PLEISTOCENE STRATIGRAPHY AND REFERENCE SECTIONS IN SOUTHERN AND WESTERN FINLAND

Keijo Nenonen

GEOLOGIAN TUTKIMUSKESKUS
GEOLOGISKA FORSKNINGSCENTRALEN

Geological Survey of Finland
Regional Office for Mid-Finland

Kuopio 1995

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by

KEIJO NENONEN

with 32 figures, 3 tables in the text and 7 papers

ACADEMIC DISSERTATION

TO BE PRESENTED, WITH THE PERMISSION OF THE FACULTY OF MATHEMATICS AND NATURAL SCIENCES OF THE UNIVERSITY OF TURKU, FOR PUBLIC CRITICISM IN AUDITORIUM 1 ON DECEMBER 8th, 1995 AT 12 NOON

Geological Survey of Finland,
Regional Office for Mid- Finland
Kuopio 1995

"What was Finland like before the Ice Age? Not until July 1991 was the door to the past prised ajar - and then quite suddenly and by sheer change. In the most amazing way, we were given a glimpse of the world as it was 200 000 years ago."

Veijo Meri: Heaven Hinges on Earth

Cover photo Keijo Nenonen 1992: White diatomite deposit at Horonkylä, Teuva. The boy is 125 cm tall.

Keijo Nenonen 1995. Pleistocene stratigraphy and reference sections in southern and western Finland. Geological Survey of Finland, Regional Office for Mid-Finland. 94 pages, 32 figures and 3 tables.

The study compiles data from seven papers dealing with the Pleistocene stratigraphy of southern and western Finland and from the author's unpublished research results. Till-stratigraphic studies launched in 1978 have produced observations on over 2500 test pits and sections made in moraine areas. Representative reference sections for Pleistocene series were selected from the survey data, and their lithofacies and the geological information relevant to the dating and correlation of the deposits are described. With the aid of the sections, an overall view of the lithostratigraphy and Pleistocene evolution of the Pleistocene deposits is given. The deposits studied are correlated with the Pleistocene stratigraphy of northwestern Europe, with the oxygen isotope curves of deep-sea sediments and Greenland ice cores and with the climatic stages deduced from them.

Till deposits preceding the last, that is, Weichsel, glaciation and the Eem Interglacial are common in western Finland. They were formed in isotope stage 8-6, during the Saale glaciation, which can probably be further divided by an ice-free interstadial in isotope stage 7. Deposits of that stage have been found at Virtasalmi in Savo and at Lappajärvi and Vihanti in Ostrobothnia. Owing to difficulties encountered with the boreal pollen assemblage and the dating methods, the deposits could not be conclusively dated or correlated. The dates given here are based on correlations with deposits outside the study area and on the oxygen isotope curve of deep-sea sediments.

The key finding of the study was the length of the ice-free interglacial and interstadial period in southern Finland, that is about 60 000 years. According to the data gathered, the ice-free period covers the time span that began with the Saale deglaciation and includes the Eem Interglacial, the Early-Weichsel interstadials and the cold substages between them, i.e. the entire oxygen isotope stage 5 of deep-sea sediments. The ice sheet that spread from the Scandinavian mountains obviously did not cover southern and western Finland during the last glaciation until isotope stage 4, which started 74 000 years ago. The spreading stage of the ice sheet was characterized by fluctuations, melting and readvances in the course of which sorted sediments were buried under till during the Middle Weichselian.

Fluctuations also occurred during deglaciation. In the Alleröd Interstadial the climate warmed rapidly and the ice front withdrew to the south coast of Finland and far inland. Thereafter, in the Younger Dryas chronozone, the climate cooled to the glacial level once again, and the ice readvanced, depositing the Salpausselkä end moraines at its front. Clay deposits and eskers were overridden by the readvancing ice sheet. Another extensive deglaciation and subsequent readvance of the ice occurred in central Finland in the early part of the Preboreal chronozone. During deglaciation, lodgement tills were formed, separated from each other by sorted sediments deposited in glacial lakes or the sea.

Key words: glacial geology, stratigraphy, till, reference sections, glaciation, deglaciation, interglacial environment, interstadial environment, Quaternary, Pleistocene, Saale, Eem, Weichsel, southern Finland, western Finland.

Keijo Nenonen
Geological Survey of Finland
Reginal Office for Mid-Finland
P.O.Box 1237
FIN-70211 Kuopio
Finland

ISBN 951-690-611-7

Kevama Graf • Kuopio 1995

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Paper II: Kujansuu, R. & Nenonen, K. 1987. Till stratigraphy and ice flow directions in North Karelia. Geological Survey of Finland, Special Paper 1. 59-66.

Paper III: Hirvas, H. & Nenonen, K. 1987. The till stratigraphy of Finland. Geological Survey of Finland, Special Paper 3. 49-63.

Paper IV: Hirvas, H. & Nenonen, K. 1990. Field methods for glacial indicator tracing. In: Kujansuu, R. and Saarnisto, M. (eds.) Glacial indicator tracing. Rotterdam: Balkema.217-247.

Paper V: Nenonen, K., Eriksson, B. & Grönlund, T. 1991. The till stratigraphy of Ostrobothnia, western Finland, with reference to new Eemian interglacial sites. In: Andersen, B.P. and Königsson, L-K. (eds.) Late Quaternary Stratigraphy in the Nordic Countries 150 000 -15 000 B.P. Striae 34. 65-76.

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Paper VII: Nenonen, K. 1995. Pleistocene stratigraphy of southern Finland. In: Ehlers, J., Kozarski, S. and Gibbard, P.L. (eds.) Glacial Deposits in North-East Europe. Rotterdam: Balkema. 11-28.

INTRODUCTION

This doctoral thesis comprises data collected in the course of studies on glacial deposits underpinning exploration and till-stratigraphic investigations undertaken by the Department of Quaternary Geology and the Mid-Finland regional office of the Geological Survey of Finland in southern and western Finland in 1978-1994. Most of the research targets were associated with exploration, mines and quarries. Some were till-covered deposits of sorted sediments important for gravel resources and groundwater management. Study materials were collected from existing sections, excavator pits and surface drillcores from the soil. Results were published at the same rate as data from analyses and measurements were received. The thesis is compiled from seven papers describing these investigations and methods in detail. The contents and implications of the papers are described in broad outline and the contribution of the author is clarified.

Paper I: Nenonen, K. 1986. Orgaanisen aineksen merkitys moreenistratigrafiassa. Summary: The significance of organic material in till stratigraphy. Geologi 38 (2). 41-44.

The publication describes the importance of organic material in dating till stratigraphy. It is based on till-stratigraphic investigations conducted in Ostrobothnia and on the Vesiperä deposit in Haapavesi discovered in the course of the investigations.

Clay deposited in deep water, a littoral deposit and a deposit of rich forest mull soil indicating an ancient ground surface were found at Vesiperä, Haapavesi. The article describes the preliminary results of studies on the Vesiperä deposit, and the organic rich soil is tentatively correlated with the Eem Interglacial on the basis of the pollen assemblage. The Vesiperä interglacial deposit was the first sequence in Ostrobothnia where it was possible to show an *in situ* interglacial formation between deposits of two different glaciations. Earlier interglacial finds in Ostrobothnia had not been linked to till stratigraphy, and the Vesiperä deposit provided an opportunity to date the till stratigraphy in central Ostrobothnia and northern Savo. The article gives examples of till stratigraphy in these areas and a preliminary till-stratigraphic correlation.

In the light of the lithostratigraphic observations described in the article, it is postulated that a continuous ice-free period comprising the Eem Interglacial and the subsequent Early Weichsel interstadials prevailed in central Ostrobothnia. The till bed of the Early Weichsel glaciation described from northern Finland has not been found in Ostrobothnia.

The existence of a prolonged ice-free period before the spread of the Weichsel ice sheets to Ostrobothnia proposed in this publication was a new interpretation corroborated only by observations of Raimo Sutinen (1982, 1984) from Peräpohjola. The earlier understanding was that in the Weichselian stage following the Eem Interglacial the ice readvanced to Ostrobothnia and southern Finland.

Paper II: Kujansuu, R. & Nenonen, K. 1987. Till stratigraphy and ice flow directions in North Karelia. Geological Survey of Finland, Special Paper 1. 59-66.

The article describes the ice flows that transported the Kivisalmi copper ore float and the stratigraphy of the till deposited by these flows.

As a result of exploration triggered in 1908 by a sample of a copper ore float found at Kivisalmi, the mine geologist Otto Trüstedt discovered the Outokumpu copper deposit in 1910. The Kivisalmi sample had been taken from a large copper ore boulder exposed from under till in the course of excavations to deepen the local canal. At Kivisalmi and Outokumpu, drift had been transported from northwest to southeast and from west to east in the main directions of ice flow. The possibility that the Kivisalmi float had been transported from the west, with its source on the west shore or bottom of Lake Orivesi, where the bedrock is of the Outokumpu zone type, is still a subject of debate today. A number of copper ore floats have been found in North Karelia. Although of unknown source, it is feasible that they originate from copper deposits in the Outokumpu zone.

The article presents research data suggesting that the Outokumpu-type ore floats found at Kivisalmi and Selkie could have been transported from the known Outokumpu copper deposit by glacial lobes flowing during deglaciation and by the preceding ice sheet that flowed from the northwest. The petrogenesis and fluid inclusions of the floats are similar to those of the Outokumpu copper ore.

The stratigraphy of the till deposited during deglaciation and its relationship with the deposition of the Salpausselkä ice-marginal formation in North Karelia are described. A map is given showing the flow directions of ice, and examples are presented of till stratigraphy in zones of ice-marginal deposits. The location and dating of the Salpausselkäs in North Karelia are still current issues and a subject of much discussion and research. The Late Weichselian glacial history of North Karelia is interpreted in the light of till-stratigraphic investigations and data on the flow directions of ice. Earlier studies and interpretations of the location of the Salpausselkäs were based on observations made in the course of mapping of Quaternary deposits.

The findings of till-stratigraphic studies, and relative dates based on the stratigraphy of glaciation events bring a new perspective to the subject. The study shows that the formation of the Salpausselkäs was preceded by extensive melting followed by a readvance of the continental ice sheet. A new observation in North Karelia, it is based on preliminary data on till stratigraphy published by Nenonen 1984. Later, Rainio (1985a) examined in greater detail the readvance of the ice sheet that generated the Salpausselkäs.

The two glacial lobes that developed in North Karelia during deglaciation are shown to have deposited tills of different stratigraphy. Thus the activity of flow and melting of the glacial lobes must also have differed. At first, the Lake Finland glacial lobe was regionally stronger. Deglaciation of this glacial lobe obviously proceeded faster than that of the North Karelia lobe, where the Jaamankangas push moraines and the Pielisjärvi ice-marginal moraine are the last signs of ice flow activity. The study concludes that deglaciation in the area of the Lake Finland glacial lobe took place mainly under subaquatic conditions, but in the east in a supra-aquatic environment. Consequently, the extensive glaciofluvial formations typical of the Salpausselkäs do not continue in the supra-aquatic area, where the position of the ice margin is recorded by end moraines. The concept derived from till-stratigraphic studies is supported by later investigations. This subdivision of the ice-marginal zone into subaquatic and supra-aquatic portions may have greater implications for glacial events than is currently realized (Nenonen 1993).

Paper III: Hirvas, H. & Nenonen, K. 1987. The till stratigraphy of Finland. Geological Survey of Finland, Special Paper 3. 49-63.

The paper summarizes the key findings of the till-stratigraphic studies made by the authors. Systematic till-stratigraphic studies were launched in northern Finland in 1972 and in southern and central Finland in 1978, when investigations of till stratigraphy and glacial flow directions in the Ladoga-Bothnian Bay main sulphide ore zone got under way. A comprehensive study on the till stratigraphy of northern Finland, in which the present author participated, was published as part of the Nordkalott project (Nordkalott Project 1986 and Hirvas et al. 1988). In 1991, Heikki Hirvas published an extensive monograph of the Pleistocene stratigraphy of Finnish Lapland. The paper deals with till stratigraphy and its dating mainly in the light of targets investigated by the authors. For Kainuu and Peräpohjola, the conclusions are based on findings published by others.

The stratigraphies of 17 example sites selected from targets excavated in various parts of Finland are discussed. The southernmost example is from Porvoo and the northernmost from Kaamanen, Inari. Till-stratigraphies are shown to differ regionally from each other. The regional till-stratigraphic subdivision of Finland comprises the distal area of the Salpausselkäs, the Salpausselkä zone and its proximal area, the Central Finland ice-marginal zone, the Ostrobothnian area, the Peräpohjola and Kainuu area, and Finnish Lapland.

According to the examples, the till stratigraphy of southern and central Finland is due to large glacial lobes active during deglaciation; tills deposited at the maximum stage of the Late Weichselian glaciation occur on the ground surface only in the distal area of the Salpausselkäs. The effect of the large deglacial oscillations of the continental ice sheet on the till stratigraphy of Finland is demonstrated for the first time.

Organic deposits between till beds are described in the light of examples from Ostrobothnia, Peräpohjola and Lapland. It is suggested that the preservation of several till beds and interglacial and interstadial deposits in Lapland is due to the weakness of erosion by the Scandinavian Ice Sheet. Most of the till-covered organic deposits in Lapland and Ostrobothnia are shown to correspond with Eem Interglacial peats and gyttjas. The paper also describes deposits from Peräpohjola and Lapland referring to a climatic period, an interstadial, when the climate was colder than it is today. The deposits are interpreted as having formed during the interstadial, called the Peräpohjola Interstadial in Finland, that divided the Weichselian glaciation into two. The Peräpohjola Interstadial is correlated with the Early Weichselian Jämtland Interstadial in Sweden and the Brørup in Denmark.

A tentative till-stratigraphic correlation is presented and the absence of till stratigraphy comparable to the Early Weichselian in Ostrobothnia is demonstrated. The till stratigraphies of southern and central Finland and Lapland cannot be correlated. More recent investigations show that the till bed deposited by ice flowing from the northwest and the horizon previously assumed to be interstadial in the till stratigraphy of Kuhmo and Koillismaa probably represent the Saale glaciation and the subsequent Eem Interglacial and Weichsel interstadials (Sutinen 1992, Nenonen 1993).

Paper IV: Hirvas, H. & Nenonen, K. 1990. Field methods for glacial indicator tracing. In: Kujansuu, R. and Saarnisto, M. (eds.) Glacial indicator tracing. Rotterdam: Balkema. 217-247

The publication describes in detail till-stratigraphic methods and their application in tracing the source rock of glacial ore indicators in tills and related deposits. The research methods were developed in the course of studies on surficial deposits underpinning exploration in northern Finland, and applied in till surveys at ore targets in southern and central Finland.

The study emphasises the importance of till stratigraphy and of ice flows of different ages in the search for the source of ore floats and indicators. A suboutcrop of an orebody covered by several till beds is comparable to a blind orebody from which boulders or ore indicators cannot enter glacial transport, and so are unable to reach the uppermost tills. However, the suboutcrops of orebodies are usually covered by only one till bed and the train of ore indicators released from the suboutcrop can be traced by studying the uppermost till bed and the flow direction of the ice that deposited the till.

The various stages of till-stratigraphic excavation and the related observations are described in detail. A code of practice is given for determining the direction of ice flow on the basis of fabric analyses of till clasts. The author investigated the magnetic, microscopic and macroscopic fabric of till as an indicator of the direction of ice sheet flow in western Lapland in his unpublished master's thesis (Nenonen 1980).

Analyses and determinations of till samples are described in broad outline, with the emphasis on rock types and the heavy mineral composition of till. The granulometric analysis of till by sieving and areometry as applied earlier is described. The areometer has now been replaced by the sedigraph, an instrument based on X-ray technology.

The correlation of till-stratigraphic sections is illustrated with examples, and the importance of key sequences containing organic deposits is described.

A research technique making it easier to trace the source of glacial ore indicators was developed with the aid of the till-stratigraphic studies. Till-stratigraphic studies underpinning exploration have been able to detect the source of 79% of the 57 ore showings investigated. On the basis of the field observations, a probability sector of glacial transport was compiled for ore indicators. The sector outlines the terrain area in which the bedrock source of ore indicator will be, provided the flow direction and stratigraphy have been correctly determined. The area of the sector is further restricted with excavations, ore boulder tracing, and geochemical and geophysical investigations. The area of costly follow-up studies can thus be demarcated. The technique has led to marked savings of both time and money in exploration in southern and central Finland.

The till-stratigraphic technique is mainly used today in exploration and the search for exploitable gravel resources and groundwater occurrences.

Paper V: Nenonen, K., Eriksson, B. & Grönlund, T. 1991. The till stratigraphy of Ostrobothnia, western Finland, with reference to new Eemian interglacial sites. In: Andersen, B.P. and Königsson, L-K. (eds.) Late Quaternary Stratigraphy in the Nordic Countries 150 000 - 15 000 B.P.Striae 34. 65-76.

The till stratigraphy of Ostrobothnia is discussed in the light of till-covered deposits in Haapavesi and Peräseinäjoki found to contain terrestrial organic matter and water-laid fine-grained sediments. The research data comprise observations on and measurements from till-stratigraphic pits and cores and samples collected from deposits. The pollen studies on the organic interlayers were made by Brita Eriksson and the diatom studies by Dr Tuulikki Grönlund, both of the Geological Survey of Finland.

The correlation and dating of the till stratigraphy observed in excavations are presented for Ostrobothnia on the basis of data on the till-covered Haapavesi and Peräseinäjoki deposits.

The lithostratigraphy and biostratigraphy of the deposits at Vesiperä, Haapavesi; and Viitala, Peräseinäjoki are described in detail. It is shown that the Vesiperä deposit represents two glacial cycles and the subsequent interglacials together with features typical of them. The Peräseinäjoki deposit is an interglacial deep-water deposit with typical early interglacial sediments. The Weichselian glaciation eroded part of the sediments in the upper sequence at Peräseinäjoki and incorporated them in the till.

In biostratigraphy the Peräseinäjoki deposit is the first to indicate a lacustrine stage at the beginning of the Eem Interglacial, that is, before the Eemian marine stage extended to the area. The *Betula* vegetation zone related to the early Eemian Interglacial also refers to a lacustrine stage. The Vesiperä deposit at Haapavesi, on the other hand, represents terrestrial evolution during the Eemian Interglacial, at a time when the *Betula-Alnus-Corylus* vegetation typical of the interglacial prevailed in the area. Both the Peräseinäjoki and Haapavesi deposits can be correlated with Eemian Interglacial deposits in Karelia, Estonia, Germany and Denmark.

It is concluded that the interglacial and interstadial sediments found in Ostrobothnia are usually covered with one till bed only. The upper till bed is tentatively correlated with the Late or Middle Weichsel deposits. The erosional and depositional activity of the glacial lobes during deglaciation hampers till-stratigraphic correlation in the zones of ice-marginal formations. The compact till bed deposited by ice flowing from the northwest in deeper sections in Ostrobothnia is tentatively attributed to the Saalian glaciation. It is suggested from their stratigraphic position that the organic deposits belong to the same continuous ice-free period that began with the Eemian Interglacial and ended with the spread of the Scandinavian Ice Sheet to Ostrobothnia after the Early Weichselian interstadials. As no continuous interglacial and interstadial deposit has been found in Ostrobothnia, the extension of the Early Weichselian ice sheet to Ostrobothnia is considered possible, albeit not probable.

Paper VI: Nenonen, K. 1992. Till stratigraphy in southern and western Finland. Bulletin of the Geological Society of Finland 64 (2). 149-160.

The paper assesses the recent results of till-stratigraphic studies and discoveries. Till stratigraphy produced by the activities of large glacial lobes during deglaciation is described with a diagram. The difficulty of correlating the till stratigraphy of southern Finland is attributed to ice sheet oscillations in the zones of ice-marginal formations and to discontinuity in till stratigraphy. The till formations in southern and western Finland are diachronous (time-transgressive), that is, the uppermost till due to a single ice flow stage is older on the south coast than on the coast of the Gulf of Bothnia in the northwest.

Deposits of the last Weichsel glaciation and till of the preceding Saale glaciation predominate in the till-stratigraphic material. The dating of till beds is feasible due to the Eemian Interglacial and Weichselian interstadial deposits found under and between the tills in Ostrobothnia. Organic deposits predating the Eemian Interglacial are rare, due to intense glacial erosion and to their setting, usually under thick, younger Quaternary sediments. The deposits at Vihanti, Lappajärvi and Virtasalmi are tentatively assumed to predate the Eemian Interglacial.

The correlation of till stratigraphy is discussed at length. The Early Weichselian ice sheet is shown to have extended to the till-covered ice-marginal formation at Pudasjärvi, north of Oulu, described by Sutinen (1992). The Eemian Interglacial and Early Weichselian interstadial deposits in Ostrobothnia are thought to refer to a long ice-free period before the glacier advanced to Ostrobothnia. According to the study, the age of the ice advance is very uncertain. Oxygen isotope investigations on deep-sea sediments, however, suggest that it possibly occurred about 75 000 years ago, at the onset of the Middle Weichselian stage.

A need is expressed to establish reference sections for the Pleistocene till stratigraphy of southern and western Finland. A synthesis of the Pleistocene stratigraphy of southern and western Finland attempts to correlate the lithostratigraphy with European climate stratigraphy, oxygen isotope stages and existing datings.

Paper VII: Nenonen, K. 1995. Pleistocene stratigraphy of southern Finland. In: Ehlers, J., Kozarski, S. and Gibbard, P.L. (eds.) Glacial Deposits in North-East Europe. Rotterdam: Balkema. 11-28

The paper reviews what is known about Pleistocene stratigraphy in Finland. The principles used in investigations and in distinguishing till beds of different age are described as are the difficulties and sources of error encountered in the absolute dating of the deposits. The lithostratigraphy of deposits related to the Eem Interglacial and the stratigraphy of the till deposited by glacial lobes during the last deglaciation are illustrated with examples based on the author's own studies.

The deposits in Ostrobothnia are correlated with the Vesiperä deposit in Haapavesi, which is dated to the Eemian Interglacial. It is suggested that the section at the Ryytimaa limestone quarry in Vimpeli represents the Weichsel and Saale glaciations and the intervening ice-free stage, i.e. the Eemian Interglacial and the Brørup Interstadial of the Early Weichsel substage. The development of interglacial vegetation and its marine stages is described with examples from Haapavesi and Peräseinäjoki. Marine and terrestrial data are correlated with other sites in northern and northeastern Europe. The study provides further confirmation that Scandinavia was indeed an island in the early part of the Eemian Interglacial.

The interstadial deposits are shown to have the same lithostratigraphic position as the interglacial deposits. The till bed deposited during the Early Weichselian has not been found in Ostrobothnia and it is suggested that the Early Weichselian ice sheet probably extended to the till-covered ice-marginal formations described from Pudasjärvi. Interstadial deposits described by other researchers are reviewed and their correlation with climate stratigraphy is discussed. It is suggested that a long ice-free stage prevailed in Ostrobothnia and southern Finland during the Early Weichselian and that the Weichselian interstadial complex is composed of interstadial deposits of different vegetation succession. Thus the interstadial deposits of Peräpohjola, Norrbotten (Sweden), Lapland and Ostrobothnia represent Weichselian interstadials differing somewhat in age and vegetation. It is estimated that, due to the long ice-free stage, the water level of the Gulf of Bothnia was 80 m lower than it is at present and that a lacustrine stage developed in the Bothnian Bay area during the Early Weichselian.

The till stratigraphy related to glacial lobe activity during deglaciation is described with seven examples. The type stratigraphies are located in southern and eastern Finland in and to the south and north of the Salpausselkä zone. The readvance of the ice sheet during the Younger Dryas, and the formation of the Salpausselkäs are recorded in Finland's till stratigraphy from Åland to North Karelia. Deglaciation predating the Salpausselkä stage is correlated with the Alleröd Interstadial, when the climate warmed to the interstadial level. The till stratigraphy contemporaneous with the deposition of the Central Finland ice-marginal formation is described.

A model of the Pleistocene stratigraphy of southern Finland is presented based on the most recent studies and interpretations. The model correlates the climate stratigraphy of the named lithostratigraphic units with the deep-sea oxygen isotope stages.

The model explains the lithostratigraphic data from Ostrobothnia and southern Finland and in broad outline the development shown by the interglacial and interstadial deposits. The model differs from earlier concepts of the history of the last glaciation, mainly by suggesting a long ice-free period after the last interglacial and a fairly late advance of the continental ice sheet to Ostrobothnia and southern Finland. According to the model, which is in harmony with stratigraphic data from adjoining areas, the ice-free period was nearly as long as the period when the ice sheet covered southern Finland.

PLEISTOCENE REFERENCE SECTIONS IN SOUTHERN AND WESTERN FINLAND

General

Southern and western Finland lies at the centre of the area affected by the Scandinavian Ice Sheet and so has several times been subjected to the erosional and depositional activities of Pleistocene glaciations (Fig. 1). Owing to glacial action, the Precambrian bedrock of Finland is covered with a thin blanket of drift. It is impossible to find a lithostratigraphic profile covering the entire Pleistocene in Finland. Being uppermost, the thin layers of unconsolidated organic sediments deposited during the Pleistocene ice-free interglacials and interstadials were often stripped away in the course of the following glaciation. In contrast, tills formed during glaciations, and sediments deposited during deglaciation were better able to resist erosion, being partly protected from removal and deformation. Thus, Finland's Pleistocene stratigraphy consists largely of sequences of glacial deposits, till in particular. Most of central Finland was still covered with ice in the early Holocene (Ignatius et al. 1980).

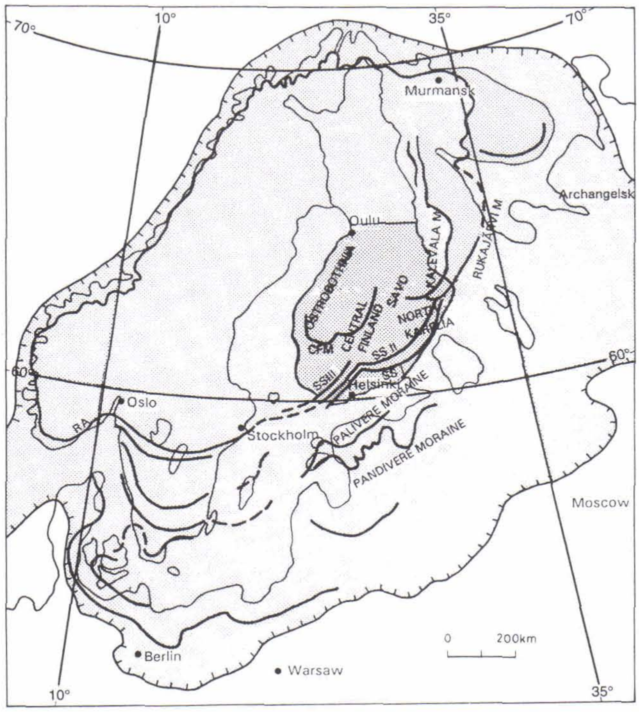


Figure 1. Location of study area, and maximum extent and most important marginal positions of the Scandinavian Ice Sheet during the Weichselian glaciation.

The first observations of glaciations of different ages and of intervening warmer ice-free stages in Finland were made in the late 19th century (historical review in Hirvas et al. 1981). From mammoth molar finds and extensive, thick, till-covered clay deposits discovered at Sulkava, Savo, Berghell (1905) concludes in his explanation to sheet D2 Savonlinna of the map of Quaternary deposits that, 'during interglacial time most of Finland was free of ice. For it is clear that the mighty mammoth, a fairly close relative of the present elephant, albeit considerably larger in body, could not have lived in ice-covered Finland during the ice age. Instead, while being in our country, it roamed over extensive grasslands that in all likelihood were here during interglacial time' (Berghell 1905, p 50-51).

It was not until Korpela (1969) discovered till-covered sediments containing organic matter that it was possible to show that some till-covered sorted deposits in the Peräpohjola area of northern Ostrobothnia had formed under interstadial conditions (Korpela, preliminary report 1962). The interpretation in the pioneering work of Korpela (1969, Fig. 47) that the Peräpohjola Interstadial, as a stage younger than the Brørup Interstadial, belonged to the early Middle Weichselian, is still a topical and possible correlation. Till-stratigraphic research methods were developed in the course of till surveys underpinning exploration launched in northern Finland in 1972. It was noted that the Pleistocene stratigraphy was most representative and best preserved in the area of the Lapland ice divide (Hirvas et al. 1976, Hirvas et al. 1977, Hirvas 1991, Paper III). The glacial stratigraphic work begun in Finnish Lapland was expanded during the joint Nordic Nordkalott project of 1980-1986 to cover the entire far north of Fennoscandia (Hirvas et al. 1988). In 1978, the studies on surficial deposits, till stratigraphy and ice flow directions extended to southern Finland (Hirvas 1980, 1989, Nenonen 1984). The Mid-Norden project has been studying till sequences and ice flow directions and mapping formations on a small scale since 1989.

Figure 2. shows the distribution of drift based on elevation data of the basic map shaded in oblique light from the northeast. The area of thick overburden in Ostrobothnia, western Finland, differs clearly from southern and central Finland as does central Lapland as an area with potential for till-stratigraphic studies. The Ostrobothnia plain might also be a neoproterozoic primary peneplain, as on a similar image of elevation data in oblique light published from Sweden, the subcambrian plain of southern and eastern Sweden continues along the west coast of the Gulf of Bothnia up to Peräpohjola (see Lidmar-Bergström 1994).

Large glacial lobes developed in southern Finland during deglaciation of the Scandinavian Ice Sheet, and in places readvanced to the ice-free area occupied by the Baltic Ice Lake and later the Yoldia Sea (Repo 1957, 1964, Hirvas & Nenonen 1985, Rainio 1985a, 1991, Rainio et al. 1986). The fast, active flow of the glacial lobes eroded the older, least resistant deposits, and large drumlin fields were formed in the central parts of the lobes, reflecting their fanlike mode of advance (Brander 1934, Aario et al. 1974, Glückert 1971, 1973, 1974, Kurimo 1974, Punkari 1979, 1980, 1984, Haavisto-Hyvärinen et al. 1989). The geomorphology created by the flow of glacial lobes is seen in Fig. 2 as a fanlike drumlin field in the Finnish Lake District. In the areas of active glacial lobe flow, the overburden deposited mainly during deglaciation at the end of the Weichselian glaciation (Papers II and III).

