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Application of geochemical methods
to regional prospecting in Finland

by Heikki Wennervirta



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APPLICATION OF GEOCHEMICAL METHODS TO
REGIONAL PROSPECTING IN FINLAND

BY

HEIKKI WENNERVIRTA

WITH 41 FIGURES AND 25 TABLES IN TEXT AND ONE APPENDIX

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ABSTRACT

The study deals with the possibility of applying stream sediment, soil and ground moraine sampling to areal geochemical prospecting in glaciated regions. Locally defined geochemical anomalies were chosen as the basis for treating the geochemical data. Attention is also paid to the construction of an optimal sampling grid for the discovery of anomalies. The treatment of the observational data is carried out in such a way that they can be processed with a computer. The results include, in addition to maps, also some statistical parameters of geochemical prospecting. The methods developed were tested in different kinds of areas and four case histories are given in the study. Further, an attempt was made to compare the results of areal geochemical prospecting with each other in order to achieve a better understanding of the potentiality of areal geochemical prospecting. The conclusion is reached that the studied methods can be applied to areal geochemical prospecting with some restrictions. However, the results must be taken only as indicative.

PREFACE

Methods of applied geochemistry are becoming increasingly prevalent in prospecting. Some geochemical methods are growing conventional while others are still at the experimental stage. Future development will surely produce methods which as yet have not even been tested. The present study deals with topical problems concerning geochemical prospecting in Finland.

Excluding some references, the material used in this paper originates from studies carried out by the Exploration Department of the Outokumpu Co., mainly since 1962. Thus the material has accumulated gradually. In the course of time, sampling and analytical methods have changed. Also the methods of data processing have progressed. The heterogeneity of the material is due to the changes which took place during the work. This is apparent also in the study in spite of the fact that only selected data have been presented.

Permission to publish this paper was given by the chief geologist of the Outokumpu Co., Dr. Paavo Haapala. Professor V. Marmo, Director of the Geological Survey of Finland, kindly arranged the publication of this paper in the Bulletin of the Geological Survey. The assistant chief geologist of the Outokumpu Co., Dr. V. O. Vähätalo, and the director of the Exploration Dept., Mr. Pauli Isokangas, aided me with their advice. The discussions with Dr. T. A. Häkli have been of great value. He also checked the English translation of the paper.

Professor Kalervo Rankama, of the Institute of Geology and Mineralogy at the University of Helsinki, guided my work and helped me in various ways. The computer programs, which were not available as ready applications, were made by Mr. Matti Kataja, in the State Computer Centre. Moreover, Mr. Kataja helped me to process the data statistically.

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Outokumpu, September 1967

Heikki Wennervirta



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INTRODUCTION

The use of geochemical methods in ore exploration can be considered as having started in the 1930's but only since the late 40's have they become prevalent. In Scandinavia, the first geochemical experiments were carried out in 1936 (Brundin, 1939) and in Finland in the late 30's (Rankama, 1940). Geochemical methods were tested in Norway a little later (Vogt, 1947). Since the beginning of the 1950's, pedogeochemical investigations have predominated in geochemical exploration in Finland. The starting point for these investigations was the observation that in those places where ore boulders appear in the moraine, also the finegrained portions of the moraine show an anomalous trace metal concentration. By analysing the trace metals, the limits of the boulder trains could be located with greater precision than on the basis of boulders often to be found only by chance. The area covered by trace metal anomalies was called a micro boulder train (Hyvärinen, 1958; Kauranne 1958, 1959). The method was also tested on an areal scale in the search for new indications (Tavela, 1957). Similar pedogeochemical exploration has been carried out in areas affected by glacial ice outside Finland, for example in Canada (Dreimanis, 1960) and in Norway (Bölviken, personal communication). In areas covered with residual overburden, pedogeochemical exploration has been employed successfully for the direct localisation of ore outcrops. In the glaciated regions, similar experiments have not always led to equally good results (Kauranne, 1959; Dreimanis, 1960).

The analysis of peat samples was tested in geochemical exploration on swamp areas (Salmi, 1955, 1956, 1959; Hawkes and Salmon, 1960). However, it seems that the use of turf as a material suitable for geochemical sampling has not been established as yet. The suitability of ground water for exploration purposes has also been studied in Finland (Marmo, 1958b), and some biochemical methods have been tested (Marmo, 1950, 1953, 1958a).

The methods mentioned above were used mainly for the study of local objects. For the localisation of new ore indications, those methods on which the most thorough experiments have been carried out are based on water assaying, stream sediment analyses and the geochemical study of the bedrock (Ginzburg, 1960; Hawkes and Webb, 1962). The stream sediment and water studies are closely connected with each other as far as their principle and application is concerned. However, any comparison of the methods has generally led to a preference for stream sediments (Warren and Delavault, 1959; Bloom, 1960).

Probably the first experiments using the stream sediment method can be considered as having taken place in USSR during the 1930's. In other countries, the method was not accepted for large scale use until 1954 (Hawkes and Bloom, 1956). The New Brunswick area in Canada served as a testing ground (Hawkes and Bloom, 1956; Fleming, 1961) and the positive results obtained there gave rise to the rapid spread of the method all over the world. In Scandinavia, the method was first brought into use in Norway, where stream sediment investigations have been carried out on a large scale since 1958, especially in the northern parts of the country, in the Pre-Cambrian areas of Inner Finnmark (Bölviken, personal communication).

The recent development of geochemical exploration in USSR is well depicted by the reports of the Interregional Seminar held in 1965 (Beus, Beus and Yanishevsky, Glazovskaya, Yanishevsky, 1965). These reports show that geochemical exploration is in wide use in USSR. The most common methods are based on stream sediments, drifts and solid rocks. To meet the requirements of prospecting, a number of applications are carried into effect from large scale mapping to very detailed local investigations.

In many countries, e.g. in France (Sakowitsch, 1965), two main trends in the use of geochemical methods are becoming increasingly prominent: regional and local exploration. The former aims at the discovery of new ore indications while the latter deals with the interpretation of the discovered indications.

In the present study, emphasis has been laid on regional methods of geochemical prospecting and attention has been paid to stream sediment, soil and moraine exploration. The paper elucidates the purpose and suitability of these methods under the conditions prevailing in Finland.

A great deal of information exists concerning methods of geochemical prospecting but noticeably less concerning the processing and presentation of the observations. These items have been treated in a general way by Hawkes and Webb (1962), Beus (1965) and Glazovskaya (1965). Smirnov (1963) has developed a detailed system for the determination of the geochemical background. Langford (1965) has treated geochemical rock sampling with special attention paid to the optimum result. He has also derived statistical definitions for geochemical anomalies. Müller-Kahle (1966) has used frequency distributions for concentration classification. The importance of frequency distributions for the interpretation of results has been discussed by Tennant and White (1959) and Brinck and Hofmann (1964). Bondarenko (1964) has investigated the significance of linear regression equations and correlation coefficients for the interpretation of geochemical data. The lively discussion which has taken place recently concerning the models of the frequency distributions of the trace-elements has dealt roughly with the same matters (e.g. Ahrens, 1954, 1963a and b; Vistelius, 1960).

In recent years automatic processing has been applied increasingly to the treatment of geochemical data. The aim appears to be to increase the information concealed in the geochemical data. Various trend- and residual-surfaces have been employed for

this purpose (Agterberg, 1964; Connor and Miesch, 1964; Nordeng and others, 1964). Also Fourier methods of analysis have been applied by some authors (Harbaugh and Preston, 1965). In Finland from 1965—1967 a committee selected by the Vuorimiesyhdistys — Bergsmannaföreningen r.y., Finnish association of mining engineers, investigated the possibilities of employing automatic processing for geochemical data. In addition to increasing the amount of information, the committee studied problems concerning the automatic processing of data and the representation of results (Vuorimiesyhdistys, 1967).

In the present study, special attention is paid to the processing and presentation of geochemical data for three reasons. The application of automatic data processing to the modification and presentation of the geochemical information requires logical models. Automatic data processing permits the computation of various statistical parameters. These are needed for the determination of geochemical anomalies and they are of importance when the data of the different areas are compared with each other.

THE METHODS

Stream sediment study

Hawkes and Bloom (1956, p. 1122) have defined the components of the stream sediments as follows:

1. Rock fragments.
2. Primary resistant minerals.
3. Secondary minerals formed at the site of weathering of rocks and ores.
4. Inorganic matter precipitated from stream water solutions.
5. Inorganic matter withdrawn from ionic solution by living organisms and by the formation of organic complexes.
6. Exchangeable ions in relatively active equilibrium with the aqueous solutions in contact with the sediment.

Hawkes and Bloom point out that the material of the first three groups is transported in water mainly as clastic particles, whereas the matter of the last three groups migrates as aqueous solutions.

There are many factors influencing the formation of the stream sediments. Varying amounts of different matter, also biogenic, accumulate in the stream sediments. The usefulness for exploration of the material drifting in the waterways and deposited on their banks is based on the fact that the trace-metal anomalies have stretched in the direction of the sampling line, so that they can also be found with a sparse sample net.

The formation of the stream sediments depends on the geochemical migration of the matter and on the environment in which this migration takes place. Consequently it

is advantageous if the geochemical transportation of the material is rapid and if as much matter as possible from the bedrock takes part in it. This involves prominent weathering and a dense network of lakes and rivers as well as a distinct relief in the terrain.

In Finland, the differences in altitude are almost invariably small, i.e. the flow of the water and the suspended particles in it is slow. In general, no local residual overburden is encountered and the surface of the crystalline rock is fresh. The bedrock is covered by moraine or by other glaciogenic or postglacial deposits. The network of rivers is fairly sparse, and moraine as well as other deposits are porous. Considerable amounts of water seep into the ground. The ground water table is generally near the surface. In addition to the material from the bedrock, stream sediments also obtain matter from mechanically disintegrated moraine. Consequently, it can be expected that the conditions in this country are unfavourable to the use of the stream sedimentary method and that the possible anomalies perhaps mainly reflect the corresponding anomalies in the moraine instead of indicating the variations of the metal contents in the bedrock.

Sampling

The sampling has been carried out according to the following instructions:

The stream sediment samples are taken from the shores of rivers or lakes at a distance of 250 metres from each other. Also the periodic beds of brooks are sampled. No samples are taken from ditches. Two samples are taken, one from either side of a river at points opposite to each other. At the confluence of two rivers, separate samples are collected about 10 metres up the river from the confluence. On the shores of lakes only one sample is taken at a certain place. However, two samples are extracted from the borders of springs. The samples are taken from as close to the border line of the water as possible. In case there is vegetation at this border line, the samples are collected from the soil immediately beneath the roots of the plants. The samples should contain as much minerogenic material as possible and they should weigh from 250 to 500 g. If the soil is rich in biogeneous material, a bigger sample must be taken. The symbol of the exploration area and the number of the sample have been marked beforehand on the bags. The samples are numbered in such a way that the sample pairs are given adjacent numbers and the even numbers correspond to the samples taken from the right bank of a river when viewed upstream. Correct numbering is important because it permits the marking of the direction of the flow of water on the geochemical map.

The following observations are recorded at the sampling site.

1. Estimated width and depth of the river.
2. The rate of flow according to the following scale:
 - 1) stagnant, 2) slow-flowing, 3) swift-flowing, 4) very swift-flowing, 5) rapids.

3. The sampling site with regard to the water level:
∩ = sample from above the water level, — = sample from the water level,
U = sample from beneath the water level.
4. The type of drift in sample: gravel, sand, silt, till, clay, mud, sapropel and peat.
5. The drift in the surroundings of the sampling site: boulder- strewn land, till, gravel, sand, silt, bog, etc.
6. Sampled ore boulders, if present; boulders of black schist are recorded as well as some other facts which may be of importance to the exploration.

