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Glacial transport of till and its influence on interpretation of geochemical results in North Karelia, Finland

by Reijo Salminen and Aimo Hartikainen

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GLACIAL TRANSPORT OF TILL AND ITS INFLUENCE ON INTERPRETATION OF GEOCHEMICAL RESULTS IN NORTH KARELIA, FINLAND

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REIJO SALMINEN AND AIMO HARTIKAINEN

with 40 figures and 4 tables

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Investigations on the transportation of till, the stratigraphy of till and the glacial history of North Karelia were carried out as an aid to the planning of geochemical till studies and the interpreting of the results of geochemical till studies.

The results from 11 separate targets representing different glaciological conditions are presented. The transport distance of 0.8—6.0 cm till fraction was studied by stone counts from pits; the transport distance of < 0.06 mm till fraction was evaluated on the basis of the metal concentration (geochemical anomalies); the source area of boulders on the surface of till was determined by a discrimant analysis of analytical data.

The < 0.06 mm till fraction was analysed by the atomic absorption technique after digestion in hot 6M HNO_3. Total analyses by optical emission spectrometry (OES-ICAP) were used in some cases, too.

Two lobes advancing from different directions were active during the deglaciation phase in the study area. Hence the transport direction of till is quite different in separate areas and complex transport is very probable. Two different kinds of transport mechanism for till can be distinguished:

1) In the area of active ice lobes glacial erosion was intense and the transport distance of till is long. In these circumstances till became more homogeneous and the anomaly/background contrast weakened.
2) Outside the active lobes there are some areas where glacial erosion and transportation of till were weak. The till is then not so homogeneous and the anomaly/background contrast is higher.

The transport distance of boulders on the surface of a till bed could be up to tens of kilometres. The shortest transport distance — as a rule only some hundreds of metres — was determined by means of the metal concentrations in the finest fraction of till (geochemical anomalies) in the bottom parts of the till bed.

Key words: geochemical methods, metals, till, glacial transport, stone counting, boulders, rocks, deglaciation, Holocene, Finland, North Karelia

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INTRODUCTION

The Geochemistry department of the Geological Survey of Finland has been carrying geochemical till studies in North Karelia since 1973. The stratigraphy of the overburden and the transportation of till were the subject of detailed study during the preliminary planning phase of regional geochemical mapping. About 330 study-pits were dug during the years 1974—1982 by tractor excavator. During these studies it was revealed that the transport direction of till varies in stratigraphically different parts of a till blanket, and that the transport distance and direction vary markedly from place to place.

The transportation of different fractions of till has been studied mainly by geochemical

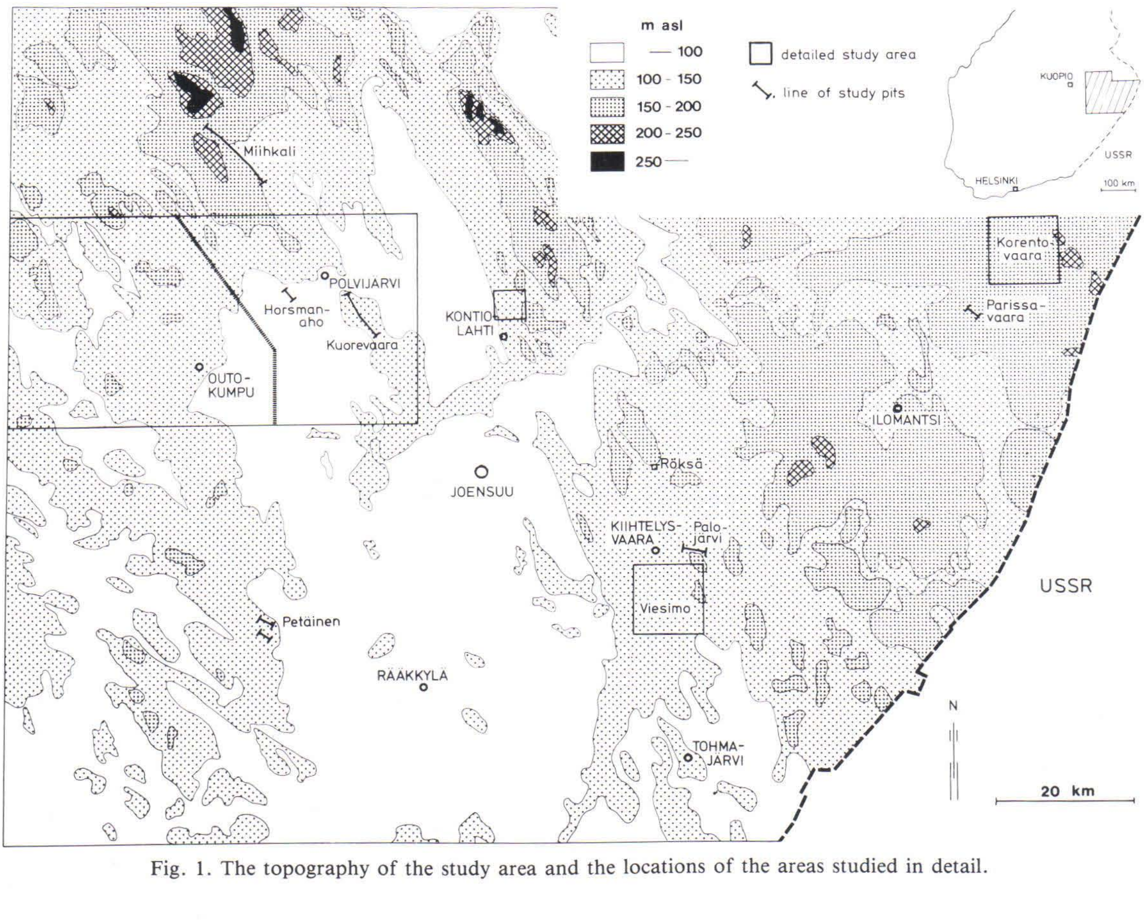


Fig. 1. The topography of the study area and the locations of the areas studied in detail.

methods and for interpretation of geochemical results, although the conventional methods for studies of this kind have also been used. From stone counts it is evident that the boulders on the surface of a till blanket have been transported from much farther off than the finest fraction of till and a geochemical anomaly in that finest fraction. This is, of course, partly ostensible, because a glacier does not scatter different fractions into different places. Nevertheless, it is usually much more difficult to find the source area of an ore boulder on the surface of a till blanket than to reveal the source of a geochemical anomaly.

This publication is a synthesis of the aforementioned studies on the transport distance and direction of till in North Karelia. Studies conducted in areas with different types of glacial ice flow have been selected and presented here as case histories (Fig. 1).

The transportation and transport distance of till in Finland have been studied by numerous scientists: Saksela (1949), Virkkala (1956, 1957, 1960, 1969), Aurola (1955), Repo (1957), Hyvärinen, L. (1958), Tynni (1969), Hirvas *et al.* (1977), Perttunen, M. (1977), Johansson (1980), Ekdahl (1981), Salonen & Kokkola (1981), Hirvas & Nenonen (1981), Peltoniemi (1981) and Nevalainen (1983). Divers transport distances have been reported, depending on many features, including the topography of the study area, the type of ice flow, the width of a certain rock type area, the dip and strike of bedrock and the sampling depth. Even different transport directions of till and complex transportation have been reported from the same place.

The transportation of till in North Karelia has been studied by Repo (1957, 1969), Hirvas & Nenonen (1980), Salminen (1980, 1981), Peuraniemi (1983) and Rainio (1983). Repo has concentrated mainly on the upper parts of till beds.

Studies on the transport of till in terms of till geochemistry are not so numerous, and in Finland they have been published by Kauranne (1951), Wennervirta (1968), Björklund (1976), Nurmi (1976), Salminen (1980, 1981), Ekdahl (1982) and Peuraniemi (1983). Most of the works are restricted case histories and do not include the glacial dispersion of elements. Nevertheless, as the results of the present study show, it is essential to know the transport distances and directions of till and their areal differences and how they depend on the glacial history of the study area if the results of geochemical till studies are to be interpreted in a reasonable way.

BEDROCK AND MORPHOLOGY

Most of the bedrock of the study area has been mapped on the scale 1:100 000 (Nykänen 1967, 1968, 1971a, 1971b; Huhma 1971a, 1971b, 1971c, 1975; Lavikainen 1973, 1975; Laiti 1983). According to these maps the bedrock (Fig. 2) is divided into two parts differing in age: the Archean basement gneiss complex and the early Proterozoic Karelidic schist belt.

The basement gneiss complex consists mainly of granitoids, which are gneisses of granodioritic or quartz dioritic composition and younger potassium granites. There are also volcanogenic and sedimentogenic schists — mainly amphibolites and mica schists. Metadiabase dykes are numerous, especially in the western part of the gneiss complex. Besides the coherent gneiss complex in the eastern part of the study area, some small gneiss domes occur among the younger Karelidic schists (Kokka, Sotkuma and Kontiolahti domes, Fig. 2).

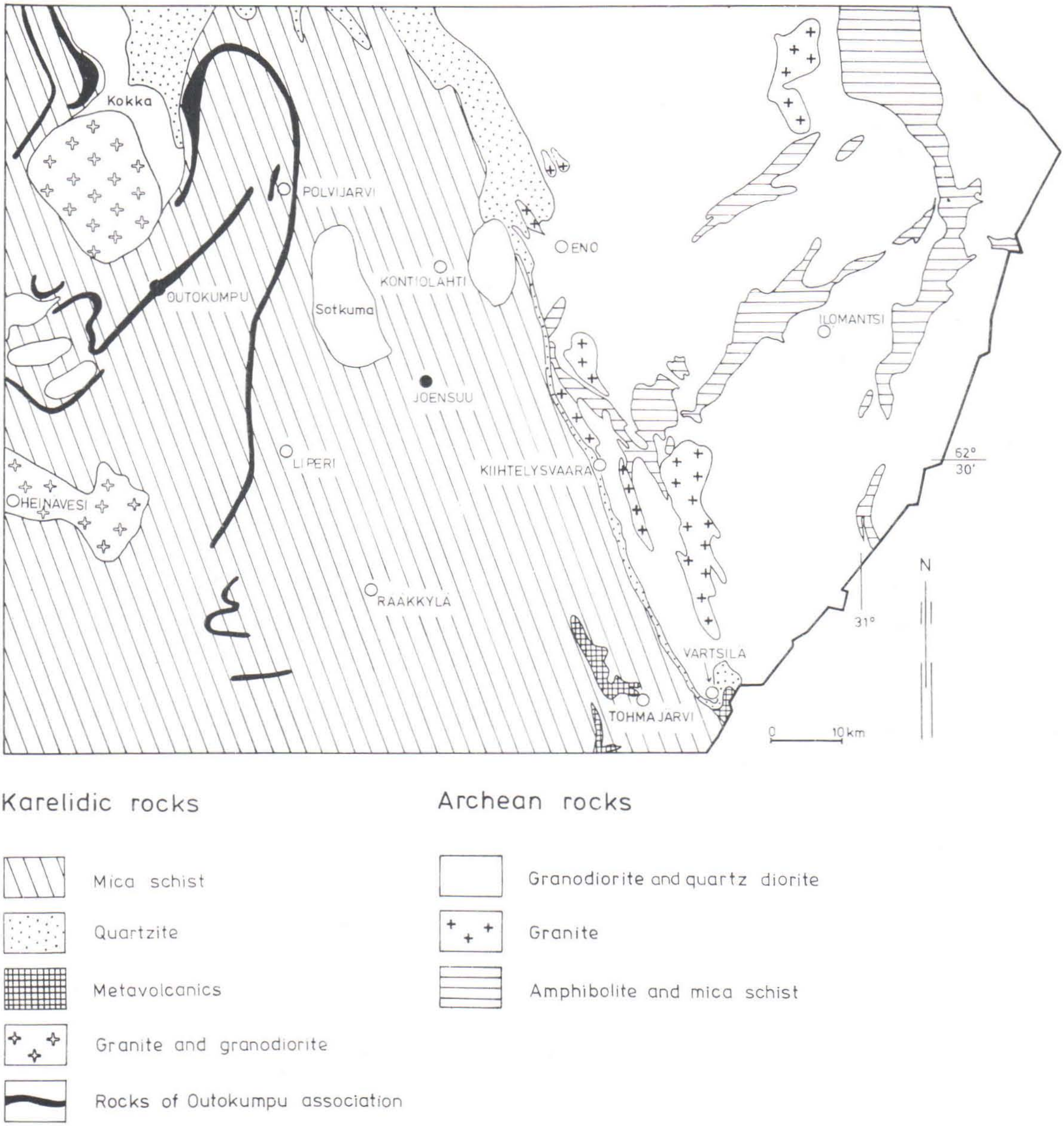


Fig. 2. The bedrock of the study area (after Nykänen 1967, 1971; Huhma, 1975; Lavikainen, 1973, 1975).

The oldest part of the Karelidic schists consists of conglomerates, quartzites and metavolcanics, but a much larger part contains mica gneisses, mica schists and phyllites with some black schist intercalations. The rocks of the Outokumpu association constitute a strikingly different zone in which the most important rock types are serpentinite, quartz and skarn rocks. Younger granites and granodiorites intersecting the schists occur in the western part of the study area.

The topography of the study area does not vary much (Fig. 1). As a rule the areas of Karelidic mica schists appear as depressions 50—100 m lower than the environment. The basement complex consists of gently sloping hills.

METHODS OF INVESTIGATION

Sampling

Most of the samples were collected from pits dug by a tractor excavator. The pits were 3—4 metres deep unless the whole overburden was thinner than that. Samples from the pits were taken separately for geochemical analysis and for stone counts. The geochemical samples represent the whole till profile, but the samples for stone counts were taken from all the stratigraphic till layers, one sample from each. If there was only one layer, the samples were taken at one-metre intervals. The stones were washed and the rock type of at least 100 stones (0.8—6 cm in diameter) was determined. In the stone counts at certain targets (Korentovaara, Viesimo, Horsmanaho) the gravel fraction of samples collected earlier for regional geochemical mapping were also used.

Chemical analyses

The geochemical samples were dried and the < 0.06 mm fraction was sieved for chemical analysis. The samples, digested in hot 7M nitric acid, were assayed for Co, Cu, Mn, Ni, Pb and Zn by atomic absorption methods at the laboratory of the Geological Survey of Finland in Kuopio. The nickel concentrations, determined by optical emission spectrometry (Gustavsson *et al.* 1979) in connection with regional geochemical mapping, were used for the Petäinen target area. Samples from boulders and bedrock in the Kontiolahti target area were analysed by plasma emission spectrometry (ICAP) in the laboratory of the Geological Survey in Espoo.

GLACIATION

Predeglaciation stage

The oldest detected directions of the movement of the ice sheet differ clearly from each other in various parts of the study area (Fig. 3). Not even the directions interpreted to be the oldest are of the same age in all areas.

In Heinävesi, Rääkkylä, Kiihtelysvaara, Tohmajärvi and Värtsilä the oldest detected striations trend NW-SE (315°—340°). In Rääkkylä in particular striae of this direction are numerous and are often crossed by striae created by a

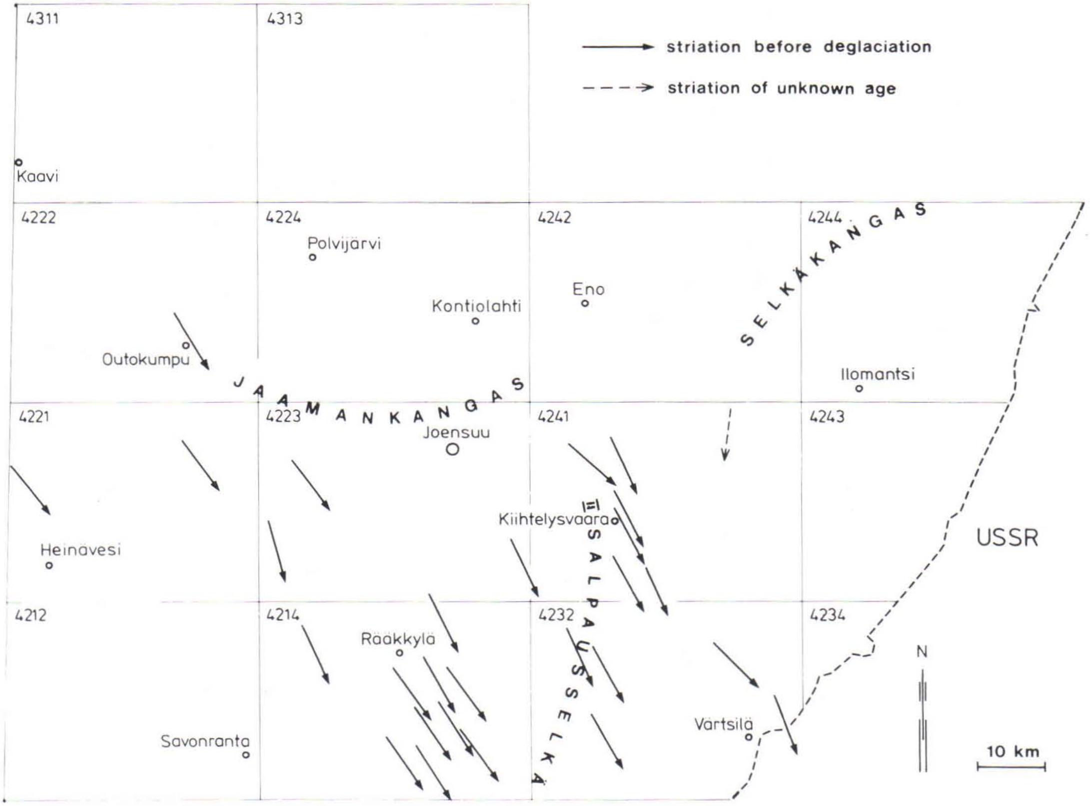


Fig. 3. The striations older than the latest deglaciation, with the biggest terminal formations (Jaamankangas, Salpausselkä II, Selkäkangas).

younger (Lake Finland ice lobe) ice movement (Fig. 3). Stratified drift and even older till under a till bed approximately three metres thick created by the younger ice movement (Fig. 3) have been recognized in Rääkkylä (Hartikainen & Salminen 1980, Hirvas & Nenonen 1981). Till stratigraphy similar to that in Rääkkylä has also been reported from Tohmajärvi and Kiihtelysvaara (Hartikainen 1980, Salminen 1980).