Figure 2. *Topographic model of Finland based on digital elevation data of National Board of Survey (basic map 1:20 000) depicted with shading in oblique light from the northeast. Areas of monotonous grey in western Finland and Lapland generally contain several till units of different ages, in places separated from each other by interglacial and interstadial deposits. The morphology caused by glacial lobes during deglaciation is seen in central Finland as fanlike drumlin fields and in southern Finland as arcuate ridges, the Salpausselkä end moraines. Processed by Geodata Oy, Helsinki. ->*

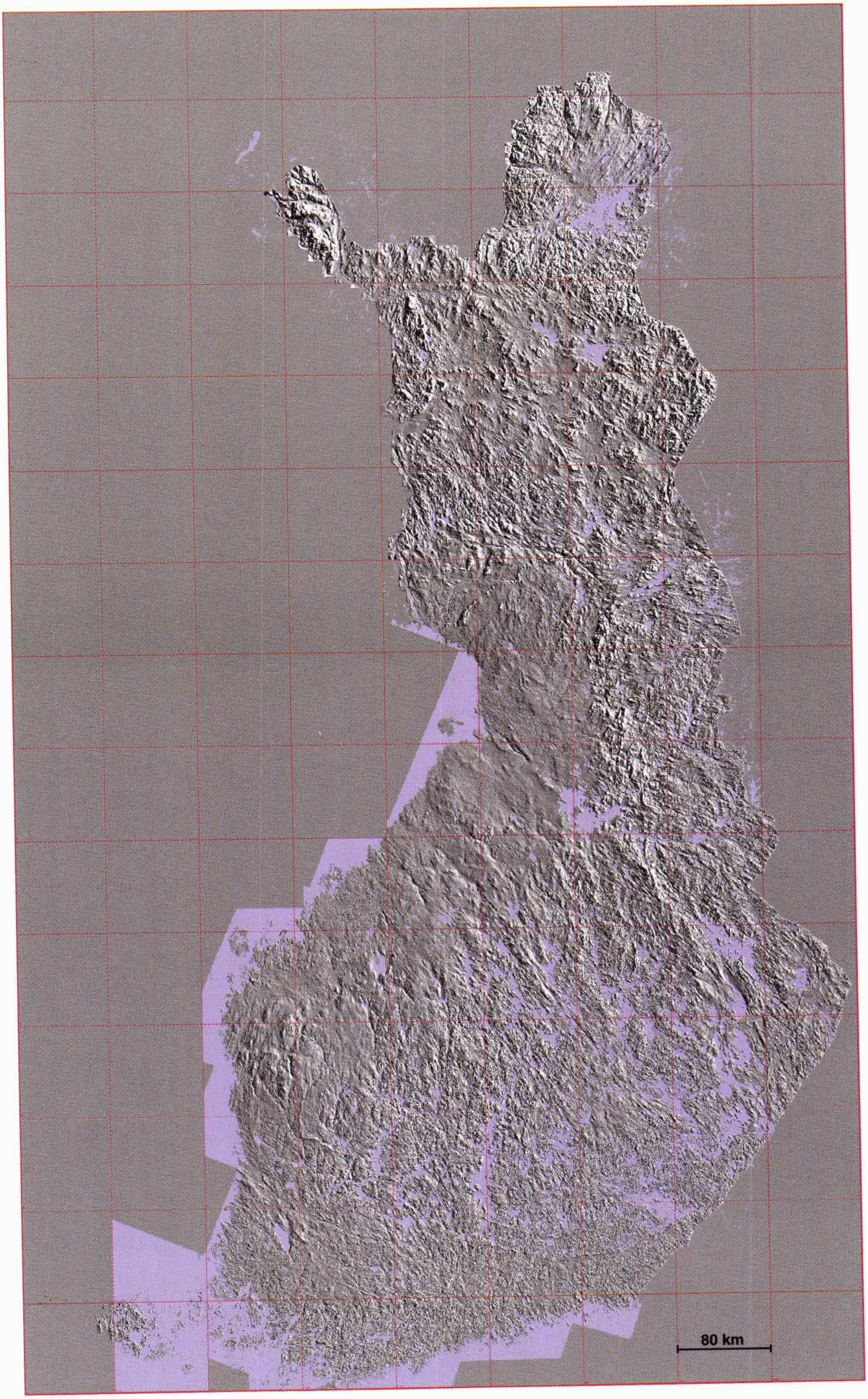

80 km

Figure 3. Locations of reference sections (black triangles) and interglacial and interstadial deposits referred to in text (crosses) and local names.

The theory of the existence of large glacial lobes at the time of deglaciation has been a key issue in glacial-geological studies in Finland. Brander (1934) described 'ice blocks' that form 'lobes' and 'fanlike' flows of ice sheets in eastern Finland, and Brenner (1944) presented a map of glacial lobes in southern Finland. Later, Repo (1957) described in detail the behaviour of glacial lobes in North Karelia. Kurimo (1974) and Aario & Forsström (1979) presented new observations on the activity of glacial lobes in Kuusamo and Kainuu. Punkari (1979, 1980) named the glacial lobe flows and emphasized their influence on lithostratigraphy (Punkari 1984, 1988). In his study of southwestern Finland (Punkari 1989), he arrived at a glacial dynamic model and a monoglacial explanation for the lithostratigraphy of the overburden in southern Finland.

The till-covered interglacial and interstadial deposits common in Ostrobothnia have enabled us to date late-Pleistocene deposits and to study their geological history in that area. These interglacial and interstadial deposits have been described by Aario (1966), Ignatius & Leskelä (1970), Iisalo et al. (1974), Kontio (1976), Niemelä & Tynni (1979), Eriksson et al. (1980), Forsström & Peuraniemi (1977), Forsström (1982), Forsström et al. (1987, 1988), Sutinen (1982, 1984, 1992), Aalto et al. (1983, 1989), Aario & Forsström (1979), Hirvas & Nenonen (1985), Grönlund (1988, 1991a and b), Punkari (1988), Donner (1988), Peltoniemi et al. (1989), Iisalo (1992) and Eriksson & Kujansuu (1995) and also in Papers I, III, V, VI and VII. Ostrobothnia was in a sheltered position in relation to the flow of the large glacial lobes formed during deglaciation, and glacial erosion was fairly weak as it was in the ice divide zone of northern Finland (Niemelä & Tynni 1979, Hirvas et al. 1981, Salonen 1987, Hirvas 1991). Consequently, till-covered, unconsolidated sediments reflecting ice-free stages have been preserved in the area. Bouchard & Salonen (1990) have described glacial domes and ice divides that, in the middle of glacial lobes, moved northeastwards as deglaciation proceeded. There were probably two ice divides in Ostrobothnia and five in southern Finland.

The Pleistocene lithostratigraphy, mainly the till stratigraphy, of all southern Finland has been described by Hirvas & Nenonen (1985), Forsström (1984) and Bouchard et al. (1990) and in Paper III. The glacial stratigraphy of North Ostrobothnia and Kainuu has been discussed at length by Aario & Forsström (1979), Saarnisto & Peltoniemi (1984) and Sutinen (1982, 1984, 1992). The glacial stratigraphy of North Karelia has been described by Hirvas (1980), Salminen (1980) and Nenonen (1984) and in Papers II and III; that of the south coast of Finland by Rainio & Lahermo (1976, 1984), Hirvas & Nenonen (1981, 1985), Bouchard et al. (1990) and Nenonen (1993). The correlation of Finland's Pleistocene deposits and the subdivision of the Pleistocene have been discussed by Donner (1971, 1976, 1983, 1986, 1988, 1995), Donner et al. (1986), Forsström (1984, 1989), Forsström & Eronen (1985, 1991), Forsström et al. (1988), Hirvas et al. (1981), Hirvas (1983, 1991), Hirvas & Nenonen (1985), Hyvärinen (1985), Nenonen (1993), Saarnisto & Salonen (1995) and in Papers III, V, VI and VII.

As the regional glacial stratigraphy of Finland was formed in the course of local or more extensive flows of the continental ice sheet, stratigraphic studies usually start with investigations of the fabric of till layers and the directions of striations, and reconstruction of the flow stages. It has been noticed that till layers in different areas can be correlated on the basis of their fabric and their physical and, sometimes, chemical properties (Hirvas et al. 1977, Hirvas 1991, Papers III and IV). A till layer in a certain lithostratigraphic position often has a considerable lateral extent. The interstratified organic deposits in glacigenic sediments can be used for the chronostratigraphic and climato-stratigraphic dating of till layers and their correlation with other deposits in Scandinavia and northeastern Europe (Paper I).

A comparative study of Forsström (1988) on interstadial vegetation showed two or more dissimilar interstadials in the Early Weichselian substage in Ostrobothnia and Peräpohjola. Forsström correlates the Oulainen deposit in Ostrobothnia with the Brørup Interstadial, and the Kauvonkangas (Mäkinen 1979), Permantokoski and Kostonniska (Korpela 1969) deposits in Peräpohjola with the Odderade Interstadial. A comparative study of Donner (1988) on the interglacial and interstadial sediments of Ostrobothnia makes a clear distinction between the Brørup Interstadial and Eemian Interglacial and the principles on which they are classified in Ostrobothnia. The studies and age determinations of Kujansuu et al. (1991) and Hütt et al. (1993) on the palaeopodzol and sand cover of till-covered eskers in Ostrobothnia have provided insight into the geological history of the ice-free stage. The organic deposit in a till-covered kettlehole in the Hietamäki esker described by Eriksson & Kujansuu (1994) is yielding information on the vegetation succession during the late Eemian Interglacial.

The need for formal stratotypes or hypostartotypes for the Pleistocene stratigraphy of Finland has become obvious with the progress made in stratigraphic studies. Aario & Forsström (1979), when describing the glacial stratigraphy of Koillismaa and Kainuu, were the first to assign informal local names to stratigraphic units. Forsström (1982) followed the same practice when naming lithostratigraphic units he had studied in Oulainen. Donner et al. (1986) proposed the organic sequences found in Ostrobothnia and Lapland as stratotype deposits in Finland. Bouchard et al. (1990) used formal lithostratigraphic units and stratotypes when describing the till stratigraphy of southern Ostrobothnia and its correlation with that of Uusimaa. Hirvas (1991) gave the interglacial and interstadial deposits informal names. Sutinen (1992), too, used informal names to describe both the stratigraphic units he had encountered and their correlations. I have avoided using informal names to describe my own till-stratigraphic observations and instead have endeavoured to correlate the tills and intervening deposits of ice-free stages with the climate stratigraphy of Northern Europe as did Hirvas et al. (1981), Lundqvist (1986a) and the Nordkalott Project (1986). This practice is justified by the abundance of sections studied and the large lateral extent of the stratigraphic units recorded. The abundant use of local informal stratigraphic names at an earlier stage of investigation might have resulted in confusion and made it difficult to correlate the deposits. The suggestion of Gibbard (1992) that a formal stratigraphy should be established for Finland and the review of Eronen (1992) on Quaternary chronostratigraphy encouraged me to select reference sections from the materials of till-stratigraphic studies conducted in southern and western Finland and to assign the formal names. Table 1 illustrates the correlation of chronostratigraphy and the deep-sea istope chronology referred in this study.

The objective of this work then is to choose and describe representative lithostratigraphic sections that would cover the Pleistocene series of southern Finland as fully as possible. The litho-, chrono- and biostratigraphic information on the formations is presented for the refernce sections. The diagrams of the sections give the geographic information on the sites in the coordinate system of the basic maps of Finland. The location of the reference sections and the place names referred to in the text are marked in Fig. 3. The descriptions of the formations encountered in the stratigraphic studies and their lithofacies types follow Hedberg (1976) and the example set by Bouchard et al. (1990) and Johnson & Hansel (1990). The lithofacies codes of Eyles et al. (1983) and Miall (1984) have been applied in the classification and abbreviation of lithofacies. The lithofacies codes and criteria for their classification are set out in Table 2. Data on the reference sections described can be selected to establish formal national stratotypes when the working comission on the national stratigraphy of Finland eventually comes to define them.

Table 1. Subdivision of the Quaternary used in this study

Epochs, series	Ages, stages		Isotope stages
Holocene	Flandrian	10 ka Bp (radiocarbon years)	1
	Late Weichselian	stadial	1-2
	Middle Weichselian	stadial, interstadial	3-4
	Early Weichselian	Odderade Interstadial	5a
Late	"	stadial, kryomer	5b
Pleistocene	"	Brørup Interstadial	5c
	"	stadial, kryomer	5d
	Eemian	Interglacial	5e
Late	Saalian	Warthe stadial ?	6
Middle	Saalian	Drenthe-Warthe interstadial ?	6 or 7
Pleistocene	Saalian	Drenthe stadial ?	6 or 8
Middle	Holsteinian	Interglacial	7 or 9-11
Middle	Elsterian	Glacial	8 or 10-14
Pleistocene			

The table is compiled from Bowen et al. (1986 chart 1), Andersen & Mangerud (1989, fig. 6), Zagwijn (1992b fig. 9), Lundqvist (1992 table 1) and Donner (1995 tables 3.2, 3.3, 7.1 and fig.10.1).

Table 2. Lithofacies codes and their sedimentary characteristics (comp. Eyles et al. 1983, Johnson & Hansel 1990, Bouchard et al. 1990). The following codes are used to describe the sections.

Code	Lithofacies
Dmm	Diamicton, matrix-supported, massive
Dmm(s)	Diamicton, matrix-supported, massive, sheared
Dmm(r)	Diamicton, matrix-supported, massive, redeposited
Dmm(d)	Diamicton, matrix-supported, massive, deformed
Dms	Diamicton, matrix-supported, stratified
Dc	Diamicton, clast-supported
Dcs	Diamicton, clast-supported, stratified
G	Gravel
G(s)	Gravel, sheared
Gm	Gravel, massive, matrix-supported
Gh	Gravel, crudely bedded
Gg	Gravel, graded
Gg(d)	Gravel, graded, deformed
S	Sand
S(s)	Sand, sheared
Sm	Sand, massive
Sh	Sand, horizontally laminated
Sho	Sand, horizontally laminated with organic material
Sh(d)	Sand, horizontally laminated, deformed
Sl	Sand, fine, laminated
Sl(d)	Sand, fine, laminated, deformed
Fm	Fine-grained sediment, massive
Fmo	Fine-grained sediment, massive with organic material
Fl	Fine-grained sediment, laminated
Flo	Fine-grained sediment, laminated with organic material
Flo(d)	Fine-grained sediment, laminated with organic material, deformed
Fl(d)	Fine-grained sediment, laminated, deformed
Op	Organic soil, pedological alteration or peat

The great unconformity of Finnish geology

The Finnish bedrock crops out from beneath the unconsolidated deposits as exposures covering about 3.1% of the land area (V. Okko 1964); 13.4% is rocky terrain with a veneer of sediments (mostly till) less than 1 m thick (Kujansuu & Niemelä 1990), and the remainder is covered with overburden more than 1 m thick. As shown by drilling and sounding data, the average thickness of the overburden, most of which was formed during glaciation, is 8.64 m; the median is 6.4 m (V. Okko 1964). Owing to their genesis the clastic sediments are mainly composed of material removed and transported from the bedrock. In places the glacier stripped off older organic deposits. The elevation model of Finland (Fig. 2) illustrates the interdependence of drift and rock. The bedrock relief is clearly visible through the veneer of drift that provides a proper cover only in valleys.

In southern and western Finland the Pleistocene deposits usually rest directly on the crystalline Precambrian bedrock. The largest Precambrian sedimentary rock basins - the Satakunta sandstone around Pori and the Muhos formation near Oulu - are on the west coast (see Simonen 1980). Palaeozoic sedimentary rocks have mainly been found on the bottom of the Gulf of Bothnia, and in some minor sedimentary basins at Lauhavuori, around Vaasa, at Karstula and Lappajärvi, in the rural municipality of Pieksämäki, on the Åland islands and on the bottom of Bothnian Bay (Winterhalter 1972). In the sedimentary rock areas the ice sheet eroded its floor and deposited till that differed from the till of the crystalline bedrock areas in particle size distribution and lithology, and was tranported for tens of kilometres on the distal side of the sedimentary rock areas (see Uutela 1989, Salonen 1991).

On the coastal strip of Bothnian Bay, between Kalajoki and Raahe, the till contains abundant sedimentary rock material transported from the sea floor, including boulders of massive sedimentary sulphide ore of the Laisvall type (cf. Veltheim 1969). According to unpublished ore investigation reports of the Geological Survey of Finland (GSF), these boulders contain economic grades of copper, zinc and lead, and also abundant sulphur, iron, manganese, arsenic and uranium. Galena grains and pebbles with sulphide matrix deriving from sedimentary rocks also occur in till far from the coast, as far inland as Haapavesi. The impact of such pebbles on till geochemistry may also be reflected in the till data of the Geochemical Atlas of Finland, as a large northwest-southeast trending multimetal anomaly begins on the coast between Raahe and Kalajoki (see Koljonen 1992). In the Muhos siltstone area and on its distal side the tills, glaciofluvial sediments and glacial clays are often tinted red by the siltstone clay (cf. Kukkonen 1978).

Weathered bedrock has been encountered beneath Pleistocene till deposits throughout Finland, particularly in Lapland and Ostrobothnia (Tynni 1982, Söderman et al. 1983, Söderman 1985, Hirvas 1991). The date of the weathering is not known for sure but it has been suggested that it occurred during the Cretaceous-Tertiary, and finally during the Pliocene (Söderman et al. 1983, Söderman 1985, Lundqvist 1985). In Scania, southern Sweden, bedrock weathered into kaolin clay is overlain by Cretaceous sedimentary rocks (Lidmar-Bergström 1994). The occurrences of kaolin in Sweden, which are usually in fracture zones, are thought to have been caused by deep Mesozoic weathering. The bedrock may have undergone substantial weathering over long times during various geological periods, as for most of its existence Fennoscandia has been located close to the equator, between latitudes 20° north and 20° south (Pesonen & Mertanen 1990).

Material from weathered bedrock transported by the continental ice sheet was incorporated in till. This then differs in grain size distribution, specific surface and geochemistry from lodgement till, which consists of material derived from fresh bedrock through abrasion. Till has received clay minerals from weathered rocks, including fines with kaolin, which have been preserved in glacial sediments for several glacial cycles (Lintinen 1989, 1995).

Till-covered kaolin occurrence at Eteläkylä, Virtasalmi, the Eteläkylä Formation

A till-covered kaolin occurrence at Eteläkylä, Virtasalmi, is a representative example of lithostratigraphy in an area of weathered bedrock and represents the oldest known lower contact of the Pleistocene in Finland. Eteläkylä is part of the Savo drumlin area (Glückert 1971). The relief is controlled by northwest-southeast-trending crag-and-tail ridges with paludified clay and silt basins in the depressions between them. The depressions, likewise northwest-southeast-trending erosional forms,are also the outcome of glacial erosion. At Eteläkylä, sedimentological studies have been conducted at the Litmanen and Eteläkylä kaolin occurrences. A kaolin deposit occurs at Eteläkylä formation on the southeastern flank of a drumlin and at the Litmanen pond in a valley between drumlins 1,5 km west from the Eteläkylä formation. At both sites the occurrences are covered with overburden, mainly till, at least 10 metres thick. In the following, the till stratigraphy is described on the basis of drilling at Eteläkylä and excavations at Litmanen (Fig. 4). The Eteläkylä kaolin occurrence lies 500 m northwest of the open pit of the exhausted Hällinmäki copper mine. According to the GSF, the kaolin occurrence is about 300 m long, less than 40 m wide and, on average 50 m thick and its kaolin derives mainly from weathered granodiorite (Sarapää et al. 1992).

At Eteläkylä the white kaolin occurrence is clayey weathering material with over 40% clay at a depth of 8.6 m under the till. At 8.6-7 m depth the kaolin is overlain by a matrix- supported till with over 5% clay and containing silty tongues. A sandy till with deformation structures and bands of sand was encountered at a depth of 3.8-7.0 m, and a compact and stony till layer - sandy till by grain size analysis - at 1.6-3.8 m. The top layer is organic rich soil underlain by 1.5 m of horizontally laminated sand and then by 20 cm of silt.

The layer containing sand bands and deformation structures is highly permeable, and its natural water content, over 14%, exceeds the liquid limit of till. Attempts were made to expose the kaolin occurrence with an excavator but, despite drainage, the walls of the pits collapsed at the level of the deformation till owing to abundant groundwater flow and hydraulic fractures.

According to till fabric analyses on the pits excavated at Litmanen, the till was deposited by ice flowing from 320°. The bearings of striations measured on roches moutonnées in the area are in the range 310-325°. The striations and till fabric demonstrate that the sandy till deposited in connection with the formation of drumlins. At that time, the ice sheet flowed freely, and pressure-melting conditions prevailed on the bottom of the ice sheet. Water therefore participated in the deposition of till. The sorting action of water is seen as frequent sand and silt layers in till cores and pits at Eteläkylä and Litmanen. The collapsing walls of the excavated pits prevented fabric analyses from being conducted on fines-rich till at greater depth and also stratigraphic observations from being made on the walls. It is possible that the deformed layer between the sandy till and fines-rich till represents a sediment deposited during an ice-free stage. The deposit contains no more humus than tills in general nor have any microfossils been found in it.

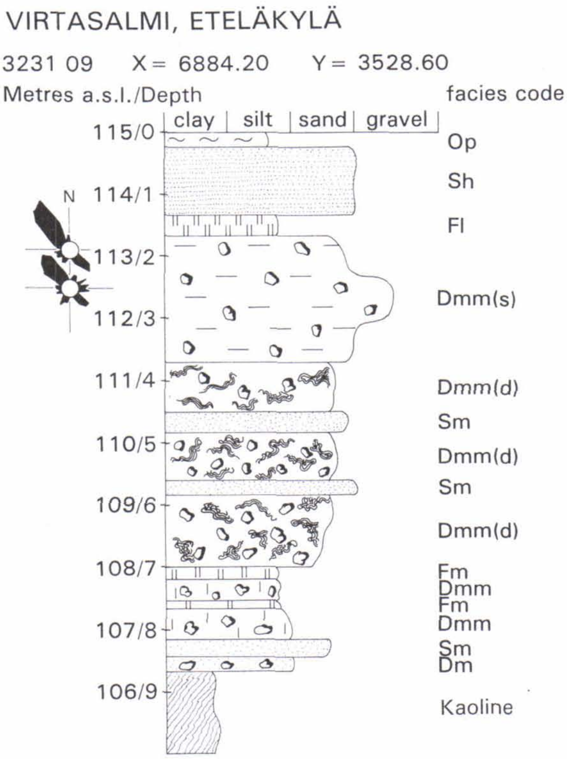


Figure 4. *Stratigraphic sequence at Eteläkylä kaolin occurrence in Virtasalmi. Till fabric is shown in rose diagrams.*

West of the Litmanen pond fully weathered rock occurs only beneath 1.5-3 m of sandy till. The weathered rock exhibits glaciotectonic structures such as folds, faults, catch structures and structures of till penetrating joints in the bedrock. The bedrock material is composed of loose weathered blocks with scattered remnants of clayey, multicolored (red, pink, yellow, green, brown) kaolin. Typical of such areas are mixing of till with upper parts of the weathered rock, and the presence of kaolin plates in till. At Litmanen, substantial amounts of kaolin occur in till only in the basal part of the till deposit at a depth of 20-22 m. A few pollen grains of *Betula* and *Alnus* and some carbon particles were found in the till and in the fines injected into the kaolin and weathered rock but they are of no use for dating the occurrence. Glacial deformation of the surface of the occurrences must be taken into account when searching for and assessing kaolin occurrences, as it affects both the localization and technical exploitation of the occurrence.

The till-covered kaolin occurrences at Litmanen and Eteläkylä escaped erosion during the last glaciation mainly due to the presence of rock sills on their proximal side and the protection provided by older till layers. Glacial abrasion is evident on the streamlined erosion surface of the Litmanen kaolin occurrence. Drilling revealed an extremely compact till layer on the adjacent Vuorijoki kaolin occurrence 5 km south of the Eteläkylä formation. The drill cores contained small amounts of modern forest pollen. The deposit cannot therefore be an old tillite.

Thick kaolin occurrences have also been found at Kainuu (Pekkala & Sarapää 1989), and small kaolin occurrences in several places in Ostrobothnia and Savo, often in bedrock fracture zones. In the Virtasalmi area, the relief and relative differences in elevations probably reflect ancient erosional planes and weathering terraces, or pediments. The Naakkima meteorite crater 25 km NW from the Eteläkylä formation contains weathered rock and kaolinitic clay beneath neoproterozoic sedimentary rocks of the Riphean era (Elo et al. 1993).

Pleistocene deposits predating the Eem Interglacial

Information on deposits of the ice-free stages preceding the Eem Interglacial in southern and western Finland is scarce and from scattered sources. Clasts of organic matter, gyttja and peat have been found in an older till attributed to the Saale glaciation and an underlying silt deposit in Vihanti, Ostrobothnia (Kontio 1976, Grönlund et al. 1985, Paper III).

The fragments of peat and gyttja transported by the continental ice sheet show pollen assemblages typical of both herb-dominant open vegetation and the subarctic *Betula* stage. The pollen assemblage of the older till bed is also dominated by *Betula*, but the proportions of *Alnus* and *Pinus* are higher than in the peat and gyttja clasts (Grönlund et al. 1985). Pollen grains of thermophilic *Osmunda* and *Ilex* have also been found in the till but they may derive from another interglacial deposit or a Tertiary deposit.

The diatom flora of the gyttja and peat fragments suggest that the material may have originally deposited in an inlet of an interglacial sea where freshwater sediments transported by rivers also deposited. The samples contain saline water diatoms, e.g. *Hemiaulus sp*, *Pyxilla sp.*, *Stephanopyxis sp.* and the dinoflagellate *Actiniscus pentasterias*, which are considered to have originated in the Tertiary period. Tertiary flora found in interglacial deposits in Finland are generally interpreted as redeposited.

On the basis of their lithostratigraphic position, the presence of a pollen assemblage differing from that of the Eemian Interglacial deposits in Ostrobothnia and partly the 'early origin' of the pollen, the peat and gyttja fragments in till in a secondary position at Vihanti, and the underlying silt deposit can be considered as interglacial material older than the Late Pleistocene. Correlation of the interglacial material at Vihanti, with the interglacial deposits at Öje in central Sweden (Garcia Ambrosiani 1990, 1991), Naakenavaara, Kittilä (Hirvas 1991, Aalto et al. 1992) or Karuküla in Estonia (Liivrand

1984, 1991), all of which are assumed to be Middle Pleistocene in origin, is difficult, as the interglacial material is mainly in a secondary position and the vegetation history of the interglacial at Vihanti is poorly known.

In the course of studies on the meteorite crater at Lappajärvi the stratigraphy and geological history of the 74-m-thick Pleistocene strata in the crater were investigated (Salonen et al. 1992). Freshwater sediments were discovered at a depth of 38-50 m under a thick sequence of Late Pleistocene tills. The diatom flora of these sediments contain abundant Tertiary diatoms that probably lived as relict species. The pollen assemblage of the sequence is dominated by *Betula* but *Alnus* is also prevalent. Redeposited interglacial materials, e.g. pollen grains of *Osmunda regalis, Larix* and *Corylus*, were found at Lappajärvi. The deposit thus reflects sediments deposited in both a glacial and a normal lake, and the spread of vegetation at the beginning of an ice-free stage. The date of the deposit is not yet known for sure. The gyttjas and underlying till obviously predate the Eemian Interglacial, and Salonen and his co-workers suggest that the deposits were formed during the Saalian glaciation and interstadial. The sedimentary sequence of Lappajärvi deposited at 20-30 m a.s.l.

Varved clay and gyttja deposited in a glacial and a non-glacial lake underlain by 20-m-thick Pleistocene till deposits were found at 62-80 m a.s.l. at Virtasalmi, Savo, in summer 1991.

Heponiemi Gyttja Formation, Virtasalmi

In the course of kaolin investigations at Virtasalmi, the GSF undertook systematic gravimetric surveys and drilled holes into the gravimetric minima, which at Virtasalmi are due to kaolin occurrences, thick overburden or a combination of the two (Jokinen et al. 1993). At Heponiemi, Virtasalmi, drill holes intersected a 6-m-thick gyttja layer under 20 m of till; the layer is underlain by 14 m of clay and silt. Bedrock was encountered at a depth of 39.4 m (Fig. 5). About 400 m northwest of the gyttja deposit, which is on the distal side of the Längelmäki rock drumlin, the till-covered bedrock is at a depth of only 1.5 m. A rock sill has presumably protected the unconsolidated strata from glacial erosion.

The entire Pleistocene sequence at Heponiemi rests on bedrock with a weathered surface. The weathered rock, which shows signs of kaolin, is overlain by 50 cm of massive diamicton, probably till in genesis. The diamicton is overlain by fine-grained clay, on top of which, up to a depth of 30 m, there is a varved clay that deposited when the front of the melting ice was still in the water basin.

The loss-on-ignition value for the organic layer in sediment at a depth of 20-25.5 m is 5-27%. The deposit is composed of silty gyttja and gyttja, and is very compact and hornlike. It contains granules (Ø 0.5-1 cm) of vivianite (iron-phosphorus hydroxide). The glacier has repeatedly overridden the deposit and compressed the gyttja into a dense substance. The deposit exhibits a distinct stratified structure.

Two till units differing in properties can be distinguished in the till deposit covering the gyttja. The lower unit is dense matrix-supported till with a clay content of 7%. The upper unit, about 12 m thick, is loose sandy till with a fines content of 2.6%. Between the till units, at a depth of 12-16 m, there is a layer of water-sorted silt and gravel that deposited when the ice melted. The till units may have been deposited by ice sheets of different glaciations or different stages of the last, the Weichsel, glaciation. Litostratigraphic information at the site of the gyttja is based on drilling.

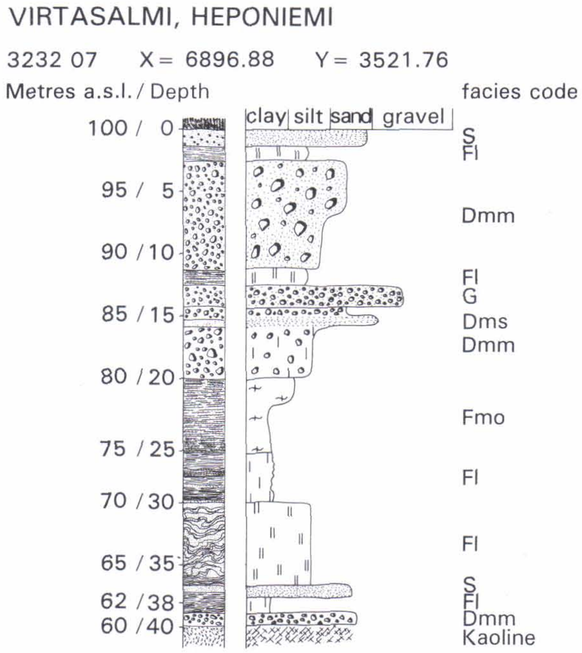


Figure 5. Stratigraphic sequence at Heponiemi, Virtasalmi.

The stratigraphy of the surficial parts of the till at Heponiemi is also studied in pits dug by excavator at 0.5-2 km distance from Heponiemi Gyttja Formation (Fig. 6). The till in these pits, too, was composed of two layers with different properties. The till at the bottom of the pits is dense lodgement till with clay bands and portions. The well-developed fabric of the lodgement till is oriented 300-320°, which is the same as the direction of the bedrock striations at the bottom of the pits and on outcrops in the vicinity. The Virtasalmi area is characterized by the numerous drumlins with an orientation of 325°. The till fabric in the drumlins coincides with this orientation. Between the till layers there is a layer of sorted material composed of sand, silt and a stony stratum. No pollen was found in the silt or clay portions in the lodgement till. The surficial part of the sections, down to a depth of 2 m, is lamellar sandy till poor in clasts. The till is weakly oriented and the direction of flow of the ice sheet that deposited the till cannot be deduced from the fabric analysis. Being at a depth of 15 m, the fines-rich till could not be reached in the pits excavated at the site of the Heponiemi Gyttja Formation.

The diatom spectra of the Virtasalmi sequence were studied with 26 samples from depths of 20-38 m. All the species were freshwater diatoms. The lowest samples were poor in diatoms probably as a result of the turbidity and coolness of the water due to the proximity of the ice front. After the withdrawal of the ice front, conditions improved for diatoms, and in the upper part of the glacial lake deposit the diatoms indicate alkaline, cool water. The lacustrine stage proper, which is represented by the gyttja deposit, begins with the deposition of diatoms requiring alkaline conditions. But the species change and, according to the diatoms, the basin continued to exist as an oligotrophic lake from a depth of about 22 m. The diatom flora also included a few species interpreted as Tertiary forms (Jokinen et al. 1993).

