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GENESIS OF THE LAMMI ESKER (SOUTHERN FINLAND)

BY

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ABSTRACT

The Lammi esker forms a part of an esker chain stretching NW from the moraines of I Salpausselkä. The described section is about 10 km long. The Lammi esker runs along the axis of a well-marked trough in the bedrock.

The esker constitutes a chain of poorly-developed proglacial deltas connected by means of short ridges. The deltas formed in the Baltic Ice Lake at the mouth of crevasses along which glaciofluvial drift was delivered. Each delta registers an ice-front of strong ablation. During the ice-front recession the subglacial crevasses were filled up with debris.

Within the described area there are also terminal-moraine forms which presumably mark the ice-front during the II Salpausselkä stage. They consist of proximal erratic debris and till overlying glaciofluvial deposits. Glaciotectonic disturbances of sand formations were found at one place.

During the field work attention was also paid to traces of former shorelines. Cliffs formed during the lowering of the Baltic Ice Lake water-level (B III) down to the level of the Yoldia Sea (Y I), as well as during later Yoldia stages, Y II and Y IV.

THE OBJECT OF STUDY

The Lammi esker (Lamminharju) is situated in the southern part of Finland, about 110 km north of Helsinki. It constitutes a part of the long esker chain stretching SE-NW, which begins from the I Salpausselkä ice-marginal belt at Kärkölä. The initial part of the esker which extends from the I Salpausselkä hills as far as Lake Pääjärvi was described by M. Okko (1962) as the Koski esker, mentioned also by Sauramo (1928). Lamminharju is an extension of the Koski esker, which runs from Lake Pääjärvi towards the village of Lammi and further on along the eastern shores of Lake Ormajärvi, totalling some 10 km in length. The genesis of this section is discussed in this paper.

The Lammi esker has not been discussed in detail in previous literature. Only a short description has been given by Leiviskä (1928). According to him the esker begins at the northern shore of Lake Pääjärvi where it forms a promontory called Kaunisniemi. Also V. Okko

(1957 a) has written about Lamminharju, yet his chief object of investigations were the local thermic processes.

The Lammi esker is situated in the area of standstill of the ice margin in the zone of II Salpausselkä (cf. M. Okko 1972). The recessional halt has left exceptionally indistinct traces of ice-marginal action; no terminal-moraine forms have been distinguished previously.

PURPOSE AND METHODS OF INVESTIGATION

The purpose of the study was to find out how the esker originated, the conditions under which it formed and how it is related to the highest water-level.

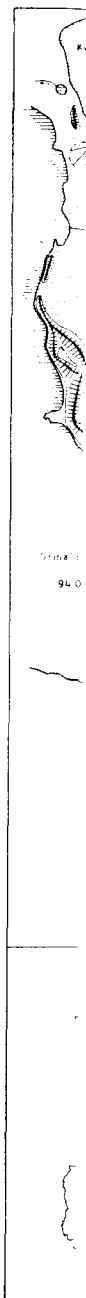
The basic method used was geomorphological mapping. The topographic base for the work was the Finnish General Survey map in the scale of 1:20 000, sheet Lammi. During field work the positive and negative forms were recorded, and geological observations concerning stratigraphy and texture were made in exposures for the genetic classification of the forms (Fig. 1). During mapping, attention was also paid to the traces of marine abrasion.

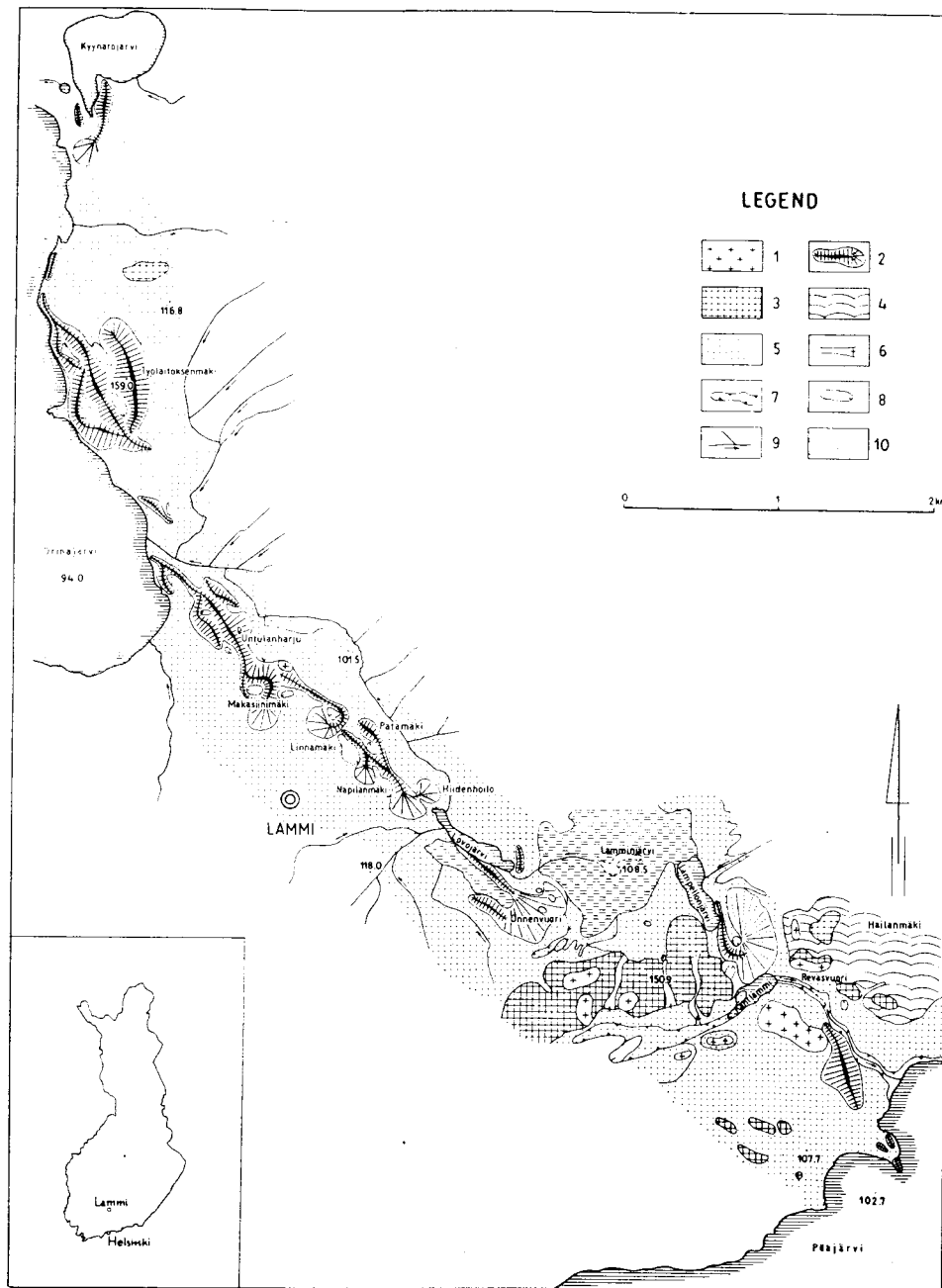
From some of the deposits, samples were taken for granulometric analyses. Their degree of grain abrasion was also studied using Krygowski's (1964) graniformameter.