In the northern part of the study area most of the striae created by the ice movement, and which are oldest in the southern areas (315°—340°), have been destroyed by younger ice movements. Nevertheless, Hirvas and Nenonen (1979) have reported a direction of 330° for striae under young till beds at Outokumpu.

The flow directions of the ice sheet

During the Weichselian epoch the NW-SE ice movement (315°—340°) was evidently common throughout the study area. But in many places the flow and oscillation of active lobes in the deglaciation phase destroyed the striae and other traces of this ice movement. The two big lobes in North Karelia, which Punkari (1979) calls the North Karelian ice lobe and the Lake Finland ice lobe, have been divided into different parts in terms of their activity. Both were active partly at the same time and partly at different times (Kontturi 1980, Lyytikäinen 1980, 1982; Kurimo 1982); part of the study area was the field of activity of both lobes. Because the lobes advanced in different directions and changed their flow directions, the traces of different ice movement directions are visible in many places. However, there is no great difference in the age of their movements.

In this study the directions of ice flow and their age relations were determined from striae, usually cross-striae, in which the directions of the crossing striations are conspicuously different from each other. The streamlined forms of the overburden were also a very important factor when evaluating the flow direction and the intensity of erosion of an active ice lobe.

Some separate observations of a still older NE-SW ice movement were also made. One argument in favour of this direction is the existence of striations at 10° in a southeastern leeside corner of an outcrop in Revon-Sonkaja, 20 km west of Ilomantsi (Figs. 3 and 5). Ice movement from the northeast was also considered to be the most probable when the source area of some boulders in Kiihtelysvaara was studied (Salminen 1980).

Salpausselkä I stage

Deglaciation began in the southeast of the study area. Subarea I in Fig. 5 was the first to be freed of the ice sheet. However, the margin of the ice sheet did not retreat at a steady rate. In the subaquatic area in Värtsilä it retreated slowly and eventually stopped to form the Salpausselkä I marginal formation.

The retreat in the area of Karelidic schists lying in a depression (Figs. 1 and 2) was almost westwards and in the area of the Archean gneiss complex northwestwards (Fig. 4). Deltas preceding the formation of the present Salpausselkä I are situated on the distal side of the formation north and southwest of Värtsilä (Rainio 1983).

Southeast of Tohmajärvi, Salpausselkä I runs in a south-north direction but west of Värtsilä it turns to east-west. The latter comprises a series of deltas caused by a separate sublobe. Farther away in the north, in the area of the gneiss complex, Salpausselkä I was formed under supra-aquatic conditions. The marginal formation in this area makes up a discontinuous row of moraine hillocks, although in places it forms a ridge more than ten metres high (Rainio 1983). Nearer Ilomantsi the terminal formation becomes more discontinuous, and the terminus of the ice sheet retreated northwestwards without any extensive interruptions. The small end moraines south of Selkäkangas evidently belong to the Salpausselkä I stage.

Salpausselkä II stage

When the terminus of the ice sheet began to retreat from the Salpausselkä I position once more the direction was to the west in the southern part of the study area but to the north-west farther north. At this time the ice sheet began to divide into two separate lobes — the North Karelian ice lobe in the north and the Lake Finland ice lobe in the west, and in the early Salpausselkä II stage a wide area of deltas was formed in the interlobate zone. On the map of Quaternary deposits (Repo 1964, 1969) this area of deltas is indicated as moraine formations, because the margin of the ice sheet oscillated and a thin blanket of till was deposited on the glaciofluvial material of the deltas (Frosterus & Wilkman 1917, Repo 1957 and Salminen 1980).

Salpausselkä II runs as a series of ridges of mainly glaciofluvial material from Kiihtelysvaara to the USSR (Rainio 1983). So the Selkäkangas formation in Ilomantsi (Fig. 5) is of approximately the same age, although the lobes from which the Salpausselkä II and Selkäkan-

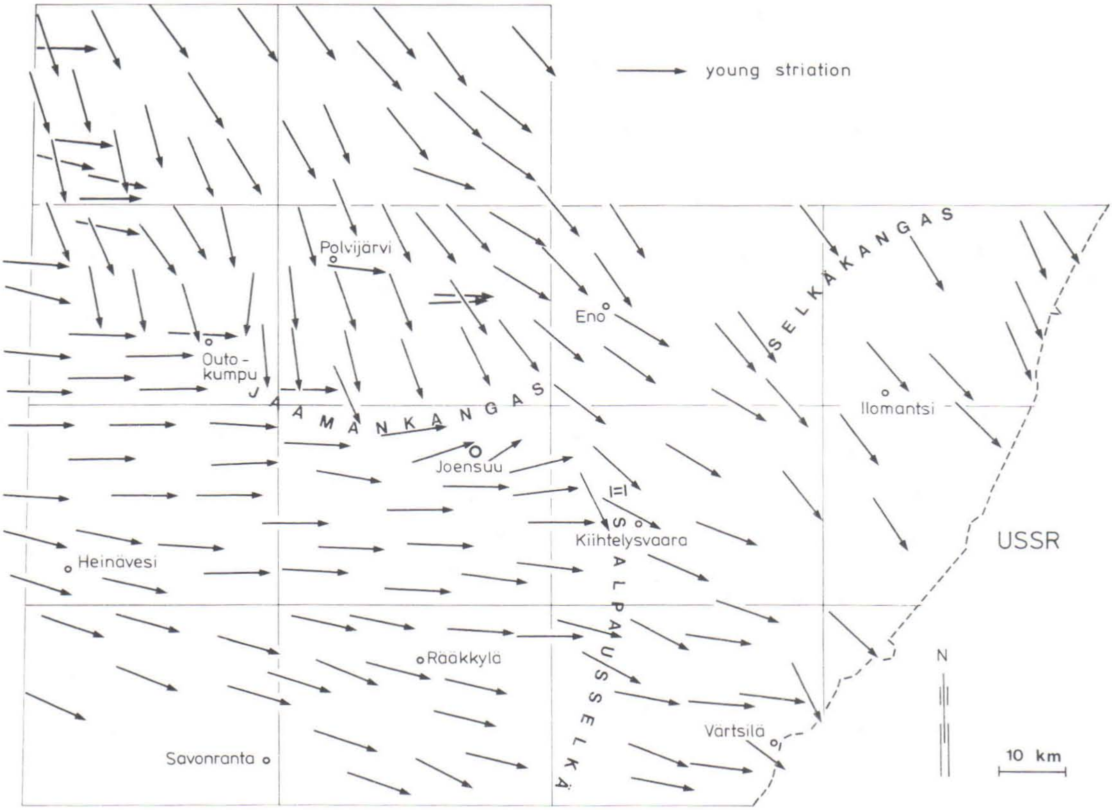


Fig. 4. The youngest striations, with the biggest terminal formations (Jaamankangas, Salpausselkä II, Selkäkangas).

gas marginal formations were deposited were active rather independently of each other. There is much more material in the marginal formation of Salpausselkä II to the south of Kiihtelysvaara than to the north of it. This means that the erosion and transportation of the lobes were more effective in the southern part of the study area and also that an appreciable part of the material there was transported quite a long distance.

When the margin began to retreat yet again, this time from the position of Salpausselkä II, it did so towards the west in the southern part of the study area and towards the north in the northern part. During this phase the Lake Finland ice lobe and the North Karelian ice lobe were separated from each other. The terminus of the North Karelian lobe began to retreat first, and the interlobate formation from Kiihtelysvaara to Lake Höytiäinen was formed (Kurimo 1982, Lyytikäinen 1980 and 1982). The Lake Finland ice lobe was still active, which is proved by striations perpendicular to that formation even in a SW-NE direction. Striations showing ice movement at 260°—275° can be seen at the southernmost ends of several small islands on Lake Höytiäinen. These striae, together with the W-E striae in the Outokumpu-Kaavi area (Figs. 3 and 4), show that the northern margin of the Lake Finland ice lobe was situated farther away north of Jaamankangas (Hartikainen & Salminen 1981).

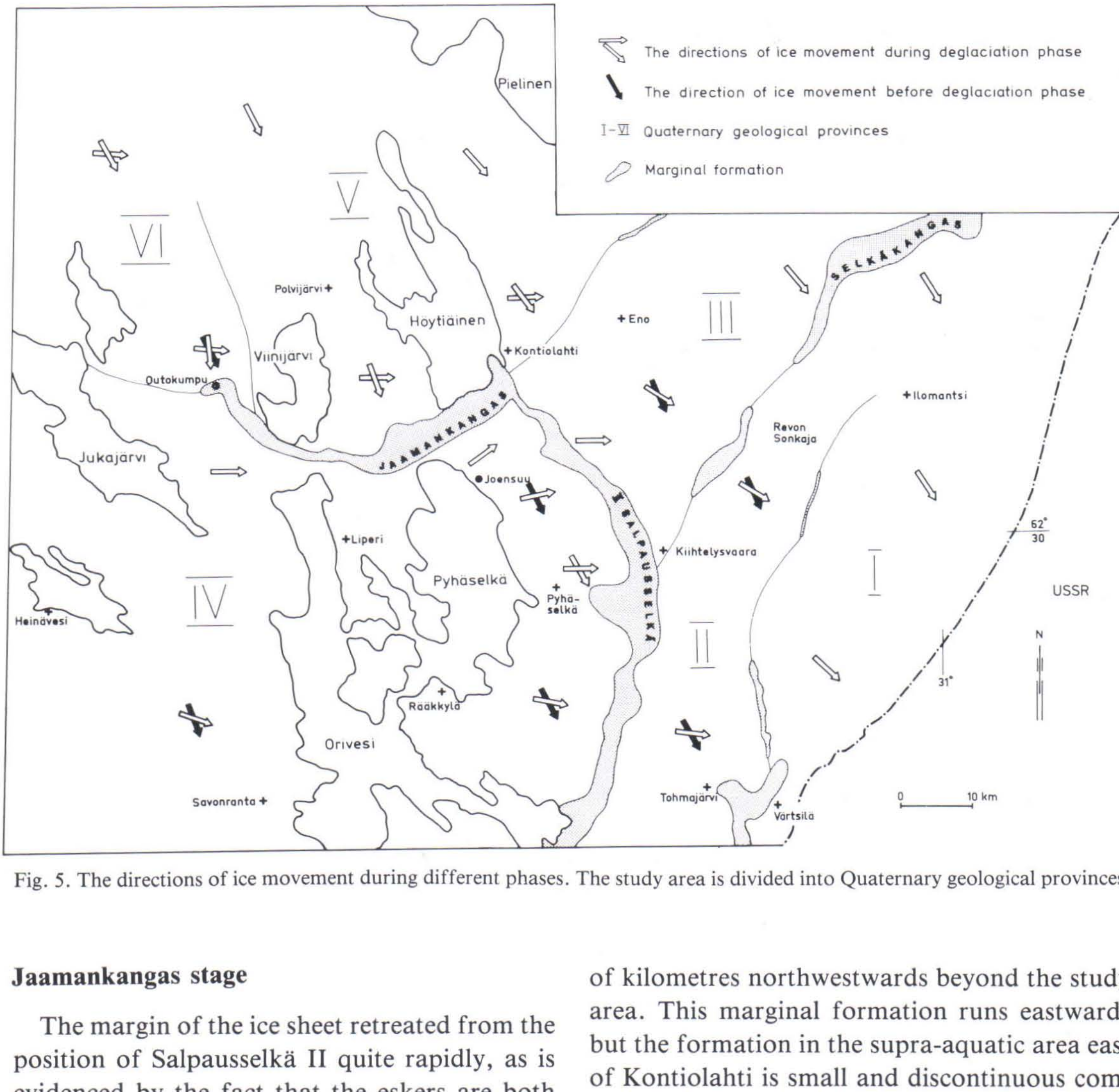


Fig. 5. The directions of ice movement during different phases. The study area is divided into Quaternary geological provinces.

Jaamankangas stage

The margin of the ice sheet retreated from the position of Salpausselkä II quite rapidly, as is evidenced by the fact that the eskers are both few and small. Changes in the movement of the ice sheet took place during this time and a new advance began from the north into the areas from which the terminus of the Lake Finland ice lobe just had retreated. The margin of the new lobe (the westernmost part of the North Karelian ice lobe) stopped at the site of the present-day Jaamankangas between Joensuu and Outokumpu. This lobe was very active, which is demonstrated not only by the massive marginal formation of Jaamankangas but also by a large drumlin field extending for hundreds of kilometres northwestwards beyond the study area. This marginal formation runs eastwards but the formation in the supra-aquatic area east of Kontiolahti is small and discontinuous compared with Jaamankangas. There was an ice lake on the distal side of Jaamankangas and the margin of the ice lobe ended in water; thus, extensive areas are covered with clay, silt and sand layers.

The westernmost part of the lobe was divided into sublobes. These were separated from each other by eskers which now have a fan-shaped configuration northeast of Outokumpu. The direction of each sublobe was towards the apex of the esker fan and the transport distance apparently differed in the area of each sublobe.

Till and its transportation

The main topic of this study is the transportation of till in terms of geochemistry. Thus, not only transport but also the chemical composition of the material is of importance. The amount of weathered bedrock in the overburden varies from place to place both in quantity and in nature, for example, a weathered bedrock layer 2—3 metres thick without any till cover has been found in Savonranta. This weathering took place during postglacial time. On the other hand weathered bedrock met with in places beneath the till blanket is evidently preglacial. The amount of weathered bedrock in till is difficult to evaluate but it should be borne in mind when considering the geochemical nature of till.

In any case, the till in the study area is mostly basal till covered by a thin layer of ablation till. Ablation till is met with as hummocks in the environment of Outokumpu and Ilomantsi and on the proximal sides of the marginal formations. As a rule the transport distance of ablation till is much greater than that of basal till, although some authors have reported a short transport distance (Salonen & Kokkola 1981, Sutinen & Kurki 1981).

Drumlins and other streamlined overburden forms are common in Polvijärvi, Kontiolahti and Ilomantsi, the areas of the most active lobes.

The transport distance of till, cannot be determined exactly, because it depends on the cross section of the source area, the fraction of the till considered, the stratigraphic horizon of the till, the rock type, mineral or element studied, and on many other points, depending on the case. Usually, when the transport distance of till is studied, the diminishing in the abundance of a certain rock type or element in the distal contact in bedrock is measured and a half distance value obtained, but this never describes the transportation of all the material in the till.

In this study, the half-distance values of a certain part of till have been determined as usual (the distance over which the percentage of the object of study proper diminishes to half measured from the distal contact). But often the distance over which the main part of the till has been transported has also been evaluated subjectively. The result is not exact but it is much better for geochemical purposes. In any case, each study line is individual but areas with very different transport distances can be distinguished on the basis of their glacial histories.

CASE HISTORIES OF TILL TRANSPORTED A LONG DISTANCE

Miihkali area

The target area of Miihkali is located at the border of the parishes of Juuka and Polvijärvi (map sheets 4311 10 and 11), in the zone of the Outokumpu association rocks (serpentinite, with minor skarn rock layers). The width of this zone in the direction of ice movement is 2.5 km. The rocks of the Outokumpu association are surrounded by mica schists with some black schist interlayers. A 4-km-wide zone of gently dipping quartzitic rocks is situated farther away on the proximal side of the Outokumpu association, and granitoids occur still farther off in the same direction.

Only one till bed, deposited by the youngest ice movement (320°), has been found in the area. The study line runs in a shallow valley

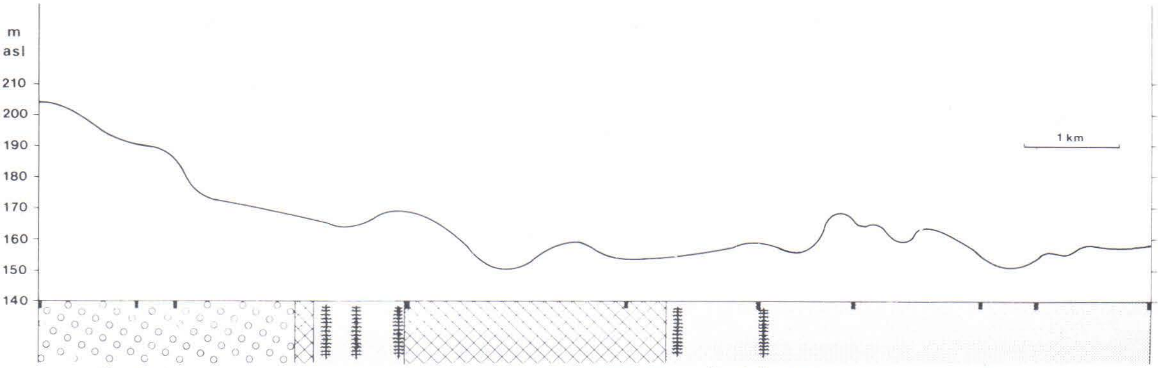


Fig. 6. The topography, bedrock and sites of the study pits along the study line at Miihkali.