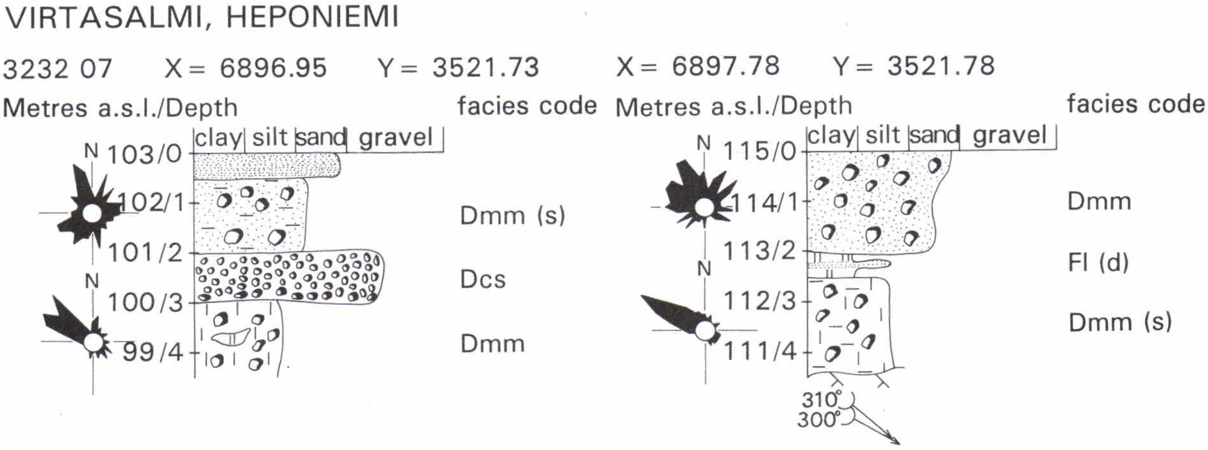


***Figure 6.** Stratigraphic sequence in test pit at Heponiemi, Virtasalmi. Arrows indicate direction of striations on polished rock surfaces.*

It is known that during the Eemian Interglacial, which preceded the last glaciation, the present Baltic Sea basin was occupied by a sea (Grönlund 1991b) with inlets probably extending to the latitude of Virtasalmi. Since no saline water diatoms typical of the Eemian Interglacial Baltic Sea have been found in the Virtasalmi sequence, the till-covered sediments at Virtasalmi could not have deposited during hydrological stages of the Eemian Interglacial. The above Tertiary diatoms have also been found in Ostrobothnia, in a deposit between two till beds at Lappajärvi, where they were interpreted as relict flora (Salonen et al. 1992).

The pollen assemblage of the Virtasalmi sequence, has been divided into four pollen assemblage zones recording changes in vegetation during formation of the gyttja deposit (Jokinen et al. 1993). The pollen assemblage of the lowest pollen zone, a, (Fig. 7) is dominated by *Betula*, with about 15% *Pinus* and 10% *Alnus*. The zone is interpreted as having formed during a glacial lake stage, in which case the pollen does not indicate the local vegetation but that which prevailed further inland. Pollen zone b contains fairly abundant non-arboreal pollen (NAP), accounting at its maximum for almost 50% of total pollen. *Betula* dominates the arboreal pollen (AP), and *Alnus* is less common than in zone a. The pollen assemblage reflects the prevailing vegetation in the area after withdrawal of the ice sheet. In zone c, *Pinus* dominates the pollen assemblage. *Betula* accounts for about 20% of total pollen but the abundances of *Alnus* and *Picea* are lower. The proportion of *Isoetes*, a water plant, increases rapidly in this zone. In the uppermost pollen zone, d, *Pinus* (50%) and *Betula* (35%) dominate the AP. *Sphagnum* abounds, and a few pollen grains of *Bruckenthalia* are also present. The pollen assemblage shows that the climate cooled slightly, causing a decline in *Pinus* and an increase in *Betula* proportions. On the other hand, the proportion of herb and shrub pollen increases at the cost of arboreal pollen. Characteristic of the whole pollen stratigraphy is the scarcity of thermophilous deciduous tree pollen, grains of *Corylus* and *Tilia* being the only ones encountered and then only occasionally.

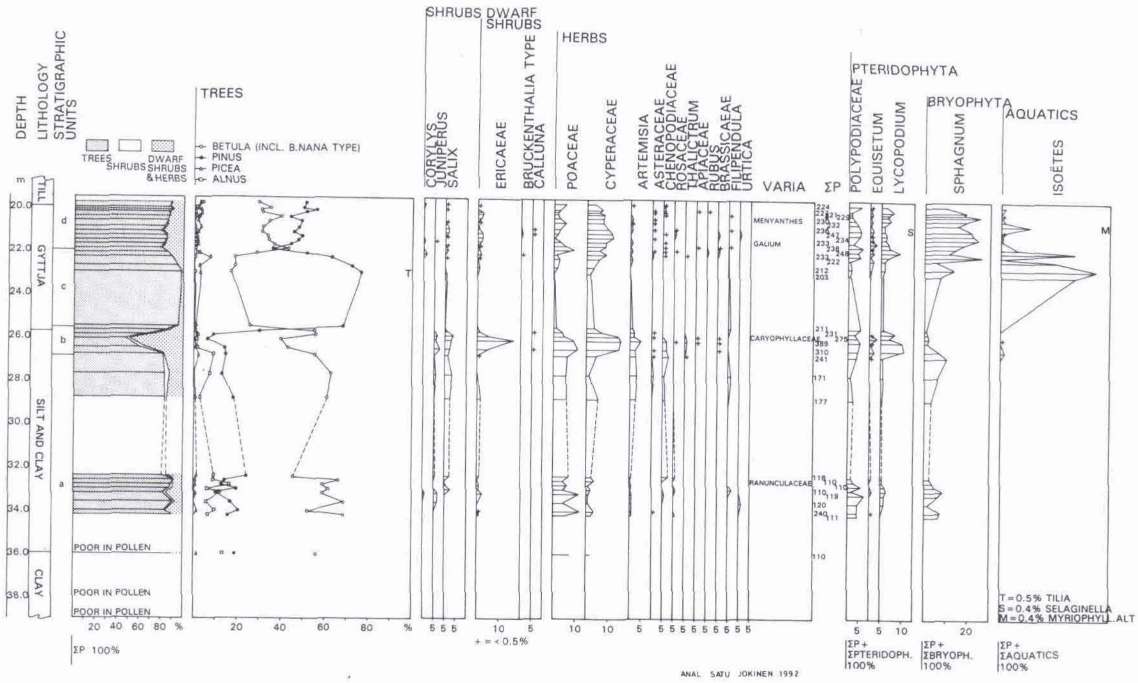


Figure 7. *Pollen assemblage of Virtasalmi gyttja deposit (Jokinen et al. 1993).*

The vegetation history of the Virtasalmi deposit resembles that of a climatic stage, an interstadial, when the climate was cooler than it is today. The pollen assemblages of Oulainen (Forsström 1982, Donner 1988), Marjamurto (Peltoniemi et al. 1989) and Harrinkangas (Gibbard et al. 1989), which have been correlated with the Early Weichselian interstadials, resemble that of the Virtasalmi sequence. Compared with the above deposits, Virtasalmi is very thick, recording changes during the early part of the ice-free stage and probably most of the warm stage and subsequent cooling as well. In all likelihood the Virtasalmi deposit represents a long period marked by sharp fluctuations in climate and vegetation.

Compared with interglacial finds in Ostrobothnia, the pollen assemblage of the Virtasalmi sequence differs clearly from that of deposits correlated with the Eemian Interglacial (cf. Eriksson 1993). The same applies to the marine deposit at Petrozavodsk, which has been correlated with the Mikulino (Eemian) Interglacial (Ekman 1982). The pollen assemblages at Naakenavaara in Finnish Lapland (Hirvas 1991, Aalto et al. 1992) and Karuküla in Estonia (Liivrand 1991), both of which are correlated with the Holstein Interglacial, contain more *Picea, Alnus* and *Larix* than the Virtasalmi assemblage. The deposits at Lappajärvi (Salonen et al. 1992) and Vihanti (Grönlund et al. 1985) probably represent an interstadial preceding the Weichsel glaciation or a cool substage of an interglacial; their pollen assemblages resemble that of Virtasalmi in that they all contain only occasional pollen grains of deciduous trees. Preliminary pollen studies suggest that the Virtasalmi deposit might best be correlated with an interstadial.

The gyttja at Heponiemi, Virtasalmi, probably represents a new stage, not previously described, in the Pleistocene history of southern Finland. As shown by oxygen isotope variations in deep-sea sediments (Fig. 28), isotope stage 7 (189-250 ka B.P.) represents a multi-stage period with three warm optima and two cooler stages (Martinson et al. 1987). For the interglacial sediments of the North Sea, oxygen isotope stage 7 has been tentatively correlated with the Holsteinian Interglacial on the basis of the relative amino-acid chronology of foraminifera (Sejrup & Knudsen 1993). Bowen et al. (1986) correlate the Holsteinian Interglacial with isotope stages 9-11 (297-440 ka BP) (Table 1.). Of the typical changes in climate and temperature during interglacial stages described by Zagwijn (1992a), those of the Holsteinian stage may best correspond to the multi-stage climate development recorded in the Virtasalmi sequence. As a section of the upper part of the gyttja deposit has been eroded, it is possible that the warm optimum at the end of the thermomer is lacking. Zagwijn (1992b) correlates the Holstein Interglacial with oxygen isotope stage 9 and the Hoogeveen Interstadial of the Saale glaciation with isotope stage 7. In its climate and vegetation history, the Hoogeveen Interstadial may well represent the conditions that prevailed when the gyttja deposited at Virtasalmi. Zagwijn (1992b) subdivides the warm-temperate stages of the upper Quaternary into a marine stage, with a high sea level, and a terrestrial stage, with a cooler climate and lower sea level. The Virtasalmi deposits clearly represent the latter.

The location of the Virtasalmi gyttja deposit under thick till beds probably deposited by different glaciations and the lack of Eemian marine sediments in the sequence indicate a Pleistocene deposit older than the Eemian Interglacial. Nor does the sequence contain redeposited Eemian Interglacial material, which usually occurs in Weichselian age deposits at elevations below 120 m a.s.l.(cf. Donner & Gardemeister 1971, Grönlund 1991a). Reliable dating of the deposit on the basis of its stratigraphic position and microfossils is not possible. Therefore correlating the Heponiemi Gyttja Formation with an Early Weichselian interstadial is not out of the question. For absolute dating the deposit should be redrilled and oriented palaeomagnetic samples taken from gyttja and the underlying varved sediments. The climatic stage that prevailed during deposition of the Heponiemi gyttja at Virtasalmi can be called the Virtasalmi Interstadial. Its accurate correlation must await further study.

Lithostratigraphy and reference sections of Eemian and Weichselian deposits

Most of the organic interglacial and interstadial deposits of southern and western Finland are in Ostrobothnia, usually covered by till deposited or oriented by the last ice flow (cf. Paper III, Niemelä & Tynni 1979, Donner 1988, Aalto et al. 1989). In Ostrobothnia, the last ice flow was that of the Näsijärvi-Jyväskylä glacial lobe, which terminated at the Central Finland ice-marginal formation. However, till had been transported and deposited before that (cf. Bouchard et al. 1990). In places, sections of till-covered eskers in southern Ostrobothnia show two till beds, of which the upper one was deposited by a glacial lobe and the lower by some earlier ice sheet. Till deposited during the Weichselian glaciation was remobilised, sheared and reoriented, at least partly, by flowing glacial lobes. Over large areas the directions of the longitudinal axes of drumlins and the fabric of lodgement till in Ostrobothnia record the flow of the

Näsijärvi-Jyväskylä glacial lobe.

Compact lodgement till deposited by ice flowing from the northwest commonly occurs beneath interglacial and interstadial deposits in Ostrobothnia (Papers I, III and IV). With the accumulation of observational data on stratigraphy it has been suggested that this till deposited in the last event of the Saalian glaciation (Papers VI and VII). The following examines the key sections crucial to the Late Pleistocene in Ostrobothnia western Finland.

Ruotanen reference section, Pyhäsalmi

The hypostratotype is located in a section in the open pit of a sulphide ore mine. The ore suboutcrop was completely covered with till. The deposit was found when a local farmer sank a new well right into the suboutcrop, which is 650 m long and up to 75 m wide. The upper part of the orebody at the suboutcrop had been mined from the open pit. According to descriptions by Martti Kokkola (pers. comm.), the suboutcrop had exhibited striated roches moutonées and part of it had been composed of a deeply weathered gossan type of ore. The impetus for detailed study of the strata in the Pyhäsalmi open pit came from Outokumpu Ltd.. In his description of the till investigations carried out in the company's open pit at Hitura, where there are six different till beds or layers, Kokkola (1975) also mentions the three till beds found at Pyhäsalmi. He suggests that the stratigraphy of glacial sediments in the open pits and those established during exploration probably reflect glacial events in central Ostrobothnia at large. The till stratigraphy of the section and concentrations of ore material in till fines and in the heavy mineral fraction on the distal side of the open pit were studied (Nenonen 1985, Hirvas et al. 1989). The further these studies proceeded, the clearer it became that the stratigraphy at Ruotanen, Pyhäsalmi, occurred over large areas of central Ostrobothnia and northern Savo (Papers I and IV).

The Ruotanen open pit section reveals two clearly different till units, and sandwiched between them a layer of deformed till incorporating material from the underlying till (Fig. 8).

In the Ruotanen section there is weathered rock, its fractures injected with till. In places the weathered rock is overlain by a layer of sorted laminated sand and gravel less than 1 m thick. The lower till, the Ruotanen Till, is grey or brownish-grey compact sandy till with sandy layers and portions. In the open pit section the Ruotanen Till is usually about 2 m thick, containing less than 5% clay and less than 0.1% humus (Fig. 9). The Ruotanen Till has a well-developed fabric indicating that it was deposited by ice flowing from the northwest, 320-330°. Polished rock surfaces in the open pit exhibit cross-striations at 330-345° on facets protected from erosion by the youngest ice flow from WNW. The orientation of clasts in the Ruotanen Till deviates consistently from the NNW orientation of the striations. It is feasible that the striations refer to the direction of glacial flow at the onset of till deposition, and the results of the fabric analysis on the till above to the direction of a somewhat later ice flow during the same glaciation. In properties the Ruotanen Till is typical lodgement till, and the sand lenses and portions in it suggest either that water was present during the depositional event or that sorted material had been incorporated from underlying sediments. The till may be basal melt-out lodgement till. In the Pyhäsalmi area similar sandy till deposited by ice flowing from the northwest occurs only in the deepest soil sections, as in Ruotanen open pit. Clasts in the Ruotanen Till are mainly granite, gneiss granite, leptite, sericite quartzite, mica gneiss and amphibolite.

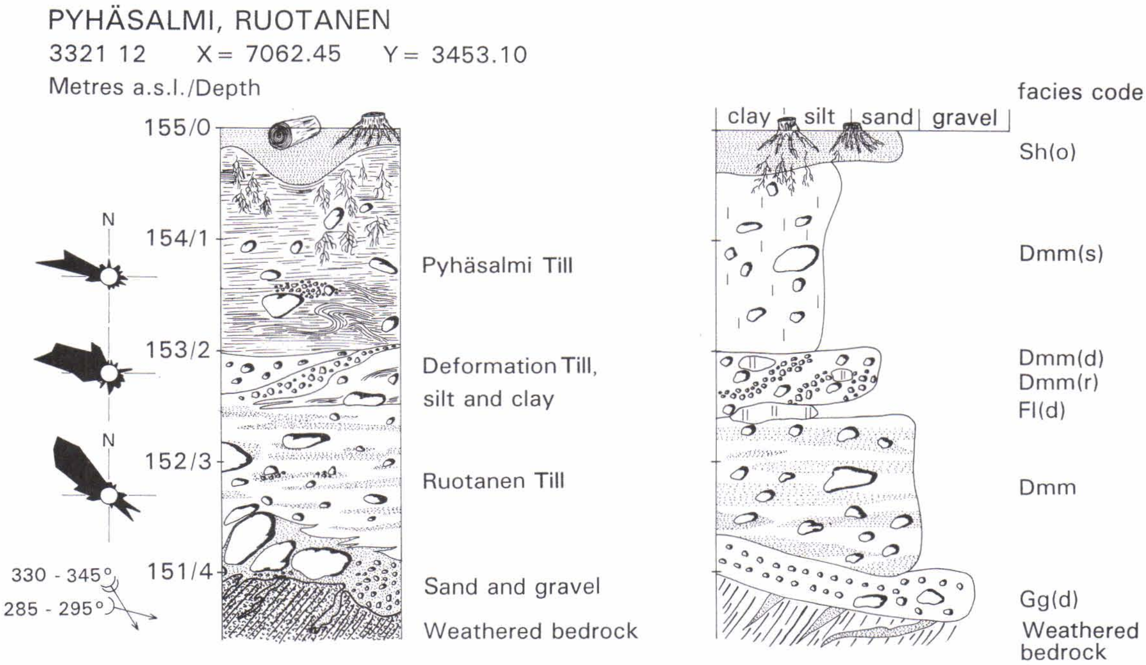
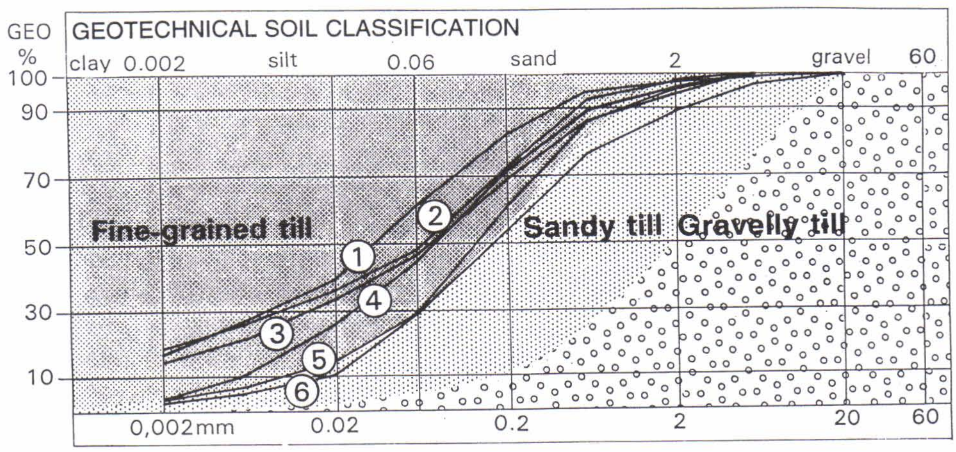


Figure 8. *Stratigraphic sequence in Ruotanen reference section, Pyhäsalmi.*



① Pyhäsalmi Till k = 1.9×10^{-11} m / s
② Haapavesi Till k = 9.5×10^{-11} m / s
③ Ylivieska Till k = 7.6×10^{-10} m / s
④ Mertuanoja Till k = 1.1×10^{-8} m / s
⑤ Vesiperä Till k = 5.7×10^{-8} m / s
⑥ Ruotanen Till k = 4.8×10^{-8} m / s

Figure 9. *Grain size distributions and permeabilities of tills in type sections. Diagram based on Finnish till classification.*

A deformed horizon, about 50 cm thick and containing clay lenses and folded layers of sorted sediment, occurs between the till beds in the open pit. A microfossil sample taken from clay at a depth of 3.5 m is rich in pollen. The analysis showed that 215 of 250 counted pollen grains were *Betula* (86% AP), 34 *Alnus* (13.6% AP) , 1 *Pinus* (0.4% AP) , 2 *Corylus* and 36 herbs. Another sample taken from a different place at a depth of 2.5 m contained 219 *Betula* (87.6% AP), 23 *Alnus* (9.2% AP), 4 *Carpinus* (1.6% AP), 4 *Pinus* (1.6% AP), 4 *Corylus* and 46 herb pollen grains. According to diatom analyses the samples contain only small amounts of freshwater diatoms, most of them as resting spores. Microfossil analyses on the Pyhäsalmi Till and clay clasts have shown the presence of pollen grains, spores and diatoms similar to those in the clay lenses between till beds. The microfossils suggest that the sorted layers and portions are sediments deposited during an ice-free stage. They refer to *Betula*-dominant forest typical of interstadials, although the presence of *Carpinus* and *Corylus* and the abundance of *Alnus* pollen also point to an interglacial. However, as the deformed minerogenic layers are thin, the material in them may be redeposited. Ignatius & Leskelä (1970) described microfossils of similar tills and tillified sediment lenses from the Hitura open pit section 60 km to the west, where the pollen assemblage corresponds to that in clay lenses at Pyhäsalmi. At Hitura the diatom flora is distinctly marine, referring to deposits of the Eem Sea, and the tillified sediments at Hitura are covered with a 2-m-thick clayey till.

The upper matrix-supported till member, the Pyhäsalmi Till, is 2-4 m thick and composed of brownish-grey or bluish-grey, clayey till. The till is laminated, and the laminae are broken in the section into small plates, resulting in what is called crumby lamellar structure. This may be caused by frost, because fines-rich till is easily deformed by frost. The clasts in the till are well oriented from WNW to ESE (280-290°) and on polished rock surfaces in the open pit the direction of the youngest striations is 285-295°. The clay fraction in the Pyhäsalmi Till is usually 10-20%, and the concentration of humus determined colorimetrically 0.3-0.5%. The till, which contains clay clasts and portions, is typical subglacial lodgement till. Similar matrix-supported till, likewise deposited by ice flowing from WNW, is common in the Pyhäsalmi area. Clasts in the Pyhäsalmi Till are mainly composed of granites, gneiss granite, amphibolitic leptite and mica gneiss. Many of them are striated and polished stones and boulders.

The till units also differ from each other in abundance of ore material. In the Pyhäsalmi Till, the copper, zinc and sulphur concentrations in the open pit section are usually many times higher than those in the sandy Ruotanen Till. Ore minerals characteristic of the ore suboutcrop were not found in the heavy mineral fraction of the till, probably because they had weathered into fines and dissolved in pore water. Part of the variation in metal content can be attributed to the deviating transport directions of the tills (Nenonen 1985). The ice flow that deposited the Pyhäsalmi Till eroded the ore suboutcrop at its widest part. As the permeability of the clayey fines-rich Pyhäsalmi Till is only a small fraction of that of Ruotanen Till, metals have been readily adsorbed in the Pyhäsalmi Till but been partly leached out from the Ruotanen Till (Fig. 10). The specific area and ion exchange properties of fines-rich till are usually higher than those of sandy till, enhancing the adsorption of metals (cf. Lintinen 1995).

The Pyhäsalmi ore suboutcrop has produced a glacigenic multimetal anomaly on its distal side. Covering 40 hectares, it can still be identified 550 m from the suboutcrop. Both flow stages of the ice sheet eroded and transported material from the ore suboutcrop, and elevated concentrations are thus encountered in both till formats (Nenonen 1985, Hirvas et al. 1989). Not a single ore boulder resembling the ore in the Pyhäsalmi suboutcrop has been found. Instead, clasts of sulphide-bearing volcanites and sericite quartzite were encountered in test pits. Farther away on the distal side, 800 m and 1300 m from the suboutcrop, there are discontinuous anomalies with an unknown source that may be due to the transport of material from the orebody or from the sediments that once rested on it. Considering that it is the largest known suboutcrop of a sulphide orebody in Finland, the anomaly caused by the Pyhäsalmi orebody is small. Wennervirta (1968) described a roughly 25-hectare hydromorphic type of geochemical anomaly from Pyhäsalmi in the flow direction of run-off waters and groundwaters, to the west of the ore suboutcrop.

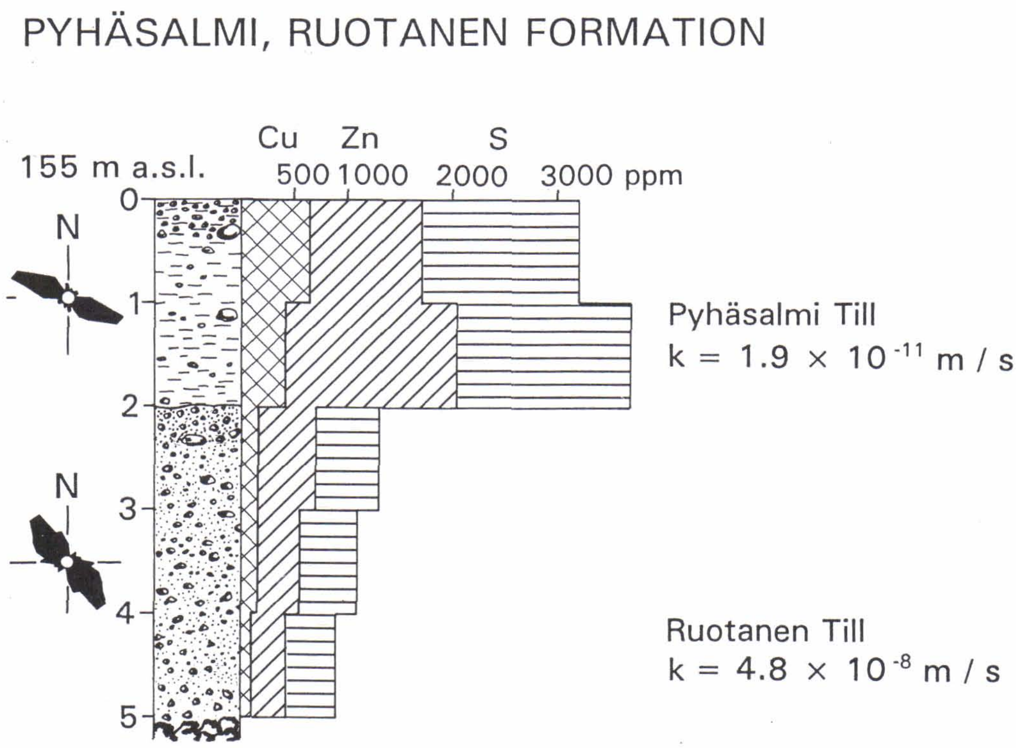


Figure 10. Concentration of material transported by ice from Ruotanen S-Zn-Cu orebody, Pyhäsalmi in till units of an open pit till section 300 m from the distal contact of the orebody in the direction of glacial flow.

The properties and transport directions of tills play a key role in tracing the sources of ore indicators in bedrock in the areas around Pyhäsalmi. Both the older northwestern and the younger WNW ice flows transported ore material and boulders from unknown suboutcrops. It is likely that the ore deposits cropping out in the depressions are covered with the Ruotanen Till, a compact till that probably protected the ore suboutcrops from the last glacial erosion. Therefore, ore indicators from suboutcrops covered with thick overburden are not necessarily present in the Pyhäsalmi Till or on the ground surface.

Vesiperä reference section, Haapavesi

The Vesiperä sequence in Haapavesi was discovered in the course of exploration undertaken by Outokumpu Ltd. Later the site was investigated by the GSF in cooperation with Outokumpu Oy Exploration (Paper I). The find turned out to be unique, as the Vesiperä sequence is a key section for the lithostratigraphy of organogenic deposits covered by and sandwiched between tills in Ostrobothnia.

In the Vesiperä deposit the sediments of two glaciations and the subsequent deglaciations and interglacials rest one on top of the other (Fig. 11), demonstrating the similarity of geological evolution during the last two glaciations. The organic deposit between the till beds is rich forest mull soil with flattened twigs and wood fragments. The sand beneath the mull soil deposit contains subfossil tree roots, showing that the deposit is an in-situ forest geosol. Microfossils of the organic deposit and its correlation are dealt with in detail in Paper V.

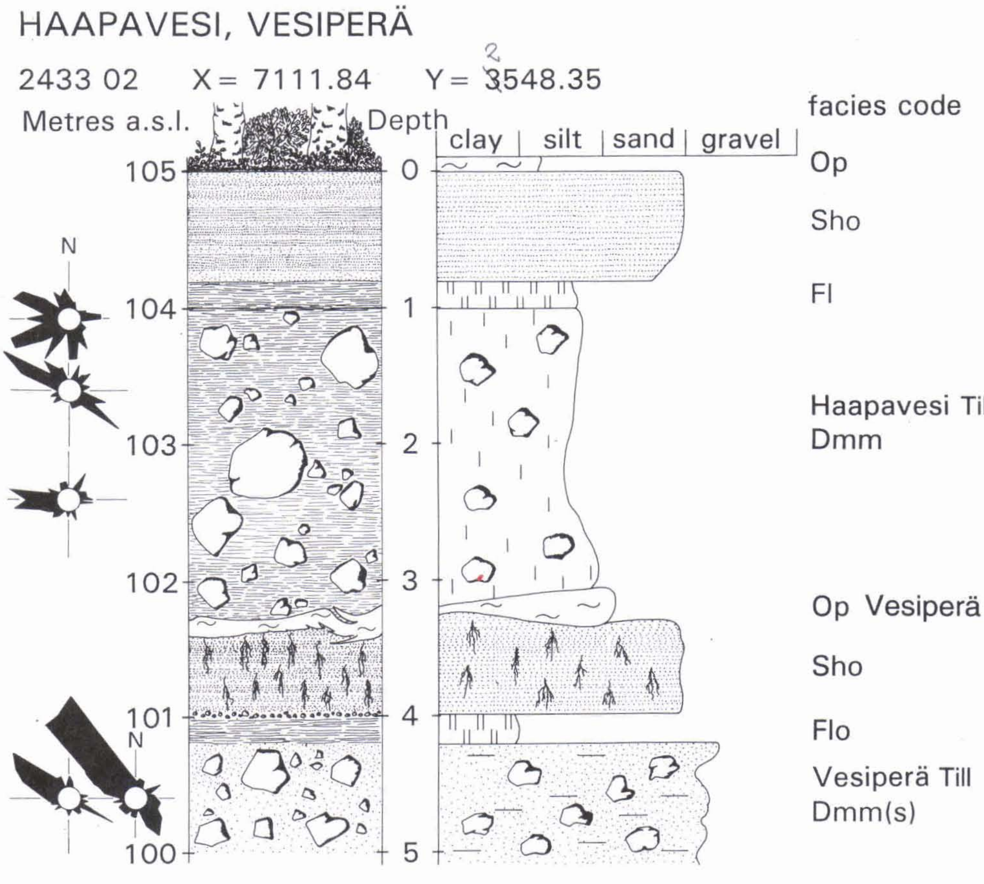


Figure 11. Stratigraphy and lithofacies of Vesiperä reference section, Haapavesi.

Lowermost in the Vesiperä sequence is compact grey sandy till, the Vesiperä Till, with shear structures and seams of sorted material. The clay content of the till is no more than 3% (Fig. 9) and that of humus 0.25%. The Vesiperä Till was deposited by ice flowing from the northwest, 310-320°. The till was deposited before the interglacial and probably represents the final part of the Saale glaciation, as the water-laid sediments rest directly on the till. It was at Vesiperä that the lower sandy till was first established as pre-interglacial and it is therefore called the Vesiperä Till.

The Vesiperä Till is overlain by a clay deposit of a deep-water phase and a sand deposit of a littoral phase, referring to a phase associated with deglaciation. According to pollen analyses, the pollen assemblage in the clay deposit reflects *Betula*-dominant vegetation early in the Eemian Interglacial. Diatom analyses show that the scarce diatom flora mainly comprises freshwater resting spores. A zone reflecting the *Betula*-dominant vegetation of the early Eemian Interglacial has been found in the basal part of clay deposited on till at Viitala, Peräseinäjoki, in which the diatoms also indicate fresh water (Paper V). The Vesiperä clay deposit is the first find in Ostrobothnia providing insight into evolution at the beginning of the Eemian Interglacial. The sand on the clay contains abundant wood remains, which extend vertically upwards to the forest mull soil. The wood in the sand deposit is in an *in situ* position, as the horizontal layering in the sand deposit continues undisturbed in the immediate vicinity of the wood fragments, which are the fossilized roots of trees that grew in the rich forest mull soil.

The fossil soil consists of dark-brown, unconsolidated, decomposed organic matter with scattered undecomposed wood remains, twigs and roots. The pressure of the overriding glacier flattened the wood into a visually unrecognizable form. The material was studied under the microscope and identified as twigs of *Picea* and fragments of *Alnus*. The vegetational history of the forest mull soil, which evidently formed when the climate was much warmer than it is today, has features in common with the Eemian vegetation cycle of organic deposits investigated in Russian Karelia (Ekman 1982), Estonia (Liivrand 1987, 1991), Denmark (e.g. S. Andersen 1964) and Germany (Menke & Tynni 1984). Characteristic of the pollen stratigraphy of Vesiperä and other sites in Ostrobothnia representing the last interglacial is the steep rise in *Quercus* pollen values at the onset of the warm substage of the interglacial and the abundance of *Corylus* during the warm stage. The forest mull soil deposit at Vesiperä represents the terrestrial substage of the Eemian Interglacial in Ostrobothnia (at 102 m a.s.l.) and it is proposed here that it should be named the Vesiperä Geosol.

