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N:o 210

ON ICE-MARGINAL FEATURES IN SOUTHWESTERN FINLAND

BY

K. VIRKKALA

WITH 33 FIGURES IN TEXT

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ABSTRACT

The author has undertaken to describe the occurrence in southwestern Finland of three major chains of ice-marginal features, which bear the collective name of Salpausselkä. The description deals with forms, structural elements and material components. Numerous marginal formations also exist in the areas situated between the three great systems as well as in the foreland. The designation of Näsijärvi marginal formation is proposed for the marginal features which stretch across the northern part of the region and the westernmost portion of which is known as Hämeenkangas.

The portions of the Salpausselkä systems that occur as ridges evolved principally in crevasses running parallel to the ice front, whereas the portions strewn out over extensive areas are mainly of proglacial origin. Climatic factors were more important than topographical features in causing the margin of the continental ice sheet to stagnate and oscillate in the Salpausselkä zone.

At least Salpausselkä I formed in the region as early as the end of the Older Dryas. However, the scantiness of the observation material obliges us to leave the problem as a whole an open one.

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INTRODUCTION

The ice-marginal features of southwestern Finland are relatively little known. With the exception of Leiviskä's (1920) weighty monograph on the Salpausselkä systems, which consists in the main of morphological description, the data concerning the marginal features to be found in the region of southwestern Finland have up to the present been limited to observations of individual sections and small areas or to scattered information obtained in other connections. Noteworthy among studies dealing with the ice-marginal features of southwestern Finland are: Leiviskä (1927), Metzger (1927), Sauramo (1931, 1958), Bauer (1939), Hyyppä (1950, 1951), Donner (1952), Okko (1957) and Virkkala (1961). In addition, many of the explanations accompanying the map sheets published by the Geological Survey of Finland include descriptions of such features, though in most cases they are of a rough or general nature (Moberg 1879, 1880, 1882, 1883; Tigerstedt 1888; Sauramo 1924). Moreover, the superficial deposits of portions of minor ice-marginal formations located in the coastal area have presented in certain soil maps (Aarnio 1934 a and b, 1936; Vuorinen 1941).
been

By southwestern Finland is meant in this study the region that extends approximately from Helsinki to the northern side of Tampere and from there due west to the coast (Fig. 1).

The glacial deposits of southwestern Finland consist in the main of four great chains, the most important of which are the long-known First, Second and Third Salpausselkä systems. Across the largest lake in the region, Näsijärvi, there also runs a fairly sizable chain of ice-marginal features. Its western portion comprises Hämeenkangas, which has previously been described, at least in part, as a marginal glacial deposit (Sauramo 1924). The ice-marginal features of Näsijärvi belong to a larger complex, which stretches far into central Finland, or, including the long gaps, all the way to the region lying north of Jyväskylä (Saksela 1930).

Besides the large chains just mentioned, quite a number of smaller marginal accumulations of glacial drift have been found in southwestern Finland. Careful exploration will undoubtedly bring to light more. These

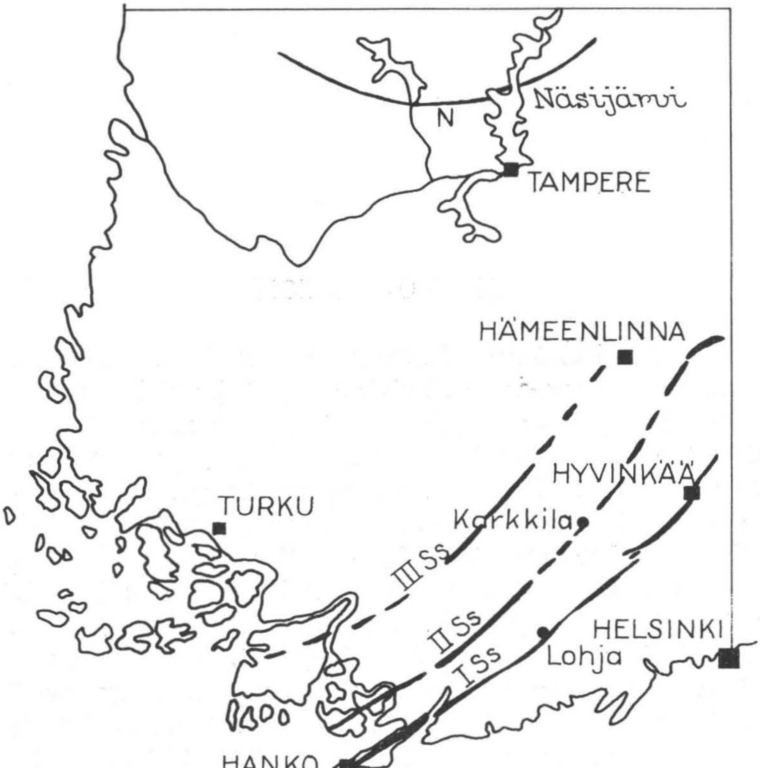

Fig. 1. The region investigated and its most important ice-marginal features. Ss = Salpausselkä, N = Näsijärvi marginal formation.

smaller glacial features occur mainly in the area between the First and the Second Salpausselkä and the near surroundings.

The author has been studying the terminal glacial deposits of the region under consideration since 1950. This research work has been conducted primarily in connection with Quaternary mapping operations, which I have carried out for the Geological Survey in the vicinity of Tampere as well as in the areas covered by the map sheets of Kerava, Hämeenlinna, Lohja and Karkkila. The tracts explored in detail are indeed limited largely to these localities. The geological investigations have been facilitated and, moreover, the Quaternary mapping on the whole made possible by the fact that during the past decade there have appeared numerous topographic map sheets of these — and other — areas published by the General Survey Office on a scale of 1: 20 000. By means of these maps it was possible in many cases to decide where marginal formations might most logically be expected to occur and where detailed investigations ought to be concentrated. In order to fill gaps in his picture of the ice-marginal features, the author has nevertheless been obliged also to utilize economic map sheets drawn on a scale of 1: 100 000 as well as old Russian topographic maps on a scale of 1: 42 000. For lack of better map material, these maps have been consulted especially in the southwestern parts of the First, Second and Third Salpausselkä systems, or in the areas located approximately southwest of the borough of Lohja and the communes of Nummi and Kiikala. It goes without saying that old topographic and economic maps and explorations carried out with them cannot give nearly so clear and complete a picture of the terrain as do the new topographic maps drawn on a scale of 1: 20 000. At least with respect to these areas, the observations on the nature and distribution of ice-marginal features will require checking at a subsequent time, after new topographical maps not yet available have been published.

In 1961 the Finnish Scientific Research Council awarded me a grant to help finance my work, and I wish to express my appreciation in this connection. Gredit is due to Mr. Paul Sjöblom, M. A., for translating the manuscript into English.

ICE-MARGINAL FEATURES IN THE FORELAND OF SALPAUSSELKÄ I

The glacial deposits on the southeastern side of Salpausselkä I are highly scattered. On the southeastern side of certain large and long fault and fracture valleys running from the southwest to the northeast in the bedrock north of Helsinki, there occur extensive glaciofluvial accumulations. Hyyppä (1950) has described them as marginal features that evolved along the ice front. The topography caused the margin of the ice sheet to remain stationary for some time, with the result that ice-marginal plains formed. The present author has also previously described the features (Virkkala 1959), which here form nearly a continuous chain extending from the seacoast to Salpausselkä I. Short eskers link the ice-marginal accumulations together.

The rest of the ice-marginal features of western Uusimaa are considerably more fragmentary. Following them in the terrain is made difficult, furthermore, by the fact that the bedrock in the region is highly broken up. The greatest local differences in elevation are some 70 or 80 meters. Under these conditions no clear and continuous chains of glacial deposits could develop. Many of the ice-marginal accumulations in this region occur in depressions of the bedrock surrounded by washed rock. Many deposits that can be interpreted as ice-marginal features rest on some side against rocky protuberances. Most commonly small glaciofluvial marginal formations line on the southeastern slope of an elevated stretch of rock. Morphologically they are not so clearly defined as the marginal glacial deposits that had formed freely, that is, independently of the bedrock. Thus, the bedrock has in many cases been the determining factor in the outward appearance of ice-marginal formations in western Uusimaa. Still, numerous minor accumulations of glacial drift do occur that need not thank the bedrock for their form.

In the coastal area there further occur thick littoral deposits, which date back to the post- and late-glacial stages of the Baltic basin. Their occurrence hinders efforts to determine the origin of the sorted material. Littoral accumulations 10 to 15 meters thick are by no means rare here. It is only when there is a clay bed to separate the littoral accumulation from the underlying glaciofluvial material that they can be confidently differentiated.

A large number of occurrences have been found in the western part of Uusimaa province that can only be identified as glaciofluvial marginal

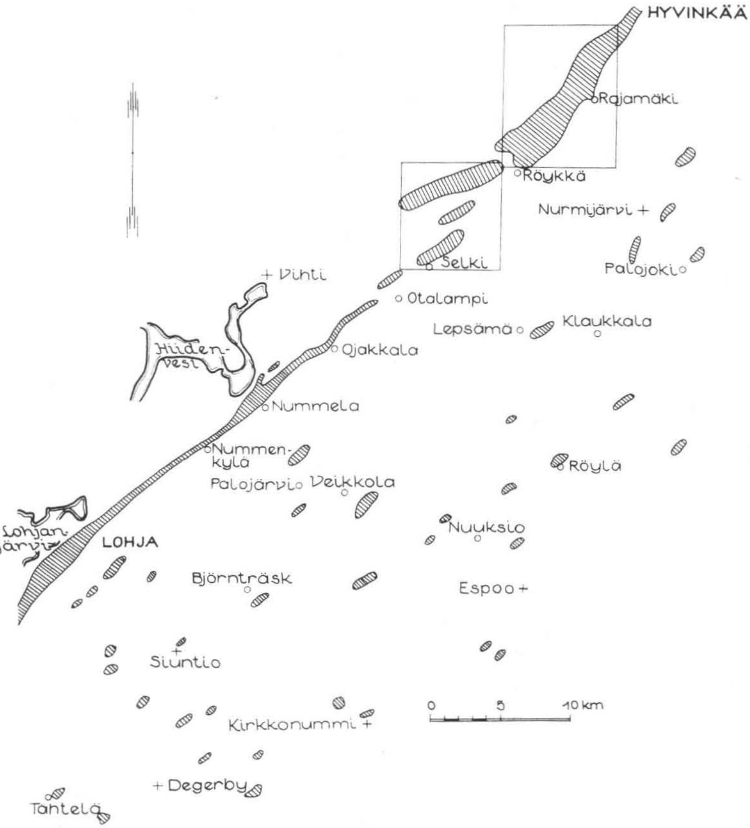

Fig. 2. Part of Salpausselkä I and the ice-marginal features situated in its foreland. More accurate maps are available of areas enclosed in squares.

deposits. They are largely situated in the foreland close to the foot of Salpausselkä I (Fig. 2). Many of them occur in the surroundings of Siuntio, Veikkola and Nurmijärvi, in particular, and small ones can be run across right on the coast. A large proportion of the ice-marginal features lie on the southeastern side of lakes and other basins. Clearly identifiable marginal accumulations have been found, for example, on the southeastern side of Björnträsk and Vikträsk, in the commune of Siuntio, and of Palojärvi and the Veikkola lakes, in the commune of Kirkkonummi.

The accumulation of the southeastern shore of Palojärvi, in particular, seems to be a typical ice-marginal feature — especially at first sight — in form and character. Its northwestern slope is steep and contains till. Closer examination has proved, however, that the occurrence cannot be considered wholly a marginal deposit. It is the bedrock that has primarily molded the steep form of the northwestern slope; indeed, the bedrock actually protrudes in places. Around the protruding rock there lies a bed of till, as is commonly the case in the Uusimaa region. Where the marginal accumulation proper is located is on the lee side of the elevation formed by the protruding rock and the surrounding till.

The ice-marginal feature of Palojärvi is typical with respect to its material and its structure. The material of its proximal portion consists in many places of fairly coarse rock fragments or boulders, which turn into progressively finer components toward the distal side. The gentle distal slope has, however, been exposed to the action of littoral forces. Many kinds of disturbances occur in the proximal portion of the glaciofluvial material. The ice front had moved there, at least to a slight extent, while the deposit was accumulating and pushed till into and on top of the sorted drift. The glaciofluvial material, which had been deposited earlier and which comprises the main part of the occurrence, was further thrust into folds and bends, and many faults resulted. Even varved clay was mixed in with the glaciofluvial material. The layers of clay were pushed upright in places and broken into small pieces. The lack of disturbances in the distal portion indicates that the re-advancing ice front pushed only as far as the middle or the proximal portion of the occurrence — but not beyond to the distal side. Fig. 3 offers a typical example of the disturbed structure of the proximal portion of the accumulation.

The bedding of the glacial deposit at Palojärvi varies considerably. The strata lie at different angles; in cross-section the ones tilted in the distal direction are the most common. In longitudinal section the strata are nearly horizontal.

No clear extensions to the Palojärvi ice-marginal feature can be traced in the surroundings. Small marginal formations, besides those already mentioned, are to be found in the area of the hamlets of Lepsämä and Palojoki, in the commune of Nurmijärvi. The one in the latter locality is a glaciofluvial accumulation of indefinite shape, from the northwestern tip of which extends a short esker. This marks the course of the glaciofluvial stream that deposited the material.

In the northern part of Espoo commune there are numerous small marginal deposits of glaciofluvial drift. The relief of the bedrock in this area is exceptionally high for southern Finland — the greatest local differences in elevation are as much as 80 to 90 meters. That is why the ice-marginal features do not appear conspicuous. Many of them occur as infillings of depressions between high walls of rock. Small glaciofluvial accumulations are to be found especially along the southeastern flanks of steep cliffs.

The material of the marginal glacial deposits consists on their distal sides of sand and on their proximal sides of gravel and in many cases of

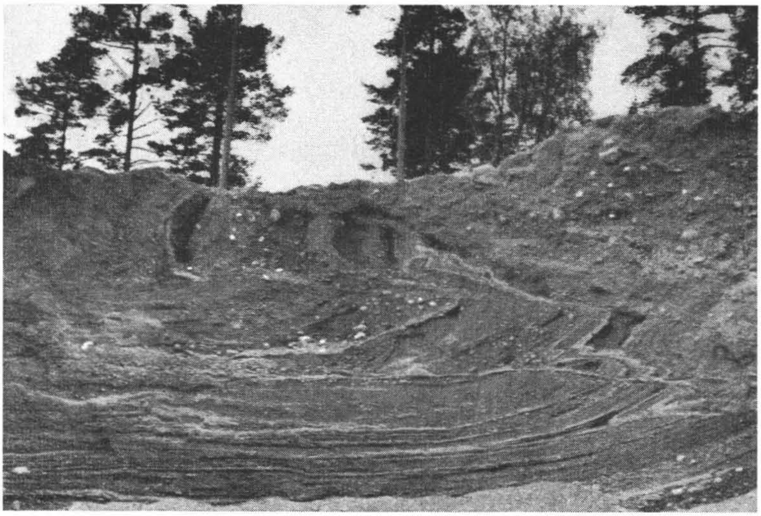

Fig. 3. Folds in the proximal portion of the Palojärvi ice-marginal feature. Covering the folds there is poorly sorted and unstratified, coarse glaciofluvial drift. The proximal portion containing the coarser material lies to the right.

even coarser components. Some of the deposits exhibit the same kind of disturbances of the bedding as was just described (p. 13). The bedding generally slopes southeastward, this likewise being characteristic of the Palojärvi accumulation. Especially in the proximal portions, till or poorly sorted drift is fairly commonly present both on the surface and within the sorted material.

The most important and most extensive of the marginal features located in the foreland of Salpausselkä I in the western Uusimaa area are presented in Fig. 2.

The existence of marginal features in the foreland of the Salpausselkä systems indicates that the ice front had halted locally even before it retreated to Salpausselkä I. The discontinuity of the marginal deposits in the foreland nevertheless suggests that their formation was not due appreciably to general circumstances. Climatic factors were evidently not solely responsible for the origin of the marginal features in the foreland. It was the topography — including depressions in the bedrock and fracture and erosion valleys — that caused temporary stagnations of the retreating ice sheet. But climatic factors undoubtedly contributed to the accumulation of marginal features in the foreland. Local advances of the ice, evidences of which have been observed in many of the foreland features, can hardly signify more than brief periods of deterioration in the climate during the general melting away of the continental ice sheet.

SALPAUSSELKÄ I

LOCATION AND MODE OF OCCURRENCE

In his extensive Salpausselkä study, Leiviskä described the southwesternmost part of Salpausselkä I, or the stretch from Hyvinkää to the southwest, in great detail (Leiviskä 1920, pp. 1—26). In the present connection, only a brief general review of this portion of the system will be undertaken, attention being concentrated primarily on the points in Leiviskä's description that require amplification or correction.

Besides Leiviskä, also Donner (1952) has studied the First Salpausselkä chain and its structure in the Hyvinkää area.

From Hyvinkää toward the southwest Salpausselkä at first narrows to form a clearly defined ridge, with a high and steep proximal flank and a lower and more gently sloping distal flank. Two short eskers branch out from the proximal portion of Salpausselkä.

A few kilometers from Hyvinkää, on the northern side of Rajamäki, Salpausselkä spreads out into broad plateau roughly 130 meters above sea level. In the vicinity of Rajamäki and to the south of it, the character of Salpausselkä is fairly complicated (Fig. 4). In addition to the main ridge, it includes on its western side a number of plateaus and lesser ridges covered in places with blocks (Leiviskä 1920, Fig. 18). According to an oral report from Hyyppä, the occurrence of rocky ground on the plateau closest to Rajamäki, at least, signifies a relict from an earlier sheet of till, which the action of littoral forces has partly washed away. At the level of Rajamäki he has run across a bed of till nearly a meter thick on the surface of the deposit. Underlying the till is a heavy accumulation of glaciofluvial sand. Similar conditions prevail on a couple of other plateaus in the Rajamäki vicinity, too. Notably on their western and northwestern sides, the margins of the plateaus are marked by steep ice-contact slopes with hummocks and kettle holes.

