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On the geochemistry of copper in the Quaternary deposits in the Kiihtelysvaara area, North Karelia, Finland

by Reijo Salminen

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ON THE GEOCHEMISTRY OF COPPER IN THE QUATERNARY DEPOSITS IN THE KIIHTELYSVAARA AREA, NORTH KARELIA, FINLAND

BY

REIJO SALMINEN

with 25 figures and 8 tables in the text

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The bedrock in the Kiihtelysvaara map-sheet (4241) area (1200 km^2) is composed of rocks of the Presvecokarelidic basement gneiss complex and younger Karelian schists, both of which show copper mineralizations. The predominant soil type is basal till with some glaciofluvial sediments in the zone of the marginal Salpausselkä formations.

Altogether 628 rock samples, 11911 soil samples, 125 samples from weathered bedrock, 6391 stream sediment samples and 177 lake sediment samples were collected from the area. The rock and soil samples were assayed by optical emission quantometer and to some extent by AAS. The stream sediment and lake sediment samples were analysed by AAS.

The liberation of copper from rock to the < 0.064 mm till fraction during glaciation depends on the mineral composition and grain size of the rocks. The copper content in the < 0.064 mm fraction of sorted soil is directly proportional to grain size. The transport distance of the fraction assayed geochemical is important for the interpretation of geochemical data; the areal differences must also be considered. The stratigraphy and source of till can be studied by geochemical methods with the aid of the polymetal ratios relevant to each target. Likewise the metal anomalies in soil that derives from different rock types can be distinguished from each other.

When the geochemical soil studies are applied to exploration, the target must be carefully outlined utilizing Quaternary geological, lithological and geophysical information. In explorational geochemical soil survey the best results are obtained if methods based on different sample types are joined appropriately.

Key words: geochemistry, copper, methods, geochemical prospecting, soil sampling, till, stream sediments, lacustrine sediments, bedrock, glacial transport, Quaternary, Kiihtelysvaara, Finland.

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GENERAL

Previous investigations

Geochemical soil studies and the application of the results to exploration are nothing new. According to Kauranne (1958 a), as early as 1887 Hj. Lundbohm published a study on the floats in a limestone area and the Ca concentration in the fine fraction of till. Nevertheless, the effective use of the method did not become feasible until the 1950s and 1960s when intense development in sampling and analytical methods and in equipment coincided with rapid progress in automatic data processing. Hence it is now possible to analyse vast numbers of samples vital for geochemical survey and to carry out the statistical processing of the accumulating analytical data without delay and at low cost.

Explorational methods based on the assaying of samples collected from the soil and living organisms have proved their value in areas where the soil is composed of *in situ* weathered crust, since direct indications are obtained from suboutcrops of ores (e.g. Hawkes and Webb 1962). In glaciated terrain, however, the application of these methods is considerably more complicated, because the soil is not local and the substances derived from the bedrock are intermixed; the metal concentration deriving from the ore suboutcrop has been diluted and the distance covered by the material transported by the glacier may differ notably between layers and areas.

As an explorational method, geochemical soil studies in glaciated terrain are based on the fact that, owing to its mode of formation, till contains ore mineral grains even in its finest fractions in the same way as ore boulders are encountered among other boulders.

Geochemical soil studies have been conducted since the 1930s when Goldscmidt (1934) and Brundin (1939) published their results. Geochemical studies on till became established as an explorational method in the 1950s. The method was applied in Finland by Tavela (1957) in connection with exploration at Kiiminki, Paltamo, Kontiolahti and elsewhere. At the same time Kauranne (1958 b) and Hyvärinen (1958) combined geochemical prospecting methods with studies on the molybdenite mineralizations at Rautio and Ylitornio and on the Korsnäs lead-ore deposit. Earlier than that Kauranne (1951 and 1956) had conducted preliminary studies on the feasibility of the method in the environment of the Outokumpu copper mine and the Makola nickel mine.

The popularity of the method grew in the 1960s when Wennervirta (1968) developed statistical methods for treating the analytical data and established the use of automatic data processing as the basis of handling the results. Somewhat later Nurmi (1976) developed the simultaneous use of different analytical methods for interpreting the results.

At the same time geochemical till studies got under way in Canada (Dreimanis 1960) and in the U.S.S.R. (Ginzburg 1960). In Canada the application of the method has progressed in same way as in Finland (e.g. Schilts 1971,1973). In the U.S.S.R., however, emphasis has been on the geochemistry of the bedrock; the soil has been of a subordinate importance (Beus and Grigorian 1977).

Even before geochemical till studies had been applied to exploration, experiments had been made on organic materials to localize ore mineralizations. One of the first studies in this line was that by Rankama (1940) on the content of nickel in birch leaves in the environment of the Makola and Petsamo nickel deposits. At the same time experiments were conducted in Norway (Goldschmidt 1934; Vogt 1939, 1942 a, 1942 b; Vogt and Braadlie 1942) and in U.S.S.R. (Vinogradov 1943).

The geochemistry of peat was later studied successfully by Salmi (1950, 1955 and 1956). Since then various biogeochemical methods have been tested extensively, e.g. by Marmo (1953, 1958), who studied the molybdenum concentration in wild rosemary, and by Björklund (1971), who investigated the lead concentration in birch leaves at Korsnäs. A number of studies have been carried out to clarify how metal concentrations in humus reflect the underlying bedrock (Kauranne *et al.* 1961; Cannon 1964; Nicolas and Brooks 1969; Kovalevskiy 1976; Kokkola 1977; Nuutilainen and Peuraniemi 1977).

Vigorous development in analytical and data processing methods has allowed geochemical survey to be extended from prospecting to regional geochemical soil mapping. The geochemical characteristics of extensive areas are readily and rapidly established and explorational follow-up activities can be focused on areas demonstrated to be ore potential. Initially, practically the only material sampled was stream sediments (Hawkes and Bloom 1956; Beus and Yanishevsky 1965; Bölviken 1967). Since then, till has become more and more popular as a sampling material for regional survey in glaciated areas (Schilts 1971; Fortescue 1972; Kauranne 1975; Kauranne *et al.* 1977).

On the geochemistry of copper

The following brief summary of the behaviour of copper under different geochemical conditions is largely based on the text book of geochemistry by Rankama and Sahama (1950).

In geochemical character copper is a typically chalcophile element. Of the trace metals that occur in nature copper has one of the highest affinities for sulphur; hence the bulk of the lithospheric copper occurs as sulphides and sulphosalts. To be sure, silicate copper minerals are also known (e.g. chrysocolla and dioptase), but they occur only in hydrothermal veins and therefore they are of small significance for copper geochemistry.

Copper tends to become enriched in mafic rocks, and it belongs characteristically to the pyrrhotite-pentlandite paragenesis. Copper occurs mainly as chalcopyrite ($CuFeS_2$) and bornite (Cu_5FeS_4). These copper minerals, which represent the last products to crystallize from magma, fill the interstices between other minerals.

Some copper remains in magma throughout the main crystallization stage and then becomes enriched in pneumatolytic and hydrothermal formations (Rankama and Sahama 1950). During weathering the surficial parts of copper orebodies are oxidized to form an oxidation zone in which sulphides are decomposed and copper is brought into solution as sulphates. Copper, however, readily reprecipitates from the water solution as sulphides (e.g. as chalcosite) and carbonates (e.g. as malachite) and is thus enriched in the lower parts of the weathering zone. In this cementation zone copper may occur as both native metal and oxides in numerous oxidation states (Nurmi 1976).

Under reducing conditions copper sulphides are precipitated in sapropelic muds from copper-bearing solutions that have migrated somewhat farther from the source; this may give rise to conspicuous sedimentary copper ores (e.g. Mansfeld). Copper may also, albeit rarely, be adsorped in hydrolyzate or oxidate sediments.

Although copper is an intensely chalcophile element it is neither present in nor lacking from any specific rock type in the Earth's crust. Turekian and Wedepohl (1961) report the following average copper contents (ppm) for some rock types:

ultramafites	10
basalts	100
granodiorite	30
granite	10
schists	50
limestone	15

Hence, the geochemical contrast between different rock types or lithological areas as denoted by copper concentrations cannot be as marked as that shown by, say, nickel concentrations, the nickel contents in ultramafites being at least a thousand times higher than those in silicic rocks. On the other hand, the geochemical behaviour of copper is both more clear and more simple than that of nickel and many other metals in that it is practically the sole constituent in the sulphide phase. In contrast, nickel, for example, substitutes diadochically for other elements in both sulphide and silicate phases, and its partition between these phases varies from one rock type to the other and even between different parts of one and the same rock unit.

The present study is restricted to the geochemical behaviour of copper in different soil samples in both regional and detailed geochemical survey. Specially emphasised is the effect of glacial and Quaternary geological factors on the interpretation of geochemical data. The target of study was the Kiihtelysvaara map sheet (4241) area (1 200 km²) in eastern Finland (Fig. 1). The bedrock in that area is composed of Karelian schists and Presvecokarelidic gneiss that include a number of copper mineralizations of various type. Although the predominant soil type in the area is till, the Quaternary geology is complicated by the large marginal formations.

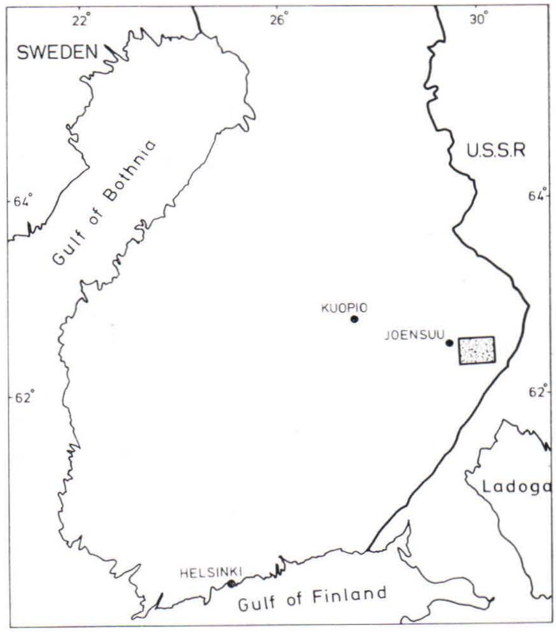

Fig. 1. The location of the the study area.

The area is well-suited for studies like the present one because it has already been submitted to geochemical survey using lake sediments, stream sediments and till as sampling materials, and also samples have been taken from the outcrops for lithogeochemical investigation. Copper was selected as the element to be investigated because there are several copper mineralizations of different ages and types in the area.

Although the geochemical character and behaviour of copper in the lithological units of bedrock are simple, there are a number of Quaternary geological factors that make it difficult to interpret the pedogeochemical data. Hence, knowledge of the fundamental aspects of the Quaternary geology in the study area and its environment is always vital for the success of geochemical soil studies.

GENERAL FEATURES OF THE BEDROCK

General

The bedrock in the study area consists of two lithological units of different age: 1) the Presvecokarelidic basement complex in the east, which covers about 70 % of the study area, and 2) the Karelian schists in the west, which cover some 30 % of the area. Both lithological units contain copper mineralizations of various size.

Presvecokarelidic basement complex

Most of the rocks in the basement complex are intensely altered silica-rich plutonites, the orthogneisses known as granite gneisses. They are grey and medium- or coarse-grained rocks. In composition they are trondhjemitic quartz diorites and granites or oligoclase granites (Nykänen 1971 b).

On the basis of the crosscutting relations it has been deduced that the granite gneiss is older than the potassium granites that occur as numerous veins and minor bodies but also as sizeable massifs (e.g. the granite massifs at Loitimo and Uramo). The potassium granites are generally pinkish, coarse-grained and cataclastic rocks. In places they form migmatite together with the granite gneiss.

A conspicuous and geochemically interesting member of the rocks of the basement complex is the Presvecokarelidic amphibolite formation. It includes volcanogenic amphibolites, hornblende schists and chlorite schists as well as leptites derived partly from weathering products of the former and partly from acid lavas (Nykänen 1971 b). The amphibolite formation is heterogeneous and the rock types vary considerably in grain size, structure and mineralogy. The tuffaceous hornblende schists and coarse, volcanogenic gabbroic amphibolites are similar in mineral composition and correspond in chemical composition to tholeiitic lavas (Nykänen 1971 b). They often contain ore minerals, e.g. minor Pb—Zn mineralizations (Kahma *et al.* 1976) and sporadic chalcopyrite. In the Otravaara—Linnansuo area (Fig. 2) the amphibolite formation contains beds a few tens of metres thick of ultramafites, predominantly serpentinites and talc schists.

The leptitic interlayers in the amphibolite formation are from a few metres to some tens of metres thick. In places, e.g. at Otravaara, they are associated with thin black schist layers. Ore minerals are common in the leptites. In and around Otravaara they contain several pyrite orebodies (Saksela 1923; Aurola and Vähätalo 1939) that do not, however, include economic amounts of any other ore minerals.

The granite gneiss, potassium granite and amphibolite formation in the basement complex are clearly cut by the younger and abundant metadiabase dykes. According to Väyrynen (1954) and Nykänen (1971 b), they are the products of the same magmatic activity as are the metavolcanics in the Karelian schist area. In composition they are generally iron-rich, tholeiitic basalts (Nykänen 1971 b). The metadiabases frequently contain ore minerals, chalcopyrite in particular, which has locally been enriched in albite-rich products of late crystallization (Nykänen 1971 b; Pekkarinen 1976). Although only a few metres to some tens of metres wide, the metadiabase dykes are so numerous that they account for 10 to 15 % of the bedrock (Kallio 1976).

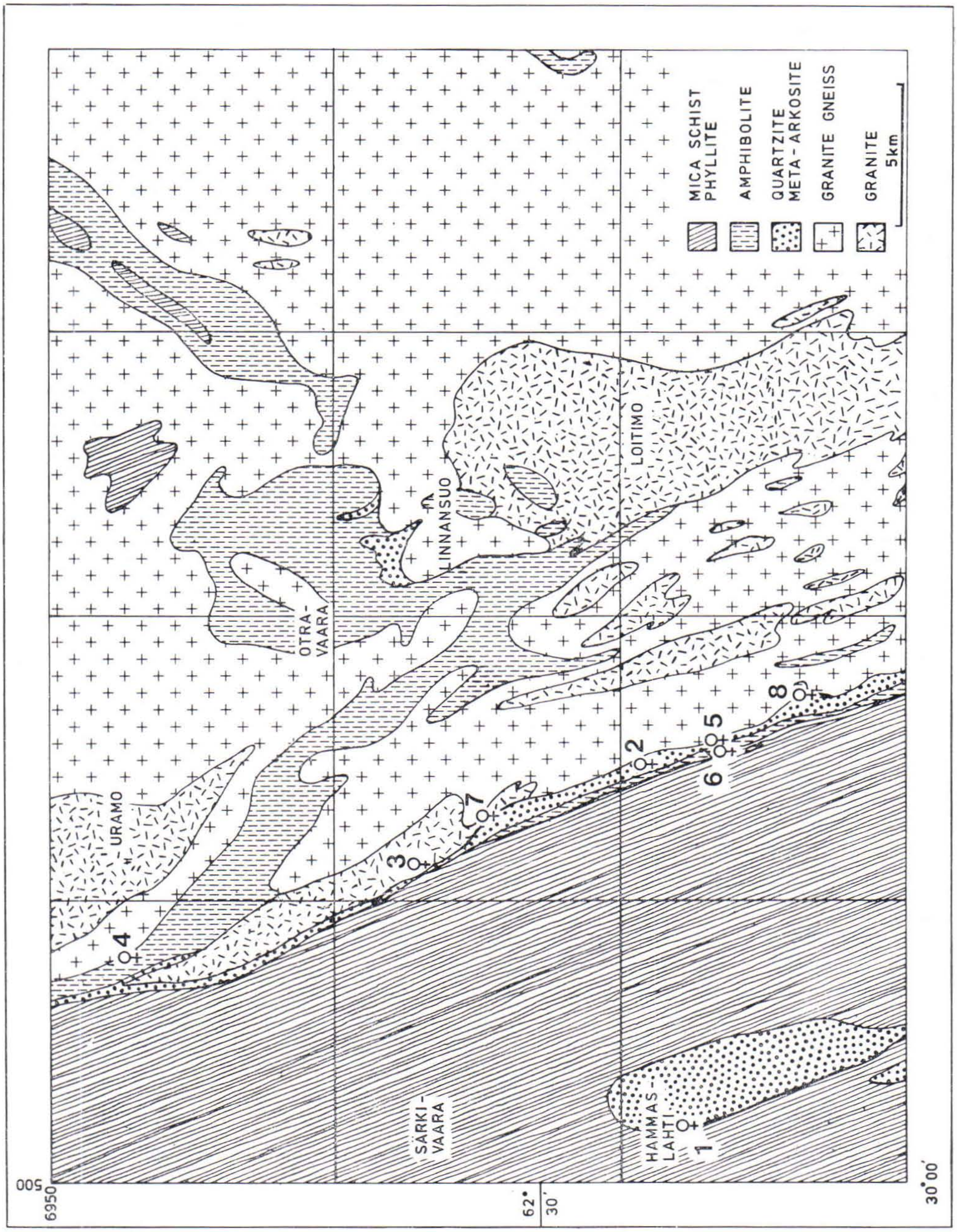

Fig. 2. The bedrock of the Kiihtelysvaara map sheet (4241) area simplified according to O. Nykänen (1971 a) and the copper mineralizations in it.

Karelian schists

Resting unconformably on the saprolitic weathering crust of the ancient basement complex are schists that dip at a high angle westwards. Lowest in the schist formation are basal conglomerates and basal arkosites overlain by a continuous and well-bordered sericite quartzite layer 200 to 400 m thick, in the southern part of the study area on top of the sericite quartzite, volcanic beds alternate with younger quartzites that are more variegated in composition and structure than the lower sericite quartzites. In addition to quartz they often show other main minerals including ore minerals. In terms of age and composition the metavolcanite beds sandwiched between the quartzite layers are products of the same volcanism as the metadiabases of the basement complex (Nykänen 1971 b).

