SUOMEN GEOLOGINEN TOIMIKUNTA || GEOLOGISKA KOMMISSIONEN I FINLAND

# BULLETIN
## DE LA
# COMMISSION GÉOLOGIQUE
# DE FINLANDE

N:o 96

# ON THE PHYSIOGRAPHY AND LATE-GLACIAL DEPOSITS IN NORTHERN LAPLAND

BY

ERKKI MIKKOLA

WITH 25 FIGURES IN THE TEXT AND 5 PLATES

HELSINKI – HELSINGFORS
MAY 1932

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## PREFACE.

The material included in the present paper has mostly been gathered in Northern Lapland during the summers of 1925, 1926, and 1927. In the summer of 1925, a small geological expedition was sent out, on the initiative of Professor P. Eskola and under the leadership of Dr. A. Laitakari; the costs of the expedition being borne by Kordelin's Foundation. The work of this expedition was principally concentrated on the valleys of the Ivalojoki river and some of its tributaries. As a member of this expedition, the author was entrusted with the study of the physiography and the Glacial geology of the region. A part of the detailed mapping was carried out during that summer. In the second summer the author continued his studies, subsidized by Sohlberg's Foundation, working along the course of the Ivalojoki river and elsewhere in the S.W. parts of the parish of Inari. The main part of the mapping of the Ritakoski area was now accomplished. In the third summer, 1927, the author's journey was again subsidized by Sohlberg's Foundation, and the special aim of his field work was to define the extension of the granulite complex of Lapland and to study its tectonics. The investigations were particularly directed to both ends of the granulite belt. In the N. they were also extended into Norwegian territory. Furthermore, the region was visited by the author in the summers of 1922, 1923, 1929, and 1931, in the last two summers in the service of the Geological Commission of Finland.

Among the persons who have contributed to the performance of this work, the author wishes especially to mention Professor Pentti Eskola, of Helsinki, to whom he is most indebted. It was on his initiative and under his supervision that all the work was carried on during the years 1925—1927. The material of the Geological Commission was kindly put at the author's disposal by the Director, Professor J. J. Sederholm. The author's companions in the field studies have been Mr. T. I. Haataja, Forester of the Forestry district of Utsjoki, in the two earliest years; Mr. Einar A. O. Nordenswan, M. A., and the author's brother, Ensign Keijo Mikkola, who assisted in the mapping of the areas investigated in detail, in 1925 and 1926; Mr. Eero Suominen,

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M. A., in the summer 1927, and Mr. Th. G. Sahlstein, student of geology, in the summer 1931.

Finally, the author wishes to express his thanks to Dr. C. E. Wegmann for his kind advice anent the drawing of the stereogram of the Ritakoski area, and to Professor J. J. Sederholm, Professor P. Eskola, and Mrs. Lily Björling (née Hird) who have kindly revised the language.

Helsinki, April 1932.

*Erkki Mikkola.*

# EARLIER INVESTIGATIONS CONCERNING THE PHYSIOGRAPHY AND GEOLOGY OF NORTHERN LAPLAND.

## PHYSIOGRAPHICAL STUDIES.

The physiography and geology of the northern part of Finnish Lapland have up to the present been very little treated in scientific literature. Therefore, the knowledge of this territory has in these respects been fairly vague. In the 18th century almost no reliable information was yet available (cf. e. g. Marelius 1772). Earlier it was often assumed that Lapland was a highly elevated and mountainous country. The main watershed of Lapland, for convenience called Maanselkä, that divides the waters running to the Arctic Ocean from those running to the Gulf of Bothnia, was sometimes, as, for instance, by Sjögren (1828), described as a real mountain chain, stretching through all Lapland. It is true that this idea was readily suggested to the mind during the passage over the watershed within the mountain group of Saariselkä. Even nowadays current expressions like ''the fjelds of Maanselkä'' or ''the divide of Saariselkä'' are survivals of the older, erroneous belief.

Among the first investigators of the region, the famous Swedish botanist Göran Wahlenberg, who in 1804 published an account of his travels in Lapland, is worthy of special mention and appreciation, because of his particularly clear and objective statements also concerning several orographic features. But even he was not yet able to realize the presence of the most important unit, the large and relatively continuous curved belt of granulite mountains. From this time no essential progress in this knowledge is to be noted, until And. Mauritz Jernström published his excellent paper ''Material till Finska Lappmarkens geologi. I. Enare och Utsjoki Lappmarker'', in 1874. It is a geological study, and, for this reason, the physiography has been considered in rather broad features only. The essential characteristics of the surface levels and orography are, however, recorded with such accuracy and objectivity that the work well deserves to be designated as classic. The territory studied by Jernström comprises the western parts of the parishes of Utsjoki and Inari, i. e. the major portion of the area dealt with in the present paper.

The first information relating to the S.E. parts of the area was gained by the travels of A. E. Tigerstedt in 1882 and J. E. Rosberg in 1890. Rosberg's paper is accompanied by an orographical map of a portion of Saariselkä. A more complete map of these tracts has been published by V. Tanner (1915, Pl. IV). During the years 1898—1904 the geological survey was carried out in the parishes of Inari, Utsjoki and Sodankylä. In connection herewith also barometrical height measurements and orographical observations were made. These data were used by V. Tanner in the compilation of a general hypsographical map of Northern Finland (on a very reduced scale, published in 1915, p. 656). It is essentially this map that constitutes a part of the orographical map in the Atlas de Finlande 1910. Mannermaa has called attention to some minor errors which were still involved in it (1915). Later on the region has been regularly mapped by the Board of Survey and Board of Forestry, which work was finished about 15 years ago. Based on this mapping, 9 sheets of the Economical map of Finland (1:100000), which cover more than half of the area shown in the maps, Pl. IV and V, have been recently issued. In the literature, however, the physiography of the area has, in recent times, been fairly little treated (cf. e. g. Sarlin 1902, Rosberg 1891, Fircks 1906). The accounts of J. J. Sederholm in the different editions of the Atlas of Finland from the years 1899, 1910 and 1925 are very short and compendious. A good general view of the topography and orography of the region may be obtained from the "Bathy-Orographical Map" in the latest edition. In the same work, on the map sheet "Geographical Regions", and also in a separate larger treatise (1931) J. G. Granö has, in a very concise form, presented the physiographical divisions of the region and the rôle of the physiography as a constituent of the geographical complexes. The author has lately written in Finnish a rather comprehensive popular work ("Suomenmaa" IX, 2, 1931) on the geography of Northern Finland. In this paper the altitudes and orography are also treated, and on the accompanying map the relative altitudes are shown in their main features.

### GEOLOGICAL STUDIES.

The first impulse towards geological explorations in Finnish Lapland was given by the discoveries of alluvial gold made by the Norwegian geologist Tellef Dahll in 1867 on the rivers Inarijoki and Tenojoki (Tana River), the frontier rivers between Finland and Norway. In the following summer these discoveries gave occasion to the Finnish

Government to send out an expedition to Lapland under the leadership of J. C. Lihr, Director of the Mint (1869). This was the expedition in which A. M. Jernström took part as a geologist. The expedition succeeded in finding rather rich deposits on the Ivalojoki, whereas those on the boundary river were found to be fairly poor. The placers on the Ivalojoki were proved to pay for working, and some hundreds of gold diggers gathered in this region in the following summers. Some geologists and many private prospectors explored the country far and wide in order to find further auriferous deposits. During the years 1871 and 1872 Jernström continued his geological explorations, and published, in 1874, his above-mentioned paper, in which a general account was given of the geology of the western half of Northern Lapland, with special reference to the extensive and interesting granulite area. In the papers of C. P. Solitander (1882), A. F. Tigerstedt (1884) and V. Tanner (1913) further reports are given about the extension of the granulite in the S.E. parts of the region. The ordinary geological survey of the whole area was undertaken during the years 1898—1904, as has been mentioned above. The leaders of this work were J. J. Sederholm and E. Sarlin, and the other surveyors L. H. Borgström, And. Brofeldt, Benj. Frosterus, E. Katila, E. T. Nyholm, J. E. Rosberg, J. H. Saarinen, J. N. Soikero, and V. Tanner. On the general maps of the pre-Quaternary rocks of Finland issued after that time (Atlas de Finlande 1910, Atlas of Finland 1925) the granulite area was drawn in accordance with these surveys. The special aim of the work was, however, to reveal the mother lode of the gold of the placers, as well to continue the search for gold in the loose deposits. For the first time, gold in place was found by a private prospector, Henry Kerkelä, at the rivulet Hangasoja in 1900 (cf. Sarlin 1902, Fircks 1906). This discovery resulted in the foundation of a company for mining of the veins supposed to be gold-bearing. An energetic search led only to the discovery of a number of very poor veins, and no economic results were obtained. Later some attempts have been made to prove the possibility of an exploitation of the placers with the aid of machinery, since the earlier, simple methods could no longer be applied with advantage, but these attempts also remained without any positive results. Recently, Professor P. Eskola began a thorough petrological investigation of the granulite rocks. Some preliminary reports of the results (1932) have already been given.

The study of the Quaternary deposits of the area treated in the present paper was likewise begun by A. M. Jernström (1874). In 1915 [1]

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[1] Published as a thesis in 1914.

V. Tanner published a voluminous and comprehensive treatise of the Quaternary of Northern Finland and the neighbouring territories of Sweden, Norway, and Russia. In this paper all information available at that time, mainly gathered in connection with the general geological survey, was summarized. This work forms a valuable base for all subsequent studies dealing with the Quaternary of the region.

## GENERAL SKETCH OF THE REGION AND ITS ANCIENT ROCKS.

The area treated in this paper covers the parishes of Inari and Utsjoki and the northernmost part of the parish of Sodankylä. Adjacent regions which also must be partly dealt with in the present paper, are the Petsamo territory, which was united to Finland in 1920, and the neighbouring parts of Northern Norway, especially those bordered by the frontier rivers of Inarijoki—Tenojoki. Nearly all the surface waters from this region drain to the Arctic Ocean; they form four individual drainage systems of a larger size: the systems of the rivers Tenojoki, Näätämöjoki, Paatsjoki and Tuulomajoki. The Paatsjoki system has as its central basin the extensive Lake Inari, measuring about 1350 sq. km. in area. The greatest of its head rivers are the rivers Juutuanjoki and Ivalojoki; the former has three important sources, Kaamasjoki, Vaskojoki, and Lemmenjoki. The rivers Inarijoki and Utsjoki may be mentioned as belonging to the system of Tenojoki. Of the drainage system of Tuulomajoki, only two head branches lie within the area in question, the rivers Luttojoki and Jaurujoki. The southern limit of the area concerned may be placed at the Maanselkä divide in the W., while more to the eastward areas S. of the watershed must still be treated. The waters in the latter tract are drained into the large Kemi River, flowing to the Gulf of Bothnia. They constitute tributaries of two of its main branches, the rivers Kitinen and Luiro.

In the first place, the present study will deal with the large area of granulite in Lapland, which stretches as a broad curved belt from Norway through the W. part of the parish of Utsjoki, W. and S. parts of the parish of Inari, bordering Lake Inari in the S.W., N.E. part of Sodankylä and southern Petsamo (cf. the map, Pl. IV). Eastward it extends into Russian Lapland at least as far as the region of Lake Nuorttijärvi. Within the frontiers of Finland, the granulite belt has a length of about 300 km. and a width varying from 40 to 90 km. It may be naturally divided into two main parts. The boundary between them lies at the river Vaskojoki—Lake Muddusjärvi. In the n o r t h e r n main part the general strike is in N.—S. direction, in the S. turning to the S.E. Its breadth is 40—60 km., partly still less, due to a large inward projection at the E. margin of the area. At the Vaskojoki river, the S.W. boundary at first turns at right angles to the S.W., on account of which the south-eastern main part is much broader, as much as 80—90 km.; in Petsamo it becomes again narrower. The general strike is in the W., in the middle part of the whole curved area, N.W.—S.E., in the E. about W.—E.

The petrology of the granulite formation was studied by Jernström only megascopically, because the microscopic method at that time had not yet been introduced into Finland. He was able, however, to recognize the obvious analogy between this newly-discovered formation and the classical granulites of Saxony and Lower Austria. Jernström distinguished four different varieties of granulites, characterized by a somewhat different mineralogical composition. He described in a very suggestive way their external appearance as well as their mutual relations. Accurate descriptions of the boundary relations were given. Jernström's record of the tectonical features still holds good in its essential points. Since then, no special study dealing with the granulite formation has been published. Four analyses were, however, published by Hackman (1905), and recently a fifth one by Eskola (1932). On his initiative a number of further analyses has been made by Einar A. O. Nordenswan and L. Lokka.

The typical granulite is a strongly schistose and banded rock with varying grain; in general it is medium- or rather fine-grained. Its main constituents are quartz, microcline, plagioclase, garnet and biotite; the last mentioned mineral may be absent. Besides these minerals, cordierite often occurs in considerable amount, and very commonly also sillimanite, though only in smaller quantity, and graphite. As conspicuous accessory minerals rutile and monazite may be noted; even the latter is of fairly common occurrence. Alternating with the granulite, hypersthene-bearing rocks occur which belong to the same peculiar mineral facies as the granulite, the "granulite facies", according to the classification of Eskola (1929, pp. 168—169). Their constituents are plagioclase, hypersthene, and often quartz, microcline, and biotite. They are most common at both ends of the granulite belt, but occur very sparsely in some other regions. There are transitional rocks between granulites and hypersthene-gneisses, containing at the same time garnet and hypersthene. More rarely rocks containing hornblende and diopside are met with, most frequently in the marginal zones of the granulite complex.

The banded structure of the granulite coincides everywhere with its schistosity. The strikes are conformable with the curved margins of the area. The dips are at moderate or low angles towards the E.—N.E.—N. At almost every outcrop the rocks show a pronounced jointing along the smooth and even planes of schistosity (Fig. 1). There are, besides, numerous steeply inclined sets of fissures. Two of them commonly are particularly well developed. They intersect each other at varying angles not far from 90°, but they do not seem to have any definite relation to the general trend. Owing to their jointing, the rocks are largely split up in parallelipipedic flattened blocks, which in many places cover wide surfaces on the mountain slopes.

The greatest part of the granulite area, viz. almost all its northern main part and also a 30—40 km. broad, outer, S.W.—S. zone of the south-eastern main part, is principally made up of the rock varieties referred to above. Towards the N.—N.E. in the S.E. part, in the region of Luttojoki and farther W.N.W. of it, as far as the region of Lake Muddusjärvi and the lower course of Vaskojoki, a gradual transition to a coarser grain may be noted. The schistosity becomes less distinct and the jointing sparser, all together giving the rock a more solid, massive appearance, although it continues to be rather inhomogeneous. A pronounced banded texture is common. The bands are, however, often more or less wrinkled. The dip is continuously inclined towards the N.—N.E., but more gently on an average. In places the layers possess a nearly horizontal position or even dip towards S.—S.W. Hypersthene gneisses occur also in this part of the granulite area, and are, in comparison with the granulites, fairly homogeneous in character. They often show but slight effects of movements. Such is the case in large areas in Petsamo, S. of the Luttojoki river. They look very much like grey granites or diorites.

At the inner margin of the S.E. main part of the granulite area, a third, quite subordinate type of the granulite development may be distinguished. It represents a transition zone between the granulite and the gneissose granite N.E. of it. The position of the schistosity is here nearly vertical. Nearest to the boundary both rocks have a similar appearance, although the garnets are lacking in the gneissose granite. Both of these rocks contain similar older fragments of gneissose and amphibolitic rocks. Next to the boundary zone, the schistosity is, in general, better developed than on both sides. On the side of the granulite, smaller portions of almost non-orientated, nebulitic garnet-bearing granites occur, which possibly have been re-fused at a late stage of the granulite-forming processes. Farther towards N.E., at Lake Inari and in its surroundings, the gneissose granites and migmatites again become distinctly schistose, dipping rather gently in a direction opposite to that of the granulite complex, towards S.W.

Along its outer margin, the granulite is in contact with a complex of banded gneisses and amphibolites. Their trend is conformable with the granulite. In the boundary zone, and also at a few places in the middle of the area, such bands are found alternating with granulite bands. Just beyond the granulite a zone is met with almost everywhere in which garnet-bearing hornblende gneisses or garnet amphibolites are abundant as intercalations or as prevailing rocks. The width of this zone varies considerably, being maximum 10 km. Jernström considered these garnet-hornblende-rocks as a variety (the fifth variety) of the granulite (cf. 1874, pp. 137, 144). The rock formation at the outer (convex) side of the granulite belt also contains sedimentogeneous intercalations; the same is apparently also true of the granulite formation. At the middle course of the river Vaskojoki, in the deep inward bend of the outer boundary of this area, the country rock of the granulite is a slightly gneissose, striped anorthosite (its boundaries are shown on the map, Pl. IV). Although this rock is certainly not at all genetically connected with the granulite, it appears to pass gradually, and very rapidly, into granulite. Striped hornblende gneisses occur as transitional rocks.

At the E. margin of the northern main part of the granulite area a transition zone of garnet- and hornblende-bearing rocks is also commonly present. The boundary zone dips also here generally eastward, but at a steeper angle than in the W. The boundary line is sinuous, showing many conspicuous projections and incurvations, and the strike of the granulite is close to the boundary conformable with all these flexures. Where the strike runs across the general trend of the granulite belt, the dip is at many places vertical.

The general impression is that the granulite complex has been very strongly affected by tectonical processes. These have taken place during different stages of the process of petrogenesis, the rocks accordingly reacting in different ways and the results being superimposed upon each other. The older features have apparently largely been obliterated by younger ones. The phenomena of jointing (cf. above p. 8) are most prominent among the very youngest features, but also interesting brecciation phenomena, perhaps indicating late overthrust movements, have been observed at the upper course of the river Lemmenjoki. Intimately crushed zones, which in most places are conformable with the granulite banding, occur here. The rock is often soft and crumbly, in places impregnated with sulphides and graphite, and becomes rusty when weathering. A few small pyrrhotitic ores in the granulite (at the mouth of the river Taimenjoki, a tributary of the Ivalojoki, and near Lake Kopsusjärvi S. of the Rautuntunturit) and elsewhere in the region have perhaps a similar origin. Dykes of different porphyries and gold-bearing mineral veins in the granulite may also be mentioned here (Fircks 1906, Hackman 1923, Mikkola 1928). Finally, there are, in the granulite area, two younger, sharply cross-cutting intrusive bodies, the granitic massifs of Nattastunturit and Juovutunturi, which are shown on the map, Pl. IV, and have been earlier described by the writer (1928).

Fig. 1. Wide naked rock surface on a hill slope in the granulite mountains (in the group of Raututunturit), obviously created by glacifluvial processes. Photo by the author.

Fig. 2. Typical view of the upland peneplain between the rivers Sotajoki and Tolosjoki, in southern Inari, at an elevation of about 280 m. above the sea. Photo by the author.

## THE SURFACE LEVELS AND OROGRAPHY IN NORTHERN LAPLAND (PLATE IV).

### 1. THE UPLAND PENEPLAIN.

The general land surface of the drainage area of the Kemi River rises with a very slight and uniform gradient from the Gulf of Bothnia towards the uplands of Northern Finland. In Lapland, the Maanselkä-divide (cf. p. 3) lies nearest to the Gulf of Bothnia at a distance of 280—300 km. The exact altitude of the watershed in these tracts is not known, but the notches lie, at any rate, at elevations from 250 to 300 metres, the average slope from the coast thus being about 1 m. per km.

The physiography of the Kemi River drainage area does not differ in any essential way from the general character of the surface in Finland. The surface is within wide limits fairly flat or gently-undulating, extensive, smoothly-shaped elevations being, for the most part, scattered, and separated by wide, shallow depressions. The height differences very rarely exceed 100 metres. The S. portion of the region, mainly underlain by granite, shows in great part a rather uneven topography, but relative altitudes of the same order prevail, occasionally rising to 200 m., even somewhat higher. There are, besides, some still more striking exceptions from the general flatness, the ''fjelds'', i. e. solitary hills or small groups of mountains towering above their surroundings and attaining altitudes up to 300—500 m. from the foot. They may be interpreted as erosion remnants. The fjelds consist, as a rule, of the most resistant rocks of the region. Most of them are made up of quartzites, many of amphibolites and gabbros, and some of granites (cf. Hackman 1927, Mikkola 1928). But in spite of this, the region in question may in its larger features, and especially in its northern portions, well be regarded as a peneplain produced by long continued processes of wearing and levelling, just like almost all the surface of Fennoscandia (cf. e. g. Sederholm 1899 b, 1911 b, A. G. Högbom 1913, Ramsay 1919, 1931). Its recent inclined position is due to a slight warping in connection with the considerable upheaval of the Atlantic portion of Fennoscandia in late Tertiary time.

This ancient and extensive surface of planation has a special significance for the present study. It may be conveniently used as a level of reference for the orographical treatment. Because of its mostly rather elevated position, it is here designated as the ''upland peneplain''.

In the western parts of Finnish Lapland, the smoothly-rolling peneplain surface continues without any interruption over the divide into the drainage areas of the rivers Ivalojoki and Tenojoki, further extending, for wide distances, into the Norwegian territory. The gently-undulating topography described by Reusch (1903) from the inland parts of Northern Norway closely corresponds to that of the drainage area of Kemi River, but ascends here to a level of 300—400 metres. Some scattered groups of quartzite and amphibolite fjelds attain still higher elevations. Also in other parts of northern Fennoscandia a similar, fairly flat land configuration in a somewhat elevated position is met with, as, for instance, in the Peninsula of Kola (Ramsay 1900), in the Petsamo territory (Hausen 1925), and in Northern Sweden (e. g. S. De Geer 1926).

It is a matter of course that all the vast area of the levelled surface referred to above has not originated at one time, during a single cycle of erosion. Farthest north, a fringe of the upland peneplain, still underlain by Archaean rocks, is sub-Cambrian in age (Holtedahl 1918). Elsewhere the present level may be a more or less lower one, owing to subsequent, apparently rather unequal removal of the most superficial rock masses. At its maximum, this downcutting is not likely to exceed some hundreds of metres. In late Tertiary time, the surface in question, at any rate, was entirely levelled, and presented nearly the same aspect as now. W. of the region of the map, Pl. IV, where the amount of the Tertiary uplift increases still more, Wråk (1908) has found the corresponding upland surface to be composed essentially of two different levels, called by him the Borsu-level (higher) and the Muddus-Guris-level (lower). As the author has not been able to discern both levels within the area studied by him, it seems likely that they converge and nearly unite with each other more to the eastward. At the same time, many slighter features may be overshadowed by the strong tectonical disturbances which will be expounded later on.

Fig. 2 presents the typical aspect of the upland peneplain in the southernmost parts of the parish of Inari, within the granulite area.

## 2. THE BELT OF GRANULITE MOUNTAINS.

In the northern part of Finnish Lapland, near to the outer boundary of the great granulite belt, the upland peneplain abruptly ends against a nearly continuous front of mountains. Their summits rise in part almost immediately from the granulite boundary, in part somewhat inside the area, within a maximum distance of 30 kilometres. The outer limit of the mountain belt is in most places very well defined, and for long distances it maintains a nearly straight or regularly curved course. At several places a gradual rising of the surface and an increase of relief may be already noted a little beyond the real foot of the mountain belt, but where it is lower and less continuous than in general, the boundary nevertheless may be rather distinct, although not so clear as commonly is the case.