The Vesiperä Geosol represents a later part of the Eemian Interglacial than the Ollala deposit, 20 km to the ESE, which refers to the Eemian marine stage and isolation (116-117 m a.s.l.) (see Forsström et al. 1987, 1988). The tree roots penetrating the underlying soil from the forest mull layer has been radicarbon-dated (Paper V). Radiocarbon ages have also been determined for organic fractions from the wood and mull (Hänninen & Kankainen 1992). All the radiocarbon ages were 50 900 yr BP or younger, although the bulk of the organic material derived from the Eemian Interglacial, from over 100 000 yr BP.

The uppermost till bed in the Vesiperä deposit is bluish-grey, clayey, matrix-supported till, the Haapavesi Till. Separated by an erosional contact, the base of the Haapavesi Till rests on the forest mull soil, whose upper surface is deformed and folded. Organic matter can be detected both as catch structures in the basal part of the till and incorporated in till fines, colouring the till brownish. The till matrix is structureless and very loose. When moist, it is readily disturbed and becomes liquid. At the Geosol site, the Haapavesi Till is about 2 m thick and contains 17% clay and 0.5% humus (Fig. 9). According to fabric analyses, the till was deposited by ice flowing from WNW, 280-300°. On the adjacent polished rock surfaces striations are in the range 275-300°. The surficial parts of the Haapavesi Till do not show orientation caused by ice flow. The unit has deposited as basal lodgement till. Similar fines-rich till commonly constitutes the uppermost till in the Haapavesi area.

The lithostratigraphy of Vesiperä represents the superimposed sediments of two glacial and interglacial cycles. The same stratigraphy repeats itself over a large area, most often, however, without interglacial organic deposits. In several sections clay deposits with a pollen assemblage referring to an interstadial and/or interglacial together with freshwater or saline water diatoms have been found between the tills.

Mertuanoja reference section, Ylivieska

The till-covered esker at Mertuanoja, Ylivieska, was discovered during the national inventory of gravel resources (Iisalo 1973). The esker lies about 5 km north of Ylivieska, to the northeast of the River Kalajoki. Trending from WNW to ESE, it can be followed for 9 km in the terrain of Mertuanoja and Mertuanjärvi. A till-covered gravel deposit at Laukkupalo, Raudaskylä, 12 km ESE of Ylivieska, is probably part of the same esker. In the course of studies undertaken for geochemical mapping in the area of the Mertuanoja till-covered esker an old littoral deposit underlain by a peat deposit was found beneath till (Iisalo 1992). The *Betula*-dominant pollen assemblage of the deposit refers to a cold subarctic climate and the diatom assemblage to a small lake. According to Iisalo, the deposit represents *Betula*-dominant Weichselian interstadials. The esker is located between two till units found during till studies in the flanks of the esker. Iisalo (1992) maintains that the till-covered esker and the lower till unit formed during the Early Weichselian glaciation but admits that the absence of marine sediments between the till beds hampers interpretation of the till stratigraphy. The Mertuanoja section is the first find of an *in situ* deposit south of Oulu representing a *Betula*-dominant interstadial. More test pits were dug at Mertuanoja in 1992 and 1993 to check the till stratigraphy and search for new till exposures. The pits were dug down to depths of over 6 m.

Till-stratigraphic studies conducted south of the esker revealed a clay deposit between two till beds and a peat deposit to the north of the esker in a littoral deposit overlain by till. By then the esker section previously investigated by Iisalo had been dug out, and the site was occupied by a pond. Therefore, pits had to be excavated on the southern and northern flanks of the esker, outside the actual esker formation. Lowermost in the pits south of the esker was a compact till, the Mertuanoja Till, next a layer of clay and silt, the Mertuanoja Clay, and uppermost clayey, fines-rich till, the Ylivieska Till (Figs 12 and 13).

The Mertuanoja Till south of the esker is compact, grey, sandy till or fines-rich till with 3.9-5.4% clay (Fig. 9) and 0.1% humus determined colorimetrically. The till was laid down by ice flowing from the northwest, 315°. The Mertuanoja Till constitutes the lowermost deposit in pits south and north of the Mertuanoja esker. The till is consolidated and so hard that digging is slow even with a powerful excavator.

The Mertuanoja Till is overlain by a dark or greenish deformed layer of sorted sediments, the Mertuanoja Clay, sand and fine sand. Fine-grained varved clay lie directly on the till, implying that the lower part of the deposit represents the initial part of an ice-free stage. Upper part of the Mertuanoja Clay is massive. In several pits the deposit is over 1 m thick but in section 1 only a few tens of centimetres. The upper part of the sorted sediment exhibits the remains of a littoral deposit composed of sand and fine sand that once covered the clay. In places the sand exhibits layering. Separated by an erosional contact, the deposit is overlain by the Ylivieska Till that incorporates materials from the sorted sediments (Fig. 13). Immediately after the ice had melted, subaqueous conditions prevailed at the site, as at Vesiperä and Peräseinäjoki (Paper V). The remains of the littoral deposit in the upper part of the sedimentary sequence probably represent a later part of the ice-free stage when the area became dry land.

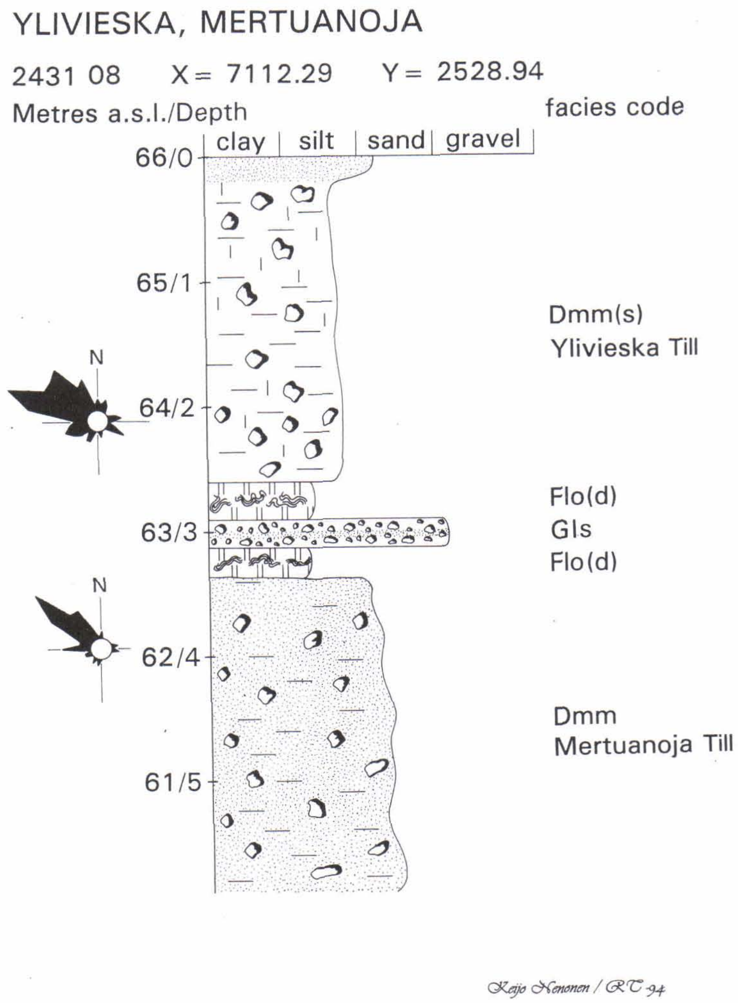
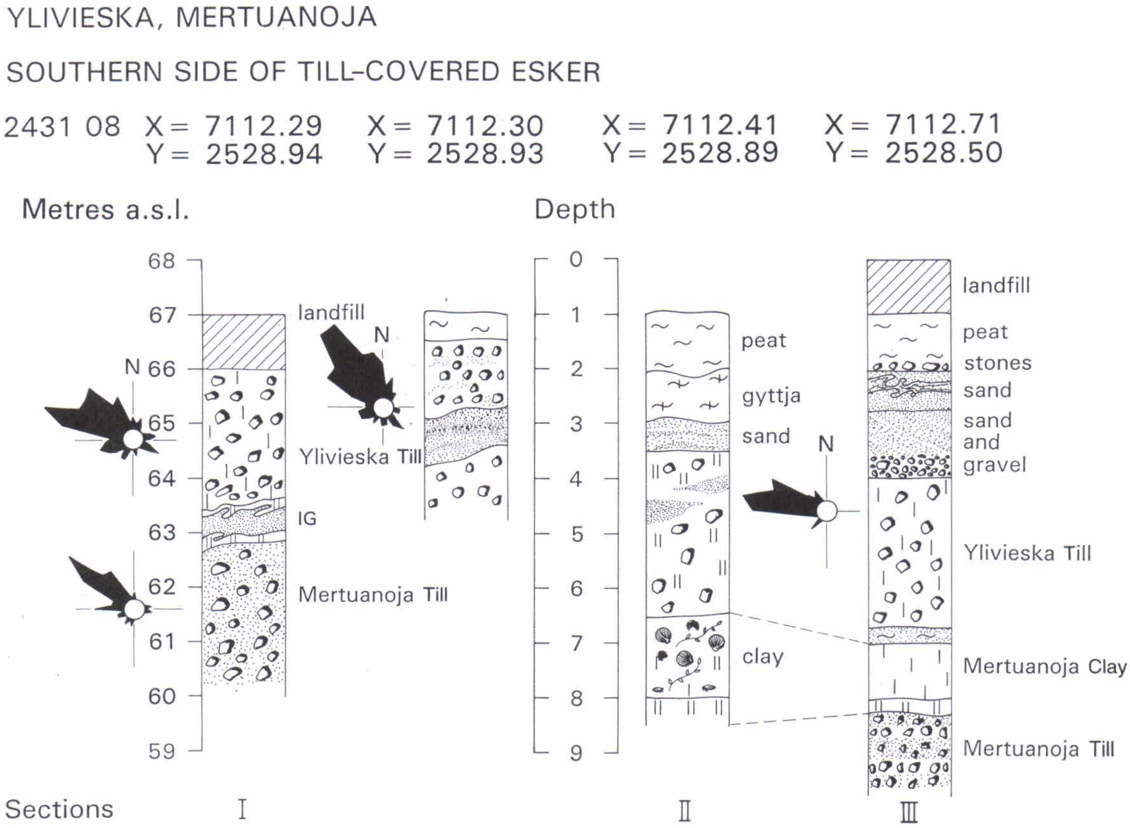


Figure 12. Lithofacies of Mertuanoja type section, Ylivieska.



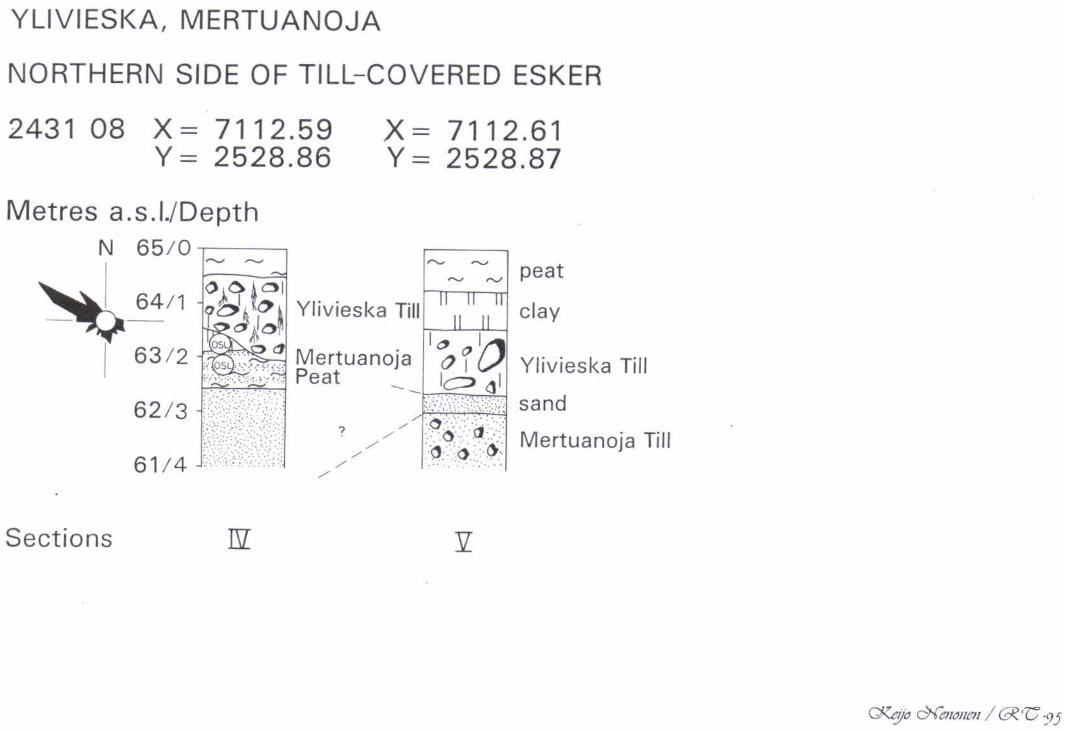


Figure 13. Stratigraphic sequence in pits excavated on flank of till-covered Mertuanoja esker, Ylivieska.

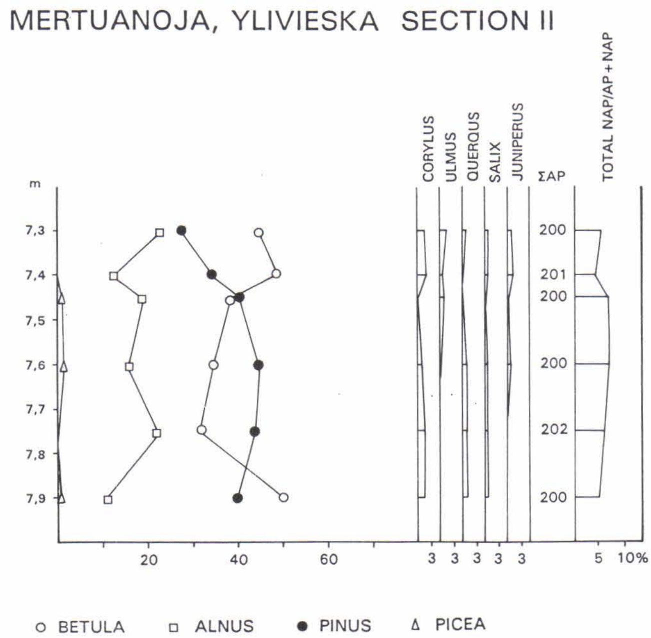


Figure 14. Pollen diagram of interglacial Mertuanoja Clay deposit.

According to microfossil studies on sections 1 and 2 at Mertuanoja, the Mertuanoja Clay has pollen and diatom assemblages typical of the Eemian Interglacial (Fig. 14). The pollen assemblage corresponds to local vegetation zone II of Eemian Interglacial deposits in Ostrobothnia (cf. Eriksson 1993), which is characterized by *Betula, Pinus and Quercus*. The high abundance of *Alnus* also refers to Eemian Interglacial vegetation zone III, in which *Betula, Alnus* and *Corylus* predominate. The pollen assemblage from Mertuanoja, section 3, includes *Betula*-dominant vegetation zone I, reflecting the early part of the Eemian Interglacial, followed by the vegetation succession of a temperate phase. In the surficial part of the Mertuanoja Clay the diatom flora is composed of freshwater forms, and in the basal part of saline water forms, including diatoms typical of the Eem Sea. The sedimentary sequence between the tills deposited at 61-63 m a.s.l.

The Mertuanoja Clay contains brittle macrofossils, imprints of algae, bright-blue elytra a few millimetres long, and aggregates, a few centimetres across, resembling radial tufts of hair. In the identification of material with the X-ray diffraction technique, simultaneous thermogravimetric and differential thermoanalytical techniques the material turned out to be opal. Under the microscope the hairs were found to be hollow, their basal parts containing remains of articulated segments. It was established that they were in fact the exceptionally well-preserved spicules of an amoeba-like sponge that floated in water (Anneli Uutela, pers. comm.). However, as the ecology of sponges is highly complex it is not possible to draw conclusions about the type of water from their fossils.

The Mertuanoja Clay is overlain by unconsolidated, clayey, structureless, bluish-grey, matrix-supported till, the Ylivieska Till. The till contains 9.7% clay and 0.2% humus determined as colorimetrically. Here and there lenses and bands of sand are seen in the till. According to fabric analyses, the till was deposited by ice flowing from WNW, 280-300°. A rock cutting on the Ylivieska-Oulainen road, 1200 m south of the excavation site, has polished surfaces with striations oriented 275-285°. In places on the southern flank of the esker the Ylivieka Till is overlain by sandy till layer separated from the former by sand less than 1 m thick (Fig. 13). The orientation of the sandy till is 330°. To the north of the esker the Ylivieska Till covers a littoral deposit of sand and fine sand containing poorly decomposed Bryales peat, the Mertuanoja Peat (Section IV, Fig. 13). This till-covered Bryales peat lies at 63 m a.s.l.

The Mertuanoja Peat occurs as layers interbedded with fine sand. Its pollen assemblage is Betula-dominant: *Betula* 80%, *Pinus* 8.5%, *Alnus* 2%, *Picea* 1.5%, *Quercus* 0.5%, *Salix* 7% and *Juniperus* 1%. NAP accounts for 40.5% of total pollen. About one-third of the *Betula* pollen in the peat deposit is of the *Betula nana* type (Brita Eriksson pers. comm.). The pollen of thermophilous deciduous trees is redeposited interglacial material. The peat deposit is underlain by horizontally laminated medium-coarse sand. Groundwater discharging from the sand unit caused the pit wall to collapse at a depth of 3.5 m. The lithostratigraphic position of the peat deposit corresponds to that of the deposit described by Iisalo (1992). Its pollen assemblage is also identical to that described by Iisalo. Bryales peat developed under conditions of a cool, or possibly even cold, interstadial, close to a shore or to a stream that, when flooding, covered the peat with fine sand from time to time. This fine sand may also be aeolian cover sand. The lithostratigraphic position and biostratigraphy of the deposit suggest an interstadial younger than the Eemian Interglacial. Its pollen assemblage differs clearly from those of the adjacent Marjamurto (Peltoniemi et al. 1989) and Oulainen (Forsström 1982, 1988) deposits, which are correlated with the Brørup Interstadial. The Mertuanoja deposit may refer to a substage of the Weichselian glaciation previously unknown in Ostrobothnia. Together with Esko Iisalo, who discovered the deposit, we have proposed that the corresponding interstadial be called by the local name, the Mertuanoja Interstadial.

The fine sand on peat protected the thin organic deposit from the ice sheet that deposited the Ylivieska Till covering the sedimentary sequence. This till, which contains 15% clay and 0.3 humus as determined colorimetrically, is structureless, bluish-grey, very loose and clearly oriented, indicating that it is deposited by ice flowing from WNE, 300°. The till bed can be correlated with the upper till unit identified in sections 1 and 3 south of the esker. Lowermost in section V, 30 m south of the pit, is compact sandy Mertuanoja Till overlain by 20 cm of sand. The stratigraphy in the pit corresponds to that of the tills in section I south of the esker (Fig. 13).

The Mertuanoja Till deposited by ice flowing from the northwest and overlain by the Eemian Interglacial sedimentary sequence has been encountered in several deep pits. The till shows a NW or NNW orientation in the range 310-340°. The orientation of older striations on protected facets at Ylivieska area is 310-330°. At Äijänneva, 10 km south of Ylivieska, the Mertuanoja Till is covered by only a thin layer of the Ylivieska Till and in places the compact sandy Mertauanoja Till is exposed. In test pits excavated in such an area the uppermost till bed may well have been deposited by an older ice flow from NW-NNW. If so, it may be difficult to interpret the lithostratigraphy and the age relations of the flow directions. The last glacial erosion and accumulation were obviously weak in the Ylivieska area because readily erodable interstadial and interglacial deposits - occurrences of kaolin and weathered rock - have been preserved there. The Ylivieska Till deposited by ice flowing from WNW and resting on the interglacial and interstadial deposits at Mertuanoja occurs in the Ylivieska area as the usual uppermost till unit. The orientation of till and the younger striations varies in the range 280-310°.

Samples were taken from the Mertuanoja deposit for radiocarbon and optically stimulated luminescence (OSL) dating. The OSL samples were collected in plastic cylinders in the field and treated at the Institute of Geology of the Estonian Academy of Science using the technique described by Hütt et al. (1993). The OSL age of the sample taken from littoral sand under the Ylivieska Till to the west of the studied sections is 70 ± 7 ka; that of the fine sand with the Mertuanoja Peat 64 ± 6 ka (Section IV, Fig. 13) and that of the sand covering the peat 38 ± 6 ka (Section IV, Fig. 13). The age of the humin fraction of the Mertuanoja Peat determined in the radiocarbon laboratory of the GSF is 36 600 ± 700 yr BP (Su-2432 A) and that of the humus fraction 25 300 ± 600 yr BP (Su-2432 B).

The OSL ages, 70 ka and 64 ka, are close with the boundary between the deep-sea oxygen isotope curve stages 5a and 4, that is, 74 ka. The Odderade Interstadial - the last warm stage of the Early Weichselian - prevailed in northwestern Europe, and in isotope stage 4 the continental ice sheets started to advance from their central areas. The vegetation reflecting a cool or cold interstadial in the Mertuanoja Peat deposit is compatible with the Odderade Interstadial, too. A great many Weichselian interstadials younger than the Eemian Interglacial are known. At least six have been recognized in the Netherlands (Mangerud 1991a) and, on the basis of climate proxes, 24 or 22 have been established from Greenland ice cores (Dansgaard et al. 1993, Grootes et al. 1993). The researchers of the ice core profiles attribute the difficulty of correlating continental interstadials to the large number of these interstadials.

Vuojalankangas reference section, Oulainen

Vuojalankangas, Oulainen, is in a key position in studies of Ostrobothnian Pleistocene stratigraphy. Forsström (1982) described in detail a peat-gyttja deposit and diatomite he found in a section in the till-covered esker of Vuojalankangas. The vegetational succession reflecting a *Pinus*-dominant warm period was originally interpreted as interglacial and was named the Oulainen Interglacial. As new interglacial finds were made it became evident, however, that the Oulainen deposit referred to a cooler stage than the last interglacial, and it was correlated with the Brørup Interstadial (Donner et al. 1986, Donner 1988, 1995, Forsström 1988). Later, Forsström (1991) interpreted the Oulainen gyttja deposit as representing redeposited material of a cool stage towards the end of the Eemian Interglacial (see also Punkari 1991). The sandy upper part of the Oulainen gyttja, the *Pinus-Betula-Corylus* vegetation zone described by Forsström (1982), contains redeposited pollen grains of *Corylus, Quercus, Carpinus* and *Ulmus*, up to several percent in total. The rest of the gyttja sequence - the *Betula*- and *Pinus*-dominant vegetation zones - represents the logical and uninterrupted vegetational history of a thermomer compatible with the interstadial in isotope stage 5c.

In his description of the Vuojalankangas lithostratigraphy, Forsström (1982, 1984) distinguishes two till beds with glaciofluvial sediments between and below them. The lower, greenish-grey melt-out till with redeposited microfossils he named the Vuojalankangas Till (Forsström 1982). An upper, reddish-brown clayey sandy till covers the esker. The till fabric shows a north-south orientation, which deviates from the direction of the last ice flow in the area, WNW, as indicated by drumlins and striations. Forsström named the upper till unit covering the Oulainen gyttja deposits and sharply cutting the underlying sand and gravel deposits the Pokelanmäki Till. As a compact till, it has been interpreted as lodgement till. The Vuojalankangas gyttja and diatomite were deposited at 76 m and 78 m a.s.l., respectively. Following the example of Iisalo (1992), we excavated pits in the flank of the Vuojalankangas esker to correlate its lithostratigraphy with that at Vesiperä and Mertuanoja.

A 6-m-deep section was excavated in the southwestern flank of the till-covered esker at the southeastern end of the Vuojalankangas section (Fig. 15). The section, which is 600 m northwest of the sections described by Forsström, contains two till units separated by layers of sand, silt, clay and gravel.

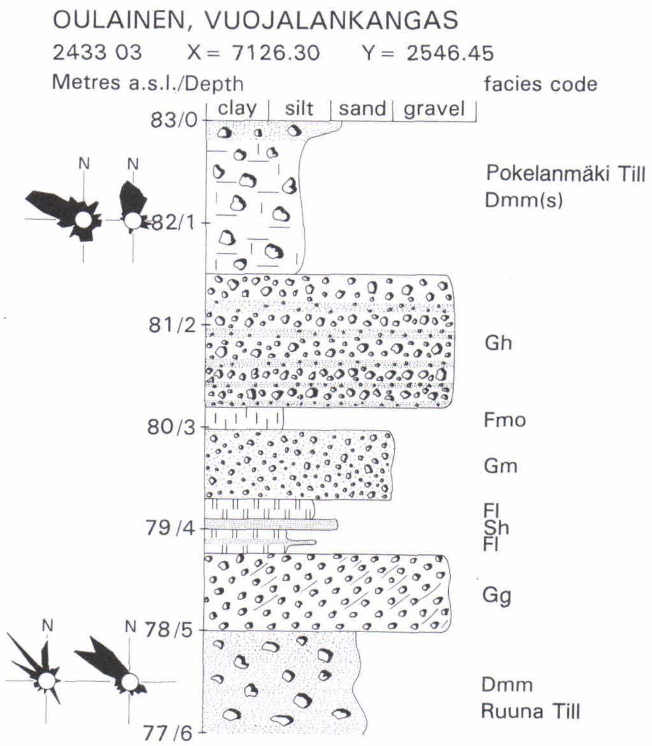


Figure 15. Lithofacies of Vuojalankangas reference section, Oulainen.

The gravel is underlain by structureless, matrix-supported till with 6.6% clay and 0.1% humus, the Ruuna Till. Digging with a heavy crawler excavator ended in compact till. According to fabric analyses, the till was deposited by ice flowing from the northwest, 310-320°. In the Ruiskallio quarry, 500 m southeast of the gravel pit, rock facets sheltered from the ice flowing from WNW exhibit cross-striations of 320-340°. The

Ruuna Till represents a lithostratigraphic unit previously unknown at Vuojalankangas, and is obviously older than the organic deposits and underlying glaciofluvial formation. The Vuojalankangas esker probably formed when the ice that laid down the Ruuna Till melted. The Vuojalankangas deposit is 15 km north of Vesiperä, Haapavesi. In its properties the Ruuna Till corresponds to the Vesiperä Till laid down by ice flowing from the northwest and overlain by Eemian Interglacial deposits. The till differs from the Vuojalankangas Till described by Forsström (1982) in both lithostratigraphic position and genesis.

The Ruuna Till is overlain by 3 m of sorted sediments, gravel, sand, silt and clay. The lowermost layer is crossbedded coarse gravel, less than 1 m thick, representing glaciofluvial sediments of the Vuojalankangas esker. The gravel is overlain by 60 cm of fine sand, clay and silt. The clay contains 0.5% humus, but only small amounts of redeposited pollen (15 grains per slide), mainly of *Betula*, were found. The silt is overlain by less than 1 m of horizontally laminated gravel and sand, evidently a littoral deposit. Over the sand there is a 20-cm-thick layer of silt with 0.4% humus and small amounts of pollen (144 grains in five slides). AP accounts for 86.2% and NAP for 13.8%. Of the forms, *Betula* accounts for 70%, *Alnus* 20%, *Pinus* 7%, *Salix* 2% and *Juniperus* 1%. The *Pinus* pollen grains are broken. The pollen flora in silt, which is probably redeposited, differs from that in the adjacent Oulainen gyttja deposit in having a high abundance of *Alnus* suggestive of interglacial material. The silt is overlain by a metre or more of horizontally laminated sand and gravel, probably a littoral deposit. The sequence refers to sediments deposited on the esker flank when the water level fluctuated at about 80 m a.s.l. Uppermost in the section is fines-rich Pokelanmäki Till visible in the walls of most of the gravel pits at Vuojalankangas.

The Pokelanmäki Till unit is reddish-brown, matrix supported till with 16% clay and 0.3% humus. It is lamellar lodgement till and rests on the underlying deposit with a sharp erosional contact. The orientation is 295° or 350° in different parts of the section. The youngest striation bearing on polished rock surfaces in the Ruiskallio quarry is 280°. The till was deposited by ice flowing from WNW, 280-295°, as demonstrated by striations and till fabric. The northerly orientations shown by the fabric of the Pokelanmäki till in the Vuojalankangas sections (Forrström 1982) are probably due to the transverse orientation of clasts in relation to the direction of ice flow. These transverse orientations, which are fairly common in lodgement tills, are due to the flow dynamics of ice.

Horonkylä reference section, Teuva

A number of till-covered esker formations with organic deposits (Niemelä & Tynni 1979, Donner 1988, Gibbard et al. 1989) and fossil podzol horizons (Kujansuu et al. 1991, Niemelä & Jungner 1991, Kujansuu 1992) are known from southern Ostrobothnia. Organic deposits occur in sand on top of esker sediments, often protected from the last glacial erosion by cover sands. The organic matter and podzol horizons are interglacial or interstadial. Hütt et al. (1993) have recently dated fossil podzols and associated deposits with OSL and TL methods at Kärjenkoski, Risåsen and Norinkylä. The OSL dates fall into two groups: (i) 120-163 ka, and (ii) 76-106 ka. The TL ages of the same deposits vary in the range 135-155 ka. The deposits are 20-40 km from Horonkylä.

The till-covered esker formation at Horonkylä has long been known to Quaternary geologists, as sections of the gravel pit once located in the esker were regularly monitored and studied in the course of gravel extraction. Two till layers resting on the primary esker sediments were visible in the walls of the gravel pit (Fig. 16). Between the tills were sand and gravel with horizontal layering and crossbedding. According to fabric analyses, the upper till was deposited by ice flowing from NNW and the lower till by ice flowing from NNW or north. No organic deposits indicative of interglacial or interstadial origin were found between the tills. When gravel extraction ceased the pit was landscaped, and local waterworks established a groundwater intake plant there.

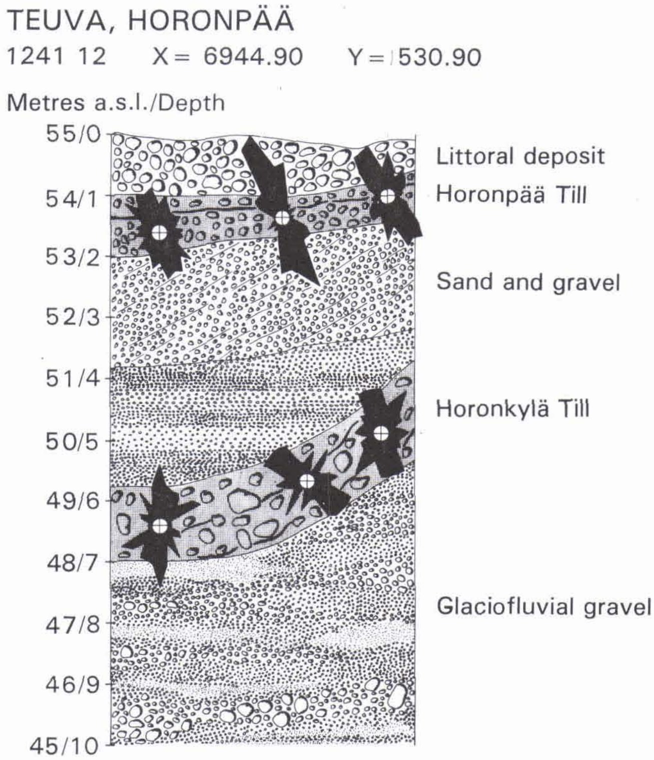


Figure 16. *Stratigraphic sequence in Horonpää esker section, Teuva.*

In summer 1992 pits were excavated in the Horonpää esker section in connection with age determinations on the till-covered eskers in Ostrobothnia by the Department of Quaternary Geology of the GSF. A pure white diatomite deposit, almost 2 m thick, was found. A sample taken from the deposit revealed that it was diatomite with 90.4% silica (SiO_2). The concentration of combustible organic matter in the diatomite as indicated by loss on ignition is 1.9-3.4%.