Most of the Karelian schists are phyllites and mica schists. The aphanitic phyllites and fine-grained mica schists are grey, layered and in places graded-bedded rocks that were primarily slightly chemically weathered sediments mixed with clay and sand. The phyllites include graphite- and sulphide-bearing variants.

The abundance of carbon and sulphur decreases from the margins of the sedimentation basins towards the phyllites of flysch type and mica schists in the centre (Nykänen 1968).

In the westernmost part of the area, in the Hammaslahti—Särkivaara region, phyllite contains black schist as interlayers 10 to 15 m thick. According to Nykänen (1971 b), in many places the black schist-phyllite formation shows dolomite and skarn layers as well as sulphides (mainly iron sulphides).

In the Hammaslahti area there is a zone, about 1 km wide, of meta-arkositic schists in which chlorite-, tremolite- and hornblende-rich layers alternate with silicic quartz- and feldspar- predominant matter; the black schist layers are often tremolite amphibolite of the Mulo schist type (Nykänen 1971 b). These schists contain portions rich in sulphides (e.g. the Hammaslahti copper deposit).

On the copper mineralizations in the study area

Several copper mineralizations (Fig. 2) have been discovered at Kiihtelysvaara area as a result of exploration conducted there. They are small and, apart from the Hammaslahti deposit, without economic significance. Nevertheless, to be able to interpret the pedogeochemical data, it is necessary to understand the characteristic features of these mineralizations.

1) Hammaslahti. The largest of the known copper mineralizations is the Hammaslahti ore deposit, which is also the only economic one. It contains chalcopyrite and locally also sphalerite in an intensely tectonized zone with quartz breccia structure in a contact between the Karelian meta-arkose and phyllite. The deposit contains several orebodies. The copper content averages 1 % (Nykänen 1971 b; Hyvärinen *et al.* 1977). The overburden is less than 5 metres thick and contains till and glaciofluvial sediments.

2) Kortevaara. Chalcopyrite occurs at Kortevaara as heterogeneous dissemination in sericite quartzite and is the only ore mineral in the occurrence. The copper content is 0.2 to 0.3 % at the most. The overburden consists of till and is less than 1 metre thick.

3) Kastelampi. Chalcopyrite is encountered as blebs and nests in amphibolitic fragments within Prekarelian potassium granite. The overburden is till that varies in thickness from 0 to 2 metres.

4) Havukkavaara. A quartz-banded magnetite orebody a few hundred metres long that shows local chalcopyrite as breccia matrix (Nykänen 1971 b) occurs in the Presvecokarelidic amphibolite leptite zone. The formation crops out locally but is mainly covered by a thin till blanket.

5) and 6) Hyypiä. Chalcopyrite and minor sphalerite occur as nests in the middle and as dissemination in the margins of a metadiabase dyke (5). Moreover, chalcopyrite bodies and dissemination have been encountered in the same area in a metavolcanite bed and in the upper quartzite (6) in association with quartz veins (Pekkarinen 1976).

7) Karsikkojärvi. Chalcopyrite in metadiabase. The occurrence is too small to warrant diamond-core drilling. The sulphides have been encountered in an outcrop. The area is covered by glaciofluvial overburden a few metres thick.

8) Särkilampi. Minor chalcopyrite in the rocks of the Presvecokarelidic amphibolite formation. The overburden is composed of a till layer less than 2 metres thick.

In addition to the above occurrences, chalcopyrite has occasionally been encountered in the metadiabases in the area as well as in the Presvecokarelidic amphibolite formation. The copper content in the metadiabases is often locally so high that it gives rise to anomalous copper concentrations in till. The phyllite layers in the Karelian schists frequently contain abundant iron sulphides; nevertheless chalcopyrite is rare. South of the ore deposit anomalous copper contents have been noted in the Hammaslahti zone.

The Mulo schist with its abundant sulphides is located immediately west of the study area. However, considering the abundance of sulphides, the copper content in this schist is low (Frosterus and Wilkman 1920). The formation dips at a low angle and hence has a surface area of tens of square kilometres. Since it is located in the direction from which glacial transport took place, it may well be that some of the copper content in the soil in the western part of the study area derives from the Mulo schist.

Tectonics

The tectonic pattern of the Kiihtelysvaara area is dominated by the roughly 330° -trend of schistosity in the Karelian schists. The same trend is recognisable in the Presvecokarelidic basement complex several kilometres from the contact with the schist area. In contrast, the trend of the rocks in the basement complex in the NE corner of the study area is 60°. The schistosity and bedding of the Karelian rocks are usually conformable (Nykänen 1971 b).

The predominant jointing direction in the area coincides with the above schistosity, i.e. 330°. Another almost equally strong and ubiquitous jointing direction is 310°. Less intense than these two but still quite distinctive are jointings that trend N—S and 50°.

Parkkinen (1975) has studied the lineament tectonics of the Haukivesi area southwest of the Kiihtelysvaara area. According to him, lineaments trending 335°, 305°, 000°, 35° and 70° are recognisable extensively throughout eastern Finland. The forementioned tectonic trends in the Kiihtelysvaara area as well as the lineaments shown in Fig. 3 coincide well with the lineament trends reported by Parkkinen (1975).

QUATERNARY DEPOSITS

General

The closing stage of the last glaciation was a very varied event in the Kiihtelysvaara area. During the withdrawal of the glacier two separate lobes, if not more, were active. Punkari (1979) calls these the Finnish Lake District lobe and the North Karelian lobe. The lobes are schematically shown in Fig. 4 under the local names of Pyhäselkä lobe and Koitere lobe.

Large marginal formations were deposited along the margins of the lobes, the most impor-

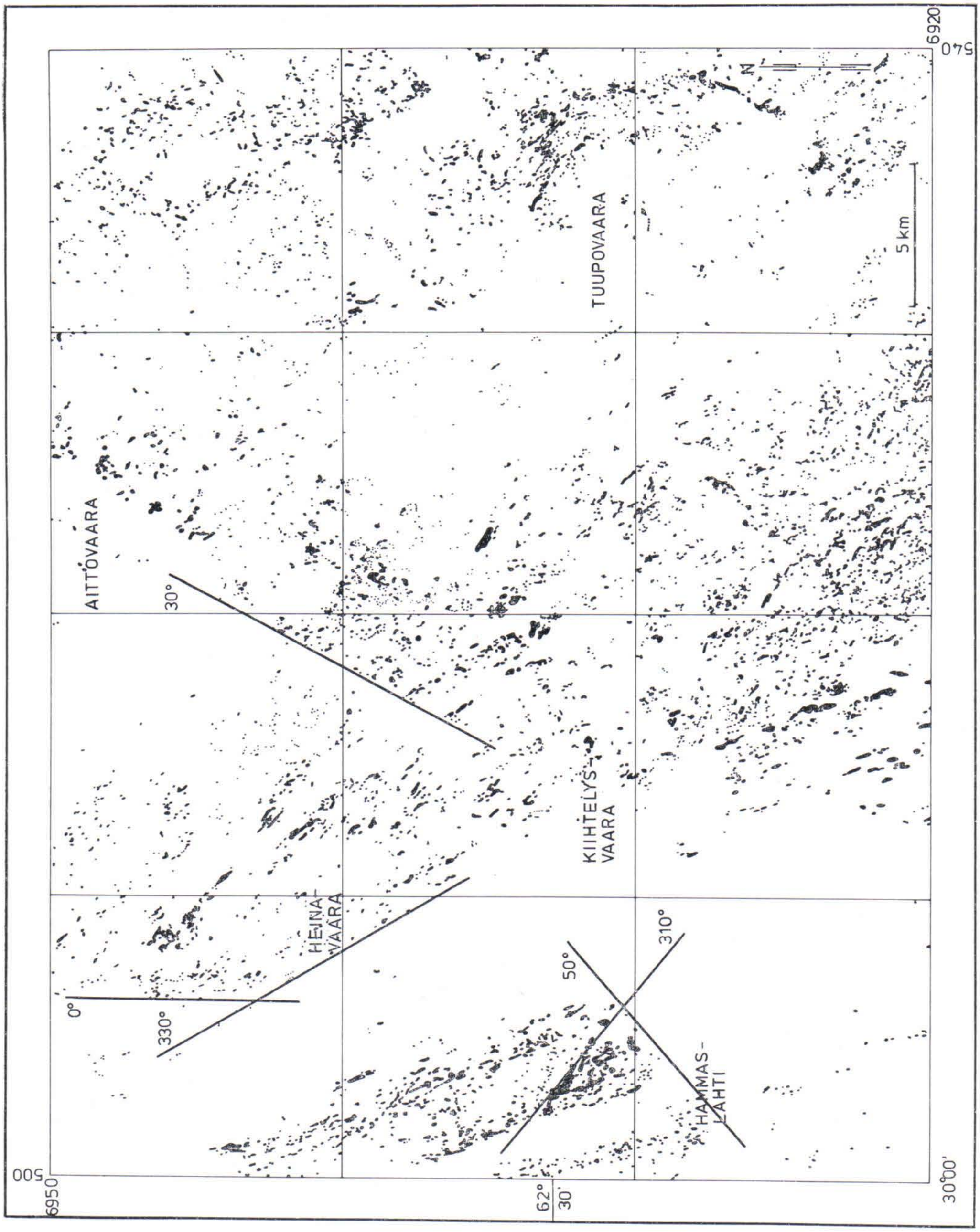

Fig. 3. The outcrops in the Kiihtelysvaara area and the predominant lineament trends.

tant being Salpausselkä I and II and Selkäkangas. These marginal formations and their age relations have been treated comprehensively in several earlier studies (Sauramo 1928; Repo 1957; Donner 1969; Repo and Tynni 1971; and Rainio 1972).

The generalized map of the Quaternary deposits shown in Fig. 5 was compiled mainly on the basis of the data of the overburden gathered from about 10 000 sampling sites in the course of geochemical soil sampling. The preliminary map was drawn by computer using the data of the overburden from the geochemical data file in such a way that the soil type of the uppermost sample at each sampling site (at a depth of c. 1.5 m from the surface) was marked on the map. The boundaries of the formations were established on the basis of base-map interpretation, aerial photos and data gathered for the gravel inventory project of the Department of Quaternary Geology of the Geological Survey of Finland. When necessary, data were checked in the field with the aid of tractor excavators etc.

The data pertinent to the thickness of the overburden given in Fig. 6 are based on map interpretation using the outcrop frequency and drilling information gathered during sampling. The thickness of the overburden varies greatly and the figures given are to be considered as the average thicknesses of rather large areas.

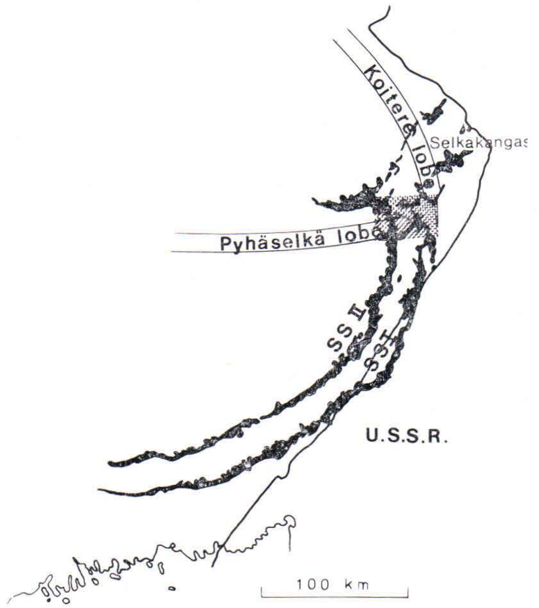

Fig. 4. A schematic representation of the lobes that were active in North Karelia. The marginal formations (SS I and SS II) according to Glückert (1974). The Kiihtelysvaara area hatched.

Occurrences of weathered bedrock

During sampling for mapping purposes, weathered bedrock was encountered at 32 sites. Of them, 17 are located within a rather limited area at and south of Linnansuo (Fig. 7). The remainder are distributed evenly throughout the area. In connection with detailed geochemical sampling, 123 new observations have been made so far on the weathered bedrock; most of them in the Linnansuo area.

The weathered bedrock layer in the Linnansuo area is usually less than 1 metre thick; elsewhere even less than that. The thickest measured occurrence of weathered bedrock is in the NW part of the Linnansuo bog, where there is a 2.2 metres thick layer that consists of weathered leptite underlain by intensely pyritized rock resting on weathered black schist.

The high frequency of the occurrences of weathered bedrock in the Linnansuo area is due to the topography of the bedrock, which has protected the weathered rock from abrasive glacial action. Oblique to the direction of glacial advance (320°—330°) there are amphibolite ridges with intervening narrow valleys 20 to 30 m deep (Fig. 8) whose bottom the glacier was unable to denude. The bedrock also includes rocks that are readily weathered (mainly leptites and ultramafites); thus, before the Ice Age, the weathered layer was presumably thicker in this area than in the surrounding granite gneiss areas. No attempts have been made to delineate the occurrences of weathered bedrock by drilling. Surface topography and outcrops indicate that they are small in size even though weathered bedrock was encountered at several sampling sites at Linnansuo.

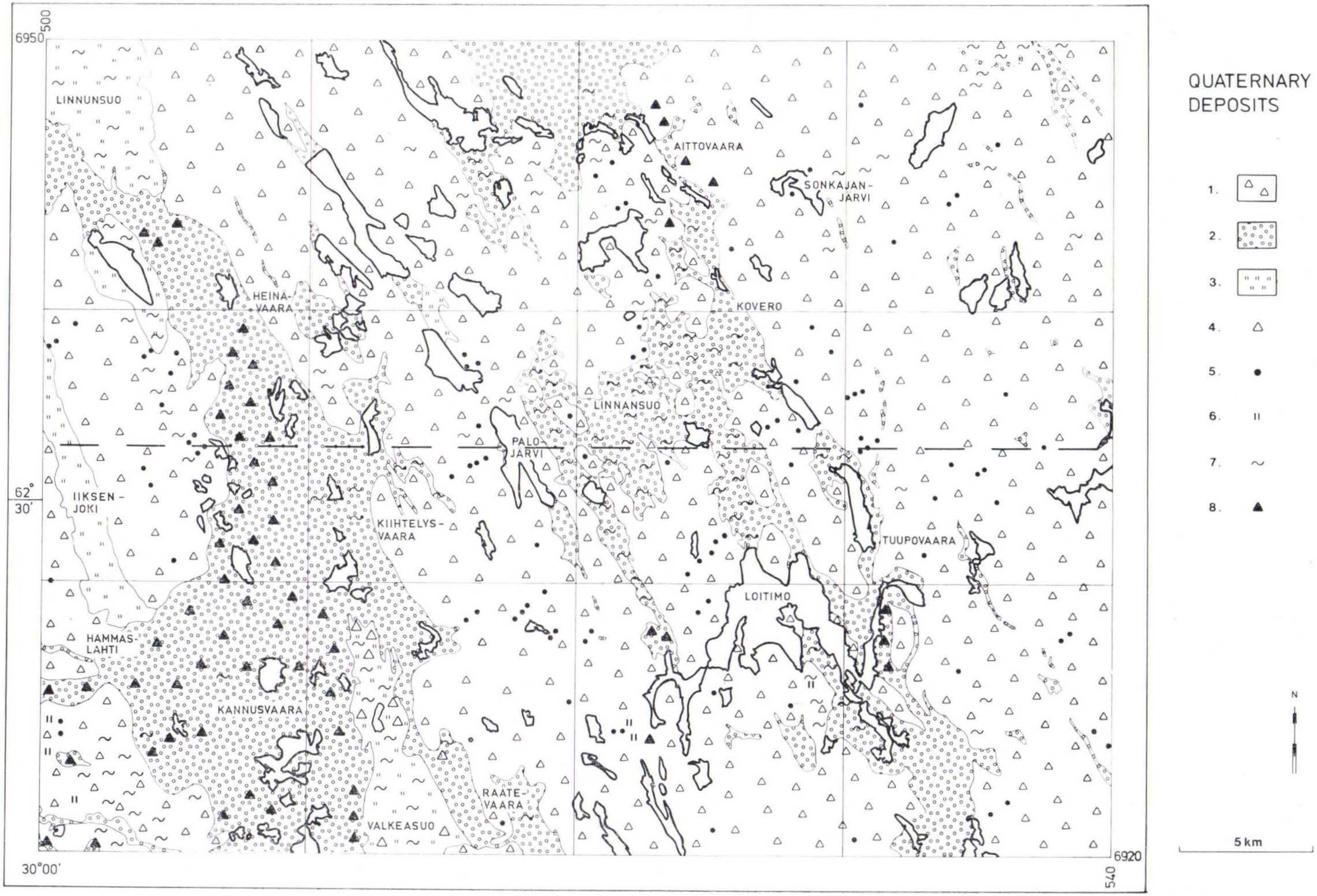

Fig. 5. The Quaternary deposits in the Kiihtelysvaara area. Delineated deposits: 1 = glacial till; 2 = glaciofluvial sand and gravel; 3 = water-laid sediments, mainly silt. Small deposits, which are not delineated: 4 = till; 5 = sand; 6 = silt; 7 = peat; 8 = till blanket on glaciofluvial sediments. The dashed line denotes the location of the profile shown in Fig. 8.