The granulite mountains stand out as an orographical type unique in Fennoscandia. The mountain groups are rather massive and fairly homogeneous in character (cf. Fig. 12). In every group the summits rise to rather uniform altitudes, and also throughout the whole area the top levels show but fairly moderate variations. Most of the individual hills are closely clustered, most of the separating narrow valleys thus lying at rather high elevations. The altitudes above the upland peneplain and some wider valleys within the mountain massifs range in general from 150 to 300 metres. In a couple of groups, they exceed even 400 metres.

The course of the western—southern boundary of the granulite area and the situation of the mountain groups are obviously in quite a definite way connected one with the other. As seen from the map, Pl. IV, the S.W. margin of the granulite belt shows four projections which are separated by three incurvations. The two northerly of these projections belong to the N. main part of the granulite belt (cf. above p. 7), the two south-easterly ones to its S.E. main part. The inward bend between the two main parts (p. 7) is much more pronounced than the two others. At this place, also the mountain belt is completely disconnected by an opening measuring about 10 km. in width. In front of the projections, within the granulite, on the contrary, the mountain belt is best closed and continuous, there attaining, as a rule, its largest dimensions both in height and width.

Beginning from the N., the first important mountain massif is situated on both sides of the frontier. On the Finnish side it bears the name Jeskadam, and has a height of 500—550 m. at its maximum. On the Norwegian side, in the W. part of the area, some hills rise even over 700 m. This group has rather scattered summits. It lies, as well as the following massif, called Paistunturit, in front of the first projection of the outer margin of the granulite area. In this latter group, the three highest peaks rise in a range trending N. 15° W. on the N.E. margin of the mountain area, and attain heights of 640—650 m. The hills are wide and rather gently sloping, but in many cases peak-like at their tops. The summit level descends fairly regularly towards the S.W.

In front of the first inward bend of the boundary, in the vicinity of the mouth of the river Karasjoki, a great head branch of Tenojoki, the mountain belt is rather discontinuous and broken into several smaller isolated groups, the other area being occupied by lower hilly relief or almost a peneplain. The northernmost of these groups comprises one solitary peak, Akuvaara, of an altitude of 560 m., and the much lower, rather insignificant hills of Piesvaarat, which remain below 450 m. Just opposite the mouth of Karasjoki, there rises the small but bold mountain massif of Karigasnjarga-Ailigas, the highest summit of which has a level of 623 m. Farther E. of both of the above-mentioned mountains, there lie, close to each other, the small, fairly smooth-shaped groups of Ruottir and Njaugoaivi, both of which have an altitude of about 550 m. Still farther E., at the E. margin of the granulite belt, the very gentle-shaped Faallis is encountered, a group of four wide ridges not much exceeding 400 metres.

In front of the second projection, the granulite belt is for the most part occupied by the very large and coherent massif of Muotkatunturit, which has roughly an alignment of a large triangle measuring in extent about 40—50 km. In spite of its wide area, it has very distinct boundaries at all its margins, excepting a part of the S.E. margin. In the N.W. corner, a narrow promontory of the area reaches the river Inarijoki, close to which the summit of Nupir has a height of 519 m. In the centre of the area, all the hills rise to levels ranging from 500 to 550 m.; many of them have sharp peak-like forms. Some still higher tops occur in the S.E. part, where the very highest one, the rugged peak of Koarvikods, attains a height of 591 m.

The wide and low-lying opening at Vaskojoki is followed, in front of the third projection of the S.W. margin of the granulite area, by two very similar twin massifs, the Marastotunturit and the Viipustunturit; these are separated from each other by the valley of Lemmenjoki. They have roughly rectangular ground plans, the corners lying in the four points of the sky. In both groups the highest summit rises in the W. corner; in the Marastotunturit, the Ladnjoaivi (591 m.), in the Viipustunturit, the Morgam-Viibus (599 m.). The W. parts of the groups are very massive in character and distinctly bounded against the lower regions in the west. Eastward the hills gradually descend, so that the E. corners no longer show any defined boundaries against the eastern area. Most of the summits have very smooth and gently-sloping outlines.

The inward bend between the third and fourth projections is exceedingly wide and shallow. In front of it, the mountain belt is again comparatively low and discontinuous. In the S.W., beyond the mountain belt, a rather broad marginal part of the granulite area is occupied by a true peneplain, or by a relief characterized by lower and isolated hills. N. of the Ivalojoki, the higher mountains are gathered in several groups around Lake Hammasjärvi. W. of it the Appistunturit rise as a narrow range with a highest summit of 499 m., and farther N. their continuation, the Haukkapesäpää. A smaller and still lower group is met with N.—N.E. of the lake, and S.—S.E. of it the larger group of Hammastunturit, with the highest peak Hammasuro attaining 531 m. In all of these massifs, rather irregular and rugged forms are common. The Hammastunturit extend very near to the Ivalojoki river which crosses the mountain belt along a narrow break. From the Ivalojoki to its tributary river, Tolosjoki, the mountain belt is represented by three very small groups, Palsi, Tolospää and Harripää, the last of which only attains a level of 500 metres.

The fourth and last, very broad and shallow projection, lies in front of a large, but comparatively narrow area of mountains trending from W. to E. Its width is somewhat over 20 km. at its maximum. The river Suomujoki, a considerable source of Luttojoki, flows across the area, dividing it into two unequal parts. The smaller, more westerly one is called Raututunturit, the larger easterly Saariselkä. The Raututunturit (Fig. 12) have the smoothest outlines, the flattest tops and the gentlest slopes of all the granulite mountains. The summits lie at almost equal levels, only the highest one, the Kiilopää, rising to 543 metres. In the Saariselkä the granulite mountains attain their highest elevations within Finnish territory, exceeding 700 metres. Probably highest of all is the Jonlaki (714 m.) within the Petsamo territory. In the parish of Sodankylä, there are two peaks which come very near to it, the Vuomapää and Sokosta, both about 700 metres. The Vuomapää rises close to the S. margin of Saariselkä. Somewhat more to the N. two hills, the Ukselmapää and the Korvapuolipää, rise to a height of about 680 m.; in the W. part of the Saariselkä, W. of Lake Luirojärvi, the highest summit is Lupukkapää (650 m.). The whole length of the Saariselkä as far as the E. boundary of the Petsamo territory measures about 90 km., but the easternmost part is comparatively low again. — As mentioned before, the divide between the Arctic Ocean and the Gulf of Bothnia lies, in the vicinity of Lake Luirojärvi, within the Saariselkä.

## 3. THE REGION N.E. OF THE MOUNTAIN BELT, THE BASIN OF INARI.

At the inner side of the curved mountain belt, N.E. of it, in the region of Lake Inari, a third main surface level is encountered which lies at a considerably lower altitude than the upland peneplain on the outer side of the mountains. The altitude of Lake Inari is 118.5 metres above sea level. Over a wide surrounding area, which may be called "the basin of Inari", the levels of the depressions do not reach 200 metres. The general level of the land surface ascends from Lake Inari in all directions, except the rather narrow valley of its discharge river Paatsjoki. In the N.E., however, the lowest parts of the divides against the other drainage systems have no high altitudes; the two lowest notches lie at 131.5 and 138 m. (Tanner 1915, pp. 481, 495). The average height, and especially that of the tops, however, rises continuously to the northeastward, very rapidly at the end in the coastal belt, there attaining elevations up to 500 metres in the Norwegian province of Sörvaranger, S. of the Varanger Fiord, and in the northernmost part of the Petsamo territory. A very regular and continuous rising of the surface is noticeable northward from Lake Inari, E. of the N. part of the granulite area. In the parish of Utsjoki, even many considerable lakes lie at 250—300 m. above the sea. S.E. of Lake Inari, several rather low-lying notches lead over to another basin, that of the Luttojoki river, descending eastward towards Lake Nuorttijärvi in Russian Lapland. The drainage basin of Luttojoki is bounded in the S. by the Saariselkä, in the N. by the divide against the drainage areas of Paatsjoki and Petsamojoki.

The basin of Inari is underlain by two different geological formations: the granulite formation, viz. the peculiar facies constituting the inner zone of its S.E. maint part (cf. p. 8), and the formation of gneissose granites and migmatites N.E. of the former. There is a great difference in the physiography of both these regions, which shows itself in as clear a way as may be expected at Lake Inari. The regions S. and S.W., in part also W. of the lake, are fairly rough, in many cases merging into wild mountain landscapes with numerous lakes with ragged contours in the depressions (Fig. 3). Next to Lake Inari some hills rise to heights exceeding 200 m. from the lake, or 300 m. above the sea. This mountainous region rises continuously to the southwestward, finally merging into the mountain groups of Hammas- and Appistunturit, and thus forming, in a way, a promontory to them. All the innumerable islands in the S.W. part of Lake Inari have steep rocky shores. At the very edge of the granulite area are situated four comparatively large islands, Petäjäsaaret and Jääsaaret, in which hills of a height of 50—100 metres exist, in striking contrast to the fairly flat and low islands and shores of the middle portion of the lake. S. of Lake Inari, the area of the mountainous relief is, to some degree, separated from the Saariselkä by the upper portion of the Luttojoki basin, where the hills are lower and more scattered. The highest tops between the basins reach over 400 m., the small group of Tsharmitunturit about 500 m. In the W., this interbasin mountainous area grades into the Raututunturit, thus appearing as a ramification of the mountain belt. In the region of Juutuanjoki river, the aspect of the landscape is very varied. The existence of some great lakes, like

Fig. 3. Lake Myösäjärvi in the rocky mountain landscape S.W. of Lake Inari, close to the Ivalo—Inari highroad. Photo by the author.

Lake Muddusjärvi and Lake Paadarjärvi, causes considerable breaks in the continuity of the hills. Their levels lie 140—145 m. above the sea. Among the mountain summits the imposing Otsamo (418 m.) near the church village of Inari may be specially mentioned; all the others remain considerably below this height. In general, the area merges gradually into the chief mountain belt. In front of the Marastotunturit, however, the peninsula of Paadarinniemi, between the rivers Vaskojoki and Lemmenjoki, is lower on the side of the mountains than in its end portion.

In the other parts of the basin of Inari the relative altitudes are insignificant; the notable hills are, in general, gently-sloping and fairly scattered. Where an extensive view can be obtained, the sky line appears exceedingly plane, although the minor topography may be extremely uneven, owing to glacial accumulations. Farther N. and N.E., the hills increase in number, and the gradually deepening valleys which lead to the Arctic Ocean add more and more to the ruggedness of the relief. — In the region of Kaamasjoki, the peneplain area of the basin of Inari projects as a large bay into the mountain belt between the Muotkatunturit and the Faallis—Ruottir.

### 4. THE RELATIONS BETWEEN THE OROGRAPHY AND HYDROGRAPHY, THE RIVER VALLEYS.

#### The Drainage System of Lake Inari and Paatsjoki River.

This drainage system presents hydrographically the most interesting and varying conditions. Its central basin, the vast Lake Inari, receives tributary water courses from all directions, appearing as a local base-level of erosion. Among the head water systems, that of Juutuanjoki has the greatest water supply. This system also has a central lake of its own, Lake Paadarjärvi, whose water empties as a sluggish stream into Lake Solojärvi, on the way receiving a large tributary from the N., the river Kettujoki, from the big Lake Muddusjärvi. Lake Solojärvi is drained by a short river with several powerful rapids, the Juutuanjoki proper, into Lake Inari.

The largest of the head rivers of the Juutuanjoki, the Kaamasjoki river rises in the Muotkatunturit, between this mountain group and the Ruottir, and on the N. slope of the basin of Inari, and empties from the N. into Lake Muddusjärvi. Like its tributaries, it has no well-marked valley. The other head rivers enter Lake Paadarjärvi direct. The next, also rather large river, the Vaskojoki, avails itself of the wide opening between the two main parts of the granulite mountains (cf. p. 14), when it passes across this belt. Owing to the rather low level of this opening, the river has not cut any noticeable valley there. In a way, the basin of Inari projects here some distance onto the outer side of the curve of the mountain belt until it gradually ascends to the general level of the upland peneplain. In the anorthosite area of Vaskojoki (p. 9), the levels of the depressions range from about 170 to 200 metres, and also the divide against the Inarijoki river is fairly low. In its uppermost course, however, the Vaskojoki river partly has a prominent, steep-sided valley of young aspect carved into the peneplain where this slopes perceptibly northward towards the anorthosite area.

The third head river, the Lemmenjoki, flows through a particularly large, imposing intermountain valley between the Marastotunturit and the Viipustunturit (cf. p. 15). It rises as far as the S.W. side of the mountain belt, and descends already there into a trench-like steep-walled valley (cf. Fig. 23), on the bottom of which the river roars and foams as continuous rapids. Where the Lemmenjoki enters between the mountains, it entirely changes its character. Here, as far as about 35 km. from Lake Paadarjärvi, but just a few metres above its level, the Lemmenjoki turns into a chain of narrow, deep lakes, which in most places entirely occupy the bottom of the valley. The uppermost of them is Lake Morgamajärvi, just close by the highest summit of the Viipustunturit, the Morgam-Viibus. A narrow flat-bottom continues headward from here for a distance of 7 km. Along this stretch some tributary valleys join the main valley; they have steep gradients, but

Fig. 4. The great valley of Vaiautsi, a tributary to the upper Lemmenjoki valley from the S. Photo by the author.

have at their mouths been cut nearly to the level of the main river. From the left the largest one is the Suoppasautsi at the very foot of the Marastotunturit, and from the opposite side the Vaiautsi (Fig. 4), which is throughout its length bordered by precipitous rocky cliffs and steep talus slopes. At the stretch between the mountains, the valley of Lemmenjoki river is quite unsymmetrical. The Marastotunturit side rises as a rather level slope of a moderate inclination. The mountain summits at this margin rise 200—300 m. from the lakes. The opposite side, Viipustunturit, is exceedingly steep, particularly the lower portion of the slope up to a height of about 100 m., is merely a continuous wall of sheer cliffs and slopes of rocky talus. The upper portion of the slope ascends immediately to the highest peaks of the Viipustunturit which are situated parallel to the valley, no more than

1—2 km. from its bottom. This border of the valley surmounts the opposite one by 100—150 metres. From the right side the Lemmenjoki receives but a few insignificant rivulets falling down as high cascades over the precipices. From the left side, a considerable river, Rovodosjoki, empties into Lake Rovodosjärvi. In its upper course, it flows rapidly in a gently-shaped and wide-bottomed valley, but at its mouth it drops into the main river through a rocky gorge as a series of falls (Fig. 5), in a typical hanging position. This gorge is of quite recent

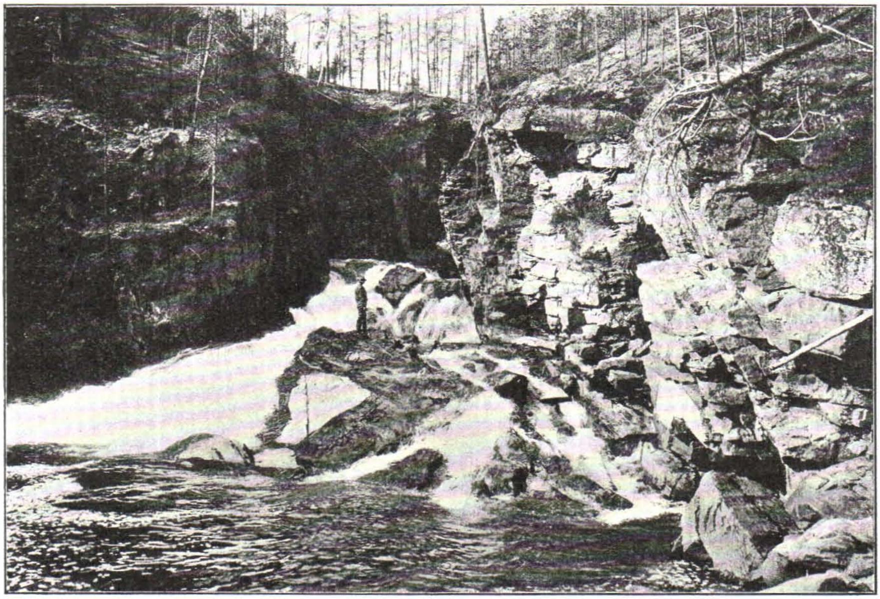


Fig. 5. Gorge and cascades at the mouth of the river Rovodosjoki in the Lemmenjoki valley. Photo V. Tanner.

origin, judging from its little advanced stage of backward erosion, which amounts to no more than a few tens of metres, the downcutting being at the same time about 10 m.

The river Ivalojoki, in size the next important drainage system entering Lake Inari, gathers the major part of its water supply on the outer side of the mountain belt. As mentioned above (p. 16), the river passes across this belt at a rather narrow break between the Hammastunturit and Palsi mountains (Fig. 10). The river valley has been sharply incised into the upland peneplain, which is here surmounted by some scattered gently-moulded hills (for the particulars cf. Plates II—III and the detailed description of the Ritakoski area on pp. 41—62). Starting from the mouth of the affluent Palsinoja, the valley of Ivalojoki may be readily followed 8—9 km. farther downward, but thence onward it widens out considerably, the sides at the same time becoming dissected to such a degree that the distinct valley character is blurred. Upwards from the Palsinoja the valley assumes the typical trench-like shape (Fig. 6) indicating a closed stage of rapid downcutting, as far as the mouth of the affluent Appisjoki, or for a

Fig. 6. The deep valley of the Ivalojoki river at Kultala, the former gold mining centre, half-way between the Appisjoki and Sotajoki rivers. Photo J. J. Sederholm.

stretch of 15 km. The water rushes on as continuous swift currents and rapids. Higher up the valley still maintains a youthful shape with gradually lowering walls, and the current is swift, till above the mouth of Kyläjoki, a tributary entering from the right. Along this stretch of a length of 13 km. the valley, however, appears to be somewhat broader at the bottom, although vertical rocky cliffs rising directly from the water are met with in the upper portion. The gradient also seems to be slighter; at the lower end, just above the Appisjoki, there is a still-water stretch called Appissuvanto. The exact altitudes in these regions are as yet hardly known, not even the river courses having been levelled, but according to a rough estimate the head of the young valley of Ivalojoki lies at a level of about 210—220 m. above the sea, i.e. still somewhat lower than the depressions of the upland peneplain in general. A shallower and rather ill-defined valley may be traced still farther headward for a stretch of nearly 30 km. Below the mouth of the tributary Repojoki, there is a succession of heavy rapids above which the river presumably reaches a level of at least 240 m.

The tributary valleys joining the main valley at its deep stretch have likewise been deeply entrenched (Fig. 7). Their widths, depths and lengths are roughly proportional to the sizes of the streams that

Fig. 7. Mouth of the Appisjoki river and lowest portion of its valley. Photo by the author.

occupy them. Among these the valley of the river Sotajoki, one of the largest tributaries, is especially noteworthy. Its lowest portion is seen on the map, Plate II. The rivers Sotajoki and Ivalojoki show, as might be expected, an apparent parallelism in the development of their courses. The well-defined valley of Sotajoki is 14.5 km. long. In the deep valley one may see a break in the gradient of the river at Halvarinniemi (cf. Figs. 11 and 21), about 5.5 km. from the mouth, i.e. where the river enters the area of the map, Plate II. From here upward the river level rises for some distance very slightly, and in the upper portion the gradient is somewhat smaller than below. A corresponding break in the fall curve of Ivalojoki exists at the mouth of Appisjoki (cf. p. 22). In each river, the mutual proportions of the gradients above and below the breaks are obviously very similar, as well as the characters of the valleys. Both of these have their most narrow-bottomed and youthful portions downward from the breaks. The length proportions of the valley portions on both sides of the breaks are also not very different, at the Ivalojoki (starting from the Sotajoki) 10:13, at the Sotajoki 5.5:9. Such complications in the valley development are due to a discontinuous sinking of the base-level that controlled the valley cutting. They indicate an intermission of the movement which was succeeded by a sudden jerk of a score of metres.

On the inner side of the mountain belt, the river Tolosjoki is the most important affluent to the Ivalojoki river. It also crosses the mountain belt, and has a large, regularly shaped valley. Lack of available information makes it impossible to consider its particulars.

### The System of Tuulomajoki River.

The valley of Suomujoki, a tributary to the Luttojoki river between the Raututunturit and the Saariselkä mountains, is rather broad, deep and wide-bottomed from below as far as 3 km. from Lake Kopsusjärvi, a lake lying on the other side of the Maanselkä-divide and draining into the Luiro river. Here the river course forms a right angle, the upper part coming from the N.W. with a steep descent, almost as a hanging tributary into the head of the regular valley, which continues towards the N.E. This valley head lies much, perhaps nearly 100 m., lower than the level of Lake Kopsusjärvi. Of the remaining rivers in the drainage system of Tuulomajoki river, the Jaurujoki river has a pronounced valley which descends rapidly eastward at the S. foot of the Saariselkä.

### The System of Tenojoki (or Tana) River.

The largest and most imposing river valley of the whole of the area is the valley of Inarijoki—Tenojoki. Like the Ivalojoki, this river collects the major part ot its water supply from the upland peneplain on the outer side of the granulite mountains, but crosses them where they are much more continuous and higher. To begin with, in the vicinity of the anorthosite area, the Inarijoki river runs as a rather sluggish stream in an ill-defined, fairly shallow valley. The Inarijoki river might here be expected to join the near-lying Vaskojoki river, instead of departing northward as if going to seek a way around the mountain belt. The river level, however, soon begins to descend rather rapidly in many currents and rapids, while the surroundings, on the other hand, gradually rise about 100 m. higher, the depth of the valley thus increasing. Almost everywhere, however, the valley bottom is considerably broader than the river bed, so that the general aspect of the valley may be regarded as fairly mature. For a long stretch the frontier river roughly follows the boundary of the granulite formation. In front of the N.W. promontory of the Muotkatunturit (p. 15), the E. wall of the valley is very steep, bold and rugged (cf. Fig. 25), reaching a height of as much as 300 m., while elsewhere the valley slopes still remain below 200 m. At its entrance, the Karasjoki river carries more water than the Inarijoki river, for which reason the former must be considered as the main river. At the junction, the river bed lies 123 m. above the sea. From here downward the

Fig. 8. The wide valley of the Tenojoki river at Nuvvus. The bold mountain Nuvvus Ailigas, which rises more than 400 m. from the river bed, is seen in the background to the right. The narrow valley portion above the Ylikongäs rapids begins in the distance. Photo E. Sarlin.

Tenojoki flows more than 50 km. rather quietly, broken only by small rapids and currents, the total fall along this stretch being about 15 m. At the end of this stretch the river already turns decidedly into the granulite area. The valley has a well-developed, mature appearance (Fig. 8) with a flat-bottom measuring about 1 km. across on an average, the width of the river bed alone often reaching 500 m. and even more. The slopes are regular and fairly steep, rising generally about 200 m. from the river, but nearly 300 m. where the N.W. end of the Paistunturit is passed. Then follows, while the river passes the Jeskadam mountains, a portion of the valley where the breadth is markedly constricted. The slopes are extremely steep, at the outer sides of the bends showing sliding talus slopes or rocky cliffs, and rise throughout 250—300 m. above the river level. The length of this part is about 25 km., but the gradient is continually fairly moderate, 8 m. in all. This stretch terminates in a long, but smooth cataract called Ylikönkäs 6 km. in length and with a fall of 14 m. Hence onward, for a distance of 55 km., the Tenojoki runs continually as a fast water with a gradient of 80 cm. per km. on an average. This stretch is followed by the heavy cataract Alakönkäs, where the river drops 25 m. during a distance of 6 km. Just below the Ylikönkäs the river level lies at 87 m., at the mouth of Utsjoki 64 m., and above the Alakönkäs

Fig. 9. A view from the lower Kevojoki valley, showing two huge cliffs in a line (a fracture escarpment) along the E. side of the valley. Photo by the author.

