LATE WEICHSELIAN END MORAINES AND DEGLACIATION IN EASTERN AND CENTRAL FINLAND

Synopsis

Heikki Rainio

Geological Survey of Finland
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by

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with 4 figures in the text

ACADEMIC DISSERTATION

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At the beginning of the Salpausselkä I phase, the front of the ice sheet run from Värtsilä along the Finnish-Russian border northeast to Möhkö, where it crossed over into Russian Karelia. During the Salpausselkä I phase, the ice sheet front, instead of remaining stationary in North Karelia as it did farther west, withdrew. *The Tuupovaara end moraine* deposited during the late Salpausselkä I phase.

Salpausselkä II and *the Koitere end moraine* are largely contemporaneous. However, the relationship between the end moraines of Tuupovaara and Koitere suggests that the part of the Koitere end moraine east of Lake Koitere may have begun to form during the last Salpausselkä I phase, at the same time as that of the Tuupovaara end moraine, and that it represents the end of Salpausselkä I phase and the Salpausselkä II phase. The Koitere end moraine is physically correlative with *the Rugozero (Rukajärvi) end moraine* in Russian Karelia.

The Pielisjärvi end moraine constitutes the third chain of ice-marginal deposits. Its position, esker analysis and the base level of erosion during its formation all demonstrate it to be younger than Salpausselkä II and the Koitere end moraine. It may be correlative in time with Salpausselkä III; physically it is correlative with *the Kalevala moraine* in Russian Karelia.

The ice sheet readvanced twice for tens of kilometres in late-glacial time, first before the deposition of Salpausselkä I, and then again before the deposition of the Central Finland end moraine. These extensive oscillations are called *the Heinola deglaciation-Salpausselkä readvance* and *the Keuruu deglaciation-Jyväskylä readvance*, respectively.

Key words (GeoRef Thesaurus, AGI): glacial geology, glacial features, ice-marginal features, Salpausselkä, Central Finland end moraine, stratigraphy, deglaciation, readvance, Quaternary, Pleistocene, Weichselian, historical geology, Finland, Central Finland, Eastern Finland, Russian Federation, Republic of Karelia.

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... reality can stand even the most improbable theoretical structures... (Hermann Broch, Sleepwalkers III)

TO KARELIA AND TO IT'S PEOPLE

CONTENTS

The thesis is based on the following papers referred to by the Roman numerals:

I **Rainio, H. 1983.** The Tuupovaara end moraine in North Karelia, Eastern Finland - an ice marginal formation of the same age as the Salpausselkä ridges. Bulletin of the Geological Society of Finland 55, 67-76.

II **Rainio, H. 1985.** Första Salpausselkä utgör randzonen för en landis som avancerat på nytt. Summary: The First Salpausselkä is a marginal formation of the outermost margin of a readvanced ice sheet. Geologi 37 (4-5), 70-77.

III **Rainio, H., Kejonen, A., Kielosto, S. & Lahermo, P. 1986.** Avancerade inlandsisen på nytt också till Mellanfinska randformationen? Summary: Is the Central Finland ice-marginal formation terminal? Geologi 38, (4-5), 95-109.

IV **Rainio, H. 1991.** The Younger Dryas ice-marginal formations of Southern Finland. Eastern Fennoscandian Younger Dryas end moraines. In: Field conference, North Karelia, Finland, and Karelian ASSR, June 26 - July 4, 1991. Excursion guide. Rainio, H. & Saarnisto, M. (eds). Geological Survey of Finland, Guide 32. 1991. Pp. 25-72.

V **Rainio, H. 1993.** The Heinola deglaciation and Salpausselkä readvance as recorded in the lithostratigraphy of the distal area of Salpausselkä I at Ihalainen, Lappeenranta, Finland. In: Geological Survey of Finland, Current Research 1991-1992. Autio, S. (ed.). Geological Survey of Finland, Special Paper 18, 53-62, 1993.

VI **Rainio, H., Saarnisto, M. & Ekman, I. 1995.** Younger Dryas end moraines in Finland and NW Russia. In: IGCP 253 - Termination of the Pleistocene - final report. Lundqvist, J., Saarnisto, M. & Rutter, N. (eds.). Quaternary International, 28, 179-192.

Preface

Thirty or so years ago it was still widely believed, mainly in the light of interpretations of shoreline displacement, that the front of the Scandinavian Ice Sheet ran from Joensuu northwards or north-northwestwards during the deposition of the Salpausselkäs. There were, however, no ice-marginal deposits to support this view, advocated mainly by Hyyppä (1936) and Sauramo (1958). Hyvärinen (1966b) raised doubts about the tenability of the concept. In his master´s thesis on the Uimaharju end moraine, Rainio (1965) had already suggested that at the time the Jaamankangas and Uimaharju moraines deposited the ice front continued eastnortheastwards to the north of Suomujärvi. The old general map of Quaternary deposits (Frosterus, 1920; Frosterus & Wilkman, 1915) also showed landforms that might serve as extensions of the Salpausselkäs. The original aim of the present study, which is a direct consequence of the above thesis, was to establish the position of the ice sheet front in eastern North Karelia at the time the Salpausselkäs were forming.

Later, however, the scope of the study enlarged to include the structure of the Salpausselkäs and the Central Finland end moraine and the stratigraphy of their proximal zones. As data on cuttings, glacial striae and stratigraphy accumulated from these zones, it became increasingly obvious that events during the final phase of glaciation in southern Finland were more complicated than had commonly been believed a couple of decades earlier, and that the ideas of "non-uniformity" of deglaciation suggested many years earlier should in fact be given serious reconsideration. Hence, the last deglaciation in southern and central Finland and the position of the large end moraines - the Salpausselkäs and the Central Finland end moraine - were included in the study (Fig. 1).

Thus this study embraces two related major topics:

1) The Younger Dryas end moraines in eastern North Karelia and their relation to the Salpausselkäs and large ice-marginal complexes in Russian Karelia, i.e. the location of the continental ice sheet margin in North Karelia at the time of formation of the Salpausselkäs (I, IV, VI) and

2) the last deglaciation and the contemporaneous large oscillations of the Scandinavian Ice Sheet in southern Finland (II, III, V and partly IV, VI).

Joint publications

Publications III and VI are joint publications. The contribution of the authors are as follows:

The material for paper III was collected by the authors in the course of various assignments, mainly the mapping of Quaternary deposits and the assessment of gravel resources. The contributions of Rainio and Lahermo were made specifically with this study in mind in connection with the investigation of the Central Finland ice-marginal formation. The observations of Kejonen and Kielosto derive mainly from the western part and those of Rainio and Lahermo from the eastern part of the area. The bulk of the paper was compiled and written by Rainio.

The authors of paper VI participated in studies on the Younger Dryas end moraines between Hanko and Kem in Russian Karelia, and the overall picture is a combination of their views. Rainio dealt mainly with the ice-marginal deposits in Finnish North Karelia and their relation to the other parts of the ice-marginal landform chains. Saarnisto alone is responsible for the discussion of late-glacial hydrology.

INTRODUCTION

General

The bedrock of southern Finland is composed of crystalline palaeo-Proterozoic rocks. The easternmost part of the bedrock, east of the Pielinen-Värtsilä area, is of older, Archaean origin.

In the southernmost part of southern Finland the local variation in elevation is slight, usually no more than a few tens of metres. In central and eastern Finland, the variation is greater but still seldom over 100 m. Movements of the continental ice sheet were probably affected most by the ridges in the Koli-Värtsilä area, where the maximum variation in elevation is 200-250 m.

Southern Finland was largely subaquatic at the end of glaciation. That there were large supra-aquatic areas in central and eastern Finland is revealed by the distribution of glacial and postglacial deposits (Kujansuu & Niemelä, 1984), which clearly depends on whether the area was supra- or subaquatic. The occurrence and structure of the Salpausselkäs and the Central Finland end moraine were also affected by the position of the front of the ice sheet at which they deposited, i.e. whether it was on land or in water (Ramsay, 1921; Rainio & Lahermo, 1985; Eronen & Vesajoki, 1988).

Fig. 1. *The Salpausselkä I, II and III end moraines in southern Finland together with their correlatives in Finnish North Karelia: the Koitere and the Pielisjärvi end moraines and the Central Finland end moraine. The Tolvajärvi and Petkeljärvi interlobate esker systems are situated on the distal side of the Koitere end moraine. The question of their belonging to the same deglaciation phase is crucial for the interpretation of the deglaciation (modified from Rainio et al, 1995).*

The uppermost shoreline in and to the south of the Salpausselkä I and II zone is that of the Baltic Ice Lake, but on the proximal side of the zone it is the shoreline of the Yoldia Sea or local glacial lakes (Donner, 1969; Saarnisto, 1970). At the time Salpausselkäs were forming the front of the continental ice sheet in eastern North Karelia was on land or in glacial lakes (Hyvärinen, 1971b; Vesajoki et al., 1986).

The Salpausselkä zone has been very important for Quaternary geological studies in Finland. An area of anomalous deglaciation, its geology is strikingly different from the rest of the Finnish Quaternary. Research into it, as into any anomalous area, provides more information on the whole deglaciation event, to say nothing of the formation of the Salpausselkäs, than would normally be available. Sederholm (1889) and Ramsay (1891), two Finnish geologists, were among the first to realize this (Rainio et al., 1982). Half a century earlier Nordenskiöld had tested the glacial theory on the Salpausselkäs, but come to a negative conclusion (Rainio & Kukkonen, 1985). Today, the Salpausselkäs are a Younger Dryas reference area of global importance (Lundqvist & Saarnisto, 1995).

Efforts to unravel the history of the Salpausselkäs constitute an important chapter in the history of research into Quaternary geology in Finland. Therefore, the course taken by Quaternary geological research, studies of the Salpausselkäs and the use of the Salpausselkä concept are treated at some length in what follows.

Concepts and nomenclature

Salpausselkä I, as an entity of that name, is here considered to terminate at a marginal plain at the village of Patsola, Värtsilä. Salpausselkä II terminates immediately south of the village of Kiihtelysvaara. Its northernmost plains on the basic maps (4241 04 Viesimo and 4241 05 Kiihtelysvaara) are Puustellinkangas, Metsälänsalo and Kirkkokangas. South of Kiihtelysvaara, Salpausselkä II continues in the east up to Sykönvaara and Kannusvaara, as agreed unanimously by researchers.

The large interlobate zone of Tervasuo (Rainio, 1990) and the large esker of Yhdysharju (Connection esker) (Frosterus & Wilkman, 1915) continue from Salpausselkä II towards Jaamankangas (Fig. 2). These interlobate formations were once included in Salpausselkä II (e.g. Repo, 1957).

Because general agreement is still lacking as to the relation of the North Karelian end moraines to the Salpausselkäs, individual names have been proposed for each apparently synchronous marginal deposit (Rainio, 1985b). In North Karelia the ice-marginal systems corresponding to the Salpausselkäs constitute three prominent rows (Rainio et al., 1995, Fig. 6 [VI]): the Tuupovaara, Koitere and Pielisjärvi end moraines (Rainio, 1985b). These "continuations" of the Salpausselkäs are not, however, parallel over their entire length, and so the corresponding positions of the ice front are not indisputable.

The above names are used here, as are the names first used by researchers when possible. Otherwise the names are those given on basic map sheets.

It is not always easy to distinguish between an ice-marginal formation and its proximal part. Here, then, the ice-marginal formation is considered to include those components that have counterparts over a fairly long distance throughout the ice-marginal formation entity; it does not include parts that were clearly formed later than the main chain, even though they may appear to join the latter. Such parts are the Tervasuo complex and the complex of ice-marginal and interlobate deposits between Kiihtelysvaara and Pyhäselkä.

The Heinola deglaciation and the Salpausselkä readvance refer to the deglaciation and readvance stage of the continental ice sheet before the deposition of Salpausselkä I as defined by Okko (1962, p. 150) (see Rainio, 1985a [II], 1991, 1993).

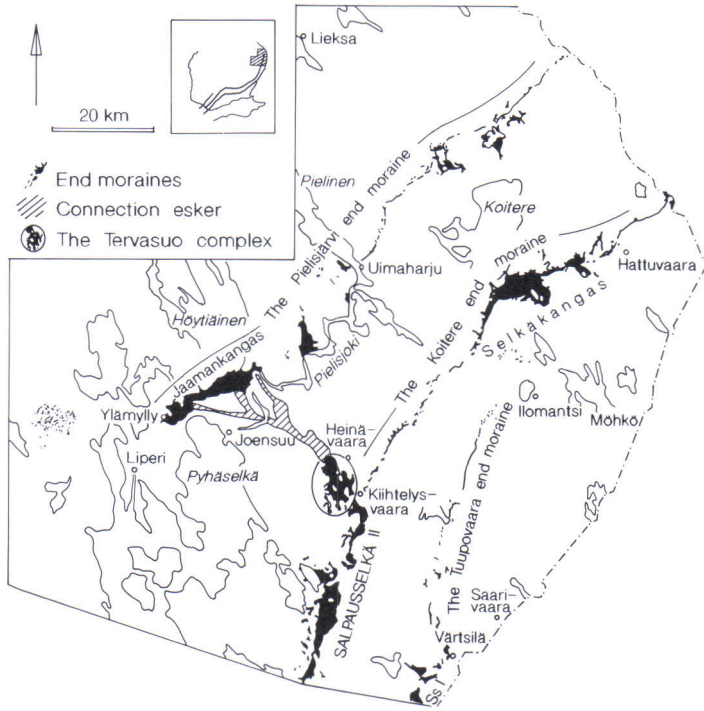

Fig. 2. Major end moraines in Finnish North Karelia: the Tuupovaara, Koitere and Pielisjärvi end moraines, as well as the Tervasuo interlobate complex and the Connection esker (Yhdysharju) (modified from Rainio et al, 1995).

In this context, the zones of the Salpausselkäs and the Central Finland end moraine refer to the glaciogeologically exceptionally complex proximal areas of these landforms.

The term *deglaciation phase* is used here for those events of the total deglaciation during which the ice sheet did not readvance significantly. Such a term is necessary when the mutual relations of glacial deposits - ice-marginal deposits and eskers in particular - are considered within the framework of large entities. The Heinola deglaciation, for example, is a deglaciation phase that ended with the Salpausselkä readvance event.

The term of base level is used as defined by Flint & Skinner (1977, p. 146-147, G2).

The geomorphological names are conventional and were often coined by chance. They do not usually refer to strictly confined entities that would not permit a single piece to be removed or added. To avoid confusion, however, these names should be used consistently and with a reasonable amount of accuracy.