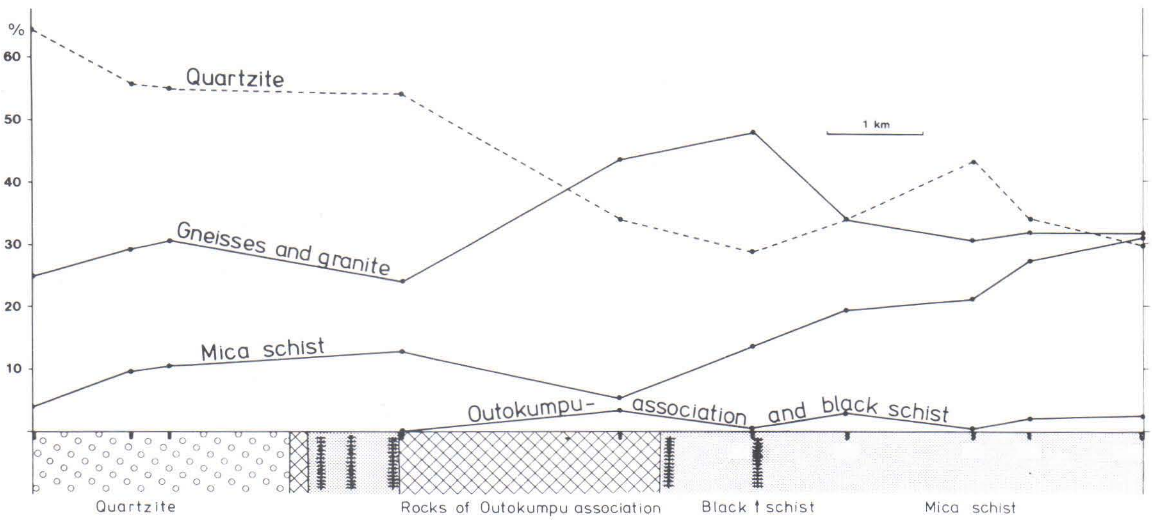


Fig. 7. The percentage of different rocks in till at Miihkali. The direction of ice movement is from left to right (320°).

parallel to the latest ice movement direction. The southeastern end of the study line is 50 m lower than the northwestern end. The overburden is thick — no suboutcrops of bedrock were found in the pits (Fig. 6). Samples for geochemical analyses and stone counts were taken from 10 pits along a 12-km-long study line.

The abundance of granitoids and quartzitic rocks in the till is still high (65 %) 8 km from the distal contact of these rocks (Fig. 7). The half-distance value (see p. 13) of quartzitic rocks is about 10 km, but the half-distance value of the granitoids is more than the length of the study line (12 km). The amount of black schists and rocks of the Outokumpu association is very small along the whole study line. But the amount of mica schist increases down-glacier from the contact of mica schist and quartzitic rocks, first at the bottom of the till blanket and farther away also in the upper part of the till blanket (Fig. 8).

In the target area the zone of the Outokumpu association rocks consists almost entirely of serpentinite assaying 1500—2000 ppm nickel. The

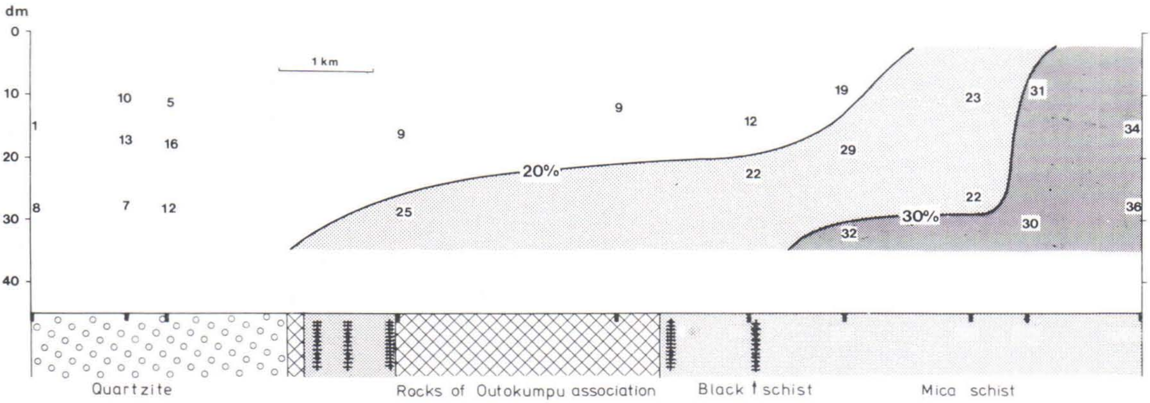


Fig. 8. The summed percentage of mica schist, black schist, serpentinite and skarn at different depths in the pits at Miihkali. The direction of ice movement is from left to right (320°).

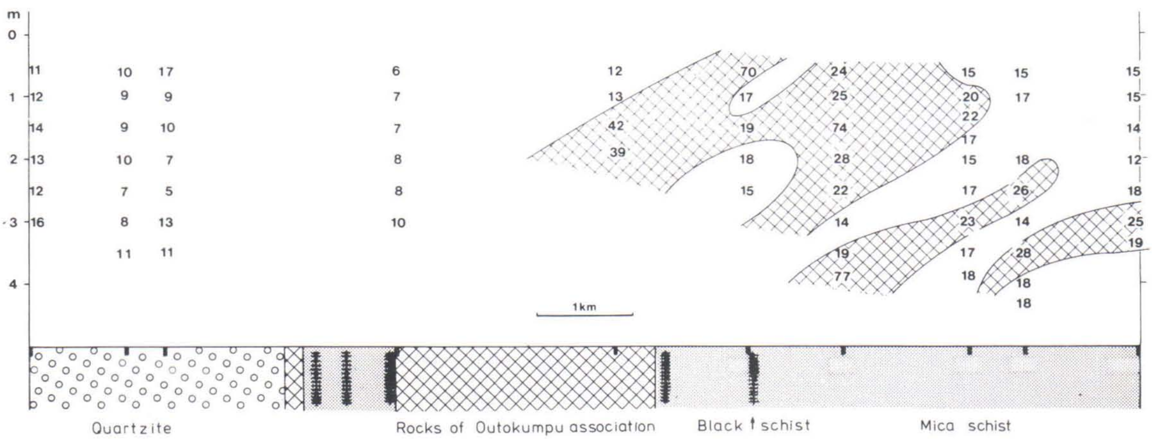


Fig. 9. The content of nickel in the <0.06 mm till fraction in the pits at Miihkali. Anomalous part (> 18 ppm) is shaded. The direction of ice movement is from left to right (320°).

Ni content of the black schist is 300 ppm, that of the mica schist 60 ppm and that of the quartzitic rocks and granitoids almost negligible (5 ppm). The Ni content of the till is, however, very low and the contrast to the background very weak compared with the contents and contrast in the bedrock (serpentinite/mica schist, quartzitic rocks). Nevertheless, the Ni anomaly caused by the Outokumpu association rocks can be seen clearly in the till, even though it is very weak (Fig. 9). The half-distance value of the < 0.06 mm till fraction is about three kilometres, measured by the decrease in the Ni content. The high half-distance values both in stones (2—20 cm) and in the finest fraction (< 0.06 mm) are due to the location of the Miihkali target area in the middle of the North Karelian ice lobe, where glacial erosion was intense and the transport distance long. These points, together with sampling from the upper part (0.6—4.0 m) of a thick till bed, caused both the strong dilution of the Ni content in till and the reduction in the anomaly/background contrast.

Kuorevaara area

The Kuorevaara target area is situated south of the village of Polvijärvi in the contact area of Karelidic schists and the Archean gneiss dome of Sotkuma (map sheet 4224 05). Eighteen pits were dug by a tractor excavator along a 4.5 km long study line. According to observations in the pits there is only one homogeneous till bed deposited by an ice lobe coming from 340°.

The Sotkuma gneiss dome is a gently sloping hill about 60 metres higher than the environment (Fig. 10). The overburden is more than 4 metres thick; only in one pit was the surface of bedrock found. Stone counts (0.8—6 cm fraction) were conducted at three different levels in every pit. One stone count (6-60 cm fraction) representing the whole pit was also done.

The percentage of mica schist does not change markedly when passing down-glacier from the contact (Figs. 11 and 12). The amount of mica schist pebbles in till on the top of the hill decreases a little but on the distal side of the top it again increases to the same level as on the proximal side. The new increase in mica schist material on the lee side of the hill top is due to the material transported a long distance within the continental ice and deposited under reduced pressure conditions. In the vicinity of the contact the percentage of mica schist is higher among the bigger stones (6—60 cm) than among the smaller ones (0.8—6.0 cm), but farther away from the contact in a distal direction this difference diminishes (Fig. 11). It was not possible to determine the half-distance value in the present study, but it is, in any case, more than 3 km. The exceptionally long transport distance is due to the location of the Kuorevaara study area in the middle of the most active western part of the North Karelian ice lobe. The distance to the big marginal Jaamankangas formation is about 15 km.

The Zn and Cu concentrations of mica schist are three times higher than those of granite gneiss, whereas the Co and Mn concentrations are only slightly higher in mica schist. The intense glacial erosion and transportation have, however, mixed and diluted the till material so much that the contact of the two different bedrock types cannot be determined from the metal contents in the finest till fraction (Fig. 13). The concentrations of Zn, Cu, Co and Mn in the < 0.06 mm till fraction increase on the distal side of the contact even though they ought to decrease according to the concentrations of bedrock. There are two possible explanations for this: 1) as mentioned before, the < 0.06 mm fraction includes long-transported material on the lee side of the hill top, 2) the overburden on the hill is thinner than in the valley and so the samples have been taken from closer to the bedrock — in many cases the metal contents of the till have been found to increase towards the bottom of the till bed (Lehmuspelto 1978, L-M Kauranne 1980, Hartikainen 1980, Hartikainen & Salminen 1982).

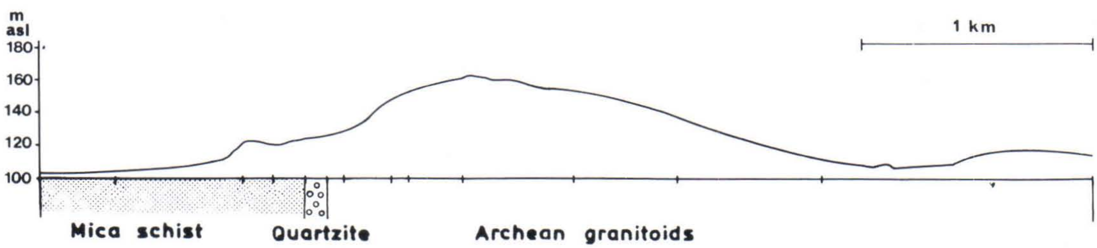


Fig. 10. The topography, bedrock and sites of the pits along the study line in Kuorevaara, Polvijärvi. Bedrock after Huhma (1971b).

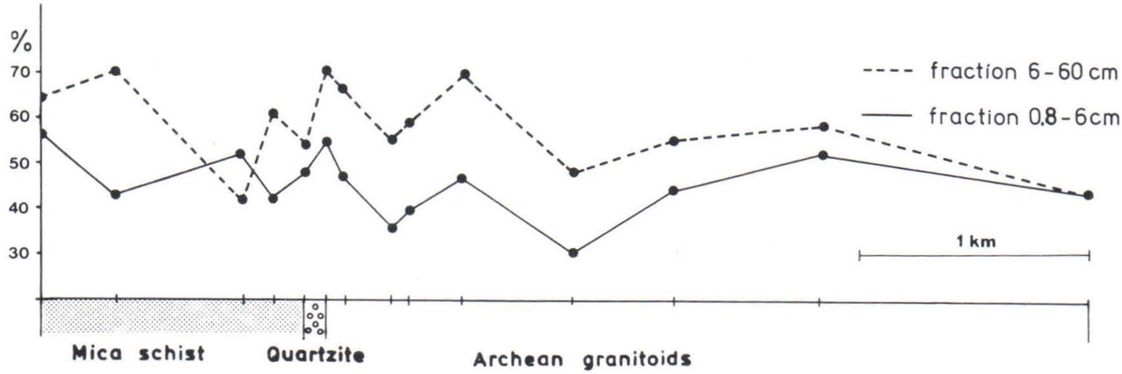


Fig. 11. The percentage of mica schist in till in Kuorevaara, Polvijärvi. The direction of ice movement is from left to right (340°).

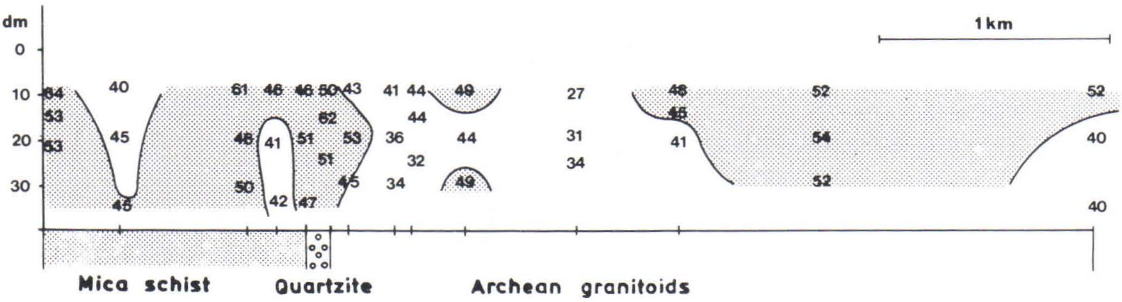


Fig. 12. The percentage of mica schist at different depths in till along the study line in Kuorevaara, Polvijärvi. The direction of ice movement is from left to right (340°).

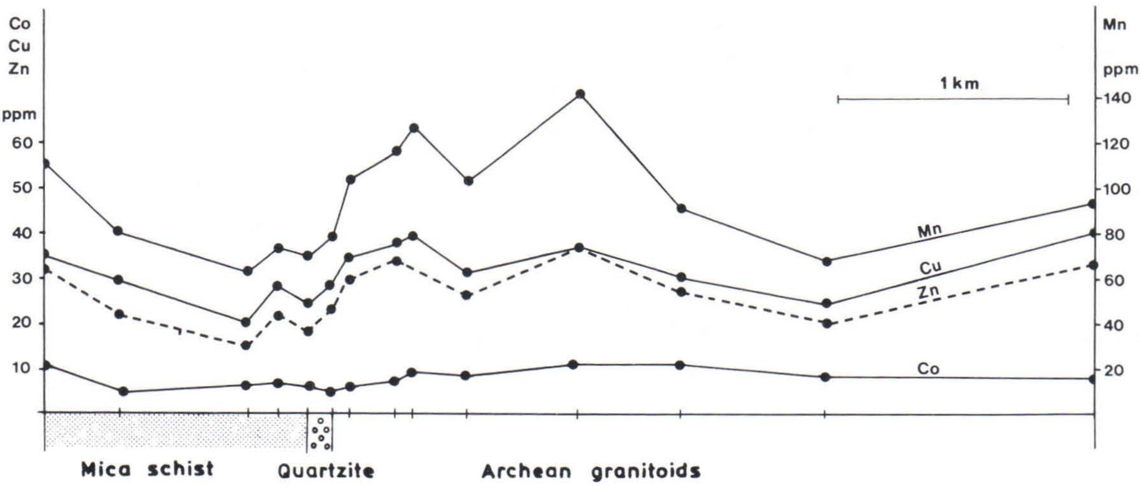


Fig. 13. The average contents of cobalt, copper, zinc and manganese in the < 0.06 mm till fraction in Kuorevaara, Polvijärvi. The direction of ice movement is from left to right (340°).

Horsmanaho area

The Horsmanaho target area is located between Polvijärvi and Outokumpu (map sheet 4224 02) in the zone of Outokumpu association rocks. The zone, which is about 1000 metres wide along the study line, is bordered against the surrounding mica schists by black schist layers, which also intercalate the mica schist (Figs. 1 and 2). The thickness of the overburden on the rocks of the Outokumpu association is less than 5 metres and in the mica schist area more than 5 metres. In some of the sampling sites a one-metre thick sand layer divides the till blanket into two layers differing in age (Fig. 14).

The Horsmanaho area is situated within the area of the most active western part of the North Karelian ice lobe, and the uppermost till layer was created by that lobe as it arrived from 330°. Because the area is close to the border zone of the lobe, glacial erosion was so slight that in places the older till deposited by the Lake Finland ice lobe has been preserved in situ in sheltered depressions of the bedrock. The target areas of Miihkali and Kuorevaara are both located in the area of the same ice lobe, but in the middle of the most active part of it where the more intense glacial erosion has destroyed the older till.

The till samples were collected by percussion drill from 116 sites along a 3.7-km-long line. The samples were taken from both the upper (1.0—1.5 m depth) and lower part of the overburden. The traverse is parallel to the direction of the latest ice movement and perpendicular to the zone of Outokumpu association rocks.

In this target area, serpentinite and quartz rock of the Outokumpu association contain 1000—2000 ppm Ni, the surrounding mica gneiss an average of 60 ppm Ni and the black schist interlayers an average of 300 ppm Ni. In spite of the strong contrast in the bedrock, the nickel content of the till samples collected from the upper part of the till bed shows poorly the nickel-bearing rocks on the proximal side (Fig. 15); only in two sampling sites have Ni-values notably more anomalous than those in the environment been recognized. These anomalous samples are at least 700 m, probably even farther, from to the source area. But in the bottom part of the overburden the Ni content is highly anomalous 100—300 m from the source area (Fig. 16). The till here has been so poorly mixed and transported such a short distance that Ni anomalies caused by black schist can be distinquished from the anomalies caused by serpentinites and quartz rocks on the basis of the metal content ratios in the samples, the Cu and Zn content of black schist being more than ten times higher than that in other rocks in the target area.

In Horsmanaho the upper part of the overburden represents till transported a long distance. Because the area is close to the border zone of the North Karelian ice lobe, the transport distance of till is not as long as in Kuorevaara (p. 16) and Miihkali (p. 13), both of which are in what was the middle part of the ice lobe. Older till either derived and deposited before the deglaciation phase of the North Karelian ice lobe or more probably deposited by the northernmost part of the Lake Finland ice lobe has been preserved in the bottom part of the overburden in Horsmanaho.

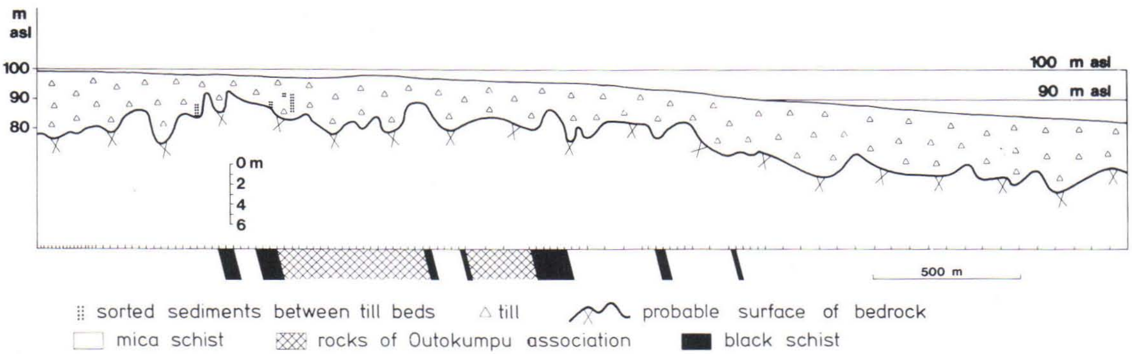


Fig. 14. The topography and bedrock along the study line in Horsmanaho, Polvijärvi.

