-advance are to be seen in, *e.g.*, the fells of the southern and central sections and in the Ounasjoki valley. The movement took place decisively from a different direction, however, than during the earlier advance, namely, mainly from the southwest, whereas the old advance had occurred from the ice divide of main glaciation from the northwest. Apparently, the accumulation of snow under these changed climatic conditions had occurred slightly farther south than earlier, or, then, the divide of the shrunken and wasted ice sheet had shifted southward for other reasons. The phase of the re-advance was probably short, at most only a few centuries, after which the process of deglaciation was continuous. It is possible that the influence of the new accumulation area did not extend everywhere in the same way, but, for example, on the northern side of the ice sheet the advancing flow may have been offset by a slowing down of the retreat.

The old melting and re-advance stages are indicated briefly by the following circumstances: 1) Eskers with their marginal formations and 2) the overlying till. 3) Striations plainly parallel to the eskers. 4) Recession of the continental ice sheet by and large at right angles to the orientation of the eskers during the last stage (as revealed by lateral and extramarginal channels). 5) The youngest direction of ice movement as reflected by fluted surfaces as well as by striations and the preferred orientation of till stones. 6) The erosion forms of the last melting stage intersect in certain cases older accumulation forms — *e.g.*, the marginal formation of Jeesiöjärvi is cut by extramarginal drainage channels.

Typical of the last melting stage in the central and southern parts of the region investigated is the fact that there are very little subglacial form elements. The hydrography of the ice sheet had been strictly lateral, which betokens a fairly cold climate (Ahlmann 1933, p. 211). Since the nature and extreme limit of the last ice movement are not known for sure, particularly in the northern section, attention must be concentrated on the depiction of the marginal positions and directions of retreat of the ice sheet evidenced by the lateral and extramarginal channels in the central and southern sections. The portion of the ice sheet divided into two lobes by the Ounasselkä range of fells retreated in northern Kittilä in approximately a straight southerly line and in northern Muonio toward the southwest. In the vicinity of the village of Kittilä, the line of retreat turns southwestward and locally even westward, owing to the massive ice tongue that established itself in the low-lying area east of the village — this situation having been partly brought about by Aakenustunturi, which had guided the flow of ice directly eastward. The fells of the Ylläs district caused a continuous turning of the flow eastward via the southern side of the fell range. This detouring movement in the ice flow caused by topographic conditions is graphically revealed by the schematic illustration depicting the trends of advance during the deglaciation stage and by the map of marginal positions (Figs. 11 and 51). Quite in the southern part of the region the retreat proceeded straight west for the foregoing reasons, and in the lowlands of Kolari—Teuravuoma there remained the same kind of lobe as in the Kittilä area. On the northern side of Kolari, the direction of retreat of the glacier margin was toward the southwest all the way from Muonio.

The Ice Age ended in western Finnish Lapland when the last remnants of the continental ice sheet disappeared from the valley of the Muonio river in the vicinity of Kolari. The very last line of retreat seems to have been straight west, but the direction was determined by the morphology also on the western side of the river.

CONCLUSIONS AND COMPARISONS

It has been demonstrated in the foregoing that there is a certain concentration of phenomena in definite zones of the region covered by the present investigation. Perhaps it is the hummocky moraine terrain of northern Kittilä and Enontekiö that is the most sharply bounded. In addition, a division of formations can be made in this region between the fell country and the peneplain.

On the northern side of the hummocky moraine zone there occurs morphology on a small scale in the form of fluting clearly determined by the trends of glacier movements. It provides evidence that the area was once the scene of actively flowing ice. Still farther north, in Finnmark, Norway, there occur drumlins and fluted surfaces in abundance, according to Norwegian investigators (Marthinussen 1961, p. 160; Holtedahl 1960, p. 430), even to the extent of composing broad fields. This zone had evidently extended all the way to the coast of the Arctic Ocean.

To the south of the hummocky moraine tracts, in the zone of the ice divide, the ground moraines are rather thin and there is an almost total lack of hummocky moraines. Similarly, few eskers occur in this area, owing to the fact that they terminate at the ice divide, which might also be designated as an esker divide. In low-lying areas of northern Kittilä, as, for example, in the valley of Ounasjoki, fluted surfaces are a common occurrence.

In central and southern Kittilä, fluted surfaces occur on the summits of hills and fells, including Aakenustunturi and Lainiotunturi. They can be used, together with reference to crag and tail forms, in determining the trend of the ice flow. Similarly, in the southern parts of the region investigated, the eskers are commonly overlain by a till blanket varying between 0.5 m and 2 m in thickness. In the same southern areas there also occur till-covered glaciofluvial formations of other types, the origin of which cannot often be accurately determined. The till in some instances forms several separate beds, and in certain spots the till is of the »Kalix pinnmo» type described by Beskow (1935), G. Lundqvist (1943), and others.

In their main features the eskers adhere to the regional zoning of the glacial elements. The large eskers with abundant material are concentrated in the hummocky moraine tracts, that is, in Enontekiö territory. In the communes of Kittilä and Muonio the eskers are on the average smaller, their material is coarser of grain and in many cases they are till-covered.

It is difficult to detect equally distinct zoning in the occurrence of the lateral drainage channels. The most prominent feature is their nearly complete absence from the Pulju moraine area. There are some channels in the Enontekiö uplands — *e.g.*, at Suppivuoma and around the central part of the Lätäseno valley — as well as in the east in the area of Inari commune, where conditions may have been similar to those that had prevailed in the Laanila area (Penttilä 1963, p. 65). Corresponding conditions had probably existed also in the area of Yllästunturi.

The extramarginal drainage channels do not seem to have conformed to any zoning pattern; but by virtue of the general gradient relations, they can be of assistance in reconstructing the marginal positions of the continental ice sheet *(cf.*, Appendix I and Fig. 51). Subglacial glaciofluvial erosive action appears to have taken place in the hummocky moraine zone, though evidences of it can be observed elsewhere, too, as at Pallastunturi (p. 69).