HOW THE GLACIAL THEORY WAS ACCEPTED IN FINLAND

(according to Rainio 1994, pp. 20-23)

Observations calling for explanation

In 1740, the Swedish prospector Daniel Tilas (1712-1772) showed that the source of erratic boulders resting on a 'wrong' rock in Finland should be searched for in the north or northwest (Nathorst, 1894, p. 50). In 1821 and 1822, the Englishman Strangways listed localities in Finland where the bedrock was a source of boulders that had migrated to Russia (Strangways, 1821, pp. 39-30; 1822, p. 10).

Networks of eskers and sandy ice marginal deposits were described from Finland in the 18th century (Heinricius, 1895; Argillander, 1784). The landforms were considered as entities and the first explanations of their genesis were made in the early 19th century. In 1819, for example, Henrik Deutsch concluded that some eskers were 'products of water' (Deutsch, 1819, p. 369) (Rainio & Kukkonen, 1985, p. 11).

Striae were known back at the time of Tilas; what was not known was that they showed parallel orientation within large areas (Sefström, 1837, p. 1). Encouraged by the example of the Swedish chemist N.G. Sefström (1787-1845), Finnish scholars began to collect information on striae in the late 1830s.

Potholes were studied at around the same time (Nordenskiöld, 1842), and the contribution of flowing water to their genesis was acknowledged. In the late 1830s, Hofmann and Boehtlingk made observations on the transport of boulders in Finland, and on uplift and ancient shores (Hofmann, 1841, pp. 119-120 and 124-125; Boehtlingk, 1839, 1840a).

The first universally applicable explanation proposed was a deluge. Next came rapid, large-scale movements of the Earth's crust, floods and parallel movements of great earth masses (Boehtlingk, 1939, p. 4).

Among the foreign scholars who studied Finland was Strangways (1821, p. 42). He deduced the direction of the flooding waters from the transport directions of erratics or from the trend of striae and eskers. Another was Sefström, a Swede whose rolling stone, or petridelaunian, flood theory had enormous influence in Finland (Sefström, 1837). According to him, a colossal stream had loosened and transported rolling stones and sand, erratics and gravel from north to south. Stones and sand had polished the roche moutonnées. As the force of the stream abated, gravel and sand deposited as long eskers parallel to its flow. (Sefström, 1837; Rainio, 1994, Fig. 4)

Observations of icebergs in polar regions in the late 19th century led to the idea that alien boulders had been transported by icebergs (Murchison et al., 1848, p. 508; Flint, 1971, pp. 11-12). Several students of Finnish geology accepted this explanation to lend weight to their own hypotheses or then they based their own ideas on it (Nordenskiöld, 1863).

Wilhelm Boehtlingk (1809-1841) studied the diluvium of Finland in detail in the late 1830s. He made the important observation that the striae are oriented radially from the head of the Gulf of Bothnia and not merely from north to south, as suggested by Sefström (Boehtlingk, 1840b; Rainio & Kukkonen, 1985, Fig. 2).

The absence of sedimentary rocks in Finland and the Kola Peninsula and their occurrence on the other side of the Gulf of Finland, the signatures of abrasion visible on hard granitic rocks and striae trending in different directions in different parts of the country led Boehtlingk to reject the theory of a deluge of short duration as inadequate and propose instead a long diluvial stage with varying flows (Boehtlingk, 1839, p. 20 and 1840a, p. 108; 1840b, p. 208).

According to him, the stage began with the sudden uplift of Scandinavia, Finland and the Kola Peninsula followed by the withdrawal of the huge water mass that had inundated these areas. The latter had caused the transportation of loose soil and old sedimentary rocks to the boundary of the present crystalline bedrock area (Boehtlingk, 1840b, p. 207-208). Mudflows streaming in different directions from the centre of uplift scoured the roche moutonnées and carved striae on their surface (Boehtlingk, 1839, p. 25 and 1840a, p. 127; Rainio, 1994, Fig. 5).

Glacial theory

From its very earliest days, the glacial theory as defined by Agassiz (1840) in his "Etudes sur glaciers" was known in Finland. Boehtlingk had started to polemize against it (Boehtlingk, 1841), but his untimely death put an end to his resistance. At first, other dissidents either referred to Sefström and Boehtlingk or elaborated their own concepts while arguing against the glacial theory.

The theory was still incomplete at that time and could not explain all that is now known about the behaviour of a glacier. The objections to the theory thus often arose from the need to point out these inadequacies.

Scholars just could not understand how apparently rigid and brittle ice could have circumflexed rock knobs and carved striae on their sides, let alone under ledges (Boehtlingk, 1841). Flowing water had undoubtedly assisted the formation of potholes.

Eskers and the ice marginal moraines of Alpine glaciers, alike in appearance but different in internal structure, were compared with each other as if the glacial theory had maintained that they had been formed in a similar manner (Rainio, 1994).

It was also difficult to understand how an Alpine glacier could have spread to cover half of Europe and to rise uphill (Rainio, 1994).

Up to the early 1860s, only one student of Finland clearly defended the glacial theory; that was Eichwald, an adherent from the very beginning (Söderbaum, 1927; Eichwald, 1843). At that time, scholars were willing enough to accept the theory, according it equal validity with many others, but they lacked the courage to make a clear break with the past (Holmberg, 1858; Thoreld, 1863). Some opinions were expressed so vaguely that no one could be quite sure what was actually meant (Moberg, 1857; Mäklin, 1863). On his field maps, now held in archives, Thoreld (1862) was the first to refer to till as 'glacierbildning'.

Adolf Moberg, a professor of physics at the University of Helsinki, studied diluvial phenomena for a good 15 years and, and from 1849, gave several lectures on the subject to the Finnish Society of Sciences and Letters. At first he favoured deluges as an explanation for his observations, but he gradually changed his mind.

At a lecture he gave to the Society in 1865, Moberg definitely came out in favour of the glacial theory. He stated that the theory was capable of explaining 'the northern diluvial and post-Pliocene formations' most logically and most naturally on the basis of physical conditions still prevailing (Moberg, 1865).

Although not often discussed in the Finnish literature, the glacial theory had obviously sparked considerable debate. The ground had been prepared for it, and the generation which had staked its honour on the old ideas was passing. After Moberg's lecture, the old theories were consigned to the past in Finland. (Rainio, 1994, pp. 20-23)

STUDIES ON THE SALPAUSSELKÄS (IV, s. 33-38)

The Salpausselkäs and eskers are understood as entities

Long before the Salpausselkäs became a subject of geological study they would appear to have aroused people's interest as formations of an exceptional nature. For example the uppermost Viipuri road seems to have followed Salpausselkäs I and II way back in the 15th and 16th centuries (Wallin, 1893, pp. 59 - 91).

Geographical descriptions started to talk of the Salpausselkäs as eskers in the late 18th century. In his description of the parish of Lohja in 1766, Heinricius showed that the network of the western parts of Salpausselkäs I and II and the associated eskers were known all the way to southern Ostrobothnia (Heinricius, 1895; Rainio, 1985c).

Writing in 1784 in the Åbo Tidningar newspaper about Tuneld's Geography of Sweden published in 1773, Abraham Argillander elaborated on Tuneld's brief reference to an esker. His full description of the esker network in southern Finland includes long stretches of the two Salpausselkäs (IV, Fig. 5) (Rainio, 1985c).

The information given by Argillander and Heinricius reveals that the course of the Salpausselkäs between Joensuu and Tammisaari had already been well established by the end of the 18th century, considering the facilities of the time. A more detailed description was to wait for almost a century.

In the early 19th century, the origin of surficial deposits - eskers and the Salpausselkäs included - was explained in terms of the diluvial theories (Rainio & Kukkonen, 1985). The first attempt to assign the Salpausselkäs to their proper position in geology was made by Wilhelm Boehtlingk in 1839.

Although N.G. Nordenskiöld did not believe in the new glacial theory he applied it to Salpausselkä I while studying the cutting for the Saimaa canal in 1846. He thought that the Salpausselkä "would be a huge ice-marginal moraine provided that the theory of Agassiz holds". However, according to Nordenskiöld, the degree of sorting of the sediments in the section demonstrated that this could not be the case. These ideas he expressed in a letter to J.J. Berzelius (Arppe, 1867, p. 34). However, it was not until a quarter of a century later that they were further elaborated by Wiik.

The first comprehensive description of the extensive ice-marginal formation of the Salpausselkäs was published by Anders Thoreld in 1863. He described a great cutting formed when the waters of Höytiäinen discharged through the large glaciofluvial delta of Jaamankangas in 1859. He considered Jaamankangas part of an extensive esker network, but was unable to decide whether or not the ice age had anything to do with it (Thoreld, 1863; Rainio & Kukkonen, 1985, p. 74 and Fig. 10).

The name Salpausselkä

The name Salpausselkä was introduced at about the same time as the glacial theory was gaining ground in Finland in the late 1850s. Originally, however, it referred to a certain part of the water divide network, not to a conspicuous geological formation.

Detailed descriptions of Finland's water divide ridges and their network are to be found in geographical papers written over two centuries ago. Until the mid-19th century Maanselkä was the only name used for long stretches of these water divides (in Swedish Landtryggen, Land-Ryggen, Landrygg, Landtryggen (Tuneld, 1795)). Part of the geological Salpausselkäs were included in that network, albeit still as nameless units, in the 18th century (Tuneld, 1795, pp. 260-261; Rein, 1839, pp. 7-9). By the 1850s it had become necessary to distinguish between the different parts of the network, a task that was undertaken by Mr Gyldén, director general of the National Board of Survey.

According to Ramsay (1921), the name Salpausselkä first appeared in notes for geography lectures given by Z. Topelius in 1854-1858. As shown by these notes, in March 1857 Topelius used the nomenclature of water divides compiled by Gyldén; in autumn 1857 he included the name Salpausselkä.

Gyldén, then, coined both the name Salpausselkä and the names of the other parts of the water divide network (Ramsay, 1921). The archive of names kept by the Research Institute for the Languages of Finland does not contain a vernacular Salpausselkä; it is in fact a scientific makeshift (Saara Welin, oral comm. 15.1.1996). Thus, there was no small ridge going by the name of Salpausselkä, which could later have been extended to cover a larger entity.

The name Salpausselkä first appeared in print in the Hallstén geography of 1858 in the form Salpausselänne. On a historical and geographical map published for schools in the same year the name was in the form Salpanselkä (Lillja, 1858), by which was meant a "southern water divide, separating central Finland from the south coast" (den södra skiljovägg, som afsöndrar det mellersta landet ifrån den södra kusten, Salpan- (rättare Salpa-) selkä) (G.R., 1859) (Saarnisto et al., 1994, Fig. 8). It seemed appropriate enough as a name for a water divide because the ridge was thought to impound the waters of the Finnish lake district. In describing the Vuoksi watercourse, Ignatius (1891), expressed it thus: "The water mass, which fills all the depressions in an almost horizontal terrain, .. meets in the south at Salpausselkä a wall that prevents it from flowing to the Gulf of Finland."

The meaning of Salpausselkä is clear enough on the map of Lillja. In present-day terms, Salpausselkä marked the southern boundary of the Eurajoki, Kokemäenjoki, Kymijoki and Vuoksi watercourses. In the west, it started south of Rauma, ran south of Lake Pyhäjärvi in Säkylä, to the areas of Somerniemi and Loppi, and from

there via Riihimäki, Oitti and Järvelä to Salpausselkä I at Sairakkala, Hollola. From there it followed Salpausselkä I to south of Lake Pyhäjärvi in Uukuniemi, and then continued west of the village of Kitee to Salpausselkä II at about Tolosenmäki, Kitee. It followed Salpausselkä II to the church at Kiihtelysvaara and then meandered to west of the village of Ilomantsi, turning there southwards to Tolvajärvi and from there north- northeastwards to join the Maanselkä water divide in Russian Karelia.

As the name of a water divide, Salpausselkä was used for the next fifteen years, though spelled in a variety of ways - Salpanselänne, Salpaselkämä and Salpaselkä all being seen (G.R. 1859). The form Salpausselkä was eventually thought up by Rein (1864, p. 55), who used it to refer to the water divide at Ilomantsi, which is outside the present ice-marginal formation of Salpausselkä.

In the early 1840s, the still anonymous Salpausselkäs were considered to be geological formations, as shown by the studies undertaken by Boehtlingk (1839) in Tartu or by thoughts expressed by N.G. Nordenskiöld (Arppe, 1867), neither of whom accepted the explanation based on the glacial theory.

Before long, geological research needed names for the "sand eskers" which had turned out to be ice-marginal features. In 1874, Wiik, for the first time, clearly linked the name Salpausselkä to a geological landform complex. This was a ridge that was part of a water divide of the same name. He also discussed the subject of eskers, and from the longitudinal eskers distinguished a transversal esker, Salpausselkä, which he explained as an ice-marginal deposit. According to him, "it extends as an arcuate landform from Lahti via Lappeenranta to Joensuu" (Wiik, 1874, pp. 290-291). He was referring partly to the central arc of the present Salpausselkä I, which begins at Sairakkala, Hollola, in the west, and partly to the eastern end of Salpausselkä II. Wiik probably based his generalization on Hallstén's map, on which the water divide from Kitee to Kiihtelysvaara in the Joensuu area is Salpausselkä II.

Over the next 15-20 years there was no clear distinction between the water divide Salpausselkä and the end moraine Salpausselkä. At the turn of the century, the geological Salpausselkä emerged as victor with the decline in importance of water divides in geographical and geological descriptions.

To begin with, the ice-marginal ridge running from Sairakkala, Hollola, via Hyvinkää, Lohja and Tammisaari to Hanko was not included in Salpausselkä (I), although, at least from 1875, it was considered contemporaneous with it (Wiik 1875, p. 233). It went by several names in the early years: Lohja-Hanko moraine, Hankoniemi ridge or Hankoniemi- Hyvinkää esker. Gradually, Lohjanselkä or Lohjanharju became the accepted "official" names, and the landform was variously known as either an extension or part of Salpausselkä.

Before long the concept Salpausselkä was extended to cover the landform complex all the way to Hankoniemi. By the early 1900s, Salpausselkä was the prevailing term, although as late as 1921 Ramsay suggested that the name Lohjanselkä should be revived. Strangely enough, Lohjanselkä was still used in an article in the Otava encyclopaedia published in 1960.