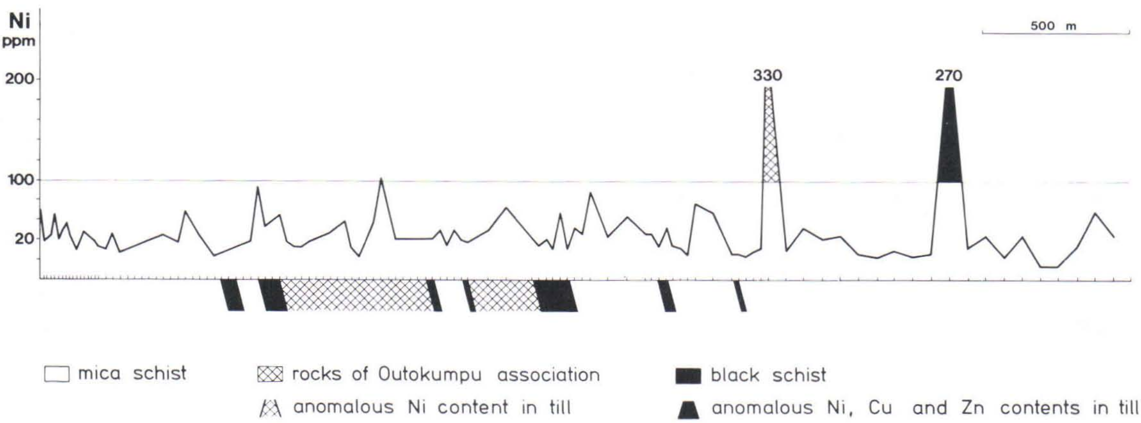


Fig. 15. The content of nickel in the < 0.06 mm till fraction on the surface of the till blanket (1.0—1.5 m) in Horsmanaho. The direction of ice movement is from left to right.

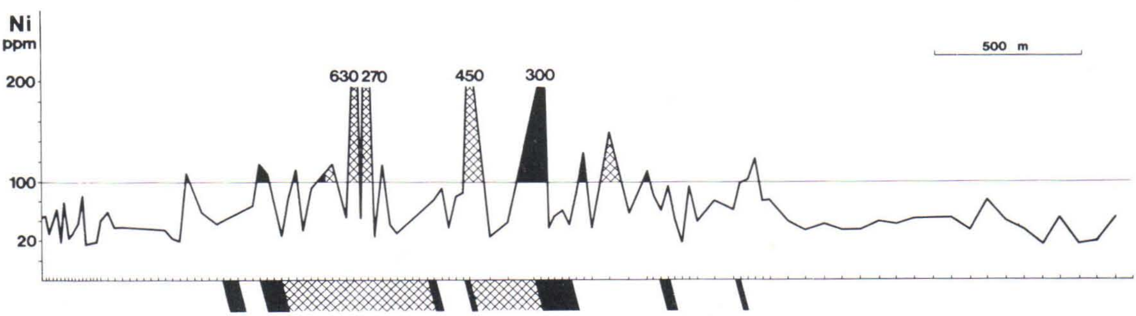


Fig. 16. The content of nickel in the < 0.06 mm till fraction at the bottom of the till blanket in Horsmanaho. The direction of ice movement is from left to right (330°).

CASE HISTORIES OF TILL TRANSPORTED A SHORT DISTANCE

Korentovaara area

The Korentovaara target area is situated in the northern part of the parish of Ilomantsi (map sheet 4244 09), where the bedrock consists of Archean granitoids and schists (Fig. 17). Only one direction of ice movement (320°) has been recognized in the area. The average thickness of the overburden is 3—5 m, but in many places thickness of even more than 10 m have been recognized. There are numerous peat bogs, and thus peat accounts for a considerable proportion of the overburden. The overburden is at its thinnest over the schist belt and there are also a row of hills and some outcrops.

The percentage of the rocks of the schist belt in the gravel fraction (2—20 mm) of till samples taken during regional mapping was counted from the bottom sample of each sampling site. The results of the stone counts are presented as

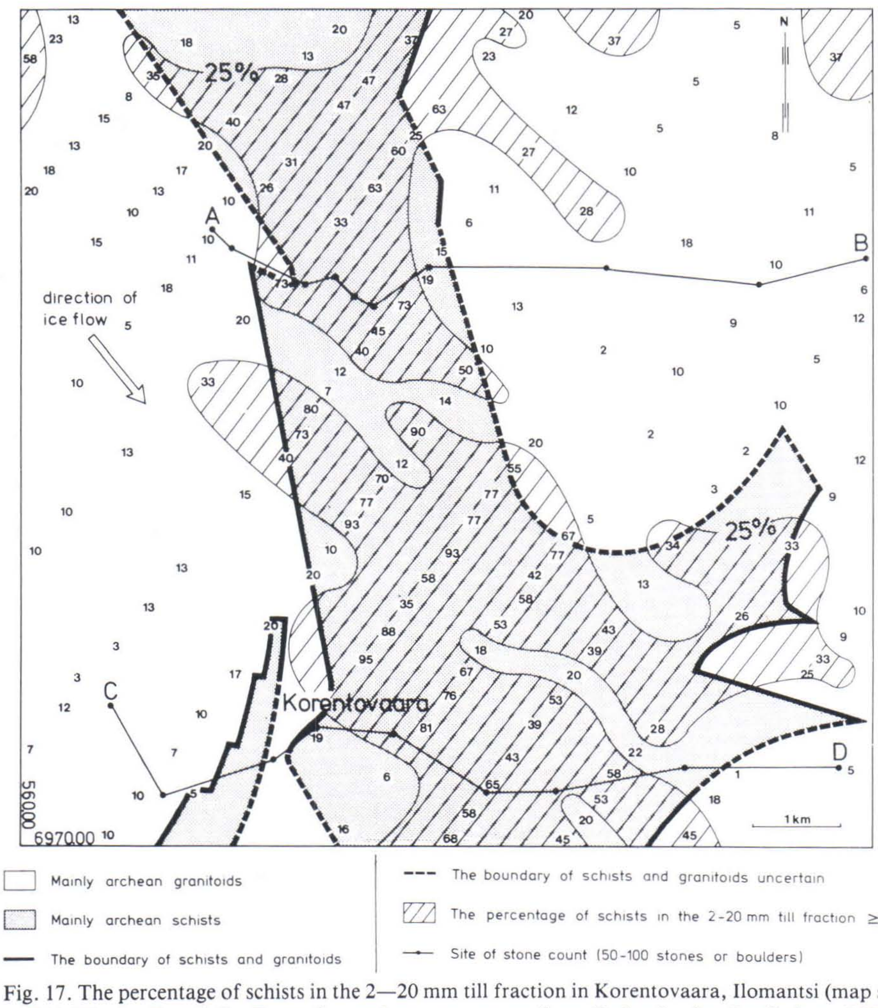


Fig. 17. The percentage of schists in the 2—20 mm till fraction in Korentovaara, Ilomantsi (map sheet 4244 09). A—B and C—D are the surface stone count lines. Bedrock after Lavikainen (1973).

averages of four adjoining samples on a traverse (Fig. 17). The percentages of schists in till demonstrate that the schist belt is not uniform but has extensive granitoid areas within it. The highest percentages of schists are right over the schist belt, so the transport distance of till was very short. Although the anomaly/background contrast is strong and the till therefore reflects the bedrock very locally, the till does, however, contain abundant granitoid stones in the schist area. These originate either from the granitoids within the schist belt or from older tills deposited before the last glaciation (complex transport).

The transportation of boulders lying on the surface of the till bed is considered later in the chapter "Case histories of transportation of surface boulders".

Parissavaara area

The target area of Parissavaara is located in the northern part of the parish of Ilomantsi, about 10 km southwest of the Korentovaara target area (map sheet 4244 05). The bedrock in Parissavaara is much like that of Korentovaara: a schist belt surrounded by granitoids and both belonging to an Archean gneiss complex. A study traverse of six pits was made across the schist belt in the direction of the latest ice movement (320°). The thickness of the overburden is more than 5 m; no suboutcrop was found in the pits. However, there is an outcrop of schists on the slope of a near-by hill. The study pits are located immediately south of the hill slope, but near the pits the surface of the overburden is flat, sloping only slightly in the direction of ice flow.

The percentage of schist stones in the 0.8—6.0 cm fraction of till is higher directly over the schist belt, but the highest values are not reached until 1.5 km from the distal contact of the schist belt (Fig. 18). The half-distance value cannot be determined from these results, but we can say that it is several kilometres. The half-distance value of the finest fraction (< 0.06 mm) estimated from the decrease in Zn content is, however, 600 m. The Zn contents of different types of bedrock are (anal. by optical emission spectrometry): mica schist 112 ppm, granitoid (granitic) 30 ppm and granitoid (granodioritic) 67 ppm. The Zn values are highest (51—97 ppm) right over the schist belt (Fig. 19) but decline rapidly in the direction of the ice flow.

Viesimo area

The Viesimo target area is situated in the parish of Kiihtelysvaara (map sheet 4241 04). The bedrock in the eastern part of the area consists of granitoids of the Archean gneiss complex and in the western part of proterozoic schists (mainly Karelian mica schists). The Karelian schists at Viesimo are almost ubiquitously covered by the marginal formation of Salpausselkä II. The overburden, which is 30 m thick or even more, consists mainly of glaciofluvial sand and gravel. In the eastern part of the target area (gneiss complex) the overburden is usually less than 3 m thick and consists of one homogeneous till bed. The direction of ice flow in this area is approximately 300°, but flow directions of 290°—330° caused by rearrangements in the ice lobe during the deglaciation phase have been recognized.

The percentages of different rocks in the 2—20 mm fraction of till samples collected dur-

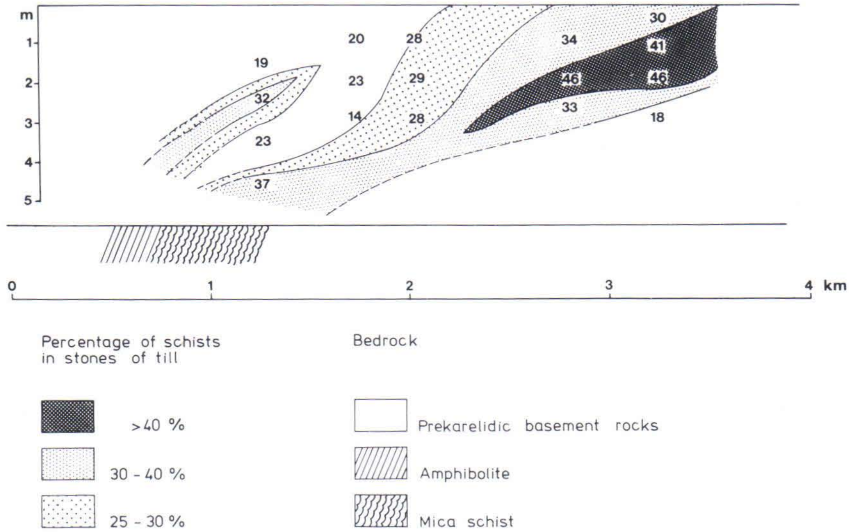


Fig. 18. The percentage of schists in the 0.8—2.0 cm till fraction in Parissavaara, Ilomantsi. The direction of ice movement is from left to right (320°). Bedrock after Lavikainen (1973).

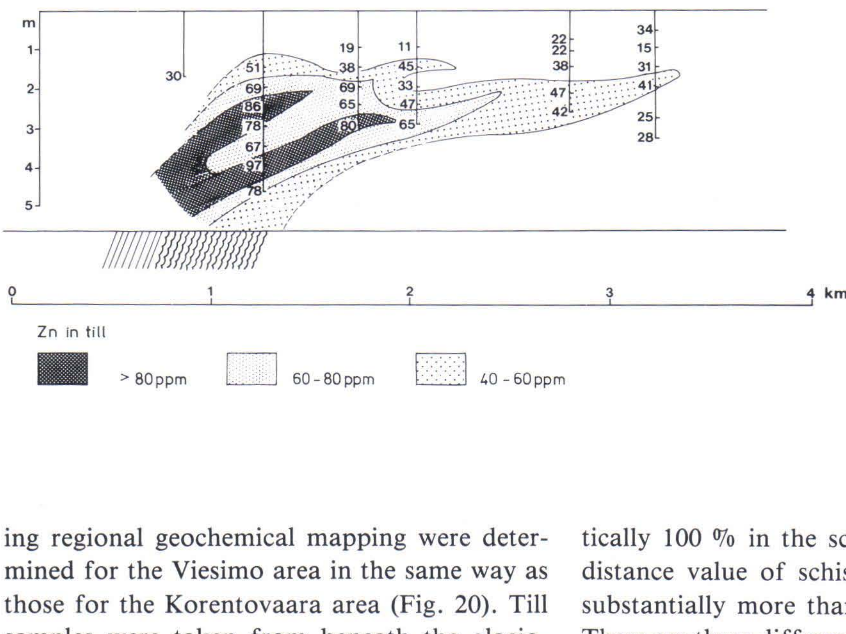


Fig. 19. The zinc content in the < 0.06 mm till fraction in Parissavaara, Ilomantsi. The direction of ice movement is from left to right (320°).

ing regional geochemical mapping were determined for the Viesimo area in the same way as those for the Korentovaara area (Fig. 20). Till samples were taken from beneath the glaciofluvial sediments of the marginal formation by an Auger drill. Elsewhere the till samples were taken by light-weight percussion drills with a miniature piston bit as sampler. This type of piston bit does not penetrate till as well as the through-flow bit used in Korentovaara.

The percentage of schist stones in till is practically 100 % in the schist belt area. The half distance value of schist transport, 2.1 km, is substantially more than that at Korentovaara. There are three different reasons for this: 1) The source area of schists in Viesimo is much larger than that in Korentovaara, 2) Viesimo is situated in the marginal area of an active ice lobe (the Lake Finland ice lobe) where there is a considerable proportion of material transported a long distance (Repo 1967), 3) different sampling techniques were used in these areas.

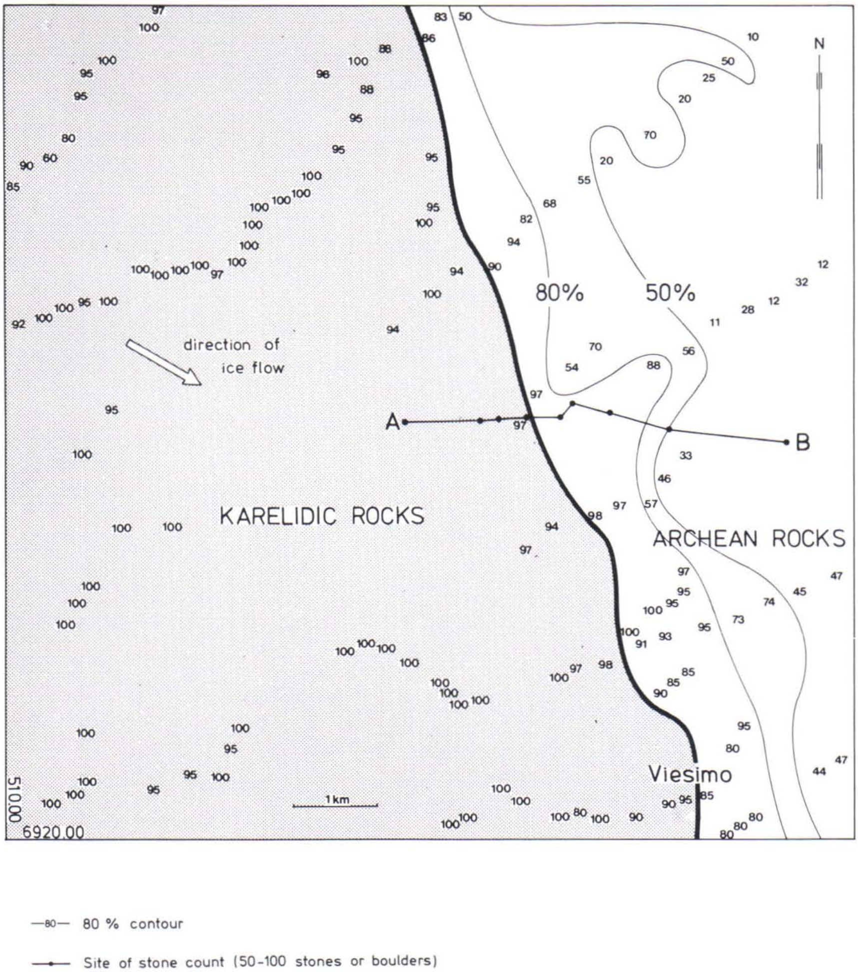


Fig. 20. The percentage of schists in the 2—20 mm till fraction in Viesimo, Kiihtelysvaara (map sheet 4241 04). A—B is the surface stone count line.

Palojärvi area

The target area of Palojärvi is in the parish of Kiihtelysvaara, immediately northeast of Viesimo (map sheet 4241 05), in an area exhibiting two narrow zones of amphibolitic rocks surrounded by granitoids. Both types of rock belong to the Archean basement gneiss complex. One till bed deposited by ice flowing from 300° has been recognized. The thickness of the overburden is usually 2—3 m, but in some places it is much greater because of the varying topography of the surface of the bedrock.

Eleven study pits were excavated along the direction of ice flow. Several stone counts (0.8—6 cm fraction) were conducted at different depths in every pit. The percentage of amphibolitic stones in till according to the averages counted by pit depends on the extent of the source area (Fig. 21). The percentages are at their highest about one kilometre from the proximal contacts of the amphibolites. The half-distance value is 1.3 km.

