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The lithologic relation between till and bedrock in the region of Hämeenlinna, southern Finland

by Marjatta Perttunen

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THE LITHOLOGIC RELATION BETWEEN TILL AND BEDROCK IN THE REGION OF HÄMEENLINNA, SOUTHERN FINLAND

BY

MARJATTA PERTTUNEN

WITH 37 FIGURES AND 5 TABLES IN THE TEXT AND TWO APPENDICES

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The ground moraine along two traverses, 33 km (I) and 24 km (II) long, running parallel to the direction of the main ice flow, was sampled. Lithologic analyses were made in five grade sizes (20—200, 6—20, 2—6, 0.6—2 and 0.2—0.6 mm) and mineral analyses in three grade sizes (0.06—0.2, 0.02—0.06 and 0.006—0.02 mm). The contents of CaO, Na_2O and K_2O in two grade sizes (0.002—0.006 and 0.0001—0.002 mm) were determined for a part of the samples.

The distance, as measured from the distal contacts, of the glacial transportation undergone by the granitoids and basic volcanics in the five grade sizes of the till, was treated according to the negative exponential function. The distribution of the microcline granite in the five grain sizes of the till, as measured from the proximal contacts, was treated according to the exponential function.

The average half-distance values for the granitoids are 3.7 km (traverse I) and 4.7 km (traverse II) and those of the basic volcanics is 5.6 km (traverse I) and 4.2 km (traverse II). The contents of quartz, plagioclase, potassium feldspar and hornblende in the till are in clear correlation to the source rock.

The roundness of the quartz grains in the 1—1.2 mm fraction was investigated with a mechanical graniformameter. Of the quartz grains, 98.6 % belong to two classes of roundness, angular and subangular.

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INTRODUCTION

The purpose of this study was to shed light on the relation of the lithology of basal till by fractions to the underlying bedrock. On the basis of the sedimentary petrographic results, it was sought to trace especially the transportation of rocks by the continental ice sheet.

The Hämeenlinna region of southern Finland, situated 100 km NNW from Helsinki (Fig. 1), was considered to be best suited as the site of the investigations because there the rock contacts run roughly at right angles to the main direction of ice flow. Previously Virkkala (1958, 1961 a and b, 1969 a) investigated the Quaternary geology of the area.

Two traverses were selected for investigation in the area running approximately parallel to the main ice movement, NNW-SSE, 315° (Virkkala 1961 b). They cross areas of granodiorite, basic volcanics, mica schist and microcline granite (Fig. 2). The two traverses investigated differ somewhat from each other in the distribution of the rock types composing the bedrock. Furthermore, the chemical composition of some of the samples was investigated.

The roundness of the quartz grains of the coarse-sand grade was also studied in the sample material to clarify the transportation of the till further.

EARLIER STUDIES

At the end of the 19th century, attention began to be paid in Finland to the lithologic composition of glacial till in conjunction with geological mapping operations (1 : 200 000). At the same time, the till was ascertained to be of local origin, as Jernström noted as early as 1876.

The first stone counts made from till were published by Sederholm in 1892 in connection with the explanatory text accompanying the geological map sheet of Valkeala, done on the scale of 1 : 200 000. He observed that the sandy till on the north side of Salpausselkä was composed mostly of stones transported from a distant source. In Sederholm's view, the material had been carried at least 30—40 km. According him this is true also of the till lying on top of Salpausselkä. Sederholm

Fig. 1. The location of Hämeenlinna region (rectangle).

found the majority of these stones to be comminuted *) at the edges and some of them to be quite conspicuously rounded. He observed the unwashed fine sandy till in the area to consist largely of local rapakivi material.

The studies relating to the lithologic composition of till have been continued in the present century to determine the transportation distances, to analyze the petrographic nature of the till, and to trace the movements of the ice sheet. Such work has also been done in conjunction with ore-prospecting surveys (*cf.*, Perttunen 1973, pp. 6, 18—20 and 1976 b, pp. 2—3, 10).

The mineral composition of till was described for the first time by Frosterus and Wilkman (1917) in the explanatory text that accompanied the Joensuu map sheet of Quaternary deposits. After this, attention began to be paid gradually to the minerals contained in till (Saksela 1930, Aarnio 1935). It was also observed that the till matrix contained material transported from a greater distance than the coarser fractions (Kivinen 1941, Okko 1949, Repo 1957).

In his extensive study, Kivekäs (1946) dealt with, among other things, the lithologic composition of tills in different bedrock areas of Finland as well as their contents of light and heavy minerals and their chemical composition. He made the observation that in an extensive bedrock area consisting of the same rock type, the till there was composed mainly of this rock. On the other hand, in a bedrock area consisting of varying rock types, the lithologic composition of the till was also seen to vary. In the main, the till in Finland is fairly local in character.

*) as defined by Dreimanis and Vagners (1971 a) p. 239.

A study dealing with the mineral composition of the silt and clay constituents (2—20 μ, below 1 μ) of till existing in different parts of Finland was made by Soveri and Hyyppä (1966). The mineral composition was studied by the X-ray diffraction and differential thermal analyses methods. There were 14 samples, which had been chosen from 3 000 samples of till. The results were compared with those yielded by Pleistocene clays previously investigated by Soveri (1956).

The lithologic and mineral composition of till in southern Finland was studied by Hellaakoski and Virkkala and in North Karelia by Repo.

In a study focussing attention on southwestern Finland, Hellaakoski (1930) compared the distances of glacial transportation with those of glaciofluvial material to till in the rapakivi and sandstone area of Laitila. He arrived at 4 km as the average distance traveled by the till in the area. He observed, however, that the finer material (0.2—2 cm) of the till had been transported farther. The local rock material in the till is at its maximum in the vicinity of the corresponding bedrock but diminishes sharply over a distance of 10 km in the direction of the ice movement.

Repo (1957) investigated the lithologic composition of till on the basis of many stone counts in North Karelia. In the light of the results, he drew conclusions regarding the nature of glacial transportation in that region. In his work, Repo made use of lithologic determinations relating to boulders on the surface as well as the following grain-size classes in the till: 30—100 cm (boulders), 3—10 cm and 0.3—1.0 cm. In addition, he studied the heavy minerals contained in the fine material (less than 3 mm). He perceived the stone size of 3—10 cm to be the best indicator, which showed the influence of the local bedrock. The boulders on the surface had been transported from a distant source — to some extent by icebergs. The 0.3—1.0 cm material had likewise come from a distance and resembles the lithologic composition of the boulders on the surface. In general, however, the material composing the till of North Karelia is of strictly local origin or derived from a nearby bedrock provenance.

Virkkala (1958) investigated the transportation of the rock material contained in the esker in the area of the present study, that is, the Hämeenlinna region. For purposes of comparison, he also made stone counts in the 5—10 cm size range in the till located in the vicinity of the esker. Virkkala noted a steep increase in the amount of microcline granite contained in the till down-glacier from its proximal contact, the local influence of the granodiorite bedrock on the till, so as the influence of the local mica schist area of Alajärvi on the till. The same features are also to be observed in the esker material.

Similarly, in his explanatory text accompanying the Hämeenlinna map sheet devoted to Quaternary deposits, Virkkala (1969 a) dealt with the lithologic composition of the tills in the area in the light of the stone counts made of the boulder fraction (> 20 cm) and large and small stones (2—10 cm). He observed that the lithologic composition of till is affected greatly by the size of the area from which the rock material of the till has been derived. Thus, for instance, the quantity of the widely distributed microcline granite contained in the till amounts to between 70 and 90 %

in the southern and central parts of the bedrock area referred to. On the other hand, in the much smaller mica schist area, the proportion of mica schist among the till stones is not quite so high as that. Virkkala has further worked out the average transportation distances of the granodiorite, tuffite and mica schist in the region.

Virkkala (1969 b and 1971) studied the lithologic and mineral composition of the till (0.002— over 200 mm) in the Hyvinkää region, some 30 km southeast of the present study area. His investigation took in the different fractions, as did the present work. The varieties of rock investigated were gabbro and microcline granite. The main minerals present in these rocks are quartz, potassium feldspar, plagioclase, hornblende and biotite. From the mineral grains, Virkkala worked out the lithologic composition of the till within the grain-size range of 0.002—2 mm. He found changes in the transportation distances calculated for the fractions investigated.

Among the latest publications dealing with the transportation of till in Scandinavia, noteworthy are Gillberg's studies (1965, 1967 a and 1967 b) done in Sweden. He investigated the distribution of the varieties of rock represented in till gravel (grain sizes: 2—20 mm) occurring immediately S of the Cambro-Silurian region. There the transportation distances are longer than in areas of plutonic rocks. Gillberg was the first in the Nordic countries to treat his results according to the negative exponential function propounded by Krumbein (1937), which is also used in the present investigation. Gillberg drew on his research results to describe, among other things, glacial activity.

Marcussen (1973) utilized by means of the negative exponential function the half-distance values and values of a lithologic nature *a* arrived at by Gillberg and by himself to correlate and determine the movements of the continental ice sheet in Denmark.

In Canada, mainly the limestone and dolomite areas, Dreimanis and Vagners (1965, 1969, 1971 a, 1971 b, 1972) investigated the lithologic and mineral composition of basal till by grain sizes (18 grain-size classes).

These investigators have concluded that the genesis and petrography of till depend on the distance from the source area, the properties and size of the source rock material, the dynamics of the glacier, which includes both the nature of the glacial transportation and the mode of deposition of the material, as well as the amount of possible older sediments.

Dreimanis and Vagners have also concluded that every lithologic component of basal till has a bimodal size distribution. This is true of rocks that are monomineralic (like limestone) or contain minerals with similar physical properties (like gabbro, which consists of plagioclase and pyroxene). The clast sizes (over 2 mm) have one of the modes and it appears near the bedrock source areas (clast mode). In the matrix (under 2 mm) the mineral fragments have modes farther away from the source area (matrix mode) that are typical of each mineral. These mineral grades (terminal grades) represent the final product of the glacial comminution. However, the classification of the terminal grades of minerals according to grain size depends not only on the durability of the various minerals under comminution during glacial transportation but also on their original grain size in the rock or older sediments. Owing to these factors, the terminal grade of the same mineral is likely to vary from area to area.

Lindén (1975) investigated the till petrography in different grade sizes (> 200 —< 0.002 mm) in an Archaean bedrock area in the region of Uppsala, Sweden. The rock types studied in clast sizes were basic granite, intermediate granite and microcline-porphyritic granite. In till matrix (< 2.0 mm) the light, mafic and clay minerals were studied. The connection between the till and the bedrock was discussed. He also gave the results as calculated by the negative exponential function according Krumbein. The distance of glacial transportation in the clast sizes was found to be very short. He concluded that 60 per cent of the whole material in till (< 20.0 mm) can be transported less than 3.5 km.

The roundness of quartz grains in till was studied in Poland, where Krygowski (e.g., 1964, 1965) has developed a mechanical graniformameter to measure the roundness of quartz grains. Krygowski regards quartz as the standard in measuring roundness.

Seppälä (1969, 1971) was the first in Finland to use the mechanical graniformameter in his investigations, mainly to measure the roundness of quartz grains in dune sands. For purposes of comparison, he published the roundness measurements of quartz grains in the 0.7—1 mm fraction contained in four samples of till collected in Finnish Lapland.

THE REGION INVESTIGATED

Bedrock

The region where the samples were collected falls into the bedrock map sheets of Hämeenlinna (Simonen 1949 a and b), Forssa (Neuvonen 1954, 1956), Valkeakoski and Toijala (Matisto 1970, 1973, 1976 a, 1976 b). The simplified bedrock map of the region (Fig. 2) is based on the afore-mentioned maps. Use was also made of the petrological study by Simonen (1948).

A fundamental portion of the local Precambrian bedrock, which belongs to the Svecofennides, consists of a well-preserved schist zone, consisting mainly of basic metavolcanics and mica schists. In these schists, there occurs an abundance of relict structures indicating volcanic and sedimentary origin. On the other hand, outside the schist belt, there are migmatite-veined gneisses.

The region contains a great abundance of plutonic rocks, among which granodiorites and microcline granites predominate, whereas the gabbros occur only as small bodies. The granodiorites are met with in the northern schist belt. Microcline granites are common in the southern part of the area and they form migmatites with hornblende gneisses and garnet-cordierite gneisses.

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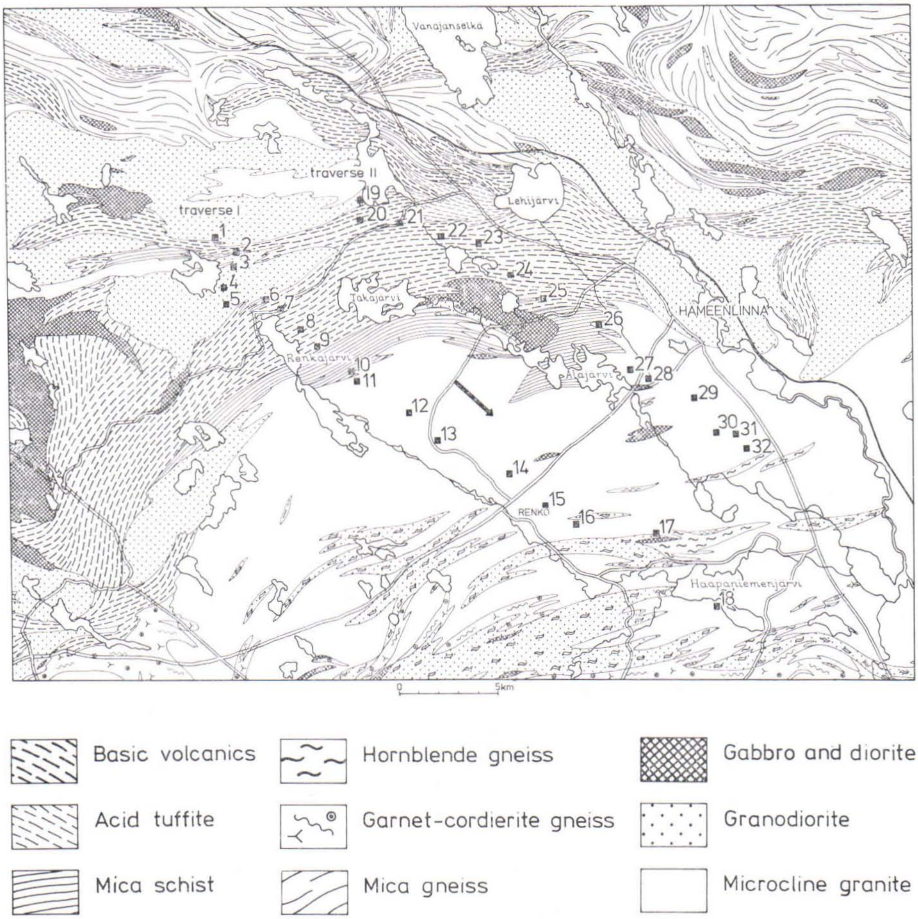

Fig. 2. A simplified bedrock map of the study area, after bedrock maps published on the scale 1 : 100 000 (Simonen 1949 a, Neuvonen 1959, Matisto 1970, 1973). Sampling traverse I and II. Sampling sites (squares). Arrow indicates direction of main ice movement (Virkkala 1961 b).

Topography

The region investigated lies between 80 m and 180 m above sea level (see Virkkala 1969 a). The sampling sites are located from 90 to 145 m above sea level (e.g., Figs. 15, 16). The height differences along the traverses can be 40—50 m but they vary mostly between 10 and 30 m. Along traverse I, the elevation varies between 125 and 145 m, but between sampling sites 16—18 it falls to 90—81.6 m. Along traverse II, the sampling sites are situated at a lower elevation than along traverse I. The elevation of the sites varies between 90 and 130 m. But between the sampling sites along traverse II it rises as high as 140 m and 150 m at some places. The highest hummocks of the area are not situated along the traverses.

Moraines and the till

On the whole, the till occurs in the region as a thin bed of ground moraine covering the bedrock, but it also occurs as thicker accumulations in the form of ablation moraines, drumlins or end moraines, which in places are about 25 m thick (Virkkala 1961 a and b, 1969 a). The samples were taken from the basal till. The composition is that of sandy till and gravelly till (Fig. 3). As an exception, sampling site 31 is composed of silty till. Their average grain-size distribution is that of sandy till. Clay (under 0.002 mm) accounts for between 0.5 and 5.5 % of the material. Fig. 4

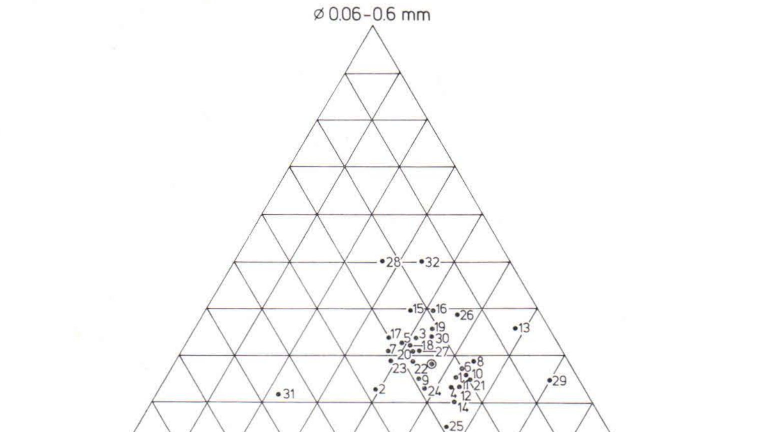

Fig. 3. Grain-size distribution of 32 till samples. Average composition indicated by larger point.

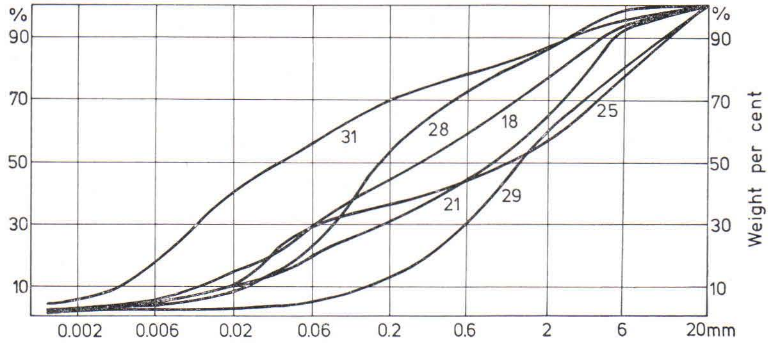

Fig. 4. Cumulative frequency curves for the till. Numbers refer to sampling sites. Nos. 29 and 31 represent extreme grain-size distribution values.

gives some examples of the grain-size analyses plotted as cumulative frequency curves. Sampling sites 29 and 31 represent the extreme grain-size distribution values of 32 samples. For the most part, the samples show only slight differences in their grain-size distribution. No clear relation between the grain-size distribution of the till and the rock types in the till can be seen.

METHODS OF INVESTIGATION

Thirty-two samples of ground moraine were taken from a depth of 0.7—1 m by either digging pits for the purpose or utilizing road cuts at intervals of a few kilometers along two investigation traverses in the direction of the main ice movement, NNW—SSE, 315° (Fig. 2). Some of the sampling sites deviate somewhat from the traverse lines. The samples were collected in the summers of 1971—1973.

From the 20—200 mm fraction, 200 stones were taken from each sample. From the < 20 mm fraction, an amount weighing about 10 kg was taken for laboratory analysis. The grain-size analyses were made first. The 0.06—20 mm fractions were sieved and the < 0.06 mm analyzed and fractioned with a hydrometer. The sample were fractioned into nine grades: 6—20, 2—6, 0.6—2, 0.2—0.6, 0.06—0.2, 0.02—0.06, 0.006—0.02, 0.002—0.006 and 0.0001—0.002 mm.

The lithologic composition of sample material containing grains ranging from 0.2 to 200 mm was studied in five grain-size classes:

In the 20—200 mm grain-size (large and small stones), the stone counts (200 stones per sample) were studied visually, with the aid of a stereomicroscope. The same method was used with the 6—20 mm (coarse gravel) and 2—6 mm (fine gravel) fractions (150—200 grains per sample), which represented mainly rocks.

An average of 86 % (67—100 %) of the grains in the 0.6—2 mm fraction (coarse sand) were rock fragments, that is, the grains were combinations of at least two minerals (e.g., granite = quartz + potassium feldspar, basic volcanics = hornblende + plagioclase) or fine-grained rocks such as acid tuffite or mica schist. An average of 55 % of the grains (22—75 %) in the 0.2—0.6 mm fraction (medium sand) were rock fragments. Acid tuffite and mica schist still occurred as rock fragments. The method of study in these two fractions involved the staining of potassium feldspar and plagioclase (Bailey and Stevens 1960) for loose grains. The stained grains (300 grains per sample) were examined under the stereomicroscope. The loose grains were counted by picking them out to include grains of different sizes. Thus the result represents the sample as a whole. The method proved good and rather fast.

First, experiments were done determining the mineral contents of grains from a thin section. In this procedure, from a thin section prepared from loose grains, the potassium feldspar was stained according to the method of Bailey and Stevens (1960), after which the thin section was studied under a polarization microscope. In Virkkala's

(1969 b and 1971) study, this method was used in the 0.02—2.0 mm grain-size range. In this range, the grains were so large, however, that a number of thin sections would have been needed for the determination of more than 100 grains. Further in some of the thin sections, there were finer fractions between the grains that hampered the study: accordingly, the method of staining loose grains and examining them under a stereomicroscope was faster.

The mineral composition of the 0.006—0.2 mm material was studied in the following three grain-size classes.

In the 0.06—0.2 mm fraction (fine and very fine sand) the grains were for the most part minerals. The acid tuffite and mica schist continued to be present as rock fragments.

The method used was one of studying the grains with two immersion liquids under a polarization microscope. The coefficient of refraction of the immersion liquid was 1.532 for the determination of potassium feldspar and 1.545 for the determination of quartz. With each immersion liquid, 200 grains per sample were counted. The method was rapid. The Fleet method was used in counting the grains, all the grains in the whole visible field being counted. In this way, grains of different sizes are included in the count, ensuring a more representative result (Galehouse 1969).

In this grain size, the thin-section method was also a possibility. Nevertheless, the determination of plagioclase and quartz in the absence of albite twinning is often liable to involve difficulties with grains of such small size.

The method of staining loose grains used in the 0.2—2 mm size range would also be a possibility. It would mean, however, differentiating the light and the dark minerals with heavy liquids, after which the light minerals would be stained in the previously described fashion (grain-size classes 0.6—2 mm and 0.2—0.6 mm). The dark minerals are then studied separately.

The 0.02—0.06 mm (coarse silt) and 0.006—0.02 mm (medium silt) grades were studied with an electron microprobe.

Saltikoff (1975) has developed a method of analysis with an electron microprobe for the investigation of the mineral composition of the fine fractions of till (in particular, 0.02—0.06 mm and 0.002—0.02 mm). This method was used in Virkkala's (1969 b and 1971) work during the investigation of the till deposits in the Hyvinkää gabbro area to determine the principal mineral composition in the afore-mentioned grain-size classes. In the application of this method, polished sections were made of the till material of each sample in the grain-size classes desired.