No specific name has ever been proposed for Salpausselkä II. Until the turn of the century it was known almost exclusively as the "parallel ridge". In the early 1890s, it was sometimes referred to as the Minor Salpausselkä as if it were somehow smaller in size. Terms such as "Both parallel ridges of Salpausselkä", the "Inner Salpausselkä" and, in the early years of this century, the "Second Salpausselkä" came and went in the literature. The terms Second and Third Salpausselkäs do not seem to have gained currency until used by Sauramo in 1915.

Berghell (1904) and Leiviskä (1920) used the term Salpausselkä collectively for Salpausselkäs I and II.

As late as 1921, Ramsay tried to bring order to the nomenclature of the different parts of the Salpausselkäs and to return partly to the old practice, but it was all too late. The first, second and third Salpausselkäs, initially written in lower case, had already found favour with younger geologists in the 1920s. Alongside these, terms emphasizing geological aspects, such as "outer and inner Salpausselkäs" are still in common use today. The names northern and southern Salpausselkäs make the odd appearance but the Minor Salpausselkä has practically died out altogether.

As a geological term, the name Salpausselkä was a great success from the very start. Kropotkin imported it into Russia in the mid-1870s, and in 1880, Salpau-Selkä was mentioned in a French geography with a reference to Kropotkin (Reclus 1880). The Swede De Geer used it in his study of 1885.

Early stages of systematic research into the Salpausselkäs (IV)

Systematic studies on the Salpausselkäs started in the 1870s, by which time they could be based on sound principles, as the ice age theory had been accepted as a research tool. It was realized how important it was for Finnish geological studies as a whole that the geology of these ice-marginal deposits be established (Sederholm, 1889, p. 29 and 40 - 41). By the end of the century basic information that is still valid today had been obtained about their course.

F.J. Wiik discussed several basic issues related to the Salpausselkäs in a number of papers (1871, 1874, 1875, 1876, 1879). Initially (1871), in accordance with earlier concepts, he described the Salpausselkäs as beach ridges. Three years later, after studying the striae, he distinguished Salpausselkä I from other eskers and advanced

the notion, rejected by Nordenskiöld 30 years earlier, that both Salpausselkä I (Wiik, 1874, p. 290) and its northern parallel ridge (Ss II) were ice-marginal moraines (op. cit. p. 293 and Wiik, 1875, p. 234). He stated that Salpausselkä I extended from Lahti to the Joensuu area (Wiik, 1874, p. 291), and, soon afterwards (1875, p. 233), that the Salpausselkä extended from Hankoniemi to Joensuu. In his doctoral thesis, Wiik declared that Salpausselkä I was a distinct ice-marginal moraine in both external and internal structure and in relation to the striation (Wiik, 1876, p. 89). Wiik's other principal theses were that the front of the ice had retreated to Salpausselkä I from its earlier, more extensive position (1874, p. 293 and 1876, p. 89), that Salpausselkä I marked the maximum level of the Diluvial, or Late-glacial, Sea (1874, p. 293 and 1876, pp. 95 - 96) and that, calculated from land uplift, no more than 25 000 years had elapsed since that time (1874, p. 293).

Around the same time, Solitander (1875) and Jernström (1876) were collecting more detailed material on Salpausselkä to support the broad general delineation of Wiik.

Information about the course, shape and structure of Salpausselkä and its parallel ridge accumulated rapidly with the start of geological mapping in Finland in 1876.

In 1885, the Swede De Geer concluded that the ice-marginal moraines in the Vänern and Vättern areas of central Sweden and the Ra moraines in Norway were contemporaneous with Salpausselkä and its parallel ridge, Salpausselkä II (De Geer, 1884 - 1885, pp. 436, 438). According to him, they all mark the position of the front of the readvanced continental glacier (pp. 443, 456). Between them, however, there had been the Baltic Ice Stream, which had flowed along the basin of the Baltic Sea far to the south. Consequently, the ice front could not have extended over the Baltic Sea (pp. 442 - 443). He also postulated that the ice front could not have passed Maanselkä, the water divide on the Finland´s eastern border, but that the margin of the continental ice sheet in Finland had trended northwards from the Joensuu area (op. cit. pp. 438, 457 and Plate 13).

In 1889, Sederholm proposed that Salpausselkä and its parallel ridges mark synchronous positions of the ice front during the retreat of the ice and that in southwestern Finland there are three of these positions. Unlike De Geer, he thought it very likely that the end moraines continued on the other side of the eastern border. He also rejected De Geer's idea that the Baltic Ice Stream had been contemporaneous with the deposition of the ice-marginal moraines of the Salpausselkäs or Vänern (Sederholm, 1889 and Appendix 1).

In 1890, Ramsay studied the course of the eastern parts of the Salpausselkäs and their continuations the ice-marginal moraines of Koitere and Pielisjärvi. He pointed out that as the course of the big ice-marginal moraines in Norway, Sweden and Finland had now been established, it was time to continue the studies in Russian Karelia. (Ramsay, 1891, Appendix 1)

Financed by the Geographical Society of Finland, Rosberg followed up Sederholm's ideas and began to study the continuation of the moraines in Russian Karelia in 1891. He elaborated on the findings of Ramsay concerning the Koitere and Pielisjärvi segments, and in 1895 set off on a new expedition to Russian Karelia (Rosberg, 1892, 1899)(IV Appendix 1 and the cover).

At the same time the staff of the Geological Commission, the forerunner of the Geological Survey of Finland, were mapping the course of the moraines in North Karelia (Frosterus & Wilkman, 1915).

Thus, by the end of the last century, Finnish researchers had largely established the course of the large end moraines, partly in Russian Karelia, too, mainly by interpreting landforms, i.e. by means of geomorphology. With Ramsay's and Rosberg's expedition into Russia, Finns became the experts in matters related to deglaciation in Russian Karelia.

Continuation of the continental ice sheet front in North Karelia and Russian Karelia at the time the Salpausselkäs were formed

Opinions differed as to the relationship between the Salpausselkäs and the ice-marginal formations of North Karelia and Russian Karelia. Initially, the Koitere end moraine was considered contemporaneous with Salpausselkä I (Ramsay, 1891; Rosberg, 1892, 1899, pp. 44, 46).

According to Rosberg (1899, pp. 47, 69), the chain of moraines contemporaneous with Salpausselkä I continued north of Lake Segozero (Seesjärvi) via Shalgovaara to east of Lake Vig (Uikujärvi) and from there to the coast of the White Sea (Fig. 3). Jaamankangas might be a part of the "second ice-marginal deposit" i.e. of Salpausselkä II. Its extensions would then be the ice-marginal formations in Russian Karelia, which, discontinuously, extend to north of Lake Topozero (Tuoppajärvi) (op. cit. pp. 46, 69).

Ramsay (1906) suggested that the position of the ice sheet contemporaneous with Salpausselkä I might be indicated by ice-marginal formations that, to modern thinking, are rather far south and east. According to him, this zone ran east of Lake Vig (Uikujärvi) through Vohtozero (Vuohtselkä), Rigasel´ga (Riihiselkä), Tivdiya (Tiutia) and Povenets to Sumskiy Posad (Suma) (Ramsay, 1906, p. 4) (Fig. 3). In that case, the ice front would have continued from Värtsilä directly eastwards.

Sederholm (1911c, p. 41; see Atlas of Finland 1910, Folio 5 III) contended that the Salpausselkäs "continue over Lake Segozero (Seesjärvi) to Onega Bay (Äänislahti)" (Fig. 3). The end moraines found by Rosberg farther west he considered contemporaneous with the Central Finland end moraine, or then of an entirely different age.

In 1920, Leiviskä published comprehensive documentation on the Salpausselkäs that he had collected in the 1910s. His emphasis was on a geographical description and classification.

Before long, however, all the leading scholars had come to the conclusion that the Koitere end moraine was indeed contemporaneous with Salpausselkä II and that the Pielisjärvi end moraine was younger than either (Sederholm, 1899a, b; Frosterus & Wilkman, 1915; Ramsay, 1921; Sauramo, 1928, p. 16). Evidently Rosberg, too, had been converted (Suomenmaa VIII, 1927, pp. 228, 326). To begin with Sauramo went along with this idea (Sauramo, 1929, Fig. 18, p. 53 and Fig. 23, p. 65). Leiviskä (1920), the geographer, was the only one left to maintain that the eskers extending from Kiihtelysvaara towards Jaamankangas were extensions of Salpausselkä II (Leiviskä 1920, p. 217; 1928, p. 59).

As far as Finland was concerned, then, the position of the continental ice sheet front during the formation of the Salpausselkäs seemed to have been more or less established. Salpausselkä I was the only one for which no "extensions" had been found northeast of Värtsilä. Once the Koitere end moraine was no longer thought to be the same age as Salpausselkä I, clear opinions on the continuation of the continental ice sheet front from the eastern end of Salpausselkä I ceased to exist. Frosterus & Wilkman (1915, p. 51) and Leiviskä (1920, pp. 110 and 228) all claimed that the then known southern part of the Tuupovaara end moraine was an extension of Salpausselkä I, but this was not very helpful.

In the 1930s, new findings (Hyyppä, 1936; Sauramo, 1937; Kilpi 1937) based on shoreline displacement studies changed opinions on deglaciation, in North Karelia in particular, to such an extent that a conclusive answer still evades scholars.

Interpretation of shoreline displacement as a dominant factor

Contact with Russian or Soviet Karelia was severed when Finland became independent, and the USSR was established. From the 1920s Finnish efforts concentrated on shoreline displacement studies and the application of the results under the supervision of Sauramo and Hyyppä. The position of the ice front in North Karelia at the time of the Salpausselkäs were deposited was re-interpreted. The ice-marginal deposits in easternmost Finland and Soviet Karelia were overlooked, presumably because they were incompatible with the interpreted shore line displacements; they were not referred to in the literature or mentioned at university lectures.

Hyyppä (1936, p. 437, app. 7) was the first to suggest that the Baltic Ice Lake (B II) had extended through eastern Finland to Kuusamo. Thus, at the time the Salpausselkäs were formed the ice front would have trended northwards from North Karelia.

His ideas were backed up by the conclusions reached by Sauramo (1937, pp. 17 - 22) and Kilpi (1937, pp. 111 - 113) from shoreline displacements studies conducted in North Karelia and Kainuu. Sauramo (1937, p. 9) summarized the old and new concepts by stating that: " ...in contrast to what has been considered thus far, Salpausselkä I does not trend to NE towards East Karelia and Lake Segozero (Seesjärvi) but directly northwards towards Lake Pielinen". Further, "at the time of the Baltic Ice Lake, the ice had disappeared from the east of the Pielinen basin and during the Yoldia stage from almost the whole basin. Hence, it was possible that already during the Salpausselkä stage the Baltic Sea extended from the south between the eastern water divide and the ice sheet as far as Maanselkä" and further still, as pointed out by Kilpi (op. cit. p. 17 - 18).

On the basis of the interpretation of shoreline displacement, Sauramo (1937, p. 9, 1958, pp. 100, 396) maintained "that the front of the continental ice in North Karelia had already lain at the morphological Second Salpausselkä at the time of the First Salpausselkä. The great end moraines of southern Finland are united in North Karelia ". The continuous Salpausselkä would accordingly start in the area of Kitee-Kesälahti (Sauramo, 1937, p. 9) or in the area of Tohmajärvi-Onkamo (Sauramo, 1958, p. 100).

In the following decades Sauramo and Hyyppä and their students refined their concepts.

Brenner was probably the only one who did not respect the findings of Hyyppä and Sauramo. In his study in which he analysed the lobate behaviour of the continental ice sheet, Brenner claimed that the ice-marginal deposits in Russian Karelia described by Rosberg most probably represented these lobes and were slightly younger than Salpausselkäs I and II. According to him, the ice front first ran from Jaamankangas via Selkäkangas to north of Lake Segozero (Seesjärvi), but later from Jaamankangas via Uimaharju to Lake Yushkozero (Jyskyjärvi) and Tuoppajärvi Lake Topozero (Tuoppajärvi) (Brenner, 1944, pp. 23-25 and Fig. 4, p. 17).

Leiviskä continued to contend that at least the northernmost fork of Yhdysharju esker (Connection esker) was part of Salpausselkä II. Jaamankangas was formed later than the forks of Yhdysharju (Connection esker) buried in it (Leiviskä 1951, pp. 67, 69), but Salpausselkä II and Jaamankangas had formed during the same marine stage. The difference in elevation was attributed to uplift and disparity of age (op. cit., pp. 69-70).

According to the interpretation of Leiviskä, the ice front withdrew from Salpausselkä II earlier in the west than in the east: "At the time the great arc of the Inner Salpausselkä was forming, ice filled the Finnish interior like an enormous giant cake whose western margin, from the position of the end formations and judging by the distribution of clay deposits, had withdrawn to the line Hämeenkangas - Pohjankangas, while the outer margin was stationary at the flank of the Inner Salpausselkä" (Leiviskä, 1951, p. 66), that is, to the level of the western part of the Central Finland end moraine.

Repo investigated the cross-striations and dispersal of pebbles in glacial deposits in North Karelia, in the Joensuu area in particular. He suggested that Jaamankangas was contemporaneous with the Salpausselkä II formations at Kiihtelysvaara (Repo, 1957, p. 149; 1960, pp. 11-16), having been deposited as an interlobate complex in a crevice between two glacial lobes. However, neither then nor later (Repo 1960; 1969, see however pp. 70-71) did he take into account the fact, as shown by the elevation of Jaamankangas and the associated esker plains, that they were formed when the base level of erosion was about 30 m lower than the plains of Salpausselkä II.

In Repo's opinion, Pöllönvaara, the northernmost ridge of Yhdysharju (Connection esker) between Kiihtelysvaara and Jaamankangas, was the northern end of Salpausselkä II, even if precisely at Pöllönvaara it was "a perfectly longitudinal ridge" (Repo, 1957, pp. 110, 148, 156-158; Rainio et al., 1995 [VI], Fig. 6, VI). His explanation was that there had been dead ice on the distal side of the ice-marginal formation and that water had streamed in a longitudinal crevasse.

Repo (1957) considered Jaamankangas and Uimaharju coeval but did not discuss the continuation of the Salpausselkäs from North Karelia in any direction.

CONTINUATION OF THE SALPAUSSELKÄS IN NORTH KARELIA IN THE LIGHT OF RECENT CONCEPTS

Biostratigraphical and morphological interpretations rehabilitated

As a consequence, the ice-marginal deposits in easternmost Finland and in Soviet Karelia were largely ignored until the 1960s, when a fresh look was taken at the concepts of shoreline displacement (Hyvärinen 1966a, b), and studies on the course of the ice-marginal landforms were reopened using a geomorphological approach (Rainio, 1972). Pollen and radiocarbon evidence was used to demonstrate presence of organic deposits of Younger Dryas age in the southern foreland of North Karelian end moraines (Selkäkangas) whereas at sites farther north the pollen record opens with Early Holocene assemblages; hence the end moraines could be biostratigraphically correlated with the Younger Dryas (Hyvärinen 1971a, 1972, 1973).