The average Cu concentrations of amphibo-

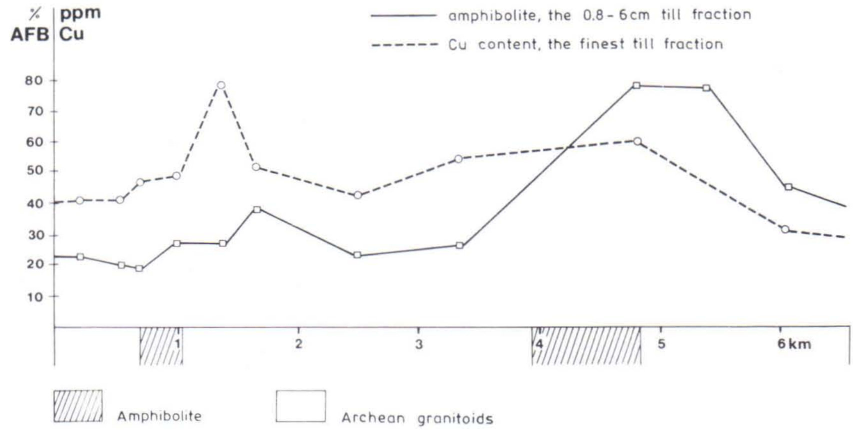


Fig. 21. The percentage of amphibolite (AFB) in the 0.8—6.0 cm till fraction and the copper content in the < 0.06 mm till fraction in Palojärvi, Kiihtelysvaara. The direction of ice movement is from left to right (300°). Bedrock after Nykänen (1971a).

lite is 75 ppm and that of granitoids (granite gneiss and granite) 9 ppm in the Kiihtelysvaara area (Salminen 1980). The average Cu concentration of the < 0.06 mm till fraction in the Palojärvi area is about 50 ppm, and the maximum concentrations (78 ppm) are reached much closer to the source area than the maximum frequency of amphibolitic rocks in the 0.8—6 cm fraction (Fig. 21). The half distance value of the transport of amphibolitic material is 400 m from the narrower zone and 1300 m from the broader zone of amphibolite. The difference between these two half-distance values in the same small target area is due to the fact that the amount of material transported by the glacier from the narrower zone is much smaller than that from the broader zone, and that the smaller amount is diluted to the background value sooner than the greater amount from the broader source area.

The transport distance of till in Palojärvi is notably shorter than in Viesimo (see page 21). This is due partly to the smaller size of the source area and partly to the fact that Viesimo is situated in the marginal zone of an active ice lobe and Palojärvi lies a few kilometres outside it.

Petäinen area

The target area of Petäinen is located near the border of the parishes of Savonranta and Heinävesi (map sheet 4221 10). The bedrock in this area consists of a typical zone of Outokumpu association rocks (serpentinite, skarn and quartz rocks) with black schists bordering the zone against the surrounding mica gneiss. The width of this zone in the direction of the ice movement is about 500 m. The thickness of the overburden (almost totally till) varies, being more than 10 m around Lake Petäinen but usually only 2—5 m. Two different directions of ice movement have been recognized: a younger one (270°—280°), which is the direction of the Lake Finland ice lobe, and an older one at about 330° (Nikkarinen & Salminen 1982).

Regional geochemical mapping of overburden has been carried out in this area, and more detailed studies have been conducted along a line crossing the Outokumpu association at 300° (Fig. 22 and 23). During these studies samples were collected throughout the whole till layer using tractor excavator and percussion drills.

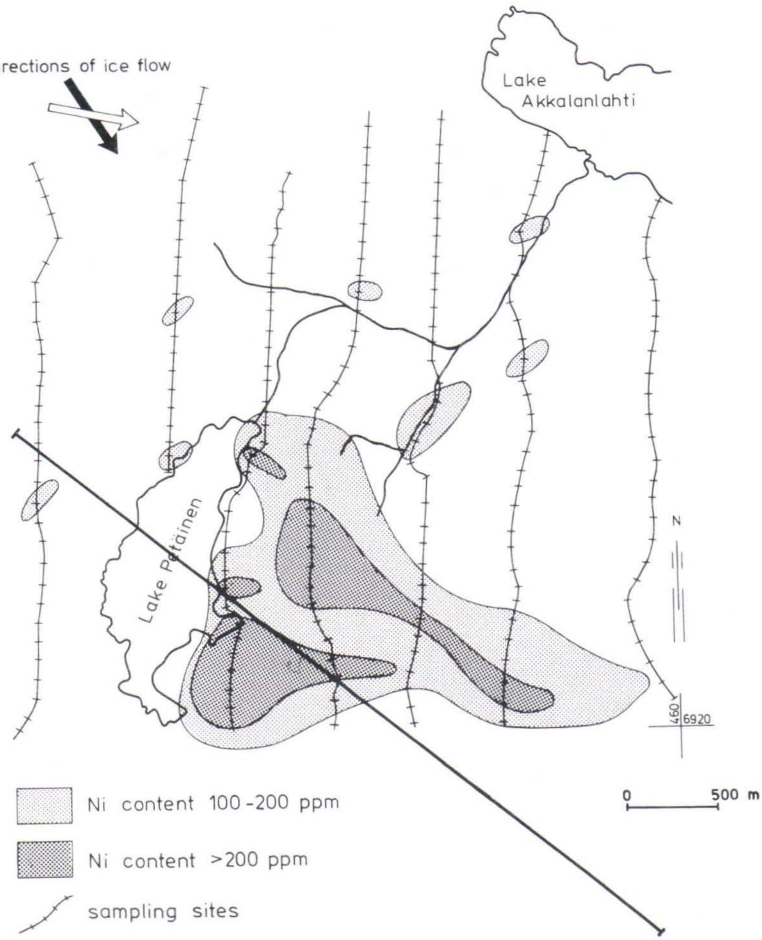


Fig. 22. The nickel content in the < 0.06 mm till fraction according to regional geochemical mapping in the area of Petäinen, Heinävesi.

The Ni content of the rocks in the Outokumpu association and also of the black schists is higher than that of the surrounding mica gneiss (see p. 18). The results of the regional geochemical mapping (Fig. 22) show that appreciable Ni has derived from the Ni-bearing rocks and spread out far and wide in the till. This is just what one would expect because of the extensive source area and easily eroding rock types. The anomalous Ni concentrations of till occur 200—2000 m from the zone of the Outokumpu association (Fig. 22). Along the line studied in greater detail the highest Ni concentrations are 200 m from the source (Fig. 23).

Both the results of regional geochemical mapping and the results of the detailed studies (including the distribution of uvarovite grains in till, Nikkarinen & Salminen 1982) indicate that the bulk of the material derived from the zone of the Outokumpu association was transported less than 500 m. The highest Ni anomaly occurs on the proximal slope of the hill (Fig. 23). No anomalous Ni contents were detected on the top of the hill, but low anomalous contents are again seen on the lee side. Because of the large area covered by the Ni-bearing suboutcrop, anomalous concentrations can also be detected farther away from the suboutcrop even though

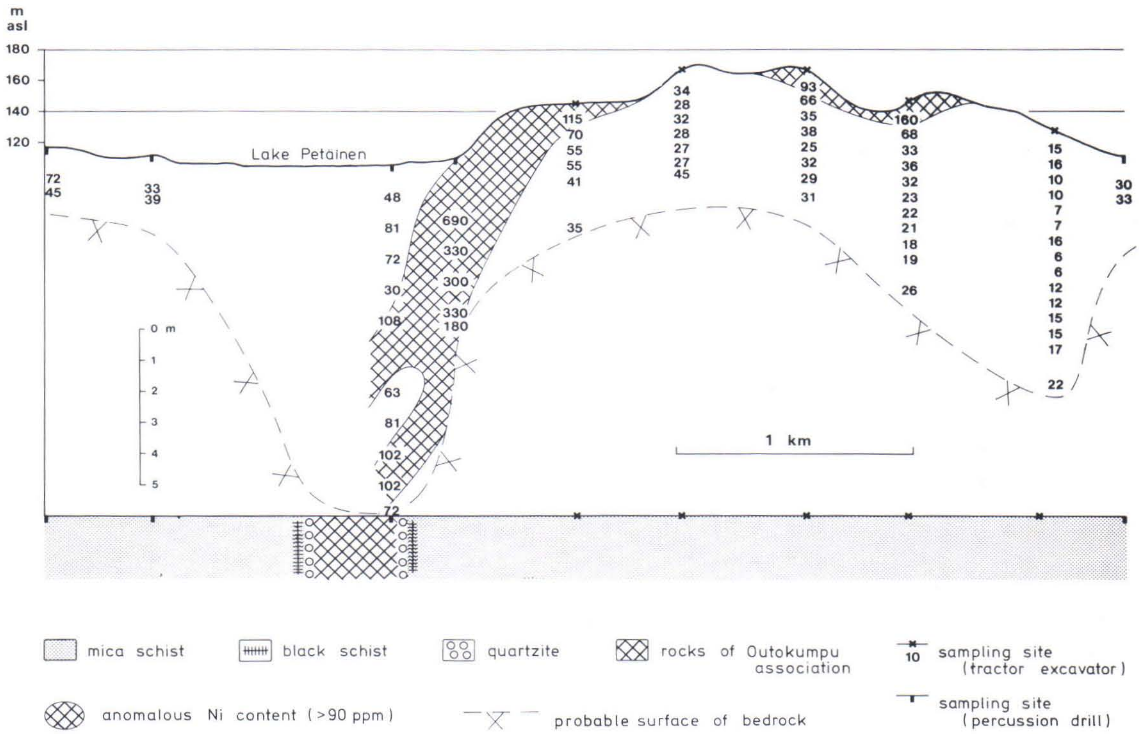


Fig. 23. The nickel content in the < 0.06 mm till fraction in Petäinen, Heinävesi.

dilution is rapid. In the stone counts (0.8—6 cm fraction) of till only a few per cent of rocks of the Outokumpu association could be detected because they erode so easily into finer grain size fractions.

Kaasila area

A detailed geochemical till study has been carried out in the environment of the Kaasila outcrop of the Outokumpu Cu-, Co-, Zn-ore (Salminen 1981). The width of the zone of Outokumpu association rocks is about 1.5 km here, and the Kaasila ore outcrop covers 30×150 m (Fig. 24).

The overburden is 3—10 m thick. Till beds deposited during at least two separate stages of glaciation have been found in the Outokumpu area. The flow direction of the youngest one, approximately from the north (350°—10°), is due to one of the western sublobes of the North Karelian ice lobe. The older flow direction, from the west (280°), is due to the northernmost part of the Lake Finland ice lobe. The oldest reported flow direction in the Kaasila area is 330°—340° (Hirvas & Nenonen 1979); no larger till beds deposited by this ice flow have been found. A thin layer of in situ weathered bedrock has been found at many sampling sites and the till contained abundant material from weathered

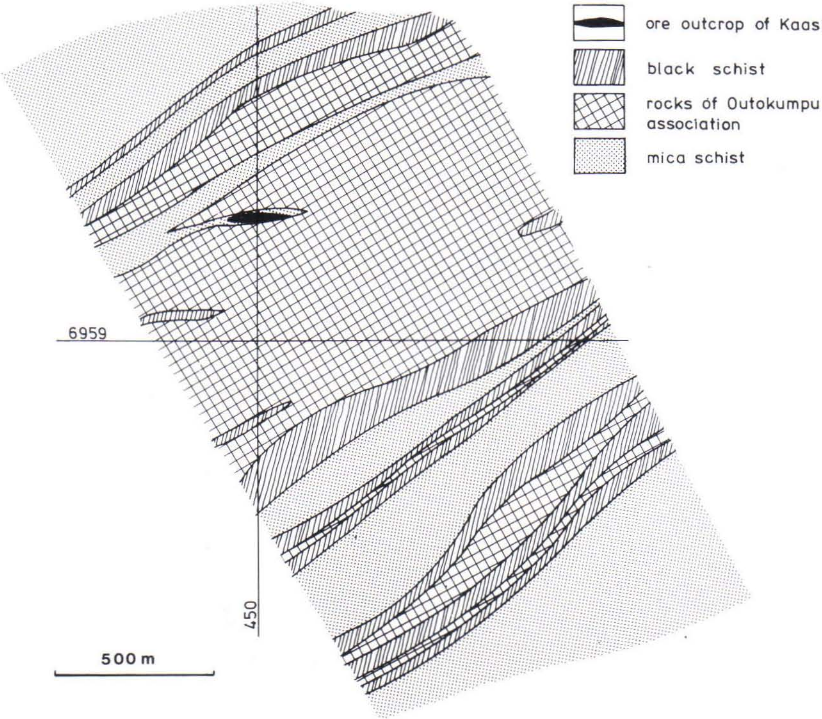


Fig. 24. The bedrock in the environment of the Kaasila outcrop, Outokumpu (after Koistinen 1981).

bedrock. Much of this has been interpreted as boulders weathered within the till after it had deposited.

Till samples were taken at 169 sampling sites in the surroundings of Kaasila ore outcrop both from the upper part of the till (1—1.5 m) and from the base of the till, close to the surface of the bedrock. Some study pits were excavated in the area to study the stratigraphy and lithology of the till.

Although the Cu content of the Kaasila ore outcrop is very high (3.8 %), and substantially higher than in the surrounding rock types, the distance the till was transported can still not be solved by studying the reduction in the Cu content in till alone. The background concentration of Cu (60 ppm in mica gneiss) is also exceeded clearly by black schist (300 ppm on average). The area of black schists is much greater than that of the ore outcrop and it was also eroded much more easily than the ore outcrop. In fact more Cu could have entered the till from black schists than from the ore outcrop. Thus the Cu concentration in the immediate vicinity of the black schists is as high as in the vicinity of ore — excluding some exceptionally high concentrations. Anomalies caused by the ore or by the black schists can be distinguished using a simple Cu/Zn ratio (Salminen 1981). The value of this ratio in the host rocks of the ore (skarn and quartz rock) is more than 1.0 (3.8 in the ore) and in the black schists less than 0.25 (Figs. 25 and 26).

In the bottom layer of the till (Fig. 25), the samples which, on the basis of the above Cu/Zn ratio, were ascribed to the ore or skarn and quartz rocks are situated south and southeast of the Kaasila ore outcrop and over the parallel quartz rock horizons. Likewise, anomalous Cu concentrations due to black schists are situated over the black schist horizons. This indicates that the transport distance of the bottom layers

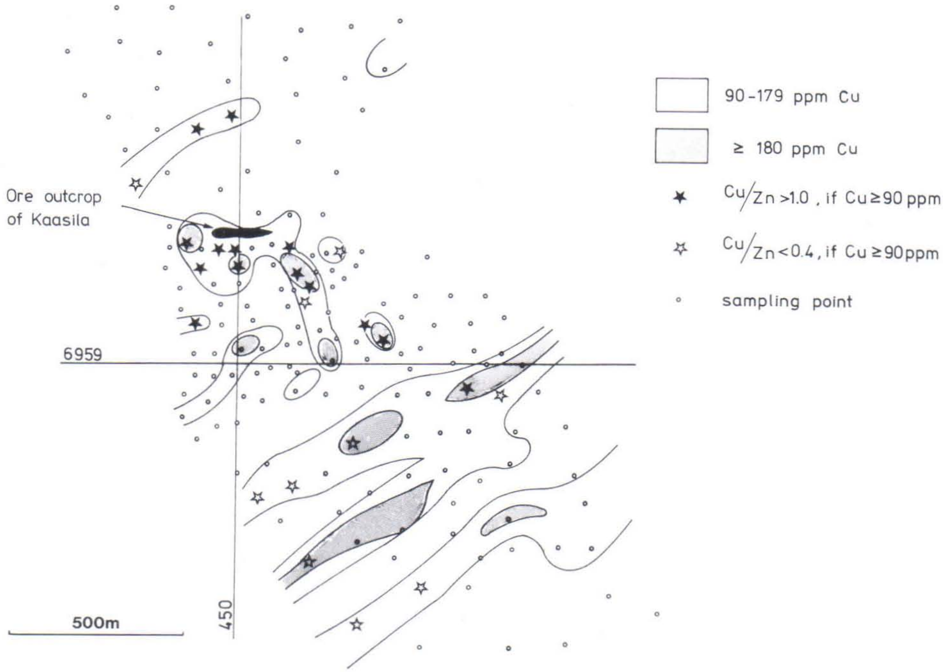


Fig. 25. The copper content and the copper/zinc ratio in the < 0.06 mm till fraction in samples taken from the bottom of the till blanket at Kaasila, Outokumpu.

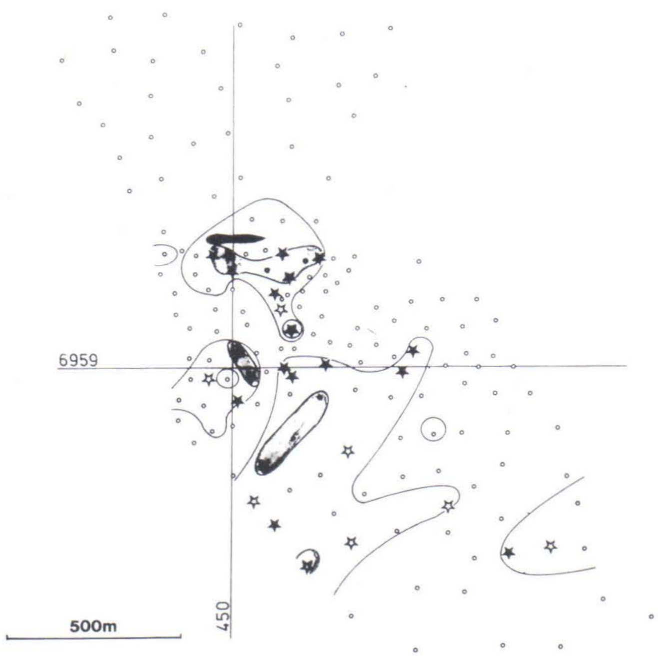


Fig. 26. The copper content and the copper/zinc ratio in the < 0.06 mm till fraction in samples taken from the surface of the till blanket (1.0—1.5 m) at Kaasila, Outokumpu. For expl., see Fig. 25.

of till in the Kaasila area is only some tens of metres, certainly not more than a few hundreds of metres.

In the upper parts of till (Fig. 26) the Cu anomalies are still quite close to their source areas, but the shapes are not as similar to those in the source areas as they are in the bottom layers of till. Further, anomalies derived both from the ore and from the black schists have spread over wider areas. The upper layers of till are the result of complex transportation and hence the transport distance and direction are not as precise as for the bottom layer. With some exceptions, the transport distance of the upper horizons of till is no more than 600 m.

