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ON THE DEVELOPMENT OF THE FIRST SALPAUSSELKÄ, WEST OF LAHTI

BY

MARJATTA OKKO

WITH 53 FIGURES IN TEXT AND ONE MAP

ACADEMICAL DISSERTATION

HELSINKI 1962

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ABSTRACT

The materials, morphology and structure of various glacigeneous elements of a segment of the First Salpausselkä (1 Ss), west of Lahti, including its foreland and hinterland, are described and interpreted. The relation between these land forms and the ancient raised beaches is studied.

The following scheme of deglaciation is presented: During its retreat towards the northwest from the foreland the ice margin terminated in deep water. It is not known how far northwest the margin retreated. It is proposed that this stage be called the Heinola deglaciation. It ended in a Salpausselkä readvance which brought the ice margin to the zone where the 1 Ss was to develop in the Lahti area. The sea was in a regressive stage, and parts of the 1 Ss formed in supra-aquatic conditions. The regression ended in the damming up of the Baltic Ice Lake.

The age of the Heinola deglaciation is not yet known. The Salpausselkä readvance in the Lahti area took place during the Alleröd period and the Salpausselkä stage lasted here into the Younger Dryas period. Also the stages of the Baltic Ice Lake and the early Yoldia Sea occurred during the Younger Dryas period.

PREFACE

The present study grew out of the observation material that I had collected in connection with the mapping of the Kärkölä area for the Department of Surficial Deposits of the Geological Survey of Finland. The field work was mainly done in the summers of 1954, 1957 and 1958, followed by some additional research in the field in 1959 and 1960.

The sequence of late-glacial events in the area discussed in this paper is essentially the same as that outlined in my licentiate's thesis, which I submitted to Professor Väinö Auer of Helsinki University in May 1959. At that time I did not touch upon the age of deglaciation. It was Professor Auer who encouraged me to go into the age problem and to treat the results from a regional point of view. I owe a debt of gratitude to Professor Auer, whose global approach to Pleistocene problems helped me to understand better the piece I was trying to fit into a large puzzle.

It is a pleasure to acknowledge my deep indebtedness to Professor Esa Hyyppä, Chief of the Department of Surficial Deposits, Geological Survey of Finland. In permitting me to work as an associate staff member, he gave me the support without which my investigations would have been impossible to carry out. Professor Hyyppä also placed at my disposal his materials relevant to the development of the Baltic Sea. Through this courtesy I gained a secure basis on which to build a discussion on the age problem. Moreover, Professor Hyyppä read my manuscript thoroughly and made a number of valuable remarks.

I also wish to acknowledge my obligation to the former Director of the Geological Survey of Finland, Professor Aarne Laitakari, and to his successor, Professor Vladi Marmo; both of them granted me the opportunity to participate in the field work program. Professor Marmo kindly accepted my paper for publication in the series Bulletin de la Commission géologique de Finlande.

During the course of my work I received assistance from several staff members of the Department of Surficial Deposits. Miss Kyllikki Salminen, Lic.Phil., and Miss Ester Uussaari, Mag.Phil., taught me in the methods of pollen analysis. Miss Salminen also investigated the diatoms of my sam-

ples. Misses Annikki and Kyllikki Parkkonen performed a good share of the grain size analyses. With her skilled hand Mrs. Lyyli Orasmaa drew the maps and graphs. My sincere thanks to these ladies!

Mr. U. Soveri, Ph.D., of the National Board of Public Roads and Waterways, Mr. Mauri Pasanen, M.S.Eng., of the firm Vesi-Hydro Oy, and Mr. O. Vainio, M.S.Eng., of the City Technical Department of Lahti provided me with data on the thickness and quality of the surficial deposits in parts of the area investigated. Mr. Mauno Lehijärvi, Ph.D., of the Geological Survey kindly compiled the petrographic map presented in this paper. Professor T.J. Kukkamäki of the Geodetic Institute supplied a copy of the original map showing the newest precision levellings and isobases of land uplift. I wish to express my appreciation to these gentlemen.

Mr. K. Virkkala, Ph.D., of the Geological Survey and Mr. Joakim Donner, Ph.D., of Helsinki University made valuable remarks regarding the manuscript. This aid as well as the tactful revision of the original English text by Mr. Paul Sjöblom, M.A., are gratefully acknowledged.

My family deserves special mention: Without fine co-operation in doing household tasks this paper would still be unwritten. In shouldering the main load of family matters my husband, Professor Veikko Okko, helped me to find the time for writing. The discussions at home on glaciological and geomorphological problems were a source of delight and learning.

Finally, I wish to acknowledge the financial aid received from the Finnish Concordia Association (Suomalainen Konkordia-liitto).

Geological Survey of Finland, Otaniemi, May 1962.

Marjatta Okko

CONTENTS

INTRODUCTION

A good many opinions have been expressed about the Salpausselkä belt and its mode of origin. The status of the results is well documented in Charlesworth's (1957, pp. 1172—1173) synopsis: »The Outer [First] Salpausselkä consists of well-washed, assorted and stratified sands and gravels. Of varied outward form, it is built asymmetrically, having . . . . a distal cross-deltaic structure and proximal push moraines, with overfolds and thrusts. It was laid down in the lateglacial sea as a frontal moraine or line of marginal deltas or, more probably, as a combination of the two by subglacial streams or by the sea working over englacial material. Its position, whether owing to a recession or a readvance . . . . , was determined mainly climatically . . . and in a less degree by festooning on rock-barriers which tended to fix the position of the front by halting the readvance . . . or by the calving of bergs.»

The Salpausselkäs are generally regarded as being contemporaneous with the Middle Swedish Moraines and the Norwegian Ras, collectively also called the Fennoscandian moraines (Flint 1957, p. 373; see also Zeuner 1958, p. 106). In De Geer's (1896, pl. 2) early map of the last Scandinavian glaciation, the Ras, the western part of the Swedish moraines, and the First Salpausselkä marked the border of the ice sheet, but along the Baltic basin a huge tongue extended to the North German moraines, to eastern Jutland and southern Scania. This view was abandoned long ago and in modern correlation maps the Middle Swedish Moraines are linked directly with the Salpausselkäs (e.g., Magnusson, Lundqvist and Granlund 1957, p. 348; Zeuner 1958, p. 30; Woldstedt 1958, p. 135). Nevertheless, the conception of live ice filling the Baltic basin has been warmed up by Wennberg (1949, p. 200), who maintained that a Baltic Ice Lake of the extent usually postulated did not exist because ice filled the Baltic. Woldstedt (1954, p. 210), Flint (1957, p. 374), and Charlesworth (1957, p. 1173), to name three renowned textbook writers, all accept the view that a readvance of the ice sheet to the Fennoscandian moraines occurred while a late-glacial Baltic Ice Lake existed.

The retreat of the Scandinavian ice sheet in the late-Weichsel time from the Pomeranian and Danish moraines to the Fennoscandian moraines is generally correlated to the late-glacial period in the vegetational history and the time since the retreat of the margin from the Fennoscandian moraines to the postglacial period. Daly (1943, p. 56) coined the term Bothnian Glacial Substage for the Fennoscandian moraines and the deposits made during the subsequent retreat. Excluding Flint (1947, p. 332), this term has not won any acceptance among the students of Pleistocene geology. Although rather arbitrarily defined, the term postglacial is in general use (compare Gams 1961). In the present paper the current continental usage is followed: The last glaciation is referred to as the Weichsel glaciation. The term late-glacial is used strictly in a local sense, referring to the time southern Finland was being freed from the Weichsel glaciation.

Flint (1947, p. 332; 1957, p. 373) describes the Fennoscandian moraines as having been built by the latest of the conspicuous readvances within the Scandinavian ice sheet; the readvance followed a deglaciation of unknown amplitude. The Swedish varve chronology and time scale for the ice recession to the Middle Swedish Moraines do not, however, leave any time for such an advance; by and large, the Middle Swedish Moraines are recessional moraines (see Lundqvist 1961, Fig. 29, p. 85 and appended maps). The Finnish varve chronology (Sauramo 1918, 1923) also points to standstills in the ice recession during the Salpausselkä stage. Flint's (1957, p. 373) statement that the readvance is C^{14}-dated at about 11000 yrs B.P. does not apply to Finland. Finnish samples relevant to the Salpausselkä stage have not been dated by the radio-carbon method. True, there is a dating of a peat sample collected from the First Salpausselkä. Unluckily, the sample was impure and gave an age of 8030 $\pm$ 140 yrs B.P. (Barendsen, Deevey and Gralenski 1957, Y-482).

Among Russian writers, Biske (1959, p. 294) speaks of a Salpausselkä readvance. In her opinion, the readvance extended as far as northwestern Karelia, U.S.S.R., where the ice soon stagnated and did not build any terminal formations.

The correlation of the Fennoscandian moraines or the Salpausselkä stage to late-Weichsel stages of other formerly glaciated areas has lately been rather in vogue, though mostly labelled »tentative.» Since Donner's (1951, pp. 76, 80) pollen-analytical dating of the Salpausselkä stage as having taken place during the Younger Dryas period, the Salpausselkä stage has been correlated to other stages included in this period, for instance, to the Highland or Moraine readvances of the British Isles (Charlesworth 1957, p. 1215; see also Donner 1957, p. 261). Flint (1957, p. 397) thinks the Highland glaciation older but lists the Moraine, Windermere and Cwm Idwal glaciations as correlatives. Transatlantic correlations have caused the

Mankato and Valders readvances to be regarded as contemporary with the Salpausselkä stage (Woldstedt 1954, p. 207; Flint 1957, p. 380; Charlesworth 1957, p. 1217; Zeuner 1958, p. 155). Antevs (1953, p. 197), on the other hand, correlates the Salpausselkä stage to the Cochraine moraines of North America. The opinion that the Salpausselkä stage has its counterpart in *Schlussvereisung* in the Alps, seems to be unanimously held (see also Gross 1957, p. 31). Van der Hammen (1951, p. 309) correlates the sedimentation of the Dutch Younger Coversand to the Salpausselkä stage in Fennoscandia. Zeuner's (1958, p. 106) view on the chronological significance of the Fennoscandian moraines completes the picture of the Salpausselkä stage obtained from well-known textbooks: ». . . it is considered possible, and by some probable, that this halt in the recession corresponded to a deterioration of the climate, which left its trace in the floral history. The pollen diagrams of southern Sweden (Nilsson, 1935) provide for only one correlation of this kind, namely with the deterioration which followed the relatively mild Alleröd phase. On the assumption that this correlation is correct, a most valuable 'land-mark' becomes available which would date the second *Dryas* Time or its equivalent at about 8 600 to 7 900 B.C. in any section within the triangle Finland—Ireland—south-west Germany. The Alleröd deposits or their equivalents would fall slightly earlier, at about 9 000 B.C. or somewhat more. Thus a valuable guide for the dating of the Mesolithic has been obtained.»

Textbook references to the Salpausselkä belt are based on Finnish studies, but results different from those presented by Sauramo have not generally gained attention or won acceptance abroad. At best, some differing results are mentioned and — rejected (e.g., Woldstedt 1954, p. 339). Yet the readvance postulated in textbook literature is in conflict with Sauramo's views of the Salpausselkäs as having evolved during halts in the ice recession.

In Sauramo's (e.g., 1958) opinion the Salpausselkäs developed during the stage of the Baltic Ice Lake. Little by little it has been shown that there was a regressive marine stage of the sea in deglaciated southern Finland which antedates the Baltic Ice Lake (e.g., Hyyppä 1943, 1951, 1961; Mölder 1944; Sauramo 1947, 1958).

The study at hand deals with a small part of the First Salpausselkä, a segment west of the city of Lahti in southern Finland. This segment is in a key position in that the First Salpausselkä here makes a sharp bend in its trend, consists of large accumulations of varying drift and form elements, and is located on higher ground than elsewhere in southern Finland. The purpose of this paper is to shed light on these local characteristics. On the other hand, the Lahti area has long been an object of interest in the study of the Salpausselkäs. In fact, many of the views presented in textbook literature are partly based on observations made in this particular area. This paper also aims at complementing these views and at adding, in the form of a case study, to the knowledge of the general conditions during the Salpausselkä stage.

LOCATION AND RELIEF

The area investigated covers that part of the First Salpausselkä where the SW—NE trend of this ridge turns W—E. The area will be referred to as the Lahti area. Its boundaries cannot be defined precisely, as it was advisable to use observations on bedrock topography, glacial abrasion and raised beaches from a wider area than the close environs of the bend of the First Salpausselkä. The map presented in Appendix I shows the area where the majority of the observations were made. Only a few observations of raised beaches come from outside the limits of this map. The quadrangle in Fig. 1 indicates the area covered by the map of App. I, the figure inside it showing the Lahti area proper, which is mapped in more detail than the environs.

The Finnish name of Salpausselkä means »the damming-up ridge.» (For a historical account of the use of the term Salpausselkä, see Ramsay 1921, p. 9, Tanner 1933, p. 3, or Bauer 1939, pp. 4—7.) The First Salpausselkä runs along the border of the Finnish lake district and the southern coastal region. It is another matter whether the ridge really does dam up the lakes

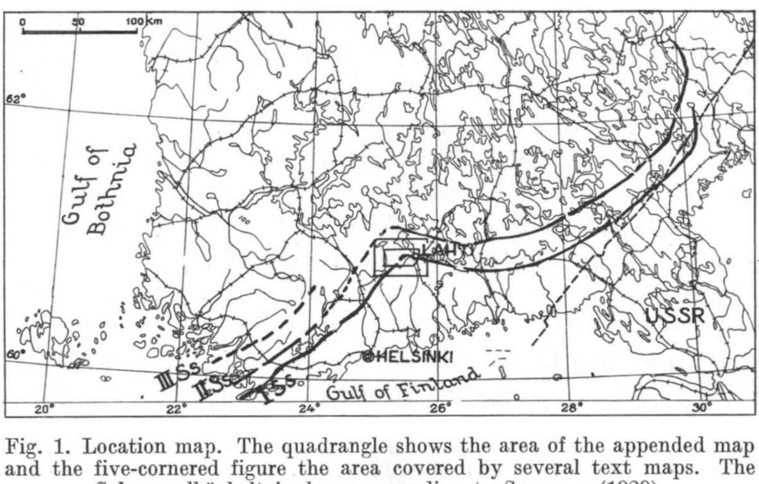

Fig. 1. Location map. The quadrangle shows the area of the appended map and the five-cornered figure the area covered by several text maps. The Salpausselkä belt is drawn according to Sauramo (1929).

north of it. For instance, Leiviskä (1920, p. 380) and Tammekann (1955, p. 100) held the view that the real dam is made up of a core of bedrock underlying the ridge.

A part of the watershed that divides the waters discharging into the Gulf of Bothnia and the Gulf of Finland is located in the Lahti area. The main watershed runs from the north into the apex of the bend of the First Salpausselkä and a short stretch along its western flank, and then southeast of the Salpausselkä in a zone, 15 km long, parallel to the western flank. Farther to the southwest the watershed coincides with the Salpausselkä. As early as 1888, Tigerstedt (pp. 10—11) remarked that the Salpausselkä does not form a watershed in this particular area.

The headwater basins of the river Porvoonjoki that discharges southwards into the Gulf of Finland border on the eastern flank of the First Salpausselkä. The waters north of it belong to the Päijänne lake system, also drained into the Gulf of Finland. On top of the Salpausselkä there are ponds with no visible outlet.

Along the watersheds, there are many bogs that discharge into two directions. In places small accumulations of washed drift or low hills with a core of bedrock occur at the divide. The main watershed, in particular, is very low and boggy, excluding the short stretch where it crosses the First Salpausselkä zone.

In the Lahti area, the First Salpausselkä is rather wide and flat-topped. At the city of Lahti, the height of Salpausselkä is 150—155 m above sea level and at the village of Sairakkala, 157—165 m a.s.l. [1] The highest elevations are not, however, located on Salpausselkä. The black spots in the relief map (Fig. 2) indicate the highest hills. In the northeastern corner of the relief map, there are four hills the summits of which reach elevations ranging from 182 to 222.6 m. The most conspicuous of them, called Tiirismaa, is the highest hill in southern Finland. Another group of high hills is in the western part of the area, near the village of Miehola. Here two of the summits reach elevations of 171 and 177 m.

The water level of Lake Vesijärvi in the northeastern corner of the relief map has an altitude of 81 m a.s.l. According to Sederholm (1932, p. 10) the lake is 10—20 m deep. Thus, in places the bottom of the lake lies at some 60 m. In the southeastern corner of the relief map there is a river valley situated 70 m a.s.l. These are the lowest elevations in the area of the relief map. Outside the relief map but within the area covered by the map of Appendix I, only the deepest part of the Pääjärvi lake basin lies lower than the two places mentioned. The depth of Pääjärvi is 80 m

[1] The source of most of the elevations given in the present paper is the topographic map, scale 1: 20 000, sheets 21 33 07 — 21 33 12, 31 11 03. Levellings made for this study and height values obtained from literature will be documented separately.

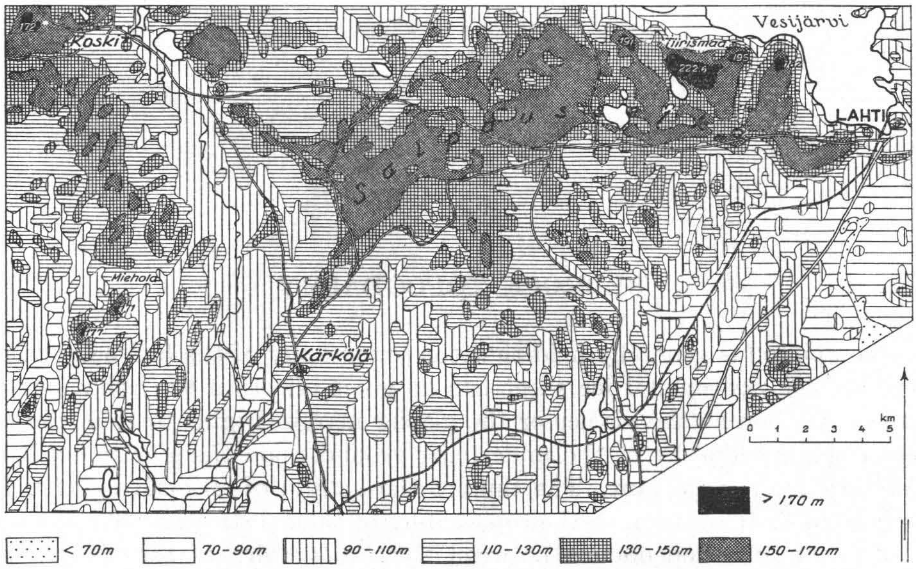

Fig. 2. Relief map. The numbers refer to altitudes above sea level.

(Renqvist 1936, p. 293) which means that its bottom is only 23 m a.s.l. The lowest-lying basins are thus located in the hinterland of the First Salpausselkä.

A look at the relief map shows that the land rises towards the north all over the area. The western flank of the First Salpausselkä does not show in the map. Instead, the zone is here rather a lowland.

BEDROCK TOPOGRAPHY

The opinion is generally held that the topography of the bedrock underlying a thick continental ice sheet has no great effect on the behaviour of the ice. As soon as the glacier or the glacier margin begins to thin, the effect of the topography of the underlying ground upon the glacier becomes more and more important. The thinner the margin of an active glacier is, the more does it conform to the topography of the substratum. Thus, there must be an interdependence between the topography of the underlying bedrock, the glacial abrasion marks and the location of the deposits originating from the glacier itself and from its glaciofluvial activity. In studying the glacial geology of a region, a critical survey of the bedrock topography is important toward gaining insight into the behaviour of the glacier during deglaciation.

GENERAL STRUCTURE OF THE BEDROCK

The distribution of outcrops of the crystalline bedrock is uneven in the Lahti area. Exposures of the bedrock are frequent in the western and eastern parts of the area, whereas in the middle outcropping bedrock is rather exceptional. In the Salpausselkä zone, bedrock is exposed in only a few places.

A study of the river pattern reveals that in the western and eastern parts of the Lahti area, characterized by abundant outcrops and rough relief, the rivers take quite haphazard directions. The valleys where the rivers run are bordered by outcropping bedrock with almost vertical slopes. The river beds are located in the sandy and clayey deposits that fill the valley bottoms; none has been cut down to the bedrock. Thus, the drainage system reflects the structure of the bedrock.

The topography of the bedrock, as far as is known, is shown in Fig. 3. When comparing the topographic map of the bedrock with the general relief map of the area (Fig. 2), it becomes evident that only a few parts of the bedrock rise as high or higher than the Salpausselkä. From the west-

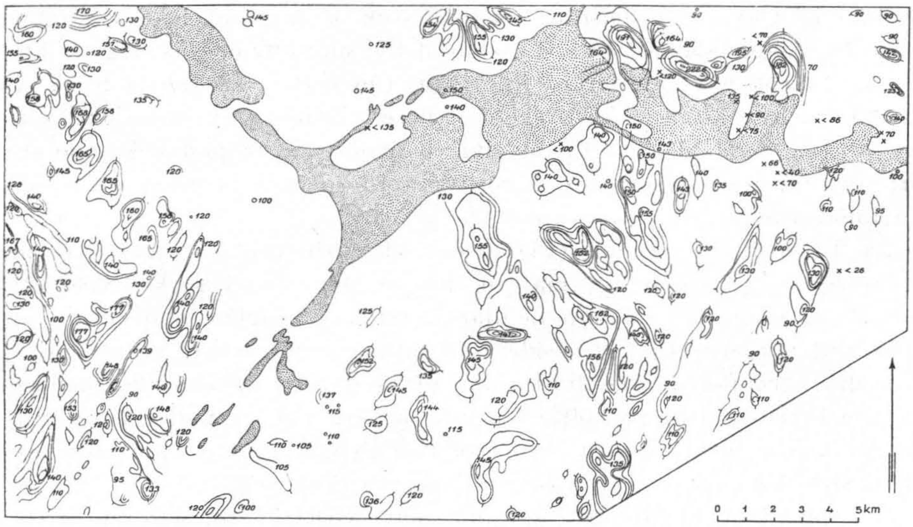

Fig. 3. Topographic map of the bedrock. The contour lines, drawn at intervals of 10 m, show the bedrock surface elevated above the sediments surrounding the hills. The tiny circles indicate small exposures of bedrock in areas where outcrops are scarce. The crosses show the locations of groundwater borings and geotechnical drillings. The numbers refer to the altitude of the bedrock surface in meters. The figures of the type < 80 indicate the altitude where fairly deep borings were stopped before reaching the bedrock surface. The Salpausselkä is denoted by dots.

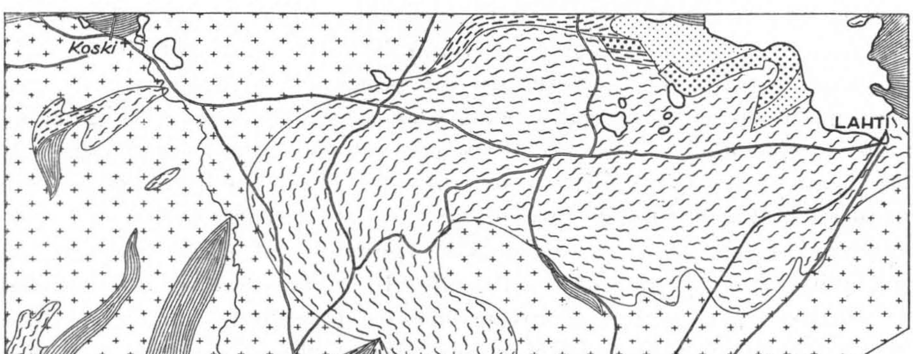

Fig. 4. Petrographic map; compiled by Mauno Lehijärvi. 1. Mica schist, 2. amphibolite and hornblende gneiss, 3. quartzite, 4. acid gneiss, 5. microcline granite with inclusions of mica schist and amphibolite, 6. quartz diorite and granodiorite, in some parts granite with microcline porphyroblasts.

ern end of the Tiirismaa range southwards, a ridge of bedrock extends across the Salpausselkä. The elevation of the summits of this ridge is 140—150 m. In the western part of the area, the surface of the bedrock rises toward the northwest. An area of exposed bedrock extends here across the western flank of the Salpausselkä. Outside the Salpausselkä the areas with the fewest outcrops are lower than those characterized by a dense distribution of bedrock exposures.

In the petrographic map (Fig. 4; excluding the eastern part of the map the rocks are shown in the map of the pre-Quaternary rocks, Sheet 2133 Kärkölä; compiled by Mauno Lehijärvi, 1961. Geological map of Finland, 1:100 000) it is seen that the bedrock is mainly composed of plutonic rocks: microcline granite, quartz diorite and granodiorite. Lenses and inclusions of mica schist and amphibolite, varying in size, occur amidst the plutonic rocks. In the northwestern corner of the area, a zone of quartzite, associated with acid gneisses, forms the Tiirismaa range.

A comparison of the petrographic map with the topographic map of the bedrock surface (Fig. 3) reveals that the uneven distribution of exposed bedrock is not caused by the different rocks.

The highest elevations, 182—223 m, occur in the Tiirismaa quartzite. The next highest elevations, 171—177 m, at Miehola, yield microcline granite and mica schist. The highest outcrop of amphibolite lies at an altitude of 160 m and that of granodiorite at 162 m. Thus, only the quartzite has an effect on the relief.

There are a couple of outcrops containing mylonites, not shown in the petrographic map. These outcrops are associated with the narrow river valleys lined up with vertically rising rock walls. There must be more mylonites, hidden under the cover of surficial deposits, than are shown in the map. Fragments of mylonitic rock occur regularly in the lithologic composition of till and washed drift throughout the Lahti area, pointing to a rather richly mylonitized bedrock (see p. 57). Remnants of slickensides are seen along quite a few of the steep rock walls. In areas where the vertical walls are common, the bedrock is rather heavily fractured. Measurements of strikes of vertical fractures and cracks give compass readings parallel or diagonal to the directions of the nearby rock walls. Horizontal jointing is common, too. The bedrock in the Lahti area is thus criss-crossed by crushing zones.

In the absence of detailed studies, it is hard to say whether the crushing zones represent faulting, fracturing, rupturing, or mere crushing caused by relatively small to-and-fro movements. The three hills of the Tiirismaa quartzite range are separated from each other by faults, as seen in the petrographic map. Following the terminology of Härme (1961, p. 439), the collective name of shear zones will be used for all other crushing zones.

A comparison of the distribution of shear zones, seen as narrow valleys in the topographic map of the bedrock, with the petrographic map shows that differential movements extended across different types of rocks. Many zones also cut the strike of foliation.

When mapping the Hämeenlinna geological map sheet, scale 1:200 000 Tigerstedt's (1888, p. 6—10) attention was aroused by the streakiness of the bedrock topography. In his opinion, this structure is due to »orographic lines which originated during the most ancient times.» [1]. Tanner (1938, p. 240) called this type of detail relief by the name »Eckenplateauländer». Kranck (1937) studied similar topography on the southern coast of Finland. He concluded that shear zones are inherent in the very structure of the Precambrian bedrock, although open cracks originated only when denudation brought the rocks to the surface of the earth's crust.

A broad zone, some 12 km wide and almost void of outcrops, extends from the northwestern corner of the Lahti area towards the southeast. This deep depression of the bedrock surface is covered by deposits of glacigeneous material. In the light of the data on bedrock topography in the densely exposed areas, the explanation is plausible that this zone represents a portion of bedrock which was lowered in the process of shear movements; that this depression is a preglacial erosion valley is an applicable interpretation, too. The available data are too scanty to support either view.

Summing it up: The surface of the bedrock in the Lahti area is rough and uneven. The relative differences in height are in places rather big. The roughness of the topography is accentuated by shear zones and long depressions, which form deep valleys in the bedrock surface. If the topography of the bedrock is of preglacial origin, as suggested by Härme (1961, p. 438), then the bedrock surface provided both channels for and obstructions to glacier flow.

GLACIAL SCULPTURE

Bedrock surfaces with glacial abrasion marks are frequently encountered in the Lahti area. The best preserved marks are found in places where the surficial deposits have recently been removed, i.e., in farm yards, road and railway cuts, and in sand and gravel pits where the bedrock surface has been uncovered. The observations on glacial erosion are plotted in the map presented in Appendix I.

The large roches moutonnées are covered with drift to such an extent that they cannot be studied as a whole. In places, small elevated portions

[1] Original text in Swedish.

of the bedrock surface have been shaped into roches moutonnées with characteristical stoss and lee sides. Their length seldom exceeds three meters. The orientation of their long axes is parallel to the trend of the striations on the rock surface. Therefore, only the direction of the striae is indicated in the map. There are, however, four outcrops where the orientation of the roches moutonnées differs from that of the striae. The two deviating directions are shown in the map and are discussed later on in this chapter.

Here and there abrasion facets pointing to glacier flow from two directions are to be seen. At one outcrop only is the angle between two facets wide enough to suggest that they were formed during two different stages of abrasion.

Striations and micro-striations occur on several outcrops. All the observation localities are shown by a circle in the map. In addition to my own observations, data obtained from the field records of Mr. Veikko Lappalainen during the summers of 1954 and 1955 are included in the map. I have also had at my disposal observations from the northwestern corner of the area supplied by Professor Veikko Okko. The source of each observation is indicated on the map by means of symbols inside the circles. The arrow attached to the circles points to the direction towards which the abrasion occurred at the outcrop.

Grooves are to be seen on many outcrops. In some places, postglacial weathering has destroyed the bedrock surface to the extent that no striations are left, but remnants of grooves are still to be identified. Such observations, although few, are plotted on the map.

Friction cracks are not uncommon. As they happen to occur on surfaces where there are also striations or grooves, none of the observations, plotted on the map, show the orientation of friction cracks only.

In a large part of the Lahti area the abrasion marks are oriented from the northwest (315—330 °) to the southeast. An exception is the northerly (360—10 °) direction of abrasion marks in the northeastern part of the area. Their southern limit coincides with the eastern flank of the First Salpausselkä. Northerly marks occur to the east and to the northeast outside the area covered by the appended map (see Frosterus 1911, p. 21).

The western limit of the northerly abrasion marks is not as sharp as that to the south. The Tiirismaa quartzite range marks the limit at Salpausselkä. The striae observed around the range are shown in Fig 5. Northwestern striae were encountered close to the top of the highest summit of Tiirismaa. At the western foot of the range, there are polished surfaces and roches moutonnées sculptured from the northwest. At three localities the northern striae have been scoured into surfaces of the northwestern sculpture. South and west of the detail map of Fig. 5, only northwestern abrasion marks have been observed. Thus, the northern abrasion

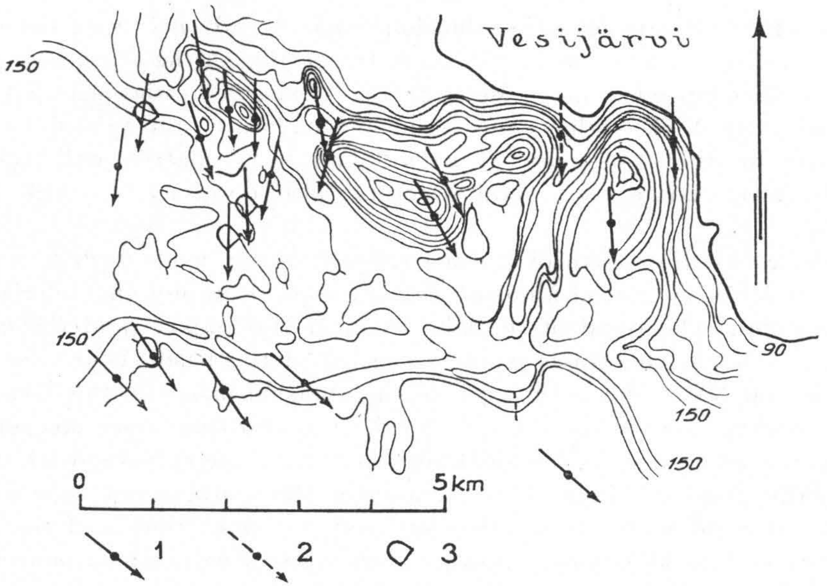

Fig. 5. Northern glacial abrasion marks run across northwestern marks around the Tiirismaa quartzite range. 1. Striae, 2. erratic transported from a known host rock, 3. roche moutonnée. The contour lines are drawn at intervals of 10 m.

marks are younger than the northwestern sculpture. Well-preserved micro-striae also show that the last abrasion occurred from the north. The highest summit of the Tiirismaa range, however, projects above the northern sculpture.

North of Tiirismaa, the western limit of the northern sculpture runs over the Kutajoki peninsula in the direction SE — NW (see Appendix I). In the central part of the peninsula, there is a small outcrop showing signs of two different stages of glacial abrasion. On top of the outcrop, there is a groove formed from the north (350 °), which also is the direction of the stoss side of the outcrop. On the lee side there is an abrasion facet with striae scoured from the direction 315 °. The outcrop itself is oriented from NW to SE, indicating the older abrasion. Both abrasion directions are shown in the map. Along the western shores of the peninsula, there are outcrops with striae formed from the northwest (330 °). At the northernmost of these outcrops, a couple of rough striae trending from NNE (20 °) were detected. The age relations between the 330 °- and 20 °-striations cannot be decided upon when examining the outcrop. Observations at other localities on the peninsula suggest that the 20 °-striae are the youngest ones. Cross-striae of the northern and northwestern abrasion are encountered farther north in the Lake Päijänne basin (Frosterus 1911, p. 21).

South of Salpausselkä the abrasion marks trend only from the northwest. North of the parochial village of Orimattila, in the southeastern corner of the appended map, Moberg (1885) reported striations that were formed from NNE. I have not been able to locate Moberg's observation locality; on the other hand, I have found at Orimattila well-preserved northwestern striae on several outcrops, also observed by Wiik (1876, p. 98).

The rocky area north of Herrala railway station lends itself to a study of the relation of glacial abrasion to bedrock topography characterized by shear zones. The trend of the lake basin of Hahmajärvi and the narrow valley, which is the northeastern extension of the basin, is transverse to the general NW — SE orientation of the abrasion marks in this area. The northwestern slope of the transverse valley is, as a rule, much steeper than the southeastern slope. The northwestern rocky slope rises stepwise, almost vertically, from the valley bottom, whereas the southeastern slope is more gentle, covered with till or other surficial deposits. Here and there, the bedrock surface is exposed, showing stoss sides of roches moutonnées. On both sides of the valley, small projecting portions of the bedrock surface have been sculptured into miniature roches moutonnées. The effect of glacial erosion upon a transverse shear zone in the substratum is that of »backward» orientation of glacial sculpture. The excavated northwestern slope is the lee side and the polished southeastern slope the stoss side of a set of roches moutonnées lining the narrow transverse valley.

Glacial erosion of a shear zone running parallel to the trend of the abrasion differs strongly from that of a transverse zone. In the Herrala area the river draining Lake Hahmajärvi runs in a narrow steep-walled valley (Fig. 6) the trend of which is the same as that of the striations on top of the wall (325°). The vertical rock wall has been polished by glacier action. The borders of the horizontal joints are rounded. On the vertical portions of the wall, there are horizontal or slightly upturned striae and grooves, which widen out toward the southeast (downstream). On the hanging wall of such grooves, there are distinct striations (Fig. 7). Glacier action thus tended to destroy the rock wall parallel to the direction of abrasion. Glacial sculpture of this type is common in the Lahti area.

Similar valleys have been described from the Joensuu area, eastern Finland (Frosterus and Wilkman 1915, p. 32). Also in the archipelago of southwestern Finland, corresponding abrasion forms on vertical walls and around horizontal joints are met with (Nils Edelman 1949, p. 134—135). Okko (1956, p. 75) has described laterally eroded valleys from Iceland. According to him, the ice, which tends to expand laterally in narrow valleys or gorges, must be in a plastic condition. Nils Edelman (*loc. cit.*), too, assumes that the striations directed upwards on vertical walls were formed under a plas-

Fig. 6. Glacially abraded rock wall which trends parallel to the direction of glacier flow. The wall is polished. The striae and grooves on the vertical portions of the wall are slightly upturned downstream. Herrala.

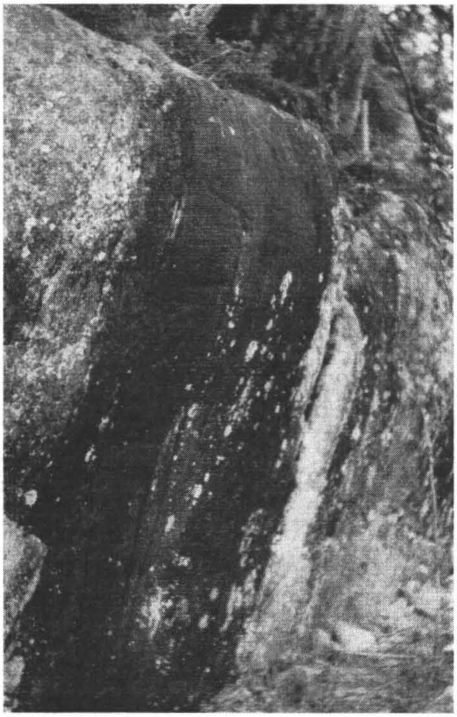

Fig. 7. Detail of the rock wall shown in Fig. 6. Striae on the hanging wall of groove scoured into a vertical portion of the wall. The glacier flowed from left to right. The abrasion shown in Figs. 6 and 7 is thought to have developed under a thick, plastic ice.

tic ice. In other words, these forms of glacial abrasion are produced under a thick glacier.

In shear zones which cut the direction of glacial abrasion at an angle of less than 90°, the abrasion forms vary. It seems to be a rule that in valleys which cut the direction of abrasion at an angle of 10—30° the striae are parallel to the trend of the valley. When the angle is more than 30°, there usually are signs of excavation on the lee slopes.

FORMS CAUSED BY STREAM EROSION

Other erosion forms than those described in the previous chapter are rather scarce on the bedrock surface in the Lahti area. Between the two hills forming the central block of the Tiirismaa quartzite range, there is a cleft called Pirunpesä (see Fig. 30, p. 71). The trend of the 1.5-m-wide cleft is NW—SE or the same as that of the vertical slickensides near the cleft. The cleft extends from 185 m to 155 m a.s.l. At a height of 180 m, on the southwestern wall of the cleft, there are two shell-shaped niches. The horizontal length of the niches is about 1.5 m and the height about 60 cm. The surface within the niches and around their edges is very smooth. Morphologically the niches are embryonic potholes.

Near the village of Marttila, south of the Lahti area proper, but still within the limits of the map in Appendix I, there is a well-developed pothole appearing in microcline granite at an elevation of 105 m. The long axis of the ellipsoid pothole measures 1 m and its depth 1.1 m. Embryonic potholes of the Pirunpesä type occur north of Marttila on the northwestern rock wall of a transverse shear valley at an altitude of 90—95 m. In the centre of the village, there is an outcrop with glacial striae on top of it and embryonic potholes on its slopes (100 m a.s.l.). The outcrop is located at the southeastern foot of a short esker running toward the northwest.

Rosberg (1925) classified the potholes of southern Finland as comprising three genetic groups: those formed on shores, in rapids, and under the glacier. Of the potholes described herein, only the fully developed pothole can be classified as belonging to the glacial group of Rosberg. Accordingly, it should have developed at the bottom of a crack or in a glacier mill underneath the ice (see also Johnsson 1956, p. 174). The niches, then, should belong to the two remaining classes.

As pointed out by Rosberg (*op.cit.*), morphologically the three genetic groups merge into each other. The difficulty of a genetic classification is accentuated by the fact that there are in the Lahti area four gravel pits, opened into eskers, where a bedrock surface exhibiting well-developed glacial sculpture is encountered. In addition, there are glacially sculptured outcrops in the midst of deposits of washed drift in the Salpausselkä zone. These observations show that glacial meltwaters carrying a load of drift did not here generally erode the substratum of the ice sheet. That stream erosion might have locally happened is shown by the intermediate type of eroded bedrock provided for by the Marttila esker where marks of both glacial abrasion and stream erosion exist.

DISCUSSION AND CONCLUSIONS

All the data on bedrock topography in the Lahti area suggest that the shear zones are of a preglacial age. According to Sederholm (1932, p. 14), the crushed and fractured parts of the Finnish bedrock, which were deeply eroded, suffered most from glacial erosion as the excavating action of the glacier was facilitated by the presence of soft zones. After the removal of weathering products, glacier action set about to erode fresh rock. Kranck (1937), too, stresses the importance of glacial erosion as a major agent in opening shear zones into valleys with vertical rock walls, whereas Härme (1961, p. 438) is of the opinion that glacial erosion was strong on the highest outcrops, leaving the bottoms of the valleys relatively untouched.

In a region as limited in size as the Lahti area, it is impossible to estimate the amount of rock material carried away by the ice sheet. The differences in elevation of the bedrock surface cannot be explained solely through different degrees of weathering and abrasion of the rock types: all the rocks form elevated areas. Of the rocks, the quartzite of the high Tiirismaa range is the most resistant to chemical weathering, but it also is subject to rather strong mechanical disintegration. Because almost all mylonitic rocks, regularly present in till, have been carried away from the shear zones, glacial erosion has been strong at the zones, also shown by abrasion marks in the Herrala environs (p. 22). On the other hand, the blocks of bedrock surrounded by shear zones have not been glacially sculptured; only small elevated portions of the bedrock were abraded into miniature roches moutonnées.

Tammekann (1958, p. 112) approached the problem of the geomorphology of the Finnish peneplain from the point of view that there ought to be traces of ancient transportation routes along which the material was carried, to be deposited as the Cambro-Silurian sediments of Estonia and of the bottom of the Baltic Sea. Also the rivers which collected in the trough north of the Cambro-Ordovician cuesta (compare Martinson 1960) should have left traces in the peneplain. According to Tammekann (*loc. cit.*), the elongated lake basins of the Finnish granite area, for instance the basin of Lake Päijänne, were originally formed by river erosion; land forms originating from shear zones should be younger. In the Lahti area, the broad depressions of the bedrock surface are curved and do not show angular forms typical of shear zones. The glacial sculpture of the few outcrops in the depressed areas shows only the general regional orientation of abrasion forms. Although no direct data are available to support the assumption that the depressions of the bedrock surface, to some degree at least, were formed by ancient river erosion, this explanation to the origin of the depressions cannot be excluded. At any rate, the broad depressions must have existed in preglacial times.

The glacial sculpture of the Lahti area may be divided into two regional groups: the northwestern sculpture in the main part of the area and the northern sculpture in its northeastern corner. The southern limit of the northern sculpture is sharp and coincides with the Salpausselkä zone. Its western limit is less pronounced; it appears as a relatively broad zone, where both northwestern and northern abrasion marks are to be seen.

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Abrasion forms pointing to erosion under a considerably thick ice are encountered in the area of northwestern abrasion. The sculpture of the shear zones was formed here under plastic ice. In the area of northern abrasion, the western limit points to a relatively thin glacier; but east of Lahti the glacier must have been very active, as no traces of older sculpture have been detected.

The erosive action of running water has been of little importance. The potholes occur on glacially sculptured surfaces and are thus the youngest.

By and large the topography of the bedrock is determined by the tectonic sturucture. The erosive action of the ice sheet accentuated the shear structure by polishing the fresh walls and by removing soft sheared debris from the zones.

