Geological Survey of Finland, Special Paper 7

Transport of glacial drift in Finland

Proceedings of a symposium at Lammi, April 12—13, 1988,
arranged by the Finnish National Committee for Quaternary Research

Edited by Marjatta Perttunen

Geologian tutkimuskeskus

Espoo 1989

Cover:
Erratic boulder. Uskaljärvi, Kiihtelysvaara. Photo W.W. Wilkman.
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The publication contains 11 articles on glacial drift in Finland. The history of the transport studies of till and glaciofluvial sediments has been reviewed. The study of indicators and erratics as well as the transport of till and glaciofluvial sediments has been discussed. The process of the formation of erratics, glacial sculpture in bedrock valleys, method to obtain information of surficial deposits and tracing the source areas by the chemical composition of garnets give more information about the subject. The aim is to help ore prospecting using glacial drift in Finland.

Key words: glacial geology, drift, till, glacial transport, glacial erosion, Quaternary, symposia, Finland

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PREFACE

The second symposium arranged by the Finnish National Committee for Quaternary research, held at Lammi Biological Station April 12—13, 1988, was devoted to the subject of the transport of glacial drift in Finland. The study of indicators and erratics has played a particularly important part in locating the outcrops of ore boulders found in glacial drift, where a knowledge of the ice flow directions of the former ice sheet is necessary. Tracing the origin of ore boulders in Finland is thus closely connected with studies of the Quaternary drift. As a result of this approach the origin of the boulder of copper ore found 1908 at Kivisalmi in south-eastern Finland could be traced, in 1910, to Outokumpu north-west of Kivisalmi (Stigzelius 1987), with far-reaching consequences to the Finnish mining industry. Several ores have since then been traced in a similar manner.

The transport distances of erratics in till and the relationship between erratics and the underlying bedrock have been studied in many areas, e.g. by Hellaakoski (1930) in the Laitila area in south-western Finland, Okko (1941) in northern Finland, Repo (1957) in eastern Finland and Virkkala (1969) in southern Finland. Perttunen (1977), in her work in the Hämeenlinna area, further developed the methods of analysing and presenting the lithologic relationship between tills and bedrock, whereas Salonen (1986), in his work on surface boulders in the whole country, developed a method which he named the 'transport distance distribution method'. With this method he demonstrated areal variations in boulder transport distances. A stratigraphical approach in the study of the lithology of tills has been used particularly by Hirvas and co-workers in Lapland but also further south in Finland (Hirvas & Nenonen 1987). The transport of erratics in esker material, as compared with till, has been studied particularly by Hellaakoski (1930) in the above-mentioned Laitila area, by Okko (1945) in Mikkeli and Virkkala (1958) in Hämeenlinna, both in central Finland. Whereas the fairly consistant transport distances in esker material have been well worked out, the composition of the glaciofluvial material in the major endmoraines, such as the Salpausselkä ridges, is less clear. No detailed studies have been made of the relationship between their erratics and the bedrock in their vicinity.

In contrast to the study of the local transport in Finland the far-travelled erratics were already studied in the beginning of the century and maps drawn of the boulder fans (Sederholm 1911, Hausen 1912). As Finland was submerged during deglaciation there are a number of ice-rafted boulders especially along the coast of southern Finland, which in sections of fine sediments can be identified as drop-stones. There are, however, no detailed studies of the extent of ice-rafting in this area.

In recent years extensive geochemical studies have been carried out of glacial drift, particularly of till, adding considerably to the knowledge of its origin and transport. The anomalies of some ore minerals have, for instance, been used in ore prospecting.

In spite of all these detailed studies there are still only very rough estimates of how much material has been transported by the ice and how much of the fresh bedrock surface was eroded. On the other hand, it has become clear that there are areas where old regolith and pre-Weichselian drift, as well as organic sediments, have been preserved and even remained in situ.

The contributions in the present volume are based on the talks at the Lammi symposium, which were given with the intention of furthering the study of the transport and sedimentation of glacial drift in Finland. This is indeed a subject of great interest and for this reason the Committee is grateful to the Geological Survey of Finland for agreeing to publish the symposium papers and to Dr. Marjatta Perttunen for editing the volume. Mr. Paul Sjöblom, M.A., is gratefully acknowledged for his help in preparing the English versions of most of the manuscripts.

Joakim Donner

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TRANSPORT DISTANCES OF FINNISH CRYSTALLINE ERRATICS DURING THE WEICHSELIAN GLACIATION

by
Joakim Donner

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In central Finland the transport distances of erratics were short and the lithology of the tills therefore largely reflects the composition of the underlying bedrock of the Baltic shield. In Estonia, in the more marginal area of the Weichselian glaciation, there is a comparatively high proportion of far-travelled crystalline erratics from areas north of the boundary of the Palaeozoic sedimentary rocks, which have been transported at least 100—500 km. The difference between the two areas can partly be explained by assuming that during the Weichselian glaciation erratics could only have been transported greater distances in the marginal parts of the glaciation in the time available, if the flow rates of the ice sheet were of the order given for ice sheets of similar extension as that of the Scandinavian ice sheet during the Weichselian. The discussion of the transport distances is only concerned with this aspect of glacial activity.

Key words: glacial geology, glacial transport, erratics, Pleistocene, Weichselian, Finland, Estonia

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INTRODUCTION

Within the area which was covered by the Scandinavian ice sheet during the Weichselian there were differences in the transport distances of erratics. In Finland the transport distances were short, as already demonstrated by Hellaakoski (1930) in his study of both till and glaciofluvial material of an esker in the Laitila area in southwestern Finland, by Okko (1945) in a similar study in the Mikkeli area, by Virkkala (1969) in a study of the till in the Hyvinkää area and by Perttunen (1977) in a detailed study of the till in the Hämeenlinna area. Perttunen, following Krumbein (1937), demonstrated that the increase in the relative amount of granitoids and basic volcanics from the proximal contacts, in the direction of ice movement, obeys an exponential function and the decrease from the distal contacts a negative exponential function. The half-distance values, i.e. the distances at which the frequencies of the rock types were halved from the frequencies from the starting point of transport, were for granitoids along two traverses 3.7 km and 4.7 km and for basic volcanics 5.6 km and 4.2 km respectively. In an extensive study of surface boulders in Finland Salonen (1986) defined the glacial transport distances for the boulders in the sample counts as the distance to the closest localities in the bedrock that could be the source of the boulders, using cumulative distance distribution curves for the various rocks. The geometric mean of the boulder transport distance varies, according to Salonen, between 0.4 km and 3.0 km, the average transport distance between 0.8 km and 10.0 km in cover moraine areas and 5.0 km and 17.0 km in drumlin areas. According to Salonen (1987) the almost 500 identified boulder fans are in Finland normally 1—5 km long, the longest, however, being 50 —100 km long and some individual boulders have been transported even further. The median length of the boulder fans is 3.0 km. The orientation of the boulder fans largely reflect the directions of the ice movements during deglaciation.

All the above-mentioned studies show that the majority of the erratics in Finland were transported a very short distance, that most of the material in the till is very local and that it was largely deposited during the retreat of the ice sheet. On the other hand erratics were also transported far outside Finland to the marginal areas of glaciation, as seen on the map of indicator fans in the area of the Scandinavian ice sheet presented by Sederholm (1911) in Atlas of Finland 1910, later slightly modified by Flint (1971, Fig. 7—18), and on the map of the spread of erratics from Sweden and Finland into the areas southeast of the Baltic Sea presented by Hausen (1912). Many of the indicators travelled as far as 500 km but none, according to Flint (1971), more than 1200 km. In North America, however, erratics from Hudson Bay travelled 1000 to perhaps 2500 km (Prest & Nielsen 1987). Many of the far-travelled indicators were transported during more than one glaciation. In northern Europe some of the indicators of crystalline rocks from Sweden and Finland were transported already during the Saalian glaciation, when the Scandinavian ice sheet was more extensive than it was during the Weichselian. Thus, the indicators in the Netherlands are Saalian. The direction of transport could also change during the same glaciation, as demonstrated in the Hamburg area (Ehlers 1983). As a result of this there is a change in the lithology within the till of the Weichselian glaciation as a result of a change in provenance. Further, the source areas in Fennoscandia of the erratics of crystalline rocks found in the marginal areas covered by the Scandinavian ice sheet have been determined (Overweel 1977) and used in reconstructing the flow patterns of the ice (Boulton et al. 1985). In a study of 961 erratics of crystalline rocks found in Latvia Eskola (1933) concluded that the percentages of the main rock types, mainly granites and migmatites, corresponded to the percentages of these rocks in the bedrock of Finland, but pointed out that the erratics were mainly from southern Finland. On the whole the great amount of large surface boulders of crystalline rocks from the Baltic shield is striking in the marginal areas of glaciation, as in Estonia south of the Gulf of Finland. Over 1900 erratic boulders with a diameter over 3 m are known in Estonia, the largest being the rapakivi block 'Kabelikivi' (Chapel Rock) near Tallinn with a diameter of 56.5 m and a pegmatite block near Kunda with a diameter of 49.6 m, reported to be the biggest

Fig. 1. Erratics of crystalline rocks in Kösnu, Lahemaa National Park east of Tallinn in Estonia (photo 1987).

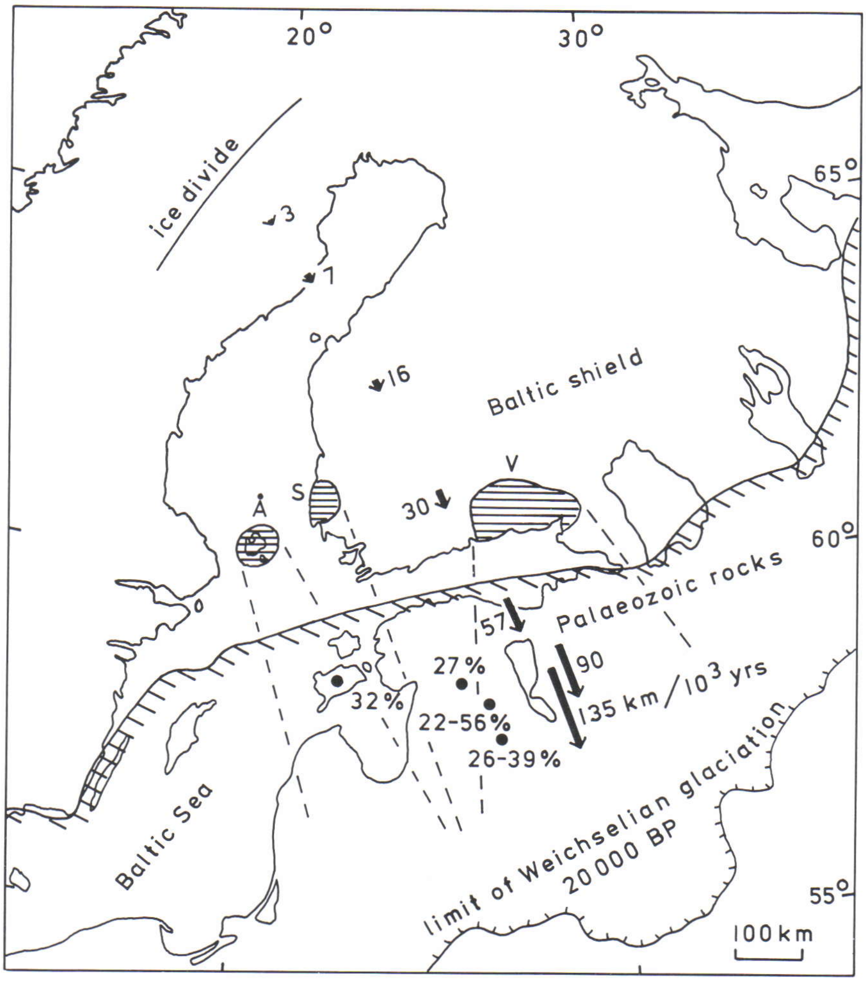

Fig. 2. The proportion of erratics of crystalline rocks (in percentages) in some areas of Estonia south of the boundary in the Gulf of Finland between the Baltic shield and the Palaeozoic sedimentary rocks. The outlines of the indicator fans for the Åland rapakivi granite (Å), the Satakunta olivine diabase (S) and the Viipuri rapakivi granite (V) are also shown, as well as the flow rates of the ice sheet (after Paterson 1981), at various distances from the ice divide, used in the discussion of the transport distances of erratics during the Weichselian glaciation. The outer limit of the Weichselian ice sheet is also shown.

Pleistocene erratics in northern Europe (Viiding 1976). In Estonia the large erratics are particularly frequent along the north coast, as in Lahemaa east of Tallinn described by Viiding (1981), of which some are seen in Fig. 1. In East Germany, which in relation to the glaciation is similarly situated as Estonia, the largest surface erratics are in the northern parts close to the Baltic Sea whereas the erratics are smaller in the southern parts closer to the marginal area of glaciation (Kahlke 1981).

The relatively large proportion of erratics of crystalline rocks outside the Baltic shield area is not only reflected in the above-mentioned surface boulders but also in the proportion of erratics in the drift generally. In Denmark, for instance, the proportion of crystalline rocks, transported from outside Denmark, is about 40— 60 % (Rasmussen 1966), in the material deposited during the recession of the Weichselian ice 30—40 % (Hansen 1965). In Estonia, in the area of Palaeozoic sedimentary rocks south of its boundary in the Gulf of Finland (Winterhalter et al. 1981), the proportion of stones of crystalline rocks is in glaciofluvial gravel on Saarenmaa (Ösel) 32 % (Hausen 1912), in the till at Viljandi 27 % (Raukas 1985), at Otepää 22—56 % and at Haanja 26—39 % (Raukas & Karukäpp 1979), as shown in Fig. 2. There are, however, great differences in the proportion of crystalline rocks in the tills within Estonia, as shown by a map published by Raukas (1969), but in many areas in the southern parts of the country the percentages are as high as in the northern parts, closer to the area from which they were transported. The origin of the clasts of crystalline rocks transported into Estonia is to a large extent southern Finland, as shown by the indicator fans, shown in Fig. 2, of the Åland rapakivi granite, the Satakunta olivine diabase and the Viipuri rapakivi granite (Raukas 1965, Viiding 1981). In eastern Estonia the proportion of the Viipuri rapakivi granite is in places as high as 50—60 % of the erratics of crystalline rocks, as is the case even in the southern parts of the country (Raukas 1986).

Because the crystalline rocks are more durable than the sedimentary rocks they may form a higher proportion of the clasts in the tills of the area of Palaeozoic sedimentary rocks in Estonia than would be the case if the local bedrock were harder, but on the other hand the local bedrock is more erodible (see Flint 1971). The proportions between far-travelled crystalline erratics from the Baltic shield and local erratics of sedimentary rocks cannot directly be compared with areas in which all erratics represent equally durable rocks. The above-mentioned examples show, however, that a comparatively large proportion of the erratics in Estonia, similarly to erratics in Denmark and other marginal areas of the Scandinavian ice sheet, are far-travelled crystalline rocks from the Baltic shield. The average thickness of the drift in Finland is 8.2 m, estimated to correspond to a lowering of the rock surface of 7 m (Okko 1964). In lowland Estonia the thickness of the drift is as a rule 5—10 m (Raukas 1985). There is thus no clear difference between the two areas in the amount of glacial drift having been deposited. In Denmark, on the other hand, the drift cover is on the average 50 m thick (Hansen 1965), in most areas, however, being less (Rasmussen 1966), but then Denmark is close to the Scandinavian mountains, where the erosion was great, particularly in the fjords formed through deepening by glaciers of pre-existing stream-eroded valleys. A large amount of material was thus transported from this area during the glaciations (Flint 1971). This is in contrast to the lowlands of Finland and Estonia east and southeast of the Scandinavian mountains, where both erosion and deposition was much less. Here, as seen above, there is a particularly noticeable difference in the transport distances of erratics in Finland, which was closer to the centre of glaciation, and Estonia in the more marginal area; in Finland the material of the till is mainly local whereas in Estonia a considerable proportion consists of far-travelled erratics. In the following the difference between these two areas is discussed.

REASONS FOR DIFFERENCES IN TRANSPORT DISTANCES

The glacial deposits in Finland and Estonia for which the figures were given about their lithological composition are, with the exception of the glaciofluvial gravel on Saaremaa in Estonia, tills of the last, Weichselian glaciation, with its southernmost limit south of Estonia dated at about 20,000 B.P. (Lundqvist 1986a) as shown in Fig. 2. Whereas, as mentioned, most erratics in the tills in Finland were transported a short distance, the erratics in Estonia have a large proportion of crystalline rocks from the Baltic shield, many transported at least as far as from southern Finland. Thus, more erratics were transported longer distances from the southern parts of Finland, into the areas of Palaeozoic rocks of Estonia, than were erratics within Finland, closer to the ice divide during the Weichselian glaciation (for its position see Lundqvist 1986b). As a basis for the discussion of the reason for this difference in glacier transport conclusions made about flow rates in large ice sheets can be used. Thus, for an ice cap in a steady state, with a parabolic profile and a total width of 2000 km, roughly corresponding to the Scandinavian ice sheet during its Weichselian maximum, Paterson (1981) has given velocities in m per year for different distances from the centre. The whole ice sheet, about 4700 m thick, was assumed to be in an accumulation area, with calving to account for the ablation. Even if the Weichselian ice sheet at its maximum differed from that given as an example, with velocities probably typical for the present Antarctic ice sheet, the differences in velocities give some indication of why transport distances have varied regionally. In Fig. 2 the flow rates are given in km per 1000 years (= length of black arrows) for the distances of 100 km, 200 km, 400 km, 600 km, 800 km, 900 km and 950 km from the ice centre, i.e. the ice divide (Paterson 1981, as also quoted by Kahlke 1981). In the even lowlands of Finland and Estonia there were hardly any ice streams with considerably higher velocities, as there will have been in the fjords and valleys of the mountains of Scandinavia, but any change in the mass balance must have affected the flow rates. It can, however, be seen how the flow rate accelerated with increasing distance from the ice divide, to reach considerable velocities in southern Finland and Estonia as compared to the low velocities near the ice divide. The effect of this difference on the transport of erratics is sche-

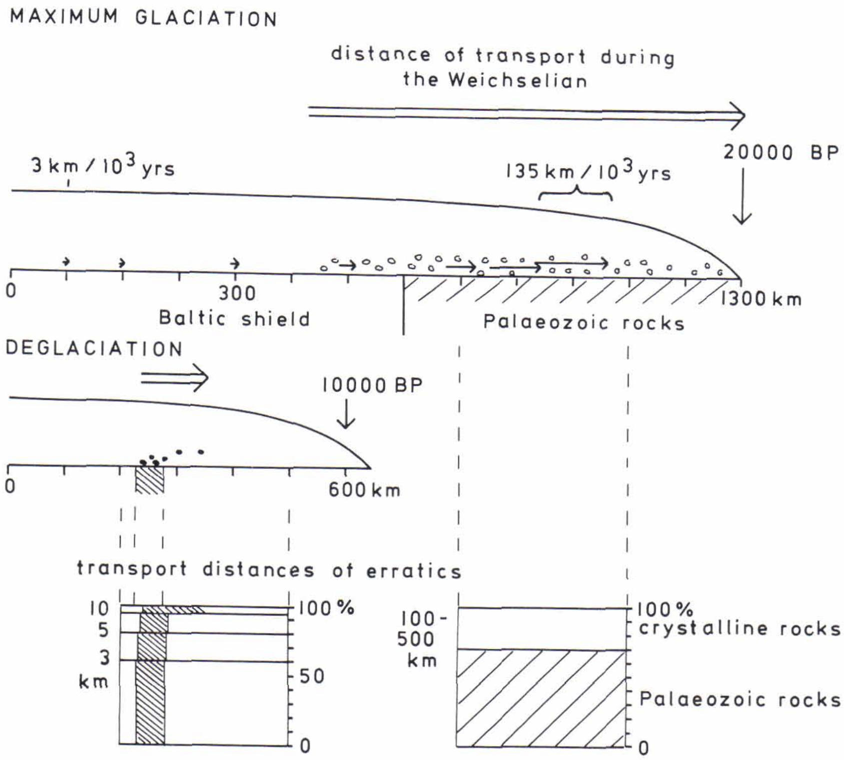

Fig. 3. Profiles of the Weichselian ice sheet during its maximum extension at about 20,000 B.P. and during deglaciation at about 10,000 B.P. and examples of transport distances of erratics of crystalline rocks from the Baltic shield in the more central part of the area of glaciation in Finland and the more marginal part in Estonia. Flow rates of the ice sheet used in Fig. 2 are also included.

matically shown in Fig. 3. The upper profile of the ice sheet shows it at its largest extent during the Weichselian maximum at about 20,000 B.P., the outer margin being about 1300 km from the ice divide. The general composition of the tills in the above-mentioned areas in Estonia is shown below. The comparatively large proportion of erratics of crystalline rocks in this area of Palaeozoic rocks were transported 100—500 km, taking into account the length of the indicator fans shown in Fig. 2. The shortest distance of transport, 100 km, is taken from the northern boundary of the Palaeozoic rocks outside the coast of Estonia. The distance from this boundary to the limit of the Weichselian glaciation is 700 km, which is the shortest distance of transport for the erratics of crystalline rocks which were carried to the outermost zone of drift deposited during the Weichselian glaciation, as shown in Fig. 3. The lower profile of the ice sheet corresponds to the time during deglaciation when the ice margin was in southern Finland at about 10,000 B.P., shortly after the standstills which resulted in the formation of the Salpausselkä moraines. In this area deglaciated between 10,000 and 9000 B.P., being less than 600 km from the ice divide, less than 10 % of the erratics were transported more than 10 km and the rest of the erratics only a few kilometres, as schematically indicated in Fig. 3 on the basis of the earlier mentioned figures given by Salonen (1986). In central Finland the Weichselian till was mainly deposited at the time of the deglaciation, the till fabric reflecting the directions of the youngest striae (Hirvas & Nenonen 1987). Some erratics, however, were even in this area transported far from their areas of origin (Salonen 1987), probably because of an englacial transport. The deposition of till in central Finland during the Weichselian glaciation must have been preceded by a period of erosion, during which the bedrock and most of the remaining regolith, as well as older drift, were eroded. The erosion was, however, clearly weaker in the areas closer to the ice divide, as in Ostrobothnia on the west coast of Finland, where organic interglacial and interstadial beds as well as older eskers have been preserved underneath the thin sheet of lodgement till of the Weichselian glaciation (Hirvas & Nenonen 1987). These conclusions would agree with the view that most of the glacial erosion took place during the early stages of the formation of the ice sheet, mainly during its advance (see Sugden & John 1979).

The buildup of the last Weichselian ice sheet probably started about 30,000 years ago and reached its maximum extent about 20,000 years ago (Lundqvist 1986a). It had again retreated to southern Finland 10,000 years ago and about 9000 B.P. the deglaciation of Finland had ended. If these time limits are correct and if the flow rates of the ice sheet used in Figs. 2 and 3 are of the correct order of magnitude large amounts of erratics could only have been carried several hundred kilometres in the marginal parts of the ice sheet in the time span available. The transport of erratics of 700 km, from the boundary between the Baltic shield and the Palaeozoic sedimentary rocks, to the outermost margin of the Weichselian ice sheet at its largest extent, would have taken over 5000 years using the value of 135 km per 1000 years, and over 12,000 years using the value of 57 km per 1000 years. This would mean that for erratics transported in the basal parts of the ice sheet there would not have been time for them to be transported during the Weichselian glaciation from the more central parts of glaciation, with its low flow rates, to the marginal parts. In Ostrobothnia in Finland it would have taken over 300 years for erratics in till to form a 5 km long boulder fan, during which the ice margin, with an annual retreat of 260 m according to the varve chronology, retreated about 80 km (Sauramo 1929). In glaciofluvial material, on the other hand, transport distances were longer. Occasional indicator erratics of Jotnian sandstone were transported at least 140 km from Satakunta in south-western Finland towards the south-east, in the direction of the last ice movement. These must represent englacial erratics, carried further by the ice than the basal till and deposited by meltwaters in the material of eskers and endmoraines (Donner 1986). Other far-travelled indicators found far beyond the main boulder fan, sometimes even in till, must also heve been transported englacially.

By using the above-mentioned chronology for the Weichselian glaciation the differences in the glacial transport of erratics between the central areas of glaciation in Finland and the marginal areas in southern Finland and Estonia could be explained as having been governed by the differences in flow rates within the ice sheet. If the Weichselian glaciation in fact lasted several tens of thousand years one has to assume that there were even longer periods during which there was hardly any transport of material in the basal parts of the ice in the central areas of glaciation. If the flow rates were generally much higher than assumed more material would have been transported longer distances throughout the whole glaciated area.

The discussion above of the reasons for differences in the transport distances of the erratics was deliberately concentrated only on chronology combined with flow rates of ice. Variations in the intensity of glacier erosion during the Weichselian glaciation or glaciations generally were not discussed, nor were the effects of possible changes between cold- and warm-based conditions (Sugden & John 1979). A meaningful discussion of these variables would require a much more detailed analysis of the origin of the drift and its landforms; the glaciodynamics of the marginal zone during the Younger Dryas time has been discussed by Lundqvist (1987). In the present account the quoted observed differences in glacial transport distances of erratics are real, whereas the conclusions about the reasons for these differences, which fit the evidence, must be considered highly tentative and represent an over-simplification of the former glacial activity.

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HOW THE GLACIAL ERRATICS WERE BROKEN LOOSE FROM THE BEDROCK

by
Ilkka Laitakari

Laitakari, Ilkka, 1989. How the glacial erratics were broken loose from the bedrock. *Geological Survey of Finland, Special Paper 7,* 15—18. 4 figures.

The study of bedrock hills reveals an obvious causality between the jointing and the morphology of the bedrock surface. This can best be seen in road cuts, which give excellent profiles across the hills. Jointing of the bedrock obviously made it possible for the continental ice sheet to break off large segments from the bedrock. The forms of the blocks also reveal the same mechanism. Large glacial erratics are almost invariably surrounded by planes, which obviously can be traced back to bedrock joints.

Preglacial disintegration along joints often resulted in the formation of ovoidal weathering remnants. Thus rounded forms of glacial boulders do not always indicate transport over any long distance.

Key words: glacial geology, glacial erosion, bedrock, erratics, Quaternary, Finland

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The present paper is not based on any specific scientific study but on scattered observations made in connection with other bedrock investigations. Accordingly, I have not become familiar with publications concentrating on this particular field of research. I have nevertheless gained the impression that the breaking loose of boulders has received rather little attention in Finland. Traditionally, a rock remains in the sphere of interest of the bedrock geologist as long as it is part of the bedrock, and it commands the interest of the Quaternary geologist only after it was broken loose. Investigating the event itself, of a rock's breaking loose, is thus nobody's particular business. It is possible, however, to draw conclusions also about the way in which the breaking took place by studying both the bedrock and the detached boulders. I shall describe them in the following.

When talking about glacial erosion, geologists usually begin by bringing up the subject of the classical ice-polished outcrop with the sheepback form. It is this form and the striated surface which has given rise to the term »roche moutonnée». My intention is by no means to maintain that there exist no typical roche moutonnée forms — this type of ice-polished rock is even frequently shown in textbook pictures. At least in Finland, however, outcrops bounded by plane surfaces are, to my mind, more common than rounded roche moutonnée forms.

The reason for the prevalence of ice-polished rocks, formed from planes, is the effect of jointing on glacial erosion. This can be seen especially clearly in many road cuts, where the rocky hill has been cut through in such a way that both the inner jointing of the rock and the morphology of the surface are visible at the same time (Figs. 1 and 2). The marks of glacial erosion, such as striae, are apt to be quite prominently developed on the rock surfaces, from which the continental ice sheet had in reality eroded only a few centimeters. It might be interesting to find out to what extent cross striae are missing from some surfaces, because a

Fig. 1. The ice-polished surface of bedrock is completely controlled by jointing. Utula, Hollola. Photo I. Laitakari (from Laitakari & Aro 1985).

Fig.2. An ice-polished bedrock surface (in foreground) continues as a joint (in background), Nokkola, Hollola. Photo I. Laitakari (from Laitakari & Aro 1985).

block overlying the joint had broken off only after the formation of striae representing the older ice flow.

The mode of breaking loose is to be seen not only on the bedrock but also on the glacial erratics. The bigger the boulder, the more likely it is to be bounded on some sides by even joint surfaces (Fig. 3). But if the boulder is rounded, that fact need not be taken as a sure sign of transport over a long distance. Progressing weathering conforming to joints of igneous rocks leads to ovoid weathering remnants (Fig. 4). As blocks undoubt-

Fig. 3. A glacial erratic, broken from the bedrock along joints. Söderskär, Porvoo. Photo I. Laitakari.

Fig. 4. Ovoidal weathering remnants in disintegrated porphyritic granite. Patalahti, Jämsä. Photo I. Laitakari (from Lahti & Laitakari 1982).

edly break loose most easily from weathered rock, already rounded boulders formed as a product of spherical weathering thus are easily broken loose by a glacier. If they are further abraded somewhat, it is nearly impossible to distinguish them from erratics rounded during long-distance transport.

In considering the mode of breaking loose, also the preglacial topography should be taken into account. When an extensive uniform continental ice sheet moves, there forms, especially in valleys running crosswise to the direction of ice flow, practically motionless dead ice. The main movement of the ice sheet takes place on the summit level of elevated landforms and above it. Boulders are therefore broken off by the ice mainly from the most resistant rocks composing the elevated areas. Only at the receding stage do glacier tongues form in the valleys, eroding less resistant rocks and the more deeply weathered bedrock of fracture zones. If this view is correct, the more resistant rocks would be more likely to be transported long distances by the continental ice sheet, while less resistant rocks would more likely be transported short distances during the receding stage of the glacier.

As really large boulders are most likely broken loose from the tops of rocky hills, the biggest drop stones, such as the rapakivi granite erratics found in the Helsinki region, also evidently originated from the summits of hills, levelled down a few meters during the Ice Age.

Although the foregoing doubtless contains some erroneous notions, characteristic of on amateur investigator, I hope it will nevertheless provoke fruitful discussion among colleagues interested in glacial erratics.