In the early 1970s, the Geological Survey of Finland and the geologists of Soviet Karelia joined forces in studying the deglaciation of the Salpausselkä phases (Lukashov et al., 1981). As a result, the work of Rosberg on Russian Karelia became topical once more (see Hyvärinen, 1973).

Position of the ice sheet front during the deposition of Salpausselkä I

The chain of ice-marginal ridges included in Salpausselkä I comes to an end at the Patsola marginal plain in Värtsilä, North Karelia (Berghell, 1904; Ramsay, 1921; Repo & Tynni, 1967, p. 136; Rainio, 1983 [I]). The terrain to the east and northeast of the plain rises and is supra-aquatic. As can be inferred from the orientation of the easternmost plains of Salpausselkä I, the front of the continental ice sheet could well have continued north-northeastwards in this area (cf. Rainio 1983 [I], p. 68).

Various ideas about the position of the ice front northeast of Patsola have been put forward since the late 1970s without, however, any distinct, continuous end moraines being found to support them. In the following these studies are reviewed.

In 1978 and 1980, Rainio suggested that at the time the Salpausselkä I was forming the front of the continental ice sheet continued from Patsola northeastwards to Möhkö and from there to Russia. He maintained that the position of the ice front, which he called the Ilomantsi zone, was indicated by the discontinuous chain of esker deltas, ice-marginal formations and areas of hummocky moraines and that the landforms of the ice front corresponding to Salpausselkä I were within a 10-km-wide zone. In other words, the ice front had withdrawn about 10 km here, whereas farther west it had remained approximately stationary at Salpausselkä I.

In this zone, which is close to the Russian border, there are valleys of the ancient Baltic Sea over a distance of 10 km from Patsola. Glaciofluvial plains developed in them indicating a base level of erosion at 106-112.5 m, which is more or less the same as the 110 m of the Patsola plain (Rainio 1991 [IV], p. 46). They represent, then, the incipient Baltic Ice Lake (BI). The farthest plains are north of Lake Kaustajärvi, close to the village of Saarivaara. There, between the ponds Mellitsan lampi, Varpalampi and Aittolampi at 106-107 m a.s.l., a group of glaciofluvial plains has developed at the 110-112.5-m level.

On the basis of shoreline displacement, Hyvärinen (1966b) first considered it possible that Selkäkangas, one of the marginal terraces of the Koitere chain, was contemporaneous with Salpausselkä I.

Aario & Forsström (1979, p. 44) deduced from glacial lobe analysis "that the train of marginal deposits, including the Selkäkangas moraine, for example, could possibly belong to the First Salpausselkä".

Punkari seems to have started off with the idea (1979, p. 25; 1980) that the Koitere ice-marginal formation with its Russian continuations was contemporaneous with Salpausselkä I. Later (1982, Fig. 8; 1984, Fig. 4) he apparently changed his mind, considering it more likely that the Koitere end moraine was approximately the same age as Salpausselkä II and that the ice front probably ran from Tohmajärvi to Himolanjärvi during the formation of Salpausselkä I. In 1995, Punkari & Boulton (1995, Fig. 6) eventually concluded that the Rugozero (Rukajärvi) ice-marginal complex represents both Salpausselkä I and Salpausselkä II.

By grouping ice-marginal moraines and esker deltas on small-scale maps, Lyytikäinen and Kontturi demonstrated that from Patsola the front of the ice sheet had run 10 km northeastwards before changing direction at Korpijärvi and crossing the Russian border (Lyytikäinen, 1980, p. 2, Fig. 1; 1982, p. 80, Fig. 60; Lyytikäinen & Kontturi, 1980, p. 8, Fig. 6). However, in Fig. 58 (p. 78) Lyytikäinen placed the ice front somewhat farther north.

Hirvas (1980) and Ignatius et al. (1980), again on a very small-scale map, showed that the ice front had curved gently northwards from Patsola, joining the Koitere chain somewhat northeast of Kiihtelysvaara. Nenonen came to the same conclusion in 1984. Till-stratigraphic studies later convinced Kujansuu and Nenonen (1987, pp. 62, 63, Fig. 2, p. 65) that the First Salpausselkä and the Tuupovaara end moraine were contemporaneous. According to Nenonen (oral communication, 13.12.1995), the Koitere end moraine is also contemporaneous with the above, as can be seen from his work (Nenonen, 1995b, Fig. 26, p. 58) if interpreted correctly.

Russian workers interpreted the Rugozero ice-marginal formation, a direct continuation of the Koitere end moraine in Russian Karelia, as a contemporary of Salpausselkä I (Lukashov & Ekman, 1982; Ekman et al., 1981; Ekman & Ilyin, 1991).

According to the interpretation of Kurimo (1982, Fig. 6), the ice front ran from Patsola for about 20 km in the Finnish side before crossing over into Russia, where it continued to the Segozero (Seesjärvi) area and from there to south of Lake Vig (Uikujärvi).

Rainio (1983, I) contended that the Tuupovaara end moraine was slightly younger than Salpausselkä I. His concept was based on the relationship between the Tuupovaara end moraine and the Patsola marginal plain at the northeastern end of Salpausselkä I.

Salminen & Hartikainen maintained that the Tuupovaara end moraine was contemporaneous with Salpausselkä I, and that " the small end moraines south of Selkäkangas evidently belong to the Salpausselkä I stage". (Salminen & Hartikainen 1985, s. 10)

In the opinion of Eronen and Vesajoki (1988, p. 321): "It is thus apparent that the Heinola deglaciation and the following readvance were limited to the region occupied by the Lake District lobe. Very probaly the margin of the North Karelian lobe was continuing its retreat at the same time being interrupted only temporarily by short standstill periods. This explains partly why there is no massive end-moraine complex corresponding to Ss I in the region of the North Karelian lobe, but instead a series of discontinuous, relatively small end moraines."

Rainio et al. suggested in 1995 that, in North Karelia, the front of the continental ice sheet withdrew from east of Kitee during the Salpausselkä I stage:

"On maps (Berghell, 1903; Frosterus, 1920; Leiviskä, 1920) Salpausselkä I in North Karelia is marked as a fairly wide ice-marginal formation composed of two parallel arms. They demonstrate that the ice front withdrew in North Karelia during the Salpausselkä I stage but remained stationary farther west. The Tuupovaara ice-marginal formation ... represents the youngest frontal position correlative with Salpausselkä I. ... The orientation of the Tuupovaara end moraine suggests that, at the end of the Salpausselkä I stage, the ice margin east of Lake Koitere was located at the same level as during the Salpausselkä II Stage. Thus the eastern part of the Koitere ice-marginal formation and its extension in Russia may represent both the late Salpausselkä I and the Salpausselkä II stage." (Rainio et al. 1995, VI, s. 185)

The only reference to end moraines in Finnish territory northeast of Patsola comes from Rosberg (1899, p. 32, p. 45), who placed an end moraine between Ilomantsi and Möhkö. He probably meant the expansion of the Petkeljärvi-Putkela esker south of Muokonjärvi, which does indeed display some features typical of an ice-marginal deposit. From Liusvaara, now in Russia, Rosberg mentioned "two small end moraines" (op. cit. p. 32).

According to Berghell (1916), there is a small "transversal esker" at Kuolismaa (p. 75) and Alasulkulampi (pp. 79-80) and a "marginal esker" at Ylimmäisenjärvi (p. 87-88), all now on the Russian side of the border. These are consistent with a discontinuous chain of ice-marginal moraines. According to Ekman, Lukashov and Iljin (personal communication), no ice-marginal deposits that might serve as extensions of Salpausselkä I are known on the distal side of the Rugozero (Rukajärvi) end moraine in Russian Karelia.

Position of the ice sheet front in North Karelia during the deposition of Salpausselkä II

Current ideas about the position of the ice front northeast, north and northwest of the Kiihtelysvaara-Heinävaara area during the formation of Salpausselkä II are very much the same as those prevailing at the turn of the century. The intervening years have embraced two main interpretations and their elaborations.

According to the first one, the Koitere chain of end moraines is approximately contemporaneous with Salpausselkä II. This idea has recently been seconded by Hyvärinen (1971a; 1973, p. 87-88), Rainio (1972, 1985b, 1991 [IV] and 1995), Kurimo (1982, p. 66, Fig. 6, p. 67), Punkari (1982, 1985) and Salminen & Hartikainen (1985, p. 10-11).

In the opinion of Saarnisto (1970, p. 22), shoreline displacement shows that Salpausselkä II started to deposit in the east during the BII stage and that the continental ice sheet withdrew from Salpausselkä II earlier in the east than in the west.

Lyytikäinen (1980, p. 2, Fig. 2; 1982, pp. 78-79, Fig. 2) and Lyytikäinen & Kontturi (1980, p. 9) considered that the front of the North Karelia glacial lobe had already reached the Koitere chain slightly before the Salpausselkä II stage and had withdrawn to the proximal side of the chain when the front of the Lake-District lobe was at Salpausselkä II.

On the basis of flow analysis of the ice sheet, Forsström (1984, p. 307) suggested that the eastern curve of Salpausselkä II-Koitere end moraine in North Karelia "is slightly younger than the western part".

Eronen & Vesajoki (1988, pp. 322-323) were of the opinion that the front of the North Karelia lobe withdrew to the Koitere ice-marginal moraine before the Lake-District lobe had retreated to the Salpausselkä II zone (see Forsström, 1989).

According to the proponents of the second main interpretation, Salpausselkä II is contemporaneous with the Pielisjärvi chain, and the glaciofluvial deposits and moraines between Kiihtelysvaara and Paihola, the deposits of the Tervasuo complex and Yhdysharju (Connection esker) all belong to it. A similar idea had been proposed by Rosberg in 1899. Backed up by more arguments it was also presented by Repo (1957, and 1960; Repo & Tynni, 1967, p. 136), whose opinions were shared (to start with) by Punkari (1979 on the basis of his ambiguous map) and Hirvas (1980, Fig. 1), Ignatius et al. (1980, Fig. 11), Nenonen (1984, 1995b, Fig. 26, p. 58) and Kujansuu & Nenonen (1987).

Position of the Pielisjärvi end moraine chain

According to Rainio (1978, 1985b), the Pielisjärvi ice-marginal formation is a chain of contemporaneous deposits that begins at Ylämylly-Honkavaara at the western end of Jaamankangas, where a glaciofluvial complex changes into a distinct ice-marginal formation, and continues via Uimaharju to the Russian border.

Divers opinions have been expressed on the relation of the Pielisjärvi ice-marginal formation, or more often its southwestern end, Jaamankangas, to Salpausselkä II. The key issue has been how to interpret the Tervasuo complex (Rainio, 1990, pp. 35-38), Yhdysharju (Connection esker) between Heinävaara and Jaamankangas (Frosterus & Wilkman, 1915, p. 55) and the associated deposits, as well as the movements of the continental ice sheet.

In Sauramo's clay chronology (1928, p. 16, Table VIII), the front of the continental ice sheet was at the Jaamankangas- Uimaharju line in years 100-200 (Fig. 6, p. 26 and Table VII). South of Jaamankangas, the ice front lay west of Pyhäselkä in year 100 and west of Orivesi in year 200.

Sauramo (1928, p. 16), among others, considered Jaamankangas contemporaneous with Salpausselkä III, in southwestern Finland. According to him (1958, p. 394), the Jaamankangas end moraine is part of Salpausselkä III (".. die Endmoräne Jaamankangas zu dem 3. Salpausselkä gehört"). He also suggested (on the basis of a superficial striation interpretation) that Jaamankangas had formed at the front of a readvanced ice sheet ("Dabei war sicherlich ein Vorrücken des Eisrandes eingetreten.") (op. cit. p. 397).

According to Saarnisto (1970, pp. 24, 77), the elevation of the Jaamankangas plains is close to that of the Yoldia Sea and so they are younger than Salpausselkä II.

Rainio (1972) proposed that Jaamankangas and the chain of ice-marginal deposits extending from Uimaharju to the Russian border were of the same age and younger than Salpausselkä II. In his licentiate thesis, Rainio (1973) demonstrated that there is a discontinuous chain of end moraines between Jaamankangas and Uimaharju, and that Jaamankangas and the contemporaneous marginal plains were formed close to the level of the Yoldia Sea.

Initially, Aario & Forsström (1978, p. 52; 1979, p. 43) supported the interpretation of Repo. But they also proposed (Aario & Forsström, 1979, p. 44) that the Pielisjärvi end moraine "together with the Jaamankangas complex would be the one correlative with the Second Salpausselkä". Later, on the basis of esker analysis, Forsström (1984, p. 307) suggested that Jaamankangas was younger than Salpausselkä II ("it would seem more probable that the eastern parts of Ss II formed diachronously and gained their final shape only at the stage when ice movement in the Lake-Finland lobe in the direction indicated by the striae had already come to an end and the ice margin had begun to retreat northwestwards towards Jaamankangas.")

After analysing the movements of the continental ice sheet, Hirvas (1980) came to the same conclusion as Repo. As mentioned above in the discussion on the continuation of the ice front during the formation of Salpausselkä II, Hirvas' opinion was shared by Punkari (1979, 1980), Ignatius et al. (1980), Nenonen (1984) and Kujansuu & Nenonen (1987).

Lyytikäinen & Kontturi (1980, pp. 9-10) and Lyytikäinen (1982, pp. 78-79, Fig. 59) contended that Jaamankangas started to form at the same time as Salpausselkä II and continued to deposit after it. As they put it: "Through gradual deposition, Jaamankangas is thus connected to the northern part of Salpausselkä II." Elsewhere the Pielisjärvi end moraine had already deposited when Jaamankangas was still building up (Lyytikäinen, 1982, pp. 78-79, Fig. 59).

According to the lobe analysis of Salminen & Hartikainen (1985, pp. 11-12), the North Karelia glacial lobe first withdrew in such a manner that the Lake District lobe could occupy the Höytiäinen basin for some time. With the departure of that lobe, the North Karelia lobe readvanced to the Pielisjärvi ice-marginal formation, generating a chain of ice-marginal landforms with different components. Eronen & Vesajoki (1988, p. 324) supported the concept of Salminen and Hartikainen.

In the opinion of Eronen and Vesajoki (1988, p. 320): "The slope of the delta surface (of Jaamankangas) in a distal direction from about 120 m to 105 m above sea level, along with the relatively rough topography, indicates that a lowering in water level took place during deposition of the glaciofluvial sediments."