40 m. above the sea. Below the Jeskadam mountains the height of the slopes remains at about 200 m. The portion between the Ylikönkäs and the Utsjoki is the narrowest and most youthful one of the valley of Tenojoki, a distinct new graded stretch of the regressive downcutting. Farther downward, the valley gradually widens out, but is again considerably restricted at the rapids of Alakönkäs which apparently mark a still more recent step of receding erosion in the valley bottom.

The Inarijoki—Tenojoki river receives from the Finnish side many short tributaries, the headwaters of which occupy gentle valleys in the mountainous uplands or the upland peneplain. Their lower courses rush on with steep gradients in deep, trench-like valleys which upward terminate in many cases in narrow rocky gorges. The only larger tributary is the Utsjoki river, which runs in a northerly direction somewhat eastward from the E. boundary of the granulite area. This river has a very deep and wide trough-shaped valley (cf. Fig. 24) which makes the impression of being disproportionally large as compared with the size of the stream. The rise of the valley bottom as far as the head of Lake Mierasjärvi is as little as about 55 m., at a distance of 50 km. At Lake Mierasjärvi, the slopes rise from the water 100—150 m., which height increases to 200 m. along the lower course of the river. The stream itself is for the most part composed of a number of elongated lakes, connected with each other by streams and rapids, these being principally due to obstructions, consisting of loose deposits on the valley bottom. The valley, again, is constituted of several rectilinear sections with interjacent sharp bends. This peculiarity must necessarily be taken as a proof of the existence of fracture lines, along which the valley has originated.

The affluents of the Utsjoki have also capacious valleys; especially is this the case with the largest of them, the river Kevojoki. It rises in the gap between the mountains Ruottir and Njaugoaivi (cf. p. 15). The character of a fracture valley is here also displayed partly by the straight-lined trend with abrupt bends, partly by huge cliffs representing obvious fracture escarpments in the E. slope of the lowest valley portion (Fig. 9). At the middle and upper course, the valley of the Kevojoki river is for the most part enclosed by sheer, rugged rocky precipices and steep walls of rock fragments; the bottom is partly occupied by lakes. It is the largest and wildest canyon valley in Finland, and also almost the only one deserving this designation.

## 5. THE DEVELOPMENT OF THE RIVER VALLEYS.

### (THE YOUNGER DEFORMATION OF THE UPLAND PENEPLAIN.)

The above description has brought forth much evidence in favour of the view that many of the large river valleys in Northern Lapland have been entirely formed through erosion by running water, i. e. by the rivers now occupying them. The most perfect valleys of this character are those of the Inarijoki—Tenojoki and Ivalojoki rivers and many of their tributaries. When we take into consideration their sizes and the negligeable work of the post-Glacial erosion (cf. pp. 60—63) that may often be ascertained, no other conclusion seems to be possible than that this valley-cutting was essentially performed already during pre-Glacial times. This has been the opinion of most geologists who have visited the region since the beginning of the regular survey, and also of those who have received sufficient information about the local conditions (cf. Fircks 1906, Sarlin 1902, Sederholm 1899 b, 1910, Eskola

1925, 1926, Sauramo 1929, p. 17). Tanner has defended another view concerning the drainage system of Ivalojoki. He thinks that an exceedingly intense late-Glacial water-action has had a greater importance than the pre-Glacial erosion (1915, pp. 473—475). This opinion is, as the present writer thinks, quite untenable, and depends on Tanner's insufficient information about the region of Ivalojoki.

If there is agreement about the decisive rôle of the normal erosion, it is, in the author's opinion, not reasonable to attribute any considerable amount of this to the supposed inter-Glacial periods during the Quaternary Ice Age. When summed up, their maximum duration might be

Fig. 10. Ivalojoki valley at Palsi, seen from the promontory W. of the Palsinoja river. Steep wall of the mountain Iso Palsitunturi to the right. Photo by the author.

as much as a few hundred thousands of years, but even that lapse of time is likely to appear insufficient to account for even as great results of erosion as are recorded by the lowest graded portions of the rivers (at the Tenojoki, heading at the Ylikönkäs, at the Ivalojoki at the mouth of Appisjoki). Thus the valley topography must, in any case, be essentially of pre-Glacial origin.

In Scandinavia, the conception of distinct pre-Glacial topographic features, which have been largely preserved from the glaciation, is familiar among all investigators (see Asklund in Ramsay 1931). From this point of view Wråk (1908) and Ahlmann (1919) have carried out detailed studies in the Scandinavian highlands with especial regard to the valleys. They have generally ascertained two distinct phases of pre-Glacial erosion in the youthful, steep-sided valleys. Thus this result seems to be in agreement with the presence of two graded stretches in the valleys of Finnish Lapland, but at present the correlation of these phenomena in both territories appears immature, information about the interjacent areas being still fairly deficient. As to the Peninsula of Kola, Ramsay clearly recognized the presence of pre-Glacial land surface, including, for instance, the large and particularly distinct valley of the Ponoi River (1900, p. 20). In the glaciated area of North America all the broader features of the landscape have long ago been regarded as pre-Glacial. One of the most interesting studies on this subject is the recently published paper of H. C. Cooke (1929) which deals with the pre-Glacial valleys in the elevated and warped peneplain of the Labrador peninsula.

The conditions necessary for the formation of the Lappish valleys must have been the following. A general surface level existed, viz. the upland peneplain, which for a long time was near to the general base-level, but later became uplifted. This change of levels was complicated by the formation of the basin of Inari. The uplifted areas were partly only warped up, so as to become sloping against the peripheric non-elevated regions, but in other places the uplift resulted in faults.

The most important fault line for the present study is that indicated by the straight coast line Norwegian Sörvaranger—Petsamo—Murman in Russia. Its character has already long ago been recognized. The whole aspect of this coast is that of a fault scarp. The Archaean rocks rise as rugged, barren rocky cliffs or steep walls, close to the sea attaining heights of 400—500 m., these being due to a further local upward warping at the margin of the block. Immediately N. of the general coast line post-Archaean deposits occur.

The great faults along the Sörvaranger—Murman line, which caused the valley-cutting, have obviously taken place in connection with the great disturbances on the Arctic and Atlantic coasts of Fennoscandia during late Tertiary (Miocene and Pliocene, perhaps even Pleistocene) time. These movements did obviously not happen at once, but at intervals during a rather lengthy period. The two latest jerks of the movements are registered by the Tenojoki river at the rapids Yliköngäs and Alaköngäs. Movements along this fault line have still taken place during the post-Glacial period, as Tanner has convincingly demonstrated (1930 a, pp. 221—230). But it can also be traced back to far remoter periods, as stated by Holtedahl (1918, pp. 264—268, 310). Already in the dawn of Palaeozoic time, before the main phase of the Caledonian diastrophism, strong disturbances have occurred there. Owing to these disturbances the region of the northernmost corner of Finland was at that time an elevated mainland area, bearing a continental ice sheet flowing northward and furnishing materials to the tillite-bearing deposits N. of the great fault line — all this according to Holtedahl. He has found at those localities intercalations of garnetiferous sandstones, the garnet being presumably derived from the granulite rocks.

In the basin of Inari, a fault line must be supposed to run across Lake Inari close N.E. of the islands Petäjäsaaret and Jääsaaret. The N.E. block has been faulted down and tilted towards the S.W. and S. It is likely that there are even more faults, ascending like a staircase inward the granulite area. The very young date of the basin of Inari, at least in its present position, is manifested by the fairly small degree of downcutting that the normal erosion has attained in dissecting the basin wall in the N.E. against the Arctic Ocean.

The Inarijoki river exhibits a typical case of a river which maintained its original course in spite of the tilting of land against its flow, and cut its lower valley portions successively deeper as the tilting went on. At the Tenojoki river, the narrow and deep, but gently-graded valley portion above the Ylikönkäs rapids, within the Jeskadam mountains (cf. pp. 25—26), possibly indicates a further slight raising of an individual block of rock-ground at this stretch, after the valley had attained a depth corresponding with that of the next upper valley portion. This supposed movement should belong to those characteristic of the mountain belt, which are, in general, of a much earlier date, and will be discussed in the following chapter.

Besides the true valleys formed by river erosion only, there are, in Northern Lapland, also other distinct valleys which furthermore owe their origin to some additional agents. These are, in the first place, the valleys of the rivers Lemmenjoki, Suomujoki, Utsjoki, and its tributary Kevojoki. All of these valleys appear to be more capacious than one would expect in view of the sizes of the rivers occupying them; the gradient of the valley floor may be out of the ordinary, and the sides may show peculiar features in their shapes. All the valleys just mentioned have an exceedingly straight trend or are composed of several straight stretches (cf. the valleys of Utsjoki and Kevojoki, pp. 26—27). As already mentioned, this is obviously, in the last instance, due to the fact that the valleys have originated along fracture lines (cf. Sederholm, 1910, 1911 b, 1913). This was, on the other hand, an important factor in facilitating the work of erosion when the valleys were excavated. The large proportions of the valleys are thus more easily understood.

As to the valley of the Lemmenjoki river, its strikingly unsymmetrical cross-section with greatly differing heights of the sides (cf. pp. 19—21) cannot be explained in any other way than by assuming the existence of a notable fault along the valley. The Viipustunturit side has thus been uplifted some 100—150 m. higher than the opposite side, the Marastotunturit. The upper portion of the Lemmenjoki valley may well chiefly be due to normal erosion, as shown by the fairly equal levels of the mouths of the tributaries (p. 20), but as the Rovodosjoki river far below is hanging at its mouth, it seems obvious that also the Marastotunturit have been at some very recent time somewhat uplifted in regard to the regions around the upper part of the valley. Finally, the great width of the valley, as well as its surprisingly slight gradient, may apparently have been due to a considerable amount of glacial scour which had even caused overdeepening at the lakes of Lemmenjoki and accentuated the hanging position of the Rovodosjoki. As to the Vaiautsi, where the disproportion between a small river and a magnificent valley (Fig. 4) is most striking, the effects of a well-developed fracture line, glacial scour and late-Glacial water erosion may have combined to produce such disproportionally large forms.

The other conspicuous valleys mentioned above (pp. 24, 27, 30) may also owe their origin partly to the glacial erosion, which was concentrated upon crushed and fractured zones of the substructure, these partly having been carved out into valleys even prior to the glaciation. Rosberg (1908) has laid much stress upon the glacial action in the Suomujoki valley. In fact the trends of these valleys coincided rather well with the directions of the advance of the land ice, as far as these have been ascertained by the studies of Tanner (1915, pp. 55—59, 74—87, 141). The trough-like shape of the Utsjoki valley may well have been due to glacial action, and the valley has, perhaps, even been overdeepened at places where some of its lakes are situated.

The fracture lines have apparently greatly influenced the trends of all the valleys in Lapland, although the erosion processes have been accomplished in a regular way only. According to the author's observations, the valley of Inarijoki—Tenojoki, for instance, in great part complies with the best-developed fissure systems in the substructure. Concerning the Ivalojoki valley, Sederholm has (1913, p. 57), in the author's opinion, even somewhat exaggerated the rôle of the fractures. The same subject was also treated by Tanner (1915, pp. 572—573). Later on (p. 43), some valleys of the Ivalojoki drainage system will be considered more closely from this point of view.

## 6. THE ORIGIN OF THE MOUNTAIN GROUPS.

### (THE OLDER DEFORMATION OF THE UPLAND PENEPLAIN).

When looking for an explanation of the general high level of the granulite area in comparison with its surroundings, one might be disposed, at first sight, to ascribe this circumstance to a greater resistance of the granulite rocks. This interpretation, however, fails to explain the conspicuously regular arrangement of the different groups, many physiographical particulars, and the fact that the mountainous areas are by far not conformable with the boundaries of the granulite area. On the contrary, also considerable areas underlain by granulite present the character of as perfect a peneplain as anywhere is found beyond the granulite area. The topography of the granitic massifs inside the granulite (Mikkola 1928) even bears evidence of a much weaker resistance of the latter than the former rock. It is evident, in any case, that such a continuous mountain belt must owe its origin to some general cause, which has acted within the granulite formation. Most probably it has been a tectonical cause, in some way connected with the tectonical peculiarities of the granulite complex.

It is easily conceivable, that fault-like changes of levels more readily take place within the granulite formation than outside of it (cf. pp. 8—9). It seems likely that the faults required for the general uplifting of the mountain belt have followed the planes of schistosity as overthrust movements towards the W.—S.W.—S. This would mean a renewal of the movements which were going on during the formation of the granulite complex. Such overthrust faults may hardly ever be demonstrated throughout their length, though the observations at the Lemmenjoki river (p. 9), for instance, render their existence very plausible. Other faults, of course, may have been almost vertical. A splendid example of the faults actually proved by physiographical evidence is the fault line at the Lemmenjoki river (p. 30). Another is the fault scarp of Petäjäsaaret—Jääsaaret at Lake Inari (p. 30).

According to this conception, the regular, massive fronts of many of the mountain groups may clearly be regarded as fault scarps. Such are, for instance, the E. slope of the Paistunturit, the W. margin of the Muotkatunturit, the W. slopes of the Marasto- and Viipustunturit, and the S. wall of the Saariselkä. When being uplifted, some of the mountain blocks were seemingly tilted, e. g. the Paistunturit, which slants towards the S.W., the Ruottir towards the S.E., while both Marasto- and Viipustunturit are fairly regularly inclined towards the E. Transverse fracture lines and faults occur furthermore, in addition to the valleys of the Lemmenjoki and Suomujoki rivers, at the valley head of the Kevojoki river between the mountains of Njaugoaivi and Ruottir, between the Ruottir and the Muotkatunturit, along the long sides of the Appistunturit—Haukkapesäpää, at the valley of the river Muorvaarakkajoki in the Saariselkä and at some transverse valleys in the Saariselkä mountains in Petsamo.

The mountain blocks have been strongly affected by erosion since they were uplifted. The largest valleys have attained wide, broad-bottomed cross-sections, the margins have been considerably reduced, and many valleys have cut through the mountain massifs, but most of the tops have obviously remained at their original elevations. All the stages of erosion are found within every single mountain group. The general stage of the mountain downcutting, however, is so far advanced, that the lapse of time required for it must be many times longer than that necessary for the excavation of the river valleys. Accordingly, the disturbances of the level of the granulite area have principally taken place much earlier than the faults discussed above on pages 29—31. They are probably also to be considered as a manifestation of the Alpine orogeny in Fennoscandia, but already during early Tertiary time. Here the movements may also have passed on in many jerks with considerable intervals, as quite young faults have been proved to exist at the river Lemmenjoki. The different mountain groups also display somewhat unequal stages of downcutting. Thus the Jeskadam and the Appis—Hammastunturit have been more dissected than the other massifs. Many scattered hills and small groups N. of the middle course of the river Ivalojoki, in the vicinity of Viipus- and Appistunturit, may be remnants of still older elevated blocks, the greatest part of which has been subsequently reduced to the general level of the upland peneplain.

Within the Norwegian territory, the relation of the post-Archaean, partly early-Palaeozoic sedimentary formation (the ''Gaisa formation'') to the granulite affords additional evidence for the view that the granulite mountains have come into being by means of late upheaval. These relations have been studied by Holtedahl (1918, 1931). In 1927, the present writer also visited the region in question. The margin of the Gaisa formation runs across the granulite belt with a general trend of W.S.W.—E.N.E (seen on the map, Pl. IV). The sedimentary series consists mainly of whitish hard sandstones, which build up large, imposing mountains, the ''Gaisas'', of a height of about 1000 m. (the highest is the Rastegaisa, 1064 m.). The loftiest of these mountains are situated upon the continuation of the granulite belt, and, on their slopes, the top of the granulite formation is found to lie at about 700 m. on an average. On the E. side of the granulite belt, 20—30 km. E. of the Rastegaisa, Holtedahl met with the bottom of the sediments at an elevation of about 400 m. (1919, p. 205), and W. of the granulite area, in the mountains Gaggagaisa and Halkkavarre at between 400 and 480 m. (1918, p. 132, 1931, pp. 252—254). In Holtedahl's opinion, these considerable differences are due to a rather strong tilting of the "sub-Cambrian peneplain" towards the N.N.W. since the deposition of the sediments. In the author's opinion, however, it is not necessary to assume any general tilting up and a locally large amount of erosion of the sub-Cambrian peneplain along the margin of the sedimentary area and S. thereof. Instead it has been broken up by faults, whereby a large block of the granulite formation was uplifted. The deposition of the sediments has obviously taken place upon a rather level surface, judging from the facies of the sediments which is fairly similar everywhere. It would also be impossible to explain how these deposits could have escaped being removed by erosion during the immense epoch since the early Palaezoic, unless they had only comparatively recently assumed their present high position.

The uplifting of the mountains has, in all probability, largely deflected the rivers from their former courses and thus caused a readjustment of the hydrography. It may be for this reason that the Inarijoki—Tenojoki river, for instance, has assumed its course along the margin of the granulite area, being forced to cross this belt only where it encountered the high escarpment of the post-Archaean sandstones. The rivers Gordshejoki and Karasjoki may originally have flowed more straightly towards the Varanger Fiord in the continuation of their present courses. Other suppositions concerning the changes of the river courses are too vague to be worth mentioning here.

## THE RÔLE OF THE GLACIAL EROSION IN NORTHERN LAPLAND.

Some of the river valleys described above display evidences of a notable amount of glacial erosion. In large areas, again, especially in the W., S.W. and S. parts of the territory, the rock-ground has hardly at all been affected by glacial scour. At some places, this has been proved with full evidence by the presence of the original cover of pre-Glacial weathering products upon the solid rock. This case is splendidly exposed in many prospecting shafts in the vicinity of Laanila, and has been mentioned in the papers of Sederholm (1913), and Tanner (1915, pp. 149—152), accompanied by fine photographs. A further proof for the same view is the almost entire absence of lakes in the areas referred to above (cf. Sederholm 1910, Granö 1931, p. 39).

The intensity of the glacial erosion is partly also indicated by the composition of the morainic drift. Tanner has expressed the idea that drift rich in boulders indicates a comparatively large amount of wear (1915, pp. 146—147), and scanty boulders, consequently, a smaller amount, or none. Where the drift contains abundant boulders, the surface topography is commonly pronouncedly knobby, while the drift poor in boulders, again, as a rule, has been spread as a rather uniform smooth mantle. As might be expected, scanty boulders and smooth surface forms really are essential characteristics of the drift in the W., S.W. and S. parts of the region dealt with in this paper, with the exception of the river valleys and steeper mountain slopes which were devoid of thick weathering mantles even in pre-Glacial times.

In the central and N.E. parts of the region, signs of an intense glacial scour and deposition occur in great abundance. It appears as if the most erosive power of the land ice had been concentrated in the lee of the mountain area where the directions of the ice movements (generally towards the N.E.) somewhat converged inside the belt, in the basin of Inari. The vast depression in which Lake Inari is situated, as well as the innumerable other lake basins of various sizes, must, at least to a great extent, be due to glacial overdeepening. The very irregular, in general highly dissected topography in the S.W. and S. parts of the basin of Inari has apparently originated, in great part, in connection with the excavation of the lake basins, thus also owing its origin to a powerful glacial erosion. This extends towards the S.W. as far as the mountain belt which here includes many lakes (Lake Hammasjärvi and others). The hills of the Hammas- and Appistunturit mountains have more rugged forms than many of the others, and rock is widely exposed on their slopes.

Everywhere in the basin of Inari the drift is rich in boulders and mostly uneven at the surface. Immediately N.E. of Lake Inari, there is a large area of an extremely stony and knobby drift which contains an astonishing abundance of tarns and lakes in its hollows. Many of the hillocks consist merely of large boulders. Tanner has described this tract as a special ''morainic hillock country of Inari'' (''moränbacklandskap'', 1915, pp. 217—222). He considers these conspicuous deposits as accumulations of ablation moraine, in analogy with the knobby drift at the margins of many recent glaciers at places where these, in their lower portions, become wholly coated with debris that has been freed from the ice by the surface melting (cf. von Engeln 1911, Tarr 1908). Tanner explains the exceedingly large local quantity of the drift as a consequence of a relative standstill during the general withdrawal of the ice margin, the whole complex thus partially having the character of recessional moraines. In the author's opinion, however, it is not necessary to assume such a delay in the recession, as the large quantity of loose materials may be simply due to an exceedingly large amount of ice erosion in the depression of Lake Inari. This lake lies just on the proximal side of the morainic hillock area in regard to the direction of the ice advance.

On the N. slope of the basin of Inari, no especially prominent glacial features can be noted any longer. It is true that the lakes are abundant there also, but generally they are shallow and mostly seem only to occupy depressions in the drift cover. As to most of the mountain groups which in general form the boundary zone between the areas of slight and strong glacial action, signs of a glacial moulding are rather inconspicuous and difficult to be proved with certainty. In many cases, no such signs can be recognized.

Fig. 11. Aspect of the Sotajoki valley at Halvarinniemi, showing a sharply incised younger valley in the bottom of an older one. The large Halvarinniemi esker rises to the left; the continuation of the esker E. of Sotajoki in indistinctly visible about 3 cm. from the right margin of the figure. Photo by the author.

Fig. 12. Typical view of a lower granulite mountain group (the Rautuntunturit), with gentle slopes and level summits. Photo by the author.

# SOME FEATURES OF THE LATE-GLACIAL FORMATIONS IN NORTHERN LAPLAND.

## INTRODUCTORY.

In two comprehensive treatises (1915, 1930 a), V. Tanner outlines the Quaternary development of Lapland also as regards the region dealt with in the present paper. He has ascertained that the land ice, in general, advanced over the area in a N.E. direction (cf. above p. 35) and that its margin, during the vanishing of the ice, receded in an opposite direction, maintaining a general trend of N.W.—S.E. (Tanner 1915, pp. 658—659). Before the basin of Inari was freed from the ice, the continental ice margin had for a long time remained in the N.E. along the coast, this delay of retreat corresponding with that registered in Southern Finland by the two great recessional moraines, the Salpausselkäs. This standstill was apparently brought to an end by a considerable amelioration of the climate (cf. Enquist 1918, Tanner 1930 a) which induced a rapid withdrawal of the ice front towards the centre of the ice propagation. As especially emphasized by Tanner, the highest summits first pierced through the lowering surface of the ice as nunataks, and the last ice remnants remained in the valleys and basins. None of the mountain groups provided conditions for surviving mountain glaciers. It may be supposed, that the marginal zone of the ice-sheet, dissected by the protruding elevations of the bed, lost its motion, and melted away as a stagnant mass. This may especially, on a larger scale, have been the case in the basin of Inari, because the ice flow from the S.W. was hampered by the middle part of the granulite mountain belt. According to Flint (1929), a wide areal ice stagnation in New England was caused by similar conditions. Where the general land surface faced against the ice, an interesting marginal hydrography with ice-ponded lakes was developed. Tanner has devoted a large part of his earlier memoir (1915, pp. 445—653) to the treatment of the last-mentioned phenomena.

It followed from the general succession of the recession of the ice margin, that the ice disappeared earlier from the basin of Inari than from the middle part of the mountain belt and the upland peneplain in the S.W. The melt waters therefore sought their ways across the mountains, partly availing themselves of the cross-cutting river valleys, but at the earlier stages they also largely discharged over the notches of the divides.