Moraine and soil study

Ground moraine is built of unsorted drift which has been transported under the glacier or in its lower part. The till contains varying amounts of heterogeneous components packed tightly together. As a result of movement, the pebbles have oriented in the till, although laminated bedding is also sometimes encountered in it. The top of the moraine, however, is less compact and the bedding, due to the fine sand and silt intercalates, is more common than in the moraine proper. In this study, soil means not only the normal top part of the moraine but also its altered superficial part and especially its podzolized part. The pebbles in the till are usually relatively local depicting the bedrock underneath. The study of pebbles and the search for ore boulders in the till is indeed one of the oldest methods of ore exploration (Sauramo, 1924; Saksela, 1949; Aurola, 1955). However, the linking of pedogeochemical exploration to the search for boulders took place fairly recently (p. 7).

When finding out the reasons for moraine anomalies, it was observed that the anomalies had been caused by the abundant ore mineral-bearing material released mechanically from the bedrock and transported by glacier. In the following, anomalies formed in this way will be called glaciogenic anomalies (formerly known as micro boulder anomalies). Geochemical anomalies which are not glaciogenic are also encountered in moraine. In order to establish the various anomaly types, moraine studies were done on the known ore outcrops. The results of these studies are presented in Fig. 1. In this figure, anomalies 2 a and 2 b as well as anomaly 4 are of glaciogenic type. The anomalies have oriented parallel to the direction of movement of the glacier. Anomalies 2 a and 2 b represent the same survey area with the distinction that Fig. 2 a depicts an anomaly in the C horizon of the moraine and Fig. 2 b an anomaly in the B horizon of the moraine. Anomalies 3 and 5 represent the so-called hydromorphic type, which arose as a result of chemical weathering. The location and shape of the anomalies is controlled by the topography of the terrain. Anomaly 6 is called sedentary without any reference to the mode of genesis, however. Anomaly 1 is of mixed type, possibly possessing features from all the forementioned anomaly types. In the planning of the pedogeochemical sampling and in the interpretation of the data one should be ready to take all of those anomaly types into consideration.

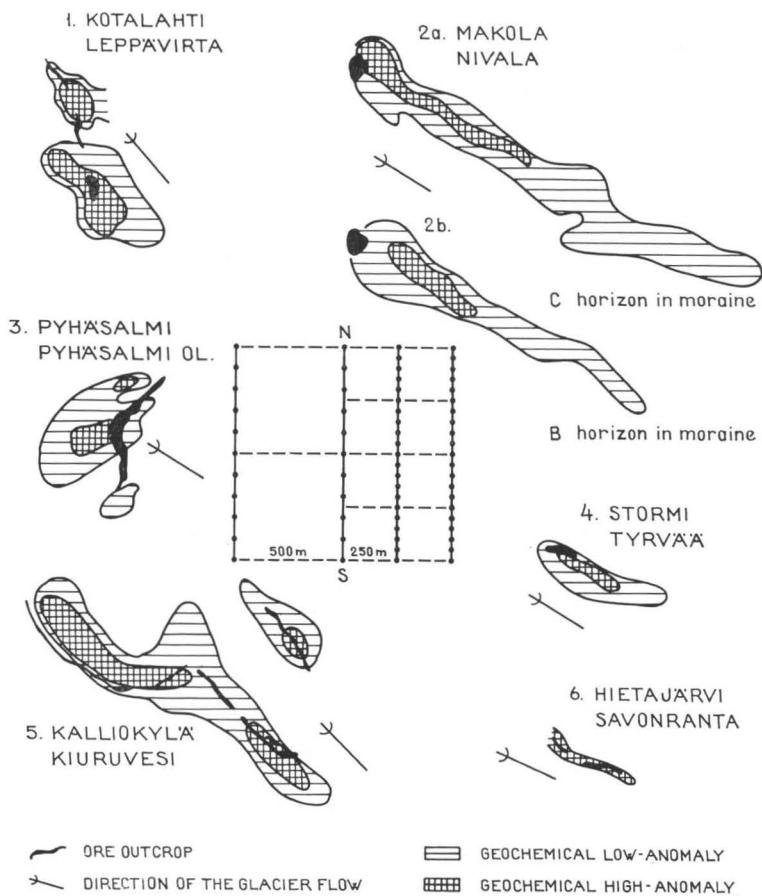


FIG. 1. Some examples of different geochemical anomaly types in moraine. In the centre of the figure, the sampling grid generally used in survey is depicted. The line spacing (D) is either 500 m or 250 m and the point spacing (H) either 100 m or 50 m. The most common bearing of the sampling lines is either N—S or E—W.

The question of the size and shape of the anomaly is also connected with sampling. As can be seen from the examples, the anomalies may be very different in shape and size (Fig. 1 and Table 11), yet the long axis of the anomalies is often either parallel to the strike of schistosity of the bedrock, the major axis of the ore outcrop or the direction of transport of the glacier. The question of the setting up of the optimal sample grid in the search for anomalies is discussed in detail on pages 29 to 32.

Another essential question in the moraine and soil studies is the sampling depth. It is known that during the formation of moraine, conditions varied both in time and place (Saksela, 1949; Okko and Peltola, 1958; Gillberg, 1965), the result of which is the

NICKEL

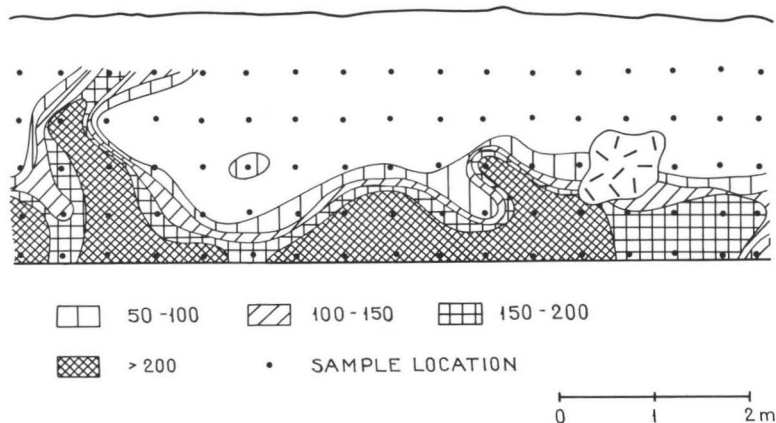


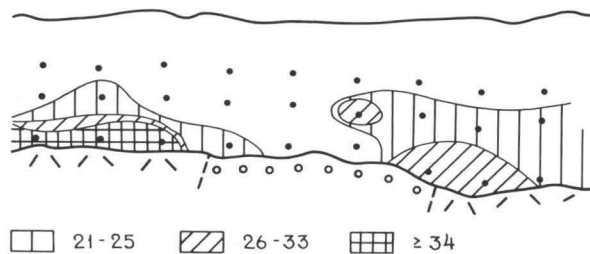
FIG. 2. The nickel concentrations (ppm) of a glaciogenic anomaly in a moraine profile. Location Tervo. According to A. Nurmi (Vuorimiesyhdistys, 1965).

heterogeneous structure of till. This structure is most distinct when the moraine is composed of several beds of different ages, whose matter has been transported in different directions. In addition to the mechanical movement, other factors also influence the distribution of trace metals in the moraine, as for example, the diffusion of cations in the ground water or their movement under conditions regulated by topography. Also the biogeochemical migration of trace metals affects the distribution of trace metals in the moraine. In the following, three examples of the distribution of trace metals in the moraine in a vertical direction are given (Figs. 2 to 4).

In Fig. 2 there is a moraine profile in which a glaciogenic anomaly occurs. The definite border of the anomaly with the nonanomalous moraine and the fold-like structure can be seen in the figure. In Fig. 3 the anomaly is weak and obviously hydromorphic in origin. The relief of the terrain is gently sloping and the flow of the surface and ground waters slow. In Fig. 4 the concentration of copper can be observed to increase with the increasing depth in the moraine. The increase of the copper concentration correlates with the number of mica gneiss boulders. This is due to the copper mineralization in mica gneiss, in which chalcopyrite is encountered as fracture fillings and disseminations. Boulders of granitoid rocks, whose number increases in the superficial part of the moraine, have travelled a longer distance than the mica gneiss boulders.

The figures show not only anomalies of various origins but also the influence of the sampling depth on the results of the moraine study. The best results would be obtained by means of a profile-like sampling carried out down to the surface of the rock, but in practice this can be seldom done. Bearing in mind both time and expenses, the sampling is limited to either soil or ground moraine.

COPPER



ZINC

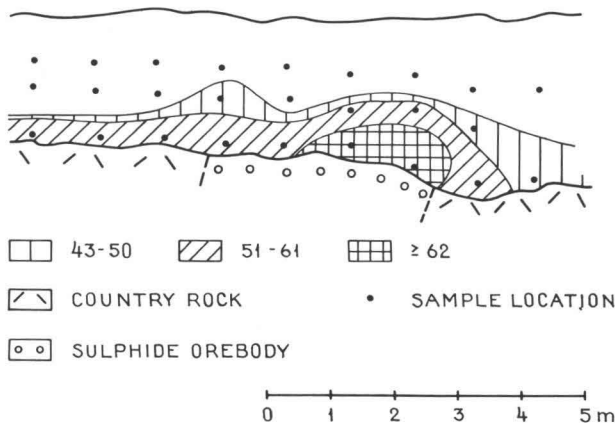


FIG. 3. The copper and zinc concentrations (ppm) in a moraine profile on top of a massive sulphide ore. The sum of the copper and zinc concentrations in the ore is 1% — 2%. The anomaly limits correspond to the concentration classification on the moraine map. The anomaly is considered hydromorphic in type. Location Kiuruvesi.

Sampling

The sampling has been carried out in accordance with the following instructions:

The samples of the soil study are taken either from the B horizon or from the upper part of the C horizon of the moraine. The sampling is always restricted to the same horizon. The depth from which the samples has been collected is thus usually 40 cm to 70 cm. If the material is not till, no samples are taken. The sample should be pure minerogenic matter about 250 g in size. The sampling lines run either in a S—N or E—W direction and the direction is chosen on the basis of information concerning the bedrock or overburden or both. The sampling grid is constructed in such a way that the ratio of the spacing parallel to the lines to the spacing perpendicular to the lines is 1: 5, e.g. 40 m/200 m, 50 m/250 m, 100 m/500 m, etc. A grid denser than 40 m/200 m is not used for the soil survey. The sampling is planned on the basis of aerial photographs or base

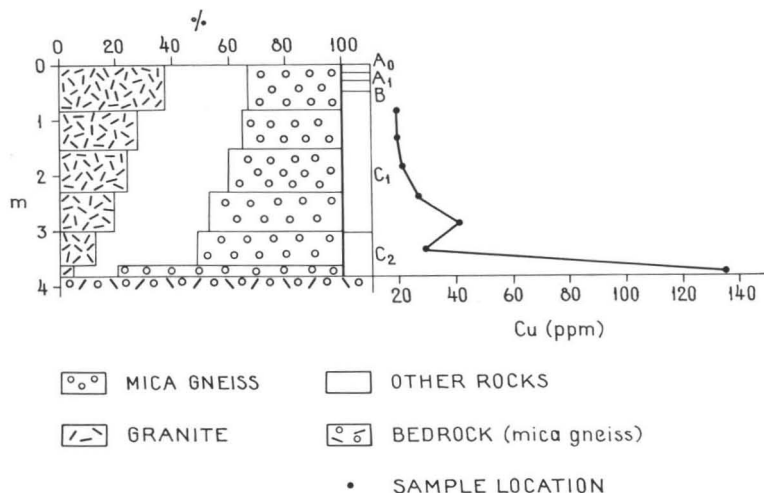


FIG. 4. The copper concentrations in the moraine profile on top of mica gneiss with a chalcopyrite dissemination. Copper concentration in the rock is roughly 0.5%. The left side of the figure represents the variation of the most common rock types in the moraine at the different levels of the profile. The normal podzol profile of the moraine is in the centre of the figure. C₁ represents sandy moraine and C₂ silt-clay moraine. At the right hand edge of the figure, the variations in the copper concentration can be seen according to the sampling depth. The concentration in each sampling site is the average of the concentrations of 4 samples. Location Haapajärvi.

maps with a scale of 1 : 10 000 or 1 : 20 000. The lines are orientated by following the easily recognisable points in the terrain and correcting the bearing of the lines with them if necessary. Should the sampling crew get out of the line, the sampling is repeated by correcting the course of the line. The coordinates of the sampling sites as well as the number and depth of the samples are marked on an observation card.