Over the years it has been deduced that the Pielisjärvi chain, or parts of it, was either contemporaneous with Salpausselkä II (Ramsay (at first), 1891, p. 7; Rosberg, 1892, p. 123, 1899, pp. 46, 68; Repo, 1957; Ignatius et al., 1980; Hirvas, 1980; Kujansuu & Nenonen, 1987; Nenonen, 1984, 1995b) or younger than it (Ramsay, 1921; Sederholm 1899a, b, 1911a, p. 11; Frosterus & Wilkman 1915; Sauramo 1928a, p. 16; Rainio 1972, 1985b, 1991 [IV], 1995; Hyvärinen 1973; Punkari 1982, 1985; Kurimo 1982, p. 66, fig. 6, p. 67; Salminen & Hartikainen 1985, p. 10-11; Eronen & Vesajoki 1988). Opinions have been based on the position of parts of the ice-marginal formation in relation to other ice-marginal formations, on shoreline displacement and on the interpretation of clast transport, striation and other fabric elements.

Nenonen (1993, pp. 49-50, 1995b, pp. 79-80) considered it possible that the Pielisjärvi end moraine and Salpausselkä III in southwestern Finland might be approximately contemporaneous with the Central Finland end moraine.

Eronen and Vesajoki (1988, p. 318, Fig. 1) have published a series of maps illustrating different concepts of the position of the front of the ice sheet in North Karelia during the formation of the Salpausselkäs.

If the action of glacial lobes is taken into account the interpretation of deglaciation by many researchers (e.g. Salminen & Hartikainen, 1985; Eronen & Vesajoki, 1988) becomes too complicated to be reviewed here.

SALPAUSSELKÄ I AND THE CENTRAL FINLAND END MORAINE, RECESSIONAL OR TERMINAL? (modified from Rainio 1991, IV, pp. 30-33)

The discussion about whether Ss I was recessional or had formed in front of the readvancing continental ice sheet was opened by De Geer (1885). Sederholm (1911b) approached the Central Finland end moraine from the same angle. For many years the view that the formations were recessional was favoured. More recently, however, evidence has accumulated to show that they are end moraines formed in front of the readvancing ice sheet and that glaciation in southern Finland and the stratigraphy of the glacigenic deposits are more complicated than had earlier been suspected (e.g. Okko, 1962; Hyyppä, 1966; Fogelberg, 1970, pp. 25, 62, 65-66; Aartolahti, 1972, pp. 11, 77; Hirvas & Nenonen, 1980, 1985, 1987; Nenonen, 1984; Rainio, 1984a; Rainio, 1985a, II; Rainio et al., 1986, III; Nenonen, 1995b).

Okko (1962) proposed that the period during which the ice sheet retreated from Finland's southern coastal area to somewhere north of Ss I should be called the Heinola deglaciation. The following advance to Ss I should accordingly be referred to as the Salpausselkä readvance. Rainio (1984a, 1985a, II) suggested that during the Heinola deglaciation the ice sheet had receded for at least 80 km on the proximal side of the present Ss I. (cf. Hirvas & Nenonen, 1987, pp. 53, 62; Eronen & Vesajoki, 1988, p. 321; Nenonen 1995b, s. 79)

Mainly in the light of his interpretations of striations, Sauramo (1958, pp. 99-100, 396) suggested that the ice sheet in North Karelia had withdrawn to the Outokumpu area at the end of the Alleröd interval. From there it had readvanced in the early Younger Dryas stage to the Salpausselkä zone, i.e. to the present Salpausselkä II, which, according to Sauramo (1937, 1958), represents both Salpausselkä I and Salpausselkä II.

The following facts support the concept of a readvance of the ice in the zone of the Salpausselkäs and the Central Finland end moraine:

1. Till-covered glacigenic deposits occur all over Finland. In the south of the country, a considerable proportion of them are concentrated in certain zones. One such zone, 50 - 80 km wide, is on the proximal side of Ss I and another, at least 50 km wide, is on the proximal side of the Central Finland ice-marginal formation. There are sites where clays and glaciofluvial deposits are overlain by till or where there are several superimposed discordant till beds. The chain of glaciofluvial deposits is discontinuous in both ice-marginal formation areas and the eskers do not extend through them. The base level of erosion at the time the till-covered glaciofluvial deposits formed was higher than that at the end of deglaciation. This is clearly visible in the zone of the Central Finland end moraine, where the difference in base levels is up to 50 m. The till-covered deposits are often deformed.

2. The striae on either side of the ice-marginal formations differ in direction. Some striae terminate abruptly at the marginal formation.

3. The uppermost till in the Salpausselkä zone is often immature, making it easy to identify the parent sediments.

From the position of the eskers at Ilomantsi, Eronen and Vesajoki (1988, p. 321) argued "that the Heinola deglaciation and the following readvance were limited to the region occupied by the Lake District lobe". Punkari & Boulton (1995) disagreed with the whole idea of a major oscillation.

Kujansuu & Nenonen (1987, Fig. 4, p. 64), Hirvas & Nenonen (1987, p. 62) and Nenonen (1995a, Fig. 15, p. 24, p. 27) have all published observations of till-covered glacial deposits that they have interpreted as representing the Salpausselkä readvance. Referring to the work of Eronen and Vesajoki (1988), Nenonen (1995b, p. 60) wrote that: "The till stratigraphy and the relations of ice flow stages show and directions to the ice-marginal formations imply that the ice sheet readvanced a fair distance in North Karelia, too".

The Central Finland end moraine has been considered as either recessional (Sauramo, 1929; Repo, 1964) or as having formed in front of a glacier that had oscillated less than 10 km (Sederholm, 1911b, p. 69; Virkkala, 1959, pp. 52-53; Aartolahti, 1972, pp. 59-66, 78; Kujansuu, 1995). The conceptions of "oscillation" were based mainly on observations, made in the proximal part of the end moraine, of some submorainic glacial deposits. It has also been suggested that the formation was formed diachronologically (Sauramo 1924, p. 65), or was deposited partly in a crevasse of the ice sheet (Repo 1964, p. 150), in a fairly large glacial bay (Sauramo 1928, p. 26, 29; Ristaniemi 1985, p. 8 and Appendix II, 1987, fig. 31, p. 43, enclosure map II) or between glacier lobes (Punkari, 1982, p. 75; see Kujansuu, 1995). According to Ristaniemi (1987, p. 88): "Observations of the highest shoreline do not attest to the Keuruu deglaciation." This opinion he arrived at by analysing movements of the ice sheet and the late-glacial base level of erosion, and interpreting varved clays on the distal side of the ice-marginal formation.

Further information on till-covered sediments, striations and the orientation of eskers was obtained from gravel assessments, mapping of Quaternary deposits; geological mapping and special investigations undertaken by the Geological Survey of Finland. These showed that glacial features in the Central Finland end moraine and its proximal zone were similar to those in Salpausselkä I and its proximal area, that is, those mentioned on pages 32 -33.

In the light of the above, Rainio & Lahermo (1985) and Rainio et al. (1986, III) concluded that the ice sheet receded from Ss I to at least 50 km north of what is now the Central Finland end moraine without any significant advances interrupting deglaciation. The ice then readvanced to where the formation now stands. Rainio et al. (III) proposed that the stages be termed the Keuruu deglaciation and the Jyväskylä readvance (Rainio, 1991, IV, Fig. 4). (cf. Hirvas & Nenonen, 1987, pp. 53, 62)

Nenonen has published a graphic diagram of the relationship between end moraines and the stratigraphy caused by readvances of the ice in southern Finland (Nenonen, 1992, Fig. 2).

MATERIAL AND METHODS OF THIS STUDY

Mapping of deposits in North Karelia (I, IV, VI)

Owing to the lack of accurate maps and aerial photos, the investigations in North Karelia were conducted on foot to begin with. Routes were planned by studying old maps and picking out points that seemed to have relevance for the investigation. Later, use was made of aerial photo interpretations, which were then checked in the field.

The basic maps at 1:20 000 scale introduced in the mid-1970s made interpretation more accurate. Most of the elevation values were obtained from these maps.

It was not long before the field observations demonstrated the existence of two continuous chains of ice-marginal ridges in North Karelia. The first extends from Kiihtelysvaara, from the known - albeit not generally accepted - eastern end of Salpausselkä, and the second from Uimaharju into Russia. Moreover, there is also a fairly continuous chain of ice-marginal deposits between Jaamankangas and Uimaharju. As it turned out, these landforms had already been largely described by Sederholm (1899a, b; Ramsay (1891) and Rosberg (1892, 1899) a hundred or so years ago.

Later, two more important ice-marginal chains were found between the two longest chains, of which the Tuupovaara end moraine deposited towards the end of the Salpausselkä I stage.

Results from North Karelia and the naming of geomorphological units (I, IV, VI)

Rainio published preliminary findings on the position of two continuous end moraine chains in 1972. His licentiate thesis in 1973 dealt with the area between Jaamankangas and Uimaharju. In 1978 and 1980, he published his observations on deglaciation and end moraines in North Karelia in excursion guides, and in 1983 the results of a detailed investigation of the Tuupovaara end moraine, which is part I of this doctoral thesis. Two years later he collected the names he had proposed for the ice-marginal formations in 1978, 1980 and 1983 and published them together with a map depicting their position (Rainio, 1985b). In 1991, he wrote a general description of deglaciation and the position of end moraine ridges in North Karelia for the excursion guide of the IGCP-253 programme. The description, which incorporates his earlier suppositions, examples of various landforms and new findings and conclusions, constitutes part IV of this thesis. Part VI is also closely related to the investigations in North Karelia; more about it on page 00.

Studies elsewhere in southern Finland (II, III, V, VI)

As a result of the sand and gravel assessments undertaken by the GSF in 1969-72 and the subsequent mapping of Quaternary deposits, the research area became larger than originally intended, eventually including the structure of the Salpausselkäs and Central Finland end moraine and the stratigraphy of their proximal zones. Observations made on cuttings and striations in these zones suggested that the late-glacial stratigraphy of southern Finland was more complex than had generally been believed a couple of decades earlier. It turned out that the ideas about the "non-uniformity" of deglaciation put forward decades ago might be worth reconsidering. Thus it was that the last deglaciation in southern and central Finland and the position of the major end moraines - the Salpausselkäs and the Central Finland end moraine - were included in the research.

In the light of material mainly collected in the course of the assessment of sand and gravel resources in Mikkeli province and mapping of Quaternary deposits in the Mikkeli, Vuohijärvi, Lappeenranta, Savitaipale, Kouvola, Heinola, Sysmä and Luumäki map-sheet areas, a paper was published vindicating M. Okko, who, in 1962, had suggested that a substantial oscillation of the Weichselian ice sheet had preceded the formation of Salpausselkä I. That paper forms part II of the present thesis.

Rainio and Lahermo together studied the Central Finland end moraine and its proximal zone. Additional observations were made during the assessment of sand and gravel resources in Central Finland province and mapping in the Jyväskylä, Jämsä and Korpilahti map-sheet areas . They published their findings in 1976, 1985 and 1986. In partnership with A. Kejonen and S. Kielosto they published a paper on deglaciation and oscillation in the proximal area of the Central Finland end moraine in 1986; it is part III of the present thesis.

In conjunction with mapping of Quaternary deposits of the Lappeenranta map-sheet area, the lithostratigraphy of bottom deposits was studied in an open pit belonging to Partek Oy at Ihalainen to see whether the signature of the Heinola deglaciation-Salpausselkä readvance was recorded in them. The results of this study constitute part V of the thesis.

Part VI, compiled together with Matti Saarnisto and Ilpo Ekman, is the final report of the IGCP 253 project dealing with Finland, Russian Karelia and Kola. It looks briefly at the mutual relations, size, location and position of the Younger Dryas ice-marginal formations and discusses their relation to the Baltic Ice Lake and the Yoldia Sea. Discrepancies in the opinions of Finnish and Russian geologists concerning the age and relations of the end moraines in North Karelia and Russian Karelia are highlighted (Rainio et al., 1995, VI).

RESULTS

I **Rainio, H. 1983.** The Tuupovaara end moraine in North Karelia, Eastern Finland - an ice marginal formation of the same age as the Salpausselkä ridges. Bulletin of the Geological Society of Finland 55, 67-76.

This report describes a previously largely unknown end moraine in the province of North Karelia. The landform, which extends from Värtsilä to Ilomantsi via Tohmajärvi and Tuupovaara, is given the name Tuupovaara End Moraine. Including a few short gaps, it is 50 km long, trends N-S and SSW-NNE and runs at distances of 12 to 22 km from the distal flank of Salpausselkä II. Striae indicate that the last movement of the ice was perpendicular to the end moraine. To the southeast of Lake Loitimo the striae extend for some 4 km to the western margin of the esker of Otmen. The parts formed in the Baltic Ice Lake and the Loitimo, a glacial lake, consist mainly of glaciofluvial material, whereas the supra-aquatic parts are composed largely of till and are much smaller than the glaciofluvial parts.

The Tuupovaara End Moraine begins at Pykälävaara, 4 km north of the easternmost part of Salpausselkä I, - the Patsola marginal delta. Pykälävaara lies 4-6 km behind the line of the glacier margin represented by the plateaus of Salpausselkä I. The trends of the striae also indicate that the delta plain of Pykälävaara is slightly younger than that at Patsola.

The Tuupovaara Moraine is thus slightly younger than Salpausselkä I, but distinctly older than Salpausselkä II, indicating that the margin of the Weichselian ice sheet did not extend from Värtsilä to the ice-marginal deposition zone between Kiihtelysvaara and Selkäkangas, and that the ice receded more rapidly in the Ilomantsi area than farther west during the deposition of Salpausselkä I.

The esker complex of Otmen, which is located about 2-5 km to the east of the Tuupovaara End Moraine, lies at the boundary between two different sets of striations. From the evidence presented by the location and structural features of the complex, it must be identified as an interlobate complex.

Twenty-seven stone counts indicate that the material was transported from between the west and northwest. Local rocks become predominant after a transport distance of a few kilometres.

II **Rainio, H. 1985.** Första Salpausselkä utgör randzonen för en landis som avancerat på nytt. Summary: The First Salpausselkä is a marginal formation of the outermost margin of a readvanced ice sheet. Geologi 37 (4-5), 70-77.

Most of the material for this paper was collected in the course of a special investigation of end moraines in North Karelia, the assessment of gravel resources in the western part of Mikkeli province and Quaternary mapping of Quaternary deposits in the map sheet areas of Lappeenranta (3134), Mikkeli (3142), Luumäki (3131), Savitaipale (3132), Vuohijärvi (3114) and Sysmä (3121).