GLACIER MOVEMENTS

The directions of glacier flow in the Lahti area, as revealed by observations on glacial sculpture and on the age relations between the different elements, are sketched in the map of Fig. 8.

Excluding the area north of the eastern flank of the Salpausselkä, the glacier flowed from the northwest. In the east the flow occurred from a slightly more northerly direction (330°) than in the west (315°). The development of the western flank of the Salpausselkä, oriented perpendicularly to the trend of northwestern abrasion marks, did not cause any changes in the direction of glacier flow.

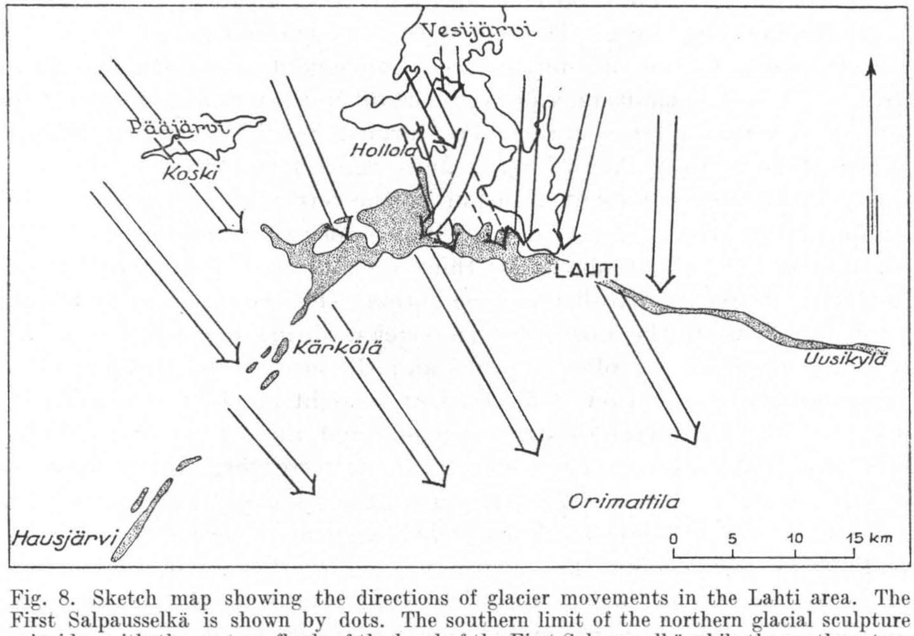


Fig. 8. Sketch map showing the directions of glacier movements in the Lahti area. The First Salpausselkä is shown by dots. The southern limit of the northern glacial sculpture coincides with the eastern flank of the bend of the First Salpausselkä while the northwestern sculpture extends across the western flank.

In the eastern part of the Lahti area, the northernmost northwestern striae occur on outcrops in the eastern flank of the Salpausselkä: at Tuhkamäki, in Lahti, at Lakkila, and at Villähde. North of the Tuhkamäki — Villähde line all the abrasion marks show that here the glacier flowed from the north. The flow extended to the eastern flank, which runs at a straight angle towards this flow. The western boundary between the northern and the northwestern flow is located in the Tiirismaa quartzite range and on the Kutajoki peninsula (p. 21). The sharp southern limit of the northern flow and the fact that northern striae run over surfaces of northwestern sculpture at the western border show definitely that the northern flow is younger than the northwestern one.

East of the western border of northern sculpture, northwestern abrasion marks are found only high up around the highest summit of the Tiirismaa range (Fig. 5, p. 21). Thus, the northwestern ice must have once covered the whole range. Because the northwestern glacier was able to flow in a permanent direction regardless of the topography of the substratum, the ice must have been of considerable thickness. The abrasion forms of the Herrala shear zones (p. 23) point to the same condition.

With the aid of erratics derived from well-known South-Finnish localities it has been shown that they were transported toward the southeast (Hausen 1912; see also Sauramo 1929, p. 13—14, Fig. 3). Thus, the direction of northwestern abrasion coincides with the last general movement of the continental ice sheet. The mode of abrasion indicating a thick ice probably points to this old northwestern movement. According to Tanner (1915, p. 72) roches moutonnées are important indicators of abrasion of long duration, whereas all the striae were formed locally during deglaciation (Tanner 1938, p. 434). Accordingly, the northwestern striae ought to be of late-glacial age and represent abrasion by the retreating ice sheet. For the purpose of the present study, it is of importance that the direction of the sculpture brought about under the thick ice and that of the northwestern late-glacial striae are parallel to each other. Therefore, it is justified to discuss the flow of the northwestern glacier during deglaciation without distinction between the old sculpture and the late-glacial abrasion marks.

Because the glacier flow is directed at straight angles to the margin of the glacier, the northwestern striae, encountered along the eastern flank of the Salpausselkä, show that the margin of the retreating northwestern glacier ran in the direction SW—NE across the zone of the eastern flank. Accordingly, the Villähde environs were deglaciated earlier than the surroundings of Tuhkamäki. The southern limit of the northern flow being sharp, the northern glacier must have advanced to the eastern flank after the Villähde — Tuhkamäki zone had deglaciated from the northwestern ice.

At the Tiirismaa range, the northern striae do not run as nearly parallel as do the marks in the east; instead they seem to follow the topography of the bedrock. This adherence to topography shows that at its western limit the northern ice was relatively passive, although thick and active east of Lahti. The missing northern abrasion marks on the highest summit of the Tiirismaa range point to the possibility that the summit formed a nunatak in the northern glacier. The northern striae in the two fault valleys west of the nuntak show that ice tongues were pressed southward through the valleys. In the fault valley east of the nunatak there are boulders the host rock of which lies north of the valley. Here, too, an ice tongue was pressed southward past the nunatak.

Because the western flank of the Salpausselkä does not mark any change in the direction of the northwestern flow, it is impossible to conclude, on the basis of the bedrock sculpture, how far northwest the margin of the northwestern glacier retreated before the northern advance set in.

FORELAND OF THE FIRST SALPAUSSELKÄ

The surficial deposits of the foreland do not differ from those of the southern coastal region. The crystalline bedrock is overlain by morainic drift, which in places is covered with water-laid sediments. Here and there chains of radial eskers run as narrow strips across the landscape in the general direction of SE—NW. On the slopes of the eskers and other elevations, there are sandy shore deposits. Traces of former shore action are also seen as bare bedrock, its cover of till having been washed away. The youngest deposits comprise limnic ooze and terrestric peat.

Although the purpose of the present paper is to elucidate the development of the big bend of the First Salpausselkä, west of Lahti, a study of the process of deglaciation in its foreland cannot be omitted. In this respect, terminal and radial formations are of primary interest. A review of water-laid sediments gives further information on the development of the deglaciated area.

TERMINAL FORMATIONS

In the chapter on glacier movement it was concluded that the ice sheet moved across the foreland from the northwest (315°—325°). Provided that the striae were formed near or at the margin of the ice sheet, the general trend of the terminus, perpendicular to the direction of glacier flow, must have been SW—NE during the deglaciation of the foreland. Accordingly, the terminal formations ought to lie perpendicular to the direction of the abrasion marks in their environs. Furthermore, it should be possible to reconstruct local positions of the terminus during different phases of deglaciation.

END MORAINE SWARMS

Small end moraines, which usually occur in groups, are frequently run across in the foreland of the First Salpausselkä (e.g., Sauramo 1918, 1929).

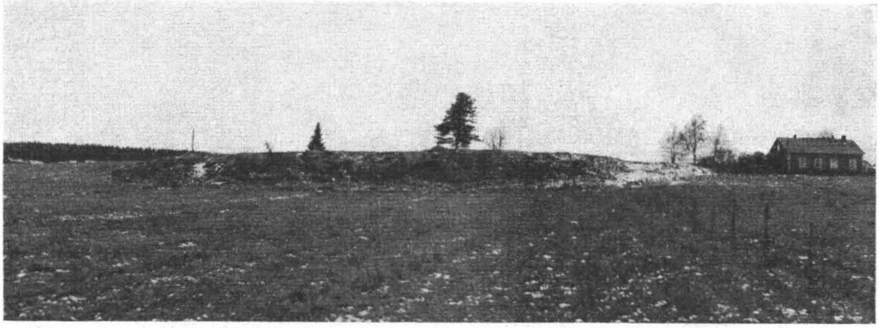


Fig. 9. Small end moraine belonging to a swarm, seen from the distal side. The swarm is partly buried under fine-grained sediments. Maavehmaa.

The Lahti area is no exception in this respect. Here, too, groups of such end moraines are found. According to Okko's (1957 a) proposal these moraines will be called end moraine swarms.

In the map of Appendix I, the end moraines are presented on an exaggerated scale. The length of the individual ridges varies. Most often they are 30 to 50 m long, but a few measure as much as 200 m in length. The ridges are 1 to 5 m high. In cross-section, many are asymmetric in shape, the distal slant being steeper than the proximal slope. A typical end moraine of a swarm, seen from the distal side, is shown in Fig. 9. The asymmetry brought about by the differently slanting inclines is shown in Fig. 10.

Near the villages of Marttila, Tennilä, and Maavehmaa the end moraines form a swarm in a particular way. The ridges occur in chains. At the place where there are ridges in one chain, there are gaps in the next chain, and so on repeatedly. Thus, there are rows, perpendicular to the chains, consisting of end moraines of every other chain. Sauramo (1929) and Okko (1957 a) have described similar arrangements within swarms of end moraines.

Usually the swarms are located on lower ground than the surroundings. Thus, the Marttila swarm lies at an altitude of 90 m, whereas the surrounding bedrock terrain rises to 120—130 m a.s.l. East of the village of Tennilä, there is a ridge of bedrock the tops of which reach the 155-m-level. End moraine swarms are met on its slopes at 120—135 m. At Maavehmaa, in front of the Salpausselkä, there is a swarm of eight ridges located on a slightly higher ground, 130 m a.s.l., than its surroundings.

Mostly the end moraines project through a cover of water-laid sediments. Hence the substratum on which they rest is unknown. One of the Tennilä swarms is known to rest on ground moraine and one swarm (four ridges) directly on a bedrock surface.

Fig. 10. The moraine ridge shown in Fig. 9 is asymmetric in cross-section. The steeper distal slope is to the right.

Clarifying the relation of the swarms to the glacial abrasion marks requires a study of the orientation elements of the moraines. It is an established fact that the long axes of stones in till tend to be oriented in the direction of glacier flow. The results of six orientation analyses are presented in the following. Two of the diagrams represent foreland ground moraine and four diagrams end moraines of different swarms. At each observation point, the direction (every 5°) of the long axes of one hundred elongated stones (3—5 cm) was measured with a field compass. The dip of the substratum on which the moraines rest being known at only one locality, there were no means to determine the relation of the long axes to the dip of the substratum (compare Johnsson 1956, p. 355). Therefore, the dip of the long axes of the stones was not measured.

The results of the analyses are presented by means of rose diagrams, the use of which is recommended by Glen, Donner, and West (1957, p. 201), among others, for deposits whose dip does not exceed 30°. In order to level down the effect of measuring errors, brought about by the roughness of the method and by the subjective choice of measured values when using intervals of 5 degrees, the number of observations at each azimuth used was added up to the number of observations at both neighbouring azimuths. The sum values were plotted into the diagram by 5°-intervals beginning from the azimuth 2.5°.

In the following discussion, the directions of the orientation maxima are stated by one figure only, namely by the northwestern direction, whenever possible. For instance, a maximum in the direction 330°—150° is referred to as a maximum at 330°.

Diagrams *a* and *b* in Fig. 11 show the orientation of stones in ground moraine. The preferred orientation of the long axes of the stones in the till in the moraine terrain southeast of Herrala railway station (*a*) is 330°, or parallel to the direction of glacial striae in this area. Although less distinct than the Herrala diagram, the preferred orientation of the long axes of the stones in the ground moraine east of Lappila railway station (*b*) is 315°, or almost parallel to the local abrasion marks, 310°—325°.

The rose diagram shown in Fig. 11 *c* depicts the orientation of the stones in the till in the central proximal slope of the largest ridge of the Marttila end moraine swarm. Most of the long axes are oriented between the azimuths 315°—340°, with the maximum occurring at 320°. The orientation maximum is approximately perpendicular to the trend of the ridge, 220° —40°, and parallel to local abrasion marks which run from the direction 330°.

The shape of rose diagram *d*, which depicts a ridge belonging to the easternmost swarm east of the village of Tennilä resembles that of the Marttila swarm (*c*). The orientation maximum at 315° deviates only little from the direction of the local striae, 325°—330°; the subordinate maximum is parallel to the trend of the ridge and perpendicular to the abrasion marks.

The results confirm the conclusion that the northwestern striations were formed near the retreating margin of the ice sheet (p. 28). Furthermore, the ridges trend perpendicular both to the orientation maxima and the glacial striae. Obviously, they represent positions of the terminus of the retreating ice sheet.

The trend of the Maavehmaa swarm is SSW—NNE. The result of an orientation analysis made in the central distal slope of the largest of these moraines (Figs. 9 and 10), 1 m below the crest, is presented in Fig. 11 *e*. The orientation maximum at 300° is distinct. No data on glacial abrasion in the vicinity of the swarm are available. The shape of the rose diagram resembles that of the ground moraine of the Herrala area (*a*) and the maximum direction deviates from the trend of the ridge in the same way as in the diagrams of the Marttila and Tennilä swarms (*c* and *d*). The orientation peak, no doubt, reflects the direction of glacier flow in the Maavehmaa environs.

A result different from the others was obtained in an orientation analysis made in an end moraine south of Tennilä (Fig. 11 *f*). Of the measurements, 40 % are grouped around the azimuth 315° and 50 % around the azimuth 230°—50°, the latter group reflecting also the trend of the ridge. Owing to a large number of processes that could have acted to give the peaks their relative magnitude, the deductions made from the transverse peak are somewhat dubious (e.g., Glen, Donner and West 1957, p. 204). According to Harrison (1957, pp. 297—300), the maximum orientation of

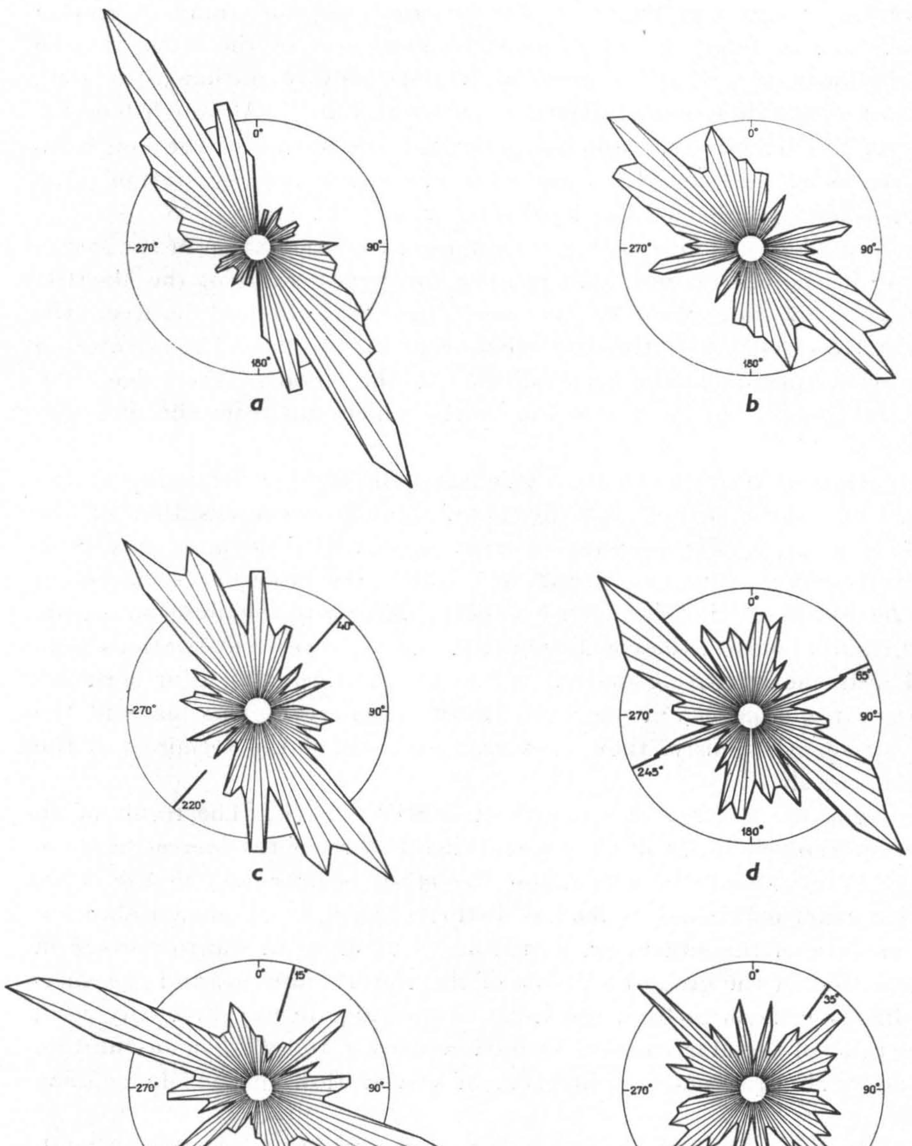


Fig. 11. Rose diagrams showing the orientation of the stones in till in the foreland of the First Salpausselkä. The circles show the 5 per cent range. The lines directed toward the centre show the trend of moraine ridges. Ground moraine: *a*. Herrala, *b*. Lappila. End moraine swarms: *c*. Marttila, *d*. east of Tennilä, *e*. Maavehmaa, *f*. south of Tennilä.

the stones of end moraine till either reflects the direction of the thrust planes of the marginal ice or it shows postdepositionary changes in the till. In the former case, the preferred orientation of the long axes is parallel to the direction of flow; in the latter case the orientation is disturbed or an orientation transverse to the direction of flow is well developed. Thus, the transverse peak of diagram *f* probably developed through postdepositionary changes.

De Geer (1889, p. 369) propounded the theory that groups of small end moraines were formed periodically: Each winter there was a standstill or a minor advance of the glacier margin and an end moraine was deposited in front of the terminus. De Geer (1932, p. 13, among his other papers on the subject) connected the successive annual moraines with his geochronology, based on varve clay studies. In Finland, Sauramo (1918, p. 26) accepted De Geer's theory. Drawing from a number of orientation analyses, Hoppe (1948, 1952, 1957) has criticized the theory. According to him, moraine ridges of this type, — »De Geer moraines» (Hoppe 1960, p. 197), as he refers to them — developed in the basal parts of fracturing and calving glaciers. Wet till having been pressed upwards into fractures, short moraine ridges, often arcuate in shape, were formed. Regardless of the direction of glacier flow, the orientation maxima of the stones are perpendicular to the orientation of the ridges (Hoppe 1957, p. 5). Järnefors (1956, p. 310) has taken part in the discussion on the genesis of these moraines. According to him, the end moraines of the Uppsala region definitely are annual frontal moraines *sensu* De Geer. Okko (1957 a, p. 21) takes an intermediate stand in the matter: the Second Salpausselkä swarms were deposited in front of the terminus, but there was no definite periodicity in the process. Virkkala (1959 a, pp. 17—18) regards end moraines of this type as frontal deposits of a thinned margin.

The foreland in the Lahti area does not lend itself to a geochronological connection of end moraines and annual clay varves: The swarms do not occur among varved clays.

The swarms east of Tennilä are located on the slopes of a bedrock ridge. The orientation of the Tennilä moraines indicates that on low ground the terminus of the glacier was convex downstream, i.e., the ice was more active when flowing on low ground. If the margin wasted by calving in the low area, where the water was deepest, then the rapid flow more than compensated for the loss of ice at the terminus. Although the termini of calving glaciers tend to be concave downstream in plan (e.g., Flint 1957, p. 16), convex calving termini are also known, for instance, in Greenland (Drygalski 1897, p. 134) and in Antarctica (Koerner 1961, Fig. 5, p. 1069).

The rows of end moraines lining up the slopes of the bedrock ridge suggest that they were pressed up into fractures that developed between portions of ice moving at different velocities. The only contradictory observation involves the four end moraines resting directly on the bedrock surface. These ridges might have developed as crevasse fillings, or the ice margin pushed a thin layer of ground moraine into frontal ridges. It may be noted that the chain of end moraines, located on the northwestern slope of a hill with a core of bedrock, near Lappila railway station, was probably deposited in front of the terminus during a minor advance, unable to overcome the obstruction set up by the hill. The arrangement of the end moraines within the actual swarms (p. 31) is, however, difficult to understand if it be assumed that they, too, are push moraines. An origin connected in one way or another to calving might be the explanation to the occurrence of end moraines in swarms.

The end moraine swarms suggest the interpretation that the glacier was rather active during its retreat across the foreland. In the depressions of the substratum, the ice flowed at a greater velocity than on higher ground. In places there were small advances of the margin. Also the fact that nowhere in the foreland are there ablation moraines points to an active glacier.

TRANSVERSE GLACIOFLUVIAL RIDGES

There is a ridge 1 km long some 3.5 km SW of the Herrala railway station. The ridge, called Toijanmäki, rises 25 m above the surrounding ground. Its trend is SW—NE or transverse to the direction of the local striae (330°). The highest part of the 20—30 m broad crest rises to an altitude of 125 m a.s.l. An abundance of boulders characterizes the crest. The slopes are quite steep. The proximal (northwestern) slope is irregularly developed and rich in boulders. In the northeastern part of the slope there is a kettle hole, which is open toward the northwest. The surface of the tiny bog filling its bottom lies 25 m below the crest. The irregularity of the slope seems to be an ice-contact feature. The distal (southeastern) slope, on the other hand, is smooth. At an elevation of 109—110 m, there is a boulder rim.

The best place for a study of the interior structure of the Toijanmäki ridge is to be found near its southwestern end, where a cutting crosses the entire ridge. Washed drift is exposed throughout the cutting. The layers dip toward southeast, also at the proximal slope, where there is only a thin mantle of sand, conforming to the slope. Cross-bedding is to be seen. In the steeper beds, there are a number of small folds (Fig. 12). The fold axes are parallel to the trend of the ridge. The folding was apparently brought about by sliding in the direction of the dip.

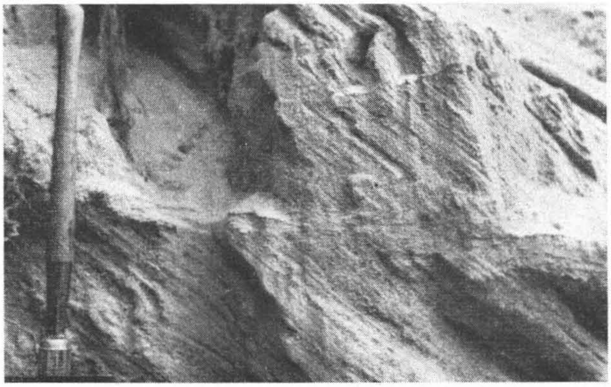


Fig. 12. Detail of the interior structure of the transverse glaciofluvial ridge of Toijanmäki. Small folds are common in the steeply inclined beds of the cross-bedded layers. The folding was brought about by sliding in the direction of the dip. The proximal slope of the ridge lies 2 m to the left of the picture site.

Another transverse ridge built of washed drift, with a large enough gravel pit to allow a good view of the structure, is located at the railway station of Lappila. The ridge is 500 m long; the crest reaches an altitude of 110 m a.s.l.

The trend of the ridge is SW—NE, or approximately transverse to the general direction of the striae (320°) in the Lappila environs. In cross-section the ridge is asymmetric, its proximal slope being much steeper than the distal slope. The material of the Lappila ridge (Fig. 13) is coarser and less well sorted than that of Toijanmäki. The dip of the layers is 15° SE and their strike is parallel to the trend of the ridge. The layers dipping southeastward begin from the proximal slope. There are a number of slip planes cutting the layers. As a rule, the proximal side of a slip plane has moved downward in relation to the distal side.

Okko (1957 a, pp. 13—16) has described ridges similar in trend, material and structure occurring in the zone of the Second Salpausselkä. According to him transverse glaciofluvial ridges — transverse eskers in his terminology — were deposited at the terminus of the glacier as a variety of glaciofluvial delta, the top of which never was built high enough to be controlled by the level of the free water in front of the glacier. Either a lack of drift or the short time the margin stayed at the ridge prevented the accumulation of a fully grown delta.

Neither of the proximal slopes of the two ridges seems to have been subject to strong washing. Apparently, the structure of the proximal parts of the ridges is original. It is thus impossible that meltwaters carrying

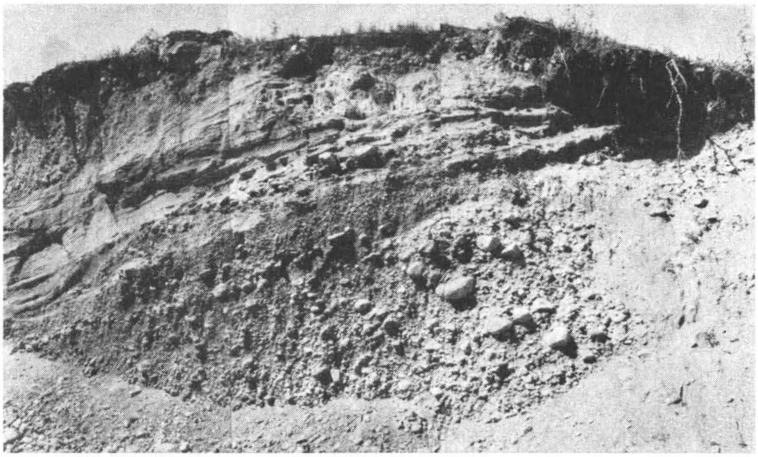


Fig. 13. The beds of the transverse glaciofluvial ridge of Lappila dip in a distal direction beginning from the proximal slope, to the right in the picture. The washed drift was deposited by waters running obliquely downward from the glacier, not by a subglacial river. The height of the cutting is 3 m.

the washed load should have discharged subglacially; instead, the material must have been deposited by meltwaters running obliquely downward from the glacier.

The dislocations in the esker material suggest that the proximal slope was originally supported by the glacier. When the glacier withdrew from the esker, the balance of the layers was disturbed and a new balance was reached through downward sliding of proximal portions of the accumulation. Also the morphology of the proximal slopes contributes to the conception of a glacier-supported terminal formation.

Where there are frontal glaciofluvial accumulations in the foreland, no calving took place at the ice margin. Here the glacier rested solidly on the underlying bedrock. Thus, transverse glaciofluvial ridges provide additional evidence to support the conclusion, based on the study of foreland end moraine swarms, that the glacier was active while retreating from the foreland.

RADIAL ESKERS

The radial formations of the foreland are not conspicuous. The northwestern ends of three esker chains which emerge at the coast of the Gulf of Finland, between Porvoo and Pernaja (see Atlas of Finland 1960, sheet 4), reach the foreland.

The westernmost esker chain runs through the village of Marttila past Järvelä railway station in the direction SE—NW. The altitudes of the tops of the ridges which form the chain rise toward the northwest. At Marttila the top level is scarcely 120 m a.s.l., at Järvelä the tops reach 20 m higher up.

The esker chain ends up at a shallow depression occupied by a swampy lake, now drained for cultivation. The diameter of the round depression is about 1.3 km. An asymmetric ridge, built of washed drift, rises at the northwestern border of the depression. The trend of the ridge is SW—NE. It is located in the zone of the western flank of the Salpausselkä. The conditions at the glacier margin favouring formation of radial eskers came to an end very near the Salpausselkä zone.

The striations observed on both sides of the Marttila — Järvelä chain generally run from northwest (315°—325°) to southeast. West of Marttila village, to the southwest of the eskers, there are striations formed from the direction 300°. Here the esker is located at the border of two slightly different directions of glacial abrasion, the marks of which are turned toward the esker. Farther northwest, around the Järvelä railway station the striations are parallel to each other on both sides of the eskers.

The tendency of striae to be turned toward eskers is rather common. Repo (1954; 1957, p. 153) interprets the phenomenon as evidence of the deposition of eskers in crevasses. Lundqvist (1955) is of the opinion that a glacial bay evolves in the terminus at the mouth of a glacial river. Glacier flow tends to straighten the terminus into an ice front; hence the flow is directed towards the »shores» of the bay. As early as 1923, Sauramo (1923, p. 146) pointed out that glacier flow is directed in this way at a glacial bay. The geochronological evidence collected by Järnefors (1956, pp. 308—309) in the Uppsala region, Sweden, supports the interpretation presented by Lundqvist. Virkkala (1960, pp. 169—170, 173—175) stresses the influence of the topography of the underlying bedrock upon the thinning glacier (see also Hyyppä 1954). The observations of glacial abrasion around the Marttila — Järvelä esker chain are too few to provide a basis for further discussion.

An esker chain running parallel to the Marttila — Järvelä chain at a distance of about 6 km to the northwest, ends up 15 km SE of the western flank of Salpausselkä, measured in the direction of glacial abrasion in the foreland. Only the northwesternmost hills and ridges of this chain are to be seen in the map of App. I. They are located on both slopes of a valley occupying a shear zone of the bedrock. The zone runs from south to north. Knobs of bedrock as well as relatively large outcrops are exposed among the esker hills and ridges.

The largest of the esker ridges, called Henna esker in this paper, is located on the eastern slope of the shear valley. The esker is oriented in the direction of the valley, i.e., south-north. The summits of this ridge reach an altitude of 120 m a.s.l, an elevation 45 m above the surface of the clays filling the bottom of the valley.

There are two large cuttings in the northern part of the Henna esker. In the cutting dug into the western slope of the esker, massive layers of stony gravel dip toward the west. A thin film of dirt covers the surfaces of the stones and pebbles. In the eastern wall of the cutting, there are beds of well sorted gravel and sand. The dip of these beds is 10°—15° E. The contact between the well sorted drift and the stony layers is irregular. The polished surface of the bedrock (ca. 95 m a.s.l.) underlying the esker has been exposed at the bottom of the cutting. On the bedrock surface there are well preserved striae formed from the direction 330°.

In the other cutting, dug into the eastern slope of the esker, nearly horizontal layers of fine gravel and sand are to be seen. Roches moutonnées with striations scoured from the direction 325° form the bottom of the pit (85—100 m a.s.l.). There are no signs of stream erosion in either of the cuttings of the Henna esker, nor in its close environs.

The preserved striae in the basement of the esker point to transport by en- or super-glacial meltwaters; the load carried by subglacial meltwaters is so coarse that it ought to have destroyed the abrasion marks. There are circumstances, however, as pointed out by Johnsson (1956, pp. 165—166), when a river running along a tunnel does not erode the basement, or the effect is very weak. West of the village of Marttila there are embryonic potholes on one side of a bedrock knob and a glacial abrasion facet on the top (p. 24). The knob is exposed at the slope of an esker ridge. Here the erosion by running water, possibly by a subglacial river, concentrated on a steep slope in the substratum. The fact that eskers often are located on the slopes and not in the middle of bedrock valleys led Okko (1945, p. 48) to doubt the role of subglacially discharged waters as major agents in the building of eskers. In his opinion, a subglacial river should discharge at the lowest place of the substratum.

The stratigraphy and structure exposed in the western pit of the Henna esker suggest that at least the northern end of the esker was deposited in front of the ice margin, in a manner resembling the deposition of transverse glaciofluvial ridges. Such a mechanism of deposition explains the preservation of striae underneath washed drift. The material of the massive stony gravel beds, a film of dirt covering the stones, was probably reworked by the glacier during an oscillation of the terminus and redeposited in the proximal part of the esker. As the Henna esker is an end member of a long chain, conditions favouring the building of eskers came to an end at this ridge. Therefore, the structure of the esker bears a resemblance to transverse glaciofluvial ridges.

The easternmost esker chain lies in the outskirts of the Lahti area. For the present study, only the Renkomäki esker, located 5 km south of Lahti, has some bearing. Sauramo (1958, p. 71) refers to the Renkomäki esker as »Parallelrücken», the ridge being parallel to the eastern flank of the Salpausselkä at Lahti. The trend of the ridge, W—E, deviates some 50—60° to the west from the direction of striae in its vicinity. In comparison, the Henna esker deviates 40—50° to the north from the direction of local striae. There are a number of cuttings in the Renkomäki esker, but I have not found anything of decisive value in them. On the slopes there are raised beaches at several altitudes. As the present shape of the esker seems to be of secondary origin, brought about by wave action, I should rather refrain from calling the ridge a »Parallelrücken». Because of its location in the area of northwestern abrasion it is justifiable to regard the Renkomäki esker a member of a radial esker chain.

From the regional point of view relatively little washed drift was accumulated in the foreland. As to their size, the accumulations are mostly small hills, only a few having developed into esker ridges of some dimensions. The scarcity of washed drift might depend on the circumstance that the glacier did not carry much load to be washed. The glacier margin having been active in the foreland (p. 28), the meltwaters might largely have flowed in the upper parts of the glacier, where the ice was clean and void of drift.

WATER-LAID SEDIMENTS

The valleys and depressions between the higher bedrock terrain of the foreland are filled with sandy, silty, and clayey sediments. North of a line drawn from Lahti to the parochial village of Kärkölä fine sand and silt dominate in the sediments. The top level of the sandy deposits at the foot of the Salpausselkä is 130—140 m a.s.l.

To the south, the sediments are richer in clay. The border between sandy silts and clays runs approximately along the contour line 115 m but clays occur here and there in basins of the sandy area. In diggings the sediment is seen to have a varved structure.

At a distance of 300 m from the distal slope of the Salpausselkä at Vesala (Fig. 14), there is a road cut where a knob of bedrock (130 m a.s.l.) with a thin mantle of till has been exposed. Layers of silt and fine sand cover the knob. A tendency to current bedding is to be seen in the sediment. In places there are folded layers between undisturbed strata. The

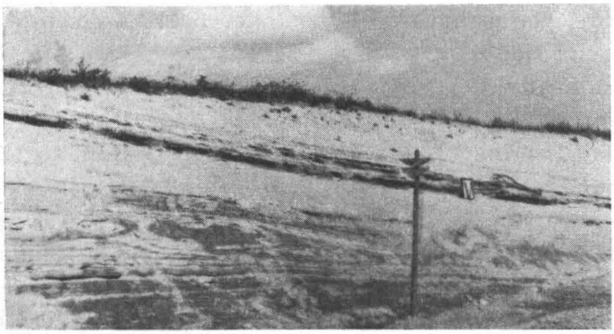


Fig. 14. Graded, silty fine sand close to the distal slope of the First Salpausselkä at Vesala. A tendency to current bedding points to deposition by a stream. The disturbances in the lower part of the cutting are due to sliding.

folding is due to sliding. The material of the undisturbed strata tends to be arranged into graded varves. The lower parts of the individual varves consist of fine sand, occasionally of sand, the upper parts being rich in silt. The thickness of the varves is 15 mm on the average.

In the central part of the sandy silt fields of Vesala, another road cut reveals silt and fine sand, with a fair share of both sand and clay, arranged into horizontal layers of varying thickness. The sandy layers are approximately 50 mm thick, while the silty layers are much thinner, or about 10 to 20 mm. Bands of clay, a couple of millimeters thick, occur irregularly in the silt. Graded structure is less well developed than in the cut described in the foregoing paragraph.

The deposits of fine sand and silt are much the same in structure elsewhere in the immediate foreland of the Salpausselkä bend. Close to the Salpausselkä, the sediments are stream-laid in structure; the material was transported from the Salpausselkä zone. Farther to the south no current bedding is to be seen; rather the layers are horizontal and relatively regular, indicating deposition into a body of standing water.

A study of foreland sediments at considerable depths was made possible through data obtained in groundwater borings by the firm of Vesi-Hydro Oy. Thirteen of the bores, whose locations are indicated in the insert map of Fig. 15, were of particular interest. They are shown as sediment columns (Fig 15). The columns are presented in the order in which the bore sites arrange themselves in relation to the general trend of glacial abrasion in the foreland: the northwesternmost bores are to the left and the southeasternmost to the right. In the figure, no account has been taken of the distance between the bore sites; instead, the columns are drawn according to the altitudes of the bore sites.

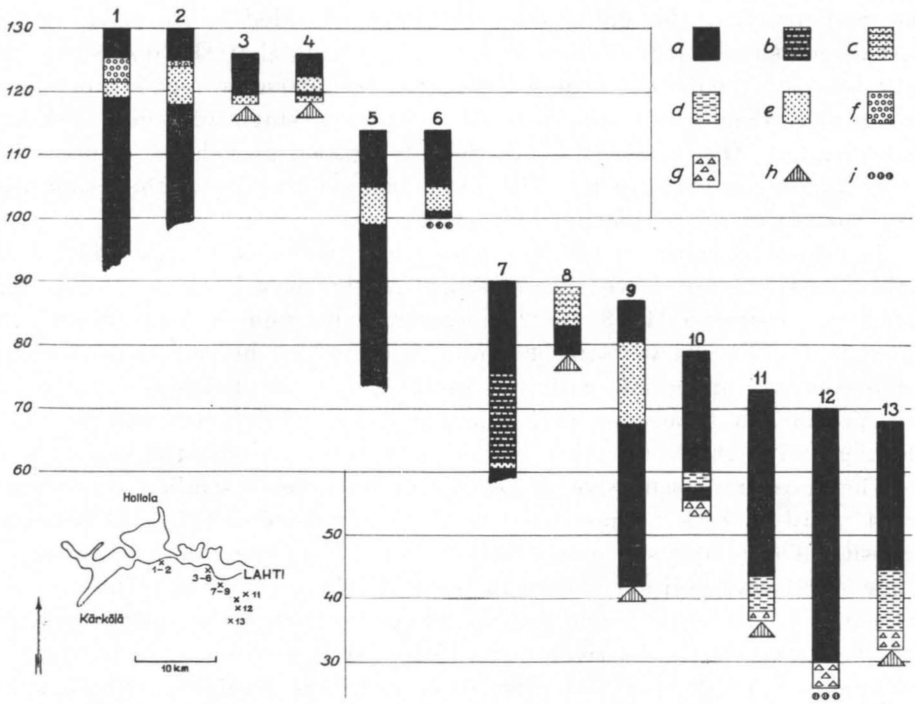


Fig. 15. Sediment columns showing the strata penetrated in thirteen groundwater borings in the foreland of the First Salpausselkä. The bore sites are shown in the insert map. The height scale refers to altitude above sea level. a. Clay and silt, b. sandy silt, c. silty fine sand, d. fine sand, e. sand, f. gravel, g. till, h. bedrock, i. stones.

The bore logs do not make a clear-cut distinction between clay and silt; therefore, these varieties of drift are represented by one and the same symbol. Varieties of coarser-grained drift are clearly indicated in the logs, and, correspondingly, each is denoted by a symbol of its own.

In eight of the bores (1, 2, 4, 5, 6, 7, 9, 10), a bed consisting of drift coarser than silt was found to be interbedded in the deposits of silt and clay. The logs indicate that the beds underlying the intermittent bed are rich in clay in all eight bores.

In the five remaining bores, no interbedded layers of coarse-grained drift were encountered. In bores 3, 11 and 13, the basal layers consist of drift coarser than the silt and clay of overlying beds. The upper part of bore 8 was found to be coarser in grain than the basal part. In the deepest bore, 12, silt and clay extended down to a basal layer of till.

The interbedded layers consisting of drift coarser than silt must have been deposited in conditions different from those favouring deposition of suspended silt and clay. In the bores located close to the distal slope of the Salpausselkä, the grain size of the interbedded sediment diminishes with decreasing altitude. This condition suggests that the deposition was controlled by the depth of the sea. Because the coarse-grained sediments are overlain by deep-water silts and clays, the low stage was succeeded by a transgression. On the other hand, the interbedded gravels and sands might be of an ice-marginal facies. This explanation necessitates the assumption that there was an oscillation of the ice.

Interbedded layers of coarse-grained drift, as thick as those met in the eight bores, do not have a counterpart in the records of varve clay published by Sauramo (1918, 1923). Sauramo distinguished in several clay diggings a sandy varve, some 200 mm thick, which he regarded as having originated in connection with the discharge of the Baltic Ice Lake into the Yoldia Sea (Sauramo 1923, pp. 122—129). This varve can hardly be identical with the very thick interbedded layers penetrated in the bores.

The most representative sequences of varve clay studied by Sauramo are 4 to 10 m thick. Nine of the bores now presented (Fig. 15) penetrate deposits of clay and silt much thicker than 10 m; the thickest continuous sequence of clay and silt, found in bore 12, measures 40 m. The bore site is located in a river valley eroded into deposits of clay, the surface of which lies 10—15 m above the river bed. Hence, it is possible that the original thickness of the deposit was close to 50 m at the bore site. Bores 10, 11 and 13 also penetrate considerable deposits of silt and clay: 30 m (11), 23 m (13), and 19 m (10). Some of the beds underlying the interbedded coarse-grained drift are very thick, too: 26 m (9), 25 m (5), 24 m (1), and 18 m (2). The beds of clay and silt overlying the intermittent bed are much thinner, their thickness varying from 3.5 m to 9 m. Incidentally, the sequences studied by Sauramo are of the same magnitude as the upper beds of silt and clay penetrated in the borings.

In Sauramo's varve series I Ss (First Salpausselkä stage), the average thickness of varves is 15—20 mm (Sauramo 1923, p. 86). A bed measuring some 3—5 m in thickness ought to have been built during this stage, the duration of which was 230 years (Sauramo, *op.cit.*). Calculating from the data published by Sauramo, the average thickness of a varve in the sequence aSs (ante-Salpausselkä) — H (Häme clay; deposits younger than the Second Salpausselkä stage) is 9.9—10 mm. [1] Locally, the average thickness of the varves varies. In the eastern part of the Kerava map quadrangle, there are localities where the average varve thickness is 5.5, 7 or 8 mm the average value for the whole area being 10—20 mm (Virkkala 1959 a, p. 55).

[1] The calculations are based on varve countings made at Herrala (Sauramo 1923, p. 70, p. 80), Jokela (Sauramo 1918, Taf. IV, 49; 1923, pp. 14—15, p. 86), Numlahti (Sauramo 1923, p. 86), Mukkula (op,cit., p. 69), Leppäkoski (op.cit., pp. 27—28), and Imatra (op.cit., pp. 71—72).

On the assumption that the deep bores penetrate varve sediments, their deposition, at an average rate of sedimentation of 9.9—20 mm a year, would have required 2 000—4 000 years. In comparison, the varve-chronological record shows that the ice sheet retreated from the Gulf of Finland to the Gulf of Bothnia during 2 800 years (Sauramo 1923). Worth mentioning are Ignatius's (1958, p. 141) recent studies which indicate that in the deep basins of the Baltic Sea the varves of the silty and sandy clay comprising the ice-marginal sedimentary facies range from 5 to 200 mm in thickness. Because bores 10—13 represent sediments of a basin, the beds of the ice-marginal facies might be quite thick.

Inspired by Soveri's (1950) studies of Quaternary clays in Fennoscandia, Virkkala (1955; see also 1959 a, p. 60) has considered the possibility that a good share of the clay minerals contained in Finnish clays be of preglacial age, derivatives of weathering products: Preglacial clays were reworked by glacial meltwaters and redeposited as glacial clays. Furthermore, in deep basins there might be preglacial clays overlain by glacial and postglacial clays.