In the tract between Rajamäki and Sääksjärvi there are no plateaus, but Salpausselkä I is represented by three separate, if broad-topped, ridges. The ridge situated farthest to the southeast is the main one, and it is wholly composed of sorted glaciofluvial drift, which littoral forces have given a

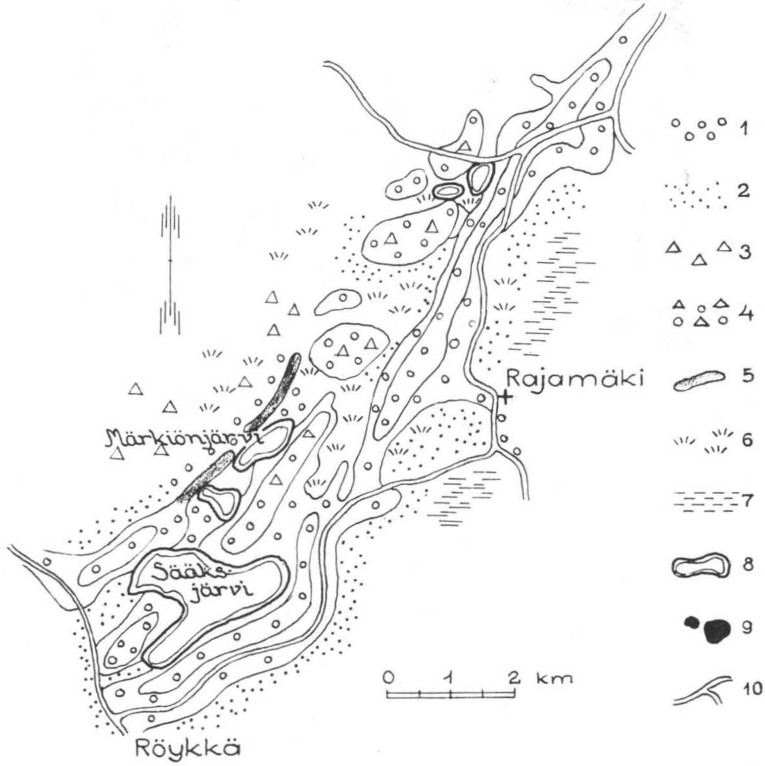

Fig. 4. Salpausselkä I in the Rajamäki—Röykkä area, which lies in the square farther to the north in Fig. 2. 1 = glaciofluvial gravel and sand, 2 = fine sand, 3 = till, 4 = till or poorly sorted drift deposited on top of glaciofluvial drift, 5 = end moraine, 6 = bog, 7 = silt and clay, 8 = lake, 9 = rock outcrop, 10 = motor-road.

thorough going-over. Kettle holes pit the proximal slope of the main ridge, and on its northwestern side is the great kettle of Sääksjärvi. Cut by the lake, the middle ridge is situated about one kilometer from the main ridge toward the northwest. It likewise has a broad, plateau-like top in places, where it is composed wholly of sorted drift. On the eastern and southern sides of Märkiönjärvi, however, the ridge narrows down and is built up of clearly washed and poorly sorted material (Fig. 5).

In its northeastern part, the proximal ridge is narrow and resembles an esker. The material is rather loosely packed but unwashed till. Toward the southwest the ridge broadens out, being composed exclusively of sorted drift.

Southwest of Sääksjärvi the ridge-like form of Salpausselkä I disappears for a distance of many kilometers. It breaks up into fragmentary portions,

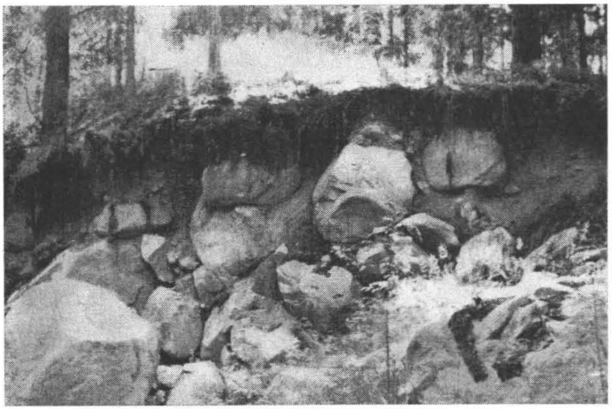

Fig. 5. Poorly sorted glaciofluvial drift contained in the midmost ridge of Salpausselkä I, on the southern side of Märkiönjärvi, between Rajamäki and Röykkä.

including short transverse eskers (Okko 1957), end moraines composed of till and sandy plains (Fig. 6). The beds of sand are relatively thin and outcropping rocks are to be seen here and there. The end moraines are of two types: small ones, occurring alone or in little clusters, and large ones, of which there are a few, reaching a height of between ten and thirty meters and a length of nearly a kilometer. A transverse esker several kilometers long and comprising two different ridges extends from the largest end moraines toward the west-southwest (Fig. 6).

Salpausselkä I occurs once again as a continuous ridge at Otalampi, east of the Vihti church. In places it has very steep slopes; but in other places it spreads out and is indefinite in form, the thickness of the glacial drift being slight, as proved by the fact that the bedrock crops out in many spots. In some places, again, the Salpausselkä system is cut by deep fault and erosion valleys of the bedrock. Here the glaciofluvial accumulations are apt to be several dozen meters thick, although the morphological Salpausselkä does not rise to a height of more than twenty or so meters (Fig. 7).

On the southeastern shore of Lake Hiidenvesi, the system is featured by an extensive spread of the glaciofluvial material, which is throughout sorted and has steep ice-contact slopes. These slopes show the effects of wave action. Ancient beaches can be observed at elevations of 70, 75, 85 and 95 meters, and its flattened summit is 110 to 112 meters above sea level, or 82 meters above the surface of Lake Hiidenvesi. A short parallel accumulation, which is more than a kilometer long, lies on the southeastern shore of lake about one kilometer from the main body of the system toward the northwest.

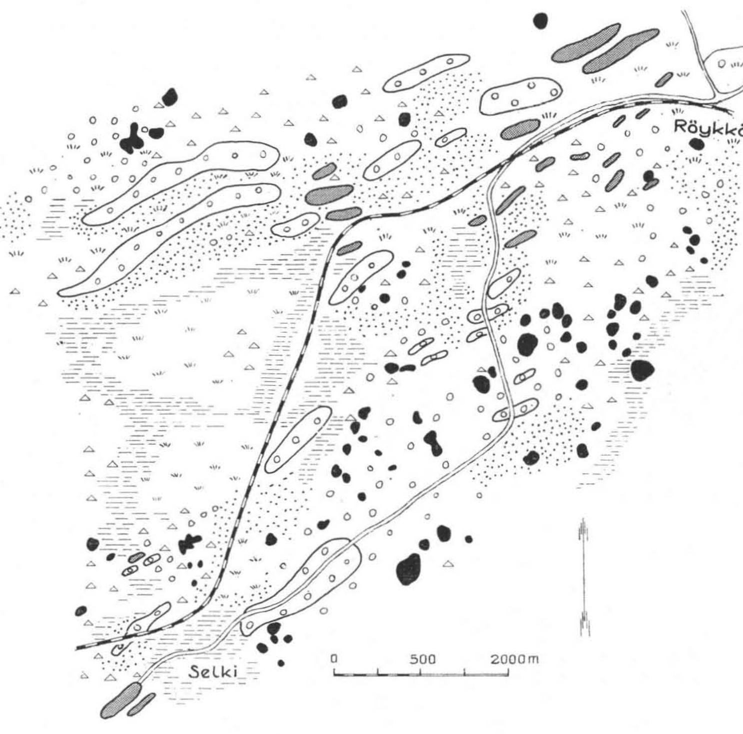

Fig. 6. Salpausselkä I between Röykkä and Selki. The area contained in the more southern square shown in Fig. 2. Explanations as in Fig. 4.

From Hiidenvesi the Salpausselkä chain runs on about ten miles as a continuous, for the most part very narrow ridge between 20 and 40 meters high and with steep, esker-like slopes. On the northwestern side of the ridge proper there spreads out in many places, as at Nummenkylä and on the northern side of the borough of Lohja, plains of glaciofluvial sand, which extend for a distance of a couple of kilometers. The sandy stretches are not, however, continuous but are cut by outcrops of rock and islets of till. On the surface the sands have been redeposited by littoral forces.

When it reaches Lake Lohjanjärvi, Salpausselkä once again broadens out into an extensive plateau, which towers some 63 meters above the surface of the lake, or about 95 meters above sea level. But the highest point of the ridge there rises ten meters more above the general level of the plateau.

From Lohja in a southwesterly direction the ice-marginal accumulation loses altitude and extends as a rather low but nevertheless in many places a clearly defined ridge all the way to the town of Tammisaari.

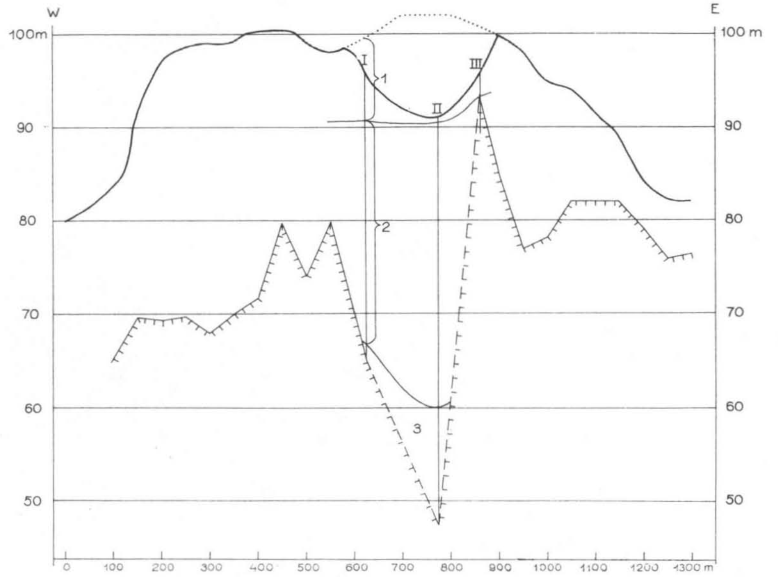

Fig. 7. Slat cross-section of Salpausselkä I and the bedrock of its base at Ojakkala, Vihti. I—III = drilling sites. The depth of the bedrock determined seismologically; noted also at drilling sites. Dotted line indicates original ground level at locality of gravel pit. 1 = gravel and coarse sand, 2 = medium sand and fine sand, 3 = fine sand and coarse silt. Geotechnical Office of the City of Helsinki.

In the area of Raasepori the system gently rises to a height of about 30 meters above its surroundings, or about 60 meters above sea level. The effects of littoral action have made its proximal slope here gentler than the distal side, but elsewhere it is somewhat steeper than the distal side. In the vicinity of the railroad station of Raasepori there extends from the proximal side of the main ridge an end moraine nearly a kilometer long and 15 to 20 meters high, the top of which is covered with blocks and the edges with littoral sand.

Even on the very coast Salpausselkä is pitted with gently sloping kettle holes five to ten meters deep, which to some extent are filled with littoral deposits. The lowest of them in the surroundings of Tammisaari are roughly 25 meters above sea level.

Between Tammisaari and Hanko, Salpausselkä I is totally levelled out across much of its extent. Moreover, it is covered with thick littoral deposits and eolian sands. On the Hanko peninsula small areas of rock break up its continuity in places. The system can be followed for some distance under the sea as shallows.

STRUCTURE AND MATERIAL

The sorted drift of which Salpausselkä I is principally composed is on the whole distinctly stratified in the region investigated. Numerous gravel and sand pits, which are to be found on both distal and proximal sides and in some places cutting across the entire accumulation, give a relatively good idea of its internal character.

In cross-section Salpausselkä I may be observed to exhibit three main types of structure. The beds either tilt across the entire accumulation from

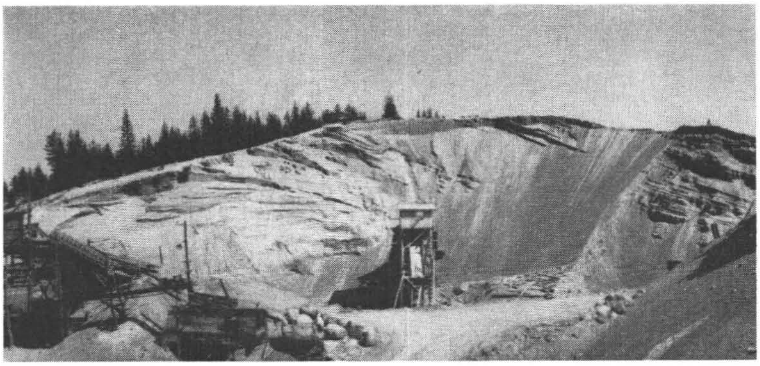

Fig. 8. In Salpausselkä I the beds tilt toward the distal side throughout many of the ice-marginal features. Otalampi, Vihti.

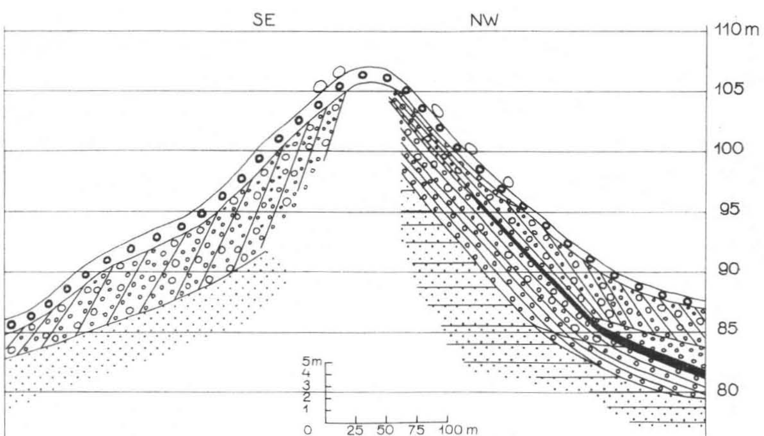

Fig. 9. Cross-section of Salpausselkä I between Ojakkala and Otalampi. 1 = varved clay, 2 = fine sand, 3 = coarse sand, 4 = gravel, 5 = pebbles.

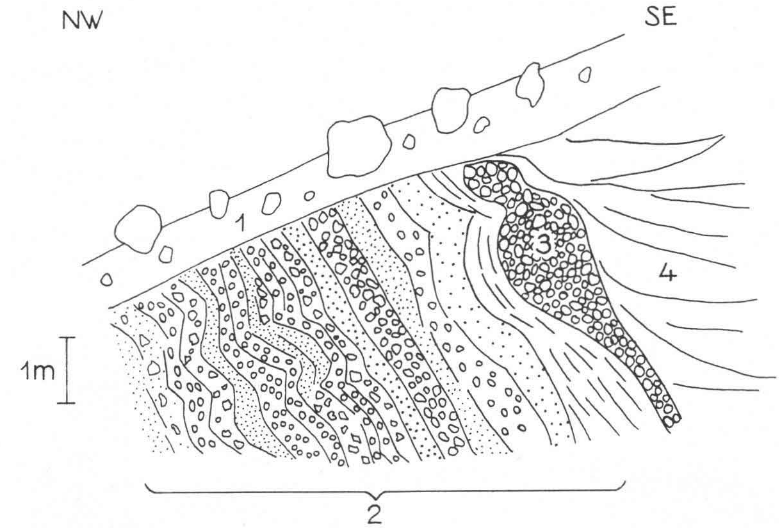

Fig. 10. The poorly sorted glacial drift on the surface has in the process of accumulation push ed upright underlying glaciofluvial layers. 1 = poorly sorted material, 2 = upright and winding layers of glaciofluvial pebbles, gravel and sand, 3 = cobbles and pebbles, 4 = nearly horizontal glacio fluvial layers of sand and gravel. Vihti, Selki.

the northwest toward the southeast, or in a distal direction (Fig. 8), or then they have a gradient conforming to the surface so that on the proximal side they tilt toward the northwest and on the distal side toward the southeast (Fig. 9). Particularly in the middle part of the feature, cross-bedding is common. In the first case, the material clearly came from the northwest, or pretty nearly at right angles to the accumulation. In the second case, the material may have come to some extent also from a direction parallel to the long axis of the system. In glaciofluvial deposits as a whole, the stratification is also likely to incline upstream, that is, whenever the process of accumulation occurred under conditions of pressure. Thus, it is quite possible that also in the second case the material was principally transported to Salpausselkä at right angles to its trend.

On both slopes of Salpausselkä I — though particularly on its distal side — underneath the surface layer of stones and gravel about one or two meters thick, there occurs in many places a nearly uniform stratum in which large blocks are mixed in with pebbles and cobbles. This rocky bed may be regarded as the boundary between the primary glaciofluvial material and the littoral accumulation derived from it. Littoral forces washed away the finer components from the glaciofluvial drift, thereby enriching the cobbles and blocks on to its surface portion.

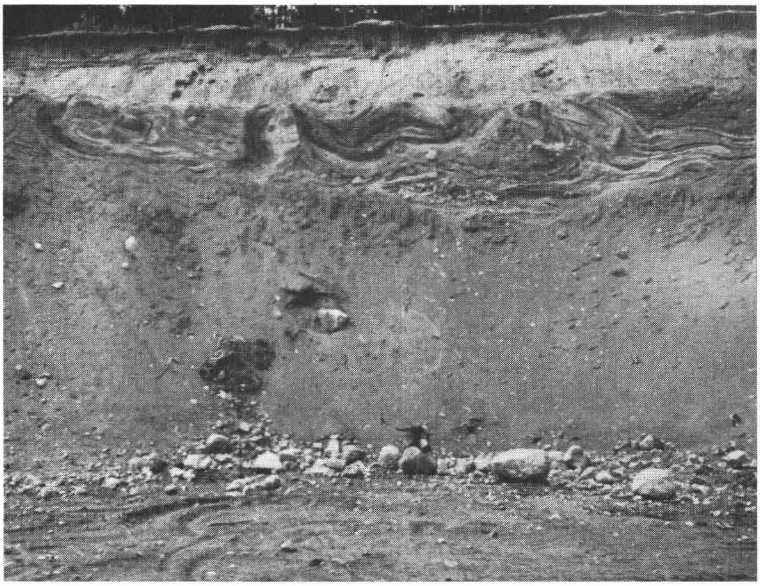

Fig. 11. Folds on the summit of Salpausselkä I in the borough of Lohja. Lying on the surface, an approximately three-meter littoral accumulation, which discordantly cuts the underlying icepushed folds, which are about two meters high and two or three meters broad. The center of the folds consists of till containing, among other components, limestone.

Generally speaking, the lower slopes and, especially, edges of Salpausselkä I are largely buried under thick littoral deposits. Only in a few places do the Salpausselkä slopes exhibit wholly original features. Quite often one will see wave-cut cliffs worn out of the slopes, below them spreading thick littoral deposits, which in many cases lie on the slopes on top of beds of varved clay (Fig. 9).

In long section the bedding is very nearly horizontal. In many cases, furthermore, the layers have a gentle inclination lengthwise. The stratification thus closely resembles that of eskers. With complete justification one might therefore in many places apply to the First Salpausselkä chain — also with respect to its material — the designation of transverse esker.