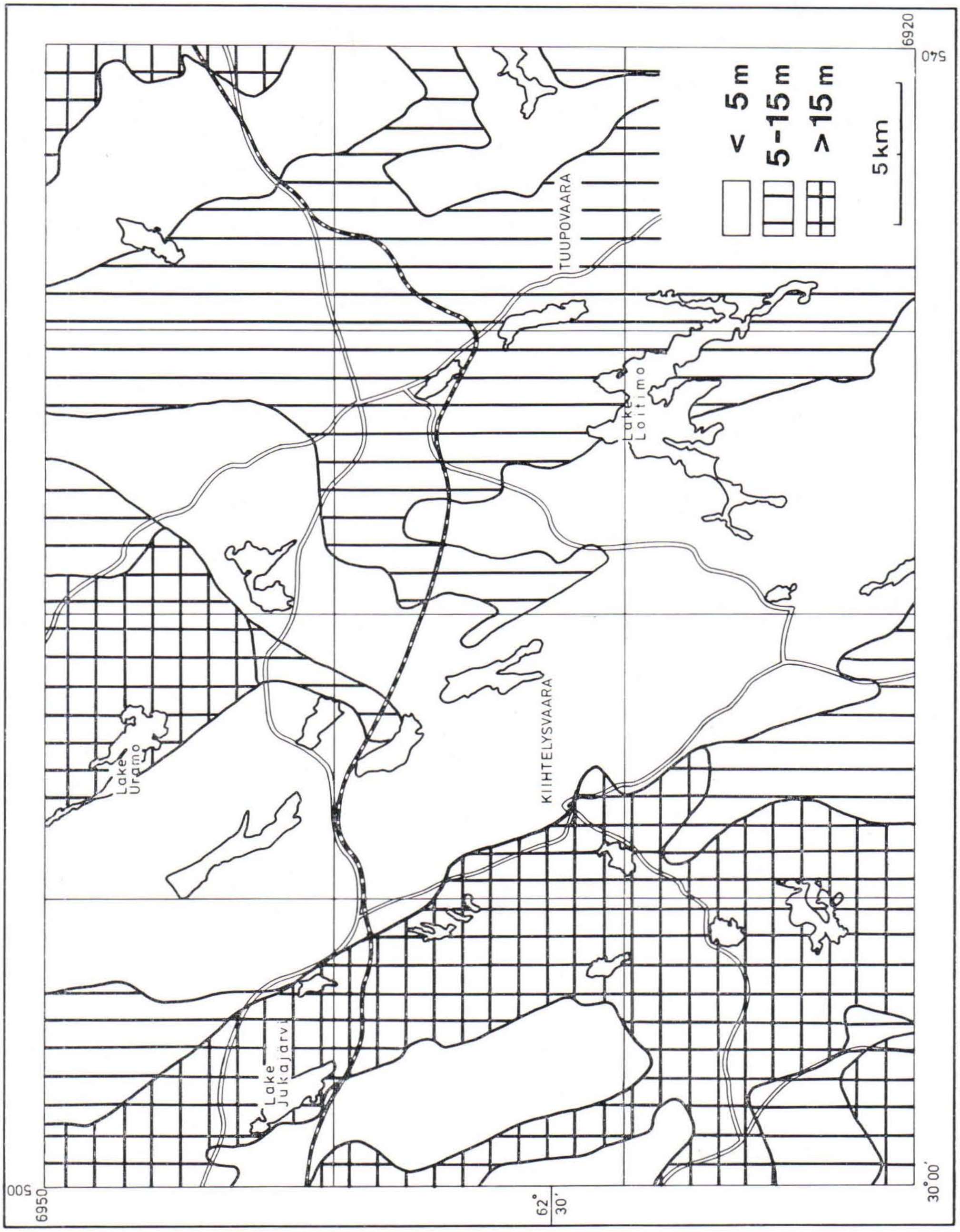

Fig. 6. The thickness of the overburden in the Kiihtelysvaara area.

Glacial deposits

The till in the Kiihtelysvaara area is covered extensively by glaciofluvial and water-laid sediments. Apart from the areas of marginal formations, the till cover consists of homogeneous basal till. Although several directions of glacial transport have been recognised in the area (Fig. 9 and Frosterus and Wilkman 1917 and Repo 1957), the basal till layer seems to be continuous

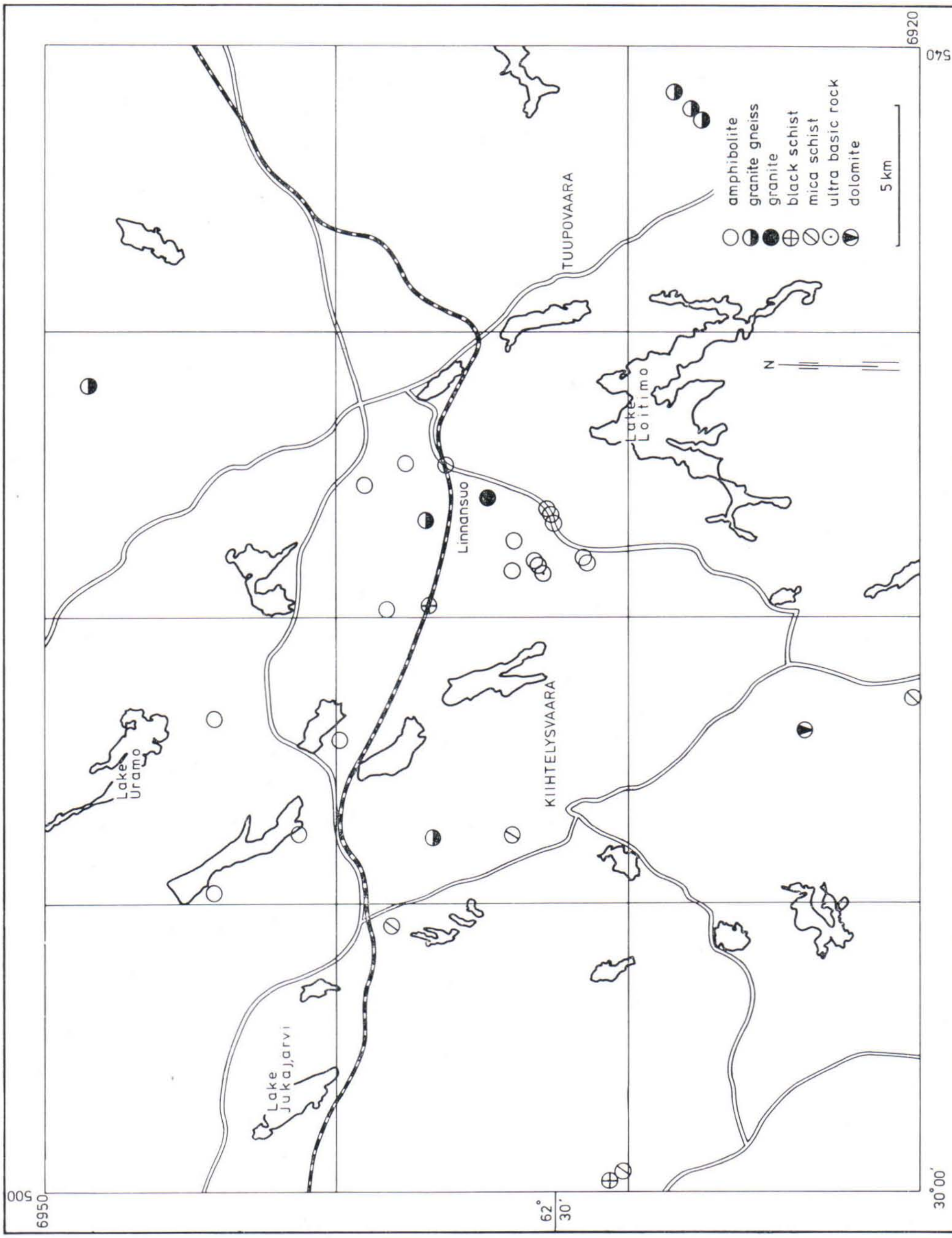

Fig. 7. The occurrences of weathered bedrock in the area of the Kiihtelysvaara map sheet established during sampling for mapping purposes.

and rather homogeneous without distinct layered structure. The areas of marginal formations excluded, extensive beds of different ages have not been found in the till. In individual test pits at Aittovaara and Palojärvi, however, separate layers have been noted in till. Nevertheless, hese observations are not sufficiently convincing to establish the existence of till beds of different ages.

Salpausselkä II is covered largely by a till blanket that is 2 to 3 metres thick in the western

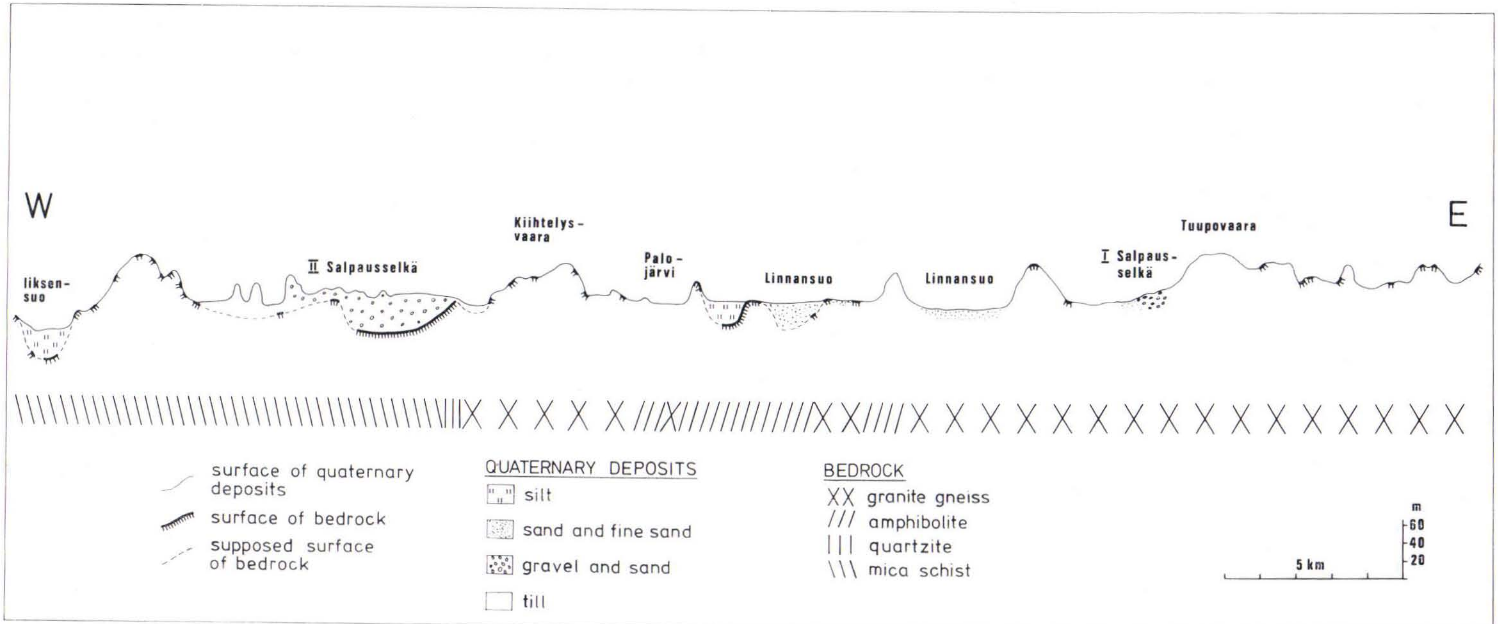

Fig. 8. An altitude profile across the Kiihtelysvaara area from west to east. The location of the profile is shown in Fig. 5. The rock types according to the geological map by Nykänen (1971 a).

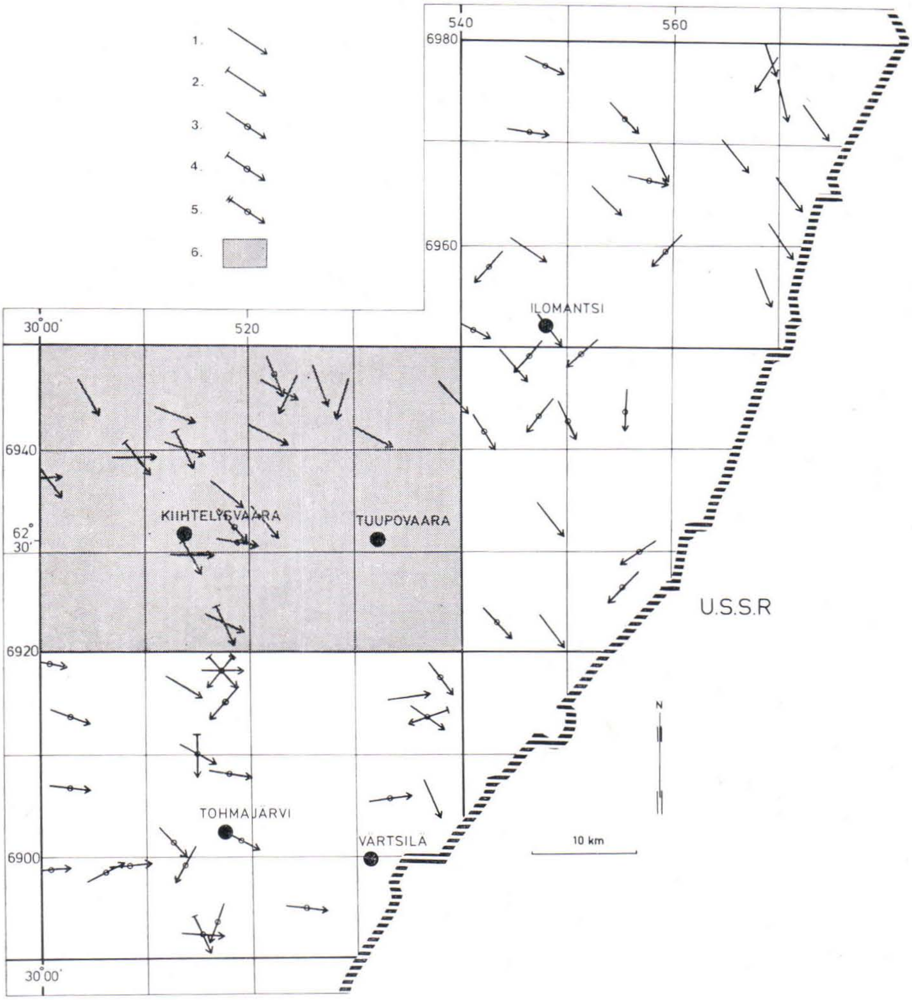

Fig. 9. The directions of glacial advance in the Kiihtelysvaara area and its environment in North Karelia. 1.—2. striae (younger and older); 3.—5. orientation maxima of till pebbles (from youngest to oldest); 6. the Kiihtelysvaara area.

part of the marginal formation at Hammaslahti but which gets thinner from there eastwards. This bed consists of outwashed material similar to ablation till. It was deposited as a result of the eastward thrust of the glacier (the Pyhäselkä lobe) although it shows only slight orientation. The bed is so homogeneous over large areas that geochemical soil sampling on a regular grid was feasible.

The average thickness of the basal till is from 3 to 5 metres. The variation is, however, large owing to the variegated topography: till beds over 10 metres thick have been encountered in the valleys between the hills. In terms of geochemical soil studies this kind of thin till cover has much in its favour because the samples can be taken from close to the surface of the bedrock and the results are easy to interpret. On the other hand, the thick and extensive glaciofluvial deposits that cover the till obstruct pedogeochemical investigations in the study area; likewise, glacial transport from different directions hinders interpretation. It has not been possible to demonstrate that the lobes transported till to any marked degree east of the line Kiihtelysvaara—Heinävaara in spite of the observed orientations 270°—280° and 10°—30° of the pebbles in till. In the interpretation of the geochemical research data, 300°—320° can be taken as the average direction from which the glacier advanced, excluding the till cover in the proximal portion of Salpausselkä II which was transported from 270°—280°. The basal till underlain by the Salpausselkä formation probably arrived from 300°—320° as did all the other basal tills in the area.

Glaciofluvial deposits

Salpausselkä II occurs in the western part of the area as a formation several kilometres wide and trending roughly N—S. Between and south of Kiihtelysvaara and Hammaslahti it spreads out until at and around Kannusvaara it covers an area several tens of square kilometres in extent. Somewhat smaller is the marginal formation associated with Salpausselkä I and which runs from Värtsilä via Tuupovaara and Kovero to Aittovaara. Moreover, between Kiihtelysvaara and Selkäkangas there is a small discontinuous zone of marginal formations trending SW—NE.

Unlike elsewhere in southern Finland, in this area Salpausselkä does not rise above its surroundings. The reason for this is that when the marginal formation deposited, the margin of the glacier was stationary against the succession of hills (Raatevaara, Kiihtelysvaara, Heinävaara) composed of Karelian quartzites and metavolcanics. West of this hill zone there is a valley in the bedrock (Fig. 8) into which the sediments of the marginal formation accumulated. The valley is so deep that the sediments that deposited along the margins of the glacier were unable to fill it. In many cases the thickness of the sediments has been noted to be 30 to 40 metres, or even more.

The sediments in Salpausselkä II vary in grain size; they are, however, mainly gravel and sand. Between the gravel and sand layers till has been found that, as suggested by its mode of occurrence, was well mixed during oscillations in the margin of the glacier and hence does not represent any particular stage of glaciation.

The glaciofluvial sediments in the proximal part of Salpausselkä II are also covered by a thin till blanket.

The Salpausselkä formation continues from Kiihtelysvaara towards NNW but grades into an esker-like deposit that was formed between two lobes as a seam formation. This formation is also often covered by till. Another prominent zone in the NW—SE-trending glaciofluvial formations is met with west of the line Tuupovaara—Aittovaara. Eastwards the formation exhibits a sharp and straight boundary caused by a threshold in the bedrock. Westwards the boundary is ill-defined, and in the Linnansuo area a continuous sand area extends about ten kilometres westwards. Similarly, north of Aittovaara in the northernmost part of the study area there is a sand plain some 30 km^2 in size. Distinctly esker-like portions occur at and south of Tuupovaara, although there too a glaciofluvial formation with less well-defined constituents is encountered. In this area till has also been observed to occur on top of or intermixed with glaciofluvial sediments. As suggested by the constituents of the formation and its position analogous to Salpausselkä II against a threshold in the bedrock, the formation is presumably a marginal formation associated with the Salpausselkä I stage.

The Salpausselkä formations are joined to each other by a discontinuous zone that runs almost perpendicular to them from Kiihtelysvaara to Aittovaara and on to Selkäkangas. The zone is composed of marginal formations of the end-moraine type. Their constituents, as well as those on their proximal side, are predominantly till and sand.

At the site of this formation the bedrock has a threshold against which the margin of the glacier was temporarily stationary (see Fig. 3). At Aittovaara some test pits have shown that in this marginal formation zone the basal till 2 to 4 m thick is underlain by current-bedded delta sediments. The formation, which joins Selkäkangas south of Koitere, deposited at the same time as Salpausselkä II (Rainio 1972 and Donner 1976).