LITHOLOGY AND TOPOGRAPHY OF THE BEDROCK

According to the petrological map sheet Lammi (Laitakari 1964) of the Geological Map of Finland, scale 1:100 000, the Precambrian bedrock along Lamminharju consists mostly of veined gneiss rich in quartz and feldspar. Only to the south-east granodiorite and peridotite occur; a small area of granodiorite also lies north of Lammi parish centre. The rock bodies are aligned perpendicularly to the esker axis. The bedrock surface is irregular, and frequently, especially in the south-eastern part

Fig. 1. Geomorphological map of the Lammi esker and its surroundings. (1) Bedrock outcrops, (2) esker continued with a delta, (3) terminal-moraine hillocks, (4) undulating ground moraine, (5) areas built of water-laid extramarginal deposits, (6) proglacial valley, (7) small trough, (8) kettle-holes, (9) streamlets, (10) peat-bog plains.





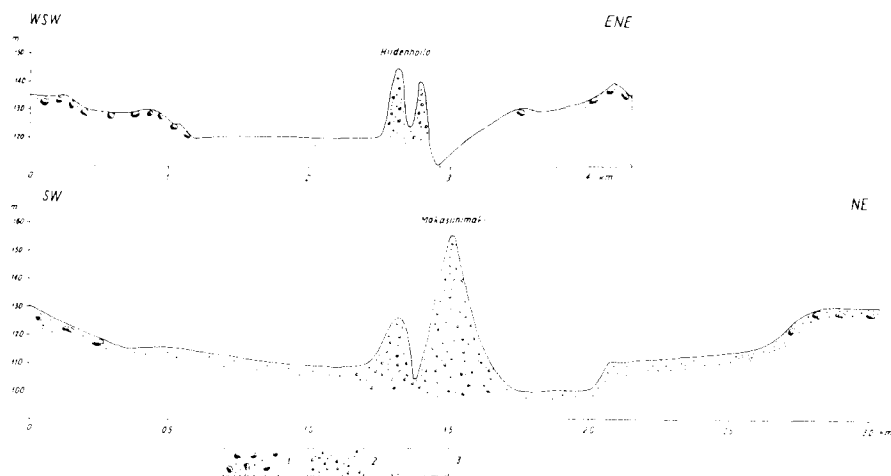


Fig. 2. Cross-profiles reflecting the location of Lamminharju in a bedrock trough. (1) Sands and boulders, (2) sands and gravels, (3) fine sands and silts.

of the study area, it crops out from beneath the Quaternary formations (see Fig. 1). The hillock south-east of Lake Kahtlammi lying on the esker axis consists of gneiss as do the hillocks south-west of the lake. North-east of Lake Kahtlammi is the Reväsvuori hillock, whose southern slope is formed by outcropping amphibolite. Also the parallel-orientated hills between Lake Kahtlammi and Onnenvuori are outcrops of amphibolite. Along the esker, northwest from Onnenvuori, outcropping bedrock has been found only at the foot of the eastern slope of the Makasiinimäki hillock.

The topography indicates that Lamminharju developed along a well-marked through in the bedrock. The hypsometric cross-profiles presented in Fig. 2 show this relationship.

MORPHOMETRIC AND MORPHOLOGICAL DESCRIPTION

THE LAMMI ESKER BETWEEN LAKE PÄÄJÄRVI AND LAKE KAHTLAMMI

Lamminharju starts with a low hillock, Kaunisniemi, jutting into Lake Pääjärvi. It is 55 m long, about 30 m wide, and 3 m high. On its western slope, 1.7 m above the level of Lake Pääjärvi, there is a lake

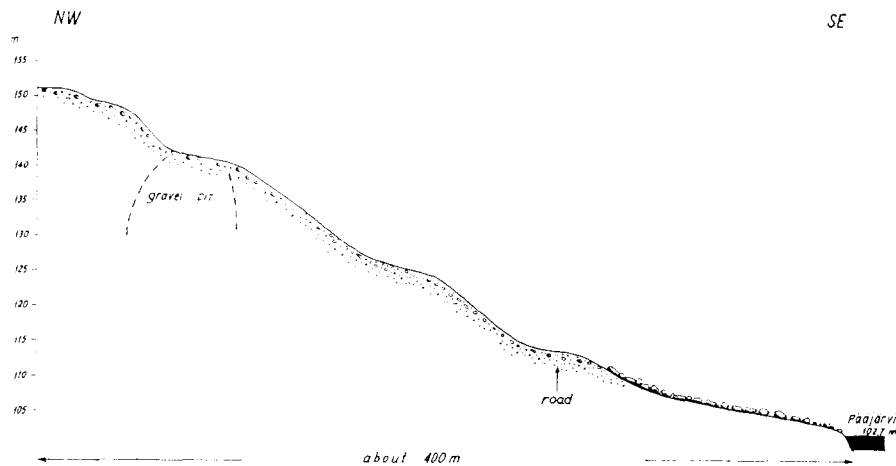


Fig. 3. Schematic hypsometric profile of the southern slope of the highest hillock north-west of Kaunisniemi.

abrasion platform about 3 m in width. In the broad part of Kaunisniemi two other low hillocks stand close to each other. The western one attains an altitude of about 4.5 m above Lake Pääjärvi water-level, the eastern one about 7 m. On the west slope of the western hillock there are two well-marked abrasion platforms 1.7 m and 3.5 m in altitude respectively. In addition to corresponding platforms on the slopes of the eastern hillock, there is a third platform at an altitude of about 4.5 m. The slopes and crests of both hillocks are strewn with pebbles and boulders. This part of the Lammi esker remained longest in the subaquatic environment, which caused considerable degradation.