A certain apparently older zone or marginal position of the ice sheet has been described in connection with the discussions on end moraines and eskers. It runs from the southern end of the region investigated, from Venejärvi roughly in a SW—NE line past the eastern side of the parish center of Kittilä, via Kuusanjärvi and Jeesiöjärvi, beyond the region, in the vicinity of Rovalaki (Fig. 51) Extensions of it have been found to the south of the region investigated but not on the northern side.

A good example of the previously described zones is to be found in Swedish Lapland. It is the so-called Lainio arch *(e.g.*, Fredholm 1886, Tanner 1915, Geijer 1917, 1948, G. Lundqvist 1943, 1960, Hoppe 1952, 1957), which, slightly younger than the aforementioned features, probably is a synchronous phenomenon. Of the same kind is also the end moraine of Suomussalmi (Virkkala 1951 and 1952).

The significance of the zoning cannot be fully clarified until glaciomorphological observations are available from the whole of Lapland. Then it can probably also be determined whether zoning existed at all in a broader framework and whether it occurred in the same way along both northern and southern margins of the ice sheet. Nevertheless, what already has been established is that zones occur; and future studies will more accurately define their boundaries and ascertain their nature.

For the time being, it is impossible to situate with certainty the system of zones and the ice cap phase, which were fundamentally dependent on climatic conditions, in the general chronological scheme of the Late Quaternary period. The reason is that pollen analyses and C^{14} datings in the region give contradictory results.

Radiocarbon datings give a considerably greater age in western Lapland than could have been concluded in the light of earlier pollen diagrams (see *e.g.*, Ruuhijärvi 1963, pp. 24 and 26). It may, indeed, be asked whether a zonation of these pollen diagrams is comparable with corresponding ones from southern Finland or whether the specimens utilized in C^{14} datings might have aged on account of, for instance, interglacial or interstadial material. Obviously, the bogs did not begin to grow immediately after the dissipation of the continental ice sheet *(cf.*, Ruuhijärvi 1960), judging by the fact that most of the fossilized dune fields are situated also under bogs. There they could not have come into existence except during a dry and windy period directly after the melting away of the ice sheet, *i.e.*, in periglacial conditions (*cf.*, Okko 1954, p. 56). Damp conditions would have bound aeolian sand to the ground right away.

It is by means of the marine stages that the best idea of the time of melting can be formed, for these stages can — as the present author is also convinced — be connected to the general chronology with the greatest certitude. The sea had extended to the southern margin of the region investigated, and it was not far away from the northwestern and northern boundaries either. Norwegian data are available for the lastmentioned sectors, and they should give the maximum age for the deglaciation of western Lapland. Holtedahl (1960, p. 415) situates the innermost marginal moraine arches of the Lyngen fjord area at approximately 10 000 y. BP. Similar moraines also occur in the vicinity of Porsanger fjord, and Martinussen (1961, p. 165) traces them back to the younger Dryas period on the basis of the marine stages and C^{14} datings. Shores of the Portlandia stage occur in the Inari basin (Tanner 1930 b, pp. 164, 457). The available data indicate that the northwestern and northeastern parts of the region of the investigation must have begun to emerge out of the ice at the beginning or during the early part of the Pre-Boreal period. This surmise is supported further by the pollen diagrams representing the territory in question. The rate of melting and the recession of the glacier margin were not, however, quite so rapid as in southern Finland (Sauramo 1929, p. 53). And the evident deterioration of the climate toward the end of the period caused the retreat of the ice to halt at the Venejärvi—Kuusanjärvi line. Indeed, a slight re-advance of the ice sheet occurred. The final disappearance of the continental ice sheet thereafter took place as a rapid and continuous process. The lateral drainage channels indicate that ice margin receded during this process in a direction deviating completely from the one that had prevailed earlier. The margin of the melting glacier had often been in line with the eskers that had been deposited during the preceding stage of deglaciation *(cf.*, Virkkala 1952, pp. 75—76). The fact that accumulations (*i.e.*, eskers) failed to appear during the final stage in the wasting down of the ice sheet can probably be attributed to two circumstances: First, climatic conditions favored a lateral flow of meltwaters. Second, the re-advance of the glacier was of short duration and weak in its effects, so the ice probably did not contain much mineral matter. The till beds betokening this glacial advance are generally only from 0.5 to 1 m thick, and at most less than two meters.

The edge of the ice sheet was followed in the lowlands of the southern part of the region by the sea, which in Hyyppä's system is situated at Kittilä Y III (1966, Fig. 13), or chronologically about 9 700 years BP and at Kolari distinctly below this level, representing about 9 400 y. BP. The formation of Helppi coincides exactly with Hyyppä's Y IV, 9 000 y. BP, and the lowest delta of Kolari at the mouth of the

Ylläs river between Y IV and A I, representing perhaps approximately 8 800 y. BP. The same development is further shown by the pollen investigations carried out by, for example, Fromm (1965) west of the region and Hyyppä (1936, 1966) in southern Lapland.

The ancient terraces (p. 82) in the southeastern part of the Kittilä commune are situated precisely at Y II (Hyyppä 1966, Fig. 13), which is the equivalent of about 10 000 y. BP. According to radiocarbon datings, the disappearance of the continental ice sheet took place earlier.

Salmi (1965) gives the data of the lowest deposits at Kalkkarovuoma as 12 700 y. BP and that of the youngest deposits as 10 000 y. BP. In addition, the date of a peat bed west of Kaukonen is approximately 9 300 y. BP (Salmi, oral report) and that of a mud 10 800 y. BP south of the parish center of Kittilä (Lappalainen, oral report). Corresponding dates have been obtained also from nearby areas of Lapland and from eastern Finland *(e.g.*, Sorsa 1965, Tolonen 1967. *Cf.*, also Vasari 1962). In eastern Finland, however, the wasting down of the continental ice sheet occured somewhat earlier than in western Lapland. An ice sheet is known to have extended down to the coast of Norway around 10 000 y. BP (Holmes and Andersen 1964, p. 159; Andersen 1965, p. 53; Holtedahl 1960, p. 415; Marthinussen 1961, p. 165). Since the data presented in this paper indicate that ice sheet covered also western Finnish Lapland, the author is disposed to support the view that the continental ice sheet wasted away in this part of northern Fennoscandia during Pre-Boreal period. The result is agreement with estimates of the disappearance of the ice sheet in Swedish Lapland *(cf.*, for example, Hoppe 1948, 1959, G. Lundqvist 1961, Fromm 1962, 1965).