Eskers proper are rare in the area. East of the Tuupovaara—Kovero marginal formation there is a discontinuous and narrow esker trending NNW—SSE. At Hammaslahti an esker trending roughly W—E joins Salpausselkä. Another esker trending in the same direction is met with south of Hammaslahti at the southernmost margin of the area.

Water-laid sediments

In addition to glaciofluvial sediments, littoral sand formations of variable thickness and surface area are encountered on the slopes of hills. They are most abundant west of Linnansuo in the area between Tuupovaara and Kiihtelysvaara (Fig. 5).

Fine-grained water-laid sediments — mainly silts — occur in the study area as formations about 10 km² in extent in the valley of the river Iiksenjoki and in the areas of Linnunsuo and Valkeasuo. Smaller silt formations occur in the valleys between the hills; yet others are encountered in the Linnansuo area, although there the coarser-grained sand deposits predominate.

During the melting of the glacier the Viesimojoki riverbed was occupied by a current of melt waters that was considerably stronger than the present one and which ran from south of Kiihtelysvaara to west of Raatevaara and from there to the area of the present Valkeasuo. This current washed out previously deposited sediments and exposed large outcrops. Later, fine-grained water-laid sediments were deposited in the glacial lake at the site of the present Valkeasuo. The washed-out rocks and minor till areas constitute islets among the sediments.

The valley of the river Iiksenjoki is a fracture zone in the bedrock that has been denuded several tens of metres deeper than the environment. Consequently, silt deposits 20 to 30 m thick are common in the area.

Silts have been encountered in the middle of the bog Linnunsuo. Coarser-grained sediments predominate at the margins of the bog. Pushed by littoral forces, these sediments have spread from the glaciofluvial formations south and west of the bog.

The transport directions of till

The directions of till transport have also been studied in a rather extensive area outside the study area proper (Fig. 9). Information on the transport directions is based on measured striae directions and on the orientations of pebbles determined at different depths in 38 test pits.

The lobes (Fig. 4) that were active in the study area caused till to be transported in conspicuously diverse directions. The greatest effect on the deposition of the present till cover was, however, given by the movement of the glacier from 300° to 320° during the main stage of Weichsel glaciation. This direction of advance shows up clearly throughout the area.

The most active of the lobes was the Pyhäselkä lobe, which moved from west to east and whose well-known marginal position is Salpausselkä II. The movement of the lobe also extended east of Salpausselkä II, as is shown by the large sets of data on striae and pebble orientation suggesting that the glacier advanced from 270° to 300°. The easternmost marginal position recorded for the Pyhäselkä lobe is a marginal formation located along the line Värtsilä—Tuupovaara—Aittovaara (the extension of Salpausselkä I). The eroding and transporting force of this lobe east of Kiihtelysvaara was, however, weaker than farther west.

Another lobe that extended to the study area advanced from the north and later from the northeast, from east of Koitere. The most well-known marginal formation of this lobe is the extensive Selkäkangas, southeast of Koitere. Pebble orientation determinations carried out on surficial till at depths of 1 to 1.5 m demonstrate, however, that south of Selkäkangas the glacier moved in a NE—SW direction. Striae have also been encountered in the same area indicating glacial advance from 20°, e.g. at Sonkajanjärvi where grooves 2 to 3 cm deep have been encountered with this orientation. These obviously refer to earlier stages of the Koitere lobe. This orientation is, however, no longer encountered in the surficial till west of the Värtsilä—Tuupovaara—Aittovaara marginal formation.

Observations on the NE—SE-trending glacier movement antedating the Koitere lobe have been recorded from three exploration pits at Viesimo, Kiihtelysvaara, at a depth of 3 to 4 metres. Similar observations have been reported from Ilomantsi.

The transport distance of till

To be able to interpret the data correctly it is important in geochemical till survey to know as accurately as possible not only the direction from which the till was transported but also its transport distance; to this end, a comprehensive investigation on the transport of till in the basal till area was carried out. The transport distance of the till blanket in the proximal part of Salpausselkä II differs from that of the rest of the till; geochemical data indicate that it is several kilometres.

The transport distance of mica schist at Heinävaara

The transport of pebbles derived from Karelian mica schist was studied at Heinävaara (Fig. 10). The average direction of glacial transport in the area was established to be 300°—320° (p. 20). Stone counts were conducted on surficial till at a depth of 0 to 2 metres along a line trending in this direction. The till blanket is thin in the area and the exploration pits went deep enough to establish the transport of the whole till bed. Samples were also taken from this line for chemical assay of the fraction under 0.064 mm. Some, but not all, of the sampling sites were the same as those for the stone counts.

The distance till was transported under these conditions (the proportion of the rock type to be studied is high in the bedrock, and its decrease in frequency is followed from the distal contact onwards) has been studied extensively, and theoretical models have been suggested for the decrease in the frequency of the rock type studied (Krumbein 1937; Gillberg 1965; Virkkala 1971 and Perttunen 1977). As assumed by Krumbein back in 1937, here too the curve that describes the decrease in frequency in mica schist pebbles (Fig. 10) is close to a negative exponential function in shape.

According to Perttunen (1977), at two research targets in southern Finland the half-distance of the granitoids in the 2—20 cm till fraction is

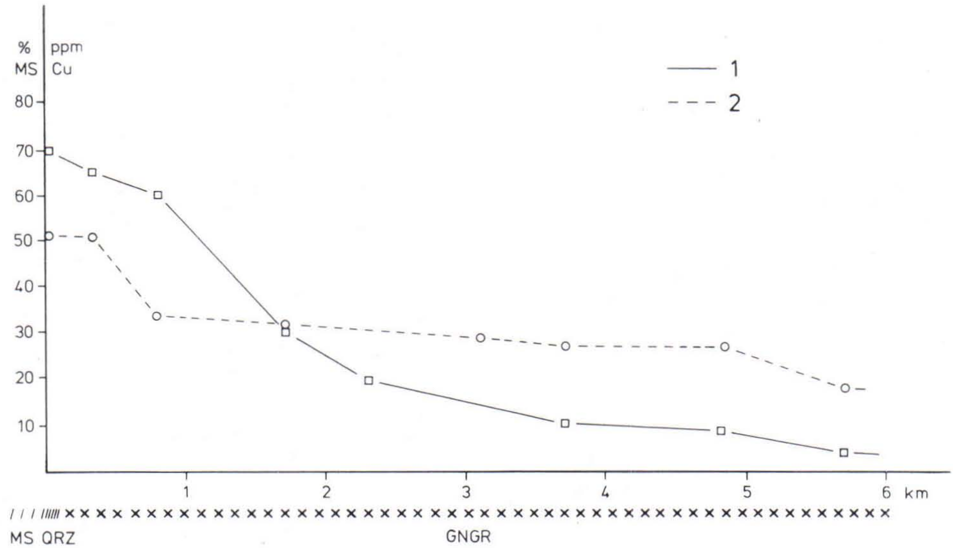

Fig. 10. The mica schist percentages in the 2—20 cm till fraction (1) and the copper concentration in the < 0.064 mm till fraction (2) at Heinävaara. MS=mica schist, QRZ=quartzite, GNGR=granite gneiss.

2.7 and 2.2 km. For a similar fraction Virkkala (1971) reports 3.0 km as the half-distance of microcline granite at Hyvinkää. At Heinävaara, however, the half-distance of mica schist turned out to be only 1.6 km.

The transport of the finest till fraction (under 0.064 mm) was studied by assaying the fraction for copper along the same line as that used for the stone counts. Mica schist is richer in copper than is granite gneiss, although in this area the copper content in granite gneiss is clearly above average. Fig. 10 shows that in the fraction under 0.064 mm the copper concentration falls to background value (the copper content in granite gneiss) about 400 to 500 m southeast of the distal contact of the mica schist. This implies that the transport distance of the finest till fraction is much shorter than that of the 2—20 cm fraction, a finding that is important for geochemical till survey. In estimations of the location of a mineralization that causes an anomaly, the investigations on the transport distance of till must be conducted on analysed fractions rather than on the pebbles in till.

The transport distance of amphibolite at Palojärvi

According to the geological map by Nykänen (1971 a), an amphibolite formation 200 to 600 m wide occurs south of Palojärvi roughly perpendicular to the main direction of glacial advance (Fig. 11). Another and thicker amphibolite occurrence that is part of the same formation is located SW of Rahalampi, about two kilometres east of the former. Studies were conducted in the area to establish the transport of the material derived from the amphibolite. The amphibolite is surrounded by bedrock composed of granite and granite gneiss but which includes metadiabases that resemble amphibolite. In the stone counts these metadiabases were not distinguished from the amphibolite; thus, the proportion of rocks labelled amphibolite is 15 to 20 %, even in the background areas.

The copper concentration in the amphibolite is by nature higher than in the surrounding granite gneiss (Fig. 12). Moreover, thanks to the geochemical till maps, it was known that the

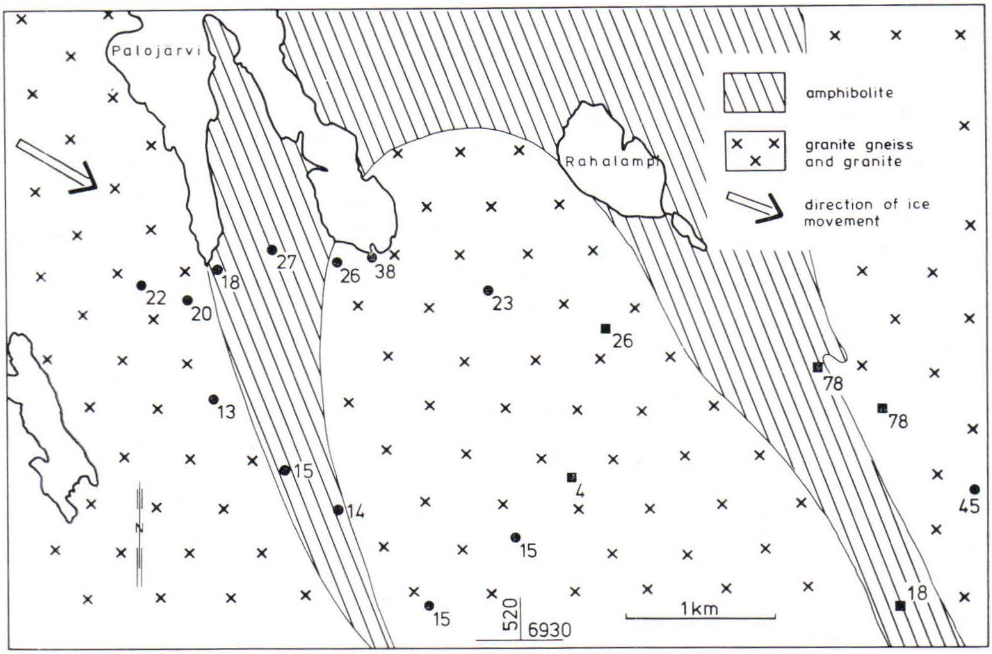

Fig. 11. The geology of the Palojärvi area according to Nykänen (1971 a) and the percentage of amphibolitic rocks determined in the exploration pits. ■ denotes the pits excavated by the Outokumpu Co. (Peuraniemi 1975).

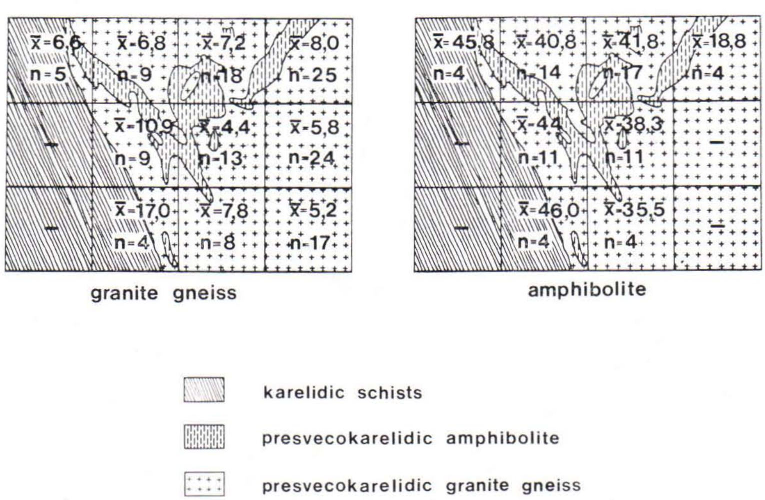

Fig. 12. The average copper concentration ($\bar{x}$) in granite gneiss and amphibolite in rock samples from the base map sheets of the Kiihtelysvaara area. n= number of samples. The geology in the background is simplified from the geological map by Nykänen (1971 a).

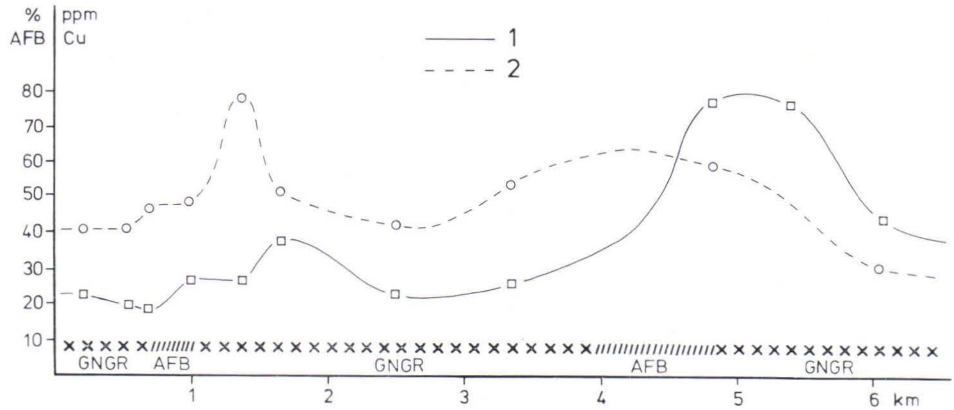

Fig. 13. The percentage of amphibolitic pebbles in till (1) and the copper concentration in the < 0.064 mm till fraction (2) on the northernmost line of exploration pits at Palojärvi. AFB = amphibolite, GNGR = granite gneiss.

amphibolite formation south of Palojärvi exhibited anomalously high copper contents. Hence, the transport distance could also be studied on the basis of the copper content in till. The amphibolite south of Rahalampi did not show anomalous copper concentrations in till.

Twelve test pits were dug in the area by tractor excavator. Also available was information from four test pits dug by Outokumpu Oy (Peuraniemi 1975). For the chemical analyses the test pits were sampled at different depths. For the stone counts till samples weighing 15 to 20 kg were taken; the fractions finer than 8 mm were washed out with water. Pebbles larger than 2 cm were also removed. The percentage of pebbles belonging to the amphibolite formation was counted from the pebbles that remained (100 to 300/sample).

Fig. 11 shows the percentage of amphibolite pebbles in each test pit. If several samples were taken from a test pit the figure refers to the average for all the stone counts. The results indicate that the percentage of amphibolite pebbles on the southernmost line did not increase when the amphibolite formation was crossed in the direction of glacial transport. No amphibolite outcrops have been found in this part of the formation, neither does the aeromagnetic low-altitude map show any anomalies due to amphibolite as it does farther north. Hence, it seems likely that at Palojärvi the amphibolite does not extend as far south as is marked on the geological map.

In contrast, a clear increase in the percentage of amphibolite pebbles in the gravel fraction is noted on the northern line. Fig. 13 illustrates the change in the percentage of amphibolite pebbles across the amphibolite formation. Marked on the same figure are the copper concentrations in the fractions under 0.064 mm taken from the test pits (averages at each site). The background value of the copper concentration in till reflects the amount of copper derived from granite gneiss.

The appearance of amphibolite in till causes a sharp increase in the copper concentration in the < 0.064 mm fraction some 600 m from the proximal contact. At the next site (300 m from the previous one) the copper content is only slightly above the background values. The percentage of amphibolite in the 8—20 mm fraction reaches the maximum value only at a distance of about 900 metres from the proximal contact; it then decreases gradually so that at a distance of 1.7 km it has reached the background value.

These results suggest that the gravel fraction at this site was transported for about one kilometre (half-transport distance 1.1 km) and the fraction under 0.064 mm about 500 m.

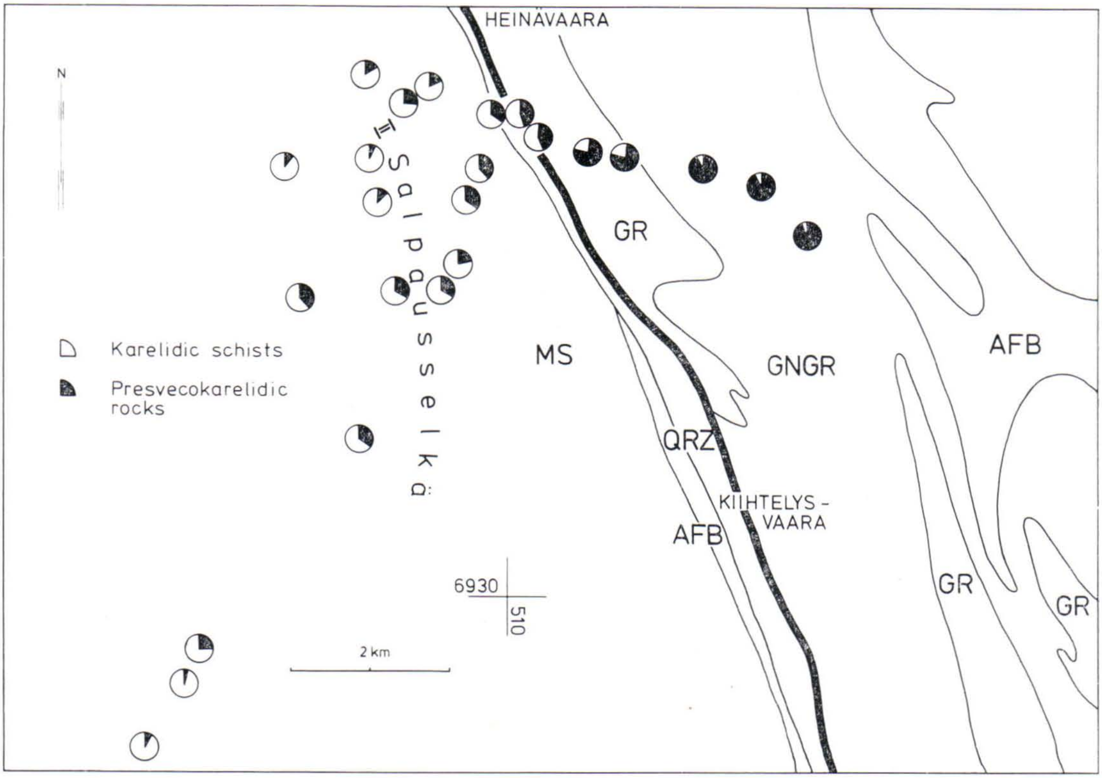

Fig. 14. The lithologic composition of till at Heinävaara on the basis of rock counts. The contact between the Karelian and Presvecokarelidic rocks marked with a heavy line. MS=mica schist, GR=granite, GNGR=granite gneiss, QRZ=quartzite, AFB=amphibolite.