North-west of Kaunisniemi, there is an elongated esker with an orientation NNW-SSE. It is about 600 m long, some 200 m wide, and 35 m high. As can be observed in the gravel-pit on its eastern side, the ridge is built mainly of pebbles, up to 30 cm in size, and gravels. The crest of the ridge is slightly convex, about 50 m wide, while its slopes are inclined at an angle of 25° – 30° . The inclination angle is more gentle in the lower parts of the slopes. The steepness of the slopes and the occurrence of single big (up to 2 m) boulders and till on the western slope indicate ice-contact deposition. Lack of boulders in the summit part of the ridge suggests that it originated in an upward-opened crevasse in subaquatic conditions near the ice margin. At any rate, the crest material has not been subject to direct ice-contact action.

A hypsometric profile of the southern slope of the esker shows well-marked steps, with the top one about 1 m below the crest, i.e. about 150 m a.s.l. (Fig. 3). The successive steps are found at the altitudes of 142 m, 127 m and 114 m a.s.l.. It is likely that they were formed through wave-action during the lowering of the Baltic Ice Lake (B III) and the subsequent Yoldia Sea.

The esker ridge is surrounded by flat and fairly extensive deposits of silts and fine sands. This area was lake bottom when the water-level of the lake was higher. Its monotonous flatness is broken by a few low hillocks only. The blocks on their surface indicate that they represent outcropping ground moraine. The author is, however, inclined to hold the view that they represent annual moraines, as well.

TERMINAL-MORAINE FORMS BETWEEN LAKE KAHTLAMMI AND LAKE LAMPELLONJÄRVI

West of the Hailanmäki hills, between Lake Kahtlammi and Lake Lampellonjärvi, stretches a hill range, which, on the basis of geomorphological studies, was classed among terminal-moraine forms. Actually these forms already occur south-east of the Reväsvuori hill. Till with boulders is found on their surface. In the trough between Hailanmäki and Reväsvuori, as well as on the surface of the low hillocks north-east of Reväsvuori, there is a considerable number of boulders; they also lie scattered in fairly large quantities on the northern slope of the hillock. The character of relief of the area and frequent occurrence of erratic boulders point to deposition at the ice-front, which rested on the amphibolite hill of Reväsvuori.

West of the narrow and deeply incised trough there is a large accumulation characterized by a flat summit surface at about 160 m a.s.l. and slopes dipping up to 30°—35°. Owing to the lack of any natural exposures its internal composition could not be examined. The western slope is extended with a short esker ridge which later on turns abruptly north. On both sides of the ridge there are small but deep, oval kettle-holes. It is likely that their genesis is bound up with evorsive action of melt-waters. On the surface as well as on the slopes of the esker there are vast quantities of boulders. This proves that the esker originated in a crevasse that was subsequently filled up with debris. In the first period, however, there was only a subglacial crevasse, or tunnel, out

of which melt-waters flowed. The waters carried along masses of sand and gravel and accumulated them at the place where they lost power of transportation, i.e. at the mouth of the ice-crevasse in subaquatic conditions. Although the internal composition of the esker is not known, it seems evident that the large accumulation with its summit altitude of 160—161 m a.s.l. was located at the mouth of the crevasse and represents a delta that reached the level of the Baltic Ice Lake (B III). It resembles in many respects the Mataramäki delta described by V. Okko (1957 b) and located 6 km south-east from here. No big boulders were found on the surface of the delta, whereas they occur in large quantities along the western, that is, the proximal slope.

The upper southern slope of the delta falls quite abruptly (inclination up to 35°) to become later on, from an altitude of about 12 m above the level of Lake Kahtlammi, more gentle. There are numerous pebbles on the surface of this part of the slope sometimes up to 0.5 m in diameter. The more gentle inclination of the lower slope profile and the materials occurring there indicate that there was a water surface at that level during a certain period of time. Traces of distinct abrasion are found around 137 m a.s.l.

West of the delta stretches a belt of hills about 400 m in width; their summit altitudes vary from 155 m a.s.l. to over 160 m a.s.l. The belt is intersected at three points by well-marked valleys which resemble poorly-developed pro-glacial valleys, as those described by Klimaszewski (1960) and Kozarski & Szupryczyński (1973). The highest summits are built chiefly of boulders and till. Although the belt does not comprise well-developed end moraines, the author classifies it as a terminal-moraine belt. Its location between the proglacial delta and a neck of outcropping bedrock does not contradict such an interpretation.

The ice-stand there is testified by other evidence, too. The proximal slopes of the moraines are heavily strewn with erratic boulders. In a freshly-made excavation in the proximal slope at the forest track crossing the moraines, beds of fine sands were exposed. The beds dipped north. That aroused the suspicion that their primary dip has been disturbed. As a matter of fact, disturbances in the sands were traced in a gravel pit in the western part of the moraines, on the proximal side. Weak but distinct folds, which probably originated owing to the pressure exerted by the ice-front, were observed there. In addition to glacitectonic, other disturbances also took place, like subsidence of strata. The



Fig. 4. A proglacial valley running across terminal-moraine belt.

disturbances recorded at the proximal side of the belt point to a halt of an active ice margin for some time.

During the standstill, meltwaters collected into rivers that flowed away from the glacier across the terminal moraine belt eroding proglacial valleys there. The moraine belt is intersected by three valleys of this type. The easternmost valley has a hanging position in such a way that on the glacier side it begins in the middle of the moraines. Its windling bed deepens towards the mouth, where it is about 2 m deep and 20 m wide. There are boulders up to 1.5 m in size on the valley floor.

The genesis of the other two valleys intersecting the terminal moraines (Fig. 4) appears more complicated. Both start at the foot of the proximal slope, climb uphill and end with their mouths on the distal part of the moraines. The long profile of the two valleys is thus convex in shape. Because they are rather small in size, they seem to have originated as a result of a short-termed but rapid flow of water. The valley in the middle starts at the foot of the proximal slope with a well-marked pot-hole. While the easternmost valley formed as a result of free flow of melt waters, the two other valleys were formed by waters emerging on to the foreland under hydrostatic pressure at the time when the active ice sheet still stood at the terminal moraine belt. The greatest problem, however, is the fact that the floors of the proglacial valleys lie 7—17



Fig. 5. Delta-stratified sand and gravel, distal part of terminal moraines.

m lower than the highest water-level recorded (B III). A situation of this type suggests that the valleys were formed in a subaquatic environment.