The relative chronology obtained from the distances separating the lateral drainage channels and from the gradient of the glacier surface indicates that it took 800 years for the ice sheet to recede from the region of the present investigation. And if the ice cap phase is estimated at only about 200 years, the total deglaciation period must have lasted one thousand years. Accordingly, the melting process might be situated approximately between the Younger Dryas and the Boreal periods.

The determination of the time of deglaciation would require sufficient both C^{14} and pollen statistics, in addition to which the Lapland territory should be related to the rest of Finland by means of, for example, sediment studies. And, above all, every effort should be made to determine the synchronous marginal positions of the ice sheet in both Lapland and the rest of the country in the light of the data on glaciomorphological zones.

REFERENCES

AARIO, LEO (1940) Waldgrenzen und subrezente Pollenspektren in Petsamo Lappland. Ann. Acad. Scient. Fennicae, Ser. A, 45, No. 8.

AHLMANN, HANS W:SON (1933) Scientific results of the Swedish—Norwegian Arctic Expedition in the summer of 1931, Pt VIII, Glaciology. Geogr. Ann., Bd. 15, pp. 161—216, 261—295.

—»— (1938) Über das Entstehen von Toteis. Geol. Fören. Stockholm Förh., Bd. 60, pp. 327—341.

—»— (1939) Vatnajökull; Scientific results of the Swedish—Icelandic investigations 1936—37—38, Pt VII. Geogr. Ann., Bd. 21, pp. 171—188.

—»— (1944) Nutidens Antarktis och istidens Skandinavien. Geol. Fören. Stockholm Förh., Bd. 66, pp. 635—654.

ANDERSEN, B. G. (1965) Glacial chronology of Western Troms, North Norway. Geol. Soc. America, Spec. Papers 84, pp. 35—54.

ATLAS OF FINLAND 1960. Geographical Society of Finland and Dept. Geography, Helsinki University 1960.

AUER, VÄINÖ (1927) Untersuchungen über die Waldgrenzen und Torfböden in Lappland. Comment. Inst. Quaest. Forest. Finlandiae 12, No. 4.

AUROLA, ERKKI (1949) Über die Verbreitung submoräner Sedimente als Widerspiegelung der Bewegungen des Inlandeises. Bull. Comm. géol. Finlande 144, pp. 41—63.

BESKOW, G. (1935) Praktiska och kvartärgeologiska resultat av grusinventeringen i Norrbottens län. Geol. Fören. Stockholm Förh., Bd. 57, pp. 120—123.

BRANDER, G. (1943) Neue Beiträge zur Kenntnis der interglazialen Bildungen in Finnland. Bull. Comm. géol. Finlande 128, pp. 87—137.

CHAMBERLIN, T. C. (1894) Proposed genetic classification of Pleistocene glacial formations. J. Geol., Vol. 2, pp. 517—538.

CHARLESWORTH, J. K. (1939) Some observations on the glaciation of North—East Ireland. Proc. Roy. Irish Acad. 45 B, pp. 255—295.

DERBYSHIRE, EDWARD (1958) The identification and classification of glacial drainage channels from aerial photographs. Geogr. Ann., Bd. 40, pp. 188—195.

ENQUIST, FREDRIK (1918) Die glaziale Entwicklungsgeschichte Nordwestskandinaviens. Sveriges Geol. Unders., Ser. C, No. 285.

ERIKSSON, K. G. (1960) Studier över Stockholmsåsen vid Halmsjön. Geol. Fören. Stockholm Förh., Bd. 82, pp. 43—125.

EVERS, W. (1941) Grundzüge einer Oberflächengestaltung Südnorwegens mit besonderer Berücksichtigung der Küstenplattform (strandflat) und der untermeerischen Bankgebiete. Deutsch. Geogr. Blätter 44, pp. 1—158.

FREDHOLM, K. A. (1886) Öfversigt af Norrbottens geologi inom Pajala, Muonionalusta och Tärendö socknar. Sveriges Geol. Unders., Ser. C, No. 83.

FRÖDIN, Gustaf (1915) Några bidrag till frågan om det afsmältande istäckets ytlutning. Geol. Fören. Stockholm Förh., Bd. 37, pp. 146—170.

—»— (1925) Studien über die Eisscheide in Zentralskandinavien. Bull. Geol. Inst. Univ. Upsala, Vol. 19, pp. 129—214.

FROMM, ERIK (1960) An interglacial peat at Ale near Luleå, northern Sweden, with contributions by R. W. KOLBE and HERMAN PERSSON. Sveriges Geol. Unders., Ser. C, No. 575.

—»— (1962) Om isrecessionens kronologi i övre Norrland. Geol. Fören. Stockholm Förh., Bd. 84, pp. 56—58.

—»— (1965) Beskrivning till jordartskarta över Norrbottens län. Sveriges Geol. Unders., Ser. Ca, No 39.

GAVELIN, Axel (1900) On the glacial lake in the upper part of the Ume-River-Valley. Bull. Geol. Inst. Univ. Upsala, Vol. 4, pp. 231—242.

—»— (1910) De isdämda sjöarna i Lappland och nordligaste Jämtland. Sveriges Geol. Unders., Ser. Ca, No. 7: 1.

GEIJER, PER (1917) Om landisens avsmältningsförhållanden inom Nautanenområdet vid Gällivare. Sveriges Geol. Unders., Ser. C, No. 277.

—»— (1948) Isavsmältningen i nordligaste Sverige. Geol. Fören. Stockholm Förh., Bd. 70, pp. 575—582.

