Geological Survey of Finland

Bulletin 379

Origin and physical characteristics of till fines in Finland

by Petri Lintinen

Geological Survey of Finland
Espoo 1995

Geological Survey of Finland, Bulletin 379

ORIGIN AND PHYSICAL CHARACTERISTICS OF TILL FINES IN FINLAND

by

PETRI LINTINEN

with 36 figures, 4 tables and 2 appendices

ACADEMIC DISSERTATION

GEOLOGICAL SURVEY OF FINLAND
ESPOO 1995

Lintinen, Petri 1995. Origin and physical characteristics of till fines in Finland. Geological Survey of Finland, Bulletin 379. 83 pages, 36 figures, 4 tables and 2 appendices.

The objective of this study was to investigate the origin of fines in the basal till of Finland and the factors responsible for the regional variation in till properties and further to provide insight into the regional distribution of the known till stratigraphic units.

Tills in Finland were divided into regional provinces on the basis of the clay fraction content and specific surface area of fines (1015 samples) and the fines content (5437 samples). The fines content was determined with wet sieving, the clay fraction content with X-ray sedigraphy and the specific surface area with nitrogen sorption. The clay minerals in the till fines was studied with X-ray diffraction and infrared analysis on samples collected from study pits.

The kaolinite in the till fines is due to intense chemical weathering of the bedrock surface before the onset of Quaternary glaciations, at a time when the climate was considerably warmer than it is today. The vermiculite in the till fines and the associated mixed-layer minerals were formed when acidic gravitational water weathered biotite or chlorite in surficial soils during postglacial time. Vermiculite was also formed during interglacial ice-free stages, when conditions were similar to those prevailing at present. As shown by the clay mineralogy of the superimposed lithostratigraphic units, the till fines contain both fines eroded from preglacial weathered bedrock and interglacial sediments.

Regional differences in the fines and clay fraction contents of Finnish tills are due to only a limited extent to the properties of the bedrock. The tills in central Lapland contain large amounts of materials from preglacial weathered bedrock, as shown by the high values of the specific surface area of fines and the high kaolinite content. More than anything else, the Gulf of Bothnia, as a sedimentation basin, has affected the properties of basal till, as southeast of it tills are rich in fines. Basal tills rich in clay fraction are located in areas with only a few eskers and other glaciofluvial formations. Dewatering of the debris depositing on the bottom of the continental ice sheet seems to have had a marked impact on the clay fraction content of basal tills.

According to this study, basal till is a polycyclic sediment in origin, and part of the fines was eroded and redeposited during the numerous Quaternary glaciations that have covered the area of Finland.

Key words (Georef Thesaurus): till, fines, grain size, specific surface, lithostratigraphy, clay minerals, kaolinite, vermiculite, mixed-layer minerals, X-ray analysis, infrared spectroscopy, glaciation, Quaternary, Finland

Petri Lintinen, Geological Survey of Finland, FIN-02150 ESPOO, FINLAND

ISBN 951-690-576-5
ISSN 0367-522X

Vammalan Kirjapaino Oy 1995

CONTENTS

INTRODUCTION

Finland (Fig.1.) is located in Fennoscandia, southeast of the Caledonian mountain range, on the peneplain of the Fennoscandian (Baltic) Shield. In topography, Finland's terrain is relatively flat, about 75% of it lying at below 200 m a.s.l. Throughout most of the country, differences in relative heights are often only a few tens of metres. In northern Finland - Lapland - an area of high hills and fells, the differences in relative heights are more striking.

Finland lies in the central area of Scandinavian glaciations, and thus the Scandinavian continental ice sheet has covered large areas of it several times during the Quaternary. During ice-free periods, low-lying parts of the country have been repeatedly covered by water as the Baltic Sea has spread to areas emerged from the ice sheet. In these areas, clay deposits, several metres thick, often rest on basal till (Fig.2).

Basal till, the most common surfical sediment in Finland, covers the Precambrian crystalline bedrock, smoothing its topography. As a surfical sediment, basal till covers 48.2% of Finland's land areas (Kujansuu & Niemelä 1984, Fig. 3). However, it covers a far greater area of bedrock, as other sediments have deposited on the basal till. The average depth of surfical sediment in Finland has been estimated at 6-7 m, the same figure as that attributed to the cumulative erosion of Quaternary glaciations (Okko 1964).

In grain size composition, Finland's basal

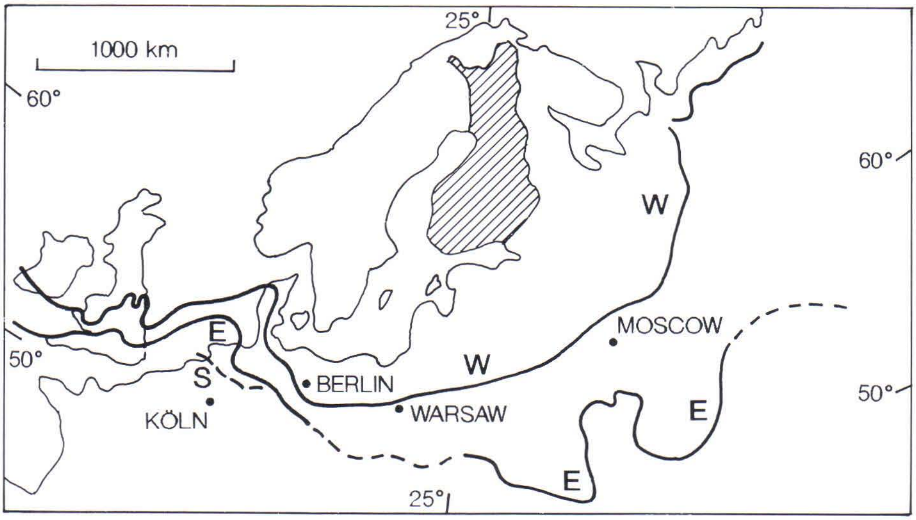


Fig. 1. Finland, the study area and the maximum extent of Pleistocene glaciations in northern Europe (compiled after Bowen 1978; Arkhipov et al. 1986; Gibbard 1988; Bowen 1991).

tills are mainly sandy tills poor in fines (Virkkala 1969a). Some, however, are rich in fines and clay fraction (Kivekäs 1946, Virkkala 1969a). The trace-metal concentrations of the fines-rich basal tills are distinctly higher than those of the sandy tills (Lintinen 1989, Räisänen et al. 1992b). It has been assumed that the high abundances of fines and clay fraction, in the fines-rich basal tills are due to the mixing of marine sediments deposited during the Eemian interglacial with tills deposited during the Weichselian glaciation (Rainio & Lahermo 1976 1984; Hirvas & Nenonen 1987; Bouchard et al. 1990). According to Hirvas and Nenonen (1987), the basal tills rich in clay fraction in Ostrobothnia contain clay clasts with a microfossil assemblage typical of the Eem interglacial; moreover, marine Eem deposits have been encountered beneath the till unit rich in clay fraction. Aario and Forsström (1979) have described a basal till rich in clay fraction, the Pudasjärvi Till, which they interpret as having deposited in a more central position beneath the ice sheet.

The number of Quaternary glaciations that have covered Finland is not known for sure. The clearest evidence of several glaciations lies in deposits in continental Europe indicating the maximum extent of three glaciations of different ages (Fig. 1). In Finnish Lapland,

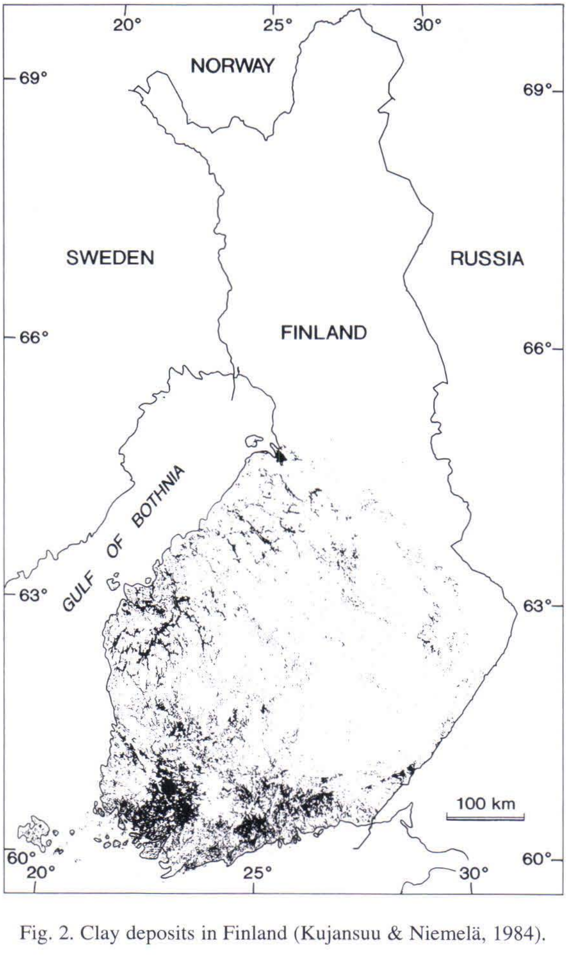


Fig. 2. Clay deposits in Finland (Kujansuu & Niemelä, 1984).

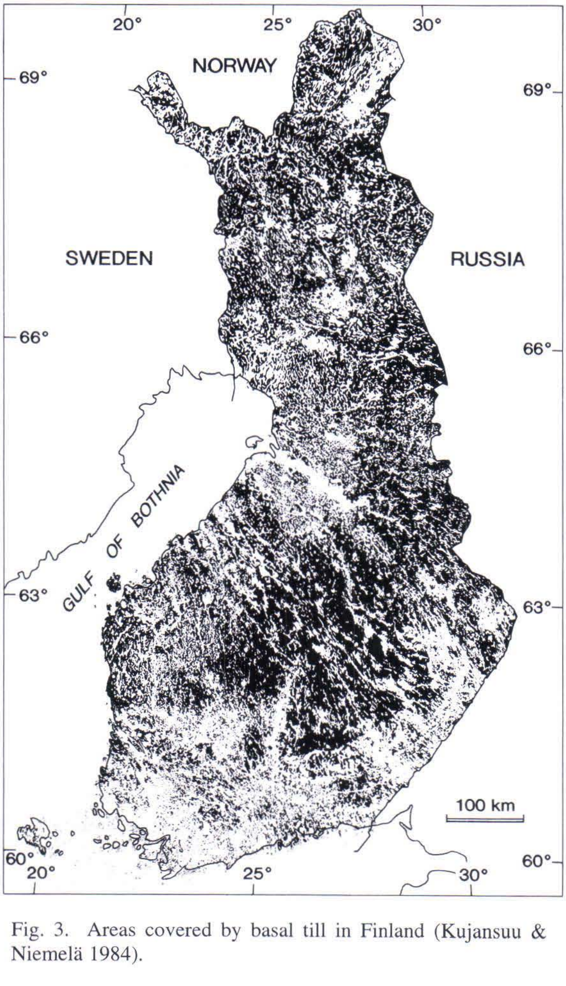


Fig. 3. Areas covered by basal till in Finland (Kujansuu & Niemelä 1984).

till units have been found that represent up to five flow stages of the continental ice sheet (Hirvas 1991). Finland's present till covers, however, deposited mainly during the last, that is, Weichselian, glaciation (Hirvas & Nenonen 1987). Biostratigraphic observations from areas beyond the maximum extent of glaciation in Holland imply that the Scandinavian ice sheet may have covered large areas as much as ten times during the last 2 million years (De Jong 1988). According to the oxygen isotope ratios of oceanic bottom sediments, the number of Quaternary glaciations in the northern hemisphere is higher still (Shackleton & Opdyke 1973).

The objective of this study was to clarify the origin of the fines in Finnish basal tills, to find reasons for the regional variation in till properties, and to establish the regional distribution of stratigraphically known till units. Mineralogical analyses were made to assess the influence of the preglacial weathered bedrock and of weathering during ice-free stages on the clay mineralogy of till-stratigraphic units.

PREVIOUS STUDIES

Regional studies

Physical properties of till

In accordance with the established practice in Finland, tills are divided into basal and surficial ones. The basal tills of this study contain a group of tills, differing in origin and difficult to define, that deposited on the bottom of the continental ice sheet. Finland's basal tills may be structureless or they may exhibit banded and fissile structure (cf. e.g. Virkkala 1948, 1952; Aario & Forsström 1979; Saarnisto & Peltoniemi 1984; Hirvas 1991). The banded and fissile basal tills often contain lenses of sorted sediments. Massive structureless basal till corresponds to the lodgement till described by Flint (1971). The banded and fissile basal tills may be melt-out tills in origin (Boulton 1970) or they may represent the A horizon of the deformation tills of Boulton (1987).

In Finland, the term fines refers to material that passes through a 0.06 mm sieve, and clay fraction to material that is less than 0.002 mm in grain size. Finnish tills have been characterized by their grain size distribution (Aarnio 1938; Kivekäs 1946; Virkkala 1969a). Aarnio (1938) noted that tills rich in clay fraction occur irregularly in supra-aquatic and subaquatic areas. Virkkala (1969a) classified Finnish tills on the basis of about 2400 samples. His classification, which was based on the percentage of mass passing, did not distinguish clearly between tills from different areas. More recent till classifications applied in geotechnics and in the mapping of surficial deposits are based on combinations of various percentages of mass passing (Korhonen & Gardemeister 1970; Lindroos & Nieminen 1982). In the mapping of surficial deposits conducted by the Geological Survey of Finland (GSF), a till sample is classified as rich in fines if it contains at least 30% fines (<0.06 mm) and at least 5% clay fraction in matter less than 20 mm in size (Lindroos & Nieminen 1982). The classification limits are determined with an areometer method and wet sieving. The mapping of surficial deposits has made it possible to delineate the regional distribution of different till types in northern Savo (Huttunen et al. 1993). Lindroos (1976) tested the usefulness of specific surface area measurements for classifying till samples and found that the specific surface area values of till samples with a similar fines content may vary markedly. According to Nieminen (1985), tills containing weathered matter have a large specific surface area for their clay fraction content.

Geochemical survey

National till-geochemical surveys undertaken by the GSF have delineated the regional distribution of the chemical properties of Finnish basal tills. In reconnaissance-scale mapping, the whole territory of Finland was covered with 1057 till samples at a sampling density of 1 sample per 300 km^2. The samples were taken with a spade from the chemically unaltered podzol C horizon at a depth of at least 0.5 m. The fines of the samples (<0.06 mm) were analysed for total concentrations and for concentrations of aqua regia-soluble elements (Koljonen 1992). In the course of the regional-scale geochemical mapping conducted by the Geochemistry Department of the GSF, about 80 000 till samples were collected at a density of 1 sample per 4 km^2 (Salminen, in print).

The geochemical survey data indicate that there are three large geochemical provinces in Finland, where the concentrations of many elements are high in relation to the averages of the whole material. Figure 4 shows the concentration of aqua regia-soluble zinc in till fines. The polymetallic anomaly that runs across the country in a northwest - southeast direction from the coast of the Gulf of Bothnia is called the geochemical Lake Ladoga-Bothnian Bay zone. Another coherent polymetallic anomaly starts on the coast of southern Ostrobothnia and continues inland to Häme, where it ends west of Lake Päijänne. The third polymetallic anomaly is in central Lapland.

The interpretation of the results of the reconnaissance-scale mapping has aroused much discussion (Saltikoff 1988a,b; Salminen 1988; Björklund 1988a,b; Hartikainen 1989; Aatos et al. 1994). The interpretation is hampered by the inadequate information available on the regional distribution of the physical properties of till (Mäkinen 1993) and their effect on till geochemistry. The results of the geochemical mapping are revealing about glaciogeological features as well as bedrock geochemical properties. According to Vallius (1993), the Central Finland ice- marginal formation acts as a boundary; on its distal side there is a polymetallic anomaly that extends from southern Ostrobothnia to Häme, and on its proximal side, the metal concentrations in till are anomalously low. Mäkinen (1993) suggests that the anomalously high concentrations in the Lake Ladoga-Bothnian Bay zone are due to the crushing activity of the continental ice sheet, which exceeded that in the areas of active lobes.

According to Björklund (1988a,b), the polymetallic anomalies do not follow the boundaries between bedrock areas but are concentrated in the interlobate areas of the deglaciation stage. He suggests that the saline ground waters that discharged to the bottom of the continental ice sheet from the ore zones could have exerted a major control over the location of the glacial lobes and the behaviour of the continental ice sheet during deglaciation. According to the hypothesis of Björklund, the superimposed till units should then be similar in grain-size composition, as the bedrock would force the continental ice sheet to behave in the same manner during each glaciation. In fact, however, the properties of the superimposed till units often differ from each other (Hirvas & Nenonen 1987).

Aatos et al. (1994) calculated normative mineral compositions from the data of geo-

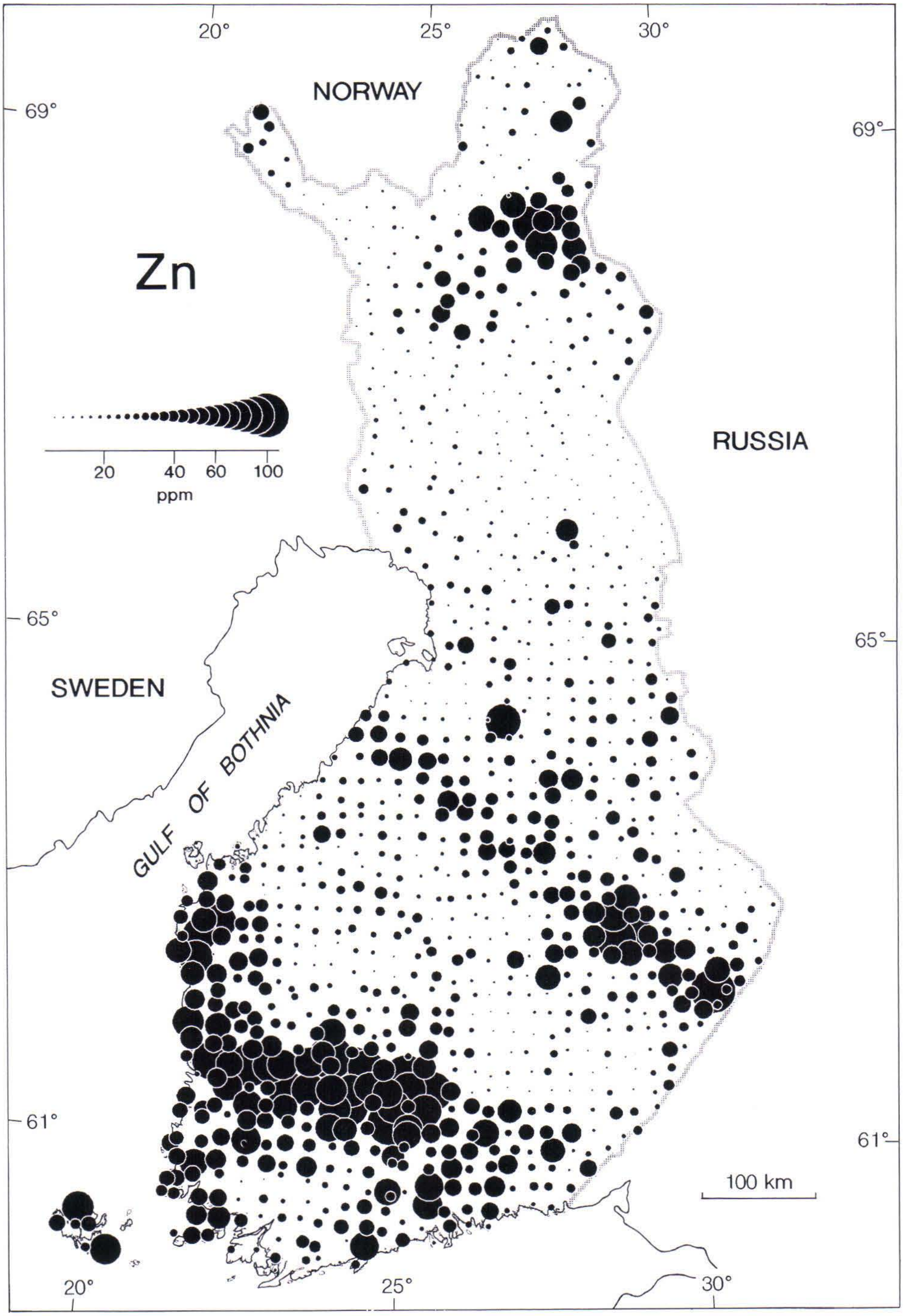


Fig. 4. Concentration of aqua regia-soluble zinc in till fines (<0.06 mm). Number of samples 1057.

chemical mapping in Finland. In addition to bedrock impact, the mineral compositions revealed features related to genetic processes not correlated with the mineral composition of the bedrock (Aatos et al. 1994).

Mineralogy of fines

Recent basal tills contain not only fines loosened from the bedrock by glacial erosion but also material from the preglacial weathered bedrock, interglacial sediments and older tills (Soveri & Hyyppä 1966). The following takes a brief look at the mineralogy of Finland's till fines, postglacial clays and weathered bedrock. In the mineralogical discussion, postglacial clays are taken to correspond to interglacial sediments, which are probably very close to recent clays in mineralogy.

Till

The mineralogy of the clay fraction in the till fines of Finland is poorly known. Based on the -0.001 mm and 0.002-0.02 mm fractions of 15 till samples collected from southern and central Finland, the study of Soveri and Hyyppä (1966) was for many years the only detailed discussion of the mineralogy of the fines in Finnish tills. The subject has been studied more recently in association with till-geochemical and soil investigations (Räisänen et al. 1992; Räisänen & Jylänki 1990).

The till fines in Finland contain quartz, feldspars, amphiboles, chlorite, illite, vermiculite and mixed-layer clay minerals as main minerals (Soveri & Hyyppä 1966; Räisänen et al. 1992). According to Soveri and Hyyppä (1966), the sum of quartz, feldspars and amphiboles in the <0.02 fraction varies in the range of 30 - 70%. Soveri and Hyyppä divide vermiculite into two types: clay vermiculite if in X-ray diffraction its 14 Å reflection shifts to the range of the 10 Å reflection of mica at temperatures of less than 200°C and if it does not expand in ethylene glycol treatment; and vermiculite if its 14 Å reflection shifts to the range of 10 Å at 200-450°C.

According to Räisänen et al. (1992), the clay minerals in fines are mixed-layer clay minerals that probably formed as alteration products of micas, mainly biotite. The alteration products include mica-vermiculite mixed-layer minerals; some of the minerals exhibit polymerization of Al-hydroxide in interlayers of clay minerals, in which case the mixed-layer mineral approaches chlorite in properties. The formation of Al-hydroxy interlayers is related to podzolization, in which mobilized Al migrate to and precipitate in lower horizons, where they form Al-hydroxy interlayers in vermiculites. Soveri and Hyyppä (1966) further maintain that clay minerals are most probably formed when acidic gravitational waters leach micas.

Soveri and Hyyppä (1966) consider it possible that clay minerals weathered during interstadials or interglacials were mixed with till fines. According to Virkkala (1969b), the vermiculite reported from a till at Hämeenlinna is a relic of mineral matter weathered during an ice-free stage and mixed with a younger till. Räisänen et al. (1992) have found kaolinite in till samples from the geochemical Lake Ladoga-Bothnian Bay zone. However, they do not discuss the origin of the kaolinite occurrence.

Soveri and Hyyppä (1966) did not find kaolinite in their till samples. Ihalainen (1994) investigated till mineralogy in different bedrock areas in Lapland and found kaolinite in till fines at the central Lapland ice divide.

According to X-ray diffraction studies of Snäll et al. (1979), Björnbom (1979), Melkerud (1984), Snäll (1986) and Snäll et al. (1992), the clay mineral composition of tills in Sweden is basically the same as that of tills in Finland. On the basis of sample profiles, Snäll (1985) and Melkerud (1985) demonstrated that mica weathers into vermiculite under the conditions prevailing close to the ground surface. Snäll et al. (1992) point out that kaolinite is an occasional constituent in the clay fraction of tills in Sweden, where its abundance is less than 3%.

Quaternary clays

The clay mineralogy of the Quaternary clays of Finland has been studied by Soveri (1950, 1956, 1957), Tynni et al. (1969), Sippola (1972, 1974), Gardemeister (1975), Punakivi et al. (1975) and Romu (1980). Mineralogical data have also been given in numerous reports for the brick industry. The mineral composition of Quaternary clays corresponds closely to that of the finest till fractions (Soveri & Hyyppä 1966). Sippola (1974) found expanding-lattice clay minerals, which are probably mixed-layer minerals of vermiculite and illite, in the surficial parts of clay deposits. No indisputable occurrence of kaolinite has been reported from Finnish Quaternary clays.

Preglacial weathered bedrock

Till-covered occurrences of preglacial weathered bedrock have been encountered in fractures and bedrock depressions throughout Finland (Härme 1949; Niini 1968; Uusinoka 1975; Niini & Uusinoka 1978; Kurkinen & Niemelä 1979; Hirvas et al. 1982; Lahti & Laitakari 1982; Lahti 1985). The largest coherent occurrences are in the ice divide zone of the continental ice sheet in central Lapland (Virkkala 1955; Kujansuu 1972; Salminen 1975; Hirvas et al. 1977; Hyyppä 1977, 1983). These occurrences were produced by intense weathering at a time when Finland was located in a zone where the climate was substantially warmer and more humid than it is at present. In places, the occurrences contain kaolinite-rich weathering clay (Hyyppä 1977, 1983; Pulkkinen 1985; Peuraniemi & Islam 1993). The largest known occurrences of weathering kaolin are in central Lapland, Kainuu and Virtasalmi (Hyyppä 1983; Pekkala 1987,1988; Pekkala & Sarapää 1989). There, clayey weathered bedrock extends to a depth of several tens of metres. The kaolin occurrences are products of advanced chemical weathering.

Most occurrences of weathered bedrock in Finland are, however, composed of more coarse, granular material (Hyyppä 1983). They are poor in fines and the proportion of clay minerals is small (Hyyppä 1983; Lahti 1985). Their clay fraction contains illite, chlorite, vermiculite, kaolinite and mixed-layer minerals (Hyyppä 1983). In Lapland, the coarse weathering occurrences may extend to a depth of up to 100 m in fractures (Virkkala 1955; Hyyppä 1983). Elsewhere in Finland, the occurrences of weathered bedrock are usually a few metres thick at the most and are composed of coarse-grained granular material (Lahti & Laitakari 1982; Hyyppä 1983; Kejonen 1985; Lahti 1985). In fractures protected from erosion by the continental ice sheet, the occurrences of weathered bedrock may be thicker. According to Hyyppä (1983), the occurrences of weathered bedrock in southern Finland are richer in expanding-lattice clay minerals than are those in Lapland.

According to Räisänen et al. (1992), some of the interlayers of mixed-layer minerals in the occurrences of weathered bedrock in the central parts of the geochemical Lake Ladoga-Bothnian Bay zone have altered into an expanding-lattice component similar to smectite. Peuraniemi and Pulkkinen (1993) have detected montmorillonite in the Raudaskylä weathered bedrock occurrence in Ostrobothnia.

According to a review by Lundqvist (1985), the occurrences of preglacial weathered bedrock in Sweden are similar to those in Finland. In Sweden, granular weathered bedrock is commonly encountered in bedrock depressions. According to Lundqvist, fractures in the Swedish bedrock also contain kaolinite. On the Kola Peninsula, in the area of the Precambrian shield in Russia, there are occurrences of granular weathered bedrock (Afans'ev & Evzerov 1981). The fines in the Kola weathered bedrock mainly contain alteration products of micas and only small amounts of kaolinite.

SAMPLES AND METHODS

Samples

Regional study

The material studied contained 1015 till samples selected from the stores of the GSF's Geochemistry Department. The samples were collected in the course of the regional-scale till-geochemical mapping at a density of one sample per 4 km^2. Each sample is composed of 3-5 subsamples taken from the same sampling station with a portable percussion drill. The subsamples, which were taken from depths of 1.5 - 2.5 m, with one sample from as deep as feasible, were compiled into samples in the field while sampling was still under way. Most of the samples were collected in 1982 - 1991. They were dried in a furnace at 70°-80°C and the fractions were separated with nylon sieves. This study was based on <0.06 mm fractions.

The geochemical macrofeatures revealed by the reconnaissance-scale mapping at a density of one sample per 300 km^2 (Koljonen 1992) do not change with the increase in sampling density (Salminen, oral comm. 1992). Hence, the 1015 samples collected on a regular grid are adequate for the mapping of the physical properties of fines on a regional scale.

Grain-size data produced with sieving and areometer data were collected from the archives of the Department of Quaternary Geology to study the fines content of Finnish tills. The study was based on the percentage by mass passing of each fraction stored in the department's database. Each sample analysed weighed about 100 g. Most of the data derive from samples collected in the course of the mapping of Quaternary deposits and taken with a spade at a depth of about 1 m from the ground surface. The databank also contains data on the till samples collected from study pits dug by excavator during explorational studies on surficial deposits. Samples were taken from these pits from different stratigraphic units; that taken closest to the surface was used in the regional assessment. Most of the samples, 5437 in all, were from basal tills; a few were from moraine formations. Regional coverage was best for the fines content in the <2.0 mm fraction.

Local studies

On the basis of the regional studies, research sites where study pits were dug with an excavator were selected in different till areas. The stratigraphic units in these pits were then sampled. The sites, which were chosen so as to represent dissimilar bedrock areas, had till

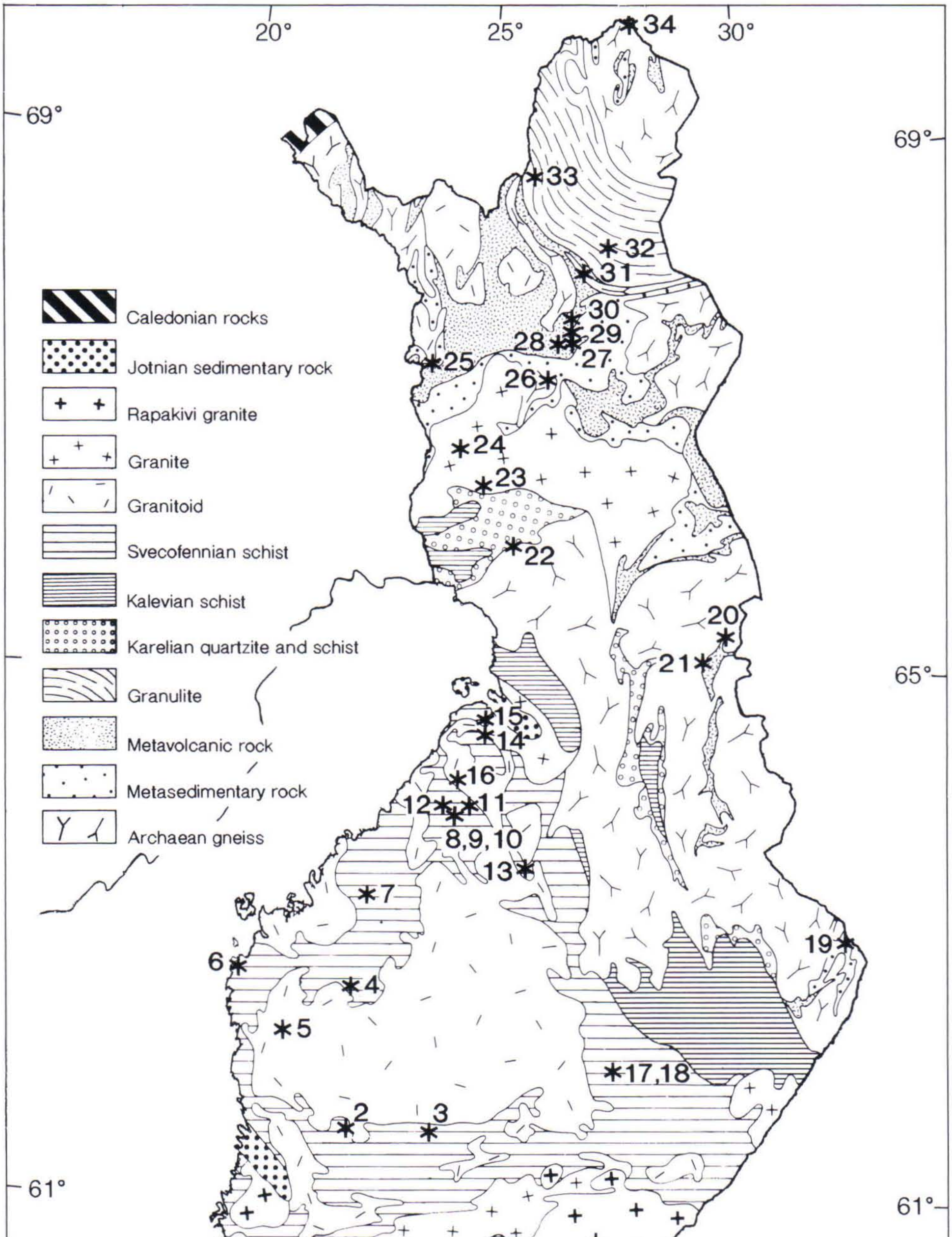


Fig. 5. Bedrock map of Finland, simplified after Simonen (1980), and sampling sites. Profiles and samples are described in Appendix 1.

units separated by fine-grained sediments; at some sites, weathered bedrock occurred on the bottom of the profiles. The properties of the stratigraphic units were recorded from the study pits (Hirvas et al. 1977; Hirvas 1991). Some of the samples were obtained from the sample stores of the till research group of the Department of Quaternary Geology and the Department of Geochemistry at the GSF. Physical properties and mineralogical data are given in the appendix. Figure 5 shows the location of the study pits in relation to the bedrock areas. Place names are given in Appendix 2.

Physical properties

Grain size distribution of fines

The grain size distribution of fines in the samples of the regional-scale geochemical mapping was determined with an X-ray sedigraph (Mikrometric sedigraf 500ET) at the soil laboratory of the GSF. The samples analysed weighed 2 - 4 g. Before analysis, the samples were stirred with an ultrasonic mixer for one minute. Figure 6 gives the reproducibility clay fraction contents in fines measured with the sedigraph as a correlation plot.

Granulometric data measured with the sedigraph and by the areometric method on duplicate samples were compared for the clay fraction contents in fines. From the determinations made on the same samples it appears that the clay fraction content measured with the sedigraph is 5 - 10% higher than that measured areometrically. The higher sedigraph clay fraction values are probably due to the ultrasonic mixer, which breaks the clay and mica mineral accumulations and thus increases the clay fraction content in the sample. Figure 7 shows the correlation between the clay fraction contents in fines measured with the areometric method and with the sedigraph. The correlation is high and the results are comparable.

In the comparison of grain size data, it is important to remember that methods based on Stokes' law give only approximate values for clay fraction content. The methods assume the particles to be spherical and equal in specific gravity. Stokes' law is not valid for colloidal particles. With a decrease in grain size, the shape of the particles becomes more platy, as the proportion of micas and clay minerals increases. At the same time the amount of material precipitated on the particles also increases. Particles similar in size may well differ in weight in different geological environments. Hence, the clay fraction content measured depends on the method applied.

Fines content

This study deals only with the abundances of wet-sieved fines in the <2.0 mm fraction extracted from the databank of the Department of Quaternary Geology at the GSF. The number of clasts remaining on the densest, 0.06 mm, sieve is the highest, and thus the percentage of fines is the most reliable of the percentages by mass passing determined with sieving. The fines content is worth considering, because the analyses for the regional till-geochemical mapping were based on fines.

Specific surface area

Specific surface area was measured with a method based on nitrogen sorption (Mikrometric Flow Sorb II 2300) on samples from the regional material and on <0.06 mm dry-sieved fines of the till samples from local study sites. The gas mixture used in measurements contained 30% nitrogen and 70% helium, and the samples weighed from 0.6 to 1.3 g. Both sample and gas mixture were cooled in liquid nitrogen. According to Brunauer et al. (1938), nitrogen molecules are adsorbed on the sample surface as a monomolecular layer at the temperature of liquid nitrogen. The reproducibility of the data produced by the instrument used is shown as a correlation plot in Fig. 8.

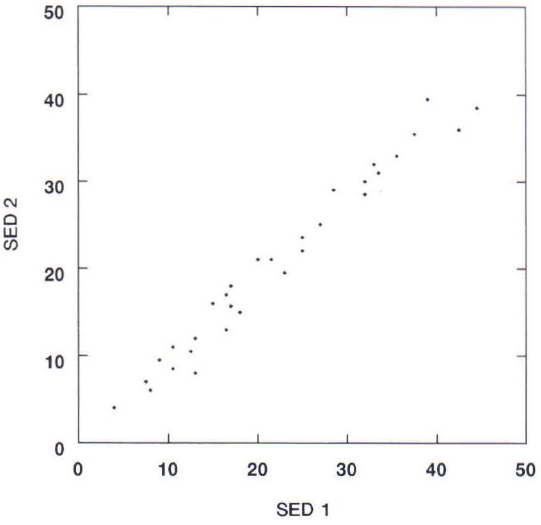


Fig. 6. Bivariate plot of duplicate clay fraction measurements. Number of duplicate samples 31. Spearman correlation coefficient 0.987.