The geological composition of the distal part of the moraines differs from that of the proximal parts. It could be studied in a 2-m-deep excavation (Fig. 5). Below the surface a 40—60 cm layer of pebbles up to 5 cm in size was found, under which rest beds of stratified coarse sand together with gravel and pebbles. The stratification is delta-like; the strike of the beds is E-W and their dip is 20° S. To the west from the excavation, the distal slope of the hills is built mainly of sand. It seems that the greatest role in the formation of the moraines can be attributed to melt-waters. During a halt of the ice front, which was anchored on the bedrock elevations, waters flowing away from the melting glacier formed subaquatic deltas in some places. Probably at the same time deposition of till took place on the proximal side. At the place where a water-carrying subglacial tunnel had its mouth, a delta was formed. The fact that the delta was built up to the level of the Baltic Ice Lake (B III) permits the conclusion that the ice-margin halted for a longer period of time at the line of the terminal moraines. The activity of the ice-margin is borne out by the occurrence of glacetectonic disturbances at some places.



Fig. 6. Fine sand and silt in the hinterland of terminal moraines south of Lamminjärvi.

THE LAMMI ESKER BETWEEN THE TERMINAL-MORaine ZONE AND LAKE KYYNÄRÖJÄRVI.

North-west of the terminal moraines runs a trough, about 2 km in width, on whose axis the main part of Lamminharju is located (Fig. 2). The trough, with a cover of fine sand and silt, is used for agricultural purposes. The geological structure of the sediment cover was studied in a cutting (Fig. 6) between the terminal moraines and the extensive

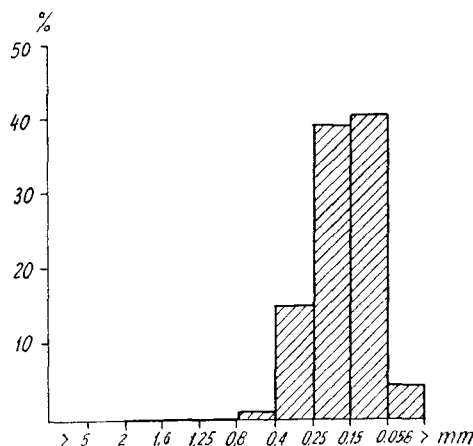


Fig. 7. Mechanical composition of a sample of sand at 2.2 m depth in the cutting shown in Fig. 6.

marsh which surrounds the strongly paludifying Lake Lamminjärvi, at the cart-track leading towards the Onnenvuori hill. The sequence of layers is as follows:

- 0 —0.5 m fine sand with an intermixture of coarse sand, sporadic boulders
- 0.5—1.0 m alternating layers of fine sand and grey-coloured silt
- 1.0—1.5 m fine sand with weakly-marked ripple lamination
- 1.5—2.0 m silt rich in sand
- 2.0—2.2 m fine sand

A sample was taken from a depth of 2.2 m for an analysis of its mechanical composition. The results presented in Fig. 7 point to considerable domination of fine, $\varnothing = 0.25\text{--}0.056$ mm, fractions. Similar materials are found in a nearby pit between the western part of the terminal-moraine belt and the Onnenvuori hill. The hillock lies on the axis of a narrow, peat-filled valley that connects the extensive trough west of Lamminharju with the Lake Lamminjärvi marsh. Its geological structure is seen in Fig. 8. A thin layer of silt overlies horizontally stratified fine sands. The presence of ripplemarks points to a slow flow of water eastwards. Both cuttings reveal water-laid extramarginal



Fig. 8. Horizontally-stratified fine sand between terminal moraines and Onnenvuori delta.

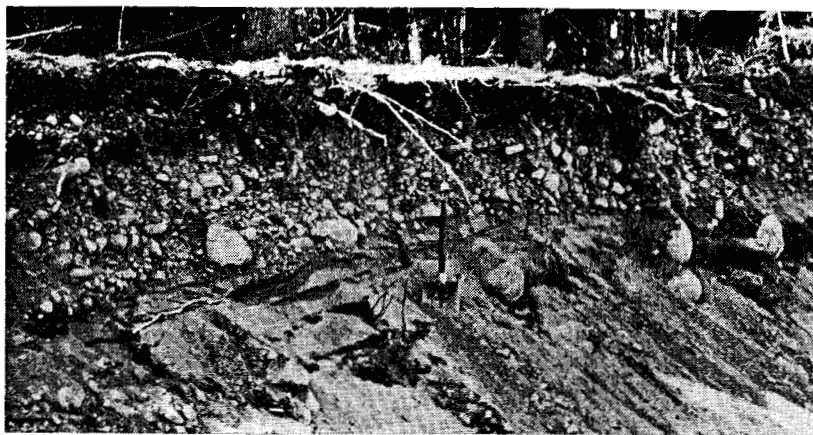


Fig. 9. Boulders and pebbles underlain by sand and gravel in summit part of the Onnenvuori delta.



Fig. 10. The Onnenvuori delta with delta-stratified glaciofluvial drift merging into extramarginal deposits.

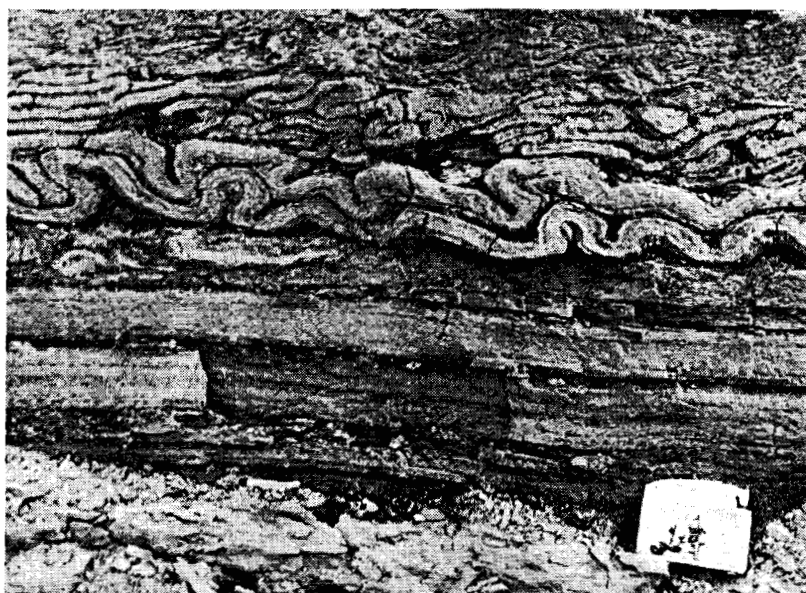


Fig. 11. Slumping structures in silts at the foot of Onnenvuori southern slope.

deposits. In the author's opinion also the remaining parts of the extensive trough are principally dominated by extramarginal sands and silts.