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GLACIAL SCULPTURE IN BEDROCK VALLEYS DIFFERING IN ORIENTATION

by
Heikki Niini

Niini, Heikki, 1989. Glacial sculpture in bedrock valleys differing in orientation. *Geological Survey of Finland, Special Paper 7,* 19—24. 11 figures.

The glacial sculpture of bedrock valleys was studied using the results of seismic refraction soundings over a total distance of about 200 km, and of 126 drill holes, in a 90-km-long zone between Koski Hl. and Helsinki in southern Finland. The cross-profiles showing the bedrock topography of the centres of the variously oriented valleys showed differences, depending on the direction of the ice movement. The author concludes that the valleys parallel with the ice movement have been eroded 3—4 m deeper on average than the others. The bottoms of the valleys cut by the ice movement are asymmetric and commonly contain blocky — presumably pre- or interglacial — weathering remnants under the till layer.

Key words: glacial geology, glacial erosion, bedrock topography, valleys, southern Finland.

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INTRODUCTION

The glacial sculpture of 56 bedrock valley centres was studied by seismic refraction sounding over a total distance of about 200 km, and by 126 drill holes, in a 90-km-long zone between Koski Hl. and Helsinki in southern Finland (Fig. 1). The field studies were carried out under the direction of the author in the late 1960's for the water-supply tunnel project of the Helsinki metropolitan area (Niini 1968a). Knowledge of the bedrock topography was deemed essential in the determination of the engineering-geological quality of the bedrock, especially in the sediment-covered valleys of the projected alternative tunnel zones.

As regards method, the emphasis in the original field studies was laid on explosion-seismic refraction soundings and diamond drillings done on the bedrock bottom of the depressions covered by surficial deposits. The bedrock surface forms were obtained by means of so-called profile interpretation, in which depth values were counted at intervals of five metres (Niini 1967a). The engineering-geological results of these field studies were aimed at (Niini 1966), needed for (Niini 1967b), and effectively used in (Niini 1968b) the planning of the 120-km-long Päijänne—Helsinki water tunnel, the construction of which was realized in 1982 (Niini 1982). The glacial sculpture of the valleys in the tunnel zone had been previously discussed in Finnish in a preliminary way by Rönkkö (1968) and Niini (1973).

The variably oriented depressions of the study zone most commonly represent fracture valleys, where the rocky bottom is generally 40—80 m below the tops of the bedrock hills between the valleys (Niini 1968a). The compositon of the rocks in the area (mostly granitoids or migmatitic gneisses) and the direction and prominence of their orientation vary in detail. Their influence on the morphological development of the varyingly oriented valleys in southern Finland had earlier been proved slight (Havula 1964, p. 36—42).

According to the observations on glacial striae, the main direction of the movement of the Weichselian ice sheet in the southern section of the zone is approximately 330° (Virkkala 1959, p. 12—14) and in the northern section 310° (Okko 1962, Appendix I). Few observations of striae have been made in the central section of the zone, but on the basis of abundant small end moraines (cf., Virkkala 1959, p. 17, and Aartolahti 1972, p. 9) the glacier has here proceeded from the direction 325°—330°. As for the direction of the ice movement, it appears to have been fairly consistent throughout the zone.

PROFILES ACROSS THE VALLEYS

Material and method

This discussion is based on all those seismic sounding lines of the study zone that cut clear bedrock valleys and in which the depth of the bedrock and the thickness of the surficial deposits were controlled by means of drillings. The last-mentioned restriction was necessary, because exactly at the bedrock depressions the depth readings based merely on seismic sounding are rather inaccurate (Niini 1967a). The material thus consists of 56 sounding lines, controlled by 116 diamond-drilling holes and 10 groundwater observation holes drilled on these lines. Of the seismic lines, 41 represent single valleys of distinct orientation, while 15 — unfortunately for the present purpose — struck sites where two or more valleys intersect.

In order to indicate the influence of ice movement on the sculpture of the valleys, the 41 single valleys were classified into four groups according to direction. Each group was additionally divided into two parts, northern and southern, because, considered from the point of view of sediment accumulation, the valleys situated north of the Salpausselkä I moraine differ essentially from those situated south of it (see Fig. 1).

To compare the slope inclinations of the valleys statistically, the relative heights of the bedrock surface were measured on both slopes of each valley at distances of 10, 25, and 40 m perpendicularly from the center (deepest point) of the valley. The average cross-profile and slope forms of each valley group (Figs. 2—9) were then calculated on the basis of the means of these readings. For comparison and to indicate the irregular distribution of these height readings, also their medians were calculated; they are indicated by straight lines in the Figures.

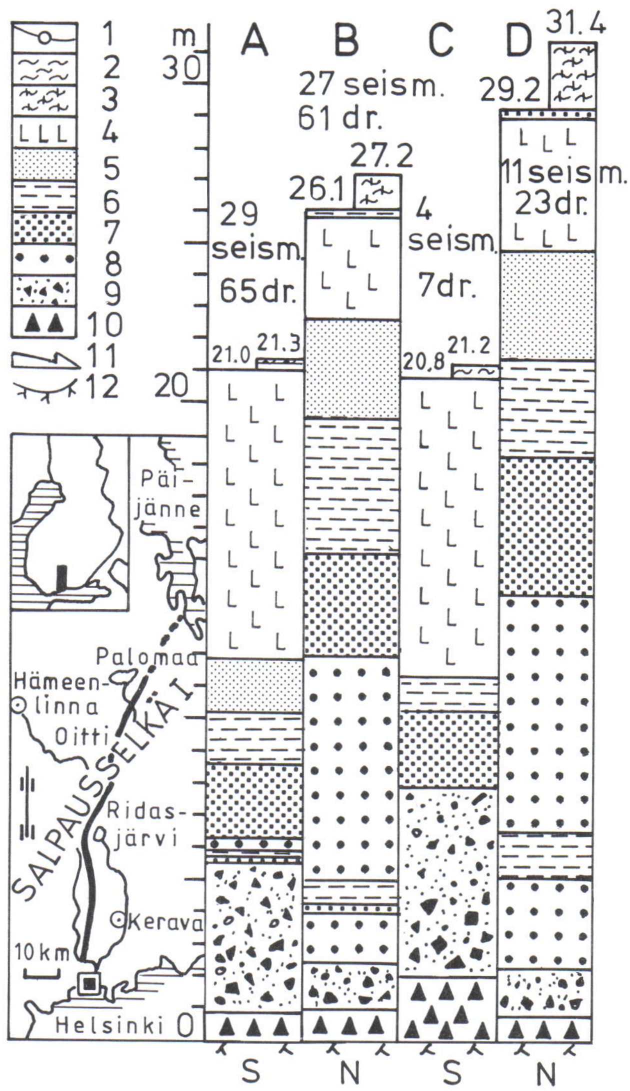

Fig. 1 (Figs. 1—9). Average profiles of valley centres, Helsinki—Palomaa tunnel zone. A. All southern valleys studied. B. All northern valleys studied. C. Southern valley crossings. D. Northern valley crossings. Key: (1) measuring point, (2) peat, (3) gyttja, (4) clay, (5) silt, (6) coarse silt and fine sand, (7) sand, (8) gravel, (9) till, (10) cobbles, boulders, and blocks, (1) direction of ice movement (the arrow is horizontal in valleys of the northern part, and inclined in those of the southern part of the zone studied), (12) surface of bedrock, (seism. = seismic lines, dr. = drill holes).

Valleys oriented differently

The valleys that are perpendicularly cut by the direction of ice movement (called simply »perpendicular valleys» in the following) are asymmetric (Figs. 2 and 3). In the southern section (Fig. 2), they have been effectively filled with till (mean thickness 10.5 m).

The slopes of the valleys parallel with the ice movement (Figs. 4 and 5) are convex and the bot-

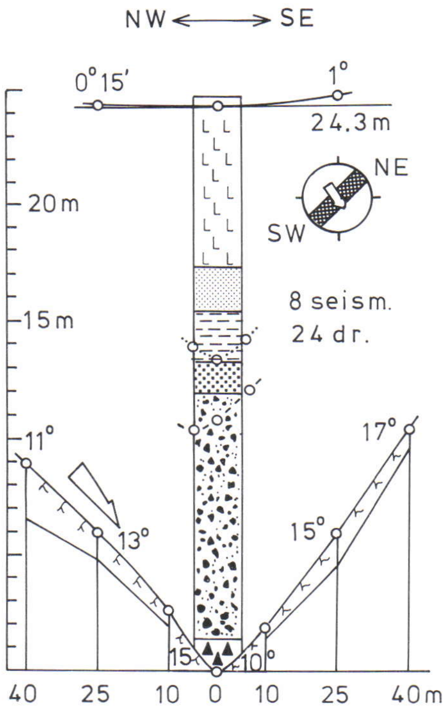

Fig. 2.

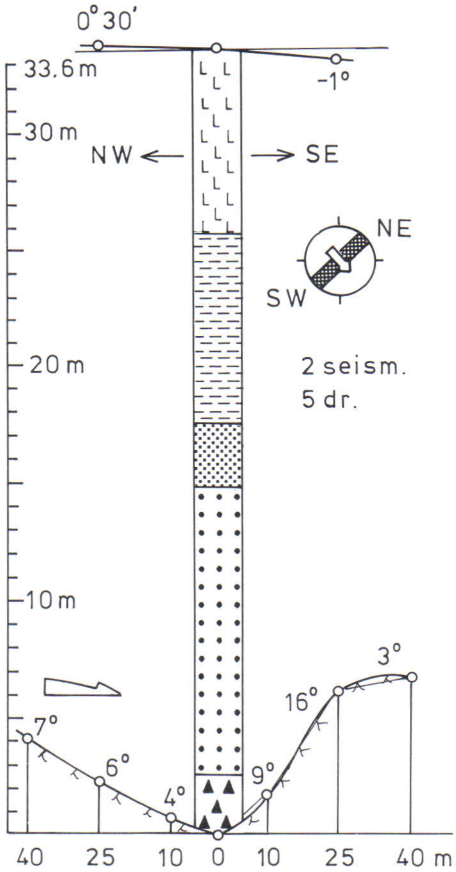

Fig. 3.

Fig. 2. Southern valleys perpendicular to the direction of ice movement (dotted line = average surface of till layer in four valleys, broken line = average bottom of clay layers in four, partly different, valleys).

Fig. 3. Northern valleys perpendicular to the direction of ice movement.

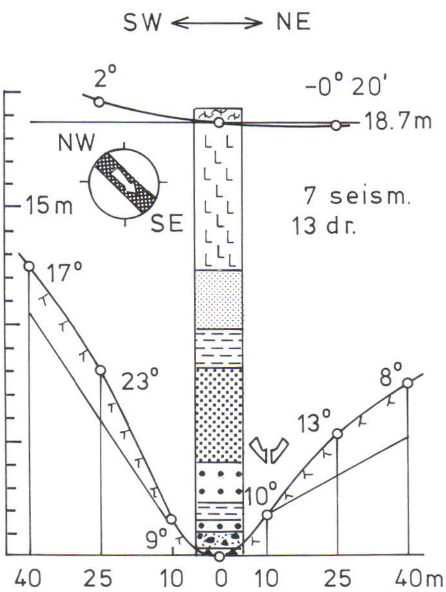

Fig. 4.

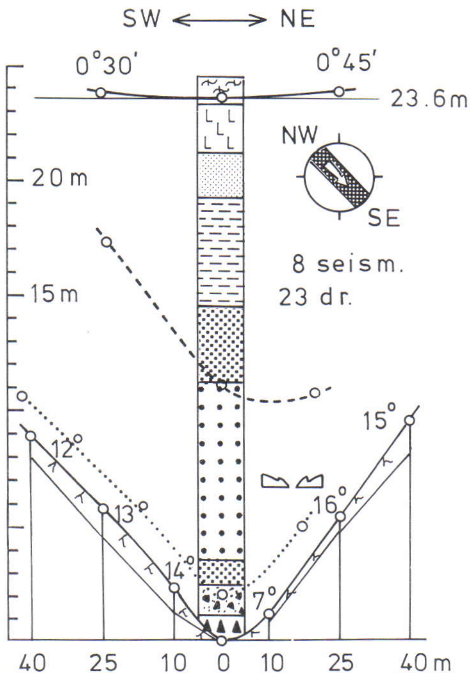

Fig. 5.

Fig. 4. Southern valleys parallel with ice movement.

Fig. 5. Northern valleys parallel with the ice movement (dotted line = surface of till in one valley, broken line = average bottom of clay layers in three valleys).

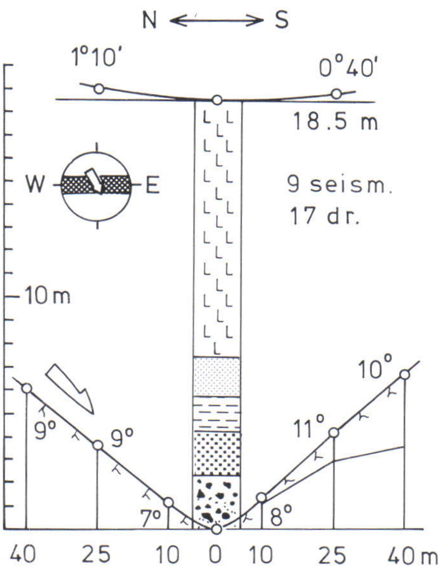

Fig. 6.

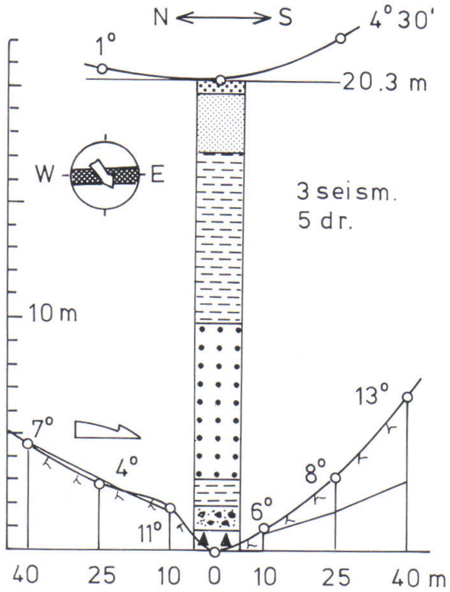

Fig. 7.

Fig. 6. Southern W—E oriented valleys.

Fig. 7. Northern W—E oriented valleys.

toms broadly rounded (U-formed). Their slopes are steeper, on the average, than those of the perpendicular valleys. In the valleys parallel with the ice movement, the mean thickness of the till is small: in the north 1.3 m (Fig. 5) and in the south only 0.9 m (Fig. 4).

In the valleys cut obliquely by the direction of the ice movement, the slope inclinations vary (Figs. 6—9). On the average, these valleys (called »oblique» in the following) are less steep than the others. The N—S-oriented valleys (Figs. 8 and 9) are steeper than the W—E ones (Figs. 6 and 7). This may be explained by the fact that the N—S valleys represent, on the basis of aerophoto interpretation, longer and much more broken fracture zones than the W—E ones (Niini 1968a, p. 36).

The average profiles representing only one to three valley sections (Figs. 7—9) indicate that the surface forms and the lowest point of the ground do not clearly correlate with the variations in bedrock topography.

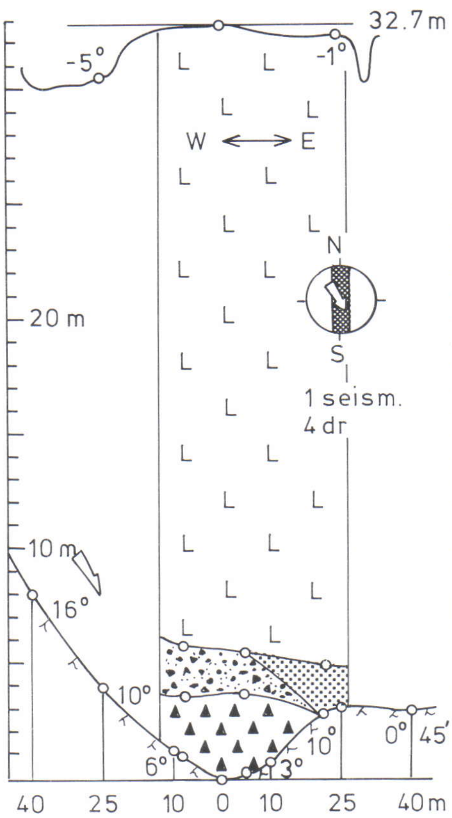

Fig. 8.

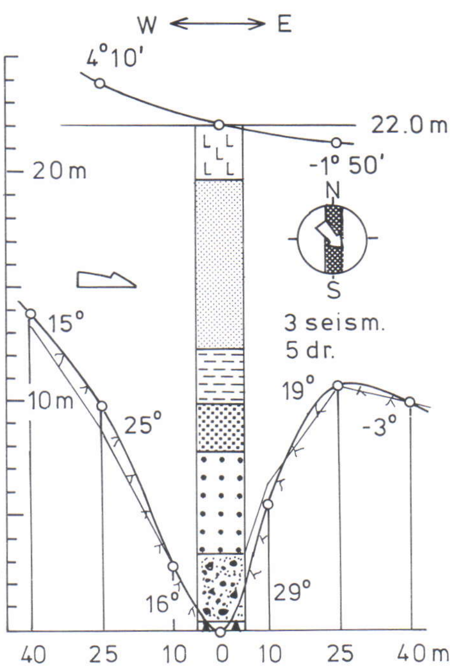

Fig. 9.

Fig. 8. The only southern N—S oriented valley.

Fig. 9. Northern N—S oriented valleys.

GLACIAL EROSION

The direction of a bedrock valley seems to have little influence on the direction of movement of the Weichselian ice sheet in the area investigated. It might therefore be assumed that the gently sloping marginal parts of the steep bedrock valleys have been worn approximately alike by glacial erosion. In contrast, the steeply sloping and heavily fractured central parts of the bedrock valleys have been subject to glacial wearing the strength of which may depend on the orientation of the valley. This circumstance is simply evaluated when the average cross-profiles of the different valley groups are drawn on each other so that the gently sloping margins coincide. This has been done in Fig. 10; however, the two groups of valleys (N—S and W—E) oriented obliquely to the ice movement have been first joined in such a way that the movement directions in the profile are the same. To avoid any unnecessary influence of other factors (e.g., tectonic), the valleys parallel with the ice movement have been assumed to be symmetric; both their slopes have been combined with the mirror image of the other slope.

Comparison of the differently oriented valley groups (Fig. 10) shows that the valleys parallel with the glacier movement have been worn deepest and broadest; the oblique valleys are the least worn. Those groups of valleys cut by the ice movement — either obliquely or perpendicularly — are asymmetric. In the parallel valleys, it is obvious that the parallelism between the valley direction and glacier movement promoted glacial erosion right on the site of the original straight-lined fracture zone of the bedrock. In these valleys, during the final stage of glacier action, the ice movement might also have lasted longest.

The fact that the perpendicular valleys have been eroded deeper than the oblique ones can be explained by the tectonic difference between these groups: the SW—NE valleys (Fig. 11) of the area are twice as fractured as those in the main directions (Niini 1968a, p. 28—33).

The perpendicular valleys seem to have eroded more on the stoss (SE) side than on the lee (NW) side of the bottom slope. In the oblique valleys, the deepest point is on the side opposite to that in the perpendicular valleys. This fact may be explained as follows: in the oblique valleys, the ice

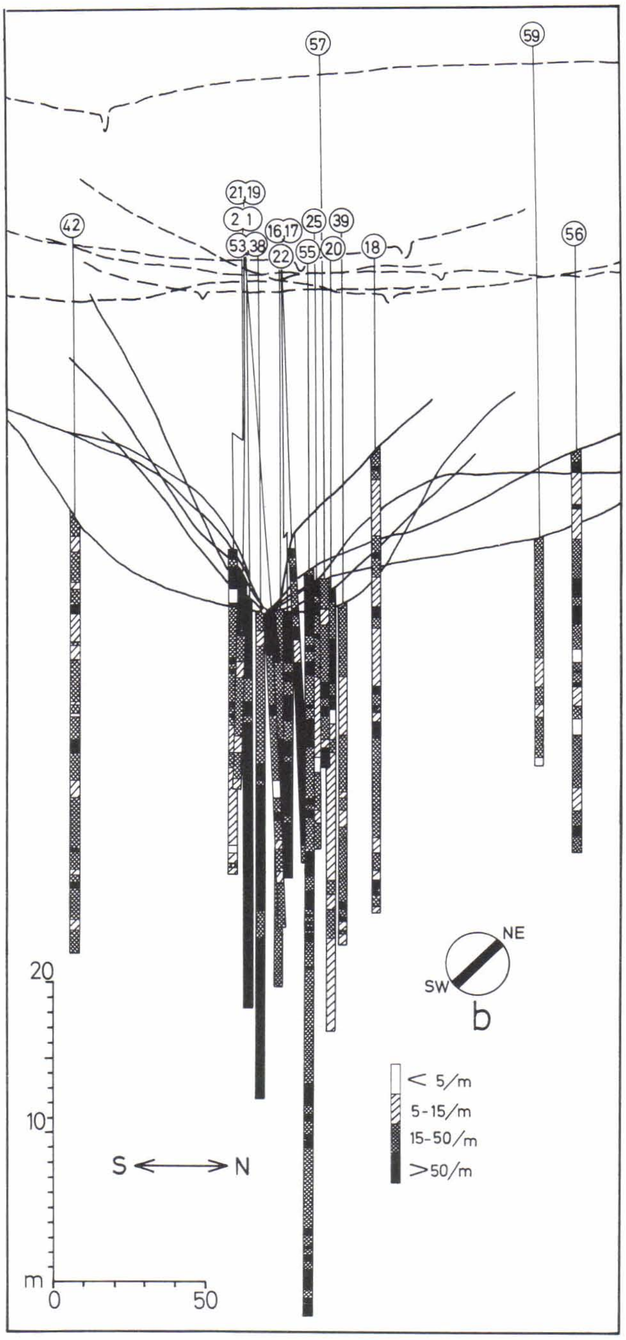

Fig. 11. Cross profiles of the SW—NE oriented valleys with results of the fracture-frequency measurements of the drill cores (Niini 1968a, p. 30).

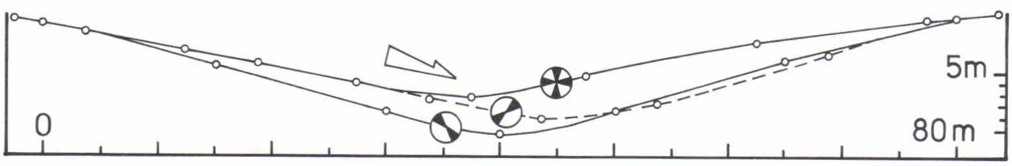

Fig. 10. Average profiles of bedrock bottoms of differently oriented valleys. Lowest line = the 15 valleys parallel with the direction of ice movement. Highest line = the 16 valleys cutting the direction of ice movement obliquely. Broken line = the 10 valleys perpendicular to the direction of ice movement. Vertical and horizontal scales are identical.

movement needed to turn upwards and to press the stoss (SE) slope much less than the ice did in the bottoms of the considerably deeper perpendicular valleys. The angle of this vertical turn (in the horizontal ice movement direction in the oblique valleys) is of course only half that of the projection (shown in Fig. 10). In such a situation, it was easy for the glacier to rip up the bedrock bottom backwards from the gentle N or W slopes, starting immediately from the most fractured centre. In the more fractured and more easily-eroded SW—NE valleys cut perpendicularly by the ice movement, the angle of the turn upwards is much greater and the SE slope has thus suffered from an extra strong ruboff, leaving the NW slope in a true lee position.

CONCLUSION

The differences in the amount of vertical glacial erosion in the varyingly oriented fracture valleys in southern Finland are, on the average, on the order of a few metres. The valleys parallel with the ice movement have been eroded 3—4 m deeper than the other valleys in which the fracture frequency of the bedrock bottom is roughly similar. The average profiles shown indicate, however, nothing about the longitudinal variation of the valleys, nor do they reveal any detailed irregularities in individual cross-profiles. It is therefore easily understood that, particularly in the least-worn valleys, cut by the ice movement, blocky weathering remnants from pre- or interglacial times (in the profiles indicated as cobbles, boulders, and blocks) are to be commonly found.

ACKNOWLEDGEMENTS

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ON MEASURING THE LENGTH OF GLACIAL TRANSPORT

by
Veli-Pekka Salonen and Jukka-Pekka Palmu

Salonen, Veli-Pekka and Palmu, Jukka-Pekka, 1989. On measuring the length of glacial transport. *Geological Survey of Finland, Special Paper 7,* 25—32. 5 figures.

The glacial transport of the coarsest fraction in till has been measured in two areas located in southern Finland. Porphyritic granite stocks were used as indicator rocks. Four different quantities representing glacial transport were determined by means of frequency counts of surface boulders: renewal distance (D_{50}), half distance ($x_{1/2}$), maximum transport distance (M.D.) and transport distance (''K''). These indices were perceived to depict different factors of the glacial transport processes. The application possibilities of the methods in the search for ores and crushable tills were briefly estimated.

Key words: glacial geology, glacial transport, till, boulders, numerical analysis, Pleistocene, Weichselian, Merikarvia, Kirkkonummi, Finland.

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INTRODUCTION

Glacial transport may be understood as the combined effect of the erosive action at the base of a glacier, gathering up of the debris produced, and ice movement resulting in the detachment of fragments of varying size from their source and their removal to the observed place of deposition. The final result, the dispersal of fragments of different sizes, was thus controlled by four different glacial processes: erosion, entrainment, transport and deposition. The numerous contributing factors connected with each process influence the size and path of each individual particle and their relation to each other to the extent that estimating the effect of separate factors is difficult. Consequently, when it is desired to characterize glacial transport, it is necessary to apply various statistical procedures.

W.C. Krumbein (1937), who developed statistical methods, made use of the half-life theory of radioactive isotopes in dealing with many different kinds of geological data sets. Among other things, he formulated the negative exponential expression by which it became possible to explain the probable occurrence of boulders in a boulder fan. It was in this connection that the term half-distance was defined as a measure of glacial transport. The half-distance theory has later had various different applications (Gillberg 1965, Perttunen 1977, Bouchard et al. 1984, Salonen 1986, Strobel & Faure 1987).

Certain other methods of measuring transport distances are based on the appearance in glacial deposits of fragments producing a distinct area of indicator rocks. Lee (1965) defined the concept ''K'' as the distance from the source area to the point where the quantity of the source material is at its maximum. Esker samples were used as observation material. Salminen (1980) applied the determination of the K distance in examining the geochemical properties of the till matrix. Puranen (1988) has analyzed the rising proximal part of the abundance curve and the factors controlling it and

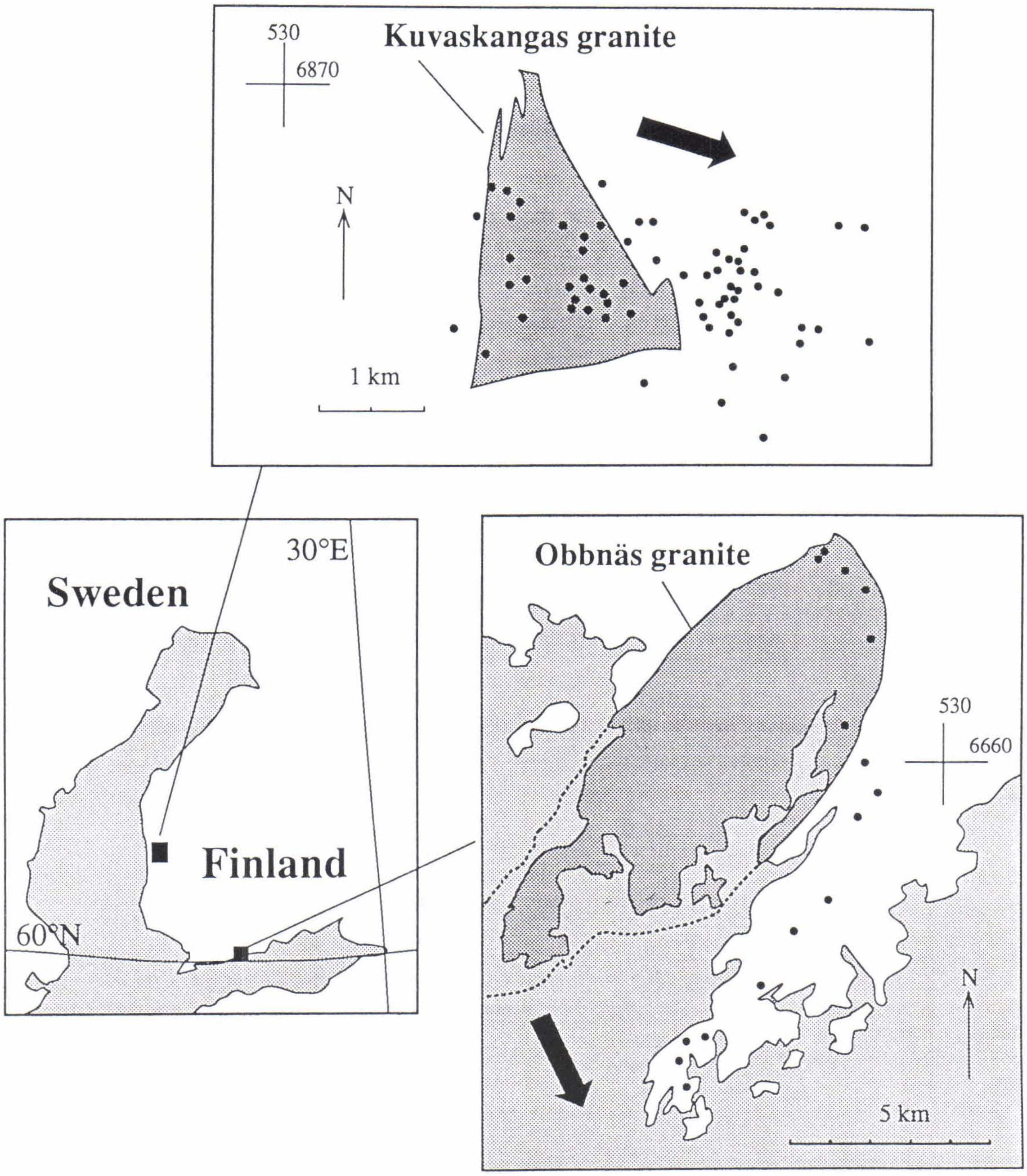


Fig. 1. The areas selected to serve as examples in southern Finland. The boulder-count points are represented as black circles, and the arrow indicates the main direction of glacial transport.

finally constructed a model representing the glacial transport of basal tills in Finland.