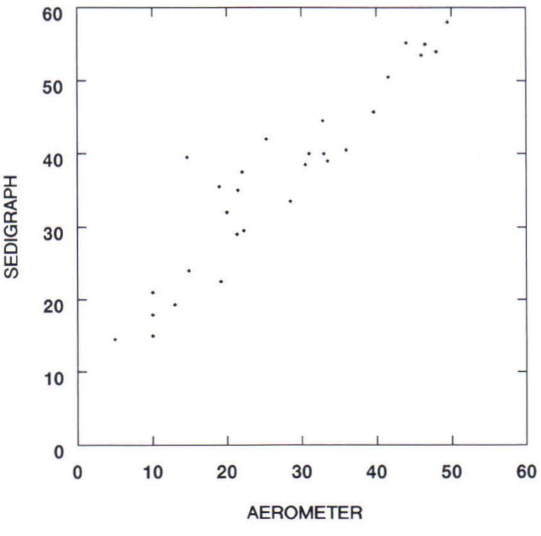


Fig. 7. Correlation between clay fraction contents measured with the areometric method and with the sedigraph. Number of duplicate samples 50. Spearman correlation coefficient 0.964.

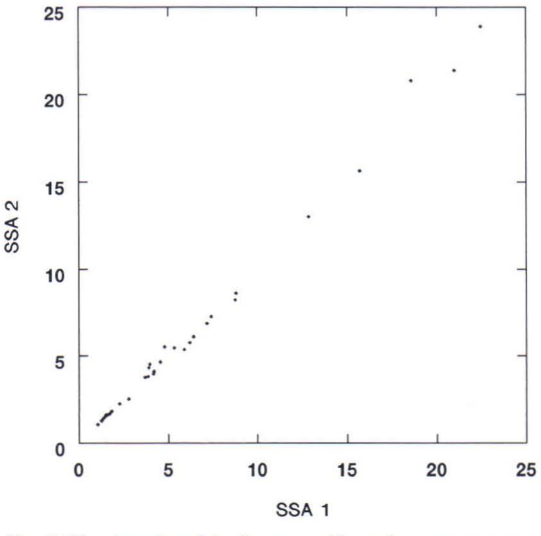


Fig. 8. Bivariate plot of duplicate specific surface area measurements. Number of duplicate samples 31. Spearman correlation coefficient 0.995.

Chemical analyses

The chemical composition of the dry-sieved <0.06 mm fines of the samples of the regional-scale geochemical mapping was analysed by inductively coupled argon plasma spectrometry in the GSF's chemical laboratory at Otaniemi. The samples were leached in aqua regia at 90°C for one hour. The leach dissolves sulphides, secondary precipitates on the surface of mineral grains and some of the micas. Biotite and chlorite and their alteration products, trioctahedral illitic micas, vermiculites and mixed-layer minerals dissolve completely in aqua regia, but the solubility of phlogopite and kaolinite varies (Räisänen et al. 1992). The solubility of hornblende increases as the mineral grains weather (Foster 1971,1973). Räisänen et al. (1992) studied the solubility of hornblende on till samples collected in central Finland. They found, however, that the 8.4 Å reflection of hornblende did not weaken in X-ray analysis after the aqua regia leach. Of the feldspars, the Ca-rich variants dissolve the most easily, particularly if weathered. Only small amounts of elements dissolve from other minerals, and then from their broken surfaces. Muscovite is insoluble in aqua regia.

X-ray diffraction analysis

Sample preparation

The mineralogy of the fines was studied with the X-ray diffraction method on samples from local study sites. Oriented aggregates were made by pipetting the desired fraction of dry-sieved <0.06 mm samples in water suspension onto a glass slide (Whitting 1973). The setting time was 3-4 minutes, corresponding to the <0.02 mm fraction. Clay mineral studies are usually based on finer fractions. However, owing to the small size of the stored samples and the paucity of clay fraction in some of the samples, the <0.02 mm fraction was also used for clay-rich samples. Many studies have shown that the fine silt in till contains the same minerals as the clay fraction (e.g. Droste 1956; Soveri & Hyyppä 1966). Reference samples were made from clay-rich samples by sucking sample suspension onto a membrane filter and turning the sample onto a slide (Drever 1973).

Three or four oriented aggregates were made for each sample after they had been: (1) dried in air at room temperature, (2) K^+ saturated at room temperature and (3,4) K^+ saturated and heated to 200°C and 550°C. In both heat treatments the sample was kept at the given temperature for one hour. The samples were K^+ saturated with a 1M KCl solution. During the saturation, the sample was stirred for 3 hours and then washed in deionized water to remove excess K^+. Expansibility was tested with ethylene glycol (5). The K^+ saturated sample was impregnated with a few drops of ethylene glycol. Till and weathered rock samples rich in iron and Al precipitates were submitted to ammonium oxalate extraction (Räisänen et al. 1992) before the K^+ saturation and heat treatments. In the extraction, the ammonium oxalate is buffered at pH 3.0 with oxalic acid. For iron-rich samples the solution to solids ratio in the extraction was 1:50; for the samples that did not remain in water suspension the ratio was 1:20. Oxalate extraction does not destroy the lattice of the clay minerals (Farmer et al.1988). The oriented aggregates were analysed with a Philips X-ray dif-

Table 1. Characteristic d-values of minerals in till sample. ETGL = ethylene glycol treatment.

Mineral	d-value
plagioclase	3.19 Å
K-feldspar	3.24 Å
quartz	4.24 Å
talc	9.4 Å
chlorite, kaolinite	7.0 Å (3.57 Å, 3.54 Å)
amphibole	8.4 Å
illite/mica	10.0 Å
mixed-layer clay mineral	12.0 Å (10-14 Å)
chlorite, vermiculite	14.0 Å
smectite	14.0 Å (16-17 Å ETGL)

fractometer in the GSF's mineralogical laboratory at Otaniemi. The samples were scanned at a rate of 1° per minute using Ni-filtered CuKα radiation. The mineralogical identification was based on the textbooks of Thorez (1975), Dixon and Weed (1977), Brindley and Brown (1980) and Wilson (1987).

Mineral identification

The mineralogy of the samples from the study profiles is based on the relative intensities of the reflections typical of each mineral (Table 1). In the classification applied, ++++ indicates a very high, and + a low abundance of the mineral in the sample; - indicates that the abundance of the mineral in the sample is very low but still measurable; ! indicates the presence of Al-hydroxy interlayers in mixed-layer minerals.

This classification gives a good enough idea of the true mineral composition of the samples for a mutual comparison of samples and study sites.

Quantitative or semiquantitative analyses were not tried as the grain size distribution of the samples varies from one area to the next. In particular, the ratio of the abundances of quartz, feldspars and amphibole to those of micas and clay minerals varies greatly, probably largely due to enrichment of the minerals in different grain size classes in till fines as a result of their dissimilar resistance to erosion (Dreimanis & Vagners 1971; Nevalainen 1983). Comparison of the samples with each other is further hampered by the dissimilar ability of the minerals to reflect X-rays, and by the large mica flakes that may occur in coarser materials. The reflection caused by a single large mica grain may occasionally be excessive.

Main silicates

Plagioclase was identified and its abundance estimated with 3.19 Å reflection. The abundance of potassium feldspar was assessed from the 3.24 Å reflection and that of quartz from 4.24 Å. Amphiboles were identified from the 8.4 Å reflection.

Micas and illites

The proportions of trioctahedral and dioctahedral micas were estimated from the 10 Å/ 5.0 Å (001/002) intensity ratios of the micas (Soveri & Hyyppä 1966; Wilson 1987; Snäll et al. 1979). Biotite and phlogopite are trioctahedral, and muscovite and sericite are dioctahedral micas. If the 5.0 Å reflection is weak in relation to the 10 Å reflection the mica is trioctahedral. Illite is a partly weathered mica with a broad 10 Å reflection sloping towards smaller angles. The proportions of mica and illite in a sample were estimated from the 10 Å intensity of an untreated sample or an oxalate-extracted sample.

Chlorite

Chlorite was identified from the 3.54 Å, 7.1 Å and 14.2 Å reflections. The abundance of chlorite was estimated by comparing the 7 Å and 14 Å reflections of K^+ saturated sample at room temperature and at 550°C. The intensity of chlorite is the residual 7 Å intensity plus the increment in the intensity of the sample's 14 Å reflection. This assessment does not distinguish between chlorite mechanically loosened from the bedrock and the secondary chlorite that forms when Al hydroxide precipitates in mixed-layer minerals.

Kaolinite

Kaolinite was identified from the 3.57 Å and 7 Å reflections. Its abundance was estimated from the 7 Å reflection by assuming the intensity of the 7 Å reflection of untreated samples to represent kaolinite, chlorite and chlorite-bearing mixed-layer minerals. When heated to 550°C, kaolinite decomposes, and the 7 Å reflection is due to chlorite (Wilson 1987). As the intensity of chlorite's 14 Å reflection increases at 550°C, the abundance of kaolinite was estimated roughly by deducting the intensity of the 7 Å reflection measured at 550°C from that of an untreated sample plus the increment in the intensity of the 14 Å reflection. In ambiguous cases the identification was checked by infra-red spectroscopy.

Mixed-layer clay minerals

It is typical of the mixed-layer minerals containing vermiculite that the 12 Å and 14 Å reflections partly shift to the range of the 10 Å reflection in K^+ treatment (Barnhisell 1977). This is due to the replacement of H^+ ions in the lattice of partially weathered mica by K^+ ions, as a result of which the mixed-layer mineral gets back the 10 Å d-value of mica. The proportion of vermiculite in mixed-layer minerals was assessed from the reduction in the 14 Å intensity of the untreated sample in relation to that of K^+ saturated sample.

Al-hydroxy interlayered clay minerals

Partial collapse of the crystal structure to the range of 10 Å in K^+ treatment is typical of mixed-layer clay minerals (14 Å, 12 Å). The final shift does not occur until a temperature of 200°C or 550°C is reached. According to Barnhisell (1977), the greater the polymerization degree of the Al hydroxide incorporated in the interlayers of 14 Å and 12 Å mixed-layer clay minerals, the higher is the temperature needed to alter a mineral into a 10 Å mica. With the filling of the interlayers and the increase in Al-hydroxy polymerization it becomes increasingly difficult to distinguish between the mineral structure thus forming and the structure of the primary chlorite, which does not alter in thermal treatment (Barnhisell 1977; Weaver 1989). Establishing the origin of mixed-layer minerals is further hampered by primary chlorite from the bedrock, which is common in the samples, and the chlorite-vermiculite interstratified clay mineral, which is also present as an alteration product of chlorite (Droste 1956).

Smectite

Expanding-lattice smectite-group clay minerals were identified, and their proportions were estimated from the shift of the 14 Å reflection of K^+ saturated sample to the 16-17 Å range with etylene glycol treatment (Macewan 1944; Wilson 1987).

Infrared spectroscopy

Infrared spectroscopy (IR) was mainly used for identifying kaolinite. Samples were submitted to IR analysis if kaolinite could not be identified for sure by X-ray diffraction. The presence of kaolinite was checked when the 7 Å reflection in diffraction traces was high in relation to the 14 Å peak of the K^+ saturated sample.

The IR samples were prepared by taking 3 mg of powder from the air-dried oriented X-ray samples and mixing it with 350 mg of KBr. The mixture was powdered in an agate mortar. Half of the mixture was pressed into a briquette and analysed by IR in the GSF's mineralogical laboratory with a Perkin-Elmer 983 instrument in a range of 4000-180 cm^{-1}. The kaolinite in the samples was identified from the 3700 and 3620 cm^{-1} absorption bands in the IR spectra (Russel 1987).

RESULTS

Regional properties of till fines

Regional variation in silt and clay fraction contents and in specific surface area of fines

Grain size distribution measured with a sedigraph is shown in the triangular diagram in Fig. 9 plotted in terms of proportions of clay fraction, fine silt and coarse silt in the whole material. The diagram does not show a clear distribution of samples into different populations. The distribution of the clay fraction content in fines into different classes is given as a histogram in Fig. 10. In about 80% of the samples the fines contained 5-20% clay

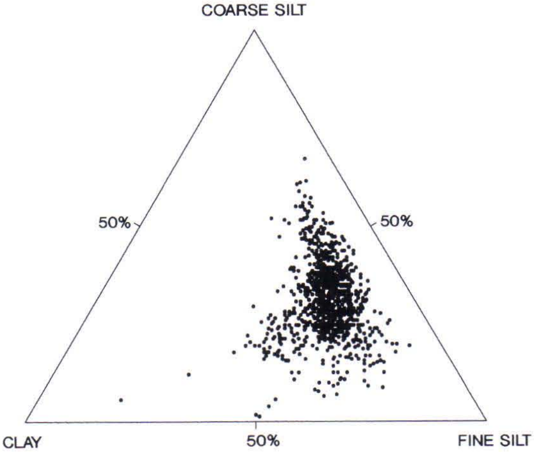


Fig. 9. Triangular diagram showing the proportions of clay (<0.002 mm), fine silt (0.002 - 0.02 mm) and coarse silt fraction (0.02 - 0.06 mm) in the till fines of 1015 samples from Finland.

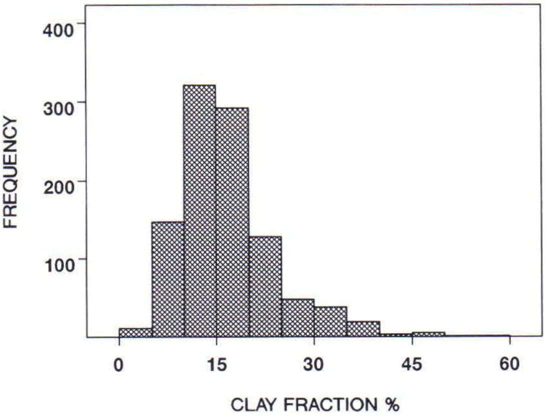


Fig. 10. Frequency distribution of clay fraction content in fines. Number of samples 1015.

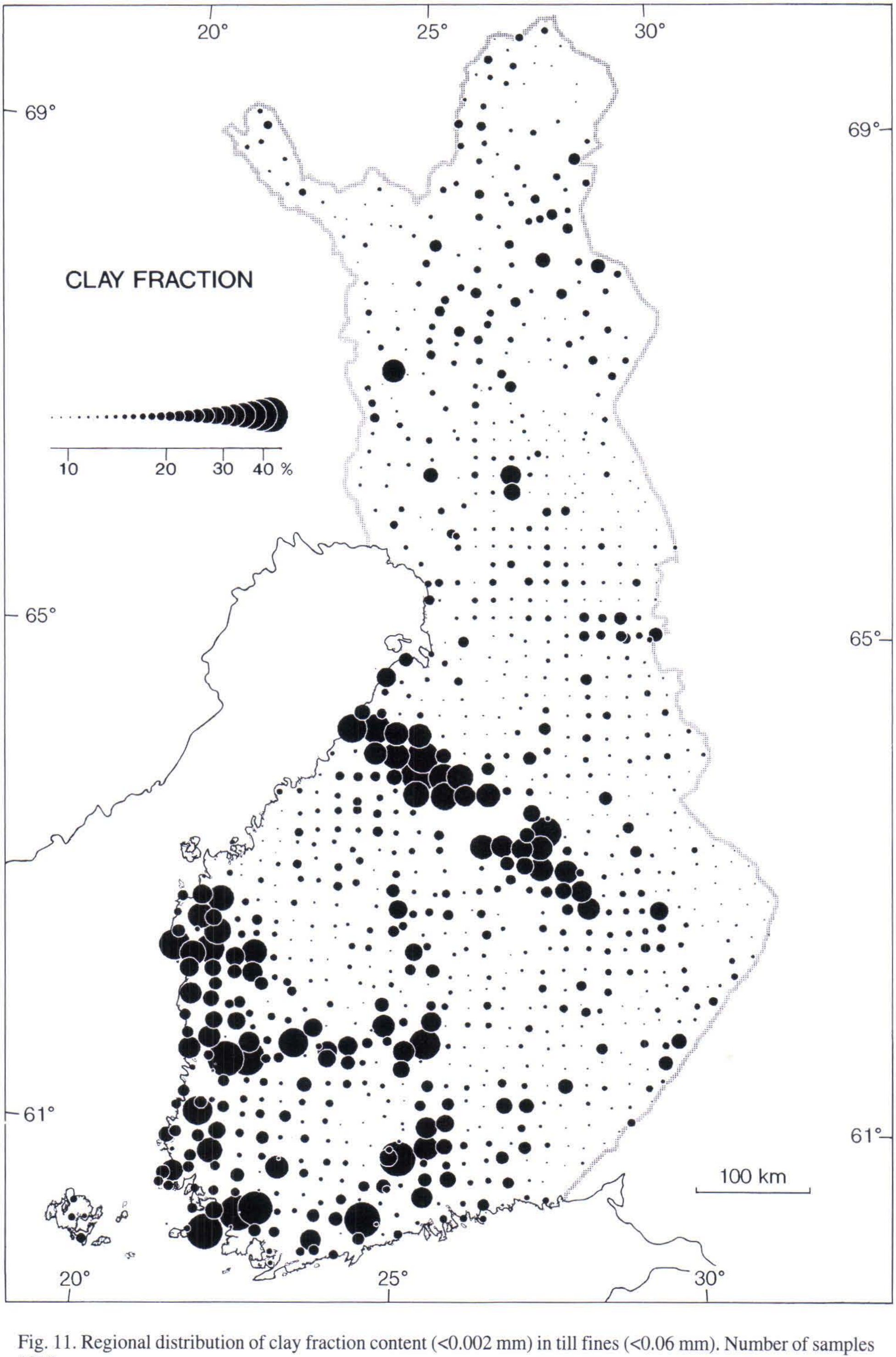


Fig. 11. Regional distribution of clay fraction content (<0.002 mm) in till fines (<0.06 mm). Number of samples 1015.

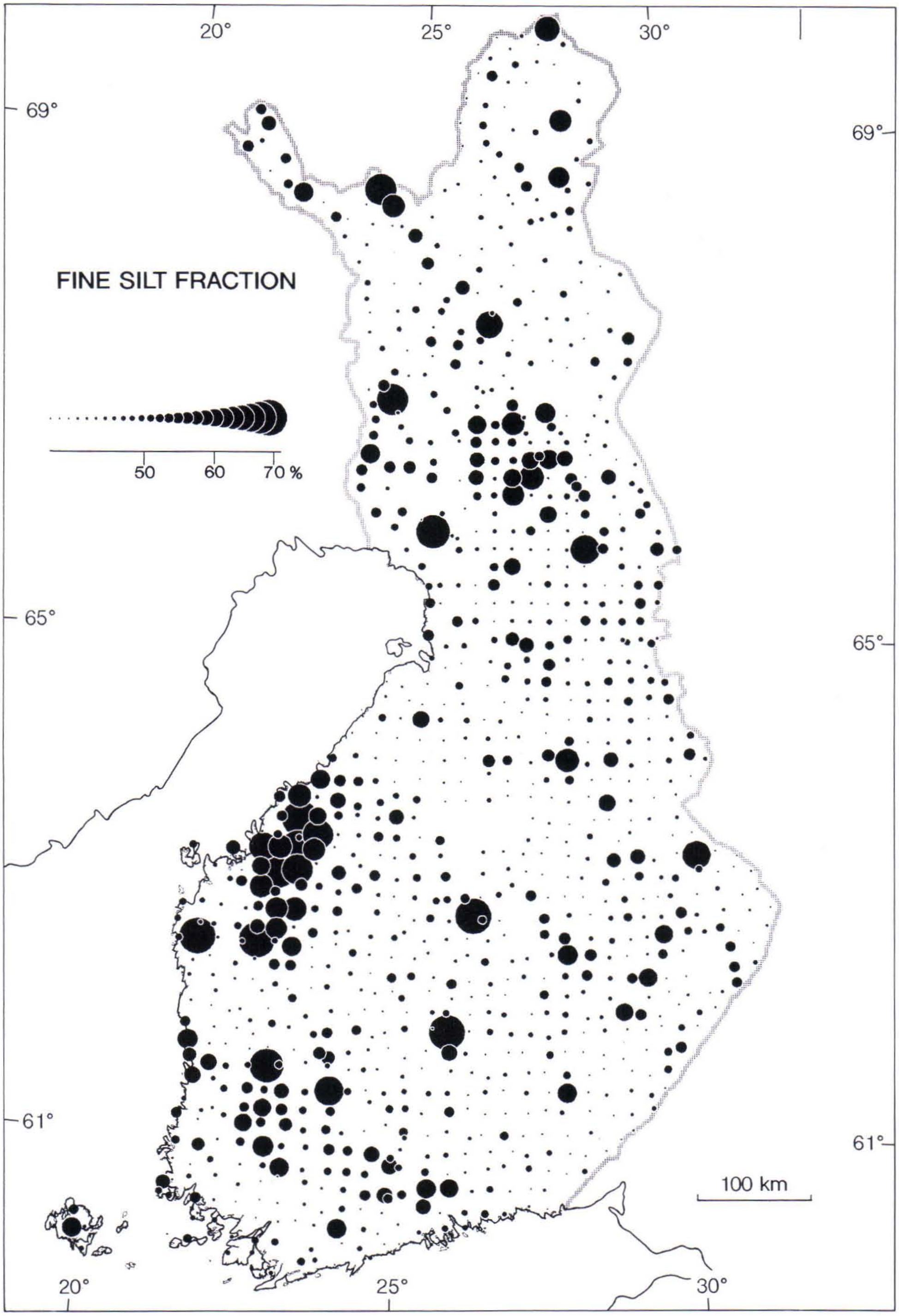


Fig. 12. Regional distribution of fine silt (0.002 - 0.02 mm) in till fines (<0.06 mm). Number of samples 1015.

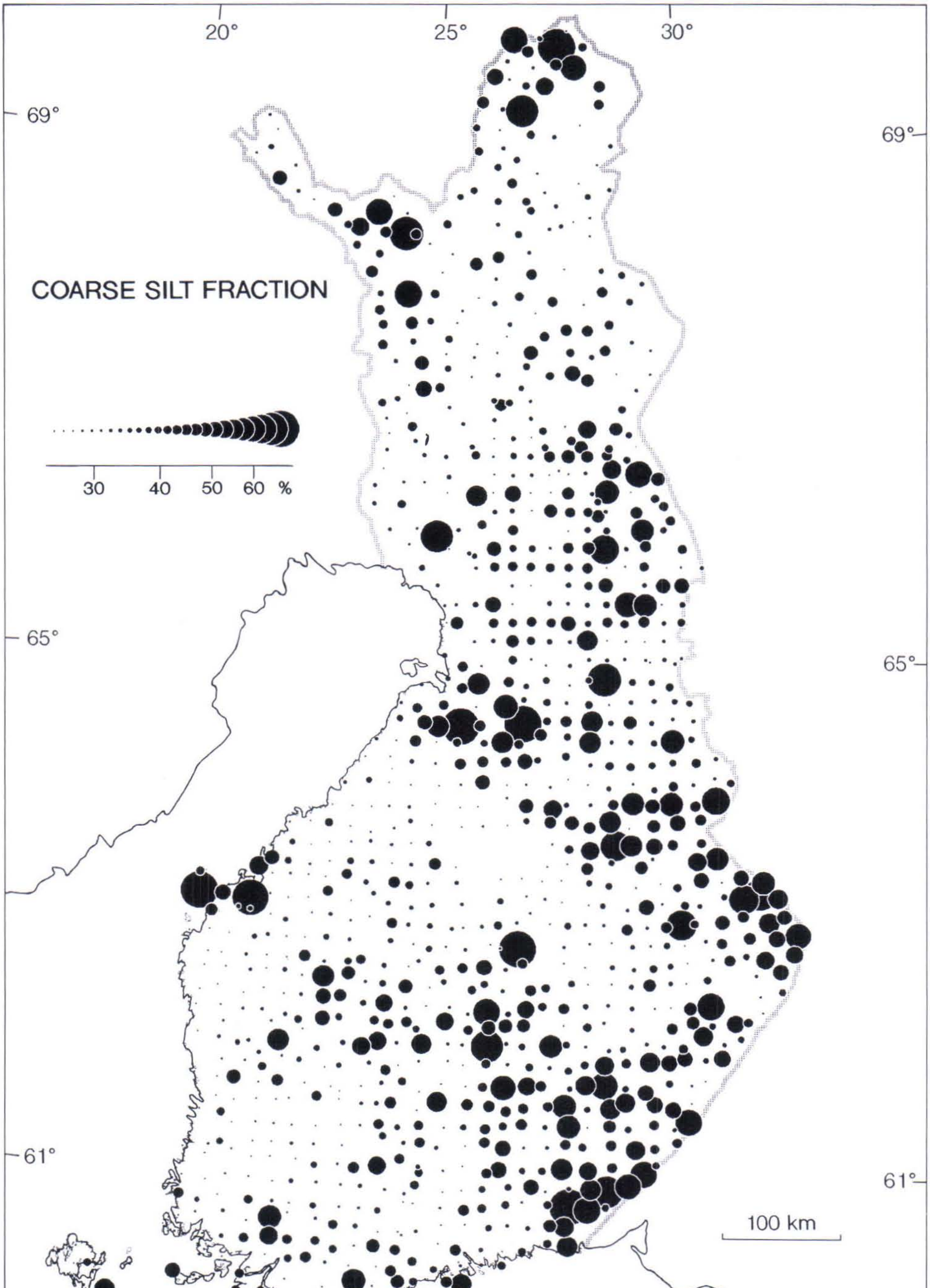


Fig. 13. Regional distribution of coarse silt (0.002 - 0.02 mm) in till fines (<0.06 mm). Number of samples 1015.

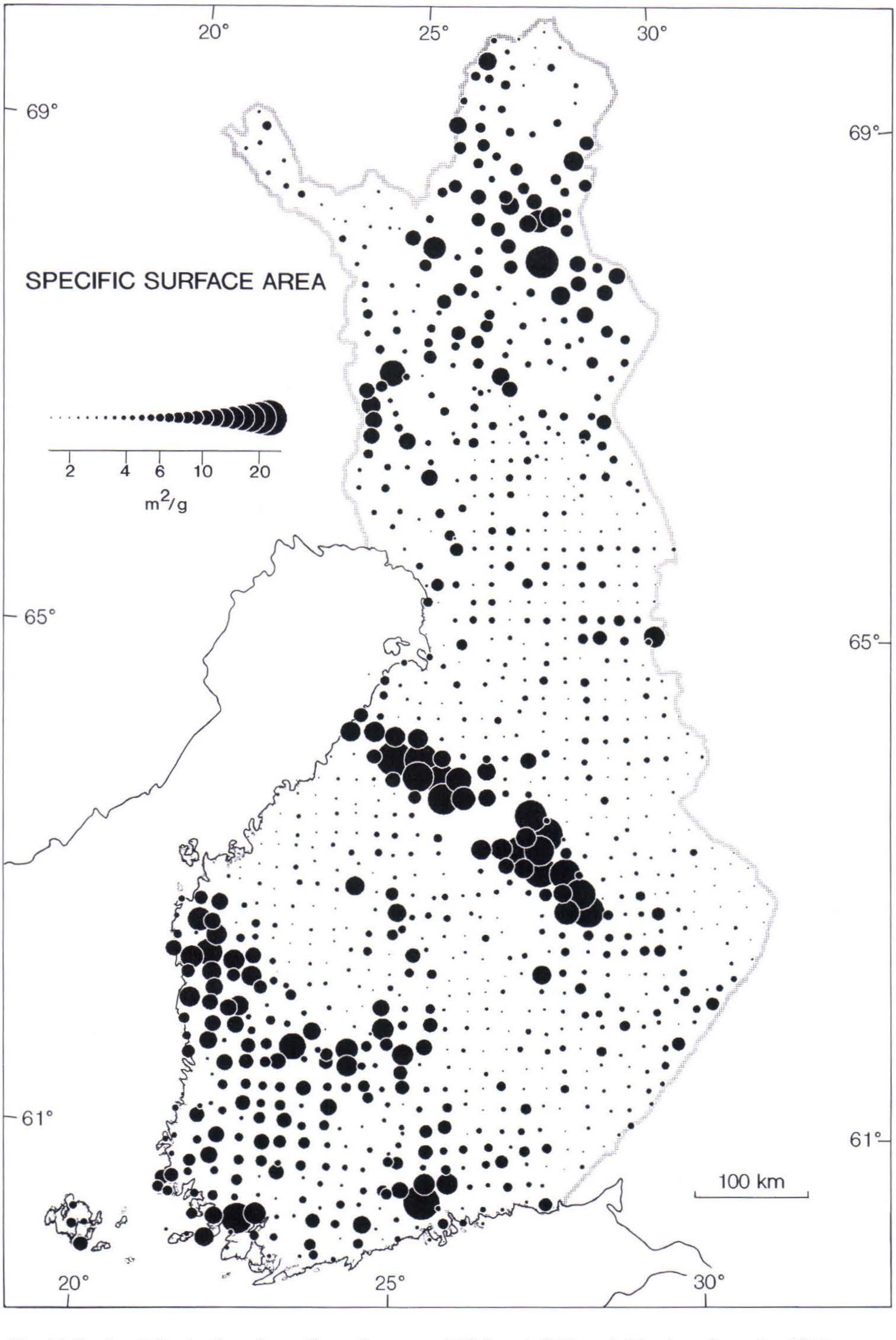


Fig. 14. Regional distribution of specific surface area of till fines (<0.06 mm). Number of samples 1015.

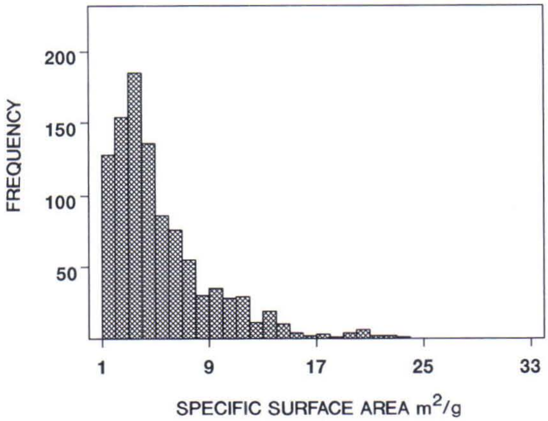


Fig. 15. Frequency distribution of specific surface area of till fines. Number of samples 1015.

fraction. High clay fraction contents, exceeding 30%, were found in only about 10% of the samples. As the samples cover the study area fairly evenly the result can be taken as an estimate of the frequency distribution of high clay fraction content in till fines in Finland. The distribution of the clay fraction content in till fines is presented as a ball symbol map in Fig. 11. The size of the ball refers to the clay fraction content in <0.06 mm fines. High clay fraction contents in fines occur in the northwestern part of the Lake Ladoga-Bothnian Bay zone, in southern Ostrobothnia and locally in Häme and southeastern Finland.

The regional distribution of the silt fraction in till fines in terms of proportions of 0.002 - 0.02 mm and 0.02 - 0.06 mm fractions are shown in Figs 12 and 13. Coarse silt is clearly most abundant in the supra-aquatic area in eastern and northern Finland. Fine silt is anomalously abundant in the area between Vaasa and Kokkola on the coast of Ostrobothnia.

The distribution of the specific surface area of till fines is given as a histogram in Fig. 15. The data show a bimodal distribution. About 70% of the samples have a specific surface area of 1 - 8 m^2/g. The specific surface area of a smaller population comprising a few percent of the samples is 20 - 22 m^2/g. The regional distribution of the specific surface area of till fines, which is presented as a ball symbol map in Fig. 14, closely resembles the distribution of the clay fraction content in fines. Anomalously high values have been measured on samples from the northwestern part of the Lake Ladoga-Bothnian Bay zone and southern Ostrobothnia and also on several samples from Häme and southwestern Finland. Values high in relation to clay fraction content have been measured on samples from all over Lapland. Especially in central Lapland the specific surface area values are anomalously high in relation to clay fraction content.

Regional variation in fines content

Figure 17 is a histogram showing the distribution of fines contents (0.06 mm) in 5437 till samples with a grain size of less than 2 mm. The data exhibit almost normal distribution. About 80% of the samples contain 20 - 55% fines. In 10% of the samples the fines content exceeds 55%.

Figure 16 gives the regional distribution of fines contents in the <2.0 mm till fraction. Unlike the material used for the regional-scale geochemical mapping, that of the GSF's laboratory is unevenly distributed. The cartographic software used computes a value for each pixel by taking into consideration the survey data within a radius of 38 km from the centre of a circle. The value of the pixel is the average in which the data from sites closest to the centre have the highest weights.

The regional distribution of the fines content differs clearly from that of the clay fraction content and specific surface area of the <0.06 mm fraction. The fines content is high

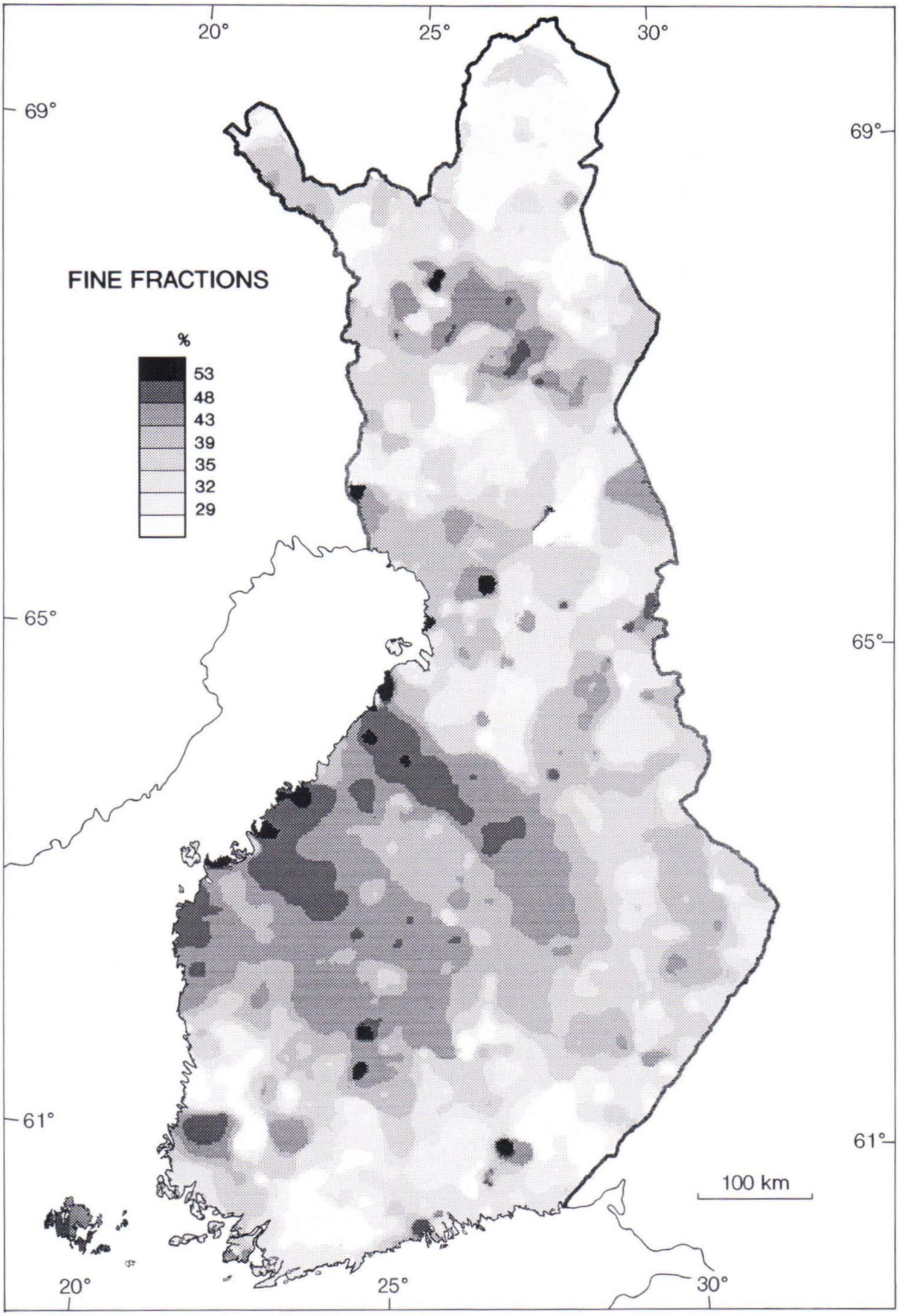


Fig. 16. Regional distribution of fines (<0.06 mm) in the <2.0 mm till fraction. Number of samples 5437. White areas are without sample coverage.

in some places in the area between the Lake Ladoga-Bothnian Bay zone and the Central Finland ice-marginal formation. Elevated fines contents also occur in Häme, central Lapland and here and there in various parts of the study area.

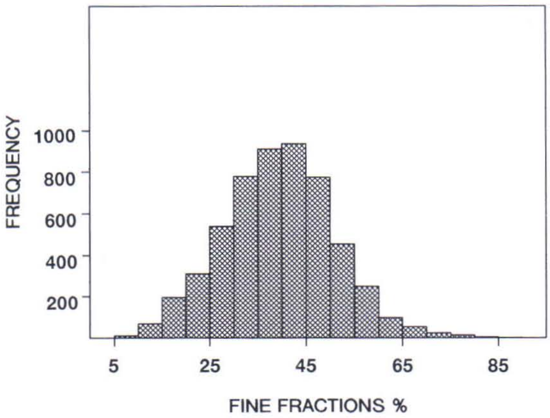


Fig. 17. Frequency distribution of fines contents (<0.06 mm) in the <2.0 mm till fraction. Number of samples 5437.

Correlation between grain size distribution, specific surface area and chemical analytical data

The correlations of the clay fraction content in till fines, proportions of fine and coarse silt and specific surface area (Spearman correlation coefficient) with the aqua regia-soluble metal concentrations were calculated. In visual examination, the anomaly patterns of the clay fraction content and specific surface area of till fines coincide partly with the results of the reconnaissance-scale geochemical mapping (Koljonen 1992). The correlations for 1015 samples collected from the material of the regional-scale geochemical mapping were calculated for three areas. The correlations were also calculated for material covering the whole of Finland; for map sheets 24 and 34, which partly cover the northwestern part of the till-geochemical Lake Ladoga-Bothnian Bay zone; and for southern Finland with the northern margin of map sheets 25, 35 and 45 as a boundary (Fig. 18). Correlation matrices are given in Tables 2, 3 and 4.