GILBERT, G. K. (1904) Glaciers and glaciation. Harriman Alaska Series, Vol. 3. New York.

GRANÖ, J. G. (1931) Die geographischen Gebiete Finnlands. Fennia 52, No. 3.

—»— (1952) Land forms and relief. Pp. 74—99 *in* Suomi, a general handbook on the geography of Finland. Fennia 72.

GRANT, U. S. and HIGGINS, D. F. (1913) Coastal glaciers of Prince William Sound and Kenai Peninsula, Alaska. U. S. Geol. Survey Bull. 526.

GRAVENOR, C. P. and MENELEY, W. A. (1958) Glacial flutings in central and northern Alberta. Amer. J. Sci., Vol. 256, pp. 715—728.

HALDEN, BERTIL E. (1925) De isdämda sjöarna i Sverige. Ymer, Bd. 45, pp. 113—160.

HAUSEN, H. (1941) Das Halditjokko-Massif; ein basischer Phakolith in finnischen Abschnitt der kaledonischen Überschiebungszone. Geol. Rundschau, Bd. 32, pp. 508—534.

—»— (1942) Der Abschnitt Finnlands der kaledonischen Überschiebungszone. Soc. Scient. Fennica, Comment. Phys.-Math. 11, No. 9.

HÖGBOM, A. G. (1892) Om märken efter isdämda sjöar. Geol. Fören. Stockholm Förh., Bd. 14, pp. 561—582.

—»— (1910) De centraljämtska issjöarna. Sveriges Geol. Unders., Ser. Ca, No. 7: 2.

HOLDAR, C.-G. (1952) Problemet Torne-issjön. Geogr. Ann., Bd. 34, pp. 73—88.

—»— (1957) Deglaciationsförloppet i Torneträsk-området efter senaste nedisningsperioden. Geol. Fören. Stockholm Förh., Bd. 79, pp. 291—528.

HOLMES, G. W. and ANDERSON, B. G. (1964) Glacial chronology of Ullsfjord, northern Norway. U.S. Geol. Survey Prof. Paper 475—D, pp. 159—163.

HOLMSEN, G. (1915) Brædæmte sjøer i Nordre Østerdalen. Norges Geol. Unders. No. 73.

—»— (1935) Nordre Femund. Norges Geol. Unders. No. 144.

HOLTEDAHL, OLAF (1960) Geology of Norway. Norges Geol. Unders. No. 208.

HOPPE, Gunnar (1948) Isrecessionen från Norrbottens kustland. Geographica No. 20.

—»— (1950) Några exempel på glaciofluvial dränering från det inre Norrbotten. Geogr. Ann., Bd. 32, pp. 37—59.

—»— (1951) Drumlins i nordöstra Norrbotten. Geogr. Ann., Bd. 33, pp. 157—165.

—»— (1952) Hummocky moraine regions with special reference to the interior of Norrbotten. Geogr. Ann., Bd. 34, pp. 1—72.

—»— (1957) Problems of glacial morphology and Ice Age. Geogr. Ann., Bd. 39, pp. 1—18.

—»— (1959) Glacial morphology and inland ice recession in northern Sweden. Geogr. Ann., Bd. 41, pp. 193—212.

HYYPPÄ, ESA (1936) Über die spätquartäre Entwicklung Nord-Finnlands mit Ergänzungen zur Kenntnis des spätglazialen Klimas. Bull. Comm. géol. Finlande 115, pp. 401—465.

—»— (1954) Åsarnas uppkomst. Geologi, Vsk. 6, p. 45. Helsinki.

—»— (1963) On the late-Quaternary history of the Baltic Sea. Fennia 89, No. 1, pp. 37—48.

HYYPPÄ, ESA (1966) The late-Quaternary land uplift in the Baltic sphere and the relation diagram of the raised and tilted shore levels. Ann. Acad. Scient. Fennicae, Ser. A, III, 90, pp. 153—168.

JÄRNEFORS, B. (1952) A sedimentpetrographic study of glacial till from the Pajala district, N. Sweden. Geol. Fören. Stockholm Förh., Bd. 74, pp. 185—211.

v. KLEBELSBERG, R. (1948) Handbuch der Gletscherkunde und Glazialgeologie I. Wien.

KORPELA, KAUKO (1962) Interglacial peat in the Rovaniemi area. Geologi, Vsk. 14, p. 30. Helsinki.

KOTILAINEN, M. (1956) Vorläufiges über die Wasserchemie der *Stratiotes*-Seen in Kittilä, Finnisch-Lappland. Arch. Soc. 'Vanamo' 10, pp. 151—160.

KUJANSUU, RAIMO (1964) Nuorista siirroksista Lapissa. Summary: Recent faults in Lapland. Geologi, Vsk. 16, pp. 30—36.

—»— (1965) General Geological Map of Finland, 1: 400 000, Quaternary deposits, Sheet No. 28, Enontekiö. Geological Survey of Finland.

—»— (1967) General Geological Map of Finland, 1: 400 000, Quaternary deposits, Sheet No. 18, Kilpisjärvi. Geological Survey of Finland.

LAGERCRANTZ, C.-L. (1951) Om geomorfologien i Kilpisjärvitrakten i Enontekis Lappland. Terra, Vsk. 63, pp. 121—128. Helsinki.

LIESTØL, O. (1963) Noen resultatet av bremålinger i Norge 1962. Norsk Polarinst., Årg. 1962, pp. 187—190.

LILJEQUIST, G. H. (1956) Halo-phenomena and icecrystals. Norwegian—British—Swedish Antarctic Expedition 1949—1952, Scientific results, Vol. II, Pt. 2 A.

LUNDQVIST, G. (1937) Sjösediment från Rogenområdet i Härjedalen. Sveriges Geol. Unders., Ser. C, No. 408.

—»— (1943) Norrlands jordarter. Sveriges Geol. Unders., Ser. C, No. 457.

—»— (1960) The interglacial ooze at Porsi in Lapland. Sveriges Geol. Unders., Ser. C, No. 575.