It is proposed that the till formation in the Horonkylä section be called by formal local names as follows: the upper till, the Horonpää Till; the lower till, the Horonkylä Till; the diatomite deposit beneath the till units, the Horonkylä Diatomite; and the sediments between the till units, the Horonpää Sponge Bed (Fig. 17).

The Horonkylä Diatomite deposit is a deformed plate in sand underlain in places by sand and gravel. The plate shows folds, overthrust structures, faults, clasts and sand wedges and, here and there, the diatomaceous earth is mixed with sand and fines-rich till. The structures imply that the material was deformed and transported by the overriding ice before being deposited at its present site in much the same way as described by Donner (1988) for the Norinkylä till-covered gyttja. Both the diatomite and the folded layer of peat in it contain wood material. The diatomite and the peat-bearing diatomite were sampled for microfossil studies at 5-cm intervals. The sediments resting on the diatomite deposit had been removed but when the gravel pit was being monitored it still contained variable amounts of glaciofluvial sand and gravel and the above-mentioned tills.

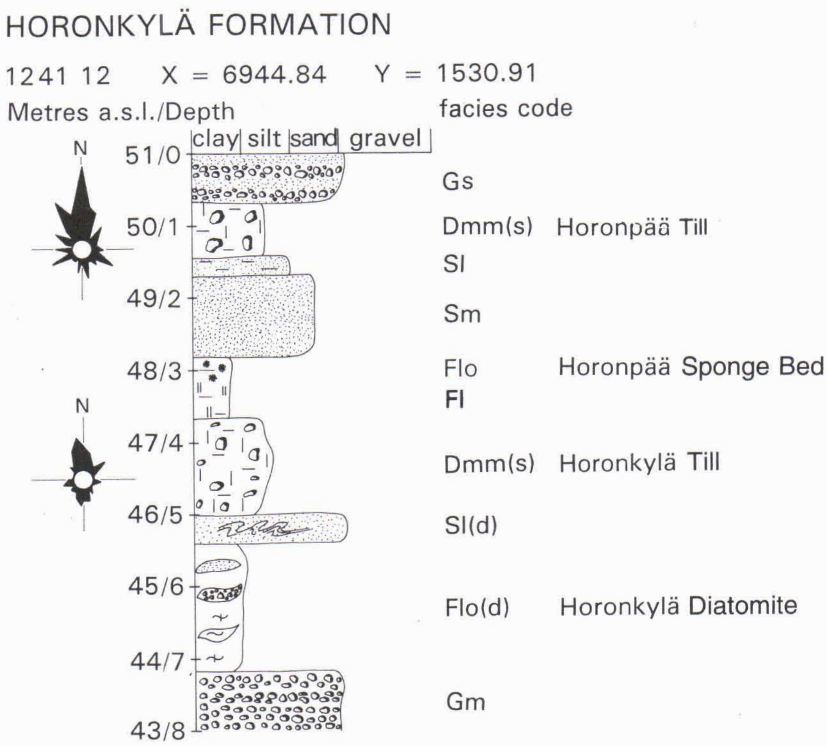


Figure 17. Lithofacies of Horonkylä reference section, Teuva.

A corresponding stratigraphy was exposed on one side of the landscaped pit (Fig. 17). Lowermost in the stratigraphy are sand and gravel, probably of glaciofluvial origin. The gravel is overlain by folded and deformed diatomite varying in thickness. On the bottom of the section, sand incorporates silt and gyttja clasts. The Horonkylä Diatomite is overlain by stratified sand with folded and deformed structures. A sample of deformed sand was taken for OSL dating (Ho 3) (Fig. 18). The other OSL dating samples (Ho 1 and 2) were taken from undisturbed horizontally laminated sand with ripple marks in section 1 beneath the fines-rich Horonkylä Till.

The heterogeneous gravel underlying the sand was submitted to fabric analysis. The orientation in the gravel is weakly developed and so differs from the well-developed orientation of the lodgement tills in the Horonkylä section. The material is not lodgement till but more likely cryoturbate. The heterogeneous gravel is underlain by a discontinuous layer of pale and folded material resembling fossil podzol with till-like grey diamicton lenses. The layer is still recognizable 30 m away in section II in the same stratigraphic position beneath horizontally laminated sand and between coarse sand and gravel.

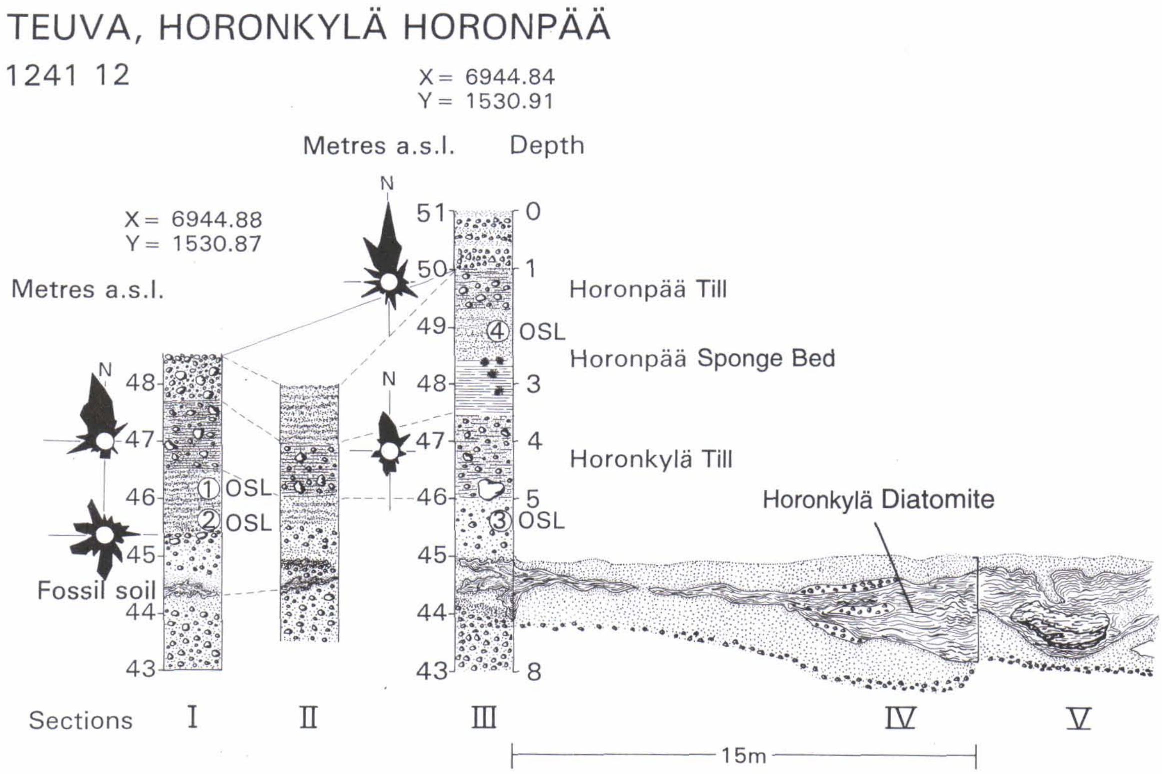


Figure 18. Stratigraphic sequence at site of Horonkylä Diatomite.

The Horonkylä Diatomite is overlain by fines-rich Horonkylä Till, over 1 m thick, which is laminated lodgement till, dark grey in colour and strongly oriented. The rose diagram shows that the till was deposited by ice flowing from NNW. The till, which has a sharp erosional contact with the underlying sand, contains 8.5% clay and 0.1% humus.

The Horonkylä Till is overlain by a sequence of water-laid sediments - silt, clay, fine sand and sand, the Horonpää Sponge Bed. The silty clay on the Horonkyä Till grades into laminated fine sand. The deposit, which is 80 cm thick, was sampled for microfossil studies at 10-cm intervals. A white and yellowish wool-like material consisting of opal sponge spicules (Fig. 19) was found in its upper part. The presence of clay demonstrates that an ice-free period prevailed during its deposition. Similar hair tufts were found at Mertuanoja, Ylivieska.

The Horonpää Sponge Bed with fossil sponge spicules is overlain by 1.5 m of structureless, massive coarse sand and this in turn by 0.3 m of horizontally laminated fine sand. An undisturbed sample was taken from the latter for OSL dating (Ho 4). Lying on silt and clay, the sand layers clearly represent an ancient littoral deposit.

Figure 19. Sponge spicules composed of opal silica from Horonkylä, Teuva. Spicules are 2 cm long. Photo Jari Väätäinen, Geological Survey of Finland.

The littoral deposit is overlain by the Horonpää Till, which is bluish-grey, unconsolidated, clayey fines-rich till containing 11.3% clay and 0.3% humus. According to fabric analysis, the Horonpää Till, which is also laminated and well-oriented, was deposited by ice flowing from NNW, 350°. It is lodgement till with a sharp erosional contact with the underlying sand. Uppermost in the section is a littoral deposit of sand, gravel and stones varying in thickness. In places littoral forces have obliterated the Horonpää Till.

Samples collected from the section (OSL Ho 1, 2, 3, 4, Fig. 18) were dated using the OSL technique. Dating of the sample from the sand between the Horonkylä Till and the horizon resembling podzol gave an OSL age of 46 ± 6 ka (Ho 1) for the upper part of the sand, and 64 ± 5 ka (Ho 2) for its lower part. The OSL age of the deformed sand between the Horonkylä Diatomite and the Horonkylä Till is 36 ± 4 ka (Ho 3). The OSL age of the sand covering the Horonpää Sponge Bed is 54 ± 8 ka (Ho 4). Interpretation of the OSL dates is problematic due to the discrepancy in ages of sediments in different stratigraphic positions. The material of sample Ho 3 is probably originally glaciofluvial or fluvial sand which is not ideal material for luminescence dating. Niemelä & Jungner (1991) dated samples collected from fine and medium coarse sand between fines-rich till, probably Horonkylä Till, and sediments of the Horonkylä esker with the TL method, and obtained ages of 159 ka and 150 ka, respectively.

The diatom assemblage of the Horonkylä Diatomite and Horonpää Sponge Bed has been studied by Grönlund & Ikonen (1996, in press). The Horonpää Diatomite lowest in the section contained 25 diatom genera and 94 species; all were freshwater forms. The study demonstrates that the sediment was mainly deposited in alkaline water, although a short acid phase may have occurred at some point. The variation in the amount of planktonic diatoms may indicate that the water level fluctuated significantly during the deposition of diatomite. In the uppermost section of the Horonpää Sponge Bed there is a diatom flora with 18 diatom genera and 18 species. In the middle of the Horonpää Sponge Bed the diatom assemblage is indicative of redeposited Eemian Interglacial material deriving from Eemian marine deposits around Horonkylä (Niemelä & Tynni 1979, Grönlund 1991b). The clay also contains freshwater diatoms that reflect the original diatom assemblage of the basin, and in the upper part of the Horonpää Sponge Bed deposit there are abundant sponge spicules. Sedimentation was tranquil as suggested by the preservation of fragile sponge spicules as unbroken accumulations and the star-shaped colonies of *Tabbellaria flocculosa*. According to Grönlund & Ikonen (1996,in press), sedimentation, which probably occurred in a shallow pond, was rapid at the time of clay deposition.

The pollen assemblage of the Horonkylä sequence and its fossil peat and wood remains has also been studied (Grönlund & Ikonen 1996, in press). *Betula*-dominant and *Pinus*-dominant zones reflecting the local vegetation have been distinguished in the Horonkylä Diatomite. The *Betula* zone contains single grains of *Alnus, Carpinus* and *Quercus* pollen, probably as redeposited material. The folded peat in the diatomite is brown moss containing macrofossil Bryales and Ericaceae tissue. The pollen assemblage in the peat layers is dominated by *Pinus*. Twigs found in the deposit are *Salix*. The vegetation shown by the Horonkylä Diatomite and peat resembles that of deposits interpreted as interstadial at Oulainen (Forsström 1982, 1988, Donner 1988), Vimpeli (Aalto et al. 1983, Donner 1988), Marjamurto, Haapavesi (Peltoniemi et al. 1989) and Harrinkangas, Kauhajoki (Gibbard et al. 1989, Kujansuu et al. 1991). The above deposits are often correlated with the Brørup Interstadial in northwestern Europe.

The Horonpää Sponge Bed between the tills is poor in pollen. Its pollen assemblage, which clearly differs from that in the underlying Horonkylä Diatomite, shows that the fine sand in the middle of the deposit incorporates interglacial material, as it contains abundant *Corylus, Carpinus* and *Quercus* as well as *Pinus, Betula* and *Alnus* pollen. The organic matter in the middle of the deposit and its pollen assemblage may reflect a pulse of secondary material from eroded Eemian Interglacial sediments. The outcome is consistent with that of the diatom analysis, which demonstrated that the same samples contained redeposited diatoms of the Eem Sea. A few pollen grains in the silty clay in the lower part of the Horonpää Sponge Bed, which may represent local vegetation, reflect an open terrain during sedimentation or the material is redeposited.

A deposit corresponding to the Horonkylä lithostratigraphy has been encountered 21 km to the east from Horonkylä, in a section of the till-covered Haapalankangas esker (Fig. 20). There, the primary glaciofluvial sediments are covered by two tills separated by stony, horizontally laminated sand. The upper clayish till, possibly correlative to Horonpää Till, occurs only in the northeastern wall of the section, beneath postglacial littoral deposits. According to fabric analyses, the till was deposited by ice flowing from the north, 360°. The lower till, possibly correlative to the Horonkylä Till, rests on sand and gravel with a sharp erosional contact. Fabric analyses show that this till was laid down by ice flowing from the northwest, 320-330°. The basal part of the till is dark grey clayey till with clasts of peat and gyttja.

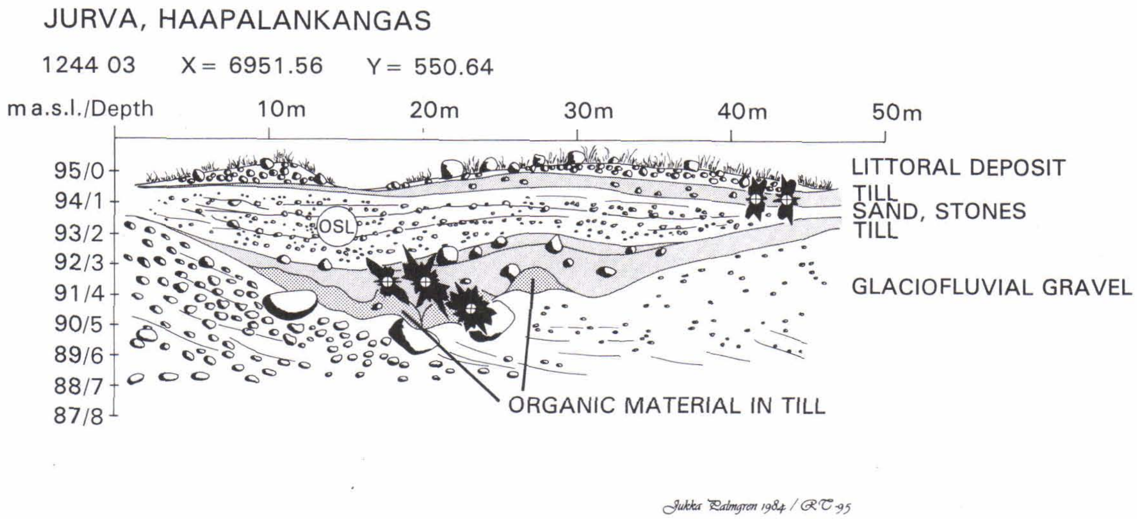


Figure 20. Stratigraphic sequence at Haapalankangas, Jurva.

Leaves of Bryales peat have been identified in the organic matter. According to pollen analyses (Brita Eriksson, pers. comm.) the gyttja and peat clasts contain 57-73% *Pinus*, 17-27% Betula , 3-4% *Alnus* and less than 2% Picea . *Corylus* accounts for 1-2% of te pollen in addition to which a few grains of *Quercus* pollen were found. The pollen assemblage of the deposit is totally different from that of the Eemian Interglacial till-covered gyttja in the same till-covered esker at Norinkylä 10 km farther south (Niemelä & Tynni 1979, Donner 1988). The pollen assemblage in the Haapalankangas deposit resembles those at Oulainen and Vimpeli, which have been correlated with the Brørup Interstadial. The abundant diatoms in organic clasts show that the diatom flora grew in the littoral parts of a freshwater basin (Tuulikki Grönlund pers. comm.).

A sample from the sand between the Haapalankangas till units, yielded an OSL age of 41 ± 2 ka. Niemelä & Jungner (1991) used TL to date till-covered geosol and sand from a littoral deposit between till and geosol in a gravel pit 200 m to the north; they obtained 156 ka and/or 124 ka for the geosol and 129 ka for the sand covering it.

Reference sections of Late Weichselian deglaciation

According to the varve clay chronology of Niemelä (1971), the front of the melting ice was at the south coast of Finland about 11 900 varve years ago, and Salpausselkä I was formed 10 950-11200 varve years ago. The age of Salpausselkä I, as deduced from the revised Swedish varve clay chronology (Cato 1987, Strömberg 1990), is 11 100-11 300 varve years ago, and the coast of the Gulf of Finland was liberated from its ice cover 12 200 varve years ago (Saarnisto 1991). Before the Salpausselkä endmoraines were formed the ice front withdrew at least 50-80 km to the proximal side of Salpausselkä I (Nenonen 1984, Hirvas & Nenonen 1985, Rainio 1985a, 1991). Marjatta Okko (1962) named the period in which the Scandinavian Ice Sheet withdrew from the present south coast of Finland to somewhere northwest of Salpausselkä I the Heinola Deglaciation. The subsequent readvance she named the Salpausselkä Readvance (cf. Mölder et al. 1957). This readvance had a strong effect on the glacial flow directions and glacial stratigraphy (Fig. 21). The cause for Yonger Dryas readvance is uncertain but is was possible triggered by the cooling climate and by changes in the relative sea level of the Baltic basin (cf. M. Okko 1962, Lundqvist 1987, 1988, Nenonen 1993).

The ice readvanced as large glacial lobes; the Baltic Sea lobe in Bothnian Sea and southwestern Finland, the Näsijärvi-Jyväskylä lobe in central Finland, the Lake District lobe in Savo, the North Karelian lobe in eastern Finland and the Kuusamo lobe in Kainuu (cf. Brander 1934, Brenner 1944, Punkari 1979). On the basis of varved clay chronology from the Ihalainen section in Lappeenranta, Rainio (1993) dated the onset of the Salpausselkä Readvance to 11 457-11 834 varve years ago. and its end to 11 303 - 11 681 varve years ago.

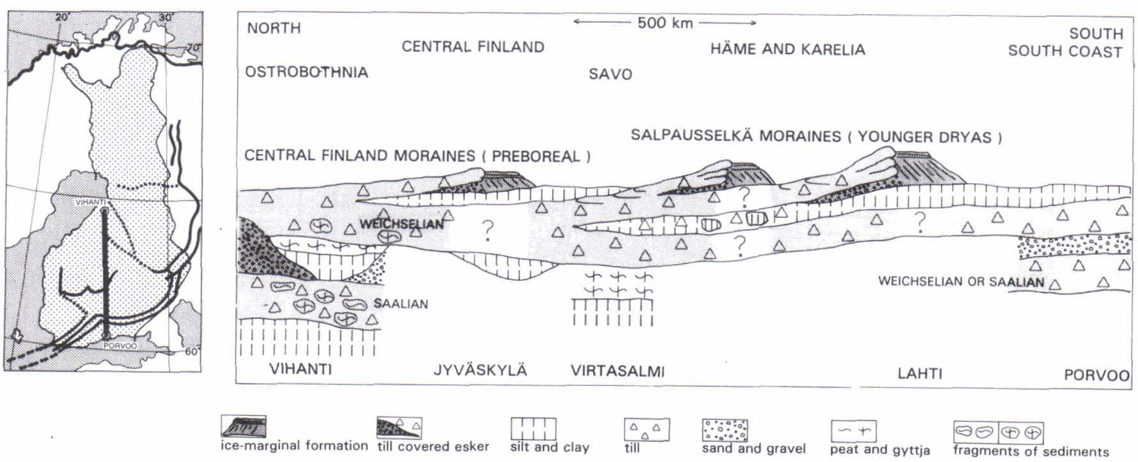


Figure 21. Diagram of relationship between end moraines and till stratigraphy produced by readvancing glacial lobes in southern and central Finland.

Jomala reference section, Åland

Boulders of limestone and sedimentary rocks are exceptionally abundant on the surface in the Jomala area, Åland (Hokkanen 1987). The bedrock in the Jomala area is Åland rapakivi granite. The limestone clasts in till are partly Baltic chalk, micrite and marl, materials that have been in heavy demand for centuries. The parent rock of the limestone boulders, searched for since the 16th century. Limestone boulders have been collected and burned for mortar and cement. The numerous shallow pits still visible in the areas where limestone boulders were collected are reminders of the centuries-long tradition of lime burning. Local farmers have also used limestone-rich till and crushed limstone to improve the soil of their clayey and silty fields.

The distribution of limestone in till was mapped in the 1970s and 1980s (Hokkanen 1987). While searching for industrial minerals Paraisten Kalkki Oy found a Cambrian-Ordovician sedimentary rock occurrence, up to 120 thick and 5 km² in extent, in the northern part of Lumparn Bay 10 km west from Jomala site (Winterhalter 1982). Various exploration organizations have also carried out drilling and sounding in the Jomala area. However, the search for the parent limestone has not revealed a new limestone occurrence on the Åland mainland. The abundance of limestone boulders can be explained by glacial activity.

The surficial part of till in pits dug in the Jomala area contains up to 86% Baltic limestone and 57% calcium carbonate. The example of stratigraphy (Fig. 22) is from the middle of the Jomala limestone boulder train, where the carbonate content in the surficial layer is 39%, The Jomala Till, and in the basal part of till 8%, in the Åland Till.

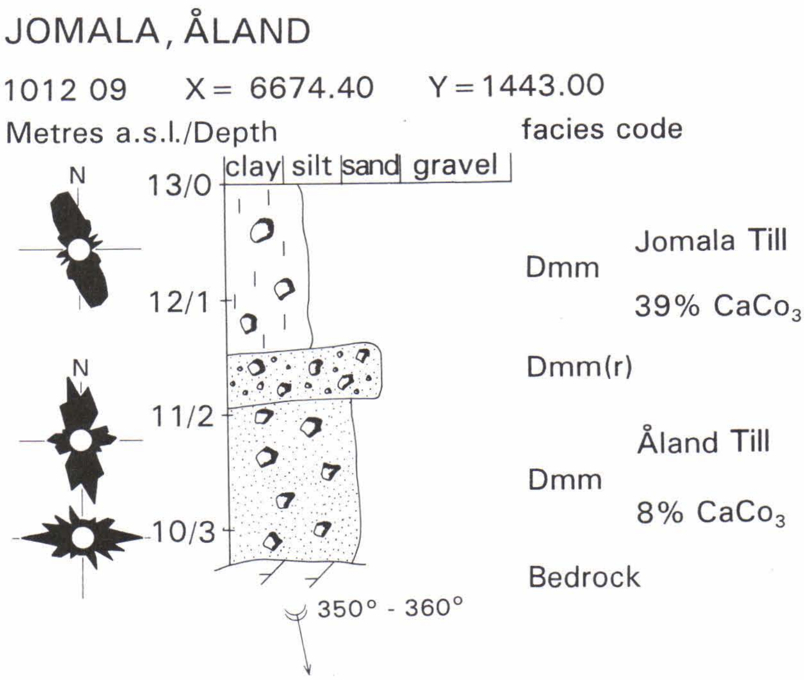


Figure 22. Stratigraphy and calcium carbonate concentrations in tills in Jomala type section, Åland.

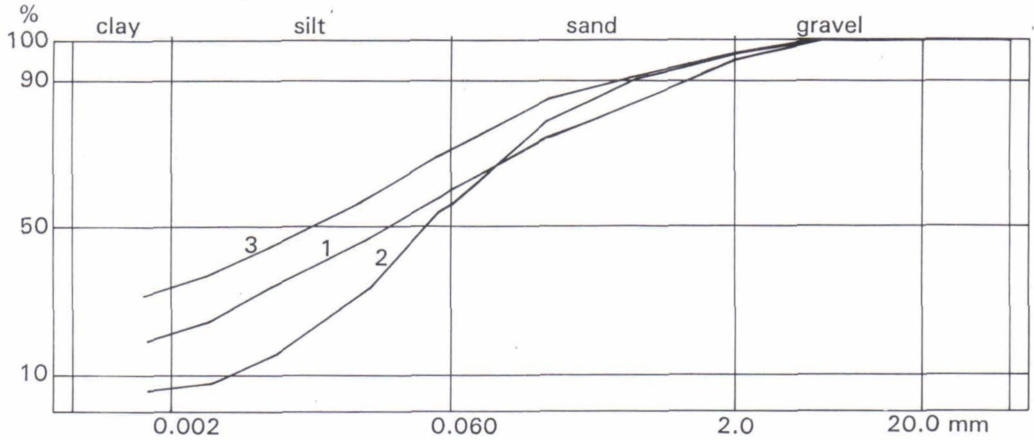


Figure 23. Grain size distribution in tills in Jomala type section. 1. Jomala Till, 2. Åland Till, 3. silty clay from bedrock hollow beneath Åland Till.

The Åland Till in the section is bluish-grey, fines-rich till with 6.5% clay and 0.5% humus (Fig. 23). The orientation of till, 350°, implies that the ice flowed from N-NNW. Another fabric analysis on the same till showed an orientation of 270° for clasts, probably indicating that the clasts were oriented transverse to the ice flow. The striations on the rock at the bottom of the section, which is rapakivi granite - pyterlite - are oriented 350-360°. Limestone account for 12%, long-distance sandstone and schist for 59% and rapakivi granites for 29% of the clasts in till. Stone counts from deeper till sections showed that around one-third of the clasts were local rapakivi granite, the majority being long-distance sandstone, schist and limestone clasts.

In some places deformed layers of sand and silt occur between the tills in the Jomala area; in others the Åland Till occurs as redeposited lenses and clasts in the Jomala Till. The tills are separated from each other by an erosional contact. The Jomala Till is marly, brownish-grey, massive, clayey, fines-rich till containing 20% clay and 0.4% humus (Fig. 23). It is oriented 345°, which is the direction of the last ice flow towards the ice-marginal formations in the Salpausselkä extension at the bottom of the Baltic Sea. Limestones account for 59%, long-distance sandstones and schists for 32% and local rapakivi granites for 9% of the till clasts.

The Jomala Till in the Jomala drumlin area is lodgement till, the youngest till deposited in the area. The limestone-bearing material may, then, have been transported as englacial debris and finally laid down in the pressure minima that developed in the basal parts of the ice on the distal side of rock knobs in the Jomala area. In his studies on the sandstone content of tills in Åland, Salonen (1991) suggests that the steep proximal slope of the main island lifted debris rich in sedimentary rocks into an englacial position. Uutela (1989) has also proposed long-distance englacial transport from the Bothnian Sea sedimentary rock areas as a possible explanation for the presence of sedimentary rock clasts in till in southwestern mainland Finland.

Most of the sedimentary rock and limestone clasts in Åland probably derive from the sedimentary rock areas on the bottom of Bothnian Bay. Lithologically diverse layers formed in basal parts of the ice sheet and were then transported tens of kilometres, probably even farther, from their sources. When depositing, englacial debris layers form till with units deviating in lithology. These may represent a short depositional event and a single glaciation stage. Ringberg et al. (1984) have described how Cretaceous sedimentary rock plates, several tens of metres thick, were transported by ice for 25 km from their sources in southern Sweden.

The Åland Till probably represents the same glaciation as the Jomala Till. There is unlikely to have been an ice-free period between their depositions as no deposits suggesting such a period have been found between them. The Åland Till presumably represents an earlier stage in the development of the Baltic Sea glacial lobe. Clay clasts occur in the Åland Till, and silty clay with 1.25% humus fills bedrock joints under the till (Fig. 23). The north-south direction of striations on the polished rocks in Åland probably refers to the ice flow that prevailed before the formation of the Salpausselkäs. In the Salpausselkä stage the ice flow turned slightly to the southeast towards the depositing ice-marginal formations.

The variation in till lithology in the till stratigraphy of Åland illustrates the strong influence that the mechanism of glacial transport and subglacial conditions can have on the lithology of depositing till, even during a single glaciation. On the south coast of the Baltic Sea, the till stratigraphy has been subdivided, and flows of ice sheets of different ages have been reconstructed partly on the basis of the lithology of the till beds (cf. Ehlers 1983, Böse 1990).

Sedimentary rock material, limestone in particular, transported from the bottom of the Baltic Sea has rendered the soil in Åland neutral or slightly alkaline over large areas. This feature manifests itself in the landscape, where rapakivi granite ledges alternate with till-covered depressions of lush vegetation. Lime-bearing Jomala Till makes a favourable substrate for rare calcicole plants and ash-oak-hazel groves (Sten 1985).

Vampula marble quarry reference section

The Sallila marble quarry of Partek Oy in Vampula lies about 80 km to the proximal side of the Salpausselkä ice-marginal formations, in the area occupied by the Baltic Sea glacial lobe during deglaciation. The Pleistocene deposits, which are up to 12 m thick in the open pit section, are mainly till overlain by silts and sand. Littoral sand covers varved clay deposited on the till. The till stratigraphy of the section exhibits four separate till units, the Vampula a, b, c, d Tills (Fig. 24).

The lowest till in the section, the Vampula a Till, is bouldery and gravelly sandy till with 1.6-4.3% clay and only 0.1% humus. The basal part of the till is rich in weathered rock material, and wedges of till have penetrated the underlying weathered rock. The till is washed and probably melt-out till in genesis. The poorly developed fabric suggests ice flow from the northwest during deposition. The Vampula a Till unit contains 6% sandstone clasts, the majority (71%) being of local amphibolite, granite and gneisses.

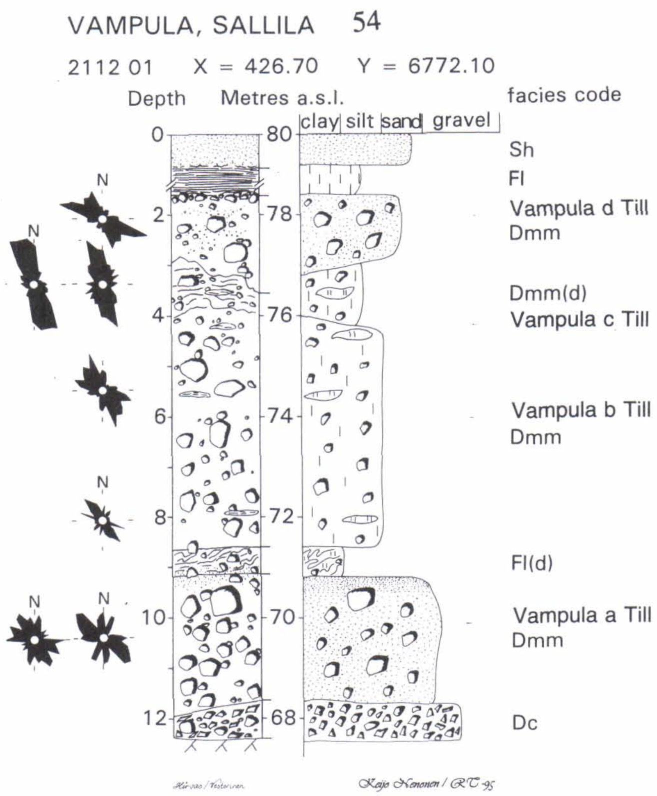


Figure 24. Stratigraphic sequence and lithofacies in Vampula marble quarry reference section.