The correlations of the clay fraction content in fines and specific surface area with the aqua regia-soluble elements are poor for the whole of Finland. The correlation coefficients for aqua regia-soluble Al, Ba, Co, Li, Mn, Cu, Fe, V and Zn concentrations are in the range of 0.38 - 0.59. The highest correlation, 0.63, is between Fe concentration and specific surface area. Other elements analysed show a positive but very weak or nonexistent correlation with clay fraction content and specific surface area. The other grain size classes, 0.002 - 0.02 mm and 0.02 - 0.06 mm, have a nonexistent or negative correlation with elemental concentrations.

In southern Finland the correlation coefficients between the Al, Co, Fe, Li, Mg, Mn, Ti, V and Zn concentrations and the clay fraction content and specific surface area are in the range of 0.52 - 0.66. The correlation coefficients between other elements and clay fraction content and specific surface area are also low. The correlations between the coarse and fine silt fraction and elemental concentra-

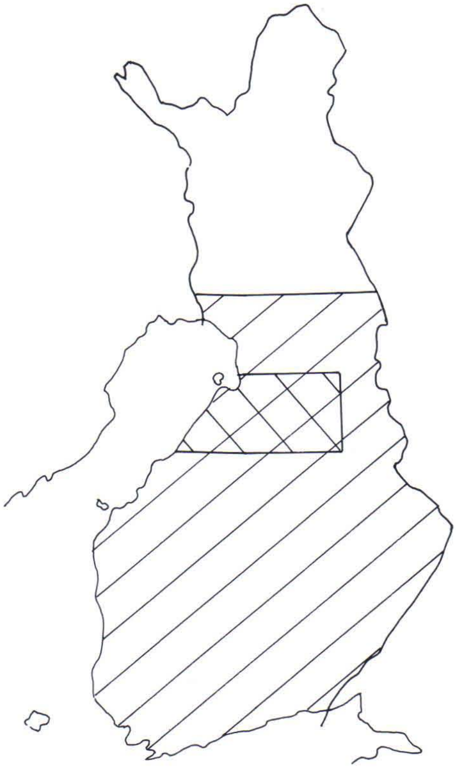


Fig. 18. Geographical subdivisions of Finland used in calculating the correlation between grain size distribution, specific surface area and chemical analytical data of till fines.

tions are low.

In the northwest of the till-geochemical Lake Ladoga-Bothnian Bay zone the correlation coefficients between the Al, Ba, Co, Fe, La, Li, Mg, Mn, Sc, Sr, V, Y and Zn concentrations range from 0.45 to 0.84. The correlation coefficients between specific surface area and Fe, La, Li and Mn concentrations are in the range of 0.72 - 0.84. The correlations of the fine and coarse silt fractions with the elemental concentrations are weak.

Table 2. Correlation matrix for aqua regia-soluble elemental concentrations and physical properties. SSA = specific surface area, clay fraction (<0.002 mm), fsilt = fine silt fraction (0.002 -0.02 mm) and csilt = coarse silt fraction (0.02 - 0.06 mm) in Finland.

	Al	Ba	Ca	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Ni	Sc	Ti	V	Zn	SSA	clay	fsilt	csilt
Al	1.00																			
Ba	.70	1.00																		
Ca	-.06	.04	1.00																	
Co	.70	.70	.06	1.00																
Cr	.45	.30	-.04	.66	1.00															
Cu	.58	.58	.07	.72	.44	1.00														
Fe	.79	.72	.03	.81	.54	.69	1.00													
K	.48	.70	.03	.53	.24	.49	.64	1.00												
Li	.54	.44	.03	.41	.19	.34	.60	.69	1.00											
Mg	.54	.60	.55	.69	.53	.56	.69	.60	.50	1.00										
Mn	.46	.57	.13	.69	.29	.46	.69	.55	.52	.56	1.00									
Ni	.49	.41	.00	.74	.83	.54	.56	.28	.19	.55	.39	1.00								
Sc	.02	.01	.00	.02	-.01	-.01	.01	.01	.02	-.01	.01	-.01	1.00							
Ti	.64	.64	.07	.66	.40	.54	.80	.67	.61	.61	.64	.36	.01	1.00						
V	.75	.67	.03	.81	.64	.66	.91	.53	.44	.68	.55	.59	-.01	.80	1.00					
Zn	.66	.66	.06	.64	.30	.55	.78	.71	.74	.59	.64	.42	.02	.67	.63	1.00				
SSA	.56	.47	-.00	.49	.27	.32	.64	.40	.48	.39	.51	.27	.00	.53	.54	.55	1.00			
clay	.40	.40	.03	.38	.17	.22	.52	.46	.59	.37	.51	.18	.00	.49	.39	.59	.76	1.00		
fsilt	.04	.01	-.05	.08	.08	.10	.10	.13	.10	.11	.08	.03	.20	.08	.09	-.05	-.08	-.02	1.00	
csilt	-.31	-.29	-.02	-.32	-.17	-.20	-.43	-.40	-.50	-.33	-.44	-.18	-.02	-48	-.32	-.47	-.49	-.70	-.72	1.00

Table 3. Correlation matrix for aqua regia-soluble elemental concentrations and physical properties in southern Finland. For symbols, see Table 2.

	Al	Ba	Ca	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Ni	Sc	Ti	V	Zn	SSA	clay	fsilt	csilt
Al	1.00																			
Ba	.69	1.00																		
Ca	-.03	.23	1.00																	
Co	.69	.75	.31	1.00																
Cr	.68	.68	.05	.79	1.00															
Cu	.61	.64	.12	.72	.64	1.00														
Fe	.83	.78	.20	.80	.77	.67	1.00													
K	.72	.80	.14	.77	.77	.67	.84	1.00												
Li	.78	.52	.11	.62	.61	.47	.79	.71	1.00											
Mg	.78	.80	.20	.86	.85	.71	.91	.88	.73	1.00										
Mn	.62	.66	.46	.78	.56	.50	.79	.66	.64	.74	1.00									
Ni	.39	.46	.06	.67	.74	.51	.50	.49	.34	.60	.44	1.00								
Sc	.02	.01	.01	.02	-.01	-.02	.00	.01	.01	-.01	.00	-.02	1.00							
Ti	.78	.73	.36	.73	.69	.57	.84	.78	.71	.82	.74	.40	.01	1.00						
V	.80	.78	.19	.80	.82	.69	.92	.85	.70	.91	.70	.51	-.01	.87	1.00					
Zn	.76	.66	.19	.75	.67	.58	.88	.77	.83	.81	.73	.49	.01	.75	.79	1.00				
SSA	.61	.48	.15	.59	.43	.32	.66	.43	.52	.53	.64	.26	-.00	.54	.60	.57	1.00			
clay	.58	.45	.19	.52	.44	.27	.64	.45	.60	.54	.63	.26	-.01	.56	.56	.63	.81	1.00		
fsilt	.07	-.00	.08	.08	.08	.07	.0.9	.14	.15	.14	.11	.06	.03	.18	.08	.11	-.08	-.02	1.00	
csilt	-.47	-.33	-.19	-.44	-.38	-.25	-.53	-.43	-.55	-.49	-.54	-.23	-.02	-.53	-.47	-.54	-.53	-.71	-.68	1.00

Table 4. Correlation matrix for aqua regia-soluble elemental concentrations and physical properties in the northwestern part of the Lake Ladoga-Bothnian Bay zone (in the area of map sheets 24 and 34, Fig. 16). For symbols, see Table 2.

	Al	Ba	Ca	Co	Cr	Cu	Fe	K	Li	Mg	Mn	Ni	Sc	Ti	V	Zn	SSA	clay	fsilt	csilt
Al	1.00																			
Ba	.87	1.00																		
Ca	.43	.12	1.00																	
Co	.88	.88	.21	1.00																
Cr	.89	.86	.02	.81	1.00															
Cu	.75	.70	.18	.75	.69	1.00														
Fe	.91	.89	.28	.91	.85	.67	1.00													
K	.89	.84	.03	.84	.84	.67	.85	1.00												
Li	.74	.79	.17	.74	.69	.46	.85	.71	1.00											
Mg	.92	.86	.18	.88	.88	.75	.90	.89	.71	1.00										
Mn	.67	.74	.36	.84	.58	.47	.83	.57	.78	.67	1.00									
Ni	.85	.85	.05	.86	.93	.72	.83	.79	.65	.87	.66	1.00								
Sc	.95	.89	.13	.89	.89	.76	.92	.91	.80	.89	.70	.86	1.00							
Ti	.89	.74	.24	.83	.79	.76	.81	.82	.56	.83	.60	.78	.89	1.00						
V	.93	.89	.26	.88	.88	.75	.96	.89	.79	.93	.73	.85	.95	.86	1.00					
Zn	.64	.74	.16	.70	.68	.46	.72	.53	.79	.63	.72	.73	.74	.53	.72	1.00				
SSA	.55	.60	.29	.66	.43	.26	.72	.45	.74	.53	.84	.45	.56	.40	.60	.55	1.00			
clay	.50	.59	.38	.59	.45	.27	.69	.36	.71	.51	.79	.42	.52	.34	.58	.60	.36	1.00		
fsilt	.27	.20	-.16	.26	.34	.23	.20	.24	.05	.31	.14	.41	.29	.40	.26	.22	-.10	-.08	1.00	
csilt	-.57	-.59	-.28	-.63	-.59	-.37	-.67	-.44	-.57	-.61	-70	-.61	-60	-.54	-.63	-.61	-.59	-.70	-.65	1.00

Till mineralogy

The relative mineralogical compositions of 34 study pit samples estimated from the X-ray diffraction data are given in Appendix 1. The location of the study sites is shown in Fig. 5 together with the distribution of bedrock areas after Simonen (1980). Figure 19 gives the study sites in relation to eskers and ice-marginal formations.

Main silicates

All the samples of till fines studied contained feldspars, quartz and amphiboles. Of the feldspars, plagioclase was clearly more abundant than potassium feldspar. The plagioclase was usually an Na-rich type as shown by distinct reflections at d-values of 6.3 - 6.4 Å, 4.02 Å and 3.19 Å. As a rule, plagioclase was the most abundant main silicate. Quartz occurred in varying abundances in all samples. Amphiboles were present in most of the samples, the coarsest one often showing the 3.12 Å reflection typical of hornblende. The abundance of hornblende varied less than those of the other main silicates.

Micas and illites

The 10 Å reflection typical of micas was recorded from all samples. For the samples poor in clay fraction, the 10 Å reflection was usually sharp and narrow, referring to the presence of unweathered biotite or muscovite in the sample. In the X-ray diffraction traces, the intensity of the 5 Å reflection was usually very weak in relation to the intensity of the 10 Å reflection. On the basis of the 10 Å/5.0 Å (001/002) intensity ratios of the micas (Snäll et al. 1979; Wilson 1987), trioctahedral micas (biotite, phlogopite) are distinctly more common than dioctahedral micas (muscovite, sericite). Soveri and Hyyppä (1966) and Räisänen et al. (1992) have also found that trioctahedral micas are more common than dioctahedral micas in the till fines of Finland.

Illite, with a broad reflection sloping towards small angles in the range of 10.0 - 10.3 Å, is typical of clay-rich samples. Illite was not of the nonexpanding-lattice dioctahedral type described by Sroden and Eberlin (1984) or of the partly expanding-lattice type with a smectite component described by Wilson (1987). According to Räisänen et al. (1992), the illite is probably a partly weathered mica. Trioctahedral types are more common than dioctahedral types in illites as in micas.

Chlorite and talc

Chlorite, which was a common mineral in fines, comprises a group of minerals varying in composition that are difficult or impossible to identify accurately from mineral mixtures (Marel 1959; Wilson 1987). The chlorite in till samples may be mechanically crushed from the bedrock or secondary chlorite formed when Al liberated in podzol processes and precipitated as Al hydroxide in interlayers of vermiculite.

Talc was identified from the 9.4 Å reflection. It occurred particularly in chlorite-rich samples from the schist belts of central Lapland and Kuhmo.

Kaolinite

Kaolinite is a common mineral in till and weathered rock samples from the weathered bedrock area of central Lapland, being in places the predominant mineral. It is also encountered in varying abundances elsewhere in Finland. In the Virtasalmi weathered bedrock occurrence kaolinite is the main mineral. Till fines in Åland contain abundant kaolinite.

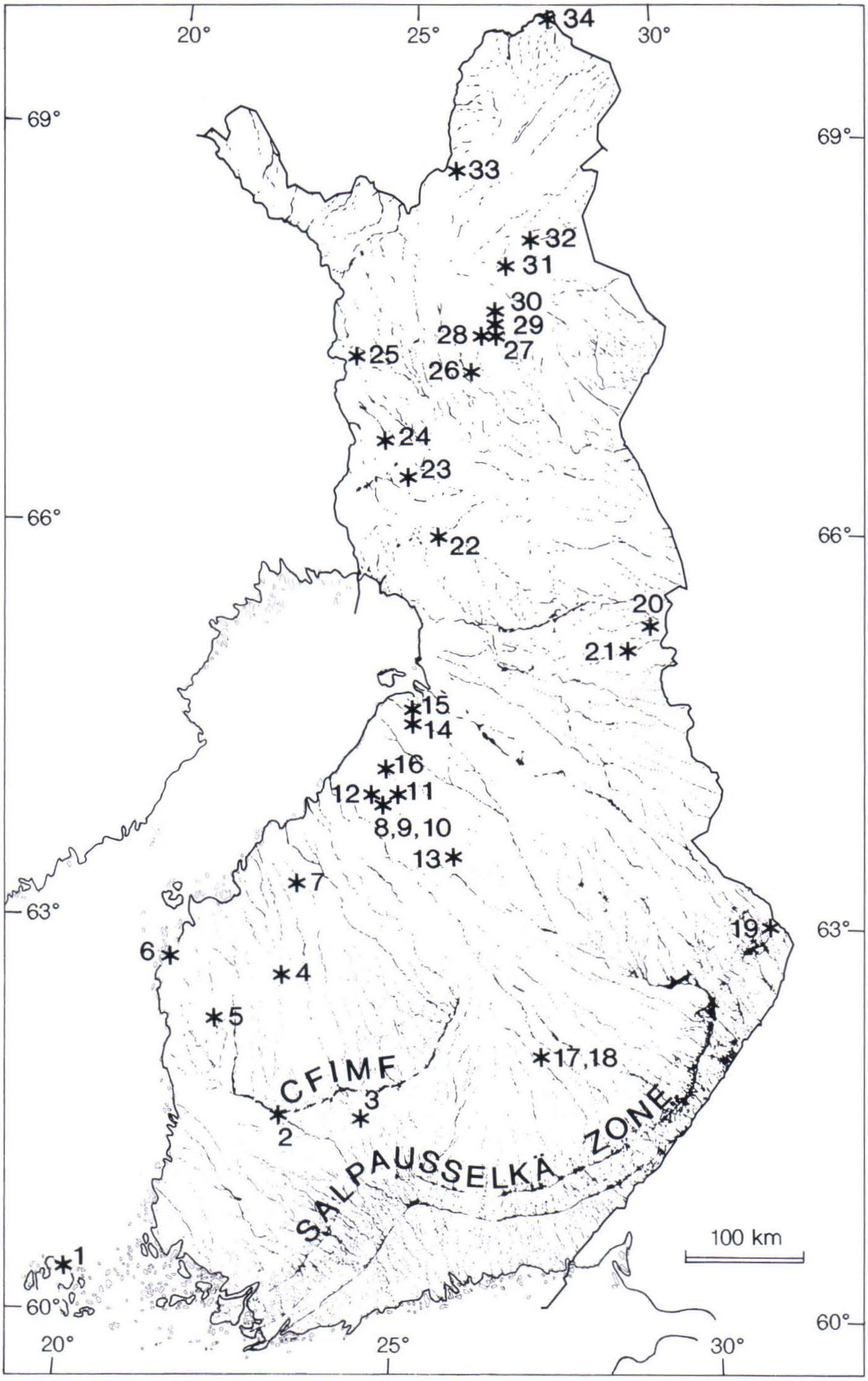


Fig. 19. Eskers and ice-marginal formations in Finland after Kujansuu & Niemelä (1984) and sampling sites. CFIMF = Central Finland ice-marginal formation. The samples are described and the mineralogical results are given in appendix 1.

The 3.54 Å reflection of chlorite minerals and the 3.57 Å reflection typical of kaolinites often formed a clear double peak in X-ray diffraction traces. The identification was not always indisputable, as absorption bands 3700 and 3620 cm^{-1} of the IR analysis were weak, even when the X-ray diffraction analysis gave a clear indication of the presence of kaolinite.

The 7 Å reflection of some samples had widened towards smaller angles. For the samples from Rautuvaara the broad reflection was in the range of 7 - 8.5 Å (Fig. 20), but shifted to 12 Å during the heat treatment. The 12 Å reflection indicates a mixed-layer mineral of mica and vermiculite. The IR analyses (Fig. 21) of the samples showed 3700 and 3620 cm^{-1} bands typical of kaolinite. The Rautuvaara samples contained a mixed-layer mineral that has not been defined in detail but whose components include kaolinite and partly weathered mica. Soveri and Hyyppä (1966) have described a similar mineral in till samples on the basis of X-ray diffraction determinations.

Mixed-layer clay minerals

The surficial samples of the profiles often show 14 Å and 12 Å reflections, which move partly or totally to 10 Å after the K^+ treatment. These reflections are typical of mixed-layer clay minerals (Wilson 1987). On the basis of the proportions of components, the 14 Å mixed-layer clay minerals are chlorite-vermiculite or vermiculite-chlorite. The partial shift of the 14 Å reflection of an untreated sample to the range of 10 Å after K^+ treatment

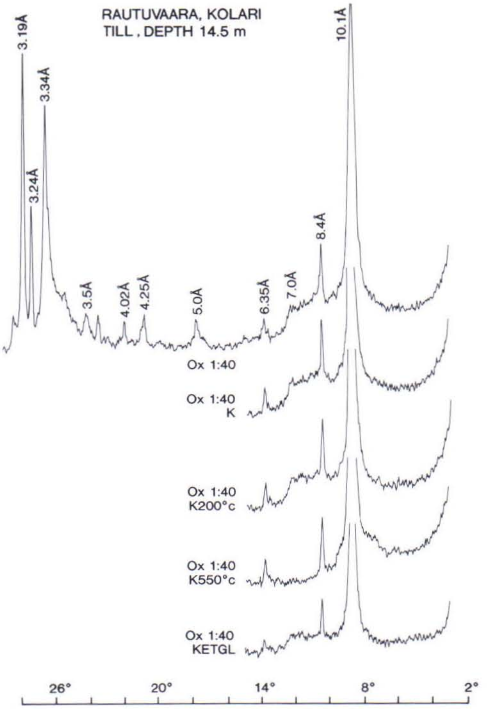


Fig. 20. X-ray diffraction traces typical of the oriented aggregates (<0.02 mm fraction) from Rautuvaara section. Note diffuse reflections between 7 Å and 8 Å. OX = oxalate extracted, K = K^+ saturated, K200°C = K^+ saturated and heated to 200°C, K550°C = K^+ saturated and heated to 550°C. KETGL = K^+ saturated and treated with ethylene glycol. The IR spectra of the same sample is shown in Fig. 21.

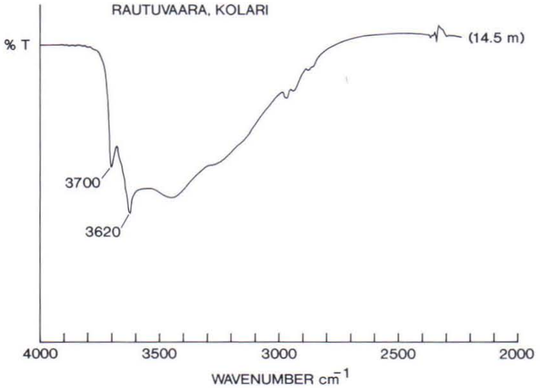


Fig. 21. IR spectra of a sample from Rautuvaara. The 3700 and 3620 cm^{-1} bands are characteristic of kaolinite. The X-ray diffraction traces of the same sample are shown in Fig. 20.

indicates the content of the vermiculite component in the mixed-layer clay mineral. In some cases, the 14 Å reflection moves entirely to the range of 10 Å, implying the presence of pure vermiculite in the sample. The samples from the surficial parts of the profiles often show a weak 12 Å reflection, usually low in intensity in relation to that of the 14 Å reflection. The mineral has been classified as a mixed-layer mica-vermiculite. It does not expand in ethylene glycol treatment.

Al-hydroxy interlayered mixed-layer clay minerals

In two-thirds of the study profiles the samples taken from the oxidized layer closest to the surface contained Al hydroxides polymerized in the 12 Å and 14 Å interlayers of the mixed-layer clay minerals. Al hydroxides occurred in the interlayers of the mixed-later clay minerals in both clay-rich and clay-poor tills, particularly in the surficial parts of the study pits with a distinct and thick oxidized horizon. Some samples from the weathered rock also contained Al-hydroxy interlayered mixed-layer clay minerals.

Smectite

The 14 Å reflection of the till and clay samples does not expand in ethylene glycol treatment. The fines of some weathered rock samples contain a partly expanding 14 Å mixed-layer clay mineral that expands and shows a diffuse reflection in the range of the 17 Å reflection. Obviously some of the components of the mixed-layer clay mineral have altered into an expanding-lattice mineral resembling smectite.

EXAMINATION OF RESULTS

Relationship between clay fraction content and specific surface area

The correlation between three grain size classes and the specific surface area of till fines is given in Table 2 for 1015 samples from a regular grid covering all Finland. Clay fraction content has the highest correlation with specific surface area. The fine silt (0.002 - 0.02 mm), however, does not correlate with the specific surface area of the samples. Coarse silt exhibits a negative correlation with specific surface area. This is to be expected, as the surface area increases with the increase in the amount of clay fraction, and the presence of coarse silt reduces the surface area. According to Nieminen (1985), the specific surface area of till fines in Finland depends mainly on the amount of clay fraction. Figure 22 shows the correlation between the clay fraction and the specific surface area of

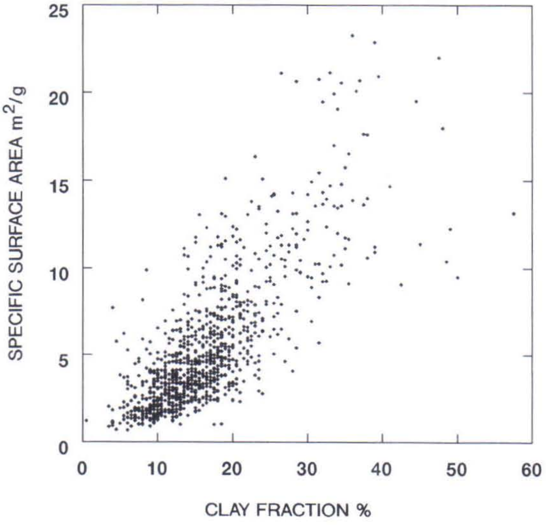


Fig. 22. Clay content of fines and specific surface area of fines. Number of samples 1015. Spearman correlation coefficient 0.81.

till fines. Some samples have a distinctly higher specific surface area than one would expect from the amount of clay fraction. Specific surface area is high in relation to clay fraction content in central Lapland. High specific surface area values may be due to precipitates on mineral grains (Carlson & Schwertmann 1981; Nieminen 1985) or to weathered minerals (Nieminen et al. 1985).

Regional till provinces

The fines content, the clay fraction content of fines and specific surface area data reveal regional differences between Finnish tills. Figure 23 distinguishes 10 till provinces denoted A, B, C, D, E, F, G, H, I and J. The tills in southern Finland, till province A, are typically poor in fines and the clay fraction content of fines is low. Occasionally, however, high specific surface area and clay fraction content values have been measured on samples from this area. In Åland (B), the fines content is high but the clay fraction content and specific surface area of the fines are low. In southern Ostrobothnia, northwestern Finland and Häme (C) the fines content of tills is medium or high, and the clay fraction content and specific surface area of the fines are both high. The highest values for clay fraction content and specific surface area were measured in southern Ostrobothnia and areas adjacent to the Central Finland ice-marginal formation. In central Ostrobothnia and central Finland (D), the tills contain abundant fines, the highest contents being encountered on the coast. The clay fraction content and specific surface area of the fines are low in samples from the area. In the northwest of the till-geochemical Lake Ladoga-Bothnian Bay zone (E) the tills are rich in fines with high clay fraction content and specific surface area values. The largest till province (F) comprises eastern Finland, Oulu province and southern Lapland. The fines content of tills is medium, and specific surface area and clay fraction content are low. In Lapland, the tills can be divided into four provinces on the basis of their properties. In province G, the fines content is low but the specific surface area of the fines is high. In central Lapland (H), the fines content and the specific surface area of fines are high. It is typical of till provinces G and H that specific surface area is high relative to clay fraction content. In western and northeastern Lapland (I,J), the fines content of till and the clay fraction content and specific surface area of fines are all low.

When considering the above regional types it should be remembered that the Geochemistry Department's samples were taken, on average, from one metre deeper than the samples for the mapping of Quaternary deposits. In a few rare cases, then, the clay fraction content of fines and the specific surface area of fines were analysed from different till units than the fines content.

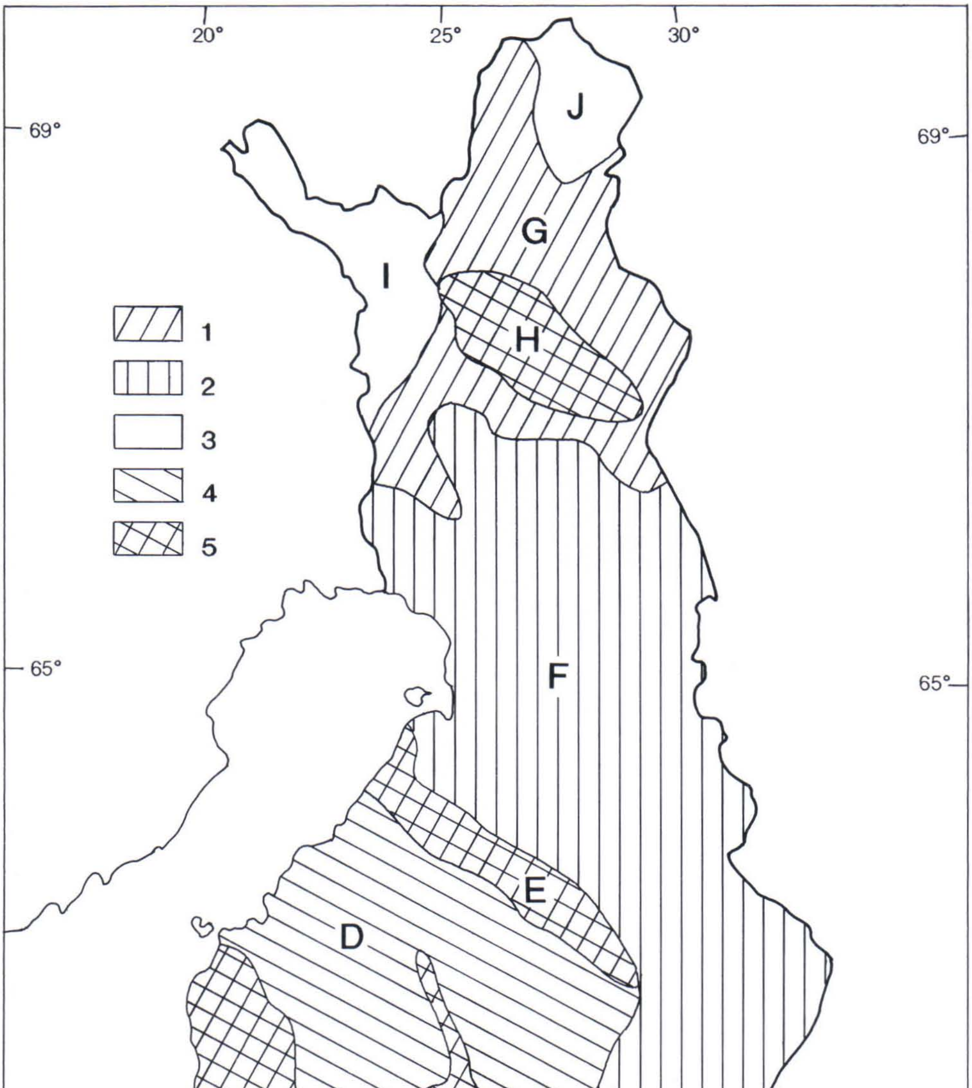


Fig. 23. Regional provinces (A, B, C, D, E, F, G, H, I and J) delineated on the basis of fines content (5437 samples) in till matrix (<2 mm) and the especific surface area of fines (SSA) (1016 samples). 1 = SSA high, fines content low, 2 = SSA low, fines content medium, 3 = SSA and fines content low, 4 = SSA low, fines content high, 5 = SSA and fines content high.

Grain size distribution and specific surface area of till fines in relation to chemical data

In till fines the abundance of micas and their alteration products is highest in the clay fraction (Droste 1956; Dreimanis & Vagners 1971; Soveri 1956, Soveri & Hyyppä 1966; Sippola 1972; Nevalainen 1989). Of the main elements of biotite and chlorite, aluminium and iron have a medium correlation ($r = 0.5 - 0.72$) with clay fraction content and specific surface area. The correlations between several metal concentrations and the Al and Fe concentrations are clearly higher than those between the metal concentrations and physical properties. The concentration of aqua regia-soluble K, which in the till fines mainly derives from biotite (Räisänen et al. 1992b), has a low correlation coefficient ($r= 0.36 - 0.45$) with clay fraction content and specific surface area. This can be attributed to regional differences in the abundances of micas and clay minerals in the clay and silt fractions.

Biotite and chlorite are probably unevenly distributed in till fines owing to the regional occurrence of biotite-rich mica gneisses and chlorite-rich greenstones (cf. Simonen 1980). This uneven distribution is shown by the regional distribution of normative minerals calculated from chemical analytical data (Aatos et al. 1994). The weak correlation can also be explained by the ratio of the abundance of aqua regia-soluble micas to the concentration of metals incorporated in precipitates, which varies from area to area. In places, sulphide minerals are substantial sources of metals, lowering the correlation between clay fraction content and metal concentrations.

The correlation coefficients given by Mäkinen (1992) between the unit weight and elemental concentration data on till fines are higher than those found in this study between metal concentrations, specific surface area and clay fraction content. It is thus clear that clay fraction content and specific surface area do not explain the variation in the metal content of the mineral matter in fines as reliably as does the unit weight presented by Mäkinen (1992). Unit weight takes better account of the uneven distribution of micas between the clay and silt fractions.

The correlation coefficients between the specific surface area and metal concentrations of till fines and those between clay fraction content and metal concentrations are higher than those given by Vallius (1992) between till and bedrock samples. It is therefore important to understand the processes leading to the formation of till and to be familiar with Quaternary history when interpreting reconnaissance-scale till maps, as these factors affect the elemental distributions and development of anomaly patterns in tills as much as do the elemental concentrations in bedrock.

According to Shilts (1971, 1975), the Zn concentration in till correlates strongly with clay fraction content in the areas of Quebec and Keewatin, Canada. There are also clear correlations between clay fraction content and Cu, Ni and Pb concentrations. The material of this study did not show similar strong correlations in Finnish tills. Outside the Canadian Precambrian Shield, the till fines derive from sedimentary rocks formed under conditions that favoured more intense chemical weathering than do those prevailing today. The finest fractions of the sedimentary rocks were enriched in metals mobilized during chemical weathering. In Canada, however, there are great differences in clay fraction contents between till units; this increases the correlations, as the range of clay fraction content variation increases. Some of the samples reported by Shilts (1971, 1975) were taken from permafrost areas, where in the active layer of permafrost intense chemical and mechanical weathering takes place (Shilts 1973). Hence, metal ions are more mobile and are able to be adsorbed on colloidal mineral grains or precipitates.

Stratigraphy of regional till provinces

Province A

In terms of regional till mapping, southern Finland is an area of low fines content where the clay fraction content and specific surface area of fines are occasionally anomalously high. The Salpausselkä zone does not form a boundary between areas of different till properties as does the Central Finland ice-marginal formation.

In some depressions outside the Salpausselkä zone, occurs occasionally a dark-grey basal till units rich in fines, overlain by a sandy basal till unit (Rainio & Lahermo 1974, 1984; Hirvas & Nenonen 1987). A till unit with abundant sorted material inclusions has been found on the surface of a sandy till interpreted as basal melt-out till formed during the liberation of abundant melt waters (Bouchard et al. 1990).

On the inner side of the Salpausselkä zone there are two till units, both usually sandy basal till poor in fines (Hirvas & Nenonen 1987). The lower till unit deposited before the readvance of the glacial lobes that terminated at the Salpausselkäs, whereas the upper unit deposited during the readvance (Hirvas & Nenonen 1987; see also Rainio et al. 1986; Rainio 1991). Sorted sediments and glaciolacustrine sediments have been encountered between the till units (Nenonen & Hirvas 1987). Basal till older than the sandy till units has been described from a few sites in southern Finland. Precrag formations have been reported from western southern Finland, e.g. from the areas of Tammisaari and Salo (Haavisto-Hyvärinen et al. 1989). The precrags, which are composed of clay-rich basal till, are partly covered by a younger sandy till unit. Kurkinen et al. (1989) have described a clay-rich basal till unit beneath an esker delta at Hyvinkää.

On the basis of the stratigraphic data the tills in southern Finland are mainly poor in fines. The occasional anomalously high fines and clay fraction contents in the regional data of this study are probably due to fines-rich basal tills preserved in topographic depressions. The regional data also indicate that the lowest clay-rich till unit occurs in a large area in southern Finland. In terms of the interpretation of the geochemical maps, the lowest fines-rich till unit is problematic, as it may occasionally raise the metal concentrations in samples.

Province B

In regional till mapping, Åland is an area of high fines content where the clay fraction content and specific surface area of fines are low. Two superimposed till units are common in the area (Nenonen 1993). The tills contain abundant Palaeozoic limestone clasts, which increase the abundance of the silt fraction in tills.

Province C

The regional till maps exhibit anomalously high clay fraction content and specific surface area values in till fines in southern Ostrobothnia. The anomaly is clearly demarcated in the east but in the south and southeast it grades into the areas of Häme and southwestern Finland that in places have anomalously high clay fraction content and specific surface area values. The fines content in the tills of southern Ostrobothnia is typically high. In southwestern Finland the fines content varies greatly.

Sorted deposits with local organic matter and covered by a clay-rich till unit have been described from several sites in southern Ostrobothnia (Niemelä & Tynni 1979; Donner 1988; Gibbard et al. 1989). Podzol horizons have also been reported from sorted till-covered deposits (Kujansuu 1992; Kujansuu et al. 1991). The horizons have been dated to the Eem interglacial and the following interstadial with thermoluminescence and optically stimulated luminescence methods (Kujansuu 1992; Kujansuu et al. 1993). Bouchard et al. (1990) have proposed the Harrinkangas Formation as the stratotype for southern Ostrobothnia; the clay-rich till has been named the Harrinkangas Till Member. The clay-rich till unit covering sorted sediments is known informally as *mäkisavimoreeni*, the "hill clay till". The name is somewhat misleading, as for instance in the Harrinkangas section (Gibbard et al. 1989) the "hill clay till" grades into a fines-poor till over a few tens of metres. The above stratigraphic studies in southern Ostrobothnia mainly deal with the description of till-covered sorted deposits, which are special cases in terms of regional till studies.

The number of excavator pits is highest in the Korsnäs area, from where one till unit rich in fines and clay fraction has been described (Huhta 1983). Mineralogical analyses on the samples from Päntäne stored in the Department of Quaternary Geology at the GSF are presented here. On the basis of the Korsnäs and Päntäne data we can be assume that the material of the regional till study represents the fines- and clay-rich till unit common in southern Ostrobothnia.

Regional till maps show high fines and clay fraction contents in the area of the Central Finland ice-marginal formation. Anomalously high values have been measured on many samples from the distal side of the formation, but in only very few from its proximal side. An important finding is that the anomalously high values for the clay fraction content and specific surface area of fines do not fully coincide. The high values for specific surface area in relation to the values for clay fraction content are attributed to the presence of iron precipitates in fines in the area. The high clay fraction contents of some samples in relation to their specific surface area shows that the clay fraction contains less micas and clay minerals than the fraction on average.

Clay-rich tills were observed in the area in the course of the GSF's mapping of Quaternary deposits (Kejonen 1981; Kejonen & Huttunen 1982). Rainio and Lahermo (1976, 1984) have also described clay-rich tills from Häme. According to them, these tills occur in depressions protected from the erosion of younger flow stages. The explorational studies undertaken by the Department of Quaternary Geology at Hämeenkyrö and Orivesi did not encounter a clay-rich till unit. The mineralogy of the stored samples from Hämeenkyrö and Orivesi was investigated here.

A clay-rich till unit was found in summer 1993 at Pirkkala in the course of exploration undertaken by the GSF (Hirvas, oral comm. 1993). According to Hirvas, lowermost in the stratigraphy there is a compact basal till rich in fines containing 14% clay fraction and 45% fines in the <20.0 mm fraction. The fines-rich till is overlain by 20 cm of varved silt. Uppermost in the pit is 2 m of sandy basal till. In a survey of surficial deposits by the GSF's Geochemistry Department in summer 1993, a fines-rich till was encountered at Teisko, where the bedrock is covered by a massive basal till unit, 3 m thick (Räisänen and Lestinen, oral comm. 1993).