In the moraine survey, the samples are taken from the C horizon of the moraine and if possible from a depth of at least 1,5 metres. Attempts are made to complete the sampling grid by also taking samples from moraine covered by postglacial deposits including bogs. The size of a sample must be at least 250 g. The direction of the lines depends on local circumstances if the lines are staked, but if the samples are taken by orientation the bearing is either N—S or E—W. In general the sampling should be carried out along the lines staked in the terrain. The ratio between the sample spacing and the line spacing is the same as that for the soil sampling but the point density is higher, e.g. 40 m/200 m, 20 m/100 m, etc. A grid coarser than 50 m/250 m is not used in the moraine survey. The coordinates of the sampling sites are marked on the observation cards, as well as the sample numbers and the following data:

1. The depth of the sampling point in metres (if a soil sample has been taken, then also its depth)

2. The quality of the till: 1) rubble, 2) stony, 3) few stones, 4) no stones.
3. The shape of the terrain: 1) steep, 2) undulating, 3) even and wet (bog), 4) even and dry (heath).
4. Vegetation.
5. Lesser vegetation.
6. The direction of flow of the surface water (compass reading).

Preparation of the samples

Stream sediment samples are dried before sieving. The composition of the samples in terms of sand, silt, clay and biogenic matter is estimated by means of numbers from 1 to 3, where 1 = minority, 2 = majority and 3 = exclusively.

The samples are divided into two lots before sieving, and one half is stored for possible future use. The other half is sieved into three fractions: > 0.84 mm, 0.84 mm — 0.15 mm and < 0.15 mm. The medium and fine fractions are preserved. The latter is used for analysis and what remains is stored. The medium fraction is employed for special determinations and is kept only as long as the investigations last.

Soil and till samples are dried and divided into two lots as before. The information concerning the composition of the samples is registered in the same manner as for the stream sediment samples. The samples are sieved into three fractions: > 0.84 mm, 0.84 — 0.074 mm and < 0.074 mm. The finest fraction is used for analysis and the other fractions are treated as described before.

Analysis of the samples

Since 1965, atomic absorption analysis, supplemented by X-ray fluorescence analysis, has been used for the determination of chemical composition. Formerly, samples were analysed colorimetrically using organic colour reagents. At that time, generally well-known instructions were followed (e.g. Ward, Lakin, Canney and others, 1963). In the following, only the present analytical methods are described.

Weighing and dissolving

3 g of the sample are weighed for analysis. The weighed sample is transferred into a test tube, about 5 ml of concentrated nitric acid is added and it is boiled for 1/2 hour on a sand bath. After boiling, distilled water is added up to the 30 ml mark, and the mixture is stirred carefully. The main part of the undissolved material is allowed to deposit and the sample is centrifuged. The analysis is done directly from the solution in the centrifugal tube.

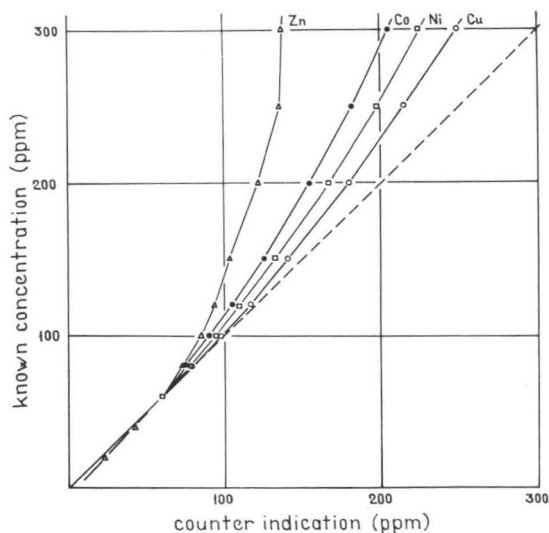


FIG. 5. Typical working curves of the Digital Concentration Readout (DCR-1) for cobalt, copper, nickel and zinc. Curvature Control of the instrument has not been used.

Analysis by the atomic absorption method

The atomic absorption spectrophotometer used was of the type Perkin Elmer 303 provided with a Perkin Elmer Digital Concentration Readout, DCR-1. In the analysis, the usual guides to analysis were used, e.g. Perkin Elmer, 1966.

The following metals were analysed in the soil samples: cadmium, cobalt, copper, molybdenum, nickel, lead and zinc, but in routine work usually only cobalt, copper, nickel and zinc. The atomic absorption spectrophotometer is employed in the following way. For the analysis, the apparatus is set at zero in the analytical conditions with pure water. A reading of 10 is set into the digital concentration readout, which is adjusted to correspond to a sample concentration of 1.0 ppm. After this, the maximum comparison value is set into the readout device using the standard solution, corresponding to a reading of 600. To this is added the basic reading of 10, that is, a total of 610. The reading of the pure water is reduced to the value of 10. With a series of comparison solutions, e.g. 1.0 $\mu\text{g}/\text{ml}$, 2.0 $\mu\text{g}/\text{ml}$ and 4.0 $\mu\text{g}/\text{ml}$, it is established that the readings of the digital concentration readout stay correct. Any possible deviations are not corrected, however, since the correction is made when the results are checked. Instead, the readout's basic reading of 10 = 1.0 ppm of sample concentration is subtracted from the analytical results. If the concentration of the sample exceeds the maximum reading of 610 set for the digital concentration readout and corresponding to 60 ppm in the sample, the result is checked with the aid of suitable standard solutions. On the other hand, if the concentration exceeds the concentration limits found by

experience to be reliable, the solution is diluted correspondingly. Practice has shown that the limit of reliability for copper and nickel is about 200 ppm, for cobalt about 150 ppm and for zinc about 100 ppm, when the 3 g of sample has been prepared as described on page 16. The reduction of the observation value to a true concentration can be done in many ways. The most common way is to employ correction coefficients whose numerical values change in steps. This is sufficient for giving the results an acceptable accuracy up to about 100 ppm. For higher concentrations, when the solution is not diluted, the correction is made by means of a working curve (Fig. 5). The samples are analysed in routine work in series of 20, starting with a set of comparison solutions and ending with the same solutions. If the standard readings of the apparatus have changed more than 5 percent while analysing the series, which does not usually happen, the analysis is repeated. The work is frequently done in groups of 5 sample series (100 samples in a group). After this, the hollow cathode lamp is changed and the same group is analysed for another metal. This is repeated until all the desired metals have been analysed.

The absorption sensitivity for different elements has been checked. The results can be seen in Table 1, which lists the concentrations of some analysed metals from the soil samples.

TABLE 1

The characteristic sensitivity values expressed as concentrations ($\mu\text{g/ml}$) per absorption percentage according to the Perkin Elmer Co. (1) and to the measurements at the Exploration Dept., Outokumpu Co. (2).

Element	1	2	Element	1	2
Cd	0.04	0.05	Ni	0.2	0.35
Co	0.45	0.4	Pb	0.7	0.4*
Cu	0.2	0.15	Zn	0.04	0.05
Mo	1.5	1.5			

* The value was obtained by employing a three-slot burner head.

The values in Table 1 correspond to the following concentrations in the samples:

Cd 0.5 ppm	Mo 15 ppm	Zn 0.5 ppm
Co 4 »	Ni 3.5 »	
Cu 1.5 »	Pb 4 »	

Since, in practice, the measuring of absorption values lower than 1 per cent causes trouble due to the instability of the apparatus, the figures correspond closely to those minimum concentrations whose analysis is possible. In some cases, e.g. when analysing cobalt and molybdenum, the lower limit of the concentration still analysable can be reduced to a certain extent by working very carefully. Analytical accuracy is discussed on pages 24 to 26.

X-ray fluorescence analysis

X-ray fluorescence analysis was employed in addition to atomic absorption techniques, especially for the determination of those elements which cannot be analysed with the atomic absorption method due to their high detection limits. The element most often determined by means of the X-ray fluorescence technique is arsenic.

Statistical approach

In the following, attention is paid to the principles which govern the processing and interpretation of the geochemical data. Since these data are based on a large amount of observations, the analysis of the information is performed statistically. The statistical approach is used to find out the answers to the following questions: what is the dispersion of the concentrations at the sampling sites and how accurately have the samples been analysed; what is a geochemical anomaly and what is the optimal sample grid.

Dispersion of concentrations

The geochemical data are inaccurate. This is due to the techniques used in sampling and analysing. The inaccuracy, which appears as a dispersion of concentrations and which is of importance for the processing of the geochemical data, will be discussed from two points of view. These are: dispersion in samples and in analyses. From now on these are called sample errors and analytical errors respectively.

The sample error is due to variations in the concentrations of the analysed elements at the sampling site, i.e. the deviation of the concentration of a random sample from the »true concentration» at the same site. The analytical error is composed of the dispersions produced by the weighing and dissolving of the samples as well as by the analytical methods involved. The analytical error, which can be determined fairly accurately, is included in the sample error. The sample error cannot be determined as accurately as the analytical error. The investigation concerning the sample error was performed by means of sampling tets, two of which will be described below.

Sample error, Test 1

From an area in which the concentrations of the trace-elements in the ground moraine were known to vary, sets of five samples were taken at 32 sites. Four of the samples were collected from the corners of a square measuring 5 x 5 metres, and one sample was taken from the centre of the square. A total of 320 samples was taken from the B and C horizons of the moraine. The depth from which the samples were extracted varied for the B horizon from 20 cm to 60 cm and for the C horizon from 1 to 1.5 metres. The weights of the samples were on an average 250 g. The samples taken from the B horizon represented point samples, whereas the length of influence of the samples from the C horizon was 50 cm due to the material adhering to the auger. The samples were treated in the usual way. The determinations were made from a sieve fraction of

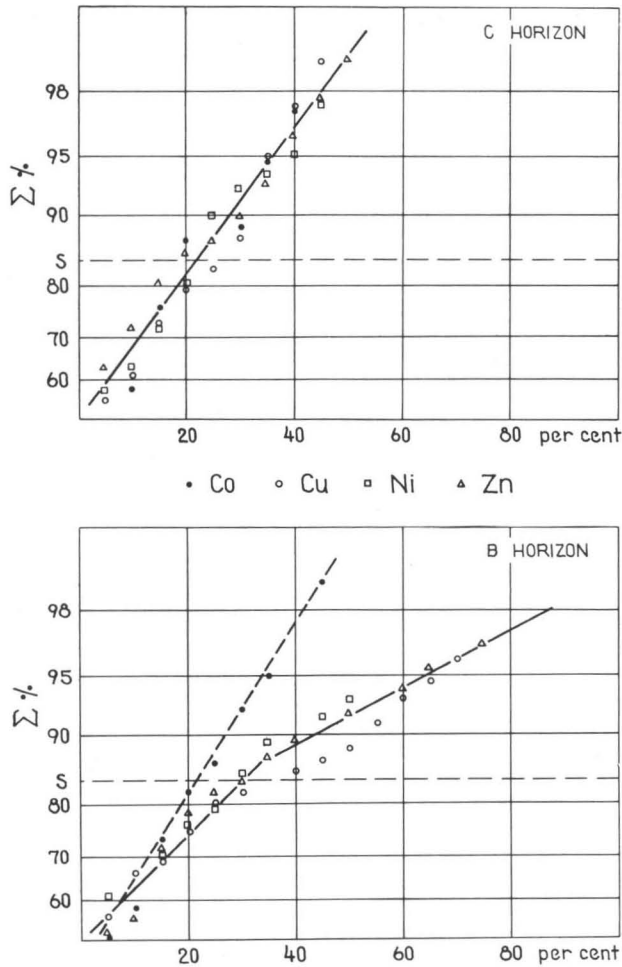


FIG. 6. The error distribution of a set of five samples normalized with the average value. The distribution expressed in percentages has been plotted on one side of the mean only. Samples are taken from the B and C horizons of the moraine.