Röksä area

The Röksä target area is situated east of Lake Ylinen in the border zone of the parishes of Kiihtelysvaara and Eno (Fig. 27, map sheet 4241 06). The bedrock in Röksä is mainly Archean granitic gneiss with some amphibolite zones. Anomalous lead concentrations (max 1.2 %) have been recognized in this zone. The overburden (one till bed) is thin (0.5—3.0 m) and was deposited by ice flowing from 315°.

Till samples were collected at 19 sampling sites as part of a follow-up study of a Pb-Zn anomaly after regional geochemical mapping. Samples of bedrock (71 altogether) were collected at the same time on a 5×10 m sampling grid.

The bedrock samples indicate that a zone with an anomalous Pb concentration exists in the bedrock (Fig. 28). The Pb anomaly in till is very local, having been shifted only a few tens of metres; geochemical anomalies in till are thus very local. Some relatively high hills occurring in the proximal direction (Fig. 27), have protected the study area from intense glacial erosion. On the other hand the part of the North

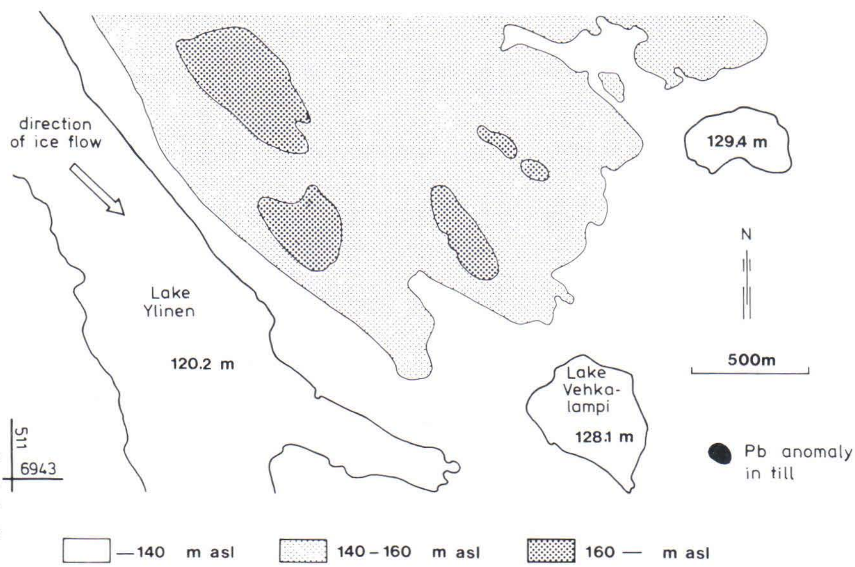


Fig. 27. The location of the lead anomaly in Röksä, Kiihtelysvaara and the topography on the proximal side of the anomaly.

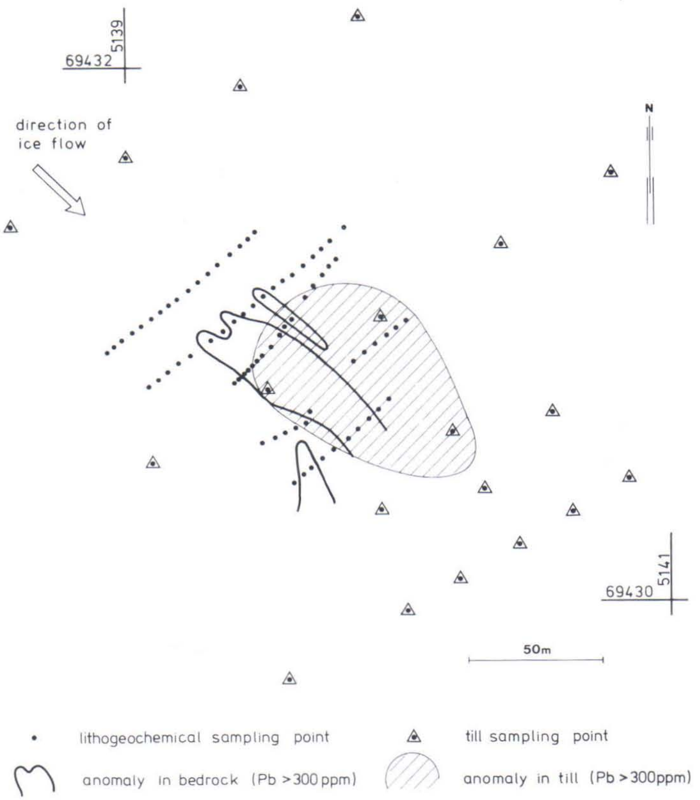


Fig. 28. The lead anomalies in the < 0.06 mm till fraction and in the bedrock in Röksä, Kiihtelysvaara.

Karelian ice lobe, that covered this area was not as active as the western and eastern flanks of the lobe, and in the Röksä area there are no marginal formations as huge as Jaamankangas in the west and Selkäkangas in the east (see Fig. 5).

AREAL GEOCHEMICAL TILL STUDY IN OUTOKUMPU AND POLVIJÄRVI

The effect of different transport distances of till on the interpretation of geochemical results was studied in the Outokumpu-Polvijärvi area (Fig. 1). The westernmost part of the North Karelian ice lobe was active for a long time (the Jaamankangas stage) in the eastern part of this study area (Polvijärvi area) and a long transport distance of till (> 3 km, see pp 13, 16) has been recognized both here and in the immediate vicinity. In the western part of this study area (Outokumpu area) the transport distance of till was notably shorter (some hundreds of metres) even though the Lake Finland ice lobe was active for a time in the southern part of the study area. The boundary between these two parts of the study area is of course not a straight line as indicated in Figures 30—33 but a wider zone.

In the bedrock of the Outokumpu-Polvijärvi area the zone of Outokumpu association rocks differs sharply from the environment in geochemistry (Fig. 29). The average Ni concentra-

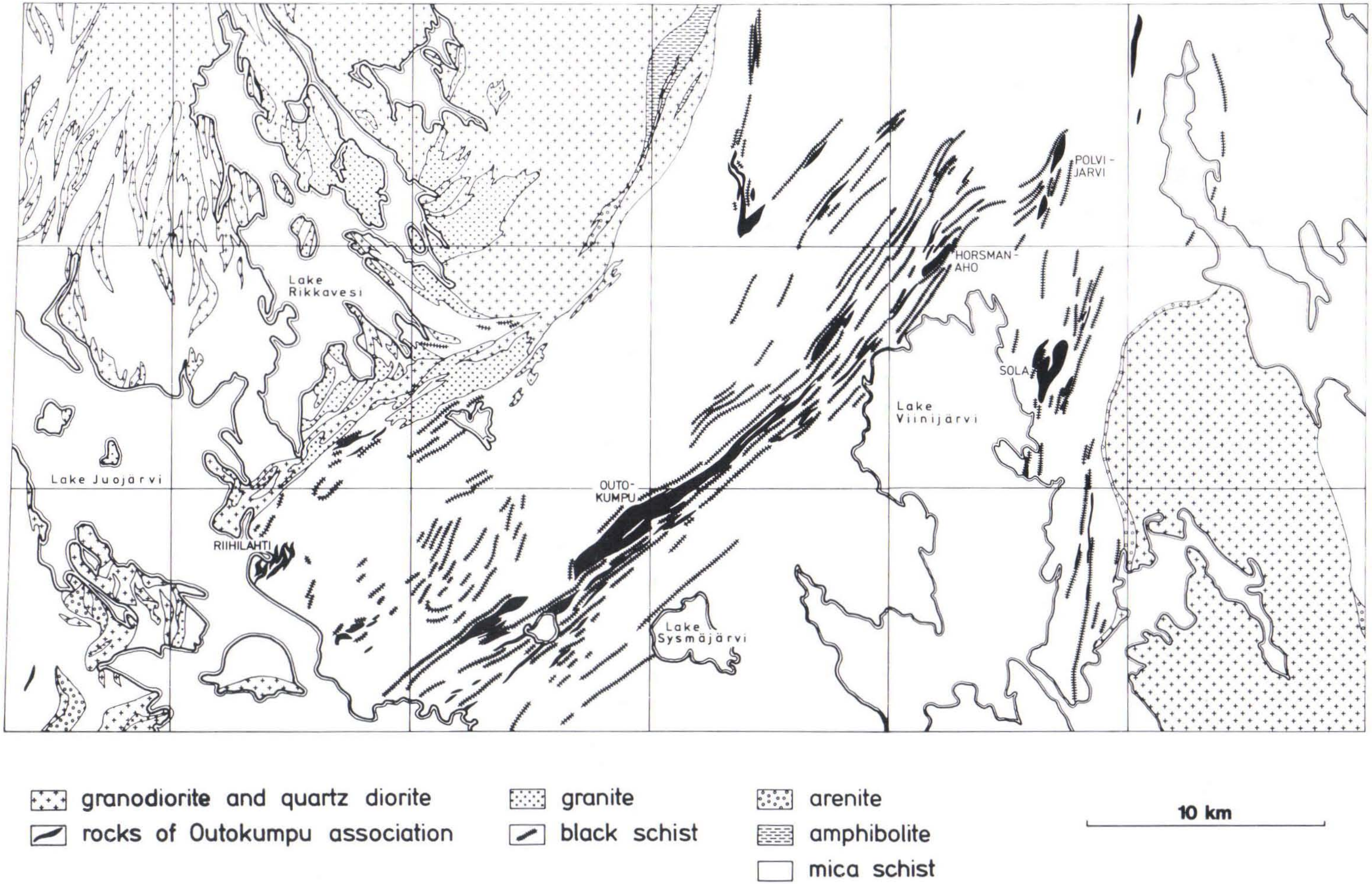
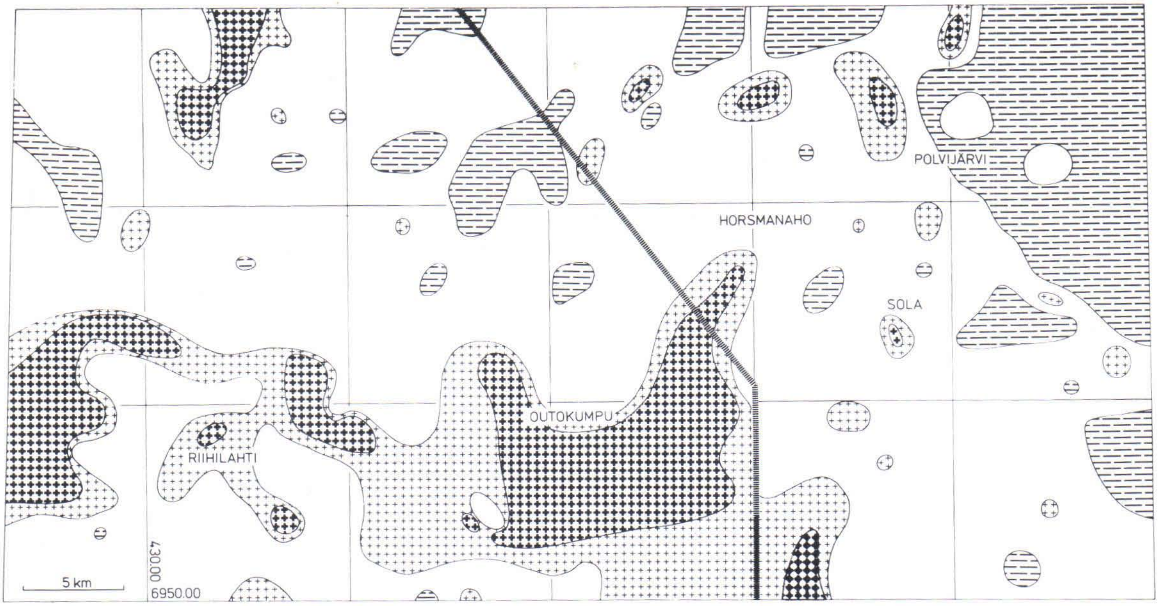


Fig. 29. The bedrock of the Outokumpu—Polvijärvi area (after Huhma 1971a, 1971b).



high positive anomaly   low positive anomaly   negative anomaly   approximated boundary of the two areas

Fig. 30. The nickel content of the < 0.06 mm till fraction on the surface (1.0—1.5 m) of the till blanket in the Outokumpu—Polvijärvi area. The anomaly thresholds are the same in the whole area. See also Tables 1 and 2.

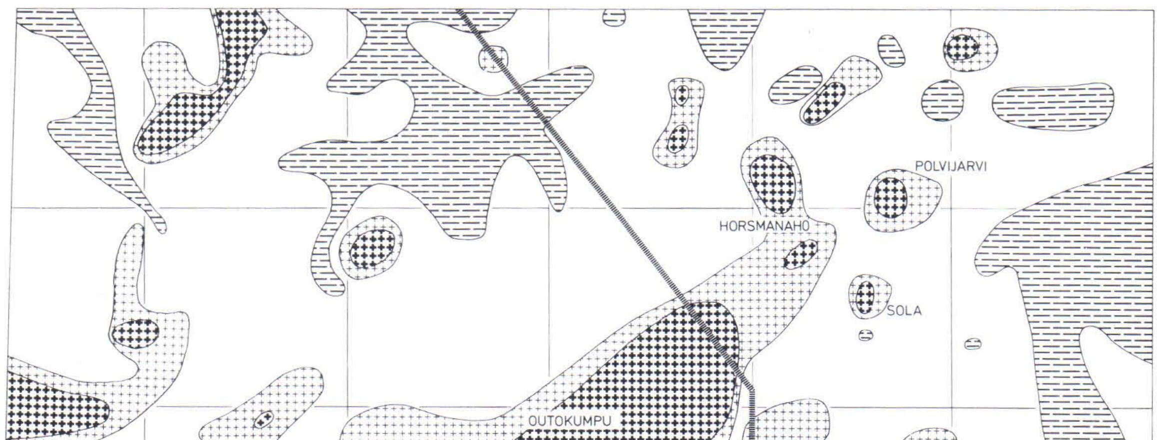


Fig. 31. The nickel content of the < 0.06 mm till fraction at the bottom of the till blanket in the Outokumpu—Polvijärvi area. The anomaly thresholds are the same in the whole area. See also Tables 1 and 2.

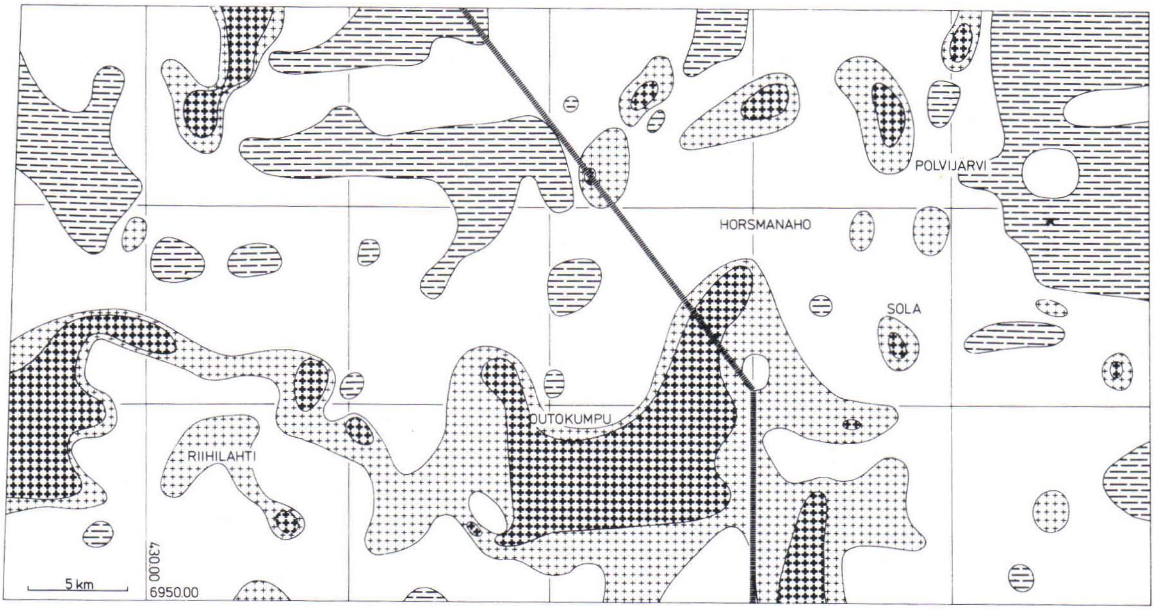


Fig. 32. The nickel content of the < 0.06 mm till fraction on the surface (1.0—1.5 m) of the till blanket in the Outokumpu—Polvijärvi area. Both subareas (Outokumpu, Polvijärvi) have their own anomaly thresholds. See also Tables 1 and 2.