Granite gneiss boulders in the till blanket of Salpausselkä II at Heinävaara

In addition to Karelian schists, the till layer above the glaciofluvial deposits at Salpausselkä II contains boulders that derived from the Presvecokarelidic basement complex (Fig. 14). They are predominantly granite gneisses but include amphibolites and metadiabases as well. Pinkish quartzite boulders that originate from the basement of the Karelian schists are also met with among the boulders in till. All of these boulders are large (in the gravel fraction they are rare), rounded and seem to have moved with the glacier for a long time. The origin of the boulders is interesting; nowhere in the direction from which the glacier advanced in the final stage (280° and 320°) is there bedrock near enough to have been the source of the boulders. The amount of Presvecokarelidic boulders in till covered by glaciofluvial sediments is so high (20—40 %) that they cannot be attributed merely to long-distance transport — the nearest occurrences in the west and northwest of rocks of this type are at a distance of 20 to 25 km. Lithologically a suitable source occurs east of Salpausselkä II, only 1 to 2 km away; the appearance of the boulders is such that they could well be from there. Another source area might be the Prekarelian rocks at Sotkuma west of Höytiäinen (Fig. 15).

The source of the boulders was traced by studying their geochemical characteristics. For this purpose samples were taken from the granite gneiss boulders in the Salpausselkä II area and from the bedrock granite gneisses at Sotkuma

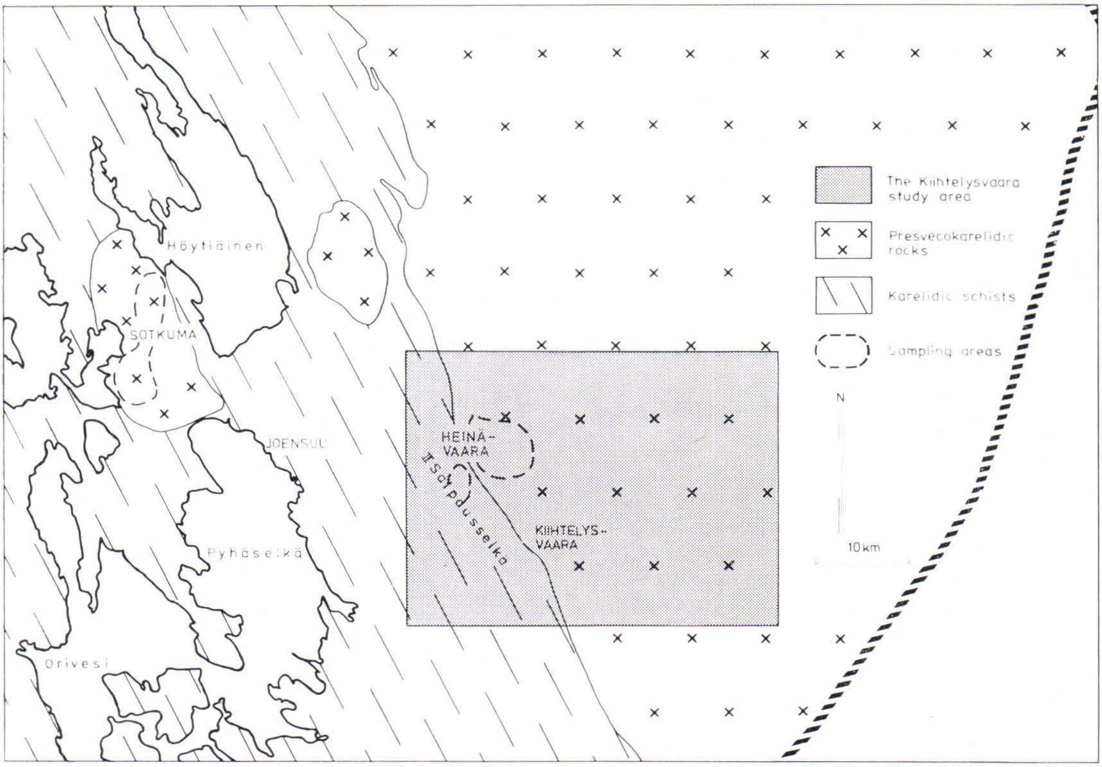

Fig. 15. Tracing the source of the granite gneiss boulders encountered in the till cover of Salpausselkä II.

and Heinävaara. The analytical data of the samples are compiled in Table 1. Fig. 16 shows the frequency distributions of the Mn/Cu ratio in the rock samples from Heinävaara and Sotkuma and in the boulders from the Salpausselkä. The bedrock at Sotkuma and Heinävaara exhibits two distinct Mn/Cu populations. As a whole, however, the distributions differ from each other so clearly that it should be possible to establish

Table 1.

The average trace element concentrations in samples taken from the Sotkuma and Heinävaara granite gneisses and in granite gneiss boulders (Ss II) from Salpausselkä II. n=number of samples. Analysed by OEQ.

	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Pb	n
Sotkuma ..	3 000	81	28	570	11	23	24	38	21	31
Heinävaara .	3 500	88	23	510	14	26	6	24	23	18
Ss II	3 800	80	21	540	12	25	11	40	23	23

whether the boulders derive from either of them by comparing their Mn/Cu distributions with those of the boulders. The Mn/Cu ratio of the boulders shows a similar bimodal distribution to that of the bedrock distributions. The peaks of the Mn/Cu distribution in the boulders coincide with those in the Mn/Cu distribution of the Heinävaara bedrock. In the Mn/Cu distribution of the boulders, however, the lower of the peaks is higher than the corresponding peak in the Heinävaara Mn/Cu distribution. This may be because boulders analysed include boulders from the Sotkuma granite gneiss.

The geochemical distribution data indicate that most of the granite gneiss boulders encountered in the Salpausselkä II area originate from bedrock east of Salpausselkä. The boulders obviously landed at Salpausselkä as a result of complex transport in the course of which a

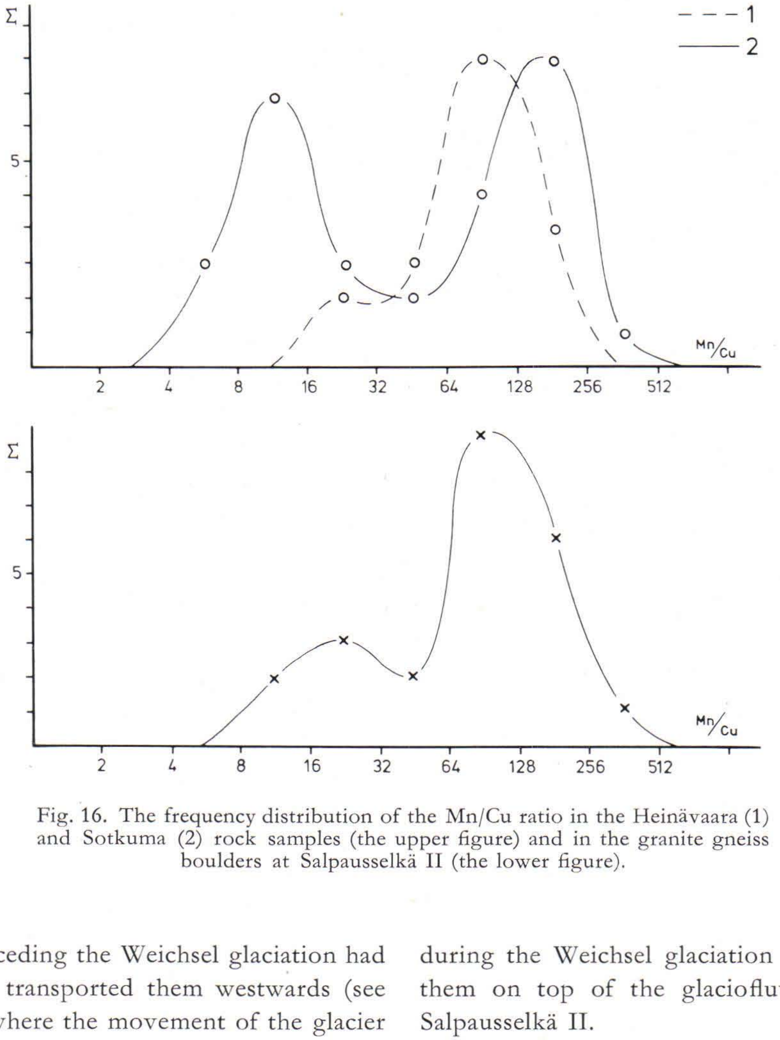

Fig. 16. The frequency distribution of the Mn/Cu ratio in the Heinävaara (1) and Sotkuma (2) rock samples (the upper figure) and in the granite gneiss boulders at Salpausselkä II (the lower figure).

glaciation preceding the Weichsel glaciation had loosened and transported them westwards (see p. 21), from where the movement of the glacier during the Weichsel glaciation had transported them on top of the glaciofluvial deposits of Salpausselkä II.

GEOCHEMICAL STUDIES

Geochemical research methods

The sampling, sample preparation, analyses and automatic data processing were conducted in accordance with the routine methods of the Geochemistry Department of the Geological Survey of Finland (Kauranne 1975 and Gustavsson *et al.* 1979). In the present context only a brief summary is given of the principles of the methods; deviations from the routine are described in the presentation of results.

Sampling

The soil was sampled in two stages. The samples for the actual mapping were taken in winter by a light-weight portable and combustion motor-driven percussion drill unit. Originally a miniature piston bit was used as sampler; later, however, it was replaced by an Irish type of through-flow bit. The sampling sites were located along lines 1 to 1.5 km apart and oriented perpendicular to the movement of the glacier that gave rise to the till bed to be sampled. The distance between sampling sites along all lines was 100 m.

In the second stage the sampling was supplemented by additional samples taken from targets of explorational interest. The equipment used was the same, but the sampling grid was more dense. The thick glaciofluvial layers were intersected by a heavy auger that allowed samples to be taken from till overlain by sorted sediments 20 to 30 m thick

At some targets a medium-heavy pneumatic percussion drill unit was also used that was able to intersect a till cover over 20 m thick and sample the underlying bedrock. In addition to these drilling units, a tractor excavator was used to dig the exploration pits needed for soil stratigraphic observations. Altogether 54 pits were dug.

Attempts were made to take the soil samples from the unaltered till below the ground-water table. A number of samples were also taken from glaciofluvial sediments and weathered bedrock. In the course of sampling for mapping purposes, samples were taken from 9360 sites (7.8 sites/km^2); at the checking stage, samples were taken from 1123 sites.

The stream sediment samples were collected in summer from the shores of each stream, pond and lake in the study area. The samples consisted of organic or mineral sediments that had been continuously submerged. The sampling sites were 50 to 250 m apart along the banks of streams but 500 m on the shores of lakes. Organic and mineral samples were collected separately; both were composed of at least five subsamples collected over a distance of 20 m. A < 0.18 mm fraction was wet-sieved from the mineral sediment at the sampling site and the organic sample was collected as received into a plastic bag. The total number of sites sampled was 5695, from which 4703 organic and 1688 mineral stream sediment samples were obtained.

The lake sediments were sampled in winter through the ice. Attempts were made to include as much organic matter as possible in the samples; they are, therefore, similar to the organic stream sediments. They were, however, taken in the middle of lake basins beyond the littoral zone and thus contain, particularly when taken from large lake basins, rather abundant silt and clay fractions. Altogether 177 sites were sampled.

The bedrock was sampled in summer. The sampling grid was planned as homogeneously as the outcrops allowed, and all the rock types were sampled according to their frequency. The average number of sampling sites per base map sheet (100 km^2) was 50; the total was 621. The samples were taken by a rotary percussion drill fitted with a 13 mm hard-metal auger. Three to five subsamples were taken at each outcrop. They were then combined to form a single sample during preparation.

The handling and assaying of samples

The soil samples were dried at 70°—80°C. The fractions < 0.064 mm, 0.064—0.250 mm and 2 mm were then sieved from the samples. The < 0.064 mm fraction was assayed on a direct reading ARL Model 31000 optical emission quantometer (OEQ) equipped with a Danielson tape unit as feed and exitation device (Danielson and Sundqvist 1959). The readouts of the intensity values were converted into concentrations by an empiric algorithm programmed to the central HP- 3000 computer of the Geological Survey. The repeatability of the concentrations by the OEQ varies from 20 to 50 % at a confidence level of 0.95 depending on the element and the concentration. In range of 10—5000 ppm the repeatability for copper (20 %) is one of the best allowed by the method. In detailed studies and when checking the anomalies detected by OEQ assaying, the metals that are soluble in hot 7 M nitric acid were also analysed from the < 0.064 mm fraction by atomic absorption technique (AAS).

The stream and lake sediment samples were analysed by the AAS technique. The mineral stream sediments were assayed in the same way as the soil samples. The organic stream and lake sediments were dried at 70°—80°C, and the organic substances were destroyed by keeping the samples at 500°C for 12 h. The ash was analysed for metals soluble in hot 6 M hydrochloric acid.

The bedrock samples were dried and the portions of the samples to be analysed were ground in a centrifugal mill. The samples were assayed by OEQ technique. For comparison, some of them were also assayed by AAS for copper soluble in hot 7 M nitric acid.

Data processing

The data were processed with the aid of programs developed by the ADP group at the Geochemistry Department of the Geological Survey and applied to the HP-3000 computer. The analytical data were grouped into 3 to 5 classes according to the concentration and presented as maps drawn automatically by a Cal-Comp plotter. For the present study an interpolation program was drawn up that allows average metal contents to be computed in samples taken from sites that fall within the area of a given ellipse weighted so that the effect of weighting decreases towards the margins of the ellipse. Figs. 21 and 22 were made by applying this technique.

Lithogeochemical studies

Considering conditions in Finland, the Kiihtelysvaara area is well-suited for lithogeochemical studies. On account of the thin overburden, the frequency of outcrops is high (see Fig. 3); only at Salpausselkä II is there a coherent area of about 20 km² without exposures. Furthermore, all the rock types encountered in the area are well represented in the outcrops, and so it was possible to construct a regular and representative grid that covered the entire area.

Average copper concentrations in different rocks

The copper concentrations in the major rock types in the study area are listed in Table 2. For comparison the table shows the AAS analytical data as well as the normal OEQ data of the same rocks. The difference between the data obtained by different methods is distinct. The mutual ratios of the concentrations indifferent rock types are, however, independent of the method applied.

Table 2.

The average copper concentrations ($\bar{x}$), standard deviations (s) and variation coefficients (v) of a variety of rocks from the Kiihtelysvaara map sheet area (4241). n=number of samples.

Rock type	Analysed by OEQ				Analysed by AAS	
	$\bar{x}$	s	v	n	$\bar{x}$	n
Mica schist ..	42.4	43.0	1.01	49	69.4	7
Black schist .	38.4	17.1	0.44	19	74.8	5
Phyllite	30.4	15.3	0.50	13	77.3	3
Arkosite	23.9	25.7	1.07	28	39.7	4
Quartzite ...	5.4	3.9	0.72	30	10.0	4
Granite gneiss	6.7	7.1	1.05	131	8.2	4
Granite	6.3	6.6	1.04	122	9.0	6
Amphibolite .	30.8	38.7	1.29	69	74.5	6
Diabase	52.8	82.8	1.56	83	139.5	5

The maximum differences between the average copper concentrations in the rocks are tenfold (granite 6.3 ppm and diabase 52.8 ppm). The variation coefficients (Table 2) demonstrate that in terms of copper the black schist and phyllite are notably more homogeneous than the other rock types. Lonka (1967) has studied the metal concentrations in similar rocks from different parts of Finland; he found the lowest variation coefficients of copper concentrations in black schists taken from Pyhäselkä — the western margin of the present study area. It is statistically unlikely that these rocks contain copper mineralizations despite their abundant sulphides. The variation coefficients were highest in rocks that are known to include copper mineralizations: metadiabases and amphibolites.

The differences between the average copper concentrations in different rock types also vary significantly in different parts of the study area. This is revealed by the average copper concentrations of granite gneiss and amphibolite in the base map sheet areas given in Fig. 12. The differences between the average concentrations shown by the different rock types are natural ones; the regional differences within one and the same rock type, however, are important for geochemical exploration.

Regional differences in copper concentrations in rocks

It is not easy to establish regional differences between rock types on account of the large variation in the differences. The copper concentrations were therefore standardized by the method suggested by Lohnes and Cooley (1968), and a new value was calculated for each sample by comparing its concentration with the average concentration and standard deviation in the same rock type, viz.

$$z_{x_i} = \frac{x_i - m_x}{s_x}$$

where x_i is the copper concentration in the sample, m_x the average copper concentration in the rock type and s_x the standard deviation in the copper concentrations in the samples of the rock type assayed for copper. The z values thus obtained are mutually comparable irrespective of rock type and form a normally distributed population for each rock type. On the basis of the z values calculated, an anomaly map (Fig. 17) was drawn on which the positive anomalies were defined to include the highest 20 % of the population (highly positive anomalies are those that include the highest 10 % of the values). The negative anomalies were defined in like manner to include the lowest 10 % and 20 % of the values. Included on the map are the predominant rock types of the area. The positive anomalies form three zones; one of them, running from Raatevaara to Heinävaara, follows the contact between the Presvecokarelidic and Karelian rocks. Note, nonetheless, that high copper concentrations occur in both the Karelian and Presvecokarelidic rocks; in other words, the copper anomalies are not associated with any particular rock type but rather with a certain area. Another zone of positive anomalies extends in a SWW—NEE direction from Hammaslahti to Aittovaara. This zone as well passes the contact between rocks of different ages and in this case, too, the anomaly is regional rather than restricted to a certain rock type. The third anomaly zone is between Huosiovaara and Heinävaara and it, too, crosses several rock types. The anomaly zones trends parallel to the most prominent tectonic lineaments in the area (see Fig. 3 p. 12) and may well be called a copper field. Beyond them the anomalies are small.