When laid bare from the ice, the upland peneplain and the mountainous regions in Northern Lapland were supra-aquatic, except the ephemeral and areally limited ice-ponded lakes. The basin of Inari, on the other hand, was connected with the sea through the valley of the Paatsjoki river. The connection was, however, so narrow that salt water may have had no entrance into the basin. In the S.W. part of the basin the water surface reached a higher level above the present one than in the N.E. part, as since the release of the Glacial conditions the land has been considerably tilted towards the N.E. At the same time as the withdrawal went on within the area concerned, the sea level was eustatically rising so rapidly, that this movement surpassed the contemporaneous isostatical upheaval of the land, thus causing a transgression of the sea. According to Tanner, this so-called fini-Glacial or *Portlandia* transgression is noticeable all over the basin of Inari. In the basin it represents the highest water level during the post-Glacial period. Even the lakes Muddusjärvi and Paadarjärvi were embraced by this water body, which also sent long, narrow fiords into the valleys of the rivers Ivalojoki and Lemmenjoki.

In order to elucidate the Glacial geology, as well as the character of the pre-Glacial topography, the present writer has carried out some detailed mapping work in two small areas (seen on the general maps, Pl. IV and V). They also offered special interest because of their gold-bearing deposits. Both these areas are situated rather close to the S.W. foot of the mountain belt and to large river valleys crossing it. Both areas are too small to give a complete idea about the topography in its larger features, but they well illustrate the character of one of the most prominent features, the valleys. In the first place, however, the conspicuous late-Glacial formations of these areas are considered as examples of their mode of occurrence in the supra-aquatic regions. The author will first describe the areas investigated in detail, and thereafter draw conclusions on a broader basis.

The present writer has not had opportunity to collect complete information about the Quaternary of Northern Lapland. Therefore he will restrict himself principally to the description of the glacifluvial formations within the mountain belt and to some general comparative remarks concerning their behaviour at different levels and in different topographical conditions. At the same time, the most important notches where the late-Glacial melt waters have overflowed the present watersheds will be mentioned. The map, Pl. V, gives a general view of the formations referred to. Where the present writer has not himself made observations, Tanner's map and the information given by him have been used.

On the maps, post-Glacial alluvial deposits have been united with the glacifluvial deposits, as they both often show gradations into each other, and the material of the alluvial deposits in many cases seems to consist of redeposited glacifluvial sands and gravels.

## THE HANGASOJA AREA (PLATE I).

The Hangasoja area is situated close by the Rovaniemi—Ivalo highroad, about 4 km. S. of the inn of Laanila. In the W., the area is bordered by the Tolosjoki river. It comprises mainly the lower part of the valley of Hangasoja, a tributary rivulet to the Tolosjoki. This valley is beyond doubt wholly pre-Glacial; just in its vicinity the most convincing evidence has been found for the absence of glacial wear and tear in the rock ground. There are, however, two conspicuous smaller valleys branching off to the right from the lowest portion of the trunk valley and joining each other where they meet the valley of Tolosjoki. These valleys are quite unaccountable from the view of a normal erosion only, although their origin may be partly explained by the presence of two pronounced fissure systems, N. 50—55° W. and N. 10—15° E., whose existence is revealed by many linear topographic features within the area.

As stated by Tanner (see his map, Plate V, in 1915), the front of the ice-sheet has at a certain stage during its retreat lain in a nearly N.—S. (partly N.W.—S.E.) direction along the S.W. foot of the Raututunturit, after these mountains had been freed from ice. When the Hangasoja map area began to be uncovered, a temporary lake must have been formed at the conjunction of the three confluents of the Hangasoja, retained in the W. by the ice that filled the deep valley portion of the brook Hangasoja. Inside the map area, this lake has received two marginal streams from the S., the lower, westerly of which was very large, having formed a pronounced channel with distinct water-cut sides. At first the lake was discharged towards N. through a notch at an elevation of about 50 m. (outside the map area, in the figures of the map) into the next tributary of the Tolosjoki river from the right. When the ablation of ice on the N. side of the valley, being more accelerated by the influence of the sun, had brought the ice surface to a lower level than the notch referred to, the outflow of the lake was changed to this spot. By the successive sinking of the stream bed, while the valley side served as another wall of the bed, this slope of the valley was for the most part stripped of its moraine to a height of 30 m. from the valley bottom. Some of the lowering stages of the ice-lake above mentioned are registered by small terraces on the S. promontory between the confluents of Hangasoja.

When flowing onward the water was at first conducted into the upper branch valley at the figure 25.1. Especially the right side was subjected to the water action, and the amount of water that availed itself of this way was apparently very considerable. It can hardly be inferred, however, that the valley in question has been formed through erosion by this water, although the local conditions afford no other possible explanations (the significance of fissures was referred to above). The matter would, however, be more easily understood, if this large amount of erosion had taken place during several separate Glacial periods with succeeding late-Glacial events. — In front of the notch of 25.1 m., just at the side of the valley of Hangasoja, water action has accumulated sandy deposits forming two terraces. When the lower of these was formed water had already abandoned the branch valley.

The following outlet of Hangasoja into the Tolosjoki was opened at the notch of 13.7 m. through the narrow trench of Kuivakuru. The carving out of this channel also involved effective water action, but at the same time it is evident that an exceedingly pronounced fracture line has enabled the water to perform the work. The loose materials which the water has carried at both of its branch courses have mainly been deposited as a big gravel terrace at the common mouth of the side valleys. At the upper end of the Kuivakuru channel small gravel banks also were accumulated, apparently at a stage when this passage was just being deserted. When the present course of the brook Hangasoja as far as the confluence with the Tolosjoki river was attained, much ice still surely lingered in this valley, forcing the river partly to flow along the valley sides, where smaller sandy accumulations or spots which have suffered erosion have been left to indicate former water courses.

## THE RITAKOSKI AREA (PLATES II AND III) [1].

### The River Valleys.

The Ritakoski area is situated at the middle course of the river Ivalojoki, where the lowest graded portion of the river valley passes over from a youthful stage of development to a mature one, the valley

[1] The map, Pl. II, was preliminarily published in Sauramo 1929, p. 33.

becoming flat-bottomed downward. The region is uninhabited and without roads. In summer it may only be reached by boat along the river upstream from the villages at the lowest course of Ivalojoki, or on foot from the Rovaniemi—Ivalo highroad.

The area mapped in detail measures 25 sq. km. It includes a stretch of 7.5 km. of the course of the Ivalojoki river. In this stretch the river receives two considerable tributaries, the rivers Sotajoki and Palsinoja, from the S., between them from the same side two small brooks, Iisalmenoja and Ritaoja, and from the opposite side only one tributary worthy of mention, the rather inconsiderable streamlet Vaskioja. In the first place, the map area comprises the valleys of the rivers Ivalojoki and Sotajoki, the latter as far as 5.8 km. from the mouth, and a promontory of the upland peneplain E. of the conjunction of the valleys.

The physiography of the Ritakoski area may appropriately be designated as valley topography. Large river valleys, in the first place those of the rivers Ivalojoki and Sotajoki, are its most prominent features. There are well-defined valleys at many different stages of downcutting, from recent-shaped canyons and gorges of the smallest streams to an early maturity at the Ivalojoki valley, showing an incipient widening out of its bottom. The fall of Ivalojoki inside the map area is no more than about 10 m., the greatest part of which is concentrated in two rapids, the upper, Sotakoski, with a fall of 2.8 m., and the lower, Ritakoski, with a fall of 6.7 m. The Sotakoski may still be included in the swiftly-flowing youthful portion of the river, heading at the mouth of Appisjoki, whereas the Ritakoski as well as all the rapids farther below are essentially due to obstructions by late-Glacial deposits on the valley bottom. Above the Ritakoski, these accumulations hold up a stillwater stretch, called Vaskisuvanto, somewhat more than 2 km. long. Below the Ritakoski, there is another stillwater, Palsinsuvanto.

The Sotajoki river enters the Ivalojoki as heavy rapids, 750 m. in length, from the head of which the river bed continually rises with a steep gradient. At the fixed point at Halvarinniemi, the river level has ascended 42 m. above its mouth, the average gradient thus being 7.5 m. per kilometre. The much smaller Palsinoja has a still steeper slope; at the limit of the map area, at a distance of 1.8 km., its bed lies nearly 40 m. above the river mouth.

As to the origin of the valleys, only the earlier conclusions (cf. p. 27) of a normal way of downcutting are confirmed, judging from the cross-sections of the valleys and their shapes in general. At least no glacial action is required to explain the larger, essential forms of the rock configuration (cf. above pp. 21—24). Especially the valleys of the smaller affluents, that of Palsinoja and the narrow, steep-sided gorge of Iisalmenoja, exhibit ideal illustrations of the work of water erosion. Paying attention to the directions of the valleys, on the other hand, one is soon able to realize that fissures and fracture lines in the rock ground have been important factors controlling the trends and the location of the valleys. The linear features of topography may readily be grouped in five systems, some of which are also represented by pronounced fissure systems. When determined on the map, the most accurate average directions of the linear elements are N. 84° W., N. 32° E., N. 24° W., N. 52° E. and N. 50° W. The first three are especially well developed.

The first system, N. 84° W., is indicated, for instance, by the trend of the Ivalojoki valley at Sotakoski—Vaskisuvanto, and partly also by the valley of Palsinoja, as well as by many rock cliffs. At the Ritakoski rapids the valley of Ivalojoki turns sharply to the N.E., and, at the same time, it suddenly broadens in a considerable degree, as if it here met with a transversal zone of weakness in the rock ground. This may be partly due to the second fissure or fracture system, running in the direction N. 32° E., which shows itself as rocky fracture channels at the sources of Iisalmenoja and Ritaoja, and as a wild rocky gorge with vertical walls near the mouth of Sotajoki, beginning from the figure 115.7. The lower portion of the Sotajoki valley is likewise at several places nearly parallel to the same direction, but is again deflected from it, obviously because the influence of the previous system is locally stronger. It is clearly to these pronounced fissure and fracture systems, and to its sinuous course that the Sotajoki owes the remarkable breadth of the lowest part of its valley. Because of the steep gradient a narrow, trench-shaped valley would else appear more natural. The third system, N. 24° W. is manifest in the next following upward portion of the valley of Sotajoki as far as the Halvarinniemi. The deep gorge of Iisalmenoja has originated along the same trend, and there are many fissure channels in the same direction in the vicinity of the mouths of Sotajoki and Iisalmenoja. The fourth system, N. 52° N., is especially represented by rocky cliffs and gorges at the sources of Iisalmenoja and Ritaoja. The fifth system, N. 50° W., is less pronounced; it is best in evidence in the small straight valley N.E. of the mouth of Palsinoja, which will be discussed later.

The immediate heights of the slopes in the steep-sided larger valleys of the area range from 100 to 160 m.; the absolute altitudes of the crests of the slopes are accordingly 240—300 m. above sea level. The steep wall of the hill Iso Palsitunturi, absolute height about 365 m., is an exception, rising 225 m. immediately from the Ivalojoki (Fig. 10).

This summit belongs to the granulite mountain belt. The other area beyond the valleys belongs to the upland peneplain, but it seems probable that also ancient valleys occur as component parts of the upland surface. They are in places distinct enough to be treated separately. The existence of such older, shallow valleys is most readily suggested by looking at the Sotajoki valley in the region around Halvarinniemi, which was once largely devastated by forest fire, in consequence whereof an open and clear view is now secured (cf. Figs. 11 and 21). The youthful, somewhat trough-like valley, the depth of which above the Halvarinniemi is no more than 40 m. on an average, appears to be sharply incised into the bottom of a wide, older valley, the cross-section of which resembles a flat bowl. The great bend of the river course at Halvarinniemi makes the impression of an entrenched meander. The level of the older valley bottom is here about 240—250 m. above the sea, the downcutting below the general level of the depressions of the upland peneplain thus being hardly more than a score of metres. For this reason these ancient valleys can only with difficulty be traced for longer distances. There is even no sufficient evidence to assume a valley of the same generation having existed at the present course of Ivalojoki within the area mapped.

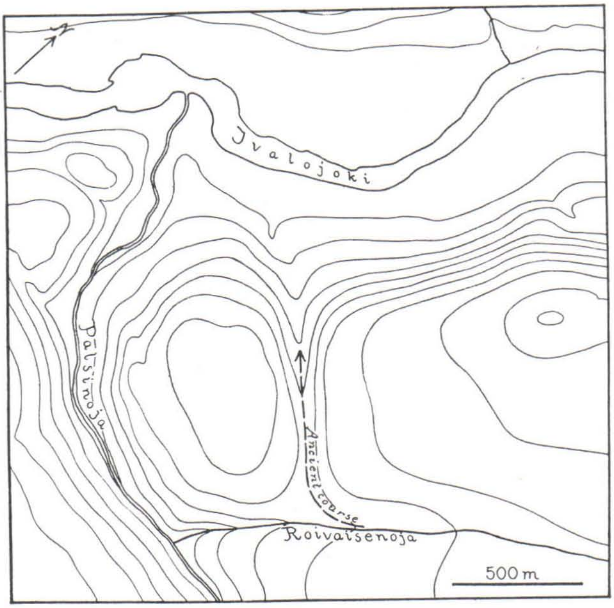


Fig. 13. Sketch map showing the formation of the dry valley between the mountain Iso Palsitunturi and the mouth of the Palsinoja river.

Among the pre-Glacial valleys of the area, there is still one more worthy of remark, that between the Iso Palsitunturi and the Palsinoja river. It joins the main valley (that of Ivalojoki) in a hanging position high above the valley bottom. The trifling rill occupying it can by no means be responsible for its carving out, and its origin by Glacial or late-Glacial action is equally unintelligible. The only possible explanation is shown by Fig. 13. Formerly, the valley in question was occupied by a somewhat larger brook which rose S.E. of the Iso Palsitunturi and approached at its lower course the Palsinoja. The latter brook, owing to its greater water supply, was able to cut down and broaden out its valley so much faster that the divide between the rivers was cut off. Thus the Palsinoja captured the smaller brook which became its tributary, the recent Roivaisenoja. Also glacial erosion may have aided in removing the divide wall, although no great amount of work was required to do this. Consequently, the lower part of the smaller valley was deserted.

## The Quaternary Formations.

As the Quaternary deposits of the Ritakoski area exhibit many features of great general interest they may be treated here in some detail.

Common moraine is the prevailing kind of drift also in the Ritakoski area. Spread out over the flat upland, it has, as a rule, a smooth surface and is poor in boulders (cf. Figs. 2 and 14). In places the same characters also prevail on the valley slopes. In the valleys, however, the drift is generally more or less rich in boulders, and, especially on the lower slopes, it shows a confused miniature relief, which is characterized by small round-shaped mounds or hummocks and, at the most typical places, by a network of more or less sharp-bottomed trenches or furrows. In most cases the origin of these formations obviously implies that a comparatively large quantity of drift has been deposited at these spots; in part it really forms a rude, hummocky drift terrace heaped up at the foot of the valley slope. Exceptionally still more conspicuous forms are met with, the most extreme case being an ose-like, narrow curved moraine ridge on the right bank of the Sotajoki river, 1.5 km. upward from its mouth. It leans at both ends to the valley wall, and encloses on its inner side, against the wall, a blind depression with an extremely irregular bottom relief.

The hummocky accumulations of the drift are mostly built up of very stony material, at the same time apparently being, in many places, nearly devoid of the finest constituents. Partly they may be composed merely of boulders. In a few cases also sandy material occurs, accumulated into similar, though mostly less typical hillocks. All these phenomena suggest the idea that water has contributed to these accumulations. It has carried much material to certain, preferably low-lying localities, and on the way partly assorted it. The final deposition, on the other hand, obviously took place upon the ice, in its cavities and among detached ice blocks. The deposits assumed their present shapes by slumping, while the buried ice masses slowly melted away. The ridge of morainic drift at Sotajoki mentioned above, for

Fig. 14. Smooth stoneless drift surface, characteristic of the upland peneplain, between the Sotajoki river and the Iisalmenoja brook. Photo by the author.

instance, must have been piled up at the foot of a large ice mass on the side of the valley wall. Debris slid down along the sloping ice front, furnishing material for the building of the ridge.

The accumulations in question represent, in a way, transitional deposits between moraines and esker gravels (cf. Fig. 15), and correspond closely to the kind of drift which was long ago described by Chamberlin (1884) under the title of ''angular gravel with disturbed stratification''. It has not been possible for the author more fully to use the wealth of evidence contained in the American literature. In this connection he wishes only to mention the instructive paper of Goldthwait (1916). Scandinavian geologists also have reported several illustrative examples of similar deposits (Eriksson 1914, A. G. Högbom

1901, Geijer 1917), and also emphasized that they occasionally grade into true eskers. Tanner has expressed similar ideas regarding the origin of stony and hummocky patches of drift, writing, for instance 1915, p. 230, in translation): "Materials accumulated by water on the ice surface may be regarded as constituents of many complicated and "untypical" morainic deposits".

The deposits described above may be called here, in view of their relief and manner of deposition, h u m m o c k y a b l a t i o n m o r a i n e s (cf. also p. 35 above).

Fig. 15. Stony accumulation, called Maailmanpankki, a former placer, situated at the foot of the W. wall of the Sotajoki valley, 1.5 km. downward from Halvarinniemi. The stones are angular in the upper part (in the foreground), rounded in the lower. Photo by the author.

Water erosion may play a rôle in the creation of such a swell and sag topography as that referred to above, but there is also another type of drift configuration, occurring chiefly on the upper portions of the valley slopes, which is essentially due to erosion. It is the same kind of phenomena which has been described in great detail by Tanner under the title of "israndrännor" (ice-margin furrows or trenches) and illustrated by detailed ground plans (cf. 1915, Plates II and III, Figs. 104, 125, 127). They are common forms in glaciated supra-aquatic regions, and have also been observed by several Scandinavian geologists (cf. Eriksson 1914, G. Frödin 1913, J. Frödin 1914, Geijer 1917), although nobody has paid so much attention to them as Tanner. When developed typically and in great completeness, they occur as broad series of steep-sided, sharp-bottomed, somewhat sinuous trenches, mostly of a depth of 1—2 m., running obliquely to the general slope of the surface and in places anastomosing with each other at acute angles. As inferred by the investigators who have studied these forms, they have been cut by brooks which have flowed along the ice margin in successively lowering positions. Thus they are of much significance when the position of a receding ice margin shall be determined. Tanner has advanced the idea that these furrows indicate the annual recession, one furrow having been cut during each summer (1915, pp. 646—653). The present writer, however, thinks that the succession of such trenches

Fig. 16. A dinstinct boundary between the common drift-covered ground (to the left) and the rocky surface (to the right) denuded by the glacifluvial torrent that flowed straightly from Halvarinniemi to the Ivalojoki valley at Ritakoski, E. of the brook Ritaoja. Photo by the author.

bears no relation to the annual withdrawal. It is difficult to imagine how water running along the ice edge could maintain one single channel throughout the whole summer, just as this margin receded. The mutual intervals of the furrows may depend on several other factors, local as well as climatical, which controlled the rate and progress of the melting at the ice margin. As to the area in consideration, the ice edge furrows are everywhere rather rudely and imperfectly developed, and deserve no special attention. They only confirm the result that the general withdrawal of the ice front proceeded from N.E. to S.W.

Rock exposures are fairly frequent within the Ritakoski area. Besides small ledges, such as often outcrop on the hilltops, on steep slopes by reason of scanty cover of moraine, in smaller water-cut channels etc., there are some large naked rock surfaces which are conspicuous by their extreme lack of drift cover, even all crevasses and hollows in the rock surface being generally swept clear of loose materials. Their distribution is seen on the map.

These rocky areas are met with in varying positions, on valley slopes as well as on the upland. In places they may be sharply bounded against the drift-covered areas, the drift mantle being bordered by a distinct slope (Fig. 16). In some cases the boundaries are lobate, and isolated hummocks of drift may occur entirely surrounded by naked rock. Very commonly drift also sets in gradually upon the bedrock. Similar rough rocky spots and zones, often trending along more or less pronounced valleys and other depressions, but in places also in wholly unexpected topographic situations on the slopes (cf. Fig. 1) or crests of elevations, are one of the typical and conspicuous features in the glaciated supra-aquatic areas of the northern countries, and very familiar to the geologists of these countries who have investigated in detail the regions in question (cf. Eriksson 1914, pp. 65—67, G. Frödin 1913, p. 161, J. Frödin 1914, Gavelin 1910, p. 16—21, Geijer 1917, Hamberg 1911, A. G. Högbom 1910, B. Högbom 1916).

In many cases it is well in evidence, that rushing water has prevented the deposition of moraine on such rock surfaces or has swept it off, if such had existed previously. Elsewhere also, in spite of the eventually strange position of these rocky patches, their origin by erosion, in general is indisputable, and the rôle of other agencies in many cases does not come into question, or is at least highly improbable. If local conditions seem to be incompatible with the assumption that the rocks have been washed bare by water, these difficulties may always be removed by assuming the presence of ice, thus that glacifluvial conditions have prevailed during the water action. This explanation allows the most different modifications as to the manner of water action —, either waters running in super-, en- or subglacial channels, under or without a hydrostatical pressure, etc. (see further below, pp. 74—78). The Swedish geologists mentioned above have expressed similar ideas.

Occurrences of esker and gravel deposits play a prominent rôle in the area under consideration. They are for the most part concentrated into the lowest-lying spots of the region, the river valleys. There they are chiefly gathered around two different centres, namely in part into the vicinity of the mouth of Sotajoki, and in part around the mouth of Palsinoja, at the rapids of Ritakoski and the stillwater of Palsinsuvanto of the Ivalojoki river.

The accumulations in the valleys have partly, mainly within the former complex, well-developed terrace-forms (cf. Fig. 20), and partly, chiefly within the latter one, rather irregular ridge- or kame-like shapes.

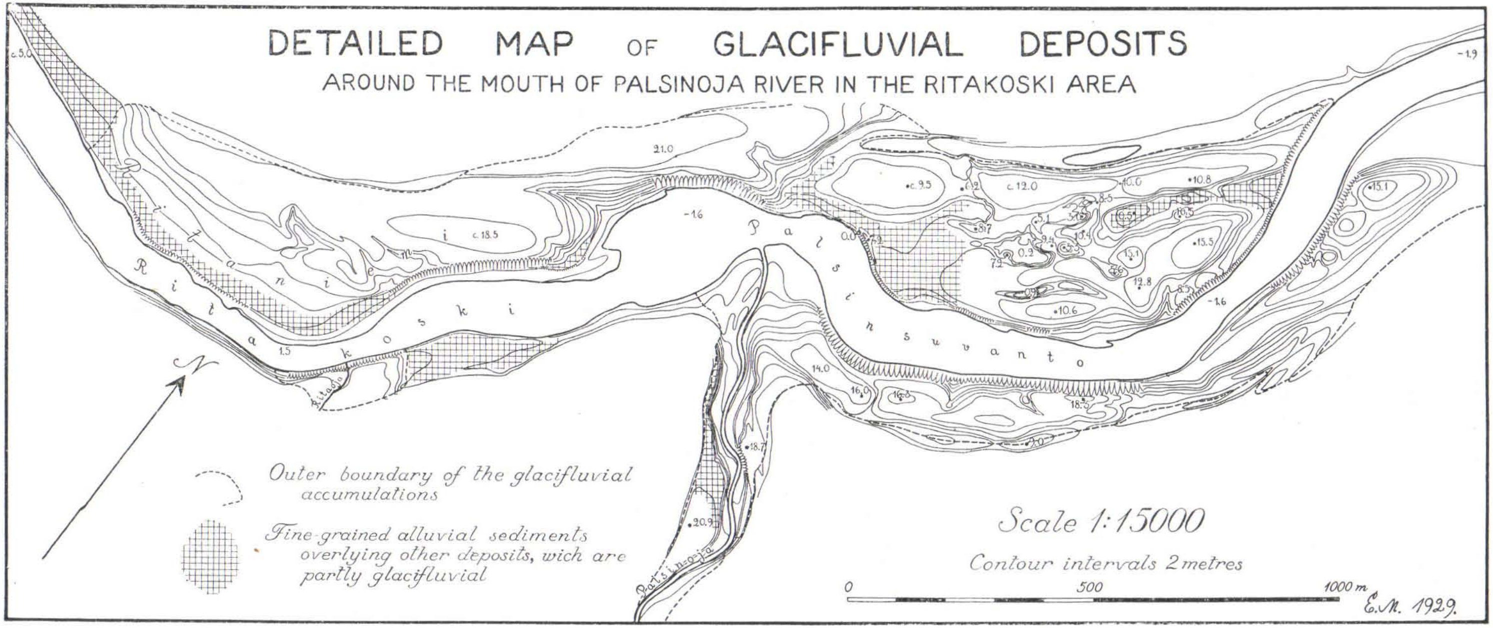



Fig. 17. Map of the complex of late-Glacial accumulations at Ritakoski—Palsinsuvanto on the river Ivalojoki.