The internal character of the system does not, however, everywhere conform to the foregoing description. The structure of the proximal and the distal portions of Salpausselkä I often reveals clear differences. Besides the feature already described of the beds tilting toward the southeast also in the proximal portion, stratification disturbances are a common occurrence in the proximal portion, whereas in the distal portion they are either lacking or their occurrence is notably weaker.

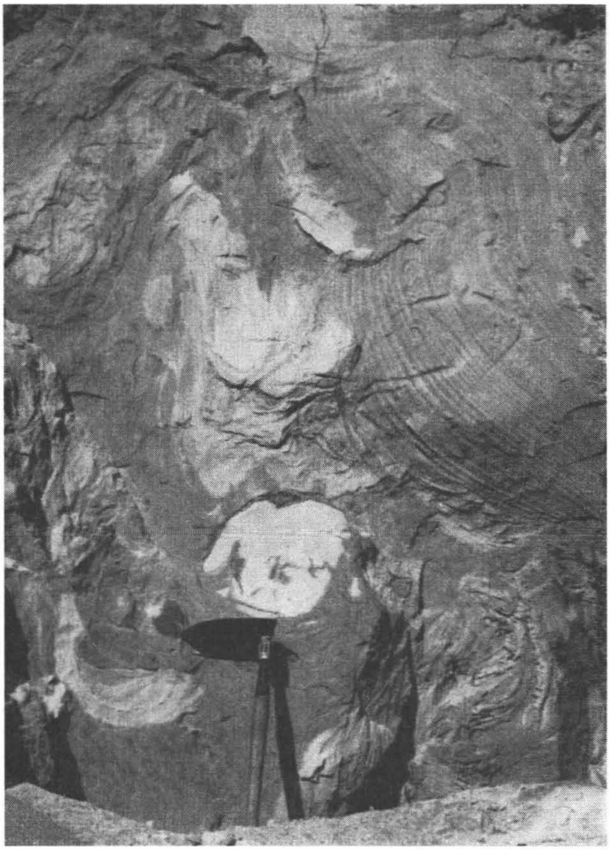

Fig. 12. Deformations of the stratification on the proximal side of Salpausselkä I, about 1 km to the northwest of Nummenkylä. At right, top, varved sediment, the light portions consisting of medium sand, the dark portions of fine sand.

In the proximal portion of Salpausselkä I many of the layers have undergone folding and in some cases have even been thrust upright (Fig. 10). Large folds are to be found on the proximal slopes and even on the summit, but never on the distal side of the chain (Fig. 11).

Many kinds of other deformations of the normal arrangement of layers commonly occur on the proximal slopes of Salpausselkä. These disturbances are not limited wholly to the chain proper. Quite strong disturbances caused by pushing action of the ice sheet and extending to a depth of several meters are also exhibited by the glaciofluvial sandy stretches on its proximal side (Fig. 12).

Fig. 13. The block-strewn summit of Salpausselkä I at Raasepori, ten kilometers to the north east of Tammisaari.

Further, till or, at least, poorly sorted drift can be found in many places in the proximal part of Salpausselkä in the region investigated on top of, within or mixed with the sorted material. In addition to the plateaus of the vicinity of Rajamäki already mentioned, till has been run across at various places in the area between Otalampi and Ojakkala, in the surroundings of Nummenkylä and in an area a couple of kilometers long southwest of it as well as along and near the harbor track leading to the borough of Lohja. Till and poorly sorted glacial drift also occur on the proximal slope of Salpausselkä, in places even near the summit, within the borough limits of Karjaa.

In mechanical composition the till is in some cases gravelly with large blocks and in other cases a sandy kind with less than the normal content of rock fragments. In the former cases, littoral forces have washed the finer constituents of the till away. The till is thus featured by either a uniform or a scattered rocky mantle, which occurs quite commonly in the areas discussed and in many other places along the proximal slopes and on the summit of Salpausselkä. A very extensive boulder field covers the proximal slope and summit of the ice-marginal accumulation in, for instance, the vicinity of the railroad station of Raasepori (Fig. 13). The occurrence of the boulder field seems to indicate here, too, the ancient distribution of the till mantle over the Salpausselkä chain.

Sandy till containing few pebbles has been found at Nummenkylä overlying the glaciofluvial drift to a thickness of a meter or a meter and a half but underlying the littoral accumulation (Fig. 14, Flint 1947, p. 128.) A fabric analysis shows that the till was transported on the average from

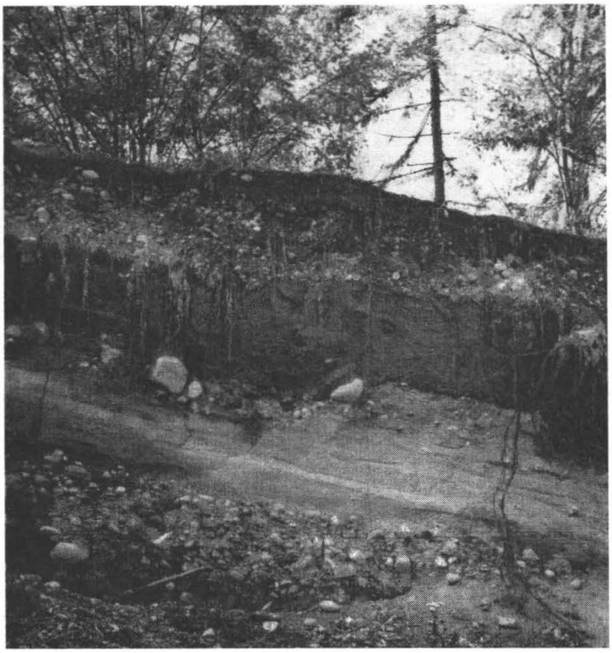

Fig. 14. Till underlying the littorl accumulation of the proximal portion of Salpausselkä I. Nummenkylä.

the northwest. The striations also bear witness to the fact that the final movement of the ice sheet in this area had very much the same direction. When the till was pushed on top of the sorted drift the original stratification was in places totally destroyed or, then, the beds were forced upright.

Besides the summit and the surface of the proximal part of Salpausselkä, till can also be found within the formation, where it occurs as small layers and lenses. Such till contains little pebbles and is densely packed (Fig. 15). Till is further present inside the foldes shown in Fig. 11. According to a fabric analysis, the ice sheet had pushed across the sorted drift here, too, from the northwest. Subsequently, littoral forces washed away part of the till, cut the folds and laid deposits over the formation.

The grain size of the material varies quite considerably in Salpausselkä I. The blocks lying on the surface in some cases measure several cubic meters in size, but there are boulders buried in the accumulation as well. They are mostly angular or rounded only at the edges (Fig. 5). The spaces between the buried boulders are sometimes filled with sand, but other grain sizes are entirely lacking.

Fig. 15. Till layer about 40 cm thick at a depth of five meters from the surface of the very top of Salpausselkä I. Lohja.

Among the boulders all grades of material down to very fine sand have been found. Generally the material is coarser in a narrow ridge than in a broader formation. The most common grain sizes are coarse sand and gravel. This makes the material highly valuable for many construction purposes. In many places there is quite a considerable difference between layers lying next to or on top of each other with respect to their mechanical composition, what with exceedingly fine sand apt to border abruptly on a bed of coarse pebbles. In other places, again, there may occur beds a dozen meters thick with practically no change in the grain size of the material.

Very fine drift has been found in drill holes in the western extension of Salpausselkä at Ojakkala. Here the material appears to turn gradually finer toward the bottom, where a mixture of coarse silt and very fine sand prevails (Figs. 7 and 9).

As a general rule the coarsest material occurs in the proximal portion of Salpausselkä (Leiviskä 1920, p. 242). Here the grain size of the components gradually diminishes toward the distal side. However, according to Hyyppä, on the plateau of Rajamäki previously referred to (p. 14) the preponderantly fine-sandy material underlying the till occurs on the proximal side of the gravelly and sandy main body proper of the ridge. The same sort of situation exists also in the Nummenkylä area. The depth and distance from the shoreline of the water determined the detailed variation in grain size of the littoral accumulation lying on the surface.

Many a stone count has been made to determine the direction of transport of the glacial drift composing Salpausselkä I. The bedrock of the region makes it a thankless task, for on both the proximal side of the chain and along its longitudinal axis it is largely identical. Certain lithological observations, however, cast light on the direction of transport of the material.

In the borough of Lohja, where on the immediate northwestern side of Salpausselkä there is the famous limestone quarry of Tytyri (Parras and Tavela 1954), limestone erratics have been run across in the corresponding portion of Salpausselkä. Boulders of limestone measuring a full meter in diameter are among them, having traveled only a couple of kilometers southeastward from the host rock. Limestone fragments are abundantly present within the folds of till shown in Fig. 11. On the southeastern side of the limestone quarry of Ojamo, in the Lohja area, no fragments of the rock have been discovered in the corresponding part of Salpausselkä, whereas finds have been made about two kilometers south-southwest of Ojamo. The limestone erratics first traveled one kilometer toward the southeast from Ojamo into the Salpausselkä chain and thereafter another kilometer parallel to the chain toward the southwest.

In numerous stone counts made between Vihti and Tammisaari, the rock components of Salpausselkä have been further found to include one to four per cent of sandstone. The proportion of sandstone increases toward the south, accounting for five to ten per cent of the total between Tammisaari and Hanko. Insofar as the sandstone erratics were not carried from still unknown sites, their host rock must be the Satakunta sandstone occurrence, the closest portions of which are located some 120 km northwest of the Salpausselkä system. For the greatest part of this distance, the sandstone fragments must have traveled together with till. The long-distance transport of the sandstones is further indicated by the fact that they occur in the main only in the grain size of pebbles. Moreover, they are all considerably rounded.

The occurrence in the Salpausselkä system of both limestone and sandstone testifies to transport rather from the northwest than in line with the long axis of the system. Still, drift must also have been carried in the latter direction, at least from the northeast toward the southwest.

It should be remarked, further, that one block of rapakivi has been found at the edge of Salpausselkä near the railroad station of Röykkä (Miss Pirjo Vaasjoki, student). And Hyyppä orally reports having discovered a couple of fragments of rapakivi on the plateau of Rajamäki as well as near the church at Kirkkonummi. The westernmost rapakivi erratics have been found, however, in the ice-marginal deposit at Veikkola, in the foreland of Salpausselkä, at a height of roughly 75 meters and in the parish center of Siuntio (Moberg 1880, p. 19). Salpausselkä I thus appears to constitute the western limit of the distribution of rapakivi in the region. These rapakivi blocks were not dumped by the ice sheet, however, but were carried from the rapakivi area of southeastern Finland by ice floes (cf. Hyyppä 1950, Virkkala 1959).

THE ORIGIN OF SALPAUSSELKÄ I

The very forms of Salpausselkä in the region make it plain that the system evolved in several stages (Hyyppä 1951). In the district of Rajamäki and Röykkä, it is divided into three parts: the distal part is built of the most highly sorted drift, the middle one represents an intermediate composition, and the proximal portion consists partly of till. The till mantle to be found also in the Otalampi—Ojakkala district, the surroundings of Nummenkylä and many other localities provides evidence that the Salpausselkä system developed in not less than two stages. Between the different stages there occurred a withdrawal of the ice margin, followed by a readvance. The ice sheet did not retreat far, however, at most a few kilometers. At Nummenkylä, at least, the distance was two kilometers. Whether the readvance brought the ice back to where there had been an earlier marginal accumulation has not yet been definitively ascertained. It is conceivable that the existing marginal accumulation formed such an obstacle to the forward movement of the thinned-down glacier that the ice was no longer capable of surmounting it. Probably there was still some stagnant ice left in front of Salpausselkä I and in its foreland. In moving forward the glacier deposited till on top of the glaciofluvial material and caused disturbances in the previously laid beds.

The margin of the ice sheet probably remained in the belt occupied by Salpausselkä I for a fairly long time. According to the varved-clay chronology drawn up by Sauramo (1918, 1923), the ice front lingered in the Salpausselkä I belt a couple of hundred years.

The retreat of the ice was not followed everywhere by a readvance. Especially in the areas of large basins, the melting and thinning ice margin stood fast — at least, no signs of ice movements have been observed in the areas of Lakes Hiidenvesi and Lohjanjärvi. The wasting away of the ice margin in these areas probably did not slow down, either. Meltwater thus collected in abundance in such places, where the stagnation of the ice was caused by the topography. As a result, broad extensions of Salpausselkä occur notably in the vicinities of Hiidenvesi and Lohjanjärvi. On their proximal side they leaned up against the edge of the live glacier, whereas on their distal side they were bounded by a band of dead ice (cf. von Bülow 1927, Woldstedt 1950). Accordingly, even where it was deposited in more or less deep water, the glaciofluvial drift was prevented from spreading far across the foreland. On the other hand, glaciofluvial deposits occur in the immediate vicinity of the proximal slope of Salpausselkä. The drift was discharged there during the local retreat of the ice front.

Moreover, the esker-like shape of the Salpausselkä ridge for long distances provides evidence that there had been walls of ice on both sides during the stage of deposition. Otherwise, the drift would have spread much farther and not piled up into a narrow esker. Such two-sided ice-contact features could develop inside tunnels running through the ice or in open crevasses. It is hard to imagine that in the marginal zone of the wasted ice sheet there could have existed tunnels of the vast dimensions presupposed, for example, by the extended accumulations of drift at Lohja and Nummela. The more plausible explanation is that Salpausselkä I originated within a crevasse or crevasse zone running roughly parallel to the glacier margin (Hyyppä 1951).

What it was that caused the crevasses parallel to the ice front to develop and the glacier to stagnate along the Salpausselkä belt has not as yet been satisfactorily explained. Certain researchers lay stress on the significance of topography (e.g., Leiviskä 1920) and of tectonic factors (Hyyppä 1950, Härme 1961). It can be seen from the topographic maps of the region that at least no great topographical differences appear to exist in the various parts of Salpausselkä. The elevations are approximately the same on both sides of the chain. No major regional variations in the topography could therefore evidently have caused the ice front to come to a standstill along the line of the Salpausselkä system.

Smaller topographical differences in elevation may have halted the advance of the ice front and caused it to crack. Such differences in elevation do occur in the surroundings of Salpausselkä and presumably also underneath it quite abundantly. The bedrock of western Uusimaa as a whole is broken up by fracture and erosion lines running in different directions. They run not only parallel to the Salpausselkä system but across it (cf. Fig. 7). Many of the differences in elevation are of such an order of magnitude — 40 to 50 meters, and even more — that it would be easy to imagine crevasses developing in the marginal parts of the shrunken ice sheet on that account and movement being prevented or at least retarded. However, the same kind of topography extends for many ten kilometers on each side of the ice-marginal feature. Moreover, in localities where the relief is more even, the feature largely has the same appearance as in localities of higher relief.

It would be strange, furthermore, if fracture valleys varying in size and trend had caused a system of crevasses as uniform and largely rectilinear as this to develop in the ice. Apparently, therefore, the topography did not alone determine the primary origin in the region investigated of Salpausselkä I.

Climatic conditions probably were thus principally responsible for the immobilization of the ice sheet along the Salpausselkä I line. Owing to a deterioration of the climate or an increase in precipitation, the processes of accumulation and ablation achieved a mutual equilibrium, with the result that the ice front remained stationary there. The topography probably had at least a local effect on this stagnation. Even during the period of stagnation of the ice margin, changes continued to occur in the climate. The extremes of variation caused the ice margin to recede for a distance and then to advance once again. During smaller fluctuations of the temperature, however, such oscillations did not occur. The coefficient of expansion for ice is so considerable that even a drop of a single degree in temperature causes a shrinkage of one meter in a distance of 20 km (Dorsey 1953). Although the compressive strength of ice is relatively great, its tensile strength is very slight. The tension created by a decrease in temperature causes crevasses to open up in the ice, mainly parallel to the margin. Repeated fluctuations in the temperature probably produced a whole system of fractures in the marginal zone of the glacier. During the summer months the meltwaters running into the crevasses warmed the surface of the ice and wore away the edges; in freezing the waters split the fractures wider. The meltwater streams further carried drift off the ice into the crevasses; the drift piled up against the crevasse walls and also spread in a lengthwise direction.

As the glacier progressively wasted away, the ice on the distal side of the crevasses eventually lost contact with the main sheet. It turned a narrow collar of dead ice, which gradually vanished by melting after the development of the marginal feature. It is owing to the local topography and the small quantity of drift contained in the ice that no tracts of ablation moraines proper evolved in the region investigated.

The meltwaters that supplied the primary components of the Salpausselkä system in this region flowed in the main at right angles to the accumulation. They have left behind memorials of their ancient courses in the form of eskers branching off the proximal margin of the Salpausselkä chain. Their comparatively small number and modest size bear no relation, however, to the monumental dimensions of the terminal accumulation. The likelihood is that the biggest part off the proximal eskers disappeared principally at the stage when the ice front moved back and forth along the Salpausselkä line and advanced over previously formed eskers.

But meltwaters flowing at right angles to the Salpausselkä system could scarcely have alone piled up material sufficient to build a transversal ridge many ten kilometers long, even though it did evolve in a glacier crevasse of limited breadth and even though there might have been considerably more meltwater rivers than the few places still betraying evidences of their existence in the past would suggest. It is necessary to assume, besides, that drift transported by meltwaters also spread lengthwise along the accumulation. In most cases there was a collar of dead ice in front of the glacier's edge to prevent the drift from being deposited in the foreland. It was the local topography that determined in which direction the material brought by the meltwaters could spread. The general gradient of the ground in the region is from the northeast toward the southwest, although locally and for short distances the land surface may tilt in the opposite direction, too. The transport of the drift toward the Salpausselkä system thus primarily occurred from the northeast toward the southwest, and there also exists lithological evidence of this (see p. 26).

However, drift was apt to be carried to the marginal accumulation also in other ways. At least in the coastal area, the glacier retreated out of deep or moderately deep water, although there, too, it stood on rock bottom. The crevasse in which Salpausselkä I was deposited was accordingly partly filled with water. Waves and currents wore away the ice and loosened the drift in it, causing a mixture with the drift swept down by streams of meltwater (cf. also Leiviskä 1920, pp. 339—360). There was not time enough for the material worn loose by the waves to become sorted so thoroughly as that transported by meltwater. This material is intermediate between till and stratified drift, and it occurs quite commonly in many places in the Salpausselkä I system in the region investigated.

Fabric analyses made of the till in the near surroundings of Salpausselkä show, along with numerous observations of the glacial striae, that the ice sheet moved across the region on the whole from the northwest toward the southeast, or at right angles to the ice-marginal feature. The mean value of the striae observations is 320° (reading clockwise from the north) and the range of variation is 295°—345°. The last and most powerful movement of the ice sheet occurred from the direction 320°.

Till fabric analyses and striae observations indicate that the glacier movement had the same direction on both northwestern and southeastern sides of the chain. Salpausselkä I does not therefore form any boundary between movements of glacier ice advancing in different directions.