Common to the methods described in the foregoing is a description of the proximal rise or distal decline in the dispersion of indicator rocks. The present paper deals with these numerical methods, by which the glacial transport of individual indicators can be characterized, and it seeks to estimate the advantages and applicability of the different measuring procedures. Presented as illustrative cases are two granite stocks located in southern Finland and the boulders derived from them that were transported by the Weichselian ice sheet. The indicator rocks in question (Fig. 1) differ distinctly from the surrounding bedrock, and the extent of their occurrence has been carefully mapped out.

RESEARCH MATERIAL

Porphyry granite of Kuvaskangas

The rock is massive, giving the appearance of variable microcline granite; the size of the microcline porphyries is generally 1—2 cm, though also even-grained varieties measuring 1—5 mm are common (Salonen 1981). The granite is in places syenitic and pegmatite dikes are generally associated with it. The stock has intrusive contacts with surrounding schists, and its limits have been confirmed with a magnetometer.

The overburden of the area surveyed is part of an elongate morainal zone, which extends from the western side of the Pirkanmaa region northwards to the Satakunta district. The main direction of glacial transport in this area is nearly from west to east (280°—290°), but the striations also reveal an earlier movement of the ice sheet from the north-northwest to the south-southeast (340°—360°).

The glacial dispersal of porphyry-granite erratics has been measured at 60 observation points (Salonen 1981). At each point, the rock type of a hundred randomly selected boulders (Ø 20 cm) was determined and the percentual occurrence of porphyry granites calculated. The investigation points were connected almost without exception with different morainal hummocks; hence the research material might be regarded as representing the glacial transport of the surficial material of a hummocky moraine containing erratics in abundance dating from the last deglaciation stage.

The granite of Obbnäs

This indicator is a coarse, usually porphyritic anorogenic rock (Härme 1980). The potash feldspar is reddish brown or red and jaggedly idiomorphic. In addition, even-grained portions and small pegmatite dikes characterize the granite. It forms a lens about 15 km long and 5 km broad (Fig. 1), the contacts of which are precisely known thanks to the thinness of the overburden.

The surficial deposits at the investigation site consist of a thin layer of patchy basal till. It varies in thickness between one and two meters (Repo 1970). The samples were collected from road cuts and ditches, and it was endeavored to avoid the washed surficial portion of the till. Altogether, 16 boulder counts were made (Fig. 1). At each point, the composition of between 100 and 170 boulders was determined and the percentual occurrence of Obbnäs granites calculated.

RESULTS

Frequency distributions

The frequency of the indicator rocks observed at the investigation points was projected on a line running parallel to the direction of glacial transport and across the source rock. The distance of each point from the proximal contact was measured and the observations thereby made were presented on a system of coordinates where the x-axis = the distance from the source area, and the y-axis = the source rock's percentage of all the fragments in this size category (Fig. 2).

The scatter diagrams give an idea of the heterogeneity of the material, and in this case it can be seen that there is no ground for the direct joining of the points on account of the great dispersion of the measurable values. Estimating the maximum frequency is also difficult for the same reason, as in the case of Kuvaskangas, for instance, the strongest peak is at a distance of less than a kilometer, though a more uniform occurrence maximum is not reached until a distance of 1—1.5 km away from the proximal contact. It can nevertheless be observed that the erratics derived from the Kuvaskangas granite are dominating the surface boulder population closer to their source area than in the case of the Obbnäs granite. In both cases till is exceptionally local in composition.

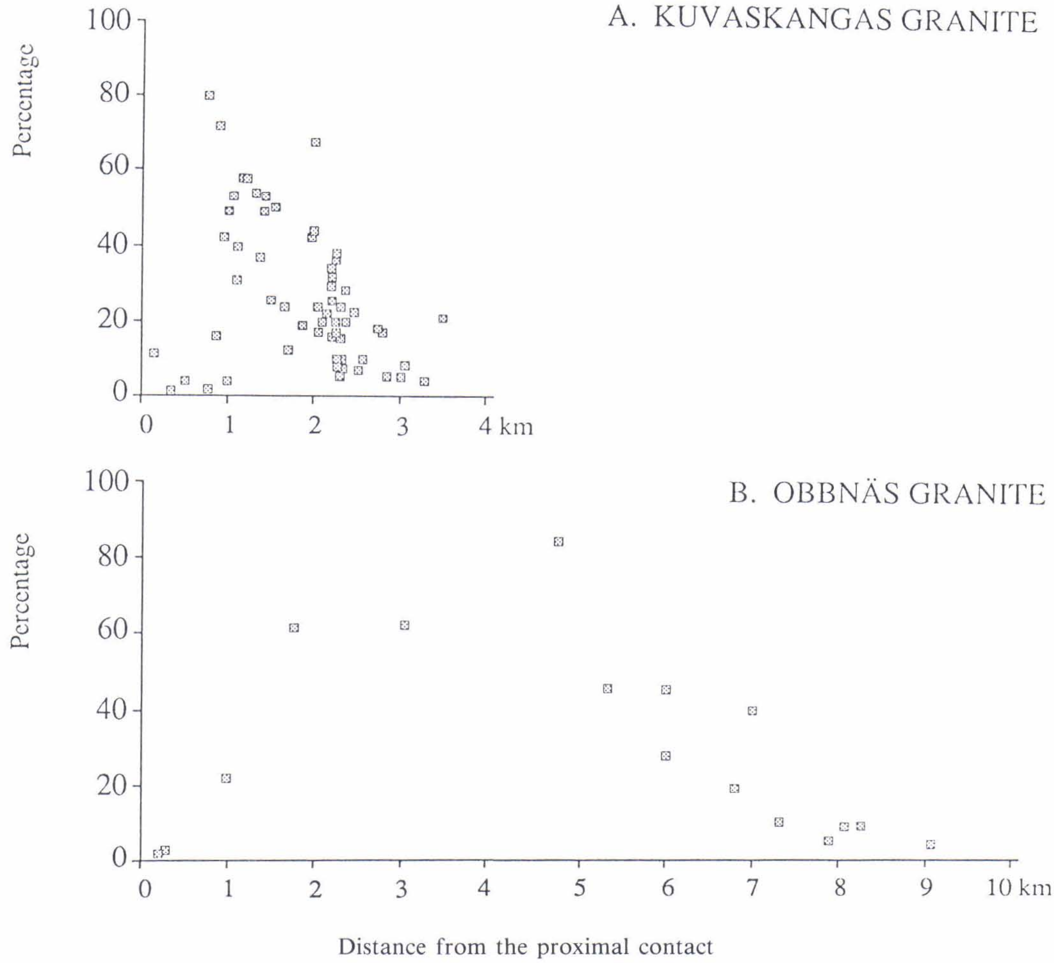


Fig. 2. The percentage of boulders originating from the Kuvaskangas granite (above) and the Obbnäs granite (below) in relation to the distance from the proximal contact of the rock.

The values of the scatter diagrams can be explained in two different parts: as a proximal rise and as a distal decline (Puranen 1988). In the case of Kuvaskangas, the first 16 points belong to the rising proximal part of the abundance curve, and the last 46 points (Fig. 2) represent distal decline. In the case of Obbnäs, the corresponding numbers are 6 and 11. Some of the observation points, the highest values, are common to both parts of the curve.

PROCESSING OF THE RESULTS

Proximal rise

The proximal rise means the rising part of the abundance curve, the area in which the amount of constituents derived from the source rock in the till increases as the distance from the contact lengthens. According to Puranen (1988), the rising curve approaches a straight line when a quarrying type of glacial erosion is dominant. Since the coarsest fractions of till, boulders, are produced mainly as a product of quarrying, it should be assumed that a straight line depicts the proximal rise best.

In the Kuvaskangas material (Fig. 3 a), a rather weak linear correlation ($R = 0.56$) is obtained between the increase in proximal distance and the

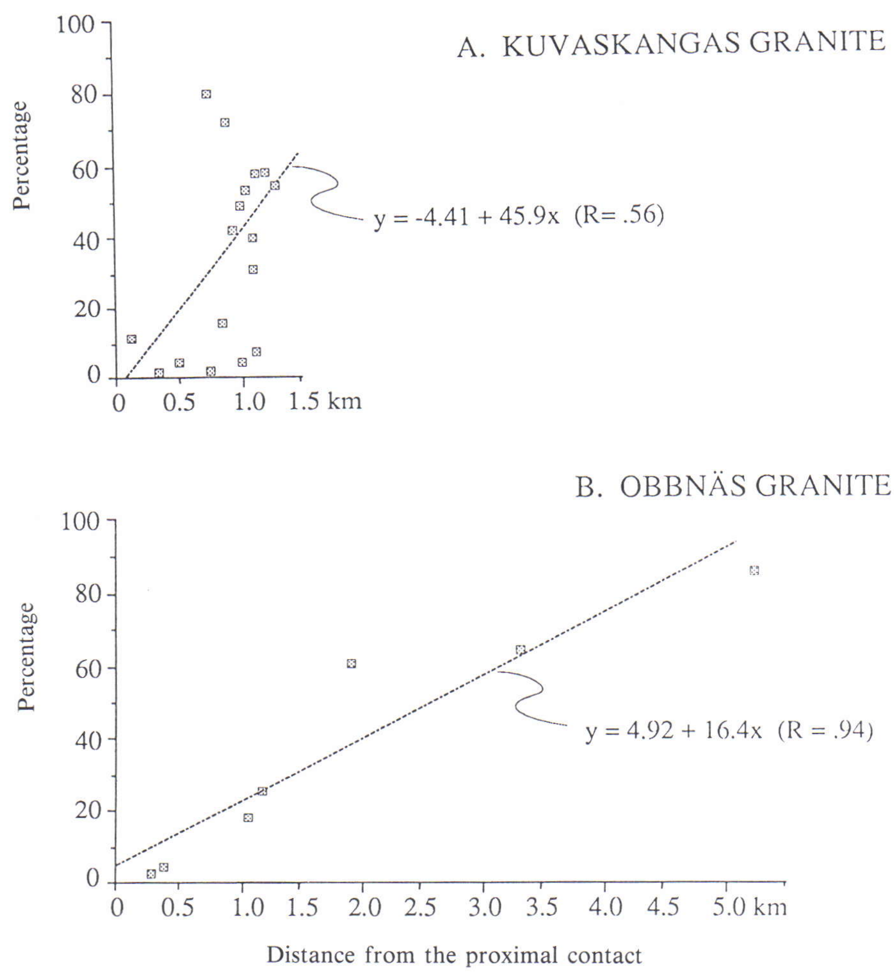


Fig. 3. The rising proximal parts of the abundance curves are represented by a straight line.

abundance of indicator boulders; but in the case of Obbnäs, the correlation is stronger (R = 0.94). As for the curves, the further observation is made that the expression representing the former has a greater slope than the latter. In both cases, the maximum frequency is reached near the distal contact, which, according to Puranen (1988), is the most likely situation.

The straight-line expression makes possible calculation of the »renewal distance.» It is, according to Peltoniemi (1985), a distance in the course of which the content of the source rock increases from zero to 50%. In the case of Kuvaskangas, this index of the transport distance is 1.1 km, and at Obbnäs, 2.8 km.

Distal decline

The half-distance was calculated after the procedure described by Strobel and Faure (1987), where abundance is presented by means of a logarithmic scale (e as base) and the distance in terms of kilometers from the proximal contact. In this scale the abundance curve takes the form of a straight line, which can be fit into place by the method of least squares (Fig. 4). The half-distance can be calculated by means of the negative slope of the straight line (Strobel & Faure 1987).

The half-distance of the boulders produced by the Kuvaskangas granite is 0.8 km, while the corresponding value obtained on the site of the Obbnäs granite is 1.1 km. It is also possible to calculate the so-called maximum transport distance by means of the distal decline. This quantity (M.D.)

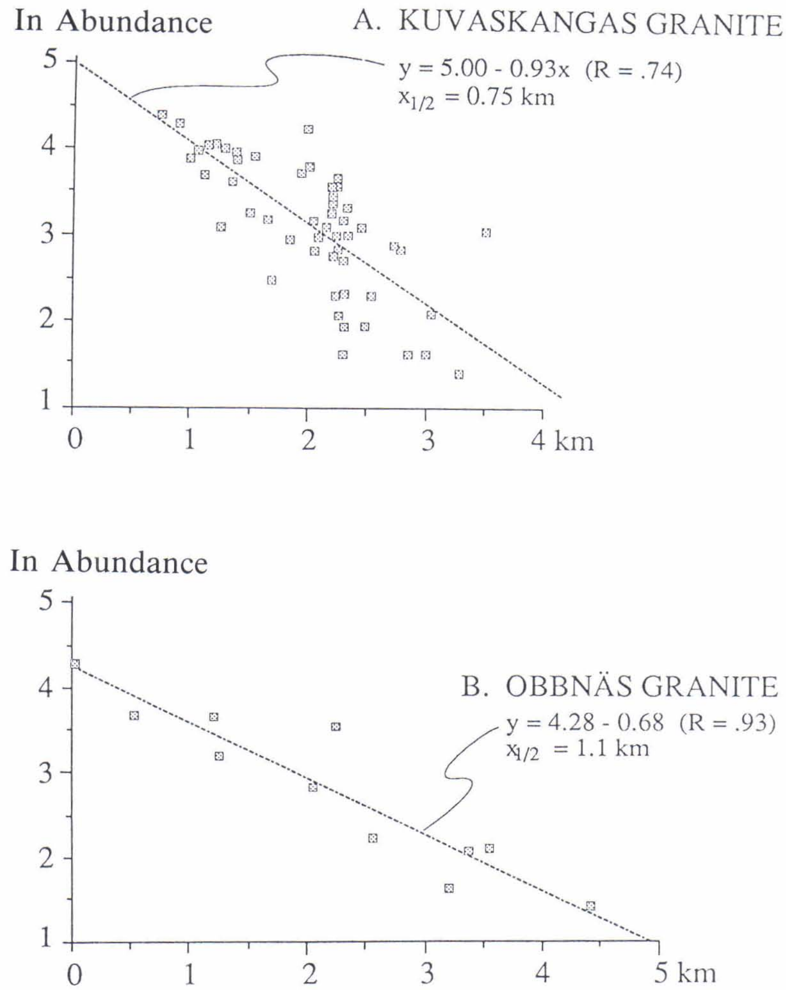


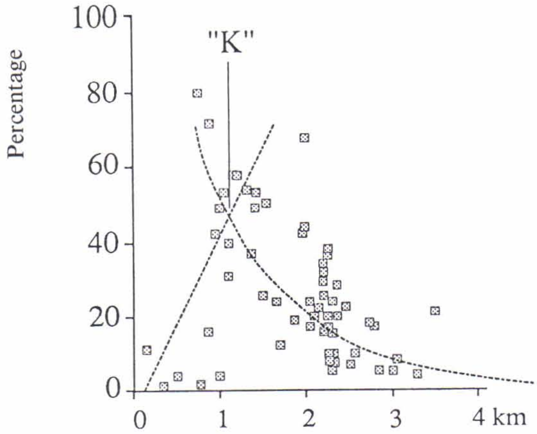
Fig. 4. Representing half-distances on half-logarithm paper.

is the probable length of the boulder fans, and it can be defined as the distance in the course of which the abundance of the source rock decreases to one per cent (Bouchard et al. 1984). Ln1 = 0, so that by means of the formulae in Fig. 4 the M.D. values may be calculated as follows: Kuvaskangas 5.4 km, Obbnäs 6.3 km.

Transport distance ''K''

For the determination of the transport distance ''K'', a point must be chosen in which the abundance of indicator fragments is at its maximum (Lee 1965). From the scatter diagram (Fig. 2), it was perceived that, owing to the great dispersal of the material, determination of the maximum point is difficult. The maximum frequency can be determined, however, by presenting in the same picture the meeting of the curves depicting both the proximal rise and the distal decline (Fig. 5). The point of intersection marks the position of the ''K'' point.

By this procedure, the transport distance ''K'' obtained for the Kuvaskangas material is 1.2 km and for the Obbnäs granite correspondingly 4.7 km. It should be noted that these values are nearly the same as the average distances for the intersection of the source rocks, which means that the maximum values are thus attained close to the distal contact. As the width of the indicator rock increases, the distal frequency approaches 100% (Peltoniemi 1985).



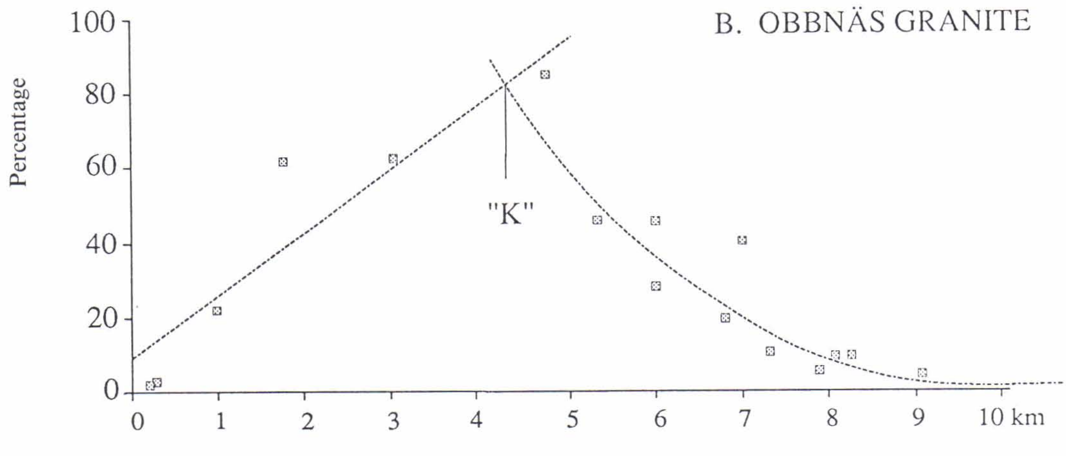


Fig. 5. Determining the transport distance ''K'' by means of the proximal rise and distal decline.

DISCUSSION AND CONCLUSIONS

The numerical parameters presented in the foregoing all represent in their own way the dispersal of the ice sheet. In the cases now considered (Table 1), certain common features as well as, on the other hand, certain differences are to be observed by means of which the applicability of the measurement methods to different research purposes can be examined.

Table 1. Numerical parameters representing the length of glacial transport.

Indicator rock	D_{50}	$X_{1/2}$	M.D.	K
Kuvaskangas granite	1.1	0.8	5.4	1.2
Obbnäs granite	2.8	1.1	6.3	4.7

The proximal rise may be represented as a straight line for the coarsest till fraction. The renewal distance, D_{50}, can be calculated by means of the equation for the straight line. Up to the maximum occurrence (K distance), the yield of material to the ice transport system is greater than the loss of material from it. The factor controlling the production of material is the intensity of the quarrying mode of glacial erosion. Factors removing material are the comminution of boulders to smaller size during the course of glacial transport and the deposition of boulders, that is, their discharge, and the »dilution» of the debris with new rock material.

The renewal distance serves well as a till *maturity index*. The lower the value, the weaker the comminution and the more usable the material as crushed aggregate from the standpoint of its grain composition. From the examples given, it may be noted that in the Kuvaskangas area the till appears to be more immature than in the vicinity of Obbnäs. In the former area, the erosion had been intense in comparison with the movement of the ice sheet, whereas in the latter area the comminution of the debris in connection with glacial transport resulted in levelling the curve representing the proximal rise.

The most important of the factors controlling the distal decline are probably associated with the differences in the rock composition of the till (Gillberg 1965, Perttunen 1977, Salonen 1986). In the cases now considered, the half-distance can be seen to be nearly the same though the glacial conditions differ. The negative slope of the exponential expression representing distal decline may be understood to be the *comminution index* by which can be depicted the relation of different types of indicator rocks to each other during glacial transport (cf., Bouchard *et al.* 1984).

The transport distance ''K'' represents the turning point, the area where erosion has produced the maximum amount of material but where the dilution of other rock material has not yet reduced the abundance of the indicator rock. It appears to combine with the till-matrix anomalies — glacigenic geochemical anomalies (Salminen 1980). On the basis of the cases herein discussed, the transport distance ''K'' is directly proportional to the size of the exposure. Determining the displacement of the maximum abundance peak is therefore a useful means of estimating the situation of rock contacts in covered areas.

An important application of glacial transport measurements is the tracing of ore boulders. The transport distance ''K'' indicates the probable distance from the highest abundance to the exposure, and M.D. indicates the probable, observable length of boulder fans.

In the the search for crushable till, measurements of glacial transport can have useful applications. The renewal distance is the maturity index of till; and since immature tills are best suited for crushing, areas should be sought with a low D_{50} value, preferably less than 1 km. The usability of immature tills may be hampered by the fact that the strength properties of the rock material are not necessarily the best possible.

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THE PROBLEMATIC BOULDERS OF JALONOJA, FINLAND

by
Martti Kokkola

Martti Kokkola, 1989. The problematic boulders of Jalonoja, Finland. *Geological Survey of Finland, Special Paper 7,* 33—36. 2 figures.

In Finland, the existence of many sporadical ore boulders is known the bedrock source of which has never been traced. In most instances, however, it has been easy to trace the bedrock source of accumulations of boulders. In some cases, as for example the boulders of Jalonoja, in southwestern Finland, the transport mechanism has yet, in spite of numerous investigations, to be identified.

Key words: mineral exploration, nickel ores, erratics, till, glacial transport, Jalonoja, Kokemäki, Finland

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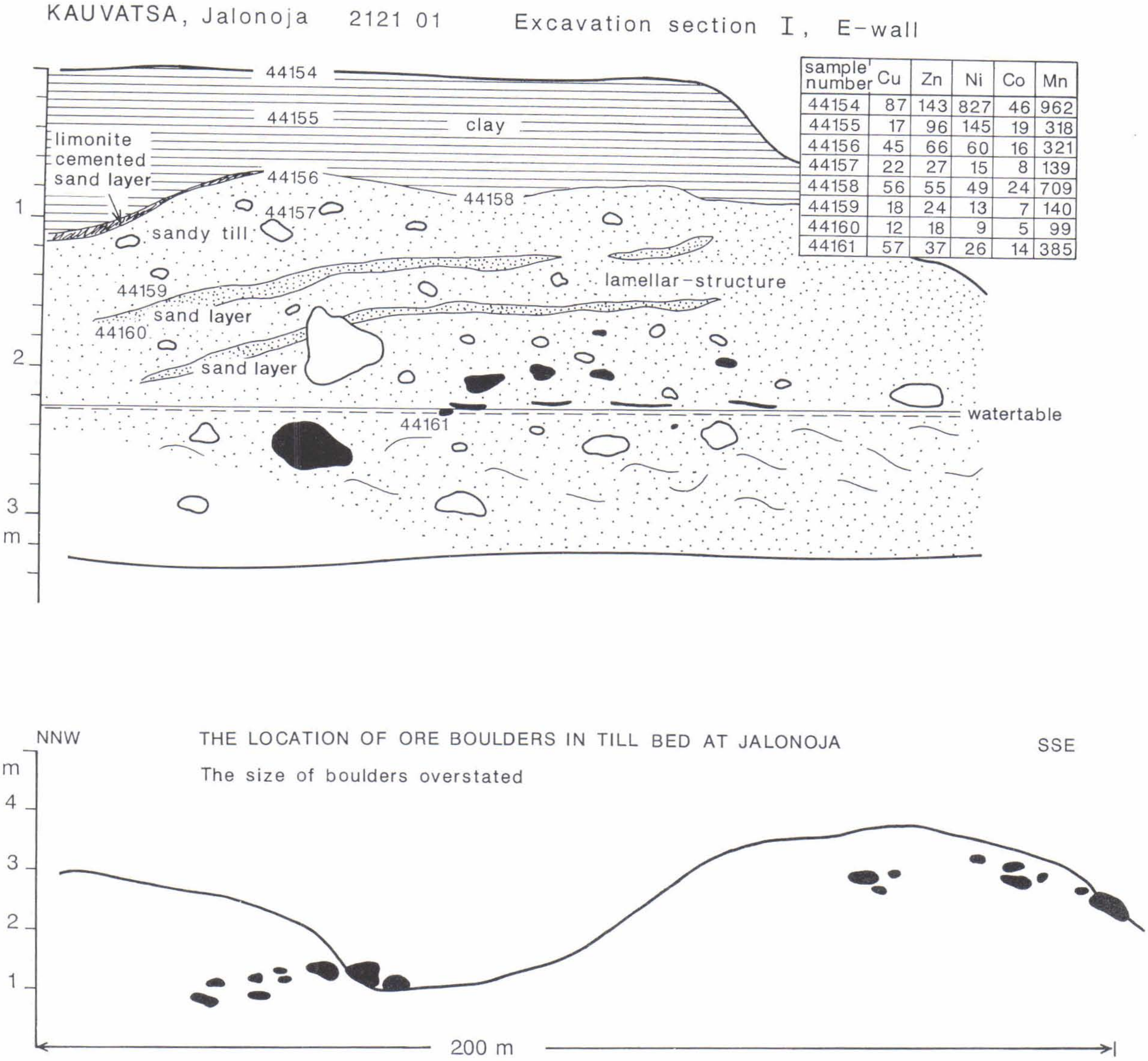
In general, ore boulders have been successfully traced in Finland to their parent rock. Applying and combining data from the various parts of a geosector, geologists have in most cases been able to trace the transport path of boulders and locate their point of origin in the bedrock to quite a high degree of probability. Unfortunately, however, the source has frequently proved to be of only minor economic interest. Locating the origin of some boulders, further, has turned out to be exceptionally difficult. An example of this is given by the case of Jalonoja, now being considered, in which it has so far not been possible to pinpoint the origin of the assemblage of many boulders. The available data are based on the investigations conducted by the Outokumpu company as well as on numerous unpublished exploration reports.

In the spring of 1972, an abundance of peridotite weathering products was met with on a farm road at Jalonoja, in the district of Kauvatsa. The weathered material had originated from a pit dug in a moraine situated next to the road. Numerous separate blocks of peridotite were found in the pit. The Ni content measured in the analyses varied between 0.67 and 2.9%, with the nickel of the sulfide facies reaching a maximum of 6.27%.

Three separate exploratory pits were dug in the area applying the available »expertise» in the field of glacial geology. From one extension of the original gravel pit, numerous PRD boulders with jagged sides were unearthed, in some cases the jagged edges having become rounded. On the other hand, no ore boulders turned up in the two other pits dug close by. The sediment in the pits was stratified; thin layers and lenses of sand alternated irregularly with sandy till. The boulders appeared to sink down into the till bed deeper in a north-northwesterly direction; and on the basis of this observation and their abundant occurrence, it was concluded that the boulders were of local origin (Fig. 1).

Electrical and magnetic measurements were carried out on the exploratory site as well as, in the near vicinity of the boulders, an electrical VLF measurement, by which a distinct anomaly trending nearly north-south was located. The anomalies registered were investigated by diamond drilling; five holes were drilled, all on the north and northwest sides of the ore boulders found. Almost directly to the north from the site of the boulder find, a basic peridotite formation was located, but the analytic results did not support the conclusion on the basis of the Ni program that it was the source of the boulders.



sample number	Cu	Zn	Ni	Co	Mn
44154	87	143	827	46	962
44155	17	96	145	19	318
44156	45	66	60	16	321
44157	22	27	15	8	139
44158	56	55	49	24	709
44159	18	24	13	7	140
44160	12	18	9	5	99
44161	57	37	26	14	385

Fig. 1. Location of Ni-bearing boulders (black) in the till. The highest Ni content has been met with in the surface portion of the clay layer.

About 3.5 km to the west-northwest from the site of the boulder find, a magnetic and electrical anomaly resembling a fold structure was discovered in the geophysical measurements, and it was investigated by taking till samples. On the basis of analyses of the fine components, only graphite gneisses appeared to be connected with the anomaly. No indication, on the other hand, could be obtained of basic rocks.

In the years 1975 and 1976, geophysical measurements were carried out in a small area on the site, with the measuring points being situated at a density of 2 x 2 m and 2 x 5 m. The results of the measurements did not, however, produce any indication of even a small ore-bearing outcrop.

In June 1975, pits were dug with backhoe at Jalonoja to investigate the till stratigraphy and the location of boulders as well as to ascertain whether the boulders found previously (in just one pit) were actually erratics or possibly had broken off a single boulder or present many primary boulders that had become dispersed in the area.

The largest number of ore boulders were found in a pit that had previously been observed to be anomalous. When the narrow pit was dug further to form a trench, boulders were discovered at its southeastern end. As the pit was extended in the directions pointing north-northwest and west, the boulders appeared mostly to have sunk below the 3.5—4 m excavation level. Peridotite boulders were found in fair abundance also in other pits, which were situated in the terrain in such a way that the direction of transport could be estimated to have been approximately 340°. No boulders were met with in the pits dug on the eastern and western sides of this »fan» (Fig. 2). The majority of the boulders were less than 20 cm in diameter, though among them were also between 30 and 40 ore boul-

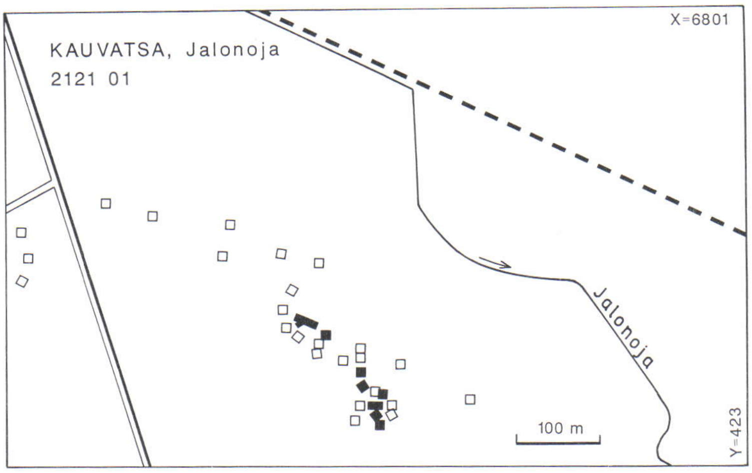


Fig. 2. Location of the boulders in the Jalonoja area. □ Test pit ■ Ore boulders in test pits

ders exceeding 40 cm in diameter. The total number of boulders was estimated to be around 200. Most of the boulders were found in the till, in the upper part of the excavated pits. Only at quite the southeastern end of the »fan» were boulders also met with on the surface of the ground; in most instances, the ore bearing blocks were intensely weathered. Only the coarser-grained type containing a slight amount of magnetic pyrites remained to some extent in original habitus.