The electron microprobe was used to photograph from the sections the distributions of the following elements: Si, K, Ca and Fe. The different combinations of these elements were interpreted to be minerals (*cf.*, Saltikoff 1975). The interpretation is not altogether unambiguous, for the same combination of elements includes other minerals too, as, in addition to plagioclase, Si + Ca is likely to be epidote, wollastonite and titanite. The mode of calculation corresponds, however, to the requirements of the study, for there occur in the bedrock of the region minerals in

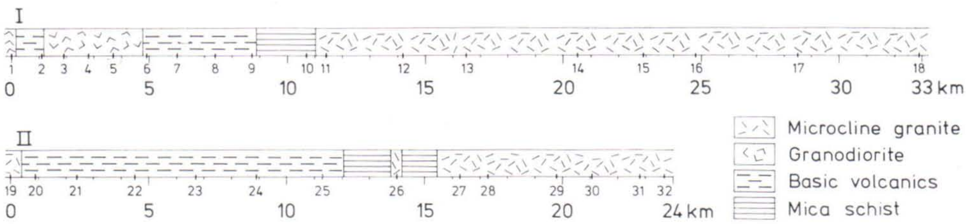

Fig. 5. Simplified bedrock along traverses I and II.

abundance adhering to the interpretative formula (Table 3, p. 42). The grains counted numbered less than 100 per sample.

The CaO, Na_2O and K_2O contents of the 0.0001—0.006 mm material were determined to complement the picture given by the rocks and the minerals of the relationship of the till material to the bedrock.

In the 0.002—0.006 mm fraction (fine silt) and the 0.0001—0.002 mm fraction (clay), material of a fineness under 0.006 mm could not be separated by pipeting from all the samples, so chemical analyses could be made of only part of the samples. The K_2O and Na_2O were determined with a flame-emission spectrofotometer and the CaO with an atomabsorption spectrofotometer. In these procedures, the samples were dissolved with a fluoric-hydrogen + perchloric acid + hydrochloric acid solvent, after which the samples were analyzed with the afore-mentioned apparatus.

The roundness of quartz grains in the coarse sand grain-size class (1—1.2 mm) was investigated with the mechanical graniformameter developed by Krygowski (Krygowski 1964, 1965, Krygowski and Krygowski 1965). The principle of the device involves the rolling of grains at different angles of inclination. The most important parts of the device are a sheet of glass with a frosted surface and, on top of it, two beams. In the measurements, quartz grains (ca. 100 per sample) are placed in front of the lower beam, which thrusts them upward. The upper beam pushes them down. The inclination of the glass can be shifted 0—32°. Depending on the degree of roundness of the quartz grains, they fall into a collecting through at different angles of inclination. The more angular the grain, the wider the angle it needs to fall. The experiment is done twice for each sample. An advantage of the device is the objectivity and rapidity of the results.

LITHOLOGY OF THE TILL

The lithologic composition of the basal till was investigated along two traverses (Fig. 5) in five grades: 20—200, 6—20, 2—6, 0.6—2 and 0.2—0.6 mm. In the 0.6—2 mm fraction, rock fragments averaged 86 % and in the 0.2—0.6 mm fraction 55 %. In these fractions only rock fragments are discussed in this investigation.

Granitoids

In this investigation, the granitoids referred to are granodiorite and microcline granite. The diagrams (Figs. 6 a and b) of two traverses reveal the influence of local bedrock on the coarser fractions (over 0.6 mm) of till in particular.

Traverse I begins in a large area of granitoids, which is 6 km long in the direction of ice flow. In the distal part of this area, sampling site 1 shows a high abundance of local bedrock fragments. The frequency is higher in the coarser than in the finer fractions. Four fractions (20—200, 6—20, 2—6 and 0.6—2 mm) have a content of 82—88 %. The content is lowest, 67 %, in the 0.2—0.6 mm fraction. This is typical of local material (e.g. Dreimanis and Vagners 1971 a). The same is true at sampling sites 4—5 in the till of granitoids bedrock. The particularly low content in the 0.2—0.6 mm fraction in No. 4 depends on the high content of monomineralic grains. Nos. 2 and 3 show the influence of small basic volcanics on till. Down-glacier from No. 2, the content of granitoids decreases rapidly to 50—70 % (No. 3). In the till of basic volcanics and mica schist areas (sampling sites 6—10), the coarsest fraction (20—200 mm) of the granitoids decreases with distance. So do the 6—20, 2—6 and 0.6—2 mm fractions, but in slightly higher amounts. At a distance of 4 km down-glacier, the granitoids in the sand fractions (0.6—2 and 0.2—0.6 mm) begin to predominate over the content of granitoids in the coarser fractions. Thus at the most distant sampling site (No. 10), 6 km down-glacier from the distal contact, the medium sand fraction contains 23.5 % granitoids, the coarse sand fraction 21 %, 2—6 mm 14 %, 6—20 mm 12 % and the coarsest fraction 20—200 mm 10 %.

The same observation has been made in the microcline granite of the Hyvinkää gabbro area (Virkkala 1971). This is a result of glacial comminution, which reduces the coarser fractions of the material into finer fractions. The comminution effect is also conspicuous at sampling sites 11 and 12 in the proximal portion of the microcline granite area, where the frequency of the sand fractions approaches that of the coarse fractions.

The coarser fractions mark the boundary of the microcline granite area. A mere 0.5 km down-glacier from the proximal contact, the frequency of the granitoids, 40 %, surpasses the 10 % for the mica schist area. Virkkala (1958) noted the same rapid increase in the present investigation area, and Hellaakoski (1930) reported a similar phenomenon in the Laitila rapakivi area. In the various granite areas, Lindén (1975) has marked the rapid increase of local material, especially striking in acid granite, down-glacier from the proximal contact of the rock.

Farther down-glacier in the microcline granite area, the till contains mostly local bedrock debris. The content is highest at the last sampling site 18, 22 km down-glacier from the proximal contact. The content of local material has risen to 92—96.5 % in the 20—200, 6—20 and 2—6 mm fractions, to 77 % in the 0.6—2 mm fraction and to 62.5 % in the 0.2—0.6 mm fraction. Along both traverses, the frequency of local bedrock can be seen to be for the most slightly higher in the 2—6 mm fraction than in the coarser fractions. This seems to be typical of the crushing

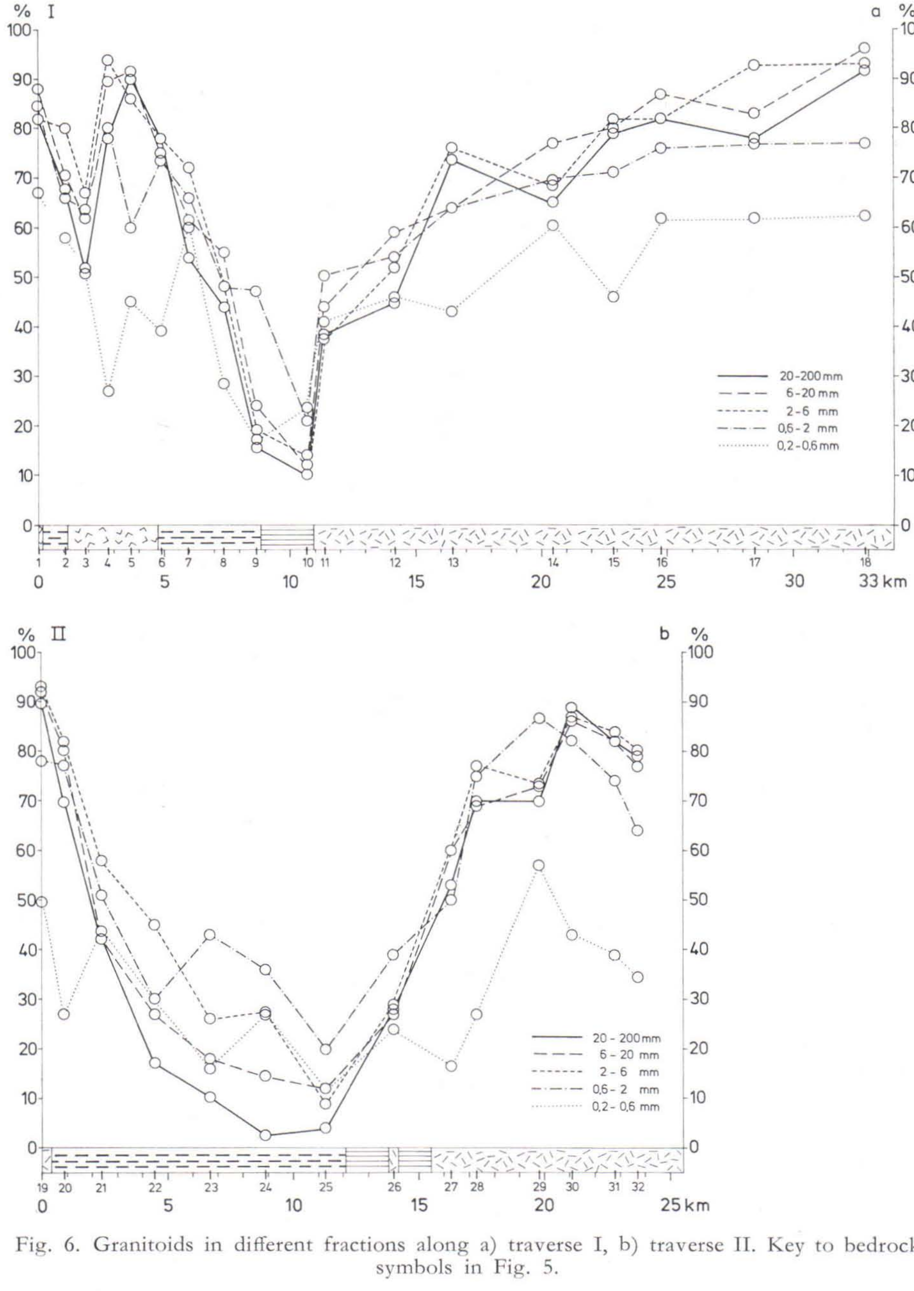

Fig. 6. Granitoids in different fractions along a) traverse I, b) traverse II. Key to bedrock symbols in Fig. 5.

procedure (Hellaakoski 1930, Lundqvist 1952, Lindén 1975). The low content of granitoids in the 20—200 mm fraction at sampling site 14 is due to the higher frequency of mica schist fragments noted in stone counts (see Fig. 8 a).

Traverse II exhibits the same features as traverse I, and the marked influence of local granodiorite and microcline granite on the till is apparent. Owing to the provenance of granitoids at the first sampling site 19, in the distal portion of the 7 km long granitoids area, the local material shows high abundances, 89—93 %, in the three coarser fractions, 78 % in the coarse sand fraction, and the least, 49.5 % in the medium sand fraction.

Granitoid debris in the till disappears rapidly 2 km from the distal contact of the granitoids area. At sampling site 21 the content is about half of that at sampling site 19. In the 20—200 and 6—20 mm fractions the content decreases gradually with the increase in distance. The same is true of the 2—6 mm fraction with some exceptions. In the coarse sand fraction the content of granitoids at a distance of 6 km from the distal contact of the granitoids area, is higher than in any other grain size studied, owing to the influence of comminution. The 0.2—0.6 mm fraction is distributed irregularly along both traverses, partly because many of the grains are already monomineralic.

Local material makes a rapid appearance in the till along traverse II down-glacier from the proximal contact of the microcline granite area. At sampling site 27, at a distance of 2 km from the proximal contact, the 20—200, 6—20, 2—6 and 0.6—2 mm fractions are 50 to 60 % local material, in spite of the small mica schist occurrence. The highest content, 86—90 % in three coarser fractions, is at sampling site 30, which lies 7 km down-glacier from the proximal contact. Virkkala (1969 a) reports a frequency of 70—90 % local material in the till in the southern and middle parts of the same Hämeenlinna microcline granite area. The decrease of local material distally from sampling site 30 in the five fractions studied is due to the increased content of basic volcanics (see Fig. 7 b). In four fractions, 20—200, 6—20, 2—6 and 0.6—2 mm in the till of the microcline granite area, the numbers of grains counted were almost equal.

In places, the 0.2—0.6 mm fraction seems to behave like the coarser fractions, except at No. 15, where the medium sand fraction shows lower frequencies owing to the numerous monomineralic grains in this sample. At No. 29, the contents of granitoids in the coarse and medium sand fractions are surprisingly high, as is the higher degree of roundness of the quartz grains (see Fig. 37 b, p. 59). These fractions seems to contain material that had been transported a long distance.

Basic volcanics

The basic volcanics include uralite porphyrite, uralite plagioclase porphyrite, plagioclase porphyrite and basic and intermediate tuffite. Like the granitoids, the basic volcanics play a key rôle in the petrography of the basal till in the investigation area (Figs. 7 a and b).

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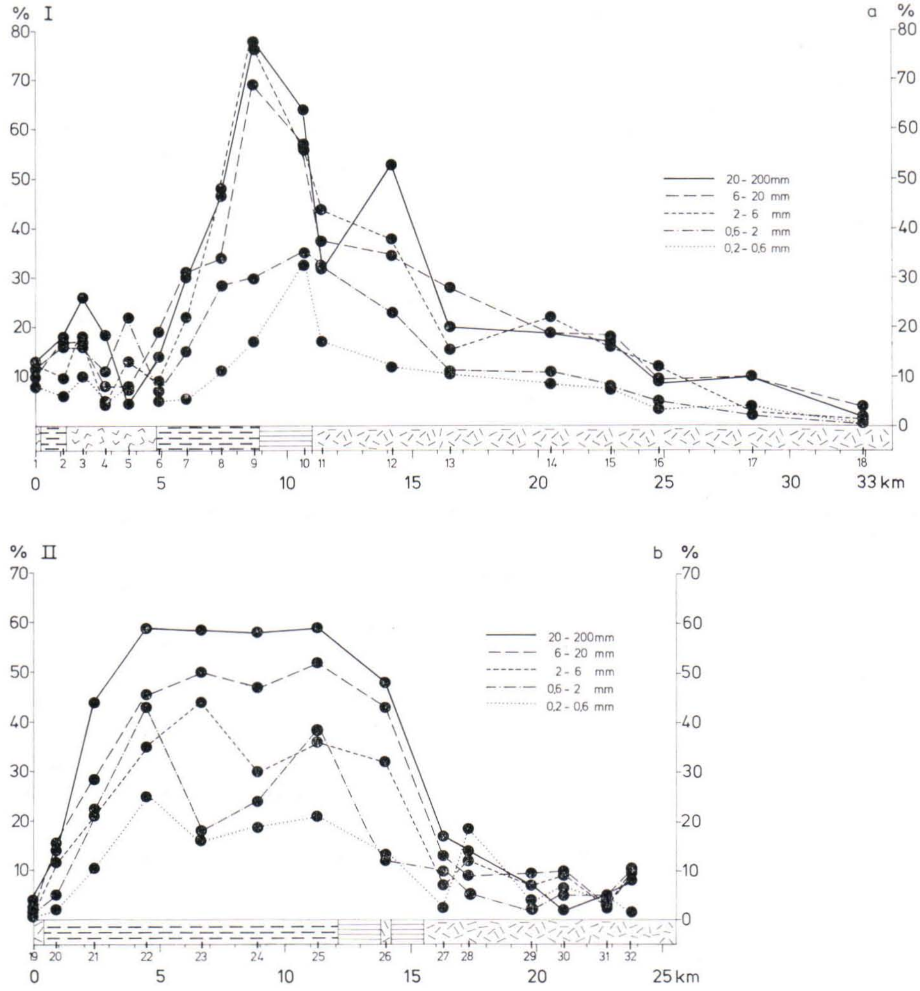


Fig. 7. Basic volcanics in different fractions along a) traverse I, b) traverse II. Key to bedrock symbols in Fig. 5.

Along traverse I, there are only small areas of basic volcanics, one of which is 1 km long and the other 4 km in the direction of ice flow. The smaller area has only a slight influence on the till. Up-glacier from the nearest basic volcanics area, the amount of basic volcanics in five fractions of till is 5—20 %. This rock material begins to increase gradually at the proximal contact, until at the last sampling site 9, 4 km down-glacier from the proximal contact, the content of local bedrock in the till is extremely high, as could be expected. About 1 km down-glacier from the proximal contact, the content has risen from about 50 % at sampling site 8 to almost 80 %

(No. 9) in three of the coarser fractions 20—200, 6—20 and 2—6 mm. In the sand fractions, the content is still low, being 30 % in the 0.6—2 mm fraction and 17 % in the 0.2—0.6 mm fraction, as typical of local till.

Two km down-glacier from the distal contact at sampling site 10, the content of basic volcanics begins to decrease. In the coarser fractions it is still rather high, about 56—64 %. Over the same distance in the sand fractions, the basic volcanics show a different behavior. They rise to about 35 %, as result of comminution. Within the next kilometer, at sampling site 11, the content of basic volcanics suddenly decreases to 32—37 % in the 20—200 and 6—20 mm fractions, which is a deficient amount, but less so in the 2—6 mm fraction, that is from 56 % to 44 %. In the 0.6—2 mm fraction, the decrease is only a few per cent. In the 0.2—0.6 mm fraction, the decrease is more, from 32.5 % to 17 %, as in the three coarser fractions. Down-glacier from sampling site 11, the basic volcanics decrease gradually with a few exceptions in the fractions of 20—200 and 2—6 mm. At sampling site 12, 5 km down-glacier from the distal contact, the basic volcanics exhibit a high content (53 %) in the 20—200 mm fraction. It is possible that some large boulders have been crushed at this spot and produced particles of over 20 mm. In the 20—200 and 2—6 mm fractions at sampling site 13 the basic volcanics show a deficiency. This heterogeneity of till is often reported by investigators of till petrography (Hellaakoski 1930, Dreimanis and Vagners 1969, Virkkala 1969 a, Lindén 1975).

Along traverse II, an area of basic volcanics, about 11.5 km in length, stretches in the direction of the ice flow. Up-glacier from the proximal contact, the till contains less than 5 % basic volcanics. At the first sampling site 20, 0.5 km down-glacier from the proximal contact, the content of local material is only 10—15 % in the three coarser fractions, 5 % in the coarse sand fraction and only 2 % in the medium sand fraction. At the next sampling site 21, after a transportation distance of 1.5 km, the content of basic volcanics rises to 44 % in the 20—200 mm fraction; it is lower, 20—30 %, in the 6—20, 2—6 and 0.6—2 mm fractions, and lowest, 10 %, in the medium sand fraction. Yet once more this is typical behavior of local till. Furthermore, the content of local material rises; at sampling site 22 it is 15 % higher in all fractions except the 0.6—2 mm fraction. The coarse sand fraction doubles. The content varies clearly, from 25 to 59 %, in the different fractions. After being transported a further 8 km, the basic volcanics in the 20—200 mm fraction remain constant (about 60 %), contrary to the behavior of this rock material along traverse I. The 6—20 mm grade displaces the same type of curve as the 20—200 mm fraction. The deficiency of local material is most marked in the 2—6 mm fraction at sampling site 24, but in fractions coarser than this it is only vaguely observable. At sampling sites 22 and 25, the 0.6—2 mm fraction is quite rich in local basic volcanics, richer than the 2—6 mm fraction. Along traverse II, the 0.6—2 mm fraction of till of basic volcanics shows uneven comminution. The curve of the 0.2—0.6 mm fraction is the same as that of the 0.6—2 mm fraction. The frequencies, however, are lower, from 15 to 25 %, which is the lowest of all the fractions studied. As a whole, in till located in basic volcanic areas, the provenance of local rock material decreases with diminishing grain size.

The rather low and regular content of basic volcanics in till composed of local bedrock may be attributed to the large amount of non-local material, especially mica schists and mica gneisses (see other rock types, pp. 20—21). The stone counts of the 2—10 cm fraction reported by Virkkala (1969 a, p. 16—18) from the investigation area show the same features in the distribution of basic volcanics in the till of this area as mentioned in the foregoing.

Over the first 3 km, down-glacier from the distal contact, the basic volcanics decrease gradually in the three coarser fractions. The same is true of the medium sand fraction, but in the 0.6—2 mm fraction they decrease rapidly from about 40 % (No. 25) to 12 % (No. 26).

At a greater distance from the distal contact, heterogeneous comminution of basic volcanics causes a slight irregularity in the distribution curves of all the fractions studied except that of 20—200 mm. For a distance of 2 km distally from sampling site 26, the content of basic volcanics decreases rapidly (as along traverse I) to about 5—20 % in different fractions at sampling site 27, but down-glacier from this site the rate of decrease becomes lower and intermittent. A conspicuously high content of basic volcanics is visible at the last sampling site 32, 12 km down-glacier from the distal contact, possibly because of the proportion of till originating from englacial drift.

Other rock types

The next largest group of rock types in the region investigated are mica schists and mica gneisses, predominantly mica schists (Figs. 8 a and b).

Along traverse I, their content is less than 20 %, except at sampling site 10 in the till of mica schist area and at sampling site 11, just distally from this area. At sampling site 10, local material amounts to 25—30 % in the three coarser fractions (20—200, 6—20 and 2—6 mm), 20 % in the 0.6—2 mm fraction and 14 % in the 0.2—0.6 mm fraction. Distally, at sampling site 11, in the 20—200 mm fraction, the mica schists still constitute about 30 %, but in the other fractions they decrease to about 10 % in each fraction. At sampling site 14, the higher content in the 20—200 mm fraction than in the nearest may be due to the crushing of large mica schist boulders.

Along traverse II, the mica schists and mica gneisses play an important rôle in the petrography of the basal till.

The content of mica schists and mica gneisses is surprisingly high along traverse II in the till of basic volcanic bedrock. Their content is 20—40 % in all the fractions studied, except the 0.2—0.6 mm fraction, which contains less than 10 % mica schists and mica gneisses.

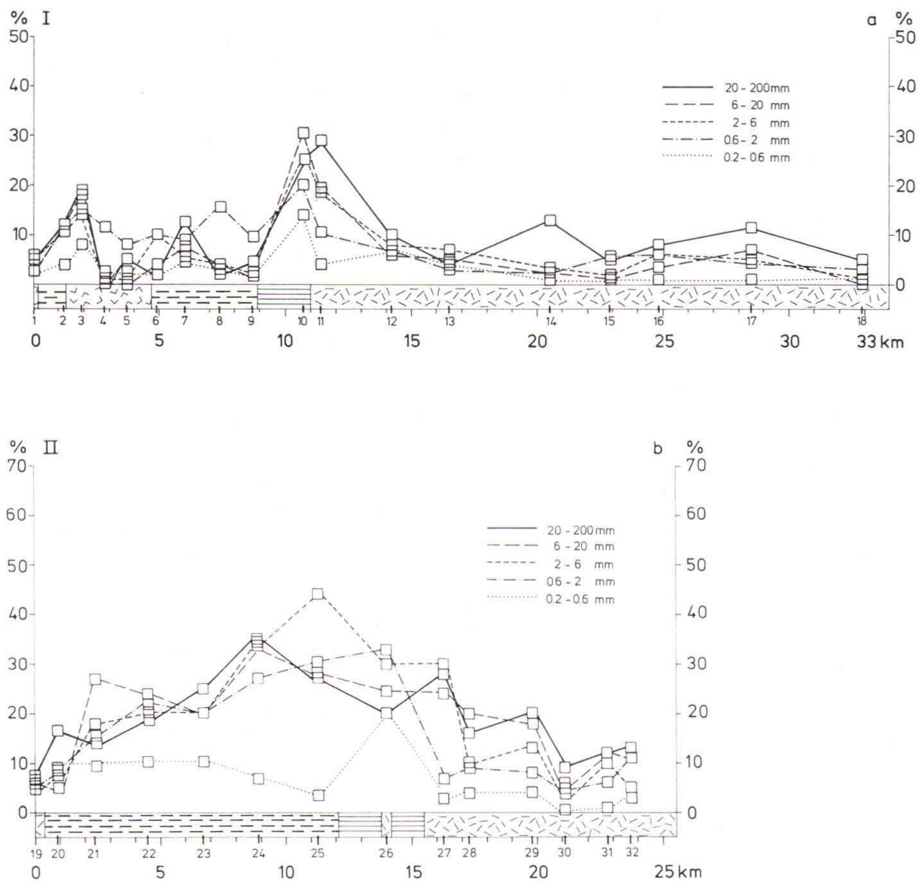


Fig. 8. Mica schists and mica gneisses in different fractions along a) traverse I, b) traverse II. Key to bedrock symbols in Fig. 5.