Close to bore sites 1 and 2 at Vesala, current-bedded layers of sandy silt occur in a road cut (p. 41) where altitude corresponds to that of the upper silty beds of the bores. As the stream-laid drift obviously was transported from the Salpausselkä zone, also the upper beds of the two bores should have been deposited during the same stage, conceivably during the late phases of the First Salpausselkä substage. By analogy this interpretation should hold for bores 3—9, too. The development of the thick deposits of clay underlying the interbedded strata probably is equivalent to that of the lower parts of bores 10—13.

DEGLACIATION OF THE FORELAND

The analysis of the northwestern glacial sculpture in the foreland gives the result that the directions of the general abrasion and the late-glacial striae are parallel to each other (p. 28); hence, there is no need to distinguish between the two, as far as the foreland sculpture is concerned. The general trend of the radial formations is, by and large, parallel to the northwestern glacial abrasion.

The trend of the terminal formations in the foreland is perpendicular to the direction of the striations. The end moraine swarms might have originated at a calving terminus, but in general they indicate trends of the glacier margin during its retreat across the foreland. Hence, it is justified to use them in reconstructing different local positions of the terminus. Correspondingly, the directions of the glacial striae may be used in

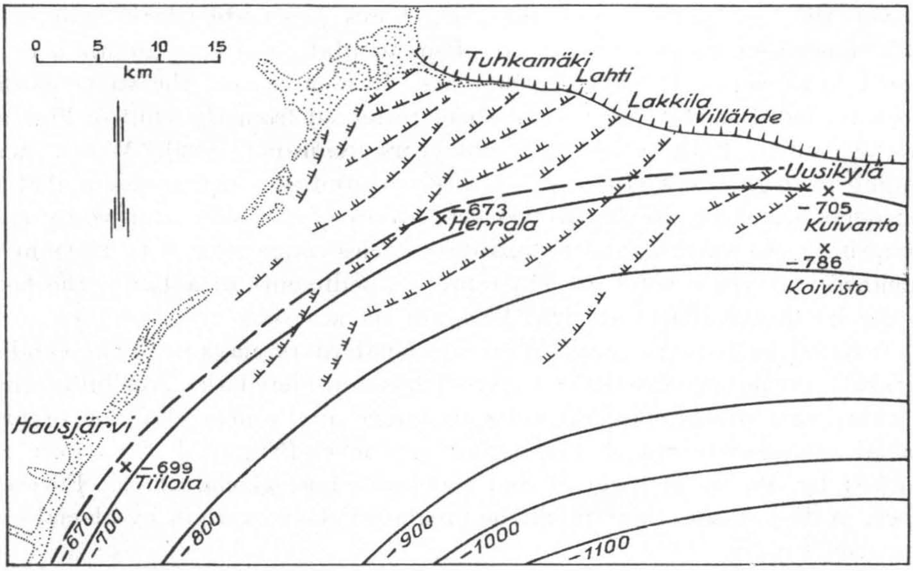


Fig. 16. Reconstructed ice-marginal positions. During the deglaciation of the foreland the ice margin maintained a SW—NE trend and extended across the eastern flank of the First Salpausselkä. The eastern flank shows the southern limit of an ice lobe that advanced from the north into the deglaciated area. The lines plotted into the map are Sauramo's (1923) recession lines, based on varve-chronological studies. The dashed line shows the position in the year —670. The crosses indicate Sauramo's observation localities and the figures there show the age of the basal varve as measured by Sauramo.

plotting recession lines in the map. A similar method has been used by, for instance, Tanner (1915, pp. 654—667), Brander (1934, p. 59) and Hoppe (1948, pp. 37, 87—89; 1960, p. 202).

A number of positions of the ice margin during its retreat across the foreland, reconstructed on the basis of the conclusions stated in the foregoing, are shown in the sketch map of Fig. 16. The reconstructed positions of the margin outside the Lahti area proper are based on my own field observations.

The map shows that the margin of the northwestern glacier must have extended across the zone of the eastern flank of the First Salpausselkä during its retreat from the foreland. The character of the northern sculpture, north of the eastern flank, as well as its sharp limit at this flank, indicate a difference in age between the two directions of glacial abrasion (p. 28): The northern sculpture is the younger one.

The conception that the margin of the northwestern glacier was directed across the eastern flank is based solely on my own field observations. The interpretation is not in accord with the view presented by Sauramo (1918,

1929) and Tammekann (1955), among others, that, during the deglaciation of the southern coastal region, there was a pre-existing bend in the ice margin, which deepened by the time the retreating margin arrived at the Salpausselkä zone.

According to Sauramo (1929, p. 54—55), the front of the First Salpausselkä *in toto* was deglaciated simultaneously; in other words, the ice margin withdrew to the Salpausselkä zone and came here to a standstill. The retreat was somewhat retarded at the bend; at the beginning of the Salpausselkä stage, in the year —670, the margin was located along the line Hausjärvi — Herrala — Uusikylä (Sauramo 1923, p. 139). Sauramo's recession lines, based on varve-chronological studies, and four of Sauramo's observation localitites are shown in the sketch map (Fig. 16).

It may be seen in the eastern part of the sketch map that the reconstructed positions of the ice margin run here at an angle to Sauramo's recession lines. If the glacier margin was directed SW—NE across the zone of the eastern flank, then the varve locality at Kuivanto was deglaciated earlier than Herrala, and this locality earlier than Tiilola; yet they all are dated close to the year —700. Sauramo sent some of his varve diagrams, the Koivisto diagram among them, to Gerard De Geer for correlative dating. Although »teleconnexions are at best premature and tend to discredit the whole method» (Charlesworth 1957, p. 1534) it may be noted that, according to De Geer's dating, the base varve of the Koivisto diagram, —786 by Sauramo, was deposited in the year —1153 (Sauramo 1918, p. 34). However, Sauramo trusted in his own dating, particularly when De Geer did his dating »mit einem gewissen Zögern» (Sauramo, *loc. cit.*). It is of interest to notice that Leiviskä (1934, pp. 122—123) criticized the dating of the Kuivanto — Koivisto diagrams. In fact, he used them in illustrating the weaknesses of the varve-chronological method. Because the ice margin was directed SW—NE while retreating from the foreland, Sauramo's recession lines, based on varve correlations, cannot be quite correct: the line Lovisa — Kuivanto (Sauramo 1918, localities 1—22) does not run at a straight angle towards the retreating ice margin as supposed by him.

On the basis that the land uplift is faster along a zone trending to the southeast from the apex of the bend of the First Salpausselkä than to both sides of this zone, Tammekann (1955, p. 99—100) surmised that on the more rapidly rising ground there evolved a bay in the glacier margin at a relatively early stage of deglaciation. This bay existed through the Salpausselkä stages. The observations on glacial sculpture and terminal formations in the foreland of the Salpausselkä bend do not support this view. It may be mentioned that, according to the newest map on the present land uplift (Atlas of Finland 1960, Sheet 2, No. 2), the isobases run almost parallel across the southern coastal region.

Mölder, Valovirta and Virkkala (1957, p. 46—47) share the opinion that the deglaciation of southern Finland was mainly due to rapid wasting caused by strong calving in the Baltic basin and in the Gulf of Bothnia. Although calving did take place in areas indicated by the Tennilä, Marttila, and possibly Maavehmaa end moraine swarms, calving did not constitute a regional mode of wastage in the Lahti area. This is shown by the presence of transverse glaciofluvial ridges and radial eskers in the foreland and by the moraines at Lappila; all call for a margin that rests solidly on the substratum.

The observation material presented in the preceding pages leads to the following conclusions regarding the late-glacial events in the foreland: During the deglaciation of the foreland of the bend of the First Salpausselkä, the margin of the ice sheet had a SW—NE trend. The margin extended northeastwards across the zone of the eastern flank. The formation of the First Salpausselkä in the Lahti area, especially of its eastern flank, was a much later event than the deglaciation of the foreland.

Although the Marttila — Järvelä esker ends close to the zone of the western flank, giving place to deposition of terminal formations, it does not necessitate the assumption that a halt at the transverse accumulations marked the dawn of the Salpausselkä stage at this point. A similar change in depositionary conditions took place also at the Henna esker, 15 km SE of the western flank. No foreland features in the Lahti area can be said to foreshadow certainly the coming of the Salpausselkä stage.

FIRST SALPAUSSELKÄ AT ITS BEND

REVIEW OF EARLIER LITERATURE

The bend of the First Salpausselkä is shown in early synopsis maps of the geology of Finland (e.g., Wiik 1876, appended map.) The area was mapped in connection with surveying for the Hämeenlinna map quadrangle, scale 1: 200 000. In the explanation to this map Tigerstedt (1888) paid some attention to the Salpausselkä accumulations but did not study them more closely. In his Salpausselkä monograph, Leiviskä (1920, pp. 36—58, map VIII) described the morphology of the big bend in detail. Leiviskä (*op.cit.*, p. 292) classed the segment west of Lahti as a good representative of combined morphological elements: Terminal ridges, small plateaus, and kettle topography are characteristic of the proximal parts of the segment, whereas in the distal parts there are plateaus of various types, often pitted with kettle holes. Drawing to a great extent on Leiviskä's data, Bauer (1939) discussed the morphology of this area from a regional point of view.

As early as 1876, Wiik (p. 96) concluded that the First Salpausselkä marks the limit of the highest glacial sea. The raised beaches of the Lahti area were studied in the 1890's by De Geer (1894, pp. 642—643; 1896, pp. 88—89) and Berghell (1896, pp. 15—16). In connection with his comprehensive studies on shoreline displacement, Ramsay (1922, p. 164; 1931, pp. 62—68) described a few localities in the Lahti area. Ramsay paid particular attention to dry channels occurring on top of the plateaus and to a shore-bar which marks the distal edge of the plateaus. Ramsay concluded that the tops of the plateaus were deposited above the water level indicated by the shore-bar. Furthermore, the shore-bar was formed at the time the plateaus were built. Leiviskä (1920, p. 371), on the other hand, was of the opinion that the distal plateaus as such indicate the highest ancient water level in the Salpausselkä belt.

Sauramo (1940, pp. 104—105, 1958, pp. 61—71), too, dealt with shoreline displacement in the environs of Lahti. He published a map of the bend of the First Salpausselkä (1940, p. 105), revising it slightly later (1958,

p. 62). Sauramo's interpretation of the plateaus as marginal glaciofluvial deltas built at the time the water level stood at the shore-bar of the distal edge is essentially the same as that of Ramsay (*loc.cit*). Donner (1951, pp. 7—11) has contributed to the knowledge of the bend of the First Salpausselkä by giving a detailed description of the glaciofluvial plateau of Lahti. He, too, regards the plateau as a marginal glaciofluvial terrace.

The structure exposed in the railway trenches dug across the First Salpausselkä east of Lahti and across the Second Salpausselkä at Vierumäki led Tanner (1933, p. 33) to distinguish three main stages in explaining the rise of the Salpausselkä ridges: 1. The deposition of morainic drift, partly subaqueously, partly possibly supra-aqueously, with intercalated beds of washed drift reflecting regressive marginal stages; 2. the deposition of washed drift at the mouth of the generally subaerial meltwater currents; and, 3. transport both of the moraine and of glaciofluvial gravel by the forces of the shore. Studying the Lahti area in the 1940's Hyyppä (1951), too, concluded that the First Salpausselkä is a threefold formation. As a working hypothesis he (*op.cit.*, p. 7) presented: »1. Primarily the 1. Ss may have been deposited glaciofluvially (ice-contact stratified drift) in a crack transverse to the ice flow. A crack may have been formed in the dead ice by crustal deformation as the ice sheet thinned and by later melting along that zone of fracture . . .; 2. Readvance of ice. There are several exposures with till on top of gravel and sand, and in some of these places there is undoubted distortion due to ice shore. 3. Eustatic rise of the sea brought the sea level to or above the present level of Ss plateaus after the main Ss had been deposited. Both Ss were trimmed by wave work as land uplift brought them above water level. In some places the trimming was complete and huge plateaus and shore accumulations were deposited . . .»

GENERAL DESCRIPTION

In the glacial map of the Lahti area and its surroundings (Appendix I), the eastern flank of the First Salpausselkä runs from the middle of the eastern border of the map in the direction ESE—WNW toward Lahti. Along this stretch, the Salpausselkä has the shape of a truncated ridge. West of Lahti, the Salpausselkä widens out to form four broad plateau complexes which occupy the apex of its bend. From the westernmost plateau complex southwestward, the western flank of the Salpausselkä assumes the shape of a 6 km wide zone where short and narrow ridges occur irregularly either in groups or alone. The ridges obviously represent successive positions of the ice margin, but Salpausselkä as a major element of the landscape is totally lacking.

In agreement with Leiviskä (1920, pp. 38—58) the plateau west of Lahti is considered to form the easternmost part of the big bend of the First Salpausselkä. The plateau or parts of it have been described under the name »Plateau von Okeroinen» (Leiviskä 1920, p. 277; Bauer 1939, pp. 45, 49; Sauramo 1958, p. 66). Donner (1951, pp. 7—11) mapped and described the plateau using the name Lahti plateau, which will be used in the present paper. The top level of the Lahti plateau reaches the height of 150—155 m a.s.l. Between the eastern end of the plateau and the shore of Lake Vesijärvi there is an asymmetric ridge, separated from the plateau by kettle topography. The plateau and the ridge form the Lahti section of the First Salpausselkä.

A short ridge whose round crest reaches an elevation of 152—153 m joins the western end of the Lahti plateau with the plateau complex south of the Tiirismaa range. The top level of the eastern part of the plateau complex is 150—160 m and that of the western part 155—160 m a.s.l. Toward the north, at an elevation of some 160 m, the plateau surface merges into ground moraine covering the quartzite hills. In the west, the plateau area, called the Tiilijärvi section in this paper, ends up at a ridge of bedrock which extends across the Salpausselkä zone (compare Fig. 3, p. 17). West of this ridge, there is a basin filled with bogs and lakes.

A narrow ridge, the sharp crest of which lies at an altitude of 145—150 m a.s.l., links the distal slope of the Tiilijärvi section to the Vesala section, situated next proceeding west. The Vesala section is formed by three plateaus and a wide area of knob-and-kettle topography. Leiviskä (1920, pp. 48—49) named the distal plateau the »Plateau von Wainio» and the plateau located at the eastern end of the section the »Plateau von Hollola». In the west, the section ends up in a sandy valley. The distal slope of the section continues southwestwards as a round-crested ridge into the Sairakkala section.

The rather complex Sairakkala section forms the westernmost part of the bend of the First Salpausselkä. A large distal plateau (155—160 m a.s.l.) is bordered in the northwest by a shallow basin filled with sand; the basin is bordered by ridges in the northwest and the north. To the southwest the section ends up rather abruptly in the low Teuronjoki valley (compare Fig. 2, p. 15). The steep slope continues northwestward as the southwestern slope of the Koski esker. At the southwestern end of the section, there is a narrow ridge, the »Plateaurücken von Maavehmainen» of Leiviskä (1920, pp. 40—42, 276), which extends into the Teuronjoki valley. The crest of the ridge reaches an elevation of 165 m; its distal slope is an extension of the slope of the Sairakkala distal plateau and its proximal slope an extension of the southwestern slope of the section. Leiviskä applied to the northern part of the Sairakkala section the name of »Plateau

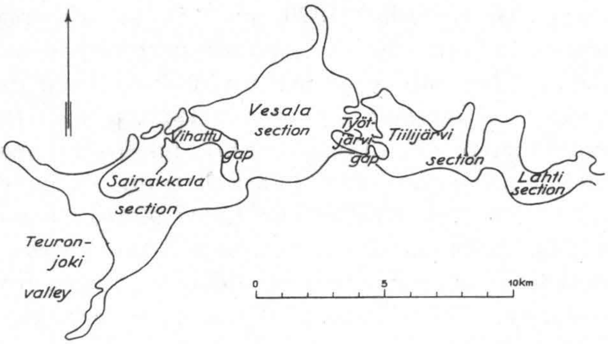


Fig. 17. Index map to explain the nomenclature of the bend of the First Salpausselkä as used in this paper.

von Vihattu», whereas Bauer (1939, p. 46) and Sauramo (1958, p. 67) used this name also for the western part of the Vesala section.

In the present paper, the valleys located between the sections are called gaps. A gap has been defined as a steep-sided furrow which cuts transversely across a ridge or rise (I.U.G.G. Newsletter 1953, pp. 551—557). Although the valleys begin at a distal ridge, they cut the bend into definite plateau complexes and form transverse gaps in the morphology of the First Salpausselkä. In this respect there are actually two gaps in the bend. The Työtjärvi gap separates the Tiilijärvi and Vesala sections from each other, and the Vihattu gap the Vesala section from the Sairakkala section. Between the Lahti and Tiilijärvi sections there is no gap valley. The Teuronjoki valley, which marks the change from plateaus into a zone of minor ridges, differs from the two gaps, but its role in forming a transverse gap in the morphology of the Salpausselkä justifies its being discussed together with the gaps.

The sections and gaps of the bend of the First Salpausselkä are shown in the sketch map presented in Fig. 17. In order to avoid repetition of the bulky designation »the bend of the First Salpausselkä,» this part of the Salpausselkä, as defined in the foregoing, will be referred to in the following as »the Bend,» whenever applicable.

The block diagram shown in Fig. 18 was prepared to give the reader a bird's-eye view of the Bend. The diagram was drawn according to contour lines in topographic maps, scale 1:20 000. The scales used in drawing the diagram are indicated in the figure. The eastern border of the block diagram cuts across the middle part of the Lahti section; the Maavehmaa ridge is seen close to the southwestern corner.

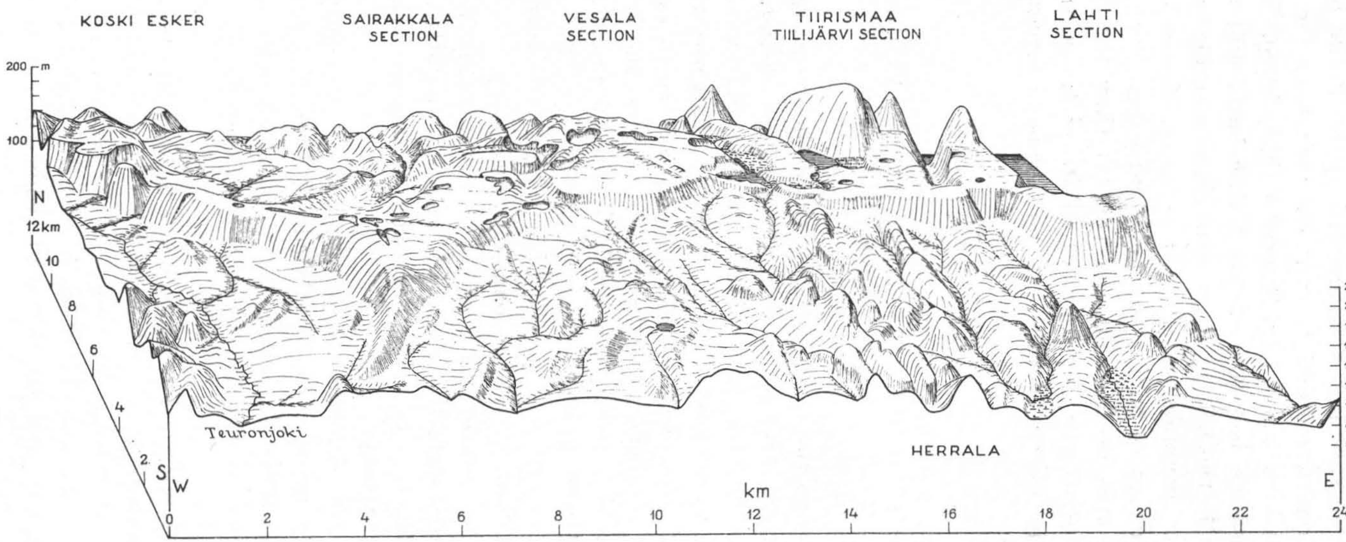


Fig. 18. Block diagram showing the bend of the First Salpausselkä and its close environs. The height scale is strongly exaggerated but serves to illustrate the difference between the smooth glaciofluvial accumulations and the rugged bedrock topography.

The study of the deglaciation of southern Finland is intimately bound up with the study on shoreline displacement in the Baltic basin. Most of what is dry land today was inundated and has risen from the waters mainly through postglacial land uplift (e.g. Sauramo 1929, 1958). The open position of the Salpausselkä belt toward the Baltic basin and the loose drift abundantly present in the belt rendered conditions suitable both for erosive wave action and for accumulation of shore deposits. These deposits will be dealt with in the chapters on the sections and gaps. Shoreline displacement in the Lahti area needs a broader context than the relation of the Salpausselkä beaches to the development of its plateaus and other land forms; therefore, the raised beaches will be discussed separately (pp. 114—133).

RELATIONSHIP TO BEDROCK TOPOGRAPHY AND GLACIER MOVEMENTS

In the discussion on the causes of the halt of the ice margin at the Salpausselkä belt there are, broadly speaking, two schools of thought. Rosberg (1892, p. 95), Leiviskä (1920, p. 380; 1934, p. 114) and recently also Tammekann (1955, p. 100) advocated the idea that the halt was mainly brought about by the topography of the substratum. According to Leiviskä (1920), the margin of the ice sheet was unable to overcome the bedrock barrier forming the threshold between the southern coastal region and the lake district. Sauramo (1918, p. 43; 1923, p. 121; 1940, pp. 250—252; 1955 a, p. 9; 1958, pp. 119—120) was of the opinion that the retreat of the ice margin came to a halt at the Salpausselkä belt because of a change in climate. In modern writing, this view is unanimously accepted. The development of the bend of the First Salpausselkä was attributed by Sauramo (1923, pp. 139, 155) to the topography of the bedrock, particularly to the high Tiirismaa range.

The location of the Bend in relation to bedrock topography is shown, as far as is known, in the morphological bedrock map (Fig. 3, p. 17). When looking at this map, it should be kept in mind that the elevation of the top level of the wide sections is 150—155 m in the east and 155—160 m in the west.

Underneath the Lahti section, the bedrock surface has been encountered between the elevations of 70 m and 120 m. The Lahti section is located at the southern border of a large depression of the bedrock, now occupied by Lake Vesijärvi (81 m a.s.l.). The bedrock probably forms a low threshold between the lake basin and the foreland, which generally slopes southward.

In the foreland of the Tiilijärvi section, the bedrock is cut by shear zones into blocks. The tops of the blocks rise stepwise toward the north, culminating at the high Tiirismaa range, in the immediate hinterland of the section. Tiilijärvi section is located in the northern part of this stepped surface; it skirts the highest blocks (Tiirismaa) from the south. Groundwater borings have revealed that the deep fault valleys, which cut the quartzite range into three blocks, continue southwards underneath the drift of the Tiilijärvi section. On the other hand, outcropping bedrock occurs at 145—155 m a.s.l. at the western end of the section, where it borders on the Työtjärvi gap. The gap opens toward the north through the narrow fault valley at the western end of the Tiirismaa range.

The top levels and structure of the bedrock are about the same both in the foreland and the hinterland of the Vesala section. Bedrock is also exposed at the eastern and western ends of the section. Most probably, the Vesala section is located in the central part of a broad area of elevated bedrock.

In the Vihattu gap, outcropping bedrock is encountered on the northern slope and at the bottom of the valley. Both outcrops are quite small and seem to belong to the portion of elevated bedrock on which the Vesala section rests.

Besides the two outcrops in the Vihattu gap, there is only one small outcrop in the close environs of the Sairakkala section. To the northwest of the section, there is a large basin covered with sandy deposits (see relief map, Fig. 2, p. 15 and Fig. 18, p. 53). The difference in elevation between the proximal ridge of the Sairakkala section and the bottom of the basin is 40—45 m, suggesting that the section is located on higher ground than the immediate hinterland.

The Sairakkala section ends at the low Teuronjoki valley (see Fig. 18). An extension of the section runs into the valley; farther to the southwest, there are only relatively short and low ridges in the zone of the Salpausselkä. The change in the mean elevation of the bedrock surface is marked by a change in the morphology of the Salpausselkä.

Still farther to the southwest, the zone of the western flank of the Salpausselkä runs across a bedrock area, characterized by frequent shear zones. The blocks rise toward the northwest. The inconspicuous ridges marking the western flank are located in the lowest (southeastern) part of this bedrock area.

In the Lahti area the First Salpausselkä forms broad accumulations when located on elevated portions of the bedrock. On a low substratum the Salpausselkä forms scattered, narrow and short ridges.

A glance at the relief map (Fig. 2, p. 15) shows that high ground occurs along a zone extending westward from the Tiirismaa range. It is known to continue in this direction to the Second Salpausselkä at Jylisjärvi. Had the ice margin halted for topographic reasons, then the eastern flank of the First Salpausselkä ought to extend as far west as the Jylisjärvi area. Instead, the Salpausselkä zone turns toward the southwest and runs across relatively low ground.

Contrary to the view that the Salpausselkä zone does not generally mark a change in the direction of the glacial striae (e.g., Leiviskä 1920, p. 296), two different glacier movements are reflected in the Bend, namely the northern and northwestern movements (see also Atlas of Finland 1960, Sheet 4, insert map).

The Lahti and Tiilijärvi sections represent the maximum expansion of the northern glacier. This is evidenced by striae which run NW—SE on the distal slopes but N—S at the proximal slopes and on outcrops projecting through the Tiilijärvi accumulations. In the Työtjärvi gap, the glacial abrasion marks run in both directions. Northern striae are to be seen on rocks of northwestern sculpture.

The Vesala section is located, on the whole, in the area of the northwestern glacier movement. Only at its eastern end are there signs of northern abrasion. The apex of the Bend in its relation to the glacier movements thus lies in the Vesala section. Deposits laid by both glaciers are to be expected in this section of the Bend.

The Vihattu gap and the Sairakkala section are both located in the area of northwestern abrasion. They form the northeasternmost part of the western flank of the First Salpausselkä.

Although topography has not determined the location of the First Salpausselkä at its bend, the behaviour of the thinning ice margin must have been affected by the big differences in elevation of the bedrock surface in the Lahti area. Because the local bedrock topography varies from section to section and from gap to gap, the ice margin probably behaved differently at each section and gap.

MATERIALS

In the Lahti area, the First Salpausselkä is mainly built of washed drift but till is also to be found. In order to avoid repetition of descriptive accounts of the materials the sections and the gaps are built of, the characteristics of the two types of drift will be treated independently. In addition, the varied drift encountered in areas of knob-and-kettle topography will be treated in connection with other materials. For lack of deep enough cuttings this survey of materials is necessarily confined to the topmost beds of the Bend.

MORAINIC DRIFT

Many a ridge and hill in the First Salpausselkä at its bend is composed of till but larger deposits of till occur as moraine terrain with no distinct morphological forms. Both till and washed drift are present in the large knob-and-kettle areas.

Lithologically, the Salpausselkä till as well as the till met in the foreland and hinterland are rather monotonous. The average lithologic composition, based on 1 400 stones from 14 sites, is shown in the following tabulation.

Microcline granites, migmatites, pegmatites	53 %
Granodiorites	12 »
Mica schists and mica gneisses	18 »
Miscellaneous gneisses	10 »
Amphibolites	6 »
Mylonites	1 »
	100 %

In comparison to the average distribution of rocks in the Lahti area (Fig. 4, p. 17), the lithologic composition reflects the local bedrock. Granites are predominant both in the bedrock and in the stones of the till. The regular presence of mylonitic stones in till is not in proportion to the small number of mylonite outcrops. Because these stones most probably derive from the abundant shear zones (compare p. 18), their proportion in the lithologic composition of the till ought to correspond to the true abundance of mylonites in the bedrock.

As the rocks represented by the stones in till are common in the bedrock throughout southern Finland, the lithologic composition of the till gives no clue to the source of the stones. Only the Tiirismaa quartzite ought to be a source rock easy to trace in the lithology of the till in the eastern part of the Lahti area. At the southern foot o f the quartzite range, the quartzite occurs mainly as blocks in the till. Farther to the southeast, quartzitic blocks are scarce. In acid pebbles rich in quartz, it is hard to distinguish, without a microscopic examination, between the glassy, highly metamorphosed quartzite and the quartz derived from gneissose rocks or pegmatites. Only when stalks of sillimanite can be identified in such pebbles is there no doubt about their source, i.e., the quartzite. Observations in the field on the distribution of Tiirismaa quartzite in till do not suffice for a closer study of the glacial transportation of quartzite.

In respect to their lithologic composition, the Salpausselkä tills do not differ from the till met in its foreland and in the hinterland. It is hardly

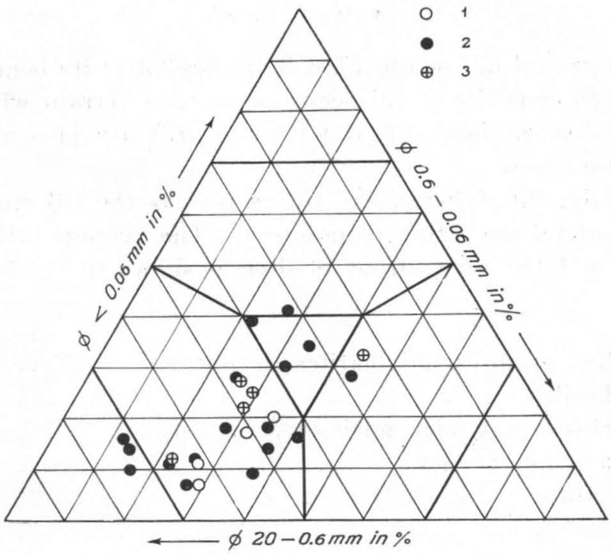


Fig. 19. Mechanical composition of till in the Lahti area. Only grades < 20 mm are shown in the diagram. 1. Foreland, 2. Salpausselkä, 3. hinterland.

possible by means of stone counts to draw in the Lahti area any reliable conclusions about the transportation of the morainic drift deposited in the First Salpausselkä zone.

Seventeen samples of till, collected in the First Salpausselkä, were selected for an analysis of their mechanical composition. The samples represent ridges, hills, knob-and-kettle areas as well as moraine terrain. Four samples of foreland till and five of hinterland till were analysed, too. Two of the foreland samples represent ground moraine and two end moraine swarms. Four hinterland samples were collected in ground moraine terrain and one in an end moraine of a swarm. In the following, the mechanical composition is discussed in terms of grades smaller than 20 mm. The results of the analyses are plotted in the triangle diagram shown in Fig. 19.

The triangle diagram shows that the mechanical composition of the Salpausselkä tills varies greatly from sample to sample. The sample containing 41 % fine grades (ø < 0.06 mm) was collected in the Sairakkala section. Together with the sample containing 39 % fine grades, it representthe proximal ridge of the section. Three samples, on the other hand, contain 72—74 % gravel and coarse-grained sand (ø = 20—0.6 mm). Two of them were collected in a knob-and-kettle area of the Sairakkala section and the third in moraine terrain of the Vesala section. One might suspect that

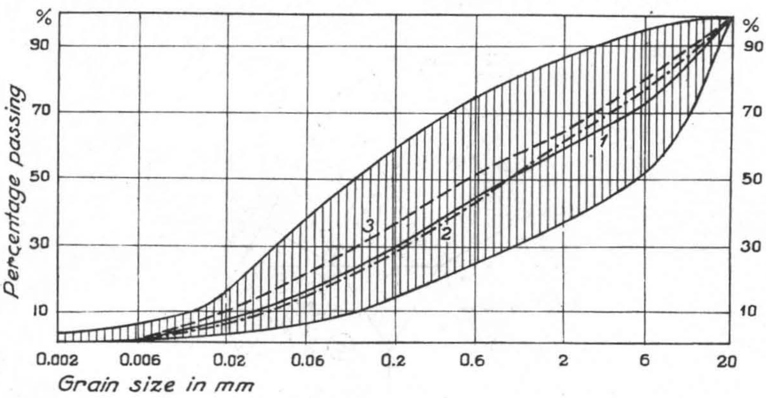


Fig. 20. Cumulative grain-size diagram showing the mechanical composition of till in the Lahti area. The lined area shows the variation range of the samples presented in the triangle diagram of Fig. 19. The curves show the average mechanical composition of till in 1. Salpausselkä, 2. foreland, and 3. hinterland.

these samples are not at all till; the particles are, however, densely packed and angular in shape. It may be mentioned that in the Hämeenlinna region, west of the Lahti area, Virkkala (1961, Fig. 7, curve 2, p. 223) described a small end moraine built of till richer in coarse-grained material than the three samples under discussion.

The analysis points of the majority of the samples form a bridge between the two groups of till dicussed in the previous paragraph. All the foreland and hinterland samples fall into this group.

The composition range of the Lahti tills is illustrated by the cumulative grain-size diagram shown in Fig. 20. In the diagram, the area indicated by vertical lines shows the range of the cumulative curves of all twenty-six samples. The shape of the composition range is rather typical of the tills of southern Finland (e.g., Virkkala 1959 a, Fig. 13, p. 24; 1960, Fig. 5, p. 171; 1961, Fig. 7, p. 223). The three curves inside the lined field show the average mechanical composition of the three groups of tills, viz., Salpausselkä, foreland, hinterland. The curves resemble each other; they also show that, on the average, the moraines of the Lahti area are composed of sandy till. This result is not surprising. According to Kivekäs (1946, p. 45) almost 3/5 (56 %) of Finnish moraines comprise sandy tills.

WASHED DRIFT

There are two main morphological classes of outwash in the Bend, namely plateaus and ridges. In Leiviskä's (1920, pp. 262—292) classifica-

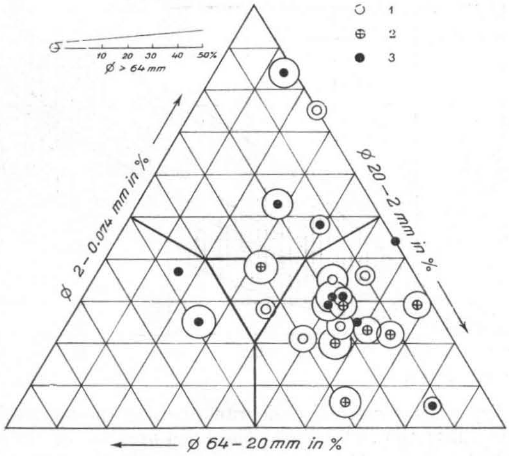


Fig. 21. Mechanical composition of washed drift in the Salpausselkä. The circles around the analysis points show the content of coarser drift than 64 mm. 1. Plateau, Vesala section, 2. glaciofluvial ridge and 3. knob-and-kettle area, both of the Sairakkala section.

tion of the morphological elements present in the Salpausselkä, these two classes attain a prominent position. Leiviskä (*op.cit.*, pp. 268—269) grouped into plateaus all the broad parts of the Salpausselkä where the shape of a ridge disappears, giving place to wide, flat-topped accumulations. His classification being purely morphological, Leiviskä did not pay particular attention to the materials of the plateaus and ridges. In the present paper, the term plateau is not used in the same sense as by Leiviskä; by definition, the plateaus of the Lahti area are broad and relatively level accumulations of washed drift. The ridges are either moraine ridges or they are built of washed drift. The latter will be called glaciofluvial ridges. In addition to plateaus and ridges, washed drift occurs also in knob-and-kettle areas.

The lithologic composition of the washed drift in the Salpausselkä does not differ from that of the till. Because the wide plateau complex of the Tiilijärvi section lies at the foot of the quartzite range of Tiirismaa, the occurrence of quartzite in the washed drift was studied more closely than in the till. It was found that pebbles and stones of quartzite are rather scarce in the outwash deposited to the south of the range. A count of a hundred stones in several well-mixed heaps yielded 0—2 % quartzite; yet quartzitic stones are easy to find in the drift. In general the quartzite does not show in stone counts. Corresponding conditions have been described by Arneman and Wright (1959, p. 554) from some Minnesota tills. They

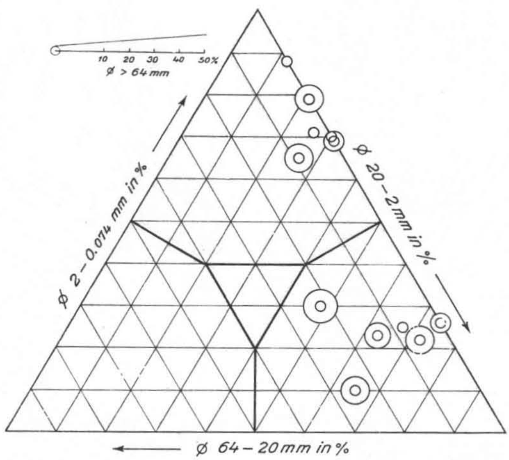


Fig. 22. Mechanical composition of washed drift in the esker of Koski, hinterland of the Sairakkala section.

stress that in such cases subjective field observations may be more critical than statistical stone counts. Among blocks and boulders, quartzites comprise some 10—20 % of the total number. The distribution of the quartzites might depend on the structure and hardness of the source rock. It also indicates that the quartzite range supplied the glacier with blocks and boulders formed *in situ* through mechanical weathering. With the blocks removed, the quartzite was resistant to glacial abrasion.

The mechanical composition of twenty-four samples of washed drift, which were collected around the apex of the Bend, is shown in the triangle diagram presented in Fig. 21. The samples represent the distal plateau of the Vesala section, a glaciofluvial ridge and a knob-and-kettle area of the Sairakkala section. The washed drift of the knob-and-kettle area will be discussed in the next chapter (pp. 63—65).

Two-thirds of the samples are gravels containing more or less sand or pebbles. All groups of deposits are represented in these samples. Only four samples, three of them from the knob-and-kettle area and one from the distal plateau, are sands. Two knob-and-kettle samples are exceedingly rich in pebbles, whereas two samples representing the distal plateau and the glaciofluvial ridge show a uniform distribution of sand, gravel and pebbles. The samples representing the glaciofluvial ridge form the most uniform group of gravels. Also the outwash on the distal plateau comprises mainly gravels, but sand is also present.

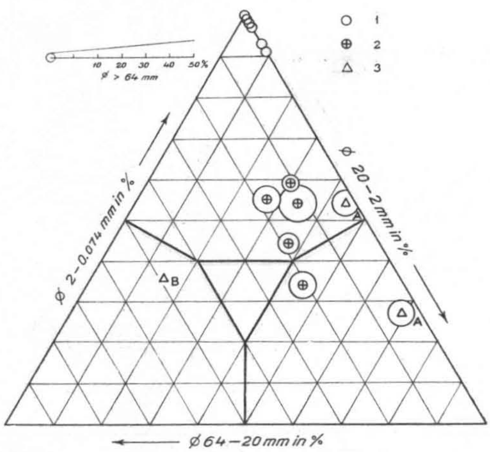


Fig. 23. Mechanical composition of shore deposits on the Salpausselkä. 1. Beach sand on the slopes, 2. terrace material built of plateau drift, 3. material of shore-bars: A. distal edge and B. distal slope of the Vesala section.

The triangle diagram of Fig. 22 shows the mechanical composition of twelwe samples collected on the radial esker of Koski, located in the hinterland of the Sairakkala section. The esker drift consists of equal amounts of sandy and gravelly material. In comparison with the diagram illustrating the mechanical composition of the Salpausselkä outwash, the drift of both the plateau and the glaciofluvial ridge resembles gravelly esker drift. The pebble grade (ø = 64—20 mm) is somewhat more strongly represented in the Salpausselkä samples than in the esker drift.

A shore-bar occurring at the edge of the distal plateau marks a distinct border between the original plateau drift and material redeposited by wave action on the slopes of the plateau. On the distal slope of the plateau there are mainly sands whose mechanical compositions appear in the triangle diagram depicting the Salpausselkä shore deposits (Fig. 23). In comparison with esker sands, the beach sands are far better sorted.

The mechanical composition of the plateau outwash redeposited as a shore terrace is represented by four samples in the diagram (Fig. 23). During redeposition the plateau outwash obviously was enriched in sand mainly at the cost of gravel.

Two samples were collected from the shore-bar at the edge of the plateau. Their mechanical composition is also shown in the diagram; they are denoted by the letter A. The samples are poorer in pebbles than the plateau drift; otherwise, they do not differ much from the regular plateau material. Sample B was collected from a shore-bar located 6 m below shore-bar A. This sample differs from the A-samples in that it contains roughly equal amounts of pebbles and sand. The lower shore-bar was built of beach sand which became enriched in pebbles. The upper shore-bar is built mainly of plateau material, showing that at the edge of the plateau very little sorting occurred through wave action. Either the shore-bar was accumulated at the high-water limit or the stage of the sea during which the shore-bar was built was of short duration.

The study of the mechanical composition of the washed drift accumulated in the Salpausselkä shows that plateaus and glaciofluvial ridges are built of the same material as the eskers. Shore deposits formed of washed drift are clearly better sorted, excluding the uppermost shore-bar, which consists of the same type of material as the plateau.

DRIFT IN KNOB-AND-KETTLE AREAS

The outwash at Salpausselkä is fairly often pitted with kettle holes. The kettles are 5—20 m deep and rather smooth in shape. The knob-and-kettle areas differ markedly from pitted outwash topography in that the tops of the knobs never lie on the same level. The drift encountered in these areas varies from boulder belts to pure gravel and sand; till is also common.

A profile levelled across the northeastern knob-and-kettle area of the Sairakkala section is shown in Fig. 24. The topography of the area is very rough. Some of the inclines are as steep as 14°—16°. All the knob-and-kettle areas of the Bend are similar in topography and structure (compare Profile A-B in Fig. 34, opposite p. 80).

The mechanical composition of fifteen samples collected along the profile line are shown in the triangle diagram of Fig. 25. The samples of till are indicated by triangles and those of washed drift by circles. The samples of washed drift are the same as those presented by black dots in the diagram of Fig. 21 (p. 60). This diagram shows that the washed drift of the knob-and-kettle area has the widest range of variation in mechanical composition.

In the profile (Fig. 24) each sample of washed drift is denoted by its d_{60}/d_{10}-value (e.g., Lomtadse 1955, p. 79): d_{60} is the diameter of the grain size at which the cumulative curve trespasses the 60 %-line and d_{10} the diameter of the grain size at the 10 %-line. When the relation d_{60}/d_{10} is < 5 the sample is well sorted. Only four samples (Nos. 2, 10, 12 and 14) consist of well-sorted drift. The d_{60}/d_{10}-values of the remaining samples range from 5.3 to 13.5. In comparison, the corresponding values of the

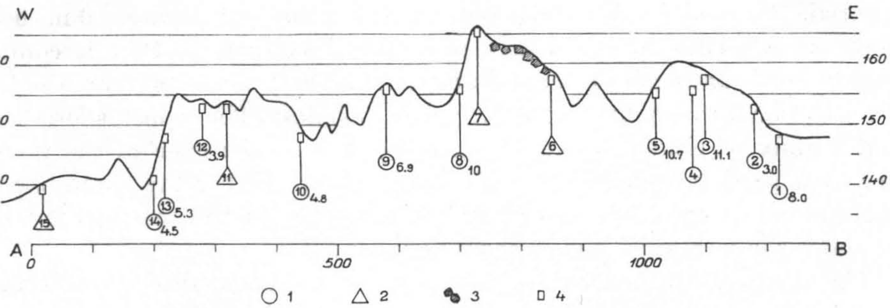


Fig. 24. Levelled profile of a knob-and-kettle area, Sairakkala section. 1. Washed drift, 2. till, 3. blocks and boulders, 4. sampling sites. The numbers below the circles indicate the d_{60}/d_{10}-value of the samples. The location of the profile line is shown in Fig. 35.

samples of washed drift collected on the distal plateau and on the glaciofluvial ridge range from 2.7 to 8.0 whereas the degree of unsorting of the samples of till (Nos. 6, 7, 11, and 15) expressed by d_{60}/d_{10}-values is of the order 56—74. The relatively low degree of sorting of the washed drift certainly reflects changes in the velocity of the meltwaters that carried the drift. In the knob-and-kettle area, the least sorted washed drift probably became mixed when slowly redeposited through melting of buried stagnant ice.