Near the Lake Lamminjärvi marsh there is the hillock called Onnenvuori. It rises about 30 m above the surrounding ground, with slope inclinations up to 30° . Its summit is of an altitude of 162 m a.s.l. Large gravel-pits on the northern, southern and eastern slopes of Onnenvuori allow for a good access to its geological structure. Close to the summit, the surface layer up to 1 m thick, consists of boulders 30–50 cm in diameter and smaller pebbles (Fig. 9). It displays a good sorting of materials as well as a good degree of abrasion. Underneath, gravel and sand with pebbles and boulders were found. The stratification is delta-like. It is perfectly well exposed on the northern side of Onnenvuori and in the deeper parts of the southern gravel pit (Fig. 10). Two strike directions dominate: $N 60^\circ W$ and $N 60^\circ E$. The dips are 15° – 20° SW or SE, respectively. The glaciofluvial formations of Onnenvuori and the extramarginal deposits merge into each other, as can be seen in Fig. 10. The extramarginal deposits reach the 135 m a.s.l. contour line. Their thickness grows southwards. Some layers of silt at the foot of the southern slope of Onnenvuori are characterized by slumping structures (Fig. 11). The beds were deformed during deposition, possibly as a result of decay of buried dead-ice. This view is based on the fact that dead ice remained amidst the Onnenvuori deposits after the ice sheet had withdrawn, as is indicated by a distinct disturbance of the upper extramarginal series built of silt and fine sand in a gravel pit on the east slope of Onnenvuori. The disturbances obviously originated as a result of subsidence of deposits when the buried dead ice was still in the process of decay.

It seems that the peat-filled marsh of Lake Lamminjärvi is an extensive trough that originated as a result of the melting of dead ice. Small but deep kettle-holes resembling pot-holes also occur in the eastern part of Onnenvuori. The number of boulders increases considerably on the northern slope of Onnenvuori. To the north-west, two narrow esker ridges run, about 200 m and 500 m long, respectively. The latter is very narrow; its height is about 10 m and slope inclination up to 35° . On its crest and slopes, boulders are frequent, and below the surface the material is mainly glaciofluvial stony gravel (Fig. 12). In the author's opinion, both originated in a marginal crevasse along which melt-waters transported drift which formed the Onnenvuori delta. The boulder cover on the northern slope is a mark of ice-front presence

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Fig. 12. A cutting in the esker NW of the Onnenvuori delta.

there. The height of the delta (over 160 m a.s.l.) indicates that it reached level B III. The geological composition of the summit part, which consists of fairly well-sorted, coarse glaciofluvial drift, is clear evidence of processes of abrasion going on there when the delta was slowly reaching the highest local water-level (B III). The formation of the delta of Onnenvuori did not, however, last long enough for the deposition to overcome the destructive wave-action, and thus no supra-aquatic part was formed. Before the ice-sheet receded, the crevasses had been filled up with drift.

North-west of Lake Lovojärvi there are two adjacent glaciofluvial hillocks called Hiidenhoilo (Fig. 13). The western hillock attains a height of 25 m (145 m a.s.l.), the eastern one 20 m (140 m a.s.l.). Both hillocks are slightly elongated. Their length is 200 m and 160 m respectively. The western hillock, as can be judged from the gravel pit there, is built of coarse gravel, pebbles and boulders up to 1 m in size. The walls of the pit had collapsed so badly that the structure of the drift could not be studied. Boulders are found on the slope surfaces and on the summit, particularly on the northern slope, where there is an extensive boulder cover. In another gravel pit on the eastern slope of the eastern hillock there were gravel, sand and pebbles stratified like foreset beds in a delta, with a strike of N 15°W, and a dip of 20°—25° E.

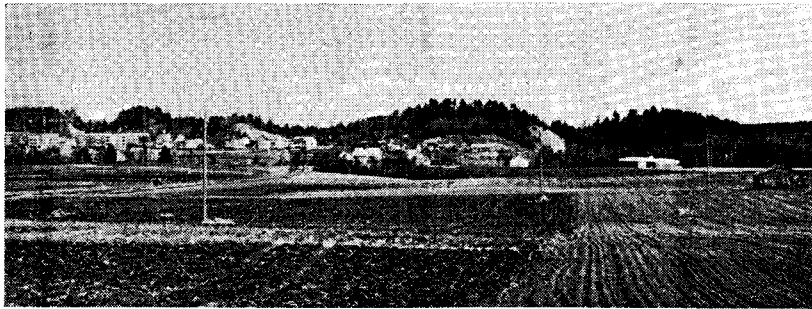


Fig. 13. Hiidenhoilo hills. In the background successive culminations of Lammiharju (Napilanmäki, Patamäki and Linnamäki). In the foreground a relatively flat area built of fine sand and silt.

Also on this hillock, boulders are frequent on all surfaces. It may be concluded that the Hiidenhoilo hillocks are deltas accumulated by glacio-fluvial waters. Judging from the quantity of boulders on both deltas they originated already in the ice-gate. Finally, attention should be paid to the fact that, similar to the Onnenvuori deltas, Hiidenhoilo is enveloped by extramarginal deposits observable in the southern part of the eastern hillock gravel-pit.

A narrow esker branches from the proximal slope of Hiidenhoilo and runs northwest. Numerous boulders rest on its surface. The esker formed in a subglacial crevasse along which glaciofluvial drift was transported to the Hiidenhoilo deltas.

At a distance of merely 200 m from Hiidenhoilo, on the western side of the esker, is the oval Napilanmäki hill, which rises well above the surrounding ground. Its relative height is about 20 m, its crest height 140 m a.s.l. As seen in the huge, almost 30 m high gravel-pit dug in the northern slope, the geological composition of the hill is dominated by gravel, pebbles and fine sand with a delta-like stratification. The layers have a strike of N 60°W, and a dip of 15°SW. Thus Napilanmäki, similar to Onnenvuori and Hiidenhoilo, also is a delta built subaquatically at the ice-front. Ice presence there is borne out by boulders on the northern slope of the delta, although they are not as numerous as on the proximal slopes of Hiidenhoilo. On the surface of the esker ridge branching from Napilanmäki there are numerous boulders and kettle-holes 10 m in depth on each side of the esker. North of Napilanmäki rises Patamäki with a crest at 136 m a.s.l. and steep

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Fig. 14. Boulders on the crest of Makasiinimäki esker.

slopes (30° — 35°). On its northern and eastern side there are numerous boulders 3—4 m long. Due to the lack of structural data, the question has to be left open whether Patamäki is a delta formed at the ice-margin or a form which originated in a subglacial crevasse. The boulders may speak for the ice-front presence there, which favours the first alternative.