At sampling sites 23, 24 and 25, the mica schists and mica gneisses have been transported from the extensive areas occupied by these rock types northwest of Lehijärvi. This explains the surprisingly low content of local basic volcanics in the till along traverse II.

Leptites are encountered in only small amounts (less than 10 %), but especially at the starting point of traverse II they have some influence on the results discussed in this investigation.

The gabbro body southwest of sampling sites 23—25 has no significance in the petrography of the till investigated.

TRANSPORTATION OF ROCK TYPES AND MINERALS IN THE TILL

Rock types down-glacier from the distal contact

The transportation of the granitoids and basic volcanics was investigated by the application of a negative exponential function. The fractions used were 20—200, 6—20, 2—6, 0.6—2 and 0.2—0.6 mm.

Krumbein (1937) showed that the frequencies of a rock type in till decrease with an increase in the distance of the distal contact from the rock and that the decrease obeys a negative exponential function. In line with this, the results relating to the distribution of rock types, as measured down-glacier from the distal contact, have been dealt with according to the negative exponential function in which the amount (y) of any given rock type is represented as a function of distance (x) (Gillberg 1965, pp. 482—483) (Figs. 9 a—b, 10 a—b, 11 a—d, 12 a—b, 13 a—b, App. 1).

The negative exponential function is given by

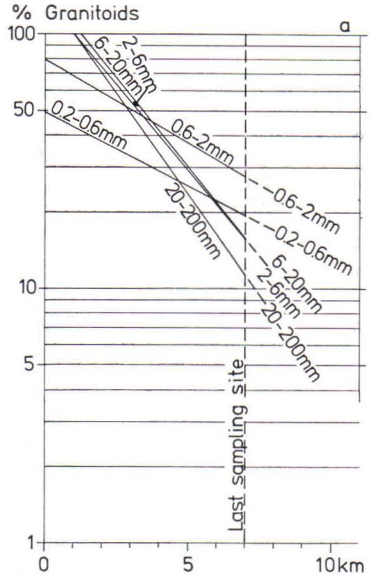
$$y = y_0 e^{-ax}, \text{ where}$$

y = frequency of rock type at distance x from the starting point
y_0 = frequency of rock type at the starting point (x_0)
e = 2,7182 the base of the natural logarithms
a = constant of lithologic nature
x = distance from starting point

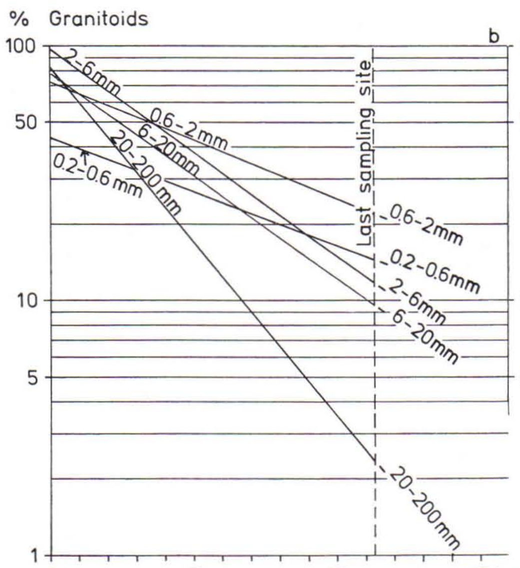
The values of lithologic nature a obtained represent the rate of decrease of the rock type down-glacier from the distal contact, or starting point. When the value a is high, the frequency of the rock type in the till decreases rapidly. The lower the value of a, the less rapidly does the amount of the rock type in the till diminish. If the values of a differ in different fractions of the same rock type, it indicates that the rock type comminute faster in some fractions than in other fractions or the rock type is more resistant in some fractions. The constant a depends on different factors (Krumbein 1937). They are, e.g., the material, the topography and the glacial activity (Gillberg 1965). The number of samples also to some extent influences the lithologic nature of a. Therefore the values for one rock type are likely to vary somewhat also in the same area.

The correlation coefficients r calculated give an idea of the suitability of the negative exponential function to the sample material. If $r = \pm 1$, the correlation is complete. If $r = \pm 0$, no correlation exists between the distribution line and the sampling sites.

The computations were carried out with the linear regression program of the Hewlett-Packard calculator model 9100 B. It was used to calculate the constants of lithologic nature a as well as the correlation coefficients r. The program likewise served to calculate the frequencies of the rock type (y) at the starting point (y_0) and

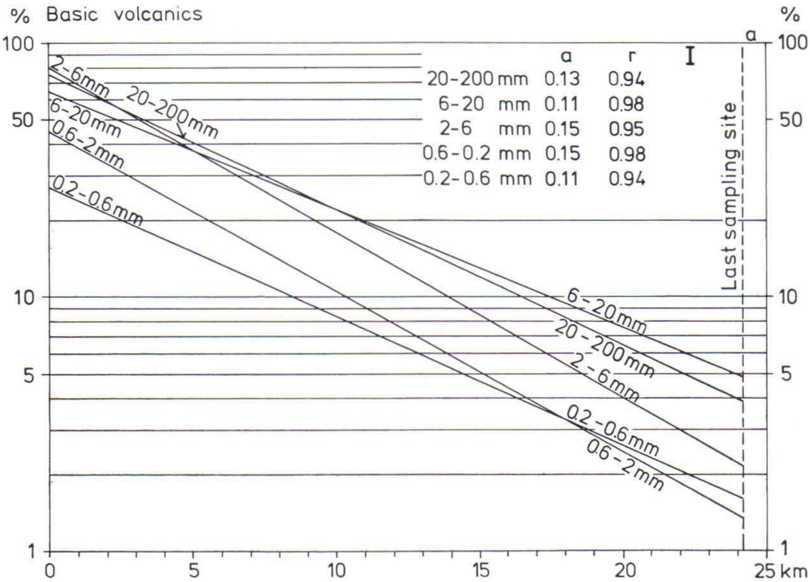


I		a	r
20 - 200	mm	0.34	0.97
6 - 20	mm	0.29	0.96
2 - 6	mm	0.29	0.95
0.6 - 2	mm	0.15	0.87
0.2 - 0.6	mm	0.13	0.75



II		a	r
20 - 200	mm	0.32	0.96
6 - 20	mm	0.19	0.97
2 - 6	mm	0.19	0.97
0.6 - 2	mm	0.10	0.87
0.2 - 0.6	mm	0.10	0.81

Fig. 9. Distribution lines of granitoids in different fractions down-glacier from the distal contact along a) traverse I, b) traverse II. Semilogarithmic scale. a = constant of lithologic nature, r = correlation coefficient.



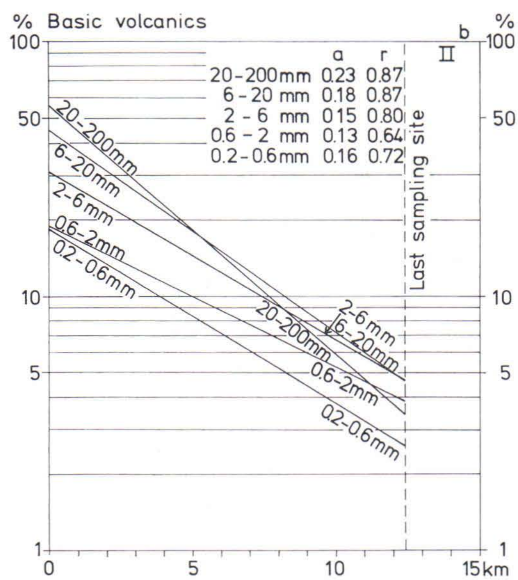


Fig. 10. Distribution lines of basic volcanics in different tractions down-glacier from the distal contact along a) traverse I, b) traverse II. See explanations given in Fig. 9.

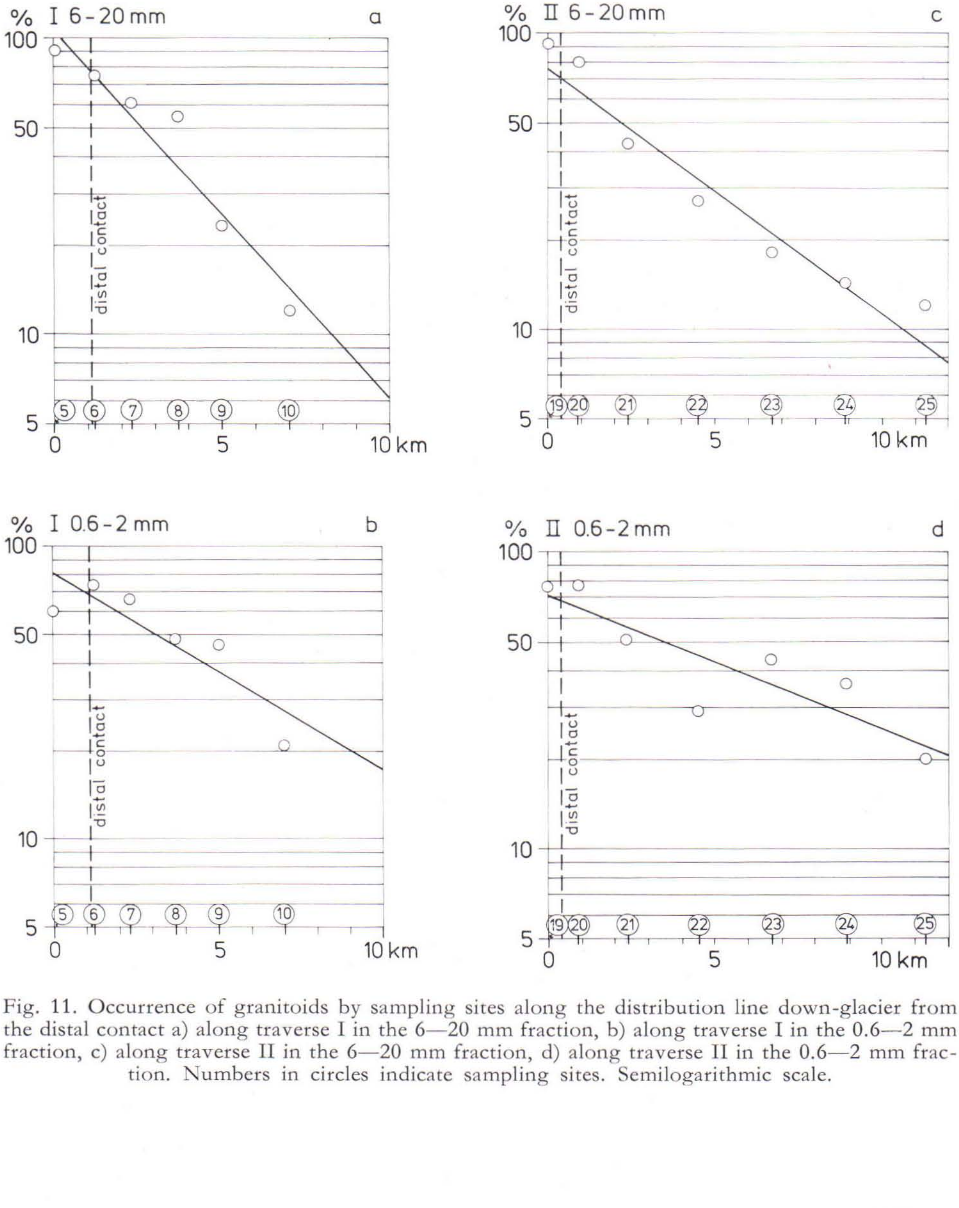


Fig. 11. Occurrence of granitoids by sampling sites along the distribution line down-glacier from the distal contact a) along traverse I in the 6—20 mm fraction, b) along traverse I in the 0.6—2 mm fraction, c) along traverse II in the 6—20 mm fraction, d) along traverse II in the 0.6—2 mm fraction. Numbers in circles indicate sampling sites. Semilogarithmic scale.

at a distance of 10 km (y_{10}). The regression lines (=the distribution lines, Gillberg 1965) were drawn on a semilogarithmic scale. The program has calculated for each distribution line the least square fits in relation to the frequencies of the rock types at the sampling sites — this being done separately for the granitoids and the basic volcanics. Selected to serve as the starting point was the last sampling site near the distal contact.

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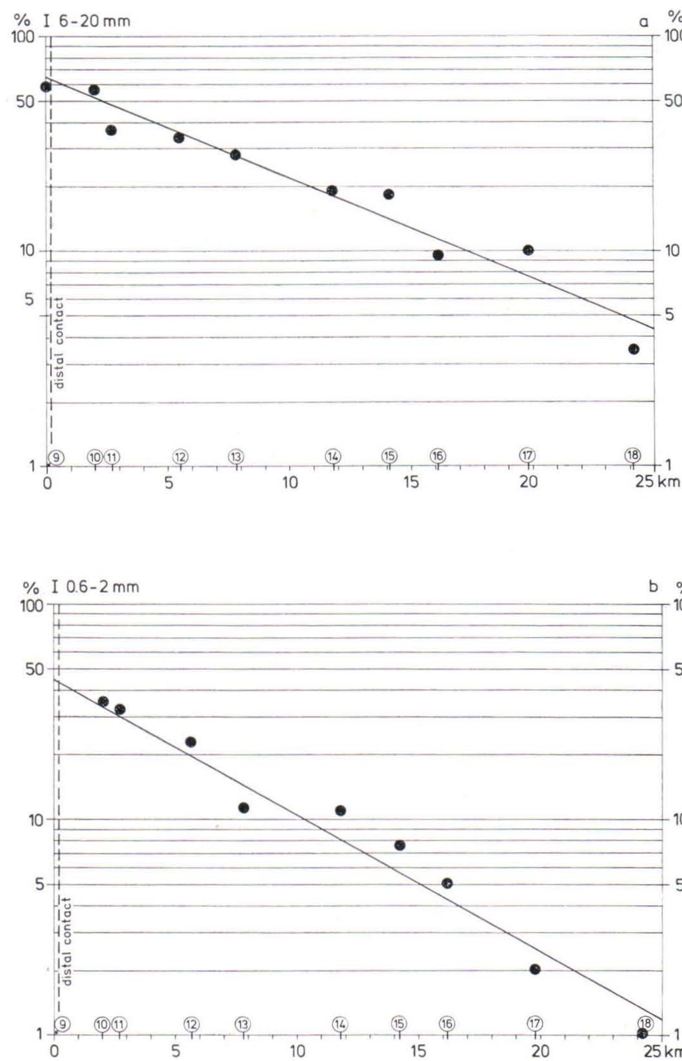

Fig. 12. Occurrence of basic volcanics by sampling sites along the distribution line down-glacier from the distal contact along traverse I a) in the 6—20 mm fraction, b) in the 0.6—2 mm fraction. Semilogarithmic scale.

The half-distance value is $x_{1/2}$. It means the distance at which the frequency of a given rock type (y) has been halved from what the frequency (y_0) was at the starting point (x_0). The half-distance values were taken from distribution lines drawn to a semilogarithmic scale in the fractions investigated (Fig. 14).

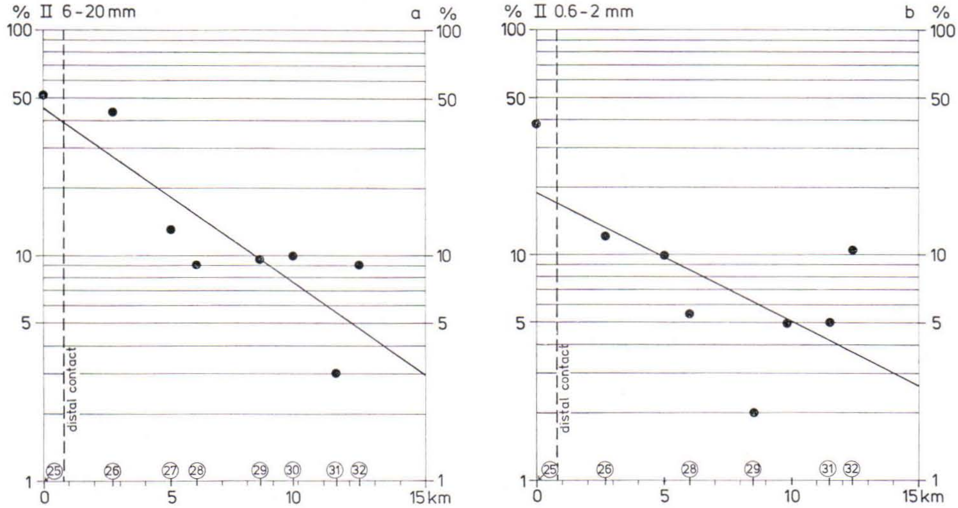

Fig. 13. Occurrence of basic volcanics by sampling sites along the distribution line down-glacier from the distal contact along traverse II a) in the 6—20 mm fraction, b) in the 0.6—2 mm fraction. Semilogarithmic scale.

The correlation coefficients *r* for the granitoids vary along traverse I between 0.97 and 0.75 (Fig. 9 a) and along traverse II between 0.97 and 0.81 (Fig. 9 b). For the basic volcanics, they are along traverse I 0.98—0.94 (Fig. 10 a) and along traverse II 0.87—0.64 (Fig. 10 b). In considering the suitability of the sampling sites to the distribution lines (Figs. 11 a—b, 12 a—b and 13 a—b) and the correlation coefficients *r*, one will note that the sites fit the lines rather well for granitoids in four coarser fractions and so conform to the negative exponential function best. In the 0.2—0.6 mm fraction, the correlation is not so good. This is because of the greater amount of monomineralic grains. For the basic volcanics, the correlation is rather good along traverse I in all the fractions studied. Along traverse II the correlation is not so good as along traverse I, and it is poorest in the sand fractions, 0.6—2 and 0.2—0.6 mm.

The values obtained for the lithologic nature *a* vary in the case of the granitoids 0.34—0.13 (traverse I) and 0.32—0.10 (traverse II) (Figs. 9 a and b). In the case of the basic volcanics, the values of *a* vary 0.15—0.11 (traverse I) and 0.23—0.13 (traverse II) (Figs. 10 a and b). In this light, it is to be seen that differences occur between the fractions (0.2—200 mm). The values of *a* for the granitoids decrease with diminishing grain size. In the fractions 6—20 and 2—6 mm, however, they are the same — as also in the 0.6—2 mm and 0.2—0.6 mm fractions. The values of *a* for the basic volcanics vary somewhat, though unsystematically in the different fractions.

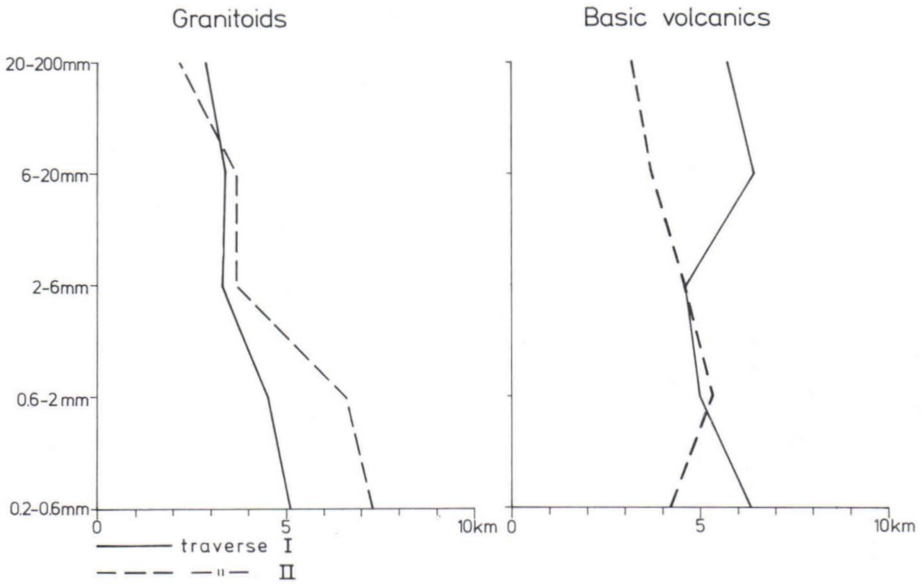

Fig. 14. Diagrams representing half-distance values ($x_{1/2}$) of granitoids and basic volcanics calculated from distribution lines.

The values for lithologic nature *a* show that the distribution of the granitoids deviates from that of the basic volcanics in the till in different fractions. In the following, they are examined in the light of the half-distance values ($x_{1/2}$).

The values for the constant *a* show that the granitoids comminute faster in the coarser than in the finer fractions. The basic volcanics are approximately equally resistant to comminution in the fractions ranging from 0.2 to 200 mm.

The half-distance values of the granitoids show the transportation distances to be shorter in the 2—200 mm fractions (traverse I 2.9—3.4 km; traverse II 2.2—3.7 km) than in the sand fractions 0.2—2 mm (traverse I 4.5—5.1 km; traverse II 6.6 —7.3 km) (Fig. 14, Table 1). Also Virkkala (1971) noted the first clear differences during the glacial transportation in the grain size of 0.6—2 mm.