THE TERRAIN BETWEEN THE FIRST AND SECOND SALPAUSSELKÄ SYSTEMS

The terrain between the Salpausselkä systems is by no means lacking in ice-marginal features, either, but here their occurrence has a distinctly local character. In the surroundings and southwest of Lake Hiidenvesi, such deposits are very scarce. The relief in this area is so high and the bedrock so broken up that features of this kind could not develop. Toward the north and northeast the relief becomes less prominent and ice-marginal features begin to make their appearance, sparsely at first but then more and more abundantly.

The densest occurrence of these features is in the tract between Röykkä and Loppi. Northeast of this occurrence, they are lacking from the gabbro area on the western side of Hyvinkää, where the bedrock is greatly broken up and split by numerous fracture valleys. Between Riihimäki and Tervakoski, again, the topography is conspicuously more even and ice-marginal features reappear, though not in so great an abundance as between Röykkä and Loppi. The general character of the ice-marginal features in the last-mentioned area is represented in Fig. 16. Quite imposing accumulations are to be seen, finally, in the surroundings of Riihimäki, particularly on the eastern side of town near the proximal edge of Salpausselkä I.

The ice-marginal accumulations in the terrain situated between the Salpausselkä chains are composed of both till and stratified drift. The till deposits form moraine ridges of different sizes, their height varying from one to about twenty meters and their length from twenty or so meters to several kilometers. The latter constitute more or less distinct transverse eskers or glaciofluvial formations of indefinite morphological character, which in all cases do not have any clear orientation. They are often, indeed, to be found filling the depressions between elevations of rock.

Large end moraines occur especially north of Vihtijärvi on the shores and in the surroundings of Valkialampi. The end moraines bounding opposite shores of the pond are particularly imposing ridges, rising to heights of 15 to 20 meters and extending for a distance of approximately three kilometers. They are esker-like in form, and on earlier Quaternary maps

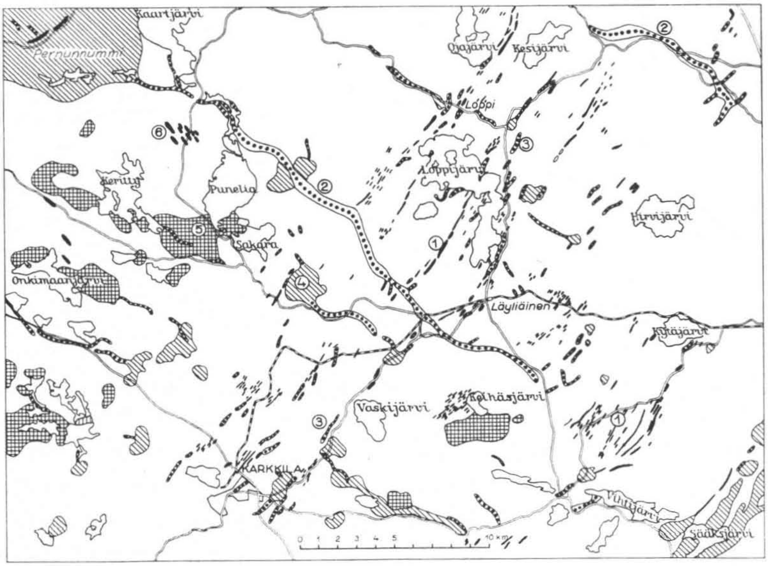

Fig. 16. Certain glacial forms in the area of the map sheet of Karkkila. Part of Salpausselkä I shown in the lower corner at right. The belt of Salpausselkä II is situated between Karkkila and Loppi. The extensive Pernunnummi in the left upper corner belongs to Salpausselkä III. 1 = end moraine, 2 = esker, 3 = transverse esker, 4 = other glaciofluvial accumulations, often forming plains, 5 = ablation moraine, 6 = drumlin.

(Leiviskä 1920, Sauramo 1918, 1923) they have been erroneously marked as composed of stratified drift. The southern ends of both moraines are relatively symmetrical and gently sloping, whereas the northern parts are asymmetrical. Their distal sides are markedly steeper than their proximal sides. In their northern parts the end moraines were evidently created by thrusting action of the glacier, while in their southern parts they had evolved subglacially (Chamberlin 1894). The more eastern moraine branches off at its northern end into numerous smaller terminal moraines, which merge at a higher elevation into an indefinite hummocky moraine tract. After only a short distance the hummocks trend approximately north and combine to form ridges ½ to 1 km long and 5 to 10 meters high.

An end moraine tract of a different character lies in the southern part of Loppi on the western side of Keihäsjärvi (Fig. 17). Some 100 small end moraines have been counted here during mapping operations, the majority of them being of the annual end moraine type. The length of the largest end moraine is roughly 600 meters, and it varies between five and ten meters in height. Its distal slope is quite steep and covered with great boulders. Seen both on the map and in side profile, the larger end moraines

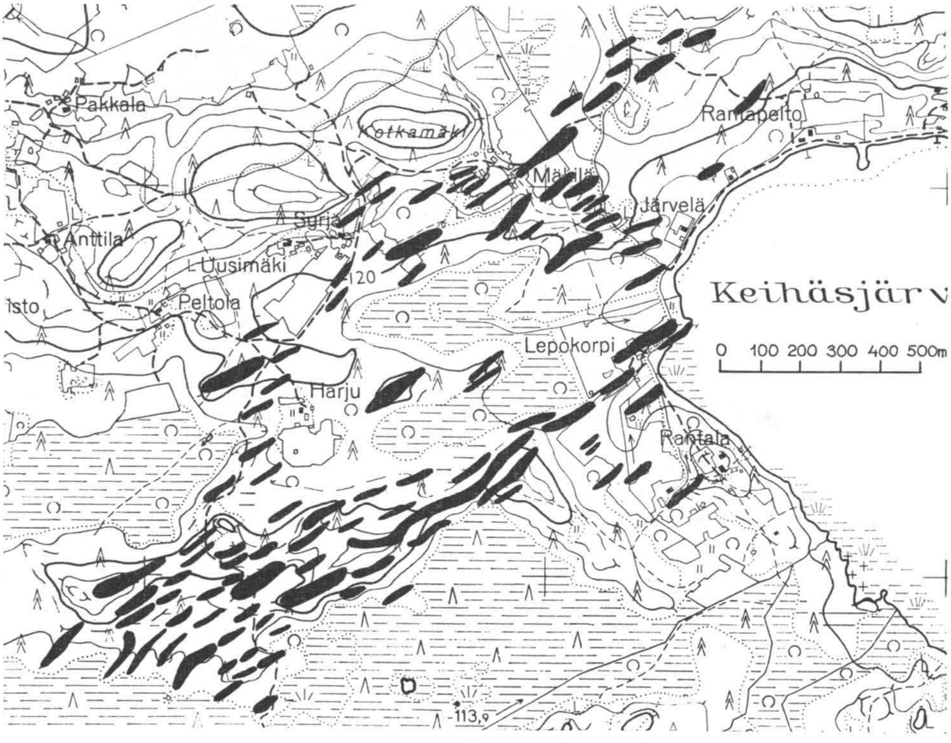

Fig. 17. Small end moraines on the shore of Keihäsjärvi, Loppi.

are serpentine. The majority of the moraines are very modest in size, however, averaging a hundred meters in length, between five and ten meters in width and one and five meters in height. They are relatively symmetrical in form. The small end moraines are in many cases situated in rows in such a way that at the point where there is a gap in one row there occurs in the next row an end moraine.

A swarm of small end moraines of the kind just described is located on the eastern and southeastern sides of Läyliäinen, where dozens of these glacial features can be seen, most of them small but some of them as much as half a kilometer long. End moraines mainly of the annual variety to be found occurring individually or in small clusters also in the vicinity of Riihimäki as well as in the area between it and Tervakoski.

Ice-marginal features composed of stratified drift are also shown in Fig. 16. Some of them are short transverse eskers, some glaciofluvial deposits of indefinite form, which along one or another edge rest against higher rocky ground. In these cases, the bed rock had apparently caused a crevasse

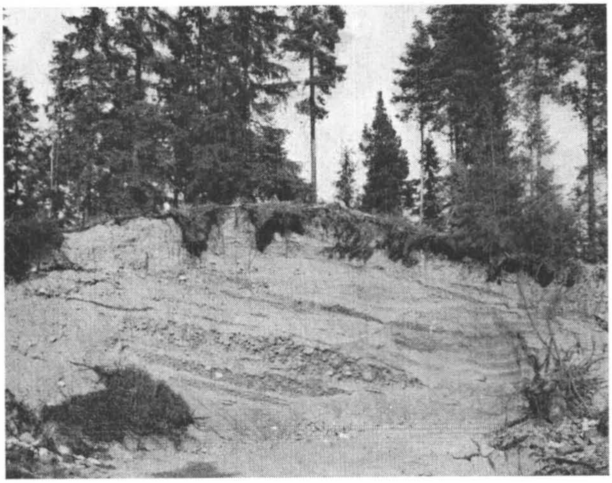

Fig. 18. Section of small transverse esker, eastern part of Loppi commune. Throughout the cross-section, the beds incline toward the distal side.

or a series of fractures to open up in the marginal zone of the shrunken glacier. Meltwaters had then deposited drift into the openings. The distances traveled by the glaciofluvial drift must have been very short. This is proved by the lithological composition of the material, which, as in the case of the till, too, bespeaks mainly a strictly local origin.

The structure of the glaciofluvial formations is in many instances — quite as in the First Salpausselkä system and its foreland — somewhat asymmetrical. Deformations generally occur in the proximal parts, represented by twisted, upthrust or folded layers. Till or poorly sorted drift occurs on the surface or imbedded in the stratified material. During the formation of these accumulations, the ice sheet was obviously active and, at least to a slight extent, oscillated locally. The stratification tilts, as in in the Salpausselkä I system, either in conformity with the slopes or throughout the feature toward the distal side (Fig. 18).

One feature deviating from the rest in the intermediate terrain lies a few kilometers east of the borough of Karkkila. It is a glaciofluvial accumulation, which rises between 20 and 40 meters above the surrounding country. The top is as flat as a table and on nearly every side it is bounded by steep ice-contact slopes. In the middle of its proximal portion there are a few large kettle holes, but no esker branches off from it. The accumulation evidently originated in an ice-free depression of considerable size situated in the marginal zone of the thinned-down ice sheet.

Between Hikiä and Hämeenlinna there is a large esker, which runs almost continuously across the terrain separating the Salpausselkä systems. Farther south there are no eskers of this kind. A couple of large eskers branch off the transverse eskers around the middle of the intermediate area (Fig. 16) and continue without a break across the Salpausselkä II belt. It is on the southeastern side of the more southern esker that the impressive end moraines of Valkialampi, which have already commanded our attention, are located (cf. p. 31).

The numerous ice-marginal features situated in the terrain between the First and Second Salpausselkä systems provide evidence that the ice front did not retreat uniformly in this area. There were periods of stagnation and the glacier's edge made local advances as well, and it was under such conditions that drift accumulated. In certain parts of the region, as in the vicinity of the great esker on the northern side of Hyvinkää, the ice margin withdrew along a continuous front. In parts of the intermediate terrain farther south, again, the glacier melted away in place to some extent, while elsewhere, especially where the ice stood in deep water, it disappeared by calving. Thus, the ice margin behaved in different ways in different sectors, largely depending on the local topography of the base.

SALPAUSSELKÄ II

LOCATION AND MODE OF OCCURRENCE

As far as the western part of it is concerned, Salpausselkä II is more poorly known than Salpausselkä I. Leiviskä has given us a less thorough description of it than he has of the other system, and to some extent the description is marred by errors (Leiviskä 1920, pp. 111—132). Okko (1957) has described in great detail a small segment of Salpausselkä II in the vicinity of Jylisjärvi, and the present writer has previously studied the system in the area of Hämeenlinna (Virkkala 1961).

In Figs. 19 and 20 there is a summary presentation of the situation of Salpausselkä II and the material composing it from Hämeenlinna to the seacoast.

According to Okko (1957), Salpausselkä II comprises three parts in the Jylisjärvi district, two of them representing an active stage in the life of the ice sheet and one a period when the ice front was stagnant. In the area of Hämeenlinna no such tripartition can be observed. Here the feature consists of end moraines, transverse eskers of various sizes, extensive glaciofluvial accumulations and even a small area covered with ablation moraine (Virkkala 1961).

Divided once again into several parts, Salpausselkä II recurs in the area of the boundary between the communes of Loppi and Janakkala (Figs. 16 and 19). On the northern and eastern sides of the parish center of Loppi, it comprises three distinct chains of ridges some two or three kilometers apart. In the surroundings of Loppijärvi, Salpausselkä II is clearly divided into four parts, the distance between the extreme chains being about eight kilometers. Small ice-marginal features are also scattered between the different chains.

Salpausselkä II keeps its four-part character in a loose way as far as the vicinity of Karkkila. Its northwesternmost sequence, however, is quite fragmentary. All in all, the breadth of the Salpausselkä II belt in the Karkkila district is ten kilometers or so.

Fig. 19. Salpausselkä II between Hämeenlinna and Karkkila. 1 = end moraine, 2 = esker, 3 = transverse esker, 4 = other glaciofluvial accumulations, in many cases forming plains, 5 = ablation moraine. The most northeastern part according to Okko (1957).

Quite different is the mode of occurrence of the Second Salpausselkä system on the southwestern side of Karkkila. High cliffs and deep valleys give the area a bold relief, the differences in altitude amounting to as much as 80 meters. The system loses its multipartite ridge character, which is

Fig. 20. Salpausselkä II from Karkkila to the seacoast. Key to symbols in Fig. 19.

replaced by glaciofluvial accumulations of indefinite shape, individual transverse eskers and a couple of end moraines. The orientation of the formations conforms roughly to the schistosity and joint system of the bedrock, which means that on the average it is from the northeast to the southwest.

Fairly distinct but indefinitely-formed transverse eskers occur, for example, in the vicinity of Ikkala and on the northern side of Koisjärvi. Indefinite glaciofluvial accumulations, the form of which was determined primarily by the bedrock, are also situated on the northern side of the western end of Lake Hiidenvesi. In the same locality there are a couple of rather sizable terminal moraines, which cover a distance of a kilometer or two. Their form has in part likewise been determined by the bedrock, each being breached by a couple of minor rock outcrops. These moraines are thus essentially of the rock end moraine type (Gillberg 1961).

Rather discontinuously and in fragmentary form, Salpausselkä II stretches from Karkkila for a distance of more than ten kilometers to the boundaries of Nummi and Sammatti communes, after which it takes on a more regular shape again, becoming a ridge composed of stratified drift and breached in many places by small outcrops of rock. On the northwestern side of the parish center of Sammatti, there occurs a short, gently sloping parallel ridge. The system continues flattened out and level on top until near the church of Karjalohja. On the southeastern shore of Puujärvi, it rises up to a height of about 35 meters to form a magnificent, steepsided transverse esker, the slopes and summit of which are strewn with boulders.

A couple of kilometers southwest of the church of Karjalohja, Salpausselkä II further includes a ridge towering some forty meters above the waters of Särkijärvi. After a short distance the system sinks lower and breaks off, vanishing for a space of a couple of kilometers into elevated rocky terrain. It reappears on the southeastern shore of Lake Seljänala with the same majestic upward sweep as at Karjalohja. In the environs of Antskog its dimensions are reduced, but on the northern side of Fiskars it recovers bulk to produce an end moraine about thirty meters high and a couple of kilometers long — indeed, this is the only portion of a considerable stretch in the Second Salpausselkä system that is built up of till. The system swells out to mighty proportions again on the southeastern shore of Kullajärvi, where it is breached by the Helsinki—Turku railroad line. Spreading out on either side of the feature here are broad sandy plains.

After another break of a few kilometers, Salpausselkä II resumes its course on the northeastern side of Tenhola, at first as a twin ridge. The ridge more to the south stretches continuously and in many places attains substantial dimensions, rising to heights of nearly fifty meters up, as it approaches the parish center of Bromarv. Here it is asymmetric in form, for its northwestern slope rests against high walls of rock, while its southern slope descends precipitously into the Gulf of Finland. The bold relief of the underlying rock gives the Salpausselkä chain a hummocky appearance in spots. To the southwest of the church of Bromarv the masses of drift have created a rather extensive plateau about thirty meters high, which, however, drops to a lower level after a modest stretch and takes the form of discontinuous sandy plains. At the very western end of Bromarv, Salpausselkä II makes a prominent appearance as a transverse esker about twenty meters high, which juts out into the sea as a short promontory.

At its most southwestern end, the Second Salpausselkä system thus appears in many places as a far bigger and more imposing feature, if a somewhat less uniform one, than the First Salpausselkä at its corresponding end. Only a dozen kilometers separate the two systems on the seaboard, but in the northern part of the region investigated the distance is twice as long.

FORMS, STRUCTURE AND MATERIAL

As it occur in the region investigated, Salpausselkä II consists of both till and glaciofluvial drift. The occurrence of these materials in the area covered by the map sheet of Karkkila, where they have been studied in considerable detail, is made clear by Fig. 16.

Till occurs far more abundantly in the Second Salpausselkä system than in the First. It occurs in the region mainly as the material composing four types of end moraines. These types are: small end moraines of the kind representing annual moraine, which occur generally in little »swarms»; larger ones, which ordinarily occur as individual formations; largish hummocks, met with rarely and then in isolation, which nevertheless run parallel to the ancient ice margin; and, finally, the rock end moraines, of which mention has already been made (p. 38). The features included in the first category will here be referred to as small end moraines, those in the second category as large end moraines, and those in the third as end moraine hummocks.

Glaciofluvial drift also occurs in the Second Salpausselkä system in several different ways. It takes the form of distinct transverse eskers, and of indefinite accumulations, which in many cases fill upp depressed portions of the bedrock, as well as of independent ice-marginal plains.

No clear regional division between till and glaciofluvial drift can be discerned. On the eastern shore of Loppijärvi, stratified material generally is preponderant, whereas elsewhere in the environs of the lake the ice-marginal feature contains a greater abundace of till. Short transverse eskers, however, break up in places the otherwise uniform occurrence of end moraines. In the Karkkila district there is a preponderance of stratified drift, yet end moraines are by no means scarce there, either. Between Karkkila and Sammatti the prevailing formations are indefinite glaciofluvial accumulations. From Sammatti toward the southwest, Salpausselkä II is composed almost exclusively of glaciofluvial drift.

Small end moraines are the most common on the northeastern side of Turenki, where Okko (1957) and Virkkala (1961) have previously made investigations. Farther south many of them are to be seen in, for example, the environs of Karkkila.