There are abundant depressions filled with blocks and boulders as well as belts of boulders in the knob-and-kettle areas. According to G. Lundqvist (1951), block depressions are formed through frost action: They occur preferably in areas with high boulder content, but also in the presence of a thin cover of fine-grained sediment which makes the soil impermeable. Furthermore, their development seems to be connected with the groundwater table (see also Jan Lundqvist 1962, pp. 74—76). In the Salpausselkä frost action might also have caused the mixing of the washed drift of the knob-and-kettle areas.

Of the four samples of till, sample No. 7 is identical with the sample of washed till containing 74 % gravel and coarse-grained sand, discussed in the chapter on morainic drift (p. 58, Fig. 19). The mechanical composition of sample No. 11 suggests that rather than till it is gravelly sand. The angular shape of its pebbles, the dense packing of the drift, and its degree of unsorting $d_{60}/d_{10} = 56.6$ point to a true till.

The distribution of the analysis points of both washed drift and till in the triangle diagram, together with the d_{60}/d_{10}-values, shows that the drift of the knob-and-kettle areas passes from till to washed drift. As a matter of fact, when mapping in detail a knob-and-kettle area, it often is difficult to distinguish till from weakly sorted washed drift. The distribution of till

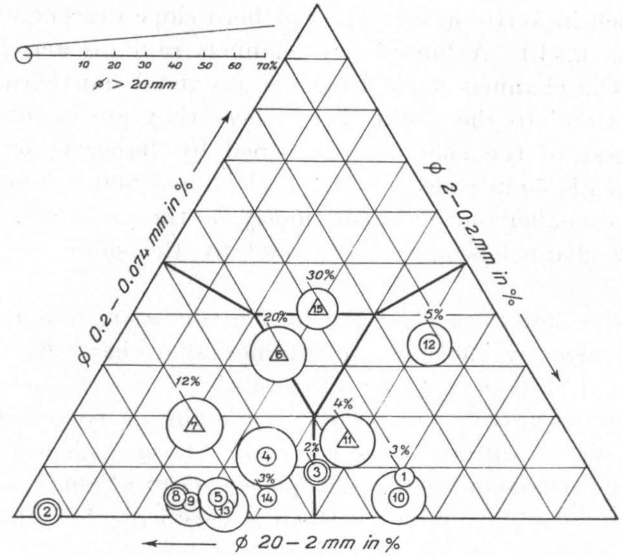


Fig. 25. Mechanical composition of knob-and-kettle drift, Sairakkala section. The circles denote washed drift, the triangles till; the numbers inside them refer to sample sites shown in Fig. 24. The figures attached to half of the analysis points indicate in per cent the content of the grade < 0.074 mm. The large circles show the content of coarser material than 20 mm.

and better or less sorted washed drift in the knob-and-kettle areas, as depicted by the profile of Fig. 24, is typical of the large areas in the Salpausselkä characterized by dead-ice topography. Mention should also made in this connection of Tanner's (1933, p. 16) observation that »the transition forms from moraine to stratified earth-masses . . . are found in Salpausselkä».

SECTIONS OF THE BEND

LAHTI SECTION

The Lahti section comprises the easternmost part of the Bend. The main part of the 3.5 km long section is occupied by the Lahti plateau. Based on a paper by Donner (1951, pp. 7—15) and supplemented by a few new data, a description of the plateau follows. The reader is referred to to the map compiled by Donner (*op. cit.*, Fig. 2, p. 8).

The Lahti plateau rises to an elevation of 150—155 m, the ground on the southern side being about 100 m a.s.l. To the north the plateau merges with terrain rich in kettle holes. The northern slope descends toward Lake Vesijärvi (81 m a.s.l.). A fan of dry channels radiates across the top of the plateau. The channels begin from the proximal (northern) part of the plateau and extend to the distal edge, where they are closed by a shore-bar. The largest of the channels, described by Bauer (1939, p. 45) and Donner (*loc. cit.*) is 50 m wide, about 5 m deep and 600 m long. This channel runs across smaller ones and, obviously, is the youngest. At its proximal head the channel is open but closed by the shore-bar at its distal end.

On the distal slope, traces of ancient shorelines are found. The highest shoreline is formed by the above-mentioned shore-bar. Below this there are two wave-cut cliffs at 144 and 140 m a.s.l. Under the lower cliff, there is a terrace, 20—30 m wide. Below these shorelines a boulder rim at 135 m and, in some places, diffuse shore marks at 112 m a.s.l. are encountered. Thus, the present shape of the distal slope is a result of abrasion and redeposition. The proximal slope of the plateau is very irregularly formed. There are abundant kettle holes, 5—10 m deep.

On the surface of the plateau there are stones and blocks embedded in sandy gravel. The share of stony material increases towards the proximal part of the plateau. The interior structure can be studied in the few cuttings in the distal parts. Underneath the surface layer, there are cross-bedded layers of washed drift. Mainly the drift consists of sand and gravel but occasionally there are beds of stones and boulders.

Since Donner's field work, a cutting has been opened into the upper proximal slope of the western part of the plateau. Here the structure of the washed drift resembles that of transverse glaciofluvial ridges (p. 37). According to several measurements, also at the proximal slope proper, the layers of well-sorted drift dip 15°—20° SSW—SW (Fig. 26). The melt-waters carrying the load thus flowed obliquely downward from upper parts of the glacier. Tanner (1933, p. 33) has remarked that »there is nothing to compel the belief that the glaci-fluvial streams issued sub-glacially» when building the Salpausselkä belt.

When my manuscript was about ready to be sent to the printers, Professor Esa Hyyppä advised me that till had recently been encountered in the upper part of the pit (Figs. 26 and 27). On top of the washed drift there is in places a layer of till about one meter thick. At its thickest the layer measures 3 m. According to Hyyppä's information, the preferred orientation of stones of the till is from NNE to SSW. Donner (1951, p. 12) did not consider the layer of coarse surficial plateau drift as stream-laid, either. He suggested that the margin of the glacier was in a somewhat more advanced position before the formation of the channels on the top; the layer of coarse, badly sorted drift was deposited during this advance.

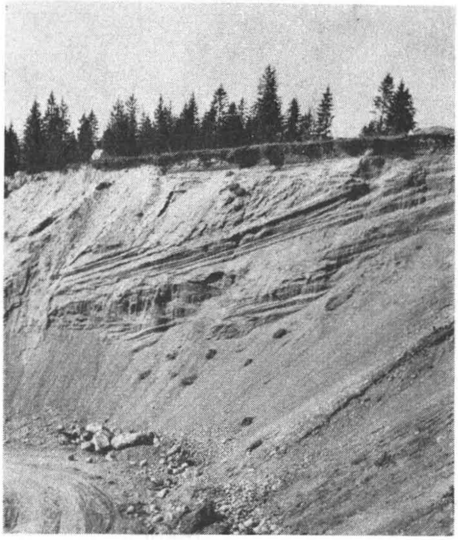


Fig. 26. In the Lahti plateau the washed drift dips in a distal direction beginning from the proximal slope, close to the right hand side of the picture. The meltwaters flowed obliquely downward from upper parts of an inactive glacier. On top of the cutting there is a layer of till. Photo: Seppo Penttilä.

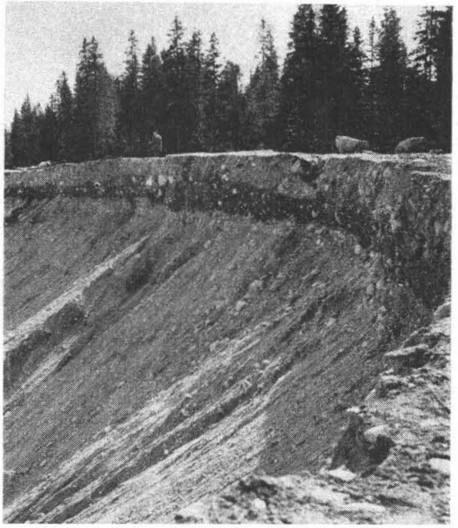


Fig. 27. Close-up of the topmost layer of till in the cutting shown in Fig. 26. The till indicates that there was a last activation of the ice margin. Photo: Seppo Penttilä.

A close study of the surficial layer in other cuttings than that shown in Figs. 26 and 27 reveals that the washed stones embedded in the layer are arranged overlappingly, as in a tile roof; the distal edges of the stones ride on top of the proximal ends of the stones situated next »downstream» (Fig. 28). This structure, common in the outwash of sandurs, shows that the material was deposited by running water. It should also be noted that the coarse surficial layers is common to almost all First and Second Salpausselkä plateaus (Leiviskä 1920, p. 242).

According to Donner (1951, p. 13), the Lahti plateau represents a marginal terrace built wholly or to a great extent of washed drift. He joins Sauramo (1940, p. 105) in regarding the plateau a glaciofluvial delta. Because the dry channels on top of the plateau can hardly be other than meltwater channels, the top of the delta is supra-aquatic, an opinion expressed also by Ramsay (1922, p. 164) and Sauramo (*loc.cit.*). Because flow along the channels must have ceased before the shore-bar could close their mouths, the shore-bar indicates the altitude of the sea level at the time and shortly after the top of the delta was built (Sauramo 1940, p. 106; 1958, p. 34; Donner, *op.cit.*, p. 15). There is a wave-cut cliff northwest of

Fig. 28. In the surficial layer of the Lahti plateau the pebbles and stones, embedded in badly sorted gravel and sand, are turned upwards downstream, to the right in the picture. The material was deposited by running water. Photo: Veikko Okko.

the Lahti plateau at the eastern end of the Tiilijärvi section (see p. 74) at an altitude corresponding to the shore-bar. This can only mean that the terminus of the glacier withdrew from the Lahti section before the end of the stage of the sea which produced the shore-bar, 150 m a.s.l. at Lahti.

The ridge located between the eastern end of the plateau and the southern shore of Lake Vesijärvi is 600 m long and runs in the direction ESE—WNW, or almost perpendicular to the direction of glacial striae north of Lahti (360°—15°). The crest of the ridge reaches an elevation of 135 m or it is 15—20 m lower than the top of the plateau. In cross-section the ridge is asymmetric in shape, as its proximal slope is much steeper than the distal slope (compare Leiviskä 1920, profile 175).

There is a cutting in the proximal part of the ridge. Beginning from the very proximal slope, layers of well-sorted sand and gravel dip 15°SSW (Fig. 29). The strike of the layers is parallel to the trend of the ridge. In the upper part of the cutting, the layers are quite undisturbed. The supply of drift at the ridge obviously occurred obliquely downward from the direction NE. At the foot of the ridge, there is a bed of till directed upwards against the proximal slope. The till is rather coarse and it also contains a number of rounded stones. Between the till bed and the layers of washed drift, there is a narrow zone of smoothly folded layers of sand. The folding was caused by a push from the northeast. Obviously the bed of till was deposited after the accumulation of washed drift had ceased.

The interior structure of the Lahti ridge is of the same type as the transverse glaciofluvial ridges (pp. 36—38) in the foreland. Accordingly,

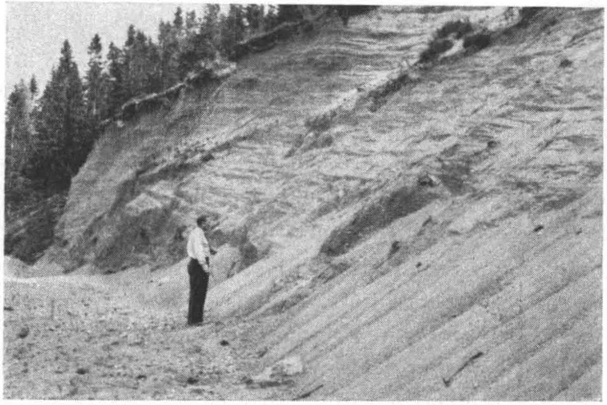


Fig. 29. Beginning from the proximal slope of the Lahti ridge, the layers of sand and gravel dip in a distal direction. At the proximal foot of the ridge there is a layer of till directed upslope. The ridge was built in front of an inactive ice margin; the till indicates a late minor oscillation.

the Lahti ridge is a terminal formation. Its geographical position shows that it is younger than the Lahti plateau. The esker was deposited either at the time the terminus began to leave the plateau or during a later oscillation [1].

At the Lahti section, the glacier unloaded mainly washed drift. Till is known to have accumulated as a relatively thin, broken layer in the western proximal part of the plateau and at the foot of the proximal ridge. The transverse glaciofluvial ridge was deposited by en- or super-glacial streams, as shown by the structure of its proximal parts. The same holds true for the western end of the plateau and also for the supra-aquatic part of the plateau with its fan of meltwater channels.

The following developmental phases are to be distinguished in the Lahti section:

1) Advance of the northern glacier (p. 28).

2) Deposition of outwash at the plateau. The glacier is rather inactive. A last ice-oscillation takes place at the plateau.

3) The margin of the glacier retreats from the plateau. Deposition of the transverse glaciofluvial ridge northeast of the plateau marks a halt in the retreat.

4) The water level of the sea lies at the 150-m-level.

[1] In the eastern part of the city of Lahti, there is a road cutting across the Salpausselkä. The distal part of the cutting consists of washed drift and the proximal part of till. The latter deposit is in a superposed position, with the border between the two being directed obliquely upwards to the south. A corresponding structure was reported by Brenner and Tanner (1930) in the railway trench dug through the First Salpausselkä for the Lahti—Heinola railway.

TIILIJÄRVI SECTION

The Tiilijärvi section comprises a 5 km long and 2—3 km wide part of the First Salpausselkä (Fig. 30). In relation to the Lahti section, the Tiilijärvi section is located in a more northerly position; a broad, short ridge links the southeastern end of the section with the Lahti plateau. In the west, the section ends up in a bedrock terrain. In the north the Tiirismaa quartzite range separates the section from the Vesijärvi lake basin.

The Tiilijärvi section is mainly built of washed drift accumulated south of the quartzite range. At the foot of the range, the glaciofluvial accumulations merge with the moraines covering the quartzite hills. Only the distal part of the section forms a continuous zone. Extensions of the fault valleys that cut the quartzite range into three blocks separate the main part of the Tiilijärvi section into partial plateaus, each lying in the shelter of a quartzite hill. Both valleys are open towards the north and drained by rivulets into Lake Vesijärvi. In the following, the eastern valley will be referred to by the name of Messilä valley; the western one is the Kiiskoja valley.

The Tiilijärvi section is located at the southern limit of the northern glacier. It was pointed out by Ramsay (1931, p. 64) and Sauramo (1958, p. 63) that during deglaciation much stagnant ice must have been left in the lee of the Tiirismaa range. Glacier tongues of the northern ice were active enough to flow over the range, excluding the highest summit, which the tongues passed at its both ends. Once thinning of the ice prevented the flow over the range, the active margin was formed at its northern slope. Owing to starvation, all the protruded ice masses on the southern side stagnated and prevented the Tiilijärvi section from becoming completely filled with drift (compare Ramsay, *op. cit.*, p. 66). The three kettle-lakes, called collectively Tiilijärvi, and the bog-filled kettle holes in their vicinity evidently represent the stagnated remnants of the ice that flowed through the Kiiskoja valley. The arcuate shape of the borders of the kettle area probably reflects the convex terminus of the tongue. Also the Messilä valley was filled with an ice tongue. It is not known whether the two tongues originally joined each other south of the central quartzite hill.

The highest shoreline of the Lahti section (150 m a.s.l.) continues westwards along the distal edge of the Tiilijärvi section. In places, the shoreline, represented mainly by a shore-bar, south of the Messilä valley by a cliff, disappears into the plateau surface, but it can still be traced to the western tip of the distal slope. In the west, the broken shoreline appears as a cliff. Owing to the length of the section, the shoreline is considerably tilted. In the east, its elevation is ca. 152 m and in the west, 156 m. The tilt amounts to 0.8 m/1 km in the direction E—W. By analogy to the Lahti

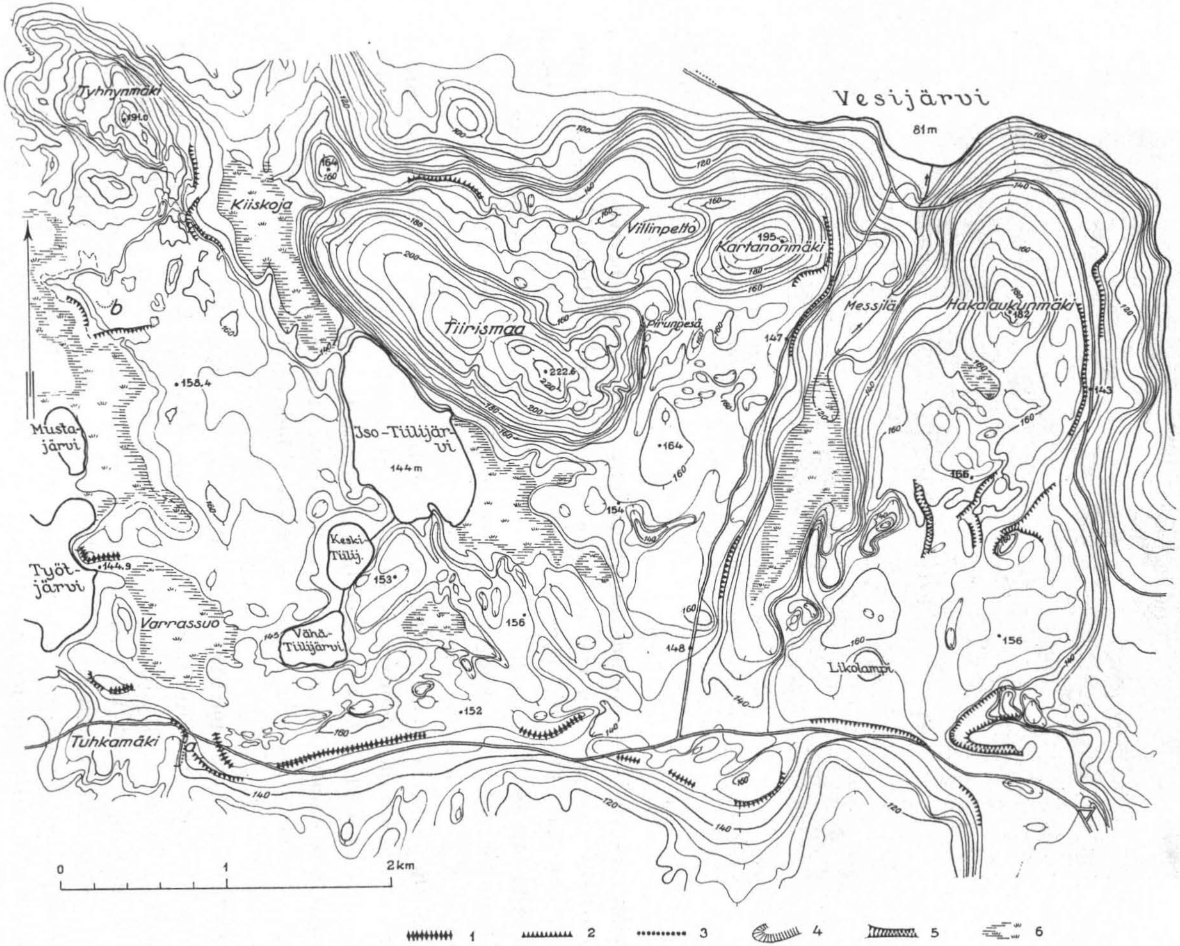


Fig. 30. Topographic map of the Tiilijärvi section of the bend of the First Salpausselkä and the Tiirismaa quartzite range. 1. Shore-bar, 2. cliff, 3. boulder rim, 4. terrace, 5. dry channel, 6. peat.

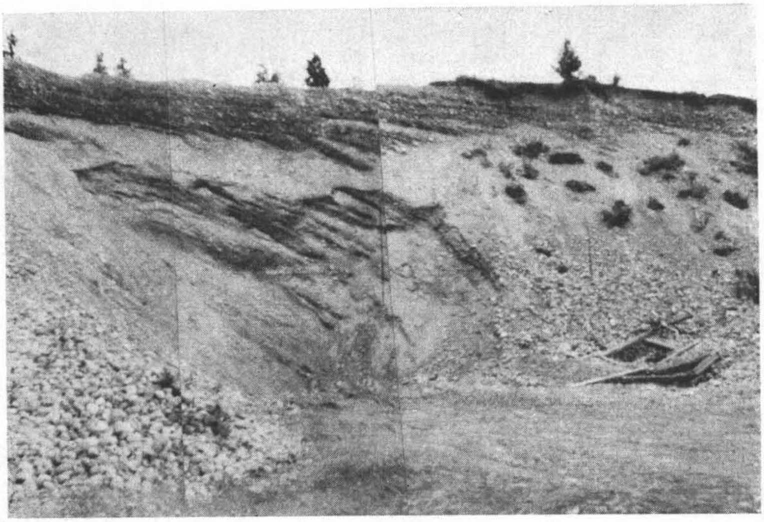


Fig. 31. Topset and foreset bedding in the distal slope of the Tiilijärvi section at Tuhkamäki; marked a in Fig. 30. The structure is thought to represent a glaciofluvial delta.

section, the distal shoreline ought to mark the border between supra- and subaquatic ground. In the proximal parts of the plateau there are a few dry channels. They begin in the moraine area, extend into the plateau, but fade out into the plateau surface far behind the distal shore-bar. It is evident, though, that the water level has hardly stood at a higher niveau than 152—156 m since the formation of the channels.

In the western part of the distal slope, in the village of Tuhkamäki, there are a couple of cuttings at different heights. In the upper cuttings, 147—154 m a.s.l., cross-bedded layers of sandy and stony gravel with embedded blocks and boulders are to be seen. The topmost layer in the cuttings consists of beach sand, deposited below the highest distal beach, 156.2 m. [1]

In the western part of the village of Tuhkamäki, there is a cutting in the lower distal slope, 140—144 m a.s.l. Distinct foreset and topset bedding is to be seen all along the 150-m-long cutting (Fig. 31). The position of the cutting is such that the structure could hardly have evolved through shore action, inasmuch as, above the cutting, there is no cliff big enough to have supplied the drift. In front of the cutting there is a washed bedrock area (150 m a.s.l.) which must have protected the slope at the cutting against strong wave action. The structure developed rather through dep-

[1] Rounded notch of a wave-cut cliff; levelling fixed at the water level of Lake Työtjärvi, 142.8 m a.s.l.

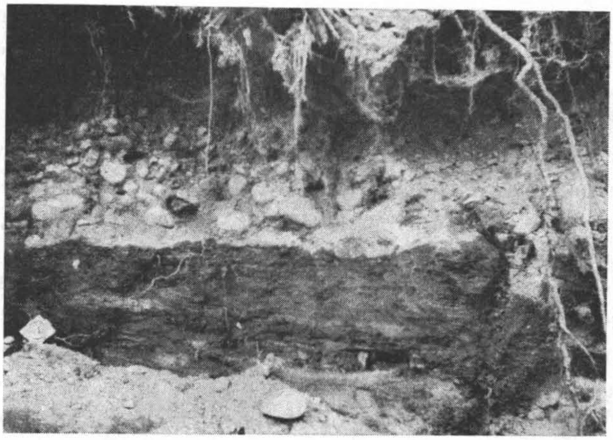


Fig. 32. In a cutting dug into the western lateral plateau of the Tiilijärvi section, marked b in Fig. 30, glaciofluvial drift is overlain by a layer of water-laid sediment and this by badly sorted shore deposits. The stratigraphy shows that there was a body of standing water in this area after the deposition of glaciofluvial drift had ceased.

osition of a glaciofluvial delta. The bedrock area helped to produce calm waters favourable to deltaic deposition. The height of the top of the delta shows that the water level reached an elevation of about 145 m during the deltaic depositionary stage.

The cross-bedded drift overlying the delta measures 9—10 m in thickness. Because the highest distal shoreline was formed in the overlying drift, the delta evidently developed at an earlier stage, when the water level of the sea stood at a lower niveau, ca. 145 m. The distal slope of the Tiilijärvi section was thus inundated by a rising sea after the delta had accumulated at Tuhkamäki. Also those parts of the highest shoreline which appear as a cliff suggest that here the beach developed in previously accumulated drift.

Signs of the highest distal shoreline are to be found at the western and eastern ends of the Tiilijärvi section. In the west, the section ends as a plateau that fills the spaces between knobs of bedrock (145—155 m a.s.l.), either washed bare or partly covered with till. The surface of the plateau (153—157 m) slopes gently westward, towards the Työtjärvi gap. The position of the plateau and the direction of its incline cause it to be called a lateral plateau.

The structure of the lateral plateau differs from that of the distal parts of the section. In the walls of a cutting, dug into the plateau at 153.5 m a.s.l., the following stratigraphic sequence is to be seen (Fig. 32): A layer of stony gravel, 0.7 m thick, covers a bed of silty fine sand containing small fragments of rock (ø < 3 cm). This bed is 0.5 m thick and overlies cross-bedded strata of sand and gravel. After the deposition of the lowermost drift, there apparently was a body of shallow water into which sedimentation of fine sand took place. As a shore-bar at the 156-m-level was found on the western slope of the section, the top layer of the lateral plateau obviously represents a terrace, which grew towards the Työtjärvi gap during the development of this shoreline.

At the eastern end of the section, Hyyppä (Donner 1951, p. 15) observed and levelled a wave-cut cliff at an altitude of 153.2—155.2 m a.s.l. In fact, this cliff occurs at the eastern slope of the eastermost quartzite hill, but traces of a shoreline at its altitude may be distinguished also in the slope of the plateau. In respect to its altitude the cliff corresponds to the highest distal shoreline and thus shows that the eastern end of the Tiilijärvi section was freed from ice before the end of the stage of the sea that produced the highest beach at Lahti plateau (compare Sauramo 1940, p. 106; Donner, *loc. cit.*; Hyyppä 1951).

The altitude of the shore marks at the northern end of the Messilä valley has been discussed every so often. De Geer (1894, p. 641) measured the height of the uppermost cliff as 152 m a.s.l., whereas Berghell (1896, p. 101) estimated it at 156 m. According to Ramsay's (1931, p. 66) levelling, the elevation of the washing limit at Messilä is 151.64 m. In his original map of the bend of the First Salpausselkä, Sauramo (1940, p. 105) marked only a wave-cut cliff at 145 m, but later on he revised his figure for the uppermost shore mark to 158 m a.s.l. (Sauramo 1958, p. 68). Because the authors, excluding Ramsay, do not state how they measured the altitude of the Messilä beach or at which altitude the levellings were fixed, it is possible that all the figures presented relate to one and the same beach.

Starting from a levelled point (147 m) indicated in the topographic map, I levelled at Messilä a wave-cut cliff at 145 m. The altitude of the edge of a narrow terrace into which the cliff is cut is 151.6—152 m. There is an upper cliff, too, the notch of which lies at 153.8 m and 152.6 m at two different observation points. According to the levellings, the cliff is tilted towards the south. The somewhat dubious washing limit might reflect the sea level, but it is as easy to regard it a stream terrace formed by meltwaters flowing between the Messilä ice tongue and the central block of the Tiirismaa range.

At the northern end of the Kiiskoja valley, there is a distinct washing limit on the slopes of both the western and central Tiirismaa hills. The altitude of the washing limit is 150 m a.s.l. [1] In comparison to the highest

[1] Levellings at three different observation points, based on the altitude of the fixed point on top of the western hill, 191.0 m a.s.l.

distal shoreline, 156 m at the western end of the section, the washing limit is clearly lower. There apparently still was unmelted ice in the Kiiskoja valley environs when the highest distal shoreline developed.

Hyyppä (1960, App. I, observation point Hyvinkää—Lahti) has found traces of erosion and washing as high up as 215—216 m a.s.l., near the highest summit of the Tiirismaa range [1]. In Hyyppä's (*loc. cit.*) shoreline diagram, these beaches arrange themselves along niveaus denoted »Carelian Ice Sea; also Ice-lakes?» Between the two tops of the central quartzite block, close to the Pirunpesä cleft, there is a broad quartzite ridge exhibiting washed bedrock at 160—200 m a.s.l. Northwest of this ridge, there is the small sandy basin of Villinpelto, mentioned by Leiviskä (1920, pp. 53—54) and Ramsay (1931, pp. 66—67). Both to the south and the north, the basin is bordered by ridges extremely rich in boulders. The elevation of the bottom of the basin is 145 m. As high up as 180 m, well-sorted littoral gravel is met on the slope towering above the Villinpelto basin. The basin probably represents a nunatak lake (Ramsay, *loc. cit.*) that discharged across the quartzite ridge at Pirunpesä (see also Donner 1951, p. 16). The embryonic pot holes in the cleft (p. 23—24) also point to stream erosion.

The bottom and the front of the cleft consist of loose non-sorted material. At the foot of the cleft a tiny pond occupies a small depression, probably formed by torrents. Southeast of the cleft a small separate plateau reaches an altitude of 164 m. Nowhere else in the Tiilijärvi section does the outwash reach such elevations. The plateau narrows towards the cleft. North of the plateau there is an area of well-developed ablation moraine, showing that here the ice melted in situ. West of the plateau, at the foot of the quartzite hill, a dry channel, some 5 m deep, leads southwards from the cleft. As I see it, the plateau was built up from the direction of the cleft, by meltwaters discharged from the nunatak lake.

The functional stages to be distinguished in the Tiilijärvi section are the following:

1. Advance of the northern glacier. Glacier tongues are pressed southward at both ends of the Tiirismaa range. Only the highest summit remains intact of the northern ice.
2. The tongues loose their connection with the main glacier and stagnate.
3. Deposition of washed drift in front of the tongues takes place. At Tuhkamäki, a meltwater stream unloads washed drift into a glaciofluvial delta. The water level is approximately 145 m. A nunatak lake evolves

[1] These data were mentioned in 1951 by Donner (p. 16), whom Hyyppä informed about his observations.

at Villinpelto, the northern slope of the central quartzite block. Plateau drift is also accumulated by the meltwaters discharging across the Pirunpesä ridge. Channels are eroded on top of the Tiilijärvi plateau.

4. The sea rises and reaches the level 152—156 m. The western and eastern ends of the section are free from ice during this stage. There is still ice left north of the western and central quartzite hills.

VESALA SECTION

The Vesala section occupies the apex of the Bend. In the direction E—W, the section is 6 km long; its width is about 4 km. The section is shown in the map of Fig. 33, opposite p. 80.

A profile was levelled across the Vesala section in the direction SSE—NNW, along the line indicated by A—B in the map. The profile is presented in Fig. 34. The levelling was begun at the bench mark 140.9 m a.s.l. on the distal slope of the section. Two shore-bars, the one at 148.1—148.9 m and the other at 154.5—157.4 m a.s.l., are encountered on the slope. The upper shore-bar marks the distal edge of a plateau 1.2 km wide along the profile line. The plateau surface rises gently towards the northwest. The material of the surface consists of stony gravel. The proportion of stones increases towards the northwest; in places, there are patches of drift rich in cobbles and stones. The surface material does not differ from that of the plateaus described in the foregoing chapters. At the depression seen in the profile at 1 800—1 900 m, marked C—D II, the profile line cuts across a large channel, which will be described and discussed on pp. 77—78.

In its northwestern part, the plateau merges with moraine terrain at 162—163 m a.s.l. The border between the two is lobate. In the border zone, the cobbles and stones of plateau drift are angular in shape, showing little signs of washing. Between the northwestward extended »fingers» of plateau drift, the accumulations of till form either low hills or small ridges. In the northwestern part of the moraine terrain, there is a chain of moraine ridges trending WSW—ENE. The crests of the ridges rise 3—5 m above the surrounding terrain. The distal inclines of the ridges are much steeper than the proximal slopes. On the distal slopes, the drift is characteristically rich in blocks and boulders. Northwest of the chain, the hitherto relatively even ground changes abruptly into knob-and-kettle topography.

The pond Ketarlampi fills the central kettle hole in a group of kettles closed by the contour line 150 m. The kettle holes occupy an area almost 1 km^2 wide. The kettles are separated from each other by ridges rich in blocks and boulders. On the slopes of Ketarlampi, drift ranging from block fields to sand is to be found. On top of the highest hills (165—168 m a.s.l.) surrounding the kettles, the drift consists of unwashed till.

Northwest of the Ketarlampi area, the differences in elevation are smaller. The highest tops consist of till. Washed stone fields and deposits of more or less sorted drift are encountered on lower ground. Here and there within the knob-and-kettle area, gravel deposits form small plateau-like portions pitted with kettle holes. In places there are stone pavements that seem to have been washed by running water.

At the edge of the proximal slope, the profile line cuts across a boulder belt 600 m long. In its WSW—ENE trend the belt is regular, but its height varies some 15—17 m. The highest point of the belt reaches an elevation of 162 m, but its southwestern end runs across a kettle hole the lowest point of which is 145 m a.s.l. Melting of the ice buried underneath the belt obviously caused the variations in height.

The proximal slope is rather steep and paved with stones at the profile line. The lower limit of the pavement lies at 131—132 m a.s.l. where the slope is bordered by deposits of sand. Mainly the proximal slope is deformed by kettle holes and channels inclined steeply down the slope. A quotation from Leiviskä's (1920, p. 47) Salpausselkä monograph gives an idea of the rough topography of the slope: »Versucht man am Rand des Steilabhangs vorwärts zu wandern so gelangt man immer in eine von Abhängen eingefasste Grube und jedesmal schiebt sich ein neues Rückenstück schräg for, sodass man immer wieder einen neuen Hügel hinaufklettern muss, um bald abermals in eine Grube zu gelangen.»

By means of the profile, the Vesala section may be divided into two distinct morphological elements: the proximal knob-and-kettle area and the distal plateau. At the border of the two elements, there is a chain of moraine ridges.

The contour lines seen in the map of the Vesala section (Fig. 33) show that the surface of the plateau does not fall uniformly in the distal direction. It undulates in a lobate manner. On top of the plateau, there are a number of dry channels, also observed by Ramsay (1931, p. 65). The channels are 1—3 m deep and 10—15 m wide. They vary in length from thirty to hundreds of meters. Many a channel merges into the plateau surface but those which extend to the distal edge are closed by the shore-bar. At a few points, there are low banks either surrounded by two channels or occurring within one and the same channel. In the western part of the plateau, the arrangement of the channels resembles a braided river pattern.

The largest of the channels is 2 km long and 60 —100 m wide. It begins south of the Ketarlampi kettle hole and extends southeastward to the distal edge of the plateau. A levelled profile of the channel bed and five cross-profiles at intervals of 500 m are shown in Fig. 34. The profile line is shown in the map of Fig. 33 and marked C—D. The levelling was begun at the fixed point 156.9 m a.s.l. close to the mouth of the channel.

At its head, the channel is cut into moraine terrain. Although not shown by the cross-profile (I), the V-shaped channel is located between two moraine ridges belonging to the chain of ridges at the border between the knob-and-kettle terrain and the distal plateau. The channel head is located some 35—40 m higher than the terrain in its immediate hinterland. The first 500 m of the channel bed is cut into till, but little by little the bed turns into gravel which contains an abundance of stones here and there (II). On the average, the upper course of the channel is 5 m deep. Farther downstream, the channel passes a moraine ridge (III), the trend of which is SE—NW. On the lower southwestern slope of the ridge, there is a washed stone pavement, some 3 m high. Southeast of the ridge, the channel, now 3 m deep, traverses a relatively even plateau area (IV). The banks are in many places rich in stones. Near the mouth, the channel is only 1.5 m deep (V). Its bottom here lies at 154 m a.s.l. At its mouth, the channel widens out but is closed by the shore-bar marking the distal edge of the plateau. The crest of the shore-bar here reaches an elevation of 157 m.

The gradient of the channel bed and the shape of its banks show that the plateau surface was fully developed at the time waters were discharged through the channel. The shore-bar obviously accumulated after the flow ceased in the channel. Ramsay (1931, p. 65) thought that in Vesala the glacier margin retreated from the Salpausselkä at the time the flow of water through the channel ended. Although it is evident that the waters derived from melting ice, it suffices to assume that the meltwaters ceased to flow across the distal plateau as soon as a discharge toward lower ground was possible, for instance, into the gap valleys.

Very little is known about the interior structure of the Vesala plateau as there are cuttings only in the distal slope. In the cuttings of the upper slope, beds of sand and gravel, inclined in the direction of the slope, are common, whereas, in the lower slope, nearly horizontal beds of sand and fine sand are encountered. The material of the slope has been redeposited by shore action.

A gravel pit has been opened across the distal edge of the western part of the plateau. The gate into the pit is dug across the uppermost shore-bar (158 m a.s.l.). In the walls of the gate, one can see that the shore-bar was accumulated on top of plateau drift. The plateau drift occurs in cross-bedded layers. In places there are thin beds rich in silty material. The topmost layer consists of coarse material, encountered also on the other plateaus. A study of the geological environs of the pit shows that the back wall of the pit cuts across a couple of dry channels, 1—1.5 m deep. Obviously the plateau drift was deposited before meltwaters eroded the channels on top of the plateau. The channels, on the other hand, are older than the shore-bar at the plateau edge since the shore-bar closes their mouths. Thus, the shore must have acted erosively at the distal parts of a plateau already present; only the shore-bar testifies to accumulative shore action.

In comparison, the distal plateau of the Vesala section and the Lahti plateau resemble each other in many respects. The material on top of the plateaus is similar in composition; there are a number of dry channels, arranged in a fan-like fashion, on both plateaus; the big channel of Vesala has its counterpart in the Lahti plateau. By analogy, the tops of both plateaus are supra-aquatic in origin. Further evidence is provided by the lobate trend of contour lines 157.5 m, 160 m, and 162.5 m, shown in the map of the Vesala section. The two plateaus differ from each other in that the Vesala distal plateau merges in its proximal parts into high moraine terrain and a large knob-and-kettle area, whereas the proximal part of the Lahti plateau is built largely of washed drift. While, in the Vesala section, the proximal slope of the Salpausselkä is located 2 km northwest of the distal plateau, in Lahti the proximal slope of the plateau is also that of the Salpausselkä.

The lobate morphology of the supra-aquatic top of the Vesala distal plateau is missing below the uppermost shore-bar (157—158 m a.s.l.). Washed drift finer in grain than sand, excluding the beach sands, are also missing from the plateau. The outer parts of the plateau must have been eroded away and redeposited in the foreland, where fine sand and silt are abundant. According to the structure and geological environs of the drift exposed in the cutting described afore, the shore at 157—158 m a.s.l. produced only the shore-bar. The erosion of the outer parts of the plateau occurred during lower stages of the sea.

The trend of the chain of moraine ridges and the morphology of the individual ridges show that they were deposited by the northwestern glacier. The trend of the moraine ridge forming the northeastern slope of the large channel along its middle course (cross-profile C—D III, Fig. 34) is perpendicular to the trend of the chain. The trend and the morphology of this ridge indicate that it was deposited by the northern glacier, probably at the limit of its maximum advance in the west. Because the ridge projects through the lobate plateau surface (Fig. 33), it is evident that the northern ice tongue wasted away from the Vesala section well before the supra-aquatic top of the distal plateau was deposited. The direction of both the lobate surface and the channels show that meltwaters flowed from the northwest. Hence, it may be concluded that the northwestern glacier acted at the Vesala section later than the northern glacier.

The proximal knob-and-kettle area of the Vesala section is 6 km^2 wide. The relief of the area is rough, the largest differences in elevation being 40—45 m, though usually 20—25 m. The deepest kettles are filled with bog vegetation or water. The contours of the kettle holes depend on the drift in which the kettles occur. In drift rich in stones and blocks, the slopes are steep and full of nooks and niches; in sandy deposits, the kettles are rather shallow and the slopes are smooth in shape. The drift is similar to that of the type locality discussed on pp. 63—65.

At or close to the proximal slope of the section, there are belts of boulders. Like the one described in connection with profile A—B (p. 77), these belts have been deformed through the melting of buried ice. The rocks occurring in the boulders are local: 70 % granites and granodiorites with or without microcline porphyroblasts, 30 % amphibolites and mica gneisses. In the immediate hinterland of the section, the ratio of rocks forming the bedrock corresponds roughly to their distribution among the boulders. Because the trend of the boulder belts is almost perpendicular to the direction of the local striae, it is suggested that they were deposited by the northwestern glacier. As pointed out by Flint (1957, p. 75), repeated slumping and sliding of drift on slopes of melting ice affords so much opportunity for washing by meltwater that much superglacial drift consists only of the coarser rock fragments originally present in the drift, the finer elements having been flushed away. The process must have been in effect when the boulder belts were deposited. The belts differ from the deformed boulder rims of raised beaches in that the highest, undeformed parts of the belts are located in a sheltered position and in cross-section they exhibit a steep distal slope, which is typical of end moraines (see profile A—B, Fig. 34).

There are two lateral plateaus in the Vesala section, one in the east, the other in the west. The eastern lateral plateau is analogous with the lateral plateau of the Tiilijärvi section, located on the opposite side of the Työtjärvi gap. Since most of the plateau is occupied by a military camp, there are numerous dug-outs showing that the surface material is the same as at the Tiilijärvi lateral plateau. In deeper cuttings, the horizontal top layer is underlain by beds of gravel and sand, which dip SE. No interbedded layers of water-laid sediments have been encountered on the Vesala side of the gap. The even surface of the Vesala lateral plateau, its incline towards the gap and its elevation 155—157 m, show that the plateau was washed by the sea at the time of the highest shoreline.

At the edge of the northern slope of the lateral plateau, there is a dry channel running from NW toward SE. Along its middle course, the channel is bilateral but its head at the slope is unilateral. The conclusion must be drawn that the northeastern bank of the channel at its head was formed by ice; otherwise a flow of water directed perpendicularly to the direction of the slope would have been impossible. Because the channel was eroded into a surface washed by the sea, there still must have been ice at the northeastern end of the Vesala section when the sea began to sink from its highest position, 157—158 m at the distal edge of the section.