In detail, in the 20—200 mm fractions (large and small stones), the transportation distance of the granitoids is shorter (h—dv traverse I 2.7 km; traverse II 2.2 km) than in the gravel fractions 6—20 mm (coarse gravel) and 2—6 mm (fine gravel) (h—dv traverse I 3—3.1 km; traverse II 3.7 km). On the other hand, the difference between these two gravel fractions cannot be detected in the half-distance values, though in individual samples it does become evident as a slight maximum in the 2—6 mm fraction (Appendix 1). In the 2—200 mm fractions the average half-distance values are 2.9 km (traverse I) and 3.2 km (traverse II). In the 0.2—0.6 mm fraction, the granitoids show a slightly longer transportation distance (h—dv trav-

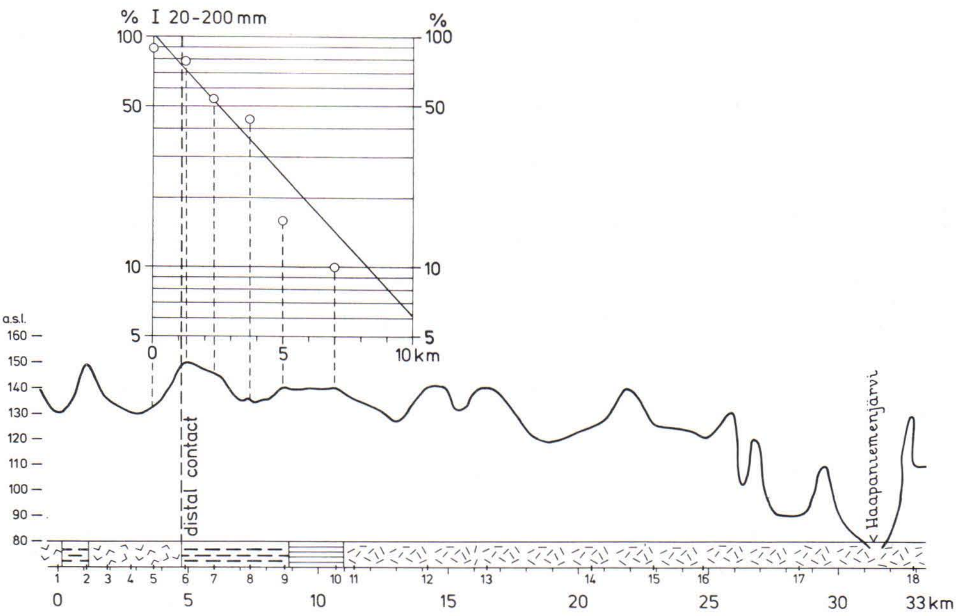

Fig. 15. Occurrence of granitoids along the distribution line in the 20—200 mm fraction in relation to topography down-glacier from the distal contact along traverse I. Key to bedrock symbols in Fig. 5.

erse I 5.1 km, traverse II 7.3 km) than in the coarse sand fraction (0.6—2 mm) (h—dv traverse I 4.5 km; traverse II 6.6 km). In the sand fractions the average half-distance values are 4.8 km (traverse I) and 7.0 km (traverse II).

The average half-distance values for the granitoids are 3.7 km (traverse I) and 4.7 km (traverse II).

In the fractions studied, the half-distance values for the basic volcanics vary between 4.6 and 6.4 km (traverse I) and 3.1 and 5.4 km (traverse II). Their average half-distance values are 5.6 km (traverse I) and 4.2 km (traverse II).

The changes in the different size grades during glacial transportation cannot be detected in the case of the basic volcanics, which differ in distribution behavior from the granitoids. This is probably due to the fact that, as bigger rock fragments the basic volcanics are resistant to comminution, as Virkkala (1969 a) has likewise observed. As they diminish in size, the principal mineral, hornblende is not as resistant as quartz, plagioclase and potassium feldspar (Goldich 1938), and so hornblende tends more readily to undergo comminution. For this reason, the differences in the transportation of basic volcanics between the grade sizes even out as a result of comminution. This finding corresponds to the results of the crushing and grinding experiments done by Niini (1963, 1967) with the amphibolites of Lapland (the main

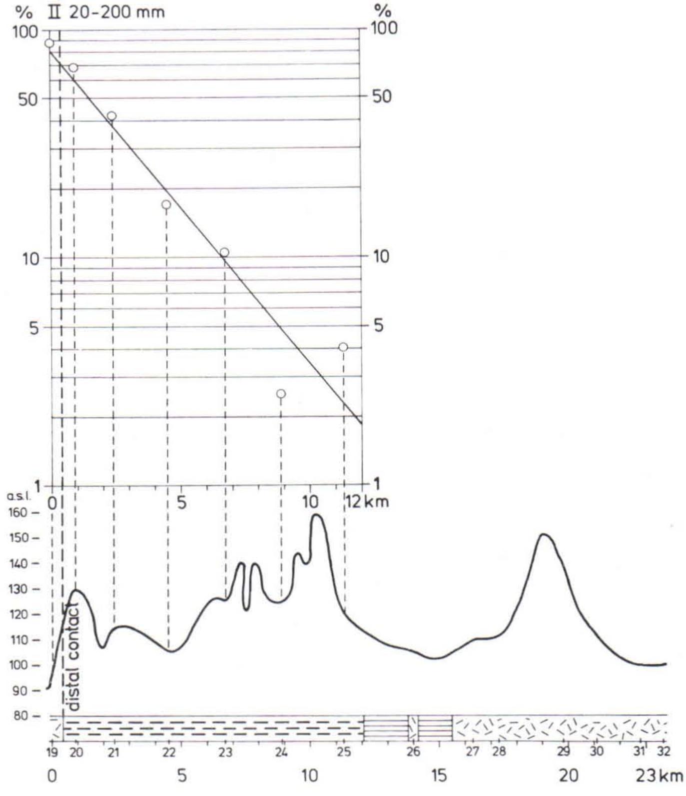

Fig. 16. Occurrence of granitoids along distribution line in the 20—200 mm fraction in relation to topography down-glacier from the distal contact along traverse II. Key to bedrock symbols in Fig. 5.

mineral of which is hornblende). In large fragments, they resist comminution exceedingly well. In small grain sizes, on the other hand, they are less resistant compared, for instance, with the results obtained with granites in the same study. Also in the region of Hämeenlinna, the granitoids is the harder to crush, the smaller the fragment of rock.

In the 20—200 mm grade, the rock types in the till were observed at certain sampling sites to behave exceptionally (Figs. 11, a—d, 12 a and b, 13, a and b).

When the rock types contained in till were compared with respect to the frequency of their occurrence in relation to the topography (Figs. 15—18), it was noted that the topography of the region has contributed somewhat to the petrography of the till.

At sampling site 25, there is an excess of granitoids in relation to the distribution line (Fig. 16). The sampling site lies on a distal descending terrain in relation

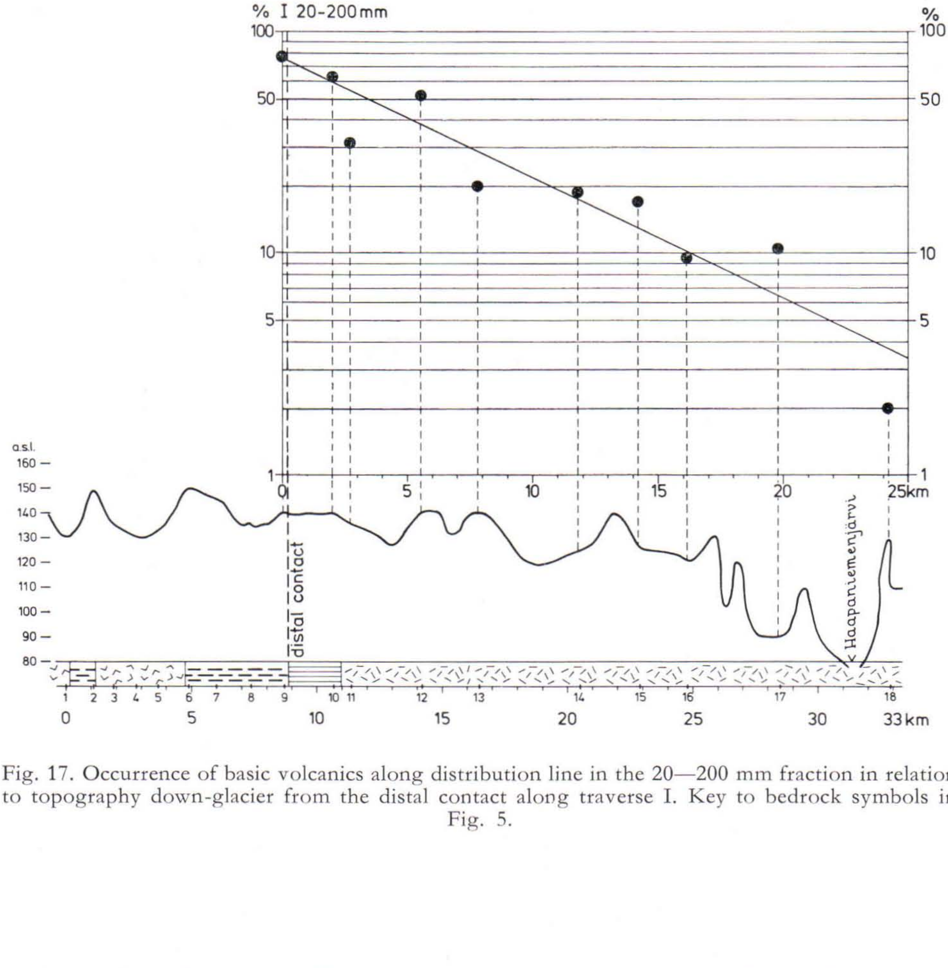

Fig. 17. Occurrence of basic volcanics along distribution line in the 20—200 mm fraction in relation to topography down-glacier from the distal contact along traverse I. Key to bedrock symbols in Fig. 5.

to the ice flow. An excess of basic volcanics in relation to the distribution lines occurs in many places. They occur at Nos. 12, 15, 17, 26 and 32 (Figs. 17 and 18). The sampling sites are located in depressions, and also on the proximal ascending or distal descending terrain in relation to the ice flow. The non-local rocks appear to have been deposited in these places in large amounts. This deposition depends on pressure fluctuations owing to flow in the areas, where the bedrock hummocks have different shapes and sizes (Boulton 1975).

On the other hand, deficient amounts of the non-local rock types in relation to the distribution lines are met with mainly on level or higher terrain (see Boulton 1975). Such is also the case at sampling sites Nos. 9, 10 and 24 with respect to the amount of granitoids, and basic volcanics (sampling sites 11, 13 and 18). The exception is No. 30, where the basic volcanics are on a distal descending terrain in relation to the ice flow.

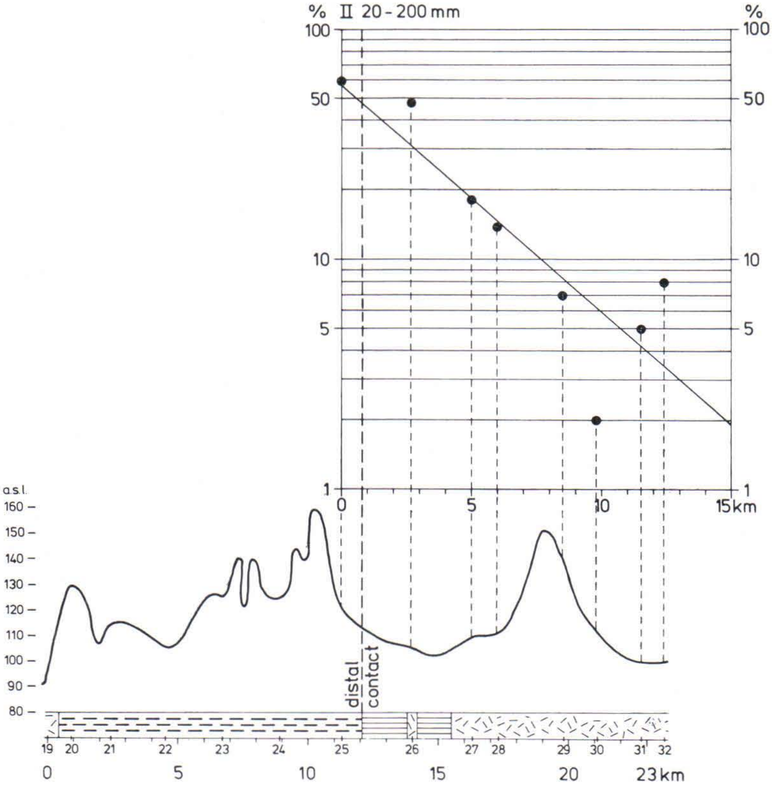

Fig. 18. Occurrence of basic volcanics along distribution line in the 20—200 mm fraction in relation to topography down-glacier from the distal contact along traverse II. Key to bedrock symbols in Fig. 5.

Afore-mentioned behavior of the non-local rock types in till is typical and particularly so in the coarser fractions (2—200 mm), but the same behavior is for the most part to be observed also in the 0.2—2 mm fractions.

The gradient of distribution lines obtained for both rock types (Figs. 9 and 10, a and b) are rather steep, especially in the clast sizes (over 2 mm). This means that the material was deposited near its bedrock source and it is thus proximally concentrated. The principal glacial activity had a crushing effect (Gillberg 1967 b). In the 0.2—2 mm fractions, the gradient of distribution lines of the granitoids is less steep, for new material was received during the glacial transportation from the coarser fractions, which extends the transportation distance (Gillberg 1965).

In the proximity of the distal contact, the granitoids and basic volcanics occur in large amounts in the coarser fractions and in the least quantities granitoids occur in the 0.2—0.6 mm fraction and basic volcanics in the 0.2—2 mm fractions. The

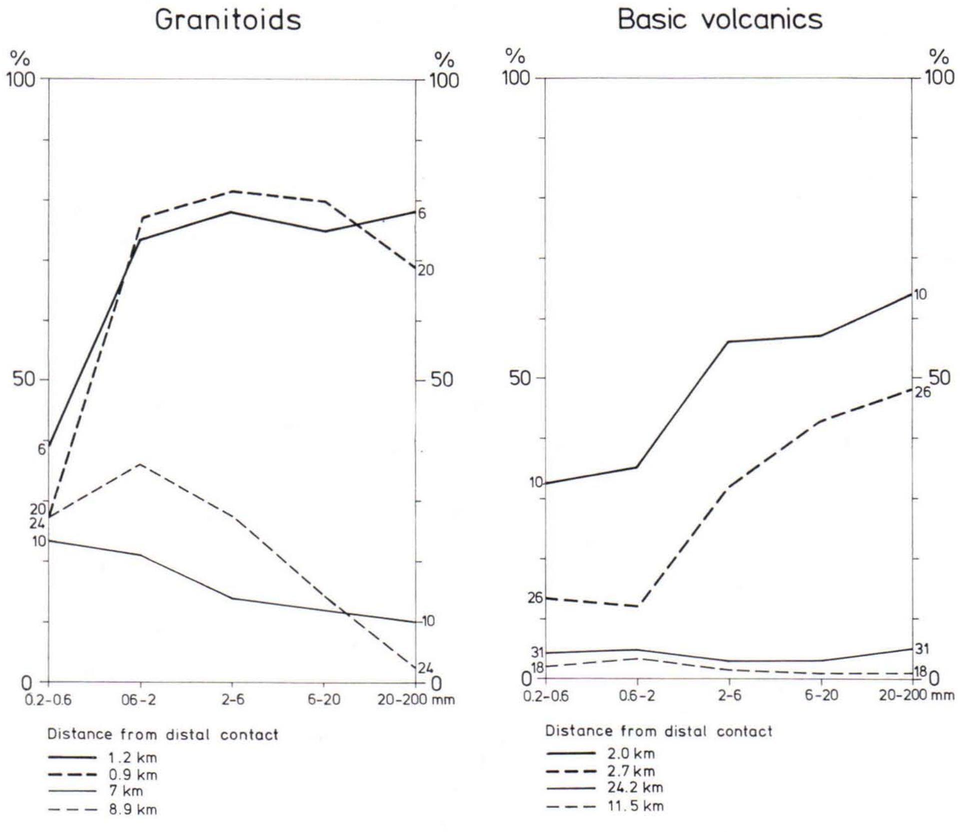

Fig. 19. Contents of granitoids and basic volcanics in different fractions of some samples down-glacier from the distal contact. Close to the distal contact occurs a clast mode. Farther down-glacier from the distal contact there occurs a matrix mode, but only in the case of the granitoids. Continuous line = traverse I, broken line = traverse II.

rock types form a clast mode (Fig. 19) (Dreimanis and Vagners 1969, 1971 a). Farther from the starting point, more granitoids are present in the sand fractions (0.2—2 mm) than in the coarser fractions, the maximum appearing mainly in the 0.6—2 mm fraction. This represents the matrix mode (Dreimanis and Vagners 1969). On the other hand, farther from the distal contact, basic volcanics occur in approximately the same or smaller amounts in the sand fractions than the coarser fractions. The basic volcanics do not form a matrix mode.

The concentration of the granitoids and basic volcanics close to the distal contact appears to be the lithologic nature of the basal till in southern Finland too (Sauramo 1924, Hellaakoski 1930, Virkkala 1958, 1969 a, 1969 b and 1971). The occurrence of local material in predominant measure seems to be in the nature of all glacial transportation and typical of basal till (Salisbury 1900, Gillberg 1965, Flint 1971, Lindén 1975).

The varying half-distance values of the granitoids and basic volcanics as well as the variations of the constant of lithologic nature *a* along both traverses are affected by the factors described by Gillberg (1965, p. 482). These are the properties of the source rock, the topographical factors as noted in the foregoing, and glacial activity, such as comminution, transportation and accumulation of material, as exemplified by the uneven occurrence of mica schists and mica gneisses.

Rock types down-glacier from the proximal contact

The results pertaining to the increase of the microcline granite in the basal till, as measured down-glacier from the proximal contact, in the 0.2—200 mm fractions were dealt with by means of the exponential function (Figs. 20 a—b, 21 a—b, 22 a—b, App. 1). The increase in the amount of basic volcanics does not show much similarity along the two traverses, so they are not discussed here.

Since a decrease in the frequency of rock types contained in basal till down-glacier from the distal contact obeys a negative exponential function, as shown in this investigation, it may be correspondingly assumed that in some cases an increase in the content of a rock type in basal till starting from the proximal contact obeys the following exponential function:

$$y - y_0 = (y_\infty - y_0)\,(1 - e^{-ax}), \text{ where}$$

y = frequency of rock type at distance x down-glacier from starting point
y_∞ = frequency of rock type at an infinite distance down-glacier from the proximal contact = 100 %
y_0 = quantity of rock type at proximal contact (x_0)
e = 2,7182 the base of the natural logarithms
a = constant of lithologic nature
x = distance from starting point

The constant of a lithologic nature *a* may again be calculated with the linear regression program by assuming that y_∞ = 100 %.

Point 0, or the starting point, is at the proximal contact of the rock type, or at the place where the rock type begins in the bedrock.

The correlation coefficients *r* for the microcline granite vary between 0.95 and 0.83 (traverse I) and 0.86—0.51 (traverse II) (Figs. 20 a and b). Along traverse I, the correlation is rather good, but in traverse II, in the 0.2—2 mm fractions, the sampling sites fit the distribution lines less well (Figs. 21 and 22).

The smaller the constant of lithologic nature *a* is, the more slowly does the frebuency of the rock type in the till increase down-glacier from the proximal contact.

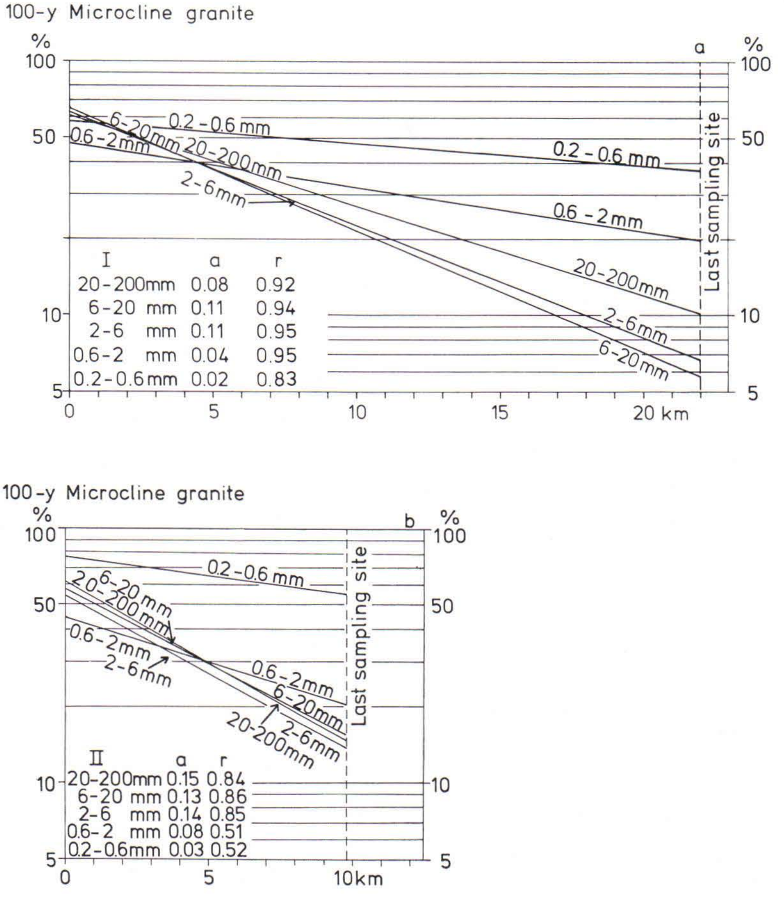

Fig. 20. Distribution lines of microcline granite in different fractions from the proximal contact along a) traverse I, b) traverse II. Semilogarithmic scale. See explanations given in Fig. 9.

Factors influencing the value of *a* are, for example, the properties of the source bedrock, the properties of the various types of rocks, the topography and the glacial activity.

The values of *a* of microcline granite vary between 0.11 and 0.02 (traverse I) and 0.15 and 0.03 (traverse II) (Figs. 20 a and b, Table 2). In the coarser fractions, 2—200 mm, the values of *a* are fairly similar in different fractions (*a* = I 0.08—0.11, II 0.15—0.13). In the coarse sand fraction, *a* is smaller but a little bigger (*a* = I 0.04, II 0.08) than in the medium sand fraction (*a* = I 0.02, II 0.03). Along traverse I, the values are slightly slower than along traverse II.

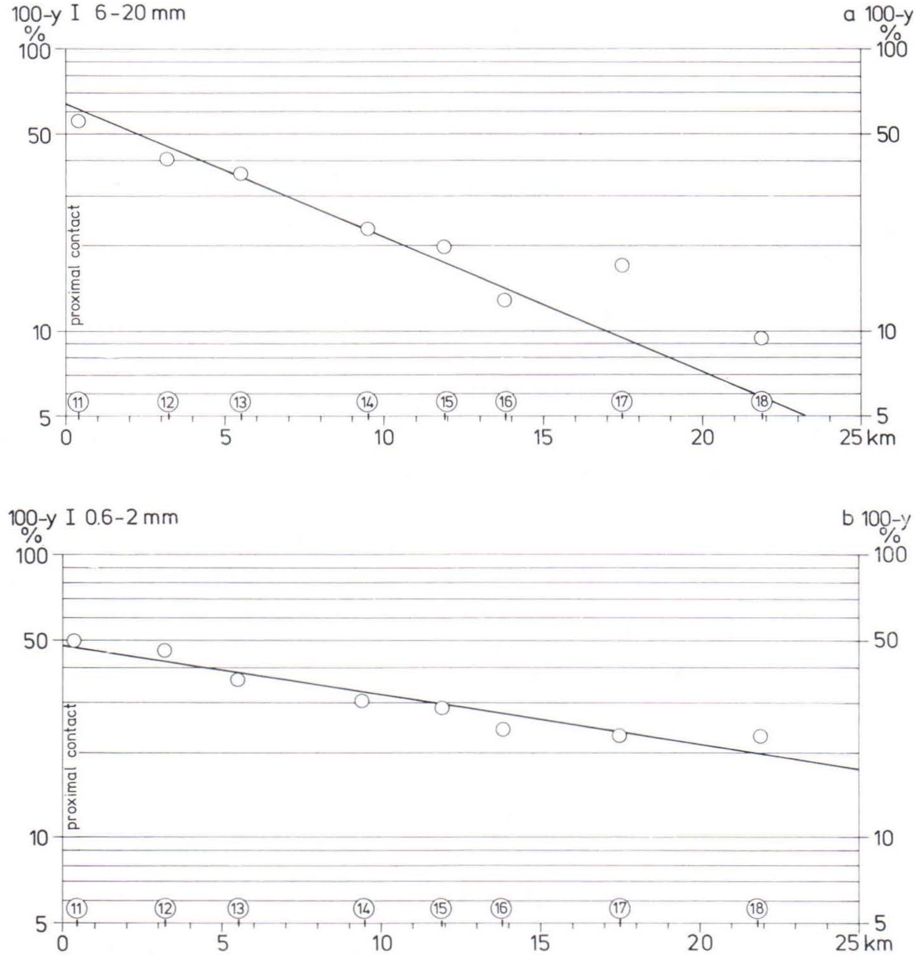

Fig. 21. Occurrence of microcline granite by sampling sites along distribution line down-glacier from the proximal contact along traverse I a) in the 6—20 mm fraction, b) in the 0.6—2 mm fraction. Semilogarithmic scale.