All these consist of gravel rich in cobblestones and boulders, which are partly large, measuring up to 1 m. in diameter, in the deposits of the upper part of Ritaniemi, on the left shore of the Ritakoski rapids. The gravel is here less assorted than elsewhere, and the large boulders are but roughly rounded. Especially in the big complex of accumulations at Ritakoski—Palsinsuvanto the gravel shows a rather feeble degree of assorting, and no distinct stratification in thin layers is generally discernible. In connection with the prospecting for gold it has been stated, that the gravel largely contains also some silty, perhaps even clayey material, which firmly adheres to the cobblestones; this variety of gravel often appears to be gold-bearing.

Fig. 18. Surface layer of fine sand on the top of the gravel terrace, W. shore of the Palsinoja brook. Photo by the author.

The detailed topography of the gravel formations at Ritakoski—Palsinsuvanto is shown on the map, Fig. 17. At the Ritaniemi peninsula, gravel has been laid down as a broad, rude terrace with some pits in the extremely stony, irregular, outward slanting top surface. The lower, narrow part of the terrace, extending as far as opposite the mouth of Palsinoja, is more regular and partly wholly flat-topped, reaching a height of 21 m. (in the figures of the maps) and at the same time the highest level of the gravel accumulations within this complex. The other, lower part of the deposits on the same shore are separated from the upper terrace and from the valley wall by a broad channel with a shallow pond at the bottom. Parallel and close to this channel there is a continuous stony ridge with three slightly separated summits, while the other area, projecting as a broad peninsula into the Palsinsuvanto water, is principally characterized by kame topography with a confusion of elongated or funnel-shaped pits and kettles. More material with simpler forms is found gathered into the outermost part of the peninsula.

On the right bank of Ivalojoki river, downward from the mouth of Palsinoja, there are two separate broad-topped gravel ridges with several gentle summits and some well-formed kettle-holes. Gravel deposits continue for a short distance upward the Palsinoja valley, there assuming the shape of regular terraces. The highest of them has a perfectly level top surface attaining a height of 20.9 m. at its maximum, almost exactly the same level as the highest terrace on the opposite side of the Palsinsuvanto water. This circumstance renders it evident, that the level into which the deposition of materials reached was controlled by a constant water level which very possibly at that time also indicated the height of the water body of Lake Inari, or at least did not lie much above it. The altitude of the terrace tops at Ritakoski, about 160 m. above the sea, as far as known at present, may well be placed into the system of the highest raised shores inside the basin of Inari, i. e. into the level of the *Portlandia* transgression (cf. p. 39). Tanner has twice expressed the view above put forth (1929 a, 1930 a, p. 164), based upon the information given him by the author. As gravel of the Palsinoja terrace is partly sharply overlain by fine sand (Fig. 18), Tanner inferred, that the transgression also occurred within the Ritakoski area, the relations of the sediments being proof of a decrease of the stream power by reason of deepening of the water. This is, however, no necessary conclusion, as the decrease of stream power and consequently a settling down of finer sediments also may have been caused by changes of the late-Glacial hydrography, as a result of a much diminished water discharge into the Palsinoja stream.

The highest shore referred to above is apparently registered by gravel terraces at the lower course of Iyalojoki also, although many distinct lower terraces confuse the observation. The height of the huge water-cut bluff (Fig. 19), called Alakosken mella, just below the Alakoski rapids, 22 km. in a bee-line from the mouth of Palsinoja, may be estimated at about 30 m., and the absolute top level is not far from 153 m. The terraces at the village of Törmänen, a photograph of which has been published by Tanner (1915, p. 479) and Sauramo (1929, Pl. XI, Fig. 19) belong to a lower level, but a little above the village there are much higher terraces, which may coincide with the previous level (here about 150 m.). The highest shore marks near the village of Ivalo, 9—12 km. from the Alakoski, quoted by Tanner (1915, p. 476, 1930 a, p. 164) according to the observations of Sarlin, lie, in the author's estimate, 147—149 m. above the sea. Still 10 km. farther towards the N.E., the elevation of the highest shore was measured by Tanner as 145 m. (1930 a, p. 162).

The gravel deposits in the vicinity of the mouth of Sotajoki mainly occur, as already mentioned, as terrace-shaped accumulations. Only the deposits at the mouth of Iisalmenoja and on the N. shore of Ivalojoki river are not perfectly levelled at the top surface; their material seems to be less water-worn, and partly they merge into hummocky

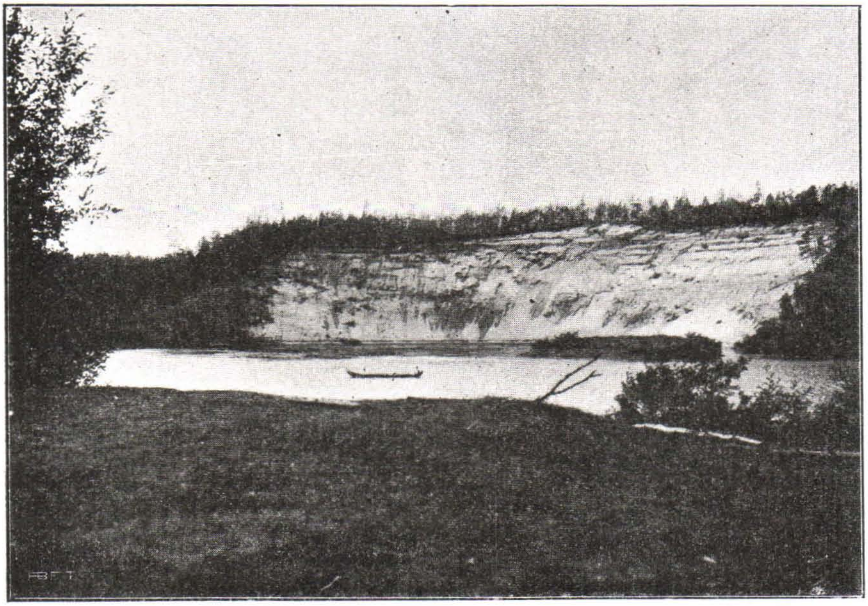


Fig. 19. Huge bluff, called Alakosken mella, in the bank of the Ivalojoki river, 7 km. W. of Törmänen. Photo J. J. Sederholm. (Tanner has published the same figure, but with an erroneous title, see 1915, p. 308).

morainic accumulations. Along the Sotajoki, well-formed gravel banks extend 2.3 km. upward from the mouth, alternately on each side. Their tops slope down the river, thus bearing witness of deposition in swiftly running water, but the terrace levels do not rise upward as rapidly as the river bed, in spite of the fact that successively higher levels are there encountered. The lowest and largest terrace on the right bank of the river, called Sotajoen Suupankki (Fig. 20), continues farther for some distance into the Ivalojoki valley, its total length being about 1.5 km. The altitude of its top surface descends from about 25 m. at the upper end to ab. 21 m. at the lower. This is the same remarkable level as that of the terraces in the vicinity of the mouth of Palsinoja.

The same level is furthermore represented by the lower part of the terrace of Iisalmenoja. Thus the same water level appears to have controlled the deposition of all these gravel terraces.

It is chiefly around the mouth of Sotajoki river and along its upper course that gold-bearing deposits are found within the Ritakoski area. Also the gravel deposits of the lower complex, those at Ritakoski—Palsinsuvanto, have been proved to contain a small amount of gold, but

Fig. 20. Gravel terrace, called Sotajoen Suupankki, seen from the N. shore of the Ivalojoki river opposite the mouth of Sotajoki. Photo by the author.

so little that placers of any noteworthy extent have never been worked here.

As to the Sotajoki, there have been large placers above the Halvarinniemi, extending at their lower end into the area mapped. Downward from the fixed point 50.0 a first stretch of 1.5 km. has been rather poor in gold, but for a length of 2.5 km. onward many considerable placers have been worked. Gold occurred here: firstly, on the lowest valley bottom, which is covered by stony gravel and has been strongly eroded and overwashed by water during the earlier post-Glacial time (cf. Fig. 22), secondly, beneath these deposits on the surface of the bedrock (the so-called bottom-gold), and finally, also in deposits related to hummocky ablation moraines (cf. Fig. 15). At the lowest end, at the upper portion of the third terrace from the mouth, just below a sharp bend of the river, gold was won from the most superficial gravel of the outer margin of the terrace. This gold, of course, derived from the immediately adjacent higher valley portion rich in gold, and had been carried with abundant loads of gravel by a powerful stream. After a short transport only the gold was deposited at its final resting place. This may be judged from the fact, that its abundant occurrence is restricted to the upper end of the terrace. No other placers have been taken up as far as the mouth of the Sotajoki river, although most of the terrace material must have come from higher up. Proceeding still farther into the valley of Ivalojoki, beginning just at the conjunction of the valleys, the level top surface of the terrace of Sotajoen Suupankki (Fig. 20) has again been worked over an area measuring about 400 m. in length and 50—80 m. in breadth. A fairly considerable quantity of fine gold seems to have been obtained there. The highest percentage of gold was found in the proximal (W.) part of the outer (N.) margin of the terrace, and there the rich occurrence also was deepest, as much as 1 m. down from the top. Lower down, again, very fine gold in a noteworthy amount was only met with at the very surface, "just underneath the lichens."

The location of the placers at the mouth of Sotajoki proves conclusively that the gold, and accordingly a large quantity of the gravel of the Sotajoen Suupankki, at the Sotakoski, derive their origin from the valley of the Ivalojoki river. This is also easily comprehensible because the large, formerly rich placers found on the Ivalojoki river continue for long stretches upward from the mouth of Sotajoki. On the inner side of the terrace, this gravel was perhaps mixed up with the non-auriferous gravel from the Sotajoki valley. When the streams entered the standing water body in the Ritakoski area, they dropped their load, and the gold from the Ivalojoki valley was, as in the case at the Sotajoki described above, laid down in the proximal part of the delta accumulation. As this part originally was built up near to its top, and the materials of the successively lower parts were dragged to their places over the upper parts, most of the gold was meanwhile left behind and thus enriched the surface of the overridden portions of the delta. It came to be deepest in the most proximal part, as the delta was here compelled to grow higher in order to maintain a sufficient gradient at the top, enabling water to carry its load to the distal margin of the delta, while this was removed more and more downward during the building up of the accumulation.

Also the N. shore of Sotakoski was formerly auriferous to such a degree that considerable placers have been worked there. A smaller placer was also opened up on the top of the terrace of Iisalmenoja.

A great part of the accumulations at Ritakoski—Palsinsuvanto may well be ranged under the title of eskers. There is, inside the area, also a typical esker, lying in a position quite different from that of the deposits in the valleys. It begins at the Sotajoki river, opposite the Halvarinniemi, at a height of 100 m., and trends in a general N. 60° E. direction uphill towards the E.N.E. for a distance of 1.5 km., terminating in a couple of flat-topped, plateau-like mounds of gravel, whose tops rise a little above 180 m. (320 m. abs.). The middle part of the esker

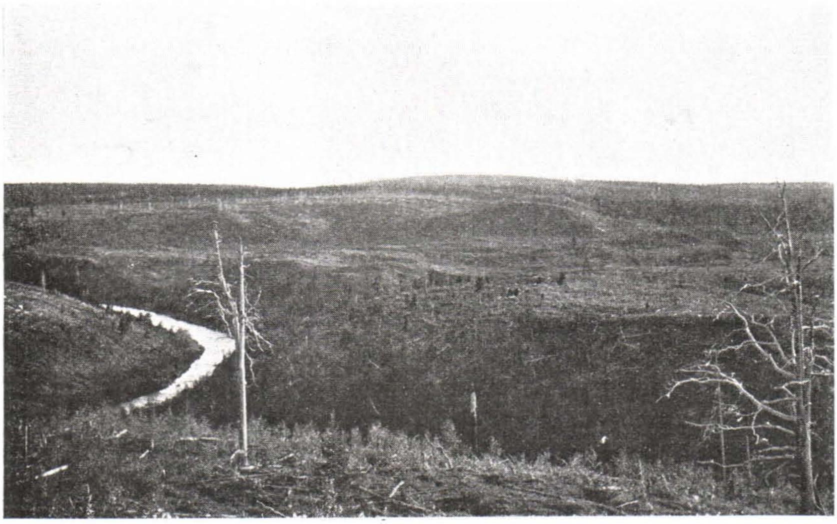


Fig. 21. View of Halvarinniemi, seen from the opposite side of the Sotajoki river. The magnificent, flat-topped esker is visible a little to the right from the centre stretching farther into the distance and bending slightly to the left. Photo by the author.

ridge is low, in part merely a step or shallow threshold between the dry land and a bog area S. of it. It is mainly composed of fine sand, as may be stated at a couple of trenches cut by small spring rills. In the E. end, there is a sharp steep-sided ridge of gravel in addition to the plains mentioned above, and some typical mounds and kettle-holes occur on the skirts of the chief esker. The other end of the esker has also assumed the shape of a plateau with some associated hummocks, and consists of gravel with small pebbles only. The ose ridge in question was not mentioned by the surveyors who carried out the geological mapping, and has been omitted by Tanner, although it was put on a small sketch map made by Sarlin (1902, p. 6).

At Halvarinniemi the esker is broken, although the sandy surface of its drift cover apparently represents the continuation of the ose.

A little outside the map area, in the same trend in the W., the ose appears again as a broad plateau-topped ridge of magnificent dimensions. Its aspect is shown in Fig. 21, taken from the esker mound 129.7 across the river, and both broken ends of the esker are seen in Fig. 11.

At its E. end the ose ridge bends slightly more northward, and in this direction, about N. 35°—40° E., there is a continuous zone of conspicuous erosion phenomena extending as far as the Ritakoski. A great part of this zone consists of naked rocky areas, such as were described above on p. 49, especially at the distal, N.E. part of the patch on the valley slope of Ivalojoki, opposite the Ritaniemi terrace. The brook Ritaoja flows in cascades through this rough rocky landscape. A salient part of the same area projects into the Palsinoja valley, thus evincing that a part of the rushing water poured also into the latter valley at the notch 86.2 and S.E. of this point. Around the W. source of Ritaoja, in the vicinity of the four small tarns, the drift cover is defective, mostly stony at the surface, and, especially around the largest pond 150.5, designated as "hummocky ablation moraine", obviously washed by water and therefore devoid of finer constituents; some of the mounds are wholly surrounded by rock. Between the tarn 175.5 and the esker plain 180.8, at the highest spot of the zone rising nearly to an altitude of 200 m., a cleanwashed rock surface is again encountered, abutting immediately on the end of the esker deposits. Between the sources of Iisalmenoja, to the left of the eroded zone looking in the distal direction, a peculiar hummocky drift area is met with. Its surface is strewn with large boulders. In the neighbouring area many other conspicuous features attract attention, such as denuded rock surfaces, patches of washed and channelled moraine and eroded spillway channels at several notches of the divides. These bear witness of water streams discharged from the side of the Sotajoki valley into the Iisalmenoja at the passes 153.5, 126.0, 117.4, and 110.7. A smaller stream led from the basin of Iisalmenoja through a channel at the figure 143.7 into the Ritaoja brook.

The erosion phenomena described above evidently bear a genetical relation to the two groups of gravel deposits in the area in consideration, viz. the esker ridge opposite the Halvarinniemi and the accumulations around the mouth of Palsinoja. These are practically connected with each other by the eroded zone just described, and thus they manifest themselves as belonging to a common continuous chain of glacifluvial formations, which at Ritakoski joins the valley of Ivalojoki (for further information about the extension of this chain, see below pp. 62—63). It is but rarely that an esker system may be observed under such exceptional conditions as in the present case, on a base with height differences up to 200 m. at short distances and, nevertheless, so well traceable and in part distinctly developed. Thus the oses in question possess great theoretical importance. The phenomena of erosion are quite naturally to be ascribed to the erosive action of the esker stream, i. e. the same water that carried, wore, assorted and finally laid down the material of the gravel accumulations.

In the present case, the simultaneous phenomena of erosion and deposition appear to depend decidedly upon the question, whether the floor slopes distally or proximally with regard to the trend of the chain. In the former alternative, on the Ivalojoki side, erosion took place, because the water could rush freely down the slope. On the Sotajoki side, again, water was retained in its ice-channel, perhaps dammed up by an obstruction of rock, and this caused a deposition on the channel bottom. On the distal side of the obstruction, where the rock surface has not been laid bare entirely, this circumstance may be due either to ice on the channel bottom (englacial channel) which protected the ground moraine, or to the circumstance that the bedrock has been subsequently coated with drift which was freed from detached ice masses. The loose material of the eroded spots was moved downward, and was deposited after a shorter or longer transport. The coarse, little worn and ill-assorted material of the terrace of Ritaniemi, for instance, was apparently caught by the violent torrent from the opposite slope, and chaotically thrown down to its place, without having been much rounded or assorted. Another part of the removed materials, perhaps, was laid down as the hummocky ablation moraines at Palsinsuvanto.

The subsequent changes of this glacifluvial hydrography, induced by the gradual lowering of the ice surface, by its separating into detached lobes in the valleys and the final stages of vanishing, are in all their recognizable details indicated on the map, Pl. II. Therefore they will be here only briefly outlined.

When the ice wall retaining the glacifluvial stream was sufficiently lowered on the left side, the torrent was deflected to this side by the rocky promontory jutting from the right in its way. As the records of erosion are rather defective on this patch, water probably rushed over the ice. The hummocky ablation moraines at the sources of Iisalmenoja (cf. p. 57) are to be regarded as its accumulations. Then, at a certain stage, nearly all this glacifluvial water was through several spillways discharged into the gorge of Iisalmenoja, where it accomplished an imposing work in removing the moraine on its right wall, and thus creating wild, adventurous, rocky landscape. The removed drift may be found partly in the gravel terrace at the mouth of Iisalmenoja, partly as the hummocky morainic accumulations at Vaskisuvanto.

At a somewhat later stage all the water, with a rich supply of glacial melting waters from the upper course of the river, was gathered into the valley of the Sotajoki river. The outermost spur of the lower promontory of the valleys was violently attacked by a heavy torrent

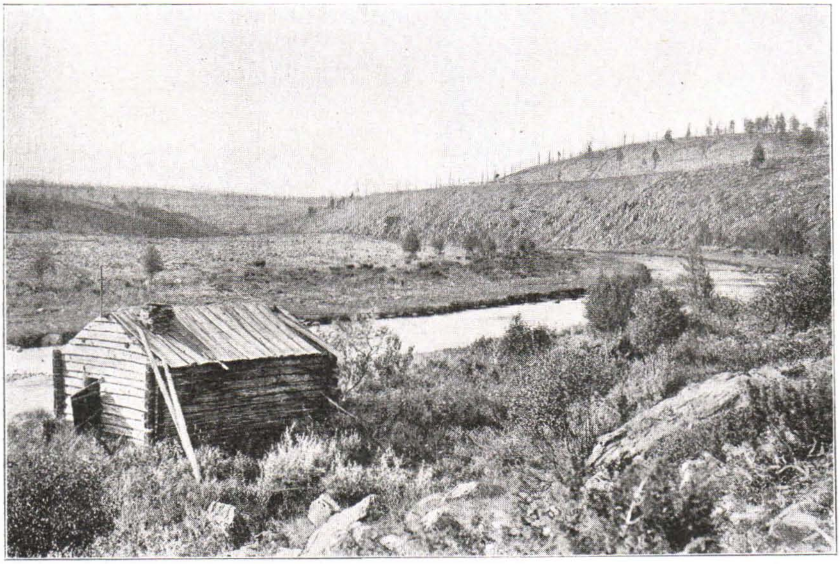


Fig. 22. Sotajoki river at the former placers, a couple of kilometres upward from Halvarinniemi. In the right valley wall a distinct shoulder exists, owing its sharpness to accumulations of lateral late-Glacial streams. Photo E. Sarlin.

at an earlier stage of this phase, and converted into a wild chaos of jagged rocks full of clefts and precipices. The solitary mound 125.1 is an unremoved moraine cap on a protuberance of the bedrock. During the sinking of its bed, the powerful stream strongly eroded the valley sides wherever it came into contact with them, especially on the outer sides of the bends, while deposits, in the form of hummocky ablation moraines, were locally laid down at the inner sides. At the Halvarinniemi, part of the water flowed directly over the spur of the W. side of the valley, and a little below, the marginal stream on the E. side of the valley cut into the rock a surprisingly regular, V-shaped ravine 10 m. in depth.

It must be regarded as most probable, and is also partly proved by facts which have been mentioned above and by observations at present glaciers (cf. e.g. von Engeln 1911, Tarr 1908), that the melt water streams in the valleys have mainly flowed marginally-submarginally, while the valleys still were in great part filled by remaining ice tongues. When the stream bed had sunk to the bottom of the valley, it apparently in most cases occupied one side of the floor, while the other side was occupied by the basal portion of the ice. During the earlier stages, at least, there were possibly marginal streams on both sides, but finally they were likely to join into one stream, which in places changed from side to side in traversing the ice. Only after this stage was it possible for also water-worn and assorted gravel to be formed and deposited, but the water power in the upper part of the valley was apparently strong enough not to allow such deposits to settle, as only small remnants of them are met with. Accumulations on a larger scale could not gather permanently until about 10 m. above the standing water level at Vaskisuvanto. The main part was carried as far as the lateral delta of Sotajoen Suupankki. The deposition took place on the river bed, when the present bed was still occupied by ice. As the ice decayed, the stream was removed to its present seat. In doing this it could wear away a part of the material just deposited, thus smoothing the terrace slopes. At the terraces erosion is continually going on in places.

The work of the lateral streams was going on in a similar manner in the upper part of the Sotajoki valley. Fig. 22 presents a fine locality about 3 km. above the Halvarinniemi, where the shoulder between the younger and older valley slope is accentuated to an extreme sharpness by narrow terrace fringes deposited there by an ancient lateral stream, the steepness of the lower slopes at the same time having been increased by late-Glacial and recent river erosion. The low flat-bottom on the left, where an extensive placer has been worked for gold, may partly have been subjected to water action even after the vanishing of the valley ice.