In form the small end moraines are either symmetrical or asymmetrical. In latter instances, the distal slope is the steeper one. They usually are covered with numerous boulders. The material of the small symmetrical end moraines is generally fairly compact, sandy basal till. The small asymmetrical end moraines, on the other hand, are composed of washed till and their structure is correspondingly looser. It is probable that the symmetrical end moraines of small size represent thickenings of lodgement till deposited

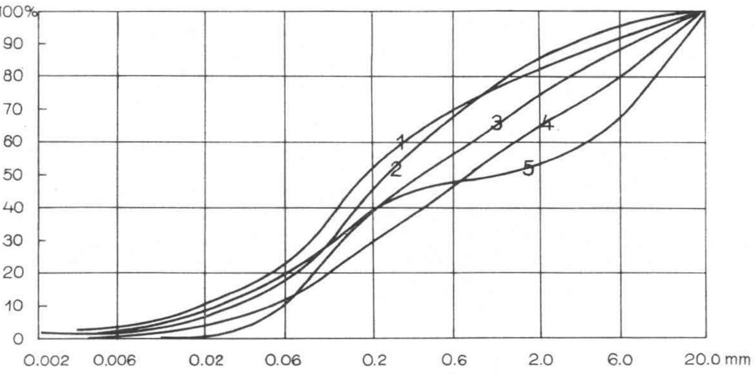

Fig. 21. Cumulative curves of till from Salpausselkä II. 1 = washed drift of small end moraine, Hunsala, Loppi, 2 = ablation moraine, Punelianjärvi, Loppi, 3 = laminated till of small end moraine, Kesijärvi N, Janakkala, 4 = material contained in a large end moraine, Anttila, Hevosoja, Loppi, 5 = washed till containing pebbles from the distal portion of a large end moraine, Järventausta, Loppi.

underneath the ice margin (Chamberlin 1894). However, in certain cases the material of the small symmetrical end moraines consists of washed and loose till. At the time of their origin the ice margin was very thin and immobile, and the crevasses in it extended down to the base or very near the base. Mainly owing to pressure from the sides, drift oozed out into the crevasses, accumulating into small ridges, which were then washed by meltwaters (Hoppe 1952, 1957; cf. also Möller 1962). The asymmetrical little end moraines, on the other hand, developed as a result of slight local oscillations of the ice sheet. This caused the material, principally glaciofluvial drift, that had been deposited in the foreland during the recession of the ice also to be mixed in with the till.

The difference between the small end moraines and the large end moraines proper is actually only one of degree: the structure and material of both are largely the same. The large end moraines, however, do not occur in groups, like the small ones, but in the main individually or, at most, in pairs.

The compact basal till composing the large symmetrical end moraines is represented in Fig. 21, curve 4.

Only a few end moraine hummocks have been met with in the region of Salpausselkä II. They range from 100 to 500 meters in length and from ten to thirty meters in height, and their long axis runs parallel to the ice margin. Their sides are quite steep ice-contact slopes, in many cases either uniformly or sporadically mantled with bouders. Their summits do not largely lie on a regular level, like those of other end moraines. The slopes are fairly steep also in the direction of the ice margin. Fig. 22 shows an end moraine hummock situated on the northern shore of Vaskijärvi, in

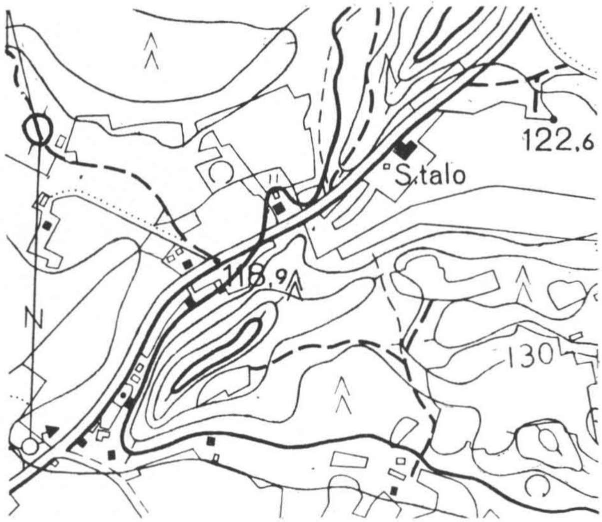

Fig. 22. End moraine hummock on the northern shore of Vaskijärvi. On its northern side is to be seen the southern part of a transverse esker of similar shape but composed of sorted drift. Scale 1: 20 000.

the commune of Karkkila. A very large end moraine hummock, which rises some thirty meters above the surrounding country, is situated on the isthmus between Ojajärvi and Kesijärvi in the southern part of Janakkala.

Shortish transverse eskers built up of stratified drift occur all over the area between Karkkila and Jylisjärvi. They are to be found in greatest abundance, however, on the northeastern side of Turenki, the eastern shore of Loppijärvi and the environs of Karkkila. Contrary to the case of end moraines, the proximal side of transverse eskers is often to be seen to be steeper than the distal slope. Ice-contact features are met with nevertheless on both sides.

In transverse eskers the bedding tilts either in the direction of the slopes or in the proximal part also in the distal direction. A good example of the last-mentioned structure is the grand Erävisharju on the western side of Loppijärvi (Leiviskä 1920, Fig. 79). The material of this esker is clearly stratified and sorted, but the large stones in particular are angular, like the rock fragments in till. Cross-bedding is likewise common in transverse eskers.

There are relatively few large sections cutting across the eskers of the Salpausselkä system in the region. Such a cross-section occurs in the borough of Karkkila. The material in the proximal part of the section is coarse and to some extent poorly sorted. The bedding is badly disturbed, but where it can be observed it is inclined in the direction of the slope.

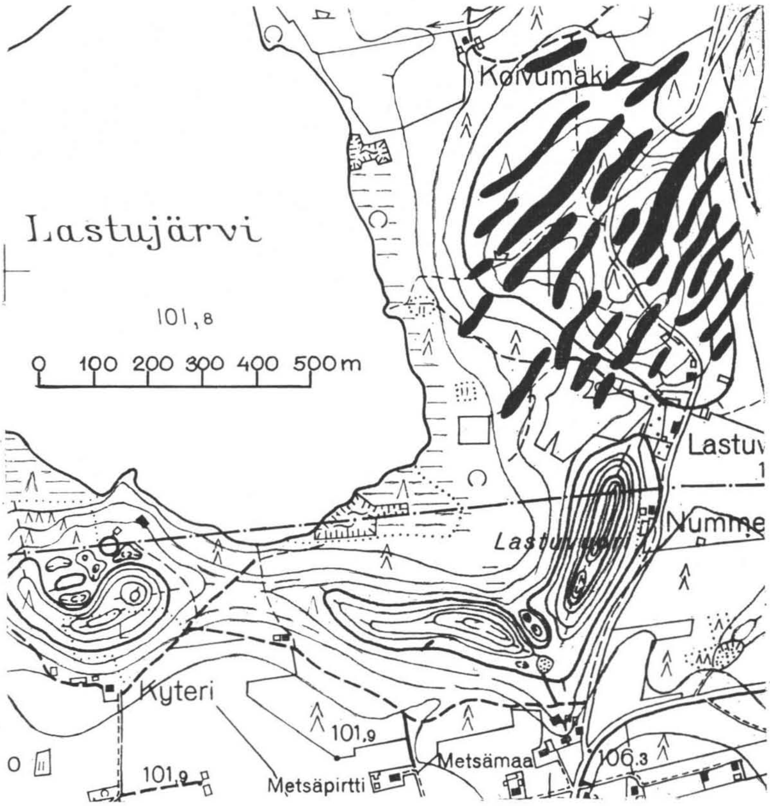

Fig. 23. The horse-shoe shaped transverse esker of Lastuvuori is situated on the southeastern shore of Lastujärvi. On the rise along the eastern shore of the lake there is a cluster of small end moraines.

In many places as far as the coast, where large sections have been cut through Salpausselkä II, there occurs — especially on the proximal side — an washed till bed varying in thickness between ½ and 1½ meters. It has usually caused a deformation of the underlying sorted drift and in some cases destroyed the bedding altogether (Virkkala 1961). One frequently also finds imbedded in the glaciofluvial drift lenses of till or commonly deformed layers of poorly sorted drift. In Fig. 79 of Leiviskä's previously mentioned work (1920), thin layers of till and gravel alternate on the top of the Second Salpausselkä's parallel ridge.

The structure and material of the transverse eskers of Salpausselkä II thus greatly resemble those of Salpausselkä I.

As Figs. 16 and 19 show, the transverse eskers extend on the north-eastern side of Karkkila as continuous ridges for distances of not more than one or two kilometers. The most usual length is only about half a

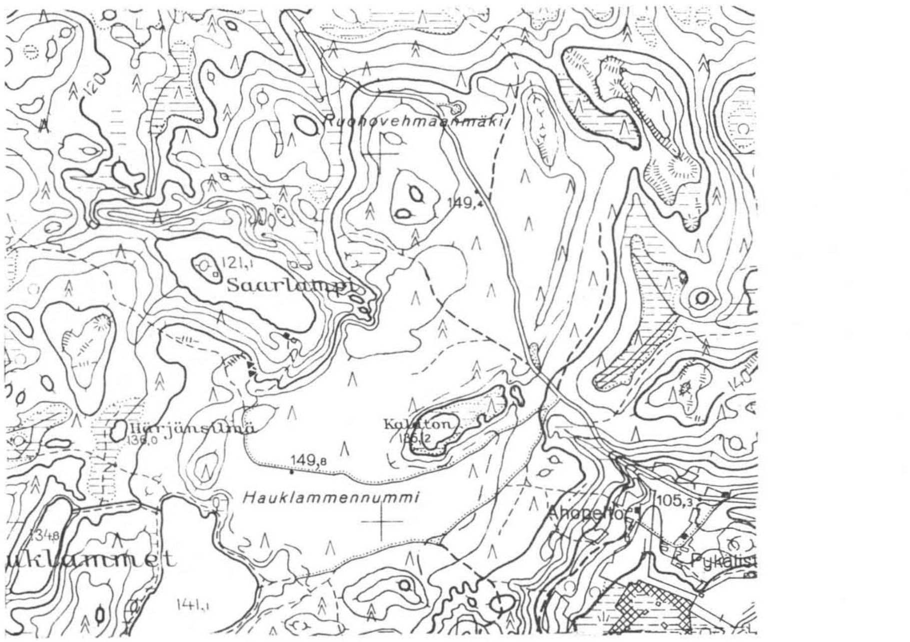

Fig. 24. Hauklammennummi, Karkkila. Scale 1: 20 000.

kilometer. One example of a transverse esker, shown in Fig. 23, is the very steep-sloped Lastuvuori, which, situated on the southern shore of Lastujärvi, towers some fifty meters above the surface of the lake.

Quite a number of glaciofluvial accumulations of indefinite form occur in various parts of the region, notably in the area between Karkkila and Nummi. Their form has been modeled by the bedrock, and rock outcrops are a common occurrence on their surface. Unmistakable transverse eskers, furthermore, are to be seen in association with these accumulations. Kettle holes marking the sites of dead ice are likewise commonly observed on them.

There are relatively few marginal glaciofluvial plains in the region of Salpausselkä II. In the main, they are located in the environs of Karkkila and in the stretch of land between Loppi and Karkkila constitute the extreme proximal and most discontinuous portion of Salpausselkä II. Littoral forces have levelled off their original surface forms and thick littoral accumulations can often be seen lying on top of them. By origin, however, the material that went into their formation was glaciofluvial. On top they are largely as flat as a table, but in some cases the surface is marked up by the remnants of gently sloping channels, which have partly been levelled off. The flattened summits lie at two levels: the plateaus of Karkkila and Ahmolampi are 137 or 138 meters above sea level, whereas the other plateaus vary in elevation between 149 and 151 meters. On the northwestern side of Salpausselkä II the elevation of the plateaus and ridge-tops descends to about 125 or 126 meters. Local shore marks have been observed in their surroundings up to elevations of 135 to 140 meters.

Fig. 24 shows the glaciofluvial plain of Hauklammennummi, in the Karkkila district. The eastern edge of the plateau is bordered for a distance of a few hundred meters by a substantial shore bar composed of sand and gravel, which attains an altitude of 150 meters. The highest points in the proximal portion of the plateau rise to about 160 meters, but the material represents something intermediate between till and stratified drift. The illustration further shows, branching off from the middle portion of the plateau, a short esker, which marks the course of a stream of meltwater that nourished the plateau during the period it was accumulating.

THE ORIGIN OF SALPAUSSELKÄ II

The Second Salpausselkä system was also formed, at least in the main part of the region investigated, in several stages. Okko (1957) observed three stages in the environs of Jylisjärvi; and in the terrain between Karkkila and Loppi, Salpausselkä II is mainly divided into four parts. It has already been pointed out that till or disturbances of the stratification have been found in many of the transverse eskers, notably on their proximal side. This means that in their present form also the transverse eskers developed in not less than two stages. Since, according to Sauramo's (1923) clay chronology, the formation of Salpausselkä II in the region investigated took some 200 years, each of its substages in the Karkkila area must have averaged only twenty or thirty years.

The commonest forms, end moraines and transverse eskers of Salpausselkä II seen to occur alternately without any perceivable rule. In generally, slowly moving and rapidly melting ice produced mainly stratified drift, and slowly melting and rapidly flowing ice, till (Flint 1947, p. 127). Climatically, numerous short-term changes occurred during the genesis of Salpausselkä II, alternately causing the ice front to advance and to recede. Such features bespeaking glacial activity as are quite commonplace in the Second Salpausselkä system could scarcely have originated except during periods of deterioration in the climate.

Also in the coastal area, from Nummi toward the southwest, where Salpausselkä II manifests itself primarily as a single ridge, it evolved in at least two stages. This is evidenced by deformations in the bedding in the proximal portion of the feature as well as by the till mantle occurring in many places. The impression is gained that climatic changes did not affect the position of the ice front on the seaboard so much as they did farther north, in the hinterland. In the coastal zone, moreover, the more rugged topography kept the edge of the ice sheet in place better, even when oscillations occurred in the interior of the country. The climatic changes that in the hinterland gave rise to the multipartite character of Salpausselkä II could not therefore have been very great and radical.

It would appear as if climatic factors had primarily determined the general position and formation of the Second Salpausselkä system in the region covered by the present investigation. No great topographical differences can be observed between the various parts of the system and its near surroundings to suggest that they might have had the effect of causing a local stagnation of the glacier margin.

Examined in detail, on the other hand, Salpausselkä II betrays the influence of topography in considerable measure. The author has endeavored to study the matter by determining the direction in which the base on which the large end moraines and transverse eskers rest is tilted.

The topography of the base of thirty-one large end moraines has been determined with this in view. Thirteen of them, or 42 per cent, are situated on a level base; eight, or 26 per cent, have been deposited on a rising slope, and ten, or 32 per cent, on a declivity. Considering that all the percentages given are roughly on the same order of magnitude, one is encouraged to conclude that the local topography did not appreciably influence the detailed position of the large end moraines. Roughly the same number of them formed on descending and ascending slopes and on a level base.

Slightly different results were given by a study of the topography underlying tranverse eskers. Thirty-nine eskers were included in the survey. Twenty-two, or 58 per cent, were built up against a rising slope; twelve, or 31.5 per cent, accumulated on level ground; and only four, or 10.5 per cent, were deposited on a declivity. Well over half of the transverse eskers thus formed uphill. It is to be expected that the mobility of the thinned-down ice front would have been greatly reduced at the time the transverse eskers evolved and that even a slight topographical obstruction could have completely checked its movement. The ice front accordingly stagnated, and during the melting stage streams of meltwater poured across the marginal zone of the glacier.

The dependence of transverse eskers on topography is illustrated on the map (Figs. 19 and 20). The largest transverse eskers and other glaciofluvial accumulations are located on the eastern and southern sides of sizable basins. Among such basins should be mentioned, above all: Jylisjärvi, Lastujärvi and Valajärvi in the commune of Janakkala, Ojajärvi and Loppijärvi in the commune of Loppi, Pyhäjärvi in the Karkkila district, Puujärvi and Seljänala in the commune of Karjalohja, and Simijärvi, Myllyjärvi, Flacksjö, Fårsjö and Lepoträsk in the commune of Pohja. This feature is particularly evident on the shore of the rather large Loppijärvi. The eastern margin of the lake is lined by an almost continuous belt of transverse eskers, but as soon as the southern end of the lake is reached, even the material of the ice-marginal accumulation changes to till. On the western and northwestern sides of the lake, again, there occurs a greater abundance of end moraines.

To summarize, it may be stated with regard to the genesis of the Second Salpausselkä system that climatic factors were of decisive importance in its formation and in determining its general position. The position of the end moraines, considered in detail, can be explained the same way. On the other hand, topography was in many cases the most decisive factor in determining the location of the transverse eskers. The ice-marginal accumulations making up the Second Salpausselkä system largely evolved in fractures and crevasses in the ice running parallel to the margin. It was the local topography that partly determined in these cases whether a crevasse spawned an end moraine or a transverse esker.

THE MIDLAND BETWEEN THE SECOND AND THIRD SALPAUSSELKÄ SYSTEMS

This midland has been surveyed in detail only between Hämeenlinna and Kiikala, an area from which new Finnish topographical maps have been made. The observations available from the shorter stretch between Kiikala and the seacoast, on the other hand, are of a much more general nature.

In contrast to the midland between the First and Second Salpausselkä systems, ice-marginal features are here conspicuous mainly by their nearly total absence. In receding the glacier behaved in this area evidently quite differently from what it did in the terrain separating the first two Salpausselkäs.

The absence of ice-marginal formations suggests that the ice front had, for one thing, receded steadily without stagnating or readvancing locally and, for another, had in part melted away *in situ*.

The several bulky eskers situated in the midland bespeak a recession of the ice sheet along an even front. On the seaboard eskers of this kind are lacking, owing partly to the bolder local relief, and partly to the fact that the formations were subsequently levelled down to a great extent by the waves beating on shore. A smallish esker can be seen in the commune of Kisko and another on the same scale in Suomusjärvi, their trend being from south to north. This orientation was probably due to the powerful influence of the fracture and erosion valleys having the same trend in the bedrock.

The first considerable esker in the midland starts from the southeastern side of Somerniemi. To the north of this locality there are quite a number of other eskers — in Karkkila, Loppi, Renko and Janakkala (Fig. 16). The esker running via Hämeenlinna is a particularly imposing landmark.

Fig. 16 shows the stretches of ablation moraine in the part of the midland included in the map sheet of Karkkila. The ablation moraines mark the areas where the ice disappeared by melting in place. Farther north in the midland the occurrence of ablation moraines lessens appreciably, but they appear sporadically all the way to the environs of Hämeenlinna. It was in the central portion of the midland that the ice tended to melt away in place, but farther north, in the area of the big eskers, it once again for the most part receded steadily along a solid front.