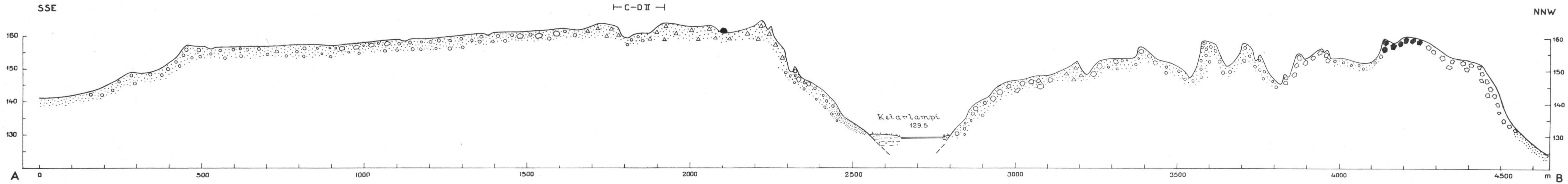
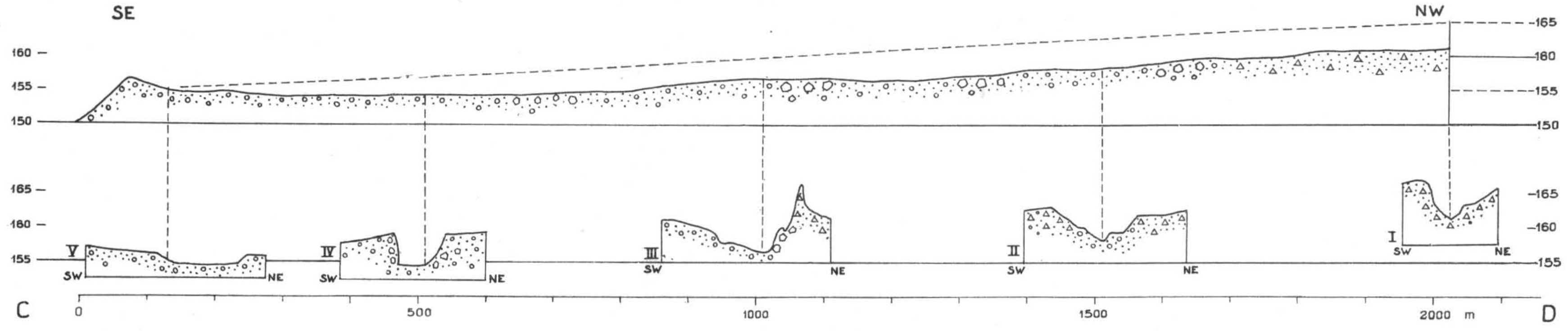


Fig. 34. Levelled profiles from the Vesala section. Profile line A—B was selected to give an average picture of the morphology of the section. The distal plateau and the proximal knob-and-kettle area are easy to distinguish. Profile C—D is the longitudinal profile of the largest dry channel running across the distal plateau. The dashed line shows the mean elevation of the surface into which the channel was cut. The five short profiles are cross-sections of the channel bed. Profile lines A—B and C—D are shown in the map of Fig. 33.



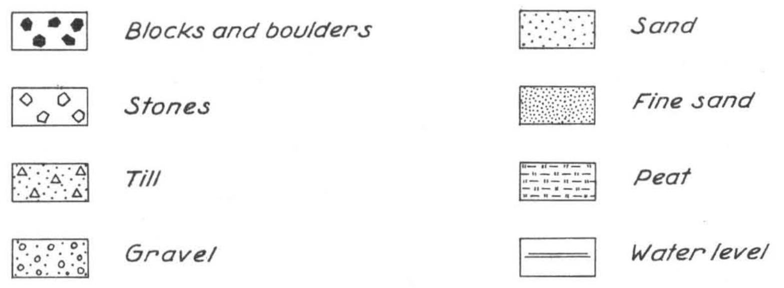


Fig. 33. Topographic map of the Vesala section of the bend of the First Salpausselkä. For explanation of the symbols see Fig. 30.

The western lateral plateau borders the Vihattu gap in the north. The plateau is analogous with the lateral plateaus facing the Työtjärvi gap. The western lateral plateau also is a terrace and shows that the sea flooded into the Vihattu gap when the shoreline at 157—158 m was formed at the edge of the Vesala distal plateau.

The following functional phases of the glacier margin may be distinguished in the Vesala section:

1. The westernmost tongue of the northern glacier advances into the eastern end of the Vesala section and melts away at a relatively early stage.
2. Accumulation of the distal plateau and the chain of end moraines in its proximal parts takes place in front of the northwestern glacier.
3. The active margin is moved into more proximal positions. Stagnated ice rich in drift is left between the active margin and the distal parts of the section. The process is repeated several times before the margin leaves the section.
4. The water level lies at an altitude of 157—158 m at the distal edge of the section. Lateral plateaus are built toward the gaps. There is still ice at the northeastern end of the section during this stage.

SAIRAKKALA SECTION

The Sairakkala section forms the northeasternmost part of the western arc of the First Salpausselkä. The section occupies an area 6 km long and and 3—4 km wide (Fig. 35). It resembles the Vesala section in many respects. A distal plateau which in its proximal parts merges with moraines and knob-and-kettle topography is to be distinguished. The drift is of the same character as at Vesala. The main differences lie in the morphology of the proximal parts of the sections. Where there is a wide knob-and-kettle area in the Vesala section, the Sairakkala section has a shallow sandy basin bordered by ridges. The proximal plateau at Hakaportti is a unique feature of the Sairakkala section.

The morphology of the distal plateau is less well developed than that of the Lahti and Vesala plateaus; yet, it is more regular than the Tiilijärvi plateau complex. In the southwestern parts of the Sairakkala plateau, there are a few channels. The largest equals in size the channels of Vesala and Lahti. It is 1.3 km long and 50—80 m wide, and its bed lies 3—5 m below the plateau surface. The channel begins in the moraine area and runs across the plateau towards ESE. The southwestern bank of the channel head forms a stony cliff, 7 m high, whereas on the northeastern side there are two banks, of which the upper one is a distinct stream terrace, tilted downstream. Evidently, the river that eroded the channel was at

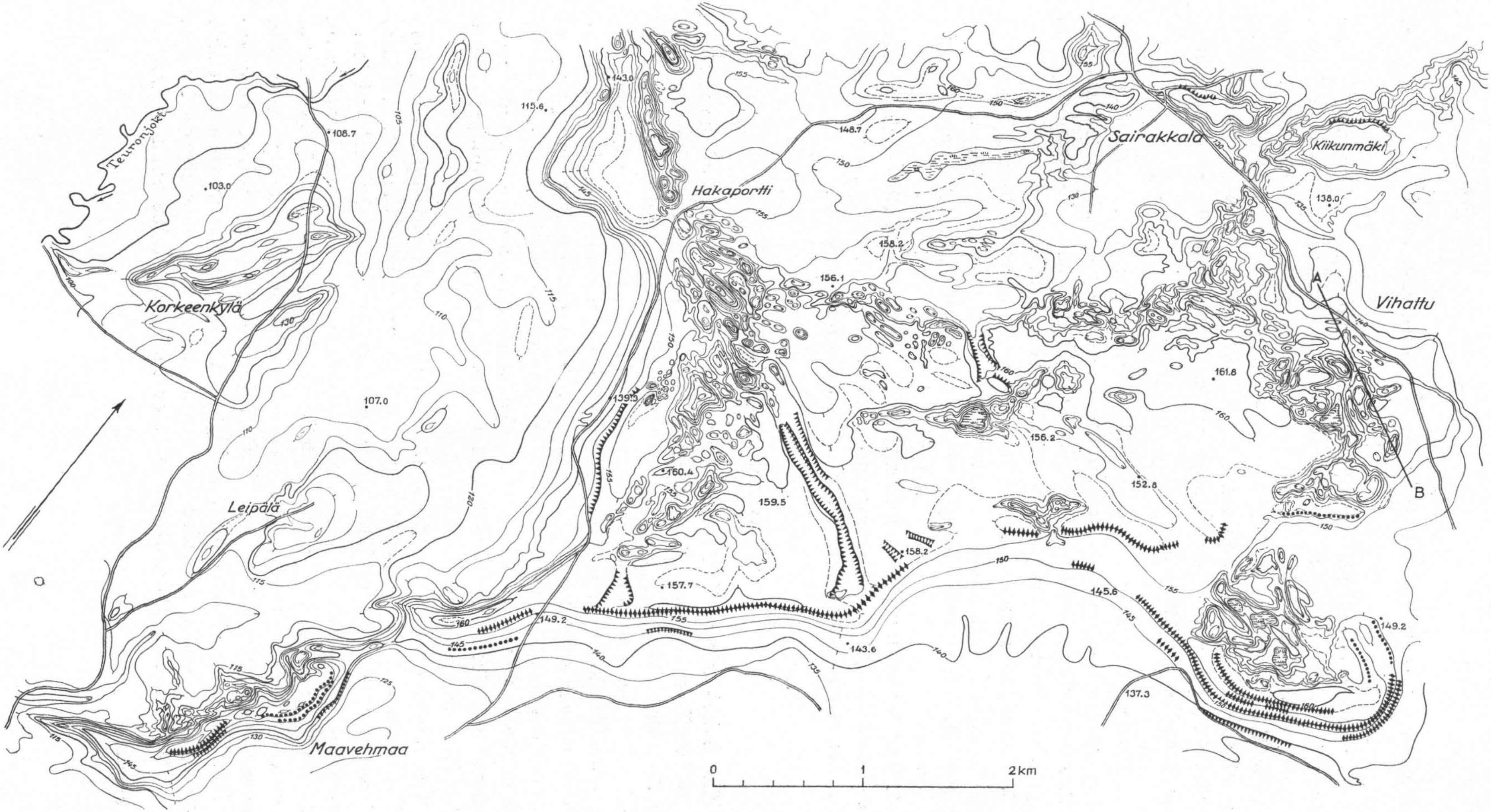


Fig. 35. Topographic map of the Sairakkala section of the bend of the First Salpausselkä and a part of the Teuronjoki valley. For explanation of the symbols see Fig. 30.

first relatively broad, but later the flow and erosive action were concentrated on the side of the southwestern bank. At its mouth, the channel is closed by the shore-bar which marks the distal edge of the plateau. The crest of the shore-bar is 157 m a.s.l.

Southwest of the large channel, there is another channel comparable in width and depth, but not in length, to the large channel. This channel begins from knob-and-kettle terrain, runs across the plateau, where it begins to narrow to form the Maavehmaa ridge, and ends up at the distal shore-bar. Two small channels are to be distinguished in the middle part of the plateau. All these dry channels show that the top of the Sairakkala distal plateau was built, like the other plateaus, above the water level in supra-aquatic conditions.

The shore-bar marking the distal edge of the Sairakkala plateau is not so continuous as that at the Lahti and Vesala plateaus. In the middle part of the Sairakkala plateau, the shore-bar disappears into the plateau surface. Here the plateau is pitted with kettle holes, 15—20 m deep. In some of the kettle holes, there is till at the bottom, overlain by washed drift; the outwash was here deposited on stagnant ice rich in till. When the ice melted, the original plateau surface sank gradually and the primary surficial features were destroyed.

The most striking break in the shore-bar at the distal edge is connected with a kettle hole. The kettle hole is located at the landward foot of the shore-bar. A gate, 5 m deep, leads out of the kettle hole. The dimensions of the kettle, 500 × 100 × 20 m, are too great to allow an interpretation of the locality as a pitted beach, known to develop in present polar climates (Nichols 1961, p. 697—701). Nor can the kettle hole have originated from melting of a stranded iceberg; the sea in front of the plateau was too shallow to allow an iceberg of dimensions corresponding in size to the kettle hole to reach the shore. The kettle hole, then, must represent stagnant glacier ice, which was buried under outwash before shore action took place in the locality. Had the stagnation occurred at the time the 157-m-shoreline developed, the thickness of the ice and its content of till could have prevented it from buoying up. Shore action, then, should have eroded the upper parts of the ice and the lower part should have extended seaward. In this case one would expect kettle topography also on the seaward side of the shore-bar. Because no such features have been found, it is probable that the sea stood at a lower level when the stagnation took place.

The relatively narrow zone of moraines and knob-and-kettle terrain occurring in the proximal part of the plateau differs only little from the corresponding formations in the Vesala section. North of the head of the largest channel, there is a moraine area the topography of which points to ablation moraine. Northwest of this area, the moraines appear as ridges scattered at varying distances from each other, their trend being uniformly SW—NE. To the south of the ablation moraine, the moraine ridges form an arc. The trend of the northernmost ridge is SE—NW; southwards the trend of the ridges turns gradually to SW—NE. The arc continues southwestwards as the Maavehmaa ridge.

The tops of the sharp-crested Maavehmaa ridge reach as high up as 165 m a.s.l. The ridge is asymmetric in shape, the proximal slope with distinct ice-contact features being the steeper one. The highest parts of the crest consist of material extremely rich in stones and boulders, all of an unwashed character. The washing limit on the distal slope lies at an altitude of 156—156.5 m or 8—9 m below the highest summits. De Geer (1894, p. 643) and Berghell (1896, p. 15—16) regarded the crest of the Maavehmaa ridge as supra-aquatic. De Geer thought that the material was accumulated by wave action above the erosion level, whereas Berghell attributed their origin to the breaking up of sea-ice in spring. Ramsay (1896, p. 2) first accepted Berghell's interpretation, but later on (1931, p. 64) he concluded that the drift on top of the ridge might have derived directly from the glacier.

On the proximal slope of the Maavehmaa ridge, there is a broad zone, 151.6—158.5 m, where there is a thoroughly washed stone pavement (compare Berghell, *op. cit.*, p. 15; Leiviskä 1920, profile 105). Below the 140-m-level, there are kettle holes, open towards NW. The material is of the knob-and-kettle type (pp. 63—65). In its relation to open sea the steep proximal slope, together with its continuation towards the NW, formed a sheltered beach, but there are no traces of shore features characteristic of sheltered beaches, such as ice-pushed stones. The pavement was produced rather as an enrichment of stones when finer-grained materials were flushed away. The pavement is probably due to washing by running water, derived from the melting glacier.

The arrangement of the moraines which border the distal plateau points to lobation of the glacier margin. In all probability, this lobation was caused by the topography of the substratum. The southwestern arc represents the terminus of the portion of ice that flowed along the Teuronjoki valley. On higher ground, the flow was retarded until the margin stagnated and began to melt *in situ*, producing the ablation moraine and knob-and-kettle topography. The position of the large channel shows that meltwaters collected into the contact of the two portions of ice flowing at different velocities.

The stagnation of marginal ice in the distal parts was followed by a retreat of the glacier margin to some position northwest of the section. The structure and stratigraphic position of the proximal ridge of the section shows that it was built in front of an oscillating margin. The ridge lies on top of a deposit of sand and fine sand at least 15 m thick. [1] The cuttings reveal that the drift forming the ridge is rather varied in character. In places, lenses of fine sand occur among boulders surrounded by gravelly till, or beds of stony gravel cemented with clayey material alternate with broken layers of fine sand. There also are portions of regular till which is richer in fine-grained constituents than the average tills of the Lahti area (see p. 58, Fig. 19).

The proximal moraine ridge continues towards NE. Here it is lower and completely buried under water-laid sediments. The morainic material of the core is marked by an abundance of blocks and boulders, probably lifted to the surface by frost action. In the moraine belt, there are two glaciofluvial ridges of which the easternmost is known by the name Kiikunmäki (Fig. 35). Their proximal slopes are steep and pitted with kettle holes. The morphology and trend of the Kiikunmäki ridges show that they are terminal formations, akin to transverse glaciofluvial ridges (p. 36). Their level tops (155 m) do not reach high enough to have been levelled down by the highest shoreline, lying 156—158 m a.s.l. in distal parts of the Vesala and Sairakkala sections, known to have reached into the Vihattu gap (p. 81) and hence to the Kiikunmäki ridges.

The thick deposit of sand and fine sand that underlies the proximal moraine ridge [2] is similar to the stratified drift filling the Sairakkala basin. The sediments are of a lacustrine facies. In the basin there seems to have been a lake located between the glacier front and the distal plateau, similar to the ice-marginal lakes developing in front of the thinning glaciers of Iceland (compare Arnborg 1955). The local advance at Sairakkala probably set in at a late stage of the development of the ice-marginal lake. The convex arrangement of the proximal ridges suggests that the glacier margin was lobate. The varied material of the proximal ridges indicates both ice-push and meltwater action.

In the southwest, the proximal moraine ends close to the point where the esker of Koski begins. The ridge appears as short crests projecting through washed drift; the trend of the southwesternmost moraines is W—E. The ridge merges here with the northwestern slope of a proximal plateau. In the map, the Hakaportti plateau is triangular in plan. At its northwestern corner, the slopes of the plateau turn so as to run parallel, marking the beginning of the Koski esker. The southern corner of the plateau triangle forms a bulge in the southwestern slope of the section, toward the Teuronjoki valley. The northeastern corner of the triangle merges with

[1] Information obtained from a local well digger.
[2] Information supplied in October 1962 by a highway construction foreman on the basis of excavation works proves that also the western Kiikunmäki ridge overlies a thick bed of fine-grained sediments.

the sediments of the Sairakkala basin. The elevation of the plateau is 155—160 m. Its summit, which is divided into two parts by a kettle hole 1.3 km long, rises gently towards NW. There are no dry channels on the top.

A cutting dug into the northeastern part of the Hakaportti plateau reveals the following stratigraphic sequence: A top layer, 3 m thick, consisting of rather poorly sorted washed drift overlies a bed of silty fine sand, which measures 30 cm in thickness; underneath the latter bed, there is a bed of stratified sand dipping towards SE. The intermittent layer of fine sand provides further evidence that an ice-marginal lake existed in the Sairakkala basin. By analogy to the cutting in the Tiilijärvi lateral plateau (p. 73), the top layer is a terrace that grew towards the basin. The funnel-like shape of the Hakaportti plateau suggests that the washed drift was supplied by meltwaters which collected into a river already in the glacier and discharged their load at the mouth of the river. Furthermore, the absence of dry channels shows that the level plateau surface was controlled by the water level of the sea. The Hakaportti plateau is thus a true glaciofluvial delta. An ice wall must have bordered the delta also from the Teuronjoki valley. In fact, there is an end moraine swarm in the valley, at Korkeenkylä (see Fig. 35), the position of which corresponds to the neck of the funnel-shaped plateau. The height of the Hakaportti delta agrees with the highest shoreline at the distal edge of the Sairakkala section, 156—157 m. The slope bulging towards the Teuronjoki valley obviously is the brink of the delta, built into deep water.

The Hakaportti delta was formed into an estuary of a lobate glacier margin. It may be noted that the delta is located in the same zone as the large channel of the distal plateau, which was also formed between two lobes. The contact between the ice of the Sairakkala section proper and of the Teuronjoki valley also marks the southwestern limit of the plateaus forming the bend of the First Salpausselkä.

Because the glacier margin conformed to the topography of the substratum, it must have been relatively thin when building up the Sairakkala section. The following functional phases of the glacier margin are to be distinguished in the Sairakkala section.

1. Glacier ice becomes stagnated in the area now occupied by the Sairakkala section.

2. The distal plateau and the moraines in its proximal part are deposited. Plateau drift covers stagnated ice. The margin is lobate.

3. Stagnation of marginal ice on high ground. The active margin is moved to some position northwest of the section. Sedimentation of sandy and silty drift takes place in an ice-marginal lake.

4. A last advance of the glacier margin takes place. The delta at Hakaportti, the proximal moraine ridge, and the transverse glaciofluvial ridges are deposited. During this stage, the lobate glacier margin ends in the sea and the water level reaches 156—160 m around the Sairakkala section.

GAPS IN THE BEND

TYÖTJÄRVI GAP

The Työtjärvi gap is located between the Tiilijärvi and Vesala sections. In the north and the east, the gap is bordered by exposed knobs of bedrock projecting through the lateral plateaus of the neighbouring sections. At the northern end of the gap, the westernmost Tiirismaa hill (191.0 m a.s.l.) towers above the surrounding ground. The gap opens towards the north through a narrow passage at the western foot of the hill. The gap valley is filled with bog vegetation, lakes and ponds. The valley widens out towards the south but is closed by a ridge extending between the two sections. The crest of the distal ridge rises towards the west; at the Tiilijärvi section its elevation is 146—147 m and at Vesala section 155—156 m. The eastern part of the section is seen in Fig. 30 (p. 71) and the western part, including the distal ridge, in Fig. 33 (opposite p. 80). A map of the southern part of the gap has been published by Donner (1951, Fig. 9, p. 37).

The lowest parts of the gap valley are occupied by lakes. Borings executed by Donner (*op.cit.*, p.46—47) prove that the bottoms of Lakes Työtjärvi and Mustajärvi consist of detritus mud underlain by fine sand rich in humus. The elevation of the sandy bottom deposit is 136 m at Työtjärvi and 139 m at Mustajärvi. A similar sediment covered by bog vegetation extends to the northern end of the gap. Here the altitude of the bottom of the bog is 144.5 m.

The distal ridge of the gap used to dam up the waters of Työtjärvi (compare Tigerstedt 1888, p. 12), but, at the turn of the century, the water level was lowered by digging a canal across the ridge. The artificial threshold of the lake (142.8 m) lies about 2 m lower than the bottom of the gap in the north.

In an area as extensively filled with both unsorted and washed glacial drift as is the bend of the First Salpausselkä an »empty» gap could hardly have evolved otherwise than by being occupied by ice (compare p. 70). The glacial striae observed in the environs of the gap (Fig. 5, p. 21) show that the westernmost tongue of the northern glacier reached into the gap area, including the easternmost part of the Vesala section. The tongue extended to the southern border of the arcuate knob-and-kettle area of the Tiilijärvi section (p. 70), to the distal ridge of the Työtjärvi gap, and to the moraine ridge met NE of the large channel of the Vesala section (p. 79). When thinning of the ice exposed the western quartzite hill the protruded tongue stagnated. Deposition of drift was prevented and a gap evolved where there had been masses of dead ice.

The terminus of the tongue withdrew from the Vesala section before the top of the distal plateau was built (p. 70). The shore marks at the western end of the Tiilijärvi section and the lateral plateaus bordering the gap (p. 73, p. 80) show that the sea extended into the gap valley when the highest Salpausselkä beach was formed, at an elevation of 156 m at Työtjärvi. In other words, at this time the stagnant ice had largely melted from the gap. As there still was ice at the northern end of the neighbouring sections (p. 74, p. 80), there was in the gap a bay, open towards the south, during this stage. The two lateral plateaus inside the gap are thus terraces built on a sheltered beach. Their material, however, must mainly have been supplied by the glacier.

In the gap valley there are raised beaches on lower levels than the 156-m-shoreline: 149—150 m, 146 m, and 144.5 m a.s.l. The 150-m-beach has its counterparts both on the distal slopes of the Salpausselkä and on the slopes of the western Tiirismaa hill. All through this stage of the sea there was a sound in the Työtjärvi gap extending across the Salpausselkä. The 146-m-beach also has its counterparts outside the gap. During this stage, the gap formed a shallow bay, which was connected with open sea in the north. There might have been a very shallow inlet to the bay over the lowest part of the distal ridge. When the sinking sea passed the 144.5-m-level, the gap became isolated from the sea (compare Donner 1951, p. 54). The beach at the elevation of 144.5 m corresponds to the water level of Työtjärvi before its artificial lowering.

Waters have collected into the gap since the melting of the stagnant ice. This is shown by a number of channels which cut across the three upper shorelines. Mainly the waters derived from the melting of ice buried in the drift of the sections.

The distal ridge of the Työtjärvi gap is covered with fine sand. The walls of the canal dug across the eastern end of the ridge show that the core consists of poorly sorted stony gravel with subangular stones. Westwards there are no cuttings. A number of typical moraine boulders are scattered on both sides of the ridge. Since the boulders are not arranged on any raised beach but occur irregularly, they seem to be, at least to a great extent, original material of the ridge, possibly lifted to the surface by frost action. In all probability, the distal ridge is a terminal formation.

In the middle part of the distal ridge, there are three short channels running perpendicularly across the crest (see Fig. 33). The channels are inclined towards the south and open at both ends. They are 3—5 m wide and 2—3 m deep. Their bottoms lie at different heights, i.e., 150, 149, 148 m a.s.l. The slopes and bottoms are covered with the same sort of sand as covers the whole ridge. Obviously, the channels were eroded by waters running out from the gap. The water level of the sea must thus have lain at an altitude of 148 m or lower when the channels were eroded across the ridge. As no features point to a high water level inside the gap since its isolation (see also Donner 1951, p. 54), the channels must have evolved before the sea reached its highest level, indicated by the 156-m-shoreline. Only during a previous lower stage of the sea had the meltwaters deriving from the stagnant ice been able to collect behind the terminal ridge and to discharge across it. The tongue of the northern glacier should thus have ended in shallow water or on dry land. Also the glaciofluvial delta at Tuhkamäki, Tiilijärvi section (p. 72), with its distinct topset and foreset bedding, points to standing water situated at a lower niveau than the highest Salpausselkä beach. By inference the highest shoreline indicates the maximum limit of a transgression of the sea. The distal terminal ridge was submerged during the transgression and the sands covering the ridge were probably deposited when the shoreline moved over the ridge.

The following developmental phases of the Työtjärvi gap may be distinguished:

1. Advance of the westernmost tongue of the northern glacier
2. Stagnation. Meltwaters discharge across the terminal ridge in front of the stagnated tongue.
3. The sea is in a transgressive stage. It extends into the gap (156 m), where most of the stagnant ice has melted.
4. The sea sinks. The gap first forms a sound across the Salpausselkä, then a bay, open northwards, and is finally isolated at an altitude of 144.5 m. After the isolation, the lakes in the gap develop independently.

VIHATTU GAP

The Vihattu gap is a sandy valley located between the Vesala and Sairakkala sections. The trend of the distal part of the valley is S—N and that of the proximal part E—W. The turn in the trend is quite sharp, as shown in the index map (Fig. 17). The eastern side of the valley is seen in Fig. 33 and the western and distal parts in Fig. 35.

In its northwestern part the gap valley ends at the transverse glaciofluvial ridge of Kiikunmäki, Sairakkala section, described on p. 85. The rivulet that drains the gap valley runs past the southern end of the Kiikunmäki ridge and joins with the rivulet draining the Sairakkala basin. Originally, the gap was separated from the Sairakkala basin by a little ridge with a core of ice. Remains of this ridge now form a short chain of esker hills with ice-contact features (see Fig. 35).

The level top of the Kiikunmäki ridge falls gently northeastwards and merges into a sandy area at the western tip of the Vesala section. The elevation of this area is 142—143 m. It forms the northern threshold of the gap.

The bottom of the gap valley rises gently in a distal direction. The sandy deposits of the valley bottom are quite thick. In a few places, it is to be observed that the sands were deposited on top of morainic deposits. In the central part of the valley, two knobs of bedrock project through the drift.

The distal ridge of the gap forms a southeasterly bulge in the distal slope of the Salpausselkä (Fig. 35). The crest and the distal slope consist of sand, somewhat coarser in grain than the sediment of the valley bottom. In the middle part of the ridge, the crest is 162 m a.s.l. Westwards it becomes lower and merges at an altitude of 153 m into the distal slope of the Sairakkala section. Beginning at its highest point, the crest turns in its trend northwards, its northern end being directed towards the gap. The lower distal slope continues northwards and merges with the distal slope of the Vesala section. At the point where the two slopes meet, there is a short, round-crested ridge with an elevation of 147 m.

North of the highest part of the distal ridge, and right behind it, there is an area, 1 km^2 wide, heavily pitted with kettle holes 15—25 m deep (Fig. 35). In the eastern part of the area, the kettle holes occur in sand and in the western part, in gravelly plateau drift. The outwash of the Sairakkala distal plateau extends here into the Vihattu gap.

On the southern slope of the distal ridge, there are raised beaches at the following altitudes: 141 m, 147 m, 151 m, and 158 m a.s.l. [1] The uppermost beach is represented by a shore-bar which limits the highest part of the crest. The shore-bar is about 1 km long. At both ends, it turns towards the gap. In altitude, the shore-bar corresponds to the shoreline marking the distal edge of the Sairakkala and Vesala sections. The beach at 151 m is also a shore-bar. It continues westwards into the distal slope of the Sairakkala section, but northeastwards it disappears in lower ground. The 147-m-beach is continued both in the Sairakkala and Vesala sections. The beach is broken only at the lowest part of the distal ridge, where there are short bars scattered diagonally on its top.

[1] The elevations are based on levellings started from a fixed point 135.5 m a.s.l. at the foot of the distal ridge.

During the stage of the sea that produced the shoreline at 158 m, the sea reached into the Vihattu gap. At the distal end of the gap, there were two inlets at both ends of a narrow longshore bar. In the deeper inlet at the Vesala section, a shore terrace was accumulated towards the gap, shown by the westward dip of the beds of terrace drift exposed in a large cutting. The mechanical composition of the terrace drift was described on p. 62. At its bend, the gap valley is bordered by lateral plateaus the height of which was controlled by a water level at 158 m (p. 81). The Kiikunmäki ridge might also have been deposited during this stage of the sea (p. 85). The sea reached here to the glacier margin.

When the sea level began to sink, the inlet between the Sairakkala section and the Vihattu distal ridge soon became shallow and rose from the sea. The 151-m-shoreline is seen as a shore-bar accumulated 2 m below the western inlet. Inside the gap, cliffs, reaching an elevation of 151—152 m, were eroded into the lateral terraces. In the hinterland there are raised beaches and washing limits at altitudes corresponding to the 151-m-beach of Vihattu, which shows that the glacier had retreated from the Sairakkala and Vesala sections when this shoreline developed. The Vihattu gap, like the Työtjärvi gap, formed a sound across the Salpausselkä during this stage.

When the sea had sunk to the 147-m-level, there was a shallow bay in the gap. The bay was open towards the northwest through the inlets at both ends of the Kiikunmäki ridge. The sheltered position of the bay probably is responsible for a good share of the thick deposits of sand at the bottom of the gap valley. A submarine ridge had accumulated across the inlet between the distal ridge and the Vesala section. The short, scattered shore-bars on top of the ridge were now built by highwater waves. Because there are no lake sediments in the gap, the valley rapidly became dry, aided by the permeable sands forming its bottom.

On the slopes of the gap valley, there are a few steeply inclined channels leading from the knob-and-kettle areas of the neighbouring sections into the gap. They cut across the shorelines of 158 m and 151 m; the relation between the channels and the 147-m-beach is less distinct.

The elevation of the level surface of the kettle area located at the distal end of the gap, is 147—150 m. In relation to the shorelines at 151 m and 147 m, the pitted area was located in the littoral zone during these stages of the sea. In these conditions, the kettle holes should have become filled with beach sand. Hence, it may be concluded that the kettle holes evolved after the gap had risen from the sea.

Sauramo (1940, p. 105; 1958, p. 67) thought that the Vihattu gap, or Sairakkala channel, as he referred to it, is analogous with the large channel of the Lahti plateau. Sauramo (*loc.cit.*) surmised that the large quantities of water discharged from the glacier at the esker of Koski flowed along the gap valley into the sea. The plateau channels and the gap cannot, however, be analogous land forms. The channels are closed by the uppermost shore-bar, whereas at Vihattu the sea extended into the gap. Nor is it likely that abundant meltwaters flowed through the gap valley. Because the bottom of the gap rises southeastwards the meltwaters should have flowed under hydrostatic pressure in order to discharge in the southeast. It is also unlikely that glacial striae would have been preserved on the outcrop in the middle of the gap valley had abundant, load-carrying meltwaters run swiftly over the bedrock surface. The ice core of the little chain of esker hills, located between the gap and the Sairakkala basin, could not have remained uneroded in river conditions. Furthermore, the meltwaters deriving from the esker of Koski, and from the Hakaportti delta, did not discharge through the Vihattu gap, as shown by the stratigraphy of the delta: at the time the top of the Hakaportti delta was deposited, there was a body of standing water in the Sairakkala basin (p. 86). The terrace at the inlet between the Vihattu distal ridge and the Vesala section was accumulated from the east, i.e., from the sea. River action would have prevented such accumulative shore action.

A good amount of dead ice was needed to bring about the development of the kettle area at the distal end of the gap. If the gap is understood to be a dry channel, it is too shallow to have allowed transport of the amount of ice to be buried into the deposits at its mouth. Had the waters discharged under hydrostatic pressure, dead ice might have developed at the mouth of the tunnel, but only features relating to different stages of the sea are to be observed in the gap.

A river theory is not applicable in explaining the development of a gap between two large plateau complexes. The trends of both the distal and proximal parts of the gap cut diagonally across the glacial abrasion in this area, 320°—340°. Because the present trend of the valley is largely due to the lateral plateau which was built towards the gap during the highest water level (p. 81), it is probable that deposition of glacial drift into the gap was prevented by its being filled with ice. The distal ridge of the gap must be understood to be a terminal ridge and the kettle area behind it to have evolved through melting of the remains of the stagnated marginal ice. In all probability, the knob-and-kettle area at the northeastern end of the Sairakkala section reflects another portion of the stagnant ice mass (see Fig. 35). The ice that occupied the Vihattu gap must have largely melted before the 158-m-shoreline could develop in the gap. A correlation to the Työtjärvi gap, as far as melting of the ice and the stages of the sea are concerned, is distinctly to be noted.

As pointed out by Hyyppä (1951), occurrences of kettle topography in extremely distal positions presuppose dry land or shallow water during the stagnation of the glacier. The stagnant margin should begin to float and waste down by calving if it ends in deep water. The convex shape of the Vihattu distal ridge suggests that the glacier which stagnated at this limit was lobate and did not end in very deep water.

At the Työtjärvi gap, stagnation was brought about through thinning, which exposed a high hill in the substratum (p. 88). In the hinterland of the Vihattu gap, the topography is opposite to that of the Työtjärvi area. Where there is a hill at Työtjärvi there is a depression at Vihattu, namely the lake basin of Sairakkalanjärvi (see relief map, Fig. 2, p. 15). Owing to thinning, the glacier flow was retarded in the marginal zone, which, conceivably, was located on higher ground than the ice masses in the hinterland. Finally, the marginal zone stagnated. The stagnant ice began to melt, but, in those parts that either contained much debris or were buried under drift deposited on top of ice, the melting was delayed. The active margin was moved to the hinterland basin, where the glacier was able to flow.

From this it follows that the 158-m-shoreline marks the limit of a transgression that took place after the melting of stagnant ice in the gap had proceeded to the point where only the buried ice had not melted. The transgression in the Työtjärvi gap occurred under similar conditions. The distal ridges of both gaps were covered by sand when the shoreline moved over the ridges. The sandy crest of the distal ridge of the Vihattu gap probably does not give the original height of the ridge; the crest is a longshore bar which accumulated during the transgression of the sea.

The following developmental phases are to be distinguished in the Vihattu gap.

1) Thinning of the northwestern glacier brings about a stagnation of the marginal zone. The ice begins to melt.

2) The transgressive sea floods into the gap. At the northwestern end of the gap, the sea reaches the glacier margin where a transverse glaciofluvial ridge (Kiikunmäki) is deposited.

3) The sea sinks. The gap forms a sound across the Salpausselkä when the 151-m-shoreline develops. When the shoreline at 147 m develops, there is a shallow bay, open towards the northwest. Finally, the gap rises from the sea and rapidly dries up. The stagnant ice buried under glacial drift and littoral sands begins to melt.

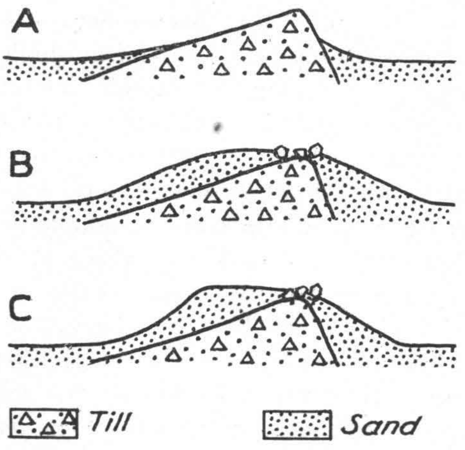


Fig. 36. Sketches showing morphological features of moraine ridges covered by water-laid fine-grained sediments, based on cuttings and morphology of the Leipälä end moraine in the Teuronjoki valley. It may be concluded that rows of blocks and boulders on top of fine-grained sediments indicate moraine ridges hidden under the sediment cover. Frost action is responsible for lifting up the boulders.

TEURONJOKI VALLEY

In the Teuronjoki valley deposits of sand, silt, and clay are predominant. Occurrences of till and washed drift are sparse. The Maavehmaa ridge which forms the southwestern extension of the Sairakkala section marks the distal zone of the First Salpausselkä in the valley. Beginning from the southwestern end of the Maavehmaa ridge Salpausselkä appears as low parallel ridges built of washed drift. Four kilometers SW of Maavehmaa Salpausselkä disappears from the landscape. The interruption is 12 km long.

The northwestern glacier was lobate when building the Sairakkala section. The Maavehmaa ridge accumulated in front of that portion of ice which flowed along the Teuronjoki valley. The margin then retreated. There was a halt in the retreat at Leipälä (Fig. 35, p. 82), 2 km NW of Maavehmaa. An end moraine was accumulated in front of the margin. The Leipälä ridge is 1 km long; its trend is SSW—NNE.

In its northern part the Leipälä end moraine is characteristically asymmetric showing a steep distal and gently inclined proximal slope (Fig. 36 A). Here the crest reaches its highest elevation, 125 m a.s.l. The Leipälä ridge is a good example of an end moraine buried under fine-grained sediments. In its middle and southern parts the end moraine is completely buried under fine sand. The crest is round and both slopes are equally inclined. Only a row of blocks and boulders shows the location of the crest of the moraine (Fig. 36 B). In places the cover of fine sand accumulated mainly on the proximal slope giving the cross-section an asymmetry opposite to that of the original ridge (Fig. 36 C). The blocks and boulders of till were in all probability lifted up to the surface by frost action (compare, for instance, Vilborg 1955). The same explanation was given for the boulders on the distal ridge of the Työtjärvi gap and the proximal moraine ridge of the Sairakkala section.

At Korkeenkylä (Fig. 35, p. 82), some 4 km NW of Leipälä, there is an end moraine swarm comprising 10 ridges. The ridges are 100—500 m long and they rise 5—10 m above the surrounding ground. The swarm is located on a hill. The spaces between the ridges being filled with fine sand it is not known what kind of material the hill consists of. The swarm is located at an altitude of 115—135 m.

The general trend of the swarm is SW—NE. The individual ridges and the distal foot of the swarm are arcuate, showing that the terminus of the glacier was convex downstream. When constructing positions of the terminus the plotted lines meet the Sairakkala section at the neck of the Hakaportti delta (p. 86). The Korkeenkylä swarm forms thus the proximal part of the Salpausselkä in the Teuronjoki valley.

At the southwestern end of the Korkeenkylä swarm there is a ridge built of washed drift. The ridge is 400 m long; its round crest rises 15 m above the surrounding ground at 100 m a.s.l. In cross-section the ridge is symmetric. The drift is rather poorly sorted. The pebbles and stones are subangular in shape and covered with a film of dirt (Fig. 37) showing that the washing was not at all thorough. The stratified drift, its layers dipping SE, i.e., outwards from the glacier, points to meltwater action. There was not, however, water enough to sort the drift well (compare Matisto 1961, p. 34). Instead, there was abundant discharge of meltwater at the Hakaportti delta the top of which rises 45 m higher than the crest of the Korkeenkylä ridge. Hence it may be concluded that meltwater action in the bottom of the Teuronjoki valley was rather weak the strongest action having been concentrated to the contact of two portions of ice, the one occupying the valley, the other moving towards the Sairakkala section.

During the deposition of the Hakaportti delta the water level of the sea reached 160 m. The lowest Korkeenkylä ridge lies ca. 60 m below that water level. In the Teuronjoki valley the glacier thus ended in rather deep water. The glacier must have flowed at a great velocity in order to

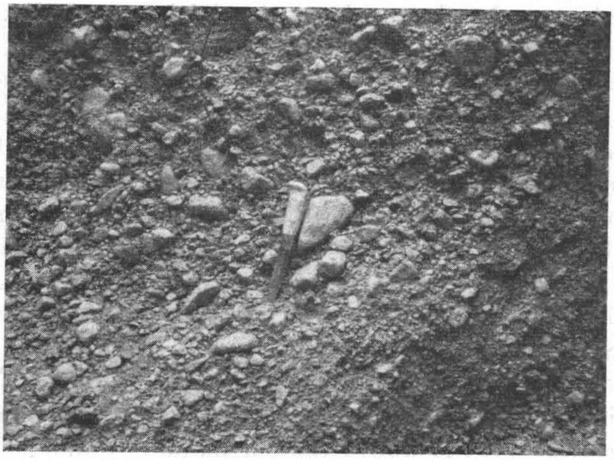


Fig. 37. Stratified drift consisting of subangular stones and pebbles forms the lowest-lying ridge of the terminal formations at Korkeenkylä, Teuronjoki valley. Meltwater action was here rather weak. A film of dirt covers the pebbles and stones.

compensate for the loss of ice at the terminus and to maintain the relatively stationary position of the margin forming the southern side of the estuary of Hakaportti.

As seen in the relief map (Fig. 2, p. 15), the northwestern part of the Teuronjoki valley runs NW—SE. It borders here on the high bedrock area of Miehola. The Korkeenkylä moraines are located at the point where the valley widens out towards the south. It is likely that in the narrow part of the valley the ice acted like a tongue developing lateral as well as frontal pressure. Because the terminus ended in deep water, it was not able to advance in the wide part of the valley but began to waste by calving. Accordingly, the Korkeenkylä end moraines should be washboard moraines *sensu* Hoppe (1957, p. 5). The lowest ridge, built of washed drift, apparently is a frontal deposit. Thus, the Korkeenkylä ridges developed in a combination of frontal and washboard processes.

Summing it up: In the Teuronjoki valley, three terminal formations occur in the First Salpausselkä belt. The southeasternmost ridge at Maavehmaa was built at the time the distal part of the Sairakkala section was deposited. The northwesternmost terminal formation, the Korkeenkylä end moraine swarm, was built at the time the Hakaportti delta and the proximal moraine ridge formed in the Sairakkala section. At that time, the depth of the sea was at least 60 m at Korkeenkylä.

REVIEW

Of the results presented in the chapters dealing with the sections and gaps of the Bend, the observed transgressive character of the highest shore is of importance. The evidence for a transgression is mainly found from the Työtjärvi and Vihattu gaps. Additional data are provided by observations made at the Tiilijärvi, Vesala and Sairakkala sections. The Tuhkamäki cutting in the Tiilijärvi section (p. 72) shows that here deposition of outwash took place into standing water the level of which was lower than that indicated by the highest Salpausselkä shoreline at the distal edge of the section. The thick deposits of cross-bedded outwash overlying the delta structure show that there is a distinct time interval between the low stage and the high stage of the sea. The latter is the younger one. In the large cutting dug across the distal edge of the Vesala plateau (p. 78), it is seen that the highest shoreline formed at a pre-existing plateau, also evidenced by the cliffs marking this shoreline in the Tiilijärvi section. In the Sairakkala section, the highest shore-bar was deposited on top of dead ice buried under plateau drift (p. 83). Had the Sairakkala outwash plateau been built as a marginal delta, preservation of dead ice at its distal edge should have been improbable during the high stage of the sea. Thus, the highest shoreline indicates here, too, the height of the maximum limit of the transgression.

The distribution of the beaches formed at the transgressive shoreline shows that the sea reached to the glacier margin in the gaps and in the lake basin of Vesijärvi, north of the Lahti section. Deposition of the outwash plateaus and flow of meltwater across them had ended when the maximum of the transgression was reached. Thus the transgressive shoreline was synchronous at the distal plateaus. The synchroneity is, of course, restricted to the distal plateaus.

In 1951 Hyyppä presented the idea that the Salpausselkä as a whole was built in supra-aquatic conditions and was inundated during a later transgression. With the provision that the highest First Salpausselkä shoreline, 150 m at Lahti, marks the highest limit of inundated land, the results on the low stage of the sea and the subsequent transgression are in accord with Hyyppä's views.