< 0.074 mm by means of the atomic absorption technique. The samples were analysed for cobalt, copper, nickel and zinc soluble in boiling concentrated nitric acid.

The analytical results were treated in two ways:

- 1) The average concentration was calculated for each set of samples and also the difference between the average and the individual samples expressed in percentages. With the aid of these percentages a cumulative frequency distribution function was constructed for each element and the curve was plotted on a normal probability paper. Since the results were normalized by means of the averages, the distribution is normal.

TABLE 2

The numerical values of the relative sample error (per cent) at some points of the cumulative frequency distribution function in the moraine samples from the B and C horizon.

Σ %	84	90	95	98	
Relative sample error	22	28	36	45	C horizon in moraine
» » »	30	44	65	87	B » » »

Consequently, only that part of the distribution which exceeds 50 per cent is considered (Fig. 6).

The error distribution in the C horizon of the ground moraine shows that the dispersion of points for the four metals overlap, i.e. the error distribution is the same for all of these metals. The corresponding graph for the B horizon of the moraine is, however, somewhat different. The points of the cobalt do not coincide with those of the other metals. In addition, the points of copper, nickel and zinc do not lie in a straight line but the graph bends in its upper part. This represents large errors which occur infrequently. Moreover, the slope of the graph depicting the sample error of the B horizon of the moraine is steeper than that of the graph representing the C horizon. Thus it can be concluded that the error distribution in the C horizon of the moraine is more regular and more narrow than in the B horizon where especially the large sample errors are encountered more frequently. The behaviour of cobalt in the B horizon differs from that of the other metals. This may be due to the fact that in the area investigated the concentration of cobalt shows considerably less variation than the other metals. Table 2 lists some numerical values of the sample errors at various percentage points of the cumulative frequency distribution function. These values are interpreted so that e.g. at the 90 percentage point the deviation from the average concentration in the C horizon of the ground moraine is ≤ 28 per cent. If the mean is denoted by k , the sample error is $\leq 1.28 \times k$ at this point. In the B horizon of the moraine, the sample error is $\leq 1.44 \times k$ at the 90 percentage point.

2) On the basis of the analytical data the standard deviation was calculated from each set of samples and the coefficient of variation. The values were combined by calculating the mean standard deviation for each metal as well as the mean coefficient of variation. The results are compiled in Table 3. For the cobalt of the B

TABLE 3

The coefficients of variation (v , per cent) and the means of the four metals in the sets of five samples taken from 32 sites from the B and C horizons of the moraine.

	Coefficients of variation				
	Co	Cu	Ni	Zn	Averages
C horizon in moraine	17.3	23.7	19.7	20.3	20.5
B » » »		33.1	24.9	31.5	29.8

horizon no coefficient of variation was calculated because the dispersion appears to differ noticeably from that of the other metals and the sample material was not as representative for cobalt as for the other metals.

If the percentages corresponding to the mean standard deviation are compared with the values obtained from the cumulative distribution curve, it is observed that they are nearly the same. This is not a coincidence but due to the manner in which the data were treated. The attempt to group the dispersions according to the increasing average concentration, in order to study the possible change in dispersion with the increase in concentration, failed due to the large dispersion of the concentrations.

Sample error, Test 2

This test was carried out in such a way that, in connection with the geochemical mapping of a different area from that of Test 1, two samples were taken systematically at every sampling site at a distance of about 3 metres from each other. The samples were collected by a hand auger from an average depth of 1 metre from the C horizon of the moraine. Each sample, weighing about 250 g, represents material adhering to the auger for a length of roughly 50 cm. The samples were submitted to the same treatment as those in Test 1. The samples were analysed colorimetrically for copper and nickel. The average concentrations were calculated for each pair of samples. After that, the pairs of samples whose average concentrations differed no more than ± 15 per cent from 20 ppm, 40 ppm, 60 ppm and, in the case of nickel also from 90 ppm, were classified into groups. For each group, the average concentration, the standard deviation and the coefficient of variation were calculated. The results are listed in Table 4.

The numerical values of the variation coefficients show that the sample areas of both copper and nickel have a probable common minimum value at the average concentration $\bar{x} \sim 40$ ppm, from which the error increases as the concentrations change. This phenomenon can probably be explained by the fact that in the < 40 ppm concentrations the analytical error increases and in the > 40 ppm concentrations the sample error increases.

TABLE 4

The standard deviations (s , ppm) and the coefficients of variation (v , per cent) of the copper and nickel concentrations (\bar{x} , ppm) in the moraine. The material has been grouped according to the averages of the sample pairs.

Copper				Nickel			
No of samples	\bar{x}	s	v	No of samples	\bar{x}	s	v
142	20	5.7	28.7	90	20	3.7	18.5
188	42	7.9	18.8	244	39	5.4	13.8
58	58	13.0	22.4	148	59.5	8.3	13.9
				48	86	13.5	15.7

TABLE 5

The average relative sample errors (per cent) at some points of the cumulative distribution function in Test 2. The corresponding values obtained in Test 1 are in brackets.

Σ %	84	90	95	98
Relative sample error	19 (22)	24 (28)	31 (36)	39 (45)

The main reason why the coefficient of variation was calculated, however, was to establish the values of the sample error at various percentage points of the cumulative frequency distribution function. This was done by calculating an average standard deviation for copper and nickel; this was 18.8 per cent. By means of this the values listed in Table 5 were obtained. The values established in Test 1 are presented for the sake of comparison. Taking into consideration the fact that the studies were carried out in two different areas and using different methods, the compatibility of the results can be considered remarkable.

The study done in the Makola area at Nivala on the concentration dispersion of trace metals in the B and C horizons of the moraine gave the following results (Table 6).

The results indicate that the concentration dispersion is greater in the B horizon of the moraine than in the C horizon. The dispersion is greater in the anomaly area than in the background area. The greatest dispersion is in the copper and nickel concentrations. Of the trace metals, copper and nickel have the strongest anomalies. Also the coefficients of variation are compatible with the results obtained from Tests 1 and 2.

It is supposed that the numerical value of a sample error is roughly independent of the area. Accordingly, the concentration dispersion of a certain area, expressed as units of median value (M), can only be \geq the sample error expressed as units of the k .

TABLE 6

The average concentrations (\bar{x} , ppm), the standard deviations (s , ppm) and the coefficients of variation (v , per cent) of the trace metals in the B and C horizons of the moraine in the background and anomaly areas. Makola, Nivala (Vuorimiesyhdistys, 1967).

		B horizon			C horizon		
		\bar{x}	s	v	\bar{x}	s	v
Background area	Co	8.3	2.4	29.4	8.9	1.0	11.2
	Cu	18.7	23.5	(125.9)	15.2	5.9	38.8
	Ni	9.1	1.7	19.0	11.6	1.6	14.2
	Zn	12.8	2.7	21.4	21.4	3.6	16.9
	\bar{x}			23.3			20.3
Anomaly area	Co	13.8	1.8	13.2	16.2	3.2	19.9
	Cu	35.6	25.5	71.8	67.6	26.2	38.7
	Ni	41.0	18.5	45.2	64.6	16.7	25.9
	Zn	22.7	4.3	19.2	28.8	5.2	18.0
	\bar{x}			37.4			25.6

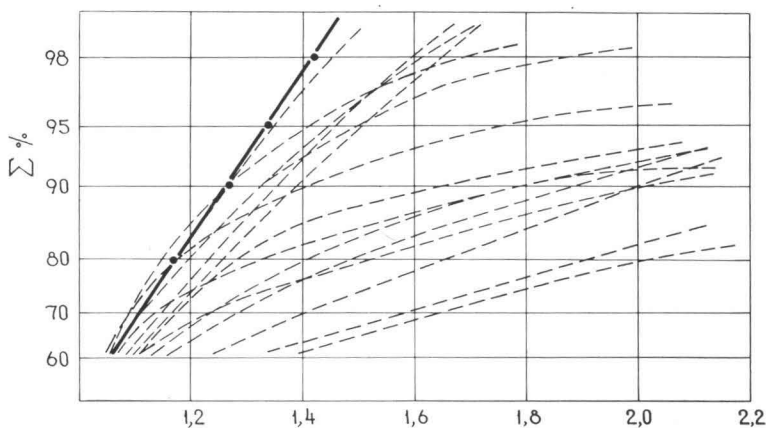


FIG. 7. The graph (continuous line) of the normal error distribution and a set of cumulative concentration distributions plotted in units of median values (broken lines).

The reliability of this statement has been studied graphically by plotting on a probability paper 15 cumulative frequency distributions expressed in units of M in addition to the graph of the sample error (Fig. 7). It is seen that the graphs of the cumulative distribution functions form a fan which for the most part stays on the positive side of the error function and thus confirms the statement.

Analytical error

The accuracy of the analytical method was investigated by means of duplicate analysis. The material of the study reported in the following was collected from an area to be described in Case History 4. (The Haukijärvi area, Enontekiö).

The study was carried out in such a way that nine samples were analysed for copper, nickel and zinc on five successive days. The whole procedure, including preliminary tasks from weighing onwards, was repeated every day. The dispersion in concentration due to repetitions thus includes all the errors involved in the analysis of samples excluding the probable errors induced by the reference solutions. The latter were not renewed during the experiment.

The results of the test are seen in Table 7. It appears that the concentration of copper greatly varies from one sample to another. The concentration of nickel shows a moderate variation and that of zinc hardly any. The coefficient of variation was used as a measure of the analytical error. The results indicate that the coefficient of variation for copper concentrations is on average 3.0 per cent, and that it changes only slightly with increasing concentration. The differences in the coefficients of variation between the analysed sets seem to be random. The coefficient of variation for nickel is on an average 4.9 per cent increasing slightly with decreasing concentrations. The value of

TABLE 7

The variations of the copper, nickel and zinc concentrations (ppm), the average concentration (\bar{x} , ppm), the standard deviation (s , ppm) and the coefficient of variation (v , per cent) between the repeated analyses carried out with the atomic absorption method.

Copper

Repeated analyses					\bar{x}	s	v
15	17	16	16	16	16.0	0.63	3.95
22	26	24	26	25	24.6	1.50	6.08
49	51	49	50	51	50.0	0.89	1.79
76	81	80	81	80	79.6	1.85	2.35
95	97	97	96	98	96.6	1.02	1.06
184	184	207	194	175	188.8	10.9	5.78
346	346	368	368	359	357.4	9.86	2.75
611	621	621	621	612	617.2	4.66	0.76
611	667	644	644	635	640.2	18.1	2.83
3.04							

Nickel

Repeated analyses					\bar{x}	s	v
12	15	15	13	14	13.8	1.16	8.41
16	20	20	21	20	19.4	1.73	8.98
34	38	39	39	39	37.8	1.94	5.13
35	40	39	42	41	39.4	2.42	6.13
59	63	63	64	65	62.8	2.04	3.25
82	88	88	90	92	88.0	3.35	3.80
86	94	89	90	91	90.0	2.61	2.90
101	108	103	105	108	105.0	2.76	2.63
106	114	109	108	112	109.8	2.86	2.60
4.87							

Zinc

Repeated analyses					\bar{x}	s	v
18	20	21	19	18	19.2	1.17	6.07
22	25	27	24	24	24.4	1.62	6.66
27	29	30	29	28	28.6	1.02	3.56
25	30	32	32	31	30.0	2.61	7.82
31	32	35	33	34	33.0	1.41	4.28
33	34	37	37	37	35.6	1.74	4.90
36	32	32	31	30	32.2	2.06	6.33
34	36	39	39	37	37.0	1.90	5.13
47	50	51	55	50	50.6	2.58	5.09
5.54							

this parameter for zinc is 5.5 per cent. Since the zinc concentrations show only a slight variation from one sample to another, the coefficients of variation reflect the random variation in the analysed sets within the range 3.5—8 per cent.