The third major glaciomorphological type occurring in the midland, though far less common than the other two, consists of drumlins. There are a few small occurrences of these features. The largest and most extensive of them is to be seen south of Hämeenlinna between Renko and Alajärvi (Virkkala 1961). Drumlins occupy smaller tracts here and there around the midland, too.

The drumlin fields are marked by the absence of both ablation moraines and eskers. On the southeastern and northwestern sides of the drumlin field of Renko-Alajärvi, portions of a long and continuous esker occur, but by the time the drumlin field is reached the esker peters out and just a few little deposits of sand are left to testify to glaciofluvial action.

The drumlins bear witness to the energetic action that occurred during the final stage of deglaciation. It is thus natural that in the areas of their occurrence there should be no ablation moraines, which are the result of melting of glacier ice on the spot, or eskers, either, during the formation of which the ice front receded at a steady rate by melting.

Insofar as it can be ascertained without the help of topographic maps, the coastal area to the southwest of Karkkila has no ablation moraines, eskers or drumlins. The seaboard consists mainly of till and bedrock, the depressed places being filled with fine water-laid sediments, silts and clays. Peat has begun to form in portions of the till or clay beds, and in certain localities fairly extensive bogs have evolved.

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SALPAUSSELKÄ III

The Third Salpausselkä system used to be even less well known than the second. It is completely overlooked by Leiviskä (1920) in the body of his study on Salpausselkä, but the appended map includes some scanty data on this system. The poor knowledge of Salpausselkä III is partly due to the fact that up to the present research and mapping work has been handicapped by a lack of satisfactory topographic maps. No such maps are available even at the time of this writing for the portion of the third system extending from Kiikala toward the southwest.

On earlier Quaternary maps (Sauramo 1929, Okko 1960) Salpausselkä III was generally depicted as a highly fragmentary system. It has been observed in the area encompassed by the new topographic maps, however, that the accumulations here stretch quite continuously for considerable distances, though the system does vary a good deal in character.

The situation and morphology of Salpausselkä III are presented in Figs. 25 and 26. The author has previously described Salpausselkä III as it appears in the northern part of the region investigated (Virkkala 1961), where it is considerably broken up. Characteristic formations here are a couple of rather broad glaciofluvial plains — in the environs of Renko and Nummenkylä —, a couple of short transverse eskers and a few glaciofluvial accumulations of indefinite form.

The most extensive plateau is known as Pernunnummi, which, situated in the boundary zone between Loppi and Tammela, covers a total area of approximately 40 square kilometers. The biggest part of Pernunnummi is nearly as flat as a table, and only faint traces of stream beds can be noticed on its surface. Littoral deposits lie uppermost, but at deeper levels glaciofluvial drift also occurs. The distal portion of the plateau is about 120 meters above sea level and the proximal portion some 130 meters. The plateau itself is pitted with kettle holes of various sizes, many of which are covered by small lakes. Here and there little patches of till rise above the level of the plateau. Accordingly, the sorted drift composing Pernunnummi does not seem to have a very great thickness.

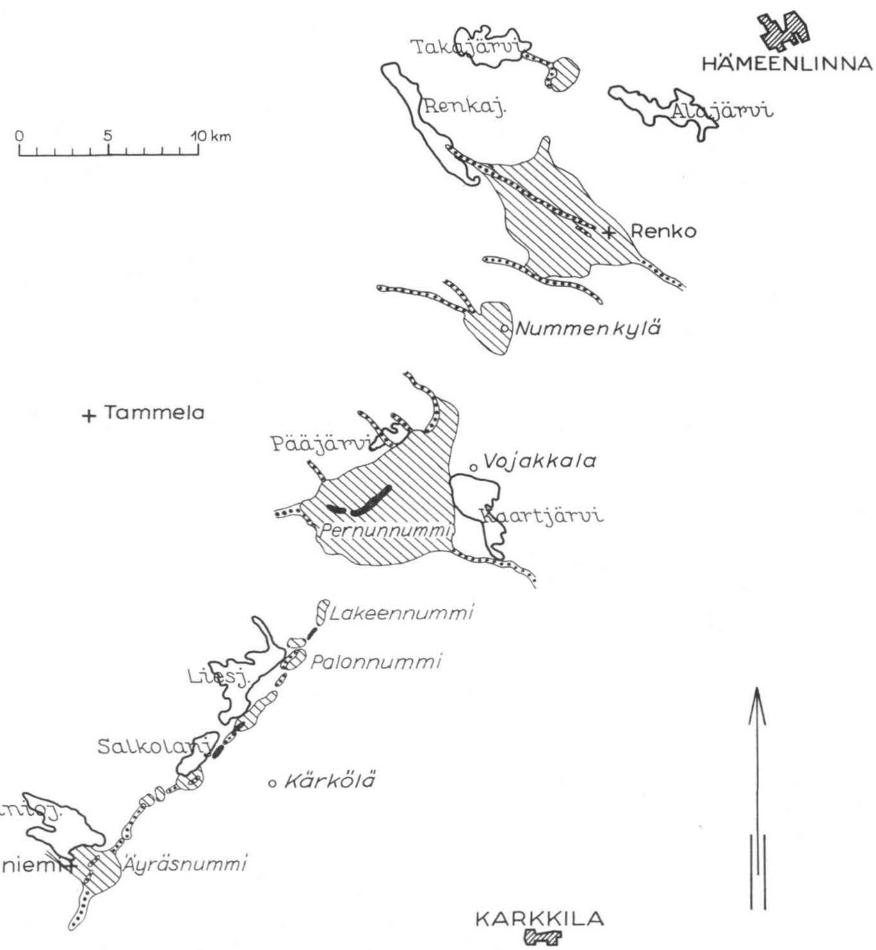

Fig. 25. Salpausselkä III between Hämeenlinna and Somerniemi. Key to symbols same as in Fig. 19.

Altogether different is the character of the proximal portion of Pernunnummi (cf. also Sauramo 1958, pp. 220—224). At its northern end is a transverse esker a couple of kilometers long, on both sides of which, but especially the distal side, extend widely plains of sorted sand. In the middle of the proximal portion is a stretch of dead ice terrain. The drift is here, too, clearly sorted, though in spots the hummocks are mantled with till. Directly to the northwest of this terrain lies the rather large Pääjärvi, in which the ice lobe that had filled its basin melted on the spot.

The southern half of the proximal portion of Pernunnummi is characterized, again, by a clear proximal ridge, which at its loftiest point towers

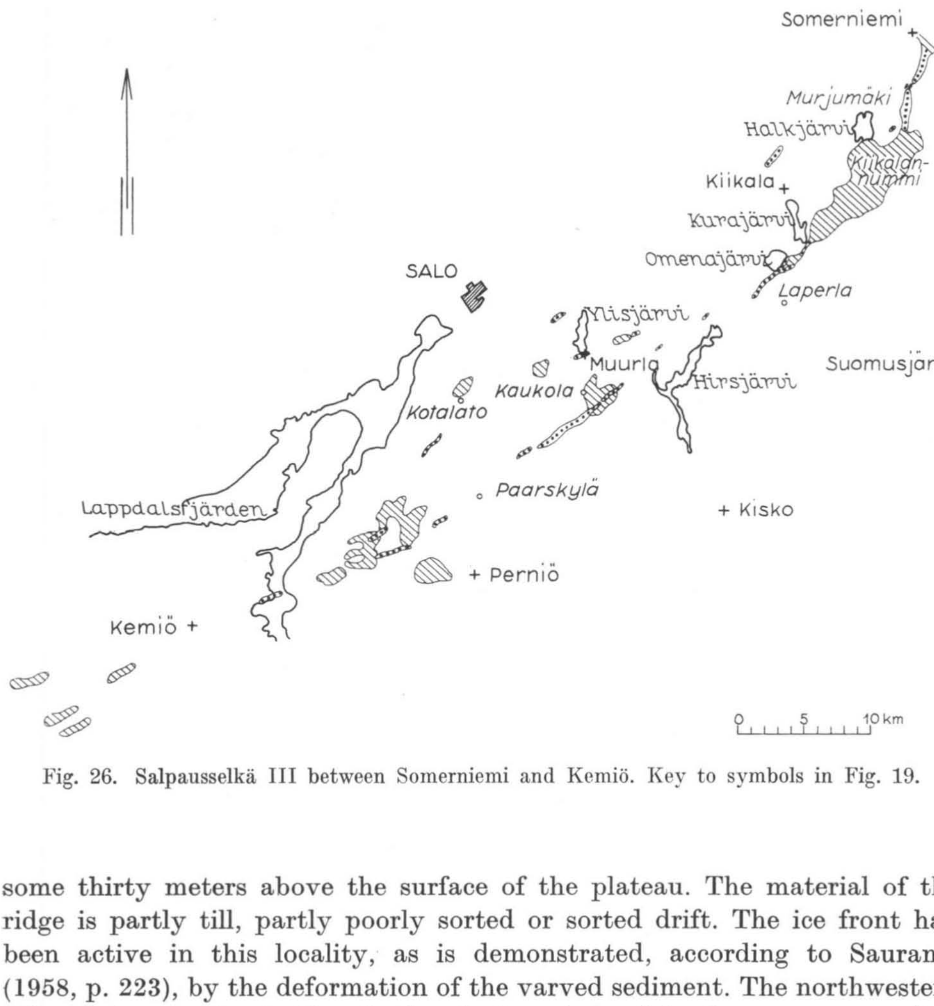

Fig. 26. Salpausselkä III between Somerniemi and Kemiö. Key to symbols in Fig. 19.

some thirty meters above the surface of the plateau. The material of the ridge is partly till, partly poorly sorted or sorted drift. The ice front had been active in this locality, as is demonstrated, according to Sauramo (1958, p. 223), by the deformation of the varved sediment. The northwestern side of the proximal ridge further lacks a large lake basin corresponding to the aforementioned Pääjärvi. Numerous eskers branch off the proximal side of Pernunnummi, marking the course of the meltwater streams that had carried the drift forming the plateau. Along the southern edge of Pernunnummi there stands, moreover, an esker which has its beginnings on the southern end of Läyliäinen and expands on the distal and proximal sides of the plateau into a landmark of estimable proportions.

On the southwestern side of Pernunnummi bogs and till terrain break the continuity of Salpausselkä III for a distance of a couple of kilometers. After that the system rises up again and extends without another break of consequence over forty kilometers, or as far as the southern part of the commune of Kiikala. It consists in its northern portion of small transverse

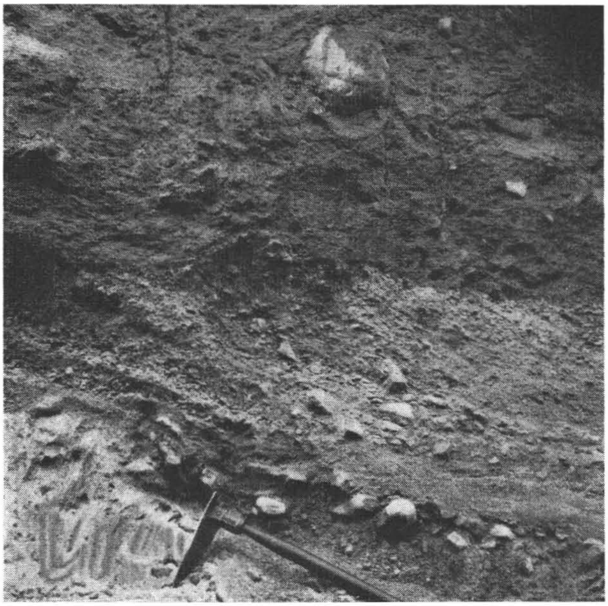

Fig. 27. At the proximal edge of the esker hummock belonging to Salpausselkä III, the till has been pushed on top of the stratified drift.

eskers, end moraines and small plateaus. The plateaus reach elevations of 125 to 130 meters. Jutting out from their proximal sides are short eskers.

On the southeastern shore of Salkolanjärvi, there is a gap about a kilometer long in the system. It takes a fresh start on the southern shore of the lake, where it proceeds to strew the landscape with short transverse eskers, esker hummocks and small plateaus across a stretch of about seven kilometers. The surface of the proximal portion of one esker hummock is covered with a meter's thickness of till, which upon being pushed over the formation disturbed the underlying stratified drift (Fig. 27).

It is in the vicinity of the church of Somerniemi, on the southeastern shore of Painionjärvi, that Salpausselkä III puts on its mightiest show with the feature of Äyräsnummi, which has a spread of several square kilometers. From its proximal edge extends a grand esker, which continues on to Somero, Koski and Säkylä and which is separated from the sandy plain by a sizable esker hollow. About three kilometers from the distal portion of the plateau there terminates another large esker, which begins at Pusula, in the terrain separating the Second an Third Salpausselkä systems. On the proximal side of Äyräsnummi there stand a few short transverse eskers, which are composed of poorly sorted glaciofluvial drift. East of these deposits extends the plateau proper, which covers an area of a couple of square kilometers. It is thus considerably smaller than, for instance, Pernunnummi, which it otherwise greatly resembles.

The distal portion of the Äyräsnummi plateau is characterized by numerous shallow channels with gently sloping sides. These channels begin in the proximal portion of the plateau at a height of about 125 meters and end at its edge at about the 120-meter level. They indicate the last beds of the meltwater streams that brought the drift out of which the plateau was built. The loftiest points of the proximal portion rise some 45 meters above the surface of Painionjärvi, just below, while the distal edge lies approximately 30 meters above the surrounding land.

Salpausselkä III continues on from Äyräsnummi directly toward the south—southwest as a majestic transverse esker, which is cut off after three or four kilometers for a very short distance by a group of small end moraines. South of this point the system rises mightily to form the towering Murjumäki, the top of which is 159 meters above sea level, or about fifty meters above the level of the lakes at its foot. Murjumäki is composed of poorly sorted, stratified drift. Up to an elevation of about 130 meters, however, its slopes consist of quite markedly sorted drift. The evidence suggests that Murjumäki, the top portion of which is pitted with spacious kettle holes, is an ice-marginal accumulation that evolved on a supra-aquatic base.

Immediately to the south of Murjumäki spreads the broad Kiikalannummi, which, over six miles long and between two and four kilometers wide, has largely levelled off at elevations of 110 to 125 meters. Parts of Kiikalannummi consist of gently undulating terrain, which on the proximal side branches off into numerous rather small transverse eskers with a NE-SW orientation. No distinct channels have been found on the surface of Kiikalannummi, the top having for the most part been levelled off by waves The accumulation has a steep ice-contact slope, and there are numerous kettle holes in its proximal half. The many rock outcrops indicate that the glaciofluvial drift is not very thick.

Toward the southwest Kiikalannummi narrows at the southern end of Kurajärvi into a transverse esker, which divides into a double ridge full of stones and boulders on the southeastern shore of Omenajärvi. The ridge stretches another three kilometers or so toward the southwest and terminates in a tract of high rocky ground on the western side of the village of Laperla, in Suomusjärvi commune.

A separate transverse esker a couple of kilometers long is situated on the northern side of the parish center of Kiikala, about five kilometers northwest of Kiikalannummi. Here too the esker is markedly asymmetrical, testifying to its ice-marginal origin.

With the exception of a couple of quite small transverse eskers on the northern shore of Hirsjärvi, there is a gap of more than six miles in Salpausselkä III on the southwestern side of Omenajärvi. In the commune of Muurla, it begins again, indistinctly and fragmentarily, forming two branches which run in a southwesterly direction. The chain situated more to the north runs as a very ill-defined feature via Kotalato to the western part of Perniö. The southern branch of the system includes, on the southern side of the village of Kaukola, an exceedingly bulky transverse esker, ranging in height between thirty and forty meters, as well as sandy tracts linked to the esker. The two scattered branches of the system merge at the western end of Perniö, where there occur a couple of small but quite distinct transverse eskers as well as broad, flattened sandy plains, which to some extent run into the eskers but are further bounded by higher rocky ground. The material consists principally of glaciofluvial drift. A couple of sand pits have revealed that the littoral accumulation at the surface has a thickness of only one or two meters. Separated by varved clay, it extends from there underneath the glaciofluvial sands for several meters.

On the island of Kemiö there is a short but clearly defined transverse esker as well as, at the western end and in the middle of the island, flat sandy accumulations that belong to the Third Salpausselkä system.

Extensive glaciofluvial marginal plains are a typical feature of Salpausselkä III to a greater extent than they are of the first and second systems. Such deposits must have required long stagnation of the ice front. However, during the process of accumulation of Salpausselkä III, there must also have been active movement of the ice in many places, resulting in deformation of the stratification, the deposition of till on top of glaciofluvial drift, and so on. To some extent evidence can be seen of a marked bipartite structure.

Topography does not appear to have played any decisive part in the formation of Salpausselkä III, either. Climatic factors were probably of primary importance. According to Sauramo (1923), the ice margin remained in this zone only a few dozen, at most about a hundred years. This period ought to have seen not only the formation of the broad plateaus but also local oscillation of the ice front in the area investigated.

THE TERRAIN BEYOND SALPAUSSELKÄ III

Ice-marginal accumulations are no longer to be found to any notable extent on the proximal side of the Third Salpausselkä system. On the seaboard the typical terrain is bold in its relief, consisting of bedrock and ground moraine, and the depressed areas are covered with broad beds of clay. In terrain of this kind, the retreat of the ice front was primarily determined by the depth of the water covering the area. Accordingly, the kinds of glacial forms that are common on the distal side of the Third Salpausselkä system in the hinterland — eskers, ablation moraines and drumlins — could not evolve here.

In the zone about thirty miles long and six miles wide between Somerniemi and Takajärvi, Hattula, there occur ablation moraines in considerable abundance. The hummocky moraine is not everywhere particularly clearly defined or typical, and it differs in material composition, which ranges through all the intermediate grades from what appears to be a compact basal till to thoroughly sorted glaciofluvial drift. The surface of the hummocks is in many cases quite stony. The largest of the hummocks are twenty or so meters high, but the most prevalent height is three to five meters. The eskers scatter and break up upon reaching the ablation moraine tract. The hummocky moraine is here situated largely in an area where the ice receded across a supra-aquatic base or at least over only shallow water. It do not occur to any appreciable extent in the region lying below the highest shore. The ablation moraine tract borders for the most part on the so-called upland of Tammela, which extends from the northern end of the commune of Somerniemi far north to the southern parts of Kalvola and Hattula.

The ablation moraine tract beyond Salpausselkä III is situated along the same line as the corresponding tract in the belt of land between the Second and Third Salpausselkä systems. The glacier ice evidently stagnated in wide areas after having receded from the Third Salpausselkä system and then gradually vanished by melting in place.