The Vampula a Till is separated from the upper tills by 60 cm of deformed, water-laid sediments - silty clay and fine sand - with 0.4% humus. Microfossil studies did not reveal diatoms in either the clay or the lenses of sorted sediments in the overlying fines-rich till, the Vampula b Till.

The Vampula b Till is about 5 m thick and reddish-brown. It contains 5.8-8% clay and 0.34-0.37% humus. It also contains clasts of sorted fine-grained sediment, which are probably of the same material as the underlying sediment. According to fabric analyses, the till was deposited by ice flowing from the northwest, 320°. Its reddish-brown colour is due to incorporated sedimentary rock material. The sandstone component amounts to 29-48%, as the Satakunta sandstone area is located about 15 km northwest of the Vampula quarry. The till also contains occasional sedimentary limestone clasts.

The Vampula b Till is overlain by a layer of very compact, deformed, clayey dark grey or bluish-grey till, the Vampula c Till, with 18.5-21% clay and 0.4-0.6% humus. The orientation of the till, 340°, shows that it was deposited by ice flowing from NNW to SSE. The Vampula c Till is less than 2 m thick in the section but in places it is no more than a layer a few tens of centimetres thick between Vampula b and d Tills. It contains 6% sedimentary limestone clasts and 30% sandstone clasts. According to Uutela (1989), the sedimentary limestone clasts are reddish-grey Middle Ordovician calcilutite. The Vampula c Till incorporates material from fine-grained sorted deposits as shown by its clay and humus contents. Microfossil studies on four samples of dark grey till taken at different sites revealed a few freshwater diatoms, implying that the sediment deposited primarily in a lake.

The uppermost till in the Vampula section is brownish-grey, unconsolidated, sandy till, the Vampula d Till, with 3.8% clay and 0.12% humus deposited by ice flowing from WNW. The till contains 60% granites, amphibolites and gneisses from the surrounding bedrock and 8% sandstone transported from distant sources. The Vampula d Till is 0.5-2 m thick in the studied section.

The tills in the Vampula section are difficult to date due to the lack of intervening organic deposits. However, the bluish-grey Vampula c Till deposited by ice flowing from NNW incorporates abundant material from fine-grained, probably deglacial or interstadial water-laid sediments, over which the ice passed as it readvanced. The age of the Vampula a Till, lowest in the section, is not known because the overlying clay and sand do not contain any microfossils or organic matter that could be used in dating.

The lithostratigraphy of Vampula c and d Tills in the upper part of the Vampula section probably reflects the flows of the Baltic Sea glacial lobe during deglaciation. According to the striations, the last glacial flow in the Vampula area was from WNW, 300°. In southwestern Finland there are also older northwestern cross-striations. Superimposed till beds deposited by ice flowing from WNE and NW occur in the Vammala area (Paper III). Till-stratigraphic investigations have shown that the last flow of the Baltic Sea ice lobe turned towards Salpausselkä III at Hämeenlinna and the Pyynikki-Kangasala esker at Tampere and that the lower till unit was deposited by ice flowing from northwest to southeast (cf. Virkkala 1962, 1963).

The flow of ice from the northwest transporting the sandstone clasts was interpreted by Salonen (1991) as the last independent glacial flow stage ending at the Salpausselkäs. Vampula c Till with sedimentary limestones can probably be correlated with the flow stage described by Salonen, whereas the Vampula b Till, also deposited by ice flowing from the northwest, may represent a flow predating deposition of the Salpausselkäs. The till deposited by the glacial flow from the northwest is the uppermost till unit to the south of the Salpausselkäs (Papers III and VII). This glacial flow could have transported a large copper ore float from Ylöjärvi 10 km NW from Tampere to Perä-Pohjakka close to Porvoo before the Salpausselkäs were formed (Hirvas & Nenonen 1981). The same glacial flow also transported material from the Lappajärvi impactite crater to southern Finland (Salonen 1986).

In Uusimaa there is a compact dark-grey or bluish-grey, clayey, fines-rich till - the Siuntio Till Member - below the Espoo Till Member, a sandy till deposited by ice flowing from the northwest. The Siuntio Till Member was deposited by ice flowing from the north or NNW (Bouchard et al. 1990, see also Paper III). Sorted fine-grained sediments occur between the tills, suggesting that their depositions were possibly separated by an ice-free stage. The tills have not been correlated or dated due to the lack of organic deposits. The genesis of the dark-grey, clayey Siuntio Till Member has been compared to that of the Kauhajoki Till Formation overlying interglacial deposits in southern Ostrobothnia. In mode of origin and generation of debris, Vampula c Till might also be comparable to these tills.

Sedimentary rock clasts found in the till of the Vampula limestone quarry were probably transported from the Ordovician limestone area on the bottom of the Bothnian

Sea. Palaeozoic limestone clasts in Vampula c Till, at a distance of over 100 km from their source, can be considered as accidental or isolated clasts (cf. Uutela 1989) transported as englacial debris farther than usual, much as were the limestone clasts in the Jomala Till described above.

Kaasila reference section, Outokumpu

The transport history of ore floats from the Outokumpu deposit has interested exploration geologists for years (Paper II). Exploration triggered by a copper ore float found at Kivisalmi in 1908 led to discovery of the Outokumpu copper ore deposit. Guided by clasts of the rock types associated with the Kivisalmi float in till and by glacial transport directions, the indicator tracing work is a classic example of exploration based on samples received from the public, a method applied with great success in Finland. Other Outokumpu-type copper ore floats were also found in North Karelia while the Outokumpu deposit was being mined (Kinnunen 1981). Till-stratigraphic studies were undertaken at the find sites of the floats and at the suboutcrop of the Outokumpu orebody, from which some of the floats were thought to have been removed and transported by ice flowing from the northwest or west. At the Kaasila suboutcrop the glacial deposits are composed of thick till with three units (Fig. 25). Tills in the Kaasila reference section and Outokumpu area can be called by the formal names as: The lowermost till unit, the Outokumpu Till; the middlemost till the Kaasila Till and the uppermost the Ruutukangas Till.

The Outokumpu Till unit in the Kaasila section is grey, massive, silty and sandy till. The weakly developed northwesterly orientation of the till and the striations on the underlying bedrock show that the Outokumpu Till was deposited by ice flowing from 340-345°. The till contains 77% Outokumpu zone rocks (serpentinite, quartzite, skarn) and 23% other local lithologies (granite, mica schist, mica gneiss, black schist). The till is overlain by about 60 cm of deformed, water-laid sorted sediments, sand and silt. The sorted layer is overlain by an unconsolidated till, the Kaasila Till, with sand lenses, which contains only 14% silt or finer material, and no more than 0.5% clay. The Kaasila Till, oriented between WNW and NE, is probably composed of redeposited sorted material and melt-out till with 8% Outokumpu zone rock types and 92% other local lithologies.

The Ruutukangas Till, uppermost in the section is laminar compact sandy till with 31% silt or finer material and 4.1% clay. The orientation of clasts varies from northwest to northeast. The fabric is poorly developed and the flow direction cannot be deduced conclusively from the diagrams. In the Ruutukangas Till, the clasts of Outokumpu-zone rocks account for 9-14% and those of other local lithologies for 85-91%. The original stratigraphy of the surficial part of the section has been disturbed by excavations undertaken in the area at different times. The surficial layer near the section is a sandy littoral deposit of outwashed till extending to a depth of 0.5 m.

Likevise in the section of the Vuonos open pit, 11 km northeast of the Kaasila section, the uppermost till, comparable to the Ruutukangas Till, was deposited by ice flowing from the NNW and the lowermost till, comparable to the Outokumpu Till, by ice flowing from the northwest. In the middle of the Vuonos section there is a till deposited by ice flowing from west to east, comparable to the Kaasila Till. Polished rocks on the bottom of the Vuonos open pit exhibit striations with an orientation of 350-360° due to glacial flow from the north and of 250-280° due to ice flowing from the west. Repo (1957) and Okko & Peltola (1958) have described northerly, westerly and northwesterly striations in the Outokumpu area. The northerly striations are the youngest and the northwesterly ones the oldest. Striations of different ages on shore ledges have been described from the Kirkkoselkä area, Viinijärvi, 8 km east of the Kaasila section. The youngest striations are oriented 0-10° and that of the oldest cross-striations 265° or 315-320° (National Board of Survey 1990).

The lithostratigraphy of the till covering the Kaasila ore suboutcrop and the directions of glacial flow explain the large sector over which ore material was transported in North Karelia. In the Outokumpu area and on its distal side ice flow and ore material transport were initially from northwest to southeast towards the Kivisalmi area 53 km souteast from Outokumpu, and the Outokumpu till deposited. Before the build up of the Salpausselkä ice-marginal formations, the ice front withdrew to the north and west of Outokumpu. It was at this time that the sorted sediment between tills, which occurs over large areas on the distal side of the Salpausselkäs, deposited (Papers II and VII). During the Salpausselkä stage the ice readvanced and formed glacial lobes: the North Karelia glacial lobe in the north and the Finnish Lake District glacial lobe in the south.

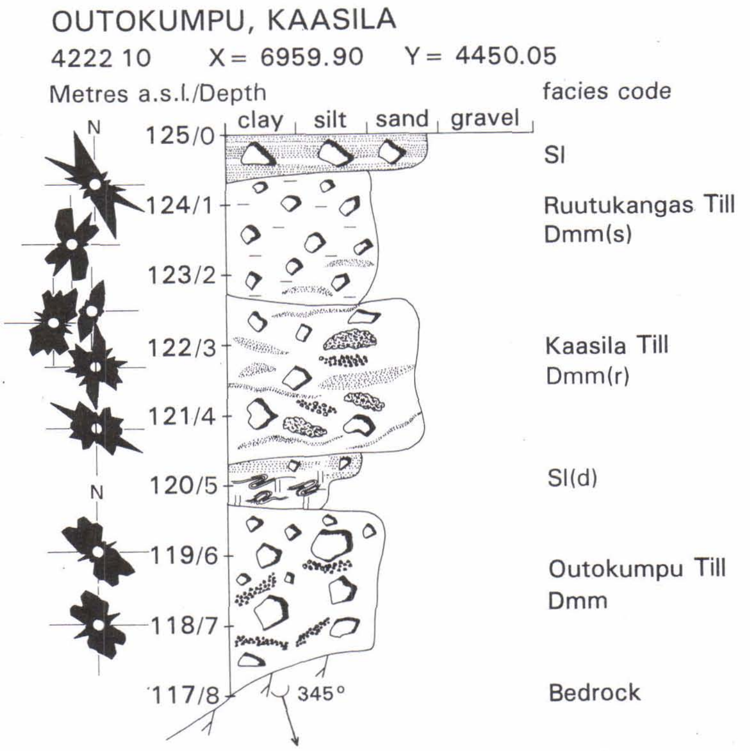


Figure 25. Stratigraphic sequence and lithofacies in Kaasila reference section, Outokumpu.

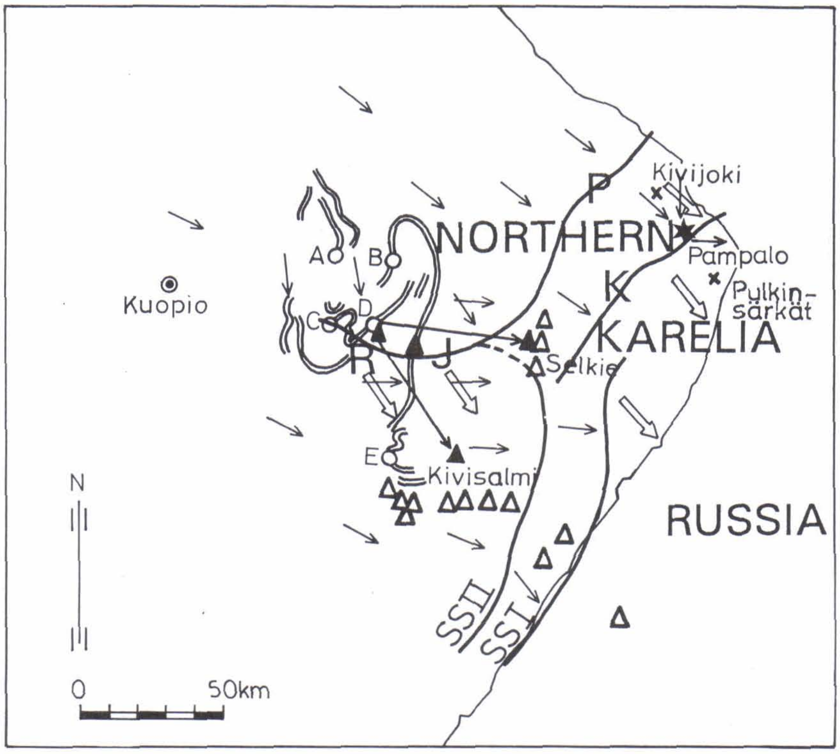


Figure 26. Location and trains of copper ore floats transported from Outokumpu (black triangles). Outokumpu-type ore floats from unknown source (open triangles). Ore-potential rocks of Outokumpu association in North Karelia (double line). Known ore suboutcrops A-E, of which D denotes Kaasila suboutcrop, Outokumpu (cf. Kinnunen 1981). Last direction of glacial flow is indicated with arrows and older one with thick arrows. Locations of ice-marginal formations are shown with a line and letters J-R, of which J denotes Jaamankangas, K Koitere end moraine, P Pielisjärvi end moraine and R Ruutukangas interlobate formation.

To start with, the Finnish Lake District glacial lobe extended to Outokumpu, and the ice flowed from W-WNW to E-ESE. Material from the Kaasila ore suboutcrop was transported to terrain east of the suboutcrop and farther on to east of Joensuu, as far as Selkie (Fig. 26). This stage is represented by the Kaasila Till. Later, when the Ruutukangas and Jaamankangas interlobate and ice-marginal formation at Outokumpu and Joensuu was build up between the glacial lobes the ice in the Outokumpu area flowed locally towards the margin of the ice sheet. At this stage the ore floats immediately south of the Kaasila suboutcrop were retransported to their site of discovery, as shown by Okko & Peltola (1958). By then the ice sheet in the Outokumpu area had probably divided into several independent glacial lobes, and glaciofluvial sediments had started to accumulate between them. At Kaasila, which was in the area affected by the North Karelia glacial lobe, the ice flowed from the north or NNE towards the ice-mariginal formation, whilst to the south of Kaasila the Lake District glacial lobe flowed from the WSW. The Ruutukangas Till in the Kaasila section deposited during this stage. As early as 1957, Repo described the glacial flow stages in North Karelia and attributed the variation in flow directions to the formation of large glacial lobes. Recent till-stratigraphic studies (Paper II) extend the train of short-distance ore floats from the Outokumpu ore deposit, attributed to three-stage glacial transport by Okko & Peltola (1958), at least as far as Selkie and Kivisalmi. The glacial transport sector in North Karelia is so wide that most Outokumpu-type ore floats could have been transported from known ore suboutcrops by glacial lobe streams during deglaciation.

The comparative study of Kinnunen (1981) on fluid inclusions in Outokumpu-type ore floats and ore suboutcrops provided further evidence that the Kivisalmi and Selkie copper ore floats had been transported from the Outokumpu ore deposit. However, most of the other floats differ from the known ore suboutcrops in composition. Despite the persistent efforts of exploration geologists, the source of these floats is still unknown. It is possible that the copper ore floats found at Vanaja and Röksä east of Joensuu were transported by ice flowing from W-WNW from an orebody cropping out somewhere north or northeast of Outokumpu (cf. Kinnunen 1981). Moreover new ore suboutcrops may well be found once the transport directions, histories and distances can be established accurately enough (Fig. 26).

Pampalo reference section, Ilomantsi

The Pampalo area, Ilomantsi, is located on the proximal side of the Hattujärvi ice-marginal formation, which is part of the Koitere end moraine (Fig. 26). Glacial geological studies serving gold ore prospecting have been conducted in this area, which area is an example of the till stratigraphy of ice-marginal zones typical of supra-aquatic areas. The ice-marginal complex is composed of coarse gravel and till accumulated into a narrow ridge with an extensive field of hummocky moraines on its proximal side. According to Rainio (1991), the Koitere end moraine is the eastern extension of Salpausselkä II, whereas Ekman & Iljin (1991) correlate it with the Rukajärvi end moraine and Salpausselkä I.

On the proximal side of the Koitere end moraine there are two till units separated by deformed sand and gravel (Fig. 27). Lowermost in the Pampalo area is grey, compact, massive sandy till, the Ilomantsi Till, with a northwesterly orientation. The till is overlain by a layer of deformed sand and fine sand and by laminated coarse gravelly till. It is composed of material sorted by meltwaters and partly of melt-out till. The upper till at Pampalo, the Pampalo Till,which consists of greyish-brown, laminated, sandy till, is lodgement till in structure and genesis, and has a NW or NNW orientation.

The polished rock surfaces in the Pampalo ore suboutcrop show two striation systems, the younger with a NNW, 340°, orientation and the older with a 315-320° orientation. The striations cross each other and occur on different facets. On some polished rock surfaces also youngest weak westerly striation 270-280° can be observed. Linear topographic features, drumlins and crag and tail formations in the Ilomantsi area are due to the older ice flow from the northwest. The drumlins trending northwest-southeast predate the Koitere end moraine (J. Nenonen & Huhta 1993). At Pampalo, the Koitere end moraine deposited on these drumlins. Flowing ice transported ore material removed from the Pampalo ore deposit southeastwards. Gold nuggets and gold ore floats are found in the Pampalo Till, the Koitere end moraine material and also in the Ilomantsi Till deposited by ice flowing from the northwest on the distal side of the Hattujärvi ice-marginal formation at a distance of at least 2 km from the suboutcrop (Huhta 1993, Hartikainen & Nurmi 1993). The last glacial flow was towards the margin of the ice sheet from the northwest or northeast, depending on the position of the ice front. At Pampalo the course of the end moraine ridge turns 70° from the south towards ENE. Younger western striations occur near an esker south of the Koitere end moraine, implying that during deglaciation the ice flowed locally towards eskers (J. Nenonen & Huhta 1993). The till stratigraphy of the Pampalo area is comparable to that of Outokumpu. Hence the Ilomantsi Till corresponds to the Outokumpu Till and the PampaloTill to the Kaasila Till.

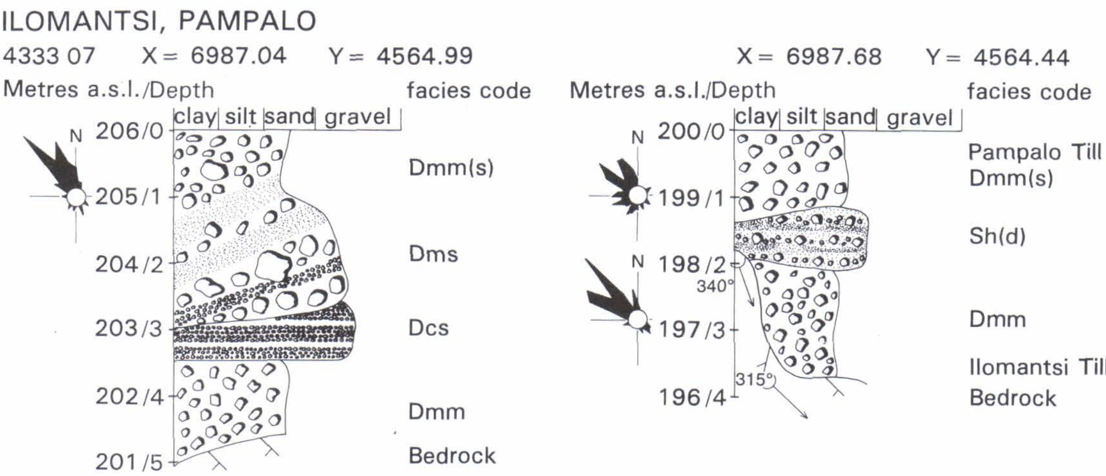


Figure 27. *Stratigraphic sequence in Pampalo reference section, Ilomantsi.*

The Pampalo Till shows that the till stratigraphy created by the oscillation of ice during the Yonger Dryas chron is also visible in supra-aquatic areas. The extent of deglaciation before the formation of the Salpausselkäs is not known north of the Ilomantsi area. South of the Koitere end moraine there is lodgement till that was deposited before the Salpausselkäs by ice flowing from the northwest (Paper II). The Koitere end moraine probably formed after the Heinola Deglaciation, when the ice sheet readvanced and the Salpausselkäs started to build up. The eastern extensions of the Salpausselkäs were mainly laid down on dry land, whereas in southern and southeastern Finland the Salpausselkäs deposited at the margin of an ice sheet terminating in water. The behaviour and oscillations of the ice sheet, the sediments deposited and the formations created all differ, depending on whether processes occurred on dry land or in water. Therefore, the eastern extensions of the Salpausselkäs do not form synchronous ridges but, as demonstrated by Rainio (1985b), break up into discontinuous formations in the supra-aquatic area of North Karelia. According to Eronen & Vesajoki (1988), deglaciation was a continuous process in North Karelia, interrupted only by short stillstands of the ice front as reflected in the presence of discontinuous chains of fanlike end moraine ridges. The till stratigraphy and the relations of ice flow stages and directions to the ice-marginal formations imply that the ice sheet readvanced a fair distance in North Karelia, too, and that some of the sorted sediments were covered with lodgement till (Paper II).

Subfossil tree trunks and twigs covered by sand and boulders were found at two sites during till-stratigraphic studies in the Ilomantsi area. The findings are in stream beds eroded into moraine terrain and thus are postglacial. At Pulkinsärkät, 62°45´N, 31°18´E (X= 6961.00, y = 566.48), 165 m a.s.l., dating of cellulose in peat and wood material (*Betula*) overlain by 1.4 m of bouldery sand has yielded a radiocarbon age of 9700 ± 110 yr BP (Su 1477). The Pulkinsärkät find lies about 20 km south of the Hattujärvi ice-marginal formation (Fig.26). The other find is located 18 km north of the ice-marginal formation, on the River Kivijoki at 63°06´N , 31° 10´E (x=7000.18, y =558.75), 172 m a.s.l. The organic layer, which is at a depth of 3 m, is overlain by horizontally laminated coarse sand and contains abundant fragments of birch trunk and twigs. According to pollen analyses by Brita Eriksson, 92.8% of the pollen is *Betula* and 1.3% *Pinus*, the remaining 5.9% being NAP. The dominance of *Betula* pollen from staminates dropped in water completely masks other local vegetation in the pollen spectra. The *Betula* pollen differs somewhat from the common type. The radiocarbon date of the wood material from the deposit is 9360 ± 110 yr BP (Su-1800 A). The dates are compatible with *Betula* zone radiocarbon ages from peat and gyttja in eastern Finland compiled by Hyvärinen (1972).

During deglaciation the Ilomantsi area was probably among the first supra-aquatic areas to be liberated from ice in Finland. The remains of subfossil *Betula* forests at Pulkinsärkät and Kivijoki may represent Finland's oldest postglacial forest at the onset of the Holocene. Hyvärinen (1971) has described a stratigraphic sequence reflecting the boundary between the Late Weichselian and Holocene Flandrian Interglacials at Suuri Joutenlampi, 192.94 m a.s.l., in Ilomantsi, 14 km south of the Hattujärvi ice-marginal formation. The radiocarbon ages of the silty gyttja in the deposit, 11 720 ± 390 yr BP and 10 790 ± 260 yr BP, have been considered too old (see also Donner & Jungner 1974). However, deposits as old as this from an early deglaciation of the Alleröd Interstadial could have been preserved in the Ilomantsi area.

DISCUSSION

Extent of Early Weichselian ice sheet

The significant lithostratigraphic difference between Ostrobothnian and Lapland tills has been attributed to the fact that the Early Weichselian ice sheet did not extend to Ostrobothnia or southern and western Finland, but that these areas experienced a continuous ice-free period during the Eemian Interglacial and the Weichselian stadials and interstadials (cf. Donner 1986, 1988, Aalto et al. 1989, Kujansuu et al. 1991).

The extent of the Early Weichselian ice sheet has been a subject of much study and debate in Finnish Pleistocene stratigraphy. Sutinen (1982, 1984, 1992) described till-covered formations from Pudasjärvi, Peräpohjola, interpreting them as ice-marginal formations of the Early Weichselian glaciation. According to Sutinen (1992), south of the Pudasjärvi MZ I end moraine (Fig. 30), interstadial and interglacial deposits rest on each other in the same lithostratigraphic position without an intervening Early Weichselian till. In the same area, the Eemian Puhosjärvi Interglacial gyttja deposit lies between two till units. Sutinen (1992) correlated the Puhosjärvi Till, an older till unit beneath the Puhosjärvi interglacial gyttja, with till unit IV of Lapland (cf. Hirvas et al. 1977, Hirvas 1991).

In the course of the Mid-Norden research project, the lithostratigraphic position of the Puhosjärvi gyttja deposit was clarified with the aid of study pits dug into the deposit. The outcome corroborated previous views that the Eemian Puhosjärvi Interglacial gyttja deposit is in an *in situ* position between two lodgement tills (176 m a.s.l.). The lithostratigraphic position of the gyttja deposit is comparable to that at Vesiperä, Haapavesi. The Puhosjärvi Till (Sutinen 1992) probably deposited during the Saalian glaciation and the upper till at Puhosjärvi, which has been correlated with the Jaalanka Till, during the Weichselian glaciation.

On the basis of deep-sea oxygen isotope curves, Forsström (1989) concluded that the Early Weichselian ice sheet extended to the Baltic countries and that Finland was largely covered by an ice sheet whose front oscillated in southern and central Finland for a long period at the end of the Early and beginning of the Middle Weichselian. Forsström (1991) suggests that the till-covered organic deposits at Vimpeli and Oulainen belong to the last part of the Eemian Interglacial and that the material in them is composed of slabs of organic matter redeposited during the last deglaciation. According to Forsström (1991), the ice sheet covered northern and central Finland during the Jämtland-Peräpohjola Interstadial.

Using the deep-sea oxygen isotope curves and data from adjacent and Baltic areas, Forsström & Eronen (1991) discussed the extent of the Fennoscandian continental ice sheet in the Early Weichselian stage. On their map the inferred location of the outermost position of the ice front in the Weichselian stadial, isotope stage 5d, is along a line extending from the White Sea to the north coast of Poland via Lake Onega, Lake Ladoga and the Gulf of Riga.

The Vimpeli I and Oulainen deposits are now considered to be from the Brørup Interstadial. Owing to their elevations, 118-119 m a.s.l. (Vimpeli) and 78 m a.s.l. (Oulainen), the deposits cannot represent the early part or warm period of the Eemian Interglacial, because the sites were then submerged under the Eem Sea (cf. Aalto et al. 1989, Donner 1988, Paper V). Still 3000-4000 years after the Saalian deglaciation, the uppermost shore line of the Eem Sea was at least at 118 m a.s.l. in central Ostrobothnia (Forsström et al. 1988).

The Vesiperä deposit at 102 m a.s.l. represents a terrestrial Eemian Interglacial in Ostrobothnia. As shown by roots radiating from the forest mull soil layer at Vesiperä and the sedimentary structure the deposit is autochthonous. The till-covered beaver dam in the Vimpeli II deposit at 114 m a.s.l. (Aalto et al. 1989) also represents an autochthonous Eemian Interglacial deposit and probably the terrestrial vegetation period of the Eemian Interglacial before the withdrawal of conifers. The vegetational history of the Oulainen Interglacial described by Forsström (1982) cannot be correlated, as suggested later by the same author (Forsström 1991), with that of the terrestrial Eemian Interglacial represented by the *in situ* deposits of the Vimpeli beaver dam or the Vesiperä Geosol. The Harrinkangas formation (140 m a.s.l.) demonstrates that the ice-free period that began in the Saalian deglaciation continued in southern Ostrobothnia far into the Weichselian Glaciation, at least to Brørup Interstadial, and that the Kauhajoki Till Formation did not start to deposit until after that, during the Early Weichselian at the earliest (Bouchard et al. 1990). The Vesiperä Geosol deposits with tree root remains and the Vimpeli Beaver Dam cannot have been laid down in subglacial water or transported as an englacial plate as proposed by Punkari (1991).

Deposits at Mertuanoja, Vuojalankangas, and Horonkylä imply that Ostrobothnia was ice-free during interstadials of isotope stages 5c and 5a and possibly also during stadials 5d and 5b (Fig. 28). In all likelihood the glacier advanced to Ostrobothnia during isotope stage 4, at the beginning of the Middle Weichselian substage at the very earliest. The reference section described from Horonkylä, in southern Ostrobothnia refers to two superimposed till units - the Horonpää Till and the Horonkylä Till - separated by clay with diatoms and sponge spicules, the Horonpää Sponge Bed. As the Horonkylä Till deposited on Horonkylä Diatomite formed during isotope stage 5c, it may represent an advance of the ice sheet during isotope stage 5b or 4. The Horonpää Sponge Bed resting on the Horonpää Till represents a periglacial polar desert period that prevailed at the margin of the ice sheet and which may be younger than interstadials 5c or 5a, during which the soil was covered with vegetation .

Lundqvist (1992) and Lundqvist & Robertsson (1994) have presented a glaciation curve and a set of maps for Scandinavia showing that the ice sheet spread to southern Sweden and Finland during the Middle Weichselian after Early Weichselian isotope stage 5a. They estimate that the margin of the ice sheet could have extended to northern Ostrobothnia during isotope stadial 5b. Lundqvist (1992) suggests that the very dark, bluish-grey, clayey till common in central Sweden may have deposited during the Early Weichselian 5b stadial, and that the westerly direction of transport shown by the bluish-grey till implies that the ice sheet had spread a great distance, perhaps reaching the extent of the Younger Dryas stadial ice sheet. Lagerbäck (1988) proposes that the Veiki moraine formations in northern Sweden were formed on the ice margin in the course of the Early Weichselian deglaciation, when large amounts of dead ice were buried under till. When the ice melted, organic material was deposited in the kettle holes during a climatic stage that can be correlated with the Peräpohjola (Brørup) and Odderade Interstadials.