The stratigraphic position of the fines-rich tills in Häme has not been established yet. It is plausible that such till units occur in several stratigraphic positions. The regional sample material used here may thus represent samples collected from till units differing in age.

Province D

On the regional till maps, the area of fines-rich but clay-poor tills extends from the coast of the Gulf of Bothnia to central Finland. The overburden in this area is very thick in some places. Till-covered organic deposits have been described from Vimpeli (Aalto et al.1983; Hirvas & Niemelä 1986), Lappajärvi (Salonen et al. 1992) and Evijärvi (Eriksson et al. 1980). Till-covered occurrences of weathered bedrocks are common in central Ostrobothnia (Hirvas & Nenonen 1987).

Several till units have been described in the stratigraphy of surficial deposits in the area (Aalto et al. 1983; Eriksson et al. 1980; Hirvas & Nenonen 1987; Salonen et al.1992). Two till units have been encountered on the proximal side of the Central Finland ice-marginal formation. The lower unit deposited before the readvance of the ice sheet and the upper one during the readvance that ended at the ice-marginal formation (Hirvas & Nenonen 1987, see also Rainio et al. 1986; Rainio 1991).

In Ostrobothnia, the till-covered sediments have been deformed in places and turned into tills. The stratigraphic investigations undertaken by the GSF in the area between Pietarsaari and Evijärvi in summer 1993 were not able to penetrate the uppermost fines-rich but clay-poor till unit. Coring demonstrated that the overburden was commonly over 30 m thick (Nenonen, oral comm. 1993). Observations of a fines-rich till unit overlain in places by a fines-poor till unit have been made in the northern part of the province (Iisalo 1992). A great number of these observations are described in unpublished GSF reports of explorational studies on surficial deposits (Nenonen & Johansson 1981; Huhta 1981, 1983b, 1984a,b,c; Johansson 1981; Hirvas & Huhta 1982; Hirvas & Nenonen 1978). The reports are unanimous that there is a sandy basal till unit in the area deposited by the youngest flow of the continental ice sheet from the west. A clay-rich basal till overlain by a fines-poor till unit has been encountered at Tervo in the east of the province (Hirvas 1980).

On the basis of available stratigraphic knowledge, the material of the regional till mapping probably corresponds to the till unit encountered in the area, which is low in clay fraction but rich in fines, varies in thickness and was deposited during the youngest flow stage of the continental ice sheet.

Province E

The clearest coherent regional feature in the till properties is an elongated anomaly of high clay fraction content in fines extending from the coast of Bothnian Bay to Riistavesi in the southeast and which is also seen as anomalously high specific surface area values.

Till-stratigrafic observations published from the Pyhäsalmi open-cast mine and from Kiuruvesi (Nenonen 1985) and Vesiperä in Haapavesi (Hirvas & Nenonen 1987) imply that there are typically two clearly different till units in the anomalous area. The lower till is of structureless basal till poor in fines with less than 5% clay fraction in its <20.0 mm fraction, whereas the upper till is a massive basal till rich in fines and clay fraction, with a clay content of 10 - 20%. At the study sites the upper till is 2 - 5 m thick and the clasts in both till units show a distinct orientation. In the upper unit the orientation is 270° - 280° and in the lower one 310° - 320°. In the Pyhäsalmi section the fines-poor basal till is underlain in places by glaciofluvial sand, gravel and weathered rock (Nenonen 1985). At Vesiperä, Haapavesi, organic matter and clay have been encountered between the till units. From their microfossil assemblages these are interpreted as having deposited during the Eem interglacial (Hirvas & Nenonen 1987). An interglacial deposit overlain by one till unit has been described from Ollala (Forsström et al. 1987). Observations of two till units similar in grain size composition to the tills of the above sites have been reported from Siilinjärvi (Nenonen, oral comm. 1993). Exploration in the area has revealed basal till rich in fines on the surface of the overburden over a large area (Nenonen, 1985; Hirvas & Nenonen 1987). The topmost fines-rich basal till is usually at least 3 m thick, with the consequence that numerous study pits failed to penetrate it.

In the northwest, the till unit continues on the bottom of Bothnian Bay, from where Simula (1988) has reported a clay-rich till. According to him, there are two till units off the coast at Raahe of which the lower one is sandy till and the upper one fines-rich till. In the present study, clay minerals were determined from Marjapuro and Mertuanoja, Ylivieska; from Vesiperä, Haapavesi; and from Pyhäsalmi.

It is clear from the till-stratigraphic studies that the anomalously high values for the clay fraction content and specific surface area of till fines extending on the regional till maps from the Bothnian Bay coast to Riistavesi are due to the topmost basal till, which occurs in the area as a coherent unit with abundant clay fraction and fines.

Province F

In this province, the fines content of till is medium and the specific surface area and clay fraction content of fines are low. Southeast of province E, in the area of the geochemical Lake Ladoga-Bothnian Bay zone, the clay fraction content and specific surface area of fines are locally elevated.

The till stratigraphy of the southern part of the province has been studied by Hirvas (1980), Hirvas & Nenonen (1987) and Kujansuu & Nenonen (1987). Uppermost is a widespread thick sandy till unit with lenses of sorted sediments. The fabric of the stones in this till points to the Salpausselkä zone. Silt and clay layers have been found beneath this fines-poor till bed. As the type localities of these layers, Hirvas (1980) and Hirvas & Nenonen (1987) have presented Heinävesi and Rääkkylä, of which the latter has several metres of silt beneath a sandy till. Basal till rich in fines with a clay fraction content of up to 17% has been encountered at Heinävesi beneath a fines-poor till layer. According to Hirvas & Nenonen (1987), the fines-poor till unit containing sand lenses deposited when the continental ice sheet readvanced to the Salpausselkäs during the deglaciation stage.

Hirvas & Nenonen (1987) maintain that silts and clays deposited in a glacial lake at the front of the ice. According to Hirvas (1980), the high clay fraction contents in the lower fines-rich till unit are due to redeposition of silts and clays initially deposited in water. Here and there in the ice-marginal zone there is a shallow layer of fines-poor ablation till as the topmost unit (Hirvas 1980; Hirvas & Nenonen 1987).

The material for the regional studies was collected from the proximal side of the Salpausselkä zone, mainly from fines-poor sandy till containing sand lenses. The till was deposited during the active flow stage of deglaciation when the ice sheet readvanced to the Salpausselkäs (Hirvas & Nenonen 1987; Kujansuu & Nenonen 1987).

The till stratigraphy of North Karelia has been described by Kujansuu & Nenonen (1987), Huhta (1992) and Nenonen & Huhta (1993). There are several till units in the area, their number depending on the location of the study site in relation to the ice-marginal formations. All the units are composed of sandy till poor in both fines and clay fraction. The samples of the regional study cannot be correlated with any of the known till units.

Stratigraphic descriptions are available from Vihanti and Ruukki in northern Ostrobothnia, north of province E. Several different till units have been reported from Vihanti (Grönlund et al. 1985) of which the uppermost one is a sandy till unit with stones oriented at 270°. Lower down is a unit that is also sandy till but with stones oriented at 330° and containing pieces of organic matter. Lowermost in the stratigraphy is a fines-rich basal till that cannot be correlated with any of the tills in other study areas. Two till units have been observed at Ruukki, an upper one poor in fines and a lower one rich in fines (Mäkinen 1992).

The till stratigraphy of northern Ostrobothnia and Kainuu has been described by Aario & Forsström (1979), Saarnisto et al. (1980, 1981), Sutinen (1984) and Saarnisto & Peltoniemi (1984). Several different fines-poor till units have been reported from a large area. Lowermost in the Koillismaa stratigraphy is a basal till rich in fines that, according to Aario & Forsström (1979), contains 10% clay fraction and about 50% fines. They have given this till unit the stratotype name Pudasjärvi Till. From Kaapinsalmi Saarnisto et al. (1980, 1981) and Nevalainen (1983) have documented a fines-rich basal till beneath sandy till units.

The material of the regional till study may represent the fines-poor basal tills described by Aario & Forsström (1979) and Saarnisto et al. (1980, 1981). The results cannot be clearly correlated with any of the till units owing to their similarity. The observations of Nevalainen (1983) support the existence of the fines anomaly found in the regional till mapping east of the Kuhmo greenstone belt. Some of the samples suggest that the greenstone belt was a source of the abundant fines in the tills on the distal side of the belt.

Provinces G, H, I and J

For Lapland the results of the regional till studies are mainly compared with the observations of Hirvas et al. (1977) and Hirvas (1991). On the basis of 1400 study pits, Hirvas described the flow stages of the continental ice sheet that deposited the till units in Lapland. His flow stage II is the most important for till sampling because the till unit deposited then is the most common in Lapland.

At the time of flow stage II, the ice-divide zone was located in central Lapland. North of the ice divide, the continental ice sheet flowed northeastwards in eastern and northern Lapland and northwestwards in northwestern Lapland. South of the ice divide, it flowed southeastwards or ESE. Within the ice divide zone the flow directions varied, and glacial abrasion was minimal, as shown by the presence of numerous till-covered organic deposits (Hirvas 1991). The till bed of flow stage II is fines-poor sandy till with 1 - 2% clay fraction. According to Hirvas, the fines and clay fraction contents in till in the ice divide zone of flow stage II are slightly higher than south and north of the zone.

The fines contents selected from the databank of the Department of Quaternary Geology mainly refer to the flow stage II till bed described by Hirvas (1991).

The regional till maps show elevated fines contents in the ice divide zone. The clay fraction content of the fines does not exhibit anomalously high values. The specific surface area values are anomalously high in central Lapland, in an area of till-covered occurrences of weathered bedrock established by field studies (Hirvas 1991). At Peurasuvanto, which is located within the area of anomalously high specific surface area values for till, the variations in the elemental concentrations of till fines reflect the variation in the elemental composition of the weathered bedrock (Lestinen 1980). According to Lestinen, the till fines at Peurasuvanto mainly derive from the fines of preglacial weathered bedrock.

Comparison of granulometric analyses

The regional data allow the tills of Finland to be roughly divided into three types on the basis of their fines and clay fraction contents: tills rich in both fines and clay fraction contain 40 - 60% fines in the <2.0 mm fraction, and the clay fraction content of the fines as measured with a sedigraph exceeds 27%; tills rich in fines but poor in clay fraction contain 40 - 60% fines, but their fines contain less than 17% clay fraction; and tills poor in both fines and clay fraction have less than 30% fines and the clay content of the fines is less than 17%.

The average fines content in the study material is compatible with the results of grain size analyses on 2406 till samples reported by Virkkala (1969a). The clay fraction contents of fines cannot be directly compared with Virkkala's data, because the values determined with a sedigraph are, on average, 5-10% higher than those obtained with an areometer. Basal tills from different bedrock areas can, however, be compared.

The average fines content of basal till in the crystalline bedrock area in Sweden and Norway is 18 - 42% and the clay fraction content of fines 9 - 18% (Lundqvist 1969; Follested 1973; Vorren 1977; Jørgensen 1977; Persson 1992). In the areas of clastic sedimentary rocks in Norway, the average fines contents in tills vary in the range of 41 - 55% and the clay fraction content of fines 10 - 30% (Jorgensen 1977; Haldorsen 1982, 1983). Tills in sedimentary carbonate rock areas in Denmark, which have an average fines content of 61 - 63% and a clay fraction content in fines of 34 - 44%, constitute a clearly different type (Petersen 1973; Vorren 1977). In the area of sedimentary carbonate rocks in Wisconsin, USA, the average fines content of till is 55% and the clay fraction content of fines 25% (Dreimanis & Vagners 1972). In Canada, the fines and clay fraction contents in tills vary clearly depending on the bedrock area (Scott 1976; Dredge & Cowan 1989); in Precambrian shield areas where the bedrock is composed of plutonic and metamorphous rocks, the tills are usually poor in fines, but in the sedimentary rock area the fines and clay fraction contents may be double those in the shield areas (Scott 1976).

The average fines and clay fraction contents in Finnish tills are compatible with the average values reported for tills from areas of crystalline bedrock in Scandinavia and the Canadian Precambrian Shield. However, in fines and clay fraction contents, the Finnish fines-rich tills approach the tills in the areas of sedimentary rocks.

Fines-rich tills have also been documented in the area of the Canadian Shield, where the readvancing ice sheet eroded glacial lake sediments and deposited clay-rich tills poor in stones (Hughes 1965; Scott 1976; Dredge & Cowan 1989). Southwest of the Hudson Bay Lowlands, the fines-rich tills continue as a zone up to 100 km wide to the areas of Precambrian crystalline bedrock. The Hudson Bay Lowlands are an important source of fines because they are composed of carbonaceous rocks and thick clay formations deposited during ice-free stages (Dredge & Cowan 1989).

Clay-rich tills have also been encountered in Sweden, outside the sedimentary rock areas (Lundqvist 1958 1973; Björnbom 1979). There the clay-rich basal tills are located lowermost in the stratigraphy, and fines-poor basal till has deposited on top of them. In mineralogy, the clay-rich tills are similar to the clay-poor tills (Björnbom 1979). The clay-rich tills often contain abundant far-travelled mica schist clasts. The clay clasts in the clay-rich tills suggest that the increment of fines and clay fraction was due to the re-deposition of older water-laid sediments (Björnbom 1979).

Postglacial weathering

The clay mineralogy of the fines of till samples from the oxidized surficial parts of sampling profiles often differs from that of the samples from the lowest parts of profiles, which are partly below the ground-water table. The mineral alterations are thought to have taken place in soil forming processes once the land surface was exposed from under the continental ice sheet or water. The mineral alterations in different study profiles are rather similar on the whole. As examples, samples from Marjapuhto, Ylivieska; and Keturinkylä, Päntäne are examined because the mineral alterations seen in them are distinct. The results are compared with the example cases discussed in the following chapters.

Marjapuhto

The Marjapuhto profile represents a basal till unit deposited during one glacial flow stage. The clay fraction contents of the samples vary, and the lowermost sample is poor in clay fraction in relation to the others. In the mineralogy of the lowest sample, the micas of the silt fraction are more prominent than in that of the other samples. As a whole, the samples of the profile show mineral alterations in the oxidized surficial part of the clay-rich till cover where mixed-layer minerals and vermiculite occur as alteration products of micas and chlorite. The X-ray diffraction traces of the oriented <0.02 mm samples studied are presented in Fig. 24. The estimated mineralogical composition of the samples are given in Appendix 1:8.

Samples from depths 5.0 and 3.8 m are dark-grey unoxidized basal till. The clay fraction content and specific surface area of the upper sample are high and those of the lower sample low.

The 14 Å reflection is relatively weak and sharp. The reflection of the lower sample does not change during treatment. The 14 Å reflection of the upper samples from a depth of 3.8 m shifts partly to the range of 10 Å with K^+ saturation. Heating to 550°C increases the 14 Å reflection slightly in relation to the K^+ saturated sample. Together with the 7 Å reflection, the 14 Å reflection clearly indicates the presence of chlorite in the samples. The chlorite is a chlorite-vermiculite mixed-layer clay mineral in which some of the chlorite layers have altered into vermiculite..

The 10 Å reflection of the lower sample is sharp and widens only slightly towards smaller angles, whereas that of the upper clay-rich sample is stronger and widens more distinctly towards smaller angles. The 10 Å reflection of both samples intensifies at 550°C. As the 5 Å reflection is weak in relation to the 10 Å reflection, the 10 Å reflection indicates an almost unweathered trioctahedral mica in the lower sample and a trioctahedral illitic mica in the upper sample.

The 7 Å reflection, which is relatively strong in relation to the 14 Å reflection, clearly weakens at 550°C. The intensity of the 14 Å reflection does not increase during heating. The sample also exhibits the 3.54 Å reflection typical of chlorite, with a widening at 3.57 Å characteristic of kaolinite.

The sample from a depth of 2.0 m represents a transitional zone between the oxidized horizon with yellowish-brown iron precipitates and the unoxidized dark-grey horizon. The clay fraction content and the specific surface area of the sample are relatively high but specific surface area is not elevated in relation to clay fraction content.

The 14 Å reflection is strong and sharp. It moves almost totally to the range of 10 Å with K^+ treatment, implying the occurrence of vermiculite and a vermiculite-chlorite mixed-layer mineral in the sample. A weak reflection in the range of 14 Å for a K^+-treated sample and a sample heated to 550°C indicates the presence of unweathered chlorite component in a mixed-layer mineral, or small amounts of independent, well-crystallized chlorite not incorporated in the mixed layer structure of the sample. Diffraction traces also show a weak 12 Å reflection, which disappears during K^+ treatment and may thus be due to the presence of mica-vermiculite.

The 10 Å reflection is relatively strong, albeit slightly weaker than that of 14 Å. The illitic 10 Å reflection loses its widening towards smaller angles with K^+ treatment and the crystal structure approaches that of unweathered trioctahedral mica.

The 7.1 Å reflection disappears almost completely at 550°C, which, together with the 3.54 Å reflection of chlorite and the 3.57 Å reflection of kaolinite, indicates the high contribution of kaolinite to the 7 Å reflection.

The sample from a depth of 1.5 m represents the oxidized, yellowish-brown surficial part of the till cover with iron precipitates as horizontal bands. The clay fraction content and specific surface area of the fines in the sample are high. Specific surface area is not elevated in relation to clay fraction content.

The 14 Å reflection is sharp and very intense. It moves almost totally to the range of 10 Å with K^+ treatment, indicating the presence of vermiculite. The weak 14 Å reflection after K^+ treatment and heating to 550°C is suggestive of small amounts of chlorite component in the mixed-layer structure. Vermiculite is probably a vermiculite-chlorite mixed-layer mineral. A weak 12 Å reflection is typical of mica-vermiculite mixed-layer minerals.

The 10 Å reflection is relatively strong and of illitic type. It grows markedly in intensity after K^+ treatment.

The 7 Å reflection disappears almost completely at 550°C, which, together with the 3.54 Å reflection of chlorite and the 3.57 Å reflection of kaolinite, indicates that kaolinite contributes almost totally to the 7 Å reflection.

The Marjapuhto samples clearly reveal the effects of postglacial weathering. The oxidized surficial layer contains abundant vermiculite, and the mica is illitic. Well-crystallized chlorite is almost totally lacking. As chlorite occurs deeper down, it has probably altered into random, interstratified vermiculite-chlorite or chlorite-vermiculite, depending on the proportions of the components, in the oxidized horizon. The alteration of chlorite can probably be explained by the mechanism described by Droste (1956). According to this, the Al-hydroxy interlayer in chlorite has reacted with the H^+ ions in gravitational water and become gradually hydrated. In weathering, the structure of chlorite becomes looser and the Al-hydroxy interlayer gradually alters into a layer containing water and Mg^{2+} ions. Chlorite has altered into a mixed-layer mineral with variably weathered chlorite layers as components that come increasingly to resemble vermiculite as weathering proceeds. The complete weathering of the Al-hydroxy interlayers in chlorite results in the formation of vermiculite (Droste 1956).

The micas in the samples of the profile have not weathered as clearly as chlorite. Il-

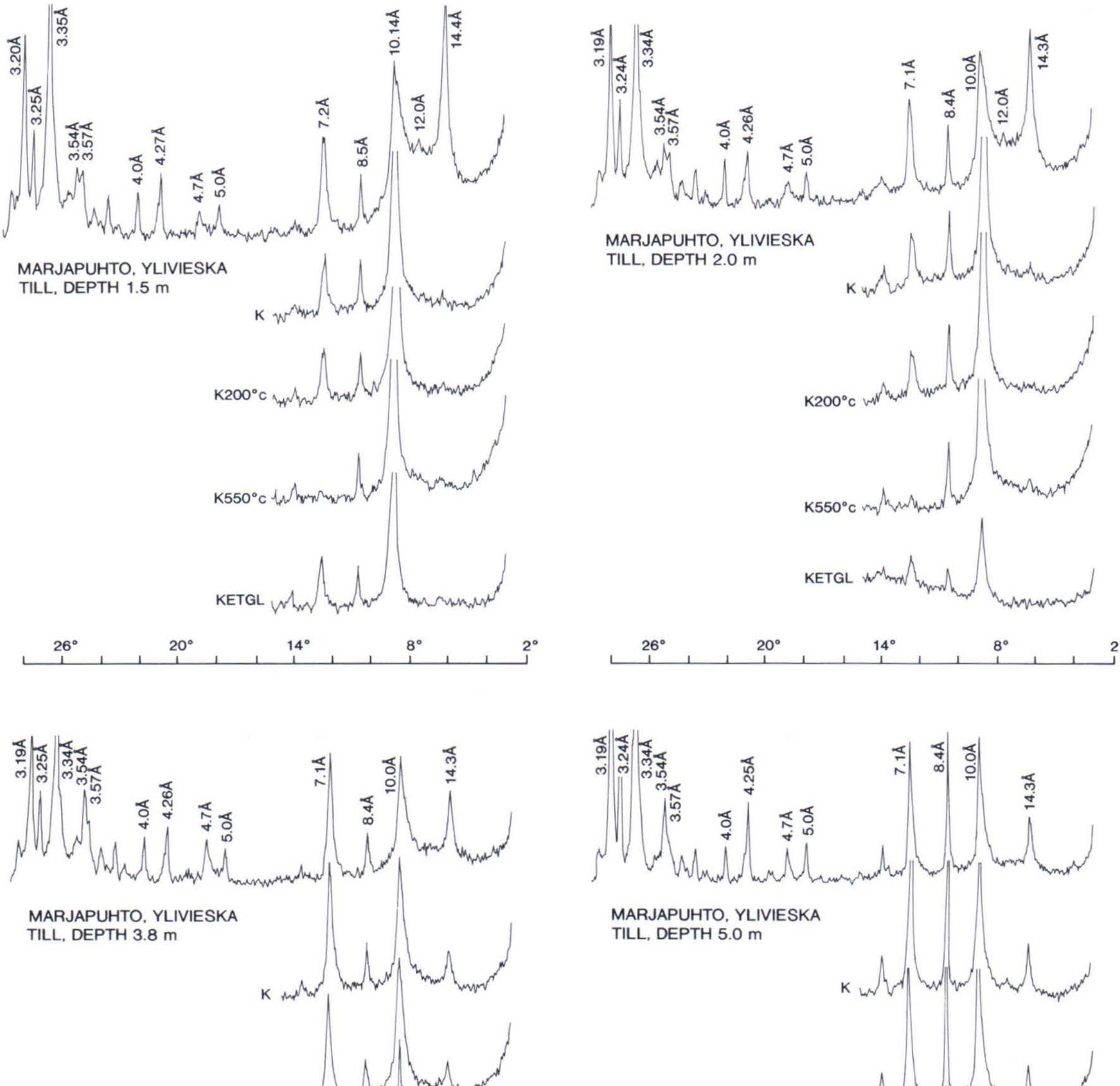


Fig. 24. X-ray diffraction traces of the oriented till samples (<0.02 mm fraction) from the Marjapuhto profile. K = K^+ saturated, K200°C = K^+ saturated and heated to 200°C, K550°C = K^+ saturated and heated to 550°C. KETGL = K^+ saturated and treated with ethylene glycol.

litic mica also occurs in unoxidized basal till. The least weathered sample in terms of micas comes from the sandy basal till on the bottom of the pit. Direct comparison is hampered by the low clay fraction content of the lowest sample, owing to which the abundance of micas is higher in the coarser fraction, which has weathered less. The 10 Å reflection of the micas intensifies after K^+ treatment, mainly owing to alteration of the vermiculite component of the 14 Å vermiculite-chlorite or the random interstratified vermiculite-chlorite into a mica with K^+ treatment (Barnhisell 1977). In the samples from the unoxidized horizon the 10 Å reflection is not intensified until a temperature of 550°C is reached, suggesting that the crystal structure is reorganized with the liberation of the water bound to the interlayers. In general, chlorite is clearly more sensitive to weathering than biotite. However, in this part of the profile, chlorite is relatively unweathered in illite-bearing samples from greater depths. The mica in the clay fraction of the till may have weathered into illite under the oxidizing conditions of an ice-free stage, whose clay deposits were the source of the fines increment in the clay-rich tills. The weathering of micas is indicated by the weak 12 Å reflection of the samples from the oxidized horizon. The mineral is mica-vermiculite, an alteration product of mica, which was formed as the H^+ ions replaced K^+ ions in partly unweathered mica. Weathering has not proceeded far, as the 12 Å reflection is faint.

Kaolinite, which occurs in all samples studied, represents far-advanced weathering that did not happen during postglacial time. The samples do not show any Al hydroxide binding or polymerization in mica interlayers.

On the basis of the profile, the weathering cycle in the Marjapuhto section is probably as follows:

Chlorite -> chlorite-vermiculite (14 Å) -> vermiculite-chlorite -> vermiculite

Trioctahedral mica -> trioctahedral illite -> mica-vermiculite (12 Å).

Chlorite has had time to alter into vermiculite almost completely, even though the mica has weathered only slightly into the 12 Å mineral.

Päntäne

The mineralogy of the Keturinkylä profile at Päntäne differs from that of Marjapuhto at Ylivieska in that chlorite occurs only in the uppermost sample from the oxidized horizon. In the surficial part of the profile, till is greyish brown but deeper down it is grey. The uppermost sample represents the greyish-brown oxidized surficial horizon with iron precipitates that extends to a depth of 2.5 m. The sample taken from a depth of 4 m is from the thick transitional horizon between the oxidized and unoxidized horizons. The lowermost sample was taken from below the ground-water table. Comparison of the clay minerals of the samples is hampered by the clay fraction content of the uppermost sample, which is double that of the lower samples. The clay fraction contents of the two lowermost samples are almost identical. The X-ray diffraction traces for the samples are shown in Fig. 25. The specific surface area, clay fraction content and estimated mineralogical composition of the samples are given in Appendix 1:5.

The mineralogy is similar in all samples. The 14 Å reflection of the two lowermost samples moves completely to the range of 10 Å during K^+ treatment, indicating the presence of vermiculite. The 10 Å reflection of the lower samples intensifies at 550°C, implying the reorganization of illite when interlayers are dehydrated or the presence of polymerized Al hydroxide in interlayers of illite. The weak 7 Å reflection disappears at 550°C and since no increase is observed in the range of 14 Å, the 7 Å mineral is kaolinite. The uppermost sample, which is richer than the others in clay fraction, differs clearly in clay mineralogy. It exhibits intense reflections at 10 Å, 12 Å and 14 Å. The 12 Å and 14 Å reflections do not move to the range of 10 Å until a temperature of 200°C is reached. The final move takes place at 550°C, resulting in a distinct increase in the intensity of the 10 Å reflection. The diffraction trace shows weak reflections at 12 Å and 14 Å at 550°C, too, indicating that the mixed-layer minerals - illite-vermiculite and vermiculite-chlorite - contain chloritized portions. The partial move of both peaks to the range of 10 Å suggests that the 12 Å and 14 Å mixed-layer minerals contain polymerized Al hydroxide.

The uppermost sample of the profile from the oxidized horizon is clearly richer in clay minerals with polymerized Al hydroxide in their interlayers. The uppermost sample is richer in clay fraction than the others, emphasizing the peaks of the clay minerals in the X-ray diffraction trace. However, the occurrence of mixed-layer minerals and polymerized Al hydroxide is probably due to postglacial weathering (cf. Soveri & Hyyppä 1966; Räisänen 1988). As the samples from the deeper parts of the profile do not contain chlorite, the 12 Å and 14 Å mixed-layer minerals of the oxidized horizon are probably alteration products of illitic mica. Al hydroxide has become so highly polymerized that mica has altered into a mineral resembling primary chlorite.

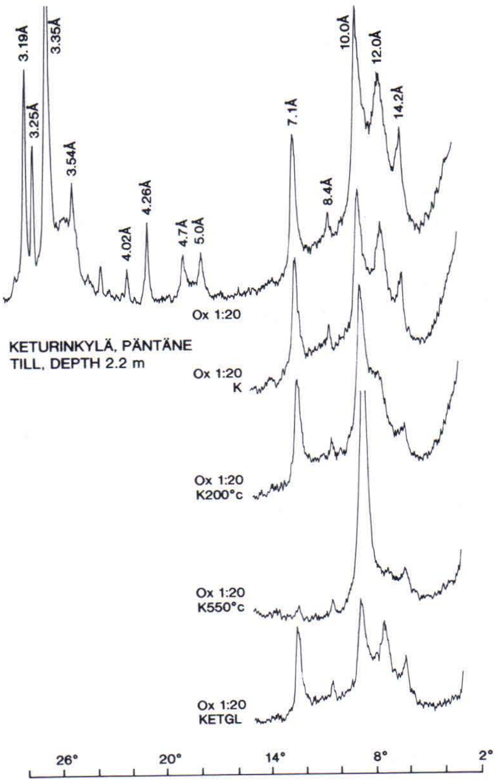
The weathering cycle in the Keturinkylä profile is probably:

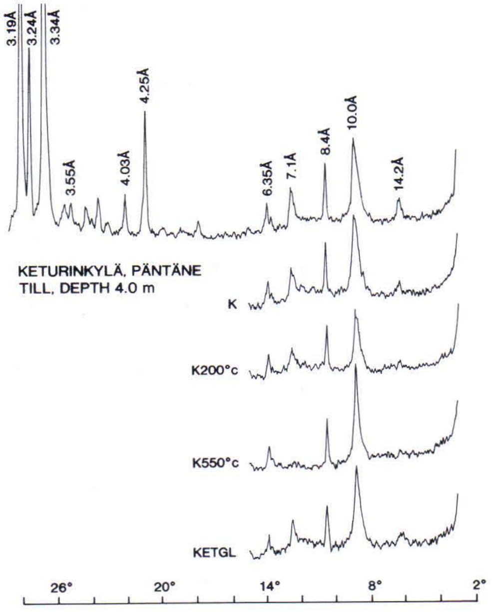
Trioctahedral mica -> trioctahedral illite -> mica-vermiculite -> vermiculite-chlorite with Al-hydroxy interlayers -> chlorite

Factors affecting postglacial weathering

In postglacial weathering, the time that has passed since the area was liberated from either the continental ice sheet or water does not seem to have a clear correlation with the progress of weathering. For example, in the Korpilampi profile at Ilomantsi (Fig. 28, 29, Appendix 1:19), the alterations in the topmost samples are slight compared with those in the Keturinkylä profile at Päntäne and the Mertuanoja profile at Ylivieska. The Korpilampi area has been submitted to weathering for 2000 years longer than either Keturinkylä or Mertuanoja. The Kaapinsalmi profile at Suomussalmi (Fig. 35, 36, Appendix 1:21), also located in a supra-aquatic area, shows a weak 12 Å reflection, indicating incipient mica weathering.

The tills at Suomussalmi and Ilomantsi are poor in clay fraction whereas those at Ylivieska and Päntäne are rich in clay fraction. The rate of postglacial weathering clearly depends on the clay fraction content of fines more than on time. Any increase in clay fraction content, then, promotes mineral alterations. The water permeability of clay-rich tills is poor in relation to that of sandy tills. Thus, acidic gravitational water has more time to leach micas. The surface area of clay-rich tills susceptible to weathering is also many times higher than that of sandy tills. In a comparison of the weathering degrees of the surficial parts of overburden, the profiles should have more or less the same clay fraction contents. At Korsnäs, which lies close to the present sea level, no mineral alterations were observed, whereas at Päntäne intense alterations were noted in the surficial part of the Keturinkylä profile. Keturinkylä was liberated from the water about 8500 years ago (Saarnisto 1981; Salomaa 1982). A long enough period has thus elapsed for distinct mineralogical alterations to appear in the surficial part of clay-rich tills. More rapid postglacial alteration is indicated by the common occurrence of Al hydroxide polymerized in interlayers in samples taken from study profiles. For example, the occurrence of Al-hydroxy interlayers is common in earth cuttings at the Pyhäsalmi open-cast mine.





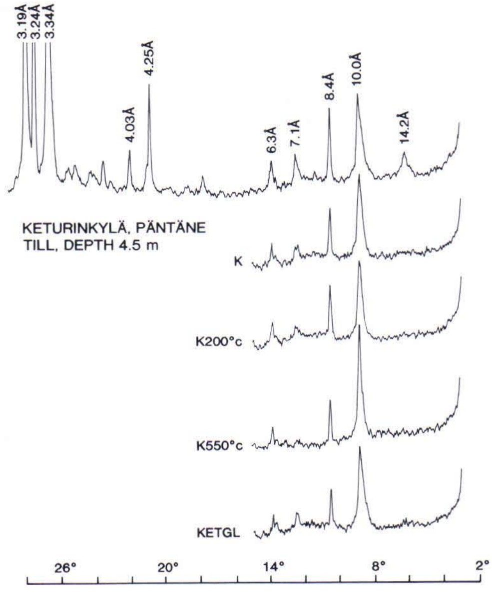


Fig. 25. X-ray diffraction traces of oriented till samples (<0.02 mm) from the Keturinkylä profile after various treatments. For symbols, see Fig. 20.

Another noteworthy feature is the great variation in degree of weathering in the topmost samples, even between adjacent profiles. The weathering in the surficial parts of tills cannot be compared between profiles located on the same uplift isobase. Alterations are not seen in the Vesiperä profile at Haapavesi (Fig. 33,34, Appendix 1:11), but they are distinct in samples from Marjapuhto, Ylivieska. The parent materials in the samples from both profiles are similar in mineralogy and their clay fraction contents are quite high. The differences in weathering are probably due to differences in redox conditions, the thickness of the oxidized surficial horizon, the availability of acid gravitational water and the time it takes for the water to infiltrate trough the soil and the till cover.

Intense variations in the ground-water table, due to which the oxidized horizon may have been deeper than it is at present, should also be taken into account as factors possibly affecting the postglacial weathering rate in the study profiles. In some cases, the redeposition of old fines weathered during an interglacial stage may explain the occurrence of vermiculitic interlayers in deep samples. At some sites, it can also be assumed that the topmost samples of the profiles contain relatively more mineral matter weathered during previous ice-free stages. For example, at Keturinkylä, Päntäne, where the clay fraction content of the topmost sample is twice that of the lower samples, it is reasonable to assume that the surficial part of the profile has been relatively enriched in previously weathered material. The Keturinkylä profile at Päntäne is a good example of the difficulties encountered in profile comparison. The samples richest in clay fraction are the most susceptible to weathering and yet they probably contain more previously weathered minerals than the other samples.

Mixing of weathered bedrock material with till

The mixing of material from the weathered bedrock with tills is examined with examples from the weathered bedrock area in central Lapland. For southern Finland, the profiles of Korpivaara, Ilomantsi; Vesiperä at Virtasalmi and Haapavesi; and Åland are discussed.

Weathered bedrock area in Lapland

The mixing of material from the weathered bedrock with till is most distinct in the weathered bedrock area of central Lapland. Lowermost in the Mäkärärova profile at Vuotso is weathered granite gneiss. The weathered bedrock grades into weathered-rock till, and above this there is basal till poor in fines. The clay fraction content and specific surface area are distinctly higher in till fines than in the fines of weathered bedrock. All the samples from the profile contain abundant kaolinite, as clearly indicated by the disappearance of the 7 Å reflection at 550°C. Secondary chlorite, which hampers the identification of kaolinite, occurs only in the uppermost sample of the profile. The two uppermost samples contain abundant 12 Å and 14 Å mixed-layer clay minerals with polymerized Al-hydroxy interlayers. The mixed-layer minerals may be alteration products of trioctahedral micas, because primary chlorite is not present in the profile. The profile probably exhibits both postglacial weathering and mixing of the products of older, more advanced weathering with till. The X-ray diffraction traces of the samples from the Mäkärärova profile at Vuotso are shown in Fig. 26 and their IR spectra in Fig. 27.

The high clay fraction contents of till samples in relation to weathered rock samples were also reported by Säynäjärvi (1953). According to Kujansuu (1976), the clay fraction content in the lower parts of the till units with intermixed material from weathered bedrock is often twice that of the rest of the till cover. According to Carrol (1970) and Ollier (1984), the weathered bedrock profiles typically have a high clay fraction content in their surficial parts where the weathering has proceeded farthest. The continental ice sheet has deposited the uppermost clay-rich parts of the weathered bedrock as clay-rich tills in areas of weathered bedrock. Hence, the material from the weathered rock in the present profiles represents the deeper parts of a weathered bedrock formed in a warmer climate.

In the mineralogy of the weathered rock sample from Mäkärärova, kaolinite represents far-advanced weathering, but the trioctahedral illitic mica is a product of mechanical weathering. Weathered rock samples lack minerals with vermiculitic interlayers and also expanding-lattice minerals with smectite components suggestive of transitional stages between an almost unweathered trioctahedral illite and kaolinite. According to Pulkkinen (1985), montmorillonite is present in the clayey part of the weathered bedrock occurrence at Mäkärärova. He does not, however, describe the method with which the mineral was identified, and so the occurrence of montmorillonite should be considered unestablished.

The mineralogy of the samples of weathered bedrock and till from Kakslauttanen (Appendix 1:32) is broadly similar to that of the Mäkärärova profile. The mixed-layer clay mineral in the weathered bedrock occurrence in the granulite at Kakslauttanen expands partly during glycol treatment, indicating that the mineral contains small amounts of smectite component. Till samples from Lintupuoliselkä, Angeli (Appendix 1:33), also contain abundant kaolinite.

The main minerals in the sample profile at Sattasvaara (Appendix 1:28) located in the weathered bedrock area are chlorite, talc, amphiboles and plagioclase; the minor minerals are potassium feldspar and quartz. The fines in the coarse granular weathered bedrock, weathered-bedrock till and sandy till are largely similar in mineralogy. Mixed-layer minerals occur in the surficial parts of the profiles, and the weathered rock material is richer in plagioclase. The mineralogy of the profile corresponds to that of mechanically crushed chlorite-talc schist. The clearest difference between the weathered rock and till is in the clay fraction content of fines, which, in the weathered rock, is twice that in till. This great difference is due to the fine grain size of the rocks, which contain abundant chlorite and talc.