Many previous investigators have expressed the idea, that the gravel accumulations at Ivalojoki are remains of an ancient valley train, into which the river has subsequently cut its bed (Sarlin 1902, Tanner 1915, Hall 1918, Eskola 1925). This suggestion may be due to the omission of many important circumstances and in part to deficient information and a too schematical comprehension of the facts. In the author's opinion, there is every probability for such an interpretation of the events as put forth above. Substantial evidence in support of the author's view appears from what follows: If the terraces at the lowest course of Sotajoki and at Sotakoski had formerly extended over the whole breadth of the valley bottom, a very considerable quantity of gravel would have been removed from them and deposited farther down, first into the Vaskisuvanto water. This stillwater is, however, rather deep and very sluggish at its lower portion, and the bottom is partly covered with large boulders, so that no coarse material can have passed it during the post-Glacial period. The upper portion is shallow and filled with fine sediments, but at most these would form a trifling part of the whole quantity required for reconstruction of a valley train. Especially at the Sotakoski rapids, hardly any secondary erosion can have occurred; the terrace slope may chiefly represent an original ice-contact slope.

The view of lateral streams in the valleys and a consequently primary lateral concentration of the deposits was already long ago a familiar conception among North-American geologists, who also have formed a designation of their own for this kind of deposits, viz. ''kame terraces''. Russell has observed the actual formation of such accumulations in lateral stream beds at the Malaspina Glacier (1893, p. 236—237). Lately Flint has especially emphasized the importance of a lateral deposition along lingering ice tongues in valleys (1929), even in many cases where the accumulations in question were formerly considered as remains of valley trains. In Scandinavia, many chains of gravel deposits in valleys display similar phenomena, sometimes running as ose ridges, sometimes expanding and coming into contact with valley slopes, thus appearing as terraces, but nevertheless showing wholly primary forms of deposition (Holtedahl 1924, Nelson 1910, Sandler 1917, Sundius 1922, Hörner 1927). In the following chapter still more examples from Finnish Lapland will be brought forth, proving that similar conditions have prevailed in practically all the defined river valleys in Lapland.

As to the accumulations around the mouth of Palsinoja brook, they display still more typical primary features, having at least been unaffected by a noteworthy post-Glacial water erosion. Gravel ridges, terraces and hummocks may here be the casts of former water channels and other open spaces in the ice, and the present channels and pit complexes indicate the last seats of the ice itself. This was already inferred by And. Brofeldt, one of the geological surveyors of this region, who stated that the Ivalojoki river at Palsinsuvanto flows in a large esker pit.

The fine-grained sediments, which are specially designated on the map, Fig. 17, are found in two different positions: on the highest terrace tops at Palsinoja (cf. pp. 52, 53) and at rather low levels, mostly below 6 m. Here they are likely to indicate a standstill during the post-Glacial sinking of the water level in the basin of Inari, and thus they may correspond to some lower terrace levels in the lower part of the valley. As they do not occur in the deep pits on the left shore of Palsinsuvanto, this may be due to the fact, that the pits were formed by melting of buried ice blocks only after the water level had sunk so much, that a direct connection between it and these pits no longer existed.

### THE GENERAL OCCURRENCE OF THE LATE-GLACIAL FORMATIONS.

The map, Plate V, shows the distribution of the glacifluvial deposits in the different parts of Northern Lapland. Considerable variations in their occurrence are at once apparent. Within the basin of Inari, attention is caught by the length and the straight, regular trend of several parallel chains. Inside the mountain belt, again, the glacifluvial material is found to be chiefly deposited in the river valleys. Elsewhere also the most prominent valleys, and even considerable basins, are largely occupied by esker accumulations. In the large mountain areas deposits of this kind are, as a rule, completely lacking. In the S.W., on the upland peneplain, their distribution seems to be rather confuse and irregular.

As for the oses in the valleys, already the above description of the relations on the river I v a l o j o k i revealed many features of general interest. Proceeding further onward, along the valley (cf. also Tanner 1915, pp. 307—310), the gravel accumulations are found to continue, following the valley bottom, and forms similar to those at the Palsinsuvanto water are met with as far as at the stillwater of Hammassuvanto, for a distance of about 5 km. On the N. shore, kame-like accumulations continually occur which greatly resemble those at Palsinsuvanto, whereas the greatest part of the deposits of the S. shore are accumulated as a rather coherent, although rude-shaped terrace, bearing some resemblance to the broad gravel ridges on the right bank of Palsinsuvanto. The material is here somewhat less coarse than at the Palsinsuvanto water, and gradually becomes finer downward. Farther down from the Hammassuvanto the valley widens very considerably, so as to be more appropriately called a basin, and this enlarging also results in a different development of the valley esker. The ose chain passes over into large gravel and sand plains, partly with very level top surfaces, in many places containing great pits, true characteristics of eskers, and also merging into typical esker ridges and mounds. These accumulations sometimes stand freely on the valley bottom, and sometimes lean against the walls, in this case appearing as gravel terraces. At the Pajakoski rapids 7 km. below the mouth of the Tolosjoki river, the river changes its character very notably. Above the Pajakoski rapids, the stillwaters are rather deep and very sluggish, like those in the Ritakoski area, but below the rapids the river becomes shallow and continually flowing, easily carrying sandy material on its bed. Along this latter stretch, the greatest part of the low valley floor may consist of alluvial deposits, which have been redeposited by the present river. The more or less continuous chain of glacifluvial deposits along the river terminates as extensive plateau-like terraces 7.5 km. downward from the head of Pajakoski, a little above the village of Törmänen, and farther down only a few eroded remnants of sandy ose deposits are encountered. Upward from Törmänen the river likewise in many places cuts into the esker sides, forming bluffs (Fig. 18); $^{1}/_{5}$ of all the banks of the Ivalojoki river from the head of Ritakoski to Törmänen are bare esker bluffs. In most cases, however, especially above the Pajakoski rapids, the total amount of this secondary cutting appears to be fairly inconsiderable. In part it may even be wholly negligeable. The earlier conclusions about the primary forms of the gravel accumulations and the essentially late-Glacial origin of the river bed may be regarded as holding good also as to the whole lower portion of the Ivalojoki valley.

Tanner supposed that the gravel accumulations of the lower valley of Ivalojoki extended upward in the upper valley portion. As demonstrated above, this continuation, however, is to be found S. of the river. Headward from the confluence of Sotajoki, there are only local small accumulations of gravel. It must be inferred, however, that large quantities of late-Glacial melt waters were discharged through the Ivalojoki valley across the mountain belt into the basin of Inari, while the ice margin was receding on the upland peneplain in the SW. It is also true that vestiges of an exceedingly strong water erosion, having affected the valley slopes as well as its bottom, are displayed everywhere throughout the deep portion of the valley, and even farther upward, occasionally on an imposing scale. They give the valley an utterly barren and desolate aspect. The steep gradient has enabled the water to carry most of the denuded material as far as the standing water at the mouth of Sotajoki, and it seems likely that the valley, and the ice filling it, contained only a fairly moderate quantity of loose materials which were removable by water.

The lower portion of the valley of the Suomujoki river is occupied by very typical, fine and picturesque oses. At the mouth of the river, they also occur as flat-topped plateaus, and therefore they have been interpreted by Tanner as late-Glacial marginal deltas (1915, pp. 315—318) which have been deposited into an arm of the sea, which at that time extended into the Luttojoki basin. A little higher up the esker chain shows varying ridge- or kame-like shapes and contains numerous tarns in the pits. Still farther on the esker decreases in height and passes gradually into low, fragmentary gravel terraces. Beyond them the valley bottom is strongly eroded by water, showing boulder channels and naked rocky surfaces. Small boulder terraces occur also on the slopes comparatively high above the valley bottom, clearly indicating a marginal water action (cf. Tanner 1915, pp. 563—564). Also the lower terraces along this stretch consist of stony material. According to Tanner, some "untypical" esker formations are found in the prolonged direction of the S.W.—N.E. trend of the valley on the S. side of the watershed, possibly indicating the continuation of the glacifluvial chain of the Suomujoki valley farther towards the S.W. As the divide and the peneplain S. of it lie at a considerably higher level than the valley bottom of Suomujoki, the ose chain should here appear in a somewhat similar position as at the Ritakoski rapids. In fact, in the S. wall of the valley the drift cover has to a great part been stripped off, and much water has, at any rate, been spilt over the divide into the Suomujoki river. This locality has not yet been sufficiently studied to warrant more accurate conclusions.

As to the valley of the J a u r u j o k i river, available information is still fairly incomplete (cf. Tanner 1915, pp. 322, 567). Extensive gravel deposits are met with also at the lower course of the river. The upper part of the valley, as far as below the boundary line of Petsamo, is characterized by records of an exceedingly strong erosion, represented by steep, bluff-like valley slopes which were once undermined by water, inclined boulder terraces up to several tens of metres from the valley floor, and wide denuded surfaces. At the source of Jaurujoki, the Maanselkä-divide lies at a comparatively low level. Owing to this fact the waters, which were ponded up by the ice on the S. side of the watershed, have especially availed themselves of this spillway, thus accounting for an enormous water supply in the Jaurujoki valley during late-Glacial times.

Tanner has convincingly demonstrated (1915, pp. 448—456) that several ice-ponded lakes have been drained into the river A n t e r i- j o k i. The character of its valley bottom bears witness of much larger water quantities than contained in the present river. The valley of Muorvaarakkajoki, again, does not appear to have formerly contained any river comparable with those occupying the above-mentioned valleys, as hummocky ablation moraines are largely preserved on the valley bottom.

The valleys of the upper L u t t o j o k i and Kulasjoki rivers have also received late-Glacial water courses from the other side of the divide, as demonstrated in great detail by Tanner (1915, pp. 466—472 and Pl. V). The deposits in these valleys are low and without any conspicuous esker relief.

The valley of the L e m m e n j o k i river is followed by a well-developed esker system, which may be traced farther towards the N.E.,

Fig. 23. Lemmenjoki valley just below the Vaiautsi. Distinct gravel terrace fringes on the valley slopes are remnants of beds of late-Glacial streams which towards the middle of the valley were retained by ice. Photo J. J. Sederholm.

as far as to the frontier of Norway. It may be considered as the longest and most remarkable glacifluvial chain in Northern Lapland. It is interrupted by three big lakes elongated in the trend of the system: Paadarjärvi, Muddusjärvi, and Iijärvi. At the isthmus between Lake Paadarjärvi—the Vaskojoki river and Lake Muddusjärvi, the ose is represented by low sandy heaths, presumably deposited at the highest ancient water level within the basin of Inari (cf. Tanner 1915, pp. 285—287, and p. 39 above). Towards the N.E. from Lake Muddusjärvi the esker, known by the name Tuuruharju, rises more than 20 m. above its surroundings and is very broad, being composed of several subparallel ridges, a confusion of humps and hollows and lower, undulating heaths on both sides (Tanner 1915, pp. 278—286). The large quantity of esker material deposited here obviously accounts for a strong glacial wear, which has even led to overdeepening, at the lake basins and in the Lemmenjoki valley on the proximal side of the accumulations. At the S.W. end of Lake Paadarjärvi the ose chain again sets in as a low, wide, partly eroded valley train. It gradually ascends upward, merging into pitted plains, kames and a plexus of esker ridges which are partly plateau-like at the top. The lowest lakes at the Lemmenjoki lie in huge esker pits. Especially fine esker forms with large dimensions are found, for instance, on the S. shore of Lake Sotkajärvi, the lowest of the lakes in the deep valley portion. Farther headward the ose becomes fairly fragmentary, occurring as islands and capes and damming up the lakes. Above the uppermost lake, Morgamajärvi, only small occurrences of gravel are encountered, partly as low valley trains, partly as narrow terrace fringes perched on the steep slopes high above the valley bottom, as seen in Fig. 23. These terraces generally consist of typical water-worn gravel of a rather "normal" coarseness. They form splendid examples of deposits in lateral stream channels, laid down when the whole of the deeper part of the valley was still filled with ice. Some portions of these terraces have evidently slid down into the valley bottom, when the retaining ice decayed. In view of the quantity of gravel in the recent delta at the head of Lake Morgamajärvi it seems impossible to share the opinion of Tanner, according to which the valley has at one time been filled, from side to side, up to the level of the terrace remnants referred to above. At the mouths of the tributary valleys of Lemmenjoki, there are in places small deltas, once laid down into the marginal streams of the main valley and afterwards left in a perching position. Such deposits have also been observed at the mouths of the smallest tributary brooks of the Vaiautsi. Both the Lemmenjoki valley and the Vaiautsi have received large late-Glacial water quantities from the upper Ivalojoki drainage area. S. of this divide, there runs a large esker, directed to the head of Vaiautsi, and extending, under the name Sallijänkän juppurat, towards the S.W. as far as the Repojoki river. In the uppermost part of the Vaiautsi itself, solitary esker mounds are found surrounded by bare-swept rocks.

At the lakes Menesjärvi and Solojärvi, there occur low, rather wide-spread sandy accumulations resembling outwash aprons. Their material has been carried from the S.—S.W., the region of Hammas—Appistunturit, by abundant melt waters, to which were further added waters from ice-ponded lakes at the S. foot of the mountains. The chief spillways, which are indicated on the map, Pl. V, have been transformed into distinct steep-sided channels, and on their distal sides wide denuded rock surfaces in the valley bottom bear signs of the powerful erosion of the late-Glacial torrents.

Along the river Vaskojoki glacifluvial deposits are only sparsely met with. At the middle course of the river, at the foot of Marastotunturit, however, the washing and wearing action of lateral streams, which flowed along the S.E. margin of an ice tongue projecting eastward into the Vaskojoki basin, is clearly in evidence. It appears, however, as if the sources of the Vaskojoki river had received considerably less melt water from the other side of the watershed than, for instance, the Lemmenjoki river. We still have little information about conditions at the river sources.

In the N. part of the granulite belt, a very interesting complex of glacifluvial formations is found within the tract between the Pais- and Muotkatunturit. The largest esker system in the region occurs in the vicinity of the lakes Luomushjärvet and farther towards the S.W., namely at the sources of the Passijoki river, a rather small tributary of the river Inarijoki. The proximal continuation of the chain has not yet been followed farther, but judging from the maps it should lie W. of the Muotkatunturit, possibly extending as far as the Inarijoki river. Thus it should on its way cross the N.E. promontory of the mountain group. S.W. of the lakes Luomushjärvet the ose landscape is so magnificently and variably developed, that but few localities in Northern Lapland can be compared with it. Very steep, sharp-topped ridges built up of coarse gravel alternate with deep kettle holes; laterally the ose is skirted by undulating sandy heaths. A lake at the W. fringe of the ose landscape, Passijärvi, is partly surrounded by rough naked rocks. Close to the lakes Luomushjärvet, the highest esker portions are flat-topped plateaus, rising up to 20 m. above the lakes. Thereafter the ose continues as a narrow, 3 km. long bridge between the two lakes, trending towards the valley head of Kevojoki in the gap between the Ruottir and the Njaugoaivi mountains. The farther one proceeds in this direction, the more the esker deposits assume smaller, simpler and more elongated forms, indicating an increasing water power of the former esker stream. About the divide the ose deposits almost disappear, being replaced by more and more pronounced marks of erosion, such as rocky patches and rude, downward inclined boulder terraces, which on the N.W. side of the valley reach high above the bottom. When the river valley becomes canyon-like, the marks of lateral streams are also met with above the precipitous walls. In places there are also small occurrences of coarse, but in other respects quite typical water-worn gravel.

The Kevojoki valley has also received considerable late-Glacial tributaries from both sides, on the left from the opening between the Njaugoaivi and Paistunturit, and on the right from the E. side of the

Ruottir. Wild, jagged, rocky valleys have served as the chief waterways: the Fiellukeädgiaudshi on the former side, and the Tsheskadasaudshi on the latter. Both these valleys are in connection with oses. In the W., the ose chain pointing towards the head of Fiellukeädgiaudshi approximately follows the middle course of Akujoki, a tributary of the river Tenojoki. At the lower part of this stretch, the river already rushes down into its canyon-like valley head as a fine series of cascades called Luövdikordshi, and the ose is mainly found, with very irregular forms, on the upper slopes and above the ordinary valley. Farther E., the esker looks at a distance like a coherent ridge, in slight windings trending uphill towards the divide, but it has not been followed throughout its length. The esker reaching the head of Tsheskadasaudshi from the S. trends in a general N. 15° W. direction. The main part of it is a large, sandy, undulating ose, known by the name Suttispuoldsha. This glacifluvial system sends out a branch against the head of the Tsuoggajoki river, consisting of an eroded zone with several cleanwashed rocky spots.

As the ice-margin in the basin of Karigas- and Passijoki had receded farther westward, the water obviously formed a temporary lake in this basin and found at the same time lower spillways into the Kaamasjoki river at the N. foot of the Muotkatunturit. There are two pronounced channels, the northerly Leämmashaudshi and the southerly Kaktsa-audshi, bearing evidence of large streams that once occupied them. In the flat basin of Kaamasjoki and its tributary Kiellajoki, one is struck by the exceedingly wide distribution of late-Glacial sands (cf. Tanner 1915, pp. 276—277) which partly occur as true esker accumulations, partly resemble wide outwash aprons, whose surface irregularities are partly due to ancient, in places also to recent dunes. A large part of this material obviously derives from the extensive mountain massif of Muotkatunturit, the glaciology of which area is still fairly little known. One larger ice-ponded lake, at least, appears to have existed in the low embayment at the W. foot of the mountains, with outlets partly northward to the Karigasjoki, partly eastward to the Kiellajoki. On the lower course of Kaamasjoki true glacifluvial deposits are probably absent, but the river sides are, at any rate, mostly built up of alluvial deposits which have been transported from the upper glacifluvial area.

Coming again to the Utsjoki drainage area, also the U t s j o k i proper has received additional waters from the other side of the divide. At least three spillway notches have been proved to exist; the middle one (cf. the map, Pl. V) being lowest and most important. In this passage there are esker deposits, which seem to have a continuation towards the S.S.W. as far as the river Kaamasjoki. In the upper part of the Utsjoki valley, along the stretch from Lake Mierasjärvi to Lake Kenesjärvi, glacifluvial deposits are met with in a similar development as in the deep valley of the Lemmenjoki river, holding up the lakes at their lower heads and jutting out as isolated capes from their shores. Close below Lake Kenesjärvi there is a very picturesque, narrow and sharp-topped esker ridge, which was already described by Jernström (1874, pp. 219—220). Farther down, the accumulations

Fig. 24. View of the Utsjoki valley at Lake Jorbajärvi, showing large accumulations of late-Glacial gravel which follow the valley bottom. Photo by the author.

expand into magnificent terraces and plateaus (Fig. 24), in places merging into lower pitted kame complexes. The basins are here, as a matter of course, typical, large, primary esker pits, as also recognized by Tanner (1915, p. 274). Also the lower part of the Kevojoki valley is followed by a large system of gravel terraces which in places grade into still more characteristic esker forms.

The large Inarijoki—Tenojoki valley is throughout its length followed by water-worn and assorted accumulations. On the upper Inarijoki river, as far as the Karigasjoki, they are large and of variable shapes, in many places terraces and plateaus, but they also merge into common narrow esker ridges orientated in the trend of the valley. In some places there are even several parallel ridges. An ose ridge is seen in Fig. 25, where the valley wall higher up is scored and trenched, in a common manner, by oblique channels and zones of erosion which are traces left by late-Glacial lateral water-rills and streams. Along the sides of Tenojoki the deposits rarely attain as large dimensions as at the Inarijoki river, and more or less typical esker forms become still sparser. Instead of eskers, terraces are the prevailing kind of accumulations, often occurring in the form of steps one above the other. They look much like common stream terraces, and as there is a strong current everywhere in the river, they may even, at least in part, be

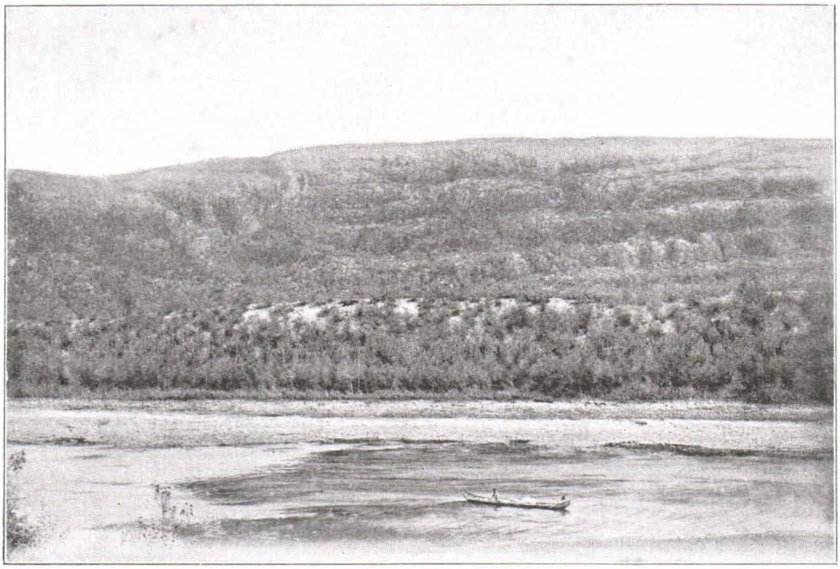


Fig. 25. E. wall of the Inarijoki valley, in front of the N. E. promontory of the Muotkatunturit mountains. The slope has been eroded along oblique zones by former lateral streams. Apparently at the foot of the wall, but in fact nearly in the middle-line of the valley, a sharp-crested ose ridge is visible. Photo E. Sarlin.

moulded by stream action. As the post-Glacial tilting of the land surface towards the N.—N.E. has steepened the gradient of the river, it would appear only natural if during the post-Glacial conditions, in spite of the uncomparably richer water supply of the river, an accumulation of gravel and building of an extensive valley train some metres above the present river bed had taken plave in the Tenojoki valley. The regular oses, on the other hand, are obviously wholly typical primary forms of the glacifluvial deposition. The view of the primary origin of the terraces, especially the higher ones, i. e., the theory of deposition by lateral streams, is, however, by no means excluded.

According to Tanner (1915, pp. 485—494), the level of the *Portlandia* transgression reached into the Tenojoki valley as far as a little below the Ylikongäs rapids. Downward from there, ancient delta deposits built up to the respective sea levels may thus be expected. In fact, from the mouth of the Utsjoki river onward the accumulations, as far as known at present, are almost exclusively of this kind, occurring as distinct terraces of fine-grained sandy and silty material.

Outside the mountain belt and the region of the defined valleys, along the Maanselkä-divide W. of the foot of Raututunturit, one is at many places able to recognize late-Glacial spillways which have conducted ice-ponded waters into the river heads drained to the Ivalojoki river. Owing to the exceedingly gentle topography of this tract, the records of water action are fairly feeble close to the water-parting line, but proceeding down the rivers they become more and more pronounced. Along the river sides, the dry land areas are very commonly bounded against the boggy depressions by low but distinct bank-like slopes, which are generally built up of rather fine-grained, in some degree assorted material. They give the impression of being sediments in former lateral stream beds, the other side of which was retained by ice. The forms of the slopes may be partly due to subsequent erosion. These phenomena are the more significant as they, as a rule, are decidedly lacking on the S. side of the divide and along those river sources which head in comparatively high notches. Farther down strongly eroded channel sides, denuded rocky and stony patches and broad stony overwashed floors are met with, before the streams enter the ordinary narrow and deep valleys.

The author has stated late-Glacial drainages over the passes of the Maanselkä-divide at the heads of the rivers Tolosjoki, Sotajoki, Vuijemijoki, Kivijoki, and Rullajoki. Many details there still await explanation, as investigations have proceeded but slowly in these desolate regions. Farther W. no studies have as yet been undertaken, but as the tract is partly still lower and flatter than in the E., the vestiges of the presumptive overflows at the divide may be very slight or barely recognizable.