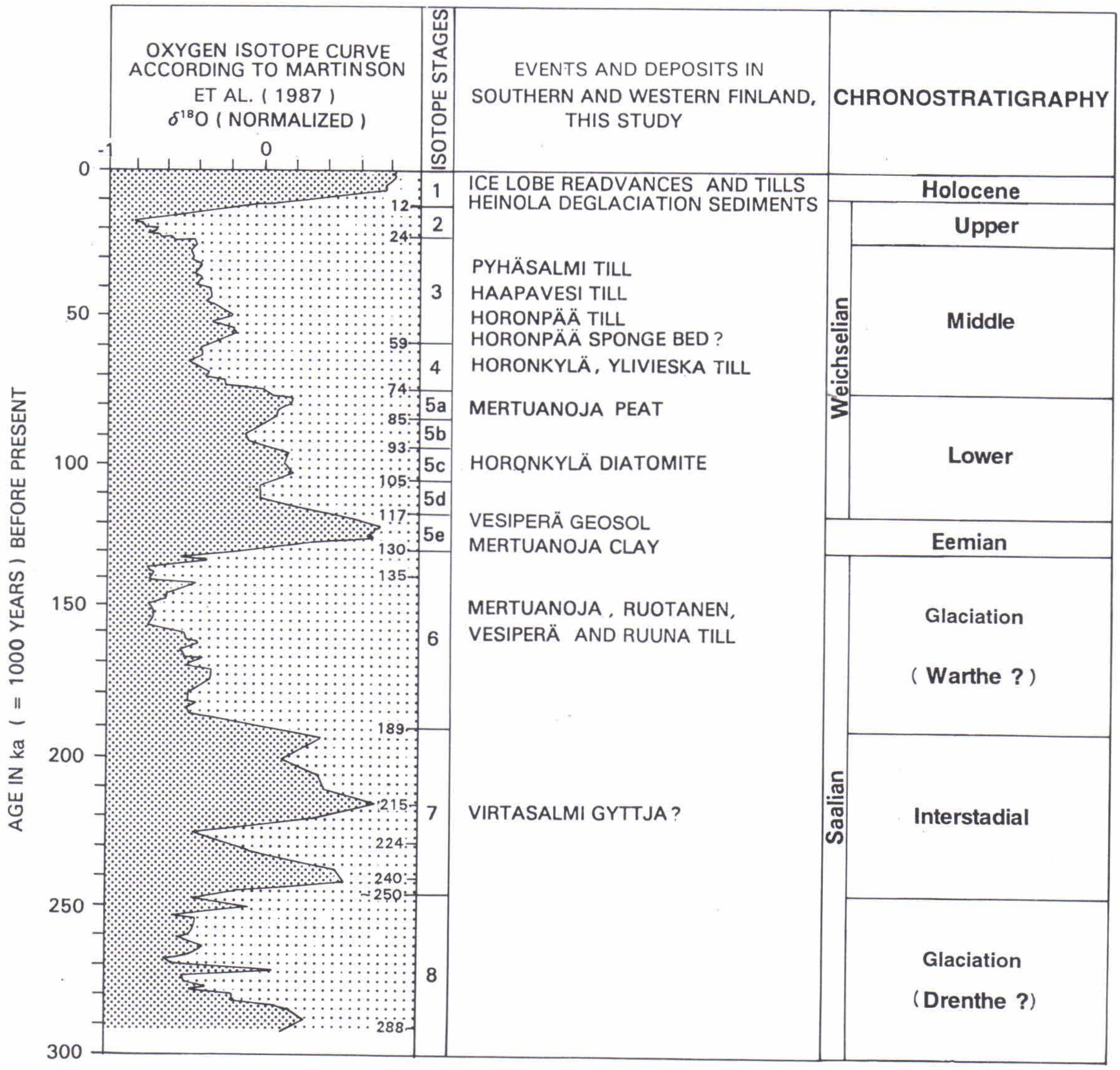


Figure 28. Events and deposits in southern and western Finland and their suggested correlation with deep-sea isotope stages and standard stratigraphy of northwestern Europe (Martinson et al. 1987, Mangerud 1991a,b).

Correlation and comparison of Weichselian interstadials with those elsewhere in Europe are hampered by the present complex till stratigraphy and changes in vegetation zones caused by the ice sheet that developed on the Scandinavian fells and its advances and withdrawals after the Eemian Interglacial (cf. Forsström 1988). It is possible that the interstadial deposits in Ostrobothnia, Peräpohjola, Lapland and Norrbotten and the corresponding stages are all part of the same Weichselian interstadial complex, whose lithostratigraphic and biostratigraphic position depends on its relation to the fluctuating Early Weichselian ice sheet (cf. Donner 1983, Donner et al. 1986, García Ambrosiani 1990, 1991, Hirvas 1991).

Expansion of the Weichselian ice sheet to southern Finland

The finite ages of the Late Pleistocene sediments in Ostrobothnia and Lapland (Kankainen & Huhta 1986, Hirvas 1991) cluster in age group 40 000-50 000 yr BP, although ages exceeding these values have also been measured for the same deposits. Similar radiocarbon ages were obtained from the Eemian Interglacial Vesiperä geosol mull and roots (Paper V). The humic fraction in the till-covered Mertuanoja Peat deposit of the Mertuanoja reference section in Ylivieska is 36 000 $\pm$ 700 yr BP in age (Su-2432 A). On the basis of mammoth finds and a reindeer antler dated in Finland, Donner et al. (1979) suggested that most of Finland was ice-free as late as the Middle Weichselian substage. Should the radiocarbon dates refer to real ages of organic activity before the ice sheet spread to Ostrobothnia after the last interstadial, then that the ice sheet may have advanced to Ostrobothnia during the Middle Weichselian substage at the latest.

The absolute dating of deposits in southern and western Finland is, however, problematic. The organic deposits from before the last Weichselian deglaciation are often too old for reliable radiocarbon dating. However, ^{14}C activity has been measured in organic material of both interglacial and interstadial deposits, thus permitting finite ages to be calculated for them (Kankainen & Huhta 1986, Donner 1988). The discrepancy may be due to later contamination of the deposits by groundwater, tree roots or bacterial activity. Because the amount of younger organic matter in random contamination events varies, the radiocarbon ages of old interglacial and interstadial deposits should fluctuate accordingly. The mechanical mixing of younger material in older deposits does not explain the radiocarbon ages measured; if it did, the ages should show random variation, for example, in the large dating data of Kankainen & Huhta (1986). From a climate stratigraphic correlation of the deposits it is inferred that their organic matter is older than the finite radiocarbon ages obtained.

The interglacial and interstadial deposits may have been near the ground surface for long periods, perhaps tens of thousands of years, before the Weichselian ice sheet advanced to southern and western Finland. During that time, frost, tree roots, bacteria and other activities of organisms in arctic soil contaminated the originally interglacial matter, which means that the radiocarbon age measured for the deposit might be the age of a periglacial contamination event preceding the spread of the Weichselian ice sheet. The postdepositional microbial activity lowers the radiocarbon ages of old material (Hänninen & Kankainen 1992). Seepage water transports young atmospheric carbon to a deposit where, through microbial metabolism, it contaminates the fractions to be dated. According to Hänninen & Kankainen (1992), microbial activity may persist for tens of thousands of years after the formation of an organic deposit. This phenomenon may explain the discrepancy between the radiocarbon ages of till-covered deposits in Ostrobothnia and the ages of their depositional event as deduced from microfossils. Microbial activity may well still be going on in till-covered deposits, thus changing the ratios of the carbon isotopes used for dating the deposits.

Pleistocene deposits in southern and western Finland have also been dated with the TL method and isotopes of the uranium series (Jungner 1987, Donner 1988, Gibbard et al. 1989, Niemelä & Jungner 1991). The TL method has mainly been used to measure absolute ages for aeolian or fluvial sands overlying and underlying Weichselian interstadial and Eemian Interglacial organic sediments. These ages have then been compared with the date of the depositional event as deduced from biostratigraphic correlation. The TL age of the sand covering the Oulainen Interstadial deposit is 94 ka and that of the underlying sand 121 ka (Jungner 1987). The TL age of the sand covering the interglacial beaver dam deposit at Vimpeli is 107 ka (Aalto et al. 1989) and that of the geosol in the Risåsen esker section in Ostrobothnia 130 $\pm$ 20 ka (Donner 1988) or 148-155 ka (Niemelä & Jungner 1991, Kujansuu et al. 1991).

The age of the sand beneath the interglacial or interstadial Harrinkangas deposit is 146-130 ka (Gibbard et al. 1989). Geosol found in sand overlain by interstadial or late interglacial organic deposits at Harrinkangas has been called 'Ostrobothnian Geosol' by Kujansuu et al. (1991), who think that it probably formed during the Eemian Interglacial. The Harrinkangas deposit may represent a prolonged ice-free period lasting from the Saalian deglaciation to the first advance of the Middle Weichselian ice sheet.

Ostrobothnian deposits and palaeosols have also been dated with the OSL method (Hütt et al. 1993). The ages fall into two groups - 120-163 ka and 76-106 ka - and their TL ages in the range 135-155 ka. The dates support the concept that the fossil podzols were formed during the last interglacial and that they continued to develop during the first Early Weichselian stadial and interstadial.

Of the Early Weichselian deposits dated here with the OSL method, those at Mertuanoja and at Horonkylä showed ages in the range 36-70 ka BP. These dates are partly compatible with the age deduced from the vegetation proxies in the deposit but are partly younger than the assumed true age. The dates differ from the radiocarbon ages of the same deposits. The OSL dates for Horonkylä are contradictory, as a deposit at a greater depth yields an age younger than the overlying one. Mejdadhl & Funder (1994) have tested TL and OSL dating methods with 94 sediment samples from East Greenland. In their study the OSL method seems to give better results than TL in Late Quaternary sediments. They used a correction equation to diminish the effect of shallow electron traps, $Y = 1.35X + 0.70$, where X is the uncorrected age (in ka) and Y the corrected age (Mejdahl et al. 1992). They applied a correction equation to ages between 15 and 150 ka. In luminescence dating of sediments, the residual luminescence signal and incomplete bleaching of sediment grains during transportation and sedimentation present a serious problem.

The deep sea oxygen isotope curve (Fig. 28) depicts the variations in the amount of water bound to glaciers (Martinson et al. 1987, Jansen 1989). It is also thought to show the fluctuations in the extent of the Quaternary Scandinavian ice sheet (cf. Forsström 1988, B. Andersen & Mangerud 1989, Mangerud 1991a). The oxygen isotope curve, which has been used as a basis for the chronostratigraphic correlation and subdivision of Pleistocene deposits in Finland (cf. Forsström et al. 1988, Hirvas 1991, Eronen 1992), suggests that the large-scale expansion of the Weichselian continental ice sheet could have started in Scandinavia during isotope stage 4, about 74 000 years ago (cf. B. Andersen & Mangerud 1989, Mangerud 1991a). B. Andersen & Mangerud (1989) have proposed that the ice sheet covered all Norway and most of Sweden and Finland in the Middle Weichselian substage. However, at that time, the Norwegian coast was repeatedly ice-free as demonstrated by interstadial deposits attributed to the Middle Weichselian substage (B. Andersen 1992). The ages of an aeolian deposit of the Sorperoa Interstadial in southern Norway (Bergensen et al. 1991) and of speleothems of the Skjong stage in central Norway (Laurizen 1991) determined with TL and uranium series isotope methods are about 30-40 ka, by which time the central area of the Scandinavian Ice Sheet was already covered by ice (Mangerud 1991b). As shown by the dates, chronostratigraphic correlations are difficult. It would seem that Ostrobothnia was still ice-free during the Odderade Interstadial. The Mertuanoja Interstadial deposit probably represents this stage.

The lithostratigraphy of southern Ostrobothnia shows that the ice sheet fluctuated there after the Early Weichselian interstadials. Thus two lodgement tills with an ice-free stage deposit the Horonpää Sponge Bed between them were formed. At Horonkylä there are no indications of forest vegetation, only diatoms and sponge spicules (see above). The deposit may be Middle Weichselian or the remains of an Early Weichselian deposit whose upper part has eroded. If the ice sheet advanced to southern Finland during isotope stages 4 and 3, it should be possible to find Middle Weichselian tills and other deposits there. However, indisputable evidence of such deposits is still lacking. The lowest till bed in the lithostratigraphy of southern Finland (Paper III), which corresponds to the Siuntio Till Member (Bouchard et al. 1990), has been suspected of being Saale glaciation till or till deposited during the Middle and Late Weichselian glaciation.

Southern Sweden was covered with ice during the Late Weichselian glaciation, that is, between 21 000 and 13 000 years ago. Between the Eemian Interglacial and the Weichselian Interstadials arctic tundra vegetation and polar desert prevailed in southern Sweden (Berglund & Lagerlund 1981). A sequence that deposited at or close to the margin of the ice sheet during the Middle Weichselian substage may be what Hillefors (1983) described as Dösebacka and Ellesbo drumlin stratigraphy from western Sweden. He is of the opinion that the ice sheet fluctuated repeatedly in western Sweden during the Middle Weichselian substage, that is, 36 000-24 000 years ago.

Liivrand (1991) maintains that the first Weichselian glacier spread into Estonia possibly at the end of the Early Weichselian or in the beginning of the Middle Weichselian substage, 65 -79 ka ago that is called the Mägiste stadial. Liivrand (1991 and 1995) correlates the Mägiste stadial to deep-sea istope stage 4. The following deglaciation characterized by periglacial conditions, the Tõravere iterstadial, prevailed until an ice sheet again covered Estonia in the Late Weichselian substage, called the Valgjärve stadial. In the Late Weicselian substage glacier fluctuated in nortern Estonia during the Haaja stadial (Liivrand 1995). According to Gaigalas et al. (1992), the ice did not override the lacustrine sediments deposited in karst ponds in northern Lithuania until 23-25 ka ago, or in the Late Weichselian substage. The radiocarbon age of a till-covered organic deposit, c. 34 ka BP, demonstrates that Lithuania was ice-free in the Middle Weichselian substage. Gaigalas et al. (1992) are of the opinion that the last glaciation covered northwestern areas of Eastern Europe for only a few thousand years.

According to Arslanov (1993), any till deposition related to Early Weichselian substage glaciation cannot be identified on the Russian plain. Moreover, the dates of organic deposits show that the major part of the plain was still ice-free during the Middle Weichselian substage. Radiocarbon dates of till-covered organic deposits in the study of Arslanov demonstrate that the ice advanced to its furthest extent on the Russian plain during the Late Weichselian substage. In the geochronology of Russian Europe the continuous ice-free period covers oxygen isotope stages 5-3, that is, 25 - 126 ka BP.

In the official stratigraphic scheme of the East Baltic area previously in general use in studies and mapping presented by Raukas & Gaigalas (1993, table 1) the last ice age is subdivided into two glaciations: the Varduva, 50-75 ka BP; and the Latvia glacials, 10-25 ka BP. New observations and dates seem to confirm that only the last ice sheet extended to the East Baltic area.

Holmlund & Fastook (1995) have calculated a time dependent glaciological model to the Weichselian ice sheet from the climatic records of the Greenland ice cores (Fig. 29). Model shows that the Scandinavian Ice Sheet could have expanded over northern Sweden and the Gulf of Bothnia in the beginning of the isotope stage 4, about 75 ka BP. Advancing ice front may have been at theYounger Dryas zone; the Salpausselkä zone about 65 ka BP or all the Finland was by then ice covered. Field observations give some support to this model though fluctuations have possible occured in the course of glacier advance and dating of sediments give conflicting ages.

Late Middle Pleistocene and Late Pleistocene history of southern and western Finland

The Pleistocene deposits found in southern and western Finland give a general idea of glaciations in this area and the relation of ice-free periods to them. In Figs 28 and 29 these deposits are correlated with the chronostratigraphy deduced from deep-sea and Greenland ice core oxygen isotope stages (Martinson et al. 1987 and Dansgaard et al. 1993). The chronostratigraphic positions of the Vesiperä and Mertuanoja interglacial deposits, the Horonkylä Interstadial diatomite and the Mertuanoja Interstadial peat are the most certain. The plotting of the deposits on diagrams is based on their climate stratigraphic correlation, not their absolute dates. The chronostratigraphic position of the Virtasalmi gyttja deposit is unsure as is that of the Horonkylä Sponge Bed deposit. The results imply that in southern and western Finland a long ice-free period prevailed between the Saalian and Weichselian glaciations. The Virtasalmi Interstadial, probably in isotope stage 7, also reflects a long ice-free period. The ice-free periods were marked by fluctuations in water level, changes in connections to the sea, uplift, and drastic changes in climate and vegetation.

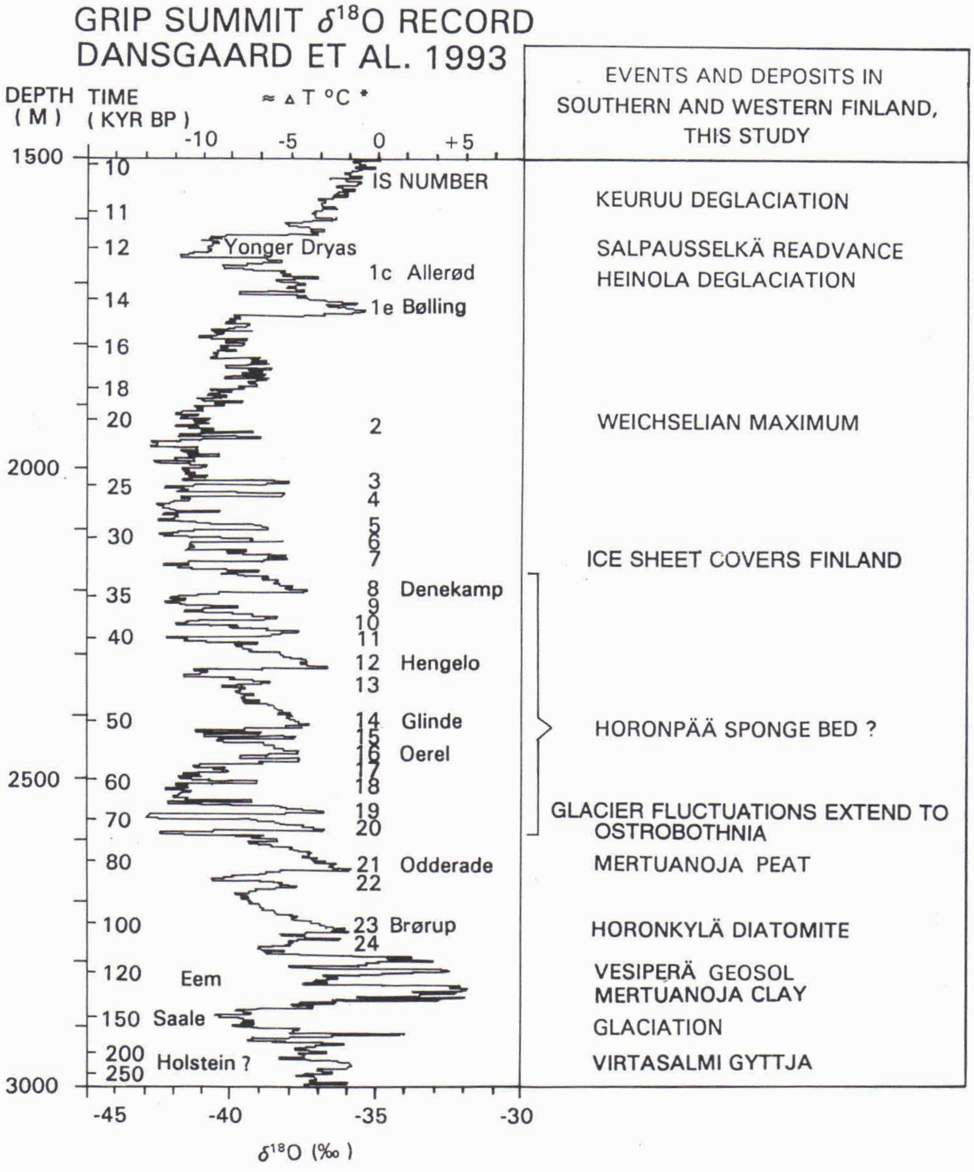


Figure 29. *Events and deposits in southern and western Finland and their suggested correlation with GRIP Summit ice core isotope record and climate stages (Dansgaard et al. 1993). The deviation from the mean Holocene temperature (AT°C) is from the unified oxygen isotope climate record from GISP 2 and GRIP ice cores (Grootes et al. 1993).*

After the Saale glaciation, the history of the Baltic Sea basin in Ostrobothnia followed much the same course as during the Weichselian deglaciation. In Ostrobothnia the evolution begins with a lacustrine stage. Sediments attesting to a freshwater stage have been recovered at Norinkylä (98 m a.s.l.) and at Peräseinäjoki (82 m a.s.l.) (Paper V). The lower part of the Eemian Interglacial deposit at Peräseinäjok is clay deposited in freshwater. Some of the diatoms in the clay are species common in deposits of large lakes, e.g. the Holocene Ancylus Lake. The lower part of the clay reflects changes in vegetation early in the Eemian Interglacial in southern and western Finland. Sediments of the large Eemian lake at Peräseinäjoki and the clay beneath a forest geosol at Vesiperä (102 m a.s.l.) are the first deposits found in Ostrobothnia from which the *Betula* zone of the early Eemian Interglacial has been recognized. Climatic amelioration was followed by inflow of warmer saline sea water into the Gulf of Bothnia in the *Betula-Pinus-Quercus-Corylus* pollen zone, resulting in deposition of the Eemian marine clays typical of Ostrobothnia.

It is well established that the Eemian Baltic Sea was connected to the North Sea and Arctic Ocean through the White Sea, because both cryophilic diatoms of the Arctic Ocean and thermophilic diatoms of the Atlantic Ocean are common in Eemian marine deposits in Ostrobothnia (Niemelä & Tynni 1979, Grönlund 1991b). In all likelihood the connection to the White Sea opened fairly early, as cryophilic saline water diatoms occur from the lower parts of the clays upwards. The development of marine phases of the Eemian Interglacial culminates in the deposits of Norinkylä (102 m a.s.l.) and Ollala (116-117 m a.s.l.). In these deposits the Eem Sea phase, after a shallow lagoonal stage, comes to an end, and the uppermost sediments were subsequently deposited in a freshwater lake (Grönlund 1991b).

The history of the Baltic Sea during the Saalian deglaciation and Eemian Interglacial was largely the same as that during the Weichselian deglaciation and the present interglacial. Phases corresponding to the Holocene Ancylus Lake phase, Litorina Sea phase and subsequent local lagoonal and isolation phases have all been identified in the Eemian Baltic Sea (Grönlund 1991b). However, the rhythmic alternation of marine and lacustrine stages typical of the Weichselian deglaciation and the records of an extensive readvance of the ice sheet have not been observed during the Saalian deglaciation in southern and western Finland. True, the lithostratigraphy and biostratigraphy are known only in broad outline and from a few scattered sites. Moreover, indications of the sudden cooling in climate indicated by the oxygen isotopes of the Greenland (GRIP) ice cores (Fig. 29) (cf. Dansgaard et al. 1993) have not been found in Eemian Interglacial deposits in southern and western Finland. The ratios of oxygen and hydrogen isotopes imply that the warmest stage of the Eemian Interglacial was c. 2°C warmer than the present climate and the coolest stages c. 5°C colder than the Holocene thermal optimum (GRIP 1993). In the core of the second hole drilled into Greenland ice, GISP 2, where observed indisputable abrupt climatic changes only in Weichselian ice layers (Grootes et al. 1993). The temperatures calculated from the isotope ratios of these cores were up to 10-13°C lower during the Weichselian stadials and c. 3°C colder during the interstadials than the average Holocene temperature. However, more detailed studies on climatic variations in Finland during the Eemian Interglacial are needed, as there are invariably disturbances in till-covered deposits, and also erosional gaps in sedimentary sequences.

The Eemian Interglacial sequences at Peräseinäjoki, Vesiperä and Mertuanoja cover a period extending from the Saalian glaciation to the end of the warmest phase of the Eemian Interglacial. The warm peak of the Eemian Interglacial was definitely warmer than the thermal optimum after the last deglaciation. Summers were warm and winters mild, and thermophilous trees - *Quercus, Ulmus, Carpinus* and *Corylus* - grew up to the latitude of Oulu (Eriksson 1993). During the Tepsankumpu Interglacial, which is correlated with the Eem Interglacial, *Corylus* and *Larix* were growing as far north as Lapland (Hirvas 1991). *Larix* did not spread to southern Finland until towards the end of the interglacial or during the Brørup Interstadial (Forsström 1990, Eriksson & Kujansuu 1994). Zagwijn (1989) places southern Finland during the Eemian Interglacial in the *Carpinus* forest zone and southern and central Finland between the July isotherms of +18°C and +16°C. This zone resembles the current temperate or hemiboreal vegetation zone (cf. Donner 1995). At present southern and central Finland is part of the middle and southern boreal zone, and the July temperature is between isotherms +17°C and +15°C. Only the coast of southwestern Finland and the archipelago lie in the hemiboreal zone (Atlas of Finland 1987 and 1988).

The vegetational history of the deposits at Horonkylä and at Mertuanoja which above were interpreted as interstadial, differs clearly from that of the Eemian Interglacial deposits. That is the case also with the deposits at Oulainen (Forsström 1982, Donner 1988), Vimpeli (Aalto et al. 1983, Donner 1983), Marjamurto (Peltoniemi et al. 1989) and Harrinkangas (Gibbard et al. 1989). Features shared by all these deposits are their lithostratigraphic position beneath a till deposited or, at least, reoriented during deglaciation and the similarity of their vegetational history. This usually begins with a *Betula* phase that develops into *Betula-Pinus* mixed forest. Later, *Pinus*-dominant forests replace the mixed forests, and the proportions of *Picea* and *Alnus* increase. At the end of the event, the proportion of herb and shrubs pollen increases sharply in the deposits of Oulainen and Harrinkangas. At Harrinkangas, the uppermost pollen zone reflects extensive open grasslands or tundra vegetation. Clearly the overriding ice sheet erode material from the surface of the deposits at Vimpeli and Marjamurto. Correlating these exceptional deposits in Ostrobothnia has been problematic. Originally, the Oulainen and Vimpeli deposits were ascribed to the Eemian Interglacial (Forsström 1982, Aalto et al. 1983a), but later they were interpreted as representing a Weichselian interstadial (Donner 1983, 1988, Hyvärinen 1985, Forsström 1988, Peltoniemi et al. 1989).

The interstadial deposit described by Iisalo (1992) from Mertuanoja and the Mertuanoja Peat deposit discussed above may belong to the same stage as the Peräpohjola and Lapland Interstadial deposits. Correlation of the deposits with the Peräpohjola (Korpela 1969, Mäkinen 1979, 1985) and Lapland (Hirvas 1991) interstadial deposits is uncertain due to the great distance between them, the shallowness of the deposits and the scarce vegetation. *Betula* has 90% dominance in the arboreal pollen of Peräpohjola Interstadial deposits in the Peräpohjola area, reflecting a subarctic climate.

Organic deposits separated by till beds in Norrbotten and Swedish Lapland are interpreted as having deposited during Weichselian interstadials (Lagerbäck & Robertsson 1988, Robertsson 1988). The interstadial deposit described by Lagerbäck & Robertsson (1988) is composed of two parts: an older part that can be correlated with the Peräpohjola Interstadial in northern Finland, and a younger part, the Tärendö Interstadial, with the Odderade Interstadial of northern Europe. Radiocarbon dating of the interstadials has given both infinite and finite ages in the range 28-46 ka BP. In both interstadials, the vegetation in Norrbotten and Swedish Lapland was that of tundra and open *Betula* forest. Forsström (1988), too, subdivides the interstadial deposits in Ostrobothnia and Peräpohjola into two groups. He correlates the Peräpohjola Interstadial deposits at Kauvonkangas and at Kostonniska and Permantokoski with the

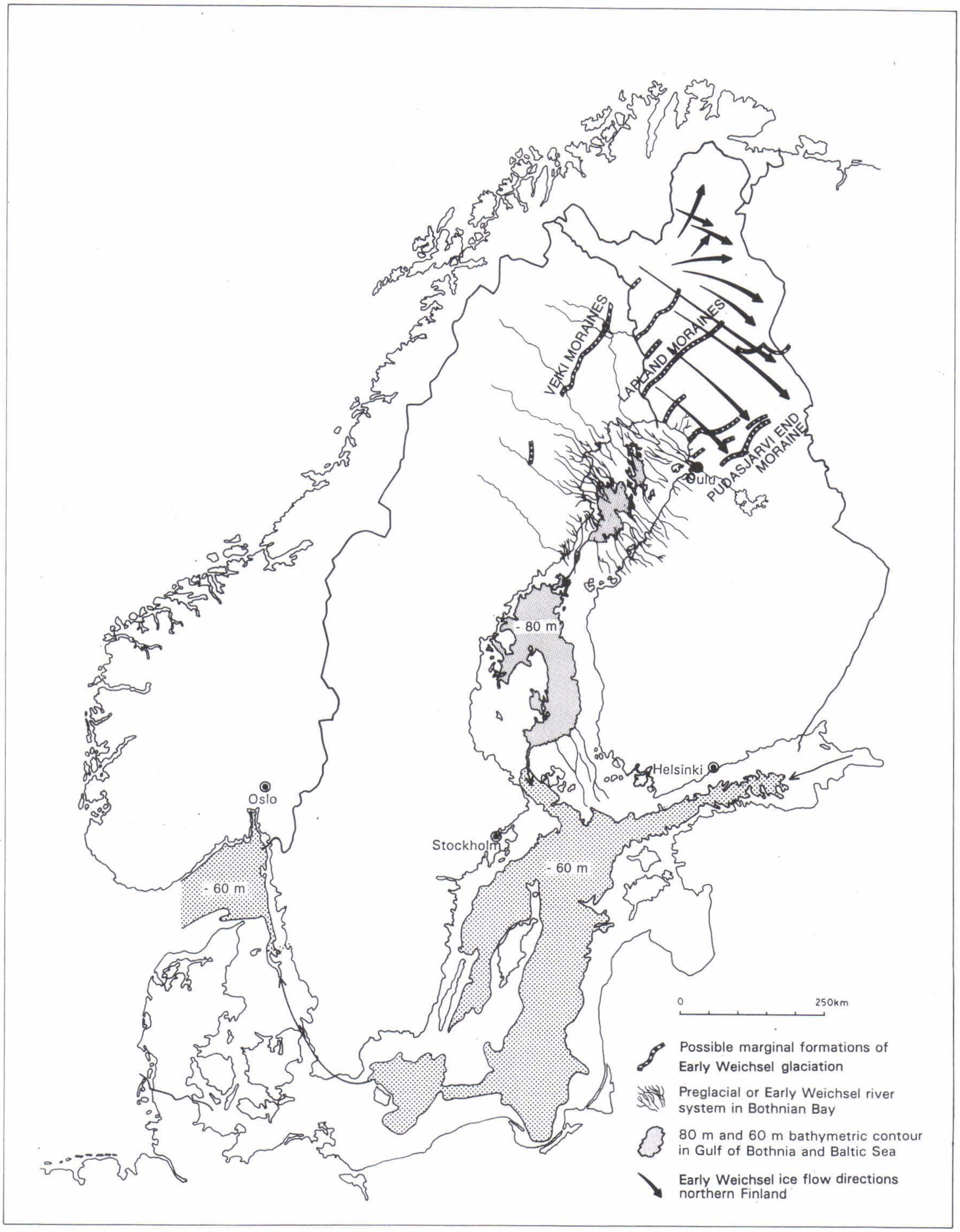


Figure 30. *Map showing inferred end moraines of Early Weichsel glaciation, lower water level in Bothnian Bay, Gulf of Finland, Bothnian Sea and Baltic Sea (not corrected for differential uplift), and continuations of river beds on sea floor (cf. Tulkki 1977, Sutinen 1984, Mäkinen 1985, Lagerbäck 1988, Lundqvist 1992 and Lundqvist & Robertsson 1994).*

correlated with the Eem Interglacial, *Corylus* and *Larix* were growing as far north as Lapland (Hirvas 1991). *Larix* did not spread to southern Finland until towards the end of the interglacial or during the Brørup Interstadial (Forsström 1990, Eriksson & Kujansuu 1994). Zagwijn (1989) places southern Finland during the Eemian Interglacial in the *Carpinus* forest zone and southern and central Finland between the July isotherms of +18°C and +16°C. This zone resembles the current temperate or hemiboreal vegetation zone (cf. Donner 1995). At present southern and central Finland is part of the middle and southern boreal zone, and the July temperature is between isotherms +17°C and +15°C. Only the coast of southwestern Finland and the archipelago lie in the hemiboreal zone (Atlas of Finland 1987 and 1988).