It is noteworthy that most of the negative anomalies are located in these same zones. This seems to indicate that copper ions migrated and were enriched within the zones; hence the corresponding depletion is now seen as a negative anomaly in the adjacent bedrock.

Copper concentrations in weathered bedrock

Weathered bedrock was observed at 123 sites in the study area. Most of the occurrences were detetcted in the area of Presvecokarelidic amphibolite formation (see p. 13) in the course of explorational geochemical soil sampling. Hence, although they are not ore deposits proper their copper concentrations are often anomalous.

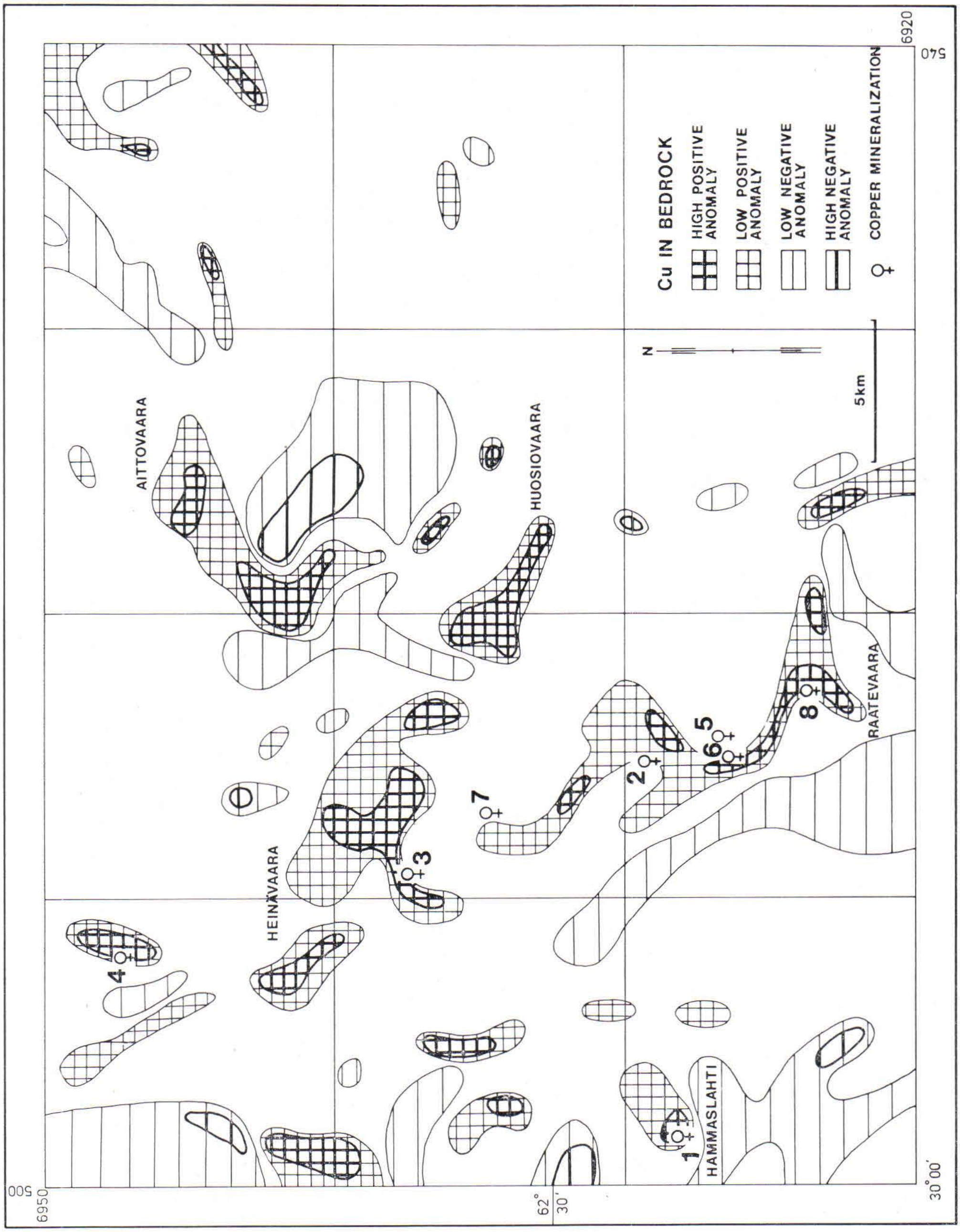

Fig. 17. The copper concentration in the Kiihtelysvaara bedrock as shown by the standardized values. The copper mineralizations numbered as in Fig. 2.

Lestinen (1980) has studied the distribution of trace elements in the weathering products of a variety of rocks in northern Finland. He noted that the copper concentration in the < 0.064 mm fraction sieved from weathered rock was markedly higher than that in the unsieved bulk sample from weathered rock or in the corresponding unweathered rocks. Table 3 shows the copper concentrations in the < 0.064 mm fractions from weathered rock types in the Kiihtelysvaara area

Table 3.
The average copper concentrations (ppm) in weathered rock types in the Kiihtelysvaara study area. 1=the > 2 mm milled fraction, 2=the < 0.064 mm sieved fraction, n= number of samples. Analysed by AAS.

Rock types	1	2	n
Presvecokarelidic			
Leptite	86.5	134.9	9
Amphibolite	132.4	131.3	59
Black schist	335.1	326.3	7
Granite gneiss	83.4	96.6	5
Karelian			
Mica schist	86.7	85.4	11

as well as those of the ground > 2 mm fractions (representing rocks not affected by chemical weathering). The differences are practically nil; the finest fraction of the weathered bedrock has not been enriched in copper as it is in northern Finland (Lestinen 1980).

This implies that the weathered bedrock so common in the Kiihtelysvaara area is only slightly chemically weathered, and that the weathering crust is younger than the Preglacial weathered bedrock in Lapland.

Lake sediment studies

Geochemical survey using lake sediments as sampling media is regional in character in that one sample represents an extensive drainage area. So that the drainage area can be outlined samples are taken from smallish lakes, less than one kilometre in diameter, or from bays in larger lakes. According to Tenhola and Lummaa (1979), small lakes of the appropriate type abound in the Kiihtelysvaara area.

With the coarse sampling grid employed in the method it is not possible to localize individual mineralizations; rather the anomalous metal concentrations in the lake sediments indicate the areas anomalous for the element to be studied, i.e. the ore fields.

The copper concentrations in the lake sediments from the study area are shown in Fig. 18 as an anomaly map on which the class limits and anomaly thresholds are at the usual percentages of 20, 80, 90, 95 and 97.5. The Raatevaara—Heinävaara copper zone stands out distinctly as an area of positive anomalies. The Hammaslahti—Aittovaara and Heinävaara—Huosionvaara zones, however, which cut the former, are shown less well. The negative anomalies are located in areas with uncommonly thick overburden. Hence, the negative anomalies do not reflect the bedrock areas of low copper content but are controlled by the thickness of the overburden; the positive anomalies, on the other hand, do coincide with the bedrock anomalies.

Stream sediment studies

As shown by the sampling site density (c. 5 sites/km^2), the stream network is dense in the Kiihtelysvaara area. It comprises the headwaters of two different waterways, between which the Salpausselkä II acts as divider. The dense network of the headwaters of the Jänisjoki waterways is located to the east of Salpausselkä II and the less dense headwaters of the Vuoksi waterways to the west of it. The flow rate in the streams is high except in some minor flat peat lands. The lakes in the northeast are over 200 m above sea level, whereas the river Jänisjoki in the southern margin of the area is only 89 m a.s.l. The average flow of water in the streams is, however, rather small and not capable of transporting heavy sediment loads. Hence the stream sediments are local and represent the soil and bedrock of the immediate vicinity.

The streams in the area are in a natural state. Even though organic sediments in particular react with heavy metal pollution (Salminen 1975), there is no observable impact of pollution on

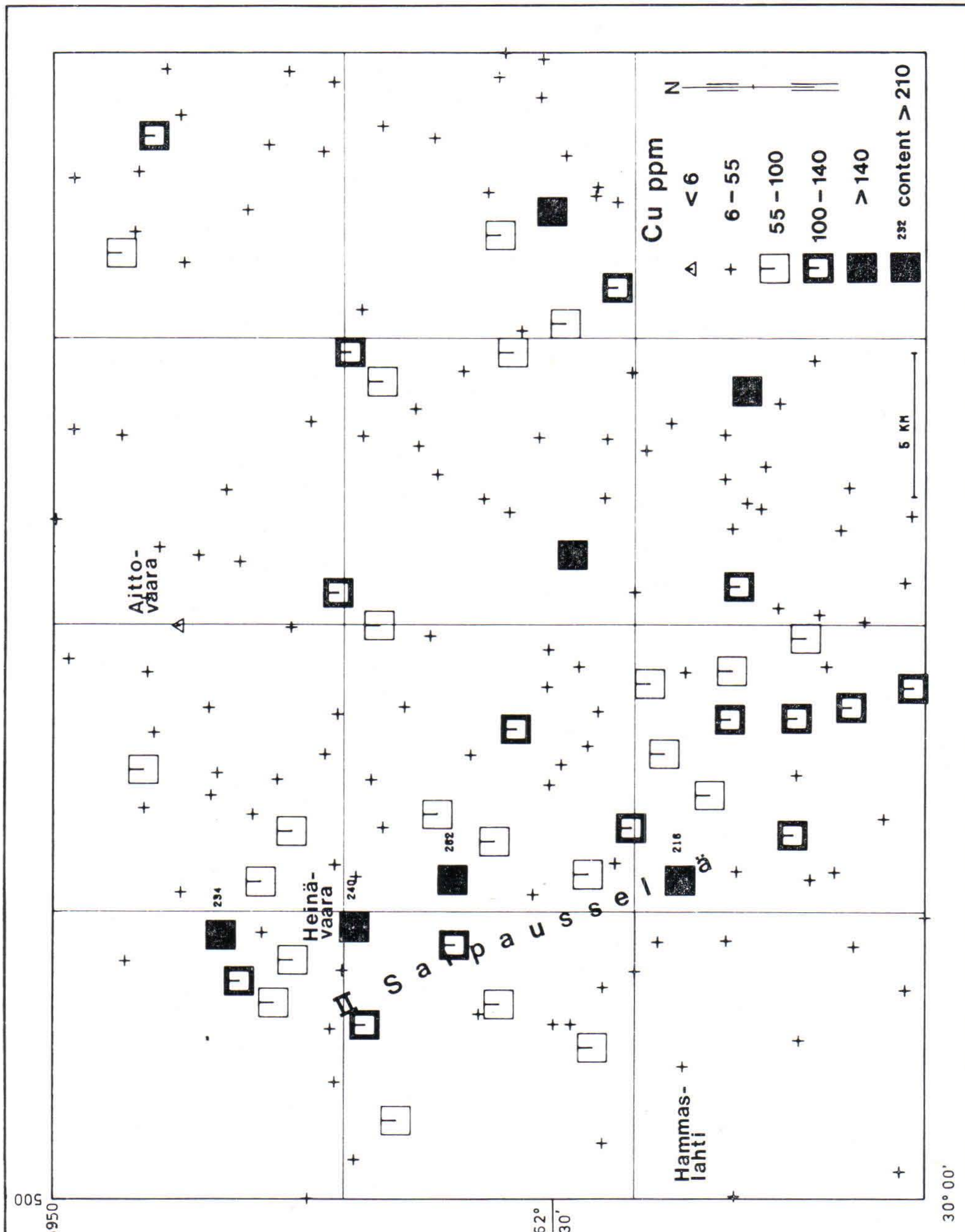

Fig. 18 The copper concentration in lake sediments in the Kiihtelysvaara area.

stream sediments in this area not even in the immediate vicinity of the Hammaslahti copper mine.

An organic stream sediment is heterogenous in physical consistency: it is mainly composed of plant debris whose grade of humification varies; it carries variable amounts of colloidal humic acids; mineral constituents are always present in variable amounts. Efforts are made during sampling to eliminate the disadvantages of this heterogeneity by compiling a sample from

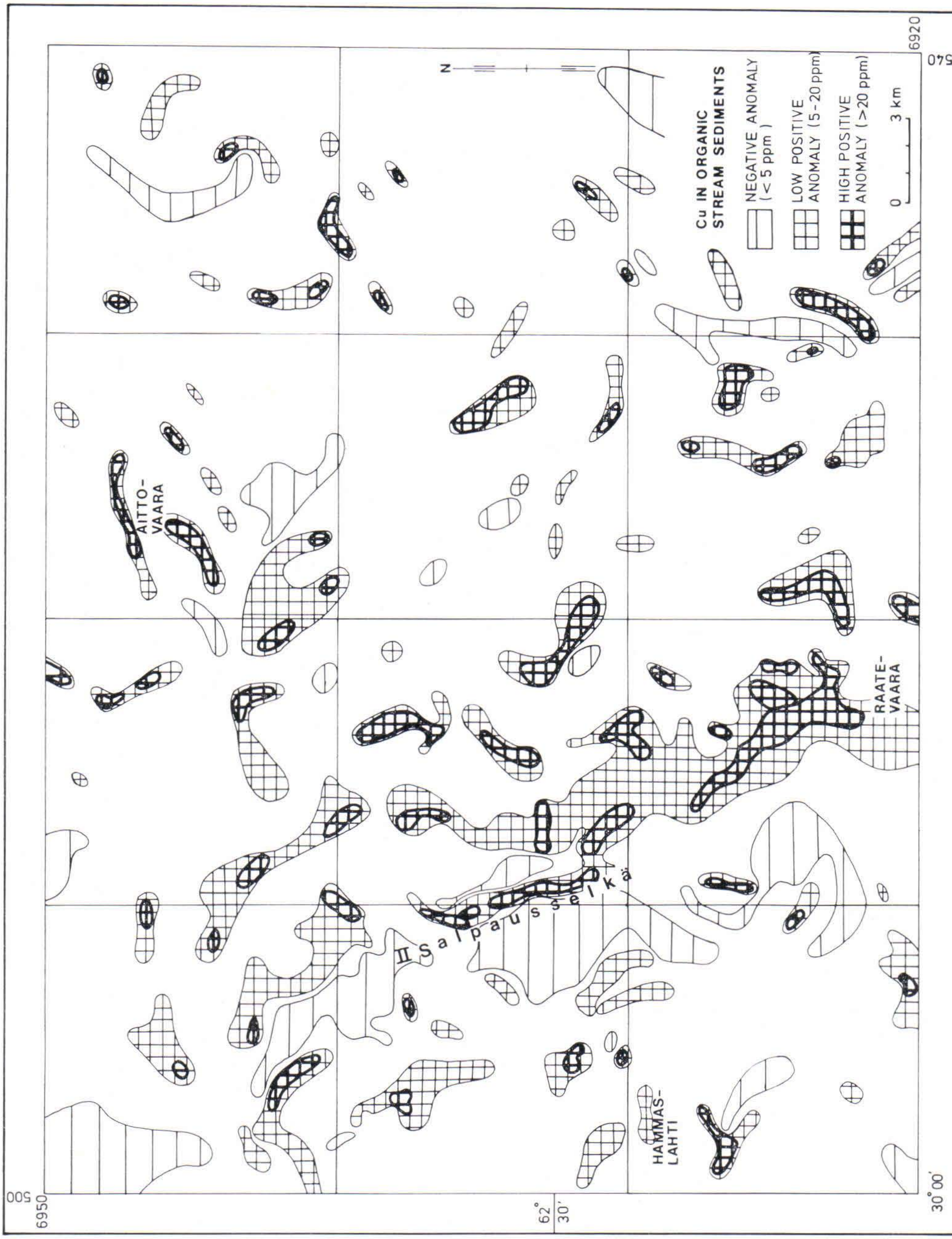

Fig. 19. The copper concentration in organic stream sediments in the Kiihtelysvaara area.

five subsamples collected from sites a few metres apart. Attempts are also made to sample material with a constant degree of humification, that is, a rather well-humified substance. The negative effect of heterogeneity — sample error — was versus kept as low as possible. Hence the results are not given sampling sites but as averages of the copper concentrations of 3 to 5 sampling sites. The averaged groups were selected on a geological basis. One group usually consists of