About 4 m below the summit of Patamäki, on its eastern slope, there is a well-marked flattening in the shape of a ledge 6—7 m wide with a considerable accumulation of boulders. It was obviously formed through wave-action, and is consequently a trace of a former shore.

The next culmination of Lamminharju, the Linnamäki hillock, attains an altitude of 150 m a.s.l.. The esker that branches from it runs at first north-east; then it loops abruptly around a kettle-hole there and turns toward the north-west. In its further course the esker joins the Makasiinimäki hillock. On the surface of Linnamäki, as well as on Makasiinimäki, numerous boulders occur. Yet most boulders are to be found on the eastern slope of the hillock. Also these forms may be interpreted as poorly-developed subaquatic deltas.

Makasiinimäki consists of two parts different one from the other as to the shape. The northern one is parabolic, with horns pointing west. An oval hillock adjoins this form from the south. Both parts are

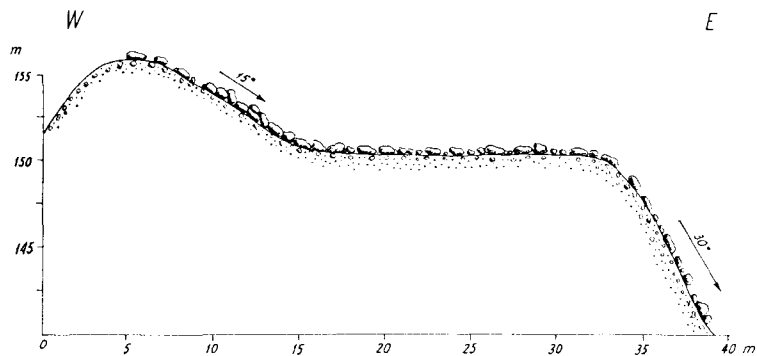


Fig. 15. Cross profile of Makasiinimäki summit.

separated from each other by a narrow but well-marked through. The hillocks dominate the surrounding area by about 50 m. Their crest height is 155 m a.s.l. Slope-inclination values vary between 30° and 35° . The northern part of Makasiinimäki is distinguished by a narrow crest with numerous boulders (Fig. 14). Large quantities of boulders are also found on the eastern slope. Shape and materials are indubitable evidence that the northern part of Makasiinimäki originated within a subglacial tunnel. In this, drift was transported and deposited to form the oval hillock, evidently a poorly-developed delta.

A cross profile of the highest part of the north-east esker of the Makasiinimäki complex is shown in Fig. 15. At first, starting from its culmination, slope inclination is fairly gentle, 15° . A considerable density of boulders is found there. Some 5 m below the summit, that is about 150 m a.s.l., there is a distinct ledge about 18 m wide and several dozen metres long. Further down, the slope falls abruptly at 30° . It is probable that the ledge resulted from wave-action at the time when the Baltic Ice Lake water-level was lowering. Corresponding traces are not found on the western slope of Makasiinimäki. There is a small but very deep kettle-hole on that side. The altitude difference between its floor and the esker summit is 50 m. Another, slightly shallower kettle-hole is at the foot of the eastern slope of the esker.

On the lower western slope of the hillocks, at an altitude slightly below the 120 m contour line, one can observe another well-marked flattening. Its surface is covered by numerous, well-abraded pebbles



Fig. 16. Boulder cover on the eastern slope of Untulanharju.

and boulders. It seems that this is a mark of a younger shoreline. The mark corresponds in height to the level noted by Sauramo (1958) at the foot of the western slope of the Untulanharju hill at an altitude of 117.5 m a.s.l. According to Sauramo, the shoreline here dates from the Yoldia Sea stage (Y IV).

North-west of Makasiinimäki stands another culmination of Lamminharju, called Untulanharju, deformed by several kettle-holes. Untulanharju actually consists of three distinct ridges of which the middle one is the longest. Its crest altitude is about 140 m a.s.l.. Yet the highest summit of Untulanharju is the hillock of the western ridge with an altitude of 147 m a.s.l.. On the middle ridge there are numerous boulders, in places in form of extensive boulder covers (Fig. 16). The boulders are considerably well rounded, which speaks for water transport. They thus represent glaciofluvial formations in contrast to the erratic debris so frequently found on Lamminharju. Erratic boulder debris is found on the middle crest of Untulanharju, thus proving that this ridge originated most probably in subglacial conditions. The shape of Untulanharju and its deformation by kettle-holes also allow the interpretation that the middle ridge originated in the ice gate. The debris for

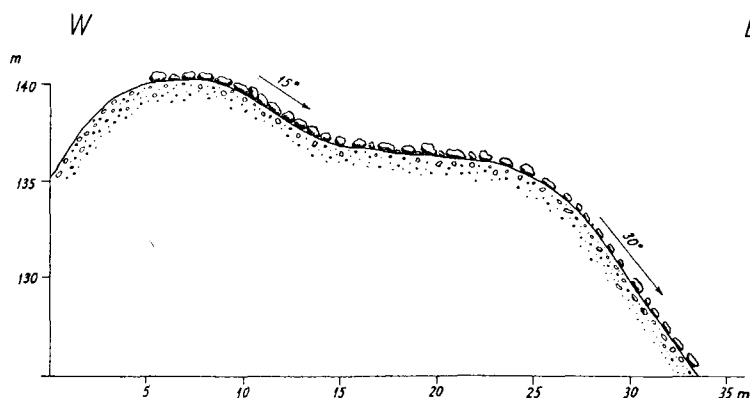


Fig. 17. Cross profile of the summit of Untulanharju middle crest.

the formation of Untulanharju was delivered along a narrow tunnel, in which was formed the esker running from Untulanharju towards Lake Ormajärvi. On its surface there are large quantities of erratic debris that was deposited in the tunnel during ablation.