—»— (1961) Beskrivning till karta över landisens avsmältning och högsta kustlinjen i Sverige. Sveriges Geol. Unders., Ser. Ba, No. 18.

LUNDQVIST, JAN (1959) Issjöar och isavsmältning i östra Jämtland. Sveriges Geol. Unders., Ser. C, No. 573.

MACCLINTOCK, P. and DREIMANIS, A. (1964) Reorientation of till fabric by overriding glacier in the St. Lawrence Valley. Amer. J. Sci., Vol. 263, pp. 133—142.

MANNERFELT, CARL M:SON (1945) Några glacialmorfologiska formelement. Geogr. Ann., Bd. 27, pp. 1—239.

MANSIKKANIEMI, H. (1965) Main features of the glacial and postglacial development of Pulmanki Valley in northernmost Finland. Publ. Inst. Geogr. Univ. Turkuensis No. 38, pp. 1—18.

MARTHINUSSEN, M. (1961) Brerandstadier og avsmeltningforhold i Repparfjord—Stabbursdal-området, Finnmark. Norges Geol. Unders. No. 213, pp. 118—169.

MATISTO, A. (1959) General Geological Map of Finland, 1: 400 000, Pre-Quaternary rocks, Sheet B 8, Enontekiö. Geological Survey of Finland.

MAWDSLEY, J. O. (1936) The wash-board moraines of the Opawica—Chibougamau area, Quebec. Roy. Soc. Canada, Trans., Ser. 3, No. 30: 4.

MERILÄINEN, K. (1965) General Geological Map of Finland, 1: 400 000, Pre-Quaternary rocks, Sheet C 8—9, Inari—Utsjoki. Geological Survey of Finland.

MIKKOLA, ERKKI (1932) On the physiography and late-glacial deposits in northern Finland. Bull. Comm. géol. Finlande 96.

—»— (1936) General Geological Map of Finland, 1: 400 000, Pre-Quaternary rocks, Sheet B 7, Muonio. Geological Survey of Finland.

—»— (1937) General Geological Map of Finland, 1: 400 000, Pre-Quaternary rocks, Sheet C 7, Sodankylä. Geological Survey of Finland.

—»— (1941) Explanation to the map of rocks, sheets B 7, C 7, D 7, Muonio—Sodankylä—Tuntsajoki. General Geological Map of Finland, 1: 400 000. Geological Survey of Finland.

MÖLDER, KARL (1949) Wassersedimente unter der Moräne in Süd-Pohjanmaa. Bull. Comm. géol. Finlande 144, pp. 65—71.

NIINI, HEIKKI (1964) Bedrock and its influence on the topography in the Lokka—Porttipahta Reservoir district, Finnish Lapland. Fennia 90, No. 1.

—»— (1967) Taka-Lapin kivilajien kuluminen hienonnuskokeiden ilmentämänä. Summary: The wearing down of bedrock in northern Lapland as indicated by rock comminution experiments. Terra, Vsk. 79, pp. 33—37. Helsinki.

OHLSON, B. (1957) Om flygsandfälten på Hietatievat i östra Enontekiö. Terra, Vsk. 69, pp. 129—137.

—»— (1964) Frostaktivität, Verwitterung und Bodenbildung in der Fjeldgegenden von Enontekiö, Finnisch-Lappland. Fennia 89, No. 3.

OKKO, VEIKKO (1941) Über das Verhältnis der Gesteinszusammensetzung der Moräne zum Felsgrund in den Gebieten der Kartenblätter von Ylitornio und Rovaniemi im nördlichen Finnland. Geol. Rundschau, Bd. 32, pp. 627—643.

—»— (1954) Periglasiaalisesta morfologiasta Suomessa. Summary: Periglacial morphology in Finland. Terra, Vsk. 66, pp. 54—57.

ØSTREM, G. og LIESTØL, O. (1962) Glasiologiske undersøkelser i Norge 1963. Norsk Geogr. Tidsskr., Bd. 18, pp. 281—340.

PENTTILÄ, SEPPO (1960) Ilmakuvantulkinta maaperäkartoituksen apuna. Geologinen tutkimuslaitos, Geotekn. julk. 65, pp. 70—86.

—»— (1963) The deglaciation of the Laanila area, Finnish Lapland. Bull. Comm. géol. Finlande 203.

PENTTILÄ, SEPPO, and KUJANSUU, RAIMO (1964) General Geological Map of Finland, 1: 400 000, Quaternary deposits, Sheet 27, Kittilä. Geological Survey of Finland.

PIIROLA, JOUKO (1965) Jäätikön Lemmenjoen laaksoon synnyttämistä muodoista. Summary: On the glacially sculptured land forms of the Lemmenjoki Valley, Finnish Lapland. Terra, Vsk. 77, pp. 112—118. Helsinki.

—»— (1967) Die glazialen Oberflächenformen und die Entwicklung der Täler auf den Fjelden Marastotunturit und Viipustunturit in Finnish-Lappland. Ann. Acad. Scient. Fennicae, Ser. A, III, 92.

RUDBERG, S. (1949) Kursudalar i Norrbotten; en preliminär översikt. Geol. Fören. Stockholm Förh., Bd. 71, pp. 442—494.

—»— (1965) Reconstruction of polycyclical relief in Scandinavia. Norsk Geogr. Tidsskr., Bd. 20, pp. 65—73.

RUUHIJÄRVI, R. (1960) Über die regionale Einteilung der nordfinnischen Moore. Ann. Bot. Soc. 'Vanamo' 31, No 1.

—»— (1962) Palsasoista ja niiden morfologiasta siitepölyanalyysin valossa. Referat: Über die Palsamoore und deren Morphologie im Lichte der Pollenanalyse. Terra, Vsk. 74, pp. 58—68.

—»— (1963) Zur Entwicklungsgeschichte der nordfinnischen Hochmoore. Ann. Bot. Soc. 'Vanamo' 34, No 2.