The distal plateaus were built prior to the maximum of the transgression. It is not known how low the sea was. At Tuhkamäki the maximum height was about 145 m (p. 72) and at the Työtjärvi gap 148 m or less (p. 89). The records on foreland sediments give an estimate close to 122.5 m at the foot of the Vesala section (p. 43). Possibly the latter figure gives a rough estimate for the lowest stage of the sea, the others being heights relating to a stage preceding the transgression. At any rate, the distal plateaus were deposited in water shallower than that indicated by the highest shoreline. Thus, the distal plateaus may be understood to be sandur fields.

The sandur fields of the Bend differ at least in two respects from the present sandurs of Iceland (Sundborg 1954; Icelandic topographic maps, scale 1:100 00, published by the Geodetic Survey, Copenhagen, were also used for a comparison) and also from the glacial valley trains of Swedish Lapland (Hoppe and others 1959): 1. The gradient of the surface of the Salpausselkä sandurs is smaller; 2. measured outwards from the glacier front, the Icelandic and Swedish sandurs are much longer in relation to the width. On the other hand, the valley trains of the Norwegian Ra-formation have a gradient (Andersen 1960, pl. 5) comparable to the Salpausselkä sandurs.

The small gradient of the Salpausselkä sandurs probably depends on the regionally even surface of the Finnish peneplain (see Tanner 1938, Fig. 3, p. 16; Bauer 1939, Tafel I). Although the topography of the bedrock often is very rugged in detail relief, regionally these features cannot affect the gradient of the ripe sandur. The slope of the substratum is too gentle to have favoured development of steep inclines in large fields of outwash. The width of the Salpausselkä sandurs probably compensates for the low gradient, i.e., on a regionally almost horizontal substratum, deposition of outwash occured along a long glacier front.

As particularly distinct in the Vesala sandur an outer part consisting of drift finer in grain than the plateau drift is completely missing. Calculating from the levelled profiles of the large Vesala channel (Fig. 34, opposite p. 80), the plateau drift carried away from the channel amounts to 500 000 m^3. The coarse drift ought to have been deposited in front of the channel if the river ended in water reaching the level of the mouth. The map (Fig. 33) shows that there are no features in the slope indicating the least remains of such a delta. Obviously, the transgression of the sea was responsible for destroying the outer parts of the sandur. The rising shoreline re-sorted and reworked the outer deposits, spreading them as sands over a large area in front of the Bend. The shoreline formed during the maximum of the transgression now borders the remains of the sandurs.

In the behaviour of the ice sheet, there are some differences between the northern and the northwestern ice. In the action of the northern glacier, two functional phases may be distinguished: the active phase, characterized by a strong advance, and a passive phase, during which stagnation and glaciofluvial action predominated. The passive stage was interrupted in the Lahti section by a late minor advance. The glacier margin is known to have pushed forward east of Lahti, but the functional changes east of the Lahti area are out of the scope of the present paper.

Oscillations were characteristic of the behaviour of the northwestern glacier. Signs of an early stagnation are to be observed in the Sairakkala section and the Vihattu gap. The stagnation was followed by an activation of the glacier margin. End moraines and sandur fields were built. This phase is to be distinguished also in the Vesala section. Eventually, the glacier became passive again. Thinning of the ice caused repeated stagnation of the marginal zone on the high ground at the Vesala section but resulted in a retreat of the margin from the Sairakkala section, where the ground was lower. The last activation of the glacier margin was felt at Sairakkala as an advance to the proximal zone of this section. The transgression of the sea reached its maximum at the time of the last ice oscillation at Sairakkala.

The First Salpausselkä was built largely in supra-aquatic conditions at its bend in the Lahti area. There are sub-aquatic parts, too, namely, the lateral terraces, the transverse glaciofluvial ridges in the proximal parts and the proximal plateau of the Sairakkala section. There still was ice north of the Tiilijärvi and Vesala sections when the peak of the transgression was passed. By and large, the First Salpausselkä in the Lahti area had been built before the transgression inundated all but the tops of the sections. The abundance of dead ice and washed drift in the Bend points to a temperate glacier margin (compare Okko 1957 a).

HINTERLAND OF THE FIRST SALPAUSSELKÄ

In the hinterland of the Bend, the distribution of surficial deposits is rather irregular. The Miehola bedrock area and the rocky terrain north of the Vesala section resemble the bedrock areas of the foreland: a partly washed moraine mantle covers the elevated bedrock and the valleys are filled with fine-grained sediments. Northwest of the Sairakkala section the surficial deposits, mainly fine sands, are exceedingly thick. Terminal formations project through the sediment at two localities. Three radial eskers begin from the Salpausselkä in the Lahti area.

The deglaciation of the Bend can be discussed only in terms of glacial accumulations in its immediate hinterland. An interpretation of their mode of origin ought to throw light upon the behaviour of the retreating glacier margin.

TERMINAL FORMATIONS

There are two end moraine swarms in the immediate hinterland of the Sairakkala section. Both are oriented SW—NE. The smaller swarm contains six end moraines. It is located at the proximal foot of the Salpausselkä. The ridges rest on ground moraine. The tallest ridge, 300 m long, 10 m high, and oriented towards NNE, forms a branch of the Sairakkala proximal moraine ridge.

The larger swarm, comprising 16 end moraines arranged into four chains, is located on a hill. The moraines project through deposits of fine sand. The top of the sand lies at an altitude of 140 m. The end moraines are 100—200 m long and 2—10 m high. Their arrangement within the swarm is similar to that of the foreland swarms (p. 31). Rows of blocks oriented SW—NE occur on top of the sandy sediment, indicating that there are end moraines on lower ground, too (compare Fig. 36 B, p. 94).

At the southern end of the Kutajoki peninsula, north of the Tiirismaa range, there is a ridge oriented W—E, or perpendicular to the trend of the northern abrasion. The crest of the 500-m-long ridge (100 m a.s.l.) rises

10 m above the clay fields on its southern side. The distal slope is quite steep. The proximal slope is gentle as it merges with ground lying 5 m higher than the ground in the south.

In the pits of the proximal slope, a surficial layer of sand overlies badly sorted drift of the type described from the Korkeenkylä area in the Teuronjoki valley (p. 95). In the distal slope, the drift is better sorted but very rich in subangular stones. No ice-contact or pushing features are to be seen in the cuttings.

North of the Tiirismaa range, the ground falls towards the lake basin of Vesijärvi, which is divided into two parts by the Kutajoki peninsula. The incline of the substratum must have expedited the melting of ice. At the southern end of the higher ground forming the peninsula, the retreat of the margin probably was somewhat retarded, whereupon the ridge was built at the terminus. No other terminal formations have been met on the peninsula. The retardation was thus of minor importance and the glacier wasted away from the lake basin without further delays.

RADIAL ESKERS

There are three systems of radial eskers in the hinterland. Two of them are located in the area of northwestern glacial sculpture and are, correspondingly, oriented SE—NW. The third esker is located at the border between the northwestern and northern abrasion. This esker is sinuous but generally oriented SSW—NNE.

Of the two northwesterly eskers, that of Koski, which begins from the Hakaportti delta of the Sairakkala section, has been described by Leiviskä (1928, pp. 16—29, pl. III) in considerable detail. Tigerstedt (1888, p. 67) described briefly the chain of small esker hills and ridges which extends from the village of Sairakkala to the Palomaa manor, SE of Lake Pääjärvi. In the present paper, this chain will be called the Hatsina esker chain.

The esker of Hollola begins from the Vesala section. Leiviskä (1920, pp. 47—48, profiles 115—116) described the southern part of the esker as far as the parochial village of Hollola. At Hollola the hitherto S—N trending esker turns northeastwards.

THE ESKER OF KOSKI

In the relief map (Fig. 2, p. 15) the esker of Koski is seen as a ridge extending from the Sairakkala section to the northwestern corner of the map. Along its southeasternmost stretch, some 3 km long, the esker traverses low ground. The southwestern slope faces the Teuronjoki valley, its foot lying at an altitude of 120 m a.s.l. The river bed lies 25—28 m lower. The northeastern slope faces a round depression, the bottom of which lies at an altitude of 112—115 m a.s.l. This depression is drained by a rivulet which runs in a deep, narrow valley across the esker into the Teuronjoki. The fall of the rivulet is 15 m in the esker zone.

The crest of the esker is 155 m a.s.l. at its southeastern end; it lies roughly 5 m lower than the neck of the Hakaportti delta. In the central part of the ridge, the crest rises to an altitude of 157 m, to fall back to the 155-m-level close to the transverse valley mentioned in the foregoing. The crest and slopes down to the 135-m-level are heavily pitted with kettle holes.

The esker continues northwestwards on the other side of the transverse valley. The southwestern slope faces the Teuronjoki valley but the northeastern slope merges with thick sandy shore deposits surrounding a moraine-clad hill. The esker is marked by kettle topography, which is totally missing from the shore deposits. The highest shore marks on the hill are a terrace on the northern slope and a shore-bar on the southern slope. The elevation of the foot of the terrace is 156.0 m and that of the crest of the shore-bar is 156.8—157.0 m. [1] The tops of the esker reach the same height, although two small ones are as high as 160 m a.s.l.

The general tilt of the crest along the part of the esker which is located within the Lahti area proper is 0.25 m/1 km towards SE. At two points, the crest is higher than allowed by the calculated tilt. According to Sauramo (1958, p. 107), the height of the Koski esker was controlled by the sea level, which stood at a niveau 5 m lower than the highest Salpausselkä shoreline. The tilt of such a shoreline, measured in the direction SE—NW, is about 0.8 m/1 km, or much steeper than the tilt of the top level of the Koski esker. In comparison to the steeply inclined synchronous Salpausselkä shoreline, the crest of the esker should represent a metachronous niveau.

Sauramo's (1928, p. 14; 1934, p. 33) presupposition that esker niveaus may be regarded as representative of contemporaneous water levels was criticized by Leiviskä (1928, p. 147) whose criticism was based upon observations of the present erosion of eskers that emerge from the sea along the coast of the Gulf of Bothnia, where the land uplift is strong (Leiviskä 1907, pp. 95—96; see also Sauramo 1926, p. 36). Hellaakoski (1934, p. 11), too, took a stand in the matter, regarding the top levels of eskers as too vague to be relied upon when fixing the tilt of a sealevel.

There are no beaches in the close environs of the Koski esker whose elevation would fulfil Sauramo's claim of being 5 m lower than the upper-

[1] Levelling based on bench marks 144.5 m and 143.3 m a.s.l.

most shoreline of the First Salpausselkä. Only the washing limit on the moraine-clad hill points to shore-action close to the top level of the esker.

The main feature in the geologic setting of the Koski esker, as far as the Lahti area is concerned, is its role as a direct continuation of the Hakaportti delta. In the discussion on the development of the delta, it was concluded that the delta was built in an estuary formed by two glacier lobes. The lobe which filled the Teuronjoki valley during the Korkeenkylä—Hakaportti phase behaved like a glacier tongue. Once the flow became insufficient to maintain a balance at Korkeenkylä, the tongue must have wasted away by calving in the deep valley. If the delta theory of esker development (De Geer 1897) is applied, the Koski esker should have been deposited at a time when the glacier on one side was wasting away rapidly by calving. In these conditions, the time limit allowed for deposition of the amount of washed drift represented by the esker is so short that esker development according to the delta theory can hardly be accepted. Correspondingly, the development of the esker does not necessarily have to be related to a given sea level.

Nor can the esker have been built into a radial crevasse in the way Repo (1957, p. 153) thinks the North-Karelian eskers developed. The glacier tongue in the Teuronjoki valley could not have moved independently if a relatively stationary crevasse existed along its one side. Filling of the terminus at Korkeenkylä also means filling of a lateral crevasse.

The consequence of the foregoing is that initially the southeastern part of the Koski esker evolved in or under the glacier. The estuary at the Hakaportti delta having been formed in the contact between two lobes moving in topographically different areas, the lobes probably moved independently from each other at different velocities. In the contact, there evolved tensions which caused the opening and closing of cracks and crevasses repeatedly (compare Okko 1945, p. 46). Also the gradient of the surfaces of the two lobes culminated in the contact zone. Because surficial meltwaters flow in the direction of the gradient (Brenner 1944, p. 14), the contact zone provided a place for meltwaters to collect from both lobes. The funnel-like shape of the Hakaportti delta shows that the waters collected into a river in the glacier itself. The river obviously ran in the contact zone, unloading its burden both at the bottom of the tunnel and at its mouth. Because of friction against the ice walls, the velocity of meltwater must be slowed down in a tunnel; therefore, deposition in a tunnel is quite possible. Findings of en- and subglacial eskers in present glaciated areas (e.g., Todtmann 1960, 1961) confirm this view.

The abundance of ice-contact features in the esker and the delta indicate that, in the process of deposition of washed drift in the tunnel and at the mouth, ice was buried in the drift. Eventually the tunnel was filled with drift, which was finally laid at the bottom of the glacier as melting and erosion proceeded. Meanwhile, the tunnel was widened upwards and the river bed consisted of previously laid drift (compare Todtmann 1960, p. 57). The controlling body of water at the outlet of the river determined only the growth of the delta. It is impossible to estimate the original height of the top of the esker. Once the esker was freed from the glacier, shore action set in to erode the crest. When the buried ice melted, most of the primary surficial structures were demolished.

HATSINA ESKER CHAIN

The Hatsina chain of esker hills is quite different from the continuous esker of Koski. The 6-km-long chain begins from the eastern end of Lake Sairakkalanjärvi (App. I). It is located on the main watershed which separates the waters running towards the Gulf of Bothnia from the waters discharging through Lake Vesijärvi into the Gulf of Finland. Northeast of the watershed, at a distance of 1 km, there is a parallel chain of minor ridges, which joins the Hatsina chain in its middle part. West of Sairakkalanjärvi, there are wide deposits of fine sand covering glaciofluvial hills and areas of distinct ablation topography.

The southeastern member of the chain is taller than the other esker hills; its crest reaches the height of 156 m a.s.l. The hill is pitted with kettle holes. In a cutting dug into the northern slope, it is to be observed that the esker hill is built of stony gravel. The stones are subangular in shape, pointing to short transport (compare Matisto 1961, p. 34).

The heights of the esker hills range from 140 to 147 m a.s.l. The lowest hills are covered up to the summit with fine sand, which also fills the spaces between them. In a number of cuttings, it is to be seen that there are still lower accumulations of esker drift completely buried under fine sand.

Some of the ridges of the chain run perpendicular to the general trend of the chain. The structure of these ridges resembles that of transverse glaciofluvial ridges as the layers dip towards SE, or towards the distal direction, beginning from the proximal slope.

The morphology and structure of the Hatsina esker chain as well as its geologic environment point to kames topography. Here the glacier probably was almost stagnant and loaded with drift. The drift became sorted and washed when the ice melted. The structure resembling of transverse glaciofluvial ridges, met in parts of the chain, does not necessitate the assumption that they were deposited at the terminus of the melting glacier. They might as well have been washed down into crevasses of the stagnated glacier (compare Virkkala 1961, p. 239).

The trend of the Hatsina chain of esker hills and ridges is parallel to the direction of glacial abrasion in its vicinity. Therefore, the chain has been treated under the caption of Radial Eskers. Although the chain occurs as a narrow, sinuous zone, like normal eskers, it mainly originated as kames. Regardless of how far the stagnation of the glacier had proceeded, glaciofluvial action and washing was strong in the area covered by the esker hills and ridges of Hatsina.

THE ESKER OF HOLLOLA

The esker of Hollola begins at the eastern end of the proximal slope of the Vesala section. The southern end of the esker is buried under the shore deposits covering the Vesala proximal slope. The esker rises from the shore deposits as a distinct ridge. In its trend it is sinuous. The southern part, which consists of a ridge 2 km long, runs in a smooth curve towards NNW. At its highest, the ridge reaches an altitude of 145 m a.s.l., and it ends up as a round esker hill with steep slopes. The esker starts 400 m farther to the north. Here it consists of a low ridge trending NE and of two round esker hills. This group ends up at the shore of Lake Vesijärvi. Next, the esker is met with about 1 km farther north where it forms a low cape into Vesijärvi. On the opposite shore, at the northwestern end of the Kutajoki peninsula the esker is encountered again. At the northern end of the peninsula, it occurs as two islands and, finally, it continues from the eastern shore of Vesijärvi towards NNE.

The southernmost ridge of the Hollola esker is located at the western border of the valley which leads down from the Työtjärvi gap. The slope facing the valley is steeply inclined, whereas the western slope is more gentle as it merges with bedrock terrain; the outcrops are 30 m higher than the valley bottom on the other side of the esker.

There are abundant kettle holes in this ridge. The effect of the ice-contact is also seen in the interior structure of the esker. Signs of slopeward slumping as well as slumping in small kettle holes is to be seen in a gravel pit. The slumping occurred along straight planes and in a few places the relative magnitude of sliding along the planes may be measured: 15—20 cm. In the pit, there is also a distorted block of glacial clay occurring close to the shore deposits of the slope. The direction of the push which incorporated the sediment with esker drift cannot be determined. The block was probably transported into the esker during an oscillation of the ice margin.

The esker of Hollola is located close to the border between the northwestern and the northern glacial abrasion, within the area of northwestern abrasion; yet, the trend of the esker conforms with the direction of northern abrasion. Obviously, the contact between the two glaciers, flowing at an angle towards each other, formed a culmination zone, where meltwaters collected. The trend of the esker suggests that the waters carrying the washed load derived to a great extent from the northern glacier. This condition is easily understood when recalling that the western end of the northern ice was very thick. The gradient of the thick margin must have been directed also towards the neighbouring ice, producing a culmination zone of the gradients as well as a culmination zone of flow. The more steeply inclined marginal portion of ice must have produced more meltwater than the lower ice.

Because the Hollola esker traverses quite varied topography, it seems that its development was solely determined by the culmination zone between the two glaciers. The mechanism by which the esker grew must be left undiscussed, because the data available are too scanty to give a reliable basis for discussion.

WATER-LAID SEDIMENTS

The sediments of fine grades occurring in the hinterland are mainly composed of fine sand and silt. Varve clays are met on the shores of Vesijärvi, in the valleys of the bedrock area north of the Vesala section, at the bottom of Lake Sairakkalanjärvi and in the Teuronjoki valley.

The deposits of fine sand have been mentioned in several connections in the preceding chapters. They are probably very thick as they cover end moraine ridges and swarms of end moraines as well as esker hills and ridges, almost up to the summit. Only the highest ridges and hills project through the sediment cover.

In many cuttings, the sediments show graded bedding, but unstratified fine sand and silt are also present. In places the unstratified variety contains fragments of rock (ø < 3 cm). When mapping the distribution of the two types of sediments, it was observed that the stratified variety is far more common than the unstratified type. The latter occurs in a random manner. The relations between the two varieties could be established when a cutting was dug into a low ridge belonging to the parallel chain of the Hatsina zone of esker hills. The stratigraphic sequence observed in the cutting is

122.8 — 122.0 m	Unstratified fine sand rich in silt. The content of rock fragments increases downwards
122.0 — 121.5 m	Graded beds consisting of a silty top and a sandy base
121.5 m —	Cross-bedded gravel and coarse sand.

A corresponding sequence was met at another locality, too, but there the contact between the two varieties was indistinct.

The stratified, graded sediment is of the usual type deposited by melt-waters discharged into the sea outside the glacier. The relative coarseness of the sediments shows that they were deposited rather close to the glacier. Later on, unstratified fine-grained sediments were deposited on top of the graded beds. Because there are reasons to assume that the unstratified deposits are of eolian origin, deposited by the wind into the sea, they will be discussed together with other eolian deposits (pp. 109—113).

EARLY PHASES OF DEGLACIATION

The final retreat of the ice sheet from the First Salpausselkä belt was not a simultaneous event in different parts of the belt. It is known that the margin had withdrawn from the Lahti section before or during the transgression which produced the highest Salpausselkä shoreline (p. 97). It will be shown in the chapter on raised beaches that the Miehola bedrock area, too, was deglaciated before the maximum of the transgression (p. 123). The glacier margin still stayed in the proximal parts of the Salpausselkä along a stretch extending from the Tiirismaa quartzite range to the Teuronjoki valley during the high stage of the sea.

It is fairly certain that, in spite of the transgression, the ice was able to remain at Salpausselkä because it was sheltered from the sea by the large frontal deposits. Only the glacier tongue in the Teuronjoki valley was exposed to the sea, but here the flow was strong enough to compensate for the loss of ice caused by the sea.

During the First Salpausselkä substage, the glacier margin had developed a topography of its own. North of the Tiirismaa range, it had grown in thickness already during the advance of the northern glacier. The melting of the thick margin was, of course, a much slower process than the melting of the thinner parts. In all probability, the eastern part of the margin of the northwestern glacier also had grown relatively thick to counteract the pressure of the northern ice. The contact zone, aided by the natural slopes of the margin, collected meltwaters. The Hollola esker was built into this zone.

Also the Koski esker developed into a contact between two ice lobes. Whereas, on the Hollola esker, waters collected at the border between two ice lobes flowing at an angle towards each other, on the Koski esker the waters collected in the contact of two lobes flowing parallelly but at different velocities. The Koski esker was formed in and under the ice. When the esker was freed from ice, the Teuronjoki tongue wasted away rapidly.

Sheltered by the high esker and the frontal Salpausselkä deposits, the ice lying NE of the Koski esker melted much slower. Around the Hatsina esker chain, the ice melted mainly *in situ*. The arrangement of the Hatsina esker hills and ridges as well as their internal structure show that the drift was washed into cracks and crevasses of dead ice.

The mode of deglaciation, as indicated by hinterland deposits, was determined by the topography of the ice margin and its substratum. Initially the retreat was due to a negative balance in the regimen of the ice sheet.

EOLIAN DEPOSITS

Three occurrences of eolian deposits have been recorded from the First Salpausselkä (Lumme 1934, pp. 14, 18, appended map). One of these is an occurrence of dunes met on the distal slope of the ridge which closes the Vihattu gap from the south, described by Leiviskä (1920, p. 49). On the sandy slope, however, only traces of ancient beaches are to be seen (compare Fig. 35, p. 82). Leiviskä either was mistaken in his interpretation of the slope or misplaced his observation of dunes during writing of his Salpausselkä monograph. An occurrence of fossil dunes in the Sairakkala basin, 3 km WNW of the slope in question, indicates an error in stating the location of the dunes.

The dunes are situated in the southern part of the Sairakkala basin. In the map of Fig. 35 the location of the Sairakkala dunes is shown by the contour line 150 m, where it forms deep curves trending SW—NE. The foot of the dune area is 148—150 m a.s.l., while the crests of the tallest dunes reach an altitude of 157—158 m. The dunes are thus located slightly below the highest shoreline, 160 m a.s.l. at Hakaportti. The fine-grained, water-laid sediments of the Sairakkala basin reach to the foot of the dune area. In the southeast, a narrow belt of hilly sand deposits separates the dune area from the proximal moraines of the Sairakkala sandur.

The dune area is oriented SW—NE, but the orientation of the individual dunes deviates from the general trend. The crest and both slopes of the dunes consist of sand, the median diameter (d_{50}) of which is 0.13—0.18 mm (cumulative curves 1 and 2 in Fig. 38). The shape of the dunes is too indistinct to allow an estimation of the direction of the wind which built them.

Because dunes connected with outwash plains are rather common elsewhere, it is strange that their occurrences at Salpausselkä are so scarce. In northern Finland dunes have been encountered in connection with glaciofluvial plains (Tanner 1915, pp. 372, 380, 529, 533). Similar dunes are also met in northern Sweden, where they occur in an area limited by the highest local shoreline and the fine-grained, water-laid sediments (Lundqvist 1943, p. 144). This is the case also at Sairakkala. According to Granlund (1943, p. 87), this manner of occurrence depends on the abundant availability of beach sand rich in grains of a size suitable for transportation by the wind. Granlund (*loc.cit.*) further thought that shoreline displacement towards lower niveaus interrupted the accumulation of dunes. According to Cooper's (1935, p. 108) studies in the Mississippi valley, lowering of the groundwater table in sand areas suffices to start the development of eolian sand. He also connects the process to shoreline displacement. An application of Cooper's conclusions to an area of vast accumulations of washed drift leads to the result that a lowering of the sea level, which causes a lowering of the groundwater table, should start, not interrupt, the forming of eolian sand, provided that the eolian sands are not of the coastal type. Because coastal dunes are absent from the Salpausselkä, the development of the Sairakkala dunes has its source in other factors than changes in water level.

Wright (1961, p. 948) suggests that the occurrence in Europe of late-Pleistocene eolian deposits may be related to the distribution of glaciofluvial plains, strong winds, and the absence of forest cover. On a small scale, as in Sairakkala, the three prerequisites were also needed. Glaciofluvial plains, represented by the sandurs, deltas and terraces of the Bend, with sorted beach sands on the slopes, provided the deflation surfaces.

An absence of forest cover is fairly certain. Donner (1951, p. 56) established that at the bottom of the Varrassuo bog (Tiilijärvi section) fine sand transported by the wind became incorporated with peat, dated Younger Dryas (*op.cit.*, p. 44). The drying up of the Varrassuo bog took place shortly after the shoreline occurring 10 m below the highest beach fell to lower niveaus. In their relation to the shorelines, measured from the synchronous highest beach, the Sairakkala dunes and the Varrassuo peat are located at corresponding altitudes. It then follows that the dunes and the peat were formed during a tundra period; in other words, the development of the dunes may be referred to a tundra climate. Moreover, Vasari's (1962, p. 126) phytopaleontological studies in northeastern Finland show that the climate of the Younger Dryas period was there of a dry continental type. If this was the case also in southern Finland, as suggested by Okko (1957 a, p. 39), the dryness together with the absence of forest cover facilitated eolian action.

The occurrence of dunes in the Sairakkala basin suggests that there might be other sands of eolian origin, as well. Microscopic studies of sieved samples proved very useful in the tracing.

The layer of sand which covers the ablation moraine of the Sairakkala section (p. 83), south of the dunes, was found to have been transported by the wind. The identification was made by comparing the roundness, frosting and black mineral content of grains of the 0.6 to 0.074 mm grade in

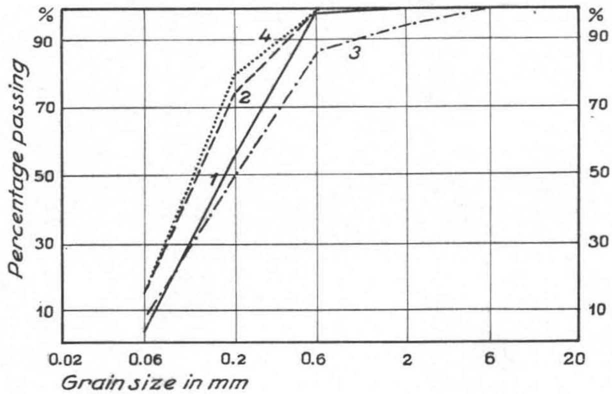


Fig. 38. Cumulative grain-size diagram illustrating the mechanical composition of eolian drift. 1—2. Dunes in the Sairakkala basin — 1. crest and 2. slope of a dune — 3. coversand on top of the Sairakkala distal plateau, 4. well-sorted beach sand, used for comparative microscopic study.

two samples of dune sand, in the sample to be identified (Fig. 38, curve 3), and in a sample of indisputable beach sand taken from a beach situated some 35 m below the highest shoreline (Fig. 38, curve 4). On an average, the grains of beach sand were very angular in shape and the majority of those of the three other samples sub-rounded (Shepard and Young 1961, p. 199). Under the microscope, it was observed that in the 0.6 to 0.2 mm grade, almost all the grains in the dune sand measured close to 0.2 mm in diameter, whereas in the two other samples the whole range was represented. In contrast to the clear grains of beach sand, the grains of the three other samples showed distinct frosting features. The following table shows the distribution of light and black minerals and rock fragments observed in the grain counts.

	1	2	3	4
Light minerals	79	91	93	87 %
Black minerals	12	5	2	11 %
Rock fragments	9	4	5	2 %

(1 = dune sand, crest, 2 = dune sand, northwestern slope, 3 = eolian sand to be identified, 4 = beach sand)

In beach sand the black minerals were flakes of mica, whereas in dune sand two thirds of the black minerals were amphiboles. The relatively high content of black minerals and rock fragments in sample 1 of dune sand may

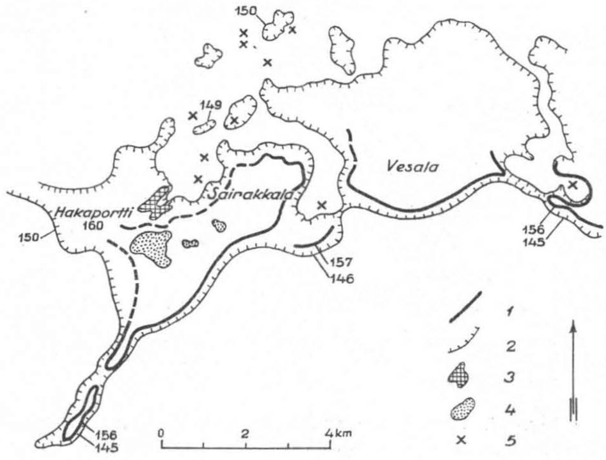


Fig. 39. Distribution of eolian deposits in the Lahti area. 1. Highest First Salpausselkä shoreline, 2. shoreline forming a 10 m lower niveau, 3. Sairakkala dune area, 4. coversand, 5. unstratified silt and fine sand of probable eolian origin.

represent a lag concentrate caused by wind transport (see Shepard and Young, *op.cit.*, p. 210). The resemblance between sample 2 of dune sand and the sample to be identified (3) is striking.

On top of the Sairakkala sandur, there are patches of sand which were also transported by the wind. Other occurrences of eolian sand were not found by the method of identification described in the foregoing.

The main difference between samples 2 and 3 is the manner of occurrence of the sample material. The latter occurs as a coversand without any wind-drift forms. Possibly this sand was deposited in niveo-eolian depositionary conditions (see C.H. Edelman 1951), i.e., in the tundra climate snow also played a role together with the wind.

In the chapter on the water-laid sediments of the hinterland (p. 106), it was noted that some cuttings reveal on top of the stratified sediments a layer of silty fine sand containing fragments of rock (ø < 3 cm). All the occurrences were found below the level of the highest shoreline, mainly 15—25 m below it. Okko (1957 b, pp. 21—22) has described similar sediments from the Lammi area, NW of Lahti area, in the zone of the Second Salpausselkä. He concluded that the sediment is eolian in origin. The rock fragments which do not belong to the eolian facies were incorporated into eolian sand deposited in water. Hörner (1927) described eolian silt in the Brattfors area, Sweden, and there, too, the subaquatic silt contains rock fragments. As pointed out by Hörner (*op.cit.*, pp. 153—154) the circumstance that a shoreline forms the boundary between the two types of silt does not indicate that they were transported by a different agent. Although further studies are needed to establish with some certainty the origin of the silty sand with rock fragments, the interpretation by Hörner and Okko is accepted for the present study.

The distribution of eolian deposits, laid both on dry ground and in water is shown in the sketch map of Fig. 39. The two critical shorelines are also indicated in the map. As shown in the map, the Sairakkala dunes occur on the shore of a sheltered bay. Their position and orientation suggest that they were deposited by northwestern winds. Sand and silt were available in an abundance in the northwestern part of the Hakaportti delta.

The winds which build dunes need not be prevailing winds because strong occasional winds whose direction allows an easy access to the supply area are also effective in building dunes (Flint 1957, p. 178). It seems certain, however, that at least southern to eastern winds were not the prevailing winds of the time of eolian action. In relation to the distal slope of the Salpausselkä from Vesala to Sairakkala, these winds would have been onshore, capable of piling up the drifting sand into dunes.

RAISED BEACHES

METHODICAL CONSIDERATIONS

Certain rules were followed when levelling the altitudes of the raised beaches. When a distinct notch was to be observed at the foot of a wave-cut cliff, the levelling staff was placed as precisely as possible at the notch (see Brander 1934, pp. 44—45). The notches are not often preserved but tend to be rounded, especially when occurring in washed drift and along open beaches (Brander, *op.cit.*, p. 44). In these cases, no attempt was made to estimate the level of the original notch; instead, the foot of the cliff was measured. The reading obtained gives a somewhat higher figure than that for a real notch (compare Bergsten 1943, p. 189). The elevation of a boulder rim was measured at the lower and upper limits of the rim. Because the lower limit of a boulder rim on an open beach is only a few decimeters higher than the mean water level (Hellaakoski 1922, p. 27), the lower limit was measured at three or more points in order to obtain a good average value for its altitude. The shore-bars were levelled so that the altitudes of three points became fixed, namely the seaward foot, the crest and the landward foot of the shore-bar (see Tanner 1930, p. 12). When levelling the elevation of a washing limit on a moraine-clad hill, both the lowest limit of unwashed moraine and the altitude of distinct shore-marks, such as ice-pushed boulders, were measured.

The level of the sea which built a shore-bar is the most difficult to estimate. Sauramo (1926, p. 62) used reduction figures ranging from 0.5 to 1.5 m. Among many investigators, Tanner (1930, p. 30) and Bergsten (1943, p. 191) report only the height of the crest of the shore-bar. Both remark that the height of the crest varies considerably from place to place, depending on the exposition and topography of the beach. Bergsten's (*loc. cit.*) estimate of the variation limit is 2.5 m. The relation of the highest beach on Salpausselkä to the open sea was by and large similar to the present beaches of Gotland, Sweden. At Katthammarsvik there are zones of shore-bars one after the other from the Litorina beach (15 m a.s.l.) down to the present shore. Near Visby there is a shore-bar the crest of which is

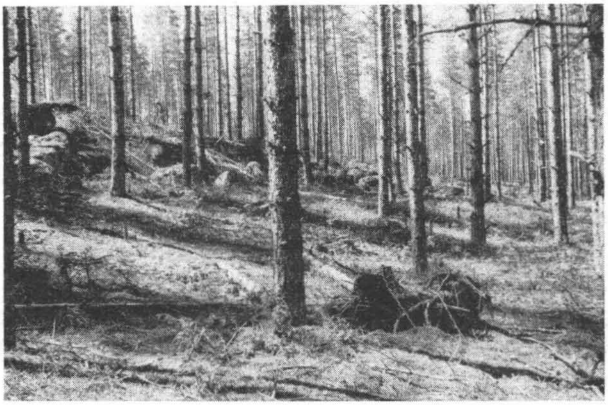


Fig. 40. The highest First Salpausselkä beach marks the limit between supra- and subaquatic ground. Mostly it occurs as a shore-bar. Vesala section.

2.4 m higher than the mean water level. The shore-bar was built during one single storm (Lundqvist, Hede and Sundius 1940, p. 93). Transferred to the distal slope of the Salpausselkä such beaches would be impossible to put into a beach system. On Kaunissaari island, located just off the Finnish coast in the Gulf of Finland, there is a broad zone of storm beaches built during the last decennia (Varjo 1959, p. 28—29). Estimating the mean water level by means of a raised shore-bar obviously promises only meager results.

In the Lahti area there are several ancient shore-bars at different altitudes. Only the shore-bar marking the washing limit of the sandurs (Fig. 40) is consistent, as it reflects the high-water level of the sea. The landward foot of the shore-bar thus gives the lowest limit of land that remained untouched by wave action and shows the uppermost limit of the surge zone.

When constructing the shoreline diagram presented in the next chapter, all the shore-bars occurring in a slope-position were omitted. These shore-bars might be storm beaches built on different slopes during different storms. Shore-bars built of sand might also have developed in the sedimentation zone below the mean water level.

In the present paper, the raised beaches are described by their levelled heights. Consequently, all the points plotted into the diagram are more or less higher than the mean water level. The washing limits stand for the highest and the boulder rims for the lowest deviations above the mean water level.

Owing to the land uplift, all the raised beaches of Finland are tilted, and, therefore, the base line of a shoreline diagram must be parallel to the direction of the maximum tilt, i.e., to the direction of the axis of land uplift in the area studied.

Establishing the direction of the maximum tilt in the Lahti area proved to be a rather complicated problem. Only one beach in the Lahti area has been verified pollen-analytically: According to Donner's (1951, Fig. 1) investigations, the 112-m-isobase of the pre-Boreal Yoldia Sea (Y I) runs obliquely across the eastern flank of the Salpausselkä in the direction SW—NE. In the Jylisjärvi area of the Second Salpausselkä, the elevation of the Yoldia niveau is 132—133 m, dated by Okko (1957a, p. 36). Northeast of the line Lahti-Jylisjärvi the Yoldia isobases can be established on the basis of studies dealing with shoreline displacement in the basin of Lake Päijänne Tolvanen 1922; Aario 1936), but west of Lake Päijänne the Yoldia niveau is markedly deformed (Sauramo 1933, p. 11). Southwest of Jylisjärvi, between Hyvinkää and Turenki, shoreline displacement has been rather irregular (Sauramo 1958, pp. 83, 111). Too many uncertain factors are involved when trying to construct the location of Yoldia isobases running across the Lahti area. Accordingly, the direction of the maximum tilt cannot be determined with sufficient accuracy by means of the Yoldia isobases.

Because of the height of the Lahti area, it was out of question to use shorelines lower than the Yoldia for reference niveaus. Therefore, a higher shoreline had to be chosen for establishing the direction of the maximum tilt. Sauramo (1934, p. 32) stressed that the highest shoreline in western and southern Finland is very capricious — »Launenhaftigkeit der höchsten Grenzen» (*loc.cit.*) — because it has been deformed through melting of stagnant ice, thawing of glacial frost, and through irregular land uplift. In addition, the highest shoreline is so roughly formed that its height can be measured only to an accuracy of 1—3 m (Sauramo, *op.cit.*, p. 33). It was shown, however, in earlier chapters in the present paper that the highest Salpausselkä shoreline is synchronous at the distal edges of the sandurs forming the Bend; hence its use as a local reference niveau is justified.

The highest beaches on the Maavehmaa ridge are located at an altitude of 156.0—156.5 m a.s.l. and the shore-bar at the distal edge of the Vesala sandur, at profile line A—B, at 156.8 m. The elevation of the highest beach inside the Työtjärvi gap is 155.7 m. The 156-m-isobase of the highest Salpausselkä shoreline thus runs from the southern end of the Maavehmaa ridge past the Vesala locality into the Työtjärvi gap (Fig. 41). In comparison to the present isobases of land uplift, shown in Fig. 41, it is seen that the constructed isobase conforms by and large with the general trend of the former. A line drawn at right angles to the constructed isobase gives the direction of the maximum tilt of the highest First Salpausselkä beach in the Lahti area.

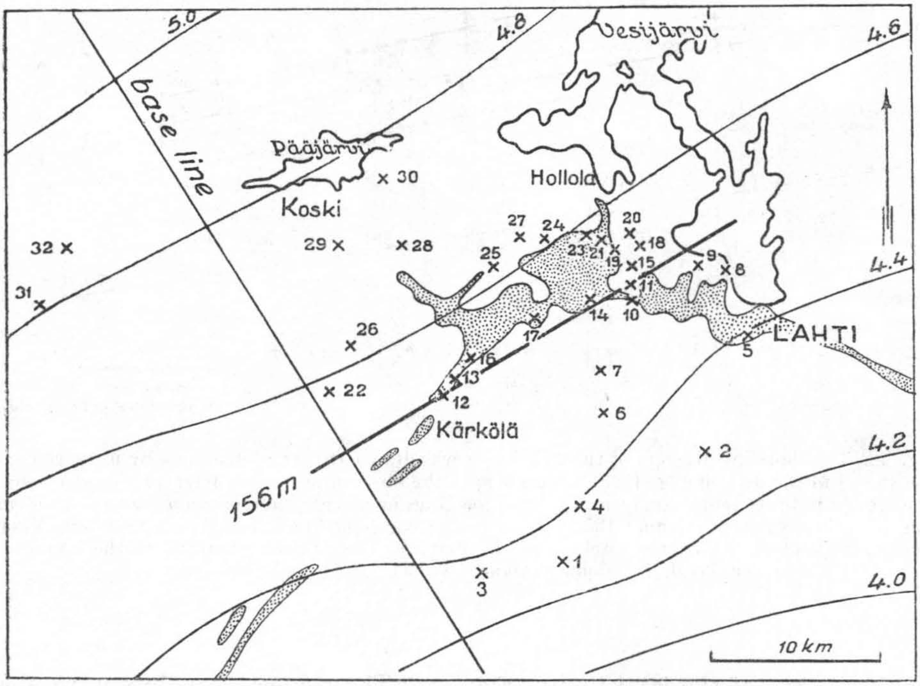


Fig. 41. Location map of beach observations plotted into the shoreline diagram. The isobases show the present annual land uplift in millimeters. They are drawn according to the original draft, scale 1:400 000, to the map illustrating the present land uplift (Atlas of Finland 1960, Sheet 2). The 156-m-isobase of the highest First Salpausselkä shoreline was calculated by means of levelled beach observations. Observation points 5 (Lahti) and 8 (Hakalaukunmäki) are from Donner (1951) and points 31 and 32 (Second Salpausselkä at Jylisjärvi) are from Okko (1957 a).

The direction of the constructed base line was checked against the highest Second Salpausselkä shoreline. The height of this shoreline is 160 m a.s.l. at Jylisjärvi (Okko 1957a, p. 25) and at Kurhila (Sauramo 1958, p. 89). A line drawn between these two localities is perpendicular to the constructed direction of the maximum tilt. It may thus be concluded that in the Lahti area land uplift was going on at a fairly regular rate during the development of the highest beaches of the Salpausselkä belt. The conclusion is in full accord with Sauramo's (1955 b) opinion that land uplift was regular and undisturbed when the highest Salpausselkä beaches formed.

SHORELINE DIAGRAM

The observation points where the height of the shore marks has been levelled were projected onto the base line parallel to the direction of the

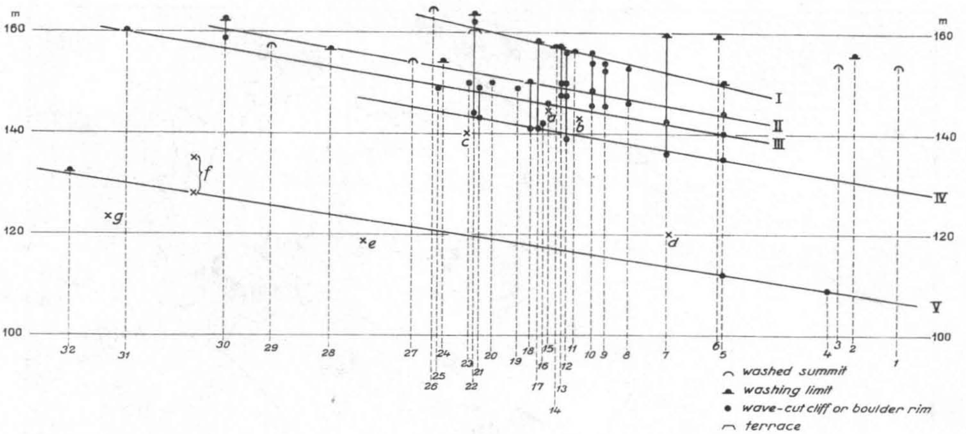


Fig. 42. The shoreline diagram of the Lahti area was drawn at correct distances by using the base line shown in the map of Fig. 41. The numbers of the observation points refer to the same map. The crosses indicate pollen-analytically dated localities or places where data on diatoms are available: a. Lake Työtjärvi (Donner 1951), b. Varrassuo bog (*op.cit.*), c. Kotajärvi kettle hole, Vesala section, d. Nokkola bog in the foreland of the Bend, e. Lake Sairakkalanjärvi in the hinterland of the Bend, f. Saloinen (Okko 1957 a), g. Suurisuo bog (*op.cit.*).

maximum tilt of the land uplift (Fig. 41). The projection points were plotted at correct distances on the abscissa of the shoreline diagram and the levelled altitudes of the shore marks on the ordinate. The diagram is presented in Fig. 42.