Also on Untulanharju, traces of former shorelines were found. A trace of the former sea-level is to be observed on the eastern slope of the middle crest. There is a well-marked, 3 m high rocky cliff, and higher, at an altitude of about 137 m a.s.l., lies an abrasion platform about 10 m in width (Fig. 17). Another distinct trace of a former shoreline, already discerned by Sauramo (1958), is an abrasion platform at the foot of the western slope of Untulanharju, at an altitude of 117 m a.s.l.

North-west of Untulanharju, at the eastern shore of Lake Ormajärvi, lies the largest expansion of Lamminharju, the Työlaitoksenmäki hillocks. They are in reality three distinct ridges separated from each other by deep kettle-holes. Slope inclination is considerable here, between 30° and 35° . The eastern crest, the highest one, dominates the surrounding area by about 50 m. The highest point is 159 m a.s.l. About 5 m below the summit, there is a well-marked boulder-strewn abrasion platform about 15 m in width on the eastern slope at 154–155 m a.s.l. The middle crest, the longest one, consists of several culminations descending in altitude: 150 m, 145 m and 120 m a.s.l. The crest is extended by a low, elongated hillock located about 200 m further north (Fig. 18).

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Fig. 18. Esker hillock north of Työlaitoksenmäki.

On the surface of the middle crest there are numerous boulders increasing in number towards the north-east. The geological composition of Työlaitoksenmäki is dominated by gravel and pebbles. Below the highest, southern culmination of the middle crest as well as on the neighbouring hillock more to the west, there are occasional patches of till on the surface. The till, together with the crest morphology of Työlaitoksenmäki, indicates that the hillocks probably developed in the ice gate. Their development thus resembles that of Untulanharju. The course of the subglacial crevasse along which the debris-carrying meltwaters flowed is shown by a short esker ridge farther north.

Between Lake Ormajärvi and Lake Kynäröjärvi lies the last part of Lamminharju to be dealt with. It is styled in the form of two elongated hillocks standing in alignment. The southern hillock has an altitude of 125 m a.s.l. and the northern one 120 m a.s.l.. The geological composition of the southern hillock is exposed in a big gravel pit: fine sand to gravel and pebbles 5—30 cm in diameter. The layers are delta-stratified; the strike of the beds varies from N 30° E to N 60° E and the dip from 7° to 25° SE. The hillock is to be considered a highly immature, truncated delta formed in a relatively short time in subaquatic conditions by glaciofluvial waters at the mouth of a glacial tunnel. Absence of boulders on the surface of the accumulation confirms the view that it formed in front of the ice margin.

As the northern hillock is similar in shape to the southern one, it can be assumed that it is the beginning of a delta, too. Boulders on its proximal slope may be taken as evidence of ice contact.

TRACES OF FORMER SHORELINES IN THE STUDY AREA

It is commonly considered that traces of the highest Baltic Ice Lake water-level (B III) attain an altitude of 160 m a.s.l. in the closest neighbourhood of the Lammi esker. V. Okko (1957 b), who conducted his research within II Salpausselkä several kilometres south-west of Lammi, states that the Mataramäki delta there developed to an altitude of 160–162 m a.s.l. and reached the B III level. According to Sauramo (1958), the flat top of the Kukkuramäki esker hillock also denotes that level. The hillock lies on the northern shore of Lake Ormajärvi and it is actually a continuation of the Lammi esker. Sauramo discovered terraces on the lower slopes of Kukkuramäki, at the altitudes 135 m, 130 m and 119 m a.s.l. According to him, the terraces originated in the Yoldia Sea stage during phases Y I, Y II and Y IV.

In the neighbourhood of Lammi, as can be judged from the diagram by Aartolahti (1969), the Baltic Ice Lake isobase (B III) runs at an altitude of 160 m a.s.l., and the Yoldia Sea isobases of phases Y I, Y II and Y IV run at altitudes of about 133 m, 128 m and 113 m a.s.l. respectively.

Within the study area the altitude of 160 m a.s.l. or level B III was reached by the delta between Lake Kahtlammi and Lampellonjärvi and by the Onnenvuori delta. The described traces of former shorelines on Työlaitoksenmäki (155 m a.s.l.), Makasiinimäki (150 m), on the esker hillock north of the Kaunisniemi Peninsula (149 m and 142 m), on the slope of the delta above Lake Kahtlammi (137 m) and Untulanharju (137 m a.s.l.) thus record water-levels of the Baltic Ice Lake from the period when its waters were lowering to the Yoldia Sea level. It seems highly probable that the abrasion terrace on the eastern slope of Patamäki, at an altitude of about 132 m a.s.l. marks the maximum reach of the Yoldia Sea (Y I). The ledge at an altitude of about 127 m a.s.l. on the esker hillock north of Kaunisniemi is probably a trace of level Y II, and the abrasion terraces at the foot of the western slope of Untulanharju and Makasiinimäki with altitudes of 117 m a.s.l. evidently mark level Y IV (cf. Sauramo 1958). The abrasion mark at 114 m a.s.l. on the