The brownish rusty colour indicating the presence of abundant iron precipitates is typical of all samples from the area of weathered bedrock. The iron content of the samples was not analysed here. The anomalous area in central Lapland shown by the regional specific surface area submaps can be explained by the occurrence of tills rich in iron precipitates and kaolinite. Elsewhere in Lapland, the clay minerals in tills are 12 Å and 14 Å mixed-layer minerals, the majority having formed in the weathering of biotite and chlorite. They are related to the incipient chemical weathering, which was mainly caused by acid gravitational waters leaching the mineral matter in the surficial parts of the soil during postglacial time. Outside the area of high specific surface area the tills do not contain much kaolinite, which would indicate

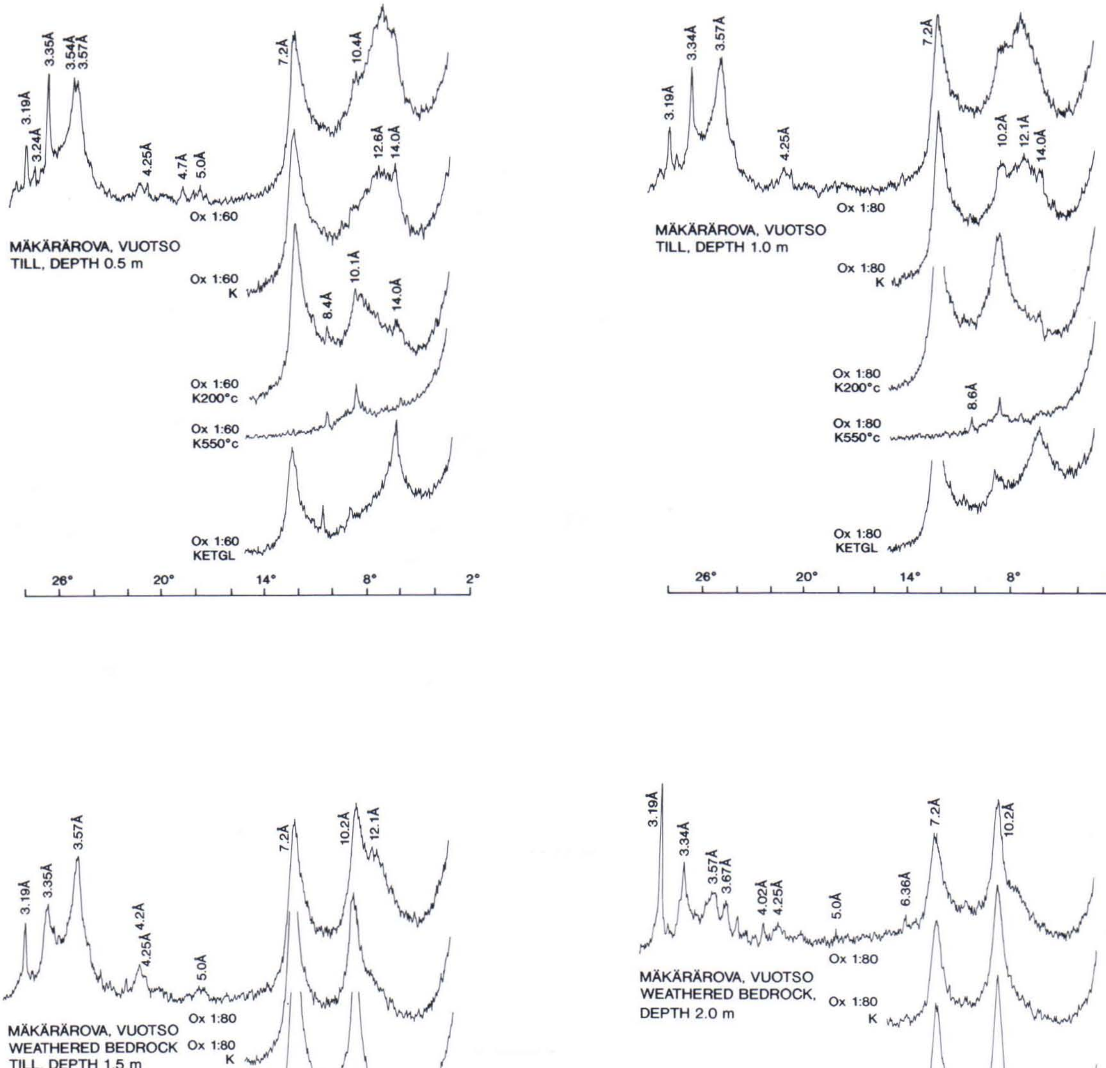


Fig. 26. X-ray diffraction traces of oriented samples (<0.02 mm fraction) from weathered bedrock and tills at Mäkärärova after various treatments. OX = oxalate extracted, OX K = oxalate extracted and K^+ saturated, OX K200°C = oxalate extracted, K^+ saturated and heated to 200°C, OX K550°C = oxalate extracted, K^+ saturated and heated to 550°C, OX KETGL = oxalate extracted, K^+ saturated and ethylene glycol treated. IR spectra of the same samples are given in Fig. 27.

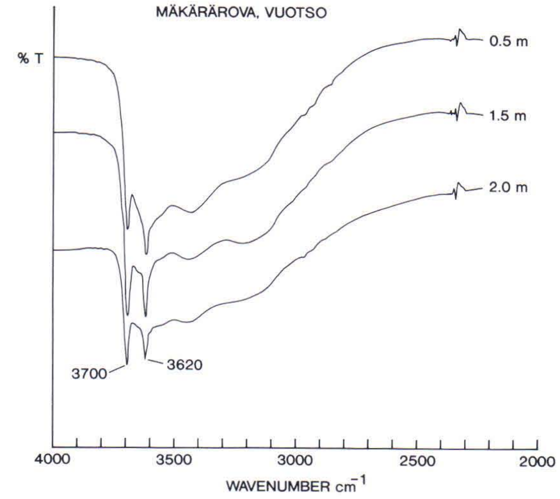


Fig. 27. IR spectra of till and weathered bedrock samples from Mäkärärova. The 3700 and 3620 cm^{-1} bands are characteristic of kaolinite. X-ray diffraction traces of the same samples are given in Fig. 26.

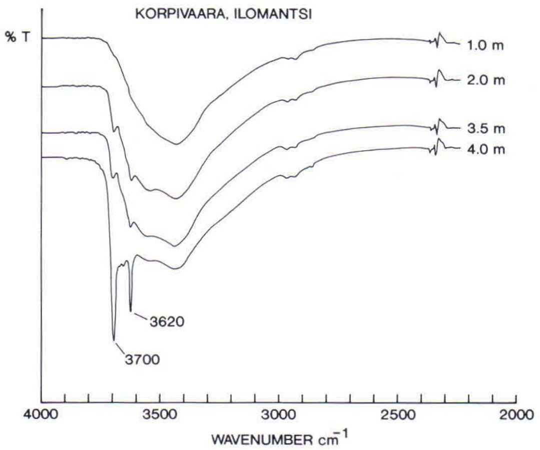


Fig. 28. IR spectra of Korpivaara samples.

far-advanced chemical weathering, even if the till cover rests on weathered bedrock. Hirvas (1991) found that till-covered weathered rocks are coarser in western and southern Lapland than in central Lapland. Time and again the flow activity of the continental ice sheet has probably been higher in the western part of the ice divide than in other parts of it. The granular weathered rock may thus represent the lower, less weathered portions of weathered rock described by Carrol (1979) and Ollier (1984).

Occurrence of kaolinite south of Lapland

Elsewhere in Finland there are only scattered occurrences of kaolinite in tills. For example, in the Korpivaara profile at Ilomantsi, where a till unit rests on weathered talc-chlorite schist, kaolinite occurs throughout the profile. The effect of postglacial weathering is slight. The abundance of kaolinite declines in the uppermost samples of the profile, implying that weathered material from a relatively small occurrence developed in a fracture has mixed with the till. X-ray diffraction traces for Korpivaara, Ilomantsi, are shown in Fig. 29 and the IR spectra in Fig. 28.

The till profiles terminating in granular weathered bedrock dealt with here include those at Rauhala, Ylivieska; and Koura, Seinäjoki (Appendix 1:10, 1:4). At these sites the mineralogy of the weathered bedrock is close to that of till samples. In places smectitic components not seen in the till samples may occur in the mixed-layer minerals of micas. Räisänen et al. (1992) also found that some mixed-layer minerals in weathered bedrock samples contained smectite that was absent in till samples. It would seem that, in these cases, material from the weathered bedrock has not been mixed with till. On the other hand, the mixing may have happened several glaciation cycles earlier due to which the component of the weathered material in the till unit resting on weathered bedrock has been strongly diluted.

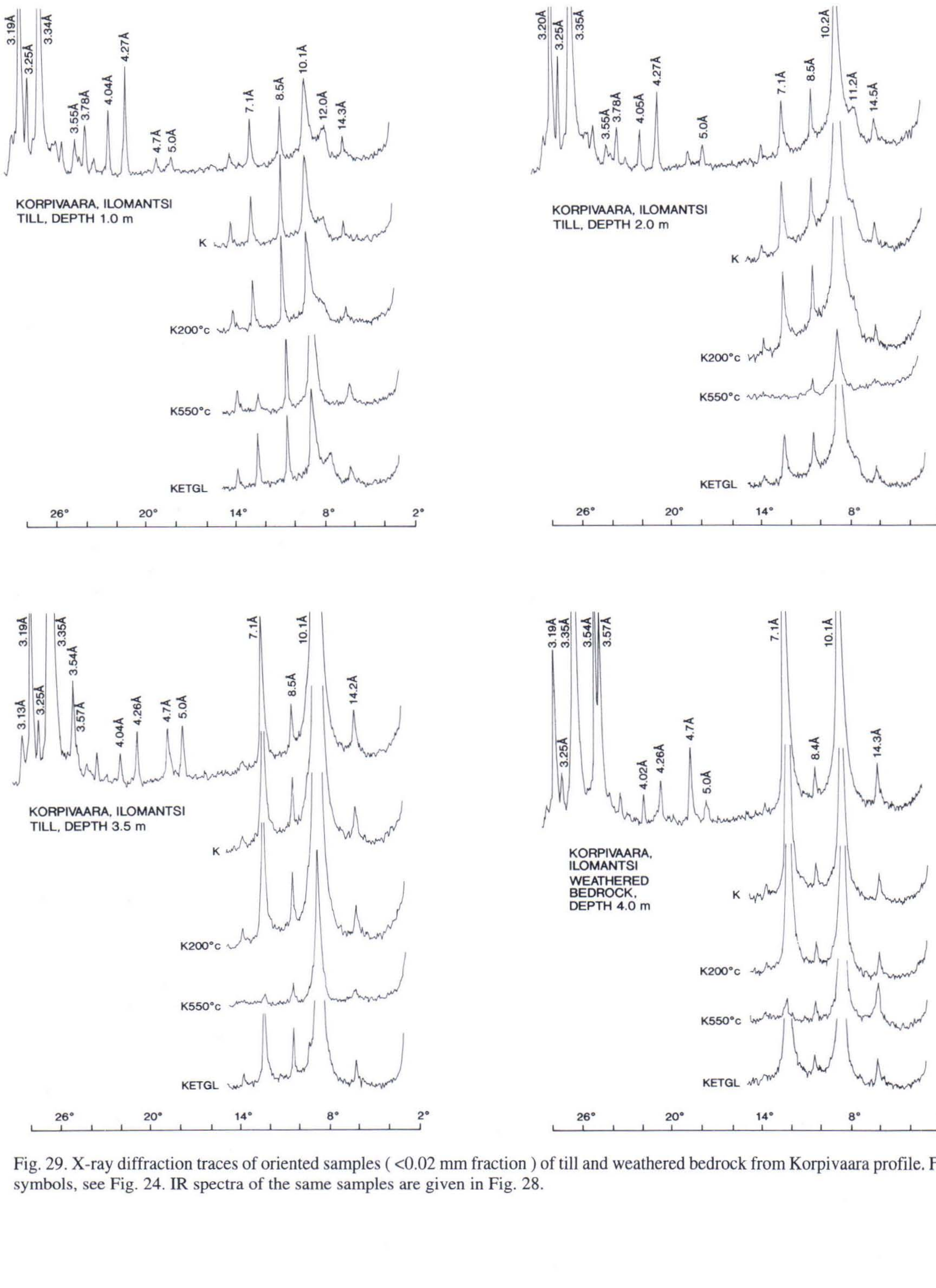


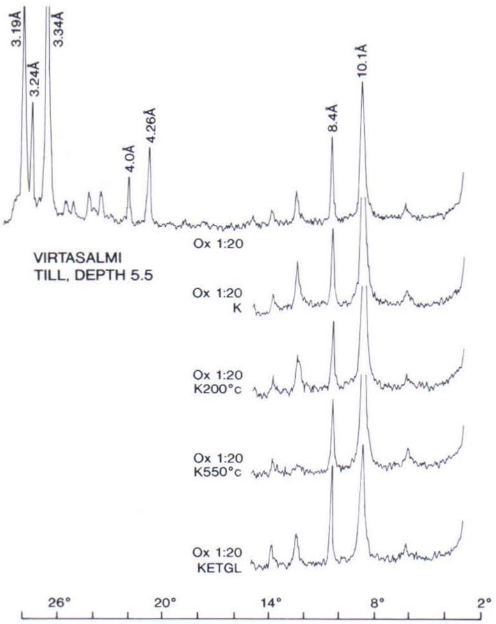
Fig. 29. X-ray diffraction traces of oriented samples (<0.02 mm fraction) of till and weathered bedrock from Korpivaara profile. For symbols, see Fig. 24. IR spectra of the same samples are given in Fig. 28.

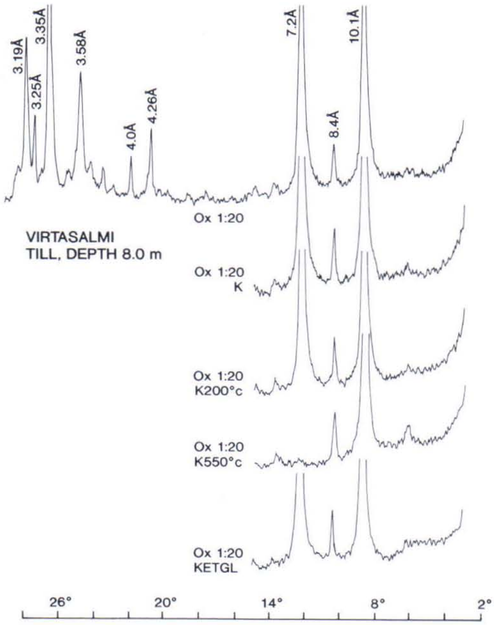
The thick overburden at the kaolin occurrence of Huuhansuo, Virtasalmi does not contain kaolinite. A large occurrence of weathering clay located in a fracture in a drumlin area has been protected from glacial erosion. In this area of active ice flow, the clayey weathering material may have acted as a sliding surface, thus protecting the weathering material from glacial erosion. Another possibility is that the upper part of the kaolin occurance was eroded several glacial cycles earlier. The lowermost till unit has then protected older deposits, and the material loosened from the kaolinite occurrence may have spread over a large area, thus becoming diluted below the detection limit. X-ray diffraction traces of weathered bedrock, weathered-bedrock mixed with till and till samples from Huuhansuo are shown as an example in Fig. 30.

The only observation of an expanding-lattice clay mineral of the smectite group comes from a sample of the lowest till unit at Vääräkoski, Hossa. The unit contains deformed sand and silt bands oxidized into material a greyish orange in colour. Figure 31 shows X-ray diffraction traces of Vääräkoski till samples. The diffraction traces of oxalate-extracted sample have a diffuse reflection between 10 Å and 14 Å, which, at 550°C, splits into independent 12 Å and 14 Å reflections. The 12 Å reflection of the K^+-saturated sample disappears with glycol treatment and moves as a wide diffuse peak to the range 16.6 - 21.5 Å. The first maximum of the peak is at 17.2 Å. The 14 Å reflection does not change with glycol treatment. According to Wilson (1987), the 17.2 Å reflection can be attributed to a random interstratified mica-vermiculite mixed-layer mineral, in which part of the vermiculitic component has weathered and altered into a smectitic expanding-lattice clay mineral. The vermiculite component of the mixed-layer mineral has probably been chloritized, as the 12 Å reflection intensifies with heating. Since the reflection is diffuse after glycol treatment, the mixed-layer mineral contains almost amorphous expanding mineral matter.

Saarnisto et al. (1980) and Nevalainen (1983) reported the common occurrence of an expanding-lattice clay mineral in tills and weathered bedrock from the Kellojärvi area, Kuhmo. As the heat treatment applied by Nevalainen (1983) does not, however, allow unambiguous identification of expanding-lattice clay minerals, the reported occurrences of expanding-lattice clay minerals should be regarded with caution. According to Nevalainen (1983), the presence of montmorillonite in the lowest till unit of the Kellojärvi area is due to redeposition of the weathered-rock material in till fines. The deformed sand and clay lenses at Vääräkoski, Hossa, dealt with here may represent material extracted from weathered bedrock or they may be deformed portions of water-lain sediment that, washed from the weathered bedrock, ended up in till. IR analyses revealed that all the till samples from Vääräkoski and Kaapinsalmi had small amounts of kaolinite.

Samples from Näs in the Åland Islands contain abundant kaolinite. The Åland samples differ from those of other sites in being rich in Palaeozoic limestones. Analyses on the mineralogy of sedimentary rocks on the bottom of the Bothnian Sea have not been published. Kaolinite is, however, a common constituent of fine-grained sedimentary rocks (Wilson, 1958a,b). In marine sedimentary rocks, kaolinite is terrigeneous clastic matter.





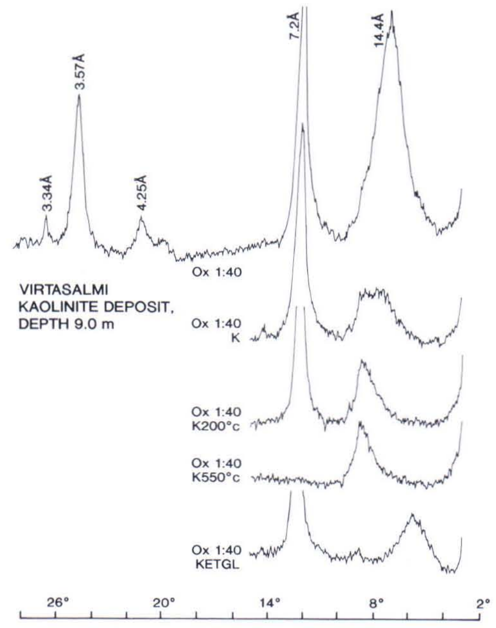


Fig. 30. X-ray diffraction traces of oriented samples (<0.02 mm fraction) from the surficial part of the Huuhansuo kaolin occurrence and of till samples after various treatments. For symbols, see Fig. 26.

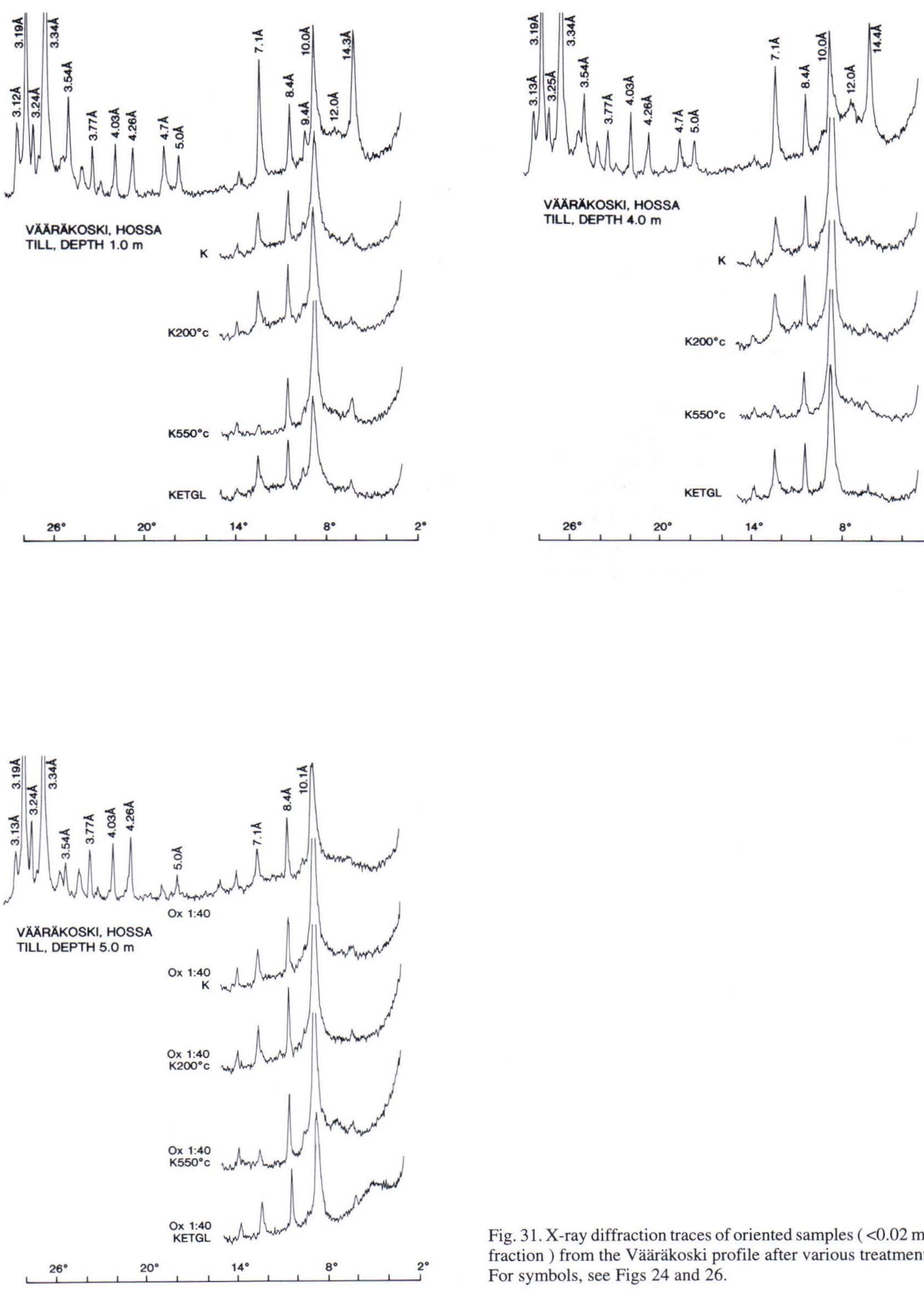
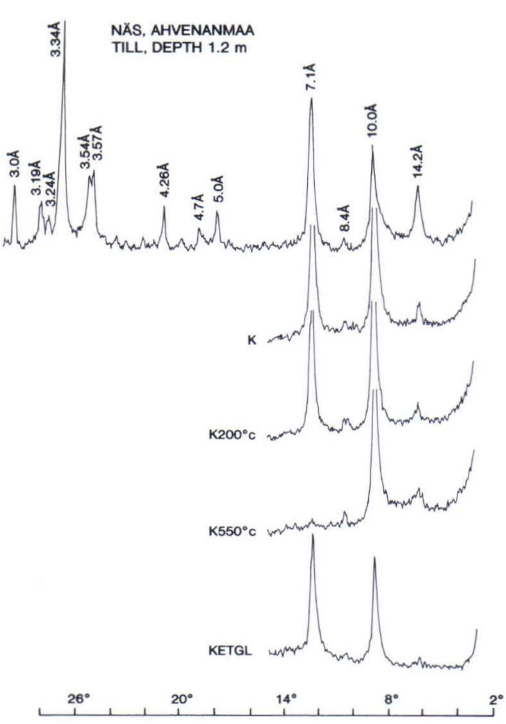


Fig. 31. X-ray diffraction traces of oriented samples (<0.02 mm fraction) from the Vääräkoski profile after various treatments. For symbols, see Figs 24 and 26.



The occurrence of kaolinite in Åland tills is thus most probably due to the sedimentary rock component in till. X-ray diffraction traces of the Näs samples are shown in Fig. 32.

Fig. 32. X-ray diffraction traces of oriented samples (<0.02 mm fraction) from Näs after various treatments. For symbols, see Fig. 24.

Influence of bedrock on regional properties and mineralogy of till

The samples studied are largely similar in mineralogy, irrespective of the part of Finland from which they originate. Differences in bedrock are mainly reflected in the occurrence of chlorite and talc in the area of greenstones containing these minerals. The Kuhmo greenstone belt, for instance, shows up clearly in the samples from Vääräkoski, Hossa, due to the presence of chlorite and talc. Likewise, in the area of the Lapland schist belt and in the komatiite zone chlorite, talc and amphibole occur in higher abundances than elsewhere. In some samples the abundances of plagioclase and hornblende are high. However, the abundances of these minerals also depend on the grain-size distribution, samples poor in clay fraction in the <0.02 mm fraction being richer in minerals typical of silt. The grain size-distribution of till samples depends on the strength properties of the minerals controlling the distribution of minerals in the grain size classes of fines (Dreimanis & Vagners 1972; Perttunen 1977; Nevalainen 1983). The anomalously high contents of fines in the Lapland greenstone belt suggest that an extensive bedrock area rich in chlorite may increase the fines contents in tills on a regional scale.

The mineralogy of the Finnish bedrock producing fines is fairly monotonous. This study investigated the influence of the Muhos sedimentary rock and the Angeli anorthosite on the mineralogy of till samples. Typical of the Muhos sedimentary rock is the presence of carbonate (Korpela 1977; Romu 1988). Analysis of a greenish-grey stone of the Muhos type from the Oulunsalo esker revealed that the <0.02 mm fraction of the sample contained illitic mica, chlorite and carbonate as main minerals, with small amounts of plagioclase, potassium feldspar and quartz. The Liminka profile showed a reddish oxidized clay band typical of the area of the Muhos formation, but carbonate was not present in till samples. The conclusion drawn from the samples studied is that the Muhos siltstone does not have a distinct effect on the mineralogy of till fines in the vicinity.

The influence of bedrock on till mineralogy was also studied in the area of the Angeli anorthosite massif (Appendix 1:33). The study pit is about 4 km from the proximal margin of the massif in the direction of flow stage II of the continental ice sheet (Hirvas 1991). Kaolinite, trioctahedral mica, hornblende and plagioclase are the main minerals in the samples. The kaolinite may derive from weathered anorthosite or from outside the massif. Mica and hornblende have been transported for at least 4 km from a source southwest of the anorthosite massif, where, according to Meriläinen (1975), there are quartz-feldspar schist, gneiss with amphibolitic interlayers, and mica gneiss. Granodiorite and quartz diorite occur at the margin of the anorthosite massif. Similarly Ihalainen (1994) concluded that till fines in the Angeli area were rich in minerals transported from beond the anorthosite massif.

As shown by the samples from Kierikkala, Hämeenkyrö; and Koura, Seinäjoki (Appendix 1:2, 1:4), the till fines in mica schist areas have higher abundances of 10 Å mica, which may also be of illitic type, than the fines in other areas. As implied by the low 001/002 (5 Å/10 Å) ratio, the 10 Å mica in the samples from both mica schist areas was mainly trioctahedral.

The 8.2 Å reflection of hornblende varies relatively little in the sample material. In samples poor in talc and chlorite the variation in hornblende abundance can probably be attributed to differences in grain size distributions.

Mineralogy of litostratigraphic units

The mineralogy of superimposed till units and intervening sediments can be studied in the profiles at several sites, e.g. at Rautuvaara, Kolari; Angeli; Kainuu; Liminka; Pyhäsalmi; Vesiperä, Haapavesi; Mertuanoja, Ylivieska; Kaapinsalmi, Suomussalmi; and Virtasalmi.

The Rautuvaara profile has five till units with silt between the lowermost ones (Appendix 1:25). The mineralogy of all the samples is almost identical, including small amounts of mixed-layer minerals of kaolinite and weathered mica. An example of the Rautuvaara samples is given in Figs 20 and 21. In other areas, too, the stratigraphic units of the profiles are almost identical in mineralogy.

At Vesiperä, Haapavesi, there are two till units that differ clearly in properties and have Eemian sediments between them. Uppermost in the profile is postglacial clay. All the units are almost identical in mineralogy. Note that all the Vesiperä samples contain kaolinite demonstrating the presence of products of old, far-advanced weathering throughout the profile. The abundance of kaolinite does not vary significantly even though the clay fraction contents of samples fluctuate markedly. The units differ in the occurrence of vermiculite. Thus the 14 Å mixed-layer minerals in the interglacial and postglacial clays contain more vermiculitic interlayers than do the mixed-layer minerals in the till units. The clays, too, contain more 12 Å mixed-layer minerals than do the till samples. Firm conclusions cannot be drawn from the occurrence of the 12 Å and 14 Å mixed-layer minerals, as the differences between them are so small. Vermiculite is also present in the lowermost till unit, implying that the vermiculite in the upper samples has been at least partly redeposited. The stratigraphy of Vesiperä and the fabric analysis of the till clasts are shown in Fig. 33, and the X-ray diffraction traces in Fig. 34.

The Kaapinsalmi study pit shows the most complete till stratigraphy of the Suomussalmi area (Saarnisto & Peltoniemi 1984). The stratigraphy and the fabric of till stones are presented in Fig. 35. Till units SI-SIII deposited during the deglaciation stage of the continental ice sheets, which flowed parallel to the Kuhmo greenstone belt, as implied by the high chlorite abundances in the two uppermost samples of fines (Appendix 1:21). The ice sheet that deposited the lowermost till unit flowed from northwest to southeast. The lowest samples are poor in chlorite, as the contact with the schist belt in the direction from which the ice flowed was closer than during the younger flow stages. Nonetheless, small amounts of kaolinite seem to occur in till units deposited during both flow stages. Figure 36 gives IR spectra with absorption bands typical of kaolinite for four fines samples from Kaapinsalmi. Hence, the occurrence of kaolinite does not seem to be related to any specific lithological unit but is a feature typical of the fines of the Kuhmo tills.

The presence of kaolinite in all samples from the Vesiperä profile at Haapavesi might be attributed to the redeposition of fines. Successive glaciations eroded and deposited till units similar in mineralogy because the starting material was composed of older till or interglacial or interstadial water-lain sediments. The mineralogy of the till samples at Kaapinsalmi, Suomussalmi, exhibits the influence of the local bedrock, but the occurrence of kaolinite in the different till units is due to the homogenization of fines caused by the recirculation of fines. The till units that deposited during younger flow stages contain materials from older till units and preglacial weathered bedrock even if the flows differed markedly in direction.

The Haapavesi profile is in the area that, according to the regional till mapping, is rich in clay fraction and fines; the Suomussalmi area, in contrast, is poor in fines and clay fraction. Haapavesi is a subaquatic and Suomussalmi a supra-aquatic area. Evidently, the profiles represent extremes of redeposition. The Haapavesi till profile contains redeposited fines in abundances several times higher than those in the Suomussalmi samples. Yet, the fines of the tills in supra-aquatic areas have also undergone recycling.

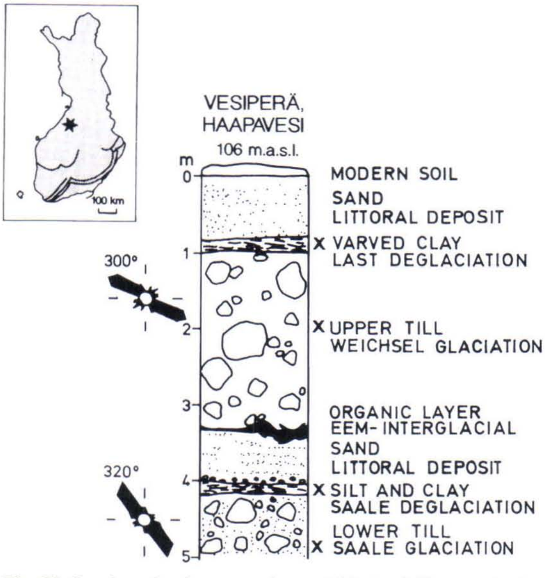


Fig. 33. Stratigraphy, interpretation and fabric of till stones in the Vesiperä profile after Nenonen et al. (1991). X = a sample analysed by X-ray diffraction.

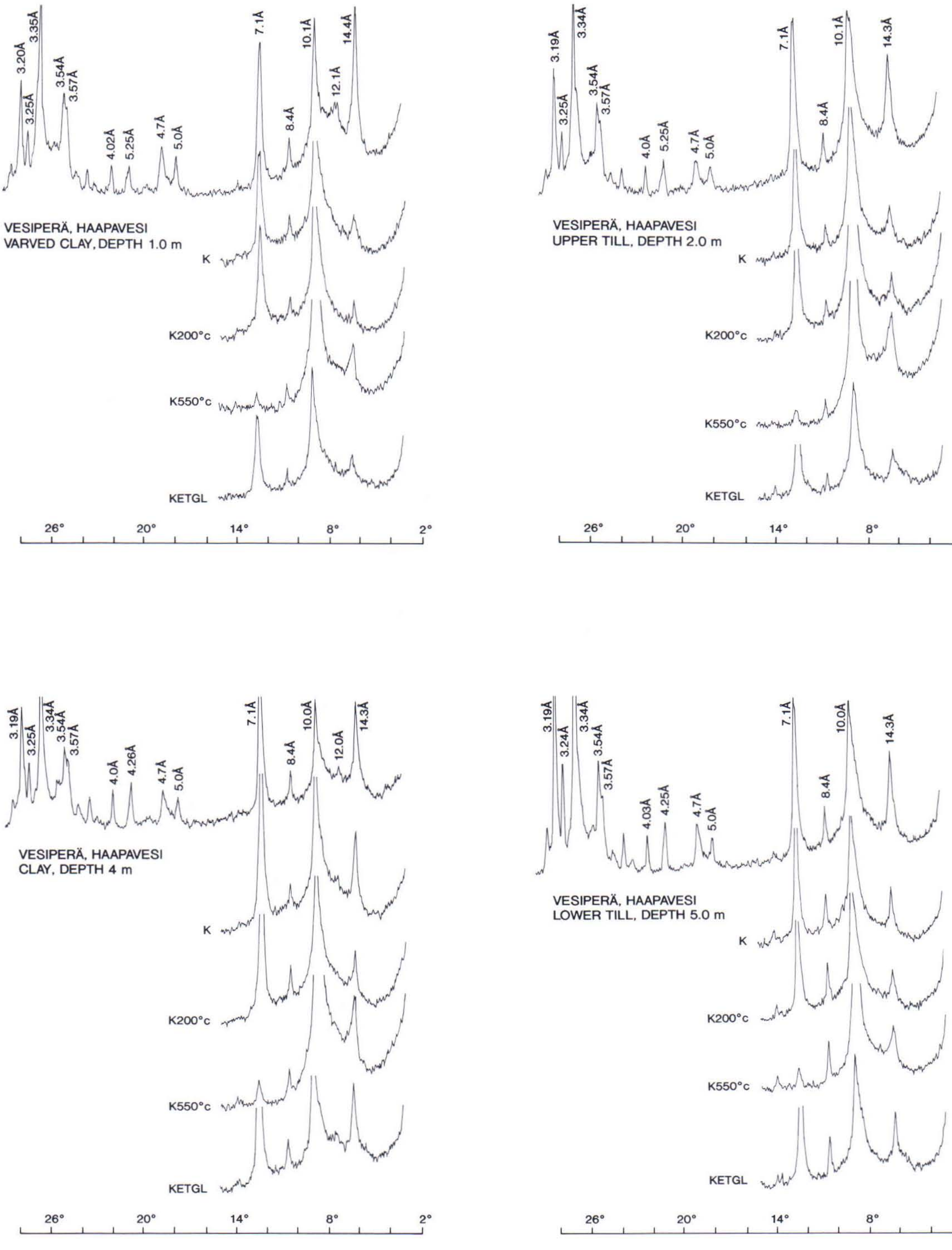
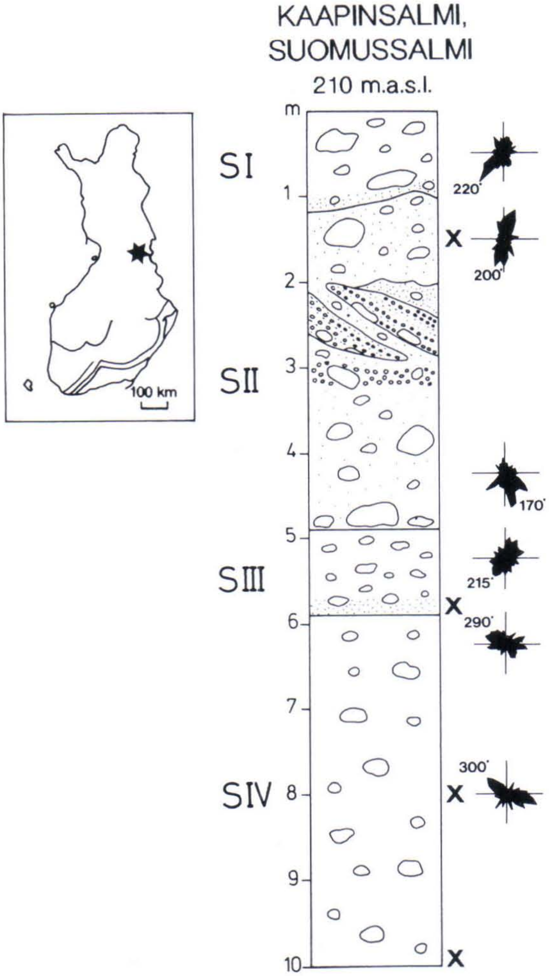


Fig. 34. X-ray diffraction traces of oriented samples from the Vesiperä profile after various treatments. For symbols, see Fig. 24.