At the cumulative frequency of 98 per cent the coefficients of variation are:

$$\text{Cu} = 6.3 \% \quad \text{Ni} = 10.2 \% \quad \text{and Zn} = 11.7 \%$$

If these values are compared, for example, with those of the sample error at the cumulative frequency of 98 per cent, i.e. 45 per cent, it appears that the analytical error is relatively small compared with the total error, that is with the sample error. The sample error is thus to a great extent due to the dispersion in concentration at the sampling site.

Geochemical anomalies

Usually a concentration exceeding the general level is considered as an anomalous concentration. By the general level is often meant a mean concentration or something equivalent, in the area under investigation or on a larger regional scale. The most common concentration is estimated visually or it is determined by computing the arithmetic (or logarithmic) mean or the median of the distribution function. The value obtained is called geochemical background. The value of the background obtained from the distribution function coincides with the average if the distribution is normal. Should it be skewed, either lognormal or resembling it, the background value is the same as the median. The stream sediment and ground moraine studies showed that the distribution function is generally non-normal; it is either lognormal or at least positively skewed. Consequently the median is considered to be the best measure for the background.

The definition of the geochemical anomalies is based commonly on the fact that part of the concentrations in the area under investigation are accepted as anomalous. The lowest anomalous value is called anomaly threshold, which is usually chosen so that it exceeds the background with a multiple of a standard deviation e.g. the level twice the standard deviation above the background (e.g. Hawkes and Webb, 1962, p. 30).

Also in this study the geochemical anomaly is defined as is usual by means of the frequency distribution of the concentrations. Due to the skewed shape of the function, the median was chosen as the background concentration. The concentration either at the cumulative frequency of 80 or 90 per cent of the distribution function is taken as an anomaly threshold where the variation in the concentration of a single metal is concerned. In case the mutual variation of different metals is investigated, the concentration at the cumulative frequency of 90 per cent is taken as a threshold. Two per cent of the concentrations at the high concentration end of the distribution function are considered as significant concentrations. Should the anomaly pattern need improvement, the range of the significant concentrations can be enlarged by accepting the concentrations exceeding the 95 percentage point.

The interpretation of the anomalies is, however, limited by the sample error which is included in the results. As has been shown in the chapter dealing with the sample error, the concentration of every random sample represents the true concentration of the sampling site (k) with a certain probability. For instance, if only one half of the

distribution function is considered, at the cumulative frequency of 90 per cent k falls within the range k to $1.26 \times k$ in the C horizon of the ground moraine and within the range k to $1.44 \times k$ in the B horizon of moraine. Thus, if in a distribution function for the concentrations of a C horizon of a ground moraine at the cumulative frequency of 90 per cent the value of $1.26 \times M$ is observed, where $M \sim k$ (M denotes median), then it is assumed that the variation of random variables represents the sample error at this frequency. This leads to the conclusion that only concentrations higher than $1.26 \times M$ at the cumulative frequency of 90 per cent can be considered anomalous. Of course, this conclusion is not wholly valid because the position of a random sample in the frequency distribution function is not known. But, on the other hand, when it is a question of determining the anomaly threshold, the fact that some anomalous concentrations are rejected and some other nonanomalous concentrations accepted has no significant effect upon the anomaly pattern.

However, this has bearing upon a single random sample only. In case the anomaly is characterised by several anomalous sampling sites, the situation changes according to the probability formula

$$P_n = 1 - (1-P)^n$$

where n is the number of anomalous sampling sites; for example

when $n = 1$,	so $P = 0.90$
2	0.99
3	0.999
etc.	

From the point of view of the interpretation of anomalies it is practical to assume that all the sites have the same probability and to change the value of the error coefficient according to the number of sites indicating the anomaly.

The equation pertinent to the solution was derived as follows:

Consider a probability q with which the observed concentration belongs the background. This concentration represents an anomaly at the probability level of $1 - q$. Let the two-point anomaly be caused by two successive anomalous sampling sites in a line. A single point has thus two neighbours with which it can form an anomaly. Consequently

$$2 \times (1 - q)^2 = 1 - P$$

and correspondingly for a three-point anomaly

$$3 \times (1 - q)^3 = 1 - P$$

The rounded values listed in Table 8 were obtained by inserting the above sample errors into this equation.

TABLE 8

The limit values of the sample errors expressed in units of median at different probability levels in the B and C horizons of the moraine. The number of adjacent samples (n) is 1, 2 and 3.

C horizon in moraine				
	P = 0.80	0.90	0.95	0.98
$n = 1$	1.17	1.26	1.34	1.42
2	1.10	1.16	1.20	1.26
3	1.05	1.10	1.14	1.18
B horizon in moraine				
	P = 0.80	0.90	0.95	0.98
$n = 1$	1.29	1.44	1.56	1.70
2	1.16	1.26	1.34	1.44
3	1.08	1.16	1.23	1.30

TABLE 9

The median values of the frequency distributions of the concentrations (ppm) in the moraine samples. Kalliokylä area, Kiuruvesi.

	C horizon				B horizon			
	Co	Cu	Ni	Zn	Co	Cu	Ni	Zn
M	11	18	18	34	9	9	13	27

TABLE 10

The threshold concentrations (ppm) of the sample errors at the 98 percentage probability level in the moraine samples. The number of adjacent samples is 1, 2 and 3. Kalliokylä area, Kiuruvesi.

	C horizon				B horizon			
	Co	Cu	Ni	Zn	Co	Cu	Ni	Zn
$n = 1$. . .	16	26	26	48	15	15	22	46
2 . . .	14	23	23	43	13	13	19	39
3 . . .	13	21	21	40	12	11	15	32

The use of the limit value of the sample error for the determination of the geochemical anomaly threshold is clarified by the following example. The concentration distributions in moraine, in the Kalliokylä area, Kiuruvesi (Case History 3), have the medians listed in Table 9. Since samples were taken abundantly and it was necessary to eliminate the sample error as much as possible, the threshold value of this error was set at the cumulative frequency of 98 per cent. The threshold values at this frequency are compiled in Table 10.

Fig. 8 shows to what extent these threshold concentrations must be taken into consideration when the threshold values of the anomalies are determined from the cumulative distribution function either at the 80 per cent or 90 per cent frequency.

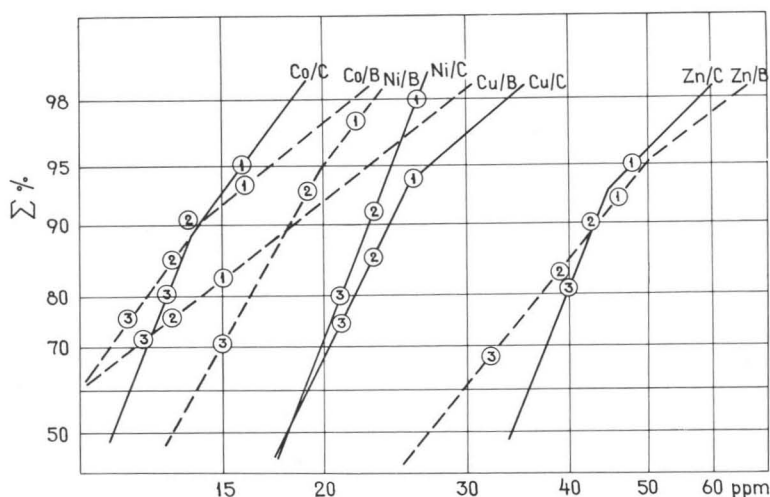


FIG. 8. The cumulative frequency distributions of the concentrations in the B and C horizons of the moraine. Location of the sample errors ($n = 1, 2$ and 3 ; $P = 0.98$) in the distributions. Kiuruvesi area, Kalliokylä.

Optimal sample grids

One of the main problems which concerns regional survey aiming at the discovery of new anomalies is the construction of a sample grid over the area to be studied. Since the survey is usually extended over large areas it is urgent, for the saving of time and expense, to establish a grid which permits the detection of all significant anomalies without its being too dense.

The determination of the optimal sample grid was carried out by studying the anomaly models connected with the known orebodies, of which Fig. 1 presents a few examples. The anomaly models include various types, all of which have a feature in common, that is, they all indicate sulphide deposits. It was important to discover these deposits in spite of the fact that they are not all economic. Since the geochemical mapping of these models was carried out with an accuracy exceeding that of an ordinary areal survey, there is good reason to believe that the anomaly patterns are reliable. The anomalies have been presented with the same scale and coordination. The two isopleths have been chosen so that they roughly correspond with each other in different anomalies. The contours divide the anomalies into two classes. The outer contour circumscribes a low anomaly, i.e. it coincides with the anomaly threshold. The inner contour circumscribes a high anomaly, i.e. a significant anomaly whose concentrations, even at one point, are so high that they render the site interesting.

Sample grids were studied by means of the elliptical anomaly model and the tables calculated by Savinskii (1965) for this model. According to the elliptical model, every anomaly is proposed to be an ellipse shaped so that its major axis is set parallel to the

TABLE 11

The dimensions (in metres) of the anomaly models of Fig. 1 computed on the basis of the ellipse model. Anomaly areas are given in units of ha (1 ha = 10 000 m²).

Survey areas	Low anomalies			High anomalies		
	a	b	area	a	b	area
Area 1, anomaly 1	400	200	6.3	250	120	2.4
» » 2	600	300	14.1	450	120	4.2
» 2, B horizon	1 500	200	23.6	500	100	3.9
» C horizon	2 000	200	31.4	900	100	7.1
Area 3	600	350	16.5	250	130	2.5
» 4	500	100	3.9	300	60	1.4
» 5	1 500	300	35.3			
» 6				400	30	0.9

longest dimension of the anomaly and the minor axis *b* perpendicular to the anomaly. The investigated anomalies are characterised by the values of *a* and *b* listed in Table 11. To ease the comparison of the anomalies, the areas of the anomalies were computed according to the ellipse model.

The following three sample grids, all used in routine sampling, were applied to the anomaly models:

spacing between the lines <i>D</i> = 500 m, sample spacing <i>H</i> = 100 m			
»	250	»	50
»	125	»	25

When the grids are placed over the above-mentioned anomalies by assuming that the major axis of the anomaly does not deviate more than ± 30 degrees from the normal of the line, the probabilities for the discovery of the anomalies are obtained. These probabilities are compiled in Table 12.

Table 12 shows that the low anomalies are so large that their probability of discovery is very high even when a coarse grid is used. It is natural that the probability of detection of the high anomalies, which usually form a part of the low anomalies, is lower than that of the latter. However, should the sample grid be required to discover an anomaly with at least one high value at a probability level of $P = 0.9$, it follows that none of the eight anomalies presented here fulfills this requirement with the grid of 500 m \times 100 m, but that with the grid of 250 m \times 50 m already 7 out of 8 fulfills it. The densest grid of 125 m \times 25 m secures the discovery of all the anomalies.

In Table 13 the numbers of the samples indicating anomalies have been compiled. The table lists the number of samples falling within the anomalies under consideration at the probability level of $P = 0.90$, when the forementioned sample grids are used.

As Table 13 shows, the low anomalies, excluding two, are indicated by several samples also when using a coarse grid, but this hold true for the high anomalies only when

TABLE 12

The probabilities for the discovery of geochemical anomalies by means of different sample grids.