SALMI, MARTTI (1963) On the subfossil *Pediastrum* algae and molluscs in the Late-Quaternary sediments of Finnish Lapland. Arch. Soc. 'Vanamo' 18, pp. 105—120.

—»— (1965) *Pediastrum* alger i den mikropaleontologiska undersökningen. Norsk Geol. Tidsskr., Bd. 45, p. 156.

SAURAMO, MATTI (1929) The Quaternary geology of Finland. Bull. Comm. géol. Finlande 86.

SCHYTT, VALTER (1958) Snow studies at Maudheim. Norwegian—British—Swedish Antarctic Expedition 1949—1952. Scientific results, Vol. IV, Glaciology II.

—»— (1959) The glaciers of the Kebnekajse-massif. Geogr. Ann., Bd. 41, pp. 213—227.

SEGERSTRÅLE, SVEN G. (1956) The distribution of glacial relicts in Finland and adjacent Russian areas. Soc. Scient. Fennica, Comment. Biol. 15, No 18.

SEPPÄLÄ, M. (1966) Recent ice-wedge polygons in eastern Enontekiö, northernmost Finland. Publ. Inst. Geogr. Univ. Turkuensis No. 42.

SJÖGREN, OTTO (1909) Geografiska och glacialgeologiska studier vid Torneträsk. Sveriges Geol. Unders., Ser. C, No 219.

SORSA, P. (1965) Pollenanalytische Untersuchungen zur spätquartären Vegetations- und Klimaentwicklung im östlichen Nordfinnland. Ann. Bot. Fennici 2, pp. 301—413.

SVENONIUS, F. V. (1887) Om oskiktade terrasser i Lappland. Geol. Fören. Stockholm Förh., Bd. 9, pp. 13—18.

—»— (1898) Strandlinjer vid Torne träsk. Geol. Fören. Stockholm Förh., Bd. 20, pp. 153—162.

SYRILÄ, SIMO (1965) Retreat of the continental ice and fluvioglacial erosion features on the Tuolbanjangoaivi fjeld in northernmost Finland. Publ. Inst. Geogr. Univ. Turkuensis No. 38, pp. 19—26.

TANNER, VÄINÖ (1907) Zur geologischen Geschichte des Kilpisjärvi-Sees in Lappland. Bull. Comm. géol. Finlande 20.

—»— (1911) Über die Verteilung einiger Vegetationslinien im finnländischen Enontekis-Lappmark. Fennia 31, No 5.

—»— (1915) Studier öfver kvartärsystemet i Fennoskandias nordliga delar. III. Bull. Comm. géol. Finlande 38.

—»— (1928) The problems of the eskers, I. The Kollaž'jokk'gæcce in Petsamo, Lapland. Fennia 50, No 38.

—»— (1929) Zur Frage der Genesis der Osar. Einige Bemerkungen. Bull. Comm. géol. Finlande 87, pp. 165—175.

—»— (1930 a) The problems of the eskers, II. The Vāčer esker, Inari, Lapland. Bull. Comm. géol. Finlande 92, pp. 33—39.

—»— (1930 b) Studier över kvartärsystemet in Fennoskandias nordliga delar. IV. Bull. Comm. geol. Finlande 88.

—»— (1932) The problems of the eskers, III. The esker-like gravel ridge of Čahpatoaivi, Lapland. Bull. Comm. géol. Finlande 99.

—»— (1934) The problems of the eskers, IV. The glaciofluvial formations of Rasse'muetke Valleys, Petsamo, Lapland. Fennia 58, No 1.

—»— (1936) Tenomuotka i Enontekis. En intermittent bifurkation på riksgränsen mot Norge. Terra, Vsk. 48, pp. 198—206.

—»— (1937) The problems of the eskers, V. The Tälisvuom'puoltsha Esker in Enontekis Lapmark. Fennia 63, No 1.

—»— (1938) Die Oberflächengestaltung Finnlands. Bidrag till kännedom av Finlands natur och folk 86.

TARR, R. S. (1908) Some phenomena of the glacier margin in the Yakutat Bay Region, Alaska. Zeitschr. Gletscherk., Bd. 3, pp. 81—110.

—»— (1909) The Yakutat Bay region, Alaska. U. S. Geol. Survey Prof. Paper 64.

TARR, R. S. and MARTIN, L. (1914) Alaskan glacier studies of the National Geographic Society in the Yakutat Bay, Prince William Sound and Lower Copper River regions. Washington.

TOLONEN, KIMMO (1967) Über die Entwicklung der Moore im finnischen Nordkarelien, Ann. Bot. Fennici 4, pp. 219—416.

VASARI, YRJÖ (1962) A study of the vegetational history of the Kuusamo district (North East Finland) during the late-Quaternary period. Ann. Bot. Soc. 'Vanamo' 33, No. 1.