The uppermost shoreline on the distal edge of the First Salpausselkä sandurs is morphologically quite distinct. In the diagram the projection points of this beach arrange themselves along a line drawn between observation points 5 (Lahti; Donner 1951, Fig. 5, p. 16) and 17 (Vihattu). The tilt of this shoreline, marked niveau I in the diagram, is ca. 1.0 m/1 km.

Another distinct niveau, marked II, is to be distinguished along a line drawn from the projection point of the 144-m-beach at Lahti (5) to the 158-m-beach at observation point 30 (Vahteristonmäki, Etola). Four washing limits in the hinterland of the Salpausselkä arrange themselves close to this niveau. In addition there are summits washed bare by wave action the heights of which lie close to niveau II. Niveau II is less tilted than niveau I, or 0.85 m/ 1 km.

A series of beaches, most of them represented by boulder rims, forms a distinct niveau 9 m below niveau II. The »boulder beach» is marked IV in the diagram. Its tilt is the same as that of niveau II.

Although not very clearly represented in the diagram, there is a set of beaches that arrange themselves loosely around the line drawn from the 140-m-beach at Lahti (5) to the 160-m-beach at Jylisjärvi (31), Second

Salpausselkä (Okko 1957 a, Fig. 3, p. 9). Most of these beaches are wave-cut cliffs. The tilt of this shoreline, marked niveau III, is also ca. 0.85 m/ 1 km.

Niveau V runs through the projection points of the 112-m-beach at Lahti (5) and the 132-m-beach at Jylisjärvi (32), Second Salpausselkä. Its tilt is ca. 0.75 m/ 1 km.

There is a group of beaches represented by washing limits and bare hilltops located in the diagram distinctly higher than the beaches forming niveau I. These beaches will be discussed in the next chapter.

HIGHEST WASHING LIMITS

Shore marks higher than niveau I are found at observation localities 2, 6, 7, and 22 (Figs. 41 and 42). Points 2, 6, and 7 are located in the foreland of the Bend and point 22 in its hinterland. In addition to these beaches, there are three high summits washed bare by wave action: Points 1 and 3 are located in the foreland and point 26 in the hinterland.

Observation localities 6 and 7 are the highest summits of the Herrala bedrock area. The summits lie 162 m a.s.l. and both are topped with a moraine cap. The washing limits around the caps were mapped in detail. The highest levelling readings were obtained at places where there are miniature ridges of the bedrock surface. The washing limit forms indentions on such ridges. In places, the washing limit is accentuated by a rim of blocks and boulders (Fig. 43), some of them showing distinctly that they were pushed by ice into the rim.

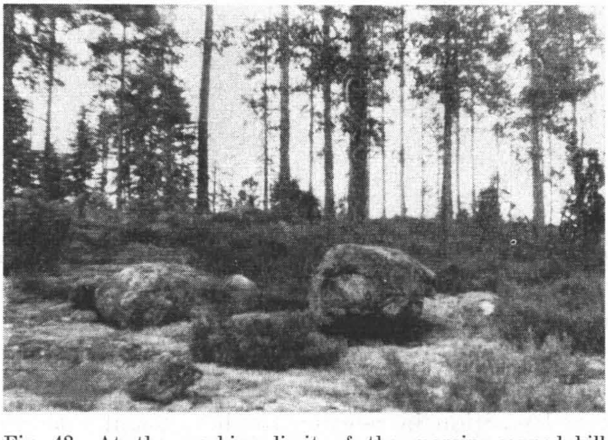


Fig. 43. At the washing limit of the moraine-capped hill Lakeamäki (observation point 6) there are ice-pushed boulders resting on washed bedrock.

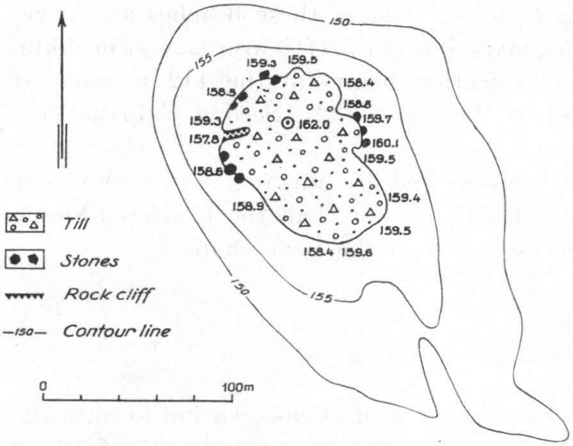


Fig. 44. Map showing the moraine cap and washing limit on top of Lakeamäki. The cap was drawn according to levelling data and the contour lines were sketched according to the topographic map, scale 1:20 000.

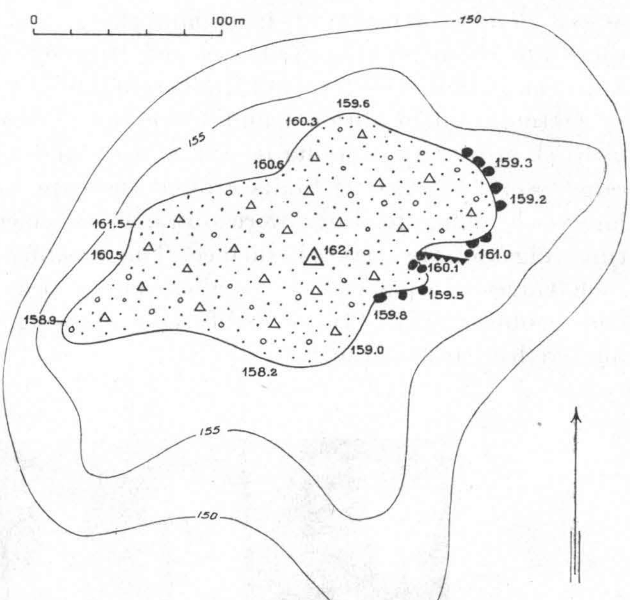


Fig. 45. The moraine cap and washing limit on Kauhalankallio (observation point 7). For explanation of the symbols see Fig. 44.

The average height of the washing limit at point 6, the Lakeamäki hill (Fig. 44), is 159.7 m a.s.l. Lakeamäki is located at the southwestern border of a deep shear valley which is about 1 km wide. In all other directions, it is surrounded by hills with somewhat lower summits (159, 153, 145 m), all washed bare. The top of the Lakeamäki is thus located in a relatively sheltered position in relation to the ancient open sea. The power of the breakers must have decreased considerably before reaching the highest top of the reef formed by the Lakeamäki area.

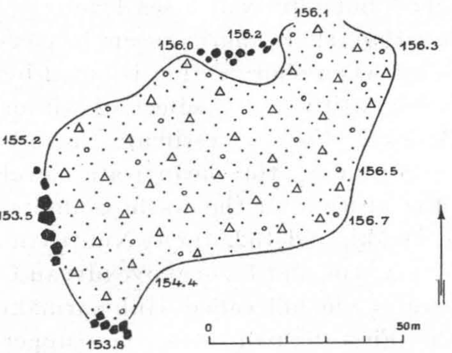


Fig. 46. The moraine cap and washing limit on Nuuttilanmäki (observation point 2). For explanation of the symbols see Fig. 44.

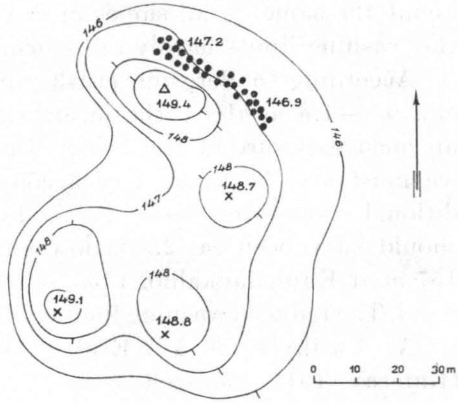


Fig. 47. The summit of Huhmarmäki near Uusikylä, Nastola, is washed bare. The boulder rim close to the summit shows that shore action took place at this altitude. The rim is thought to have developed during the same stage as the three high washing limits.

Ramsay (1917; 1931, No. 138) knew the Kauhalankallio hill, point 7. He reported an H.G. (Höchste Grenze) at an elevation of 159 m. Calculating from the levelled altitudes of the washing limit the Kauhalankallio washing limit averages 159.7 m a.s.l. (Fig. 45). The hill is located 2 km north of Lakeamäki, on the opposite side of the shear valley. To the north and east, it is surrounded by hills whose bare tops reach an altitude of 155 m. Kauhalankallio, too, is located in a relatively sheltered position in relation to the open sea.

The moraine cap topping the Nuuttilanmäki hill, point 2, measures only 45 by 100 m in area (Fig. 46); yet it was easily identified from an air photo, scale 1: 100 000. The average altitude of the Nuuttilanmäki washing limit is 155.4 m a.s.l. The hill forms the northernmost summit in an area of elevated bedrock, southwest of Lahti.

In the shoreline diagram (Fig. 45, p. 118) the moraine caps arrange themselves on a distinctly higher level than niveau I, Nuuttilanmäki 10 m, Lakeamäki 8.5 m and Kauhalankallio 7.5 m above it. Estimating the mean water level of the sea that produced the washing limits is a difficult task. According to recent studies of waves in the Baltic (Davidsson 1961, p. 96), the highest sea at Gotland and Öland, Sweden, is as much as 9 m, or of the same magnitude as the difference in elevation between the washing limits and the calculated height of niveau I in the three localities. Although the northern and southern slopes of each hill have been exposed to wave action differently, the elevation of the washing limit is about the same on all slopes of each hill. Hence it may be concluded that the washing limits hardly are storm beaches, but represent a sea level.

According to Bergsten (1943, pp. 192—193), shore marks occur in general 0.7—1.0 m above the mean water level when shore action is aided by an open exposure of the beach. In northern latitudes the effect of winter ice must also be taken into account. Bergsten *(loc.cit.)* estimates an additional shore zone, some 1.5 m high. Accordingly, the mean water level should have been ca. 2.5 m lower than the altitude of the washing limits: 157 m at Kauhalankallio, 156.5 m at Lakeamäki, and 152.5 m at Nuuttilanmäki. The reduced washing limits still are 4.5 m, 6 m, and 7.5 m above niveau I.

At Uusikylä, 20 km E of Lahti, there is the hill called Huhmarmäki (Ramsay 1917), located 2 km S of the First Salpausselkä. The upper slopes of the hill are washed bare but on the top (149.4 m a.s.l.) there are thin patches of washed till. No moraine cap is to be distinguished but there is a boulder rim, 30 m long. The foot of the rim lies at 147 m a.s.l. Three tops occurring to the south of the highest point are all washed bare (Fig. 47). At Nastola, 4 km NW of Huhmarmäki, Sauramo (1958, p. 72) reported a glaciofluvial delta at an altitude of 144 m. If this delta corresponds to the height of niveau I, the tilt of which is 1.0 m/ 1 km in the Lahti area, the altitude of niveau I at Huhmarmäki is ca. 140 m. The boulder rim occurs 7 m higher than niveau I, and it thus corresponds to the washing limits of points 2, 6, and 7 in the shoreline diagram.

Observation points 1 and 3 are hills whose summits are formed by bare bedrock. Littoral gravel and sand fill small cracks and depressions close to the top at both observation points. The calculated height of niveau I is 143 m at point 1, where the height of the summit is 153.9 m a.s.l. The corresponding figures at point 3 are 145.5 m and 154 m. The distance of the washed summits from niveau I is somewhat greater than that of the three washing limits. Both hills form solitary summits rising above relatively low ground. They were, in all probability, washed bare by the same sea which produced the washing limits.

Although it is hardly possible to infer the position of a sea level by means of washing limits and washed hilltops, the highest shore marks in the foreland seem to form a niveau less tilted than niveau I. The higher niveau has the appearance of a metachronous shoreline. As I see it, this feature shows that the difference in elevation between niveau I and the washing limits cannot be explained through land uplift of longer duration in the foreland (see Ramsay 1922). Correspondingly, the washing limits represent a sea level higher than niveau I.

There are two high hills capped with moraine in the hinterland of the western flank of the Salpausselkä. Observation point 22, the Paaskallio hill, is located in the southern part of the Miehola bedrock area. The elevation of the summit of Paaskallio is 171 m. The other hill, Mustikkamäki, is even higher, 177 m, but because its projection point in the shoreline diagram is the same as that of Paaskallio, it is not included in the diagram.

The moraine cap of Paaskallio is bordered on the southeastern slope by a washing limit with a stone rim at an altitude of 163.3 m. Bedrock is widely exposed at the washing limit. On its northern side, the moraine cap is bordered by a wave-cut cliff, not dug through the moraine to the bedrock surface. The height of the notch of the cliff is 162.2 m. A narrow terrace the edge of which is situated at an altitude of 160.5 m occurs in front of the cliff. The washing limit and the notch correspond to each other. The mean water level should have been lower than 162.2 m, yet higher than 160.5 m. Ramsay (1931, p. 63) estimated the height of the mean water level at Paaskallio as low as 158 m. The height of the washing limit on the southeastern slope he attributed to the open position of the hill in relation to the sea.

According to the shoreline diagram, the altitude of niveau I at Paaskallio is 160 m. The difference between the washing limit and the calculated height of niveau I is 2—3 m. This figure stands close to the shore zone estimated at 2.5 m by Bergsten (1943, p. 192—193). The washing limits at Paaskallio and Mustikkamäki probably represent washing limits of niveau I.

The summit of Hinkankallio, observation point 26, is washed bare. Its elevation, 165 m, is 3.5 m higher than the calculated height of niveau I in this locality. In relation to the washing limits at Paaskallio and Mustikkamäki, the washing of Hinkankallio obviously is of the same age.

The washing limits at Paaskallio, Mustikkamäki, and Hinkankallio show that the sea, depicted by niveau I in the shoreline diagram, reached to the proximal side of the western flank of the Salpausselkä at Miehola. The Miehola bedrock area was thus deglaciated before the highest Salpauselkä beach was formed. Moreover, the terminal formations occurring in the southeastern part of the Miehola area, seen in the appended map, are older than the proximal accumulations of the Sairakkala section, built during the stage of niveau I.

Considering the fact that niveau I marks the boundary between supra- and subaquatic land on the First Salpausselkä in the Lahti area, the geographic position of the highest foreland beaches necessitates the assumption that they are older than those marking niveau I.

ERRATICS TRANSPORTED BY ICEBERGS

In his lecture before the Geological Society of Finland, on December 8th, 1960, Professor Esa Hyyppä presented the idea of the Rapakivi Sea

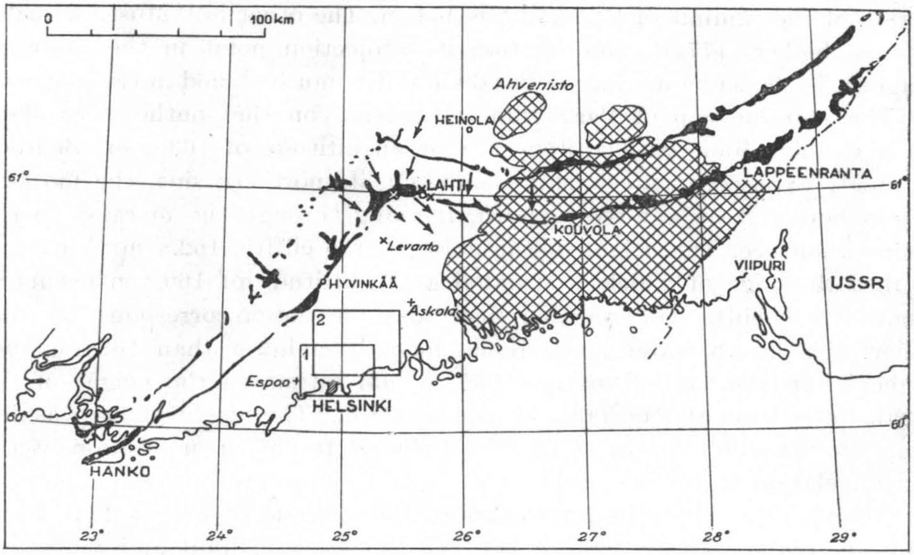


Fig. 48. Map to illustrate the discussion on erratics transported by icebergs. The Salpausselkä belt and the striae (arrows) are drawn according to Atlas of Finland 1960, Sheet 4 and the southeastern Finnish rapakivi massifs according to Atlas *cit.*, Sheet 3. The crosses indicate findings of rapakivi erratics in the Lahti area. 1. Helsinki area (Hyyppä 1950), 2. Kerava area (Virkkala 1959 a).

that existed in front of the glacier margin during its retreat from the southern coast of Finland. In the history of the Baltic Sea the Rapakivi Sea antedates the Baltic Ice Lake. As early as 1954 Professor Hyyppä asked me to watch out for rapakivi erratics, in particular since he had run across the first erratic of the four so far found in the Lahti area. This chapter is intended as a preview, based on my own observations, of the Rapakivi Sea, to be treated comprehensively in a forthcoming paper by Hyyppä.

Erratics of Viipuri rapakivi granite are frequently run across west of the Viipuri rapakivi area (Fig. 48). Such erratics have long been known, for instance, in the Helsinki area (Moberg 1881, p. 42). Although heavily used as building stone (Moberg, *loc.cit.*) almost 300 rapakivi erratics were still found when the surficial deposits of the Helsinki area were mapped in the 1940's (Hyyppä 1950, p. 41). According to Hyyppä (*op.cit.*, p. 40), rapakivi erratics occur east of the line drawn from Espoo at the coast to the First Salpausselkä at Hyvinkää and from Hyvinkää to the Lahti area, somewhat east of the town [1]. Along the coast, the frequency of rapakivi erratics increases eastwards (Moberg, *loc.cit.*). In the Kerava map quad-

[1] Hyyppä has since found rapakivi erratics west of Espoo (oral communication 1962).

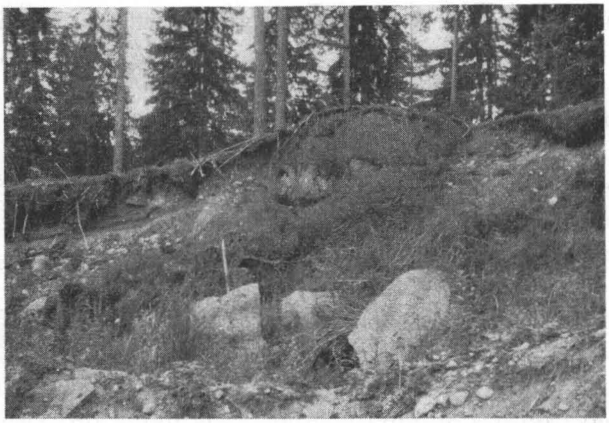


Fig. 49. A boulder of rapakivi together with non-local till rests on the slope of an esker in the village of Levanto. An iceberg touched bottom at this spot.

rangle, only six erratics were found in the northwestern subquadrangle (Nurmijärvi), whereas in the southeastern corner (Hangelby) as many as 361 erratics were counted (Virkkala 1959 a, p. 22). There seems to be a similar decrease in frequency also towards the north as only four erratics have so far been found north of Hyyppä's *(loc.cit.)* boundary line Hyvinkää —Lahti.

The southernmost of the four erratics is located at a height of 110 m a.s.l. on the slope of a glaciofluvial ridge belonging to the Marttila—Järvelä esker chain, in the village of Levanto. The dimensions of the boulder are 2.5 × 4 × 4.5 m. The erratic is underlain by a thin layer of till (Fig. 49). The petrographic compositions of the till and of the esker drift are the following:

	till	esker drift	
Microcline granite and pegmatite	40 %	41 %	48 %
with garnets	— »	5 »	
Quartz-diorite and granodiorite	8 »	7 »	
Porphyritic granite	4 »	— »	
Mica schist and mica gneiss	34 »	25 »	32 %
with garnets	— »	7 »	
Other gneisses	12 »	8 »	10 %
with garnets	— »	2 »	
Amphibolite	2 »	3 »	
Uralite porphyrite	— »	2 »	
	100 %	100 %	

Garnet-bearing rocks and uralite porphyrites, which are present in the local bedrock and in the stones of the esker drift, are totally lacking from the till.

Three erratics were found on the First Salpausselkä. The one boulder was found on the distal slope of the Vesala sandur below the shore-bar marking its edge (158 m). The boulder was in a secondary position, having been moved in connection with operations at the gravel pit described on p. 78. The original position of the boulder could not be established by interviewing the workers at the site. When found the boulder was located at an altitude of 153 m. Also the second rapakivi erratic was found in a secondary position, namely, at the bottom of the cutting across the Salpausselkä at Lahti, described briefly in the footnote on p. 69. The third boulder, also moved from its original position, was found on the proximal slope of the Lahti plateau in the cutting described on p. 66. It may be mentioned that at Uusikylä railway station, 20 km E of Lahti, there is an abundance of boulders, rapakivi granites among them, on top of the Salpausselkä at an altitude of 125—130 m.

In the southern coastal area, the general orientation of the glacial striae is NW—SE (Atlas of Finland 1960, Sheet 4, insert map). Rapakivi boulders transported by the advancing glacier were thus spread southeast of the Viipuri rapakivi area (compare Sauramo 1929, Fig. 3). Regarding the rapakivi erratics in the Helsinki area, Moberg (1881, p. 42) assumed that at least some of them had fallen from ice floes into deep water. This view has been developed further and nowadays it is generally held that the erratics met west of the Viipuri rapakivi area were carried by drifting icebergs. If this hypothesis is correct, then the occurrence of iceberg-carried rapakivi erratics would prove that, at the time the boulders were transported, the glacier margin ended in deep sea and wasted by calving.

Icebergs are known to drift in the direction of sea currents, determined by prevailing summer winds. The dispersal of rapakivi erratics west of the Viipuri rapakivi area indicates that the winds blew from E—NE. During the Weichsel glaciation, eastern and northeastern summer winds prevailed at the southern and southeastern border of the continental ice sheet (Poser 1948, Fig. 3; see also Hoppe and Liljequist 1956, Fig. 4). Although eastern winds were soon replaced by western winds, for instance in Poland (Galon 1959, p. 101), after deglaciation was well under way, they still prevailed in southern Finland during the transportation of rapakivi erratics by icebergs.

In the chapter on the deglaciation of the foreland, the view was presented that, during its retreat from the southern coastal area, the terminus of the ice sheet was directed SW—NE across the zone of the eastern arc of the Salpausselkä. If the prevailing winds blew from the east, the sea currents must have turned southwestwards in front of the glacier margin.

Meltwaters discharging from the ice might have turned the sea currents in a slightly more southerly direction. Meltwater currents transported the icebergs away from the glacier margin into the main stream and prevented them from drifting back to the margin.

Because of the meltwater stream, the margin must have withdrawn a good way from each locality where rapakivi erratics dropped down from icebergs. The geographic position of the Levanto erratic (Fig. 48) shows that it probably derived from the northwestern part of the Viipuri rapakivi area or from the Ahvenisto massif. The iceberg which carried the Levanto boulder must have touched bottom, as shown by the till underlying the erratic. As the till does not contain stones of rapakivi, its material must derive from the country rocks of the rapakivi massifs. The petrographic composition of the till (p. 125) corresponds roughly to the country rocks of the previously mentioned rapakivi areas (compare Savolahti 1956, appended map). Such rocks as gabbros, anorthosites, and diabases, which are characteristic of the Ahvenisto massif (Savolahti, *loc.cit.*), were not found among the stones of the till.

Proof for the view that icebergs were able to drift southwestwards across the zone of the eastern arc is presented by occurrences of water-laid sediments in and under the First Salpausselkä. At Kouvola thick deposits of fine-grained stratified sediments form the core of the Salpausselkä (Frosterus 1890, p. 9). The beds have been pushed from the north into folds turned obliquely upwards (Sederholm 1892, p. 29). This feature is to be interpreted as evidence of a strong oscillation of the glacier margin at Kouvola (Frosterus, Sederholm, *loci cit.*) At Lappeenranta, farther to the east, Berghell (1898, p. 35) found chunks of clay shaped into elongated balls, embedded in the washed drift of Salpausselkä. Berghell (*loc.cit.*) assumed that after the deposition of water-laid clay, the glacier advanced to the Salpausselkä zone, picking up sediments laid earlier. This view has been seconded by Brander (1943, p. 112) and Okko (1951, p. 130). Repo (1957, p. 141) has shown that the Salpausselkä belt marks the limit of an ice oscillation in the Joensuu area, farther northeast.

Sauramo (1958, p. 396) accepted oscillations along the eastern arc, whereas Hyyppä (1937, p. 169; 1951) thinks there were oscillations all along the First Salpausselkä. Donner (1952, p. 4) has described from Hyvinkää two beds of silt occurring at a depth of 10 m in the First Salpausselkä (western arc). The silty sediments were deposited into open water at a time the glacier margin had retreated some distance from Hyvinkää; later on, the margin advanced back to the First Salpausselkä (Donner, *loc.cit.*). According to Heinonen's (1957, p. 31) micropaleontological studies, the age interval is a very long one between the deposition of the basal till and the till laid in the proximal parts of the Salpausselkä during the advance.

Transportation of rapakivi erratics to Hyvinkää obviously took place at a time when there was deep enough water to allow sedimentation of silt.

The highest washing limits met with in the foreland of the Bend indicate the highest stage of the sea hitherto observed south of Salpausselkä. Judging from the shoreline diagram, the depth of the sea was some 40 m at the Levanto site of the rapakivi erratic during this stage. It seems reasonable to assume that an iceberg of large enough size to carry the erratic touched bottom at this depth.

The sandurs of the Bend having been deposited when the sea was low, the rapakivi erratic found close to the distal edge of the Vesala sandur must have been carried to the Vesala environs before the low stage of the sea, in deeper water. It is out of question that the erratic could have been carried during the transgression which followed the low stage: In the rapakivi area, the accumulations of the First Salpausselkä blocked any drifting ice and at Vesala the iceberg should have had to drift upstream towards the Salpausselkä. The rapakivi erratic found in the proximal part of the Lahti plateau presumably dropped from an iceberg during the high stage of the sea and was picked up by the northern glacier when it advanced towards the zone of the First Salpausselkä.

Summing it up: During the deglaciation of the southern coastal area, there was a period when the water level stood high in front of the continental ice sheet. At least in the Viipuri rapakivi area, the margin wasted by calving. Easterly summer winds prevailed outside the ice sheet, producing sea currents that streamed towards SW. During this period, the margin trended towards NE past the First Salpausselkä zone. The stage of the Rapakivi Sea or the Karelian Ice Sea of Hyyppä (1960, 1961) took place before the First Salpausselkä stage in the Lahti area.

SHORELINE DISPLACEMENT

All the data relevant to shoreline displacement in the Lahti area point to the following changes in the sea level.

1. H i g h s t a g e, about 156 m at Lahti. The stage is represented by the highest washing limits in the foreland (pp. 119—123). Erratics of rapakivi were transported by icebergs into the area studied.

2. L o w s t a g e, at least 140 m, possibly less, at Lahti. The stage may be inferred from a number of land forms and other features in the bend of the First Salpausselkä, the origin of which can be understood only by assuming an occurrence of shallow water or dry land in front of the glacier margin (pp. 97—98). The stage might be represented by layers

of gravel and sand interbedded in the fine-grained foreland sediments laid into deep water (p. 44).

3. Transgression, 150 m at Lahti, or niveau I in the shoreline diagram. The stage is represented by the shore-bar, replaced in places by a cliff, at the distal edge of the Salpausselkä plateaus and by the glaciofluvial delta of Hakaportti. The shoreline marks the limit between supra- and subaquatic land on First Salpausselkä.

4. Lowering of the water level to niveaus II—V.

COMPARISONS

In comparison to Sauramo's (1949; see also 1958, Fig. 16, p. 76) system of shoreline displacement in southern Finland niveaus I—V are arranged in the following way:

Altitude in meters at Lahti	Niveaus in the present diagram	Niveaus according to Sauramo	
150	I	B I	(Baltic Ice Lake I)
144	II	B II	
140	III	B III	
135	IV	B VI	
112	V	Y I	(pre-Boreal Yoldia I)

According to Sauramo (*op.cit.*), the high plateaus of the First Salpausselkä were built as glaciofluvial deltas and marginal terraces onto the water level of the B I. This shoreline (niveau I) was, however, distinctly transgressive in the Lahti area. The development of the plateaus thus antedates stage B I.

Sauramo (1958, p. 185) regarded the highest raised marine beach on the island of Suursaari in the Gulf of Finland as equivalent to the oceanic niveau *l* in Tanner's (1930) shoreline system. Stage by stage, the ocean level sank to niveau *g*. Right after this stage, the Baltic Ice Lake was dammed up into an independent body of water the level of which began to rise. The transgression reached a niveau 28 m higher than *g*. Sauramo (*op.cit.*, pp. 401, 410) marked this niveau with the symbol *h*. The water level was then lowered 4 m to niveau B I (96 m at Suursaari).

In the Lahti area, the transgression did not reach higher up than niveau I. The peak of the transgression occurred during the very last phases of the First Salpausselkä substage. Whether the low stage that preceded the transgression is equivalent to niveau *g* at Suursaari cannot be deduced from the observation material so far collected in the Lahti area.

According to Sauramo, the Baltic Ice Lake I was discharged into the ocean, level *g*, during the First Salpausselkä substage. This view is based on a discharge varve the geochronological position of which has been established at several localities (Sauramo 1918, p. 122) and on two series of First Salpausselkä plateaus built onto different water levels (Sauramo 1937). The difference in height is 25 m. The release of counterpressure at the glacier margin should have been felt as local advances, for instance, in the Vesijärvi lake basin, and in the Teuronjoki valley. No features pointing with certainty to such advances or to a lowering of the water level to a niveau 25 m lower than niveau I have been traced in the Lahti area (see also Donner 1951, p. 15).

Sauramo's stage B II marks a new damming up of the Baltic Ice Lake. In the Lahti area, this shoreline is rather well developed. There is nothing transgressive about it. The observation material points to a gradual lowering of the water level while the land uplift increased the area of dry land.

During the development of the Second Salpausselkä, the lake had sunk to the B III-level. After this stage, there was an abrupt sinking of the water level to niveau Y I. This change in the water level, amounting to 28 m, has recently been documented by Okko (1957 a) in the Jylisjärvi area and by Virkkala (1961) in the Hämeenlinna region. According to these writers, this niveau marks the limit of supra- and subaquatic land northwest of the Second Salpausselkä. Swedish geologists also regard the fall of the water level down to Yoldia at Billingen, Sweden, as the end of the Baltic Ice Lake (e.g., Caldenius 1944, p. 377; E. Nilsson 1960, p. 105; G. Lundqvist 1961, pp. 90—91).

A rise of the sea from Y I to the level of the Third Salpausselkä, B IV — B V — B VI, as suggested by Sauramo (1949), has not been detected in the Lahti area. Shoreline B VI, niveau IV, is well developed here. At eight observation points out of nine, the beach is represented by a boulder rim. The boulder beach extends across the zone of the First Salpausselkä and is thus younger than niveau I. The observation material at hand does not give any reliable clues to the age relation of the boulder beach to the other beaches. The chronological position of the Second Salpausselkä shoreline as the closing stage of the Baltic Ice Lake, as established by Okko (1957 a) and Virkkala (1961), suggests that the boulder beach developed before the Second Salpausselkä shoreline. Hyyppä (1962) also correlates the lowering of the lake level from the Second Salpausselkä level with the only and final discharge of the Baltic Ice Lake at Billingen.

Hyyppä's (1960, 1961, 1962) system of shoreline displacement differs from Sauramo's system in that the raised and tilted shorelines group themselves in a linear way without any hinge lines upon which Sauramo's mechanism of upheaval is based. A comparison of the shorelines of the

Lahti area to Hyyppä's (1962) relation diagram showing the raised shorelines of the Baltic basin is given in the following tabulation:

Altitudes in meters at Lahti	Niveaus in the present diagram	Niveaus according to Hyyppä (1962)
170—200	(Nunatak lake at Tiirismaa, not shown in the diagram)	Karelian Ice Sea; also ice lakes
150	I	B I
144	II	Salpausselkä beaches
140	III	Salpausselkä beaches
135	IV	Gotiglacial Yoldia?
112	V	
100		Finiglacial Yoldia

The niveau tentatively designated Gotiglacial Yoldia, according to Hyyppä's (1962) latest interpretation, corresponds to the highest level of the Baltic Ice Lake at Billingen in E. Nilsson's (1958) system of shoreline displacement: The Baltic Ice Lake was discharged from this niveau down to the Finiglacial (pre-Boreal) Yoldia Sea.

According to Donner's (1951, pp. 47—53) pollen-analytical datings, the 112-m-beach at Lahti is the beach of the pre-Boreal Yoldia I whereas its correlative, the 132-m-beach in the Jylisjärvi area, was dated by Okko (1957 a, p. 38) the Yoldia I of the late Younger Dryas period. Here the stage is represented by halophile diatoms. Of the two projection points denoted by the letter *f* in the shoreline diagram (Fig. 42, p. 118) the lower shows the altitude where fragments of salt water diatoms were encountered; no traces of salinity were to be detected at the upper locality (Okko, *op. cit.*, p. 36). Projection point *g* in the diagram shows the location of the Suurisuo bog, Jylisjärvi area, where salt water diatoms were identified in the bottom layers (Okko, *op.cit.*, pp. 34—36). Also in Hyyppä's (1962) relation diagram the niveau under discussion belongs to the Younger Dryas period. According to the present shoreline diagram, niveau V is 28—29 m lower than the Second Salpausselkä shoreline (niveau III). The difference in height is of the same magnitude as the discharge at Billingen (e.g., G. Lundqvist 1961). Niveau V thus corresponds to the marine Billingen level.

The Karelian Ice Sea (Rapakivi Sea) is separated from the Baltic Ice Lake by an erosion level which Hyyppä (1962) has traced in several sediment sequences in the Helsinki area: A basal, silty varved clay is separated from mainly symmict ice-lake clay either by a layer of interbedded sand and gravel or by a structural discordance. Boulders of rapakivi have been found in the silty varved clay and in the underlying ice-marginal fine sand, both of the Karelian Ice Sea. The discordance, obviously, was brought about by a low stage of the sea.

In his working hypothesis for the study of the development of the First Salpausselkä, Hyyppä (1951) assumed that a readvance of the ice sheet to the zone of the First Salpausselkä took place during the marine regression that has been documented from the Karelian Isthmus (Hyyppä 1933) and from East Karelia, U.S.S.R. (Hyyppä 1943). Sauramo (1947; 1958, p. 185) also thought there was a marine regression that preceded the stage of the Baltic Ice Lake. Mölder, Valovirta, and Virkkala (1957) have found traces of this regression in southern Finland. Virkkala (1959 b, pp. 23—26, 30, 35) has observed ancient involutions at Nurmijärvi, Järvenpää and Seutula, all located in the southern coastal area, at altitudes too low to allow other interpretations than an occurrence of dry land in the deglaciated area. It should be noted, however, that Jan Lundqvist (1962, p. 88) doubts the cryoturbate origin of these involutions. Tynni (1960, p. 153) was able to establish that in late-glacial times, there was a shallow body of water at Askola; the water level stood there at about 57.5 m. Mention should also be made of Kullenberg's (1954) findings in Sweden, which show that the bottom waters of the early Baltic Ice Lake were saline.

A late-glacial marine regression in southern Finland is fairly well documented. In the Lahti area, this regression coincided with the readvance of the glacier margin to the First Salpausselkä and with the development of the sandur fields. The height of the sea was at Työtjärvi 146—147 m at the most. The corresponding figure at Lahti is 139—140 m.

It was pointed out on p. 122 that the highest washing limits form a niveau that has the appearance of a metachronous shoreline. In other words, this shoreline might have developed in front of the retreating glacier margin. According to Hoppe (1948, p. 32), washboard moraines are built when the glacier ends in water at least 30 m deep. Applied to the Tennilä end moraine swarms in the foreland the water level of the sea should have lain as high as 165 m, or some 9 m higher than niveau I at Tennilä. This figure corresponds to the distance of the highest washing limits from niveau I.

As to its altitude, the highest niveau might correspond to Sauramo's (1958, p. 185) level *h* but it cannot be chronologically equivalent to his level *h* at Suursaari. Because the high water level eroded the washing limits before the lowest regressive stage, it must represent one of the substages from the high marine level *l* (Sauramo, *loc.cit.*), or rather from the high levels of the Karelian Ice Sea (Hyyppä 1961). The glacier thus retreated from the foreland of the Bend during a substage of the regression. In the Viipuri rapakivi area, the glacier margin wasted largely by calving. The icebergs carried boulders of rapakivi into the Lahti area during the high water level.

The comparisons lead to the following view of shoreline displacement in the Lahti area:

1. The high stage of the sea, represented by washing limits, corresponds to a substage of the late-glacial marine regression.
2. The lowest stage of the regression is comparable to the low stage established at Askola.
3. The transgression depicted by niveau I marks the highest level of the Baltic Ice Lake. Land uplift increased the area of dry land, causing gradual lowering of the lake. Simultaneously, the retreat of the glacier margin added to the area of the lake basin. The last stage of the Baltic Ice Lake corresponds to niveau III, the Second Salpausselkä beach.
4. The lowering of the water level from niveau III to niveau V marks the end of the Baltic Ice Lake.

THE DEVELOPMENT OF THE FIRST SALPAUSSELKÄ AT ITS BEND

The observation material and its interpretation, as presented in the previous pages, leads to the following view of the late-glacial development of the Lahti area.

The ice sheet retreated from the foreland of the Bend, in all probability from the whole southern coastal area, towards the northwest. The ice margin maintained the general direction SW—NE during this stage and, thus, extended across the zone of the eastern arc of the Salpausselkä. The margin retreated to some position northwest of the western arc. During this retreat, the glacier ended in deep water. Icebergs drifted in the sea, carrying boulders of Viipuri and Ahvenisto rapakivi towards the southwest. Eastern winds prevailed.

The sea was in a regressive stage. Meanwhile, there was a major change in the regimen of the ice sheet, registered as a readvance that brought the ice margin to the zone where the First Salpausselkä was to develop. East of Lahti, the glacier movement was strong enough to obliterate all signs of the northwestern general abrasion. The signs of an advance towards the western arc are less pronounced because the direction of movement was here parallel to the direction of the older northwestern abrasion. The Bend developed in front of two glacier lobes, indicated by its eastern and western flanks.

While building the Bend, the ice margin behaved like that of a temperate glacier. The margin was relatively thin but active, and it adhered to the local topography. Much dead ice was formed in the shelter of nunataks (Tiilijärvi section, Työtjärvi gap) and in places where the marginal ice flowed towards high ground (Vesala section, Vihattu gap, Sairakkala section). Adundant meltwaters discharged from the glacier. The washed drift was first deposited as glaciofluvial deltas (Tuhkamäki in the Tiilijärvi section), but, later on, the deposition of washed drift went over into building of sandur fields.

Meanwhile, a transgressive stage began in the Baltic basin. The transgressive shore destroyed the distal parts of the sandurs by eroding and transporting away the loose, fine-grained drift: only their proximal parts were left intact. The glacier margin had withdrawn from the Lahti section before the transgression reached its maximum height, 150 m. It still remained along the northern slope of the Tiirismaa range, in the proximal parts of the Vesala and Sairakkala sections and at the Korkeenkylä moraines in the Teuronjoki valley. The high bedrock area of Miehola was free from ice and the active margin stayed somewhere northwest of the Paaskallio, Mustikkamäki and Hinkankallio hills, which were washed by the sea during the maximum of the transgression. Glaciofluvial activity was still vivid in the estuary of Hakaportti.

Land uplift increased the area of dry land and the water level began to sink gradually. The last place to be deglaciated was the area around the border between the northern and northwestern ice lobes. Here the margin had been the thickest, mainly due to its growth north of the Tiirismaa range. At the northeastern end of the Vesala section, which occupies the apex of the Bend, a unilateral, glacier-supported channel was eroded into a lateral terrace controlled by the water level during the maximum of the transgression. In the Hatsina environs, NW of the Vesala section, a part of the northwestern ice stagnated and melted in situ. The whole First Salpausselkä at the bend was deglaciated before the end of the lower stage of the ice lake depicted by niveau II in the shoreline diagram.

More and more land rose from the waters. The Työtjärvi and Vihattu gaps passed through their stages as sounds and bays, and were isolated when the water level was lowered from niveau III, i.e., from the niveau of the Second Salpausselkä.

The climate seems to have been of a periglacial or arctic character during the stages of the Baltic Ice Lake. The vast accumulations of glacial drift that emerged from the waters provided deflation surfaces for wind action. Eolian silt and sand were deposited on top of the Salpausselkä (Sairakkala section in particular) and into the waters of the ice lake. Owing to the lowering of the water level, the eolian silt laid in water was mixed with littoral sediments. During the last stage of the Baltic Ice Lake (niveau III) sand dunes accumulated in the Sairakkala basin close to this shoreline.

The development of the First Salpausselkä had its primary source in a major change in the regimen of the continental ice sheet. The rapid deglaciation of the southern coastal area went over into an advance of ice. The outermost limit of the readvance, at least in the Lahti area, is marked by the First Salpausselkä. Once the readvance had brought the margin to the Salpausselkä zone, the behaviour of the margin at the Bend was largely determined by the topography of the underlying bedrock. The types of terminal deposits were determined by the water level of the sea in front of the glacier. The sandur fields and parts of the dead ice areas of the Bend developed in supra-aquatic conditions. The proximal glaciofluvial delta, the transverse glaciofluvial ridges, the lateral terraces, and the end moraine swarm testify to accumulation in subaquatic conditions during the transgression of the Baltic Ice Lake.

ON THE AGE OF THE SALPAUSSELKÄ STAGE

REVIEW OF FINNISH LITERATURE DEALING WITH THE AGE PROBLEM

The first attempt to date the Salpausselkä stage was made by the varve-chronological method (Sauramo 1918, 1923). According to varve chronology, the Salpausselkä stage lasted 800 years; the first 200 years were spent in building the First Salpausselkä. It has not been possible to connect the Finnish varve chronology to the pollen-analytical time table. By comparing the Finnish and Swedish varve chronologies, Sauramo (e.g., 1949) concluded that the Salpausselkä stage began around the year 8800 B.C. and ended around the year 8000 B.C. Sauramo *(op.cit.*, p. 24) regarded this dating somewhat uncertain from the varve-chronological point of view.