In conjunction with the digging operations, the boulders were separated from the till by screening which were counted. Rocks of the peridotitic type are susceptible to weathering under natural conditions, frequently breaking up into fairly rounded, separate blocks conforming to the cleavage planes of the original rock. Such blocks tend to break during excavation work, and several separate blocks are likely to be detached from a single larger one — and after rolling around in the excavated material, they are apt to take on the appearance of genuine boulders. Certain discretion is needed in estimating numbers of boulders.

In any case, even by a cautious estimate, the number of boulders in the area would come to between ten and twenty. The size of the original blocks would naturally have been considerably larger.

Regrettably few till samples were taken from the pits dug for geochemical analysis. The highest contents in them, however, appear to be situated either in the immediate vicinity of a contaminating boulder or in the upper part of varved clay quite close to the surface of the ground.

In 1976, glacialgeological investigations were carried out in the area by T. Äikäs and H. Ollila, who noted three different directions of ice flow there: the oldest, 325°—345°, the next oldest, 300°—315°, and the youngest, 270°—280°. The till, according to the observations of these researchers, appeared in all likelihood to have originated on the western and northwestern sides of the ore boulders between Sääksjärvi and Jalonoja. It is improbable that the boulders had traveled from the north side of the place where they were found. On the basis of the morainal forms, however, directions of ice flow have been submitted in studies where the more northern direction dominates.

In May 1979, a joint investigation of surficial deposits was carried out by a group (H. Hirvas, K. Nenonen) specializing in soil research in the line of ore exploration for the Geological Survey of Finland. In a small area, 18 investigative pits were dug, from which 81 geochemical and four special samples were collected, in addition to which seven orientation measurements and 14 boulder counts were done. Previously classified as stratified and lamellar in structure, the till in which the boulders were situated was identified as an ablation moraine — on the basis of both its structure and other features. This view is supported further by the fact that morphologically the formation has the shape of a mound and that the drift composing the till is unoriented. Underlying this till layer is a gray, unstructured sandy till of greater than normal density, which represents basal till. At the contact of the till beds, a precipitate with the density of concrete was met with. No clear, unambiguous orientation could be determined in the layer of ablation moraine. The transverse trend observed in two different pits indicates a direction of ice flow possibly between 295° and 310°. The local striation observations vary from 295° to 305°, while in the lower till layer there occurs quite a distinct 305° orientation.

The heavy metal contents of the till matrix were mainly background values. Only on the southeast side of the site of the boulder find were slightly elevated nickel and copper contents noted — in two of the pits.

The two aforementioned till layers differed lithologically from each other to some extent. Dominant components of both are acid plutonic rocks: quartz diorites and granodiorites as well as granites and pegmatites. In the lower till bed, there occur in a few places impactites and basic porphyrites. On the other hand, surprisingly small amounts of gabbro and peridotitic rocks were met with in the pits. Few ore boulders proper were found in the pits now dug, and these pits were situated in the area of the »fan» mentioned in the foregoing.

The direction of transport and the distance traveled remained in this study too uncertain. The distance might therefore be quite long, though the dense occurrence of the boulders, on the other hand, suggests a rather short transport distance. The direction of transport falls between 295° and 305°.

In the summer of 1981, V.-P. Salonen investigated the area, with particular attention being paid to the boulders. A boulder count was done in the stretch covered by the linear boulder fan mentioned earlier, the total reaching the figure of 1060. Two smaller counts were carried out in the area of the pit at Jalonoja containing an abundance of boulders, another count of the material composing the nearby eskerlike formation, and a fifth one on the Karhiniemi esker about 5 km from Jalonoja to the southeast. On the basis of these counts, it would appear as if the ore boulders of Jalonoja were not connected with the Jalonoja peridotite met with in the drillings; nor do they appear to be connected with the transport that took place from the direction of the Sääksjärvi occurrence. The source of the ore boulders would probably have to be sought along a 290°—310° line, and a long transport distance appeared likely.

The next year, these indications were followed by searching for boulders in the direction mentioned, but no new evidence pointing to the possible source of the Jalonoja boulders could be found. Either the boulders originated from a source closer than any suggested by previous investigations, or then the mechanism of their transport was exceptional.

In the spring of 1982, the magnetic anomalies on the northwest side of the Jalonoja boulders were investigated by crushed bedrock sampling, but the result on the part of the basic formations proved very poor.

In the autumn of 1984, the investigations were resumed with an A-sonde drill, this time closer to the source of the boulders, on the south side of the railroad tracks. The result was the observation right under the Jalonoja boulder fan of a separate basic formation, which proved, however, to have a very slight content of commercially valuable metals. The thickness of the till cover at this point is about six meters. On the other hand, more substantial Ni, Cr, Cu and Co contents were discovered on the immediate southern side of the railroad, that is, the northern part of the basic formation of Jalonoja. In the light of this finding, it appeared possible that the boulders might have originated somewhere in this vicinity, even though the outcropping of the mineralization might be rather small. Interestingly enough, this anomaly was investigated as early as 1973 by drilling about 100 meters from the present site to the north.

At the turn of the years 1984—1985, till sampling was carried out with Cobra equipment at Jalonoja in the surroundings of the known basic formation. The traverses were laid over the basic formation parallel to the direction of movement of the ice sheet. The analyses showed that hardly any anomalous indictions existed in the samples taken from the upper till layer. The analytic results for the samples taken from lower depths were similar, although clear indications were obtained of the existence of a basic formation. The analyses proved that the Jalonoja boulders had not originated from the now known formation, provided the geochemical dispersion of the till was normal. On the other hand, it should be noted that even in the bedrock sampling the weakly Ni-anomalous rock formation was hardly reflected in the till. This might be due to the fact that the mineralization in question is exceedingly small in its dimensions or that for some reason anomalousness observable by usual geochemical means could not form in the intensely washed ablation moraine.

The problem of the Jalonoja boulders is made interesting by the fact that virtually all the geologists who have worked in the area have arrived at nearly the same probable transport direction, the sector pointing west-northwest. The rock assemblage at the site investigated indicates the possibility of quite a long transport distance. On the other hand, the large number of ore boulders and their nearly linear position in the terrain within a small area tends to point more to the north and to a considerably shorter transport distance. New ideas are really needed to locate the original source of the boulders.

PEBBLE COUNTS USED AS INDICATORS OF THE BEDROCK IN THE HYVINKÄÄ GABBRO AREA

by
Pekka Vallius

Vallius, Pekka, 1989. Pebble counts used as indicators of the bedrock in the Hyvinkää gabbro area. *Geological Survey of Finland, Special Paper 7,* 37—44. 5 figures.

The bedrock in the western part of the Hyvinkää gabbro complex (the area on the west side of the Helsinki—Hyvinkää highway) consists of gabbro, as judged also on the basis of pebble counts along the western traverse: the till contains 73% of local gabbro rocks in the distal part of the gabbro bedrock. On the map drawn of the bedrock, the greatest part of the eastern area of the gabbro complex, where outcrops are almost completely lacking, was classified as a hornblendegranodiorite—granite area. The gravity values measured in the middle of this extensive granitoid area are quite low (0.6— 2.1 mGal) compared with the western gabbro area (over 20 Gmal). In the aeromagnetic grey-tone photo as well, the area is free of anomalies. The small gabbro content of the bedrock in the granitoid area is indicated also by the results of the pebble counts done on the Hyvinkää esker, on the basis of which the gabbro content is at most only 17% at a distance of 6.4 km from the gabbro complex. In the terrain through which the Helsinki—Hämeenlinna highway runs, the composition of the bedrock varies typically in the series gabbro—diorite—hornblendegranodiorite-granite. Owing to the variation in the rock types composing the bedrock, the proportion of gabbro in the till of the eastern traverse is at most only 26 per cent.

Key words: gabbros, granites, indicators, till, glaciofluvial features, stone counts, gravity anomalies, magnetic anomalies, Hyvinkää, Finland

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INTRODUCTION

In the area of the Hyvinkää gabbro complex, in southern Finland, pebble counts have been previously carried out by R. Tynni, K. Virkkala and J. Donner. Tynni (1969) made the observation that at the southern border of the complex, the till contains 80% of gabbro. The rocks contained in the glaciofluvial sediments appear to have been transported a greater distance than that in the till. According to Tynni, this is clearly shown by the fact that the gabbro content in the Hyvinkää esker does not reach its maximum before a distance of 5 km from the distal contact (ca. 20%). Virkkala's (1971) investigations bring out the fact that from the gabbro bedrock area (gabbro 74%) the gabbro percentage decreases very rapidly: at a distance of 1—3 km from the source area, the gabbro content amounts to 20%, 4.5 km away it is down to 10% and 6.0 km away, 4%. Donner (1986) has investigated by the pebble count method the gabbro contents of the glaciofluvial sediments in the Hyvinkää region. His observations show low contents there in both the Salpausselkä

I and the Hyvinkää esker. On the evidence produced by the pebble counts, the gabbro complex is thus not so extensive as it is represented on the regional 1:100 000 bedrock map.

Since preliminary investigations revealed that the composition of the bedrock in the gabbro area of Hyvinkää varies greatly, the present study has taken a closer look at the bedrock in this area. Owing to the scarcity of rock exposures in the eastern part of the gabbro area, the local bedrock has also been investigated by means of gravimetric and aeromagnetic interpretations.

THE BEDROCK OF THE HYVINKÄÄ REGION

In the mapping of the bedrock, it was observed that on the immediate western side of the Helsinki—Hämeenlinna highway as well as especially the eastern side, there occur areas of rock varying in composition from gabbro to granite. On the other hand, the western part of the gabbro complex consists of gabbro with small portions containing diorite and peridotite. In the western part of the complex, the granite and the granodiorite occur as cutting dykes. In the eastern part of the

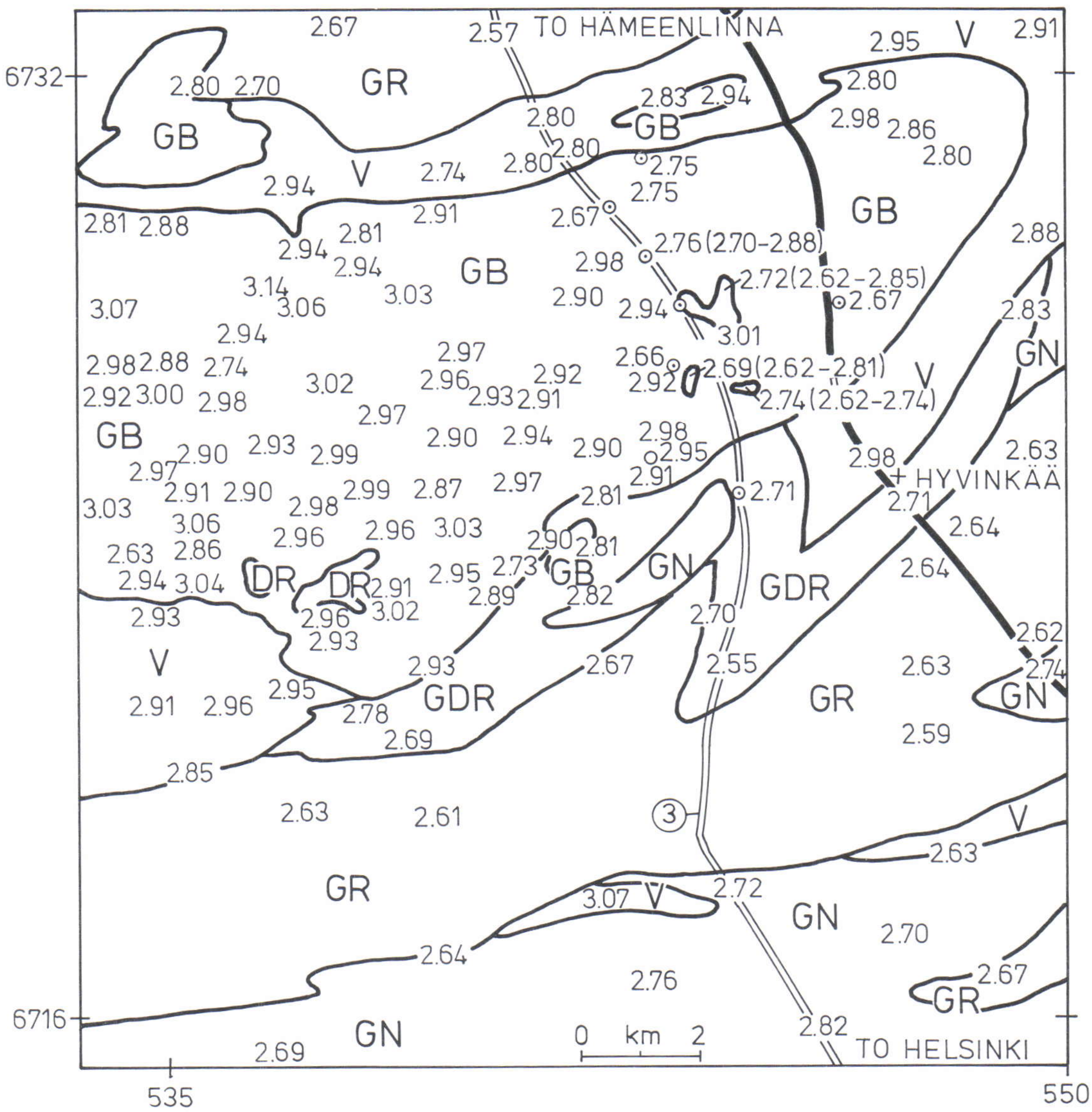

Fig. 1. The results of the density determinations of bedrock samples taken from the area surveyed (values g/cm³). In Puranen's (1971) density determinations, a point in the number (e.g., 2.90) indicates the location of an observation site. The determinations done by the present author are marked by circle (e.g. ⊙ 2.76) while the larger bedrock areas are marked off by a line, in addition to which the mean value and range of variation of the bedrock samples taken from the area are also recorded [e.g., 2.72 (2.62—2.85)]. GB = gabbro, Dr = diorite, GDR = granodiorite, GR = granite, V = volcanic rocks, GN = gneiss, SVGDR = hornblendegranodiorite.

region studied, cutting dykes and sharp rock contacts do not generally occur, but the transition of gabbro-diorite—granodiorite-granite is gradual.

Characteristic of the granodioritic material in the eastern part of the gabbro complex is a hornblende content and, in places, a pyroxen content. To simplify the classification, the rocks here has been designeted as hornblendegranodiorite. The granitic rocks in the gabbro complex that does not clearly contain hornblende is classified as granite. The hornblendegranodiorite in the area appears macroscopically to be of the same kind as the granodiorite occurring in the southern granodiorite bedrock area, which Härme (1978) has termed hornblendegranodiorite.

On the basis of the density determinations of the rock samples presented in Fig. 1, it may be noted that the largest part of the bedrock in the western part of the gabbro complex within the area studied is gabbro (density >2.85 g/cm³). On the other hand, the density determinations done from the rock samples taken from the eastern part of the gabbro complex reveal clear variation in the types of rocks. In addition to the densities of the rock samples, Fig. 1 also shows the range of variation in the densities of the rock samples from certain areas in the eastern part of the complex together with their mean values. Marked in Fig. 1 are all the rock exposures in the area of the gabbro complex on the east side of the Helsinki—Hämeenlinna highway, with the exception of the very northeastern portion. It can be seen from the picture that there are very few rock outcrops on the east side of the Helsinki—Hämeenlinna highway.

GRAVIMETRIC INTERPRETATION OF THE HYVINKÄÄ AREA

The gravity anomaly map of the area investigated is presented in Fig. 2. The east-west-oriented Hyvinkää gabbro complex and the two smaller gabbro areas associated with it have been marked out on the map. The gravity-measurement points have been marked on it with dots. The area registering the maximum, where the values exceed 30 mGal, is located in the western part of Fig. 2. It can be clearly perceived by means of the figure that the gravity values decrease in an easterly direction in the locality of the gabbro complex. The problem involved in the drawing of the map representing isoanomaly lines arose from the fact that the network of observation points in the area

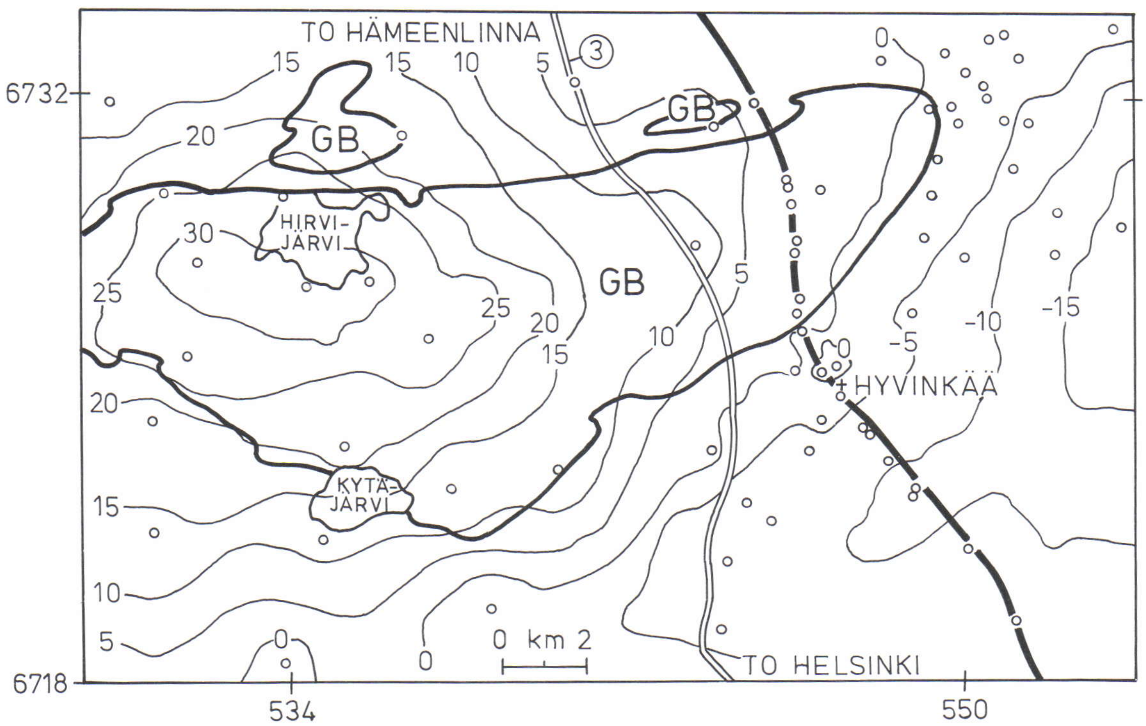

Fig. 2. The Bouger anomaly map of the area surveyed (contours interval 5 m Gmal). The locations of the gravity measurement points are marked with dots. The gravity values are based on data compiled by the Finnish Geodetic Institute. Also demarcated in the picture are the boundaries of the gabbro complex.

investigated is too sparse, especially between the Helsinki—Hämeenlinna highway and the railroad line as well as on the western side of the highway. The presentation of the isoanomaly lines is thus only indicative. On the north side of Hyvinkää, alongside the railroad tracks, however, there are numerous gravity-measurement points. The values of the points (0.6—2.1 Gmal) are very low for a gabbro complex, and they deviate markedly from the values measured in the western gabbro area. The low gravity values are likely to be due to the fact that the composition of the bedrock on the north side of Hyvinkää is mainly granodiorite—granite, a rock material more acid and lower in density than gabbro. Also the density determinations of the bedrock samples and the bedrock mapping done on the eastern side of the Helsinki—Hämeenlinna highway (Fig. 1) have shown that the composition of the bedrock varies greatly in this region.

AEROMAGNETIC INTERPRETATION OF THE HYVINKÄÄ REGION

In the Hyvinkää region, the proportion of remanent magnetization in the genesis of magnetic anomalies is somewhat greater than that of induced magnetization. For the most part, the directions of remanent magnetism are concentrated around the direction of the Earth's present field

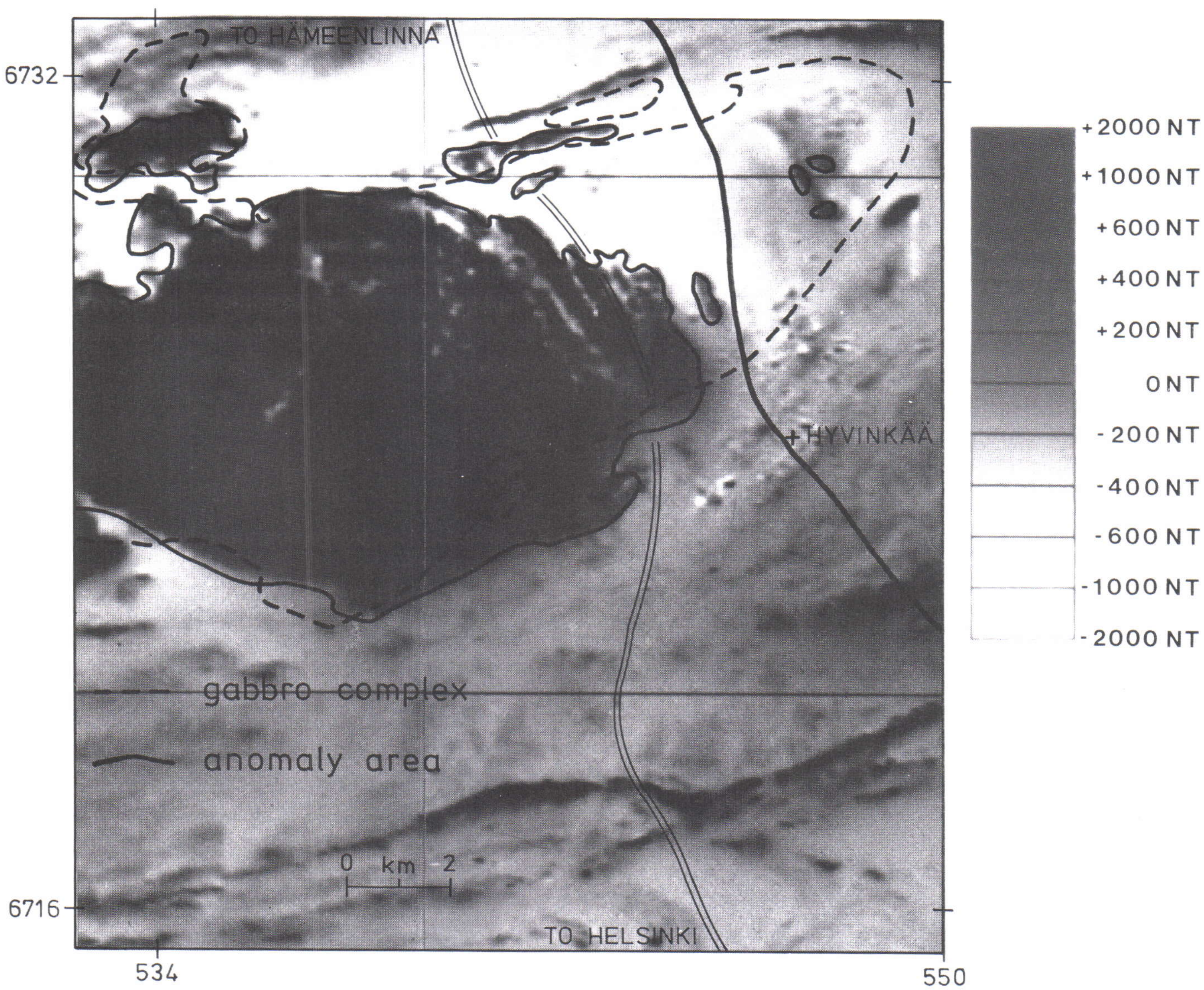

Fig. 3. Grey-tone picture of the area surveyed (Korhonen & Airo 1983, 1987). Demarcated on the covering figure are the boundaries of the gabbro complex (Härme 1953, 1980, Kaitaro 1956) and the highly magnetic part of the complex as drawn by Vallius (1987).

(Puranen 1968). On the basis of Puranen's (1968) susceptibility measurements done in the area of the Hyvinkää gabbro complex the dependence of the susceptibilities of solid samples on their magnetite content is nearly linear. One per cent by volume of magnetite corresponds on the average to a susceptibility of 3400 x 10^{-6}. The susceptibility mean values obtained in the Hyvinkää region for gabbro and diorite are markedly higher than those reported by various researchers and for granites and volcanites on the same order of magnitude. It is thus evident that there prevails in the gabbros of the Hyvinkää region a highly magnetic type with an abundant magnetite content, which accounts for the exceptionally high average susceptibility (Puranen 1968).

Fig. 3 presents an aeromagnetic map of the region studied as a grey-tone photo. In the figure are marked the limits of the Hyvinkää gabbro complex, which have been drawn on the basis of bedrock maps of the region. In addition, the strongly magnetic anomaly areas in the bounds of the gabbro complex have been marked out.

Associated with the separate gabbro area located in the northwestern part of the region surveyed is a conspicuous magnetic anomaly, which has been registered in its southern half (Fig. 3). An idea of the composition of the bedrock in the northern part of this gabbro area is given by the high susceptibility value 3580. On the basis of a magnetic interpretation, the bedrock here consists of gabbro—diorite.

The extensive, strongly magnetic anomaly area appearing in the grey-tone photo adheres fairly closely to the boundaries of the gabbro complex as represented on the bedrock maps at the scales of 1:100 000 and 1:400 000 (Härme 1953, 1980, Kaitaro 1956), that is, as far as the area on the west side of the Helsinki—Hämeenlinna highway is concerned. The high susceptibility values also registered in this area indicate that the bedrock is mainly composed of gabbro.

On the basis of the grey-tone photo, the southern portion of the gabbro complex is more extensive than marked out on bedrock maps. In this area, however, there occur many rock exposures, on the basis of which the bedrock has been classified in the bedrock map No. 2044 as granodiorite and quartz-feldspar-gneiss/schist. Inasmuch as the susceptibility values of the gneisses and granodiorites in the region surveyed are low, the magnetic anomaly in this area is probably due to an anomaly deeper in the earth's crust.

Magnetic anomalies occur in a small area in the northeastern part of the gabbro complex (Fig. 3). Also judging by the high susceptibility values, there is present in the bedrock of this area material that is distinctly magnetic (susceptibility value 2690).

Most of the area of the gabbro complex on the east side of the Helsinki—Hämeenlinna highway is free of aeromagnetic anomalies. This indicates that the bedrock in the region contains very little magnetite and thus the composition of the bedrock is evidently more granitic than the gabbro.

PEBBLE COUNTS IN THE HYVINKÄÄ REGION

In Fig. 4, the results of the pebble counts done in the region studied are represented in the form of a circular diagram. At the western traverse (observation points 33—39), the breadth of the gabbro complex is approximately 9.6 km. The bedrock in the area of the western traverse is composed almost entirely of gabbro. This becomes evident also in the abundant gabbro content in the glacial till. After the maximum content (73%) at the distal part of the gabbro complex, the proportion of gabbro in the till decreases sharply. At a distance of 2.1 km from the source area, the percentage of gabbro is down to 37% (observation point 37); at 3.5 km its content is 21% (observation point 38), and at 5.5 km, as little as 2% (observation point 39). There is a distinct difference between the bedrock surface at the south side of the gabbro complex (130 m above sea level) and in the area of clayey deposits on its distal side (ca. 60 m above sea level). The downward trend of the topography down-glacier from the source area evidently caused the basal till to be discharged into the distal contact of the gabbro area, and thus very little gabbro has been transported farther.