The microcline granite content near the proximal contact is the largest in the 0.6—2 mm fraction. This behavior is due to the granitoids transported from a greater distance that are present in the sand fractions. In the 0.2—0.6 mm, the content is equal to or smaller than in the 2—200 mm fractions.

According to distribution lines, the frequency of microcline granite increases along both traverses the most in the 2—200 mm fractions (Figs. 20 a and b, App. 1). The increase is smaller in the coarse sand fraction and smallest in the medium sand fraction.

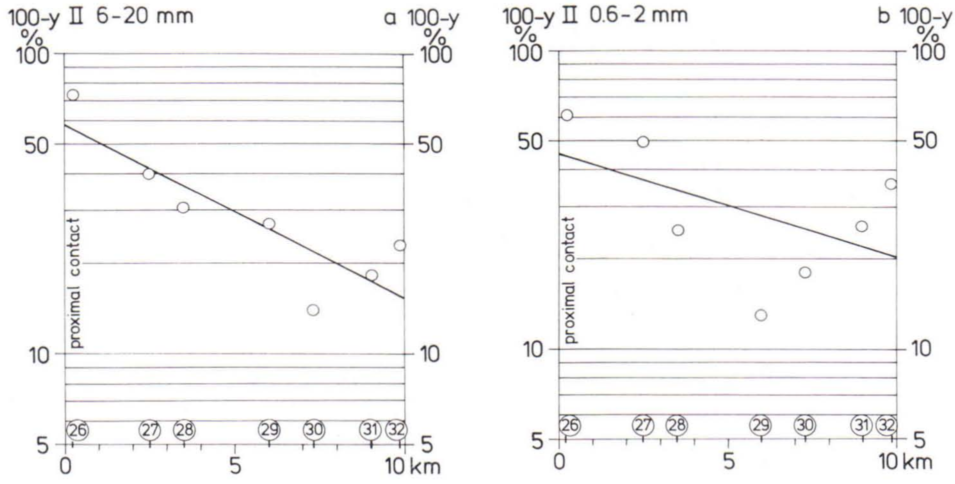

Fig. 22. Occurrence of microcline granite by sampling sites along distribution line down-glacier from the proximal contact along traverse II a) in the 6—20 mm fraction, b) in the 0.6—2 mm fraction. Semilogarithmic scale.

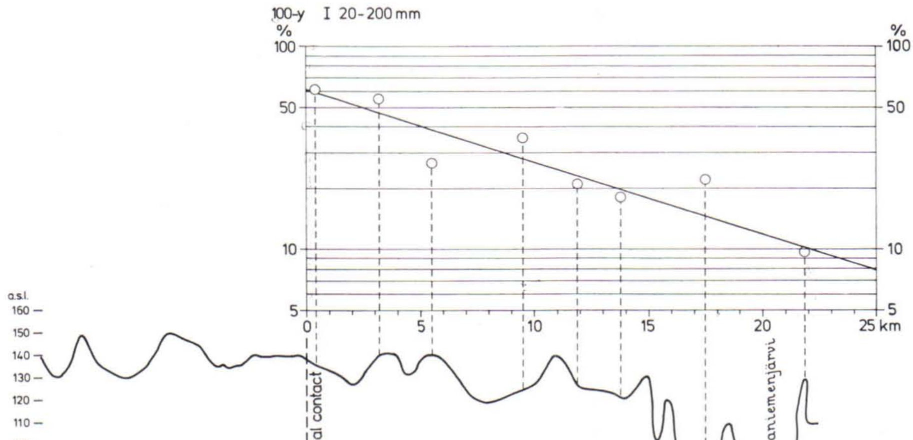

Fig. 23. Occurrence of microcline granite along distribution line in the 20—200 mm fraction in relation to topography down-glacier from the proximal contact along traverse I. Key to bedrock symbols in Fig. 5.

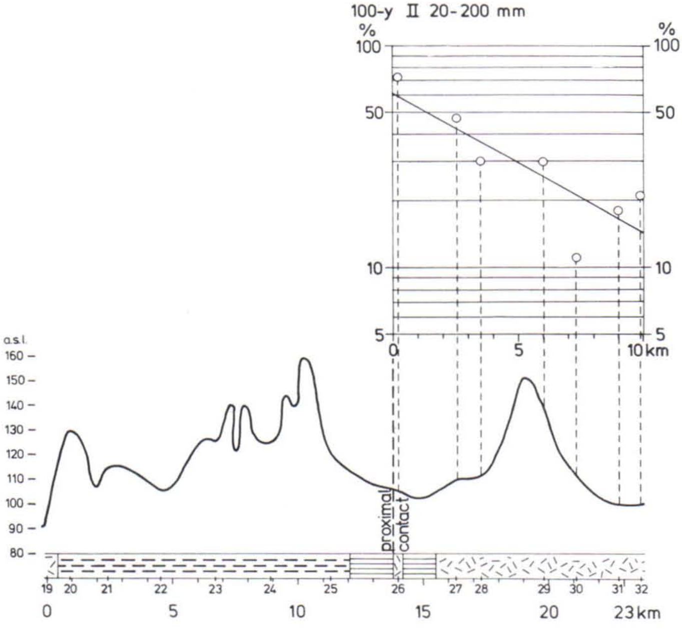

Fig. 24. Occurrence of microcline granite along distribution line in the 20—200 mm fraction in relation to topography down-glacier from the proximal contact along traverse II.

In the 0.6—200 mm fractions occurring, for example, 5 km down-glacier from the proximal contact, the microcline granite content of the till amounts to ca. 60—70 %. At the same distance, its content in the 0.2—0.6 mm fractions is about 35—50 %.

Ten kilometers down-glacier from the proximal contact, the amounts of microcline granite in the 2—200 mm fractions rise 15—20 %, signifying a content of about 75—80 % in the till along traverse I, and 85 % along traverse II. In the 0.6—2 mm and 0.2—0.6 mm fractions, the increase in the microcline granite content is slightly smaller. In the former fraction, its content rises by about 10 % along both traverses, or the amount of it in the till comes to 75—80 %. In the latter fraction (0.2—0.6 mm), the increase is about 10 % along traverse I and 5 % along traverse II. The microcline granite content is thus in this fraction just over 50 % along traverse I and 45 % along traverse II.

Along traverse I, where there occurs a more extensive uniform area of microcline granite, at the last sampling site, 22 km down-glacier from the proximal contact, the 2—200 mm fractions in the till consist of local material in concentrations of about 90 %, the 0.6—2 mm fraction about 80 % and the medium sand fraction still less, or about 65 %.

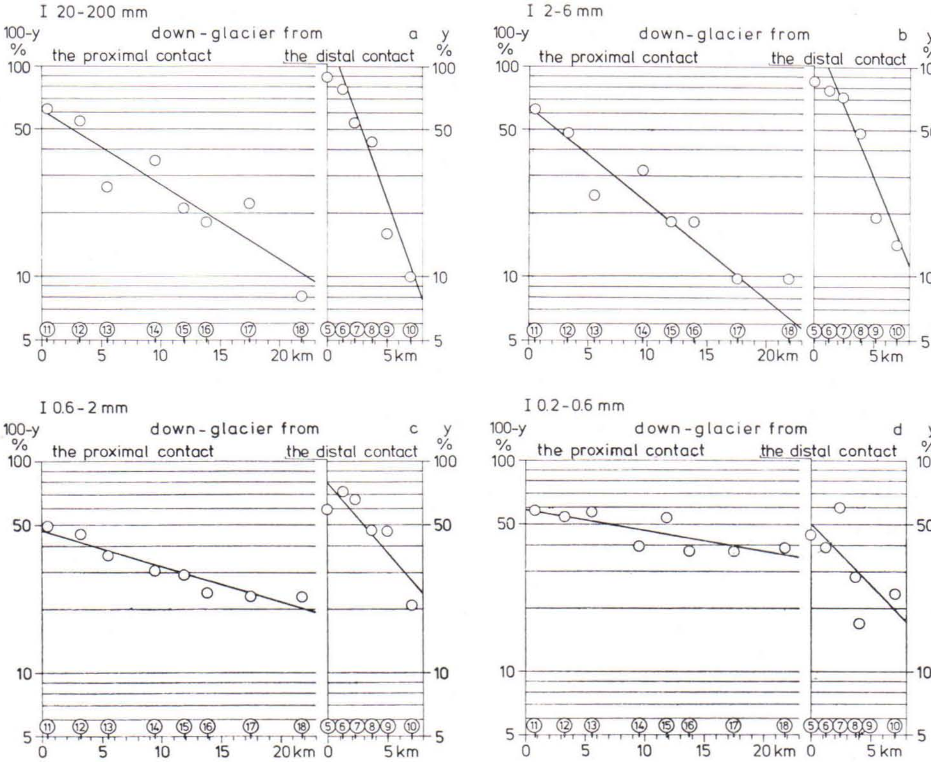

Fig. 25. Distribution lines of granitoids down-glacier from the proximal and distal contacts along traverse I a) in the 20—200 mm fraction, b) in the 2—6 mm fraction, c) in the 0.6—2 mm fraction, and d) in the 0.2—0.6 mm fraction. Semilogarithmic scale.

The influence of the topography on the petrography of the till down-glacier from the proximal contact in the 20—200 mm fraction is also to be observed as down-glacier from the distal contact (Figs. 23 and 24). An excess of local microcline granite in relation to the distribution lines occurs at sampling sites 13, 28 and 30. They all lie in different positions in the topography.

The content of local microcline granite is deficient at sampling sites 14, 17, 26 and 32, which all are situated on level terrain. This is the same as noted down-glacier from the distal contact. The rock material in the other fractions conforms mainly to the behavior of the 20—200 mm fractions. Deviations are met with mainly in the 0.2—2 mm fractions.

The values of *a* for microcline granite are higher down-glacier from the distal contact than down-glacier from the proximal contact. It means that the content of microcline granite decreased at a faster rate down-glacier from the distal contact than it increased in abundance in the till down-glacier from the proximal contact (Figs. 25 a—d).

Comparisons

The average distances of glacial transportation for granodiorite and tuffite (= basic volcanics) in till material in the over 20 mm grain size worked out in the Hämeenlinna region by Virkkala (1969 a) correspond to the transportation distances measured in the present study for granitoids and basic volcanics. This is true especially when the range of variation in the contents of the constituent rock types reported by Virkkala is taken into account.

On the basis of the data presented by Virkkala (1969 b, 1971) on the distribution of the microcline granite and gabbro of the Hyvinkää region and Hellaakoski's material (1930) on the distribution of the Laitila rapakivi, calculations have been made on the constants of lithologic nature *a* and the correlation coefficients *r* and the half-distance values ($x_{1/2}$) determined (Tables 1 and 2).

The correlation coefficients for microcline granite and gabbro in Virkkala's (1969 b, 1971) study are exceedingly good, except in the 0.6—2 mm fraction. It may be noted that in the Hyvinkää region the occurrence of these rock types in the till conforms to the exponential functions down-glacier from both the distal and the proximal contacts.

Table 1

Values of lithologic nature (*a*), correlation coefficients (*r*) and half-distance values ($x_{1/2}$) down-glacier from the distal contact

	granitoids						basic volcanics					
	a		r		$x_{1/2}$		a		r		$x_{1/2}$	
	I	II	I	II	I km	II km	I	II	I	II	I km	II km
20—200 mm	0.34	0.32	0.97	0.96	2.7	2.2	0.13	0.23	0.94	0.87	5.7	3.1
6—20 mm	0.29	0.19	0.96	0.97	3.1	3.7	0.11	0.18	0.98	0.87	6.4	3.7
2—6 mm	0.29	0.19	0.95	0.97	3.0	3.7	0.15	0.15	0.95	0.80	4.6	4.6
0.6—2 mm	0.15	0.10	0.87	0.89	4.5	6.6	0.15	0.13	0.98	0.64	5.0	5.4
0.2—0.6 mm	0.13	0.10	0.75	0.81	5.1	7.3	0.11	0.16	0.94	0.72	6.3	4.1
				average	3.7	4.7				average	5.6	4.2

Hämeenlinna region — Hämeenlinna region

	microcline granite			gabbro		
	a	r	$x_{1/2}$ km	a	r	$x_{1/2}$ km
over 20 mm	0.23	0.92	3.0	0.40	0.96	1.6
0.6—2 mm	0.13	0.72	5.4	0.04	1.00	16.4
0.02—0.06 mm	0.08	0.99	8.6	0.07	1.00	10.7
0.002—0.02 mm	0.05	0.96	6.6	0.06	0.96	11.0
		average	5.9		average	9.9

Hyvinkää region, recalculated from Virkkala 1971.

	rapakivi		
	a	r	$x_{1/2}$ km
over 6 cm	0.15	0.99	4.6
2—6 cm	0.14	0.99	4.8
		average	4.7

Laitila region, recalculated from Hellaakoski 1930.

On the basis of the correlation coefficients of rapakivi reported in Hellaakoski's (1930) study, the distribution of rapakivi down-glacier from the distal contact conforms to the negative exponential function. On the other hand, the distribution of rapakivi down-glacier from the proximal contact does not obey the exponential function.

The values of the lithologic nature *a* of microcline granite in the Hyvinkää region are slightly lower than the corresponding values for granitoids in the Hämeenlinna region. Correspondingly, the half-distance values for microcline granite are slightly higher than for granitoids. This is probably due to the fine-grained, durable rock structure of microcline granite compared with the coarse-grained granodiorites of the granitoid group. The values of *a* for the rapakivi of Laitila are the lowest and correspondingly the half-distance values the highest. Accordingly, the rapakivi would be the most durable of the rock types of the granite group. Possibly, its resistance to glacial comminution was due to the fact that it does not conform to the exponential function down-glacier from the proximal contact.

The half-distance values of the granitoids and microcline granite increase with a decrease in grain size, but their differences in the fractions under 0.02 mm are smaller, as may be seen from the results arrived at by Virkkala. Though both the gabbro and the basic volcanics contain hornblende and plagioclase as the principal minerals, they appear to be altogether different types of rocks with respect to their resistance to comminution during the glacial transportation. The gabbro content diminishes very rapidly down-glacier from the distal contact in the fraction of over 20 mm, but in the 0.6—2 mm fraction the gabbro grains were transported farthest. In the material under 0.06 mm, its distribution levels out. On the other hand, the basic volcanics travel in the same pattern in all the fractions investigated. In the fractions of over 2 mm, they resemble rapakivi in durability.

The values registered down-glacier from the proximal contact show that gabbro has a high value of *a* (0.28) in the fraction of over 20 mm (Table 2). In the fraction of 0.6—2 mm, the lithologic nature *a* (0.05) has decreased rapidly. In the matrix of under 0.06 mm, the values of *a* (0.02) are slightly lower than in the 0.6—2 mm frac-

Table 2

Values of lithologic nature (*a*), and correlation coefficients (*r*), down-glacier from the proximal contact

grade	microcline granite			
	a		r	
	I	II	I	II
20—200 mm	0.08	0.15	0.92	0.84
6—20 mm	0.11	0.13	0.94	0.86
2—6 mm	0.11	0.14	0.95	0.85
0.6—2 mm	0.04	0.08	0.95	0.51
0.2—0.6 mm	0.02	0.03	0.83	0.52

Hämeenlinna region

grade	gabbro	
	a	r
over 20 mm	0.28	0.99
0.6—2 mm	0.05	0.35
0.02—0.06 mm	0.02	1.00
0.002—0.02 mm	0.02	0.99

Hyvinkää region, recalculated from Virkkala 1971.

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tion. Here too it is to be noted that the distribution of gabbro evens out in the matrix of under 0.06 mm.

Comparing the values obtained in Finland with those arrived at by Gillberg (1965, 1967 a, and 1967 b) from the Cambro-Silurian rocks of Sweden, it can be observed that the values deviate appreciably in the rock types contained in the till deposits of the Cambro-Silurian rock areas and those contained in the tills of the Precambrian bedrock areas in Finland. The average values of *a* obtained by Gillberg (1967 a) for the following rock types are: limestone 0.14, shale 0.08, sandstone 0.05 and diabase 0.02.

The influence of the bedrock environment on the results can be seen plainly. On the other hand, the values of *a* arrived at by Lindén (1975) for the granitic material occurring in the Precambrian bedrock area of Uppsala, Sweden, are considerably higher than the values recorded in Finland. In the 2.0 — over 200 mm fractions, the values of *a* are 0.4—1.0. Correspondingly, the half-distance values are exceedingly low, 0.7—2 km. The till in the Uppsala region is more local than in the Hämeenlinna region. According to Lindén, crushing action was the prevailing mode of behavior of the land-ice and, in addition, possibly erosion during the deglaciation stage. In the Hämeenlinna region, during the glacial erosion and the relatively short transportation, the comminution was the chief factor.

Minerals

The 0.006—0.2 mm fractions are composed mainly of minerals. In the following, the mineral contents of these till fractions will be considered in both the areas of granitoids and the areas of basic volcanics.

Table 3

Mean mineral composition of rock types composing bedrock

	1. %	2. %	3. %	4. %	5. %
quartz	30.7	30.5	10.2	28.9	39.0
plagioclase	43.2	29.0	41.0	14.8	40.8
potassium feldspar	13.1	34.0	—	—	4.3
hornblende	3.0	—	33.4	—	—
biotite	7.3	1.0	7.8	—	—
muscovite	—	—	—	40.8	—
chlorite	1.2	—	4.1	—	14.1
accessories	1.5	5.5	3.5	15.5	1.8
	100.0	100.0	100.0	100.0	100.0

1. Granodiorite (Simonen 1949 b, p. 44, Simonen 1960, p. 18)
2. Microcline granite (Simonen 1960, p. 66)
3. Basic volcanics (Simonen 1948, p. 22—23)
4. Mica schist (Simonen 1948, pp. 22—23)
5. Acid tuffites (Simonen 1948, pp. 22—23)

The principal minerals contained in microcline granite and granodiorite are quartz, potassium feldspar and plagioclase. The principal minerals of the basic volcanics are plagioclase and hornblende (Table 3). In the fractions investigated, these minerals as well as the biotite contained in granitoids constitute the main portion of the mineral composition of the till, between 75 and 99.5 % in the 0.06—0.2 mm (fine and very fine sand) fraction, 85 and 99 % in the 0.02—0.06 mm (coarse silt) fraction, and 75 and 96 % in the 0.006—0.02 mm (medium silt) fraction. Other minerals met with in small quantities were, for instance, garnet, pyroxene and ore grains (App. 2). The triangular diagrams (Figs. 26, 27 and 28) show the quartz, potassium feldspar and plagioclase proportions of the till samples. The proportions were calculated in the miciocline granite and granodiorite areas as well as the area of basic volcanics. The behavior of hornblende is also described.

Fraction 0.06—0.2 mm

In the 0.06—0.2 mm fraction (fine and very fine sand), quartz occurs in the largest amounts among the minerals, exceeding its content in the bedrock (Figs. 26 a and b).

There is a larger amount of plagioclase than potassium feldspar. In some of the samples from the granitoids areas, the plagioclase content is the same as in the bedrock or slightly higher. In the till of basic volcanics areas, the content is half of that in the bedrock. It appears as if the plagioclase in the till of granitoids areas is derived partly from the basic volcanics.

The potassium feldspar falls under the content of that in the granitoids of the bedrock. Its content is the least in their proximal portions (Nos. 11, 12, 26, 3, 4). At the proximal portions of basic volcanics areas this mineral occurs in greatest abundance. The influence of the granite and granodiorite areas is thus to be perceived.

The hornblende content amounts to 4—11 %. Primarily, it occurs most abundantly in the samples from the granite and granodiorite areas, where the plagioclase content is highest. In the till of basic volcanics areas, the hornblende maximum occurs at the distal part.

In this fraction, the influence of the local bedrock in the till extends distally over a distance of some kilometers. The maxima of the minerals are soon observable down-glacier from the distal contact in the »new» bedrock area.

Fraction 0.02—0.06 mm

In the 0.02—0.06 mm (coarse silt) fraction the mean quartz content is the same as in the fine and very fine sand fraction. It is the highest recorded for any of the minerals, exceeding that in the bedrock (Figs. 27 a and b).

The plagioclase content is smaller than in the fine and very fine sand fraction. In the till of granitoid areas, it is to some extent the same as that in the bedrock or higher. In the till of basic volcanics areas the plagioclase content is half that in the

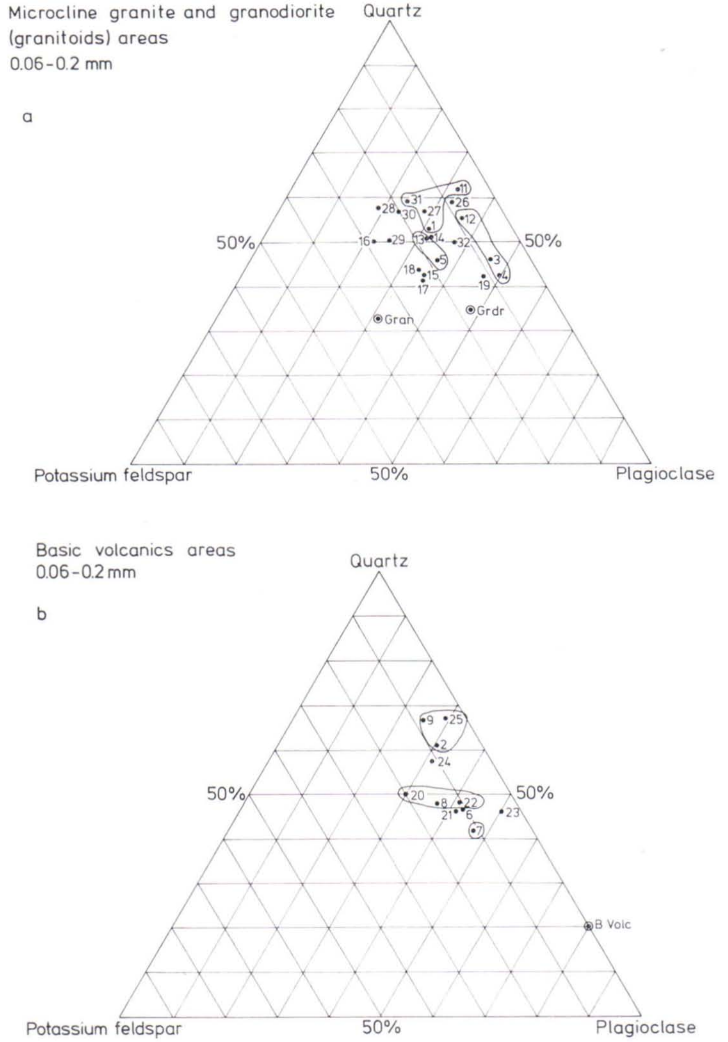

Fig. 26. Relative contents of quartz, plagioclase and potassium feldspar in the 0.06—0.2 mm fraction of the till of a) granitoids areas, b) basic volcanics areas. Hornblende maxima (5—10 %) appear as enclosed dots. Numbers refer to sampling sites. Grdr = Granodiorite bedrock, Gran = Microcline granite bedrock, BVolc = Basic volcanics bedrock. Key to bedrock symbols in Fig. 5.

bedrock. In the areas of basic volcanics, its content is higher than in the areas of granitoids.