Survey areas	Sample grids	Low anomalies					High anomalies				
		P ₀	P _{>1}	P _{>2}	P _x	//	P ₀	P _{>1}	P _{>2}	P _x	//
Area 1, anomaly 1											
D = 500	H = 100	0.26	0.75	0.50	2	—	0.57	0.43	0.06	1	—
250	50	—	1.00	1.00	4	0.60	0.06	0.94	0.78	2	—
125	25	—	1.00	1.00	>8	—	—	1.00	1.00	≥8	0.92
Area 1, anomaly 2											
D = 500	H = 100	—	1.00	1.00	3	0.19	0.21	0.79	0.18	1	—
250	50	—	1.00	1.00	>8	—	—	1.00	1.00	3	0.56
Area 2, B horizon											
D = 500	H = 100	—	1.00	1.00	>8	—	0.23	0.77	0.01	1	—
250	50	—	1.00	1.00	>8	—	—	1.00	1.00	3	0.84
Area 2, C horizon											
D = 500	H = 100	—	1.00	1.00	>8	—	0.12	0.88	0.21	1	0.21
250	50	—	1.00	1.00	>8	—	—	1.00	1.00	>8	—
Area 3											
D = 500	H = 100	—	1.00	1.00	3	0.19	0.57	0.43	0.06	1	—
250	50	—	1.00	1.00	>8	—	0.06	0.94	0.78	2	—
125	25	—	1.00	1.00	>8	—	—	1.00	1.00	8	0.92
Area 4											
D = 500	H = 100	0.23	0.77	0.01	1	—	0.73	0.27	—	1	—
250	50	—	1.00	1.00	3	0.84	0.01	0.99	0.24	1	0.08
125	25	—	1.00	1.00	>8	—	—	1.00	1.00	3	0.84
Area 5											
D = 500	H = 100	—	1.0	1.0	>8	—	—	—	—	—	—
Area 6											
D = 500	H = 100	—	—	—	—	—	0.76	0.23	—	1	—
250	50	—	—	—	—	—	0.12	0.88	0.21	1	0.21
125	25	—	—	—	—	—	—	1.00	—	>2	—

Explanations: D, line spacing (m); H, point spacing (m); P₀, probability for the fact that the sample grid meets no anomaly points; P_{>1} and P_{>2}, probability for the fact that the sample grid meets > 1 or > 2 anomaly points; P_x, the number of the anomaly points most probably met by the sample grid; //, probability for the occurrence of the anomaly points along two lines.

a grid of 250 m × 50 m is employed. The more dense grids give abundant indicative samples including high value samples. The results indicate that in the cases investigated the sampling grid of 250 m × 50 m is the most practical for areal geochemical prospecting.

It is evident that in any area under investigation, anomalies of different size and magnitude are to be expected. Regional survey is carried out generally by using a sampling grid of D = 250 m, H = 50 m. In Table 14, some examples of the ellip-

TABLE 13

The number of sampling points with which the anomalies depicted in Fig. 1 are revealed while using different sampling grids. $P = 0.90$.

Survey areas	Sample grids					
	500 m × 100 m		250 m × 50 m		125 m × 25 m	
	1	2	1	2	1	2
Area 1, anomaly 1	<1	<1	4	2	>8	≥ 8
» » 2	3	<1	>8	3	>8	>8
Area 2, B horizon	>8	<1	>8	3	>8	>8
» C horizon	>8	1	>8	>8	>8	>8
Area 3	3	<1	>8	2	>8	8
Area 4	<1	<1	3	1	>8	3
Area 5	>8	—	>8	—	>8	—
Area 6		<1		1		>2

1. The number of the anomaly points within low anomalies
2. The number of the anomaly points within high anomalies

tical minimum anomalies have been compiled. These are established with at least one sample at the probability levels of 90 per cent and 70 per cent. The results obtained correspond in two cases. In the first case, the major axis of the anomaly deviates from + 30 to — 30 degrees from the normal of the line. In the second case, the bearing of the anomaly is arbitrary.

Presentation of the results

In geochemical sampling applied to ore exploration, emphasis is laid upon those variations in the concentration of the analysed metals which form geochemical anomalies. On page 26 the method by which the anomalous concentrations are discerned from the background is described. The definition of the geochemical anomalies does not, however, resolve the problem of the best way of describing anomalies.

TABLE 14

Examples of the minimum anomalies (in metres) computed with the aid of the ellipse model. At least one sample from a sampling grid of 250 m × 50 m is required to meet the anomaly at a probability level of $P = 0.90$ or $P = 0.70$.

	b^1	$-30^\circ \leq \theta \leq 30^\circ$				$-90^\circ \leq \theta \leq 90^\circ$			
		$P = 0.90$		0.70		0.90		0.70	
		a	b	a	b	a	b	a	b
line spacing	0.1	420	42	360	36			400	40
D = 250 m	0.2	280	55	320	44	500	100	290	60
point spacing	0.3	250	85	210	65	420	125	260	80
H = 50 m	0.5	220	110	190	95	330	165	230	115

$b^1 = b$; a, i.e. the minor axis of anomaly: the major axis of anomaly

Various points of view must be taken into consideration when the most suitable way of presentation is considered.

1) The way in which the results are presented depends on the methods used. For example the results of the stream sediment study cannot be treated on the same basis as those of the moraine survey.

2) Particularly with the results of the stream sediment survey, facts must be taken into consideration which do not exist to the same extent with the results of the moraine study. One of these facts is the relationship between the samples and the waterways. Attention must be paid to the fact that the composition of the samples varies as does also the amount of biogenic material.

3) The significant variations in concentration occur generally at two levels, first as extensive but weak concentration maxima called low anomalies, and secondly as limited peaks well-defined in concentration and called high anomalies. Both types of anomalies must be made visible in the anomaly pattern.

4) An anomaly pattern is often characterised not only by the relative concentration variation of a metal but also by the mutual relationships of various metals, or by the fact that the metals show no intercorrelation. Also there must be a way of presenting the multi-metal anomalies.

5) The geochemical features of a certain area are not necessarily explained by the anomaly pattern alone but it may be necessary to present the concentration variations also with mathematical quantities, e.g. as correlation and regression values, concentration distributions, etc.

It is not always possible to take all of these points of view into consideration. Further, some of them exclude some others. Thus the manner of presenting the geochemical anomalies is only one among many possibilities. This leaves the door open for the future development of the modes of presentation.

Thus, important as it is to keep an eye continuously upon the possibilities of developing the presentation of the results, it is equally important to establish ways of presentation which can be applied to all data and on the basis of which, different areas can be compared with each other. Above all, this has been the goal at which the standardization of presentation has aimed.

The results can be presented in two ways:

- 1) as maps
- 2) and as statistical data.

There are numerous ways of collecting and presenting statistical data. The studies to be described contain information concerning the distribution of the concentrations in the areas investigated, the coefficients of correlation and the regression between the analysed elements and the data for the relationship of the concentrations of the metals. Especially in the regional survey, the geochemical results are based on extensive observational data. The statistical processing of this data and the presentation of the results as maps requires much time and work. Consequently, the possibility has been studied of changing to automatic data processing.

Presentation of computerized data

The aim of the data processing is naturally to augment the information received from the data, but also to render the presentation of the results as automatic as possible. Apart from the program required for the computing and producing the triangular diagrams, the computer programs used in this study were applications of those programs presented in Vuorimiesyhdistys, 1967.

The employed computer application gives the following information.

1. Observational data listed in the order of sample numbers (Fig. 9).
2. Smoothed observational data ordered according to the coordinates (Fig. 10).
3. The histograms of the frequency distributions from the smoothed data (Fig. 11).
4. Distribution information from the smoothed data (Fig. 12).
5. The linear and logarithmic regression and correlation coefficients (Fig. 13).
6. The lists printed out by a line printer from the smoothed data for each analysed metal in each soil horizon (in the B and C horizons of the moraine). The spacings of the lines and points of the line printer were adjusted to the same arbitrary scale, in which the ratio of line spacing to point spacing is 1 : 5 (Fig. 14).
7. The same lists of data with the distinction that only 20 per cent of the highest concentrations are printed out as numbers, the rest being marked with an asterisk. The scale is the same as in paragraph 6 (Fig. 15).

The meaning of the term smoothed data, used in the above list, will be explained in the following.

It is known that the concentration variations of trace metals in a survey area are stochastic, but, however, not completely random if samples have been taken sufficiently close to one another. Thus, the concentration variations of samples taken from sufficiently close to one another represent a certain concentration function. The purpose of smoothing the data is to eliminate the random variations from around a particular concentration function. Of the possible smoothing methods available, the method of the moving weighted averages was used, by adding weighting coefficients to the analytical data. The use of the weighting coefficients was due to the fact that the aim was to get the smoothing in the background area more effective than in the anomaly area, and the smoothing had to be prevented from changing the anomaly data more than ± 30 per cent. The smoothing can be applied to 2-dimensional data, but since the spacing of lines in sampling is normally much larger than that of the points, it has been sufficient so far to smooth the data only in the direction of the lines. Therefore, in this study, smoothing only refers to the so-called line smoothing. The smoothing procedure is only applied to pedogeochemical data (Vuorimiesyhdistys, 1967, p. 83—89).

ALUE: HAUKIJÄRVI, ENONTEKIO
TUNNUS: H2, LAATU 600 KARTTALEHTI 1834

ALUE: HAUKIJÄRVI, ENONTEKIO
TUNNUS: H2, LAATU 600 KARTTALEHTI 1834
LINJATASOITETTU

X	Y	NRO	CO	CU	NI	ZN
1916	1663	916	15	34	28	38
1911	1663	917	16	63	36	34
1901	1663	918	19	127	51	45
1886	1663	919	11	29	27	36
1861	1663	920	15	70	33	39
1975	1683	821	9	112	44	31
1904	1643	801	13	72	33	31
1909	1643	702	13	56	31	27
1915	1643	803	14	40	33	40
1968	1643	804	10	76	18	23
1964	1643	805	10	23	21	27
1959	1643	806	8	18	16	18
1954	1643	807	9	31	25	23
1950	1643	808	13	40	37	51
1945	1643	809	16	67	37	40
1939	1643	810	12	28	32	31
1934	1643	811	11	22	32	29
1930	1643	812	10	32	36	23
1926	1643	813	12	50	32	32
1902	1643	814	16	43	44	50
2003	1683	815	8	19	21	18
1998	1683	816	10	21	26	22
1994	1683	817	5	10	14	11
1989	1683	818	6	14	16	12
1984	1683	819	14	33	30	29
1979	1683	820	14	37	24	28
2006	1703	741	5	12	13	11
2011	1703	742	7	13	13	11
2016	1703	743	7	16	17	15
2021	1703	744	6	8	10	9
1907	1704	721	9	27	17	31
1911	1704	722	8	17	13	31
1917	1704	723	8	15	14	23
1922	1704	724	8	19	16	22
1927	1704	725	12	24	23	29
1932	1704	726	15	45	28	33
1937	1704	727	12	23	19	35
1942	1704	728	8	15	14	15
1947	1704	729	9	22	18	34
1952	1703	730	6	12	12	14
1957	1703	731	10	15	18	34
1961	1703	732	5	9	11	12
1967	1703	733	11	36	21	30
1972	1703	734	10	38	20	29
1977	1703	735	9	32	22	25
1982	1703	736	11	27	19	29
1987	1703	737	12	30	23	32
1992	1703	738	8	16	16	21
1996	1703	739	11	22	19	25
2001	1703	740	5	8	12	9
1783	1705	701	17	118	51	40
1788	1705	702	17	66	51	69
1793	1705	703	43	96	90	207
1802	1705	704	16	139	59	32
1817	1705	705	15	114	65	30
1827	1705	706	16	93	51	44
1837	1704	707	16	143	58	33
1842	1704	708	17	106	50	34
1847	1704	709	14	76	51	35
1852	1704	710	10	30	31	30

X	Y	B-KERROS			
		CO	CU	NI	ZN
1686	1464	11	29	22	33
1691	1464	12	35	24	38
1697	1464	13	35	28	45
1701	1464	18	45	44	71
1706	1464	15	33	29	51
1711	1464	14	29	29	47
1716	1464	14	26	25	42
1721	1464	16	27	27	49
1726	1464	13	26	23	41
1731	1464	13	33	23	42
1736	1464	12	30	25	44
1740	1464	12	32	26	41
1750	1464	16	45	35	54
1755	1464	20	53	42	58
1760	1464	17	62	42	50
1770	1464	21	97	70	71
1780	1464	13	45	37	38
1785	1464	12	35	33	35
1789	1464	10	25	27	29
1799	1464	14	31	31	38
1809	1464	12	24	26	35
1813	1464	16	26	28	40
1560	1465	8	27	20	42
1570	1465	7	24	17	38
1575	1465	8	31	22	43
1580	1465	6	25	15	40
1585	1465	7	35	19	38
1593	1465	10	59	24	37
1598	1465	14	60	41	47
1593	1475	10	37	20	39
1570	1484	9	33	17	29
1575	1484	9	35	17	28
1580	1484	10	43	19	33
1585	1484	12	53	25	38
1590	1484	12	52	25	38
1594	1484	12	75	25	39
1600	1484	10	47	20	36
1605	1484	11	55	21	37
1610	1484	9	39	16	34
1619	1484	11	42	19	40
1627	1484	11	31	20	40
1664	1484	12	38	23	34
1684	1484	10	29	20	28
1689	1484	10	27	19	29
1694	1484	11	27	22	32
1699	1484	11	26	22	33
1703	1484	12	29	24	34
1708	1484	14	28	34	38
1714	1484	12	25	20	38
1721	1484	11	26	22	38
1726	1484	13	25	24	44
1733	1484	13	26	23	44
1738	1484	12	31	24	40
1743	1484	10	28	21	34
1748	1484	9	32	20	30
1753	1484	10	46	23	32
1758	1484	11	43	23	39
1763	1484	12	40	25	38
1768	1484	11	30	24	34
1773	1484	10	26	24	33

FIG. 9. An example of the print-outs of the original analytical data. The list gives the coordinates, numbers and analytical results (ppm) for the samples. The Finnish text of the table contains information concerning the survey area and method. The text is part of a computer printout.