In the area of the eastern traverse (observation points 24—32), the breadth of the gabbro complex in the direction of flow of the continental ice sheet is 5.6 km; it is thus markedly narrower than the part of the complex along the western traverse. The gabbro content of the eastern traverse does not increase steadily from the proximal contact of the gabbro area, as in the case of the western area, for the content varies over a very short stretch. Further, the largest gabbro content does not occur in the distal contact of the gabbro area. Moreover, there is a marked difference between

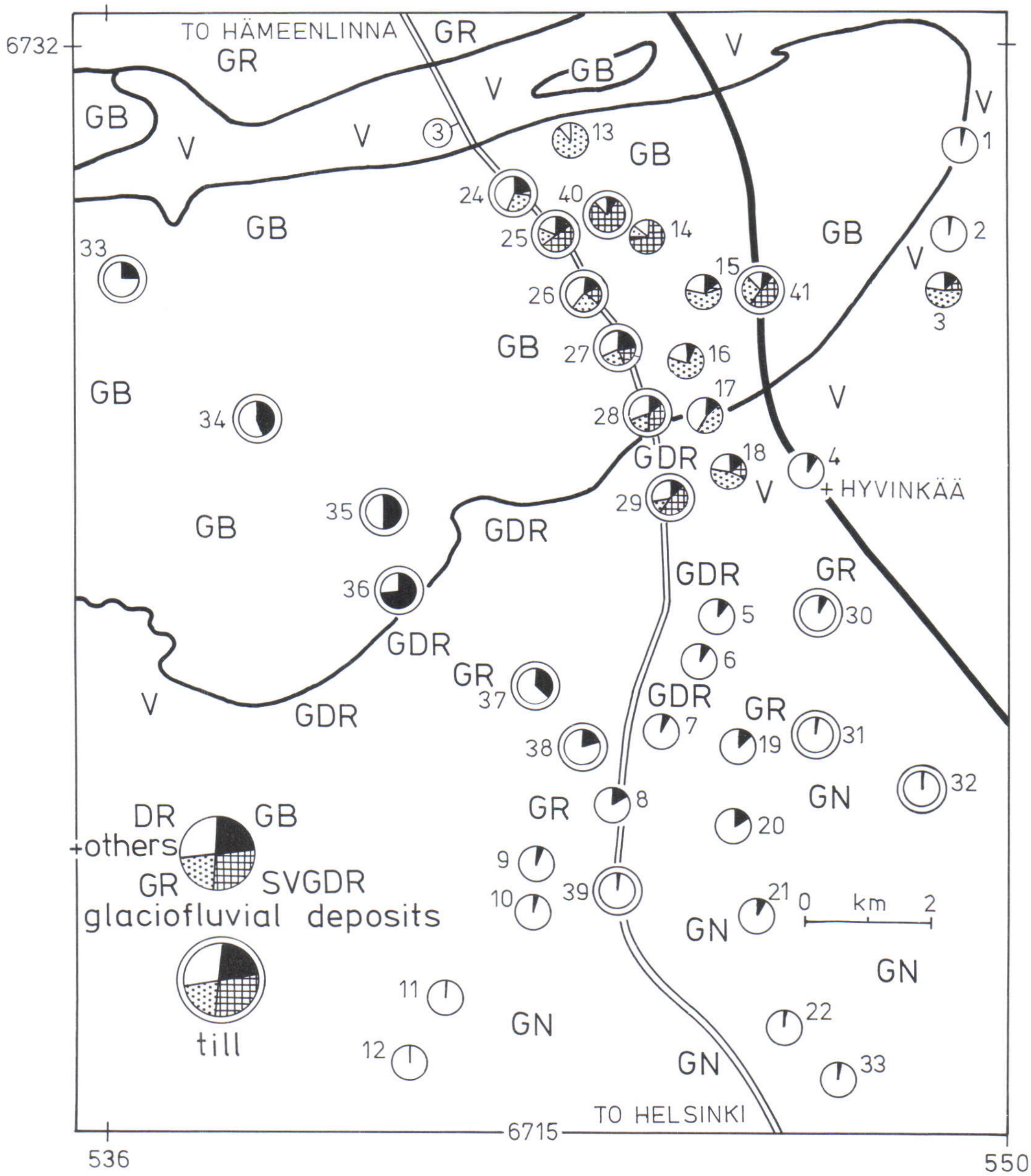

Fig. 4. Results of the pebble counts carried out in the area surveyed. The numbers 1—12 fall on Salpausselkä I, 13—23 on the Hyvinkää esker, 24—32 on the eastern traverse and 33—39 on the western traverse. The abbreviated bedrock symbols are explained in Fig. 1.

these two areas with respect to their maximum contents in the till: in the western area 73% and in the eastern 26%.

The variation in the composition of the bedrock over even a short distance in the terrain adjacent to the Helsinki—Hämeenlinna highway appears as a low gabbro content in the till and as variation in the composition of the till within the space of close observation points (Fig. 4). As the composition of the gabbro complex varies from gabbro to granite in the area of the eastern traverse across the moraine, the pebble counts have served to bring out the proportions of hornblendegranodiorite, granite and other rock components (on the whole, mostly diorite), in addition to the gabbro, in the areas marked by observation points on the north side of Salpausselkä I.

At the observation points (13—18) on the Hyvinkää esker, the influence of the extensive granite area located on the north side is clearly to be seen. The composition of the bedrock on the west side of the Hyvinkää esker could not be determined on the basis of the bedrock mapping on account of the lack of rock exposures. The low gabbro contents of the Hyvinkää esker registered by means of pebble counts indicate that the composition of the bedrock is more granitic than gabbroic.

Observation point 14 (Fig. 4) on the Hyvinkää esker is situated at a distance of 2.2 km from the proximal contact. Here the sediment is not glaciofluvial, however, but more like glacial till. In the surface portion of this material, there occurs many hornblendegranodioritic stones measuring Ø 10—20 cm. The composition of the till-like sediment at this observation point deviates markedly from the sediment met with at other points in the Hyvinkää esker, where a typical feature is an abundant occurrence of granite. The composition of the till-like sediment at observation point 14 is similar to that of observation point 40 in the adjacent moraine area.

The presence of till-like sediment at observation point 14 on the Hyvinkää esker points in all likelihood to the deglaciation stage of the Weichselian ice sheet, when the direction of the retreat of the ice sheet turned quite westward on account of the topography of the gabbro area on the west side of the Helsinki—Hämeenlinna highway. Weak westerly striation trends (295°—305°) associated with this stage are to be observed in the area of rock cuts along the Helsinki—Hämeenlinna highway.

Also in the Salpausselkä I, the gabbro content is low. The variation in the bedrock deviating from the gabbro on the eastern side of the gabbro complex has also evidently played a part in producing a low gabbro content at observation points 1—4 in the northeastern portion of Salpausselkä. Evidently, the low gabbro contents at least in the southwestern part as registered at observation points 7—12 are due to englacial transport of the glaciofluvial deposits.

CONCLUSIONS

On the bedrock map shown in Fig. 5 there are two separate gabbro areas on the north side of the gabbro complex. These areas have also been marked out in the 1:100 00 and 1:400 000 bedrock maps of the region. The composition of the bedrock in the area in the northwestern part of the region surveyed is gabbro and diorite, as judged also in the light of aeromagnetic interpretation and the densities of the bedrock (Figs. 1 and 3).

No magnetic anomalies have been registered in the small gabbro area on the north side of the gabbro complex (between the Helsinki—Hämeenlinna highway and the railroad). The density values, however,indicate that the bedrock in this area consists of gabbro and diorite.The western part of the region surveyed has been interpreted to be a gabbro area in the light of bedrock mappings, density determinations of the bedrock and geophysical studies. This is also indicated by the results of the

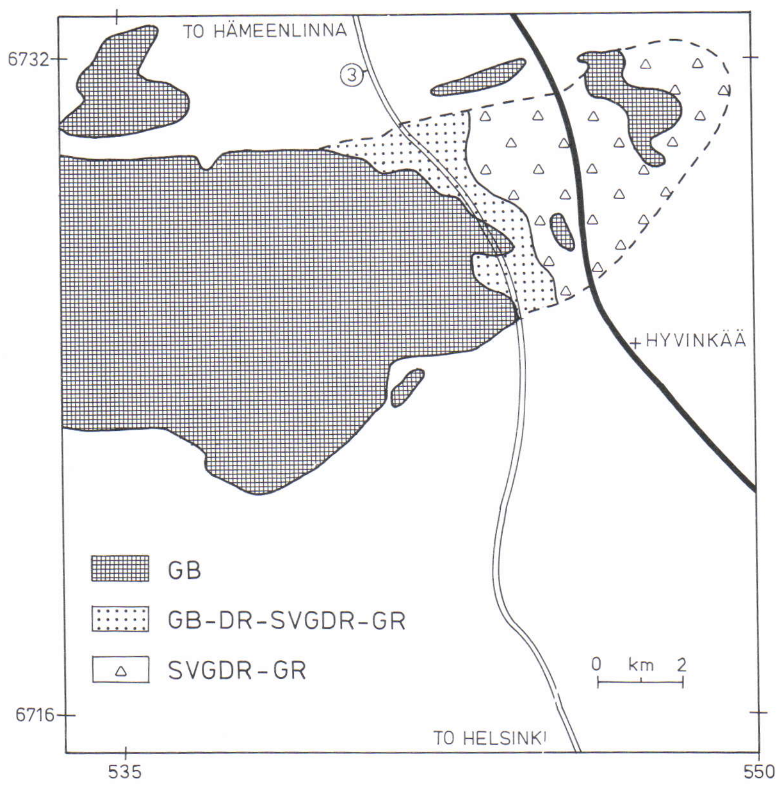

Fig. 5. Bedrock map of the area of the Hyvinkää gabbro complex. GB = gabbro (in the northeastern part and the areas north of the complex GB—DR; DR = diorite; SVGDR = hornblendegranodiorite; GR = granite.

pebble counts along the western traverse: in the the distal contact of gabbro area, gabbro accounts for 73% of the rocks in the till.

A small gabbro-diorite area has been marked in the northeastern corner of the gabbro complex on the bedrock map shown in Fig. 5. The area has been interpreted to be gabbro—diorite on the basis of aeromagnetic interpretation and density determinations.

On the northwest side of the town of Hyvinkää, west of the railroad line, there is a small gabbro area (Fig. 5). In this area, there are no rock outcrops. It has been marked off solely on the basis of a strong anomaly appearing in the aeromagnetic grey-tone photo (Fig. 3).

In the bedrock map of Fig. 5, the narrow gabbro—diorite—hornblendegranodiorite—granite area on the west side of the Hyvinkää esker has been marked mainly on the basis of bedrock observations and density determinations done from bedrock samples, as well as to some extent also by means of aeromagnetic interpretation and pebble counts in glacial till. In the bedrock mapping carried out in this area, it was noted that the composition of the rocks generally varies between gabbro and granite. This conclusion is also supported by density determinations done from samples taken from the bedrock (Fig. 1).

The demarcation of the extensive granitic area (hornblendegranodiorite—granite) inside the bounds of the Hyvinkää gabbro complex is based — owing to the nearly total lack of rock exposures — on aeromagnetic and gravimetric interpretations as well as the results of the pebble counts. On the basis of the small-sized exposure located at observation point 41 (the observation point of the pebble count), the rocks occuring in this granitic area consists of granodiorite—granite (hornblende-granodiorite, with a density of 2.67 g/cm^3). By the result of the pebble count done on the till at this observation point the proportion of granitoids amounts to 77%. Also on the till at observation point 40 the proportion of hornblendegranodiorite is high, 78% of the rocks (Fig. 4). A low gabbro content in the local bedrock is also indicated by the results of the pebble counts done on the Hyvinkää esker, on the basis of which the gabbro content reaches a maximum of only 17%. The gravity values measured gravimetrically along the railroad line next to observation point 41 are quite low (Fig. 2). This stretch of ground appears also on the aeromagnetic map as free of anomalies. Judging by all these circumstances, it has been concluded that the composition of the bedrock is mainly hornblendegranodiorite—granite.

In the area of the Hyvinkää gabbro complex right on the west side of the Helsinki—Hämeenlinna highway and particularly on the east side, the composition of the bedrock was observed to vary typically in the series gabbro—diorite—hornblendegranodiorite — in many places all the way to granite. In some of the rock outcrops, the predominant rock is hornblendegranodiorite—granite. The transitions were observed to be generally gradual, and no sharp rock contacts occur. The areas characterized by different varieties of rock shown in the bedrock map reproduced in Fig. 5 probably derived from a common parent magma (= comagmatic) and represent the primary composition produced in the magmatic differentiation of the Hyvinkää complex.

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COMPOSITION AND PROVENANCE OF TILL IN THE MARGINAL AREA OF THE GRANULITIC TERRAIN OF FINNISH LAPLAND

by
Matti Saarnisto and Esko Tamminen

Saarnisto, Matti & Tamminen, Esko, 1989. Composition and provenance of till in the marginal area of the granulitic terrain of Finnish Lapland. *Geological Survey of Finland, Special Paper 7,* 45—53. 4 figures, 2 tables.

The till in the marginal area of the granulitic terrain of Finnish Lapland is mostly composed of local material, and the bedrock units can almost be mapped on the basis of pebble counts. The underlying bedrock is also clearly reflected in the trace metal content of the silt + clay fraction of the till. On the other hand, on Härkäselkä inside the granulitic terrain, the till material consists of both local and abundant long-distance components, as shown by its clast lithology, heavy minerals (including gold) and geochemistry. The greenstones and granite gneisses in the till clasts, for example, accounting for up to 21 and 41%, respectively, have been transported approximately 20 km. The underlying sorted material indicates that the till contains redeposited glaciofluvial material, which may explain the long transport distance. The grain size classes in the area are lithologically quite homogeneous. It is proposed that this homogeneity somehow reflects the abundance of easily erodable regolith on top of the unweathered bedrock.

Key words: provenance, till, stone counts, rocks, chemical composition, heavy minerals, glacial transport, Quaternary, Ivalojoki, Härkäselkä, Inari, Finland.

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INTRODUCTION

The present article is based on the data collected during the »Lapland gold project» in 1982—1985 (Saarnisto & Tamminen 1985; 1987), the aim of which was to investigate the origin of placer gold in the Ivalojoki area of Finnish Lapland. Most of the gold has been panned from glacial deposits sorted to various degrees by meltwater. Research into glacial deposits formed the major part of the work, including determination of their stratigraphy, lithology, heavy minerals and trace metal composition. In addition, the bedrock of the area was mapped and sampled for mineralogical and lithochemical analyses.

The lithological and chemical compositions of the tills are considered in the following in order to work out their transport distance and lithological homogeneity along a transect which crosses different lithologies of the marginal zone of the granulitic bedrock terrain of Lapland, the principal placer gold area, in the direction of the last ice flow towards the north-northeast. Another area studied is Härkäselkä, inside the granulitic terrain (Fig. 1).

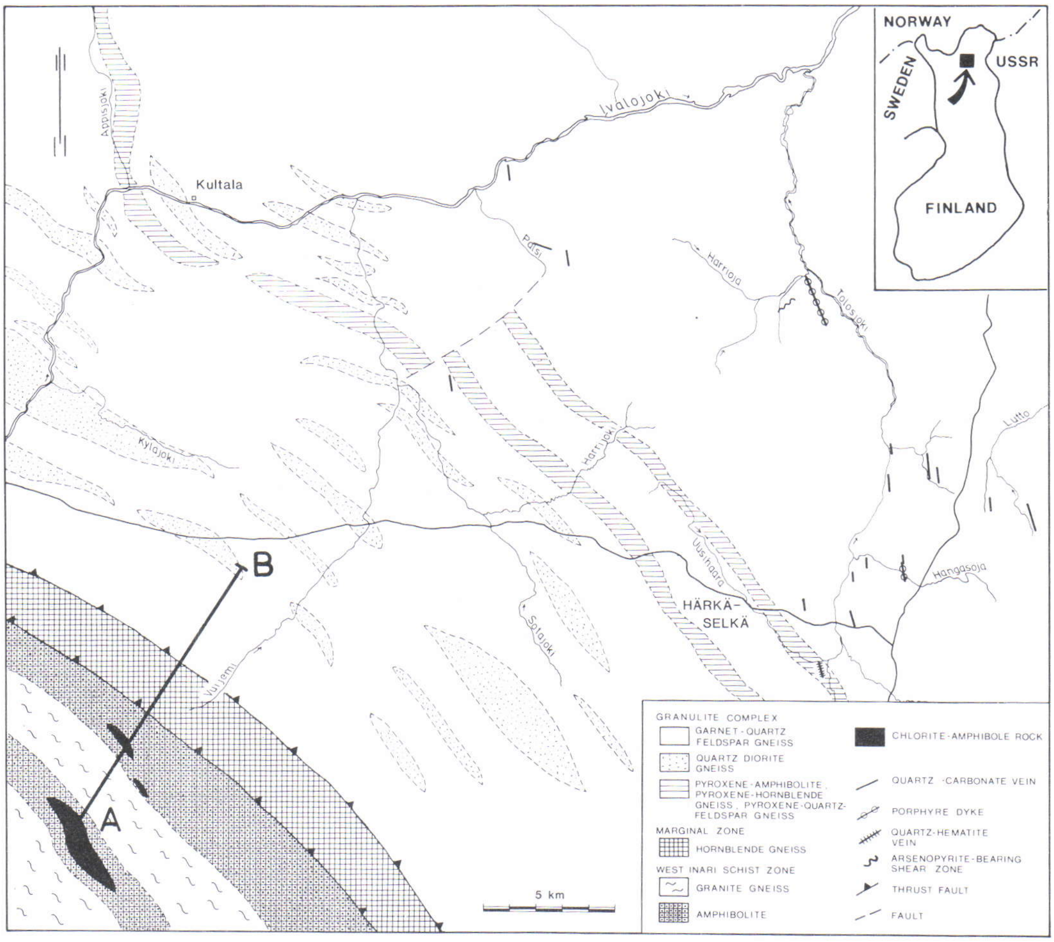

Fig. 1. Main features of the bedrock in the Ivalojoki area. Line A—B shows the till survey transect across the bedrock units from the West Inari Schist Zone to the Granulite Complex, presented in Fig. 3. The Härkäselkä area is also indicated. Map compiled by E. Tamminen.

MATERIAL AND METHODS

Glacial deposits were investigated in 263 pits dug using a mechanical excavator. The maximum excavation depth was normally 4 m, and 155 pits extended to the bedrock, which was often weathered and could be easily penetrated. Unweathered bedrock is to be found only in the valley bottoms and on exposed hill tops. Observations were made on the glacial stratigraphy, direction of ice transport and till lithology.

A 50-litre sample of each bed of till and glaciofluvial material was panned for gold and other heavy minerals. Trace metals, including gold, in the till fines (less than 0.063 mm) were analysed by instrumental neutron activation analysis (INAA) at the State Technical Research Centre. Stone counts were performed in the field on all the beds of till or glaciofluvial material in all pits, using pebbles of size 2 to 6 cm (183 counts), and in the laboratory on the gravel-size fraction, grain size 16—20 mm (142 counts), employing a stereo microscope. Thus 325 analyses were performed in all. In addition, surficial boulders were analysed at 35 sites. The number of boulders identified in each count was between 50 and 100, that for pebbles 100, if possible, and 200 for the gravel size fraction.The counts performed on pebble and gravel fractions at the same site gave practically identical results.

GLACIAL DEPOSITS

The till cover of the area is thin, often only 1 - 2 m, and mostly composed of only a single till bed. Sorted glaciofluvial material was also found beneath the till at several sites (Fig. 2). At three

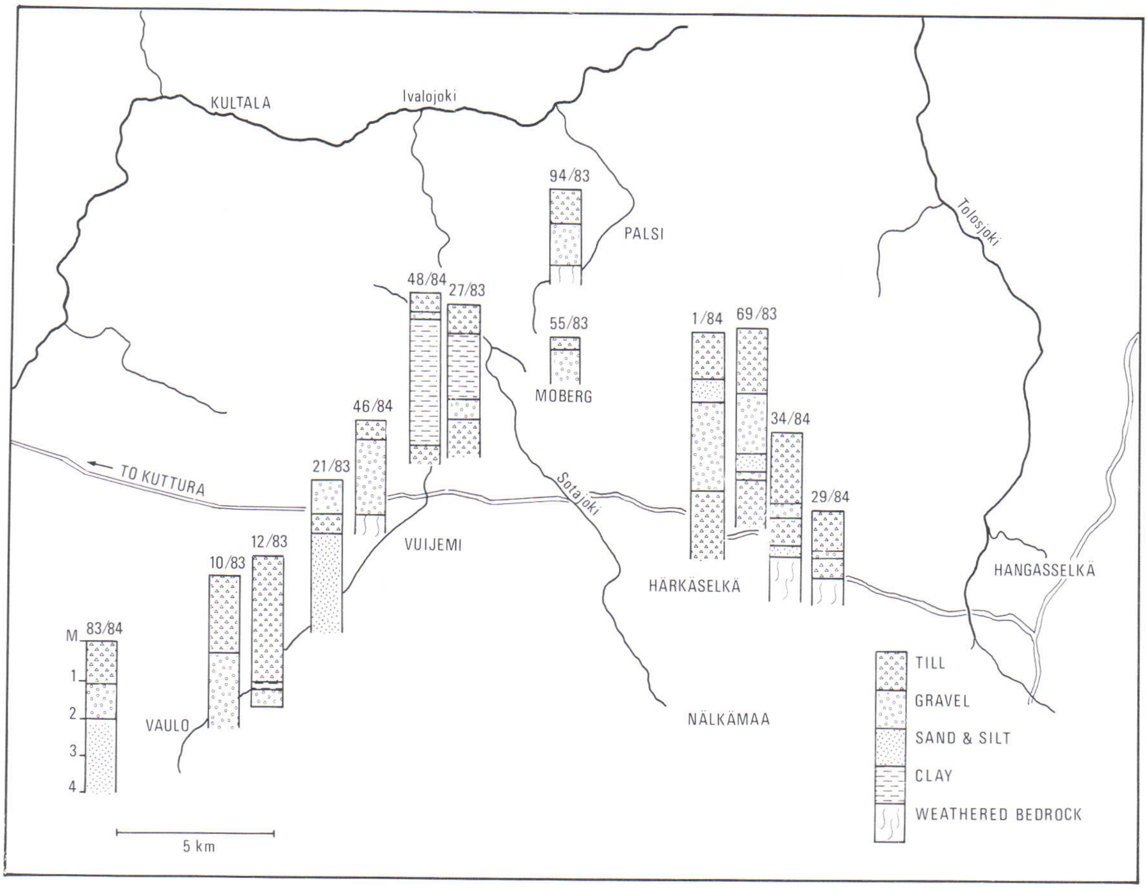

Fig. 2. Examples of glacial stratigraphy in the area.

being particularly in evidence at Härkäselkä, that they may represent a proglacial environment, i.e. sandur deposits. The finest silty sediments found may be glaciolacustrine in origin.

The material of the proglacial sorted sediments has become mixed with the upper till, as indicated by the presence of entirely rounded clasts. This may explain the abundance of long-distance transport material in the till in some areas such as Härkäselkä, as will be discussed below. Similarly material from the weathered bedrock is common in the till.

The principal transport direction of the last continental ice sheet, the Weichselian, was from south-southwest to north-northeast, as indicated by till fabric analyses performed in connection with the present work (Saarnisto & Tamminen 1985) and sites another till was found underlying this sorted deposit (sites Härkäselkä 1/84, Vuijemi, 48/84 and 27/83; Saarnisto & Tamminen 1985), but often the sediments were so thick that they could not be penetrated. They cover such a wide area, extending from Vaulo in the south to Palsi in the north, the earlier extensive survey covering the whole of Lapland by Hirvas *et. al.* (1977). The southern marginal area of the granulitic terrain is one in which the ice flowed across lithological boundaries and is therefore suitable for studying till transport distances. The test pits were located along a profile which follows the direction of transport. This was the case especially in the southern part of the area where distinct lithological units are crossed. The drawback in the data arises from the fact that the pits were not located at regular intervals, as their sites were also determined by the local bedrock and the occurrence of sites of special interest with regard the search for gold, e.g. shear zones, veins etc. deviations from the usual rock types. This is especially the case within the granulitic terrain proper.

BEDROCK AND STONE COUNT CLASSES

The bedrock of the area can be divided into three units: the Granulite Complex proper, its marginal zone and the West Inari Schist zone (Fig. 1.). These primarily Archaean (Meriläinen 1976) or early Proterozoic units (Barbey et. al. 1984) were metamorphosed during the Svecokarelian orogeny 2.1 to 1.9. G.A.

The Granulite Complex consists mainly of garnet-quartz-feldspar gneisses with variants, and quartz diorite gneisses are also common. Two narrow zones composed of hypersthene amphibolite, hornblende gneisses and quartz-feldspar gneisses run northwest to southeast across the area. The southern marginal zone of the Granulite Complex consists of banded hornblende gneisses, while the main rock types in the West Inari Schist Zone are granite gneisses, amphibolites and ultramafic chlorite-amphibole rocks.

All the above mentioned rocks strike to the northwest, i.e. perpendicular to the last ice flow, and dip gently to the northeast. The marginal zone and the West Inari Schist Zone posses distinct lithological boundaries whereas within the Granulitic Complex proper the various lithologies are mixed and cut into each other in a conformable manner thus making this area less suitable for till provenance studies. All these rocks are cut across by younger, usually N-S-oriented, veins composed of quartz-feldspar porphyres, quartz-carbonates and quartz-haematite. These may be broadly correlative in age with the post-orogenic Nattanen granite (1.735 G.A.; Meriläinen 1976), small, isolated batholiths of which occur to the south of the present area. These veins are important for the oc-

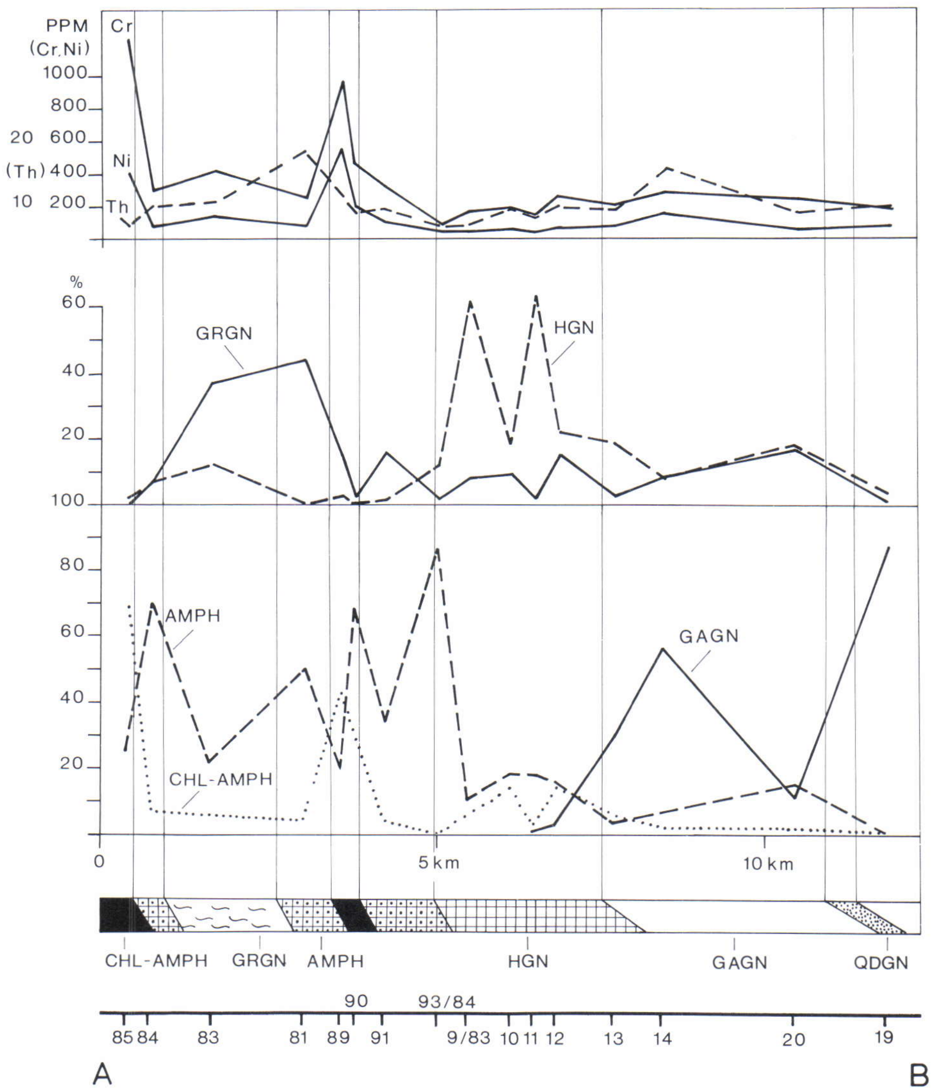

Fig. 3. Distribution of chlorite-amphibole rocks (greenstones) (CHL—AMPH), granite gneiss (GRGN), amphibolites (AMPH), hornblende gneiss (HGN), garnet gneiss s.l. (GAGN), together with Cr, Ni, and Th in till along a transect from the West Inari Schist Zone to the Granulite Complex (line A—B in Fig. 1.). Numbers refer to sites: 9—20/83 and 81—93/84 (Saarnisto & Tamminen 1985). QDGN = quartz diorite gneiss.

currence of gold (Tamminen 1986). The average trace metal contents of the principal rock types are listed in Table 1. These will be used for calculation purposes when considering the lithological homogeneity of the till.

The following classes were used in the stone counts: — Rocks present within the Granulite Complex proper: garnet gneiss and garnet - biotite gneiss, pyroxene gneiss, alkali feldspar gneiss, pegmatite and granite, quartzite and felsic schists; — Rocks present in the marginal zone of the Granulite Complex: hornblende gneiss; — Rocks present in the West Inari Schist zone: greenstones (= chlorite-amphibole rocks), and granite gneiss; — Rocks present in the West Inari Schist zone and the Granulite Complex: amphibolite; — Rocks present throughout the area: vein quartz.

In the later analysis some of the classes were combined because these rocks occur intermixed in the bedrock or because their macroscopic identification was not altogether clear. The rocks originating from the West Inari Schist Zone or the marginal zone of the Granulite Complex were the most useful for studying till provenance and transport distance. These included the chlorite-amphibole rocks and granite gneisses in the former area and the hornblende gneisses in the latter. The amphibolites were also significant, in spite of being present in the Granulite Complex as well. The hornblende gneisses in the marginal zone do not generally contain pyroxene and thus deviate from the general pattern for those within the Granulite Complex, but since pyroxenes are sometimes present, differentiation between the hornblende gneisses form the different source areas is not a straightforward matter. Only the chlorite amphibole rocks, amphibolites, granite gneisses and hornblende gneisses will be considered in the following in addition to the garnet gneisses s.l., the principal rock type in the Granulite Complex. These selected rock types and some trace metals analysed in the till samples are presented in Fig. 3 in the form of a profile across the marginal area of the granulite terrain from Vaulo to Vuijemi (Fig. 1.). Chromium and nickel are abundant in the greenstones and amphibolites of the West Inari Schist zone, whereas thorium is abundant in the felsic rocks, both the granite gneiss of the West Inari Schist Zone and the garnet gneiss of the Granulite Complex. Th originates mainly from monazite, which is quite a common mineral in these rocks.

The clast material in the till clearly reflects the underlying bedrock. There is a 0.4 km wide zone of chlorite - amphibole rocks on top of which these rocks account for up to 44% of the till clast composition, while at the distal margin of the 2 km wide amphibolite zone they account for up to 86%, decreasing to 10% within half a kilometre. The granite gneiss seems to be less erodible. Its amount increases to 44% within a unit of width 1.6 km, while Th in the till fines, obviously originating from granite gneiss, reaches its highest values with only a moderate delay, on top of the amphibolite rock in the distal direction. Cr and Ni reflect the underlying mafic rocks in a highly sensitive manner, indicating that the fine fraction of the till is also mostly composed of local material, although the absolute values remain well below those in the bedrock values (Table 1), which suggest the additional presence of foreign lithologies. Hornblende gneiss increases to 62% within 0.5 km of the proximal contact, but declines rapidly thereafter because of the large amounts of vein rocks in the till, mostly pegmatite and vein quartz. These vein rock types form significant components of the till lithology within the granulite terrain. The garnet gneiss rises to 57% about one kilometre from the proximal contact of the granulite terrain, its maximum values in this terrain reaching well over 90%. The amphibolite and quartz diorite gneiss units within the granulite complex are immediately reflected in the till lithology, as are the pegmatites and vein quartz.