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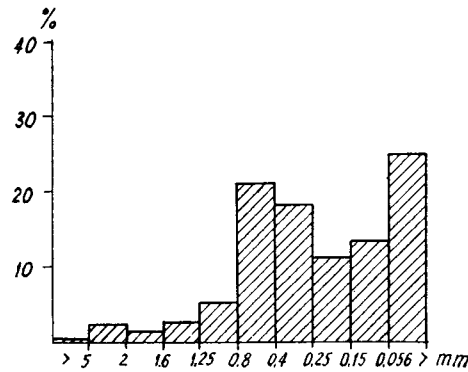
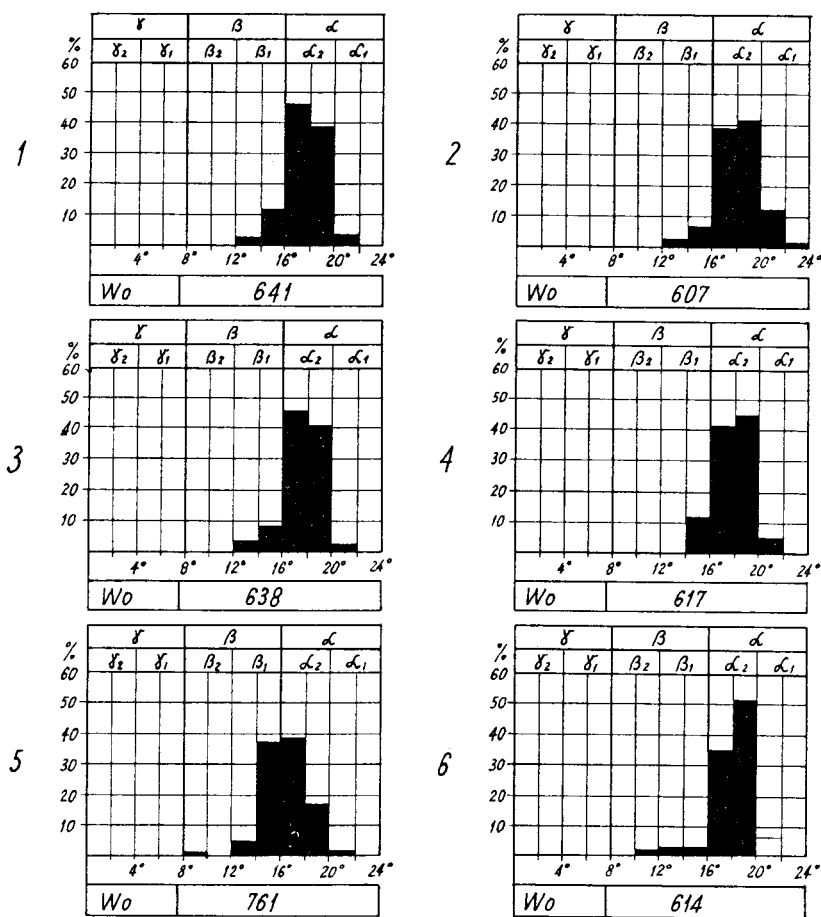


Fig. 19. Mechanical composition of slope-cover deposits, Hiidenhoilo.

southern slope of the esker hillock near Lake Pääjärvi may also derive from the same period.

During the lowering of the water level, the supra-aquatic area expanded. The emerging glacial forms were subject now, *inter alia*, to eolian activity; dunes and cover sands formed in places (cf. M. Okko 1962). During our joint excursion along Lamminharju, Professor V. Okko pointed out the structureless slope cover composed of fine sand in the gravel-pit of Hiidenhoilo. He suspected that this cover deposit originated in a combination of deposition of wind-blown drift into water and resorting of esker drift by shore action. The author took a sample for an analysis of its mechanical composition and grain abrasion. The analysis of the mechanical composition (Fig. 19) showed that the bulk of the examined deposit was constituted of fine sand and silt fractions with a small intermixture of coarse sand grains. The great differentiation of the mechanical composition, and especially the high content of silt fractions shows that the deposit as a whole is not eolian in character. The low index of abrasion (641) of quartz grains of fractions 0.8—1.25 mm obtained during the analysis is a proof that the grains are characterized by only very slight wearing of edges and corners. The majority of them falls in the subtype α_2 (angle class 16° — 20°). According to Krygowski (1964), grains with a 0—800 index of abrasion represent the juvenile type (no abrasion), those from 800—1600 represent the mature type (grains have markedly worn edges and corners), and those from 1600—2400 represent the old-age type (grains are thoroughly abraded). The low abrasion index obtained, 641, for the slope cover material does not



Wo = index of abrasion

Fig. 20. Histograms of quartz-grain abrasion of some formations within the investigated area. (1) Slope-cover deposit, Hiidenhoilo, (2) glaciofluvial drift, Hiidenhoilo, (3) glaciofluvial drift, Onnenvuori, (4) glaciofluvial drift, proximal part of moraines, (5) glaciofluvial drift, distal part of moraines, (6) glaciofluvial drift, northern part of Lamminharju.

reveal eolization. The grains of glaciofluvial deposits from other parts of the study area are characterized by similar abrasion indexes (Fig. 20). If the slope cover contains wind-blown grains they have not taken

part in any long-lasting eolian process. Mention should be made of Seppälä's (1971) study of the periglacial dunes of north Finland. He obtained still lower abrasion indexes for dune sands but higher values for glaciofluvial and till materials. Seppälä accounts for low abrasion indexes of north-Finnish dune sands by referring to the destruction of grains in periglacial environment. It seems, thus, that customary granulometric methods alone are not applicable for identification of periglacial or late-glacial wind-blown deposits. The partially eolian origin of the slope cover at Hiidenhoilo thus remains an open question (see, however, Jauhiainen 1972).

CONCLUSIONS

The Lammi esker appears as a range of hillocks varying in size and altitude. They stand in alignment and are usually connected by means of short and narrow eskers. The glacial crevasse system that Lamminharju genesis was bound up with ran along the axis of a well-marked bedrock trough. The study area was deglaciated in subaquatic conditions; only the Onnenvuori delta and the delta between Lake Kahtlammi and Lake Lampellonjärvi were deposited up to the B III level. The last-mentioned delta originated among a terminal-moraine range, the accumulation of which was bound up, as it seems, with the II Salpausselkä ice-marginal stage. When these moraines formed, the ice front was active, as shown by glacetectonic disturbances in the proximal part of the moraines. Because there was sufficient time for melt waters to nourish the delta until it reached up to the B III level, this marginal stage must have lasted relatively long.

Despite the fact that Lamminharju follows the course of a crevasse system for a distance, all formations along its axis did not originate synchronously. A number of expansions of Lamminharju represent deltas deposited at the mouth of the ice-gate in subaquatic conditions. The deltas originated at places of abrupt loss of carrying power of debris-transporting waters, that is at the place of contact with the Baltic Ice Lake.

Some deltas accumulated in the ice-gate, where the ice-ceiling was still above them. Evidence for this is provided by the following facts: considerable deformation of the deltas by blocks of dead ice detached from the ice-front, vast quantities of erratic debris on their surface, as

well as sporadic patches of till (e.g. Työlaitoksenmäki). Thus, each delta marks an ice-front position of stepwise deglaciation. When the ice-front was receding, the crevasses along which glaciofluvial transport took place, were filled up with debris, and blocks of dead ice were buried in the esker deposits. Most of the esker was submerged at deglaciation. Owing to subsequent regression of the water-level the glacial forms were abraded through wave-action that washed finer fractions away from glaciofluvial formations.

The lowering of the Baltic Ice Lake water-level (B III) to that of the Yoldia Sea was recorded at several places on delta slopes in the form of abrasion platforms or cliffs. Traces of former shorelines were observed chiefly on the eastern slopes of the deltas. Abrasion terraces from the Yoldia Sea stage (Y I, Y II and Y IV) were also recorded.

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