FIG. 10. An example of the listing of the smoothed concentrations (ppm) printed out in the order of the coordinates. The explanation concerning the text of the table is in the explanation of Fig. 9.

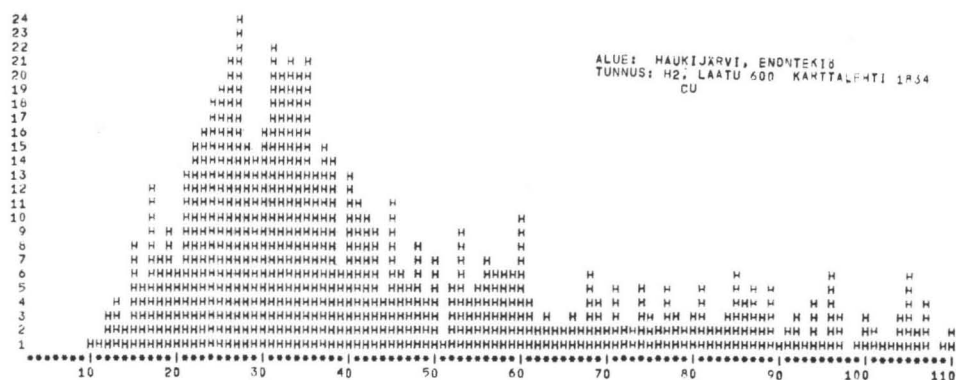


FIG. 11. An example of a frequency distribution of concentrations presented as a histogram. The explanation concerning the text of the table is in the explanation of Fig. 9.

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ALUE: HAUKIJARVI, ENONTEKID
TUNNUS: H2, LAATU 600 KARTTALEHTI 1834

JAKAUTUMATIEDOT
    
```

	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	98%	MAX	KES
CO	7	8	9	10	10	11	11	12	12	12	13	13	14	14	15	16	17	18	20	23	97	12.9
CU	18	22	24	26	28	30	32	34	36	39	43	48	56	62	74	86	90	118	170	258	24	61.7
NI	15	17	18	20	21	23	24	25	26	28	30	32	34	36	42	45	49	54	69	84	37	33.7
ZN	20	24	26	27	29	30	31	32	33	34	35	36	37	38	39	40	42	44	49	62	49	34.6

FIG. 12. An example of the print-out for the cumulative frequency distribution of the concentrations. The explanation concerning the text of the table is in the explanation of Fig. 9.

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TUNNUS: H2, LAATU 600 KARTTALEHTI 1834

REGRESSIOT JA KORRELAATIOKERTOIMET
    
```

CU/R	= -37.5 + 7.69*CO/R	.537	761	LOG(CU/R)	= -.073 + 1.56*LOG(CO/R)	.688	761
NI/R	= -11.1 + 3.45*CO/R	.803	761	LOG(NI/R)	= .166 + 1.28*LOG(CO/R)	.847	761
ZN/R	= 8.31 + 2.04*CO/R	.693	761	LOG(ZN/R)	= 1.71 + .712*LOG(CO/R)	.728	761
NI/B	= 17.9 + .250*CU/B	.835	761	LOG(NI/B)	= 1.13 + .590*LOG(CU/B)	.881	761
ZN/B	= 31.8 + .046*CU/B	.225	761	LOG(ZN/B)	= 2.81 + .180*LOG(CU/B)	.417	761
ZN/B	= 23.4 + .339*NI/B	.493	761	LOG(ZN/B)	= 2.23 + .373*LOG(NI/B)	.579	761

FIG. 13. An example of the tabulation of regression equations and correlation coefficients. The explanation concerning the text of the table is in the explanation of Fig. 9.

ALUE: HAUKIJÄRVI, ENDOTEKIM
 TUNNUS: H2, LAATU 600 KARTTALEHTI 1834

CU KUVA NO 1

15												
19	27											
24												
37												
40	24	33										
48	31	35										
14	25	43	34									
30	35	33	34									
	59	52				58						
		75	31			35						
28	60	42	36			32						
24	33	55				30						
22	31					29						
19	28	39	57			34						
	27		48			37				16		
17		42	49			12						
17	29		36			43			50			
15		31				28			42			18
19	28		30			29			46			15
			32			30			41			
14			35			27			37			21
17	25		40			27			37			29
23	29					27			37			59
11	31		35			98			37			52
26	45		34			30			33			
			49			38						36
25	42	38	41			40			34			27
22	38		54			40			33			23
21	37					36			34			37
22						31						23
						32			48			34
24	28	29				46			27			39
31	29	27				41			41			25
25	35					35			49			26
26	35	27				37			50			31
	45	26				33						28
			24									32
30	29											27
34	33	28	26			34						35
	29					27						30
58	28	25	27			25						
40	27	26	27			25						
			23									
			22			28						48
36	26	25	22			28						47
45	33	26	35			35						50
			26									43
	32	31	41									47
37		28	49			28						52
35		32	58			34						50
34	45	46				42						78
33	53		77									84
33	62	43	74			45			44			
		40	68			45			46			100
		30				49			49			
37	97	26							52			
23						43			60			56
30	45	32	76			56			51			47
	35	34	81			49			178			72
31	25	51	91			86			86			92
						57						81
29		38				169						77
36	31	37	598			185			68			83
		44				226			80			110
						229			81			78
	24	71	116			118			94			74
	26	35				346			158			80
												118
		31							277			
		53							399			
		41							391			
		26							164			
		25							278			
		34							226			
									244			
									119			
									134			
									94			
									120			
		46										125
		36							54			154
									56			194
									116			239
									68			
		63							71			
									58			69
									56			60
									54			57
									53			
									60			
									57			
									33			
									36			
									60			
									39			
									41			
									34			38
												36
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									26			33
									33			
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												24
												24
												21
												22

FIG. 14. An example of a print-out of the sample concentrations according to their coordinates at the sampling sites. Spacing between the lines (D) 200 m, and between the sampling sites (H) 40 m. The explanation concerning the text of the table is in the explanation of Fig. 9.

ALUE: MAUKIJÄRVI, ENONTEKIJÄ
 TUNNUS: M2, LAATU A00 KARTTALEHTI 1834

CU KUV: NO 1

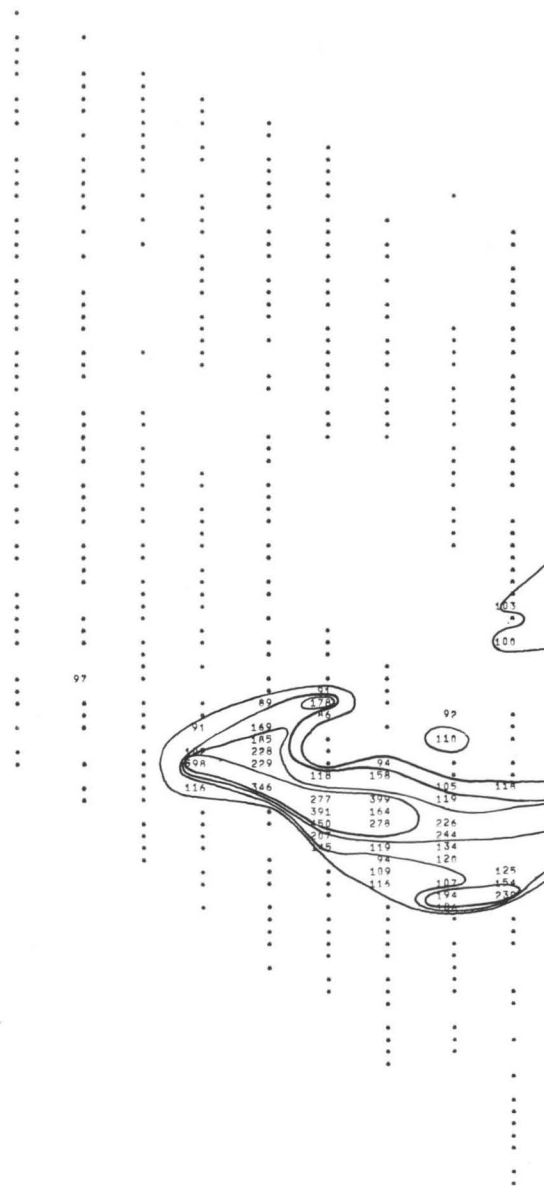


FIG. 15. An example of a print-out in which only the concentrations surpassing the anomaly threshold (Σ % 80) are depicted by numbers and the rest of the data is indicated by an asterisk. The concentrations are printed out according to the coordinates. The contours were added later by hand. The explanation concerning the text of the table is in the explanation of Fig. 9.

Geochemical maps

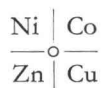
Geochemical maps are the most important means of presenting the results. The manner in which the results are presented on the maps depends partly on the methods of exploration used.

Stream sediment maps

The waterways from which the samples were taken are marked on the maps by means of a solid line should the samples be mainly mineral soil (> 90 w-%) and by a broken line should the samples contain abundant biogenic matter (> 10 w-%). The variations in the concentrations of metals are marked point by point on separate maps based on the percentage values obtained by means of the cumulative frequency distributions. The percentage limits may be e.g. at 80, 90, 95 and 98 points. The concentrations are indicated usually by circles of different kinds (e.g. Fig. 19). The results are not smoothed. The scale of the maps is usually 1 : 40 000 but maps on a scale of 1 : 20 000 are also employed.

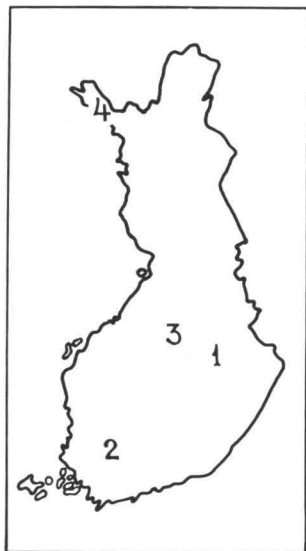
Soil and moraine maps

The results of the moraine and soil survey are generally presented with two sets of maps. The first set shows the variation of the concentration of an element in the area under consideration while the other set presents the mutual relationships of four elements. Maps of this type are called multi-metal maps. Should the concentration distribution in a survey area be regular enough, contours are drawn on the concentration maps, e.g. for concentrations at the cumulative frequencies of 80 to 98 per cent and ≥ 98 per cent (e.g. Fig. 18). Whenever necessary the sample error is taken into consideration. If the concentration maps are made by a line printer the maps are reduced photographically to the right scale for copying. The concentration variations are now smoothed (e.g. Fig. 15). In the preparation of multi-metal maps the environment of each sample point is divided into 4 parts in such a way that the sampling point coincides with the centre of the rectangle. Each of the parts is reserved for one analysed metal, e.g.