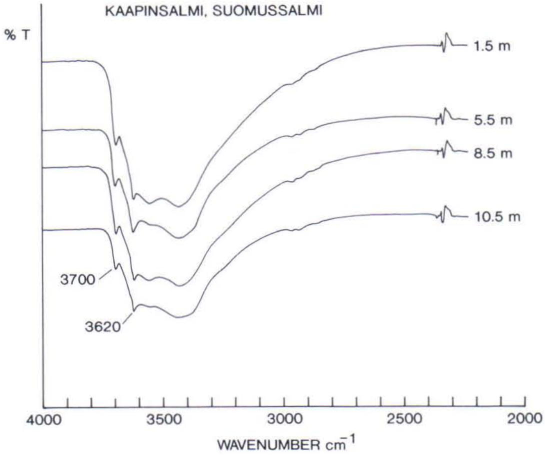


Fig. 36. IR spectra of the Kaapinsalmi samples.

Fig. 35. Stratigraphy and till fabric in the Kaapinsalmi study pit after Saarnisto & Peltoniemi (1984). X = a sample analysed by IR spectroscopy.

DISCUSSION

Origin of clay minerals in till

As shown by the presence of kaolinite in different stratigraphic units in study pits, part of the till fines has been redeposited from older tills to younger till units during glaciation cycles. In a number of profiles, the samples from the topmost oxidized horizon contain mixed-layer minerals with vermiculitic interlayers in an abundance that is not seen in samples taken deeper down. The surficial samples also show polymerization of Al hydroxides in the interlayers. Both the mixed-layer minerals and the Al hydroxides were weathered during postglacial time due to the action of acid gravitational waters. In several profiles, deep samples, too, contain mixed-layer minerals and Al hydroxides in interlayers. Variations in the ground-water table may have caused the deeper layers to weather, but cannot have been the reason for all the mineral alterations encountered below the ground-water table. There, the mixed-layer minerals and those with Al hydroxide in their interlayers were partly redeposited after having been eroded from the surficial parts of older tills. The presence of mixed-layer minerals in deeper horizons thus implies redeposition of till fines from older sediments.

The scarcity of mixed-layer minerals with vermiculitic interlayers in deep samples cannot be easily attributed to the redeposition of till. Some of the micas that weathered during ice-free periods deposited in marine and lake basins, where ion-exchange reactions replaced H^+ ions with K^+ ions in interlayers and mica was transformed back into an unweathered state (cf. Weaver 1958a,b,c; Roalsed 1972). A starting material rich in illite and chlorite deposits as a till in which mixed-layer vermiculitic minerals are formed when micas and chlorite weather in the course of podzolization. At a later stage of the fines cycle, weathered micas may resume their unweathered state when fines deposit in saline water. The vermiculitic mixed-layer minerals deep in till sheets may be remnants of material weathered close to the ground surface during earlier cycles and which has not been in contact with seawater. Thus, they have preserved mineral alterations produced during former ice-free stages.

Genesis of till fines

A number of studies have shown that the coarse fractions in Scandinavian tills correspond to the local bedrock in lithological composition (e.g. G. Lundqvist 1935, 1951; J. Lundqvist 1969; Gillberg 1964, 1967; Virkkala 1969b; Linden 1975; Perttunen 1977; Saarnisto et al. 1980, 1981; Nevalainen 1983; Saarnisto & Peltoniemi 1984; Salminen & Hartikainen 1985; Salonen 1986). Investigations of surface boulders have shown that Finland's till has been transported for only a short distance (Salonen 1986). The stones and boulders used as indicators decrease in frequency in the direction of glacier flow, eventually disappearing altogether. Consequently, it is assumed that till fines are formed as the material loosened from bedrock is pulverized while being transported in the base of the continental ice sheet. In the course of transport, debris is reduced in grain size as the clasts are ground against each other and against the bed. This process is called comminution.

Dreimanis and Vagners (1972) have assigned each mineral a terminal grade grain size class in which its fines fraction becomes enriched during comminution. However, mineral grains occur fairly abundantly in fractions finer in grain size than those of the terminal grades (Linden 1975; Perttunen 1977; Nevalainen 1983, 1989). The abundance of monomineralic grains increases in the till matrix and their source is less easy to establish from bedrock lithology. The variation in fines mineralogy is not always as evident in sample profiles across different bedrock areas as it is in rock fragments (Linden 1975). Material deriving from sources clearly definable in mineralogy can, however, be irrefutably identified. A good example is the tills on the distal side of the Kuhmo greenstone belt, which contain abundant amphiboles, serpentine and chlorite (Nevalainen 1983). Till fines often represent the farthest-travelled and most homogenized component of till (Gillberg 1977; Perttunen 1977; Saarnisto et al. 1980, 1981; Taipale et al. 1986). Till fines derive from a larger area than the coarser fractions.

The geochemical anomalies in till fines are now known to be of local origin. Glacigenic geochemical anomalies caused by sulphides, which are less wear-resistant than silicates, eroded from ore outcrops are roughly 2 - 4 times wider than the outcrop itself (Salminen 1992). Geochemical anomalies may even rest almost directly on top of mineralizations (Kokkola 1989). Some bedrock areas, e.g. rapakivi granite massifs, are clearly delineated by some aqua regia-soluble elements in till fines (Vallius 1993). According to Saarnisto et al. (1980, 1981), the increase in the trace-metal concentration in till caused by the Kuhmo greenstone belt is local, but concentrations exceeding the background values are still observed for 30 km on the distal side of the schist belt. The increase in metal concentrations caused by the Kuhmo greenstone belt is clearly visible because the concentration level in the granitoids in the background is low.

The genetic processes of basal till are not fully understood due to the lack of direct observations on the bottom of the continental ice sheet (Dreimanis 1990). In the margins of glaciers, it has been possible to examine glacial debris transported under subglacial conditions. In a warm based glacier, the debris being transported is concentrated in a bottom layer, rarely more than 10 - 20 cm thick, with 5 - 50 wt % mineral matter by volyme (Boulton 1975). The comminution caused by glacial transport has been simulated in laboratories with crushing tests (Salminen 1980; Haldorsen 1983; Salminen et al. 1989; Mäkinen 1993). By wet-grinding stones from till in a ball mill, Mäkinen (1992, 1993) succeeded in producing fines that, in terms of unit weight, corresponded to those of natural fines-poor sandy till. Stones from tills rich in silt and clay fraction could not be ground into fines corresponding to natural fines in unit weight.In certain circumstances the crushing tests can simulate comminution at the bottom of a continental ice sheet. This seems to apply to tills poor in fines. On the basis of crushing tests, Mäkinen (1993) suggests that reconnaissance-scale geochemical differences between tills are due to differences in comminution processes in areas of dissimilar flow activity of the continental ice sheet.

In the area of the Great Lakes of North America, mineral counts show that younger till units have received a large input of material from older tills (Sitler 1963; Gross & Moren 1971; Wickham et al. 1988). In Sweden, Gillberg (1977) emphasizes the redeposition of old sediments as a possible contributing factor in the genesis of till fines. He attributes the homogenization of till fines to the redeposition of fines from older sediments that have gone through several glacial cycles. According to Gross & Moran (1971) and Gillberg (1977), comminution of material loosened from bedrock and of that eroded from older glacigenic deposits takes place simultaneously during glacial transport.

In many Scandinavian tills, fines have been enriched in quartz in relation to the source rock (Virkkala 1969b; Linden 1975; Rosenqvist 1975; Perttunen 1977). According to Gillberg (1977), the enrichment of quartz is due to the polycyclic genesis of till. When till is submitted to several successive comminutions, the silt fraction is enriched in the mineral with the greatest resistance of common minerals. Haldorsen (1982) suggests that the enrichment of basal till in quartz in the Åstadalen area in Norway may be due to above-average abrasion. This produced quartz and feldspars in such abundance that eventually the fines were relatively impoverished in micas. According to Haldorsen, quartz is also enriched if clay fraction is partly winnoved from the depositing till.

Evidence for recycling of fines

The material of this study provides clear mineralogical evidence of the mixing and preservation of material from preglacial weathered bedrock in tills in Finland. Kaolinite is a product of far-advanced chemical weathering and cannot have formed in weathering in a climate similar to that of Finland today (Weaver 1989). Kaolinite is often the predominant mineral in till fines in the area underlayn by weathered bedrock in central Lapland. Outside this area it occurs in clay-rich tills in particular. In the Vesiperä profile at Haapavesi, kaolinite is present in all litostratigraphic units, suggesting that material from preglacial weathered bedrock has redeposited throughout all glaciation cycles. Small amounts of kaolinite are also encountered in the Suomussalmi till units; the redeposition of kaolinite is thus not restricted to the fines-rich tills of Ostrobothnia. It is also present in sedimentary rocks, and material from them may occur in the tills of Ostrobothnia and Åland.

On the basis of the mineralogy of till samples, it used to be assumed that the fines derive in part from preglacial weathered bedrocks or from sediments deposited during interglacial ice-free stages (Soveri & Hyyppä 1966; Virkkala 1969b). The profiles studied here suggest that Finnish tills have obtained incremental matter in varying amounts from deposits predating the flow stage of the continental ice sheet in question.

Other observations, too, support the concept of till redeposition. According to Heinonen (1957), the microfossils in the till cover indicate redeposition of interglacial or interstadial material in till units. Tills resting on deposits interpreted as Eemian sediments are often rich in fines and clay fraction and frequently contain clay clasts with the same microfossil assemblage as the interglacial sediment at lower levels (Hirvas & Nenonen 1987). In the till samples from Paltamo, the corroded surfaces of quartz grains, which are very resistant to weathering, suggest that residual clasts produced by weathering considerably more intense than would be possible in the present climate have redeposited in till (Nieminen 1985). According to Perttunen (1977), small amounts of well-rounded quartz grains are present in tills of the Hämeenlinna area, implying that the tills contain minerals rounded by fluvial or glaciofluvial processes predating the last glaciation.

A comparison of the data on transport distance distribution of surface boulders published by Salonen (1986), and the regional fines and clay fraction anomalies of the present study leads to the conclusion that till fines evidently have more complicated transportation histories than do the glacially transported surface boulders.

Intensity of glacial erosion

Interglacial and glacial periods have alternated repeatedly several times in Scandinavia. Drawing on the principles of actualism, then, we can assume that overburden similar to that of today has been eroded several times by waxing and waning continental ice sheets. According to Boulton (1979), the bottom flow of Breidamerkurjökull in Iceland is deforming previously deposited tills. He is of the opinion that the flow of Breidamerkurjökull is largely due to the deformation of older sediments. On the basis of this and theoretical considerations, Boulton and Jones (1979), Boulton (1987) and Boulton and Hindmarsh (1987) have proposed that the deformation of previously deposited sediments and their gradual conversion into massive basal till may have been an important factor in the genesis of till in all glaciated terrains. The deformation of till-covered sediments and their mixing with the lower parts of massive basal till units is visible in Ostrobothnia (Nenonen 1993), and examples of the reorientation of the clasts in an older till unit by a younger ice flow have been reported (Virkkala 1960; MacClintock & Dreimanis 1964; Ramsden & Westgate, 1971). The reorientation of the clasts shows that the older till units are capable of being deformed and that they can even form "new" till units from the material loosened before that particular glacial flow stage.

Studies on surficial deposits conducted by the departments of Quaternary Geology and Geochemistry at the GSF in summer 1993 revealed that younger glacial flow had deformed the surface of a till unit deposited during an older glacial flow stage, reorienting stones down to a varying depth. The phenomenon was observed over a large area in Pirkkala and Laitikkala (Hirvas, Nenonen & Huhta, oral comm. 1993), and was particularly clear in a study pit excavated in the Laitikkala area (map sheet 2132 06, x:6793 33, y:2514 58, z:100 m a.s.l.). The one till unit in that area exhibits a northwest-southeast-trending till geochemical anomaly on regional-scale geochemical maps. The geochemical felsic anomaly, in which the concentrations of aqua regia-soluble trace metals in till are anomalously low in relation to the local bedrock (Lestinen, oral comm. 1993), preserved its older northwest-southeast-trending fabric, even when the whole till mass was reoriented during the youngest flow from WSW. This is an extreme case in which a younger till unit was formed from till deposited during an older flow stage by deformation. Glacial striae of both flow stages were observed on the bedrock beneath the till unit.

Studies on the relationship between till and the underlying bedrock have usually examined the influence of only a very restricted source on till. Clasts, minerals or trace element concentrations have been used as indicators. Till matrix, largely composed of durable silicate minerals enriched during comminution, tends to be neglected. Local tillgeochemical studies often concentrate on the recognisable anomaly in the matrix caused by a well defined source. However, the genesis of the fine fractions cannot be established from indicators. In extreme cases, the till fines may be composed entirely of redeposited older sediments or of fresh material loosened from the bedrock by the last glaciation.

If we assume that the till is a sediment of one cycle, we can conclude that glacial erosion has been intense and that the till mass is renewed during each glaciation with material from the bedrock. Glacial erosion should then lower the surface of the bedrock by almost the average thickness of the till unit in question. It is difficult, however, to envisage a mechanism whereby the old deposits would be totally removed before the new till sheet was deposited. The purely monocyclic concept of till genesis requires powerful glacial erosion and transport distances of hundreds of kilometres.

Studies of striations indicate that glacial erosion has been very slight in Finland, as many outcrops show cross-striae. At Pyhäsalmi open pit, for example, cross-striae found under the overburden correspond to the fabric of stones in till units deposited by two different glaciations (Hirvas et al. 1988). Till-covered occurrences of weathered bedrock and sorted formations also imply glacial erosion of low intensity (Lundqvist 1985; Hirvas & Nenonen 1987).

Dewatering during till deposition

When a warm based continental ice sheet transports its bottom load, some of the fines may be removed when the depositing till is dewatered under pressure-melting conditions (Drewery 1986; Clarke 1987). The water expelled from the depositing debris may flow as a thin water layer - Weertman film - between the ice and the bottom (Weertman 1972). Water may also be removed through the depositing debris and depositional floor (Boulton 1975; Boulton & Hindmarsh 1987; Alley et al. 1989; Murray & Dowdeswell 1992); in that case, the outwashing of the finest fractions is probable (Clarke 1987).

Regional differences in the grain size distribution of till have been attributed by Feininger (1971) to the water removed from depositing debris. According to him, melt waters percolate through the depositing debris, and transport finer fractions towards the margin of the glacier. Depending on the case, the washing effect of water is restricted to grains below a certain threshold value in size. The threshold value varies with the pore water pressure and the grain size of the depositing debris. The concept put forward by Feininger (1972) is similar to that of Boulton (1975) according to which pore water flows from the depositing till into subglacial channels through either the depositional base or debris. Feininger's (1972) idea about the washing of till has, however, not attracted wide attention, because he also suggested that all till material, from clay fraction to boulders, derives entirely from preglacial weathered bedrock. The mineralogical analyses made for this study show that, with the exception of the tills in central Lapland, the proportion of clay minerals from preglacial weathered bedrock is low in Finnish tills.

According to Muller (1983), massive basal till is formed in a lodgement process (Flint 1971) if the till is not sorted by dewatering. He further maintains that many of the bands of sorted sediment in till produced by the lodgement process can be attributed to sorting caused by waters liberated during the deposition of till. Microstructures in tills caused by dewatering have also been described by van der Meer (1987), although most of the microstructures in till are due to subglacial deformation during the deposition of till (van der Meer 1993).

Under extremely dry and cold conditions, till may deposit slowly by sublimation, without free water (Shaw 1976, 1989). Lundqvist (1989a,b) reports that sublimation is an important till-forming agent in Antarctica. Although the till is eroded under pressure-melting subglacial conditions, free water does not play any role in till forming proceses when the ice mass disappears and the bottom load is deposited. The sparsity of water is particularly evident in the lack of sorted deposits in Antarctica. The tills at Vestfold Hills and at Vestfjella areas in eastern Antarctica, are very rich in fines and clay fraction (Hirvas & Nenonen 1991; Lintinen 1991; Hirvas et al.

1993). According to Hasegawa et al. (1992), even supraglacial debris is rich in clay fraction in the areas of Sør Rondane crystalline bedrock in eastern Antarctica. Clearly the high clay fraction content in Antarctica tills is not due to the underlying bedrock, as the mineralogy of the till fines varies from one area to the other (Hirvas et al. 1994). We can assume then that meltwaters liberated during the deglaciation of the Scandinavian continental ice sheet removed finest fractions from depositing till in the rapidly melting margins of the ice sheet, thus producing basal tills poor in clay fraction and fines.

The effect of meltwaters on depositing debris on the floor of warm based continental ice sheets is difficult to assess. Let us therefore examine the removal of fines from the depositing till hypothetically with a simplified balance calculation. To make things easier, we shall consider the clay fraction only. The estimated volume of sorted deposits in Finland is $67.5\ 10^9\ m^3$ (Niemelä 1979). Assuming that these deposits are originally composed of average Finnish till with 20 - 30% silt and about 3% clay fraction (<20 mm fraction), we can estimate the volume of clay fraction produced by sorted deposits. The mean thickness of clay deposits in Finland is about 6 - 7 m (Hyyppä 1990). The average clay fraction content of 1000 clay samples analysed in the course of the national assessment of clay resources is 37% (Sahala, oral comm. 1993). Clay deposits cover 8.3% of the country's surface area (Kujansuu & Niemelä, 1984). Thus, the average thickness of the clay fraction in clay deposits is 2.4 m. The hypothetical average starting material from sorted formations converted into till yields a layer of clay fraction only 0.1 m thick to cover the entire area of present clay deposits. This consideration has omitted the clay deposits on the bottom of lake basins, which would reduce the difference between the observed and calculated clay volumes somewhat. The calculation involves a great number of imponderables. Even so, it is obvious that the amount of clay fraction in clay deposits is higher than the amount that could have been washed from sorted formations by an order of magnitude. As large amounts of clay have also deposited on the present sea bottom, the volume of clay fraction removed from Finnish tills is probably much higher than that estimated.

Judging by the occurrence of esker chains and drumlines, Punkari (1980) divided the country into active lobe areas and passive interlobate areas. In his regional division, the high clay fraction content anomalies are largely located in passive interlobate areas. However, the fabric of the stones in the basal tills of these areas is typically well developed (Hirvas & Nenonen 1987), implying an actively flowing continental ice sheet when the till was depositing. What is more, the high clay fraction content anomalies do not fully coincide with the interlobate areas of Punkari (1980). The regional clay fraction anomalies in southern and northern Ostrobothnia lack drumlin fields, and the number of sorted formations in clay-rich areas is markedly lower than that in the area of glacial lobes.

From the occurrence of clay-rich till, it can be deduced that the hydrological and hydrographic states of the continental ice sheet have a major effect on till properties. In the area of clay-rich tills, clay fraction was not removed from the depositing debris owing to the scarcity of meltwater channels (cf. Boulton & Hindmarsh 1987). According to Virkkala (1948), the till in the vicinity of some esker chains at Nurmes grades into sorted matter, and the impact of washing by subglacial rivers on the till sheet is visible within a small area. In central Lapland, too, till is locally richer in fines than elsewhere in Lapland. The number of eskers in the area of high fines content anomalies in central Lapland is lower than elsewhere in Lapland.

Polycyclic formation of till

When a flowing ice sheet erodes or deforms old tills and water-laid sediments, large quantities of old fines that have gone through several glacial cycles end up in the bottom load. At the same time "new" fines are generated continuously due to crushing and abrasion processes on the bottom of the continental ice sheet. Fines are formed by comminution from material loosened from the bedrock during each flow stage and also from stones of older tills and weathered bedrock. The grain size of the fines eroded from older deposits diminishes even further in comminution.

The polycyclic formation of till must also involve a mechanism for removing fines from the system. Otherwise, as the till fines pass through increasing number of glaciation cycles, the fines and clay fraction contents in tills should increase towards the younger till units where the final products of the previous comminution processes are concentrated. It is assumed that, in the lodgement process depositing massive basal tills, sorting by water is minimal or nonexistent (Dreimanis & Lundqvist 1984; Dreimanis 1990). On the other hand, the selective washing proposed by Feininger (1971), which begins with the finest grains, does not necessarily result in more than partial removal of fine grain sizes, leaving the depositing till unsorted. The variation in clay fraction contents of tills found here is clearly related to the occurrence of esker chains in certain areas. Thus, the filtering of water from depositing debris to the nearest subglacial channels to the front of the continental ice sheet (cf. Boulton & Hindmarsh 1987; Clarke, 1987) is the most probable fines-removing mechanism in the polycyclic formation of till.

Regional differences between tills

According to mineralogical observations made during this study, Finnish till fines are almost always only slightly weathered. An exception is central Lapland with its numerous occurrences of preglacial weathered bedrock. Kaolinite and iron precipitates, which are common in the tills of central Lapland, derive from preglacial weathered rocks. Considerable quantities of weathered material have been intermixed with till sheets over a large area, as shown by the anomalously high specific surface area values in relation to the clay fraction content of fines (provinces G and H in Fig. 23). In the weathered bedrock area, erosion by continental ice sheets has repeatedly been very weak (Kujansuu, 1976; Hirvas 1983, 1991), which has allowed the preglacial weathered bedrock to survive. However, it can also be proposed hypothetically that before the glaciations the weathering crust was not evenly distributed over Lapland. Before the spread of the first continental ice sheets, the impact of Tertiary fluvial erosion was powerful in river valleys.

The till areas classified by the specific surface area and clay fraction content of till fines and by fines content do not follow lithological boundaries or the border between supra-aquatic and subaquatic areas. The high fines and clay fraction content anomalies have no clear connection to areal variation of the glacial transport distance distribution of surface boulders determined by Salonen (1986). Clay- and fines-rich tills (province E and the northern part of province C, Fig. 23) seem to be located partly in the interlobate areas determined by Punkari (1980). The present study suggests a model for the regional-scale distribution of till properties, with the emphasis on ice dynamics, hydrology, hydrography and the regional distribution and recycling of fines-rich material during the waning stages of the continental ice sheet. The quantitative contribution of the different factors cannot be established, as their impact has varied from one area to the other during the numerous glaciations. The existence of the marine basin of the Gulf of Bothnia during ice-free periods is, however, indisputable (cf. Forsström et al., 1987). Hence, the high values of clay fraction and fines contents southeast of the basin (provinces C, D and E, Fig. 23) reflect the repeated influence of this large sedimentation basin on tills.

As shown by the regional till material, areas with anomalously high fines and clay fraction contents following the general flow trends of the continental ice sheet extend from the coast of Ostrobothnia to central Finland. Owing to the macrotopography of Scandinavia, the flow patterns of the continental ice sheets changed little from glaciation to glaciation. During each ice-free stage, the Gulf of Bothnia acted as a basin for fine sediments deposited by rives. Fine-grained sediments were deposited as fines-rich till sheets in the lowlands of Ostrobothnia during the glaciations and were then converted by younger flows into fines-rich till units.

The till areas rich in fines but poor in clay fraction, which extend from central Ostrobothnia to central Finland (Province D, Fig. 23), probably also represent an area of fines redeposition. In that area, conditions on the bottom of the continental ice sheet differed from those prevailing in the area of the present fines-rich tills. In areas of clay-rich tills, sorted formations and drumlins are rare, whereas in areas poor in clay fraction but rich in fines esker chains are usually located at a distance of 15 - 25 km from each other (Kujansuu & Niemelä 1984). The active flow of the continental ice sheet divided into lobes during deglaciation, probably transporting material for a considerable distance. As a result, the fines content declined in relation to that of clay fraction. The esker chains occurring regularly in areas of active lobes indicate that there was abundant meltwater in subglacial channels on the bottom of the continental ice sheet. The pressure of subglacial water in such areas was probably high, resulting in relatively more active flow (cf. Boulton 1975; Boulton & Hindmarsh 1987; Brown et al. 1987; Allay et al. 1987) and the partial removal of the clay fraction from the depositing debris to subglacial channels and ultimately to sites outside the ice sheet (cf. Clarke, 1987).

The anomalies of the regional clay fraction content in till in subaquatic areas are probably due to the clay increment eroded from old interglacial sediments (provinces C, D and E, Fig. 23). This increment is seen in areas where the flow activity of the continental ice sheet was lower than average or the washing less effective, or both. It is possible therefore that till units in the same stratigraphic position differ markedly in clay fraction content. An example of this occurs in province E, where there there is a sharp demarcation between the lithostratigraphic till unit and the area in the southwest with a till poor in clay fraction but rich in fines. Clay-rich tills evidently deposited while the sediments of ice-free periods were eroded by the continental ice sheet during the first flow stage of each glaciation depositing tills (Rainio & Lahermo 1976, 1984). Clay-rich tills thus occur in different stratigraphic positions and are, at least partly, different in age.

Explanations based on polycyclic genesis

The polycyclic process of till fines formation explains many earlier observations otherwise difficult to interpret. Long transport distances of boulders and mineral grains are not inconsistent with the local character of geochemical anomalies. The geochemical indicator determined on till fines has been intermixed with large amounts of homogenized fine matrix that has passed through several glaciation cycles, thus moderating the influence of the indicator. The transport of the whole mass of fines cannot be examined merely on the basis of chemical data and the stones and minerals used as indicators. The influence of the recycled fines in matrix is clear in the mineralogy of till samples from the area of the Angeli anorthosite massif (Appendix 1:33). The study site is located about 4 km down-glacier from the proximal margin of the massif. The fines in till samples contain minerals typical of matrix, i.e. quartz, plagioclase, potassium feldspar, hornblende, illitic trioctahedral mica and kaolinite. These are present in all the till samples investigated from Angeli. Note, however, that chlorite is absent, implying that mineral matter has not been transported from the greenstone belt to the study site. Thus, till fines have been transported for at least 5 km, but no more than 30 - 50 km. Bedrock areas containing chlorite show up clearly in samples from various study sites despite the diluting effect of fine matrix, as considerable amounts of fines were loosened from a source susceptible to erosion during each glacial flow stage.

The variation in the oxygen isotope ratios of ocean-floor sediments has been attributed to global variation in the volume of glaciers. The number of oxygen isotope stages implies that there have been more than ten glaciations during the Quaternary (Shackleton & Obdyke 1973). However, only a few superimposed till units are encountered in Finland. The discrepancy between the great number of oxygen isotope stages of marine sediments and the small number of superimposed till units can be explained by the hypothesis of recycled till fines, that is, that till units deposited during older glaciations were eroded and deposited during the flow stages of younger glaciations. Only at very protected sites have older tills survived as erosion remnants. At the onset of continental glaciation, glacial erosion was restricted to the preglacial weathering bedrock. Thus, the till deposited by the first glaciation was composed almost exclusively of material from the weathered bedrock. During subsequent glaciations the older tills were the principal source of new till. Their material was comminuted and part of the fines was removed by the dewatering of subglacial debris deposited as basal till. After the glaciation cycles had repeated themselves over and over again the abundance of kaolinite, a mineral indicative of far-advanced chemical weathering, was diluted to its present level in till fines.

Till-geochemical mapping

The polycyclic origin of till fines provides a new approach to the examination of the findings of regional-scale till-geochemical mapping and contributes to the assessment of the regional anomalies. Till is a sediment with variable amounts of material that has passed through several glaciation cycles, depending on the fines production of the starting material, the activity of comminution during the last glacial flow stage and the removal of fines by water from depositing till.

In the northwest of the till-geochemical Lake Ladoga-Bothnian Bay zone (province E, Fig. 23), a significant proportion of the aqua regia-soluble metal concentrations in till fines derives from biotite and chlorite and the mixed-layer minerals that are their alteration products (Räisänen et al. 1992). The concentrations of soluble metals analysed from oxalate extract are very low in relation to the concentrations of aqua regia-soluble elements. A hydromorphic component does not play any role in the anomaly (Räisänen et al. 1992b). The aqua regia-soluble minerals in clay-rich tills are for the most part in the clay fraction and, according to Räisänen et al. (1992b), the anomaly is mainly due to the high abundances of micas. With some reservations, the results of Räisänen et al. (1992b) could be applied in other areas of clay-rich tills, too.

Examination of the results of the reconnaissance-scale geochemical mapping together with the regional distribution of the clay fraction and specific surface area shows that, in some areas, the clay fraction is a significant source of aqua regia-soluble metals. True, the medium correlation (r = 0.59) between Zn concentrations and the abundance of clay fraction noted here shows the effect of the minerals in the silt fraction on chemical data. Younger tills contain varying amounts of fines that have passed several cycles. Tills rich in fines have probably obtained an increment of aqua regia-soluble micas from the clay fraction of fines that has passed through several cycles.

In the Päijänne area, the correlation between the chemical data of till fines and the chemical bedrock data is weak or nonexistent (Vallius 1992), which shows how difficult it is to compare the till fines and the metal concentrations of bedrock. Quartz, feldspars and hornblende, which occur in high abundances in the silt fraction and do not dissolve in aqua regia (Räisänen et al. 1992b), dilute till and thus make it difficult to interpret anomalies. Despite the diluting effect of fine matrix, some bedrock areas show up well on geochemical maps. For instance, the high Li concentrations of a rapakivi granite massif manifest themselves as elevated concentrations on geochemical maps (Vallius 1993). This is a good example of an indicator showing up even when the till fines have probably gone through several glacial cycles and are thus homogenized.

The elevated Cr and Ni concentrations on the distal side of the Kuhmo greenstone belt, still detectable outside the anomaly proper 30 km from the source (Saarnisto et al. 1980, 1981), can be attributed to the presence of greenstone material transported in the matrix, some of which has been recycled a number of times. The continuation of each local till-geochemical anomaly on the distal side of the source depends on the ratio of fines produced by the last glaciation to the increment eroded from the older till sheets. Hence, the small size of local till-geochemical anomalies is due to the large amount of diluting material.

In terms of regional interpretation, the grain size distribution of till controls the effect of the primary bedrock sources, either enhancing or moderating it. As shown by the study material, the tills in the till-geochemical Lake Ladoga-Bothnian Bay zone can be divided into two populations by clay fraction content. In the northwestern part up to Riistavesi a substantial part of the till is of redeposited material from the sediments of the Eem Sea (province E, Fig. 23). Here, the high metal concentrations in till fines are due to clay fraction. In the southeast of Riistavesi the tills are poor in fines, and the elements soluble in aqua regia mainly derive from silt fraction.

Shilts (1984) and DiLabio (1990) have suggested that geochemical anomalies varying in size occur one on top of the other. The anomaly patterns of the reconnaissance-scale geochemical mapping (Koljonen 1992) refer to the largest regional anomalies produced by a variety of factors. In addition to elemental ratios in bedrock, variations in fines and the clay fraction content of till reflect the contribution of glacigenic processes to the formation of till-geochemical anomalies.

Vallius (1992) points out that the Central Finland ice-marginal formation divides the geochemical anomaly pattern. The division is seen clearly in the clay fraction contents of the regional samples. The low metal concentrations in tills on the inner side of the ice-marginal formation are caused by the low trace metal concentrations in the central Finland granite complex and the low clay fraction content of till. The low clay fraction content is due either to the impoverishment of till in clay fraction caused by the dewatering of depositing debris or to an increase in the volume of silt fraction during comminution. The high fines content implies that the area has received a fines increment from older sediments.

The key finding of this study for till-geochemical mapping is the regional distribution of till properties. The regional till provinces are partly genetic units, some of which are of known lithostratigraphic position. It would make sense, then, if geochemical mapping were to examine the elemental variation originally due to the bedrock within each till province separately. The <0.06 mm fraction analysed in till-geochemical mapping is, however, problematic because it does not take into account the natural variations in bulk sample till fines contents (Fig. 16).

SUMMARY

The basal tills of Finland were classified by fines properties measured on regional-scale sample material consisting of 1015 regular-grid samples taken from the stores of the Geochemistry Department at the GSF. The samples were taken with a percussion drill from a depth of 1.5 - 3 m. The <0.06 mm fractions of the samples were measured for grain size distribution with a sedigraph and for specific surface area with nitrogen sorption. The regional variation in the fines content of Finnish tills was studied using the grain size data in the databank of the GSF's Department of Quaternary Geology. These samples were taken from a depth of 1 m. On the of both sets of sampling materials, 34 sites were selected for mineralogical studies. Samples from stratigraphically known units were collected at the sites to establish the origin of till fines. The mineralogical determinations were made by X-ray diffraction and IR spectrometry.

The tills were divided into provinces by their fines content, and the clay fraction content and specific surface area of the fines. In the northwestern part of the till-geochemical Lake Ladoga-Bothnian Bay zone, the fines and clay fraction contents of tills and the specific surface area of fines are anomalously high (province E, Fig. 23). Tills rich in clay fraction and fines also occurred in southern Ostrobothnia and southwestern Finland (province C). In central Ostrobothnia, between the Central Finland ice-marginal formation and the Lake Ladoga-Bothian Bay zone, the content of till fines is high in places but the clay fraction content and specific surface area of fines are low (province D). In southern and southeastern Finland the fines and clay fraction contents are low, although occasional high clay fraction values are also encountered (province A). Throughout most of Finland the fines contents and the clay fraction contents and the specific surface area of fines are low (province F); in these areas, too, occasional high values were encountered. In a large area in Lapland the specific surface area values are elevated in relation to the clay fraction content (provinces G, H). In central Lapland, the contents of till fines are locally high (province H). In northwestern and northeastern Lapland, the fines content and specific surface area of till are low (provinces I, J).

Some of the till samples of the regional mapping were from stratigraphically known till units, e.g. in province E where there are two stratigraphic basal till units. Stratigraphic studies have shown that lowermost in the area is a till unit poor in fines and uppermost a continuous, 2 - 5 m thick basal till unit rich in fines. The samples of the regional study on fines derive from the fines-rich uppermost basal till unit. Tills in supra-aquatic and subaquatic areas do not differ markedly from each other in fines and clay fraction contents. The tills in supra-aquatic areas are usually sandy tills poor in clay fraction. In subaquatic areas the basal tills may contain abundant clay fraction, but fines-poor tills also occur. The Salpausselkä zone does not show up in the regional till properties, but the Central Finland ice-marginal formation clearly separates tills into two groups based on regional properties. Regional studies reveal that bedrock properties have only a slight influence on the fines and clay fraction contents of the tills of Finland.

Samples from the study sites have quartz, feldspar and micas as main minerals. Only in areas with lithological units rich in chlorite and talc does the mineralogy of tills differ significantly from those of other areas. The disparity is due to the high abundance of chlorite and talc. In other bedrock areas the abundance of micas varies in till fines. The sample material does not allow firm conclusions to be drawn concerning the effect of bedrock on the till mineralogy. This is in harmony with previous concepts of the homogenization of till fines. Small amounts of kaolinite are also present in the till fines. A product of far-advanced chemical weathering, kaolinite forms when the climate is distinctly warmer than it is at present. It occurs abundantly in central Lapland, in the area of high specific surface area tills, where the preglacial weathered bedrock has a marked impact on till fines. Kaolinite also occurs in Ostrobothnia, in various stratigraphic units of the study pits, and occasionally in samples from other areas, too. Mineralogical alterations have taken place in till fines during postglacial time, as shown by the weathering of biotite and chlorite in the topmost samples into mixed-layer minerals with vermiculitic interlayers. Postglacial weathering has been most powerful in tills rich in clay fraction. Time is not a significant factor in explaining the difference in weathering intensity between areas.

Till fines have been recycled several times in Finland. During each glaciation the continental ice sheet erodes the overburden and fresh bedrock and deposits new till units composed of material that is a mixture of the two. New till fines are produced subglacially in comminution processes from boulders extracted from the bedrock and from the coarse fractions of older tills. Thus, the ratio of "new" material comminuted during the most recent glaciation cycle to the "old" fines entering each glaciation cycle from the overburden varies from region to region. In the area of clay- and fines-rich tills in particular there is abundant redeposition of "old" fines in younger till units. During the successive ice-free periods, the Gulf of Bothnia has been an important sedimentary basin and thus a source of fines for the fines-rich tills of Ostrobothnia. Sedimentary rocks, too, have produced fines-rich tills, as in Åland.

Basal tills rich in clay fraction are located in areas with only few glaciofluvial formations. This lead to the conclusion that dewatering of debris during the deposition of till may have had marked contribution to regional differences in the clay fraction contents of tills. The removal of clay fraction has been more effective in the areas of active lobes through abundant subglacial channels. The occurrence of the fines-rich but clay-poor tills of central Ostrobothnia between two clay-rich till zones may be due to the relative difference in glacial flow rates when these tills deposited. During the last deglaciation stage of the continental ice sheet, clay-rich tills probably deposited in an area of less active flow, where the production of "new" fines was less intense. The regional distribution of till properties is due to the combined effect of many processes whose individual contribution is impossible to evaluate.

The regional dissimilarity in tills should betaken into account in till-geochemical investigations. Till-geochemical maps should be considered for each till area separately to ensure that chemical differences better reflect internal concentration variations in each area.

ACKNOWLEDGEMENTS

I am very grateful for the financing I received from the Finnish Academy as this allowed me to concentrate fully on my study. Most of the work was done at the Geological Survey of Finland (GSF) in Espoo, where Professor Kauko Korpela gave me permission to use the laboratory. Professor Veikko Lappalainen, director of the GSF, accepted the manuscript for publication in the GSF's Bulletin Series. I express my cordial thanks to both of them.

The idea for the study came from Professor Matti Saarnisto, at whose suggestion I studied the importance of the clay fraction in geochemical till analyses for my master's degree. Now in my doctoral thesis, I have expanded the scope of the original idea of Professor Saarnisto with problems pertinent to clay mineralogy and the genesis of till fines. Professor Reijo Salminen put a large number of samples from the stores of the GSF's Geochemistry Department at my disposal. I am grateful to both of them for their help and for critical comments on my work during its various stages.