The debate over whether Salpausselkä I formed during a temporary halt of a withdrawing ice front or at the front of readvanced ice was opened in Finland and Sweden a century ago. Salpausselkä I has usually been considered a recessional deposit, although several researchers have not excluded the possibility of a readvance. Marjatta Okko became the chief advocate of readvance when, in 1962, she introduced the concepts *Heinola deglaciation* and *Salpausselkä readvance*.

In this paper new evidence is presented that the deposition of Salpausselkä I was preceded by deglaciation, during which the margin of the ice sheet receded tens of kilometres north of the line of Salpausselkä I. The observations are mainly from the part of Finland lying east of Lake Päijänne.

Sections where till overlies glaciofluvial deposits are a common occurrence in a 40-km-wide zone on the proximal side of Salpausselkä I. Some of these deposits are longitudinal eskers; others are more difficult to define. They frequently display deformation structures and, in the Lappeenranta-Savitaipale-Mäntyharju area, a base level of erosion 10-20 m higher than that of younger deposits.

The network of glaciofluvial deposits does not continue through Salpausselkä I. Only at four sites does an esker that started some kilometres outside Salpausselkä I continue into Salpausselkä I, its extent demonstrated by kettles in the marginal plateaus.

Three new observations of till-covered varved clays, one of them 55 km on the proximal side of Salpausselkä I, are described. Balls and lumps of clay have been found in glaciofluvial deposits, end moraines and till. The most recent till there frequently contains remnants of other sediments as well as clay.

The differences between the sets of striae on either side of Salpausselkä I, especially in the vicinity of Joensuu and Päijänne, lend fuel to the idea of a readvancing ice sheet.

Thus Salpausselkä I marks the limit of a number of glacigenic phenomena. The sequence of glacigenic deposits is much more complex on the proximal than on the distal side of the formation. The till separates two sequences of deglaciation deposits of different age. The network of glacial streams does not clearly continue through Salpausselkä I, and the set of striae on its proximal side frequently differs from that on its distal side. The uppermost till is rather immature, and thus the original sediments can still be identified. These phenomena are most obvious in an area extending from Salpausselkä I to about 20 km on the proximal side of Salpausselkä II, i.e. for 40-45 km. Farther away they are less numerous, but till-covered sediments are still found 70-80 km or more from Salpausselkä I. During the Heinola deglaciation the ice sheet seems to have receded to at least 80 km north of Salpausselkä I, to a line extending from Koli to Turku via Viinijärvi, Heinävesi, Rantasalmi, Mikkeli, Kuhmoinen, Toijala and Loimaa.

Certain factors, however, argue against the idea presented above. There is nothing in the varve chronology to corroborate the Heinola deglaciation (Niemelä 1971). The base level of erosion shown by the till-covered glaciofluvial deposits is incompatible with what is known of late-glacial development on the distal side of Salpausselkä I. Many phenomena could also be explained by several short oscillations of the ice margin.

It is pointed out that neither the clay chronology of Niemelä nor the earlier chronology of Sauramo support the concept of substantial oscillation. The high base level of erosion indicated by the till-covered glaciofluvial deposits was found to be incompatible with the fact that the g level, which is markedly lower than the B level and is interpreted as the base level of erosion in the distal area of Salpausselkä I, should also have existed in the north of Salpausselkä I during the Heinola deglaciation.

III **Rainio, H., Kejonen, A., Kielosto, S. & Lahermo, P. 1986.** Avancerade inlandsisen på nytt också till Mellanfinska randformationen? Summary: Is the Central Finland ice-marginal formation terminal? Geologi 38 (4-5), 95-109.

Although generally considered a recessional formation, the Central Finland ice-marginal formation - the fourth large chain of ice-marginal formations in southern Finland - has also been regarded as a formation deposited in front of an ice sheet that had readvanced for a few kilometres. This latter concept is based on the presence of a few till-covered glacial deposits on the proximal side of the formation. It has also been suggested that the Central Finland ice-marginal formation is a diachronous formation or that it deposited in a wide crevasse in the ice or in a large glacial bay or even that it is an interlobate deposit.

This article presents new observations of submorainic glacial deposits from a zone about 50 km wide on the proximal side of the Central Finland ice-marginal formation. In 60 deposits the till-covered material is glaciofluvial, and in 10 still-water sediments, that is, varved silt or clay. Information is also given on striae, the continuity of eskers, and variations in the late-glacial base level of erosion.

The structure of the Central Finland ice-marginal complex is that of a typical large end moraine, even in parts earlier thought to have formed in a crevasse or between glacial lobes.

Observations show that the surroundings of the Central Finland end moraine are similar to those of Salpauselkä I. Most observations, old and new, were made on the proximal side of the formation. The till cover is generally 1-3 m, most frequently 1-1.5 m, thick.

The eskers do not continue across the end moraine. On the proximal side, the base level of erosion shown by the submorainic glaciofluvial sediments is considerably higher, 20-60 m, than that indicated by the sediments without a till cover. The directions of striae differ on the two sides of the marginal formation. Distal striations seem to occur as older striations on the proximal side of the ice-marginal formation. A particular group of striae on the proximal side suddenly disappears at the end moraine.

These findings support the views of earlier researchers that the ice sheet readvanced before deposition of the Central Finland ice-marginal complex. It now seems, however, that the ice margin retreated farther than was previously believed, that is, at least 50 km from the zone of the end moraine.

In short, the Central Finland end moraine marks a limit separating areas of different striae directions, different erosion base levels, and different groups of eskers. The area of submorainic sediments extends for at least 50 km from the end moraine.

A cursory study of the continuity of the eskers outside the Central Finland ice-marginal formation seems to imply that the margin of the ice sheet receded from the Salpausselkä zone to the vicinity of the Central Finland end moraine without any major readvances. Thus the Salpausselkä readvance and the deposition of Salpausselkä I were probably followed by recession of the ice to a location at least 50 km behind the zone of the Central Finland end moraine. The recession turned into readvance, and the margin of the ice sheet advanced to the zone of the end moraine. To facilitate discussion of the above events, it is suggested that the deglaciation following the readvance of the ice-sheet to Salpausselkä I should be known as *the Keuruu deglaciation* and the subsequent readvance as *the Jyväskylä readvance.*

IV **Rainio, H. 1991.** The Younger Dryas ice-marginal formations of Southern Finland. Eastern Fennoscandian Younger Dryas end moraines. In: Field conference, North Karelia, Finland, and Karelian ASSR, June 26 - July 4, 1991. Excursion guide. Rainio, H. & Saarnisto, M. (eds). Geological Survey of Finland, Guide 32. 1991. Pp. 25-72.

The paper reviews the genesis, location and structure of the Younger Dryas end moraines in southern Finland and the Central Finland end moraine and their relation to the highest shore line.

The structure of the glaciofluvial end moraines and their relation to glacial rivers are described with reference to data on a 170-km-long strip mapped between Lahti and Joutseno. It is concluded that the moraines are not glaciofluvial deltas in the true meaning of the word. The structure of ice-marginal deposits shows that these landforms received similar amounts of material along the entire margin of the ice sheet. The ice never ceased to flow while the end moraine was depositing, and local melting and flow were approximately in equilibrium. As shown by the structure of Salpausselkä II in North Karelia, the ice may still have been very active right up to the end of deposition of the moraine.

Clearly different in structure and also less common are the glaciofluvial deltas *sensu stricto* that deposited at the mouth of glacial rivers, in their discharge bay.

It is discussed whether Salpausselkä I is a recessional or terminal sedimentary event and demonstrated that it is most likely terminal, having deposited in front of a continental ice sheet that withdrew tens of kilometres north of the place now occupied by the Salpausselkä and then readvanced.

The history of research into the Salpausselkäs is reviewed, with special emphasis on information gleaned from investigations and concepts of the 18th and 19th centuries put forward by Rainio elsewhere.

The problematic area of North Karelia is discussed in the light of results presented earlier by Rainio. It is pointed out that the scope of the Salpausselkä concept has not been defined with sufficient accuracy.

Examples of Salpausselkäs I and II, the Tuupovaara, Koitere and Pielisjärvi end moraines and the interlobate complex between Kiihtelysvaara and Jaamankangas are given in site descriptions based on updated versions of Rainio´s previous excursion guides. The examples were selected either because they represent the general features of the ice-marginal deposits or because their location is important for the interpretation of the North Karelia deglaciation and the genesis and correlation of the Younger Dryas end moraines.

V **Rainio, H. 1993.** The Heinola deglaciation and Salpausselkä readvance as recorded in the lithostratigraphy of the distal area of Salpausselkä I at Ihalainen, Lappeenranta, Finland. In: Geological Survey of Finland, Current Research 1991-1992. Autio, S. (ed.). Geological Survey of Finland, Special Paper 18, 53-62, 1993.

A sequence of fine-grained varved sediments, 22 m thick, mainly composed of clay and fine silt was studied in a limestone quarry 1 km from the distal flank of Salpausselkä I.

The flat surface of the fine-grained, water-laid deposits is at 65-70 m a.s.l. The level of the Baltic Ice Lake (BI) was at no more than 105 m a.s.l. at this site. Hence, the elevation of the Yoldia Sea (YI) was at 67-68 m a.s.l.

Between 23 and 16.75 m the abundance of clay fraction (Ø<0.002 mm) and fines in general (Ø<0.02 mm) increases steadily upwards, amounting to 75% and 95-98% in the upper part of the layer. An the depth of 16.75 m the abundance of clay fraction begins to decline. Between 16.75 and 10 m the abundance of clay fraction gradually decreases to 10% and 20%. Nevertheless, the total abundance of fines remains at 75-90% from 18.5 to 10 m. The number of varves between 23 and 16.75 m is 364 and between 16.75 and 10 m 154.

At 10 m the clay fraction decreases, on average, from 20% to 10% and that of fines to 50%. The sediment, which is silt or coarse silt and occasionally current-bedded fine sand to 4.25 m, seems to be of ice-marginal facies. The layer has undergone abundant deformation. There are 193 varves between 10 and 4.25 m.

Between 4.25 and 3.0 m the abundance of clay fraction increases sharply from 20% to 80% and the varves become thinner. In this layer the number of varves is 186.

At a depth of about 3 m the sediment passes sharply from fat clay to coarse silt, of which there is about 3 m. The latter is without varves but contains clay fragments a few millimetres in diameter. This layer exhibits distinct features of a "catastrophic varve".

The total number of varves between 23 and 3 m is 897. They are at their clearest when deposited far from the ice sheet. Deformation structures are most common in layers deposited close to the front of the continental ice sheet. Erosion surfaces were found in at least 15 places.

The consistent variation in grain size and thickness of the varves in varved clay and silt can be explained if we assume that the front of the Scadinavian ice sheet first withdrew for at least 350 years northwards from the study site and the readvanced to Salpausselkä over a period lasting at least 150 years. The deposition of Salpausselkä I took at least 193 years, probably longer. The front of the ice sheet

withdrew again from Salpausselkä I for at least 186 years before the Baltic Ice Lake drained to the level of the Yoldia Sea. The sharp change from fat clay to coarse silt manifests the discharge of the Baltic Ice Lake (BIII) to the level of the Yoldia Sea (YI).

The findings presented here are imcompatible with the varved clay chronology of Sauramo and Niemelä. The Ihalainen sequence shows that Salpausselkä I is terminal, not recessional, and that there is a gap of at least 500 years in the varved clay chronology of Southern Finland. The Lappeenranta results are, however, from a different glacial lobe area that those of Sauramo and Niemelä.

If the bottom of the discharge varve was deposited 10 643 years before AD 1950 (Strömberg, 1990), the bottom-most layers of the fine-grained sediments started to deposit no later than 11 543 years before AD 1950. According to Sauramo´s chronology, the ice margin stopped at Salpausselkä I 660 years before the Baltic Ice Lake (BIII) dropped to the Yoldia (YI) level. Niemelä maintains that 1037 years separated the beginning of the sedimentation of Salpausselkä I and the discharge of the Baltic Ice Lake. If these figures are applied to Ihalainen, the Salpausselkä readvance came to an end and Salpausselkä I started to deposit at 11 303-11 680 years before AD 1950. The turning point of the Heinola glaciation and the Salpausselkä readvance would then have been at 11 457-11 834 years before AD 1950, and the fine-grained sediments would have started to deposit at Ihalainen at 11 821-12 198 years before AD 1950. These figures are minimum ones.

VI **Rainio, H., Saarnisto, M. & Ekman, I. 1995.** Younger Dryas end moraines in Finland and NW Russia. In: IGCP 253 - Termination of the Pleistocene - final report. Lundqvist, J., Saarnisto, M. & Rutter, N. (eds.). Quaternary International, 28, 179-192.

This paper is the final report of project IGCP-253 on Finland, Russian Karelia and Kola. It describes briefly the location, structure and the relation to the highest sea line of the Younger Dryas end moraines in these areas. Problems related to the correlation of the ice-marginal moraines, including the Keiva moraines on the Kola Peninsula, are discussed and issues are defined that require further research. The connection of the late-glacial Baltic Sea to the White Sea and the drainage channels of Lake Onega are discussed.

The paper summarizes the views expressed by the authors in their earlier papers. It is emphasized that the front of the continental ice sheet responded to climatic and glaciological changes differently in different parts of the ice sheet. This may partly explain the age discrepancy between sectors of chains of morphologically apparently continuous end moraines. In any case the ice margin responded to climatic and glaciological changes at somewhat different times in different sectors of the Scandinavian ice sheet.

The conclusion is that at the time Salpausselkä I was formed in southern Finland the margin of the continental ice sheet withdrew in North Karelia, depositing a set of ice-marginal deposits over a wide zone. The Tuupovaara end moraine represents the youngest frontal position correlative with Salpausselkä I. Its position suggests that the sector of the Koitere end moraine east of Lake Koitere, which is contemporaneous with Salpausselkä II, had already started to deposit towards the end of the formation of Salpausselkä I. The orientation of the Tuupovaara end moraine suggests that, at the end of the Salpausselkä I stage, the ice margin east of Lake Koitere was located at the same level as during the Salpausselkä II stage. Thus, the Koitere end moraine and its extension in Russian Karelia may represent both the late Salpausselkä I stage and the Salpausselkä II stage.