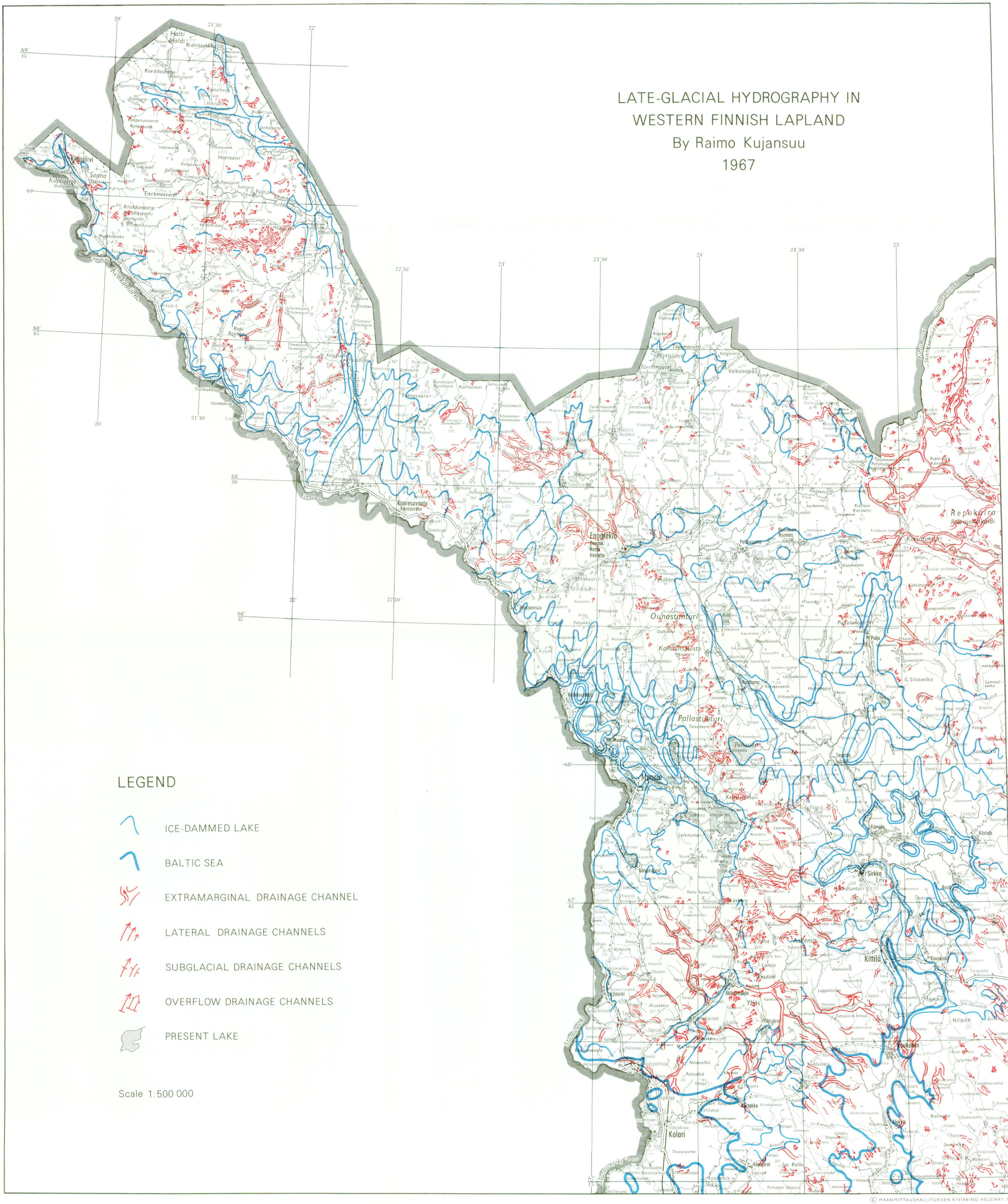
VIRKKALA, K. (1951) Glacial geology of the Suomussalmi area, East Finland. Bull. Comm. géol. Finlande 155.

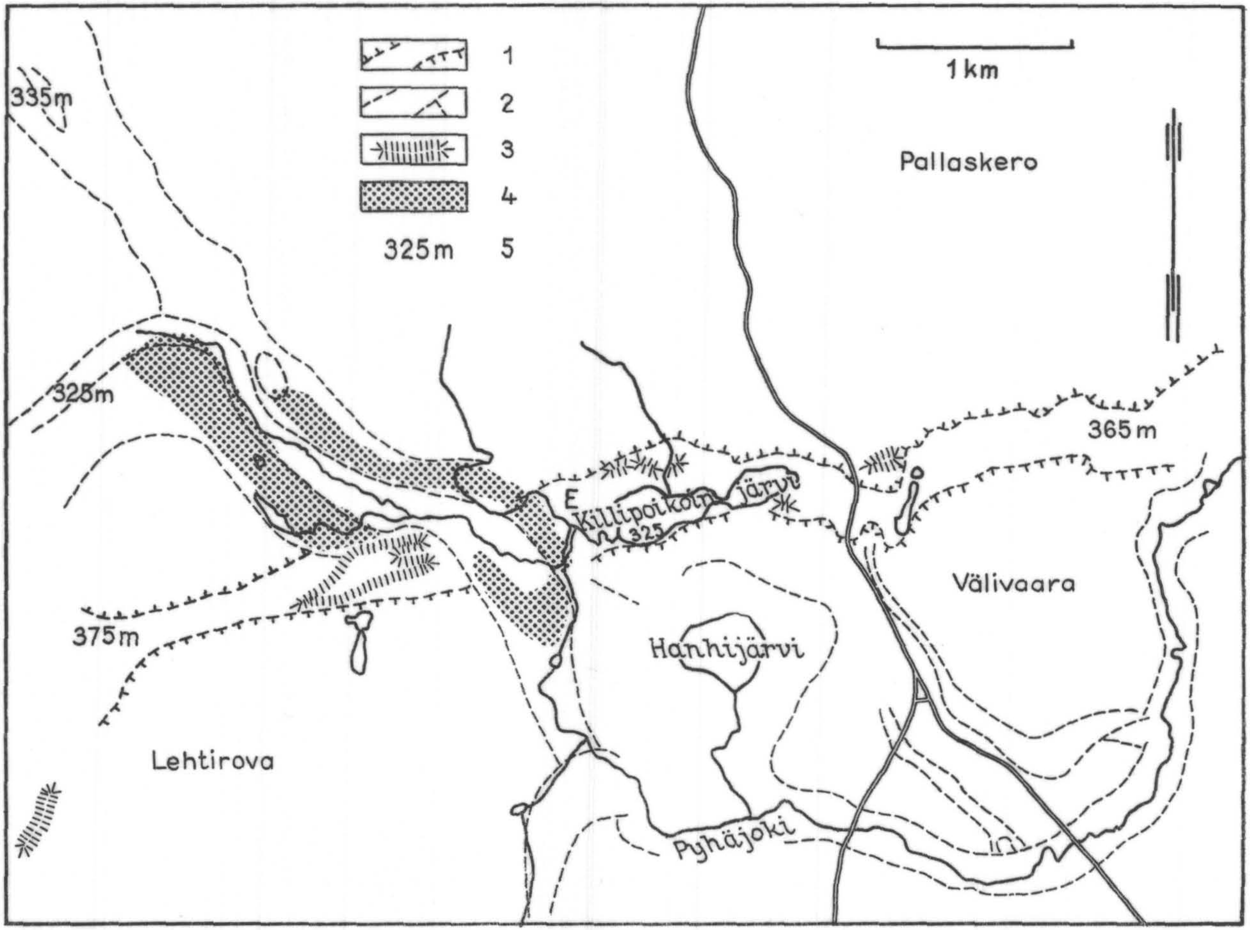
—»— (1952) Suomussalmen päätemoreeni. Summary: The Suomussalmi end moraine. Terra, Vsk. 64, pp. 65—76.