There have been many attempts to date the Salpausselkä substages by relating them to shoreline displacement in the Baltic. In these studies, the glaciofluvial plateaus of the Salpausselkä belt have been considered indicative of the water level of the sea into which the glacier terminated (Ramsay 1922; Sauramo 1928). Sauramo's system of shoreline displacement in late-glacial times was discussed on pp. 129—130. The dating of the Salpausselkä stage in Sauramo's (1958, Fig. 8, p. 44) last general diagram presenting the late- and post-glacial development of Finland is largely based on Donner's (1951) pollen-analytical studies. Donner worked from the thesis that the Second Salpausselkä substage and the Baltic Ice Lake III were synchronous; niveau B III he dated Younger Dryas. The retreat of the glacier from the southern coastal area took place during the Alleröd period and the halt in ice recession in the Salpausselkä belt was caused by the climatic deterioration marking the Younger Dryas period (Donner, *op.cit.*, p. 80—81). According to Donner *(loc.cit)*, the Baltic Ice Lake existed during the Younger Dryas period and the stage of the Yoldia Sea began at the transition from the Younger Dryas into the pre-Boreal period.

Hyyppä (1933) was the first to trace a late-Weichsel period of warm character in southeastern Fennoscandia. In addition to his findings on the Karelian Isthmus (1933) he found in northeastern Finland (Hyyppä 1936) deposits indicating a similar favourable climate. Hyyppä *(op.cit.*, p. 453; see also 1933, p. 35) concluded that the Alleröd period of southern Sweden and Denmark should be climatically fully analogous with the Salpausselkä stage. The subarctic period marking a deterioration of the warmer climate Hyyppä (1936, Taf. VIII) considered to be synchronous with the Yoldia Sea. Later on, Kanerva (1956) confirmed Hyyppä's results of 1936 when he was able to demonstrate that the ice margin retreated into the Hyrynsalmi area, northeastern Finland, during the Alleröd period.

Hyyppä (1941, p. 597) developed his idea further and presented a climatological basis for a warm Salpausselkä stage: A rise in temperature both in the air and on the ground, brought on by the increase of solar heat in summer 10 000 years ago, caused a general melting of the continental ice sheet. A standstill of the ice margin, such as that of the Salpausselkä stage, might have been due to an increased precipitation of snow when the glacial winds turned to the present wind conditions, allowing the North Atlantic minimum to send rainy syclones eastwards to the southern part of Fennoscandia. The rapid melting of ice, also witnessed by the thick clay varves of the Salpausselkä stage (Sauramo 1923, 1929), points to a rise of summer temperature. Worth mentioning is Sauramo's (1940, p. 230) early acceptance of Hyyppä's idea concerning the relatively warm climate of the Salpausselkä stage. Nevertheless, Sauramo soon rejected the idea.

On the basis of his investigations in East Karelia, U.S.S.R., Hyyppä (1943) concluded that the Salpausselkä belt was formed during the Alleröd before the development of the Baltic Ice Lake. Later on, Hyyppä (1951) specified his conception of the development of the First Salpausselkä: A readvance of ice when till was deposited on top of the old glaciofluvial core of the Salpausselkä took place during a regressive stage of sea. The regression was succeeded by a marine transgression that reached a somewhat higher niveau than the Baltic Ice Lake, which succeeded the marine stages. Hyyppä regards the First Salpausselkä a double glacial formation with a considerable age interval between the formation of the glaciofluvial core and the morainic mantle; vast shore accumulations form the third group of its building materials (see. p. 50). The Baltic Ice Lake is regarded by Hyyppä (1960, Fig. 6, p. 13) as contemporaneous with the Younger Dryas period.

On the basis of raised beaches and microstratigraphic observations, Mölder, Valovirta and Virkkala (1957) consider the Salpausselkä stage older than Alleröd and even older than the last sub-age of the Older Dryas period *(op.cit.*, p. 47). This they regard the minimum age of the Salpausselkä stage. The rapid retreat of the ice sheet from the Salpausselkä belt occurred during the Alleröd period. The stages of the Baltic are dated by them *(op.cit.*, pp. 32—33) as follows: During the Older Dryas there was a marine regression, continued into the Alleröd. The Baltic Ice Lake developed during the Alleröd and ended at the transition from Alleröd to Younger Dryas. This period began with a marine transgression, which marks the beginning of the Yoldia Sea. It may be mentioned that Caldenius[1] criticized, on methodical grounds, the results of the three writers.

Okko (1957a, pp. 39—40) relates the age problem to the regimen of the continental ice sheet and to the temperate behaviour of the margin during the Salpausselkä substages: Deposition of the vast glaciofluvial accumulations in the Salpausselkä belt was possible only at a rapidly melting thick margin. On the grounds of his pollen-analytical material, Okko (*loc.cit.*) showed that the Second Salpausselkä at Jylisjärvi was free from ice during the Younger Dryas period. Furthermore, the Yoldia stage of the Baltic began before the end of the Younger Dryas. Okko thinks it improbable that a temperate margin could have existed during the cold and dry tundra climate of the Younger Dryas period. In his opinion the Salpausselkä belt was formed mainly during the Alleröd period (Okko, *op.cit.*, p. 41).

In connection with his studies on an occurrence of calcareous concretions at Vuolenkoski, Second Salpausselkä, Salmi (1959, p. 15) expressed the view that the margin of the ice sheet retreated to the zone of the Second Salpausselkä at the latest during the Alleröd period. The Salpausselkä belt would have become formed for the most part already during the final phase of the Older Dryas period.

The views concerning the age of the Salpausselkä stage are rather varied. There are two schools of thought, the one stressing the importance of a cold climate in causing a halt of the ice margin at the Salpausselkäs (Donner 1951; Sauramo 1955 a, 1958; Mölder, Valovirta and Virkkala, 1957; Salmi 1959), the other stressing the effect of a relatively mild climate on the behaviour of the glacier during the Salpausselkä stage (Hyyppä 1933, 1936; Okko 1957a). Correspondingly the dates presented are spread from the Older Dryas period (Mölder, Valovirta and Virkkala, Salmi) through Alleröd (Hyyppä, Okko) to the Younger Dryas period (Donner, Sauramo). In international textbooks, only the last view has obtained a foothold.

POLLEN DIAGRAMS FROM THE LAHTI AREA

In Donner's (1951) investigation of the late-glacial development of southern Finland, the essential part is based on pollen diagrams from the Varrassuo bog and Lakes Työtjärvi and Mustajärvi (*op.cit.*, pp. 35—47),

[1] Carl Caldenius (1958). Geol. Fören. i Stockholm Förh., Bd. 80, p. 130—131. — Anmälanden och kritiker.

all located in the Työtjärvi gap. The survey of raised beaches inside the gap (p. 89) showed that the gap was linked to the sea through three stages higher than the isolation level of 144.5 m. According to Donner (*op.cit.*, p. 54), the isolation level falls between shorelines B II and B III of the Baltic Ice Lake (*sensu* Sauramo). The gap cannot, however, have become isolated so early, as also shown by the shoreline diagram (Fig. 42, p. 118), in which the isolation point of the Työtjärvi gap is denoted by the letter *a*. According to the diagram, isolation was possible only after the water level had been lowered from niveau III, in other words, after it had sunk from the niveau of the Baltic Ice Lake III. Donner (*loc.cit.*) further thought the altitude of the Varrassuo basin corresponded exactly to niveau B III. As shown in the shoreline diagram (Fig. 42, point *b*) the basin is located 2 m below this level (niveau III); i.e., the Varrassuo basin, too, was isolated after the water level had sunk from niveau III below the threshold at 143 m. The positions of the isolation points of the gap and the bog basin, *a* and *b*, in the diagram, suggest that the Varrassuo basin was isolated from the gap at about the same time the whole Työtjärvi gap was isolated from the ice lake.

Because of these differing results, it is of significance to relate Donner's diagrams to the shoreline diagram and to the system of shoreline displacement, as presented in this paper. Although I am hesitant to re-interpret the material of other writers, I do not see any reasons to present pollen diagrams of my own from localities previously subjected to thorough pollen analyses.

Morphologically, the Varrassuo basin is a kettle hole (p. 70). Dead ice melted from the basin before the transgression which filled the Työtjärvi gap and adjoining basins up to the 156-m-level (p. 88), niveau I in the shoreline diagram. According to Okko (1957 a, pp. 31—32), the silt rich in humus underlying the Varrassuo peat contains a rather rich diatom flora, indicating fresh-water conditions of deposition. Probably the basal sediment was mainly deposited during stages I—III of the Baltic Ice Lake. The silt having been laid in pollen zone III (Okko, *loc.cit.*), the transgression and the lower stages of the Baltic Ice Lake (BI — B III) took place in pollen zone III.

In Donner's (1951, p. 54) opinion the two lake basins became isolated even before the lowermost layers of mud extensively mixed with sand were formed. The bottom sediments were laid in pollen zone III (*op.cit.*, pp. 45—47). Formation of peat in the Varrassuo basin also began in zone III (*op.cit.*, p. 44). The isolation thus took place during the Younger Dryas period after the stage of the Baltic Ice Lake III. Since the lowering of the ice-lake level from niveau III corresponds to the discharge of the Baltic Ice Lake at Billingen and to the beginning of the Yoldia stage (discussed on p. 130), the formation of the bottom layers of lakes Työtjärvi and

Mustajärvi and of the lowermost peat in the Varrassuo bog took place at the earliest during the Yoldia stage. In fact, Okko (1957 a, p. 31) has shown that the stage of the Yoldia Sea began in pollen zone III.

In order to gather additional data for pollen chronology, several kettle holes of the Bend were investigated pollen-analytically. Because the reinterpretation of Donner's material led to the conclusion that sedimentation of organic matter in the Työtjärvi gap began during the early Yoldia stage, the result was checked by investigating bogs located close to the Yoldia niveau.

KETTLE HOLES IN THE FIRST SALPAUSSELKÄ

Eight series of samples, all collected from kettle holes of the Bend, were investigated. The kettle holes are located in the Vesala and Sairakkala sections. They are filled either with bog vegetation or bog-rimmed ponds.

It was found that formation of detritus mud or peat began in six kettle holes in pollen zone VI. The pollen spectra of the lowermost samples were rich in pollen of *Alnus* (8—16 %); as a rule, pollen of *Corylus* (2—4 %) and *Ulmus* (1—4 %) were present. In the diagrams, the continuous *Tilia* curve begins somewhat higher up. The seventh diagram began in zone VII, indicated by the presence of *Tilia* in the pollen spectra of the lowermost layers. The regular start of deposition of organic matter in the kettle holes in pollen zones VI and VII, also in the northern part of the Työtjärvi gap, indicates a general rise of the groundwater table during the humid Atlantic period (VI—VII).

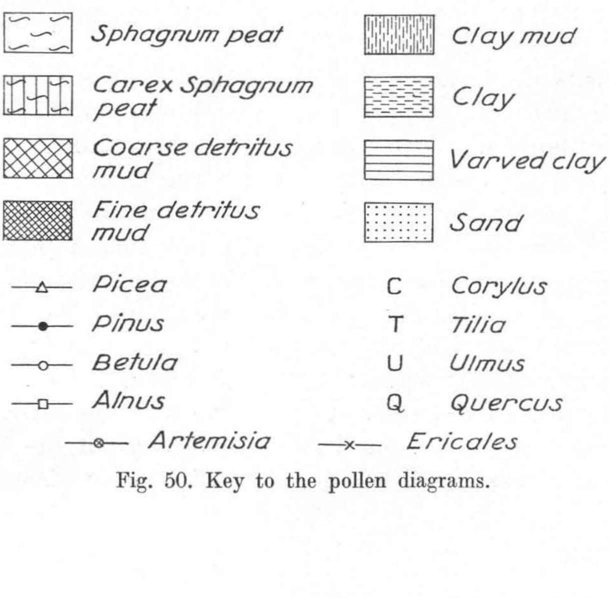


Fig. 50. Key to the pollen diagrams.

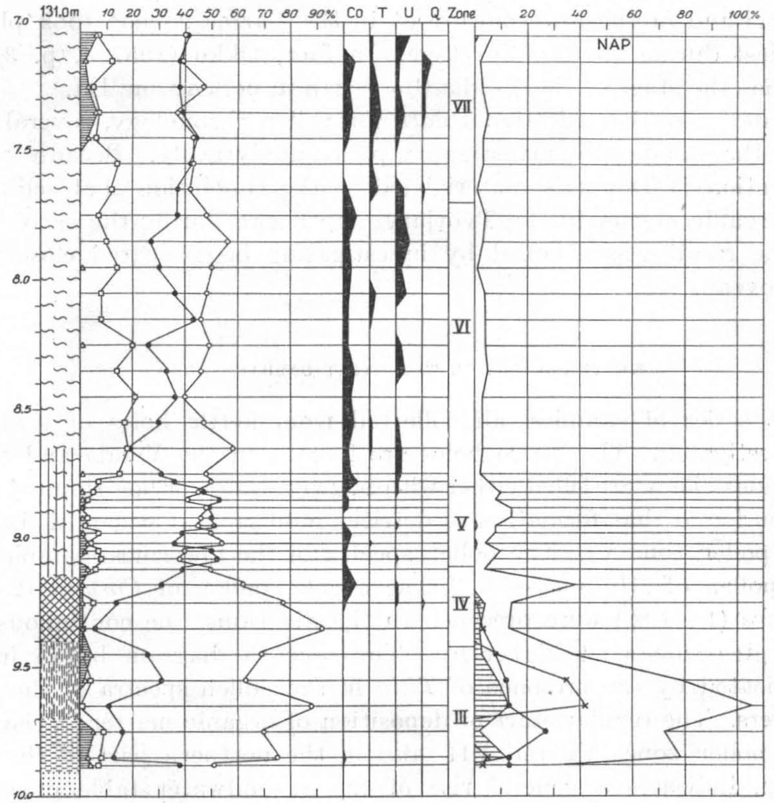


Fig. 51. Pollen diagram of the bog at the bottom of the Kotajärvi kettle hole, Vesala section. The horizontally lined field in the NAP column shows the number of *Salix* pollen /100 AP. Pollen analysis checked by Kyllikki Salminen.

Older deposits than those of pollen zone VI were encountered in the kettle hole occupied by the pond known as Kotajärvi, Vesala section (see Fig. 33). The bottom of the kettle hole is located at an altitude of 121 m the highest tops of its edge reaching the height 165 m. The stony slopes suggest that the kettle hole formed mainly in morainic drift. On the southwest it is bordered by the lateral terrace built towards the Vihattu gap during the transgression of the Baltic Ice Lake. The dead ice of Kotajärvi must have melted mainly after the formation of the terrace, the material of which was supplied by the glacier, whereas in the Työtjärvi gap the dead ice melted away mainly before the transgression.

The lowest point of the edge of the kettle hole has an elevation of ca. 140 m. This point is located on the proximal slope of the Vesala section, 10 m below the highest local shore marks. In many places, the slope is

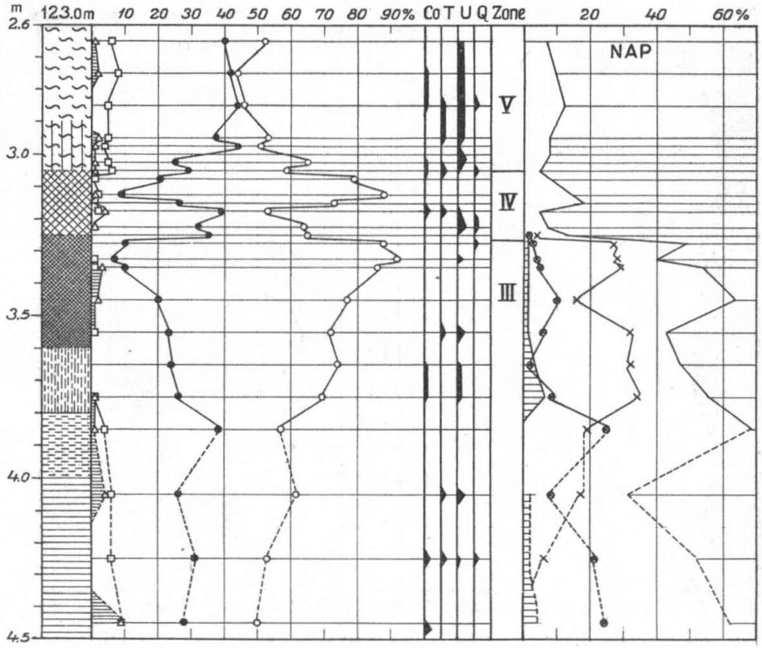


Fig. 52. Pollen diagram from the Nokkola bog in the foreland of the bend of the First Salpausselkä. This bog is located at the northeastern foot of of the Kauhalankallio hill, point 7 in Fig. 41. *Salix* is shown as in Fig. 51.

strongly deformed by dead ice topography. In all probability, the lowest point of the edge has nothing to do with isolation of the pond; it indicates only the altitude at which slumping and redeposition ended. The kettle hole probably developed independently of any larger body of water. The projection point of the Kotajärvi pond, marked *c* in the shoreline diagram, thus shows only the location of the kettle hole.

The sedimentary sequence encountered in the bore begins with sand and a thin layer of homogeneous clay. The clay is overlain by clay mud and detritus and, from 121.85 m upwards, by peat (Fig. 51). According to the pollen diagram, the clay and the clay mud were deposited in pollen zone III. Sedimentation of organic matter began here, as it did in the Työtjärvi gap, as early as in pollen zone III. The homogeneous clay was laid down by water derived from melting dead ice.

THE NOKKOLA BOG

The Nokkola bog is located in the foreland of the Bend, at the eastern foot of the Kauhalankallio hill. The isolation level of the bog basin is

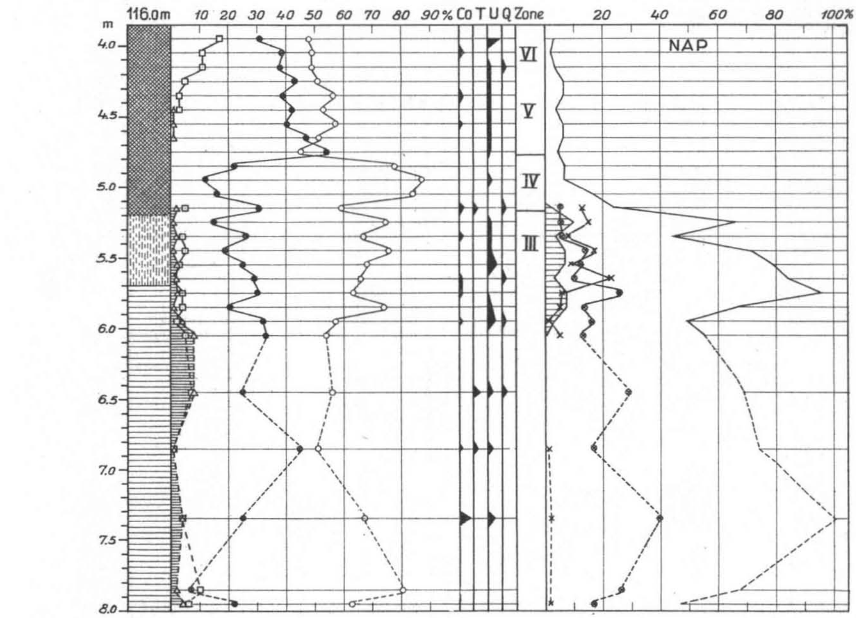


Fig. 53. Pollen diagram from Lake Sairakkalanjärvi in the village of Sairakkala in the immediate hinterland of the Sairakkala section. *Salix* is shown as in Fig. 51.

120 m and the inferred height of the Yoldia niveau at this site 113.5 m. The bog basin was thus isolated in connection with the lowering of the water level down to the niveau of the Yoldia I. The projection point of the Nokkola basin is indicated by the letter *d* in the shoreline diagram (Fig. 42, p. 118).

The sedimentary sequence penetrated by the bore (Fig. 52) indicates a normal development from a large body of water into a pond with a subsequent development of bog vegetation. The diatoms indicate a freshwater flora of small bodies of water. As the isolation level of the basin is 120 m the border between clay mud and detritus mud, 119.4 m at the bore site, evidently indicates a change in sedimentary facies due to isolation (see also Donner 1951, p. 55). According to the pollen diagram the isolation took place in pollen zone III.

LAKE SAIRAKKALANJÄRVI

Lake Sairakkalanjärvi occupies an elongated basin in the immediate hinterland of the Vihattu gap and the Sairakkala section. The elevation of the present lake is 116 m. According to information obtained from local farmers, the water level of the lake sank about 2 m a hundred years ago. The isolation level of the lake basin is thus approximately 118 m.

The isolation level of the Sairakkalanjärvi basin is indicated by the letter *e* in the shoreline diagram (Fig. 42, p. 118); it lies about 3.5 m below niveau V or the Yoldia I. The connection of the lake basin to the Yoldia Sea was very slight, also shown by the lack of halophile diatoms in the sediments of the lake bottom. Probably the lake basin was isolated from the Yoldia Sea at a relatively early stage. If the beginning of deposition of detritus mud is considered indicative of isolation (compare the Nokkola bog), it occurred well before the *Betula* maximum of pollen zone IV (Fig. 53), slightly before the transition from pollen zone III into zone IV.

DISCUSSION AND CONCLUSIONS

In none of the diagrams were pollen zones older than zone III encountered. Zone III is characterized by an abundance of pollen of non-arboreal (NAP) plants, *Artemisia* and *Ericales* forming the majority. In addition, pollen of *Cyperaceae*, *Gramineae*, *Chenopodiaceae*, *Caryophyllaceae*, *Rosaceae*, *Ranunculaceae* and *Compositae* were found. Pollen of *Salix* were also common. The border of pollen zones III and IV was drawn at the point where the NAP-curve passes the figure 30 NAP / 100 AP (arboreal pollen). According to the investigations of Aario (1940, 1944), this figure suffices as an indicator of woodless conditions, provided, however, that not more than half of the amount is of one and the same type of pollen. In some of the samples, pollen of different *Ericales* formed as much as 55—62 % of the total NAP. Donner (1951, tables 2, 7, 11 and 12, p. 83—86) has reported corresponding and larger figures from zone III. Although Aario's (1940) investigations have shown that *Ericales* pollen alone cannot be used as an indicator of tundra, it seems sensible to regard the samples rich in them as representative of a woodless period, especially when the samples occurred in the midst of typical pollen spectra of zone III.

In the Varrassuo diagrams (Donner 1951, p. 35—45), zone III occurred in peat and was also found in the silt underlying the peat (Okko 1957a, pp. 31—32). In the diagrams of Lakes Työtjärvi and Mustajärvi, pollen zone III was found in sand at the bottom of the lakes (Donner *op.cit.*, p. 45—47). In his pollen diagrams from the Yoldia level at Seesta Donner (*op.cit.*, p. 47—49) dated zone III in clay, but also in fine detritus mud (*op.cit.*, Fig 23, p. 50). In the diagrams presented on the previous pages, zone III has been identified in the sedimentary sequence clay — clay mud — detritus mud.

At lower altitudes, pollen zone III has been encountered in clayey and sandy sediments. Valovirta (Mölder, Valovirta and Virkkala 1957, p. 44), therefore, concluded that the production of organic matter, i.e., mud and peat, began at the transition from pollen zone III to IV when the cold and dry Younger Dryas period ended; the subsequent increase of humidity caused a rise of the groundwater table which favoured the formation of peat in depressions. The Kotajärvi, Nokkola, and Sairakkalanjärvi profiles show that the formation of organic sediments was here related to a sinking water level. According to the evidence of these localities formation of organic sediments could begin as soon as the basins were isolated, and, conceivably, as soon as the water was no longer contaminated with glacial milk. This occurred as early as in pollen zone III. Also in northeastern Finland, peat (Kanerva 1956, p. 97) and mud (Kanerva, *op.cit.*, p. 42; Vasari 1962, Pls. III, IV) started to form as early as in pollen zone III.

The drainage of the Baltic Ice Lake into the ocean, amounting to 28 m in height (see p. 130), increased rapidly the area of dry land in deglaciated southern Finland. The first vegetation to obtain a foothold on the emerged land consisted of non-arboreal shore plants. This might show up as a pseudotundra in pollen diagrams. Donner (1958) has pointed out that a tundra-like anomaly caused by shore vegetation might easily be misinterpreted as zone III. In the case of the Nokkola bog, this pitfall might not have been avoided but in the Sairakkalanjärvi diagram the *Betula* maximum of zone IV is so distinctly developed that there should be no doubt about the dating of the diagram. An interesting feature in the latter diagram is the relatively slow incline of the NAP-curve in zone IV. As a matter of fact, the NAP-pollens in the lower part of zone IV are the same as those found in zone III. This might reflect an occupation of virgin land by shore plants, but it has no great effect on the trend of the AP-curves.

The lowering of the water level in the beginning of the Yoldia stage must have been felt as a fall of the groundwater table, particularly in the Salpausselkä belt, largely built of permeable sands and gravels. The subsequent lowering of the water level in the Kotajärvi kettle hole probably started the deposition of detritus mud in pollen zone III. Here the pioneer plants which invaded the emerged land had no effect. Only the vegetation already flourishing on the Salpausselkä produced a pollen rain into the kettle hole.

Okko (1957a, p. 38) seems to be quite cautious in naming the period during which the sinking of the water level occurred. He calls it a forestless period. As I see it, pollen zone III in the present diagrams indicates the Younger Dryas period. This view is not only based on the foregoing arguments but also on Fries's (1951) investigations in southwestern Sweden. He was able to identify there pollen zone III as the Younger Dryas period. The characteristics of his zone III are quite similar to those of pollen zone III in the Lahti diagrams. When correlating Fries's results from the ocean side to the Baltic side of Sweden, Lundqvist (Magnusson, Lundqvist and Granlund 1957, p. 484—485) places the Baltic Ice Lake, its drainage into the ocean at Billingen, and the early Yoldia stage contemporaneous with zone III in Fries's pollen chronology. The same stages of the Baltic have been established in the Lahti—Jylisjärvi region and dated pollen zone III. Pollen zone X, roughly equivalent to the Younger Dryas, in T. Nilsson's (1935) pollen chronology for Scania, Sweden, also ends after the drainage of the Baltic Ice Lake, some 100 years later (see Magnusson, Lundqvist and Granlund, *loc.cit.)*.

According to Fries *(op.cit.)*, pollen zone III began in the year 8500 B. C. and ended in the year 7200 B.C. The corresponding age for zone III, the Younger Dryas period, is 8800 — 8000 B.C. in Sauramo's (1958, Fig. 16, p. 78) diagram. Zone III is thus roughly contemporaneous in southwestern Sweden and in the Lahti area. In Fries's chronology, however, the period lasted 700—800 years later than in Sauramo's and T. Nilsson's systems. Wenner (1960, p. 47) suspects there is an error of more than 500 years in the Swedish time scale; the start of the *Alnus* curve, hitherto dated 6300 B.C., has recently been C^{14}-dated 9100 $\pm$ 120 yr B.P. (Wenner, *loc.cit.)*. With this correction, Fries's pollen zone III would end around the year 8000 B.C. The correction does not, however, alter the fact that Fries's pollen zone III is 500 years longer than that of Sauramo and zone X of T. Nilsson. Regardless of these differences, the end of pollen zone III is simultaneous with the end of the Younger Dryas period as established in Sweden. The shoreline displacement in the Baltic has not caused any transition of pollen zone III in the Lahti area.

THE AGE PROBLEM IN THE LIGHT OF THE LAHTI AREA

In relation to the development of the Salpausselkä belt in the Lahti area, the pollen-analytically dated stages of the Baltic arrange themselves as follows: The margin of the ice sheet had started to retreat from the First Salpausselkä when the transgression of the Baltic Ice Lake reached its maximum. The ice had not yet melted away from the apex of the Bend. The maximum of the transgression and the subsequent stages of the Baltic Ice Lake as well as the drainage of the ice lake and the early Yoldia stage were events of the Younger Dryas period.

The First Salpausselkä distinctly antedates at its bend the transgression of the Baltic Ice Lake. The readvance of the glacier to the zone of the First Salpausselkä in the Lahti area probably occurred during a regressive stage: a part of the dead ice topography (Tiilijärvi section, Työtjärvi and Vihattu gaps) was formed and the sandur fields were deposited during a low stage of the sea.

Tynni (1960, p. 154) has recently established at Askola, in the southern coastal area, a low marine stage during the Alleröd period. This is in accord with Hyyppä's (1933, 1943) results in Karelia and in the Helsinki area (1962). According to von Post (1947) and E. Nilsson (1958), however, there was a marine transgression in southern Sweden during the same period, also traced in southern Norway (Andersen 1960) and, contrary to earlier views, in the Kola Peninsula in the U.S.S.R. (Nikonov and Lebedeva 1959). On the other hand, Auer (1959, p. 44) has shown on the basis of his observation material from Patagonia and Tierra del Fuego that the ocean level was lower during the Alleröd period than during the Older and Younger Dryas periods. Sauramo (1958, p. 44) correlated Auer's (*loc.cit.*) eustatic curve to his own curve for shoreline displacement in Fennoscandia. According to Sauramo, there was a regressive marine stage that began at the end of the Older Dryas period and was interrupted by the damming up of the Baltic Ice Lake. A low marine stage during pollen zone II has been traced by Donner (1959, p. 18) in Scotland. No transgressions are known to have taken place in Ireland during the Alleröd period (Synge and Stephens 1960). On the grounds of his Icelandic material, Einarsson (1961, pp. 40—41) has shown that the ocean was in a regressive stage during this period. It seems fairly certain that a part of the First Salpausselkä in the Lahti area was built during the low sea level of the Alleröd period.

The reason why pollen zone II has not been encountered in the pollen diagrams of the Lahti area is probably that, if there was vegetation in front of the glacier, it was of a tundra character, strong enough to endure long winters and the proximity of the ice sheet. Therefore, zone II cannot be distinguished with certainty from pollen zone III, the true tundra period.

The conclusion that the First Salpausselkä substage lasted in the Lahti area from the Alleröd into the early Younger Dryas period does not necessitate the generalization that the First Salpausselkä as a whole was built during this span of time. On the contrary, that the temperate margin of a glacier should have remained in one and the same position along a long front is highly improbable. As has been pointed out by Brenner and Tanner (1930, p. 13), »South [First] Salpausselkä indicates the geographical limit which the edge of the land ice reached during several minor successive oscillations.» It might show the outer limit of an original readvance, but in many places the active margin might have withdrawn to the zone of the Second Salpausselkä at an early stage, leaving dead ice in the inter-Salpausselkä zone. At the apex of the Bend the ice margin remained active relatively late because the two ice lobes had here grown quite thick. On the other hand, vast areas of dead ice and ablation topography extend from the Miehola bedrock area to the Second Salpausselkä at Jylisjärvi; also the kames topography of the Hatsina esker chain reflects strong stagnation. The abundant ablation that still took place during the Younger Dryas period might partly be due to eolian action, for wind-blown dust has the effect of furthering ablation, also in present polar glaciers (e.g., Hattersley-Smith 1961).

REVIEW ON LATE-GLACIAL EVENTS IN THE LAHTI AREA

1. The margin of the continental ice sheet withdrew from the southern coastal area of Finland to some position in the northwest. During this retreat the glacier ended in deep water. Abundant calving took place at the margin, particularly in the rapakivi area of southeastern Finland but also to some extent in the foreland of the First Salpausselkä in the Lahti area. The ice margin was probably rather thick; its glaciofluvial action was weak. Prevailing eastern summer winds of this time point to glacial conditions outside the glacier.

It is suggested that this period be referred to as the H e i n o l a d e g l a c i a t i o n. It is not known how far northwest the ice margin retreated during this period but the northwesternmost source of rapakivi erratics, transported by drifting icebergs, is the Ahvenisto massif, which is located mainly in the parish of Heinola.

2. The Heinola deglaciation ended in a readvance, which brought the ice margin to the position where the First Salpausselkä was to develop. The readvance in the Lahti area was, in all probability, a part of a S a l p a u s s e l k ä r e a d v a n c e, caused by a change in the regimen of the ice sheet. The Salpausselkä readvance occurred during a regressive stage in the Baltic basin.

3. In the Lahti area the First Salpausselkä marks the maximum of the Salpausselkä readvance. The regression in the Baltic continued. During the early First Salpausselkä substage, the water level of the sea in front of the glacier stood at 146—147 m at Työtjärvi (ca. 140 m in Lahti); possibly the regression lowered the water level still more.

In its general behaviour, the glacier margin was temperate. It conformed to the topography of the substratum; ice lobes and tongues developed in the margin; abundant stagnation took place in the marginal ice; owing to strong glaciofluvial action, sandur fields accumulated in front of the glacier; frontal ice lakes evolved between the margin and the frontal deposits; at the Tiirismaa nunatak there evolved a nunatak lake; stagnated tongues of ice melted rapidly. The climatic conditions at the ice margin were rather mild; in other words, the relatively warm Alleröd period is reflected in the behaviour of the ice margin at the First Salpausselkä in the Lahti area.

4. The regression in the Baltic was interrupted by the damming up of the Baltic Ice Lake. The transgressive shore eroded away a good part of the sandurs of the Bend. At its maximum, the transgression reached up to the 150-m-level in Lahti. In places, the ice margin had already left the First Salpausselkä; only the most active and thickest tongues still remained in this belt. All the active ice had disappeared from the Lahti area when the water level of the Baltic Ice Lake stabilized at a niveau 6 m below the level of the maximum transgression. The peak of the transgression and the subsequent stages of the Baltic Ice Lake took place during the Younger Dryas period. In the Lahti area the deterioration of the climate during the Younger Dryas period was marked mainly by eolian action.

5. The stage of the Baltic Ice Lake ended when the lake discharged into the ocean and the Yoldia stage began in the Baltic basin. The drainage of the ice lake occurred during the Younger Dryas period and thus only marks the end of the Baltic Ice Lake.

6. Formation of organic sediments set in during the Younger Dryas period whenever clear-water basins were isolated from the ice-lake or from the Yoldia Sea. In suitable conditions also the formation of peat started in emerged basins. A rise of the groundwater table as late as the humid Atlantic period accelerated the formation of organic sediments and peat, also in formerly dry basins, as, for instance, in the kettle holes of the First Salpausselkä.

CHRONOLOGICAL COMPARISONS

According to Sauramo's (1918, 1923) varve chronology, the deglaciation of southern Finland was an orderly retreat of the ice margin, interrupted by halts at the Salpausselkäs. There are no provisions in the time scale for the Heinola deglaciation and the Salpausselkä readvance. One source of error probably lies in that Sauramo's eastern varve line — contrary to his presupposition — runs at an angle toward the trend of the glacier margin retreating from the southern coastal area. The low stage that preceded the Baltic Ice Lake might also have caused gaps in some varve sequences.

Starting from De Geer's O-year (6893 B.C.) and by using Sauramo's correlation according to which the year + 1300 in his varve chronology is equivalent to the year —64 in the Swedish one (Antevs 1953), the calculated absolute age of Sauramo's O-year (Second Salpausselkä) is 8202 B.C. (Hyyppä 1962). By means of pollen analyses, varve countings, and careful correlations to the C^{14}-dated Swedish time table, Hyyppä (1962) has dated the varve —660 of Sauramo 8900 B.C. Counting from this varve the absolute age of Sauramo's O-year is 8240. The difference in the ages obtained in these procedures is only 38 years.

Radio-carbon datings of the Younger Dryas period in northwestern Europe and in Britain (e.g., Gross 1958, pp. 179—180) provide an absolute age for its beginning, 8800 B.C., more often regarded among Scandinavian and Finnish geologists as 8900 B.C. In southern Finland the beginning of the Baltic Ice Lake coincided with the transition Alleröd/Younger Dryas (Hyyppä 1960; Tynni 1960) or with the year 8900 (Hyyppä 1962). The Karelian Ice Sea (Rapakivi Sea) as well as the following low stage during which the sandurs of the First Salpausselkä in the Lahti area were built antedate the Baltic Ice Lake and, correspondingly, the Younger Dryas period.

A comparison of the results presented in this paper with the Swedish chronology of deglaciation (Lundqvist 1961, södra bladet; see also E. Nilsson 1960) leads to the conclusion that the Salpausselkä stage at Lahti began earlier than the stage of the Middle Swedish Moraines: In Sweden the deglaciation proceeded towards the north, the southernmost moraine belt lying close to the recession line 8900 B.C. Southern Finland was deglaciated during the stage of the Karelian Ice Sea (Rapakivi Sea); during the subsequent low stage the Salpausselkä readvance brought the ice margin to the First Salpausselkä zone. Because the low stage and the deposition of the First Salpausselkä sandurs in the Lahti area took place before the year 8900 B.C., in Sweden the ice margin must have lain south of the southernmost Middle Swedish Moraines when the formation of the First Salpausselkä was already going on at Lahti. In Sweden the ice margin lay still farther south when the Heinola deglaciation and the stage of the Karelian Ice Sea took place in Finland.

The drainage of the Baltic Ice Lake into the ocean at Billingen close to the year 8300 B.C. in the Swedish chronology, — in the year 8315 B.C. according to E. Nilsson (1960, p. 106) — gives a reliable correlation date. In Finland the drainage is registered along a line located some 3—5 km NW of the western flank of the Second Salpausselkä (e.g., Okko 1957 a, Virkkala 1961). According to C^{14}-datings (e.g., Gross 1957, 1958) the Younger Dryas period ended around the year 8000 B.C. The beginning of the Yoldia Sea in the Baltic basin during the Younger Dryas period was also shown (p. 146) on the basis of pollen diagrams from the Lahti area.

The picture of the contemporaneous Fennoscandian Moraines is correct only for the very last stage of the Baltic Ice Lake. The Middle Swedish Moraines of the year 8300 B.C. may be linked to Finland in a zone somewhat behind the Second Salpausselkä belt. To correlate the Swedish Moraines to Finland during the development of the First Salpausselkä has no safe grounds: As yet, we do not know the age of the maximum of the Salpausselkä readvance, except that in the Lahti area it occurred during a regression, presumably during the Alleröd period.

During the early late-Weichsel the eastern part of the Scandinavian ice sheet shrunk considerably (e.g., Biske 1959, p. 294). Then there evolved an active ice lobe and the Salpausselkä readvance set in. The development of the ice lobe obviously registered a change in the regimen of the glacier, possibly caused by increased precipitation of snow in the firn area. In regard to the character of the three sub-ages of the late-Weichsel, the assumption is presented that the change took place during the middle Alleröd period, when, for instance, in the Netherlands the climate changed over from continental to maritime (van der Hammen and Maarleveld 1952, p. 53). The increased maritimity must have been felt all along the west coast of northwestern Europe, including the Scandinavian mountains, which were covered with the ice sheet. Increased precipitation in the western part of the ice sheet would explain the delay of the ice in southern Sweden and the formation of an ice lobe towards the east, into Finland. (Worth mentioning in this connection is Hattersley-Smith's (1960, p. 48) forecast concerning the glaciers of the northern Ellesmere Island: A milder and moister climate in the Arctic, with the effect of a rise in temperature on the high level accumulation areas, might lead not only to higher precipitation but to an advance of the main glaciers.) The Salpausselkä readvance thus represents a feature of its own, apart from the stage of the Middle Swedish Moraines. The Finnish part of the Fennoscandian Moraines began to develop much earlier than the western parts, that is, during the Alleröd period.

For the time being, it is advisable not to correlate the Salpausselkä readvance to any readvance of the Younger Dryas period. The Salpausselkä stage in Finland should not be correlated directly to other areas, either. However, the position of the ice margin at the end of the Baltic Ice Lake, an event of the Younger Dryas period, is known by its traces in many localities in Finland and Sweden.

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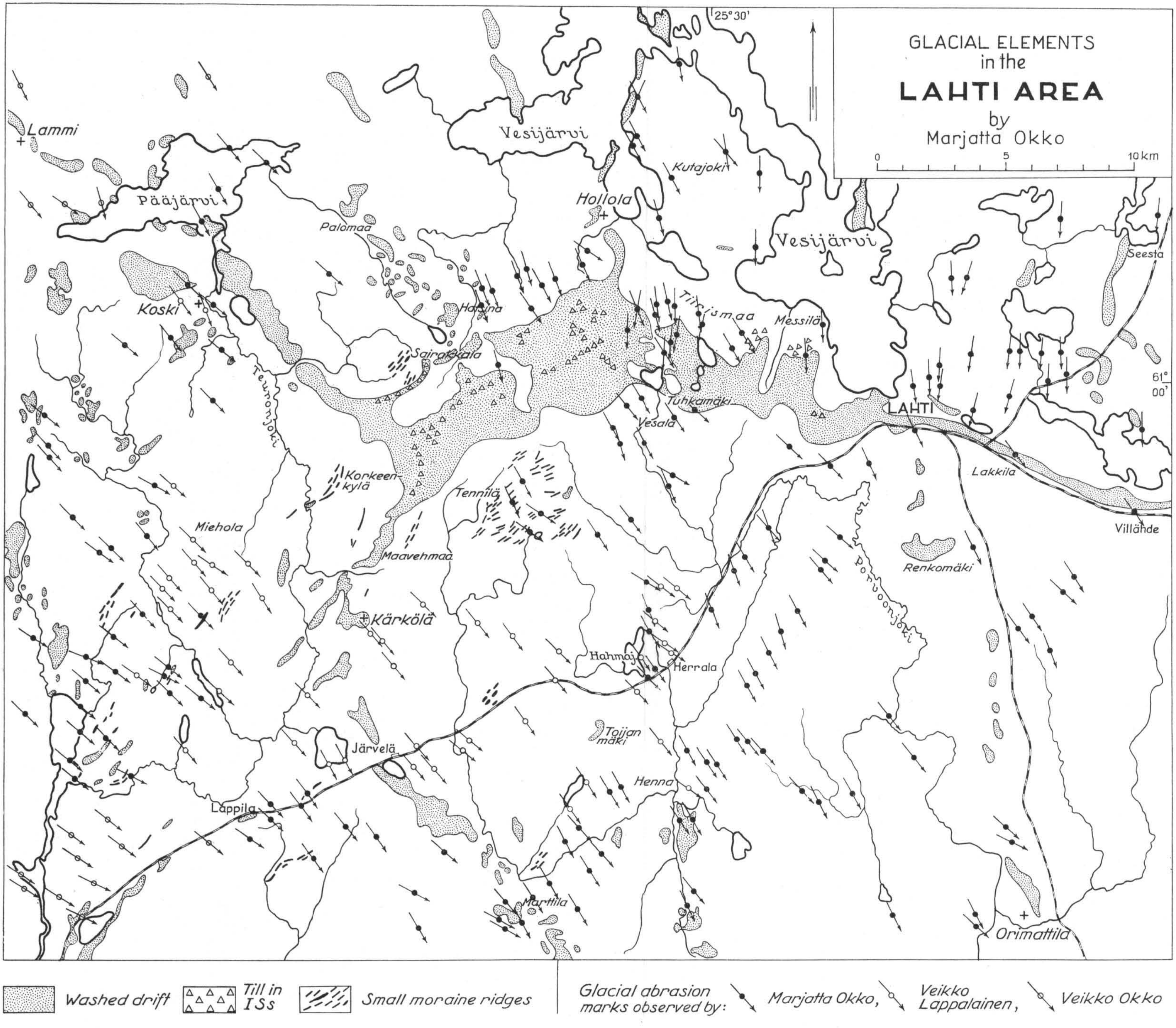

Marjatta Okko: On the Development of the First Salpausselkä, West of Lahti.