In the granitoid areas, the potassium feldspar content is greater than in the 0.06—0.2 mm fraction, as also in all the samples from the areas of basic volcanics. The

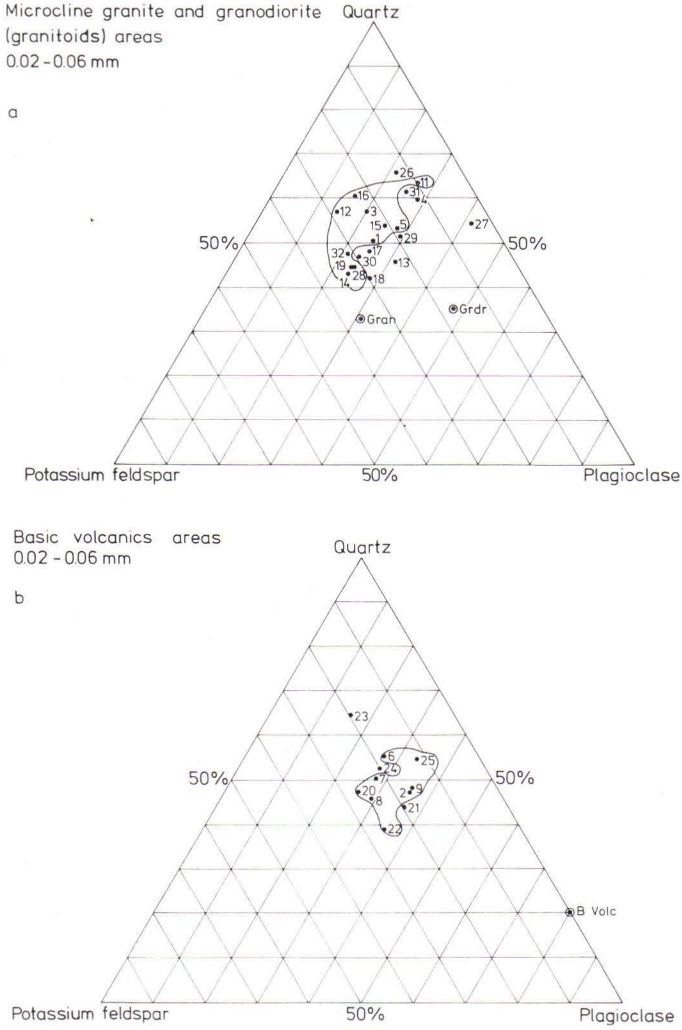

Fig. 27. Relative contents of quartz, plagioclase and potassium feldspar in the 0.02—0.06 mm fraction of the till of a) granitoids areas, b) basic volcanics areas. Hornblende maxima (10—20 %) appear as enclosed dots. For further details, see caption for Fig. 26.

mineral still occurs in amounts below its content in the bedrock. It occurs in greatest abundance in the areas of granitoids, where the minimum falls in the proximal part (Nos. 26, 27, 4).

The hornblende content is 2—20 %. The amount has risen in comparison with the preceding fraction. The maximum hornblende content (10—20 %) is distributed fairly evenly throughout the till along the traverses.

In this fraction the mineral composition of the till still shows some local influence. It appears both as a plagioclase maximum in the area of basic volcanics and in the occurrence of potassium feldspar as a minimum in the proximal parts of the granitoids. The enrichment of the potassium feldspar in this fraction is perceivable. The transportation of the material over a distance of some kilometer can also be clearly observed through the excess of plagioclase in the areas of granitoids and the increase in the potassium feldspar content in the area of basic volcanics. The even occurrence of hornblende indicates that also homogenization of the material has taken place. Virkkala (1971) has also observed the homogenization of the material in this fraction along with a distinctly longer transportation distance compared with the coarser fractions.

Fraction 0.006—0.02 mm

In the 0.006—0.02 mm (medium silt) fraction quartz is still the most abundant of all the minerals. Its content in the till is higher than in the bedrock (Figs. 28 a and b).

The plagioclase content has partly decreased and partly increased in relation to the 0.02—0.06 mm fraction in the till of the granitoids areas. It has distinctly decreased in the till of the areas of basic volcanics. It is under the proportion of this mineral in the bedrock of the granitoids areas. In the till of the areas of basic volcanics its content is appreciably less than in the bedrock. The plagioclase content is approximately the same in the till of both bedrock areas. In the granitoids areas, the plagioclase content of the till is smaller than the potassium feldspar content. In the till of the areas of basic volcanics, these two minerals occur in approximately equal proportions.

The potassium feldspar content has increased in comparison with the preceding fraction. To some extent, the till of the areas of granitoids contains the mineral in amounts equal to the content in the bedrock or even more. In both bedrock areas, the contents are the same.

The hornblende content is 2—27 %. This signifies a rise in part compared with the preceding fraction. The maximum is reached in the till of the areas characterized by the occurrence of granitoids. This indicates an increased transportation distance of the material.

The mineral composition of the till in the granitoids areas and the areas of basic volcanics in medium silt indicates clearly homogenization of the material and lengthening of the transportation distance. The potassium feldspar has become enriched also in this fraction.

Review of mineral contents

In the three fractions investigated (0.06—0.2, 0.02—0.06 and 0.006—0.02 mm), quartz occurs in higher concentrations than any of the other minerals. The average quartz contents in the 0.06—0.2 mm fraction are 41 % (traverse I) and 45.1 % (trav-

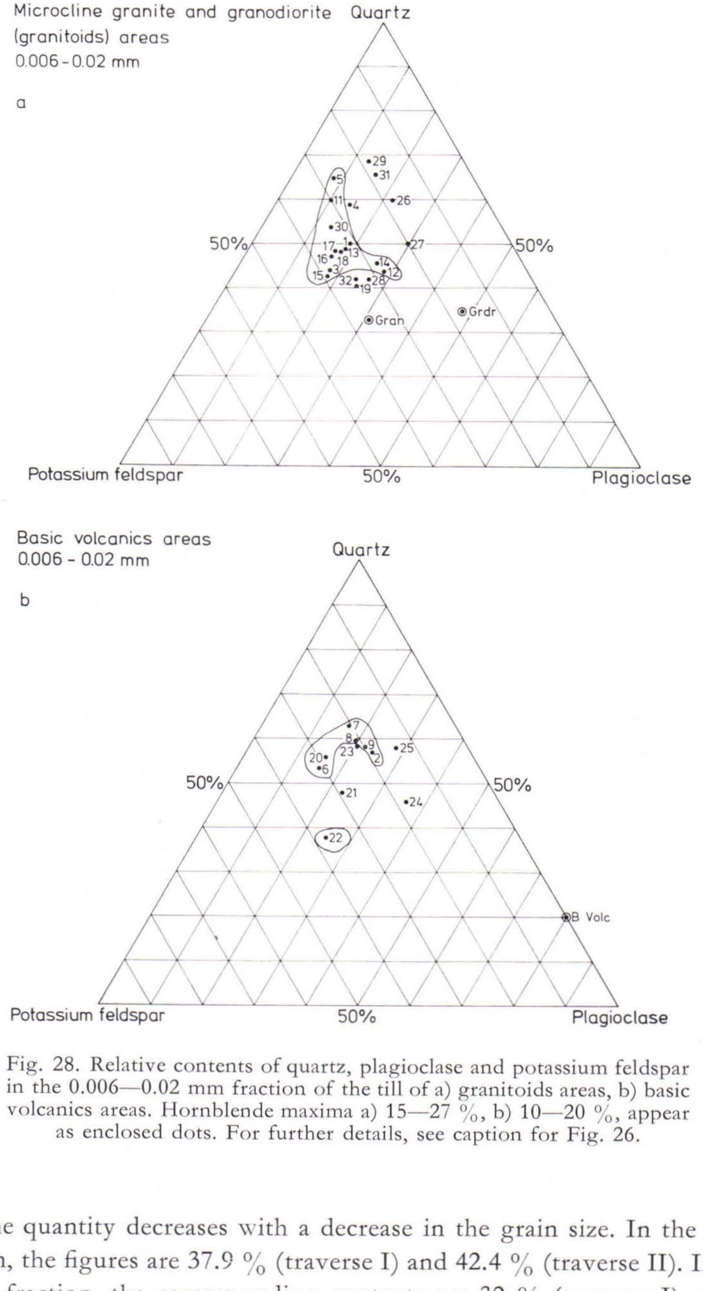

Fig. 28. Relative contents of quartz, plagioclase and potassium feldspar in the 0.006—0.02 mm fraction of the till of a) granitoids areas, b) basic volcanics areas. Hornblende maxima a) 15—27 %, b) 10—20 %, appear as enclosed dots. For further details, see caption for Fig. 26.

erse II). The quantity decreases with a decrease in the grain size. In the 0.02—0.06 mm fraction, the figures are 37.9 % (traverse I) and 42.4 % (traverse II). In the 0.006 —0.02 mm fraction, the corresponding contents are 32 % (traverse I) and 39.3 % (traverse II). It occurs in amounts exceeding the content of the mineral in the bedrock. The same observation has been made by, among others, Virkkala (1969 b and 1971), Rosenqvist (1975), and Lindén (1975). (The origin of quartz excess, see p. 59).

The plagioclase content also decreases with a diminishing in the grain size. In the 0.06—0.2 mm fraction, it amounts to 29.9 % (traverse I) and 27.7 % (traverse II). In the next fractions, the corresponding figures are 18.3 % and 12.8 % (traverse I) and 22.4 % and 17.4 % (traverse II). In the 0.06—0.2 mm fraction, there is more plagioclase than potassium feldspar, but the ratio evens out in the finer fractions with the result that in the 0.006—0.02 mm fraction some of the samples contain more potassium feldspar than plagioclase.

The potassium feldspar content increases as the grain size diminishes. In the 0.06—0.2 mm fraction, it amounts to 12.6 % (traverse I) and 12.1 % (traverse II). In the next fractions, the figures are 16.1 % and 17.3 % (traverse I) and 17.3 % and 18.9 % (traverse II).

The content of hornblende, like that of potassium feldspar, increases with diminishing grain size. It yields a low figure in the 0.06—0.2 mm fraction, averaging 4.8 % (traverse I) and 3.7 % (traverse II). The quantity rises steeply in the 0.02—0.06 mm fraction, where the mean percentages are 14.1 (traverse I) and 8.0 (traverse II). Along traverse I, the quantity rises to 17.3 % in the 0.006—0.02 mm fraction, while along traverse II it remains constant at 7.1 %. Hornblende occurs in till in concentrations below the content in basic volcanic bedrock (2—27 %).

Surprising is the low content of hornblende in the 0.02—0.06 mm and 0.006—0.02 mm fractions in the till of basic volcanics along traverse II compared with traverse I. The content of hornblende is at sampling sites, Nos. 6—9 (traverse I) between 2.5 and 8 % (0.06—0.2 mm), 12 and 20 % (0.02—0.06 mm) and 16 and 20 % (0.006—0.02 mm) (see Appendix 2). At sampling sites 20—25 (traverse II), its content varies between 2.5 and 9 % (0.06—0.2 mm), 2 and 16 % (0.02—0.06 mm) and 2 and 16 % (0.006—0.02 mm). Along traverse II, the content of hornblende is extremely low at sampling sites, No. 21 (6 % in 0.02—0.06 mm, 7 % in 0.006—0.02 mm), No. 23 (3 % and 2 %), and No. 24 (2 % and 3 %). It is rather low also at the last sampling site, No. 25 (11 % and 2 %). These low contents along traverse II are, however, in relation to coarser fractions, where the basic volcanics appear in rather low contents at these sampling sites compared with the till of the corresponding bedrock areas along traverse I (see Fig. 7). Also down-glacier from the distal contact of basic volcanics, the hornblende appears in the 0.006—0.02 mm fraction in extremely small amounts (1—4 %) at sampling sites Nos. 26, 27, 29 and 31.

The biotite content in the samples averages between 2.4 and 6.9 %.

The contents of quartz, plagioclase, potassium feldspar and hornblende have been calculated as weighted means in each fraction (0.06—0.2 mm, 0.02—0.06 mm, 0.006—0.02 mm). The mineral maxima are presented on traverse I and traverse II in the diagrams (Fig. 29 a and b).

The quartz maximum occurs mostly in the 0.06—0.2 mm fraction (fine and very fine sand). Along traverse I, it appears evenly in the 0.06—0.2 mm fraction from No. 7 to the end of the traverse over a distance of 27 km. Over this transportation distance, the quartz was not comminuted to a finer fraction. Along traverse I, Nos. 4

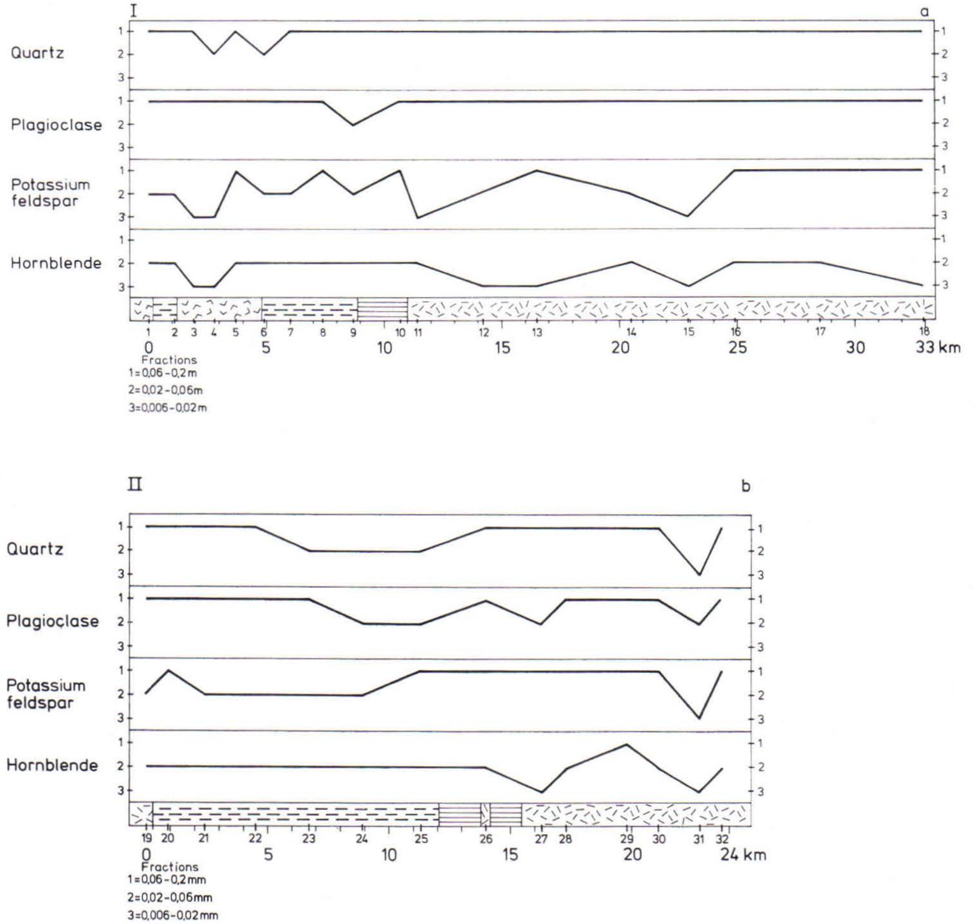

Fig. 29. The placing of maximum concentrations of quartz, plagioclase, potassium feldspar and hornblende on different fractions along a) traverse I, b) traverse II.

and 6 represent an exception. At these sites, the maximum content occurs in the 0.02—0.06 mm fraction (coarse silt). Along traveıse II, deviating from the other samples of the traverse, the maximum content at Nos. 23—25 in the area of basic volcanics occurs in the 0.02—0.06 mm fraction (coarse silt). At No. 31, the maximum also in coarse silt appears at a distance of 9 km down-glacier from the proximal contact of the granite. At this site, the maxima recorded for the other minerals are also in a fraction finer than in the nearest sampling sites. Here englacially transported material is likely to be mixed in the till. Virkkala (1971) has recorded the quartz maximum in the Hyvinkää region as occurring in a smaller fraction (0.02—0.06 mm, coarse silt), as has Lindén too (1975) in Sweden.

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According to Dreimanis and Vagners (1971 a, 1972), the maximum quartz content, defined as its »terminal grade», tri-modal, occurs in the 0.125—0.25 mm, 0.032—0.06 mm and 0.004—0.008 mm fractions. In the present study, the occurrence of quartz in a fairly coarse fraction (0.06—0.2 mm) would indicate the source of the quartz to be the granitic rocks of the area (*cf.* Dreimanis and Vagners 1972). In the area of basic volcanics, along traverse II the quartz has become comminuted to some extent into a finer fraction (0.02—0.06 mm). Owing to the relatively short transportation distance prevailing in the Hämeenlinna area, the quartz has not been comminuted to any finer fractions.

The plagioclase maxima fall mainly into the 0.06—0.2 mm fraction (fine and very fine sand) and to a certain extent the 0.02—0.06 mm fraction (coarse silt), which are comparable to the results arrived at by Dreimanis and Vagners (1971 a, 1972). Along traverse I, the only maximum plagioclase content in coarse silt occurs at No. 9, the last sampling site in the area of basic volcanics, which is located only about 4 km from the proximal contact. In the present study, the maximum potassium feldspar content occurs in samples 3, 4, 11, 15, 31 also in the 0.006—0.02 mm fraction (medium silt), indicating in the medium silt fraction transportation over a longer distance at these sampling sites.

The maximum hornblende contents occur mostly in the 0.02—0.06 mm fraction (coarse silt) and, in certain samples, the 0.006—0.02 mm fraction (medium silt), Dreimanis and Vagners (1971 a) situate the »terminal grades» of amphibole-pyroxene partly in the same, partly in a coarser fraction, 0.032—0.062 and 0.125—0.25 mm. The occurrence of the hornblende maximum in finer fractions is due partly to the fact that it is fine-grained even in its main source rock, basic volcanics, of which it is the principal mineral. Furthermore, its appearance in the 0.006—0.02 mm fraction (medium silt) down-glacier from the area of basic volcanics indicates that it is comminuted rapidly owing to its soft mineral nature. Only at No. 29 along traverse II is there an exception in the maximum contents. It is in the 0.06—0.2 mm fraction (fine and very fine sand), which is hard to explain. At No. 27, the plagioclase and the hornblende are at their maximum in a fraction finer than in the nearest sampling sites. This reveals the influence of the basic volcanics.

Chemical composition

In the fractions under 0.006 mm, it was not possible to determine the minerals by the methods applied in the present study. Therefore the chemical composition of some of the samples in the 0.002—0.006 mm and 0.0001—0.002 mm fractions (fine silt and clay) was determined with respect to the CaO, Na_2O and K_2O concentrations. The results are given in the diagrams for traverse I and traverse II as total amounts (Fig. 30 a and b).

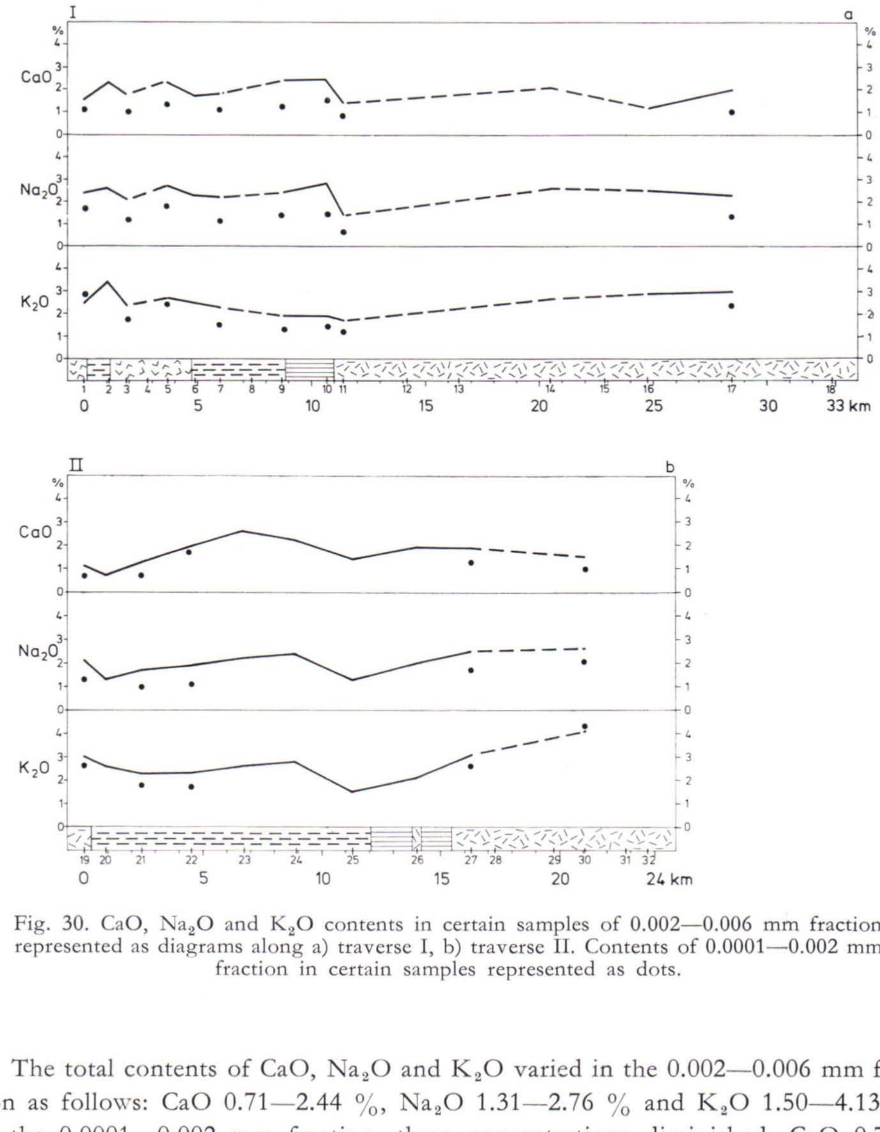


Fig. 30. CaO, Na_2O and K_2O contents in certain samples of 0.002—0.006 mm fraction represented as diagrams along a) traverse I, b) traverse II. Contents of 0.0001—0.002 mm fraction in certain samples represented as dots.