Table 1. Average trace metal contents (ppm) of various rock types in the area. These values were used to calculate the expected metal content of the till. Average trace metal values for the weathered rock samples are shown for comparison, together with average values for all the till samples. Method INAA.

Unweathered rocks					Weathered rocks			
Rock type	n	Cr	Ni	Th	n	Cr	Ni	Th
Garnet gneiss	28	283	32	7.5	25	245	58	12.5
Hornblende-pyroxene gneiss	22	256	36	0.8	6	114	17	0.4
Amphibolite	27	311	102	0.9	8	200	61	2.4
Chlorite-amphibole rock	18	2 812	850	0.3	3	2 360	616	0.6
Granite gneiss	1*	209	13	7.8	-	-	-	-
Granite, pegmatite	9	149	14	7.8	-	-	-	-
Vein quartz	9	280**	10	1.3	-	-	-	-
Average content in all till samples n = 276						230	102	11.7

* Representative analysis. ** Contaminated by chromium steel mortar.

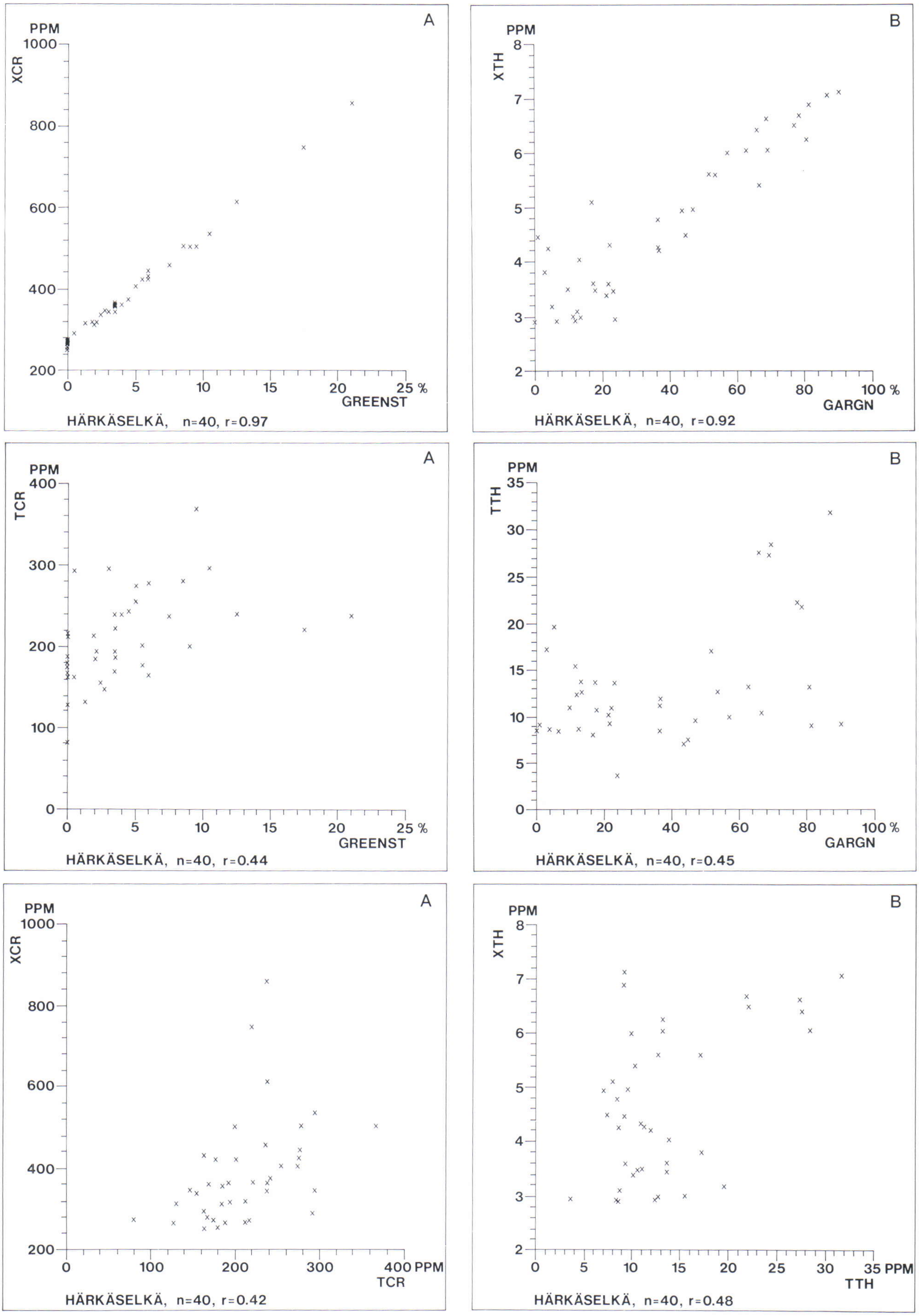

Fig. 4. A. Correlations between greenstones (GREENST) and expected Cr content (XCR), greenstones and measured Cr content (TCR), and measured and expected Cr content in the till of Härkäselkä. B. Correlations between garnet gneiss (GARGN) and expected Th content (XTH), garnet gneiss and measured Th content (TTH), and measured and expected Th content in the till of Härkäselkä.

HÄRKÄSELKÄ

Härkäselkä is a somewhat elevated hill which rises 50 to 80 m above the surrounding mires. It is situated inside the Granulite Complex proper, nearly 20 km northeast of the West Inari Schist Zone. It was one of the main areas studied in terms of till lithology, stratigraphy and geochemistry in view of the activity of gold panning there at an exceptional high ground as compared with most placers alongside rivers and brooks at lower levels.

The tills in the Härkäselkä area are exceptional, on account of their highly heterogeneous lithology, i.e. they contain both local and long-distance material. The maximum proportion of greenstones was 21% in the till and 33% in the poorly sorted gravel underlying the uppermost till bed, while granite gneisses from the West Inari Schist Zone accounted for up to 41% of the till pebbles. These rocks had obviously been transported a distance of some 20 km. Extensive attempts were made to locate a closer source for both the greenstones and the granite gneiss but with no success, and thus it was accepted that they must be the result of long-distance transport. Further support for this was gained from the till geochemistry, heavy minerals and the composition of the placer gold.

In order to work out the lithological homogeneity of the tills in Härkäselkä, i.e. the degree of lithological similarity between the fine and coarse fractions, the lithological and geochemical data were used as follows (c.f. Saarnisto & Taipale 1985). Trace metal contents for the till were predicted from the average metal contents of each rock type in the bedrock (Table 1) and the proportions of these rock types in the till. The *expected* values were then compared with the actual *measured* values in the silt + clay fraction (less than 0.063 mm) at the same sites. Only two sets of correlations are considered here: greenstones vs. chromium and garnet gneiss vs. thorium. Cr is very abundant in the greenstones and Th is elevated in the felsic rocks such as garnet gneiss and granite gneiss. The correlations are presented in Fig. 4.

The proportion of greenstones in Härkäselkä and the expected chromium values show a distinct correlation of 0.97, indicating that most of the chromium can be explained by the presence of greenstones. Greenstones then correlate reasonable well with the measured Cr in the till fines ($r = 0.44$), and the measured and expected Cr contents are similarly correlated ($r = 0.44$), which means that the till fines also contain greenstone material. Garnet gneiss and expected thorium also show a distinct correlation of 0.92, and thus most of the Th can be explained by the presence of garnet gneiss, the most common rock in the till at Härkäselkä. Garnet gneiss and measured Th also correlate moderately well ($r = 0.45$), as do the measured and expected Th values ($r = 0.48$), indicating that the amount of garnet gneiss in the fine fraction reflects reasonable well the amount in the clast fraction i.e. the till is lithologically homogeneous as far as its different grain sizes are concerned even though its lithology varies a great deal.

The uppermost till in Härkäselkä is commonly underlain by glaciofluvial sand and gravel, and therefore also contains redeposited glaciofluvial material, which would explain the long transport distance. Glaciofluvial material is so abundant in places in the lower part of the till that genetic differentiation of the sediments is sometimes problematical. Glaciofluvial transport of the long distance material is further indicated by the roundness of the greenstone and granite gneiss boulders. On the other hand, Härkäselkä is an elevated hill area and could also have attracted long-distance englacial debris.

HEAVY MINERALS

The results of heavy mineral analyses from five subareas, including Vaulo in the West Inari Schist zone and Hangasoja, Moberg, Vuijemi and Härkäselkä within the granulitic terrain, are presented in Table 2. The material is from panned heavy mineral concentrates, and the analyses were made from polished thin sections. 1000 mineral grains were identified in each sample.

Iron oxides, i.e. magnetite, haematite, ilmenite and ilmenohaematite, are common heavy minerals, together with garnet and less common rutile, zircon, monazite and epidote. No sulphide minerals were detected. Platinoid minerals were not present in the samples, but they did accompany gold in small quantities, the most common being sperrylite and ferroplatinium (Saarnisto & Tamminen 1987; c.f. also Vuorelainen & Törnroos 1986).

The heavy mineral composition of the till clearly reflects that of the surrounding bedrock. The samples from the granulitic terrain at Hangasoja,

Table 2. Heavy minerals in panned till concentrates in different subareas. 1 = Hangasoja (Hangasselkä), 2 = Moberg, 3 = Vuijemi, 4 = Härkäselkä, 5 = Vaulo. The localities are indicated in Fig. 2. Analysed by E. Tamminen.

	1	2	3	4	5
Magnetite	6.9	15.2	6.9	45.3	52.6
Ilmenite	4.8	10.7	15.7	3.7	6.0
Ilmenohaematite	6.0	13.5	26.2	5.1	3.4
Haematite	0.2	2.0	6.7	12.2	3.8
Garnet	60.9	46.6	31.3	14.11	11.9
Amphibole	+	0.7	0.4	11.4	18.5
Pyroxene	0.4	0.8	4.6	4.8	1.1
Rutile	10.8	4.3	5.0	1.2	-
Sphene (titanite)	-	-	-	-	0.7
Zircon, monazite	4.4	4.9	1.9	1.2	1.6
Epidote	0.1	0.5	1.3	1.0	0.4
Sillimanite	5.5	0.8	+	-	-
Sum	100.0	100.0	100.0	100.0	100.0
Others:					
Apatite	+	+	-	+	+
Chromite	-	+	-	+	+
Green spinel	-	+	-	+	-

Moberg and Vuijemi all contain large amounts of garnet as well as rutile, zircon and monazite together with iron oxides. The samples from Vaulo contain over 50% magnetite, and amphiboles are also common. Härkäselkä is again an exception. The sample analysed is very similar to that from Vaulo, with high amphibole and magnetite, indicating that the material is partly of long distance origin.

There are areal differences in the silver and copper content of the placer gold grains, and in their Ag/Au and Cu/Au ratios. Gold panned from the West Inari Schist Zone or from the marginal area of the Granulite Complex contains approximately twice as much silver as that found within the Granulite Complex proper, where it tends to be rich in copper (Saarnisto & Tamminen 1987). In the Härkäselkä area the grains vary greatly in composition, including both of the above types. This can be attributed to the heterogeneity of the till lithology, which involves both very local and long-distance material, the latter originating from the marginal zone of the Granulite Complex and from the West Inari Schist Zone.

CONCLUSIONS

Investigation of the till composition in the granulitic bedrock terrain of Finnish Lapland indicates lithological homogeneity among the grain size classes. This was shown by lithological and chemical analysis of samples taken along a transect extending in the direction of the last ice movement from the West Inari Schist Zone across the marginal zone of the Granulite Complex to the Granulite Complex proper, and also in the Härkäselkä area nearly 20 km inside the granulitic terrain.

The greenstones and amphibolites in the West Inari Schist Zone are immediately reflected in the till clast lithology and till fines in terms of elevated Cr and Ni content. The presence of granite gneiss in the bedrock is also distinctly reflected in the till, but the maximum values are slightly delayed and remain lower than for the amphibolites and greenstones, even though the latter rocks originate from narrower bedrock units. Similarly Th in the till fines, obviously originating from granite gneiss, reaches its highest values only somewhat distally of the bedrock occurrence. Granite gneiss seems to be more resistant to glacial erosion than greenstones or amphibolites.

The till in Härkäselkä contains large amounts of long distance material originating from the West Inari Shist Zone nearly 20 km to the SSW, including granite gneiss and greenstones, and the good correlation between greenstone clasts and chromium in the till fines indicates that the fine fraction also contains long distance material. Similarly, heavy minerals indicate both local and distant elements, the high magnetite content in particular being similar to the situation in the sample analysed from the Vaulo area in the West Inari Schist Zone. Further evidence for long distance material is provided by the composition of the gold grains in the till, those found at Härkäselkä being heterogeneous regarding their silver and copper content, possessing both grains rich in silver, typical of the marginal areas of the granulite terrain, and grains rich in copper, typical of the Granulite Complex. Despite the lithological heterogeneity of the till in Härkäselkä as far as its provenance is concerned, the different grain size classes seem to be lithologically reasonable homogeneous.

The lithological homogeneity of the till in the present area is exceptional when compared with the Kuhmo area in eastern Finland, for example, where the till fines represented a much wider provenance area than the clasts (Saarnisto & Taipale 1985, Taipale *et. al* 1986). In the present area the bedrock is extensively covered by a soft preglacial regolith, which has provided large amounts of material which is readily crushed into various grain sizes. Weathered rock material is abundantly visible in the lower parts of the till beds and indicates a very local provenance. The ubiquitous soft regolith also explains the high trace metal content of the till fines, as many metals have been enriched in the regolith during preglacial weathering. In Kuhmo the last glacier eroded fresh till and exposed unweathered bedrock surfaces, so that the fine fractions are to a great extent the product of glacial comminution.

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IS THE TILL MATRIX TRANSPORTED — OR IS THE WAY TO ITS STUDY WRONG?

by
Martti Kokkola

Kokkola, Martti, 1989. Is the till matrix transported — or is the way to its study wrong? *Geological Survey of Finland, Special Paper 7,* 55—58. 5 figures.

The transport of the till matrix has been studied in the light of chemical analyses. This may, however, be the wrong approach, for recent regional and detailed investigations have shown anomalies noted geochemically to be almost totally local. The transport distance of till matrix studied by geochemical analyses ranges from some tens to less than 200 metres.

Key words: geochemical methods, till, anomalies, glacial transport, Finland

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The transport of the till matrix has often been studied in the light of the results of geochemical analyses. The analysis of geochemical till samples has concentrated on the fine-grained material, consisting mainly of clay and mica minerals as well as feldspar and quartz. The combined surface area of the different particles composing the material in this grain size is quite noteworthy.

The sampling points have been placed on sampling lines running across a known movement of the Weichselian ice sheet, with the spaces between the lines varying from 100 to 1000 meters and the intervals between the points on any given line from 20 to 100 meters. With such an arrangement and manual visualization of the result, beautiful glaciogenic fans have been produced.

On the Atlas maps published by the Geological Survey of Finland, it is possible in places to observe anomaly structures conforming to the movement of the ice sheet. Rarely have such structures been interpreted on this scale, however, as glaciogenic. On the other hand, sample density 1/4 km^2 appear to have a certain correlation with glacial geological structures. The anomalies seem to be situated in the marginal parts of glacial lobes or in the terrain between lobes. Would this be a question of cause or effect — or might these features have been produced by possibly the same, so far unknown factor?

On sheet 21 of the 1:400 000 -scale map of Tampere, the main direction of the anomaly zone is east-west, but in addition geochemical anomalies follow a distinct northwest-southeast longitudinal line. This direction appears, however, to deviate about 15° from the youngest known direction of ice flow in the region. It has a deviation of the same magnitude also in relation to the older direction of flow. On the southeast side of the basic formation of Vammala, there occurs an extensive anomaly over 20 km long according to the till matrix, an anomaly that most probably is not glaciogenic notwithstanding the fact that the bedrock of the region as known does not seem to explain it sufficiently.

In the same area, on the east side of Vammala, the Geochemistry Department of the Geological Survey has mapped a sheet on the scale of 1:20 000 representing an accumulation of more than 900 samples. The geochemical picture presented by this sheet is surprising (Fig. 1); it shows no beautifully formed glaciogenic fans formed by known basic formations. On the other hand, some sort of block

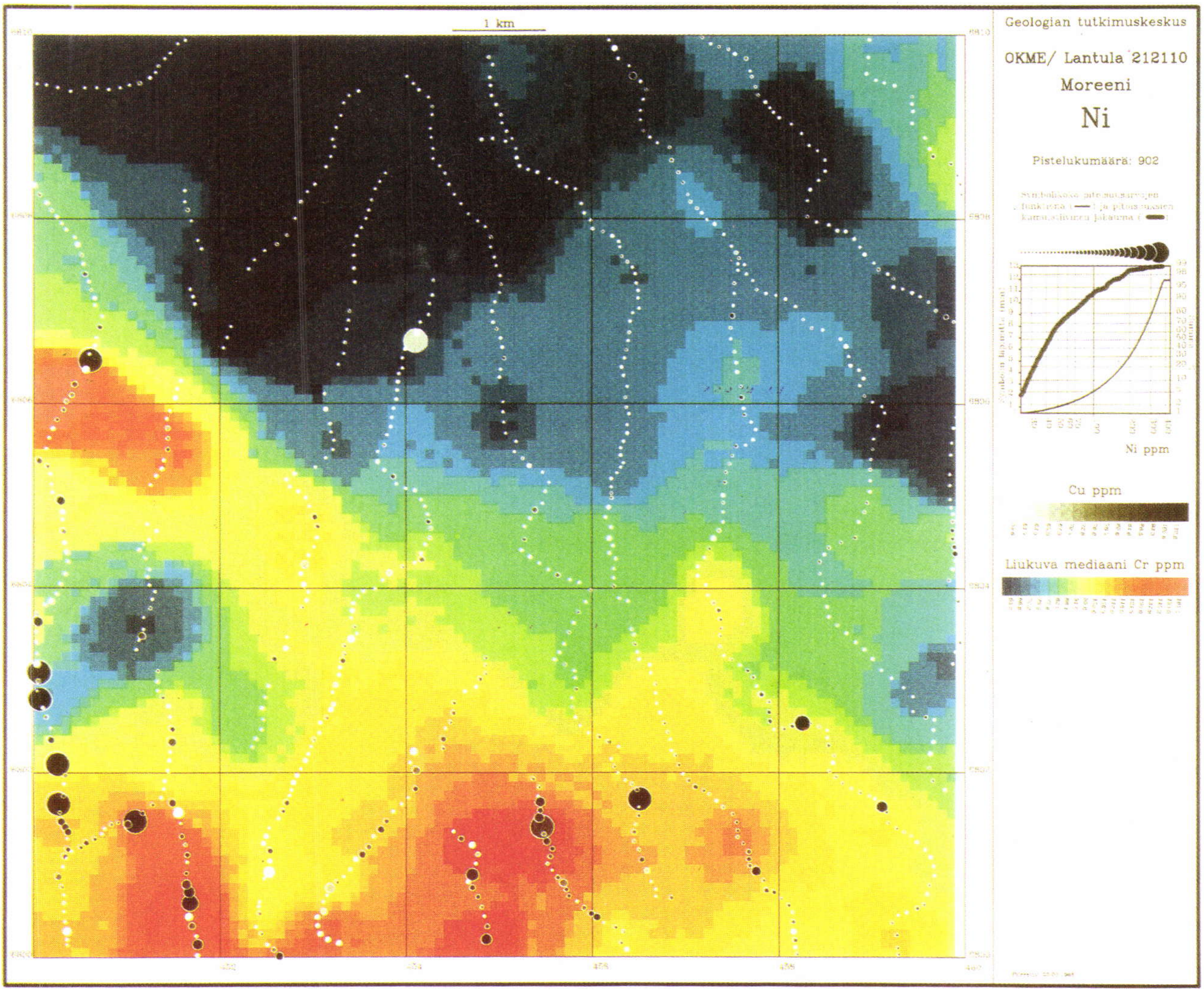


Fig. 1. The geochemical picture in map sheet 2121 10 clearly shows a »block structure». The glaciogenic feature turns out to be slight.

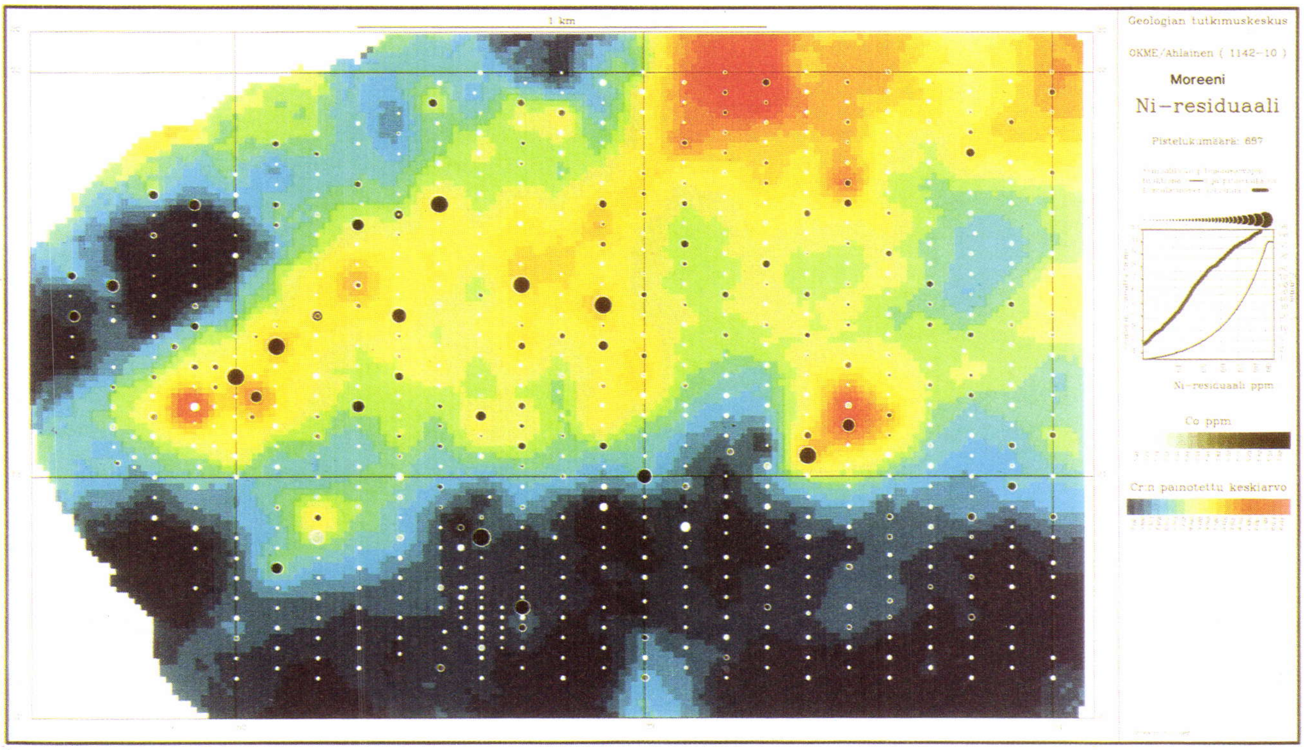


Fig. 2. The contact between the granodiorite (dark) and mica gneiss areas is clearly observable in the detailed geochemical study made of the Ahlainen district. The glaciogenic feature remains weak here too.

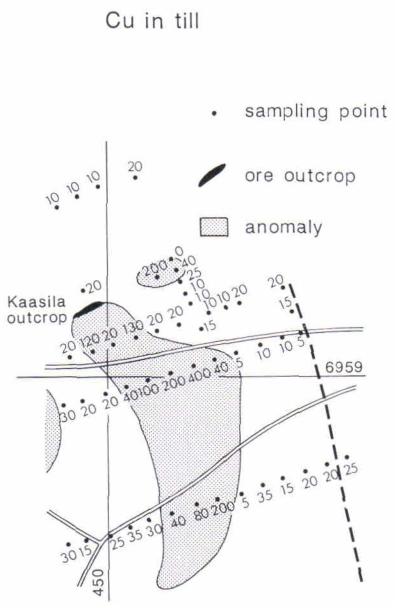


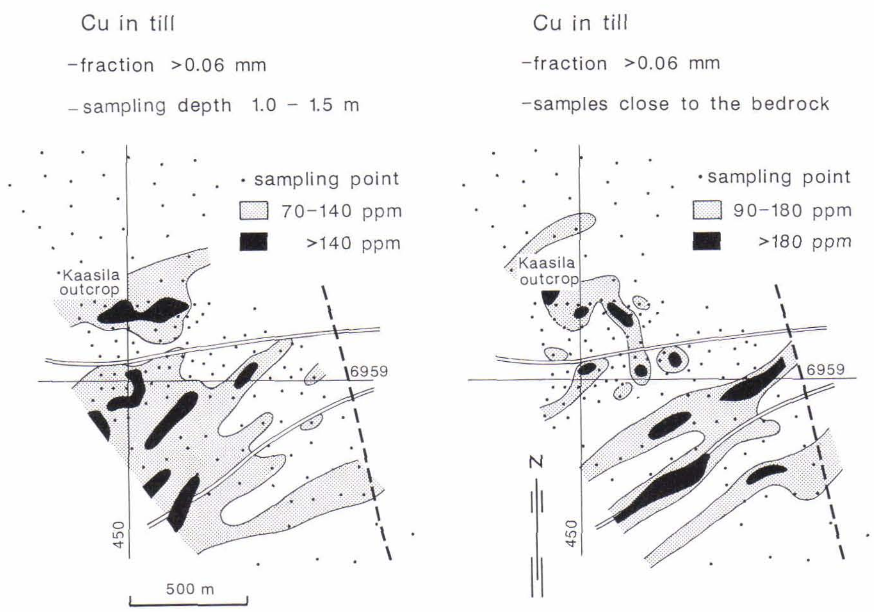
Fig. 3. An old geochemical picture representing the Kaasila area of Outokumpu.

or fracture structure can be observed, one that, however, deviates essentially from the ENE—WSW-trending rock structures and geophysics.

At Alhainen, on the north side of Pori, two intersecting directions of ice flow are known, together with corresponding till beds. Nearly 700 samples have been collected at even intervals in an area of three square kilometres. The geochemical picture thereby obtained would seem to represent the underlying bedrock quite clearly to the extent that it is accurately known (Fig. 2). The contact between the granodiorite and the mica gneiss is seen to be sharp. The chromium and nickel anomaly on the map is rather amoeboid and localized. No distinct glaciogenic feature can really be detected in the anomalies; rather, its measurable effect in the density of sampling points used would appear to be limited to at most 100 meters, possibly even less.

From Kaasila, in the district of Outokumpu, there occurs an old, known geochemical anomaly in the till, in which the glacial transport is plain to be seen (Fig. 3). In later samplings, done from more densely placed points, the Geochemical Department of the Geological Survey has succeeded in dividing the beautiful glaciogenic fan into a number of separate anomalies (Figs. 4—5). On this basis, it appears that the anomalies are caused by the underlying black schist with its high Cu content rather than by an outcropping of Outokumpu ore (Salminen and Hartikainen 1985).

In the foregoing there have been presented some findings based on recent observations. Do these findings mean that the till matrix does not move or that the results of geochemical analyses represent a wholly different measurable phenomenon? Might not the geochemical picture obtained of the anomalies rather represent adsorption or absorption in the interaction between free metal ions and the till matrix and not necessarily actual glaciogenic transport? In any case, it appears as if glaciogenic transport had surprisingly little effect on the till matrix, provided a geochemical picture of the anomalies in glacial till is used as the measuring device.



Figs. 4. and 5. In closer investigations, the uniform anomaly broke up into several different anomalies, the cause of which proved to be the underlying black schist.

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LITHOLOGY OF FINE TILL FRACTIONS IN THE KUHMO GREENSTONE BELT AREA, EASTERN FINLAND

by
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Nevalainen, Raimo, 1989. Lithology of fine till fractions in the Kuhmo greenstone belt area, eastern Finland. *Geological Survey of Finland, Special Paper 7,* 59—65. 4 figures, 2 tables.

The mineralogical composition of basal till and the influence of the Kuhmo greenstone belt upon the homogeneity of the till was investigated from 9 carefully selected samples. From every sample, at least 13 different fractions were analyzed within the sand, silt and clay grain size classes. These results were compared with the results of numerous stone counts done in the area and with the composition and properties of the bedrock. The heavy minerals of the till were also studied.

The results show that the quartz in the till matrix was enriched in the fraction (0.074—0.177 mm), which corresponds to its original grain size in the bedrock. As soft or brittle minerals, the feldspars, amphiboles, micas and serpentines were enriched in smaller fractions than their grain size in the bedrock.

The influence of the local bedrock upon the till material is most clearly shown in the boulder and pebble fractions. As the grain size becomes smaller, the homogeneity of the till increases; the till matrix represents bedrock material from a much wider area than the coarse fractions do.

Besides other things, the differences between various rock types in their resistance to erosion during glacial transport also have an effect on the transport of the rocks as well as on the transport of the till matrix derived from them. The tendency of different minerals to undergo enrichment in certain fractions during glacial transport, because of different tenacity properties, might prove of some importance in prospecting.

Key words: minerals, enrichment, till, grain size, glacial transport, rocks, Kuhmo, Finland

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INTRODUCTION

This study deals with a part of the results of the Kuhmo ore research project, which was carried out in the Department of Geology, University of Oulu. The aim of the Quaternary subproject was to determine the influence of the Kuhmo greenstone belt upon the till material and its geochemistry, and to investigate the glacial stratigraphy and glacial transport distances in the area. The field work was carried out in the summers of 1979 and 1980. The results have been published in several reports and publications (Saarnisto *et al.* 1980, 1981, Saarnisto and Taipale 1984, Nevalainen 1983, Saarnisto and Peltoniemi 1984, Peltoniemi 1985, Taipale *et al.* 1986).