The vegetational history of the deposits at Horonkylä and at Mertuanoja which above were interpreted as interstadial, differs clearly from that of the Eemian Interglacial deposits. That is the case also with the deposits at Oulainen (Forsström 1982, Donner 1988), Vimpeli (Aalto et al. 1983, Donner 1983), Marjamurto (Peltoniemi et al. 1989) and Harrinkangas (Gibbard et al. 1989). Features shared by all these deposits are their lithostratigraphic position beneath a till deposited or, at least, reoriented during deglaciation and the similarity of their vegetational history. This usually begins with a *Betula* phase that develops into *Betula-Pinus* mixed forest. Later, *Pinus*-dominant forests replace the mixed forests, and the proportions of *Picea* and *Alnus* increase. At the end of the event, the proportion of herb and shrubs pollen increases sharply in the deposits of Oulainen and Harrinkangas. At Harrinkangas, the uppermost pollen zone reflects extensive open grasslands or tundra vegetation. Clearly the overriding ice sheet erode material from the surface of the deposits at Vimpeli and Marjamurto. Correlating these exceptional deposits in Ostrobothnia has been problematic. Originally, the Oulainen and Vimpeli deposits were ascribed to the Eemian Interglacial (Forsström 1982, Aalto et al. 1983a), but later they were interpreted as representing a Weichselian interstadial (Donner 1983, 1988, Hyvärinen 1985, Forsström 1988, Peltoniemi et al. 1989).

The interstadial deposit described by Iisalo (1992) from Mertuanoja and the Mertuanoja Peat deposit discussed above may belong to the same stage as the Peräpohjola and Lapland Interstadial deposits. Correlation of the deposits with the Peräpohjola (Korpela 1969, Mäkinen 1979, 1985) and Lapland (Hirvas 1991) interstadial deposits is uncertain due to the great distance between them, the shallowness of the deposits and the scarce vegetation. *Betula* has 90% dominance in the arboreal pollen of Peräpohjola Interstadial deposits in the Peräpohjola area, reflecting a subarctic climate.

Organic deposits separated by till beds in Norrbotten and Swedish Lapland are interpreted as having deposited during Weichselian interstadials (Lagerbäck & Robertsson 1988, Robertsson 1988). The interstadial deposit described by Lagerbäck & Robertsson (1988) is composed of two parts: an older part that can be correlated with the Peräpohjola Interstadial in northern Finland, and a younger part, the Tärendö Interstadial, with the Odderade Interstadial of northern Europe. Radiocarbon dating of the interstadials has given both infinite and finite ages in the range 28-46 ka BP. In both interstadials, the vegetation in Norrbotten and Swedish Lapland was that of tundra and open *Betula* forest. Forsström (1988), too, subdivides the interstadial deposits in Ostrobothnia and Peräpohjola into two groups. He correlates the Peräpohjola Interstadial deposits at Kauvonkangas and at Kostonniska and Permantokoski with the

Odderade Interstadial and deep-sea isotope stage 5a (c. 80 ka BP), and the Oulainen and Ruottisenharju deposits with the Brørup Interstadial and isotope stage 5c (c. 100 ka BP). Figure 29 gives 24 interstadial stages distinguished by Dansgaard et al. (1993) from the ice core oxygen isotope curve. It is not possible to state conclusively to which interstadial the cold stages with ***Betula, Betula nana*** and herbs as the only plants belong. Only refinements to absolute dating methods and the simultaneous use of several methods can help us establish the correlation between the chronostratigraphy and climato- stratigraphy of the cool Weichselian interstadials.

The lithostratigraphic positions of the interstadial deposits in Ostrobothnia differ from those of the Peräpohjola, Norrbotten and Lapland deposits. In Peräpohjola, the interstadial deposits are underlain by a till bed interpreted as deposited by the Early Weichselian ice sheet (Korpela 1969, Mäkinen 1979, 1985). In Lapland this bed, till bed III, separates interstadial from interglacial deposits (Paper III, Nordkalott Project 1986, Hirvas 1991). In the Early Weichselian substage the ice sheet fluctuated in Lapland and Peräpohjola, as demonstrated by Sutinen (1992) and Lagerbäck (1988). In Ostrobothnia, the interstadial and interglacial deposits seem to be superimposed, without an intervening Early Weichselian till, being covered by only one or two Middle and Late Weichselian till units.

A continental ice sheet that fluctuates and occasionally melts in Norrbotten and Lapland can be assumed to cause large meltwater streams. Thus, channels, tens of metres deep, have been found on the bottom of Bothnian Bay and the Bothnian Sea as extensions of present-day rivers (Tulkki 1977, Ignatius et al. 1980). The channels extend to the central parts of the marine area, to a depth of about 80 m (Fig. 30). Previously they were interpreted as preglacial (Tulkki 1977, Ignatius et al. 1980), but Tynni (1982) has suggested a Tertiary origin. As the water level in the Gulf of Bothnia and Baltic Sea basin was much lower during the Early Weichselian glaciation than it is today, that the termination of the channels at a depth of 80 m may well record the water level during the maximum extent of the Early Weichselian ice sheet, provided that Ostrobothnia and southern and central Finland were not then covered by ice. The illustrative maps of Lundqvist (1992) and Lundqvist & Robertsson (1994) delineates the palaeohydrography of the Baltic Sea basin and the Gulf of Bothnia during the Eemian Interglacial and Weichselian interstadials. The area with the highest rate of uplift is Bothnian Bay, and during a long ice-free period glacial isostatic uplift probably proceeded further than uplift today. Assuming that the present residual uplift, 100-125 m (Kakkuri 1991), is fully covered during the next ten thousand years or so, it is possible that during a long ice-free period, for example at the end of the Early Weichselian substage, the Bothnian Bay area may have risen more than 100 m above its present height.

A rise in the Bothnian Bay area of even 100 m from its present level would change the hydrography of the whole area. Bothnian Bay and obviously the entire Baltic Sea were isolated from the ocean during the Early Weichselian substage, as the ocean level was then lower than it is today and the area was undergoing uplift. Many water courses in Finland flowed southeastwards, discharging their waters into Lake Ladoga and the Gulf of Finland. As indicated by the deep-sea oxygen isotope curve, the amount of water bound to ice sheets during the Early Weichselian glaciation was a good half of that bound during the Weichselian glaciation maximum, and would have lowered the ocean level by about 50 m (Fig. 30). During the last glacial maximum (about 18 ka BP) glacial eustasy dropped the level of the oceans over 100 m below the present level (cf. Pirazzoli et al. 1989).

It is also claimed that the Weichselian ice sheet covered Finland and Scandinavia continuously for a long period of about 100 000 years and that the ice-free stages lasted no more than tens of thousands of years (cf. Forsström 1991). New deposits found and the interpretations given here demonstrate that the ice-free stage in southern and western Finland was as long as or slightly longer than the ice-covered stage. The previous ice-free stage, which began with the Saalian deglaciation, occurred at 130 ka BP-70 ka BP, whilst the Middle-Late Weichselian glaciation took place at 70 ka BP-10 ka BP. During the many climatic stages of the long ice-free period, Nordic nature adapted to the climate of the Weichselian glaciation, and had time to develop the biodiversity we see today. Advancing glacier forced biota to withdraw southwards and eastwards beyond the maximum extension of the Weichselian glaciation. From their remote refuges vegetation, wildlife and palaeolithic man followed the melting edge of the Scandinavian Ice Sheet back to Fennoscandia.

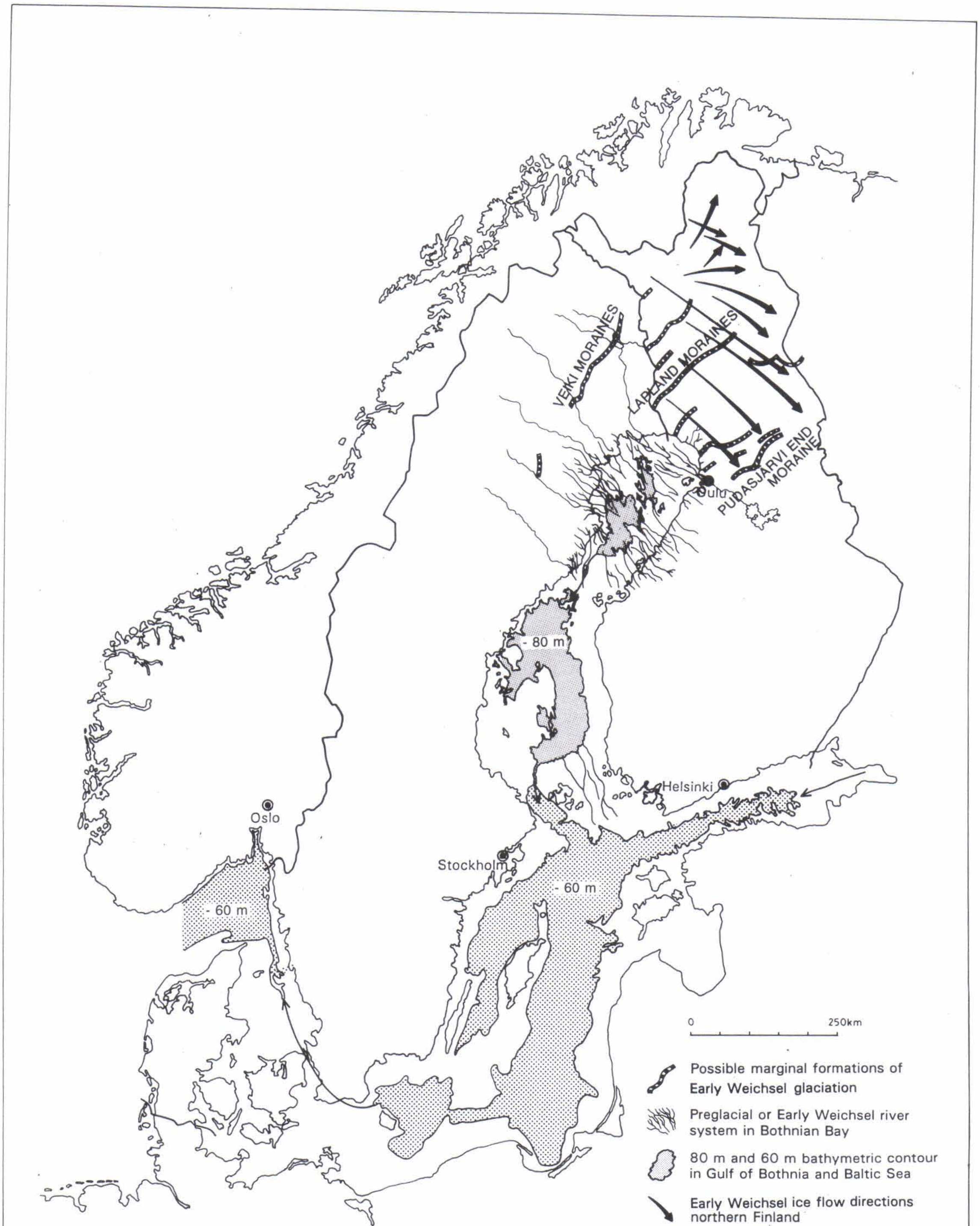


Figure 30. *Map showing inferred end moraines of Early Weichsel glaciation, lower water level in Bothnian Bay, Gulf of Finland, Bothnian Sea and Baltic Sea (not corrected for differential uplift), and continuations of river beds on sea floor (cf. Tulkki 1977, Sutinen 1984, Mäkinen 1985, Lagerbäck 1988, Lundqvist 1992 and Lundqvist & Robertsson 1994).*

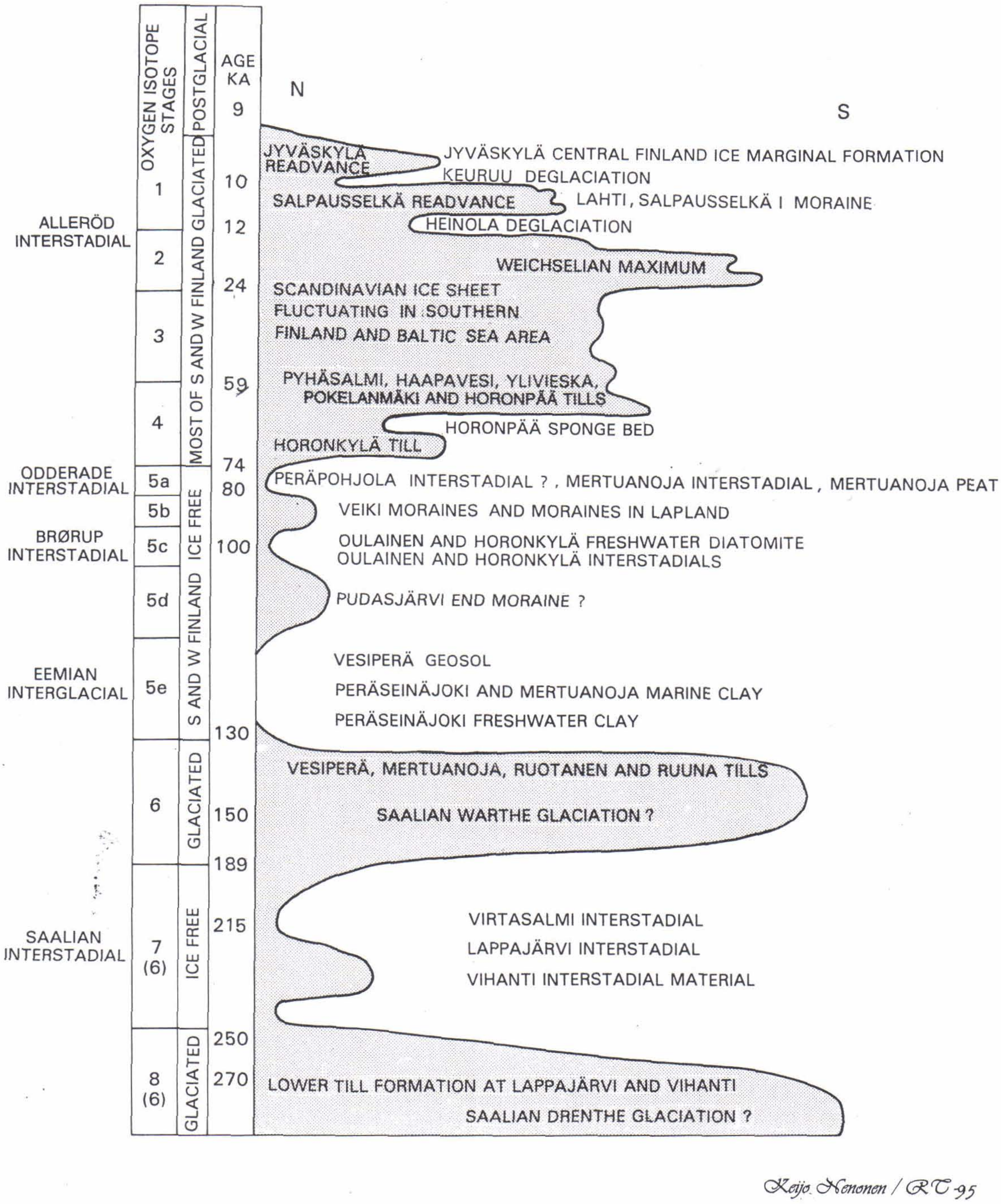


Figure 31. *Glaciation curve for Weichsel and Saale stages, and correlation of deposits and events in southern and western Finland. Extent of ice during stages 7, 5d, 5b and 4 is hypothetical (cf. Lundqvist 1986a and 1992). Age data from deep-sea isotope record (Fig. 28).*

SUMMARY AND CONCLUSIONS

Lying at the central area of the Scandinavian Ice Sheet, southern and western Finland has been submitted to the erosional and depositional activities of Pleistocene ice sheets several times. As a result of glacial action, Finland's bedrock, which is mainly Precambrian, is covered by a thin veneer of sediments, and it is almost impossible to find a lithostratigraphic profile covering the whole Pleistocene epoch. The uppermost, shallow and unconsolidated organic deposits that formed during the Pleistocene ice-free periods - interglacials and interstadials - were generally removed in the course of the following glaciation. In contrast, tills formed during glaciations and sediments deposited during deglaciations were better able to resist erosion, being sheltered from subsequent wear and deformation. Consequently, Finland's Pleistocene stratigraphy largely comprises sequences of glacial and till deposits. Figure 31 and Table 3 summarizes the history of glaciation in southern and western Finland and the correlation of deposits discovered.

No interglacial deposits older than Eemian Interglacial have been found in southern and western Finland. The Naakenavaara Interglacial deposit in Lapland (Hirvas 1991 and Aalto et al. 1992) has been correlated with the Holsteinian Interglacial and to deep-sea istope stage 7 (Saarnisto & Salonen 1995), although it may be older (Table 1).

The oldest Pleistocene non-glacial sediments recorded to date in southern and western Finland have been found at Virtasalmi, Vihanti and Lappajärvi. The till-covered gyttja deposit at Virtasalmi may correspond to deep ocean oxygen isotope stage 7. The Pleistocene sequence of the Lappajärvi meteorite crater described by Salonen et al. (1992) contains a deposit that differs from the deposits of the Weichsel interstadials and which probably represents the Saale interstadial. Clays and gyttjas deposited in Virtasalmi at 62-80 m a.s.l. and in Lappajärvi at 20-30 m a.s.l. reflect freshwater conditions and the varved clays the proximity of the ice front. At the time the Lappajärvi Interstadial deposit was laid down, the sea had not even reached the 20-m level in Ostrobothnia.

The interstadial deposits at Vihanti and Lappajärvi are underlain by till with redeposited microfossils. The tills may represent glaciation of isotope stage 8, which is considered to be part of the Drenthe substage of the Saale glaciation (cf. Bowen et al. 1986, Forsström 1989, Eronen 1992). Isotope stage 8 glaciation has been also correlated to Elster glaciation (cf. Lundqvist 1992 and Donner 1995).

The Eemian Interglacial deposits are commonly underlain by till of the oxygen isotope stage 6 glaciation, which is generally correlated with the Warthe substage of the Saale glaciation (see Bowen et al. 1986, Forsström 1989). Till that is identifiably Saalian tends to be encountered in deep pits and sections. In the last stage of the Saale glaciation, the ice sheet flowed from northwest to southeast in Ostrobothnia and Kainuu and from NNW to SSE in Savo and southern Finland. The Ruotanen, Vesiperä, Mertuanoja and Ruuna Tills deposited by the Saale ice sheet are coarser than the overlying tills of the Weichsel glaciation. In the interstadial of isotope stage 7 preceding the Warthe substage, large areas in southern and western Finland were probably dry land, and there were no extensive clay deposits to be eroded by the Saale ice sheet.

The deposits overlying the Saale tills and reflecting a warmer climatic stage than the present one are correlated with the Eem Interglacial. As shown by the deposits, the interglacial started with a freshwater phase of the Baltic Sea. After the *Betula* phase at the beginning of the interglacial a sea connection opened to the White Sea and the North Sea. During the warmest stage of the interglacial, southern and central Finland were part of the Scandinavian insular mainland. The Eem Sea extended at least to Haapavesi and Kuopio at 120 m a.s.l. Isostatic land uplift caused shoreline displacement and inlets were isolated from the sea as iakes towards the end of the warm period of the Ollala interglacial deposit (Grönlund 1991b). At this phase of the Eem Interglacial, *Picea* became a dominant forest species. The terrestrial deposits at Vesiperä and at Vimpeli quarry indicate that *Betula-Alnus-Picea-Corylus* forests grew at that time in Ostrobothnia, later being replaced by *Pinus-Betula-Picea* forests (see Eriksson 1993). At the end of the Eem Interglacial, *Larix* spread to Ostrobothnia and formed forests together with *Pinus* and *Picea*, probably in the regressive stage of the vegetational history of the interglacial (Eriksson & Kujansuu 1994). Tills overlying Eem Interglacial deposits, e.g. the Haapavesi and Ylivieska Tills, contain abundant redeposited fine grained material removed from interglacial clay deposits.

After the Eem Interglacial, uplift continued in southern and western Finland and, as shown by deposit finds, the ice sheet related to isotope stage 5d did not extend to Ostrobothnia. However, as suggested by Sutinen (1992), this Early Weichselian ice probably extended to Pudasjärvi. Aeolian cover sands with signs of intense frost action, ice wedges and cryoturbation were laid down on interglacial deposits and geosol profiles in Ostrobothnia (cf. Kujansuu et al. 1991, Kujansuu 1992, Hütt et al. 1993). In Ostrobothnia, isotope stage 5d was probably an ice-free kryomer in which periglacial conditions prevailed. During isotope stage 5c, an interstadial characterized by *Pinus-Betula* forests prevailed in Ostrobothnia. Diatomites formed in freshwater basins at Horonkylä and Oulainen. The climate was colder than it is today and the data on vegetation history contain only a few short vegetation zones of *Betula* and *Pinus* (cf. Donner 1988, 1995).

The interstadial was succeeded by the cold period of isotope stage 5b, from which no till deposits have been found in southern or western Finland. Cover sands may have deposited during this stage, too, and frost may have disturbed the deposits. The ice front was probably then located in Norrbotten and Swedish Lapland, from where Lagerbäck and Robertsson (1988) have described deposits of the Early Weichsel Brørup and Odderade Interstadials, which they call the Peräpohjola and Tärendö Interstadials. Lagerbäck (1988) has interpreted the Veiki moraine zone in northern Sweden as indicating the marginal position of the ice sheet during the Early Weichsel deglaciation. Sutinen (1992), too, has described till-covered ice-marginal formations from north of the Arctic Circle in Finnish Lapland. He postulates that the Lapland moraines of Kuusanjärvi-Nuonospuljut and Niliharju represent the marginal position of the Early or Middle Weichsel ice sheet (Fig. 30). The interpretation of the extent of the ice sheet in Lapland and Ostrobothnia during Early Weichsel stadials in Figure 31 is hypothetical. Reliable dating of deposits and marginal formations with the absolute methods currently in use is difficult. Different hypothetical concepts of the extent of the ice sheet during the Early Weichselian 5d and 5b stadials have been presented by Forsström (1991), Forsström & Eronen (1991), Lundqvist (1992) and Lundqvist & Robertsson (1994).

In Ostrobothnia, the interstadial of isotope stage 5a is probably represented by only one deposit, that of Mertuanoja (cf. Iisalo 1992). Except for a phase when *Betula nana* and shrubs were dominant, forests were almost totally dominated by *Betula*. The vegetation of the Mertuanoja Interstadial resembles that of the Peräpohjola Interstadial described by Korpela (1969) from the Kemijoki river valley, Kainuu and that of the Kauvonkangas interstadial deposit described by Mäkinen (1979). The Mertuanoja deposit lies 200 km farther south than that of Peräpohjola. According to Eronen (1992), no forests could have grown in the North during interstadials younger than Odderade Interstadial 5a, as the vegetation of these stages was that of tundra even as far south as northern continental Europe.

After the deposition of the Mertuanoja Interstadial sediments, during oxygen isotope stage 4, in the early part of the Middle Weichselian, the continental ice sheet overrode the deposits formed in Ostrobothnia during the ice-free stage. The advance of the ice was probably preceded by a periglacial polar desert stage in the course of which aeolian cover sands and water-laid sediments deposited. The ice sheet did not advance synchronously, it withdraw and fluctuated, covering the Horonkylä Sponge Bed deposit. The till stratigraphy of southern Ostrobothnia may reflect advances of the ice sheet towards the end of the Early Weichselian or during the early Middle Weichselian. The dates of the events are ambiguous due to discrepancies in age determination. All southern Finland was covered by continental ice during the Middle Weichselian. Large-scale ice sheet advances and deglaciations during isotope stages 4 and 3 are possible but no dated events referring to them have been recorded from Finland (cf. B. Andersen & Mangerud 1989, Lundqvist 1992, Liivrand 1995).

In southern Sweden, Middle Weichselian interstadial deposits were covered by Late Weichselian till during isotope stage 2 (cf. Berglund & Lagerlund 1981, Lundqvist 1992). Periglacial polar desert prevailed in ice-free areas in Scandinavia during the Middle Weichselian. The continental ice sheet reached Estonia, south of the Gulf of Finland, at the earliest in the early Middle Weichselian Mägiste stadial in istope stage 4 (Liivrand 1992, 1995) or northern Lithuania during the Late Weichselian substage, at the latest 23-25 ka ago (Gaigalas et al. 1992).

Southern and western Finland was covered by the continental ice sheet during isotope stages 3 and 2, from 54 ka to 12 ka BP. Various dating methods have produced ages of organic sediments and cover sands falling within this range, but because they are unlikely to be the true ages of these deposits they have not been applied when constructing the Pleistocene chronostratigraphy of the area. The OSL method has given promising results and perhaps the corrected OSL ages, when eventually available, will be close to the true ages (cf. Mejdahl & Funder 1994).

The abrupt climatic variations of the last glaciation are clearly visible in the oxygen isotope record of long ice cores (Fig. 29, cf. Dansgaard et al. 1989, Alley et al. 1993).

The front of the melting ice sheet withdrew to the south coast of Finland about 12 200 years ago (Saarnisto 1991, see also Lundqvist 1986b) and, according to varved clay chronology (Rainio 1993), reached Lappeenranta about 11 800-12 200 years ago. Till-covered deposits of varved clay and silt on the proximal side of the Salpausselkäs, for example in the Kaasila reference section, were laid down when the ice front withdrew to a position up to 80 km north of what is now Salpausselkä I, during the Heinola Deglaciation (Fig. 29). The Heinola deglaciation may have occurred during the warm Alleröd Interstadial (11 800-11 000 ^{14}C yr BP) at the beginning of isotope stage 1.

No microfossils have been found in till-covered deposits but beneath Salpausselkä I in Lahti and in the basal parts of clays on the distal side of Salpausselkä I, there are deposits compatible with the Alleröd chron in vegetation (cf. Hyyppä 1966). Pollen diagrams for southern and southeastern Finland reveal features of late glacial sediments suggestive of the Alleröd Interstadial (M. Okko 1962, Glückert 1990). Salpausselkä I and II formed during the Younger Dryas chron, at 10 000-11 000 ^{14}C yr BP, when the climate suddenly cooled back to the glacial level. Triggered by the cooling climate and probably by canges in the relative sea level of the Baltic basin (cf. Lundqvist 1987, 1988, Nenonen 1993) the ice sheet readvanced. From varved clays at Lappeenranta, Rainio (1993) dated this Salpausselkä Readvance to ca. 11 700 - 11 800 yr BP, which was when the Kaasila Till of the Kaasila reference section in Outokumpu and the Pampalo Till in the Pampalo reference section in Ilomantsi deposited.

The coldness of the Younger Dryas in southern Finland is demonstrated by fossil periglacial ice wedges and sediments deformed by cryoturbation in Salpausselkä I, and the *Artemisia* zone reflecting open vegetation in organic deposits on the outer side of Salpausselkä II (Donner 1978). The discrepancy between radiocarbon and varved clay dates is due to the fact that the radiocarbon ages of the boundary between the Younger Dryas and Preboreal chronozones deduced from pollen analysis are 700 years younger than the age of the boundary in Fennoscandia determined with varve chronology (Rainio et al. 1995). Also the ice core record (Fig. 29) calculated from annual ice layers (Dansgaard et al. 1993) assigns ages over a thousand years older to the late glacial chronozones than the conventional radiocarbon chronology.

The last extensive readvance of the ice sheet, the Jyväskylä Readvance, occurred when the Central Finland ice-marginal formation deposited. Glaciofluvial formations and sorted fine-grained deposits, which formed during the Keuruu Deglaciation were then covered with till in central Finland. The ice sheet also oscillated when Salpausselkä III formed in the Hämeenlinna area. At Tampere the ice sheet oscillated or changed direction, starting to flow towards the Pyynikki-Kangasala interlobate deposit.

When the Central Finland ice-marginal formation and Salpausselkä III were formed, the glacial lobes of the Baltic Sea, Näsijärvi-Jyväskylä and North Karelia were reorganized, and the Finnish Lake District lobe ceased to exist in terms of glaciodynamics. It was at this stage that the Jomala Till of the Jomala, Åland reference section and the Vampula d Till of the Vampula reference section probably deposited. Salpausselkä III, the Pyynikki-Kangasala interlobate formation, the Central Finland ice-marginal formation, the Siilinjärvi-Outokumpu interlobate formation and the Pielisjärvi end moraine all demarcate the marginal positions of glacial lobes when the Pleistocene epoch was brought to an end by rapid climatic amelioration at the end of the Younger Dryas chron. The oscillations of the glacial lobes that generated the above formations were probably caused by ephemeral cooling of the climate in the early part of the Preboreal chron. At that time the Baltic Sea was at the Yoldia stage and the Holocene epoch had started. In Ilomantsi, *Betula* forests spread to the supra-aquatic area that emerged from the ice sheet.

Table 3. Summary of present knowledge of the Finnish Pleistocene stratigraphy

Isotope stage	**Environment in Finland**
1	Holocene interglacial, 10 ka BP (radiocarbon years)
2	Weichselian maximum. The ice margin outside Finland.
3+4	Glacial stage with the ice margin in southernmost Finland and Estonia. Series of short retreats and readvances.
5a	Mertuanoja Interstadial (Odderade). Birch dominated forests, dwarf-shrub vegetation. Possibly Peräpohjola Interstadial in northern Finland.
5b	Ice free cold stage in southern Finland. Ice margin possibly in Lapland. Polar desert.
5c	Oulainen and Horonkylä Interstadial (Brørup). Cool- temperate climate, pine dominated forests. Possibly Peräpohjola Interstadial in northern Finland.
5d	Ice free cold stage in southern Finland. The ice margin possibly in Northern Finland. Polar desert.
5e	Eemian Interglacial. Warm climate with temperate forest, alder-hazel groves in southern and western Finland. The Eemian Sea covers large areas in southern and western Finland.
6	Saalian (Warthe) stadial. Ice margin outside Finland.
7 or 6	Virtasalmi Interstadial, possible Saale interstadial deposit with cool-temperate climate, birch and pine forests with spruce.
8 or 6	Saalian (Drenthe) stadial. Ice margin outside Finland.
7 or 9-11	Naakenanvaara Interglacial, possible Holstein Interglacial deposit in Lapland. Pine, spruce and larch forests in northern Finland.
8 or 10-14	Elsterian Glacial. Ice margin outside Finland.

Acknowledgements

First of all I express my gratitude to the till survey team of the Geological Survey of Finland: Dr Heikki Hirvas, Pertti Hakala, Pekka Huhta, Dr Petri Lintinen and all the intrepid students and research assistants who helped me to examine the treacherous test pits, the sections and the drill cores. I also thank professor Raimo Kujansuu, who helped me in many ways in the course of the field survey and in taking the OSL samples.

Ritva Harinen, Esko Iisalo, Tapio Kuivasaari, Esko Koivisto, Martti Kokkola, Esko Nylander, Raimo Rajalin, Esa Sanberg and Olli Sarapää - all sharp eyed observers of stratigraphical phenomena - gave me valuable samples and useful hints about localities worth studying. To them I express special thanks. The ore prospecting department of GSF, Outokumpu Finnmines Ltd. and Paraisten Kalkki Oy also provided generous support for the till stratigraphical studies conducted at their claims and mines.

Brita Eriksson, Dr Liisa Ikonen and Satu Jokinen were responsible for the pollen analyses, Dr Tuulikki Grönlund made the diatom analyses and Tuovi Kankainen the radiocarbon analyses; Eila Paavilainen prepared the samples. Dr Anneli Uutela studied the sponge spicules and Kristian Lindqvist analysed them in the X-ray laboratory of GSF. Anneli Putkinen and Liisa Savolainen performed the granulometric, humus and permeability analyses. Dr Galina Hütt from the Institute of Geology of the Estonian Academy of Science carried out the OSL dating.

Professors Raimo Kujansuu, Matti Saarnisto and Veli-Pekka Salonen did an invaluable job in instructing me in the course of study. They together with professor Matti Eronen provided constructive criticism and corrected manuscript where necessary.

Gillian Häkli translated the manuscript into English, and Riitta Turunen gave graphical form to the field drawings and my stratigraphical correlations.

The GSF Regional Office for Mid-Finland financed the study and gave me all the support I needed. I thank all the above people and the members of the numerous ore prospecting and survey teams not mentioned here who facilitated my work at all its stages.

Finally, I thank my wife Eila, daughter Mira and son Rainer for their patience at home when I borrowed family time to work on the manuscript during holidays and in the evenings.

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