The interest shown by the GSF's Quaternary geologists in the subject has contributed to the success of my work. Dr Heikki Hirvas, Pekka Huhta, Keijo Nenonen and Pertti Hakala were generous with samples and unpublished material. Numerous discussions with Professor Raimo Kujansuu helped me to clarify my thoughts as the work proceeded. Marja Liisa Räisänen instructed me in the complexities of clay mineralogical determination. To all these people I express my warmest thanks for their help and for their companionship on our unforgettable field excursions up and down the country.

Tarja Koski determined the grain sizes of till fines. Most of the X-ray diffraction and IR determinations were made by Mirja Saarinen. Satu Moberg clean-drew the X-ray diffraction traces. The computer printout maps were prepared by Pekka Hänninen, Heimo Savolainen and Timo Tarvainen. The critical comments of Dr J-P Lunkka contributed to the final form of the manuscript. Gillian Häkli translated the manuscript into English. Without the help of all the above people this work would not have been possible. I thank all those who, although not mentioned here, facilitated my work at its all stages.

Finally, I thank my wife Kaija and our children Katariina and Juho for patience at home during my numerous field trips and for providing me with the extra time needed for preparing the manuscript for publication.

REFERENCES

Alley, R.B., Blankenship, D.D., Rooney, S.T. & Bentley, C.R. 1987. Till beneath Ice Stream B, 4, a coupled ice-till flow model. Journal of Geophysical Research 92 (B9), 8931-8940.

Aalto, M., Donner, J., Niemelä, J. & Tynni, R. 1983. An eroded interglacial deposit at Vimpeli, South Bothnia, Finland. Geological Survey of Finland, Bulletin 324, 42 p.

Aario, R. & Forsström, L. 1979. Glacial stratigraphy of Koillismaa and North Kainuu, Finland. Fennia 157 (2), 49 p.

Aarnio, B. 1938. Moreenin mekaaninen kokoomus Suomessa. Referat: Die mechanische Zusammensetzung der Moräne in Finnland. Agrogeologisia julkaisuja 45, 14 p.

Aatos, S., Tarvainen, T., Räisänen, M-L. & Salminen, R. 1994. Moreenin hienoaineksen normatiivisen mineralogian määritys. Summary: Methodology for determining the normative mineralogy of fine fraction of till. Geologi 46 (3), 39-42.

Afanas'ev, A.P. & Evzerov, V.Ya. 1981. Sources of the material of glacial deposits of the eastern part of the Baltic Shield. In: Gorbunov, G.I. (ed.) Glacial deposits and glacial history in eastern Fennoskandia. Kola Branch of the USSR Academy of Sciences. 55-62.

Arkhipov, S.A., Besplay, V.G., Faustova, O.Yu., Isaeva, L.L. & Velichko, A.A. 1986. Ice-Sheet reconstructions. In: ,ibrava, V., Bowen, D.Q. & Richmond, G.M. (eds.) Quaternary Glaciations in the Northern Hemisphere. Oxford: Pergamon Press. 475-483.

Barnhisell, R.I. 1977. Chlorites and hydroxy interlayered vermiculite and smectite. In: Dixon, J.B. & Weed, S.B. (eds.) Minerals in Soil Environments, Soil Science Society of America, Madison, Wisconsin. 331-356.

Bergman, L. 1981. Berggrunden inom Signilskär, Mariehamn och Geta kartblad - Signilskärin, Maarianhaminan ja Getan kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of Signilskär, Mariehamn and Geta map-sheet areas. Explanation to the maps of Pre-Quaternary rocks, sheets 0034+0043 and 1012. Geological maps of Finland 1 : 100 000, 72 p.

Björklund, A. 1988a. Regional geochemistry: Fingerprint of mineralization and control on glacial geology. 18th "Nordiske Geologiske Vintermøde", 12-14. January 1988, Copenhagen, Geological Survey of Denmark, 54-55.

Björklund, A. 1988b. Relation between structures of bedrock and geochemistry and morphology of glacial deposits. In: Mörner, N-A. (ed.) Present Processes and Properties in the Lithosphere: A part of Swedish ILP, Report, November 1988, University of Stockholm, 64-65.

Björnbom, S. 1979. Clayey basal till in central and northern Sweden. Sveriges Geologiska Undersökning Årsbok 72 (15), 62 p.

Bouchard, M., Gibbard, P. & Salonen, V-P. 1990. Lithostratotypes for Weichselian and Pre-Weichselian sediments in southern and western Finland. Bulletin of the Geological Society of Finland 62 (1), 79-95.

Boulton, G.S. 1970. On the deposition of subglacial and melt-out tills at the margins of certain Svalbard glaciers. Journal of Glaciology 9 (56), 231-245.

Boulton, G.S. 1975. Processes and pattern of subglacial sedimentation: a theoretical approach. In: Wright, A.E. & Moseley, F. (eds.) Ice Ages: Ancient and Modern. Liverpool: Seel House Press. 7-42.

Boulton, G.S. 1979. Processes of glacial erosion on different substrata. Journal of Glaciology 23 (89), 15-38.

Boulton, G.S. 1987. A theory of drumlin formation by subglacial sediment deformation. In: Menzies, J. & Rose, J. (eds.) Drumlin Symposium. Rotterdam: Balkema. 25-80.

Boulton, G.S. & Jones, A.S. 1979. Stability of temperate ice caps and ice sheets resting on beds of deformable sediments. Journal of Glaciology 24 (90), 29-43.

Boulton, G.S. & Hindmarsh, R.C.A. 1987. Sediment deformation beneth glaciers: rheology and geological consequences. Journal of Geophysical Research 92 (B9), 9059-9082.

Bowen, D,Q. 1978. Quaternary Geology. Oxford: Pergamon Press. 221 p.

Bowen, D.Q. 1991. Time and space in the glacial sediment systems of the British Isles. In: Ehlers, J., Gibbard, P.L. & Rose, J. (eds.) Glacial deposits in Great Britan and Ireland. Rotterdam: Balkema. 3-11.

Brindley, G.W. & Brown, G. 1980. Crystal structures of clay minerals and their X-ray identificaton and crystal structures of clay minerals. Mineralogical Society Monograph 5. London. 495 p.

Brown, N.E., Hallet, B. & Booth, D.B. 1987. Rapid soft bed sliding of the Puget Glacier Lobe. Journal of Geophysical Research 92 (B9), 8985-8997.

Brunauer, S., Emmett, P, H. & Teller, E. 1938. Adsorption of gases in multimolecular layers. Journal of American Chemical Society 60, 309-310.

Carlson, L. & Schwertman, U. 1981. Natural ferrihydrites in surface deposits from Finland and their association with silica. Geochimica et Cosmochimica Acta 45 (3), 421-429.

Carrol, D. 1970. Rock Weathering. New York, London: Plenum Press. 203 p.

Clarke, G.K.C. 1987. Subglacial till: a physical framework for its properties and processes. Journal of Geophysical Research 92 (B9), 9023-9036.

De Jong, J. 1988. Climatic variability during the past three million years, as indicated by vegetational evolution in northwest Europe and with emphasis on data from the Netherlands. In: Shackleton, N.J., West, R.G. & Bowen, D.Q.(eds.) The past three million years: Evolution of Climatic Variability in the North Atlantic Region. Philosophical Transactions, Royal Society London B 318 (1191), 135-150.

DiLabio, R.N.W. 1990. Glacial dispersal trains. In: Kujansuu, R. & Saarnisto, M., (eds.) Glacial indicator tracing. Balkema, Rotterdam, 109-122.

Dixon J.B. & Weed, S.B. 1977. Minerals in Soil Environment. Soil Science Society of America. Madison, Wisconsin. 947 p.

Donner, J. 1988. The Eemian site of Norinkylä compared with other interglacial sites in Ostrobothnia, western Finland. Annales Academiae Scientiarum Fennicae A III 149, 31 p.

Dredge, L.A. & Cowan, W.R. 1989. Quaternary geology of the southwestern Canadian Shield. In: Foulton, R.J. (ed.) Chapter 3 of Quaternary Geology of Canada and Greenland. Geological Survey of Canada. Geology of Canada 1. 214-249.

Dreimanis, A. & Vagners, U. 1971. Bimodal distribution of rock and mineral fragments in basal till. In: Goldtwait, R.P. (ed.) Till, a Symposium. Ohio State University Press. 237-250.

Dreimanis, A. & Vagners, U. 1972. The effect of lithology upon texture of till. In: Yatsu, E. & Falkoner, A. (eds.) Research Methods in Pleistocene Geomorphology. Proceeding of the 2nd Guelph Symposium on Geomorphology 1971, 66-82.

Dreimanis, A. 1990. Formation, deposition, and identification of subglacial and supraglacial tills. In: Kujansuu, R. & Saarnisto, M. (ed.) Glacial Indicator Tracing. Rotterdam: Balkema. 35-59.

Dreimanis, A. & Lundqvist, J. 1984. What should be called till? In: Köningsson, L.K. (ed.) Ten years of Nordic till research. Striae 20, 5-10.

Drever, S.I. 1973. The preparation of oriented clay mineral specimes for X-ray diffraction analysis by a filter - membrane peeltechnique. American Mineralogist 58 (5-6), 553-554.

Drewry, D. 1986. Glacial Geologic Processes. London: Edward Arnold Ltd. 276 p.

Droste, J. 1956. Alteration of clay minerals by weathering in Wisconsin tills. Geological Society of America, Bulletin 67 (7), 911-918.

Eriksson, B., Grönlund, T. & Kujansuu, R. 1980. Interglasiaalikerrostuma Evijärvellä Pohjanmaalla. Summary: An interglacial deposit at Evijärvi in the Pohjanmaa region, Finland. Geologi 32 (6), 65-71.

Farmer, V.C., Smith, B.F.L., Wilson, M.J., Loveland, P.J. & Payton, R.W. 1988. Readily-extractable hydroxyaluminium interlayers in clay- and silt-sized vermiculite. Clay minerals 23 (3), 271-277.

Feininger, T. 1971. Chemical weathering and glacial erosion of crystalline rocks and origin of till. U.S. Geological Survey Professional Paper 750-C, 65-81.

Flint, R. F., 1971. Glacial and Quaternary Geology, John Willey and Sons. New York. 892 p.

Follested, B.A. 1973. Løten. Beskrivelse till kvartaergeologisk kart 1916 I-M 1 : 50 000. Norges Geologiske Undersøkelse, 41 p.

Forsström, L., Eronen, M. & Grönlund, T. 1987. On marine phase and shore levels of the Eemian interglacial and Weichselian interstadials on the coast of Ostrobothnia, Finland. Geological Survey of Finland, Special Paper 2, 37-42.

Foster, J.R. 1971. The reduction of matrix effects in atomic absorbtion analysis and the efficiency of selected extractions on rock-forming minerals. CIM Special 11, 554-560.

Foster, J.R. 1973. The efficiency of various digestion procedures on the extraction of metals from rocks and rock-forming minerals, CIM Bulletin 66, 85-92.

Gardemeister, R. 1975. On engineering-geological properties of fine-grained sediments in Finland. Building Technology and Community Development, Publication 9. Technical Research Center of Finland, 91 p.

Gibbard, P.L. 1988. The history of the great northwest European rivers during the past three million years. Philosophical Transactions of the Royal Society of London B 318, 559-602.

Gibbard, P., Forman, S., Salomaa, R., Alhonen, P., Jungner, H., Peglar, S., Suksi, J. & Vuorinen, A. 1989. Late Pleistocene stratigraphy at Harrinkangas, Kauhajoki, western Finland. Annales Academiae Scientiarum Fennicae A II 150, 36 p.

Gillberg, G. 1964. Till distribution and ice movements on the northern slopes of the South Swedish Highlands. Geologiska Föreningens i Stockholm Förhandlingar 86 (4), 433-484.

Gillberg, G. 1967. Further Discussion of the lithological homogenity of till. Geologiska Föreningens i Stockholm Förhandlingar 89 (1), 29-49.

Gillberg, G. 1977. Redeposition: a process in till formation. Geologiska Föreningens i Stockholm Förhandlingar 99 (3), 246-253.

Gross, D.L. & Moran, S.R. 1971. Grain-size and mineralogical gradations within tills of Allegheny Plateau. In: Goldtwait, R.P. (ed.) Till, a Symposium. Ohio State University Press, 251-274.

Haavisto-Hyvärinen, M., Kielosto, S. & Niemelä, J. 1989. Precrags and drumlin fields in Finland. Sedimentary Geology 62, 337-348.

Hackman, V. 1914. Geologisk översiktskarta över-Finland, Sektionerna C6 Rovaniemi, B5 Torneå, B6 Över-Torneå. Geologiska Kommissionen, 86 p.

Haldorsen, S. 1982. The enrichment of quartz in tills. In: Evenson, E.B., Schlüchter, Ch. & Rabassa, J. (eds.) Tills and Related Deposits. Rotterdam: Balkema. 141-150.

Haldorsen, S. 1983. Mineralogy and geochemistry of basal till and their relationship to till-forming processes. Norsk Geologisk Tidskrift 63 (1), 15-25.

Härme, M. 1949. On a pre-glacial weathering in Tyrvää, southwestern Finland. Bulletin de la Commission Géologique de Finlande 144, 87-89.

Hartikainen, A. 1989. Edelleen geokemiallisista Atlas-kartoista. Geologi 41 (3), 61-62.

Hasegawa, H., Iwata, S. & Matsuoka, N. 1992. Observations of clayey till and underlying glacier ice in the central Sør Rondane Mountains, East Antarctica. In: Yoshida, Y., Kaminuma, K. & Shiraishi, K. (eds.) Recent Progress in Antarctic Earth Science. Proceedings of the Sixth International Symposium on Antarctic Earth Science, Ranzan, September 9-13, 1991. Tokyo: Terra Scientific Publicing Company. 679-681.

Heinonen, L. 1957. Studies on the microfossils in the tills of the north European glaciation. Annales Academiae Scientiarum Fennicae A II 52, 92 p.

Hiltunen, A. 1982. The Precambrian geology of the Rautuvaara area, northern Finland. Geological Survey of Finland, Bulletin 318, 133 p.

Hirvas, H. 1980. Moreenistratigrafiasta ja sen merkityksestä malminetsinnässä. Geologi 32 (3), 33-37.

Hirvas, H. 1983. Correlation problems of interglacial deposits in Finnish Lapland. IGCP, project 73/1/24: Quaternary Glaciations in the Northern Hemisphere, Report 9, 129-139.

Hirvas, H. 1991. Pleistocene stratigraphy of Lapland, Geological Survey of Finland, Bulletin 354, 123 p.

Hirvas, H., Alftan, A., Pulkkinen, E., Puranen, R. & Tynni, R. 1977. Raportti malminetsintää palvelevasta maaperätutkimuksesta Pohjois-Suomessa vuosina 1972-1976. Summary: A report on glacial drift investigations for ore prospecting purposes in northern Finland 1972-1976. Geologian tutkimuskeskus, Tutkimusraportti - Geological Survey of Finland, Report of Investigation 19, 54 p.

Hirvas, H. & Nenonen, K. 1978. Malminetsintää palvelevat maaperätutkimukset Laatokka-Perämeri-vyöhykkeellä v. 1978. Raportti P 13.2.007. Unpublished report, Geological Survey of Finland, 26 p.

Hirvas, H. & Huhta, P. 1982. Malminetsintää palvelevat maaperätutkimukset Raution alueella. Raportti P13.2.032. Unpublished report, Geological Survey of Finland, 6 p.

Hirvas, H., Lahti, S. & Niemelä, J. 1982. Pirunpesä - Preglasiaalinen rapaumaonkalo Jalasjärvellä. Summary: Pirunpesä (Devil's Hole) - a preglacially weathered hollow in Jalasjärvi. Geologi 34 (4), 61-64.

Hirvas, H. & Niemelä, J. 1986. Ryytimaa: Vimpeli, Site 9. In: Haavisto-Hyvärinen, M. (ed.) Excursion Guide, excursion no. C 2 Quaternary geology, southern Finland. Geologian tutkimuskeskus, Opas - Geological Survey of Finland, Guide 15, 47-50.

Hirvas, H. & Nenonen, K. 1987. The till stratigraphy of Finland. In: Kujansuu, R. & Saarnisto, M. (eds.) INQUA Till Symposium, Finland 1985, Geological Survey of Finland, Special Paper 3, 49-63.

Hirvas, H, Kujansuu, R., Nenonen, K. & Saarnisto, M. 1988. Glacigenic deposits as indicator of glacial movements and their use for indicator tracing. In: Goldthwait, R.P. & Matsch, C.L. (eds.) Genetic Classification of Glacigenic Deposits. Rotterdam: Balkema. 173-182.

Hirvas, H. & Nenonen, K. 1991. Glacial history and paleoclimates of the Vestfold Hills area, East Antarctica. FINNARP-89 symposium, 20-22 March, Espoo, Finland, Antarctic Reports of Finland 1, 31-38.

Hirvas, H., Nenonen, K. & Quilty, P. 1993. Till stratigraphy and glacial history of the Vestfold Hills area, East Antarctica. Quaternary International 18, 81-95.

Hirvas, H., Lintinen, P. & Nenonen, K. 1994. Properties of till fines in the Vestfold Hills and Vestfjella areas, Antarctica. FINNARP symposium, 5 October, Helsinki, Finland, Antarctic Reports of Finland 4, 20-27.

Hughes, O.L. 1965. Surficial geology of part of the Cochrane District, Ontario, Canada, In: Wright, H.E. & Frey, D.G. (eds.) International Studies of Quaternary, Geological Society of America, Special Paper 84, 535-565.

Huhta, P. 1981. Malminetsintää palvelevat maaperätutkimukset Saarijärven Muittarissa kl 2244 04. Raportti P13.2.026. Unpublished report, Geological Survey of Finland, 6 p.

Huhta, P. 1983a. Malminetsintää palvelevat maaperätutkimukset Korsnäsissä vuosina 1983-1984. rap. P13.2.049. Unpublished report, Geological Survey of Finnland, 8 p.

Huhta, P. 1983b. Malminetsintää palvelevat maaperätutkimukset Perhon alueella. Raportti P13.2.040. Unpublished report, Geological Survey of Finland, 5 p.

Huhta, P. 1984a. Malminetsintää palvelevat maaperätutkimukset Viitasaaren Lahnasessa. raportti P13.2.052. Unpublised report, Geological Survey of Finland, 3 p.

Huhta, P. 1984b. Malminetsintää palvelevat maaperätutkimukset Alajärvellä. Raportti P13.2.053. Unpublished report, Geological Survey of Finland, 2 p.

Huhta, P. 1984c. Malminetsintää palvelevat maaperätutkimukset Alahärmän Fleinissä. Raportti P13.2.050. Unpublished report, Geological Survey of Finnland, 4 p.

Huttunen, T. & Kejonen, A. 1993. Maankamara. In: Pohjois-Savon ympäristön tila 1990 luvun alussa. Vesi- ja ympäristöhallitus. 57-71.

Hyyppä, J. 1977. Kaoliinia Sodankylän Siurunmaalla. Geologi 29 (4-5), 52-56.

Hyyppä, J. 1983. Suomen kallioperän preglasiaalisista rapaumista. Summary: Preglacial weathering of Precambrian rocks in Finland. Papers of the Engineering-Geological Society of Finland 15. II/1-18.

Hyyppä, J. 1990. Clay resources. In: Alalammi, P. (ed.) Atlas of Finland, 123-126, Geologia. Helsinki: National Board of Survey & Geographical Society of Finland. 124 p.

Ihalainen, P. 1994. Moreenin fysikaalisten ominaisuuksien tutkimusmenetelmiä, esimerkkejä Pohjois-Lapin alueelta. Summary: Methods applied in determining some physical properties of glacial tills, examples from northern Fennoscandia. Acta Universitasis Ouluensis A 251, 24-35.

Iisalo, E. 1992. Observation on the stratigraphy of Weichselian tills and subtill eskers in Central Ostrobothnia, Finland. Geologian tutkimuskeskus, Tutkimusraportti - Geological Survey of Finland, Report of Investigation 112. 42 p.

Johansson, P. 1981. Malminetsintää palvelevat maaperätutkimukset Toholammilla kl. 2342 04. Raportti P13.2.025. Unpublished report, Geological Survey of Finland. 6 p.

Jokinen, S., Grönlund, T. & Nenonen, K. 1993. Virtasalmen Heponiemen moreenin alainen liejukerrostuma. Summary: A till covered gyttja deposit from Heponiemi, in Virtasalmi, eastern Finland. Geologi 45 (3), 82-87.

Jørgensen, P. 1977. Some properties of Norwegian tills. Boreas 6 (2), 149-157.

Kejonen, A. 1981. Teiskon alueen (2124) kartoitukset vuonna 1981. Raportti P 13.1.055, Unpublished report, Geological Survey of Finland, 30 p.

Kejonen, A. 1985. Weathering in the Wyborg rapakivi area, southern Finland. Fennia 163 (2), 309-313.

Kejonen, A. & Huttunen, T. 1982. Teiskon alueen (2124) maaperäkartoitus v. 1982. Raportti P 13.1.062, Unpublished report, Geological Survey of Finland, 40 p.

Kivekäs, E. K. 1946. Zur Kenntnis der mechanischen und mineralogischen Zusammensetzung der finnischen Moränen. Acta Agralia Fennica 60 (2), 122 p.

Kokkola, M. 1989. Is the till matrix transported - or is the way to its study wrong? Geological Survey of Finland, Special Paper 7, 55-58.

Koljonen, T. 1992. The Geochemical Atlas of Finland, Part 2: Till. Espoo: Geological Survey of Finland. 218 p.

Korhonen, K-H & Gardemaister, R. 1970. Geoteknillinen maalajiluokitus, Maansiirto 1970 (6), 50-52.

Korpela, K. 1977. On the engineering geological properties of the Muhos siltstone. Publications of the Department of Quaternary Geology, University of Turku 31, 39 p.

Kuivasaari, T., Niemelä, M, & Sarapää, O. 1991. The kaolin deposits of the Virtasalmi area in SE Finland. Proceeding of the 7th Euroclay Conference, Dresden '91. GreifsWald, 1 p.

Kujansuu, R. 1972. On landslides in Finnish Lapland. Geological Survey of Finland, Bulletin 256, 22 p.

Kujansuu, R. 1976. Glaciogeological surveys for ore-prospecting purposes in northern Finland. In: Legget, R.F. (ed.) Glacial Till, Royal Society of Canada, Special Publication 12, 225-239.

Kujansuu, R. 1992. Paleosols as Quaternary key horizons in Ostrobothnia, western Finland. Bulletin of the Geological Society of Finland 64 (2), 161-167.

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

Kujansuu, R. & Niemelä, J. (ed.) 1984. Suomen maaperäkartta - Quaternary deposits of Finland. Kartta - Map 1 : 1 000 000. Geological Survey of Finland.

Kujansuu, R., Saarnisto, M., Räisänen, M-L. & Hansel, A.K. 1991. Fossil soil of Kärjenkoski and its correlatives in Ostrobothnia, western Finland. Geological Survey of Finland, Special Paper 12, 119-126.

Kurkinen. I. & Niemelä, J. 1979. Rapaumahavainto Kauhajoella. Summary: Weathered bedrock in Kauhajoki. Geologi 31 (5), 79-81.

Kurkinen, I., Niemelä, J. & Tikkanen, J. 1989. Hienoainesmoreenia harjudeltan pohjalla. Summary: Fine-grained till underneath an esker delta. Geologi 41 (3), 47-50.

Lahti, S. 1985. Porphyritic pyroxene-bearing granitoids - a strongly weathered rock group in central Finland. Fennia 163 (2), 315-321.

Lahti, S. & Laitakari, I. 1982. Hämeen rapakallioista ja muista kalliorapaumista. Summary: Weathered bedrock in Häme, Finland. Geologi 34 (6), 109-115.

Laitakari, A. 1942. Kivilajikartan selitys, Suomen geologinen yleiskartta. Lehti B3 Vaasa, 1:400 000, 66 p.

Laitakari, I. 1986. Pre-Quaternary rocks, Sheet 2142 Orivesi. Geological map of Finland 1 : 100 000.

Lestinen, P. 1980. Peurasuvannon karttalehtialueen geokemiallisen kartoituksen tulokset. Summary: The results of the geochemical survey in the Peurasuvanto map-sheet area. Explanatory notes to geochemical maps, Sheet 3723. Geological Survey of Finland. 97 p.

Linden, A. 1975. Till petrographical studies in an Archean bedrock area in Southern Central Sweden. Striae 1, 57 p.

Lindroos, P. 1976. Moreenin luokittelusta ominaispinta-alan perusteella. Summary: Classification of till by specific surface area. Geologi 28 (2), 17-21.

Lindroos,P. & Nieminen, P. 1982. Maaperäkartoituksen uusi moreeniluokitus. Geologi 34 (4), 64-67.

Lintinen, P. 1989. Onko moreenin hienoaineksen savipitoisuudella vaikutusta hivenmetallipitoisuuksiin? Summary: The effect of clay content on trace metal contents in till. Geologi 41 (9-10), 179-183.

Lintinen, P. 1991. Quaternary studies on the northernmost Vestfjella nunataks, Western Dronning Maud Land, Antarctica. FINNARP-89 symposium, 20-22 March, Espoo, Finland, Antarctic Reports of Finland 1. 16-19.

Lundqvist, G. 1935. Blockundersökningar. Historik och metodik. Sveriges Geologiska Undersökning C 390, 45 p.

Lundqvist, G. 1951. Beskrivning till jordkarta över Kopparbergs län. Sveriges Geologiska Undersökning Ca 21, 213 p.

Lundqvist, J. 1958. Beskrivning till jordkarta över Gävleborgs län. Sveriges Geologiska Undersökning Ca 42, 181 p.

Lundqvist, J. 1969. Beskrivning till jordkarta över Jämtlands län. Sveriges Geologiska Undersökning Ca 45, 418 p.

Lundqvist, J. 1973. Dark bluish boulder-clay: a possible deposit from the first Würm glaciation. Bulletin of the Geological Institutions of the University of Uppsala, New Series 5, 19-20.

Lundqvist, J. 1985. Deep-Weathering in Sweden. Fennia 163 (2), 287-292.

Lundqvist, J. 1989a. Till and glacial landforms in a dry, polar region. Zeitschrift für Geomorphologie, N.F. 33 (1), 27-41.

Lundqvist, J. 1989b. Former extension of the East Antarctic Ice Sheet, Polar Research 7 (2), 109-177.

MacClintock, P. & Dreimanis, A. 1964. Reorientation of till fabric by overriding glacier in the St. Lawrence valley. American Journal of Science 262 (1), 133-142.

Macewan, D.M.L. 1944. Identification of the montmorillonite group of minerals by X-rays. Nature 154, 577-578.

Marel, H. W. van der 1959. Identification of chlorite and chlorite-related minerals in sediments. Beiträge zur Mineralogie und Petrographie 9, 462-480.

Marttila, E. 1993. Pyhäjärven kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Pyhäjärvi map-sheet area. Explanation to the maps of Pre-Quaternary rocks, sheet 3321. Geological map of Finland 1 : 100 000. 64 p.

Matisto, A. 1958. Kivilajikartan selitys. Suomussalmi D5. General geological map of Finland 1 : 400 000. 115 p.

Meer, J.J.M. van der 1989 Micromorphology of glacial sediments as a tool in distinguishing genetic variates of till. In: Kujansuu, R. & Saarnisto, M. (eds.) INQUA Till Symposium, Finland 1985, Geological Survey of Finland, Special Paper 3, 77-89.

Meer, J.J.M. van der 1993. Microscopic Evidende of subglacial deformation. Quaternary Science Reviews 12 (7), 553-587.

Melkerud, P-A. 1984. Distribution of clay Minerals in soil profiles - a tool in chronostratigraphical and lithostratigrahical investigations of Till. Striae 20, 31-37.

Meriläinen,K. 1965. Pre-Quaternary Rocks, Sheet C 8-9 Inari - Utsjoki. General geological map of Finland 1 : 400 000.

Meriläinen, K. 1976. The Granulite complex and adjacent rocks in Lapland, northern Finland. Geological Survey of Finland, Bulletin 281, 129 p.

Muller, E. 1983. Dewatering during lodgement of till. In: Evenson, E.B., Schlücter, Ch. & Rabassa, J. (eds.) Tills and Related Deposits, Rotterdam:

Balkema. 13-18.

Murray, T. & Dowdeswell, J. A. 1992. Water throughflow and the physical effects of deformation on sedimentary glacier beds. Journal of Geophysical Researc 97 (B6), 8993-9002.

Mäkinen, J. 1992. The relation between unit weight and geochemical and mineralogical composition in the fine fraction of till. Bulletin of the Geological Society of Finland 64 (1), 59-74.

Mäkinen, J. 1993. Mitä jauhatuskokeet kertovat moreenin hienoaineksen synnystä? Summary: What can the grinding experiments reveal from the genesis of the fine fraction of till? Geologi 45 (2), 38-42.

Mäkitie, H. & Lahti, S. 1991. Seinäjoen kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Seinäjoki map-sheet area. Explanation to the Maps of Pre-Quaternary Rocks, sheet 2222. Geological map of Finland 1 : 100 000. 60 p.

Nenonen, K. 1985. Till stratigraphy in the open pit section of the Pyhäsalmi, Pyhäjärvi, and a glacigenic Zn-Cu-S anomaly in the Pyhäsalmi ore body. In: Saarnisto, M. (ed.) INQUA till symposium, excursion guide, Geological Survey of Finland, 75-79.

Nenonen, K. 1993. Etelä- ja Keski-Suomen Pleistoseenistratigrafia. Publications of the Department of Quaternary Geology, University of Turku 76. 62 p.

Nenonen, K. & Johansson, P. 1981. Malminetsintää palvelevat maaperätutkimukset Jalasjärven scheeliittilohkareella kl. 2221 06, 08, 09. Raportti P13.2.024. Unpublished report, Geological Survey of Finland, 6 p.

Nenonen, K., Eriksson, B. & Grönlund, T. 1991. The till stratigraphy of Ostrobothnia, western Finland, with reference to new Eemian interglacial sites. In: Andersen, B.G. & Köningsson, L.K. (eds.) Late Quaternary Stratigraphy in the Nordic Countries 150,000-15,00 B.P. Striae 34, 65-76.

Nenonen, J. & Huhta, P. 1993. Quaternary glacial history of Hattu schist belt and adjacent parts of eastern Finland. In: Nurmi, P. & Sorjonen-Ward, P. (eds.) Glacial development, gold mineralization and exploration methods in the late Archean schist belt, Ilomantsi. Geological Survey of Finland, Special Paper 17, 185-191.

Nevalainen, R. 1983. Moreenin hienoaineksen mineraalikoostumus ja kulkeutuminen Kuhmon liuskejakson alueella Kellojärvellä. Oulun yliopisto, Arkeeisten alueiden malmiprojekti. Raportti 8, 102 p.

Nevalainen, R. 1989. Lithology of fine till fractions in the Kuhmo greenstone belt area, eastern Finland. Geological Survey of Finland, Special Paper 7, 59-65.

Niemelä, J. 1979. Suomen sora- ja hiekkavarojen arviointiprojekti 1971-1978. Sumary: The gravel and sand resources of Finland; an inventary project 1971-1978. Geologian tutkimuskeskus, Tutkimusraportti - Geological Survey of Finland, Report of Investigation 42, 119 p.

Niemelä, J. & Tynni, R. 1979. Interglacial and interstadial sediments in the Pohjanmaa region, Finland. Geological Survey of Finland, Bulletin 302, 48 p.

Nieminen, P. 1985. Moreenin hienoaineksen laatu ja sen vaikutus routimisherkkyyteen. Summary: The quality of the fine fractions of till and its influence on frost susceptibility. Tampere University of Technology, Publications 34, 81 p.

Nieminen, P., Salomaa, R. & Uusinoka, R. 1985. The use of specific surface area, pore volume, and pore area in evaluating the degree of weathering of fine particles: an example from Lauhanvuori, western Finland. Fennia 163 (2), 373-377.

Niini, H. 1968. A study of rock fracturing in valleys of Precambrian bedrock. Fennia 97 (6), 60 p.

Niini, H. & Uusinoka, R. 1978. Weathering of precambrian rocks in Finland. Proceeding of the III International Congress IAEG 4-8 September 1978, Section 11 (1), 77-83.

Nykänen, O. 1959. Raahe-Paavola. Explanation to the map of rocks, sheets 241, 2443 and 1242. Geological map of Finland 1 : 100 000. 36 p.

Nykänen, O. 1960. Korsnäs. Explanation to the map of rocks, sheet 1242. Geological map of Finland 1 : 100 000. 34 p.

Okko, V. 1964. Suomen maaperä. In: Rankama, K. (ed.) Suomen geologia. Helsinki: Kirjayhtymä. 239-332.

Ollier, C. 1984. Weathering. London, New York: Logman. 270 p.

Pekkala, Y. 1987. Aspects on kaolinization and kaolin potential in Finland. The sixth Meeting of European Clay groups. Euroclay 87, 7-10 September 1987, Seville, Spain, 429-431.

Pekkala, Y. 1988. Kaolin potential in Finland. 8th "Industrial Minerals" International Congress. 24-27 April 1988, Boston, USA. 131-137.

Pekkala, Y. & Sarapää, O. 1989. Kaolin exploration in Finland. Geological Survey of Finland. Special Paper 10. 113-118.

Pekkarinen, L.J. & Hyvärinen, L. 1984. Pre-Quaternary rocks, Sheet 3231 Haukivuori. Geological map of Finland 1 : 100 000.

Persson, C., 1992. The latest ice recession and till deposits in northern Uppland, eastern central Sweden. Sveriges Geologiska Undersökning Ca 81, 217-224.

Perttunen, V. 1991. Kemin, Karungin, Simon ja

Runkauksen kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of Kemi, Karunki, Simo and Runkaus map-sheet areas. Explanation to the maps of Pre-Quaternary rocks, sheets 2541, 2542+2525, 2543 and 2544. Geological map of Finland 1 : 100 000. 80 p.

Perttunen, M. 1977. The lithologic relation between till and bedrock in the region of Hämeenlinna, southern Finland. Geological Survey of Finland, Bulletin 291, 68 p.

Peuraniemi, V. & Islam, Md.R. 1993. The weathering crust in the Vuotso-Tankavaara area - The first evidence on the occurrence of halloysite in Finland. Chemical Geology 107 (3-4), 307-311.

Peuraniemi, V. & Pulkkinen, P. 1993. Preglacial weathering crust in Ostrobothnia, western Finland, with special reference to the Raudaskylä occurrence. Chemical Geology 107 (3-4), 313-316.

Pihlaja, P. & Manninen, T. 1993. Pre-Quaternary rocks. Sheet 3723 Peurasuvanto. Geological map of Finland 1 : 100 000.

Pulkkinen, E. 1985. Vuotson rapakalliosavi. Lapin tutkimusseura. Summary: Weathered bedrock of Vuotso area. The Research Society of Lapland. Year Book XXVI 1985. 41-45.

Punakivi, T., Ericsson, T. & Wäppling, R. 1975. Clay mineral fractions studied by Mössbauer spectroscopy and conventional methods. Geological Society of Finland, Bulletin 47 (1-2), 171-174.

Punkari, M. 1980. The ice lobes of the Scandinavian ice sheet during the deglaciation of Finland. Boreas 9, 307-310.

Rainio, H. 1991. The Younger Dryas ice-marginal formations in southern Finland. In: Rainio, H. & Saarnisto, M. (eds.) IGCP project 253, Termination of the Pleistocene. Eastern Fennoscandia Younger Dryas End Moraines. Field conference North Karelia, Finland and Karelian ASSR, June 26. - July 4, 1991. Geologian tutkimuskeskus, Opas - Geological Survey of Finland, Guide 32, 25-72.

Rainio, H. & Lahermo, P. 1976. Observations on dark grey basal till in Finland. Bulletin of the Geological Society of Finland 48 (1-2), 137-152.

Rainio, H. & Lahermo, P. 1984. New aspects on the distribution and origin of so-called dark till. Striae 20, 45-47.

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

Räisänen, M.L. & Jylänki, J. 1990. Mineraalimaan happamoituminen Marsjön-järven valuma-alueella Inkoossa. Imatran Voima Oy, T&K-tiedotteita IVO-B-04/90, 33 p.

Räisänen, M.L. 1988. The acidification of podzolized mineral soils in background areas and near industrial areas in Finland. Geologian tutkimuskeskus, Tutkimusraportti - Geological Survey of Finland, Report of Investigation 91, 74 p.

Räisänen, M.L., Hämäläinen, L. & Westerberg, M.-L 1992a. Selective extraction and determination of metals in organic stream sediments. Analyst 117 (3), 623-627.

Räisänen, M.L., Tenhola, M. & Mäkinen, J. 1992b. Relationship between mineralogy and the physico-chemical properties of till in central Finland. Bulletin of the Geological Society of Finland 64 (1), 35-58.

Ramsden, J. & Westgate, J., A. 1971. Evidence for reorientation of a till fabric in the Edmonton area, Alberta. In: Goldtwait, R.P., (ed.) Till, a Symposium. Ohio State University Press, 335-344.

Romu, M. 1980. Etelä-Suomen savikerrostumista ja niiden tiiliteknisistä ominaisuuksista. Unpublished phil.lic. thesis, in Finnish. University of Turku, Geological Institute, 177 p.

Romu, M. 1988. Muhoksen savikivimuodostuman keraamisteknillisistä ominaisuuksista. Annales Universitas Turkuensis C 68. 159-169.

Roalsed, E. 1972. Mineralogy and geochemistry of Quaternary clays in the Nummedal area, southern Norway. Norsk Geologisk Tidskrift 52 (4), 335-369.