NÄSIJÄRVI MARGINAL FORMATION

LOCATION AND MODE OF OCCURRENCE

The name Näsijärvi marginal formation is here given to the system of ice-marginal features which begins with the series of accumulations known as Hämeenkangas in North Satakunta, then stretches in a west-east direction across Näsijärvi and continues in fragmentary form far into Central Finland. In the explanatory text accompanying the Quaternary map of Tampere, Sauramo (1924) comments that Hämeenkangas has the character of a marginal formation except that »it is not of contemporaneous origin as a whole but accumulated piece by piece against the more slowly receding wall of the glacial bay».*) Similarily, Sauramo regards as occurrences »resembling marginal features» the »esker extensions» situated on the borders of Orivesi and Ruovesi on the eastern side of Näsijärvi.

It is hard to guess from the Quaternary map sheet of Tampere published in 1904 by Sederholm that Hämeenkangas and the esker extensions mentioned belong together. The broad sandy stretches in the southern part of Ruovesi, however, comprise together with Hämeenkangas a very beautiful marginal lobe, which runs continuously for about 100 km with only a short break where it is cut by Näsijärvi.

According to Sauramo (1924, p. 29), the starting point of Hämeenkangas is a »little stony ridge»*) on the western shore of Lavajärvi. As a matter of fact, this ridge extends for a distance of about 50 km as an almost continuous marginal lobe from Lavajärvi toward the east (Fig. 28). Since this Näsijärvi marginal feature has been to a great extent unknown up to now, a detailed description of the portion stretching east from Lintuharju will be given in the following (Fig. 29 and 30). The place names used have been borrowed from the following topographic map sheets published by the General Survey Office: Viljakkala, Kyrönlahti, Länsi-Teisko, Teisko and Murole.

Fig. 28 shows the situation of the Näsijärvi marginal feature in its entirety as well as its relation to the most important eskers and to the direction

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*) translation from the Finnish.

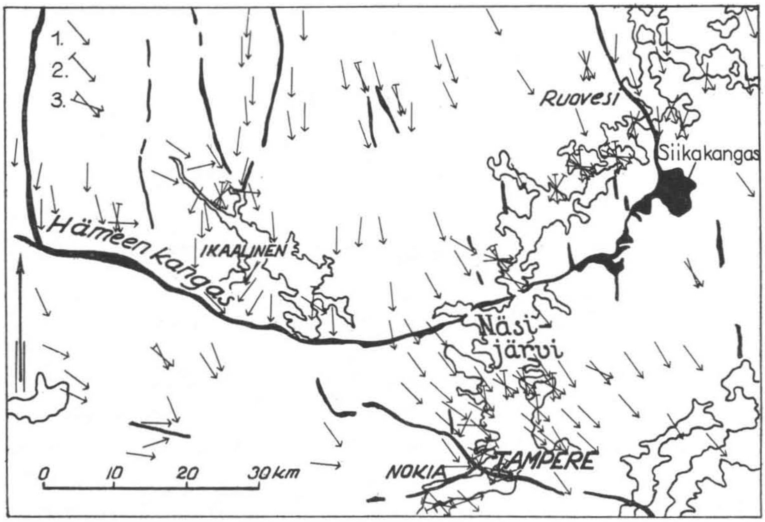

Fig. 28. The ice-marginal feature of Näsijärvi, and its relation to the most important eskers and the directions of the ice flow.

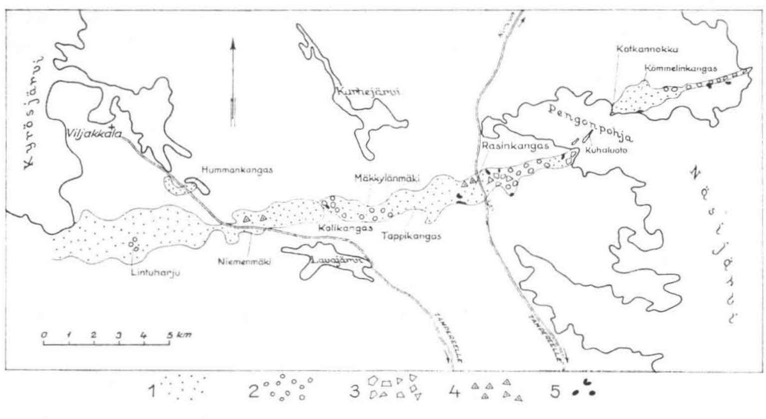

Fig. 29. Näsijärvi formation and its material between Näsijärvi and Kyrösjärvi. 1 = sorted drift, 2 = poorly sorted drift, 3 = till, 4 = till overlying sorted drift, 5 = rock outcrop.

of glacier flow. Some of the striae observations have been borrowed from Sauramo's (1924) work, but the majority have been made by the present author.

Lintuharju (Fig. 29) constitutes a plateau nearly ½ km long and a couple of hundred meters wide, which rises to an elevation of between 165 and 168 meters. The main body of the ridge extends eastward from Lintuharju

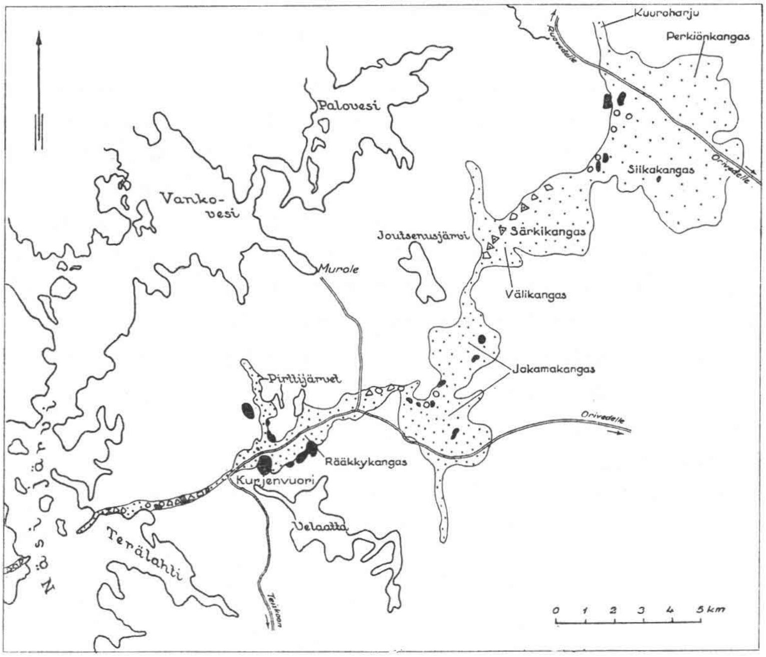

Fig. 30. Näsijärvi formation and its material east of Näsijärvi. Key to symbols in Fig. 29

as less elevated and poorly defined accumulations, along both sides of which sands stretch for distances of more than a kilometer. Examples are the sandy heaths on the western side of Lavajärvi as well as Hummankangas on the western side of Hirvijärvi, in the commune of Viljakkala.

About 4 km east of Lintuharju, the Tampere-Viljakkala highway follows the ice-marginal accumulation for about a kilometer. From this stretch the accumulation extends eastwards south of Karhejärvi and where, between this lake and Lavajärvi, it forms the ridges of Kolikangas, Aurankurki and Mäkkylänmäki. A short distance to the east of this area it spreads out to form Tappikangas. As a direct extension eastward there is the broad Rasinkangas, which is intersected by the Tampere-Kuru highway.

East of Rasinkangas the marginal feature becomes less definite in form, although the central ridge can be followed without trouble. The feature lies on top of a rather high base of bedrock and ground moraine, which disturbs its continuity. Broken up by ground moraines and bedrock, accumulations of gravel and sand are situated for a distance of a couple of kilometers on each side of the ice-marginal feature alongside the Tampere-Kuru highway as well as on the southern shore of Pengonpohja. About ½ km broad, the features then continues on to the shore of Pengonpohja, an arm of Näsijärvi.

Next follows a gap of over a kilometer in the system. In the bay of Pengonpohja there is, however, a narrow and low island named Kuhaluoto, which apparently is part of the Näsijärvi formation. On the northern shore of the bay it soon widens out into the accumulation known as Kömmelinkangas, which measures more than a kilometer in breadth and a couple of kilometers in length. After that the system grows narrower once again to form a poorly defined ridge, which after running some 3 or 4 km is broken off when it plunges into Näsijärvi as a headland.

The gap in the system now stretches for a distance of about 1½ km. It reappears on the eastern shore of Näsijärvi, where it takes the shape of the kilometer-long peninsula of Vetämäkannas. The system next takes the shape of a narrow ridge cut by a couple of small outcrops of bedrock, extending for a few kilometers to the northern side of Velaatanjärvi, where its southern margin leans against the 180-meter high Kurjenvuori. From this point there begins the formation known as Rääkkykangas, which, 4 km long and 1 km wide, terminates in the vicinity of the junction of the Orivesi and Murole highways, at Kaanaa, in the commune of Teisko.

East of Rääkkykangas the Näsijärvi formation broadens out into the extensive Jakamakangas, the highest summits of which attain to an elevation of 175 meters. Jakamakangas runs for a distance of 5 km toward the north-northeast across a belt of land varying between 1 and 3 km in breadth, after which it is squeezed between high hills of bedrock and ground moraines rising to heights as much as 200 meters above sea level into small sand deposits and short ridges.

Nearly 2 km east of Joutsenusjärvi, the system broadens out into the small heathy tract of Välikangas and to the northeast of it into the considerable Särkikangas, which covers an area of several square kilometers. The level surface of the latter accumulation lies some 170 to 175 meters above sea level, whereas its highest proximal ridges ascend to elevations of some 180 to 185 meters.

On the northeastern side of Särkikangas the system is narrower and partly broken up by the rocky topography until it spreads out into the Siikakangas, a heath lying at an elevation of 170 to 180 meters and covering an area of some 20 sq.km. The Tampere-Ruovesi highway runs along its northeastern and eastern margins for a long distance, and on its table-flat distal surface there is the Ruovesi airfield. From between two high walls of rock at the proximal end of Siikakangas there begins the long esker of Ruovesi, which is famous for its beauty and the initial portion of which is known by the name of Kuuroharju.

Between 1 and 2 km to the east of the Tampere-Ruovesi highway, the system gradually merges into an elevated tract of bedrock and ground moraines. Extensions can no longer be found in the surroundings, but between Kuorevesi and Jämsä there are broad stretches of sandy heaths, which, occurring now as well-defined transverse eskers, now again as level stretches of sandy heath, continue in fragmentary fashion via Korpilahti, Muurame and Jyväskylä on to Laukaa to form the easternmost portion of the ice-marginal formation (Saksela 1930).

FORMS, STRUCTURE AND MATERIAL

The situation of the Näsijärvi ice-marginal features is shown in Figs. 29 and 30. On the eastern side of the lake, broad glaciofluvial plateaus are a common occurrence. On both sides of the plateaus, ice-contact features are often to be seen. Proximal ridges occur furthermore in association with all the plateaus. Transverse eskers and poorly defined forms prevail, on the other hand, on the western side of Näsijärvi. A couple of short ridges occur on the western shore of the lake — likewise intersecting the general line of the system.

Dead ice terrain occurs most prominently on the northern side of Lavajärvi as a small but well-defined area. The long axis of the hummocks and the pits runs parallel to the trend of the ice-marginal feature. On the eastern side of Näsijärvi the knob-and-kettle terrain borders principally on the proximal sides of the plateaus.

Fig. 31 presents a detail of the proximal part of Särkikangas and the western part of its plateau. The ice-contact features of the proximal slope are indicated by sinuous altitude curves. Half-open kettle holes are to be seen also on the proximal slope. The proximal ridge is bipartite, the western one occurring in fragmentary fashion.

The broad distal portion of Särkikangas has a gentle gradient toward the southeast. Its western portion is intersected by a long, shallow channel, along the extension of which in the proximal portion of the plateau is situated a prominent wave-cut cliff at an elevation of 175 meters. The most proximal part of the plateau, which rises to a height of 175 meters, thus clearly evolved under supra-aquatic conditions. On the surface of the plateau itself no other channels can be observed. Waves have obviously levelled the channels and only the largest of them can any longer be seen as a shallow feature.

For lack of large sections, reliable data regarding the internal structure of the ice-marginal feature are not available. At a couple of spots the observation has been made that the layers of stratified drift tilt clearly in a distal direction, as in the case of numerous other marginal formations described

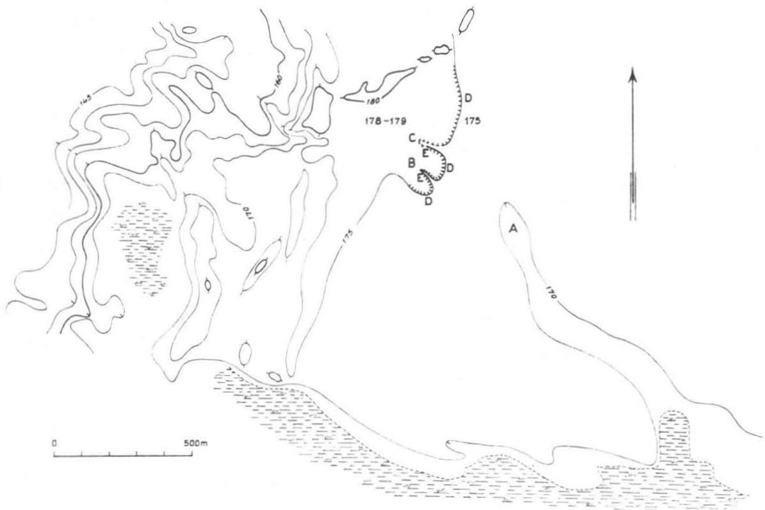

Fig. 31. Detail from proximal portion of Särkikangas and the western portion of the plateau. The numbers denote altitudes above sea level. The distance between elevation curves is five me ters. A—C = channels on plateau, D = wave-cut cliff, E = stream terrace, with shading indicating bog.

previously in the present study. Stratification conforming to the slopes has also been observed.

Fig. 29 and 30 show that the system consists mainly of well sorted material. Till and poorly sorted drift really represent only the exception. The stratified drift is the chief component not only of the narrow transverse eskers and broad ridges but also the extensive plateaus and knob-and-kettle tracts.

There is a considerable range of variation in the grain size of the sorted drift. The prevailing grains are coarse sand, gravel and pebbles; but also large boulders as well as medium sand, fine sand and even silt are to be found fairly commonly. The material is very fine in, for instance, the knob-and-kettle area of the northern side of Lavajärvi, where the knobs consist of medium sand and fine sand and the depressed places of silt. The material of the transverse esker situated on the northwestern side of Velaatanjärvi consists, at least in its surface portion, of silty fine sand. Immediately west of this transverse esker there begins another, which is composed of till.

In the distal and middle portions of the plateaus, the main components are sand and fine gravel, while toward the proximal side the material turns coarser. In the proximal ridges the most common grain sizes are represented by gravel and pebbles.

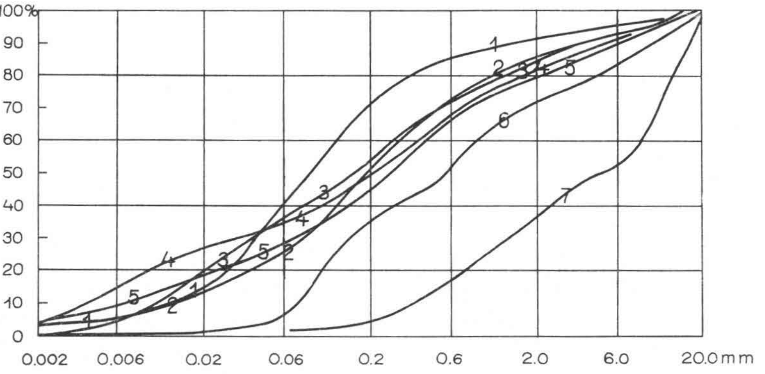

Fig. 32. Cumulative till curves from the Näsijärvi formation.

It should be pointed out that the sorted drift that has here commanded attention most often does not give an accurate picture of the sorting of the original material. Secondary factors — primarily the waves of the post-glacial aquatic stages — have to a great extent re-arranged the material.

Till has been found at few points in the ice-marginal feature. On the steep proximal slope of Särkikangas (Fig. 31) a till bed ½ to 2 meters thick occurs on top of the sorted sand. The proximal portion of Välikangas has also been partially built up of till. Further, till occurs in the eastern extension of Rääkkykangas (Fig. 32, curve 3). Certain ridges on the northern shore of Terälahti consist of typical till (Fig. 32, curve 4). Till overlies the stratified drift on the proximal slope of Rasinkangas, on the western side of Näsijärvi. The small knob-and-kettle area on the eastern side of the same sandy stretch is likewise composed of till (Fig. 32, curve 5). Also on the eastern side of Lavajärvi a thin layer of till overlies the sand (Fig. 32, curve 2).

The cumulative curves show that the material is real unsorted till. The curves are quite similar to the cumulative curves made by the present author to represent the till occurring in the environs of Tampere (Virkkala 1962).

Besides till and generally well-sorted glaciofluvial drift, there occurs in the marginal feature small amounts of poorly sorted glacial drift, which however is somewhat more commonly present than till. This material is marked separately in Figs. 29 and 30. In view of its lack of sorting and its angular, unworn stones, it resembles till. On the other hand, it is to some extent washed but without any clear stratification. Curves 1, 6 and 7 represent the grain-size analyses made of this material.

Poorly sorted glacial drift has been found in the proximal portions of Siikakangas and Jakamakangas, the northern shore of Terälahti and the eastern extensions of Kömmelinkangas and Rasinkangas (Curves 1 and 7,

Fig. 32). Also the surface parts of the Lintuharju plain can be classified as belonging to this category (Fig. 32, curve 6). At a greater depth here too, clearly stratified glaciofluvial drift may presumably be found.

THE ORIGIN OF NÄSIJÄRVI FORMATION

The structure and the material composition of the Näsijärvi ice-marginal feature suggest that it too evolved as a product of stagnation and slight oscillation of the ice front. However, oscillations of the ice front had happened in the area even before the genesis of the morphological marginal feature. In the proximity of the church of Kiikoinen, about 30 km to the southwest of Hämeenkangas, the author has found a small ice-marginal ridge, in the poorly sorted drift of which lumps of varved clay are embedded. The clay contains salt-water diatoms as well as typical late-glacial *Betula*-dominated pollen flora.

Even before the turn of the century Sederholm (Sauramo 1924) reported having found, underneath layers of clay, in the parish center of Hämeenkyrö, two beds of till between which was wedged a deposit of clay ½ meter thick. The upper till bed contained sandstone from Lauhavuori, having therefore been transported approximately from the northwest. The lower till bed again, according to Sederholm, indicated a westerly movement of the ice sheet.