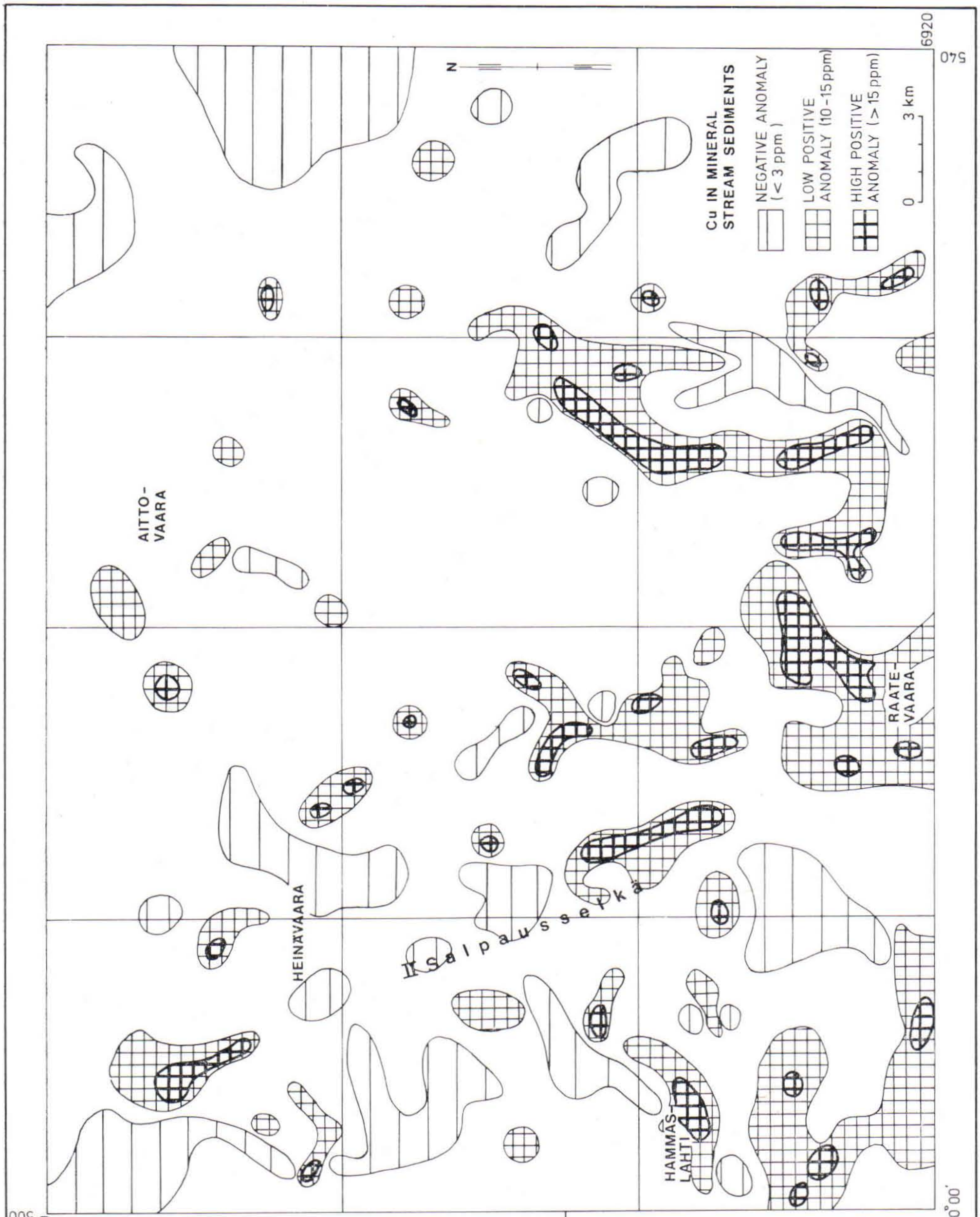

Fig. 20. The copper concentration in mineral stream sediments in the Kiihtelysvaara area.

samples collected from between two forks of a stream or from a shore of a bay in a lake. If a stream did not fork the number of samples that formed one group was restricted to include only samples taken from a stretch of the stream no longer than 1 km. On the basis of the averages thus obtained the maps were drawn with the class limits at percentages of 20, 80, 90 and 95. The isopleths referring to these anomaly limits are shown in Figs. 19 (organic) and 20 (mineral).

The anomaly map exhibits the same copper zones noted in the bedrock (Fig. 18) and with which distinct negative anomalies are associated. The anomalies of the bedrock and the organic stream sediments are not wholly analogous in shape, because the density of the sampling grid for the stream sediments was several times higher than that for the bedrock samples. Owing to the higher sampling density the map shows more details. Intense anomalies are also encountered outside the above copper field and reflect the copper concentrations in dyke rocks — mainly metadiabases.

Copper concentrations in organic stream sediments are highest at Raatevaara, where the bedrock exhibits copper abundances higher than in the environment.

Studies on restricted targets showed that organic stream sediments indicate the underlying bedrock much better than do the mineral sediments (Salminen 1979). The findings allow us to generalize that the copper contents in the bedrock are well reflected in organic stream sediments not only in terms of their location but also in terms of concentration differences.

Pedogeochemical studies

General

It was pointed out on p. 21 that the finest till fraction that incorporates copper had been transported for a short distance. It is generally accepted that the finest till fraction migrates the farthest (Levison 1974; Dreimanis and Vagners 1971). The studies supporting this point of view, however, are based on investigations of the transport distances of minerals more resistant to wear, such as quartz and feldspars (Virkkala 1971 and Perttunen 1977). The resistivity to wear of the sulphides is, however, lower than that of quartz and feldspars, and hence sulphides are presumed to be able to migrate only short distances (Lee 1971 and Garret 1971). This concept is corroborated by the data on transport distances from Palojärvi and Heinävaara.

Copper concentration in soil

Although the main task of the sampling was to take till samples from each site, other mineral soil sediments were also sampled. All the samples were handled and assayed in the same way regardless of the soil type. Table 4 lists the average copper concentrations, standard deviations and variation coefficients for fractions < 0.064 mm from different soil types. The copper concentrations in sorted soils decrease notably with the decrease in grain size. This is probably because in sorted soils copper is adsorped hydromorphically on the surfaces of the mineral grains. The grain surface area is considerably smaller in the coarse-grained soils than in the fine-grained variants. Thus, a given amount of copper ions produces a higher ion concentration per unit grain surface area than in the more fine-grained soil, and the result is an apparently high copper concentration in coarse-grained soils. In till, however, the copper concentration is mainly due to the clastic components and only subordinately to hydromorphic constituents (Nurmi 1976). In this respect till and sorted sediments differ from each other geochemically.

Table 4.

The average copper concentrations ($\bar{x}$) ppm, their standard deviations (s) and variation coefficients (v) in the < 0.064 mm fractions of a variety of soil types. n=number of samples. Analysed by OEQ.

Soil type	$\bar{x}$	s	v	n
Till	91.1	142.5	156.3	8 073
Clay	34.5	26.9	77.8	89
Silt	53.4	31.8	58.1	321
Fine sand	66.2	33.2	50.1	131
Sand	85.7	97.0	113.3	962
Gravel	100.0	63.1	63.2	433

Table 5.

The average copper concentrations (ppm) in various rock types (KA) and in the < 0.064 mm till fractions (MR) collected from the areas of these rock types. n_{KA} = number of rock samples, n_{MR} = number of till samples Analysed by OEQ.

Rock type	MR	KA	n_{MR}	n_{KA}
Mica schist	105	40	1 981	71
Granite gneiss ..	70	7	4 236	131
Granite	70	6	792	122
Amphibolite	90	30	1 119	69

Enrichment of copper in the finest till fraction

Table 5 shows the copper concentration in the rock types of the study area and in the fine till fractions collected from the areas occupied by those rock types. The difference between the copper contents in bedrock and in till is so large that it cannot be attributed to the heterogeneity of the bedrock.

The subject was studied by preparing rock samples in different ways. When a rock sample is crushed in a jaw crusher it breaks into particles in which all sizes are represented, the finest fractions included. A product like this corresponds to natural till in grain-size distribution, and the minerals are ground in it just as they are when milled by the glacier; in other words the natural resistivity to wear and the grain size of the minerals control the final degree of comminution. On the other hand, when a rock sample is milled all the minerals are forceably reduced into a roughly constant size, irrespective of their hardness.

A number of rock samples from the study area were crushed to < 10 mm in a jaw crusher. They were then ground in a centrifugal mill for periods of various length. Furthermore, the fraction < 0.064 mm was sieved from the crushed product without grinding. The samples were assayed by OEQ technique. The data are listed in Table 6. The length of the grinding had little effect on the results, which are comparable to those obtained previously (Table 2, p. 29). The samples sieved from the crushed products,

Table 6.

The average concentrations (ppm) in ground samples from some rock types and in sieved samples from crushed rock. 1. metadiabase, 2. granite gneiss, 3. amphibolite, 4. black schist, 5. mica schist. Analysed by OEQ.

	1.	2.	3.	4.	5.
Ground samples	170	5	82	57	5
Crushed samples	305	62	216	169	85
Number of samples	1	3	1	3	1

however, showed different values, the concentrations being many times higher than in the ground samples. Moreover, the ground samples and the samples sieved from the crushed products were very different in concentration, depending on the rock types. Copper is liberated from metadiabase clearly less readily than from the other rock types studied; on the other hand, it is liberated very easily from granite gneiss and mica schist into the fraction < 0.064 mm. The copper concentration in the crushed product is close to that of the till derived from the same rock type. This suggests that chalcopyrite (copper exists predominantly as chalcopyrite in rocks) is liberated readily from rocks in the glacial mill, that it is reduced rapidly in grain size and that it remains in basal till close to its source.

Copper anomalies in till

Since the transport distance of till is short (p. 21), one would expect the differences in the trace element contents in bedrock — due to both

Table 7.

The medians (m), averages ($\bar{x}$) and standard deviations (s) of the copper concentrations (ppm) in the < 0.064 mm till fractions from different lithologic areas. n = number of samples. Analysed by OEQ.

Lithologic areas	m	$\bar{x}$	s	n
A. Mica schist	104.9	105.2	42.1	1 981
B. Granite gneiss near mica schist	75.7	80.7	51.8	1 226
C. Amphibolite	81.8	91.1	70.0	1 119
D. Uramo granite	70.0	73.1	28.2	292
E. Aittovaara granite gneiss	62.7	66.4	32.2	680
F. Loitimo granite ..	64.1	68.9	60.0	500
G. Tuupovaara granite gneiss	56.0	58.8	34.5	2 330

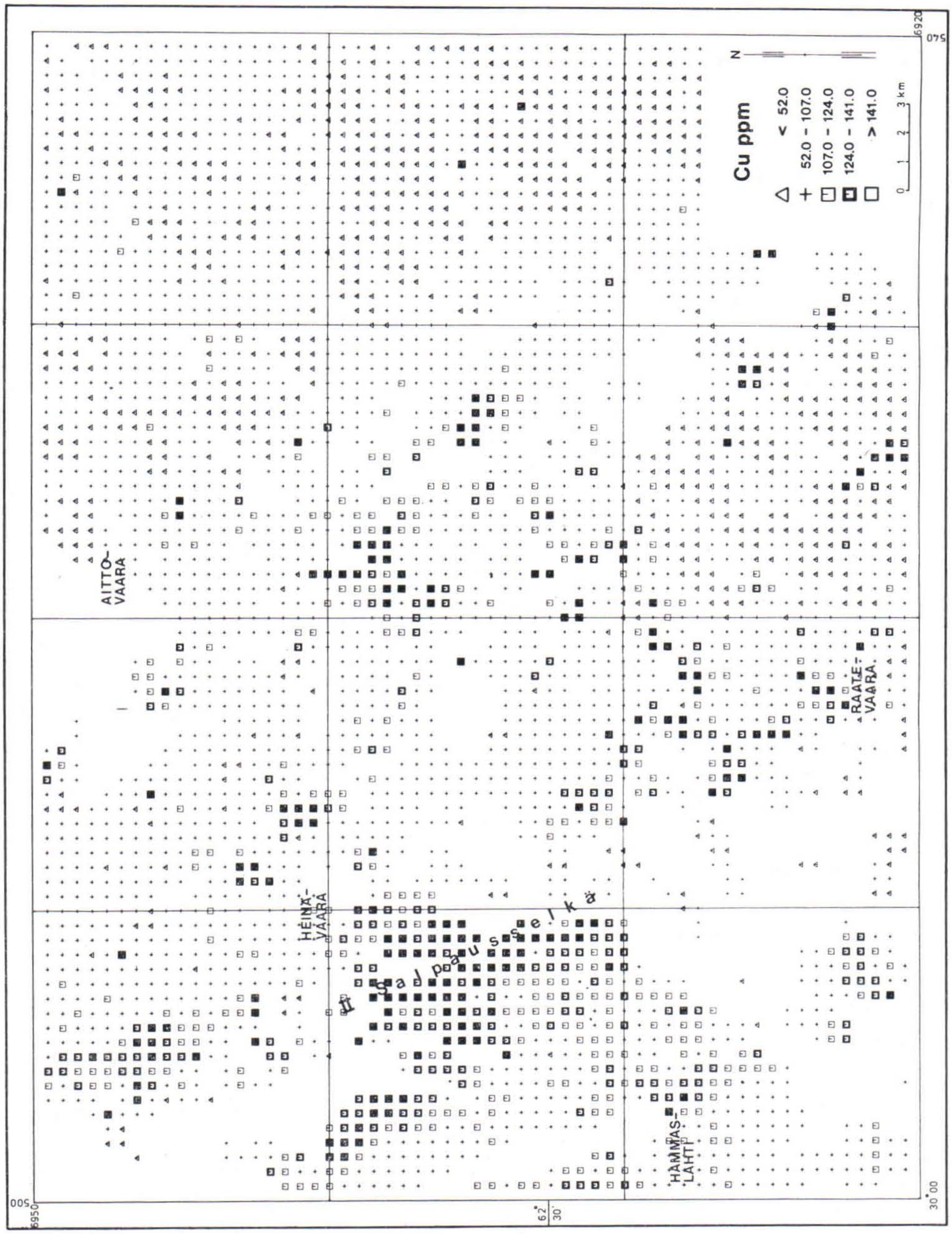

Fig. 21. The copper concentration in till in the Kiihtelysvaara map sheet area. The analytical data interpolated. The class limits determined on the basis of pooled data.

rock types and mineralizations — to be reflected distinctly in the metal concentrations in till. The data could of course be standardized as in the bedrock samples (p. 30) to filter out the variation in concentration level due to rock types. The metal contents in till, however, are also affected by other factors, e.g. the degree of homogeneity and thus there is no justification for standardizing the till samples data. It would be unnecessary in any case, because the areas with anomalous copper abundances had already been outlined by stream sediment survey.

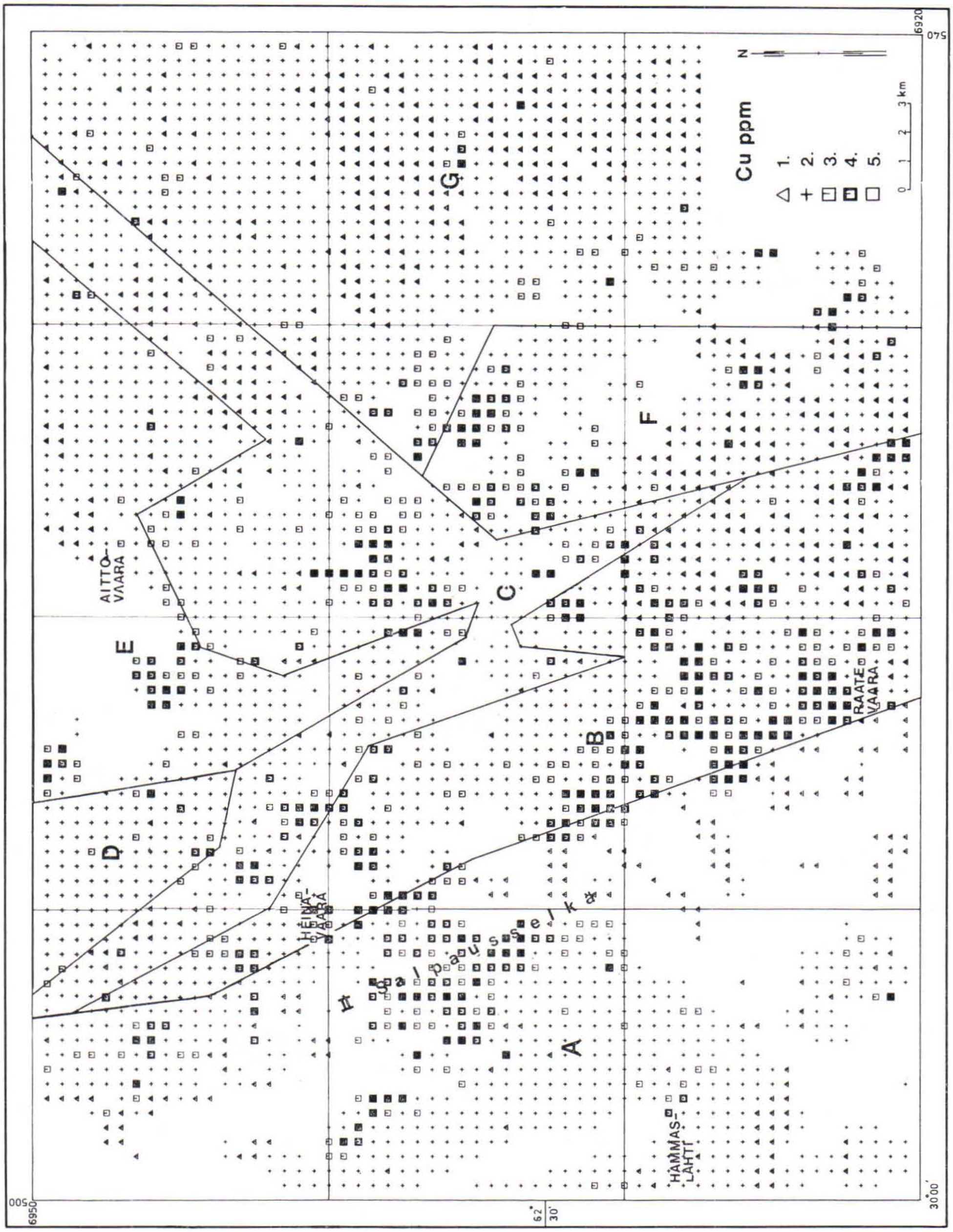

Fig. 22. The copper concentration in till (ppm) in the Kiihtelysvaara map sheet area (4241). The data interpolated. The class limits determined separately for each lithological area:

Rock types	1.	2.	3.	4.	5.
amphibolite area (C)	< 66	66—112	112—130	130—152	> 152
granite gneiss area (B + E + G)	< 44	44—90	90—104	104—120	> 120
mica schist area (A)	< 81	81—132	132—146	146—157	> 157
granite area (D + F)	< 43	43—96	96—111	111—128	> 128

The average copper concentrations in the rock types in the study area are very different from each other (Table 2). Likewise, the tills in the areas of different rock types differ from each other in copper content (Table 7). Thus, when the anomaly limits for the pooled data are calculated on a conventional basis the anomaly map mainly reflects the bedrock of the area; the anomalies caused by possible mineralizations, low in concentration and small in size, are lost in the geochemical landscape produced by the rock types and by the variation in sample and analytical errors. Since, as pointed out earlier, copper is liberated from the rocks in different ways, each lithologic unit should be treated separately, unless even smaller units are required for explorational or other purposes.