The findings presented by Rainio on the relation of the end moraines in the eastern part of North Karelia to the Salpausselkäs since 1972 are summarized as follows (Fig. 3):

1) At the beginning of the *Salpausselkä I* phase the front of the continental ice sheet ran from Värtsilä along the Finnish-Russian border to Möhkö, where it crossed into Russian Karelia. 2) *The Tuupovaara end moraine* probably deposited at a late Salpausselkä I phase. 3) *Salpausselkä II* and *the Koitere end moraine* are largely contemporaneous. However, deposition of the eastern part of the formation, east of Lake Koitere, may have started during the late Salpausselkä I phase, at the same time as that of the Tuupovaara ice-marginal formation. The Koitere end moraine is physically correlative with *the Rugozero (Rukajärvi) end moraine* in Russia. 4) *The Pielisjärvi end moraine* was deposited after the Baltic Ice Lake had drained and is probably contemporaneous with *Salpausselkä III* in southwestern Finland. It is physically correlative with *the Kalevala moraine* in Russia.

The divergent concepts of Finnish and Russian researchers and their grounds for correlating East Karelian end moraines with the Salpausselkäs and the end moraines of North Karelia are discussed.

DISCUSSION

A hundred years ago, Salpausselkäs I and II could be traced without difficulty from western Finland to North Karelia despite the inadequacy of research tools, from maps to communications. This was possible because, in the supra-aquatic areas of southern Finland, the Salpausselkäs are very distinct, wide landforms rising above their surroundings; besides, the best roads ran along them. No wonder then that already in the 18th century, Argillander had been able to unite, not only the various parts of the Salpausselkäs, but also those of the Jaamankangas-Yhdysharju-Salpausselkä II chain at a time when there were no scientific grounds for classifying these "sandy eskers" or explaining their origin.

The trouble started in North Karelia, where the ice-marginal formations are discontinuous, and smaller ridges are often mainly composed of till. Salpausselkä I has, accordingly, not only one, indisputable extension.

The main reason for this change in the mode of occurrence of the end moraines seems to be that the eastern part of North Karelia is supra-aquatic and so unfavourable to the deposition of major glaciofluvial end moraines. They tended to prefer sites with glacial lakes in front of the ice. Glaciofluvial marginal plains continue right up to the border of the supra-aquatic area.

The investigation of the frontal positions of the ice sheet and deglaciation has been problematic in North Karelia and numerous opinions have been expressed about the question in the course of this century. North Karelia is also a key area in solving the relation between the Salpausselkäs and other Finnish end moraines with the end moraines in Russian Karelia.

The front of the Scandinavian ice sheet at the time Salpausselkä I was formed

In the Kitee-Värtsilä-Tohmajärvi area, the northeastern end of Salpausselkä I looks as if it has been divided into several parallel, but large, ice-marginal formations. This is clearly visible in the big interlobate esker at Peijonniemi, where there are three successive ice-marginal formations of some size over a distance of 5 km: the marginal plains of Päivärinne and Kaurila-Musko and the Nenosenlampi esker delta, which is also the youngest. The 1- km-long Kiimakorpi ridge extends from the esker delta towards the Pykälävaara ice-marginal formation, the southern end of the Tuupovaara end moraine, 5 km away. Hence, the Tuupovaara moraine is at the same level as the youngest part of Salpausselkä I.

Judging by the general trend of the outermost parts of Salpausselkä I and the striations, the search for the extensions should start in the northeast or north-northeast. There is no distinct continuous chain of end moraines in that direction.

In a zone about 10-km wide there are, however, a number of moraines deposited at the front of the ice sheet that constitute a chain possibly indicating the position of the ice front during the early stage of Salpausselkä I. This chain crosses the Russian border at Möhkö, Ilomantsi (Rainio, 1978, 1980, 1991 [IV]).

The glaciofluvial plains between Patsola and Saarivaara that developed at the level of the Baltic Ice Lake (BI) support the hypothesis that the front of the ice sheet ran from Patsola to Möhkö during the early stage of Salpausselkä I.

From the above and the location of the successive end moraines at the northeastern end of Salpausselkä I and the Tuupovaara end moraine, we can conclude that the front of the ice sheet withdrew from Kitee and from northeast of Patsola in particular, whereas farther west it remained stationary at Salpausselkä I.

The Salpausselkä arcs east of Lake Päijänne are at a fairly constant distance, 20-25 km, from each other. The southern end of the Tuupovaara end moraine is 22 km from Salpausselkä II (Rainio, 1983 [I], p. 73), whereas its northern end is 10 km from the Koitere end moraine. Hence, the Tuupovaara moraine marks the site to which the ice sheet had retreated at the time Salpausselkä I was forming. If the Patsola-Möhkö line refers to the initial situation, then the ice sheet had retreated at Petkeljärvi 15 km farther than during the same time at Värtsilä.

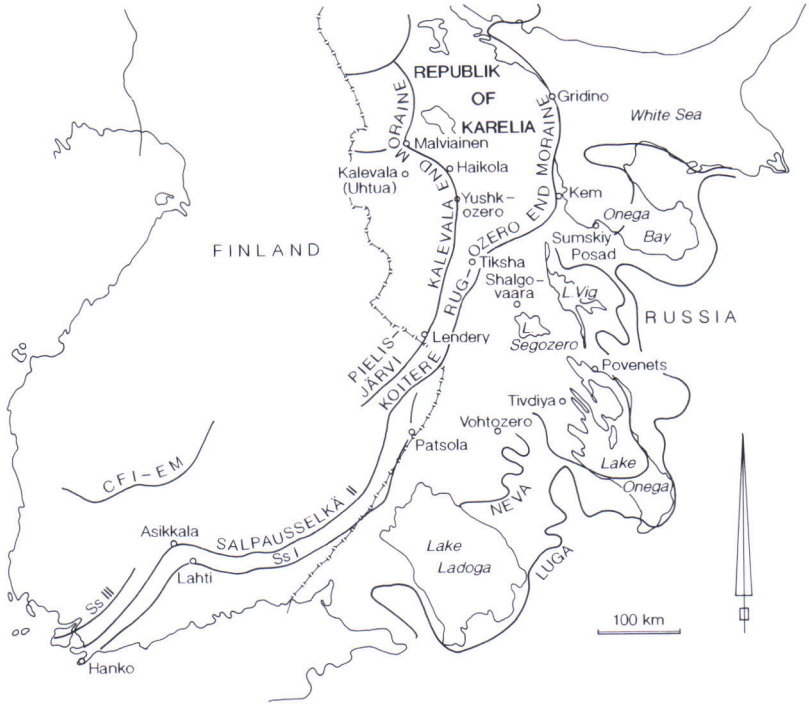

Fig. 3. Major end moraines in Finland and Russian Karelia (modified from Rainio et al, 1995).

The orientation of the Tuupovaara end moraine suggests that, at the end of the Salpausselkä I phase, the ice margin east of Lake Koitere was located at the same level as during the Salpausselkä II phase. Thus, the eastern part of the Koitere ice-marginal formation and its extension in Russia may represent both the late Salpausselkä I phase and the Salpausselkä II phase.

The Tuupovaara end moraine excludes the possibility suggested by Hirvas (1980), Ignatius et al. (1980) and Nenonen (as late as 1984) (see Kujansuu & Nenonen, 1987) that during the Salpausselkä I phase the front of the ice sheet extended from Värtsilä to the Koitere end moraine immediately northeast of Kiihtelysvaara (Rainio, 1983, p. 75).

The relationship between Salpausselkä II and the Pielisjärvi end moraine

According to Sauramo (1958, p. 397), Jaamankangas was a landform complex deposited at the front of a readvanced ice sheet ("Dabei war sicherlich ein Vorrücken des Eisrandes eingetreten"). Analysis of glacial lobe dynamics led Salminen & Hartikainen (1985, pp. 11-12), later supported by Eronen & Vesajoki (1988, p. 324), to much the same conclusion, namely, that after the Salpausselkä II phase the Lake-District glacial lobe was initially in the southern part of the Höytiäinen basin and that after it had withdrawn the North Karelia lobe readvanced to take its place.

Together with their bordering kettle holes, the components of Yhdysharju (Connection esker) that join Jaamankangas and are buried in its ice-marginal deposits imply that the ice sheet withdrew from Salpausselkä II to the level of Jaamankangas and that the end moraine deposited at the front of it without the oscillation of ice extending to the distal side of Jaamankangas (Rainio, 1973, pp. 11-13, 70-71; 1990, p. 33; 1991 [IV], p. 43).

According to Eronen and Vesajoki (1988, p. 320), "the slope of the Jaamankangas delta surface in a distal direction from about 120 m to 105 m a.s.l., along with the relatively rough topography, indicates that a lowering in water level took place during deposition of the glaciofluvial sediments." This is possible but, then again, the part of Jaamankangas above the 105-m level may be a sandur as are the uppermost parts of many other marginal plains (Repo 1957, pp. 149, 166; 1960, pp. 10-11). The upper part of Jaamankangas has abundant meltwater channels, which become shallower and less frequent in a distal direction (Rainio 1973, pp. 14-16; Lyytikäinen 1982, p. 39).

The relationship between the Central Finland and Pielisjärvi end moraines

Nenonen (1993, pp. 48-50; 1995b, pp. 79-80) has postulated that the Central Finland end moraine might be contemporaneous with Salpausselkä III and the Pielisjärvi end moraine. The Jyväskylä readvance would then have occurred at least in central Finland. This concept requires, however, the ice sheet to have withdrawn for about 80-200 km at the central part of the Salpausselkä arc and remained behind Salpausselkä III and the Pielisjärvi end moraine. Such an event would have lasted several centuries.

A network of eskers ties Jaamankangas, but also the rest of the Pielisjärvi end moraine, to the same deglaciation cycle as the chain of the Salpausselkä II- Koitere end moraine. The Sarvinki-Vallisärkkä-Ahveninen esker clearly passes through the formation. The Marjosärkkä esker runs through Jaamankangas, every now and then

being buried in it. An event corresponding to the oscillation of ice - the Keuruu deglaciation - Jyväskylä readvance - could not have occurred in North Karelia.

Had it done so, shoreline displacement at the Lake-District glacial lobe would have been quite different from that at the neighbouring lobes. Owing to uplift, the highest shoreline on the proximal side of the Pielisjärvi end moraine and Salpausselkä III would be at a distinctly lower level than at the Lake-District glacial lobe. There is, however, nothing to support this concept, at least on the proximal side of the Pielisjärvi ice-marginal formation. The highest shoreline in the subaquatic areas of Höytiäinen and Pielinen is at the same level as it is in the end moraine, not conspicuously lower (Sauramo, 1928; Saarnisto, 1970; Hyvärinen, 1966a).

Besides, the ice front would have twisted and turned so much that, for that reason if no other, the hypothesis seems improbable.

At sites where end moraines connecting ice-marginal complexes should exist, there is no sign of them for hundreds of kilometres, only interlobate deposits, and most of them are distinct longitudinal eskers. This does not necessarily nullify the hypothesis, but nor does it support it.

Shoreline displacement in North Karelia

At some key sites in North Karelia shoreline displacement is still not known well enough, and very specific claims cannot therefore be based on it.

At Valkeasuo, on the distal side of the northern end of Salpausselkä II, the levels of ponds are only 5 m below the base level of late-glacial erosion. Somewhat farther north, at Kiihtelysvaara, the levels of ponds are about 10 m lower than the surfaces of adjacent plains. Taking into account the gradient of uplift, it may well be that there was once a late-glacial lake at the present site of the ponds. Being at a slightly higher level than the Baltic Ice Lake, this lake then regulated the level of deposition. Therefore, the plains are at a higher level than might be expected from the rest of Salpausselkä. The conclusion drawn from this is that the ice sheet withdrew from Salpausselkä II at Kiihtelysvaara somewhat earlier than elsewhere (Saarnisto 1970).

The same situation prevails at the front of Salpausselkä II over a distance of 20 km south of Onkamo. A few tens of metres above the level of BIII, there seem to have been several small lakes that regulated the growth of the Salpausselkä plains. The elevations of these plains and those formed in the Valkeasuo glacial lake may have prompted Sauramo to conclude that Salpausselkäs I and II joined each other in North Karelia.

When the ice sheet withdrew from Salpausselkä II at Kiihtelysvaara, a glacial lake formed in the valley of the present river Pielisjoki and drained to the Jänisjoki watercourse between the Yhdysharju-Tervasuo deposits and Heinävaara along the distal side of Salpausselkä II (Rainio, 1990, p. 35). At that site there is a very distinct ancient channel, whose threshold, at an elevation of about 120 m, is at the Ilomantsi railway. The level of this glacial lake controlled the growth of the plains of Yhdysharju (Connection esker). The elevations of the summit plains are almost the same as those of the plains at the northern end of Salpausselkä II attributed to the Baltic Ice Lake. Consequently, they, too, are included in the same group (e.g. Eronen & Vesajoki, 1988, Fig. 2, pp 319 and 323). Among them are the plains at Kruununkangas and Kerolankangas, Paihola, and the Kaukaansärkät esker.

It is not known for sure when the waters of the Pielisjoki valley north of Yhdysharju (Connection esker) started to flow along a new channel, thus causing the water level and the base level of erosion to drop. The first low-lying tracks lead to the distal side of Salpausselkä II, to Valkeasuo, where the base level of erosion was, as mentioned above, still close to the level of the Baltic Ice Lake, even after drainage of this lake.

We cannot, therefore, state categorically what the base level of erosion was at the time Jaamankangas started to deposit. It may have been the same as the level of the Pielisjoki glacial lake or some other ephemeral water surface at a considerably higher elevation than the contemporaneous Baltic Sea. It is also possible that Jaamankangas did not start to deposit until after the drainage of these ephemeral glacial lakes and the Baltic Ice Lake (Saarnisto, 1970). The surficial parts of

Jaamankangas are composed of sandur deposits up to 15-20 m thick, as indicated by the abundance of channels. At any rate, the channels show that towards the end of deposition of Jaamankangas the base level of erosion was close to that of the Yoldia Sea (Saarnisto, 1970; Rainio, 1973). The same elevation is also represented by the other plains of the Pielisjärvi end moraine and the extramarginal plains in the Pielisjoki valley (Rainio, 1973).

Final phases of the Alleröd chron at Ilomantsi

Eronen and Vesajoki (1988, p. 321) pointed out "that there is no distinct break-off zone in the eskers in the domain of the Norht Karelian lobe. It is thus apparent that the Heinola deglaciation and the following readvance were limited to the region occupied by the Lake District lobe."