In 1945 the author found two beds of till around the open quarry at Haveri, in the commune of Viljakkala. The stones in the upper bed were quite clearly oriented and indicated a movement of the glacier ice from approximately a northerly direction. The till fabric of the lower bed was less definite but a broad maximum was situated between the west and northwest. The orientation of the till stones thus coincided with the striations occurring in the area: the direction of the youngest striations is from the north, and that of the older ones from between the west and the northwest (Fig. 28). In addition, other, local directions are exhibited by the striations occurring in the Kyrösjärvi basin.

Between each of the till beds in the Haveri section there lay a ½-meter deposit of varved clay, in which at least a hundred varves could be counted. The clay further contained an abundance of subfossils. The pollen flora chiefly comprised *Betula*, but in addition there was a 5 to 10 per cent content of pine, a couple of per cent of spruce and alder as well as 1 per cent of *Corylus*. The diatoms reveal a very strong marine character. The sample analyses contained 30 to 40 per cent of salt-water diatoms, among them the following species: *Rhabdonema arcuatum*, *Grammatophora oceanica*, *Coscinodiscus* spp. The rest of the diatoms comprise indifferent forms, including certain *Epithemia* specimens and representatives of a small fresh-water habitat, among which certain species belonging to the *Pinnularia* and *Eunotia* families are the most common.

The observations just discussed indicate that the oscillations of the ice front occurred here along a considerably broader zone than the ice-marginal formation itself. Estimating that the formation of the feature lasted at least a few score years, perhaps as much as a century, it may be stated in the light of the foregoing that the recession of the glacier ice in the belt of the Näsijärvi formation took approximately 200 years. This is approximately the same length of time as, according to Sauramo (1923), it took to form the First and Second Salpausselkä systems. Näsijärvi formation is in many places comparable in its dimensions the Salpausselkä systems. The summit of Lintuharju rises 82 meters above the waters of Kyrösjärvi, Vatulanharju is 100 meters above the surface of the lake and Soininharju reaches a height of 85 meters above the waters of Jämijärvi. Each of the »eskers» is situated along the southern edge of an extensive lake basin. Here the ice lobe was thickest and remained in place for the longest period of time. Comparable extensions are not to be found at the corresponding point in the Näsijärvi basin, but the broad Siikakangas is situated only a few kilometers south of the Jäminginselkä open stretch of Näsijärvi.

Matisto (1961) has made a number of detailed stone counts of the material composing Hämeenkangas. They show that to a notable extent, perhaps primarily, the stony components have originated from the northern side of the feature. To some degree the material has also spread, however, along the long axis of the system.

The ice-marginal feature of Näsijärvi, of which Hämeenkangas is the westernmost portion, is, taken as a whole, quite a beautiful formation, which was deposited in front of a glacier lobe. At certain points where ice-contact features have been observed on both sides of the feature, it evolved in a crevasse running parallel to the margin and dividing dead ice from the active glacier. Accordingly, the ice-marginal feature represents by and large a contemporaneous origin throughout its length. Sauramo (1924) assumes that Hämeenkangas evolved in front of successive positions of the ice front. His thinking is based mostly on the clay chronological researches he carried out in the area (Sauramo 1923). Sauramo's clay investigations do not, however, indicate that Hämeenkangas evolved either by successive stages or synchronously. Furthermore, he noticed disturbances in certain of the clays of Ylöjärvi and Hämeenkyrö that have confused the clay chronology. The deformations evidently are the result of local oscillations of the ice margin, mention of which has been already made. Considering furthermore that the oldest varves, comprising at least one hundred annual layers, are situated underneath the till and thus did not come to Sauramo's attention, the arguments in favor of the successive character of Hämeenkangas do not carry conviction. Possible future clay chronological investigations in the region may provide additional illumination in seeking a solution to this problem. Furthermore, the higher plateaus of the feature, Siikakangas, Välikangas, Jakamakangas, Vatulanharju and Soininharju appear to have originated on the level of a contemporaneous aquatic surface. This level represented the maximum height of the Yoldia Sea, or Y I (Virkkala 1957, Hyyppä 1960). Sauramo (1958, p. 319) has placed the plateaus of Vatulanharju and Soininharju into a considerably later stage of the Yoldia Sea — Y IV.

To summarize: the ice-marginal feature of Näsijärvi evolved fairly contemporaneously throughout its entire length along the edge of a stagnant ice front. Before and after as well as, in part, during the formation of the feature, local oscillations of the ice margin occurred.

SUMMARY ON THE ICE-MARGINAL FEATURES OF SOUTHWESTERN FINLAND

In southwestern Finland there occur parts of three systems of ice-marginal features, collectively known as Salpausselkä, which run across the region investigated approximately in a southwestern—northeastern direction. The First and Second Salpausselkä systems extend continuously across the whole of southern Finland, but Salpausselkä III is more fragmentary and runs only from the seacoast to the area of Hämeenlinna. In the present paper the author has further made the proposal that the ice-marginal system that is located around the middle of the environs of Näsijärvi, be called the Näsijärvi marginal formation.

Salpausselkä I runs almost without a break across the region investigated. Its most characteristic form is a simple ridge which has either a narrow or a broad summit and is composed primarily of glaciofluvial drift. Only in the eastern part of the region is the system clearly tripartite for a shorter distance. In places it occur also fragmentarily and as an extensive zone, in which its material and forms vary to a greater extent. Especially in its proximal portion, ice-contact features are common. The highest points rise some 80 meters above the surrounding country. Many of the narrow transverse eskers contain till in their proximal portions, but the broad extensions consist of stratified drift. Littoral forces have greatly modified the original form of the feature. The stratification in many places resembles the structure of the eskers: the strata tend to tilt approximately in conformity to the surface or then are nearly horizontal. It is not uncommon, either, for the stratification to tilt towards the distal side throughout the breadth of the feature. Neither is cross-bedding by any means rare.

In the terrain dividing the First and Second Salpausselkä systems in the hinterland there occur numerous small ice-marginal features, too. In the main, they are short transverse eskers and end moraines of different sizes. The Second Salpausselkä is appreciably more diversified than the First. In the hinterland it occurs as several series of ridges, which run almost continuously from the northeast toward the southwest. Usually several chains run parallel to each other, in the middle portion of the region there being for a long distance as many as three and even four of them. The ridges are composed of both till and stratified drift. In the coastal area, where the relief is bolder, Salpausselkä II forms a single ridge consisting principally of stratified drift and extending fragmentarily all the way to the shore line. The stratification and internal structure closely resemble those of Salpausselkä I.

The terrain lying between the Second and Third Salpausselkä systems is almost totally lacking in ice-marginal features. The glacier margin melted here to some extent in place, but to another extent, again, receded along a solid front.

Salpausselkä III deviates considerably in character from the first two. The system appears only in the area southwest of Hämeenlinna. Its northern and southern portions are fairly fragmentary, but in its central portion it is very unified for a distance of over 25 miles. Broad glaciofluvial plains are typical of Salpausselkä III. One of the largest plateaus in Finland, Pernunnummi, in Tammela commune, is an organic part of the system. Near the seaboard the system has a more sporadic occurrence again. It consists here only of short transverse eskers and scattered glaciofluvial plains.

Ice-marginal features are almost totally lacking in the hinterland beyond the Third Salpausselkä system. Great eskers and ablation moraines are typical of the northern and central parts of the region.

Näsijärvi formation is a fairly continuous chain of ice-marginal features extending for a distance of about 100 km. Its westernmost portion constitutes the extensive Hämeenkangas, its middle portion is more diversified in character, while its eastern portions is characterised by broad glaciofluvial plains. In the plains it is possible to distinguish a distal portion and a steeper proximal portion marked by ice-contact features. There are only a few end moraines. In general, till occurs sparsely in the system, being largely confined to the proximal edge.

Among earlier investigators of the Salpausselkä systems, Hyyppä (1951) and Okko (1957), for example, have also made reference to the part played by till in the composition of the features. On the other hand, Leiviskä (1920) did not find till in them, although he seems to have travelled from one end to another of both the First and the Second Salpausselkäs. On page 240 he writes, for instance: »In den mehreren hundert verschiedenartigen Aufschlüssen, die ich in den verschiedenen Teilen des Salpausselkä gesehen und studiert habe, war überall fast ohne Ausnahme ein deutlich geschichtetes Schuttmaterial zu beobacten ...» But Sauramo (1940, 1958), for his part, appears again to have greatly overestimated the occurrence of till in the Salpausselkä features. In his view, the Salpausselkäs consist in their most typical form of proximal end moraines composed of till and deltas spread out in of front them. This conception of the ice-marginal formations of south-western Finland is quite as erroneous as that presented by Leiviskä. In the parts of the Salpausselkä systems dealt with in the present study, covering an aggregate length of more than 500 km, at only one point has Sauramo's »typical» occurrence proved its validity — namely, in the southern proximal portion of Pernunnummi, in the commune of Tammela. Here, to be sure, one will find a broad glaciofluvial plain and a proximal end moraine composed of till or poorly sorted drift.

THE GENESIS OF THE ICE-MARGINAL FEATURES IN SOUTHWESTERN FINLAND

The parts of the Salpausselkä systems discussed in the present paper originated during the general recession of the continental ice sheet. The ice did not recede continuously, however; there were periods of stagnation, and from time to time it even readvanced locally. Individual features of the systems were formed during the periods of stagnation or as products of oscillation of the ice margin. The sites of formation were in the marginal zone of the glacier, whether in its foreland or, in most cases, in crevasses running along the edge. The ice-contact features occurring on both sides of the systems provide the evidence that major portions of the Salpausselkäs accumulated in crevasses or fracture zones running parallel to the ice front.

The large features marking stagnant stages of deglaciation can be attributed mainly to climatic circumstances. At least, no distinct differences can be observed in the local topography that might have caused the ice sheet to stagnate for lengthy periods. On the other hand, local differences of elevation often determined the position of individual features belonging to one or another of the Salpausselkä chains. Basins and depressions in the bedrock caused the ice margin to stand still, with the result that thick layers of glaciofluvial drift were deposited at the foot of the glacier lobes. More movement occurred where the bedrock lay flat, and in such areas the features took the form of end moraines of various sizes, which are composed of till.

The question as to whether the retreat of the ice front occurred in the region investigated under sub-aquatic or supra-aquatic conditions must, for the time being, be left open. The opinions of different researchers conflict in this matter. Donner (1951) and Sauramo (1958) look upon the Salpausselkä features as of sub-aquatic origin. The great plateaus that are a common occurrence in southwestern Finland, too, would in that case have formed along the ice edge as deltas. Unmistakable deltas have actually been met with in certain districts, and Okko (1957), for instance, has described some from the vicinity of Jylisjärvi. Especially in the most proximal part of the stretch of Salpausselkä II in the hinterland, typical features are deltas of small extent on the surface of which occur indistinct traces of channels and the distal edge of which is bordered by a shore bar of later origin. In the coastal area, however, the recession of the ice probably occurred in the main in conditions of fairly deep surrounding water, though not so deep as to cause the ice to break loose off the bottom and to float. Here, too, the ice front must have stood solidly on its rock base, for otherwise no ice-marginal features could have evolved in the area.

Hyyppä (1951), on the other hand, regards the Salpausselkä features as having had a supra-aquatic origin. Subsequently, the ice sheet re-advanced, depositing till on top of the earlier accumulations; and then the waters in the Baltic basin transgressed their bounds, washing away part of the till cover and causing the primary ice-marginal features to become blanketed under littoral deposits. Certain of the plateaus in the region investigated are clearly secondary forms, on the surface of which occur thick littoral deposits.

A plausible view is that in the largest part of the region the glacier ice withdrew over shallow water and in the upland district of Tammela to some extent over totally dry ground. Since the relief is relatively varied in the region, the depth of the water had to vary locally a great deal. Accordingly, the ice front receded in some places over dry land, and in other places over stretches of shallow or rather deep water. The ice sheet thus disappeared under constantly varying conditions, and its behavior was dependent on the presence and depth of the waters lapping about its margin. This makes more easily understandable the great local diversity of the Salpausselkä features in various parts of the region investigated.

While the ice sheet was receding from the Second Salpausselkä system, a great change occurred in the depth of the water filling the basin of the Baltic Sea. The classical conception is that the Baltic Ice-Lake drained down at that time to the level of the ocean. The drop in the water level has not yet been dated accurately, but it is clearly to be observed in the region investigated in that the highest plateaus on the northwestern side of the proximal series of features belonging to the Second Salpausselkä system lie at a niveau about 25 meters lower down. This is to be seen, for instance, in the Hämeenlinna area and its southern environs. With certain slight exceptions representing supra-aquatic conditions, everywhere on the proximal side of Salpausselkä II do the glaciofluvial features lie below this niveau.

THE DATE OF ORIGIN OF THE SALPAUSSELKÄ SYSTEMS

There has been conflict of opinion not only regarding the mode of origin of the Salpausselkä systems but also regarding the period of their formation. According to Donner (1951) and Sauramo (1958), the Salpausselkä chains date back to the Younger Dryas. V. Okko (1957) and Marjatta Okko (1962) favor the Alleröd. Hyyppä (1951) considers the Alleröd as the very latest possibility, but he would not dismiss the claims for the Older Dryas, either. Mölder, Valovirta and Virkkala (1957) as well as Salmi (1959) take the stand that the time of origin goes back to the last stage of the Older Dryas period. This question must, taken as a whole, also be left open. For some reason only the conception mentioned first has won widespread recognition in the literature.

The author has previously published a collection of pollen diagrams which show that sediments occurring in the foreland of the Salpausselkä systems date from the final stage of the Older Dryas period (Mölder, Valovirta, Virkkala 1957). From this evidence the author has drawn the conclusion that it marks only the minimum age of the features, which probably did evolve during the Older Dryas. The diagrams of Donner (1951) and Sauramo (1958) likewise indicate only the age of the bogs investigated — and not the age of the Salpausselkä systems.

Fig. 33 contains a pollen diagram of Katajalammensuo, which is located in the commune of Vihti in the midland between the first two Salpausselkä chains. The bog borders a small pond and the specimens were collected with an ordinary Hiller peat borer.

The pollen diagram only represents in this connection the most important lower part of the profile. At the bottom lies a half-meter thickness of silty ooze, which upward gradually, without any clear boundary, changes into purely organic ooze. The pollen zones have been presented separately in the diagram. Lowermost is sediment belonging to the Older Dryas. This is indicated by the exceedingly abundant NAP flora, in which *Artemisia* species are prominently represented.

The next pollen zone, marking the Alleröd period, is represented by a bed of sediment only 20 centimeters thick. The proportion of organic matter

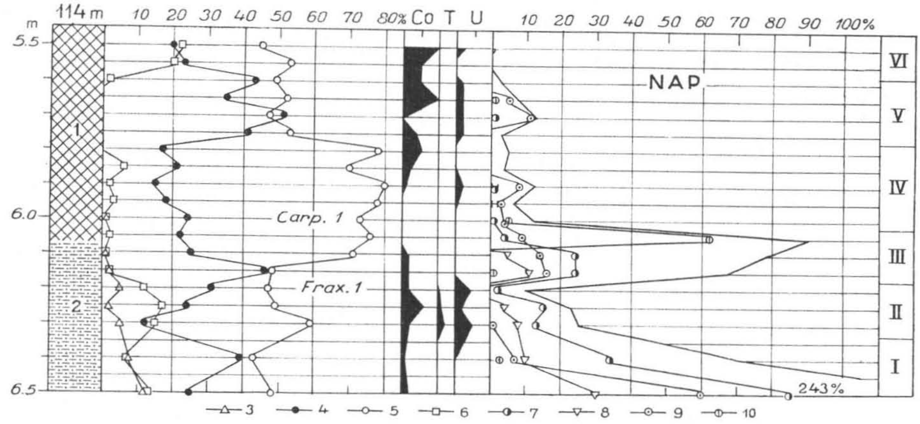

Fig. 33. Pollen diagram of Katajalammensuo. 1 = ooze, 2 = silty ooze, 3 = pollen of spruce, 4 = of pine, 5 = of birch, 6 = of alder, 7 = of *Artemisia*, 8 = of *Chenopodiaceae*, 9 = of *Graminae*, 10 = of *Ericaceae*, I—VI = forest historical division of zones indicating changes of climate. Anal. R. Tynni.

contained in it is notably greater than in Zone I. Noteworthy in particular is the small amount of NAP and the heavy concentration of pollens of rare deciduous trees compared to Zone I.

Zone III consists of a layer about 10 cm thick. The proportion of NAP increases once again, though it does not reach the value of Zone I. Among the NAP should be mentioned the *Ericaceae* pollens in especial, for in the latter half of Zone III they indicate a relatively dry stage. There is less organic matter in this sediment than in Zone II. Moreover, the value registered by the rare deciduous trees is at a minimum.

In Zone IV the proportion of arboreal pollens increases considerably compared to that of NAP. This indicates the growth of forests in the region and the beginning of a new, damper climatic stage.

The diatoms in the sediments of the bog are throughout species native to small fresh-water lakes. The water level of the Baltic basin must thus have been below the threshold of the bog, now at an elevation of about 114 meters, from at least the final stage of the Older Dryas.

Katajalammensuo casts additional light on the time of origin of the Salpausselkä features. It does not, to be sure, directly indicate their age: but the bog does provide the researcher with revealing evidence as to when the locality emerged out of the glacier ice at the very latest. In view of the fact that sedimentation occurred in the locality as early as the end of the Older Dryas, the conclusion seems inescapable that at least Salpausselkä I had formed before that time. Notwithstanding arduous explorations, no other profile has yet been discovered in the region which shows features of equally great age. To arrive at definitive conclusions would, however, require the support of additional material. It is highly possible that the Second Salpausselkä system also originated during the final stage of the Older Dryas, or at least by the turn of this period into the Alleröd. The formation of the Third Salpausselkä would accordingly have to be placed in the Alleröd.

As for the time of origin of the Näsijärvi formation the author (Virkkala 1962) has previously expressed the opinion that it dates from the Younger Dryas period. Justification for this view lies in the fact that, at least as far north as the latitude of Tampere, sediments dating from the very final stage of the Younger Dryas period have been found at the bottoms of numerous bogs. The duration of the Alleröd, in the light of this explanation, would encompass the retreat of the continental ice sheet from the Second Salpausselkä to the Näsijärvi formation. According to Sauramo's (1923) clay chronology, this process lasted roughly seven centuries. This time is somewhat shorter than that generally arrived at by means of radiocarbon dating (e.g. E. Nilsson 1960). Possibly this matter also has a natural explanation. Näsijärvi formation extends to such northern latitudes that boreal influences are far stronger there than in Central Europe or in southern parts of Northern Europe. Accordingly, in the Tampere district favorable climatic periods are bound to be shorter and, correspondingly, harsher climatic periods longer than in regions farther south.

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