As for the esker systems at the Maanselkä-divide, information is likewise still fairly incomplete. At the sources of Sotajoki, they do not seem to be continuously traceable over the watershed, although certain esker stumps on both sides of it may belong to common chains. In the N.E. corner of the parish of Sodankylä, as far as can be judged from the meagre data available, the eskers appear to arrange themselves into a long, curved and somewhat sinuous chain, forming, perhaps, the upper continuation of the glacifluvial system descending into the Ivalojoki valley at the Ritakoski. Meanwhile this chain is very discontinuous, but at least in part the breaks are here also bridged by eroded zones in which naked rock surfaces have been exposed.

The chain traversing the Sotajoki river at its upper course, above the defined valley head (Tanner's Härkäselkä—Vaulo ose chain, 1915, pp. 313—315) involves many conspicuous details and interesting problems concerning the genesis of the eskers. At its W. end, it runs through a narrow, rather steep-sided valley between two gentle hills (cf. Fig. 58 on p. 314 in Tanner 1915). A low ose ridge appears in front of both its ends, but the channel itself, although it obviously conducted the esker stream, shows absolutely no signs of erosion, with the exception that its general shape decidedly suggests a rapid cutting. Every spot is coated with dusty drift, but on the floor, however, digging resulted in water-worn gravel being found underneath. Thus the morainic cover may be of secondary occurrence, having been freed from the walls and the roof of an ice tunnel after this had been deserted. Farther. E. the S. foot of the esker complex is followed, for some distance, by a very distinct water-cut channel, and on the N. side of the esker there is a broad zone of an overwashed, channelled moraine leading towards the N.E. to the Sotajoki river. At the upper course of Sotajoki, a temporarily formed lake appears to have existed, in the N. having in part been held up just by the ose in question. Several outlets have been cut across the esker, the present channel of Sotajoki being the largest and lowest one. At the higher portions of the esker, common ridges are the prevailing forms, associated with varying combinations of humps and hollows; in places they occur as several subparallel ridges which may be partly connected by intervening transverse swells. Some distance E. of the Sotajoki, at the foot of the hill Härkäselkä, much material has been accumulated as a wide flat-topped delta, which has been subsequently trenched by many sharply incised channels. The smaller occurrences of ose deposits S. of the chain described above show partly typical forms of sand plains, presumably attributable to deposition in the temporarily existent lake above referred to.

As a really singular instance of the oses which have been studied by the present writer in Northern Lapland, an esker on the hill Etelä Sarveskäydniloaivi may still be mentioned. The locality lies N. of the Ivalojoki river, in the vicinity of the sources of the river Menesjoki. The summit of the hill is, for the most part, swept clean of moraine, just in the manner of the characteristic water-washed rocky spots. A low, hummocky esker trends in slight windings uphill the proximal rocky slope, pointing towards the top, breaks off there, but occurs again as a single, small plateau on the distal slope close to the summit, wholly surrounded by naked rock. A very similar case from the N.E. part of the parish of Inari was lately reported by Tanner (1930 b). There the esker forms the highest top of the mountain, and likewise bears a relation to magnificent feats of erosion.

As in their dimensions and external shapes, the eskers of the upland peneplain area are extremely variable also with regard to their materials. Small dimensions are often connected with a sandy composition, but in other places, on the contrary, the material becomes coarser as the size decreases, and, at the same time, other indications of erosion are usually in evidence in the vicinity. In the swells of the esker chains, in general, coarse- and fine-grained materials have been deposited simultaneously. The stones and gravel, and partly also sand, build up ridges and mounds; the sand has, in many cases, been spread out at the skirts or concentrated into separate form complexes which mainly lie at the sides of the chief ose. At the same time, very slightly water-worn and ill-assorted material may occur as a constituent of eskers.

The transition of esker material into a moraine-like drift within ordinary esker chains has also been noted by several other investigators. The material of the ose chains has been found to grade over into a little-worn morainic variety, especially in the proximal portions of the systems. Tanner has found this to be generally true regarding the oses of Lapland (cf. e. g. 1929 b, p. 167). The same feature has been ascertained more decidedly by G. H. Stone, the monographer of the eskers of Maine, who writes, for instance (1899, p. 40): "In some of the shorter systems and toward the northern ends of many of the longer systems the stones and grains are but barely polished at the angles and differ so little from till in their shapes that the mass may be regarded as a slightly water-washed till". The occurrence of morainic material in the eskers of the upland peneplain even means its presence in the proximal portions of the systems, as these partly extend in the distal direction as far as the basin of Inari. A little degree of wear indicates, as a matter of course, a comparatively short transport by water, and it is quite natural that the materials transported the shortest distance are found in the proximal ends of the systems.

It is a circumstance worthy of special emphasis that particularly on the upland peneplain the eskers in Northern Lapland in great part are supra-aquatic, i.e. formed above the level of large continuous water bodies. In some cases their material may have been laid down in temporary ice-ponded lakes, but very commonly it has apparently settled in the stillwaters of the esker streams, or has come to stay in the tunnels and crevasses, containing flowing or standing water, which were to be found in the decaying ice margin. The above-described features, characteristic of the eskers on the upland peneplain area, such as the extremely variable size and especially the variable breadth of single systems, reticulate ridges and frequent kame forms as well as the common occurrence of sharply separated portions of materials having a different coarseness, may be readily understood from this manner of deposition. These features may be regarded as the special characteristics of the supra-aquatic eskers, as well as of those deposited in very shallow water, the latter including the greatest part of the subaquatic eskers in Northern Lapland. The special characteristics of the supra-aquatic eskers have occasionally been considered as far back as in the earliest days of the glacifluvial esker theories. They have not, however, received the attention they deserve, probably due to the fact that ampler and easier opportunity was offered for the study of the subaquatic eskers, and that these are, in addition, larger in size and more conspicuous in the landscape. Among the investigators in Fennoscandia, who have been aware of the special characteristics of the supra-aquatic oses and their conditions of origin, mention may be made of A. G. Högbom (1913, p. 99), Ahlmann (1911) and Sauramo (1929, p. 32).

## SOME REMARKS CONCERNING THE ORIGIN OF THE ESKERS.

It is not the author's purpose more closely to discuss the different esker theories. Some remarks, however, may here be made. In an attempt to explain the origin of the eskers, one can in general not aim at any definite answer to the question, whether they have been formed by waters that flowed in open superficial channels, englacial tubes, or subglacial tunnels. The possibility of each of these alternatives must be admitted. As to the supra-aquatic oses, it is rather natural that the esker streams in the thin marginal portions of the ice ultimately have been open above, as a consequence of surface melting. It is obvious, however, that the trunk streams of the large glacifluvial systems, in the greatest part of their course, cannot have been superficial, but must have run under the ice or near to its bottom. Otherwise, it would be difficult to explain the big masses of gravel in the great esker chains. The character of the land ice itself and experiences from recent glaciers make it evident that the melt waters have had but little possibility of flowing in open channels. The lengths of the individual chains, often enormous, are also, in the author's opinion, only possible to explain by assuming that the glacifluvial streams have mainly flowed under the ice. From this point of view, on the other hand, the forms of the eskers are of secondary importance. When the commonly steep slopes of the eskers, their sharp crests and summits, and the occurrence of subparallel ridges and kettle-holes are closely considered in comparison with the phenomena at the margins of recent glaciers, the prominent rôle of slumping as a shape-giving agency is strongly suggested. The slumping took place when many retaining ice walls and buried ice masses disappeared. This view, however, is not favourable to a very broad application of the theory which regards the eskers mainly as rows of successively-formed extraglacial or submarginal deltas.

Many students of eskers have expressed somewhat undecided opinions regarding their origin, and have assumed different ways of action for the glacifluvial processes in different cases. This seems to be the case especially with nearly all of the American investigators. Stone, who is so thoroughly acquainted with the esker formations, writes, for instance (1899, p. 430): "While there are a large number of cases, where the subglacial hypothesis is equally in accord with the facts, and in some cases better in accord with them than the hypothesis of superficial streams, there are other cases where superficial streams are as strongly indicated by the facts. All this points to the conclusion that the osar rivers were in some places subglacial and in other places superficial or englacial. This may be bad for the symmetry of theories, but seems to be true to nature." Among the latest investigators, Flint has especially emphasized the origin of the ose-like accumulations under supra-aquatic conditions and in stagnant ice in the way set forth above, p. 73, viz. in open spaces and crevasses of the marginal zone of the ice. He explains the deposition of the Irish eskers mainly in this manner (1930), and also gives a special designation to this variety of glacifluvial deposits, viz. *crevasse fillings* (1928). The scientist who has most experience of the eskers of Lapland, V. Tanner, has taken the most neutral and elastic standpoint possible in the question, writing (1929 b, p. 175): "Die Osar sind durch die Ablagerung glazifluvialer Flüsse entstanden, die während des Abschmelzens des Eises teils supraglazial, teils infraglazial und teils subglazial nach der Peripherie der schrumpfenden Landeiskalotte hingeflossen sind. Es lässt sich schon jetzt denken, dass die Transportprodukte solcher Flüsse teils subaeril, teils unter oder in dem Eise stagnierten."

In his two last esker studies (1928, 1930 b), Tanner describes oses which he thinks have first, in their whole length or at least in great part, been deposited in the channel of a superficial stream, having then, when the subjacent ice melted away, sunk gradually to the land surface. Both these eskers lie on a floor ascending in the distal direction.

Especially in the first-mentioned case, already known to Hausen (1925. pp. 13—15), where a surprisingly ''typical'', simple, coherent ose ridge with a sharp crest is dealt with, the present writer thinks that Tanner's explanation cannot be correct. The subsidence, in the imagined manner, and amounting to several tens of metres, of the presumed gravel filling in the ice channel, while the ice was slowly melting away beneath the gravel, lingering there longer than at other places, would in no wise result in a sharp-topped ridge, but instead in a rather broad, undulating patch of gravel. Narrow and in general very ''typical'' esker forms may, on the contrary, be regarded as criteria for the deposition of the respective materials directly upon a land floor. If the floor rises in the distal direction, a rather high hydrostatic pressure must have prevailed in the glacifluvial drainage system, in order to give water the necessary transporting power.

Among the above-described glacifluvial systems there are some which extend more or less continuously from the upland peneplain in the S.W. as far as the basin of Inari. They show certain important analogies to each other. Three of them stand out as very notable, long and large systems of the first order, viz. the chain of Luomushjärvet —Kevojoki, that of Sallijänkän juppurat—Lemmenjoki—Tuuruharju, and that of Ivalojoki. The esker of Akujoki—Fiellukeädgiaudshi and the esker chain of Suomujoki may be considered as smaller and less complete systems of a similar character. In analogous positions, although entirely on the inner side of the curved mountain belt, occur the system of Suttispuoldsha—Tsheskadasaudshi and the esker coming into the head of the Utsjoki valley. The five first-mentioned systems cross the mountain belt, availing themselves of the gaps and valleys which interrupt it. Thus they follow the general rule of adjusting themselves to the larger topographic features. It is likewise a general rule, that no eskers are found within high and mountainous regions. All the above esker systems run across the most important divides. In this respect the chain of Ivalojoki is a less typical representative, and the continuation of the esker of Suomujoki is very ill-developed, almost questionable on the proximal side of the watershed. On the proximal side of the divides other chains generally are large, well-developed, and continuous for long stretches. At the watershed and immediately on its distal side the ose disappears and is replaced by magnificent feats of erosion along the stretch on which the floor of the system rapidly descends much below its level on the proximal side. Still farther onward the ose appears again, sometimes abruptly, sometimes gradually, attaining here, in many cases, imposing dimensions. Many esker chains which run across the Scandinavian mountain range between the watershed and the ice-divide (cf. e. g. A. G. Högbom 1910, G. Frödin 1913, Gavelin 1910), may be regarded as similar instances, although the esker deposits, in most cases, do not occur more to the W. of the watershed. Stone has noticed an exactly similar relation between the eskers and the inclination of their floor in Maine, although this phenomenon seems to be less pronounced there. His statement is as follows (1899, pp. 413—414): "Where they (the eskers) go up and over hills, the gravel is usually abundant on the northern slopes, while little and sometimes no gravel is found on the tops of the hills, especially when penetrating narrow passes. On steep southward slopes the gravel is often scanty or absent for long distances, and then at the foot of the slope large ridges or often plains are found. Here and there on the steep southern slopes (20 to 80 feet per mile) may be found small masses of boulderets and boulders that are well rounded by water. These as truly are the local representatives of the osar as if they formed a large ridge."

The phenomena of erosion in connection with the oses form one of the most substantial proofs for the glacifluvial origin of the eskers, in view of which fact they have been too little considered up to the present. It is true that wholly unequivocal and convincing cases can be seen only in connection with the supra-aquatic oses. On a subaquatic ground they are but seldom left uncovered by a subsequent deposition or occur in a condition which makes it possible to discriminate them from the omnipresent signs of wave-erosion. Nevertheless, some geologists have succeeded in ascertaining indubitable glacifluvial erosive records formed below the sea level also (cf. Munthe 1913). It is especially in the Swedish literature dealing with the oses, that remarks anent vestiges of glacifluvial erosion are rather commonly met with, e. g. in the works of A. G. Högbom (1901, 1910, 1913, p. 93), B. Högbom (1916), J. Frödin (1914, pp. 116—119), and Gavelin (1910, pp. 16—21, 91—94). These vestiges are often connected with marks of marginal erosion (described above on pp. 63—70), or grade over into such. In Tanner's memoir there are several mentions of glacifluvial erosion (1915, pp. 230—234, 280—281, 284, 296—297, 299—302, 312, 317—318, 386, 397, 410, 423—424, 597). In fact, such traces occur, as the author has been able to state, still more commonly in all parts of Finnish Lapland than might be judged from Tanner's descriptions. Most of the geological surveyors have obviously not been aware of, or have not considered worthy of mention, the frequent association of eskers and eroded spots, or even naked rocks. Similar cases are described in the two esker studies of Tanner (1928, 1930 b). As to North America, the valuable monograph of Stone is again the best source of information, containing, for instance, the following statement (1899, pp. 429—430): ''Along the courses of the osar rivers are many gaps in the ridges where we can now see the former beds of these rivers. In a few places, — — —, a ravine of erosion has been excavated in the till. Generally where the larger glacial rivers crossed the hills, or on steep down-slopes, we do not find a definite ravine of erosion, but the till is scanty or almost wholly absent over an area several times as broad as the ordinary breadth of the osar. In these places there is less till than in the surrounding country, and we must admit a large removal of till, both the englacial and the subglacial. On the other hand, there has been but little erosion of till in several places and on several divides where the circumstances would appear to be favourable to erosion.''

At the well-known locality of Dal's Ed in Sweden, described by G. De Geer (1910), there may possibly occur signs of glacifluvial erosion on even a larger scale than De Geer has assumed. According to his interpretation, the two large gravel plains surrounding Lake Lilla Le have been deposited by an esker river that followed the deep valley which now forms the basin of Lake Stora Le, extending in the N. 10° W. direction northward from the plains. It seems, however, possible to form, even at a distance, another conception of these phenomena, assuming a certain analogy with the facts observed in the Ritakoski area. The main part of the glacifluvial waters may have poured into the valley from the supra-aquatic upland in the N.N.E., in their course nearly coincident with the direction of the striae. On this patch there is, according to De Geer's maps and descriptions (1910, pp. 14—17), an exceedingly barren, rocky landscape with a number of lakes. This might well have originated just through the erosion caused by the esker stream during the relatively long standstill of the ice margin.

In spite of all the ample evidence in favour of powerful glacifluvial action, there are still some naturalists who do not feel convinced by it. Thus Leiviskä denies again, in a paper lately published (1928), the importance of glacifluvial erosion also, rejecting entirely the glacifluvial theory concerning the origin of the eskers. He considers them, according to conceptions which in the eighties were maintained by Gumaelius in Sweden (1876), as accumulations of englacial drift. Leiviskä's arguments and conclusions have already called forth grave and pertinent objections (Sauramo 1928, Tanner 1929 b, Hellaakoski 1929, p. 40), which are summarized by Tanner in the following words (1929 b, p. 166): ''Herr Leiviskäs Schrift hat keine Belege erbracht, welche die Auffassung von der Entstehung der Osar durch glazifluviale Sedimentablagerung hätten erschüttern können.'' As Leiviskä's conclusions have been mentioned, without criticism, even in the literature abroad, it seems necessary here to refute them once again.

Leiviskä's endeavour simply to explain away all signs of glacifluvial erosion (1928, p. 170) is characteristic of his way of treating the results of other scientists, if these are not in harmony with his own subjective conceptions. He has himself, in studying especially the subaquatic eskers of Southern Finland, had hardly any opportunity of observing phenomena of the character here described, nor, in general, of becoming acquainted with the characteristic features which occur scattered over the wide supra-aquatic territories. These are, on the other hand, very familiar to Tanner and to the Swedish geologists mentioned above. Leiviskä has, however, a priori become convinced of the invalidity of the glacifluvial esker theory (1928, pp. 167, 185), and has imagined that the explanation of the origin of the forms of the eskers is of fundamental importance for the solution of the esker problems (p. 185). In order to ascertain whether ''esker forms'' still originate at recent glaciers which bear resemblance to the extinct continental ice sheets, he undertook a journey to Iceland. In describing the drift accumulations at the ice edges of Iceland and comparing them with Finnish eskers, he does not sufficiently take into account the results obtained in other areas, as given in the bulky literature concerning glacial formations, which in great part seems to be unknown to him. On p. 181 one reads, for instance: ''Da ich früher nur die Alpengletscher kennen gelernt hatte, überraschte mich bei den Gletschern auf Südisland die grosse Masse der Innenmoräne und der aus dieser durch Ablation entstandenen Obermoräne an den Gletscherrändern.'' He proceeds to describe the forms of this ablation moraine, and accounts for their origin, arriving at the result that all the characteristic forms of the eskers, also those belonging, in his opinion, exclusively to the eskers, occur here in more or less perfect development. As to the kettle-holes, for instance, he is led to the conclusion (p. 189), ''dass an der Entstehung von Osgruben durch Schmelzen von Eisblöcken, die sich aus der Eismasse loslösten und ganz oder zum Teil von Schotter bedeckt wurden, nicht zu zweifeln ist.'' Not a single reference is given to other, earlier investigations dealing with similar, often still more typical examples. Leiviskä even seems to be ignorant of the excellent descriptions given by American geologists of the Alaskan Piedmont glaciers which are regarded, by glaciologists all over the world, as throwing more light than any others on the formation of glacial marginal deposits under recent conditions (cf. Russell 1893, Tarr 1908, 1909, Tarr—Martin 1914). As to the kettle-holes, Leiviskä would have found an illustrative and convincing demonstration in the well-known paper, so rich in information, of Tarr (1908, pp. 94—96).

Leiviskä has, as Tanner points out (1929, p. 173), wholly confounded the conceptions of marginal drift accumulations and glacifluvial deposits, which are, however, decidedly different kinds of glacial deposits. In the marginal complexes of accumulation, they may certainly possess wholly similar forms, become intricately mixed up with, and grade into each other, so that large masses of rather undefined transitional deposits, the "ablation moraines" in the above sense (p. 47) occur, but this does not prove that they are of similar origin. Leiviskä goes as far as to assume that in general no eskers can have been deposited by glacifluvial streams, "dass dort, wo grosse Gletscherflüsse geflossen sind, keine Ose haben entstehen können." Further, "die Tätigkeit der Gletscherflüsse kann keine anderen in den Oslandschaften auftretenden Formen bilden als Schotterfelder" (p. 191). To all other investigators it has been a matter of course that at the recent glaciers, whose margins are comparatively stationary, only chains of marginal accumulations, including the types of glacifluvial deposits occurring in association therewith, can be observed in the moment of creation. Nevertheless, the formation is not yet seen in the same shape as it receives after the definite withdrawal of the ice edge, the total melting away of the buried ice blocks and an eventual considerable upheaval of land, if the deposition takes place in the sea. The longitudinal oses which possibly are just being formed necessarily escape all observation, as Tarr has emphatically pointed out (1908, p. 97). Also Leiviskä admits that the formation of radial ose chains cannot be observed in the present conditions. This is, however, the crucial test of the esker problem. The forms alone are, in most cases, a rather indifferent and incidental matter, essentially due to slumping and many secondary agencies. In most cases, however, also the forms of ridges consisting of moraine and oses consisting of sand and rolled pebbles, are so different that it is possible to distinguish between both phenomena already at a distance. And as to the material, the difference is essential between the common till which is so rich in fine silt, and the esker gravel which bears indubitable evidence of the action of flowing water.

## SUMMARY.

In the first part of his study (pp. 12—36), the author endeavours to show that the considerable differences of the levels in Northern Lapland are due to fault movements of comparatively recent date. The previous form of the topography was probably a gently-rolling, for the greatest part almost peneplain-like surface, which in the W., S.W. and S. parts of the region still is nearly unchanged and wholly preserved in its pre-Glacial shape. It now lies 250—350 m. above the sea. Towards the E.—N.E.—N., this surface is bordered by a large, nearly continuous, curved belt of mountains, whose summits in general rise to absolute levels of 500—700 metres. The mountain belt is situated along an outstanding, peculiar unit of Archaean rocks, the so-called granulite formation of Lapland. The regular and smoothly curved outer (S.W.) boundary of the granulite area consists of four subordinate outward projections with three inward turned bends. The middle one of these bends is very pronounced and more acute than the others, and in front of it the mountain belt is wholly broken by a low-lying (below 200 m.) opening. In front of the projections, again, the hills stand most closely clustered and attain their highest altitudes. The mountain belt is composed of a row of uplifted blocks of the ancient peneplain, every block now forming an individual mountain group. Some of the mountain blocks have been tilted during the upheaval, and all have later been considerably dissected and reduced by erosion, although several boundary fronts still vividly resemble fault scarps.

On the inner zone of the granulite curve, in its middle and E. portion, the country relief is continually very uneven and irregular, but this region lies at considerably lower levels than the chief mountain belt. Its topography has been notably affected by glacial action. Farther N.E., mostly beyond the granulite area, the gentle-shaped peneplain is encountered again, but here it is faulted down to a lower level than on the other side of the mountain belt. Around Lake Inari it lies only 120—150 m. above the sea level, forming the "basin of Inari", but ascends gradually again towards the Arctic Ocean, N. of

Lake Inari reaching as high a level as 300 m. The scooping out of the big rock basin of Lake Inari is to be attributed to the land ice.

The mountain belt is crossed by several rivers which have excavated deep valleys of a youthful shape. The largest of them extend far into the peneplain area beyond. Some of them are wholly typical, pre-Glacial river-cut valleys, others exhibit, in addition, a considerable effect of glacial erosion in their carving out. Most of the valleys have largely adjusted themselves to fissures and fracture lines in the substructure, partly revealing this relation in their shapes also. In the normal valleys, not modified by glacial action, one is able to distinguish several steps of backward erosion, indicating pauses during the general lowering of the base-levels that controlled the valley cutting. The origin of the young valleys, and the date of the corresponding faults, may be placed within the late Tertiary periods. The uplift of the mountain massifs, on the other hand, has apparently taken place already during the early Tertiary or still earlier, but local faultings within this zone have occurred even fairly recently. All the faults referred to may be regarded as remote expressions of the Alpine orogeny.