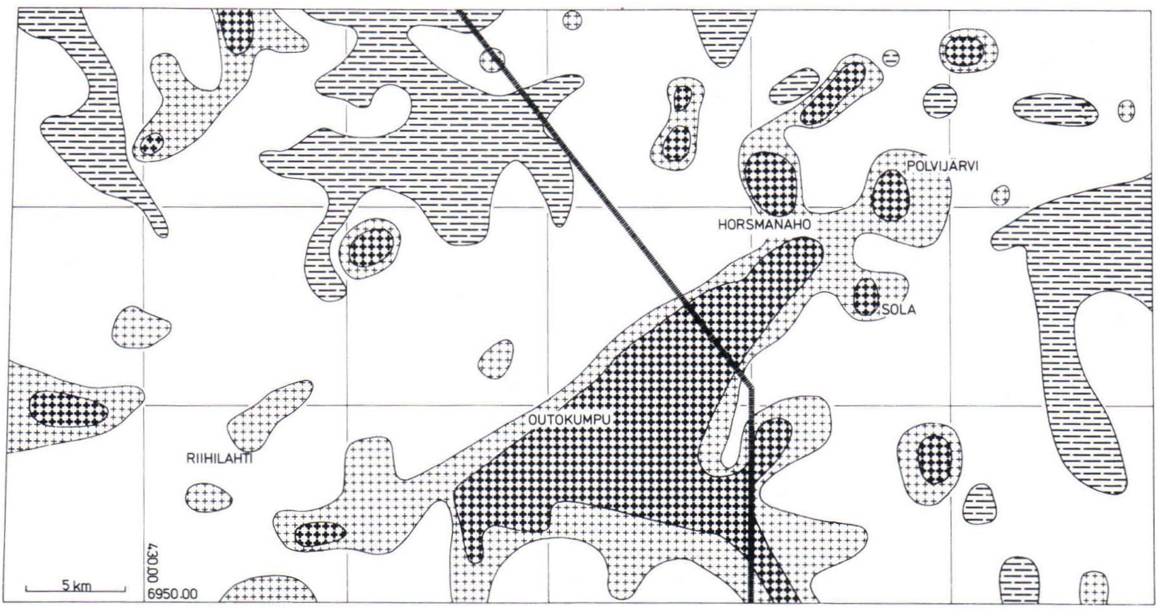


Fig. 33. The nickel content of the < 0.06 mm till fraction on the bottom of the till blanket in the Outokumpu—Polvijärvi area. Both subareas have their own anomaly thresholds. See also Tables 1 and 2.

tion of these rocks (serpentinite, skarn and quartz) is 1500—2000 ppm, whereas the Ni concentration of the surrounding mica gneiss and granitoids is 10—60 ppm (Huhma, M. & Huhma, A. 1970). The area covered by the rocks with a high Ni concentration is practically the same in both parts of the study area, and so any differences in the Ni-concentrations of till are the result of the difference in the intensity of glacial erosion in the two areas.

Till samples were collected at 347 sampling sites, from the upper part of the till bed (depth 1.0—1.5 m) and from the bottom part of the till bed as each site. The difference in Ni concentrations between the samples taken from the upper and the lower part of the till bed is clear, showing that the Ni concentration increases towards the bottom of the bed regardless of the intensity of glacial erosion (Table 1). In contrast, in the area of strong glacial erosion with a long transport distance (Polvijärvi area, Table 1) the Ni concentration of till is markedly lower than in the area of slight glacial erosion with a short transport distance (Outokumpu area, Table 1). This shows that the glacier transported material poor in Ni into the Polvijärvi area from outside the area and that much of the Ni-bearing material was transported to Jaamankangas by the glacier. Another conspicuous difference between the two areas is the homogeneity of the till: the coefficient of variation of the Ni concentrations is greater in the area of slight glacial erosion than in the area of strong glacial erosion (Table 1).

Anomaly maps were compiled using values of Σ%20, Σ%80 and Σ%90 points in the frequency distribution as anomaly thresholds (Table 2, Figs. 30—33). In one case the anomaly thresholds are the same for all data (Figs. 30—31) and in another the threshold values were determined separately for the data from the area of slight glacial erosion (Outokumpu area) and for the data from the area of strong glacial erosion and long transport distance (Polvijärvi area, Figs. 32—33). The values of the anomaly thresholds in these two areas differ from each other. When the anomaly thresholds are the same throughout the study area, most of the positive anomalies are situated in the area of slight glacial erosion and short transport distance (and a higher mean of Ni concentration). The best geochemical map of till for describing the bedrock is obtained when using samples from the bottom part of the till bed taking into account the differences in the nature of the glacial erosion (Fig. 33).

An interesting point about the data on the upper part of the till bed revealed by the maps (Figs. 30 and 32) is that one sublobe of the North Karelian ice lobe has pushed and bent the Ni anomaly in Outokumpu southwards in the direction recognized to be that of the youngest ice flow in this area (see p. 11). Since an anomaly of corresponding type is not detectable in the lower part of the till (Figs. 31 and 33), the latest ice flow in this place influenced only the upper part of the till bed. This observation is consistent with the results from Kaasila (p. 26).

Table 1. The mean contents (x), standard deviations (s) and variation coefficient (v) of nickel contents in the < 0.06 mm till fraction, and the number of till samples (N) taken from the surface (1.0—1.5 m) and from the bottom of the till blanket in the Outokumpu and Polvijärvi area.

	Outokumpu area			Polvijärvi area		
	surface	bottom	all samples	surface	bottom	all samples
$\bar{x}$ ppm	34.7	42.0	38.4	24.2	29.9	27.0
s	37.1	44.6	41.3	19.0	19.0	19.2
v	106.9	106.2	107.6	78.5	63.6	71.1
N	200	200	400	147	147	294

Table 2. Anomaly thresholds (Σ%20, Σ%80 and Σ%90 in the frequency distribution) of nickel in the < 0.06 mm till fraction on the surface (1.0—1.5 m) and in the bottom of the till blanket in the Outokumpu—Polvijärvi area. The material is the same as in Table 1.

	The whole area		Outokumpu area		Polvijärvi area	
	surface	bottom	surface	bottom	surface	bottom
Σ 20%	13	16	16	17	10	14
Σ 80%	35	44	39	50	30	37
Σ 90%	50	63	55	69	44	54

TRANSPORT OF SURFACE BOULDERS

Korentovaara area

The amount and transportation of boulders on the surface of the till bed was studied in the Korentovaara target area in Ilomantsi (p. 20). The study lines (A—B and C—D in Fig. 17) crossed the schist belt. A rock type of 50—100 boulders (Ø 6—60 cm) was determined at each observation site.

The percentage of schist boulders was at its maximum 500 m from the proximal contact of the 2-km-wide schist belt, along the line A—B (Figs. 17 and 34). Over this distance the percentage of schist boulders increases from the background value of 5 % to 15 %. The percentage of schist boulders does not fluctuate appreciably over a distance of 3.5 km but thereafter it decreases rapidly to the background value. The percentage of schist boulders along the line C—D (Figs. 17 and 34) begins to increase immediately after the proximal contact, but the maximum value — 35 % — is not reached until 2 km from the proximal contact of the wider schist belt.

The percentage of schists among the boulders on the surface of till along the northernmost line A—B is so low that the contact of the schist belt cannot be localized on that basis. The percentage of schists is higher, it is true, along the southernmost line C—D but here, too, the schist belt does not manifest itself too well in spite of its width (5 km). The half distance value of glacial transport cannot be determined from these data along either of the study lines. Nevertheless, the data do show that the extent of the source area has a conspicuous effect on the percentage of schists in the boulders on the surface of the till bed. In spite of the large source areas the percentage of schists is low and thus it can be concluded that the boulders have travelled a long way and that, as a whole, they are from a really extensive source area. What is more, the contents and the transport distance of boulders on the surface of the till bed are quite different from those in the gravel fraction of basal till (see p. 20).

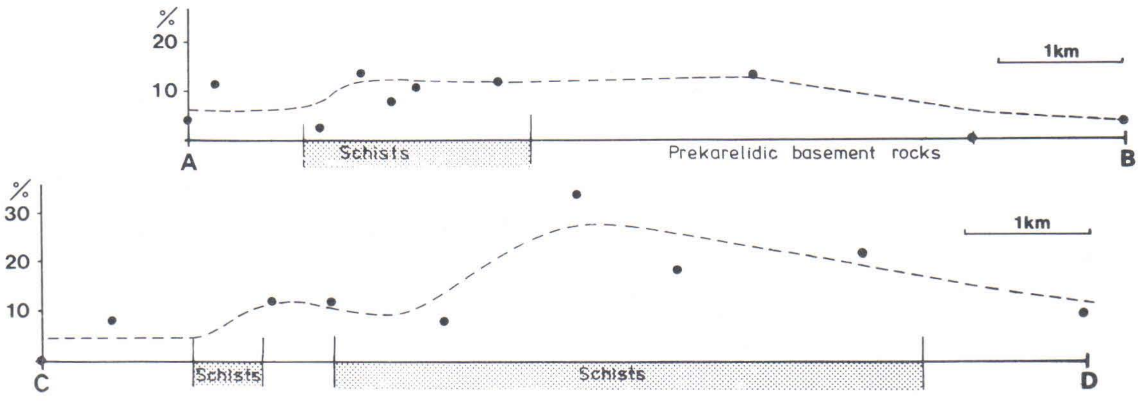


Fig. 34. The percentage of schist boulders on the surface of the till blanket along study lines A—B and C—D (see Fig. 17). The direction of ice movement is from left to right (320°). Bedrock after Lavikainen (1973).

Viesimo area

Not only the glacial transportation of the gravel fraction of till but also the transportation of boulders on the surface of the till bed was studied in the Viesimo target area. The rock types of boulders (Ø 6—60 cm) were determined at nine observation sites on the study line (A—B in Fig. 20) crossing the contact between Karelidic schists and Archean basement gneiss. Quartzites form a high, steeply sloping range of hills in the contact zone with Archean gneisses. The difference in height between the mica schist area and the quartzites is more than 100 metres at its greatest; on the study line the difference is about 50 m (Fig. 35).

The threshold in bedrock almost perpendicular to the direction of flow of the ice sheet has had a pronounced influence on the transportation and abundance of boulders on the surface of the till bed. The transportation of Karelidic schist (mica schist, quartzite, metavolcanics) as a whole beyond the distal contact can be described by an ordinary, gently sloping curve (Fig. 35B). But once the rocks forming the high hill range (quartzites and metavolcanics) were considered as their own groups, the curves describing the decrease in the abundance of rocks after the distal contact are no longer of an ordinary type (Fig. 35C). The share of mica schist in the boulders on the surface of the till bed decreases conspicuously while the share of local material increases over the threshold in bedrock formed by quartzites and metavolcanics. However, beyond the hill range, the share of mica schist increases once more, almost reaching the maximum value. This means that the material in the upper of the glacier passed the hill range and that the material was not deposited until the distal side, whereas the local material derived from the area of the hill range was not transported far and deposited as basal till quite close to the source area.

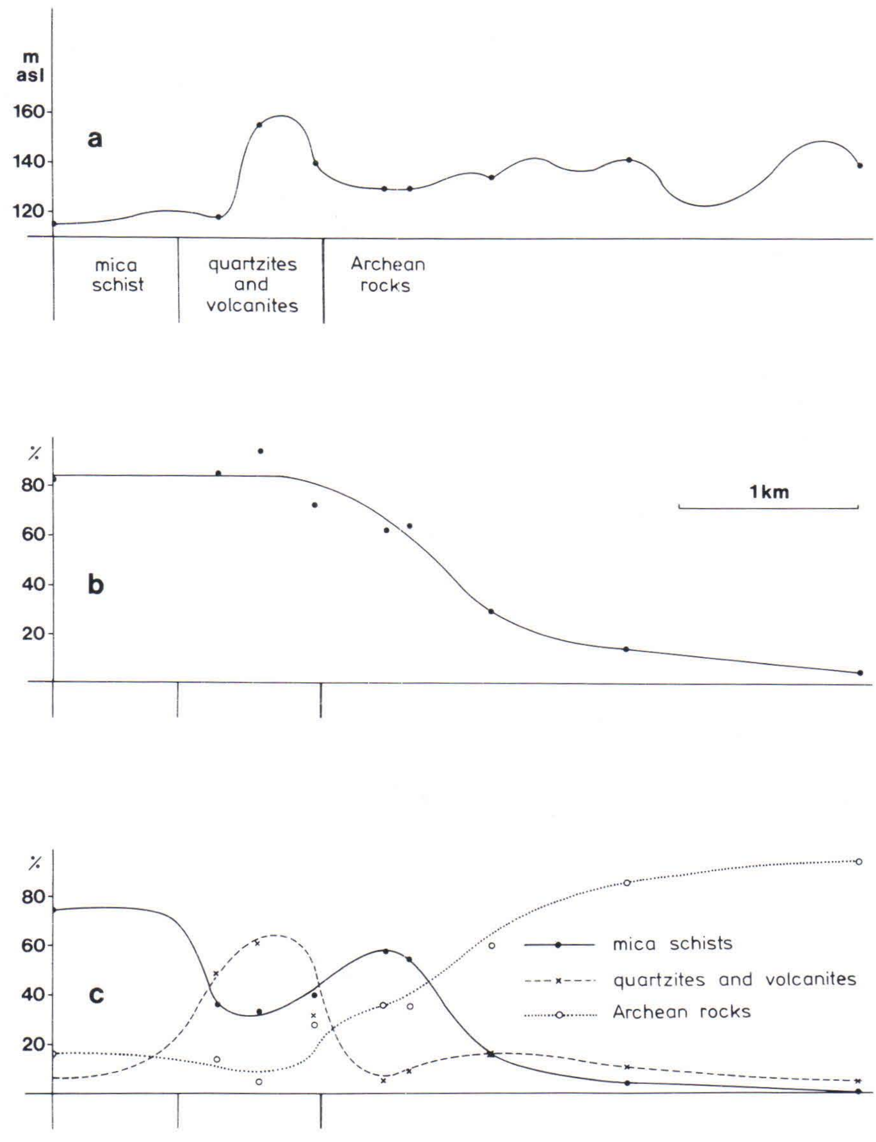
That the material within the glacier passed hills has been recognized earlier (Kuorevaara p. 16, Petäinen p. 24). As a rule the share of material transported by glacier reaches its maximum value quite soon after the proximal contact (see e.g. Palojärvi target area, p. 23). But the share of material transported as boulders on the surface of the till bed increases slowly as with the granitoids in Viesimo (Fig. 35C). The percentage of granitoids over the schist area is already 15—20 %, which shows that these boulders include abundant material transported a long distance. The granitoids reach their maximum percentage three kilometres from the proximal contact (Fig. 35C).

The transport distance of till cannot be determined unambiguously in an area with such marked contrasts in topography as Viesimo. The material on the lee side of hills may have been transported much farther than that deposited on the proximal side.

Kontiolahti area

The Kontiolahti target area lies north and northeast of the village of the same name (map sheet 4242 10 and 11) in the area of the Kontiolahti gneiss dome and the surrounding Karelidic schists (Fig. 36). The Kontiolahti dome consists of Archean granitic gneiss and younger granites and metadiabases. North of the dome these are Karelidic conglomerates and quartzites, and west of the dome extensive areas of mica schists and phyllites (Fig. 36).

The youngest direction of ice flow in the area is from 295°—320° (Repo 1957). The morphology of the overburden shows strong orientation (in the direction 320°) west and south of Lake Miklinlampi, where drumlins are long and narrow. The overburden is usually 3—6 metres



a) Topography and bedrock
b) Percentage of Karelidic rocks
c) Percentages of different rock groups

Fig. 35. The transportation of boulders on the surface of the till blanket in Viesimo, Kiihtelysvaara. See also Fig. 20. Bedrock after Nykänen (1971).

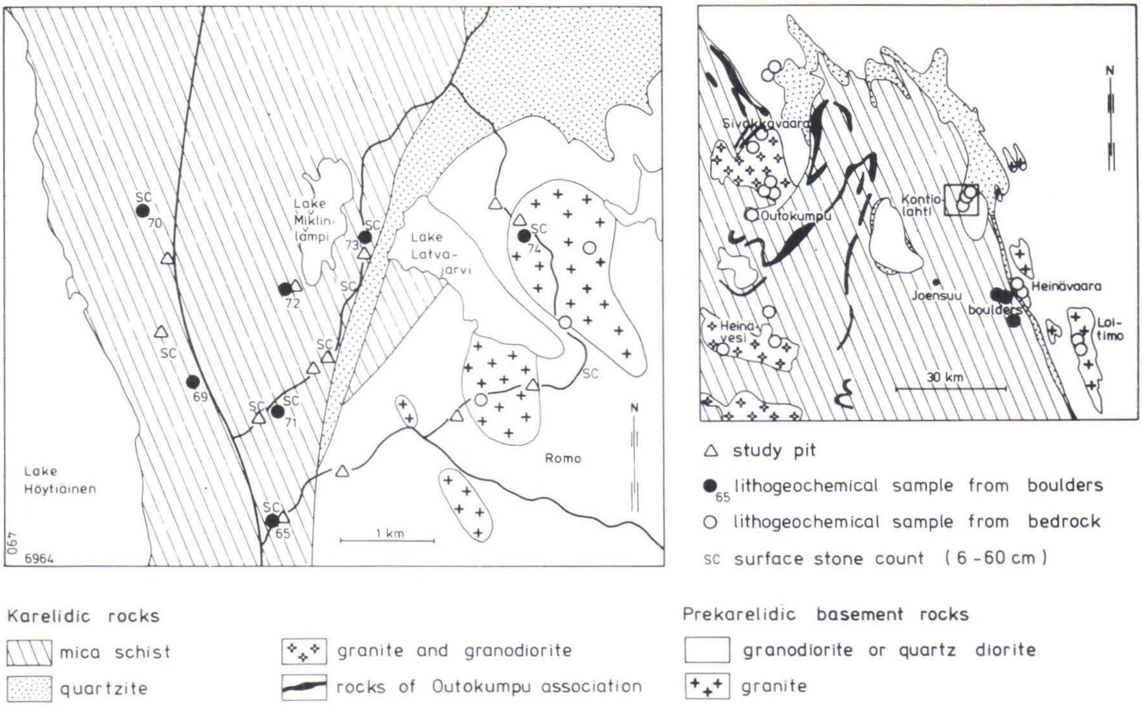


Fig. 36. The bedrock and the sampling sites in the study area of Kontiolahti (left) and in the whole study area (right). Bedrock after Huhma (1971a, 1971b, 1971c, 1975 and Nykänen 1973).

thick. The western part of the study area is relatively gently sloping with only small differences in height; but in the east and northeast the differences in height are greater and the topography is more variable.

The rock type of the boulders on the surface of the till bed was determined at ten observation sites. Fifty boulders 6—60 cm in diameter were counted at each site. So that the boulders on the surface of the till could be compared with the boulders within it 13 study pits were dug by a tractor excavator, and altogether 34 stone counts were carried out on the 0.8—6 cm fraction.