The copper anomaly map of the study area shown in Fig. 21 was compiled with the aid of the interpolated data (p. 29), the class limits being set at percentages of 20, 80, 90 and 95 %. A conspicuous anomaly is visible in the mica schist area, partly in the till cover of Salpausselkä II and partly in basal till. In the area of the Presvecokarelidic basement complex the anomalies are weaker and occur mainly within the amphibolite formation. The exception is the anomaly in the area of the Raatevaara—Heinävaara copper field, which, although not very marked, is still distinct. Individual anomalous points due to metadiabases occur elsewhere within the basement complex. The anomalies in the figure reflect quite correctly the average differences in concentration between the rock types, although the Raatevaara—Heinävaara zone with its several copper mineralizations cannot be distinguished from the »rock-type anomalies».

Fig. 22 shows an anomaly map on which the data are divided into the lithological units. The class limits were calculated for each unit on the basis of the percentages, and the whole data were then united. The large copper anomaly in the mica schist area is now reduced and subdivided into separate anomalies that presumably reflect the anomalous copper concentrations in the rocks, i.e. the copper mineralizations (e.g. the anomaly due to the Hammaslahti ore deposit shows up). Likewise, the copper anomalies caused by the Raatevaara—Heinävaara copper

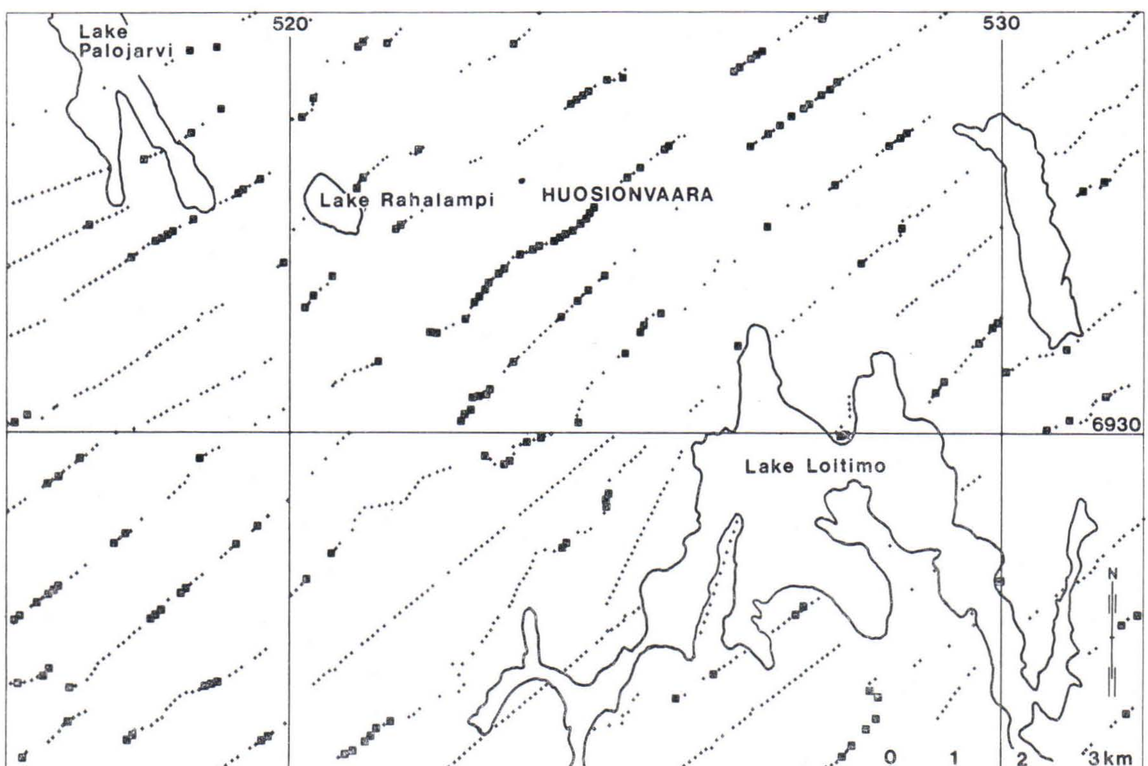

Fig. 23. The copper anomalies in the < 0.064 mm till fraction in the Huosiovaara study area.

field and the Hammaslahti—Aittovaara copper field are much more distinct. Thus, the anomaly map drawn on the basis of the data processed in accordance with the rock types compares better with the map showing the copper concentration in the bedrock on p. 31 than does the anomaly map compiled in the conventional way by using the pooled data of the whole map sheet (Fig 21).

Classification of the anomalies on the basis of metal ratios

Chalcopyrite-bearing metadiabases abound in the Kiihtelysvaara area. Although the grade might meet the requirements of an economic ore deposit, chalcopyrite occurs so sporadically and the total tonnages are so low that the metadiabases are currently without explorational importance (Pekkarinen 1976). Nevertheless, the copper-bearing metadiabases give rise to numerous anomalies on the geochemical copper maps. Hence, means were sought to eliminate the copper anomalies due to metadiabases from the maps on the basis of analytical data.

The Huosiovaara area with its numerous copper anomalies (Fig. 23) was chosen for detailed investigation. Covering some 176 km², it is located between Palojärvi and Loitimojärvi in the middle of the study area. Some of the anomalies were known to be due to the copper-bearing metadiabases and some to the chalcopyrite-disseminated amphibolites of the Presvecokarelidic basement complex. The average chromium content in amphibolite was almost 300 ppm whereas in metadiabase it was less than 10 ppm (Table 8). Both rock types exhibit

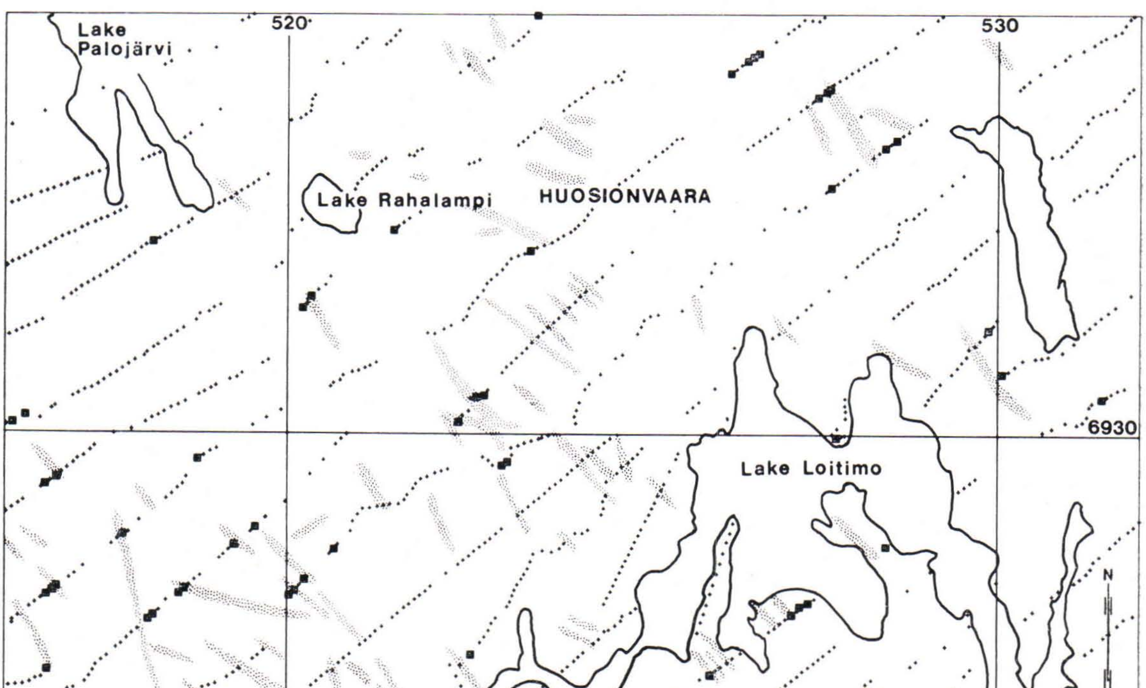

Fig. 24. The copper anomalies due to diabases (■) in till samples from the Huosiovaara study area.

Table. 8.

The averages ($\bar{x}$) and standard deviations (s) of the chromium and copper concentrations in metadiabases and amphibolites. n=number of samples. Analysed by OEQ.

Rock types	Cr		Cu		Cr/Cu	n
	$\bar{x}$	s	$\bar{x}$	s		
Metadiabase	6.7	3.2	90.2	60.9	0.07	19
Amphibolite	285.7	153.2	63.6	33.7	4.48	11

moderate copper contents even without anomalous chalcopyrite abundances. Also shown in Table 8 are the Cr/Cu ratios, which for the amphibolite is 4.48 and for the metadiabase 0.07.

Fig. 23 depicts the copper anomalies in the Huosiovaara area (the anomaly threshold was 106 ppm corresponding to the value at Σ % 80). The Cr/Cu ratio was calculated for these copper anomalous samples. The amphibolite and diabase samples were distinguished from each other by subdividing them into two classes with the Cr/Cu ratio 0.75 as the limit between them. Fig. 24 exhibits the anomalous points of Fig. 23 that have a ratio less than 0.75, that is, copper anomalies produced by metadiabases. Marked on the same figure are the metadiabase dykes that are known to exist in the area (Nykänen 1971a and Kallio 1976). It is seen that most of the anomalies are located on or in the immediate vicinity of the metadiabases. Some anomalies do not seem to be associated with any of the known metadiabase dykes. There are, however, more metadiabase dykes in the area than could be marked on the small-scale lithological map (Kallio 1976) and hence all the anomalies can be attributed to metadiabases.

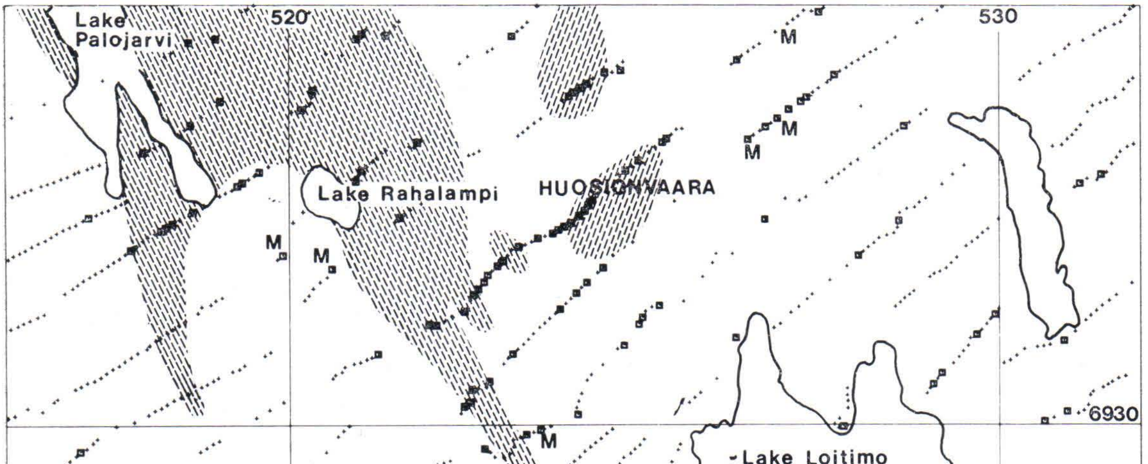

Fig. 25. The copper anomalies due to amphibolite (■) in till at Huosiovaara. Hatched areas refer to known amphibolite occurrences (Nykänen 1971 and Kallio 1976). M=an anomaly on the aeromagnetic low-altitude map outside the amphibolite area.

The sites whose Cr/Cu ratio exceeds 0.75 and whose copper concentration is anomalous are shown on Fig. 25. Most of the sites are located on the known amphibolite formation. Some of the anomalies, however, occur in areas that do not show amphibolite in exposures but which on the low-altitude aeromagnetic maps, have magnetic anomalies, that are probably attributable to amphibolite. Hence in this area the samples that show an anomalous copper concentration and whose Cr/Cu ratio exceeds 0.75 derive from the amphibolite formation.

DISCUSSION

Ore deposits are seldom discovered by geochemical survey alone. Only in areas where the in-situ weathering products of the bedrock can be sampled, can geochemical methods be expected to lead directly to the discovery of underlying ore mineralizations. In glaciated areas, however, the geochemical data have to be interpreted and the interpretation relys on the assessment of all the geological information available.

The importance of bedrock data

The geochemical anomalies obtained by routine statistic methods can only be classified into the explorationally significant and nonsignificant, and the anomalies due to a certain rock type can only be sorted if we know the distribution of the trace elements in the bedrock of the study area and the differences between the trace element ratios in the different rock types. In the present study basic information of this kind was employed to discriminate between explorationally less important copper anomalies due to metadiabases and other copper anomalies. The Cr/Cu ratio, which in the study area was invariably markedly lower for diabases than for other rock types, proved to be an effective discriminating factor (p. 41). This characteristic feature of diabases was also noted in till samples collected from the vicinity of the metadiabases.

The trace element concentrations, however, vary regionally even within a given rock type and mineralization. Hence, the trace element concentrations and their ratios must always be handled target-wise particularly when applying geochemical survey to exploration. Oversimplified application of old data may lead to wrong conclusions.

The distribution of the trace elements in the rock types and in the subareas must be known when those areas are outlined whose data are treated as a unit. The variation in metal contents between rock types also causes variation in the trace element concentrations in till. In the Kiihtelysvaara area, for example, the copper content in till averaged 105 ppm in the mica schist area and 70 ppm in the granite gneiss area. If the data from lithological units are treated together the anomalies accumulate in the mica schist area. Although this portrays the difference between the rock types, the result may be misleading for exploration.

In comparisons of the copper contents in till derived from different rock types we noted that copper is not always liberated from rock to till in the same way (p. 37). Thus, in relation to the copper contents in the rocks about five times more copper is liberated from granite and granite gneiss than from amphibolite to the < 0.064 mm till fraction.

To maximize the usability of the geochemical data, the geophysical data must also be taken into account in the interpretation, because they contain information relevant to the properties of the bedrock covered by overburden.

When the bedrock in covered areas is being mapped, far-reaching conclusions concerning the distribution of the rock types can be drawn by joining the geophysical and geochemical results. A case in point is Palojärvi (p. 22). The geochemical results can also be used to classify the geophysical anomalies according to explorational significance.

The simultaneous use of different sample types

The use of different sample types in geochemical survey gives us results that are of different character but that, when joined, complement each other. Lake sediment survey is applicable to regional studies over vast distances in the search for areas anomalous for copper. To use this method, however, there must be a sufficient density of lakes of the appropriate size.

Stream sediments allow a denser and more regular sampling grid than do lake sediments, particularly in the headwaters of river systems where small streams abound, as in the Kiihtelysvaara area. Stream sediments notably enhance the details in the geochemical »landscape» delineated by the lake sediments but which owing to the coarse sampling grid is rather generalized. Organic stream sediments and lake sediments are often similar in geochemical character; the most prominent difference between them is that the lake sediments are taken from beyond the active littoral zone.

The variation in the copper content in organic sediments reflects well the variation in the copper content in the bedrock. In contrast, the results obtained from the mineral stream sediments were difficult to interpret.

Till has turned out to be the best sampling material in detailed studies. If the anomaly limits are determined in routine fashion on the basis of sample data from an extensive area, the anomaly map illustrates the lithological units that differ from each other in geochemical characteristics, provided that the Quaternary geological conditions are similar throughout the area. If ore mineralization anomalies are aimed at, special attention must be paid to outlining the area. Quaternary geological factors and the geochemical characteristics of the bedrock must also be carefully established.

The importance of Quaternary geological data

In addition to the geochemistry of the bedrock the Quaternary geological conditions should always be established in survey. It is imperative to determine the transport distance for till so that the location of possible mineralizations can be estimated. The classic studies on the transport distance of pebbles in till are not enough for interpreting geochemical data; the studies on transport distance must be directed at the fraction being analysed. For the finest fractions it should also be noted that ore minerals are ground markedly more easily and quickly than are quartz and feldspars, which predominate in these fractions as well. The transport distance of the till fractions studied in the Kiihtelysvaara area was found to be significantly shorter than that reported from southern and western Finland (Virkkala 1971 and Perttunen 1977). The transport of the fraction < 0.064 mm, which was studied by means of the copper concentration, was found to be 500 to 600 m outside the area of the marginal formation.

The transport distance of till is generally expressed as the halfdistance of transport of a certain rock type. The geochemical data can, however, be interpreted by examining the distance over which the material to be studied attains its maximum abundance in till. The distance is measured from the proximal contact of the material being studied. In this way the transport distance can be determined accurately, because the maximum abundance is reached over a short distance while the falling of the abundance to the background value takes place gradually over a longer distance.

The area of marginal formations is seldom suitable for geochemical soil studies (Salminen and Iisalo 1978) because till and glaciofluvial sediments are intermixed to such an extent that the advance direction and the transport distance of till are difficult to establish. Furthermore, the overburden is exceptionally thick. Although till survey in the area of the Kiihtelysvaara marginal formations produced data difficult to interpret, the variations in the copper concentrations in bedrock are satisfactorily reflected in the organic stream sediments.

In studies on till stratigraphy the beds can be distinguished from one another by their geochemical characteristics, provided the beds derive from different bedrock areas. Mixing and diluting prevent the analysis of the finest till fraction from indicating clearly the source of the matter. Nevertheless, by studying the trace element ratios in one or more rock types, as was done at Heinävaara (p. 25), the source can be pinpointed a higher probability. Do not forget, however, that in each study area these metal ratios — the factors — must be selected on the basis of the geochemical character of the area.

In interpretations of geochemical data the framework is provided by the general geochemical relationships; the final touch, however, can only be given if we take into consideration the special features of each area. The lithological and geophysical data are of great use but it is the Quaternary geological conditions of the area that must be studied the most carefully. Without detailed knowledge of soil stratigraphy and glacial transport directions the geochemical data can only be partially interpreted.

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