The second part of the study principally deals with the occurrence of glacifluvial deposits and the records of late-Glacial hydrography in the valleys. The eskers of the region in question have been deposited on a supra-aquatic floor or in shallow water. Some of the long and well-developed ose chains run across the mountain belt, availing themselves of gaps and river valleys. In crossing watersheds, the eskers, as a rule, are large and very continuous on their proximal (S.W.) sides, but about the divide they disappear, and are absent for long stretches on the distal (N.E.) sides of the divides. The bed of the esker chain here usually descends with a marked slope to a much lower level than on the proximal side of the divide. The ose reappears lower down, often showing imposing dimensions. On the distal slope the seat of the esker chain is indicated by denuded rocky surfaces and other signs of strong glacifluvial erosion, and elsewhere also eroded zones often alternate with esker accumulations (cf. the description of the Ritakoski area, pp. 41—62, and Pl. II—III). On the valley slopes marks of lateral streams which flowed along the margins of ice tongues are of common occurrence. Also in rather narrow valleys the larger gravel deposits have generally assumed typical esker forms, partly expanding into wide flat-topped terraces, all of which, at any rate, are primary late-Glacial deposition forms, and have not been noticeably changed or reduced by post-Glacial river erosion. In some cases it is clearly in evidence that also very distinct gravel terraces in narrow valleys have been deposited unilaterally on one side of the valley bottom only, the other side having been occupied by the basal portion of the valley ice tongue.

On pp. 54—55 the author presents some views concerning the occurrence of gold in late-Glacial gravel terraces of the Ritakoski area.

## REMARKS TO THE MAPS, PLATES IV AND V.

On the orographical map, Pl. IV, four different categories are indicated. The areas without any shading are more or less perfectly peneplain-like in character. All the other areas are ruled with checkered lines in different shades. The darkest shade indicates the strongest relief, as represented by the mountain groups on the granulite belt. The boundaries of this belt are also drawn out in broken lines. The next lighter shade (obliquely ruled) has been given to a single, rather large area only, lying on the inner (concave) side of the curved mountain belt. This area is very mountainous also, but exceedingly irregular in character, only a few elevations attaining relative heights equal with those prevailing within the mountain belt. All the other, less important supplementary kinds of relief are indicated by the lightest shade, including lower and disconnected parts of the mountain belt, scattered, comparatively low groups of mountains elsewhere, and areas highly dissected by valleys.

The Norwegian territory is left out of consideration and without designations, except for the continuation of the high granulite mountains on that side, and the boundary of the post-Archaean Gaisa formation.

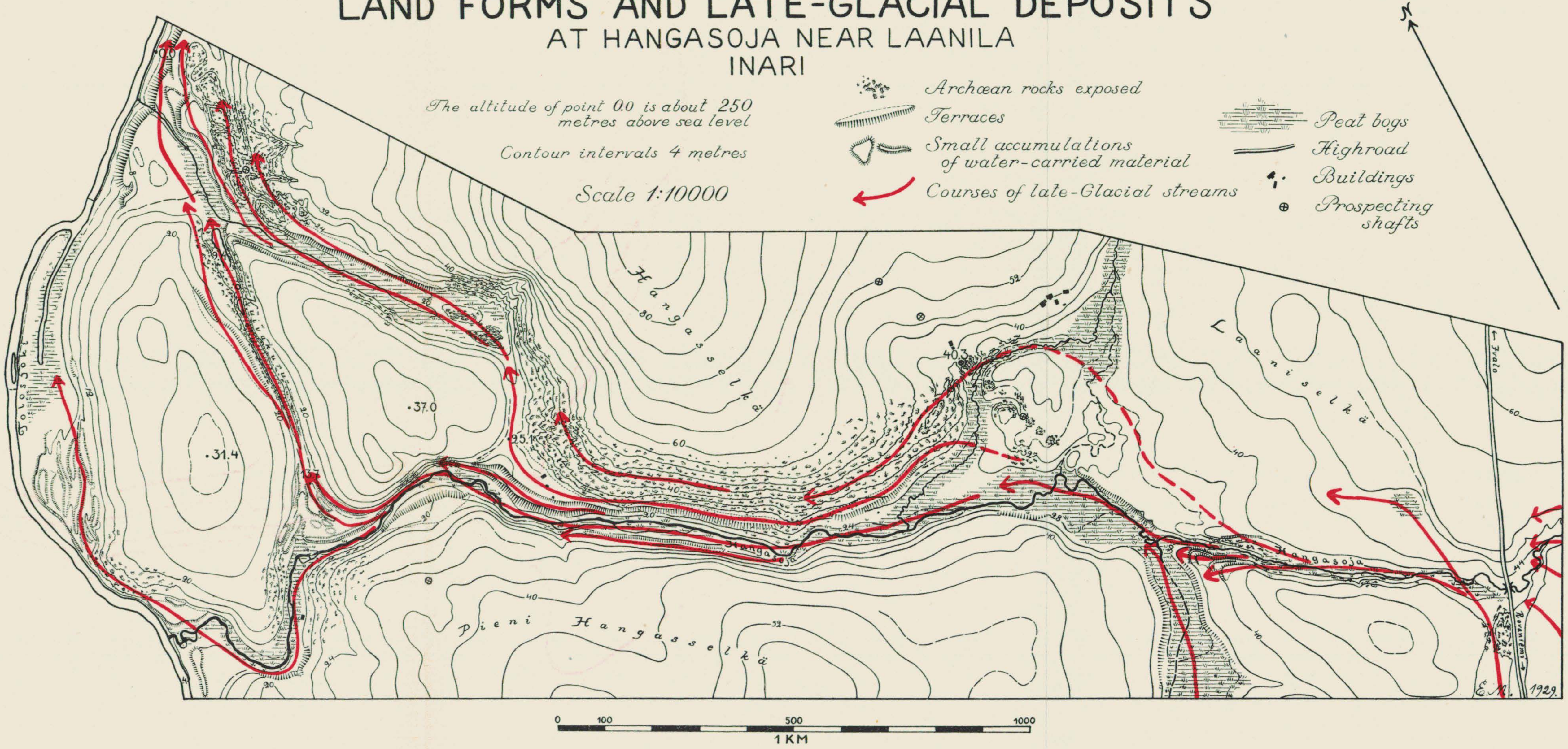
On the map of the late-Glacial formations, Pl. V, the glacifluvial (and alluvial) deposits are indicated by the shaded areas. The arrows denote the most important late-Glacial spillway channels (locally also lateral erosion zones) known up to the present. The Maanselkä-divide is marked by a dotted line. Besides Norway, also the Petsamo territory has been left out of consideration owing to insufficient information.

The boundaries of the areas of Hangasoja and Ritakoski, which have been mapped in detail, are designated on both maps.

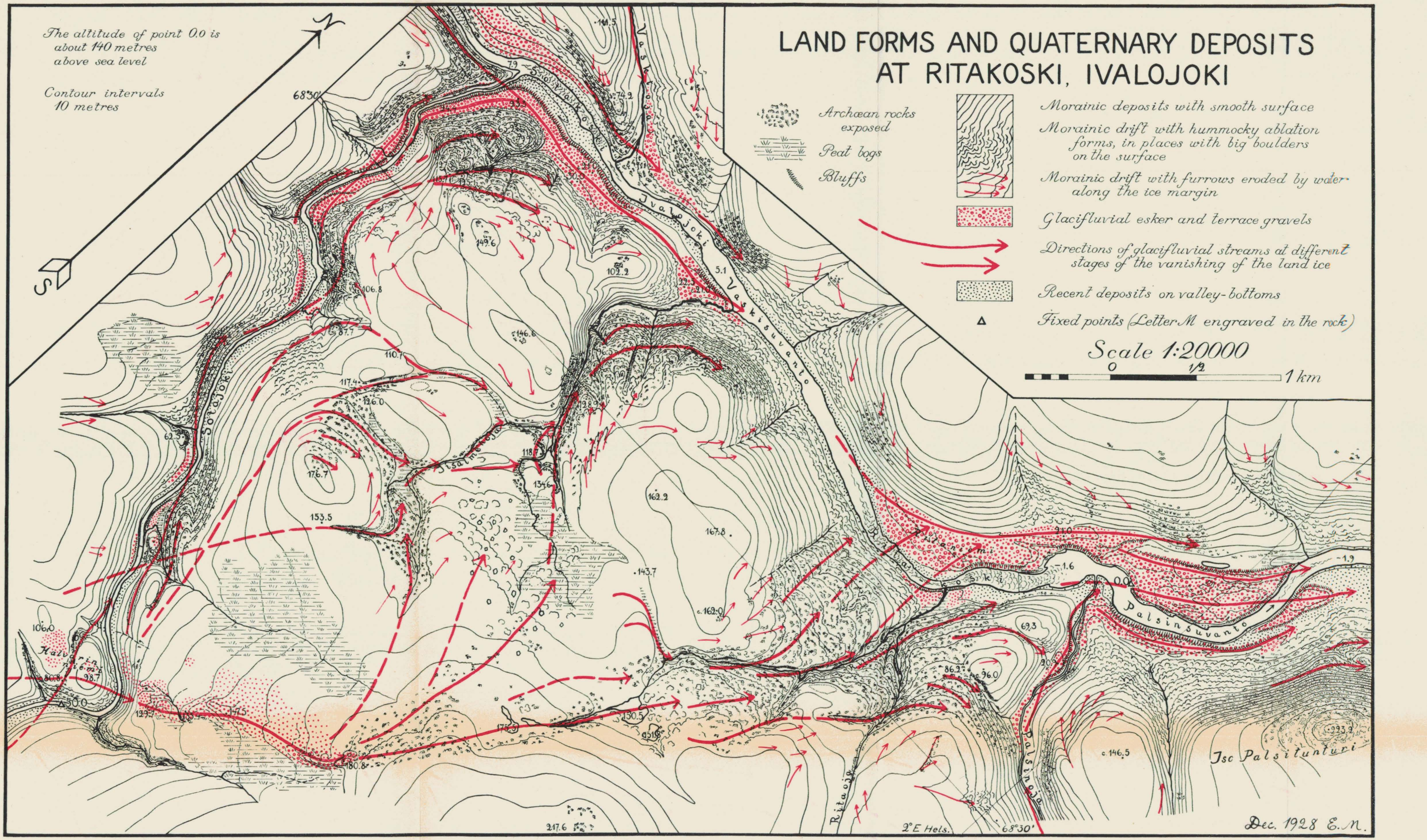
Explanation of some Finnish (and Lappish) words entering into the composition of topographic names.

| | |
|---|---|
| järvi | lake |
| joki | river |
| oja | brook |
| koski | rapids |
| köngäs | cataract, waterfall |
| suvanto | stillwater |
| saari | island |
| niemi | cape, peninsula |
| vaara, tunturi | hill, mountain |
| tunturit | group of mountains |
| pää, laki, oaivi | hill, summit |
| autsi, audshi, kuru | gorge, canyon, channel |
| harju, puoldsha | esker, ose |
| pankki | gravel terrace |
| mella | bluff |

# LAND FORMS AND LATE-GLACIAL DEPOSITS AT HANGASOJA NEAR LAANILA INARI



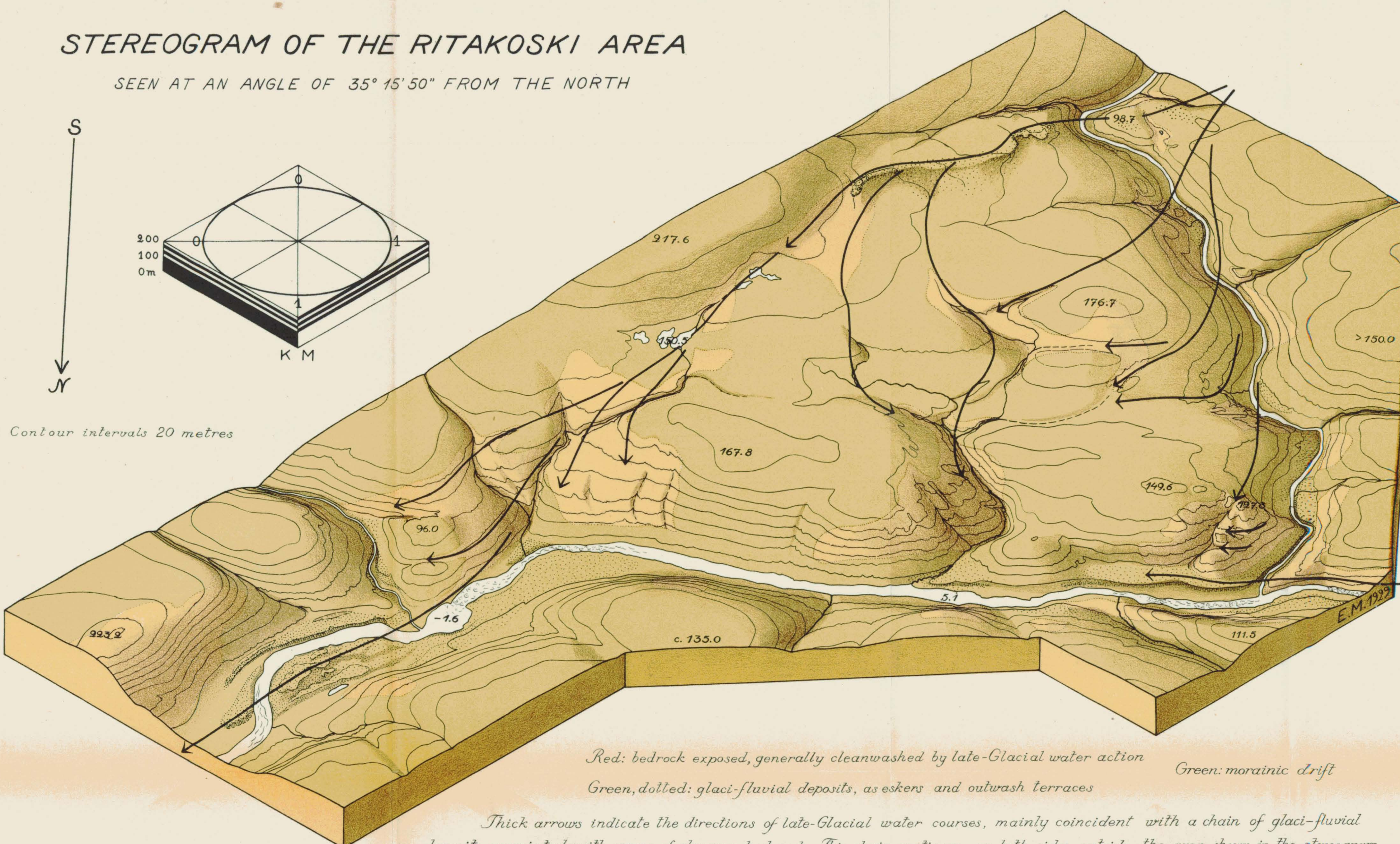

Erkki Mikkola: On the Physiography and Late-Glacial Deposits in Northern Lapland.




Erkki Mikkola: On the Physiography and Late-Glacial Deposits in Northern Lapland.

# STEREOGRAM OF THE RITAKOSKI AREA

SEEN AT AN ANGLE OF 35° 15' 50" FROM THE NORTH



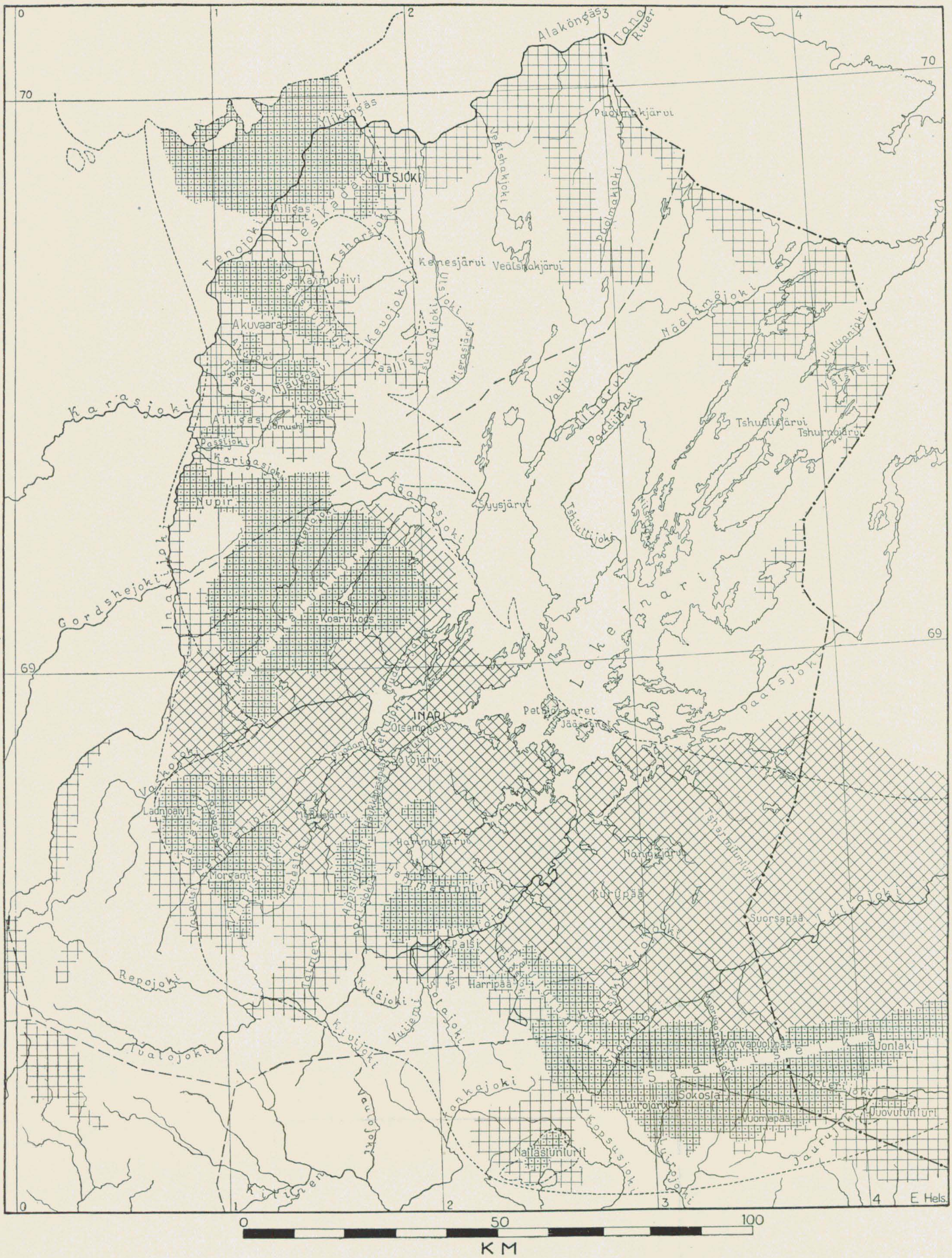

*Red: bedrock exposed, generally cleanwashed by late-Glacial water action*

*Green: morainic drift*

*Green, dotted: glaci-fluvial deposits, as eskers and outwash terraces*

*Thick arrows indicate the directions of late-Glacial water courses, mainly coincident with a chain of glaci-fluvial deposits associated with areas of cleanwashed rock. This chain continues on both sides outside the area shown in the stereogram.*

TILGMANNIN KIVIPAINO.




Orographical Sketch Map of Northern Lapland.

Scale 1: 1000000.

Explanations on p. 83.

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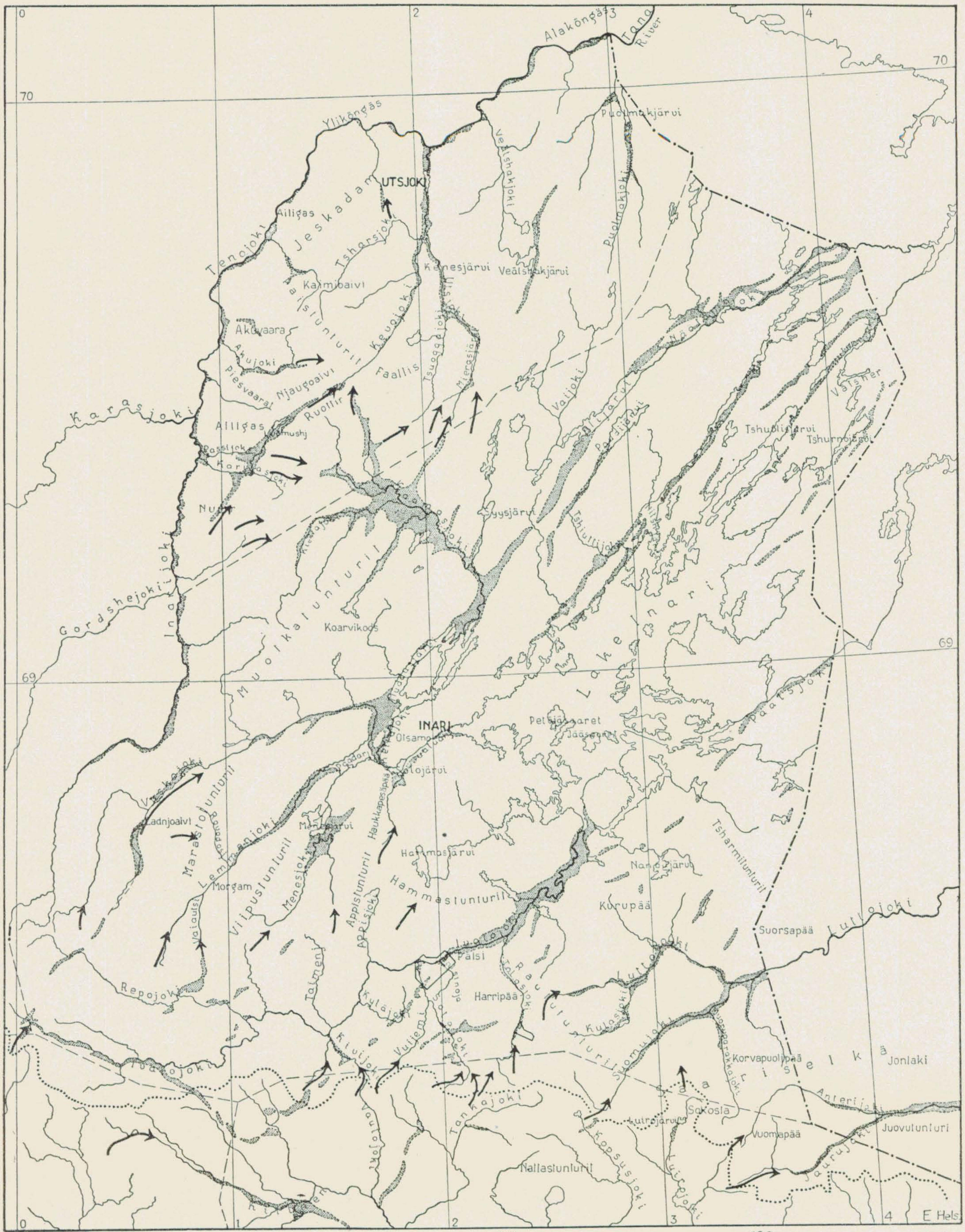


General Map of Glacifluvial Formations in Northern Lapland.

Scale 1: 1000000.

Explanations on p. 83.

*Erkki Mikkola:* On the Physiography and Late-Glacial Deposits in Northern Lapland.

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N:o 65. Über die Petrologie des Otravaaragebietes im östlichen Finnland, von MARTTI SAXÉN. Mit zwei Karten, 13 Abbildungen im Text und 5 Figg. auf 1 Tafel. Dezember 1923.................................................................. 30: —
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