Eronen and Vesajoki are referring to a very small-scale map (op. cit. p. 319, Fig. 2). Most of the eskers on it are short and discontinuous, and do not continue through the Salpausselkä I zone. The large Petkeljärvi-Putkela interlobate esker, however, seems to begin outside the Salpausselkä I zone and to pass through it. As the key area for interpreting the continuity of the esker is located at the Finnish-Russian border and also on the Russian side of it, the issue is difficult to settle. The part of

the Petkeljärvi esker close to the Russian border displays features typical of an ice-marginal formation. It is possible that the esker and its apparent continuation, the Tolvajärvi esker, represent two different deglaciation cycles.

If, on the other hand, the Tolvajärvi esker and the Petkeljärvi-Putkela esker are part of the same esker chain (cf. Frosterus & Wilkman, 1915, pp. 70-72) (Fig. 1), they represent the very deglaciation cycle during which the ice sheet withdrew through the Salpausselkä I zone. The relationship of the Petkeljärvi-Putkela chain and the associated lateral eskers to the other Quaternary formations in the vicinity, the Koitere ice-marginal formation in particular, is such that the chain probably represents the last deglaciation stage. This would imply that there was no readvance to Salpausselkä as concluded by Eronen and Vesajoki, at least at the North Karelia glacial lobe.

It is hard to imagine a fairly large oscillation taking place at one glacial lobe and not in an adjacent area. For the deglaciation history of Finland as a whole, it would be important to establish whether the Petkeljärvi-Putkela esker was deposited by the same glacial river as the Tolvajärvi esker, which has been associated with it (Frosterus & Wilkman, 1915, pp. 70-72). In other words, did the Petkeljärvi-Putkela and Tolvajärvi eskers deposit during the same deglaciation stage?

Interpretation of bottom deposits

Punkari & Boulton (1995, Fig. 4, p. 7) have reinterpreted the succession of bottom deposits at Lappeenranta immediately on the distal side of Salpausselkä I described by Rainio (1993, V) and the very aspects on which Rainio based his conclusions.

According to them, the lowest part of the succession, the A layer, in which the material is fine grained and mainly composed of clay, represents a short withdrawal during the deposition of Salpausselkä I, when the ice sheet was 2-4 km from the site of deposition. Rainio interpreted this as representing the withdrawal of the ice, whilst the following B layer referred to readvance during the Heinola deglaciation-Salpausselkä readvance. According to the interpretation of Punkari and Boulton, the B layer and the roughly 6-m-thick, fairly coarse-grained silty, in places, coarse silty C layer refer to the time when the ice front withdrew from Salpausselkä I to Salpausselkä II. For Rainio, the C layer represents the time when Salpausselkä I deposited. Boulton and Punkari postulate that the shallow clayey layer overlying the C layer is contemporaneous with Salpausselkä II and, in general, with BIII. Rainio contends that it also represents the withdrawal of ice from Salpausselkä I to Salpausselkä II.

The interpretation of Punkari and Boulton turns cause and effect upside down: At its front an ice sheet creates a large glaciofluvial ice-marginal formation and immediately outside it a clayey deposit. During the first hundred years of withdrawal the sediment becomes coarser. Enough coarse silt and fine sand are available to form deep layers over a distance of up to 20 km from the withdrawing ice front. When a really large ice-marginal formation, the Taipalsaari marginal plain, starts to deposit, the bottom sediment becomes rich in clay fraction; not a very convincing interpretation.

Even more compelling evidence for the interpretation of Rainio against that of Boulton and Punkari is the existence of the supra-aquatic ridge of Salpausselkä I between the Ihalainen sampling site and the ice sheet withdrawing from Salpausselkä I. The ridge extended for at least 5 km in both directions and thus prevented coarser material from being transported en masse from the direction of the ice sheet to Ihalainen. Moreover, bottom deposits are rare between Salpausselkäs I and II and there do not seem to be any flat-lying deposits corresponding to the Ihalainen C layer in the 1:100 000-scale map sheet area of Lappeenranta. According to the interpretation of Punkari and Boulton, these deposits should abound there.

The arguments presented by Rainio in 1985 can be used as supplementary evidence. Thus, between Salpausselkäs I and II there are till-covered deformed glaciofluvial deposits over a large area. Remains of clay deposits occur in many places and chains of eskers do not pass through the end moraines.

Referring to Okko (1962) and Rainio (1985a [II]), Punkari and Boulton (p. 7) write that the readvance has been justified by the presence of cross striations and attribute the turning of flow directions to glacial lobe dynamics. The use of a single argument like this is misleading, for the readvance of the ice sheet is based on several arguments, as shown above. Among other things, striations with different orientations support the concept of the readvance.

The Salpausselkä readvance

Inferences about the readvance of the ice sheet to Ss I and the Central Finland ice-marginal formation are based primarily on the fact that many glacial features change sharply at these formations.

It has also been argued that the concentration of till-covered sediments in certain zones need not necessarily be due to one single advance. In Sweden, Persson (1983) and Lundqvist (1987) have attributed similar stratigraphies to a series of halts in the receding ice front (Lundqvist, 1990, p. 20).

A series of brief halts does not, however, explain the sudden change in striation, the difference in the base levels of glaciofluvial sediments and the break in the network of glacial rivers. The eskers continue across the marginal terraces of Ss II and the Pielisjärvi end moraine, which were formed during long-lasting stillstands, but not across Ss I and the Central Finland ice-marginal formation.

The most important points supporting the readvance are the presence of abundant till-covered, varved bottom sediments on the proximal side of Salpausselkä I (Berghell, 1904; Frosterus & Wilkman, 1915; Virkkala, 1948, p. 31; Sauramo, 1958, p. 274; Hirvas & Nenonen, 1980, 1985, 1987; Rainio, 1982, 1985a [II]; Nenonen, 1984; Kujansuu & Nenonen, 1987) and the numerous observations of clay lumps transported by the ice sheet or of deformed clay (Berghell, 1898, pp. 35-36; Rainio, 1984 a,b, 1985a [II]). These subtill varved clays are most easily attributed to readvancing ice.

The Keuruu deglaciation and Jyväskylä readvance

The same argumentation also provides the strongest support for the long readvance of ice to the Central Finland ice-marginal formation. A wide oscillation of the ice front is the most natural explanation for the occurrence of many till-covered varved bottom sediments (Sauramo, 1929; Aurola, 1949, p. 54; Virkkala, 1963, p. 64; Alhonen, 1971, p. 41; Aartolahti, 1972, p. 59; Niemelä & Tynni, 1979; Rainio et al. 1986 [III]).

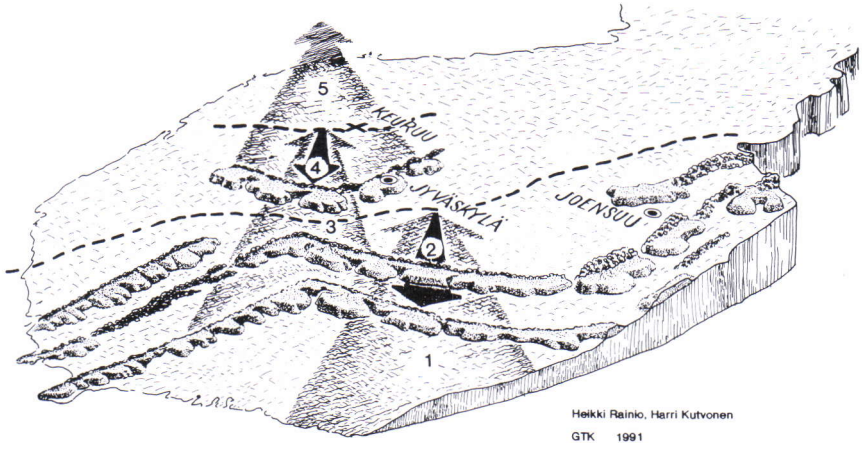

Fig. 4. The large end moraines in southern Finland and the wide late-glacial oscillations of the ice sheet. 1. The Heinola deglaciation; 2. the Salpausselkä readvance; 3. the Keuruu deglaciation; 4. the Jyväskylä readvance. (Rainio, 1995)

CONCLUSIONS

In the course of time, different methods have been used in attempts to establish the position of the ice sheet front in North Karelia at the time the Salpausselkäs formed. Results have differed accordingly. The greater the emphasis on one particular method, the more surprising the findings have been. This is partly due to the fact that the nature of the material on which one particular method was based was not studied sufficiently and partly because the basic principles and the nomenclature were only poorly defined.

The introduction to the present thesis outlines the arrival of the principles of modern geological thinking in Finland and the history of research into the Salpausselkäs - from a convenient roadway to part of a network of sandy eskers, and from a water divide to an ice-marginal formation.

The original objective of the study, to establish the position of the continental ice sheet front in eastern North Karelia, has been achieved. All three Salpausselkä end moraines have their counterparts in North Karelia. The front of the ice sheet continued from the Salpausselkäs eastwards more or less as proposed at the turn of the century. The main difference lies in the position of the ice front during the deposition of Salpausselkä I.

Both the differences between chains of ice-marginal deposits and the lack of distinct end moraines can be attributed to differences in the behaviour of the ice sheet at different times and under different conditions. In North Karelia, Salpausselkä I and Salpausselkä II differ in structure. Salpausselkä I is mainly composed of glaciofluvial marginal plains, but in the proximal part of the wide glaciofluvial plains of Salpausselkä II there is a very large end moraine ridge. Even in supra-aquatic areas, Salpausselkä II has a clear counterpart, the Koitere end moraine, but Salpausselkä I has none.

One reason for this seems to be that during the Salpausselkä I stage the continental ice sheet front, instead of remaining stationary in North Karelia as it did farther west, withdrew. This is indicated by the presence of a wide zone of successive end moraines at Kitee-Tohmajärvi; moreover, the ice front seems to have been at the Patsola- Möhkö line at the time of formation of the Salpausselkäs, and the northern end of the Tuupovaara end moraine chain is about 10 km closer to the Koitere end moraine than its southern end is to Salpausselkä II.

In the supra-aquatic area northeast of Värtsilä, Salpausselkä I does not have such a well-developed counterpart as the two other Salpausselkäs. Close to the Finnish-Russian border, there is a discontinuous zone of ice-marginal deposits and

hummocky moraines that may represent the early stage of Salpausselkä I, particularly as, direction-wise, it could be an extension of Salpausselkä I. The plains in the Baltic Ice Lake about 10 km northeast of Patsola corroborate the concept that the ice front initially ran from Patsola to Möhkö at the time Salpausselkä I formed.

The Tuupovaara end moraine deposited during the late stage of Salpausselkä I. The relationship between the end moraine at Tuupovaara and Koitere suggests that the part of the Koitere end moraine east of Koitere represents the end of the Salpausselkä I phase and the Salpausselkä II phase.

The landform system most clearly contemporaneous with Salpausselkä II is the Koitere end moraine. Running uninterrupted from northeast of the village of Kiihtelysvaara to the Russian border (Rainio, 1978, 1985b, 1991 [IV]; Frosterus & Wilkman, 1915), the moraine continues without a break into Russian Karelia. It includes the Selkäkangas ice-marginal formation, known since the early days of work on these formations (e.g. Ramsay, 1891).

The boundary between these ice-marginal formations is marked by the contact of two large glacial lobes, The Lake District and the North Karelia lobes, where there is a gap in the chain of ice-marginal deposits.

The third chain of ice-marginal deposits, the over 100-km-long Pielisjärvi moraine, is fairly continuous, extending from Jaamankangas to the Russian border. From its position, if nothing else, it is younger than Salpausselkä II. Between the north end of Salpausselkä II at Kiihtelysvaara and Jaamankangas there is an interlobate complex and three eskers. These eskers extend to Jaamankangas and are buried by its delta deposits. Shoreline displacement shows that this chain of end moraines did not deposit until after the drainage of the Baltic Ice Lake, and that it is of about the same age as Salpausselkä III in southwestern Finland.

The Pielisjärvi end moraine extends 50 km northeastwards from the large marginal plain of Jaamankangas to Uimaharju (Rainio, 1985b). The marginal plains and valley trains of the formation are at about 105 m a.s.l., clearly below the level of the Baltic Ice Lake (Saarnisto, 1970; Rainio, 1985b). The Pielisjärvi end moraine was thus formed after the drainage of the Baltic Ice Lake and, accordingly, is younger than Salpausselkä II. The Pielisjärvi end moraine may also be time-correlative with Salpausselkä III (Sauramo, 1929, Rainio, 1985b).

Northeast of Uimaharju, the ice-marginal deposits was deposited mainly on supra-aquatic terrain except north of Lake Koitere where it was deposited in a glacial lake. This area excluded, the ice-marginal formation extends as an almost unbroken moraine ridge across the Russian border.

The Pielisjärvi end moraine does not have a distinct counterpart at the Lake District glacial lobe between Päijänne and North Karelia, demonstrating that the glacial lobes differed in dynamics.

Numerous arguments support the concept that the continental ice sheet readvanced twice for tens of kilometres in late-glacial time, first before the formation of Salpausselkä I and then again before the deposition of the Central Finland end moraine. For one thing, in the proximal zones of these end moraines the younger till is underlain by a sequence of older deglacial deposits. Most of the observations of this sequence are of deformed glaciofluvial deposits. Till and bottom deposits have been observed in cuttings, although less often. Striations can usually be attributed to readvance of the ice. Differences in base levels of erosion between glaciofluvial deposits of different ages are sometimes considerable. Eskers do not pass through these ice-marginal formations. The lithostratigraphy of the bottom sediment on the distal side of Salpausselkä I also supports this interpretation.

The outcome of the present study is briefly:

1) Arguments presented to support the major oscillations in southern Finland - the Heinola deglaciation-Salpausselkä readvance and the Keuruu deglaciation-Jyväskylä readvance - are more conclusive than those presented to refute them.

2) At the beginning of the Salpausselkä I phase the front of the ice sheet ran from Värtsilä along the Finnish-Russian border to Möhkö where it crossed the border to Russian Karelia.

3) The Tuupovaara end moraine was deposited during a late Salpausselkä I phase.

4) Salpausselkä II and the Koitere ice-marginal systems are largely contemporary. However, deposition of the eastern part of the moraine, east of Lake Koitere, may have started during the late Salpausselkä I phase, at the same time as that of the Tuupovaara end moraine.

5) The Pielisjärvi end moraine was deposited after the Baltic Ice Lake had drained and is probably synchronous with Salpausselkä III in southwestern Finland. It is physically correlative with the Kalevala moraine in Russia.

Closing words

A hundred years ago, Rosberg summed up the situation in research into the Salpausselkäs with the words: "Men frågan är ännu långt ifrån slutdiskuterad" (But the issue is still far from settled") (Rosberg, 1899, p. 1).

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