Rosenqvist, I. 1975. Chemical investigations of tills in the Nummedal. Geologiska Föreningens i Stockholm Förhandlingar 97 (3), 284-286.

Russel, J. 1987. Infrared methods. In: A handbook of determinative methods in clay mineralogy. Blackie, Glasgow and London. 133-173.

Saarnisto, M. 1981. Holocene emergence history and stratigraphy in the area north of the Gulf of Bothnia. Annales Academiae Scientiarum Fennicae A III 130, 42 p.

Saarnisto, M., Peltoniemi, H., Uusikartano, K., Tuokko, T. & Koivumaa, S. 1980. Malminetsintää palvelevat maaperägeologiset tutkimukset Kuhmon Kellojärven alueella. Summary: Studies on glacial geology and lake sediments for prospecting purposes in the Kellojärvi area of the Kuhmo greenstone belt, eastern Finland. University of Oulu, Raportti 39, 127 p.

Saarnisto, M., Nevalainen, R., Peltoniemi, H., Taipale, K. & Tuokko, I. 1981. Kuhmon malmiprojektin maaperägeologiset tutkimukset v. 1980. Summary: Studies in glacial geology in the Kuhmo geological research project, 1980. University of Oulu, Raportti 44, 95 p.

Saarnisto, M. & Peltoniemi, H. 1984. Glacial stratigraphy and compositional properties of till in Kainuu, eastern Finland. Fennia 162 (2), 163-199.

Salli, I. 1961. Kalajoki-Ylivieska-Haapavesi. Explanation to the map of rocks, sheets 2413, 2431 and 2433. Geological map of Finland 1 : 100 000. 48 p.

Salli, I. 1965. Pyhäjoki-Vihanti. Explanation to the map of rocks, sheets 2432 and 2434. Geological map of Finland 1 : 100 000. 50 p.

Salminen, R. 1975. Moreenin ja rapakallion geokemiallisista eroista. Unpublished phil.lic. thesis. University of Turku. 85 p.

Salminen, R. 1980. On the geochemistry of copper in the Quaternary deposits in the Kiihtelysvaara area, North Karelia, Finland. Geological Survy of Finland, Bulletin 309, 48 p.

Salminen, R. 1988. Lukee kuin piru Raamattua. Geologi 40 (7), 136-137.

Salminen, R. 1992. Geochemical dispersion in the secondary environment. In: Kauranne, L.K., Salminen, R. & Eriksson, K. (eds.) Regolith Exploration Geochemistry in Arctic and Temperate Terrains. Amsterdam: Elsevier. 93-125.

Salminen, R. (ed.). Alueellinen geokemiallinen kartoitus Suomessa vv. 1982-1994.(In print) Summary. Regional Geochemical Mapping in Finland in 1982-1994. Geologian tutkimuskeskus, Tutkimusraportti - Geological Survey of Finland. Report of Investigation.

Salminen, R. & Hartikainen, A. 1985. Glacial transport of till and its influence on interpretation of geochemical results in North Karelia, Finland. Geological Survey of Finland, Bulletin 335, 48 p.

Salminen, R., Hartikainen, A. & Lestinen, P. 1989. Enrichment of As and S in the finest fraction of crushed rock samples - an experimental study simulating the formation of till. Journal of Geochemical Exporation 32 (1-3), 287-290.

Salomaa, R. 1982. Post-glacial shoreline displacement in the Lauhanvuori area, western Finland. Annales Academiae Scientiarum Fennicae A134, 81-95.

Salonen, V-P. 1986. Glacial transport distance distribution of surface boulders in Finland. Geological Survey of Finland, Bulletin 338, 57 p.

Salonen, V-P., Eriksson, B. & Grönlund, T. 1992. Pleistocene stratigraphy in the Lappajärvi meteorite crater in Ostrobothnia, Finland. Boreas 21 (3), 253-269.

Saltikoff, B. 1988a. Mitä geokemiallinen kartta kertoo. Summary: What a geochemical map tells. Geologi 40 (4-5), 102-107.

Saltikoff, B. 1988b. Vielä kommentteja geokemiallisesta kartasta. Geologi 40 (9-10), 176-177.

Säynäjärvi, K. 1953. Mineraalimaiden aineksesta Lapin granuliittialueen eteläisellä reunavyöhykkeellä. Unpublished master´s thesis. University of Helsinki, Departement of Geology. 110 p.

Scott, J. S. 1976. Geology of Canadian tills. In: Legget, R.F. (ed.) Glacial Till, Royal Society of Canada, Special Publication 12, 50-66.

Shackleton, N.J. & Opdyke, N.D. 1973. Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year scale. Quatenary Research 3 (1), 39-55.

Shilts, W. 1971. Till studies and their application to regional drift prospecting. Canadian Mining Journal 92 (4), 45-50.

Shilts, W. W. 1973. Drift prospecting; geochemistry of eskers and till in permanently frozen terrain, District of Keewatin, N. W. T., Geological Survey of Canada, Paper 72-45, 34.

Shilts, W. 1975. Principles of geochemical exploration for sulphide deposits using shallow samples of glacial drift. Canadian Institute of Mining and Metallurgy, Bulletin 68 (757), 73-80.

Shilts, W. 1984. Till geochemistry in mineral exploration. Journal of Geochemical Exploration 21 (1-3), 119-122.

Shaw, J. 1976. Tills deposited in arid polar environments. Canadian Journal of Earth Sciences 13 (9), 1239-1245.

Shaw, J. 1989. Sublimation till. In: Goldthwait, R.P. & Match, C.L. (eds.) Genetic Classification of Glacigenic Deposits, Rotterdam: Balkema. 138-139.

Simonen, A. 1980. The Precambrian in Finland. Geological Survey of Finland, Bulletin 304, 58 p.

Simula, K. 1988. Merenpohjan geologiasta Raahen edustalla. Unpublished master's thesis. University of Oulu, Department of Geology. 71 p.

Sitler, R,F. 1963. Petrography of till from northeastern Ohio and northwestern Pennsylveinia. Journal of Sedimentary Petrology 33 (2), 356-379.

Sippola, J. 1972. Quantitative determination of minerals in Finnish soils by chemical methods. Annales Agriculturae Fenniae 11, 159-166.

Sippola, J. 1974. Mineral composition and its relation to texture and to some chemical properties in Finnish subsoils. Annales Agriculturae Fenniae 13, 169-234.

Snäll, S. 1986. Weathering in till indicated by clay mineral distribution. Geologiska Föreningens i Stockholm Förhandlingar 107 (4), 315-322.

Snäll, S., Persson, C. & Wikström, A. 1979. Mineralogisk undersökning av morän från ett område väster om Katarineholm. Summary: Mineralogical investigation of till from an area west of

Katrineholm, Sweden. Sveriges Geologiska Undersökning C761, 1-32.

Snäll, S., Brusewitz, A-M. & Ålinder, C. 1992. Mineralogisk analys av moräner. Sveriges Geologiska Undersökning. BRAP 92005. 16 p.

Sorjonen-Ward, P. 1993. An overview of structural evolution and lithic units within and intruding the Late Archean Hattu Schist Belt, Ilomantsi, Eastern Finland. In: Nurmi, P. & Sorjonen-Ward, P. (eds.) Glacial development, gold mineralization and exploration methods in the late Archean schist belt, Ilomantsi. Geological Survey of Finland, Special Paper 17, 9-102.

Soveri, U. 1950. Differential thermal analysis of some Quaternary clays of Fennoskandia. Annales Academiae Scientiarum Fennicae A III 23. 103 p.

Soveri, U. 1956. The mineralogical composition of argillaceous sediments of Finland. Annales Academiae Scientiarum Finnicae A III 48, 32 p.

Soveri. U. 1957. Om finska kvartära lerors mineralproblematik. Geologiska Föreningens i Stockholm Förhandlingar 79, 62 p.

Soveri, U. & Hyyppä, J.M. 1966. On the mineralogy of fine fractions of some Finnish glacial tills. The State Institute for Technical Research, Finland Publication 113, 31 p.

Sroden, J. & Eberln, D. D. 1984. Illite. In: Bayley, S.W. (ed.) Micas. Mineralogical Society of America Short Course Notes, 495-544.

Sutinen, R. 1984. On the glacial stratigraphy in Pudasjärvi area. Striae 20, 91-94.

Taipale, K., Nevalainen, R. & Saarnisto, M. 1986. Silicate analysis and normative compositions of the fine fraction of till: examples from eastern Finland. Journal of Sedimentary Petrology, 56 (3), 370-378.

Thorez, J. 1975. Phyllosilicates and clay minerals. A laboratory handbook for X-ray diffraction analysis. G Lelotte Dison, Belgique, 579 p.

Tynni, R., Härme, M., Valovirta & Hyyppä, J. 1969. Riihimäki. Explanatory text to the map of Quaternary deposits, sheet 2044. Geological map of Finland 1 : 100 000. 95 p.

Tyrväinen, A. 1983. Sodankylän ja Sattasen karttaalueiden kallioperä. Summary: Pre-Quaternary rocks of the map sheet areas of Sodankylä and Sattanen. Explanation to the maps of Pre-Quaternary rocks, sheets 3713 and 3714. Geological map of Finland 1 : 100 000. 59 p.

Uusinoka, R. 1975. A study of composition of rock-gouge in fractures of Finnish Precambrian bedrock. Societas Scientiarum Fennica, Commentationes Physico-Matematicae 45 (1), 1-101.

Vallius, H. 1992. The geochemical correlation between bedrock and the fine fraction of till in the Lake Päijänne area, Finland: regional study. Geologian tutkimuskeskus, Tutkimusraportti - Geological Survey of Finland, Report of Investigation 110, 68 p.

Vallius, H. 1993. Some quaternary and bedrock features of southern Finland reflected in regional geochemical till data. In: Geokemian päivät - Geochemistry 1993. Geocenter, University of Turku. 64-68.

Västi, K. J. 1989. Geology of the Rauhala stratiform massive Zn-Cu-Pb sulphide deposit. In: Kojonen, K. (ed.) The early Proterozoic Zn-Cu-Pb sulphide deposit of Rauhala in Ylivieska, Western Finland. Geological Survey of Finland, Special Paper 11, 5-18.

Virkkala, K. 1948. Suomen Geologinen yleiskartta. Lehti D 4. Nurmes. Maalajikartan selitys. Geologinen tutkimuslaitos.

Virkkala, K. 1952. On the bed structures of till in eastern Finland. Bulletin de la Commission Géologique de Finlande 157, 97-109.

Virkkala, K. 1955. On glaciofluvial erosion and accumulation in Tankavaara area, Finnish Lappland. Acta Geocraphica 14, 393-412.

Virkkala, K. 1960. Kallioiden glasiaaligeologiset kulutusmuodot ja moreenitutkimus malminetsinnän apuna. Summary: The glacial erosion forms of rock and the study of till facilitate ore prospecting. In: Virkkala, K. (ed.) Sovellettua maaperägeologiaa, Geologinen tutkimuslaitos, geoteknillisiä julkaisuja 65, 7-24.

Virkkala, K. 1969a. Suomen moreenien rakeisuusluokitus. Summary: Classification of Finnish tills according to grain size. Terra 81 (3), 273-278.

Virkkala, K. 1969b. On the litology and provenance of the till of a gabbro area in Finland. VIII INQUA congres, Paris, 711-714.

Virransalo, P. & Vaarma, M. 1993. Pre-Quaternary rocks, Sheet 2122 Ikaalinen. Geological map of Finland 1 : 100 000.

Vorma, A. 1971. Pre-Quaternary rocks, Sheet 3232 Pieksämäki. Geological map of Finland 1 : 100 000.

Vorren, T. O. 1977. Grain-size distribution and grain-size parametres of different till types on Hardangervidda, south Norway. Boreas 6 (2), 119-227.

Weaver, C.E. 1958a. Geologic interpretation of argillaceous sediments. Part I. Origin and significance of clay minerals in sedimentary rocks. American Association of Petroleum Geologists, Bulletin 42, 254-271.

Weaver, C.E. 1958b. A discussion on the origin of clay minerals in sedimentary rocks. Clays & Clay Minerals 5, 159-173.

Weaver, C.E. 1958c. The effects and geologic significance of potassium "fixation" by expandable clay minerals derived from muscovite, biotite, chlorite, and volcanic material. American Mineralogist 43 (9-10), 839-861.

Weaver, C.E. 1989. Clays, Muds, and Shales. Developments in sedimentology 44. Elsevier, Amsterdam. 819 p.

Weertman, J. 1972. General theory of water flow at the base of a glacier or ice sheet. Review of Geophysics and Space Physics 10 (1), 287-333.

Whitting, L. 1973. X-ray diffraction techniques for mineral identification and mineralogical composition. In: Methods of soil analysis, Part 1. American Society of Agronomy. Wisconsin. 671-698.

Wickham, S. S, Johnson, W.H. & Glass, H.D. 1988. Regional geology of the Tiskilwa Til Member, Wedron Formation northeastern Illinois. Illinois State Geological Survey, Circular 543, 35 p.

Wilson, M. 1987. X-ray powder diffraction methods. In: Wilson, M. (ed.) A handbook of determinative methods in clay mineralogy. Glasgow and London: Blacie & Son Ltd, 27-99.

Appendix 1. Location of the test pits and estimated mineralogical composition of the studied samples

Abbreviations and explanations:

Bedrock refers to the most abundant bedrock type which could be the potential source of the studied till samples

till = basal till, Wb = weathered bedrock, Twb = till which material is composed mainly of weathered bedrock.

Mineralogy of the oriented aggregates <0.02 mm:
Plg = plagioclase, Kfs = K-feldspar, Q = quartz, Chl = chlorite, Horn = hornblende, Kaol = kaolinite, Mi-ill = illitic mica (10 Å), Ver = vermiculite component in (14 Å) mixed layer clay mineral, Int = interstratified clay mineral (12 Å). Sm = expandable smectite component in mixed layer clay mineral, Talc = talc, ! = Al-hydroxy interlayers. Estimated abundance of mineral: + to ++++, - trace.

Physical property:
Clay = clay fraction % of fines (<0.06 mm), SSA = specific surface area of fines m^2/g.

1. Näs, Ahvenanmaa

Map sheet: 1021 08 x:6690.28 y:14450.04 z:013
Bedrock: rapakivi granite (Bergman,1981)
Lithostratigraphy: two till units interbedded with fine sand. Bedrock not reachted.
Note: oxidized surface layer 2 m thick

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.2 m	+	-	+	+	++	-	++		+	10.6	20.0
sand	1.5 m	+	+	+	+	+++	-	+++	+		4.6	7.0
till	1.5 m	+	-	+	+	+++	-	++			6.3	16.0

2. Kierikkala, Hämeenkyrö

Map sheet:2122 10 x:6831.30 y:2458.81 z:115
Bedrock: basic metavolcanite and mica schist (Virransalo & Vaarma 1993).
Lithostratigraphy: one till unit
Note: oxidized surface layer 5 m thick

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	2.0 m	+	-	-	+	++	+	++++	-	+	10.8	8.5
till	4.0 m	+	-	-	+	++	+	++++		-	9.2	9.0
till	5.5 m	+	-	-	+	++	++	++++		+	6.6	5.5

3. Solttila, Orivesi
Map sheet: 2142 07 x:6836.58 y:2521.60 z:137
Bedrock: gabbro (Laitakari 1986)
Lithostratigraphy: one till unit, with clay fragments in lower part.
Note: oxidized surface layer 4.8 m thick.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.0 m	++	++	+	+	+	+	+	+!	+++!	11.2	31.0
till	2.0 m	+++	++	+	+	+	+	++	+!	-!	9.3	23.5
till	3.7 m	+++	++	+	-	++	+	++++	-	++	10.8	22.5
till	4.6 m	+++	+	+		+	+	+++	+	+++	15.5	32.5
till	5.2 m	++	+	+	+		+	++++	+	+	9.2	25.0

4. Koura, Seinäjoki

Map sheet: 2222 10 x:6958.20 y:2452.75 z:095
Bedrock: mica schist (Mäkitie & Lahti 1991)
Lithostratigraphy: one till unit, underlain by weathered mica schist.
Note: ground-water table at 2.8 m depth.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.5m	+++	++	+	+		+	++++	++!	+!	4.0	9.0
till	2.8m	++++	+++	+	-	-	+	+++	-	-	2.7	5.0
Twb	3.5m	+++	++	+	-	+	-	++++	+!	+	7.0	11.0
Wb	4.0m	+++	++	-		++	+	++++	+++!	+++	5.9	19.0

5. Keturinkylä, Päntäne

Map sheet: 1234 06 x:6916.58 y:1555.08 z:115m
Bedrock: granite and granodiorite (Laitakari 1942).
Lithostratigraphy: one till unit, with upper part rich in clay fraction.
Bedrock not reached
Note: oxidized surface layer 2.5 m thick.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	2.2 m	+++	++	+	+	++	+	++++	+++!	++!	10.6	21.5
till	4.0 m	++++	+++	+++		+	++	+++		-	5.1	11.0
till	4.5 m	++++	+++	++		+	++	++		+	6.0	10.0

6. Vadbacken, Korsnäs

Map sheet: 1242 05 x:6966.49 y:1512.69 z:003.5
Bedrock: migmatitic mica gneiss (Nykänen 1960)
Lithostratigraphy: one till unit; bedrock not reached (Huhta 1983a).
Note: ground-water table at 2 m depth; no distinctive oxidized surface layer.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.5 m	+++	++	++	+	-	+	++			10.2	25.5
till	2.0 m	+++	++	+	+	-	+	++			8.4	25.0
till	2.5 m	+++	++	+	++	++	+	++++	-	+	8.0	22.5

7. Kerttuankylä, Evijärvi

Map sheet: 2314 03 x:7037.02 y:2466.30 z:070
Bedrock: migmatitic mica schist (Laitakari 1942).
Lithostratigraphy: one till unit; bedrock not reached.
Note: oxidized surface layer 2.5 m thick

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.0 m	++++	++	++	+		+	+	+!		3.8	4.4
till	3.0 m	+++	+	+	+	-	+	++	-!		7.7	21.6
till	6.0 m	+++	+	+	+	-	+	++			6.6	15.0

8. Marjapuhto, Lumikangas, Ylivieska

Map sheet: 2431 10 x:7103.22 y:2533.11 z:078
Bedrock: quartz and granodiorite is the main rock type, also mica shist and amphibolite occurs (Salli 1961).
Lithostratigraphy: one till unit; bedrock not reached.
Note: oxidized surface layer 2.5 m thick

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.5 m	+++	++	+	-	++	+	+++	++	++++	10.2	20.5
till	2.0 m	+++	++	+	-	++	+	++	+	+++	8.8	18.0
till	3.8 m	+++	+	+	+	++	+	++	-	+	11.6	32.0
till	5.0 m	++++	++	+	+	+	++	++			2.9	5.5

9. Marjapuhto, Ylivieska

Map sheet: 2431 10 x:7103.31 y:25334.36 z:077
Bedrock: quartz and granodiorite is the most abundant rock type, also mica schist and amphibolite occurs (Salli 1961).
Lithostratigraphy: deformed clasts of weathered clay in till unit
Note: no distinctive oxidized surface layer

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
clay	0.9 m	-	-			++++				+	16.6	30.0
till	1.4 m	++	+	+	+	+++	+	+++		++	16.0	30.5

10. Rauhala, Ylivieska

Map sheet: 2431 10 x:7107.03 y:2538.63 z:079
Bedrock: mica schist and quartz-feldspar schist also quartz diorite and diorite occours (Västi 1989).
Lithostratigraphy: one till unit underlain by weathered bedrock
Note: ground-water table in weathered bedrock

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.9 m	+++	+	+		+	+	++	+	++	17.9	30.0
till	2.4 m	+++	+	+	-	+	+	++		++	18.2	30.0
Twb	2.5 m	++++	++	++	+	+	+	++		+	6.7	15.5
Wb	2.6 m	+++	+	+		+	++	+++	-	+++	6.6	7.5

11. Vesiperä, Haapavesi

Map sheet: 2433 02 x:7111.84 y:2548.35 z:105m
Bedrock: feldspar-bearing mica schist (Salli 1961).
Lithostratigraphy: two till units, which represent two different glaciations (Hirvas ja Nenonen 1987). Silty clay Between two till units, glacial clay at top of section. Bedrock not reached.
Note: ground-water table at 3 m depth, no distinctive oxidized surface layer

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
clay	1.0 m	++	+	+	++	++	+	+++	++	+++	21.4	58.5
till	2.0 m	++	+	+	++	++	+	+++	-	++	14.6	31.0
clay	3.0 m	+++	+	+	++	++	+	+++	+	++	14.8	51.0
till	4.0 m	++++	++	+	++	++	+	+++	-	++	3.1	16.0

12. Mertuanoja, Ylivieska

Map sheet: 2431 08 x:7112.37 y:2528.92 z:066
Bedrock: uralite porphyyrite, feldspar bearing mica schist and granodiorite (Salli 1961).
Lithostratigraphy: test pit situated on till covered sorted formation (Iisalo 1992). Two till units interbedded with silt and sand. Bedrock not reached.
Note: ground-water table at 2.5 m depth, no distinctive oxidized surface layer.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	2.3 m	++++	++	+	+	+	++	++	-	-	5.1	20.5
clay	3.0 m	++++	++	+	++	+	+	+++	-	+	4.1	13.5
till	5.3 m	++++	++	++	+	+	+	+++	-	+	3.7	14.0

13. Ruotanen, Pyhäsalmi

Map sheet: 3321 12 x:7062.52 y:3453.21 z:152
Bedrock: sericite schist, acidic and basic metavolcanites and porphyritic granite (Marttila 1993).
Lithostratigraphy: two till units (Nenonen 1984)
Note: section has been exposed for many years

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	Sm	SSA	Clay
till	1.3 m	++++	++	++		++	++	++++	+!			10.3	21.0
till	2.0 m	++++	++	+	+	+	++	++++	++!			10.8	16.5
till	3.2 m	++++	+++	+	+	+	++	++	+!	+!		1.7	2.6
till	3.7 m	++++	+++	+	-	+	++	+++	+!	-!		2.0	1.7
Wb	5.0 m	+	+			+++	-			+++!	+++	21.7	

14. Lammassaari, Ruukki

Map sheet: 2443 05 x:7172.57 y:2556.90 z:053
Bedrock: quartz and granodiorite (Nykänen 1959)
Lithostratigraphy: two till units interbedded with sand and gravel. Bedrock not reached.
Note: no distinctive oxidized surface layer

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	2.5 m	++++	+++	+	+	+	++	++			1.70	4.0
till	4.5 m	+++	++	-		+	+	++++	+		1.83	3.0

15. Navettakangas, Liminka

Map sheet: 2443 09 x:7183.28 y:2564.10 z:043
Bedrock: granite (Nykänen,1959)
Lithostratigraphy: two till units interbedded by sand containing thin reddish layers. The provenance of the reddish fine material is most probably the Muhos siltstone (cf. Korpela 1977, Romu 1988). Bedrock not reached.
Note: oxidized surface layer 3 m thick.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.2 m	++++	+++	++	+	-	+	+	-!	-	1.7	8.0
till	4.2 m	+++	+	+	+	+	-	++	-	+	5.1	17.0

16. Likala, Oulainen

Map sheet: 2432 10 x:7138.65 y:2533.64 z:080
Bedrock: porphyritic microcline granite (Salli 1965)
Lithostratigraphy: two till units, bedrock not reached.
Note: oxidized surface layer 2 m thick.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.4 m	+++	+	+	-	+	+	++	+	+++	14.1	24.0
till	3.0 m	+++	+	+	++	++	+	++		+	6.9	23.0
till	4.5 m	++	+	+	++	+	+	+		+	6.8	22.0

17. Huuhansuo, Virtasalmi

Map sheet:3231 09 x:6883.12 y:3528.58 z:105

Bedrock: hornblende gneiss and amphibolite (Pekkarinen & Hyvärinen 1984); kaolin derived from quartz-feldspar-gneiss (Kuivasaaari et al. 1991)

Lithostratigraphy: several till units overlying kaolin deposit.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.3 m	++++	++	++	-		++	+	-!		3.5	8.0
till	1.8 m	++++	++	++	-		+	+	-!		3.3	8.5
till	2.3 m	++++	+++	++	-		++	++			2.0	7.5
till	4.0 m	++++	+++	++	-		+	++			2.1	9.5
till	5.0 m	++++	+++	++	-		++	++			1.5	8.0
till	5.5 m	++++	++	+	-		+	++			1.5	8.5
Twb	8.2 m	++	+	+	-	++++	+	++++			3.9	12.5
Wb	9.0 m			+		++++		+		++++!	14.6	49.5

the reflection at 14 Å in Wb-sample expands to 15.5 Å by ETGL-treatment

18. Heponiemi, Virtasalmi.

Map sheet:3232 07 x:6896.88 y:3521.76 z:101

Bedrock: mica gneiss (Vorma 1971)

Lithostratigraphy: two till units underlain by organic material, sand and clay (Jokinen et al. 1993).

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	14.5 m	+++	++	++	+		++	++++			1.4	10.0
till	18.5 m	++	+	+	+		+	++++			5.9	22.0
silt	26.0 m	++	+	+	+		+	+++			16.1	45.5
silt	34.0 m	+++	++	++	+		+	++++			2.2	9.5
clay	38.0 m	++	+	+	+		+	++++			8.8	70.5
Wb	43.5 m	+++	++	+	+++		++	++	-		11.8	13.0

19. Korpivaara, Ilomantsi

Map sheet:4333 08 x:6992.25 y:4561.74 z:220

Bedrock: Hattu schist belt (Sorjonen-Ward,1993).

Lithostratigraphy: one till unit, resting on weathered chlorite schist.

Note: ground-water table at 2.5 m depth.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.0 m	++++	++	++	+		+	++	+!		1.1	8.0
till	2.0 m	++++	++	++	-	-	+	+++	+!		3.2	12.0
till	3.5 m	+++	+	+	+	+	+	++++			3.7	15.0
Wb	4.0 m	+++	-	+	+++	++	-	++++			3.7	10.5

20. Vääräkoski, Hossa

Map sheet: 4514 04 x:7257.19 y:4478.88 z:217
Bedrock: gneiss granite (Matisto 1958)
Lithostratigraphy: two till units. Bedrock not reached.
Note: ground-water table at 5.2 m depth.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Talc	Horn	Mi-ill	Int	Ver	Sm	SSA	Clay
till	1.0 m	++++	+	+	+	-	+	++	+++	+	+++		4.0	11.0
till	4.0 m	++++	+	+	-	-	-	+	++	+	++		4.9	16.0
till	5.0 m	++++	++	+	-		-	++	++	+		+	6.3	10.0

21. Kaapinsalmi, Suomussalmi

Map sheet: 4511 11 x:7231.96 y:4458.93 z:210
Bedrock: basic volcanite and serpentinite (Matisto 1958).
Lithostratigraphy: several till units interbedded by sorted sediments (Saarnisto & Peltoniemi 1984). Bedrock not reached.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	int	Ver	SSA	Clay
till	1.5 m	+++	+	-	++	+	++	++	+!	+++!	3.2	5.0
till	6.0 m	++++	+	-	+++	+	++	+++	+	+	2.0	2.0
till	8.5 m	++++	+	+	-	+	+	++		+	2.6	13.5
till	10.5 m	++++	++	+		+	++	++	+		2.5	9.0

22. Ahmavaara, Tervola

Map sheet: 3522 06 x:7332.12 y:3432.28 z:134
Bedrock: granite gneiss (Perttunen 1971)
Lithostratigraphy: one till unit
Note: the section as a whole is oxidized, ground-water table at 3.2 m depth.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Talc	Mi-ill	Int	Ver	SSA	Clay
till	1.2 m	++	+	+	+	+++	++	++	+++	++!	++!	10.9	18.0
till	2.2 m	+++	+	+	+	-	++	++	+++	+!		8.8	36.0
till	3.2 m	++	+	-	+	-	+	+	+++	-		6.2	8.5

23.Tiskiaapa, Ylitornio, Rovaniemi

Map sheet: 2634 02 x:7370.60 y:2544.75 z:165
Bedrock:gneiss and mica schist (Hackman 1914).
Lithostratigraphy:one till unit
Note:no distinctive oxidized surface layer, ground-water table at 3.0 m depth.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.0 m	++++	++	++	-		++	+	-!		2.6	8.5
till	2.0 m	+++	++	+	-		++	+	-!		2.7	6.5
till	3.0 m	+++	++	+	-		++	+	-		2.6	7.0

24. Vuoskunoja, Pello

Map sheet: 2641 08 x:7413.75 y:2523.45 z:120
Bedrock: granite (Hackman 1914).
Lithostratigraphy: one till unit
Note: oxidized surface layer 2.2 m thick

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	0.7 m	+++	++	+	-		++	+	+	+	5.6	8.5
till	1.7 m	+++	++	+	-		++	+	+	+	4.7	12.5
till	2.7 m	++++	++	+	+		++	++	+	+	5.1	11.0
till	3.0 m	++++	++	++	-		++			+	2.6	9.0

25. Rautuvaara, Kolari

Map sheet: 2713 12 x:7490.00 y:2497.27 z:215
Bedrock: quartzite, amphibolite and monzonite (Hiltunen 1982).
Lithostratigraphy: section contains 5 distictive till units interbedded by sorted sediments (Hirvas,1991).

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	0.5 m	++++	++	+	-	-	+	+		++!	10.9	14.5
till	2.0 m	++++	+++	+		-	++	+++	+!	++!	6.4	2.0
till	7.8 m	++++	++++	+		-	++	++++			4.9	10.0
till	12.8 m	++++	++	+		-	++	++++			7.7	9.0
till	14.5 m	++++	++	-		-	++	++++			7.5	13.0
till	15.3 m	+++	++	-		-	++	++++			7.3	10.0
till	16.2 m	+++	+	-		-	+	++++			7.4	13.5
till	20.6 m	++++	+	-		-	+	++++			4.0	9.0
silt	21.0 m	++++	++	+		-	++	++++			5.1	7.0

26. Paitinmaa, Sodankylä

Map sheet: 3713 02 x:7475.85 y:3463.30 z:130
Bedrock: granodiorite (Tyrväinen 1983).
Lithostratigraphy: one till unit, resting on weathered coarse grained granodiorite.
Note: oxidized surface layer 1.2 m thick.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Talc	Mi-ill	Int	Ver	SSA	Clay
till	1.2 m	++++	++	+	++++		++	++	+++	++!	-!	7.3	19.0
till	1.6 m	++++	++	+	++++		++	+	+++	+!	-!	6.4	13.0
Wb	1.7 m	+++	+	+	++++	+	+	+++	+!	-!	7.1	19.0	

27. Postovaara, Sodankylä

Map sheet: 3714 08 x:7506.15 y:3481.50 z:220
Bedrock: basic volcanite (Tyrväinen 1983).
Lithostratigraphy: one till unit
Note: ground-water table at 2.6 m depth.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Talc	Mi-ill	Int	Ver	SSA	Clay
till	0.6 m	+	-	-	++++		+++	+	++	++++!	++!	16.4	18.5
till	1.6 m	++	-	+	++++		+++	++	+++	+!	+!	15.4	20.0
till	2.6 m	+	-	-	+++		++	+	++	+!	++!	15.0	14.5

28. Sattasvaara, Sodankylä
Map sheet: 3714 05 x:7504.86 y:3474.66 z:250
Bedrock: basic volcanite (Tyrväinen 1983).
Lithostratigraphy: one till unit, resting on weathered bedrock.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Talc	Mi-ill	Int	Ver	SSA	Clay
till	0.5 m	++	+	+	++++		++	++	+	++!		6.7	21.0
till	1.0 m	+	-	-	++++		++	++++	+	++!		11.3	23.5
Wb	1.5 m	+++	+	-	++++		++	++++				9.5	41.0
Wb	2.0 m	+++	-	-	+++		-	++++				21.2	43.5

29. Kopsuskuusikko, Sodankylä
Map sheet: 3714 09 x:7518.10 y:3481.20 z:230
Bedrock: mica schist (Tyrväinen 1983).
Lithostratigraphy: one till unit, resting on coarse grained weathered bedrock.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Talc	Mi-ill	Int	Ver	SSA	Clay
till	1.0 m	++++	++	+	++++	++		++	++	++!	++!	6.5	16.0
till	1.4 m	++	+	+	++++	++		++	++	++!	++!	14.3	23.5
till	2.5 m	++	+	+	++++	++		++++	+++	-!	+	13.5	17.5
Wb	2.6 m	++	+	+	+	++		+	+	+!	+	10.7	6.0

30. Peurasuvanto, Sodankylä

Map sheet: 3723 07 x:7527.80 y:3487.70 z:200
Bedrock: chlorite-amphibolite-schist (Pihlaja & Manninen 1993).
Lithostratigraphy: one till unit, underlain by weathered bedrock.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Talc	Mi-ill	Int	SSA	Clay
Twb	0.7 m	++	-	-	++++	+	+++	+++	+++	+!	4.5	6.0
Wb	1.3 m	++		-	++++	+	++++	-	+	+!	3.7	3.5

31. Mäkärärova, Vuotso, Sodankylä

Map sheet:3724 11 x:7567.53 y:3494.31 z:265
Bedrock: granite gneiss, interbedded by amphibolite (Säynäjärvi 1953).
Lithostratigraphy: two till units underlain by weathered bedrock. The lower unit probably correlates with the widespread till unit II (Hirvas 1992). Weathered bedrock is rich in clay fraction.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	0.5 m	+	-	-	-	++++	-	+++	++++!	++++!	20.4	43.5
till	1.0 m	+	-	-		++++	-	+++	++++!	+++!	24.5	41.0
Twb	1.5 m	+	-	-		++++		++++	+++		21.1	28.0
Wb	2.0 m	+++	-	-		+++	-	+++	-		7.6	13.0

32. Kakslauttanen, Sodankylä

Map sheet:3831 04 x:7583.50 y:3514.60 z:285
Bedrock: coarse grained granulite (Meriläinen 1976).
Lithostratigraphy: weathered bedrock, the uppermost part of which is mixed with till unit.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
Twb	1.0 m	+	-	+		++++	-	++	+	+!	24.4	25.5
Twb	1.5 m	+	-	+		+++		+++	-		24.4	20.5
Wb	1.9 m	+	-	-	-	+++	+	++++	+		29.7	13.5
Wb	2.0 m	+	-	+		++++	-	++++	-		21.7	18.0
Wb	2.1 m	+		+		++++		++	-		20.0	18.0

33. Lintupuoliselkä, Angeli, Inari

Map sheet: 3821 10 x:7647.75 y:3450.20 z:230

Bedrock: anorthosite. Approximately 4 km to south-west in ice flow direction occurs quartz-feldspar schist, granodiorite and quartz diorite (Meriläinen 1965).

Lithostratigraphy: two till units interbedded with clay.

Note: oxidized surface layer 1.6 m thick.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.6 m	+++	+	+	-	++++	++	++		+!	12.9	16.5
till	2.4 m	+	-	-		++	++	++++	-!		18.7	22.0
clay	2.5 m	+++		+		+++	+++	+++			20.7	33.5
till	2.7 m	+	-	-		++	++	++++			15.2	14.0

34. Stuorrakeädggevarri, Nuorgam

Map sheet: 3941 11 x:7775.35 y:3533.95 z:215

Bedrock: hornblende gneiss (Meriläinen 1976).

Lithostratigraphy: thin till unit resting on top of blocky weathered bedrock.

sample	depth	Plg	Kfs	Q	Chl	Kaol	Horn	Mi-ill	Int	Ver	SSA	Clay
till	1.0 m	++++	-	+	+++		+	+	+!		2.1	7.0
till	1.3 m	++++	-	+	+++		++	+	++!		4.5	8.0

Appendix 2. Place names referred to in the text.

Tätä julkaisua myy

GEOLOGIAN
TUTKIMUSKESKUS (GTK)
Julkaisumyynti
02150 Espoo

☎ (90) 46 931

Teleksi: 123185 geolo fi
Telekopio: (90) 462 205

GTK, Väli-Suomen
aluetoimisto
Kirjasto
PL 1237
70211 Kuopio

☎ (971) 205 111

Telekopio: (971) 205 215

GTK, Pohjois-Suomen
aluetoimisto
Kirjasto
PL 77
96101 Rovaniemi

☎ (960) 3297 111

Teleksi: 37295 geolo fi
Telekopio: (960) 3297 289

Denna publikation säljes av

GEOLOGISKA
FORSKNINGSCENTRALEN (GFC)
Publikationsförsäljning
02150 Esbo

☎ (90) 46 931

Telex: 123185 geolo fi
Telefax: (90) 462 205

GFC, Distriktsbyrån för
Mellersta Finland
Biblioteket
PB 1237
70211 Kuopio

☎ (971) 205 111

Telefax: (971) 205 215

GFC, Distriktsbyrån för
Norra Finland
Biblioteket
PB 77
96101 Rovaniemi

☎ (960) 3297 111

Telex: 37295 geolo fi
Telefax: (960) 3297 289

This publication can be
obtained from
GEOLOGICAL SURVEY
OF FINLAND (GSF)
Publication sales
FIN-02150 Espoo, Finland

☎ +358 0 46 931

Telex: 123185 geolo fi
Telefax: +358 0 462 205

GSF, Regional office for
Mid-Finland
Library
P.O. Box 1237
FIN-70211 Kuopio, Finland

☎ +358 71 205 111

Telefax: +358 71 205 215

GSF, Regional office for
Northern Finland
Library
P.O. Box 77
FIN-96101 Rovaniemi, Finland

☎ +358 60 3297 111

Telex: 37295 geolo fi
Telefax: +358 60 3297 289

ISBN 951-690-576-5
ISSN 0367-522X