The total contents of CaO, Na_2O and K_2O varied in the 0.002—0.006 mm fraction as follows: CaO 0.71—2.44 %, Na_2O 1.31—2.76 % and K_2O 1.50—4.13 %. In the 0.0001—0.002 mm fraction, these concentrations diminished: CaO 0.73—1.51 %, Na_2O 0.64—2.05 % and K_2O 1.16—4.30 %. Only at the last sampling site (traverse I), in the area of microcline granite, did the K_2O content rise in a smaller fraction.

Along traverse II, the CaO concentrations reach their maximum in the till of the area of basic volcanics. The CaO contents in this bedrock are appreciably larger than in the bedrock of granitoids (Table 4). Thus the influence of the local bedrock on the till can be observed. The amount of CaO is less in the till, however, than in the basic volcanic bedrock.

Table 4

CaO, Na_2O and K_2O concentrations of rocks in the region of Hämeenlinna

	1. %	2. %	3. %	4. %	5. %
CaO	8.50	4.01	1.63	0.91	2.25
Na_2O	2.83	3.48	2.83	1.43	3.38
K_2O	1.18	2.08	5.93	3.45	1.34

1. Basic volcanics, average of 3 analyses (Simonen 1948, p. 22)
2. Granodiorite. One analysis (Simonen 1948, p. 22)
3. Microcline granite. One analysis (Simonen 1948, p. 24)
4. Mica schist. One analysis (Simonen 1949 b, p. 44)
5. Acid tuffites. One analysis (Simonen 1948, p. 22)

Along traverse II, the K_2O concentrations are observed to diminish somewhat in the till of the area of basic volcanics. The basic volcanics contain very little K_2O (Table 4). The amount of K_2O in the till exceeds that of the bedrock consisting of basic volcanics. Thus some transportation is seen to have taken place. At No. 25 the content is surprisingly low, as is also that of CaO and Na_2O. In the areas of granitoids, the K_2O content rises markedly and reaches its maximum. Also Kivekäs (1946) observed the K_2O to occur in distinctly larger amounts in the till deposits of granitic rocks than in the till of basic volcanics. On the other hand, the granitic rocks and the mica schist contain about 3 % K_2O, signifying that the K_2O occurring in the area derives from these rocks. The occurrence of K_2O in the till of the granitoids areas indicates therefore the influence of the local bedrock. The till, however, contains less of it than the bedrock does.

Along traverse II, the Na_2O content is lower in the till than in the bedrock. The Na_2O content is largely the same in the various rocks composing the bedrock. It is also apparent in the occurrence of Na_2O in the local till.

Along traverse I, chemical analyses have been made of only a few of the samples. From these, it may be concluded, however, that the results conform to the findings along traverse II. The amounts of CaO are at their maximum in the till occurring in the range of influence of the basic volcanics. Along traverse I, the behavior of the Na_2O is the same as along traverse II.

Along traverses, the same features as in the coarser fractions are seen in the chemical composition. Besides the transportation distances, the influence of the local bedrock on the till is seen in the behavior of CaO, Na_2O and K_2O.

Roundness of quartz grains

The roundness of quartz grains depends on the distance they have been transported as well as the environmental factors — glacier, river, winds (Kuenen 1960 in Seppälä 1971). It is useful to study the degree of abrasion undergone by material in interpreting its transportation and deposition (Richter 1958, Krygowski 1965) as well as in drawing conclusions about the relative distance of glacial transportation (Dreimanis 1969). The roundness of quartz grains was investigated from the samples collected along the traverses and the relation of the roundness to the distances of glacial transportation in the till of the region. Krygowski (1965) has observed in Poland that the roundness of the sand fractions in till increases with the length of the distance of their glacial transportation.

From the results obtained with a mechanical graniformameter, two parameters were calculated: the index of abrasion = W_0 and the index of heterogeneity = N_m (Krykowski 1964; see also Seppälä 1969, 1971). A tenfold rolling test performed with the device on the same sample showed the standard deviation $\delta = 19.5$.

The values of W_0 obtained vary from 939 to 1076 (Table 5). According to the W_0 values, the quartz grains are slightly abraded (Krygowski 1964; see also Perttunen 1976 a and c).

Table 5

Roundness of quartz grains found in till samples. The grain size 1—1.2 mm.

No	W_0	Q_3	Q_1	Nm	α_1	α_2	β_1	β_2
1	1003	15.25	12.71	2.54	0	49.8	49.8	0.5
2	983	15.29	13.11	2.18	0.5	59.5	38.5	1.5
3	1004	15.19	12.80	2.40	0.4	50.7	47.0	1.8
4	1028	14.87	12.55	2.32	0.9	37.9	61.2	0
5	939	15.62	13.52	2.11	1.3	67.1	31.6	0
6	1018	14.91	12.75	2.15	0.4	43.1	56.5	0
7	951	15.59	13.23	2.36	1.7	61.0	36.9	0.4
8	974	15.32	13.04	2.28	1.7	53.1	45.2	0
9	1052	14.61	12.44	2.17	0.4	33.6	64.6	1.3
10	1000	15.08	12.90	2.18	0	48.8	51.2	0
11	1069	14.62	12.15	2.47	0.9	34.1	63.1	1.8
12	975	15.31	13.05	2.26	0.8	53.4	45.0	0.8
13	1004	15.13	12.85	2.28	0	52.1	47.4	0.5
14	1052	14.36	12.56	1.81	0	30.0	69.2	0.8
15	1003	15.13	12.91	2.22	0	51.6	46.6	1.8
16	967	15.45	13.10	2.35	0.9	57.7	40.9	0.5
17	1030	14.78	12.64	2.14	0	38.4	61.6	0
18	1066	14.41	12.27	2.14	0.4	29.8	69.3	0.4
19	947	15.68	13.41	2.27	0.4	66.8	30.4	2.3
20	1015	15.08	12.71	2.37	0.6	45.6	51.3	2.5
21	994	15.23	12.94	2.29	0	53.4	45.0	1.7
22	990	15.29	12.86	2.43	0.4	51.3	47.8	0.4
23	1061	14.08	12.52	1.56	0	26.0	74.0	0
24	1076	13.96	12.38	1.57	0	23.6	74.8	1.6
25	1026	14.90	12.69	2.21	0	42.0	56.6	1.4
26	1021	14.97	12.72	2.24	0	43.6	55.1	1.3
27	1009	15.01	12.80	2.20	0	45.5	54.5	0
28	973	15.40	13.12	2.28	0.9	58.1	38.3	2.8
29	1050	14.17	12.56	1.60	0.8	26.1	73.0	0
30	1002	15.16	12.81	2.35	0	49.1	50.4	0.4
31	1032	14.73	12.63	2.11	0	37.0	63.0	0
32	982	15.29	12.91	2.38	2.4	48.0	48.8	0.8
$\bar{x}$	1009	14.99	12.80	2.19	0.5	45.9	52.8	0.9
s	36	0.44	0.31	0.24	0.6	11.7	12.1	0.9

Q_3 = the angle at which 75 % of the grains rolled.
Q_1 = the angle at which 25 % of the grains rolled.

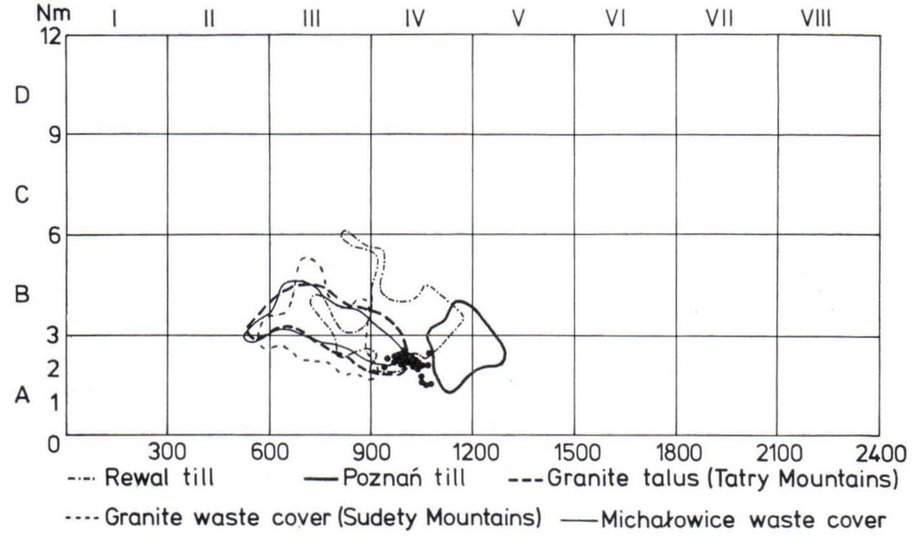


Fig. 31. Rectangular graph showing degree of abrasion W_0 and graniformametrical heterogeneity N_m in certain Polish tills (Krygowski 1964, 1965, Krygowski and Krygowski 1965). The values obtained for Hämeenlinna till are plotted in the graph as dots.

The N_m value shows the heterogeneity of the material in relation to its roundness. The higher N_m value, the greater the heterogeneity. The N_m values vary between 1.56 and 2.54. They are fairly low and nearly the same in all the samples (Table 5). The roundness of the material is quite homogeneous, which points to a common origin.

The W_0 and N_m values have been situated in a rectangular diagram (Fig. 31). The quartz grains studied are to be found in a small area, A III—IV. The roundness of the quartz grains is closer to the values obtained by Krygowski (1964) at Michałowice, Poland, for weathering products of granite than the values reported by him for moraine deposits in Poland (Fig. 31). Nevertheless, the heterogeneity (N_m) of the weathering product of the Michałowice granite is greater than the heterogeneity of the roundness of the quartz grains included in the material of the present study.

As the index of heterogeneity shows, the distribution of the roundness of the quartz grains in the different angle classes deviate somewhat between the samples (Table 5, Fig. 32). The classification of the average roundness of the quartz grains of 32 samples presented in the diagram (Fig. 33), is as follows: The roundness of individual samples falls into only a few angle classes, the maxima varying in the classes 16—18°, α_2, and 12—14°, β_1. Very angular = α_1-grains 0.5 %, or close to nil, the proportion of angular = α_2-grains is slightly lower (45.9 %) than that of subangular β_1-grains (52.8 %). The content of subrounded = β_2-grains amounts to only 0.9 %. Thus

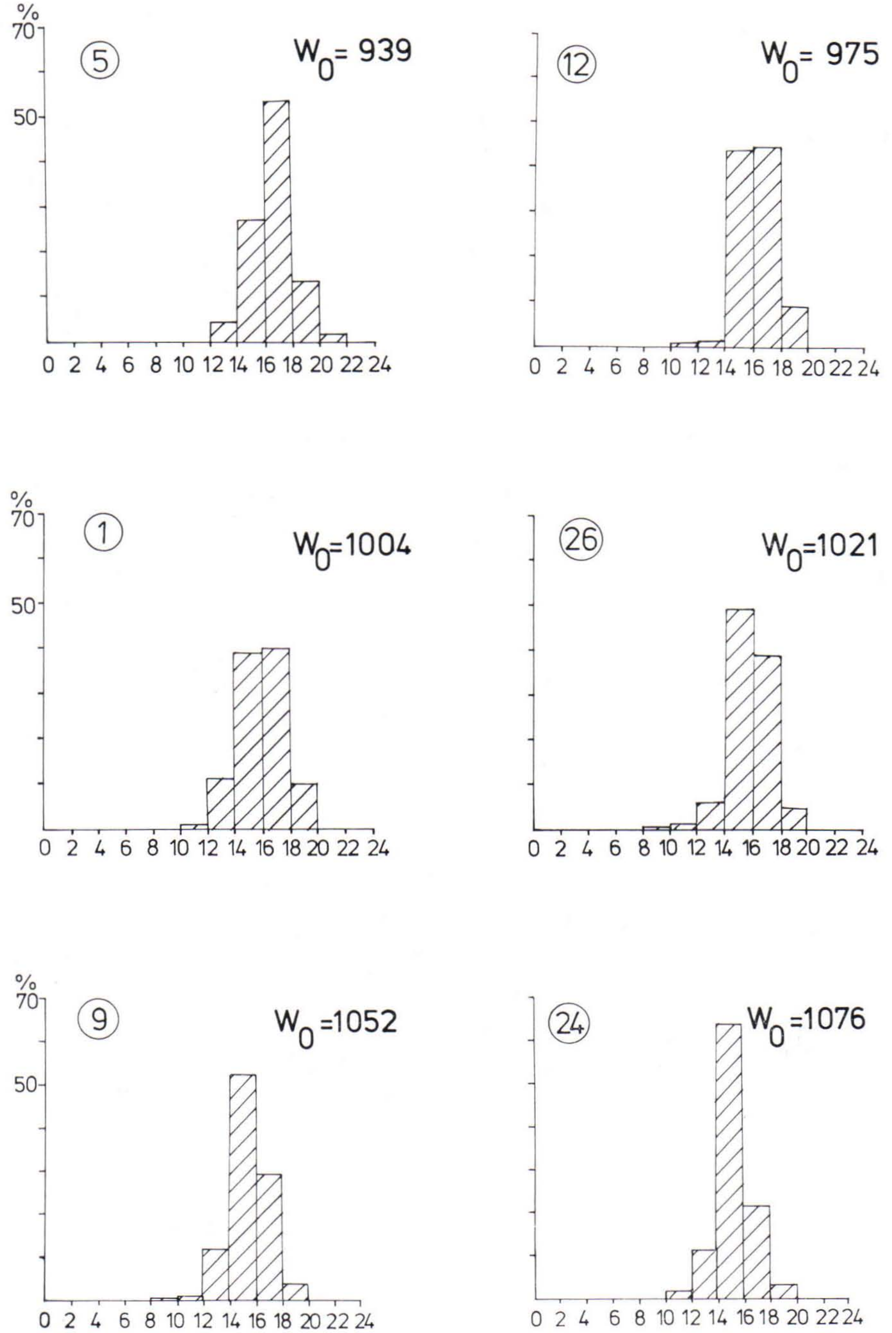


Fig. 32. Roundness of quartz grains in certain samples in the 1—1.2 mm fraction in granifformametrical angle classes. Numbers in circles refer to sampling sites.

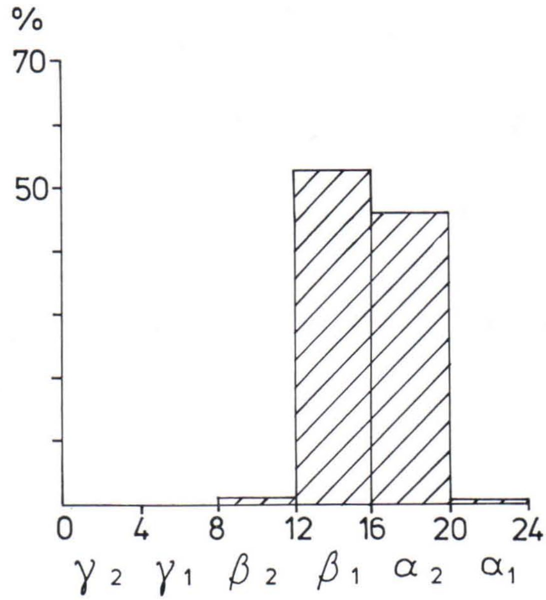


Fig. 33. Mean distribution of roundness of quartz grains in 32 samples from Hämeenlinna region. The 1—1.2 mm fraction.

it may be said that the material is characterized by a content of angular and subangular grains and a lack of rounded grains (Fig. 34).

In certain of the samples, a portion of the β_2 = subrounded group grains included with a frosted surface that deviate in outward appearance from the rest (Fig. 35). According to Seppälä (1969, 1971), in Lapland grains of this type would have originated in preglacial sediments. In the Hämeenlinna region, it is also possible that quartz grains of this type had been transported from the Jotnian sandstone area of Satakunta. The area is located about 100 km in a NNW—SSE line from the Satakunta sandstone occurrences, the direction of the main ice movement. Virkkala (1958) has found Satakunta sandstone in gravel pits in the Hämeenlinna region.

In sandstones, the original form of the quartz grains is roundish to begin with and the grains are frosted in appearance (Lundqvist 1952). The quartz grains from the till profile (depth: 24 m) located at Kiukainen in the Satakunta sandstone area *) are to some extent identical with these frosted grains of the subrounded group (Fig. 35). In the till of the sandstone area at Kiukainen, about 10 % of the quartz grains (determined by the author) fall into the 4—10° (γ_1 and β_2) angle classes, the largest portion of them, or 67 %, belonging to the 12—14° (β_1) class (Fig. 36). Of these,

*) Research material kindly furnished by P. Lindroos

Fig. 34. Photograph of quartz grains. Sample No. 17. The 1—1.2 mm fraction. Very angular (α_1), angular (α_2) and subangular (β_1) classes. Photo: E. Halme.

Fig. 35. At left, photograph of quartz grain of subrounded (β_2) class contained in the till from the Hämeenlinna region. Sample No. 30. At right, photograph of quartz grain of subrounded (β_2) class from the till occurring in the Jotnian sandstone area of Satakunta. Till profile from Kiukainen. Sample No. 17. The 1—1.2 mm fraction. Photo: E. Halme.

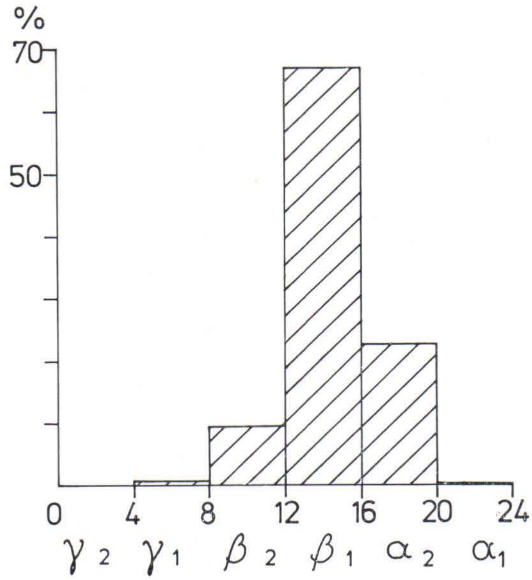
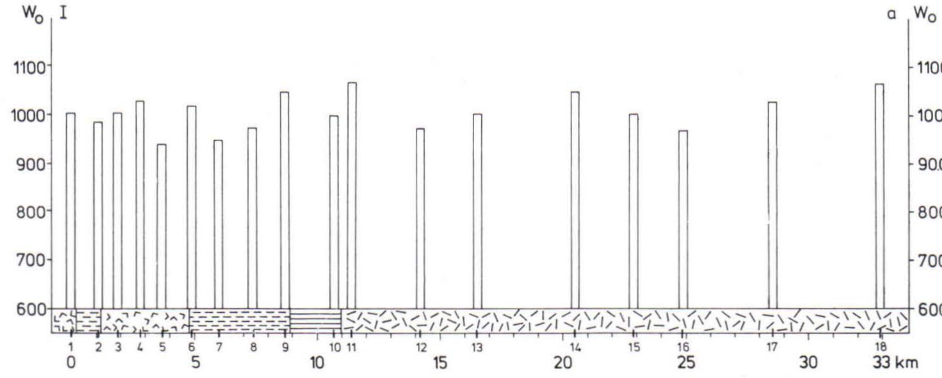


Fig. 36. Mean distribution of roundness of quartz grains contained in 16 till samples from the Jotnian sandstone area of Satakunta. Till profile from Kiukainen. The 1—1.2 mm fraction.

the quartz grains in the 12° angle class or the ones that have rolled under it have originated from sandstones. Also the majority of the rolled grains in the 14° angle class have their source in sandstones, but they had been crushed by the force of the ice sheet. The grains in the 16° angle class or those that had rolled over this angle have their source mostly in plutonic rocks. They account for 22.5 % (α_1 and α_2) of the total. On the whole, the quartz grains contained in the till of the Satakunta sandstone area are more rounded than the quartz grains of the till in the Hämeenlinna region. Thus the form of the grains in their source rock should be taken into consideration in examining the roundness of the grains in till.

Incidentally, the scarcity of β_2 grains and the lack of γ grains is apt to indicate that the quartz grains contained in the till in the Hämeenlinna region originated for the most part from the local bedrock. The granitoids contain 30 % quartz, while the basic volcanics contain less than 10 %. So the quartz grains originate mainly from the granitic rocks of the study area and their weathering products. Nearly all the grains are clear, which also indicates their origin from plutonic rocks (Lundqvist 1952, p. 7). The same finding was made in the maxima and excess of quartz in the



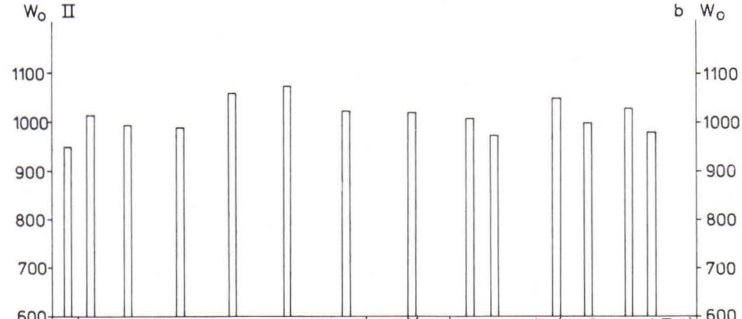


Fig. 37. Roundness of quartz grains represented as W_0 values along a) traverse I, b) traverse II. Key to bedrock symbols in Fig. 5.

fractions of under 0.2 mm (see p. 47). This suggests that the excess of quartz in the till in relation to its content in the bedrock is due to the enrichment of the quartz in the weathering process in Preglacial time at the expense of the other, softer minerals, as was noted in connection with the mineral composition (Rosenqvist 1975, Collini in Lindén 1975).

Although the roundness of the quartz grains along the two traverses (Figs. 37 a and b) show only slight differences, some tendencies emerge indicating wether the granitoids are local or non-local in origin.

Along traverse I, at sampling site 9 in the basic volcanics area, granitoids predominate in the 0.6—2 mm till fraction (c. 50 %). This corresponds to the high W_0 value

(1052), and shows that non-local quartz material has the higher roundness values. The first sampling site (No. 11) in the area of this rock type reveals a high percentage (50 %) of granitoids in the 0.6—2 mm fraction, some of which is non-local as seen in the high W_0 value (1069). After this site W_0 values are lower. At the last sampling site 18, in the till of the microcline granite area the W_0 value has risen highest (1066), where the transportation distance from the proximal contact of the microcline granite area is over 20 km.