The aim of the present study was to work out the distribution of the rock types and minerals in different fractions of the basal till and to obtain information on the lithological homogeneity of the

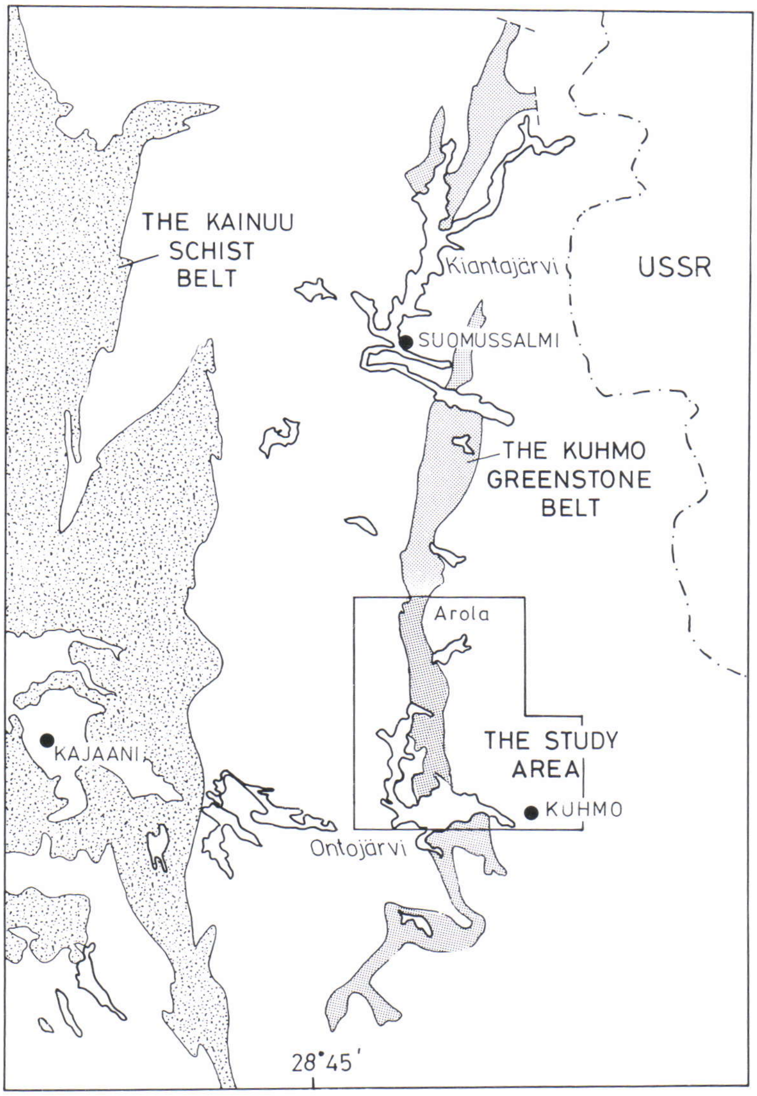


Fig. 1. Index map of the area studied in Kainuu, eastern Finland.

till by comparing the results with the known composition of the bedrock.

The Archaean Kuhmo greenstone belt forms a narrow (mean breadth 5 km) north-south oriented zone some 200 km long, which is composed mainly of mafic and ultramafic rocks, differing markedly from the surrounding granitoids (Fig. 1). The bedrock is well known thanks to extensive mapping carried out over a period of several years (Taipale *et al.* 1983).

The known principal flow directions of the Weichselian ice sheet cross the greenstone belt almost perpendicularly, from WNW to ESE. The area is therefore suitable for studying till transport distances. The stratigraphy consists of two basal till units: the oldest, rarely occurring K-III till and the most widely spread K-II till. In places, the K-II till is overlain by loose surficial till, K-I. The deposits are all sandy and do not markedly differ in grain size, although the K-I till is somewhat coarser than the others on the average and the K-II till is the best sorted.

METHODS OF INVESTIGATION

The field work included a total of 149 excavation pits along five profiles crossing the greenstone belt in the direction of the ice movement.

The distribution of rock types and mineral types in the till and the influence of the greenstone belt upon it were studied from seven samples, which

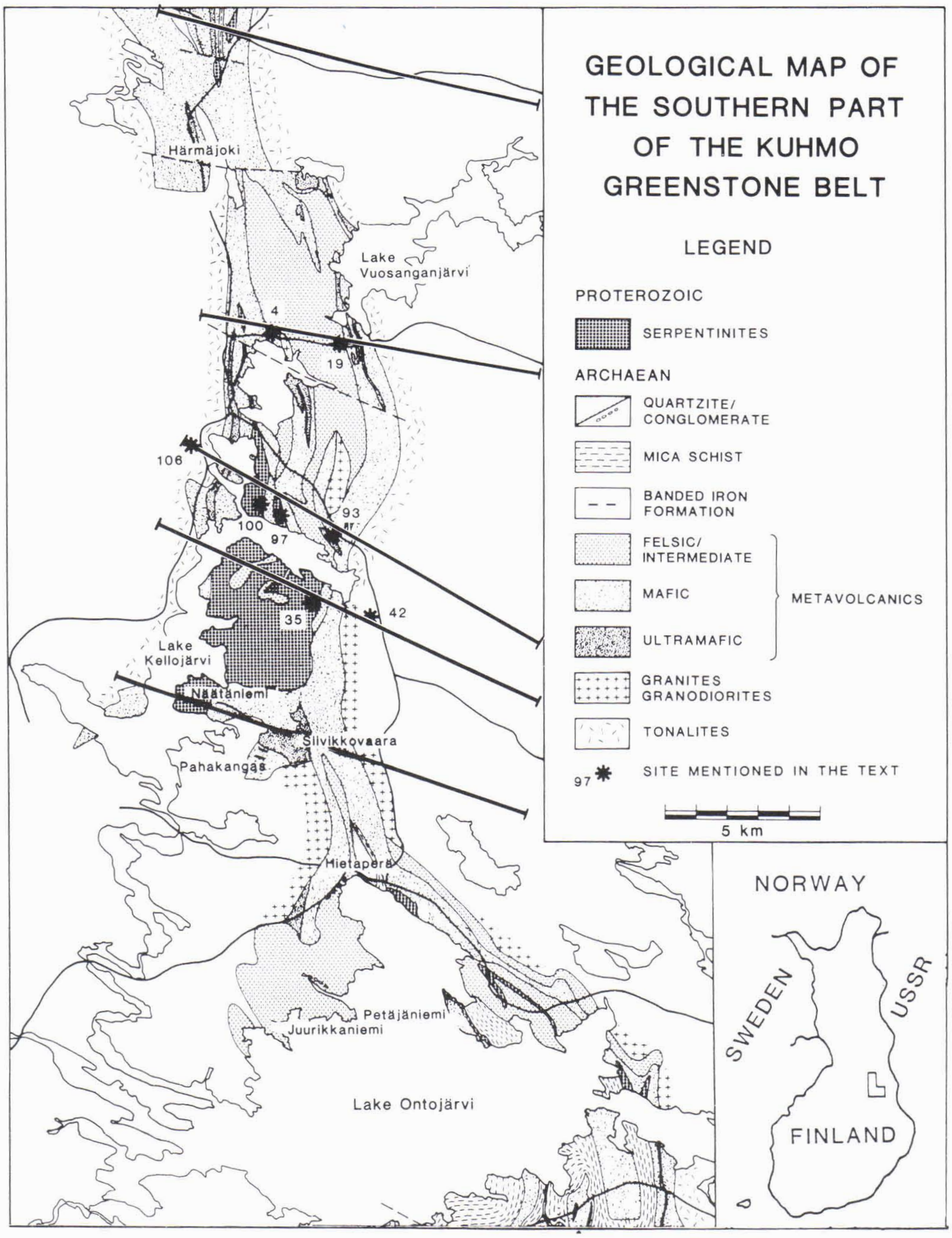


Fig. 2. The area of the Kuhmo greenstone belt studied, showing till sampling transects across the belt and the sites mentioned in the text. The principal ice flow direction was from WNW to ESE.

were carefully selected from areas representing different types of underlying bedrock. All the samples discussed in this paper are from the same till unit (named K-II; see Saarnisto and Peltoniemi 1984). The pits are located in Fig. 2, which also shows the bedrock and the profiles.

From every sample, 16 different fractions were investigated. The stone counts from three fractions, boulders (20—50 cm), cobbles (6—20 cm) and pebbles (2—6 cm) were made in the field. The mineral analyses were made in the laboratory, including 10 or 11 fractions measuring from 4 mm to 0.053 mm. The mineralogical contents of two fractions, silt (0.002—0.02 mm) and clay (less than 0.002 mm) were analyzed by x-ray diffractometry, and the results were interpreted semi-quantitatively (see Lindén 1975).

The results of the stone counts were combined to form eight classes corresponding to the major types of bedrock. Table 1 lists the rock types and the grain size and type of occurrence of the minerals.

The mineralogical analyses were made using a stereomicroscope. The following five main minerals or mineral groups were distinguished: quartz, feldspar (plagioclase and potassium feldspar), mica, hornblende and serpentine. In order to separate the quartz and the feldspar from each other, several samples of the finest fractions were stained after etching with hydrofluoric acid (Bailey and Stevens 1960). Also some thin sections were made from the whole material and from the separated heavy fraction for checking the results. In every sample, 500—1000 grains were identified.

For comparing the mineral analyses with the stone counts the results from last mentioned were computed to mineralogical composition by using the average mineralogical contents of the rock types in the area shown in Table 2 (Nevalainen 1983).

Table 1. The grain size and mode of occurrence of minerals in the rock types in the area studied from numerous thin sections.

Rock types	Main minerals		Grain size (mm)	Mode of occurrence	Texture
Granitoids (granite gneiss and granodiorite)	Quartz	large	0.5—1	Granulated	Main part from quartz as small grains
		small	0.1		
	Plagioclase	large	1—3		Main part of plagioclace as large grains
		small	0.1—0.5		
	Biotite		0.1		
Granite	Quartz	large	0.5—1.5	Granulated	Main part from quartz as large grains, sometimes very large plg-particles
		small	0.1—0.5		
	Potassium feldspar		1		
	Plagioclase		< 1		
Serpentinite	Antigorite		< 1	Conchoidal	Tough
	Magnetite		very small		
Diabases	Hornblende		0.5—2		
	Plagioclase		0.5—2		
Mafic volcanites (metalavas and -tuffs)	Hornblende	Lavas	0.05—0.3	Fibrous	Lavas foliated,
		Tuffs	0.4—0.3	Idiomorphic particles	tuffs bedded and foliated
	Plagioclase		0.01—0.1		
	Epidote		0.4—0.6		
Ultramafic volcanite	Amphibole		0.1—0.8	Fibrous	Foliated
	Chlorite		0.1—0.3		
Felsic volcanite	Quartz		0.1—0.3		Bedded and foliated, sometimes 0.5—2 cm particles of plg
	Plagioclase		0.1—0.3		
	Biotite		0.1—0.3		
	Muscovite		0.1—0.3		
Quartz porphyry	Plagioclase		0.2—0.4		Lightly bedded and foliated
	Quartz		0.2—0.4		
	Potassium feldspar		0.2—0.4		
	Micas				

Table 2. The average mineralogical compositions of the rock types in the area.

Mineral	1	2	3	4	5	6	7	8
Quartz	35.0	37.6	54.9	26.0	1.6	4.2	—	—
Plagioclase	38.0	30.3	8.1	34.3	28.1	20.5	2.4	—
Potassium felspar	3.2	25.9	3.2	1.3	—	—	—	—
Muscovite	1.1	1.7	4.8	23.0	—	—	—	—
Biotite	14.1	3.5	27.5	12.8	2.2	2.4	—	—
Chlorite	—	—	—	2.0	—	—	29.8	—
Hornblende	3.2	—	—	—	56.8	56.4	—	—
Tremolite-actinolite	—	—	—	—	—	—	52.5	—
Serpentine	—	—	—	—	—	—	8.2	76.3
Epidote	1.4	—	—	—	6.7	12.3	—	—
Opaque	—	—	—	0.5	1.7	0.8	2.2	17.5
Others	4.0	1.0	1.5	0.1	2.8	3.4	4.9	6.2

1. Granitoids. Mean value of 21 analysis (Taipale and Tuokko 1981).
2. Granites. Mean value of 11 analysis (Taipale and Tuokko 1981).
3. Mica schists (Saarnisto et al. 1980).
4. Felsic volcanite. Mean value of 6 analysis (Hyppönen 1978).
5. Metadiabase. Mean value of 4 analysis (Hyppönen 1978).
6. Mafic volcanite. Mean value of 8 analysis (Hyppönen 1978).
7. Ultramafic volcanite. Mean value of 3 analysis (Hyppönen 1978, Hanski 1979).
8. Serpentinite. Mean value of 2 analysis (Hyppönen 1978).

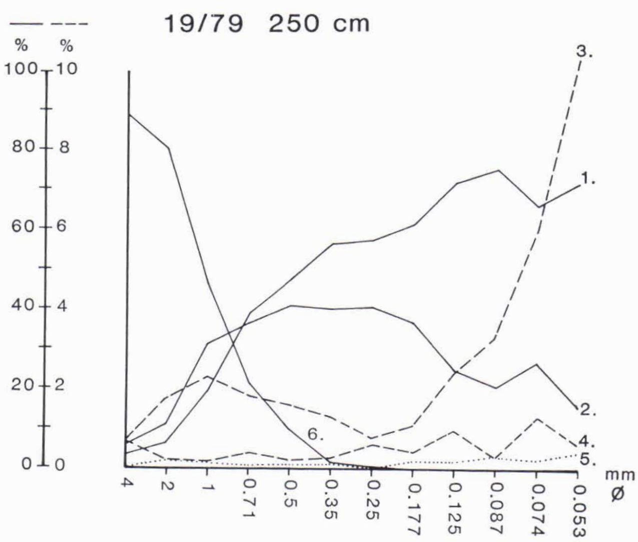
RESULTS

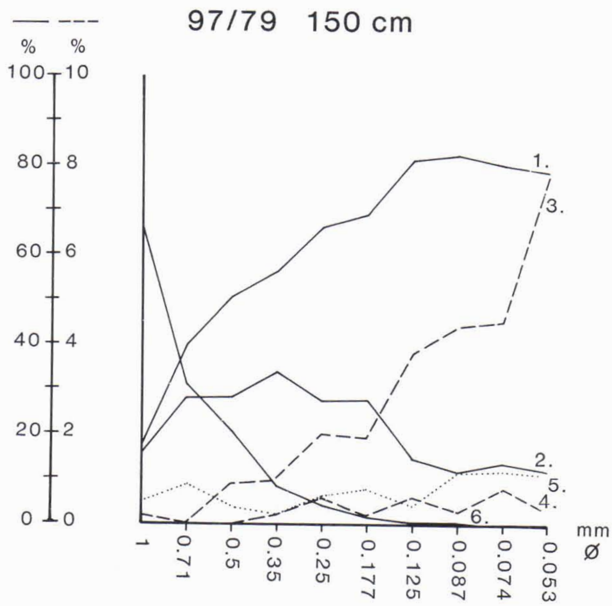
Lithology of different till fractions

Figure 3 represents three samples from the area. Pit 106 is located at the proximal side of the greenstone belt, pit 97 at the middle of the belt in an area of mafic volcanics, and pit 19 at the very distal side of a wide zone of felsic schists and quartz porphyry.

Quartz has been enriched in the 0.074—0.177 mm fraction (Fig. 3), corresponding closely to the size of the quartz grains in the local granitoids. Therefore the quartz in the till is in its »terminal grade» size (Dreimanis and Vagners 1971 a and b).

The feldspars have a bimodal distribution, occurring abundantly in the coarse sand (0.177—0.71 mm, pits 97 and 106 in Fig. 3) as well as in the silt and clay fractions (Fig. 4). The coarser fraction matches the original grain size of the feldspars in the bedrock. The proportion of this fraction in the till fines is higher when the till is of local origin. For example, in pit 19, the influence of the coarse-grained feldspar-rich quartz porphyry bedrock appears as a larger amount of feldspars in the coarse sand fractions. The feldspars, being brittle minerals, were partly comminuted during glacial transport to a finer fraction than their origi-





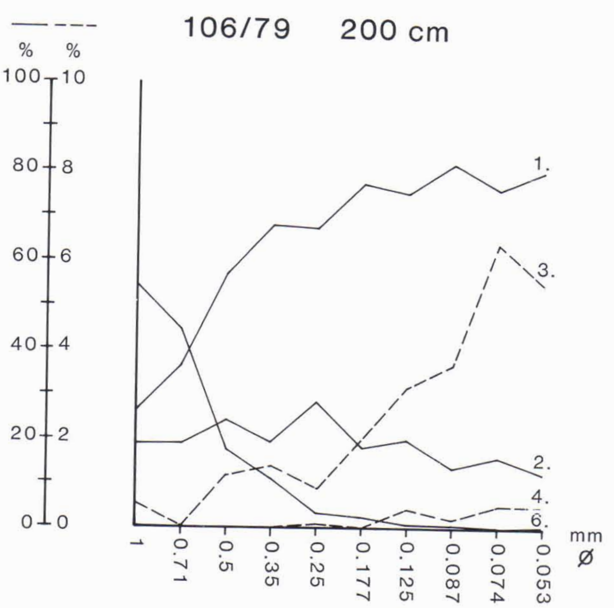
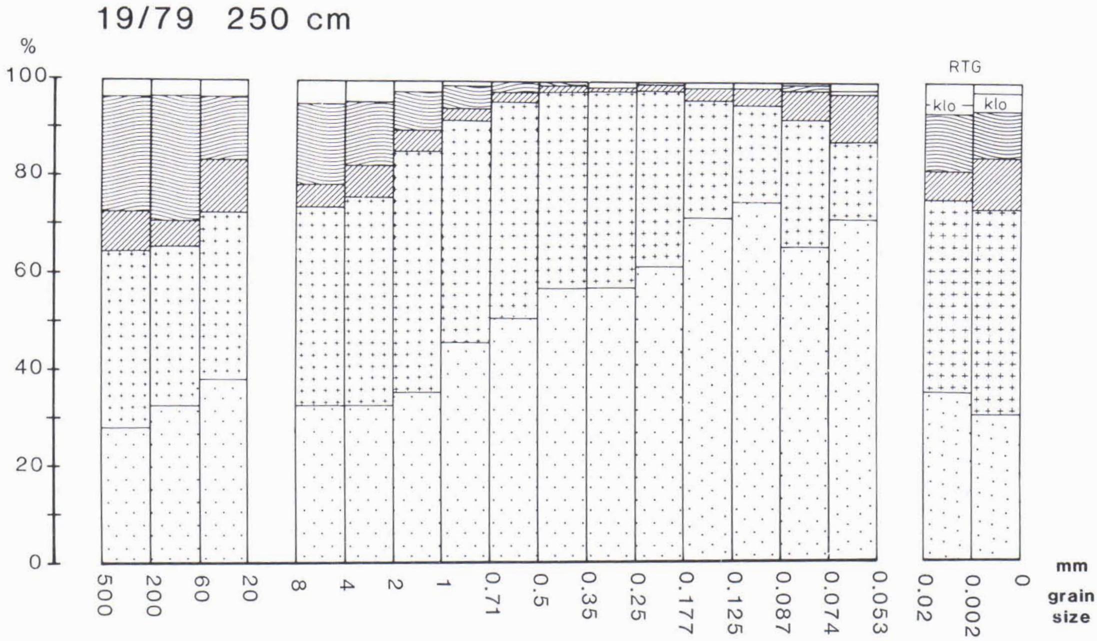


Fig. 3. The results of mineralogical analyses with a stereomicroscope in pits 19, 97 and 106. (1) quartz, (2) feldspars, (3) amphibole (hornblende), (4) micas, (5) serpentine and (6) rock fragments. On the x-axis the grain size, on the y-axis 1., 2. ja 6 from 0 to 100 %; 3., 4. and 5 from 0 to 10 %.


19/79 250 cm
%
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80
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40
20
0
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klo
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mm
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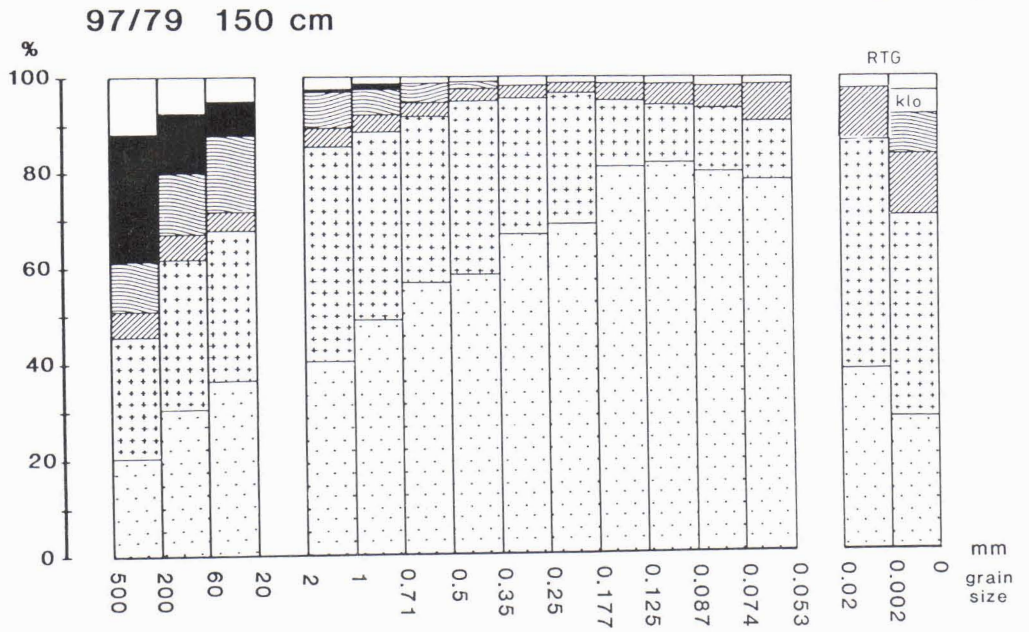
97/79 150 cm
%
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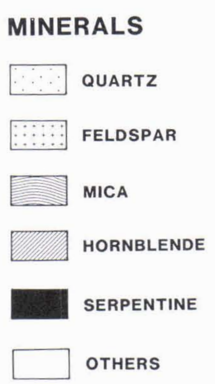
MINERALS
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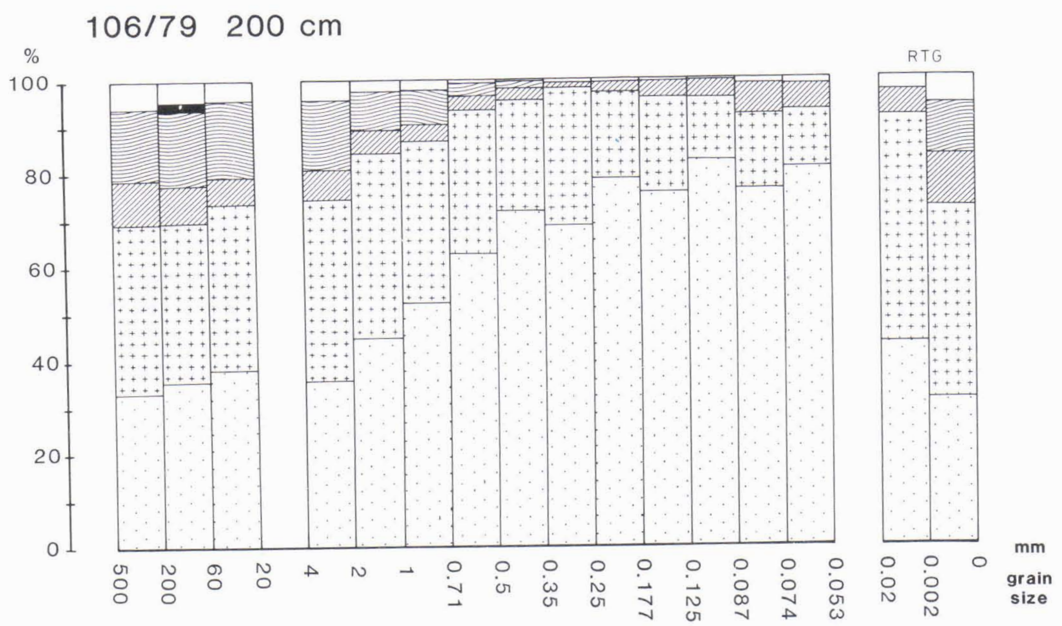
HORNBLENDE
SERPENTINE
OTHERS


106/79 200 cm
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nal grain size would presuppose. Lindén (1975), Haldorsen (1977) and Perttunen (1977) have also noticed that owing to their cleavage, the feldspars are undergoing comminution to fractions smaller than their original grain size.

In addition to the feldspars, other brittle or soft minerals such as amphiboles, micas and serpentine minerals, have also become enriched into finer fractions than their original grain size in bedrock (Fig. 3). The amphiboles have been enriched to 0.053—0.074 mm fractions and, on the other hand, to the clay fraction. Micas occur most abundantly in silt and clay fractions.

In general, it seems quite clear that the most notable differences in the lithology of the different till fractions lie in the boulder and pebble fractions (20—500 mm), which represent the most locally derived material at each site. This is illustrated in Fig. 4, which shows the same pits as Fig. 3. While the boulder fraction (200—500 mm) contains nearly 50 % mafic minerals and the pebble fraction (20—60 mm) as much as 30 % in pit 97, for example, the fines (less than 0.02 mm) contain only 10 %. The composition of the fine fractions seems to be quite similar in every pit investigated. It may be concluded that the material of the till fines represents glacial debris from much wider areas than that of the coarser fractions. This was demonstrated in earlier studies done in Finland (Virkkala 1969, Perttunen 1977) and elsewhere, as for example, in Sweden (Lindén 1975) and North America (Harrison 1960, Dreimanis and Vagners 1971a and b) too.

The lithological fluctuations in the till fines seem, however, to have an effect also on the granulometric properties of the till. In the area of serpentinite rocks, there was more silt and clay material in the till; and in the area of felsic volcanites, there was a larger amount of the fine sand fraction (Nevalainen 1983).

Heavy mineral content of the till

The composition of the heavy minerals in the till was more closely investigated from 24 samples in the 0.053—0.125 mm fraction. The total amount of the heavy fraction (>2.89 g/m^3) was between 8 and 11 per cent in general (boundaries: 6—32 %).

Hornblende was the most abundant heavy mineral, amounting to ca. 70 %. The others were opaque, epidote, tremolite-actinolite, titanite and biotite. No clear influence of the greenstone belt on the amount of heavy minerals could be observed. This is because the hornblende, which was derived from the greenstone belt, has been enriched in a fraction smaller than the one investigated. The amount of tremolite-actinolite, which appears only in the belt, was larger, however, above the greenstones.

It seems obvious that the heavy minerals should always be analyzed in many different fractions owing to their enrichment in certain fractions, as noted earlier.

Till transport and rock types

Till transport in the boulder, cobble and pebble fractions has been studied by Peltoniemi (1985) in the Kuhmo area. When these results and those of the mineral analyses made of different till fractions are examined closely, some general observations concerning the effect of rock types on the transport distances and lithological variations in till matrix can be made.

In the Kuhmo area, the felsic schists are foliated and brittle and therefore could be easily crushed to pebble fractions even during short transport. The granitoids are rather resistive to abrasion but more brittle than the mafic rocks. The tough, massive mafic and ultramafic metavolcanics have been only slightly quarried out of the bedrock; but in the pebble fraction they can be seen to have been transported a great distance. After having reached mineral size, their most common mineral, hornblende, is easily comminuted to a smaller fraction.

Similar conclusions concerning the differences between various rock types during glacial transport have been investigated in the laboratory using crushing, grinding and drilling tests (Niini 1967, Kauranne 1970, Pitkämäki 1973 and Visti 1973).

From the standpoint of exploration, these results are interesting. It is safe to assume that tough and tenacious rock types are transported longer distances in the cobble fraction. By contrast, 'soft' ore minerals like sulfides are comminuted to the finest fractions over short distances. Hard minerals, like oxides, are enriched to their original grain size and transported long distances in this fraction. When trace metals are analyzed, the right fraction should be chosen in every case separately to obtain the best result.

Fig. 4. Mineralogical composition of certain till size fractions in pits 19, 97 and 106. The mineralogical composition of the fractions containing rock fragments is obtained by weighing the average mineralogical composition of each rock type by its value in the stone count and summing the weighted averages. RTG means x-ray diffractometric analysis.

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CHEMICAL COMPOSITION OF THE GARNETS IN GLACIOFLUVIAL DEPOSITS AND TRACING THE SOURCE AREAS

by
Kalevi Korsman and Marjatta Perttunen

Korsman, Kalevi and Perttunen, Marjatta, 1989. Chemical composition of the garnets in glaciofluvial deposits and tracing the source areas. *Geological Survey of Finland, Special Paper 7,* 67—72. 7 figures, 1 table.

Since the composition of garnet is bound to the total composition of the bedrock and depends on the variations in the crystallization conditions, it is possible to determine by means of the chemical composition of the garnets the bedrock source areas of placer garnets. In the light of the present investigation, especially the iron, magnesium and manganese contents of the garnet provide clues to the original source of the garnets contained in the eskers. An interesting group is formed by the highly manganese-bearing garnets, which are generally met with in association with certain sulfide ores but which, however, are not known to occur in the area investigated.

The transport distances of garnets have been studied in the eskers of southeastern Finland. Basically, the percentual content of garnets decreases as the transport distance increases. In the area within Salpausselkä II moraine, the greatest abundance of garnets occurs at a distance of 8 km from the source area. The amount of garnets is at first small between Salpausselkä I and Salpausselkä II moraines, but it surprisingly increases at a greater distance from the source area. Garnets are met with abundantly even in the eskers downstream from Salpausselkä I moraine. The occurrence of deviating garnets has been investigated on the basis of its chemical composition, and a large part of it has been observed to have traveled quite a long distance.