—»— (1955) On glaciofluvial erosion and accumulation in Tankavaara area, Finnish Lapland. Acta Geographica 14, pp. 393—412. Helsinki.

WOLDSTEDT, PAUL (1954) Das Eiszeitalter I. Stuttgart.

WRÅK, W. (1908) Bidrag till Skandinaviens reliefkronologi. Ymer, Bd. 28, pp. 141—191.


LATE-GLACIAL HYDROGRAPHY IN
WESTERN FINNISH LAPLAND
By Raimo Kujansuu
1967
LEGEND
ICE-DAMMED LAKE
BALTIC SEA
EXTRAMARGINAL DRAINAGE CHANNEL
LATERAL DRAINAGE CHANNELS
SUBGLACIAL DRAINAGE CHANNELS
OVERFLOW DRAINAGE CHANNELS
PRESENT LAKE
Scale 1:500 000
© MAANMITTAUSHALLITUKSEN KIVIPAINO HELSINKI 1967


1
2
3
4
325m 5
1 km
335m
325m
375m
365m
Pallaskero
Killipoikoin järvi
E
325
Välivaara
Hanhijärvi
Lehtirova
Pyhäjoki

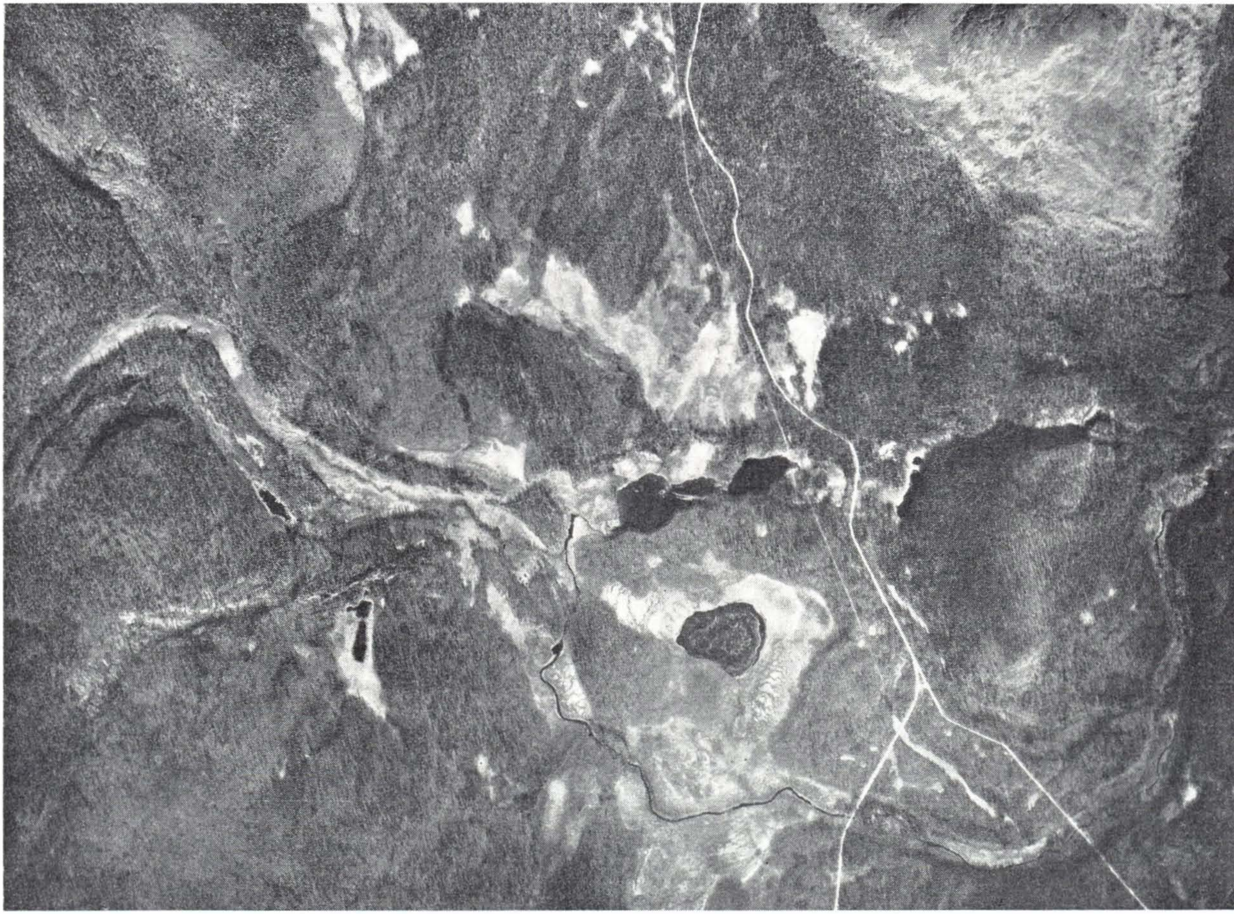


FIG. 48. Excellent aerial photograph of a subglacial channel cut by an extramarginal channel (*cf.*, Fig. 47). The direction followed by the former is topographically quite independent, whereas the latter follows the lowest level of the valley. 1) Subglacial channel, 2) extramarginal channel, 3) subglacial accumulation, 4) stream terrace, 5) elevation, in meters. By permission of General Survey Office.