Along traverse II the highest W_0 values are at sampling sites 23 (1061), 24 (1076) and 29 (1050). In these samples the highest frequency of granitoids is in the 0.6—2 mm fraction. Non-local material is indicated by the roundness of the quartz grains; the local granitoids show lower W_0 values, e.g., Nos. 5 and 19. At No. 32 the lower W_0 value suggests that the granitoids are local, despite the presence of englacially transported basic volcanics.

The roundness of the quartz grains reflects the comminution and accumulation that took place during glacial transportation in the present investigation area.

Seppälä (1971) has reported W_0 values of 476—729 and N_m values of 2.39—3.20 for tills in Lapland (four samples) in the 0.7—1 mm size class. Compared with the till in the Hämeenlinna region, the quartz grains are less rounded in Lapland, where the material is relatively fresh. To some extent, also the smaller grain size affects the lower W_0 values (Seppälä 1971). In Lapland, the material is more heterogeneous, as in the weathering products described from Poland (Krygowski 1964). Accordingly, the till in the Hämeenlinna region is not so fresh as material that has just undergone weathering. Its transportation distance, though rather short, is reflected in the degree of roundness of the quartz grains. This is particularly true of the homogenization of the grains, through comminution, with respect to their roundness.

Mansikkaniemi (1972) has recorded W_0 values of 229, 448 and 617 for the quartz grains contained in the 1—2 mm fraction of three till samples from Lapland. Like the results arrived at by Seppälä, these values indicate that the quartz grains in Finnish Lapland are less rounded than the quartz material contained in the till deposits of the Hämeenlinna region. According to Mansikkaniemi, in the Tana river valley of Lapland, where he collected his samples, the glacial transportation of the till was very short — 90 % of the stone material was transported over a distance of less than 2 km. The W_0 values show great differences in the transportation distance of the till in different regions.

Mansikkaniemi (1973) has measured the roundness of quartz grains contained in two De Geer moraines and two samples of basal till from the Turku region. The grains measured between 1 and 2 mm in diameter. Their W_0 values were found to be slightly higher than in the till of Finnish Lapland (Seppälä 1971, Mansikkaniemi 1972). These values vary somewhat — between 605 and 721. However, they are lower than the W_0 values representing the roundness of the quartz grains contained in the till of the Hämeenlinna region. The material of De Geer moraines is therefore less transported than that of Hämeenlinna region.

SUMMARY

The lithology of till was investigated in the region of Hämeenlinna, southern Finland. The samples were taken from ground moraine mainly in areas of granodiorite, microcline granite and basic volcanics. A total of 32 samples was collected along two investigation traverses. The traverses run parallel to the most prominent direction of ice movement (315°) and cross the areas of granodiorite, basic volcanics, mica schist and microcline granite. The lithologic composition of five fractions of the till in the grain-size range of 0.2—200 mm was studied. In the 0.006—0.2 mm fractions, the mineral composition in three size grades were studied. The chemical composition — CaO, Na_2O and K_2O — of two fractions was studied in the grain-size range of 0.0001—0.006 mm in part of the sample material. The roundness of the quartz grains was determined in the coarse sand fraction (1—1.2 mm).

In the present investigation, the granitoids refer to granodiorite and microcline granite. The basic volcanics include uralite porphyrite, uralite plagioclase porphyrite, plagioclase porphyrite and basic and intermediate tuffite. Other rock types met with were mica schist and mica gneiss, as the group ranking next after the granitoids and basic volcanics, and also worthy of mention are the leptites.

The clear influence of local material is to be seen along both traverses, as shown especially by the granodiorite and microcline granite. In the distal portion of the microcline granite area of traverse I the content of local material in the till has risen to 92—96.5 % in three coarser fractions (20—200, 6—20 and 2—6 mm), but less in the sand fractions, 77 % (0.6—2 mm) and 62.5 % (0.2—0.6 mm). Along traverse II, the content of local material is highest in No. 30: in three coarser fractions (20—200, 6—20 and 2—6 mm), 86—89 %. In the 0.6—2 mm fraction it is 82 % and 43 % in the 0.2—0.6 mm fraction.

In both rock types, granitoids and basic volcanics, a marked increase of local material occurs in the proximal part of their bedrock in the till in the coarser fractions (0.6—200 mm).

The decrease in the content of granitoids and basic volcanics down-glacier from the distal contact is rather rapid. The granitoids become predominant in the sand fractions over their content in the coarser fractions with increased transportation distance down-glacier from the distal contacts. For example: at the sampling site 10, 6 km down-glacier from the distal contact, the content in the 2—200 mm fractions is 10—14 % and in the sand fractions 21—23.5 %.

The mica schists and mica gneisses, which are the next larger group after the granitoids and basic volcanics, play an important rôle in the petrography of the basal till along traverse II.

The results relating to the transportation of granitoids and basic volcanics in the till, as measured down-glacier from their distal contacts were treated according to the negative exponential function (Krumbein 1937). The microcline granite was

studied down-glacier from the proximal contact according to the exponential function.

In the light of the correlation coefficients *r*, it is seen that the conformity of the sampling sites to the distribution lines down-glacier from the distal contact for the granitoids is rather good in the 0.6—200 mm fractions (r = 0.97—0.87). In the 0.2—0.6 mm fraction, the conformity is not so good (I r = 0.75, II r = 0.81). For basic volcanics, the correlation is rather good along traverse I in all the fractions studied (r = 0.98—0.94). Along traverse II, the correlation is not so good (2—200 mm, r = 0.87—0.80), being poorest in the sand fractions (r = 0.72—0.64).

The correlation coefficients down-glacier from the proximal contact for microcline granite are rather good (r = 0.95—0.83) along traverse I. Along traverse II, the correlation is also rather good in the 20—200, 6—20 and 2—6 mm fractions (r = 0.86—0.84) and rather poor in the sand fractions (r = 0.52—0.51).

Down-glacier from the distal contact, the values of lithologic nature *a* show a lengthening in the distance of glacial transportation for the granitoids with decreasing grain size. In the 2—200 mm fractions, the values of *a* are 0.34—0.29 along traverse I and 0.32—0.19 along traverse II. In the 0.2—2 mm fractions, they are 0.15—0.13 along traverse I and 0.10 along traverse II.

In the values of *a* for the basic volcanics no consistency with respect to grain size can be detected. The values of *a* recorded for them vary between 0.15 and 0.11 along traverse I and between 0.23 and 0.13 along traverse II.

The half-distance values were taken from the distribution lines which were drawn to the semilogarithmic scale. For the granitoids in the 2—200 mm fractions they are 2.2—3.7 km. In the sand fractions (0.2—2 mm), the granitoids underwent longer transportation (4.5—7.3 km) than in the coarser fractions. The transportation distance of the basic volcanics is about the same in all the grades (0.2—200 mm). Their half-distance values vary between 4.6 and 6.4 km (traverse I) and between 3.1 and 5.4 km (traverse II). The basic volcanics, as bigger rock fragments, seem to be resistant to comminution. As they diminish in size, the principal mineral, hornblende, with its low resistance, tends to undergo comminution.

In the 0.2—200 mm fractions, the average half-distance values for the granitoids are 3.7 km (traverse I) and 4.7 km (traverse II). Those for basic volcanics are 5.6 km (traverse I) and 4.2 km (traverse II).

In the proximity of the distal contact, granitoids and basic volcanics occur in large amounts in the coarser fractions and in the least quantities granitoids occur in the 0.2—0.6 mm fraction and basic volcanics in the 0.2—2 mm fractions (clast mode). Farther from the distal contact, more granitoids are present in the sand grades (matrix mode) than in the coarser grades. At the corresponding distance, basic volcanics are present to approximately the same or smaller amounts in the sand fractions as in the coarser grades. They do not form a matrix mode.

The granitoids and basic volcanics have become enriched in the 0.2—200 mm fractions of the till near the distal contact, and this seems to be the lithologic nature of the till in southern Finland (Sauramo 1924, Hellaakoski 1930, Virkkala 1958, 1969 a, 1969 b, 1971) and typical of basal till (Dreimanis 1969).

The value of *a* given by the increase of the local bedrock in the till down-glacier from the proximal contact for the microcline granite along traverse I was 0.11—0.02 and along traverse II 0.15—0.03. The values of *a* are highest in the three coarser fractions and lower in the sand fractions. It means that the increase in the proportion of microcline granite is smaller in the finer grades, 0.2—2 mm, than in the coarser grades. Down-glacier from the proximal contact, the values of *a* are distinctly lower than down-glacier from the distal contact. The microcline granite decreased at a faster rate down-glacier from the distal contact than it increased in abundance in the till down-glacier from the proximal contact.

The topography of the region has had a bearing on the till accumulation. Abundant deposition of non-local rock types in relation to the distribution lines down-glacier from the distal contact occurs at least in three fractions in depressions, or on the proximal ascending or distal descending terrain in relation to the ice flow, according to Boulton (1975). Down-glacier from the proximal contact, the abundant deposition of local material exhibits no regularity in its occurrence. The deficiency in rock types occurs on level or higher terrain, both down-glacier from the distal contacts and the proximal contacts.

In all three fractions investigated (0.006—0.2 mm), quartz is the most abundant mineral. Its proportion decreases as the grain size decreases (traverse I average 41.0—32.0 %; traverse II 45.1—39.3 %). The mineral occurs in till in larger abundance than in the bedrock, which, according to Rosenqvist (1975) and Collini (*in* Lindén 1975), is due to the derivation of the quartz from preglacial weathering products, in which it was enriched at the expense of other, softer minerals.

Also the plagioclase content decreases along with diminishing grain size (traverse I averaging 29.9—12.8 %; traverse II 27.7—17.4 %). The potassium feldspar content increases as the grain size decreases (traverse I averaging 17.3—12.6 %; traverse II 18.9—12.1 %). The plagioclase content is higher than that of the potassium feldspar in the coarser fractions (0.02—0.2 mm). But in the 0.006—0.02 mm fraction, the potassium feldspar content exceeds the plagioclase content in some of the samples. The hornblende content also increases with a decrease in the grain size (traverse I averaging 17.3—4.8 %; traverse II 7.1—3.7 %). The hornblende content in the till is less than in the bedrock consisting of basic volcanics (27—2 %). The biotite content in the samples averages between 6.9 and 2.4 %.

On the basis of the mineral composition, it may concluded that in the 0.06—0.2 mm fraction the influence of the local bedrock can be perceived in the till also down-glacier from the distal contact some kilometers away. In the 0.02—0.06 mm fraction, a slight local influence is still revealed as both plagioclase maxima in the till of basic volcanics areas and the occurrence of potassium feldspar as a minimum in the proximal portions of the granitoids areas. The transportation of the material can be perceived in the excess of plagioclase relative to its content in the local bedrock in the till of granitoid areas as well as in the increase in the potassium feldspar content relative to the preceding fraction in the till of basic volcanics areas. The even occurrence of hornblende indicates a homogenization of the material. In the 0.006—0.02 mm grade, the mineral composition clearly shows homogenization of the material and distinct lengthening of the transportation distance. The potassium feldspar has become enriched in the 0.02—0.06 mm and 0.006—0.02 mm fractions. The maximum proportions of the minerals fall into different grades. The quartz maximum occurs mostly in the 0.06—0.2 mm grade (fine and very fine sand), but also in the 0.02—0.06 mm fraction. The plagioclase maximum occurs for the most part in the 0.06—0.2 mm fraction as well as to some extent in the 0.02—0.06 mm fraction. The potassium feldspar maxima fall into all three fractions studied (0.06—0.2 mm, 0.02—0.06 mm, 0.006—0.02 mm). This is due to differences in the source material as well as to the transportation distance. The hornblende maximum occurs mainly in the 0.02—0.06 mm fraction and in certain samples in the 0.006—0.02 mm fraction. Its occurrence in the finer grades can be attributed partly to the fine-grained source rock, that is, basic volcanics, but also to its easy comminution owing to its soft mineral nature.

In the 0.002—0.006 mm and 0.0001—0.002 mm fractions, the CaO, Na_2O and K_2O concentrations fall below those found in the local bedrock. Besides the transportation distances, the influence of the local bedrock on the till is seen in the behavior of CaO, Na_2O and K_2O.

In the 1—1.2 mm fraction, 98.6 % of the quartz grains were found to belong to two grades of roundness, angular and subangular. The W_0 values (index of abrasion) obtained, 939—1076, indicate that only slight comminution has taken place. This signifies homogenization of the roundness of the quartz grains during the rather short glacial transportation that took place in the region. The majority of the quartz grains come from granitoids in the bedrock of the investigation area. This corresponds to the noted quartz excess, which seems to derive from the preglacial weathering of the local bedrock. A portion of the grains in the subrounded class possibly originated in the Jotnian sandstone area of Satakunta or in preglacial sediments. A connection between the lower degree of roundness of the quartz grains along the traverses and the high local content of the granitoids is faintly apparent (Nos. 5, 19 and 32). The higher degree of roundness (W_0-values) shows the presence of non-local granitoids (Nos. 9, 11, 18, 23, 24 and 29).

Among the factors mentioned by Gillberg (1965) and Dreimanis and Vagners (1969) as affecting the composition of till, the main ones in the Hämeenlinna region have been the following: the properties of the rock types, the extent of the parent rock, the distance between sampling site and source rock, the presence or absence of other material — like the uneven occurrence of mica schists and mica gneisses in the till of the present investigation area —, the nature of the glacial transportation and deposition, and also the influence of the topography.

The basal till of the region is composed of material mainly eroded from the bedrock by the ice sheet as well as of preglacial weathering products and englacially transported drift (far-traveled material). Comminution during glacial erosion and transportation was the chief factor in producing the basal till. Furthermore, the process of deposition by the ice sheet left its marks most clearly on the depressions and on the proximal ascending or distal descending slopes in relation to the ice flow. On the whole, the influence of the local bedrock on the composition of the basal till is apparent.

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Appendix 1

The percentage of granitoids and basic volcanics in the till samples studied in five fractions. The material was used in the transportation study.

Down—glacier from the distal contact

Granitoids

Traverse I

Samples No.	20—200 mm	6—20 mm	2—6 mm	0.6—2 mm	0.2—0.6 mm	distance from starting point km
5	90	91.5	86	60	45	0
6	78	75	78	73.5	39	1.2
7	54	61.5	72	66	60	2.3
8	44	55	48	48	28.5	3.7
9	16	24.5	19	47	17	5.0
10	10	12	14	21	23.5	7.0
			Traverse II			
19	89	92	93	78	49.5	0
20	69	80	81.5	77	27	0.9
21	42	42	58	51	44	2.4
22	17	27	45	29.5	30	4.5
23	10.5	18	26	43	16	6.7
24	2.5	14.5	27.5	36	27	8.9
25	4	12	9	20	12	11.3
			Basic volcanics			
			Traverse I			
9	78	69	76	29.5	17	0
10	64	57	56	35	32.5	2.0
11	32	37	44	32.5	17	2.7
12	53	34	38	23	12	5.5
13	20	28	15.5	11.5	10.0	7.8
14	19	19	22	11	8.5	11.8
15	17	18.5	16	7.5	7.5	14.2
16	9.5	9.5	12	5	3.5	16.1
17	10.5	10	3.5	2	4	19.8
18	2	3.5	1.5	1	1	24.2
			Traverse II			
25	59	52	36	38.5	21	0
26	48	43	32	12	13.5	2.7
27	17	13	7	10	2.5	5.0
28	14	9	12	5.5	18.5	6.0
29	7	9.5	7	2	4	8.5
30	2	10	9	5	6	9.8
31	5	3	3	5	4.5	11.5
32	8	9	10	10.5	1.5	12.4
			Down—glacier from the proximal contact			
			Granitoids			
			Traverse I			
11	38.5	44	37.5	50.5	41	0.4
12	45	59	52	54	45.5	3.2
13	73.5	64	76	64	43	5.5
14	65	77	68.5	69.5	60.5	9.5
15	79	80	82	71	46	11.9
16	82	87	82	76	62	13.8
17	78	83	93.5	77	62	17.5
18	92	96.5	93	77	62.5	21.9
			Traverse II			
26	28	27	29	39	24	0.2
27	53	60	60	50	16.5	2.5
28	70	69	77	75	27	3.5
29	70	73	73.5	87	57	6.0
30	89	86	87.5	82	43	7.3
31	82	82	84	74	39	9
32	79	77	80.5	64	34.5	9.9

Appendix 2

Minerals of all samples in three fractions in per cent

0.06—0.2 mm

Traverse I

Sample No.	quartz %	plagioclase %	potassium feldspar %	hornblende %	biotite %	others *) %
1	42.5	25.5	12.5	8.0	6.5	5.0
2	54.5	27.5	7.5	7.0	2.0	1.5
3	33.5	42.0	6.5	8.0	6.5	3.5
4	29.5	43.0	4.5	4.0	11.0	8.0
5	39.5	30.5	15.5	5.0	5.0	4.5
6	38.5	35.0	9.5	2.5	6.0	8.5
7	36.0	40.0	9.5	8.0	3.0	3.5
8	39.0	30.0	12.0	4.5	2.0	12.5
9	43.0	16.5	5.5	6.0	4.0	25.0
10	32.0	20.5	14.5	7.5	10.0	15.5
11	51.0	26.0	4.5	7.0	11.0	0.5
12	45.0	29.0	7.0	5.5	4.5	9.0
13	44.5	27.5	15.5	4.0	1.5	7.0
14	45.5	29.5	15.0	2.0	2.0	6.0
15	39.0	31.5	20.0	2.5	4.0	3.0
16	47.0	20.0	26.0	2.5	2.0	2.5
17	38.0	32.5	21.0	1.5	5.0	2.0
18	41.0	31.0	21.0	0	5.0	2.0

Traverse II

Sample No.	quartz %	plagioclase %	potassium feldspar %	hornblende %	biotite %	others *) %
19	39.0	42.5	10.5	2.5	3.0	2.5
20	43.0	26.5	17.0	5.5	7.0	1.0
21	33.5	31.0	9.0	3.5	15.5	7.5
22	37.5	33.5	8.5	5.5	4.5	0.5
23	39.5	42.5	3.5	3.0	6.0	5.5
24	49.5	27.0	10.0	2.5	4.0	7.0
25	43.0	18.5	2.5	9.0	17.0	10.0
26	51.0	28.0	8.0	3.0	4.5	5.5
27	51.0	25.0	13.5	4.5	2.5	3.5
28	55.0	17.5	22.0	2.0	1.0	2.5
29	42.5	21.0	21.0	2.0	7.0	6.5
30	52.0	21.0	18.5	2.0	2.5	4.0
31	49.5	19.5	14.0	5.0	9.0	3.0
32	45.0	34.0	11.5	2.0	2.0	5.5

*) Group contains garnets, pyroxenes, ore grains, and other accessories.

0.02—0.06 mm

Traverse I

Sample No.	quartz %	plagioclase %	potassium feldspar %	hornblende %	biotite %	others %
1	39.0	19.0	19.0	13.0	3.0	7.0
2	36.5	27.0	12.0	13.5	4.0	7.0
3	42.0	15.0	17.0	12.0	5.0	9.0
4	42.0	20.0	8.0	7.0	9.0	14.0
5	38.5	12.5	13.5	20.0	6.0	9.5
6	40.0	19.0	13.0	12.0	5.0	10.0
7	34.5	18.5	15.0	20.0	4.0	1.0
8	35.0	22.0	19.0	19.0	3.0	2.0
9	33.0	24.0	11.0	18.0	8.0	6.0
10	34.0	17.0	13.0	13.0	8.0	15.0
11	36.0	8.0	5.0	23.0	13.0	15.0
12	44.0	11.0	22.0	11.0	6.0	6.0
13	38.0	26.0	19.0	8.0	4.0	5.0
14	32.0	18.0	24.0	14.0	5.0	7.0
15	36.0	17.0	14.0	18.0	5.0	10.0
16	49.0	13.0	19.0	11.0	0	8.0
17	36.0	19.0	20.5	11.5	4.5	8.5
18	36.0	24.0	26.0	9.0	1.0	4.0

Traverse II

Sample No.	quartz %	plagioclase %	potassium feldspar %	hornblende %	biotite %	others %
19	36.0	19.0	26.0	6.0	3.0	10.0
20	34.5	18.5	20.0	16.0	6.0	5.0
21	35.0	29.0	16.0	6.0	6.0	8.0
22	28.0	25.0	19.0	14.0	4.0	10.0
23	54.0	13.0	17.0	3.0	2.0	11.0
24	48.0	25.0	18.0	2.0	2.0	5.0
25	46.0	28.0	10.0	11.0	2.0	3.0
26	58.0	19.0	11.0	7.0	1.0	4.0
27	43.0	33.0	3.0	9.0	0	12.0
28	37.0	20.0	27.0	10.0	3.0	3.0
29	48.0	27.0	18.0	1.0	1.0	5.0
30	37.5	19.0	23.5	6.5	5.0	8.5
31	53.0	22.0	11.0	6.0	0	8.0
32	36.0	16.0	23.0	15.0	1.0	9.0

App. 2, contd.

0.006—0.02 mm

Traverse I

Sample No.	quartz %	plagioclase %	potassium feldspar %	hornblende %	biotite %	others %
1	32.0	21.0	24.0	12.0	2.0	9.0
2	38.0	16.0	12.5	23.0	5.0	5.5
3	29.0	17.0	28.0	18.0	3.0	5.0
4	35.0	8.0	16.0	13.0	10.0	18.0
5	39.5	5.0	16.5	19.0	9.0	11.0
6	26.0	9.0	18.0	20.0	9.0	18.0
7	42.5	11.5	14.0	18.5	4.5	9.0
8	34.0	11.0	12.0	16.0	11.0	16.0
9	29.0	11.0	10.0	17.0	8.0	25.0
10	24.0	16.0	15.0	19.0	7.0	19.0
11	28.5	10.0	14.5	27.0	4.5	15.5
12	29.0	19.0	18.0	19.0	7.0	8.0
13	24.0	9.0	16.0	23.0	12.0	16.0
14	28.0	16.0	17.0	19.0	9.0	11.0
15	31.0	13.0	28.0	16.0	6.0	6.0
16	38.0	13.0	29.0	8.0	4.0	8.0
17	31.5	11.0	23.0	18.0	5.0	11.5
18	36.0	13.0	25.0	15.0	7.0	4.0

Traverse II

Sample No.	quartz %	plagioclase %	potassium feldspar %	hornblende %	biotite %	others %
19	29.0	18.0	25.0	11.0	11.0	6.0
20	31.5	9.0	16.0	16.0	14.5	13.0
21	37.0	18.0	23.0	7.0	5.0	10.0
22	27.0	18.0	27.0	10.0	7.0	11.0
23	50.0	17.0	18.0	2.0	1.0	12.0
24	38.0	30.0	15.0	3.0	1.0	13.0
25	45.0	22.0	11.0	2.0	2.0	18.0
26	53.0	19.0	16.0	2.0	1.0	9.0
27	38.0	23.0	15.0	3.0	3.0	18.0
28	32.0	20.0	24.0	11.0	5.0	8.0
29	52.0	10.0	14.0	1.0	1.0	22.0
30	33.0	8.0	20.0	17.5	4.5	17.0
31	53.0	13.0	15.0	4.0	1.0	14.0
32	31.0	18.0	25.0	10.0	4.0	12.0

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