Key words: provenance, garnet group, chemical composition, eskers, glacial transport, Quaternary, southeastern Finland

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INTRODUCTION

Almandine-pyrope or iron-magnesium garnet is often met with in the metapelites of southern Finland. The composition of the garnet depends on the composition and crystallization conditions of the bedrock. The pyrope content of Archean garnet is apt to rise to 50 per cent by weight, while the pyrope content of the garnet contained in Proterozoic granulites that crystallized under considerably lower pressure does not exceed 35%. In the zonally metamorphosed Rantasalmi—Sulkava area, the pyrope content of the garnet increases 10—25% as the degree of metamorphism rises. In the proximity of sulfide ores, where the total composition of the rock may have become enriched with manganese, the manganese content of the garnet also rises exceptionally high (Korsman 1984, Paavola 1986, and Pajunen 1988).

On the basis of the foregoing, the composition of garnet reflects faithfully the composition of the bedrock and variations in the crystallization conditions. Accordingly, the composition of the garnet can be made use of tracing the source areas. One of the objectives of the present study has been to ascertain the transport distances of esker sediments by means of the composition of the garnet. The investigation was carried out by studying the eskers and Salpausselkä moraines in the rapakivi granite region, in southeastern Finland. The rapakivi granite itself contains no garnets, which occur, however, abundantly in surrounding rocks.

THE CHEMICAL COMPOSITION OF GARNETS IN BEDROCK

The Precambrian bedrock of the region studied consists mainly of Viipuri rapakivi granite and metapelites, which are migmatitic and in many cases garnet-bearing. The metapelites are comparable to the rocks of the biotite-garnet-cordierite-sillimanite zone in the Rantasalmi—Sulkava area (Korsman 1984). Also the composition of the garnet of the metapelites corresponds to the composition of the garnet of this zone. The sampling points are marked on the geological map in Fig. 1 and the chemical compositions of the garnets are presented in Table 1. Another garnet-bearing rock in the study area is the Mäntyharju granite located in the western part (Fig. 1).

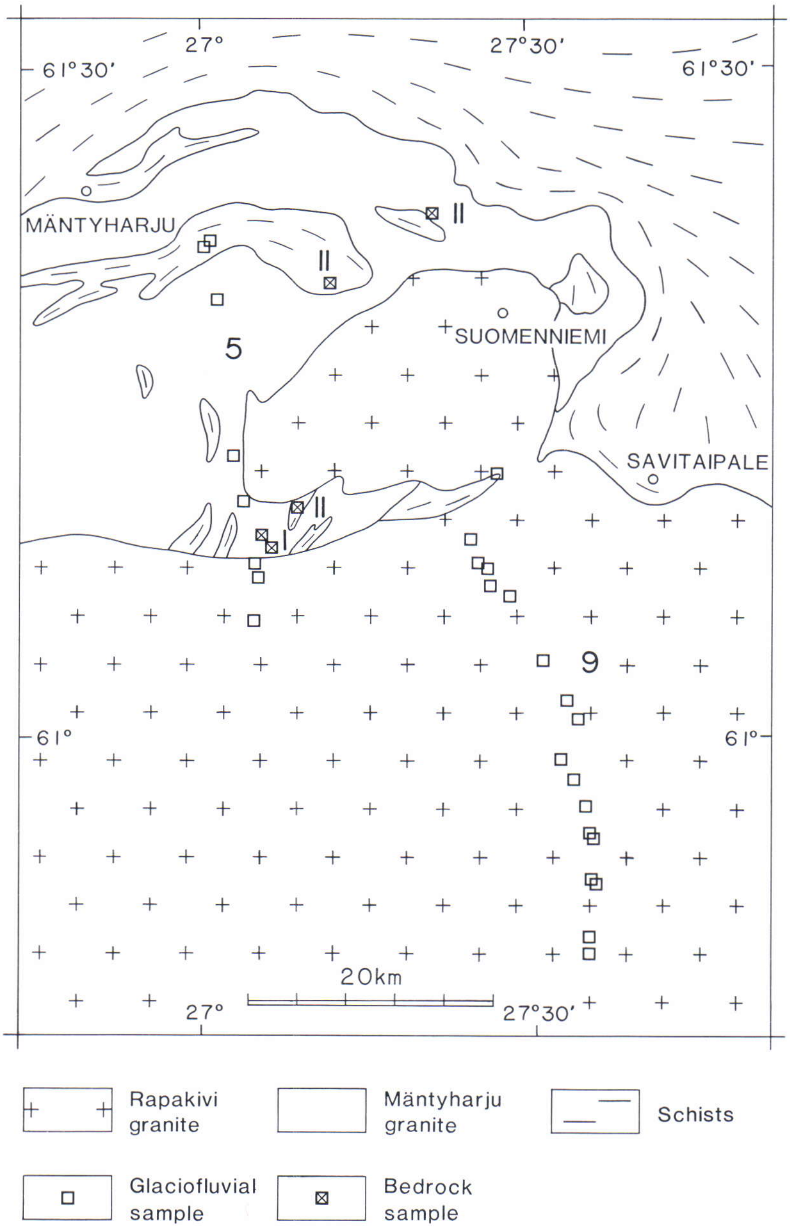

Fig. 1. Simplified geological map of the area studied showing the sampling points — open squares representing the eskers and the crosslets the bedrock.

Table 1. Compositions of bedrock garnets.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	36.40	36.10	37.50	37.30	36.60	36.60	37.50	36.90	37.00	36.90	36.70	35.70	36.60	36.50	36.60
TiO_2	0.00	0.02	0.02	0.04	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.02	0.00	0.01	0.01
Al_2O_3	20.90	20.90	21.10	21.50	21.40	21.10	21.60	21.20	20.80	20.90	21.50	20.50	20.60	21.10	21.20
FeO	35.50	36.00	35.20	35.70	35.70	36.40	36.50	35.60	39.20	39.70	37.80	38.70	39.30	37.00	39.80
MnO	0.56	0.58	0.40	0.52	0.62	0.75	1.09	0.86	0.22	0.50	0.51	1.05	1.00	0.91	0.86
MgO	4.25	4.62	5.35	4.60	3.76	3.59	3.88	4.67	2.34	1.85	2.14	1.59	2.28	2.44	1.86
CaO	0.74	0.71	0.73	0.69	0.67	0.68	0.89	0.89	0.61	0.57	0.62	0.67	0.59	0.47	0.47
Na_2O	0.03	0.03	0.02	0.03	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.03	0.00
K_2O	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00
	98.38	98.97	100.32	100.39	98.80	99.13	101.47	100.15	100.19	100.43	99.27	98.28	100.40	98.47	100.80

Samples 1 - 8: metapelites; 9 - 15: granites.

The microprobe analyses were made by Mr. Bo Johanson, B.Sc., Geological Survey of Finland, Ore Department.

The Fe/Mg ratio of the garnet contained in the granite is markedly lower than the corresponding ratio of the garnets contained in the metapelites. In the light of the analytic results, the composition of the garnet is divided into two different groups (Fig. 2). The manganese content of the garnet in both rocks is small, almost invariably about one per cent.

The composition of the garnets was examined along two glaciofluvial Traverses, both of which have their own special features. Traverse 5 cuts across the garnet-bearing granite of Mäntyharju; and along Traverse 9, the garnet content was observed to increase between the Salpausselkä moraines and downstream from Salpausselkä I.

On the basis of the composition, 54% of the garnets of Traverse 5 derived from local metapelites (Fig. 3). Although the Traverse is situated almost entirely on Mäntyharju granite, only six per cent of the granitic garnets were found in the eskers. Of the garnets occurring along the Traverse, 40% have originated from an unknown source area. The manganese content of the garnets happens to be exceptionally high.

In the northern part, 70% of the garnets along Traverse 9 have a composition corresponding to that of the garnets analyzed from the bedrock; but in the southern part of the Traverse, only 37—47% of the garnets correspond in composition to the garnets of the bedrock (Fig. 4). Both the manganese and the magnesium contents of the exceptional garnets are high.

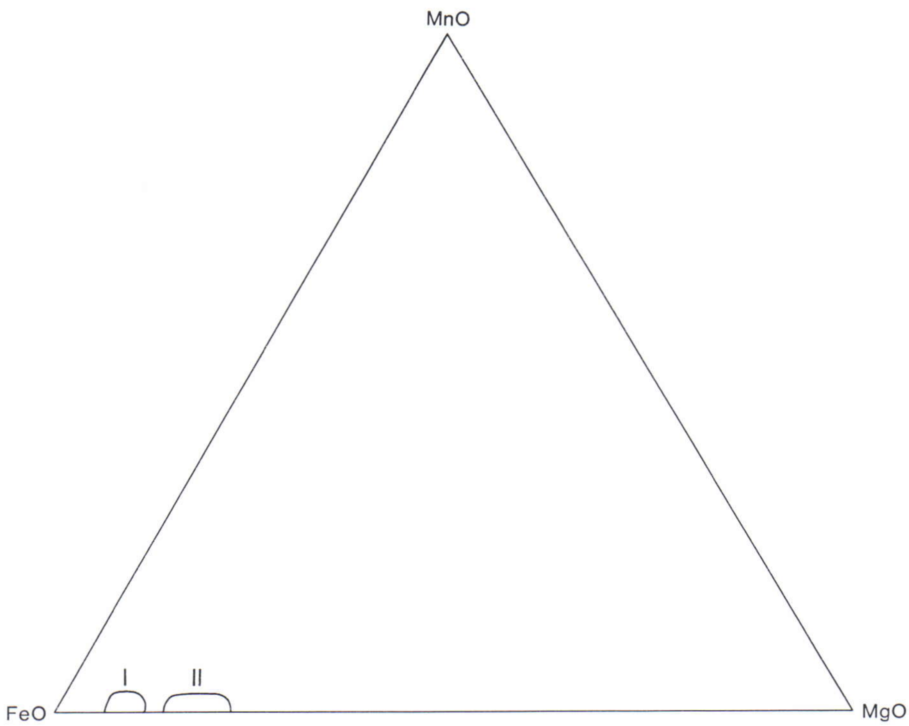

Fig. 2. The MnO, MgO and FeO contents of the garnets analyzed from the bedrock as mole percentages. I. Mäntyharju granite. II. Metapelite.

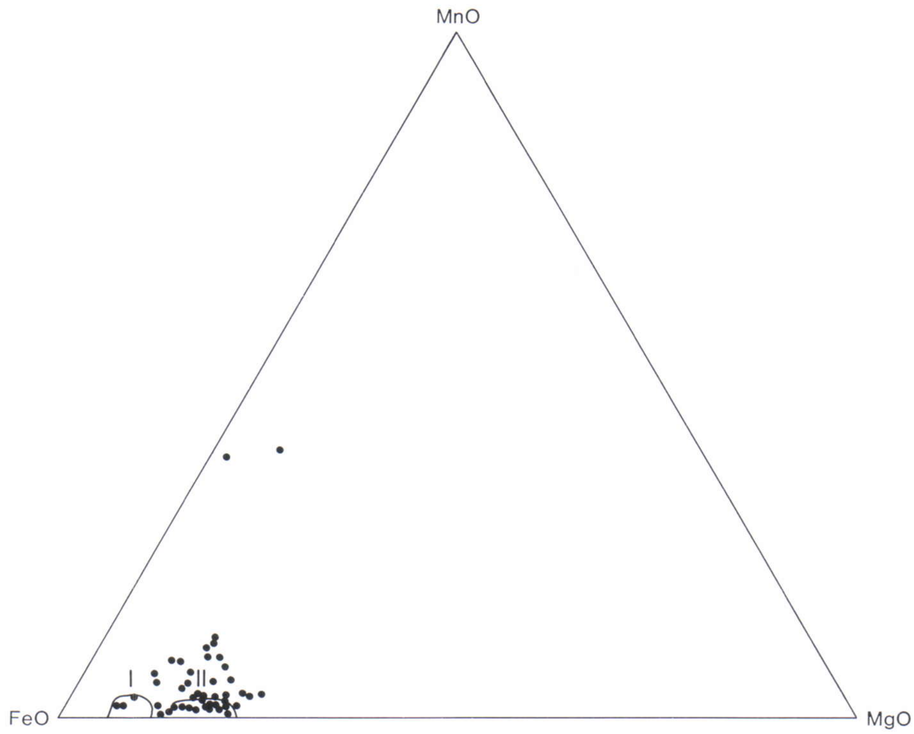

Fig. 3. MnO, MgO and FeO contents of garnets analyzed from esker material along Traverse 5 and corresponding contents analyzed bedrock, the symbols of which are as in Fig. 2.

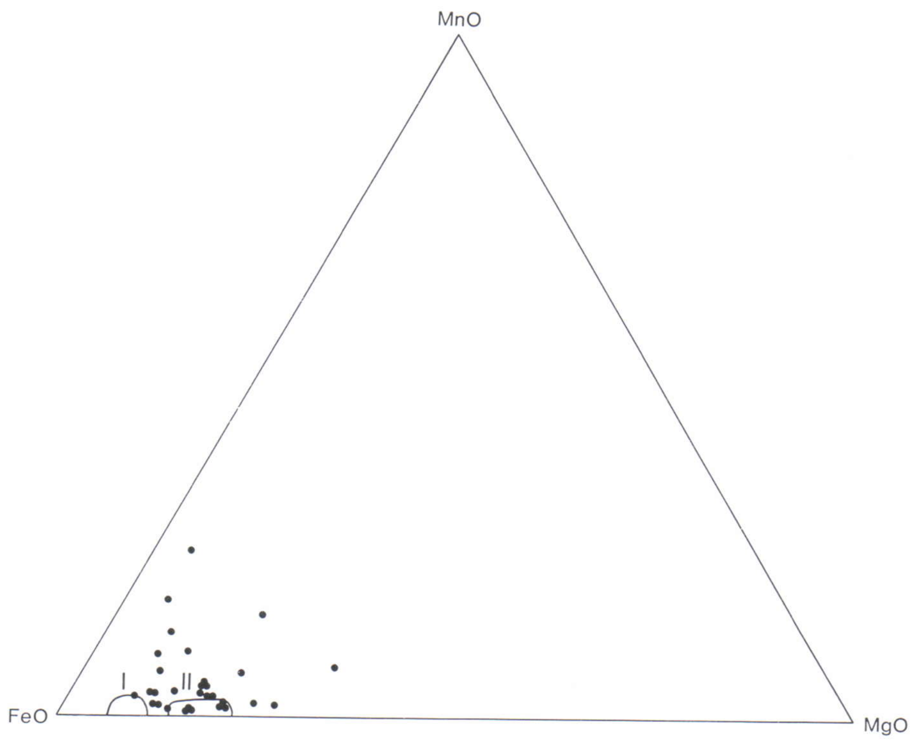

Fig. 4. MnO, MgO and FeO contents of garnets analyzed from esker sediments along Traverse 9 and corresponding contents of garnets analyzed from bedrock, the symbols of which are as in Fig. 2.

GARNETS IN THE ESKERS

The highest garnet contents are met with in the metapelite or source-area eskers (Fig. 5). The amounts measured vary markedly, ranging from 0.3 to 40%, depending on how much garnet is contained locally in the bedrock of the source area. Another factor determining the amounts of gar-

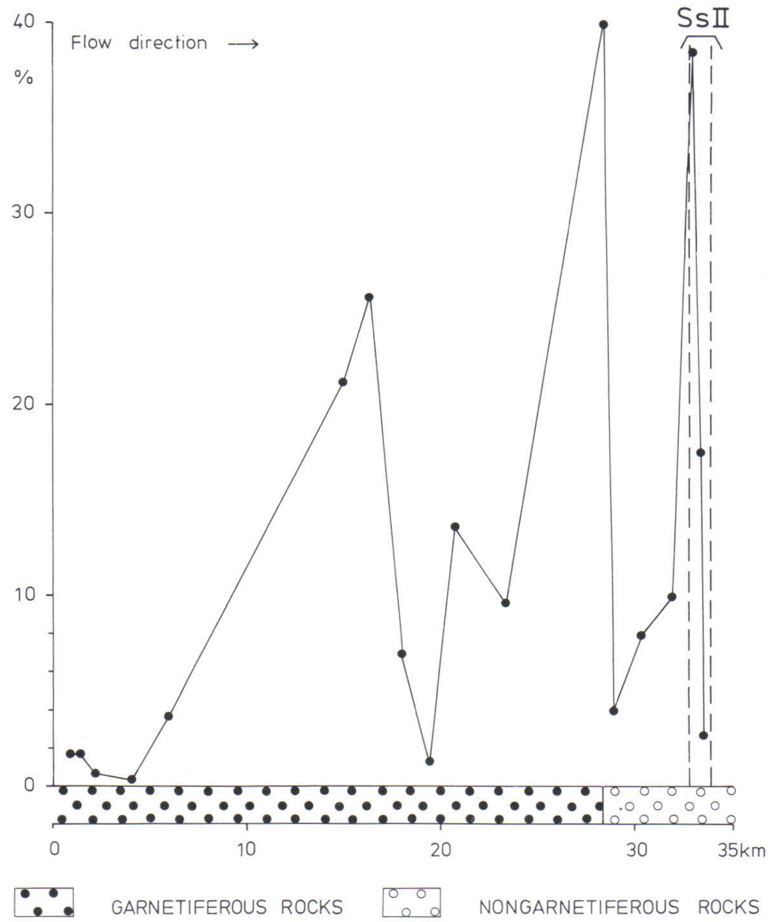

Fig. 5. Garnet contents in eskers and Salpausselkä moraines along Traverse 5.

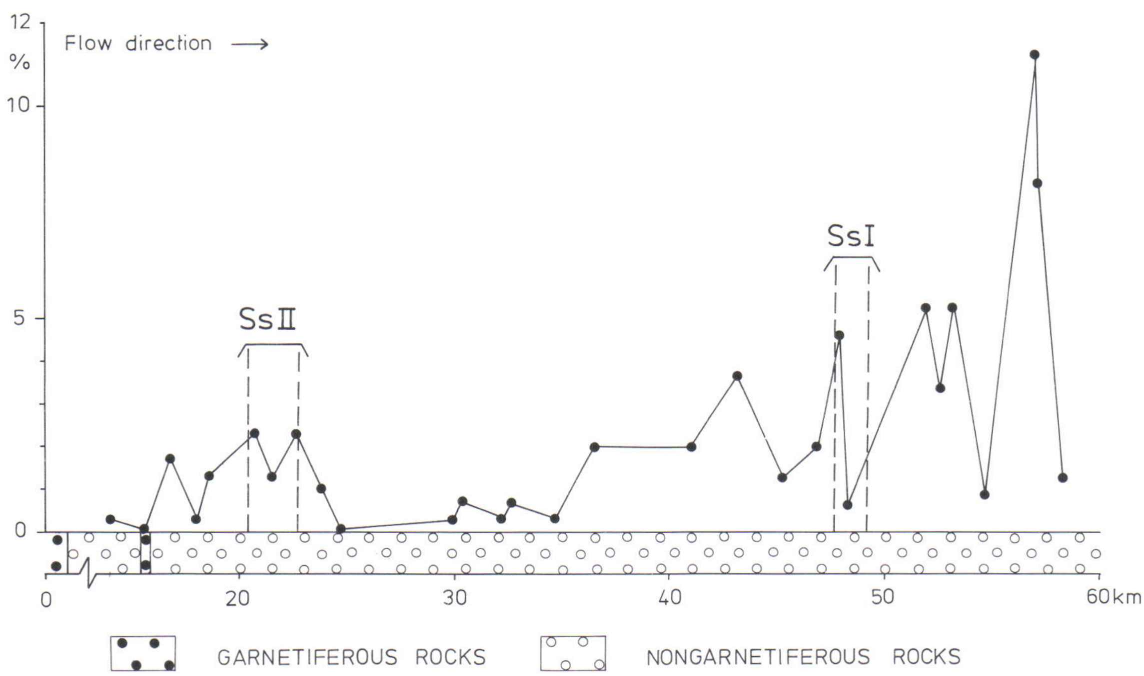

Fig. 6. Garnet contents in eskers and Salpausselkä moraines along Traverse 9.

nets was the behavior of the glaciofluvial streams — for depending on the rhythm of melting during deglaciation; the volume of water and the rate of flow varied considerably (Perttunen 1989).

In Salpausselkä II, there is a maximum, which finds its explanation in the sorting that took place in the deposition of sediments over a long period during the stagnant stage of the Weichselian ice sheet. It is noteworthy that also low contents occur. Along Traverse 9 between the two Salpausselkä moraines, the garnet content rises even though the distance from the source area increases (Fig. 6). The content rises downstream from the delta which formed during the brief stagnation of the Weichselian ice sheet. Downstream from Salpausselkä I, the garnet contents are still high.

CONCLUSIONS

Of the garnets occurring in the northern part of Traverse 5 and Traverse 9, between 60 and 70 per cent might have derived from fairly local bedrock, whereas garnets met with in the southern part of Traverse 9, only 37—74% correspond to the bedrock garnets. Moreover, the sampling sites in the southern part of Traverse 9 are located at a distance of some 40 km from the closest possible garnet-bearing bedrock source areas, that is, considerably farther away than the rest of the sampling sites (Fig. 1). Inasmuch as the amount of garnet in the southern part of the Traverse is exceptionally high, the observation supports the view of the esker sediments having been transported over a long distance in many phases. The proportion of englacial drift is presumably high.

Along both traverses the amounts of manganese-bearing garnets are notable. This observation is surprising, for the metapelite areas situated close to rapakivi granite are migmatitized and highly metamorphosed, and garnets with high manganese contents have not generally been met with in such areas. Manganese-bearing garnets are apt to be found closest to the region studied in the so-called Kiuruvesi—Haukivesi zone, the southern margin of which is located about 80 km from the northern rapakivi granite boundary (Fig. 7). Also the pyrope content of certain esker sediments is exceptionally high. Similar garnets have been met with in the Kiuruvesi—Haukivesi zone. The manganese content of the garnets in particular is so high that in future studies the effect of solutions moving in eskers on the composition of the garnets should be noted more closely than ever.

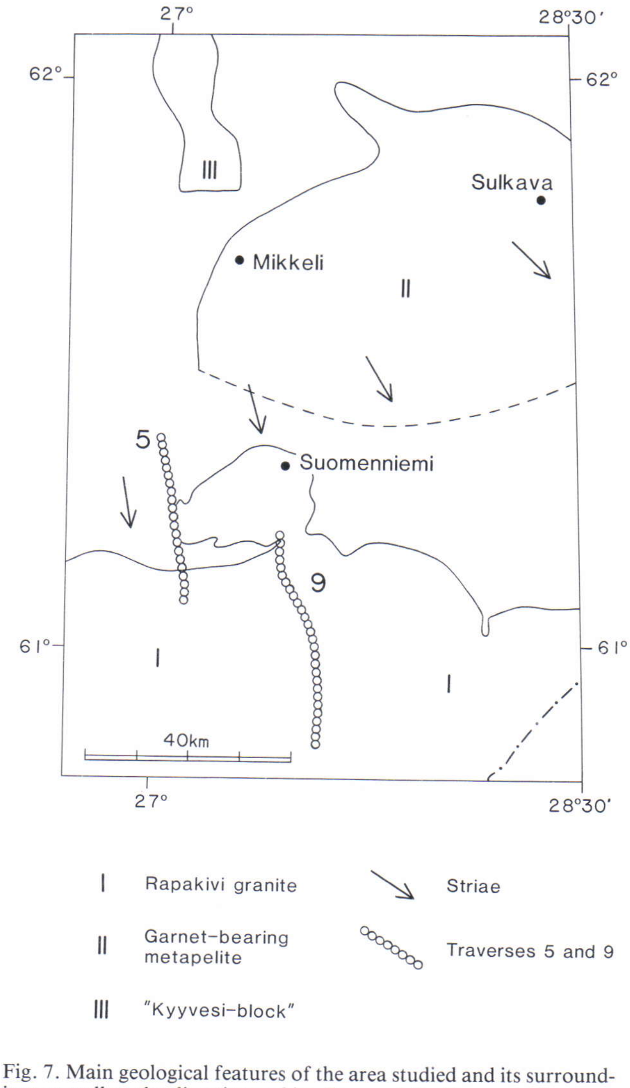

Fig. 7. Main geological features of the area studied and its surroundings as well as the directions of ice flow and the Traverses for sampling glaciofluvial sediments.

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GEORADAR — AN EFFECTIVE WAY TO OBTAIN INFORMATION ABOUT THE SURFICIAL DEPOSITS

by
Pekka Hänninen

Hänninen, Pekka, 1989. Georadar — an effective way to obtain information about the surficial deposits. *Geological Survey of Finland, Special Paper 7,* 73—74. One figure, 1 table.

Georadar is an efficient tool for Quaternary geologists. It is a cheap method to find the best places for drilling and the application of other geophysical procedures. It also gives a comprehensive picture of the structure of surficial deposits. Only conductive deposits (such as clays) are impossible to examine by georadar. In sandy materials, the penetration reaches over thirty meters (in bedrock, even more).

Key words: sediments, surficial geology, radar methods, Quaternary

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Actually, georadar is not a new system. The first measurements applying this kind of method were done about sixty years ago. But much progress has been made in developing instruments, and as a result we can say a new effective system for the examination of Quaternary deposits is now available to us (e.g. Annan & Davis 1977, Ulriksen 1982).

Georadar is an electric geophysical method, which transmits 80—1000 MHz pulses into the ground and receives the part of the signal that has been reflected from some electrical boundary situated in the ground. With the georadar system, we measure only the time of reflection and the strength of the reflected pulse. It is impossible to do an interpretation on the basis of these values, because the sediment structure is an unknown value. But georadar transmits and receives pulses so often that, generally speaking, we obtain a continuous profile of the electrical properties of the overburden.

Different types of surficial deposits produce dissimilar profiles. Generally speaking, in sandy deposits we have clear boundaries and the structure of the deposits can be visualized. In gravel and till deposits, the profiles are not distinct, and they appear highly similar. The interpretation of different deposits must proceed indirectly by the application of geological knowledge.

Generally, the ground-water table constitutes one of the clearest electrical boundaries in Quaternary deposits. It can be perceived as a 'mirror image' of the topography passing through other boundaries.

The velocity of electrical waves depends on the water content of the sediments. If the velocity is known it is easy to calculate the thickness of different sediment layers.

$$S = t * 0.3 / 2 * e_r^{1/2} \quad (1)$$

, where S = thickness
t = time between two boundaries in nanoseconds
e_r = dielectrical constant of the sediment level

Because the whole time scale of our profile is known, this function is modified to

$$S = 0.3 * x * t / 2 * h * e_r^{1/2} \quad (2)$$
$$x = 2 * h * S * e_r^{1/2} / 0.3 * t \quad (3)$$
$$e_r = (0.3 * x * t / 2 * h * S)^2 \quad (4)$$

, where S = thickness in meters
t = the whole time scale of the profile
x = the thickness of the level in the profile in mm
h = the total height of the profile
e_r = dielectrical constant of the sediment layer level

By applying function two, it is possible to calculate the thickness of any given layer in meters. If the thickness of the layer is known, function three can be used to find the boundary in the profile. If we know the boundary and the thickness, we can calculate the e_r value, with which the sediment type can be classified.

In dry materials, the e_r value is nearly a constant. We can say it is four, and it depends of the water content of the layer. Because of the use of the square root of e_r, the velocity of the electrical wave changes rapidly in low e_r values. For instance, e_r four changed to e_r sixteen halves the velocity, but a change from e_r 36 to 49 reduces the velocity only 18 per cent So values given in Table 1 are only for primary interpretation (see also Fig. 1).

Table 1. The e_r values and velocities of some of the most common sediments.

Type of sediment	e_r	velocity m/10ns
Air	1	3.0
Dry gravel	4	1.5
Wet gravel	16	0.75
Dry sand	4	1.6
Wet sand	25	0.6
Peat	64	0.37
Till	9—36	1—0.5
Fine sediments	9—49	1—0.43

easiest places to secure the information and when this has been obtained it is possible to follow the levels for considerable distances on the profile, and to get a good picture of the sediment structure. Especially in sandy areas, the whole depositional mechanism can be visualized.

Because of its electrical pulse, radar cannot be used to investigate conductive materials. As Fig. 1 shows, almost all the clays are excessively conductive; also some fine sediments and tills are in the bad sector of the picture.

To summarize: It might first be pointed out that the geologist in charge of a research project should always be present when georadar is used. This is bound to help him understand the profiles better.

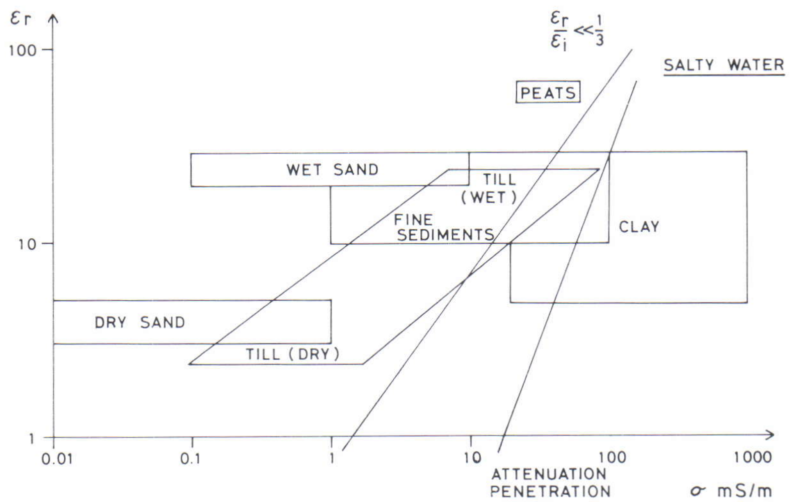

Fig. 1. The conductivity and dielectrical values of different sediment types. In the area to the left of line one, georadar is effective. To the right of line two, it is ineffective.

As in the case of every geophysical method, it is not possible to give exact values to different sediment types; for this reason, other data must be available for application together with the radar profile. But what is important, one can choose the

In the second place, the level of the interpretation desired should be decided upon. If exact data are needed, one should be prepared to do some drilling or seismic soundings in places selected from the radar profile.

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