At most of the observation sites granitoids (Archean granite gneiss and granite) accounted for 50—70 % of the boulders on the surface of the till regardless of the bedrock in the area and the direction from which the latest ice flow came (Fig. 37). In the western part of the study area (the mica schist area), the nearest area where granitoids occur in bedrock against the direction of the latest ice movement is some 50 km away in the Sivakkavaara-Outokumpu region. But in the mica schist area, there was only one sampling site — on the isthmus between Lake Miklinlampi and Lake Latvajärvi — where mica schist was the main rock type among the boulders on the surface of the till. The morphology and the topography of the overburden change substantially at Lake Miklinlampi, indicating that the latest ice flow on the western side of the lake was essentially different from that on the eastern side. The morphology between Lake Höytiäinen and Lake Miklinlampi shows strong streamlined features and the direction of flow of the latest ice can easily be recognized from the orientation of the overburden. In the eastern part, the streamlined orientation of the overburden is lacking, the differences in height

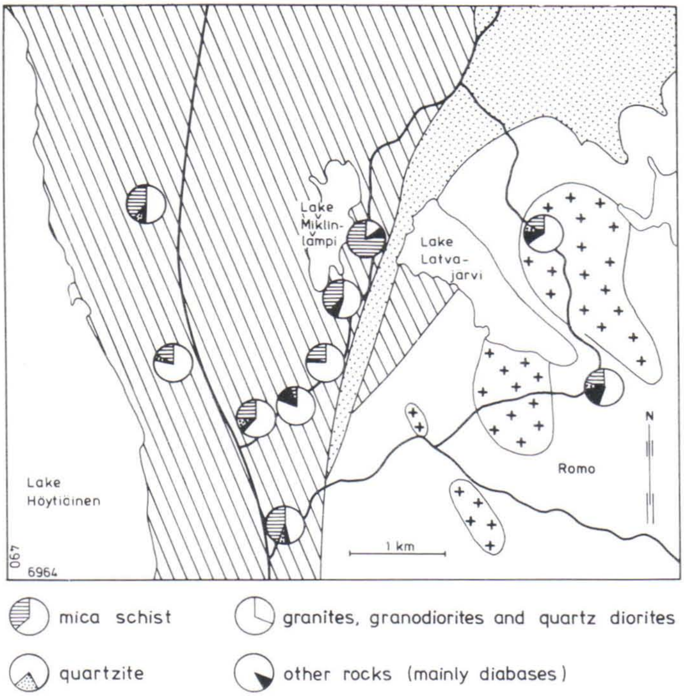


Fig. 37. The distribution of boulders of different rock types on the surface of the till blanket in the study area of Kontiolahti. Bedrock after Huhma (1971b). For expl. see Fig. 36.

are greater and the trend of the bedrock is reflected in the morphology of the overburden, too.

The share of granitoids in the surface of till over the Kontiolahti dome is 60 %. The share of metadiabases, one of the rock types of the dome, is also higher over the dome than in the mica schist area. Because the observation sites are located in the area where the ice flow and glacial erosion were slight it is obvious that most of the granitoid boulders have derived from the dome.

The percentage of granitoids among the boulders on the surface of the till was unexpectedly high in the mica schist area. There are numerous other possible source areas for these granitoid boulders besides the aforementioned Sivakkavaara-Outokumpu region (Fig. 36), even though the known transport directions do not agree well with them. The movements of the glaciers were so complicated in this area, however, that a complex transport of boulders is to be expected. Hence, to ensure the source area of the boulders a discriminant analysis was carried out on the basis of their chemical composition.

For the discriminant analysis samples were collected from homogeneous, medium-grained granite boulders poor in biotite at seven separate sites. Each sample was a composite of three subsamples. In the possible source areas (Fig. 36) granite outcrops were sampled in the same way. In Heinävaara samples were also taken from boulders lying in places similar to the Kontiolahti boulders. Both main and trace elements were analysed by the ICAP method and the concentration of 26 elements in all were used as characterizing features in the discriminant analysis (Gustavsson 1983). Classification of the boulders into categories that chemically correspond to the bedrock in a specific area showed that the source area of three out of seven boulders is in the Sivakkavaara area (Table 3) at the highest probability level. The most probable sources for three other boulders are

Table 3. The probabilities of the different source areas for the granite boulders in Kontiolahti based on discriminant analyses of analytical data (26 elements). Sampling sites as in Fig. 36.

GRANITE BOULDERS OF KONTIOLAHTI	GRANITES OF BEDROCK: Kontiolahti	Outokumpu	Heinävaara	Loitimo	Heinävaara (boulders)	Heinävesi	Sivakkavaara
65	$0.7 \cdot 10^{-1}$	0.2	$0.5 \cdot 10^{-11}$	$0.7 \cdot 10^{-4}$	$0.5 \cdot 10^{-10}$	0.7	$0.9 \cdot 10^{-1}$
69	0.3	$0.7 \cdot 10^{-1}$	$0.8 \cdot 10^{-13}$	$0.3 \cdot 10^{-1}$	$0.3 \cdot 10^{-9}$	$0.5 \cdot 10^{-1}$	0.5
70	0.8	$0.1 \cdot 10^{-3}$	$0.9 \cdot 10^{-5}$	$0.7 \cdot 10^{-5}$	$0.7 \cdot 10^{-1}$	$0.1 \cdot 10^{-1}$	0.1
71	$0.2 \cdot 10^{-2}$	$0.9 \cdot 10^{-6}$	$0.1 \cdot 10^{-4}$	$0.1 \cdot 10^{-5}$	0.9	$0.6 \cdot 10^{-2}$	0.1
72	0.9	$0.3 \cdot 10^{-6}$	$0.3 \cdot 10^{-11}$	$0.4 \cdot 10^{-7}$	$0.2 \cdot 10^{-3}$	$0.9 \cdot 10^{-4}$	0.1
73	$0.7 \cdot 10^{-5}$	$0.1 \cdot 10^{-11}$	$0.1 \cdot 10^{-10}$	$0.2 \cdot 10^{-7}$	$0.2 \cdot 10^{-1}$	0.5	0.5
74	1.0	$0.4 \cdot 10^{-6}$	$0.2 \cdot 10^{-10}$	$0.5 \cdot 10^{-5}$	$0.1 \cdot 10^{-1}$	$0.2 \cdot 10^{-4}$	$0.2 \cdot 10^{-6}$

the granite outcrops of the Kontiolahti dome. According to the data on sample no. 71 (Table 3), boulders of the same type and derived from the Sivakkavaara area should also exist in Heinävaara. The results of the discriminant analysis imply that the most probable source area of boulder no. 65 is Heinävesi granite. This is impossible, however, considering what is known about the flow directions of the Lake Finland ice lobe. The granitoid boulders in Kontiolahti were probably transported from the Kontiolahti dome, from Sivakkavaara or even from Outokumpu.

The comparison of the stone count results from the material on the surface of the till with the results from within the till showed that the percentage of granitoids is many times higher on the surface (Fig. 37 and 38). The boulders within the till are therefore much more local than those on the surface. Two till beds of different ages were recognized in three study pits. The granitoid boulders are dispersed fairly homogeneously (15—33 %) in the younger till.

The older till in the southernmost pit contained 41 % granitoids and 15 % quartzites.

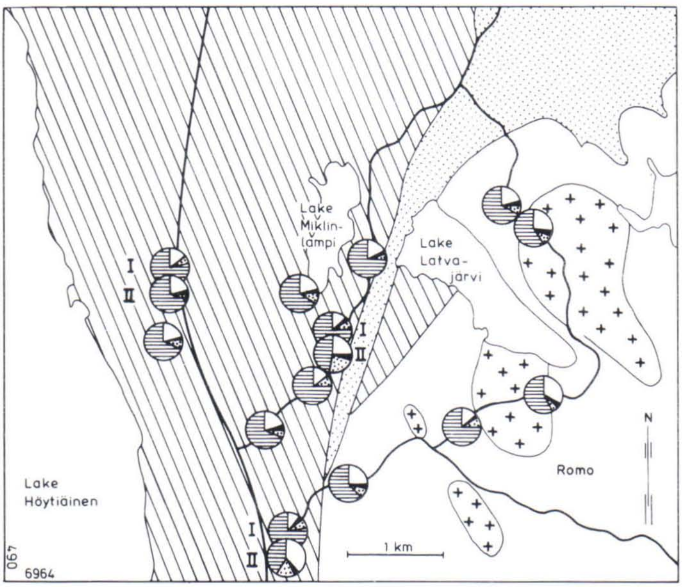


Fig. 38. The distribution of stones (0.8—6.0 cm) of different rock types in till in the study area of Kontiolahti. I = upper till bed, II = lower till bed. Other expl. see Figs. 36 and 37. Bedrock after Huhma (1971b).

This is the natural composition of till if the material has been transported from the northeast. An analogous composition with a high percentage of quartzites was found in the older till in the pit south-southeast of Lake Miklinlampi. The third pit with double till is situated so far north that even if ice had flowed from the north-east it would not have made any difference to the composition of till compared with ice flowing from the northwest or west (Fig. 38).

In the older till of the southernmost pit the pebbles exhibited an orientation maximum of 345° at a depth of 7.5 m. Ice flowing from this direction, however, would not have been able to transport material from the gneiss dome to the schist area; the material from the northeast must have been transported in various steps to the places where it now lies. These results, as well as the results of the discriminant analysis, support previous reports of ice flowing from the northeast (Salminen 1980, Hartikainen ja Salminen 1982, Damsten person comm.). This ice flow from the northeast must have taken place long before the latest deglaciation phases, and so only a few observations can be made of it today.

DISCUSSION

The glacial history of North Karelia is more complicated than elsewhere in Finland. During the deglaciation phase two separate ice lobes were active, partly at the same time, and at one stage of their history they must have been involved in some kind of collision. Besides these areas of active lobes there are also areas of passive ice, where the ice flow was slight. No lobe was equally active throughout the whole lobe, but more or less active parts and small sublobes in marginal zones can be distinquished. Likewise the flow direction of the lobe changed depending on local circumstances and rearrangements giving rise to striae differing from the main ones in direction (Kurimo 1982).

The differences in transport distance within one lobe are seen clearly if the results from the Miihkali (see p. 13) and Kuorevaara (see p. 16) target areas are compared with those from Horsmanaho (see p. 18). All these target areas are in the area of the North Karelian ice lobe. Horsmanaho is close to the edge of the lobe, where the ice sheet was thinner and the transport distance of till therefore only about one kilometre. But in Miihkali and Kuorevaara, which are in the middle of the lobe, the transport distance was several kilometres. Further, glacial erosion was so weak in Horsmanaho that older till beds have been preserved in places.

Another kind of local divergence from the ordinary transport direction and distance has been noted in the Outokumpu region (see p. 34). There the youngest direction of flow of the ice is that of a sublobe of the North Karelian ice lobe. This is exhibited in the shape of the Ni-anomaly in the upper part of the till (but not in the bottom part), where the sublobe has pushed the Ni-bearing material some hundreds of metres forwards (Fig. 30).

In some places it is easy to recognize the age relations between separate till beds and the glacial phases causing these separate till beds, but it is seldom so easy to connect the data between one place and another. In North Karelia the oldest recognized direction of ice flow during the Weichselian ice age was NW-SE (c. 330°) throughout the area.

In the southwestern part of the target area (subarea IV in Fig. 5) the youngest till bed was deposited by the Lake Finland ice lobe (flow direction 270°—290°), but in the northwestern part of the area the till bed deposited by this ice

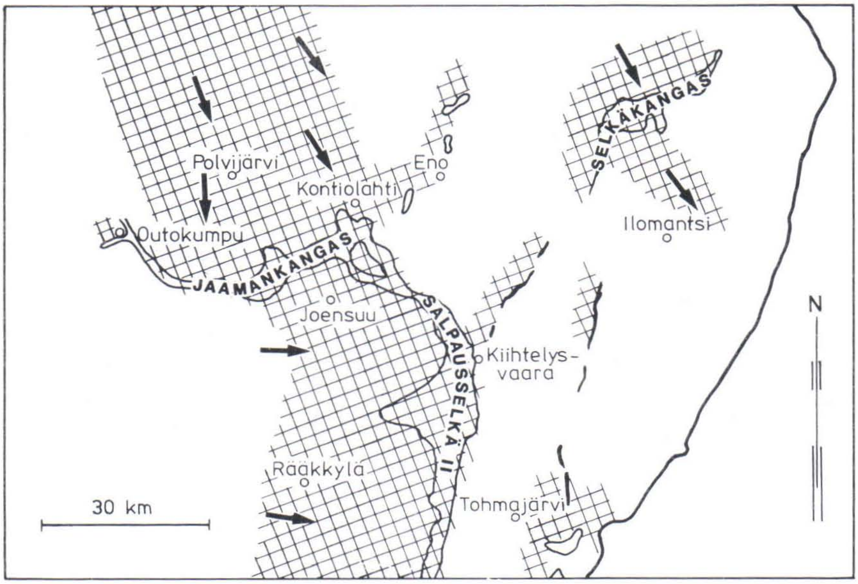


Fig. 39. The zones of active ice movement during the latest deglaciation (areas of long transport distances). The arrows show the main directions of the ice flows in the active lobes.

flow is the second youngest because the North Karelian ice lobe (flow direction 320°—10°) advanced into the area from where the Lake Finland ice lobe had retreated (subareas V and VI in Fig. 5). The erosional force of an ice lobe was often so strong that most of the traces of an earlier flow were swept away.

The intensity of glacial erosion and the transport distance during the deglaciation phase can be established from the size of the marginal formation. All the material in a marginal formation was taken by an ice lobe from the bedrock on the proximal side of the formation. As a rule glacial material was transported in a zone tens of or even over a hundred kilometres wide inside the margin of an ice lobe. When the huge marginal formations (e.g. Salpausselkä II) formed both the ice margin and the erosion zone stayed in the same place for a long time. In North Karelia this zone of transport over a long distance is about 30 km wide within the area of Salpausselkä II, but on the proximal side of Jaamankangas it is even wider, reaching far beyond the study area (Fig. 39). Hence the transport distance the proximal and distal sides of a big marginal formation are conspicuously different.

Many of the studies on the transport distance of till in Finland have been done in the zone of greatest glacial activity. The area studied by Perttunen (1977) lies south of Hämeenlinna, 30—40 km on the proximal side of Salpausselkä II, and so she could report quite long transport distances (half-distance values were 3.7—5.6 km). The same applies to Kuhmo, from where Peltoniemi (1981) and Nevalainen (1983) reported even longer transport distances. They also found differences in the transportation of different grain size fractions. In North Karelia, where there are areas of both active and passive ice flow, transport distances were either long or short, respectively (Table 4). The same bipartite system is a reality in till geochemistry as far as the length of geochemical anomaly in the finest fraction of till is concerned. Figure 40 compiles some results of the length of geochemical anomalies in Scandinavia (Kauranne 1976) and in Canada (Bradshaw 1975). It is obvious that differences in the lengths of anomalies depend on the activity of the ice flow as described above.

Table 4. The transport distance (usually half-distance value) of the different till fractions in the target areas.

Target area	Fraction <0.06 mm	Stones 0.8-6 cm within the till	Stones 6-60 cm on the surface of the till	Width of the source area
Miihkali	3 km	≥10 km	-	1000 m
Kuorevaara	-	≫ 3 km	-	several kilometres
Horsmanaho	>700 m (1 100-300 m (2	-	-	700 m
Kontiolahti	-	-	15-50 km	tens of kilometres
Korentovaara	-	local	3-5 km	100-2000 m
Parissavaara	800 m	>3 km	-	100 m
Viesimo	-	2 km	0-2 km	tens of kilometres
Palojärvi	400 m (3 1500 m (4	1.3 km	-	100 m 300 m
Petäinen	700 m	-	-	500 m
Kaasila	700 m (1 <100 m (2	-	-	<100 m
Röksä	local	-	-	<100 m

1) upper part of till
2) bottom part of till
3) narrow source area
4) wide source area

In some target areas in North Karelia differences in the transport distances of separate grain size fractions have also been recognized (Miihkali, Kuorevaara, Palojärvi, Parissavaara). This difference is not real, however, because no grain size fraction of till is transported as such, the grains being continually ground finer and finer in the course of transportation. Minerals easily eroded, such as most sulphides, are rapidly ground into the fraction that is ordinarily used in geochemical till studies. Many base metals in till are incorporated largely in these easily erodable minerals. Even if sulphides from a certain deposit were transported a much longer distance in till, they would soon have been diluted to the background level by other materials of the source rock as well as of the surrounding rocks. Even as single 'grains' big-

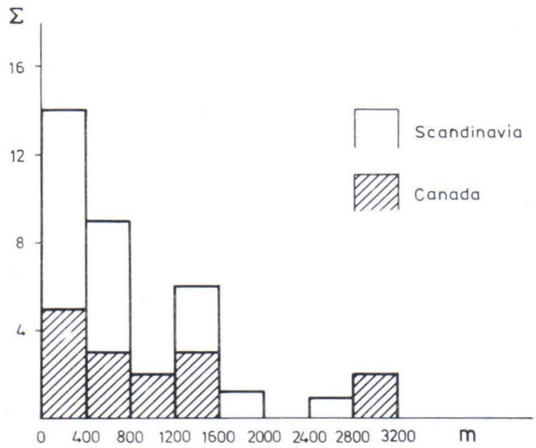


Fig. 40. The length of geochemical anomalies in Scandinavia (Kauranne 1976) and in Canada (Bradshaw 1975).

ger boulders can be identified to be derived from a known deposit after long transportation; this is not true of finer grains, however.

In some cases when the till has been transported only a short distance, the correct source can be identified on the basis of simple metal ratios (Horsmanaho and Kaasila, p. 18 and 26). But when the transportation is longer and the homogenization more thorough it is unreliable to interpret geochemical results in this way.

Marked homogenization of till together with long transport distance is due to the active ice lobes as is the dilution of the material derived from a certain source area. The degree of dilution during glacial transport has a considerable influence on the anomaly thresholds in some cases (see Outokumpu-Polvijärvi area, p. 30). If the anomaly thresholds in regional geochemical mapping are determined without considering the glacial geology of the region, then the anomaly maps probably do not describe the bedrock and mineralized deposits very well but rather give knowledge of glacial geological features of the study area. However, the intensity of glacial erosion varies much from one place to another and its influence on the interpretation of the geochemical results must be evaluated for each case separately.

In a study area with a glacial history like that of North Karelia, the possibility of transportation in two or more phases (complex transport) must always be taken into account. This applies especially to the boulders on the surface of the till (Kontiolahti, p. 36) but features of the complex transport can even be seen in the geochemical anomalies in the finest fraction of till (Kaasila, p. 26).

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