For the anomaly points of each metal a square, rectangle or some other such mark is made in the part reserved for the metal. By changing the mark, the concentrations between the 90 to 98 percentage points are distinguished from the concentrations at the 98 percentage point or from larger concentrations. The picture can be made even clearer by using colours as was done on the multimetal map, Appendix I.

APPLICATIONS



The following four case histories are the applications of the methods described above. These case histories are from those survey areas whose data obtained with different methods are typical of various parts of Finland. In addition, in the choice of case histories the fact that the investigations were done by different methods was taken into account. Attention was also paid to the results which are partly positive, but partly also negative. The locations of the survey areas are shown in Fig. 16.

FIG. 16. Location of areas discussed in Case Histories 1 to 4.

Case history 1

Stream sediment and soil study

Losonmäki, Säyneinen

The investigated area is situated on map sheet 4311 of Finland, on the border between the Säyneinen and Kaavi communes in the Kuopio province. The area is part of a larger region in which geochemical surveying was carried out. However, it includes all the essential features of the whole prospect. In the results described below, emphasis is laid upon the relationship existing between the nickel concentrations in the bedrock, soils and stream sediments.

Physiographic features

The terrain is only gently sloping the variations in altitude being within tens of metres but shows a distinct parallelism in the bearing of the hills. This is further accentuated by the waterways. The shapes of the waterways are characterized by small but long and narrow lakes and a network of shallow brooks. The water flows towards the centre of the area and from there to the NW and W. The terrain is dry on the hill tops but marshy in the low-lying places.

The geology of the glacial drift is characterized by drumlins parallel to the direction of the movement of the ice (about 140°). The basement is poorly exposed.

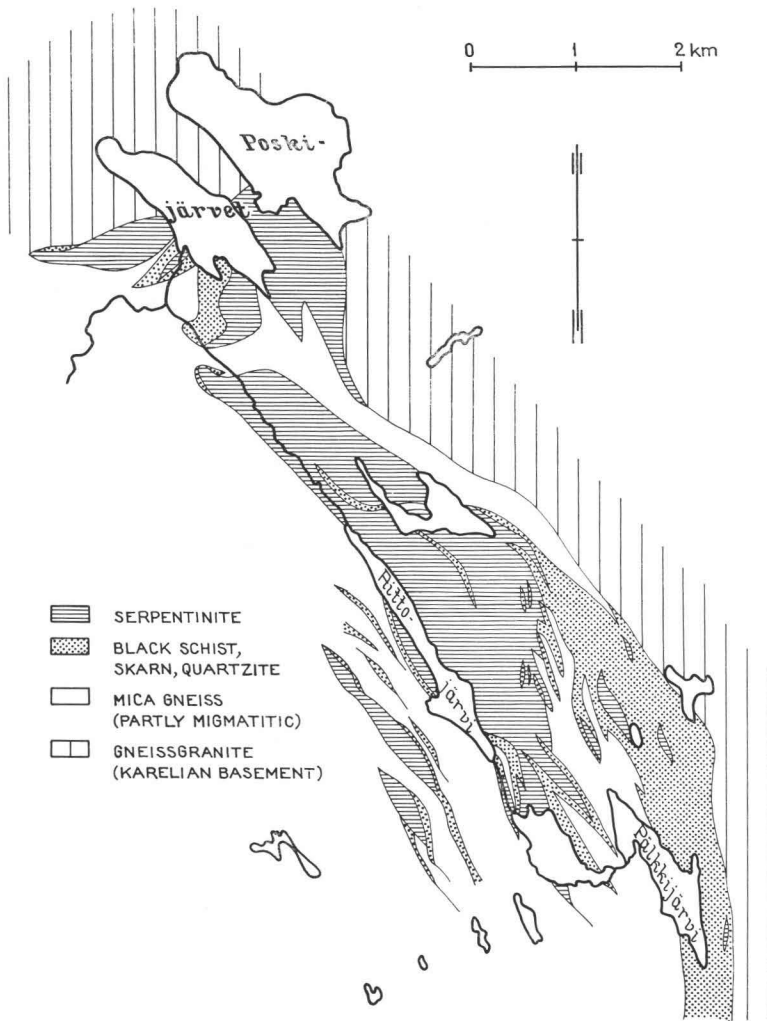


FIG. 17. A simplified geological map on the Losonmäki area, Säräsenen. According to A. Huhma.

Bedrock

The bedrock of the area belongs to the eastern border zone of the Karelian schist belt (Fig. 17). On its eastern edge it is bordered by the Pre-Karelian gneiss granite, forming the basement for quartzite and mica gneiss. Fairly abundant black schist is encountered together with quartzite and mica gneiss, especially close to the Pre-Karelian unconformity. There are large serpentinite bodies, which on the whole, are situated in the proximity of the Pre-Karelian unconformity.

The rocks show a clear NW—SE orientation and usually dip gently to the west. The structure of the complex and the texture of the rocks indicate strong movements. The movements have been partly block movements.

No ore deposits have been encountered in the area. However, a sulphide mineralization of a skarn type occurs in places at the edges of the serpentinite bodies in contact with quartzite and black schist. A scattered pentlandite dissemination whose nickel content is apparently below the economic grade, is peculiar to these mineralization.

Soil study

Since the intention of the study was only to obtain a general picture of the variation in the nickel content in the superficial parts of the ground moraine, samples were collected from the scattered network, distance between lines (D) 500 m and distance between points (H) 100 m, established by orientation. The samples were taken from the B horizon of the ground moraine from a depth of 20 cm to 40 cm. Only one sample weighing about 250 g was collected from each site. The samples were prepared as has been described (p. 16) and the samples were analysed colorimetrically for nickel soluble in boiling concentrated hydrochloric acid.

The limits of the anomaly were established on the basis of a frequency distribution. The following concentration limits were distinguished.

Σ % limits	80	90	95	98
Ni (ppm)	36	73	130	190

Since the median value of distribution is 10 ppm, sample errors need not be taken into consideration.

The anomalies are relatively clear-cut, so that the result can be depicted by contours (Fig. 18). Upon examining the results, the anomalies can be observed to group into a line in a direction NW—SE of Lake Aittojärvi and to divide into two parts: the widespread, coherent anomalies on the northwestern and northern sides of Lake Aittojärvi and the small separate anomalies on the southern and southeastern sides of the same lake. In part the anomalies have an obvious major axis which coincides with the direction of movement of the glacier and thus reflects the nickel-rich material transported mechanically by the glacier. Judging by this, the anomalies are at least partly glaciogeneous.

If the geochemical and geological maps are compared with each other, it is observed that the nickel anomalies in the soil are not always connected with the serpentinites of the bedrock. On the contrary, the anomalies are often encountered outside the serpentinites. Especially obvious is the lack of anomalies in the large serpentinite body situated on the eastern and northern sides of Lake Aittojärvi. Some anomalies have an apparent tendency to occur at the edges of the serpentinites.

It is not easy to interpret the results. However, it seems that many of the anomalies do not come from serpentinites. In some cases the cause of the anomaly has been discovered. Thus, the separate nickel anomaly on the northern side of Lake Pälkkijärvi has been interpreted as being caused by the pentlandite dissemination in the skarn zone formed at the edge of the serpentinite body. The same interpretation has been given to the anomaly on the southwestern shore of Eastern Lake Poskijärvi. The usual conclusion has indeed been that the nickel anomalies are mainly connected with skarn rocks, even though the connection is not always clear due to the displacement of the moraine by the glacier.

Stream sediment study

Stream sediment samples were taken following the method described on page 10. The material was suitable for sampling since it contained chiefly mineral soil. Abundant biogenic matter only had to be taken in exceptional cases. In the preparation of the samples an exception was made from the customary method in that those samples containing abundant biogenic matter were burnt before screening. The screen fraction < 0.15 mm of all the samples from which the determinations were made was ignited at a temperature of $+700^{\circ}\text{C}$ for 15 minutes before analyzing. The samples were analyzed colorimetrically for nickel soluble in boiling concentrated hydrochloric acid.

The anomaly limits below were established on the basis of the frequency distribution:

Σ % limits	80	90	95	98
Ni (ppm w/v)	40	70	115	175

The concentrations in the stream sediment samples give the concentrations per unit of volume.

The results have been depicted on a map (Fig. 19) using symbols to indicate concentrations. Wherever the sample is of biogenic matter, the shore has been drawn with a broken line. It can be observed from the map, that the nickel concentration of the stream sediments in the area varies considerably. Distinct anomalies appear on the bed of Lakes Pälkkijärvi-Aittojärvi-Poskijärvi, especially in the tributary of the stream. Further, an isolated anomaly site can be seen on the southwestern shore of Lake Poskijärvi. But, the waterways flowing into the centre of the area both from east and west are without anomalies.

For comparison, the general data of the soil study have been marked on the stream sediment map. The similarity in the distributions of the anomalies in the area in question is clear, but the variations in concentration in the soil reveal considerably more details.

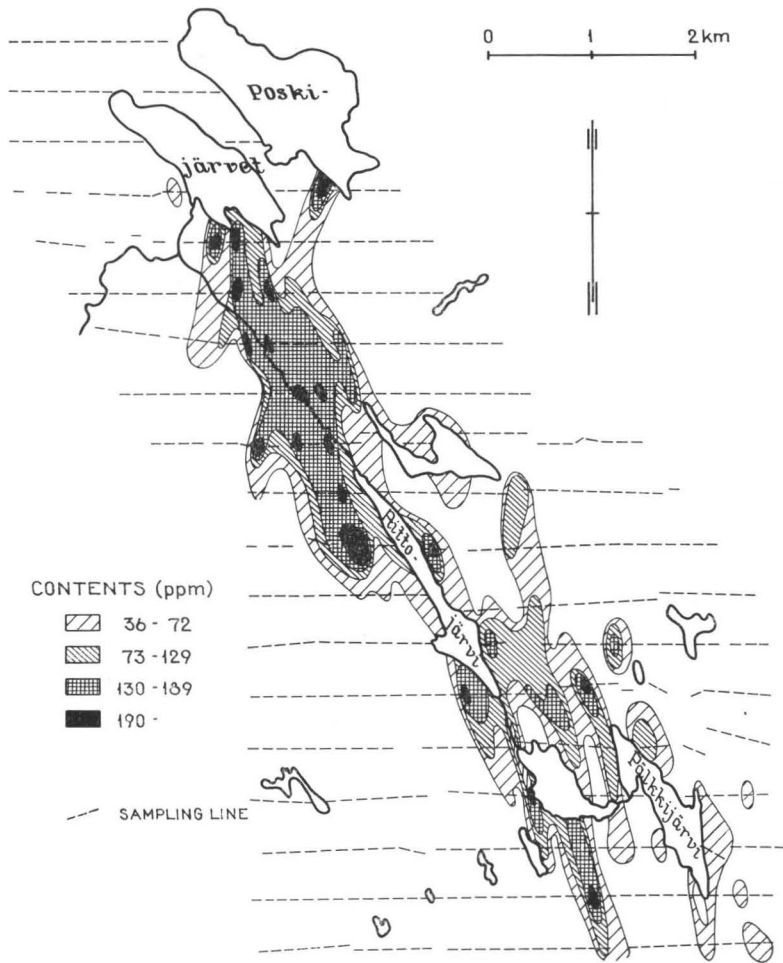


FIG. 18. The nickel anomalies in the B horizon of the moraine. Spacing between the lines (D) 500m, and between the sampling sites (H) 100m. Losonmäki area, Säyneinen.

Evaluation of results

The purpose of the geochemical investigation was the mapping of the main features of the variations in nickel concentration and the explaining of the concentration variations of nickel in the stream sediments and soil of certain areas. The work was made particularly interesting by the abundant serpentinite bodies in the survey area

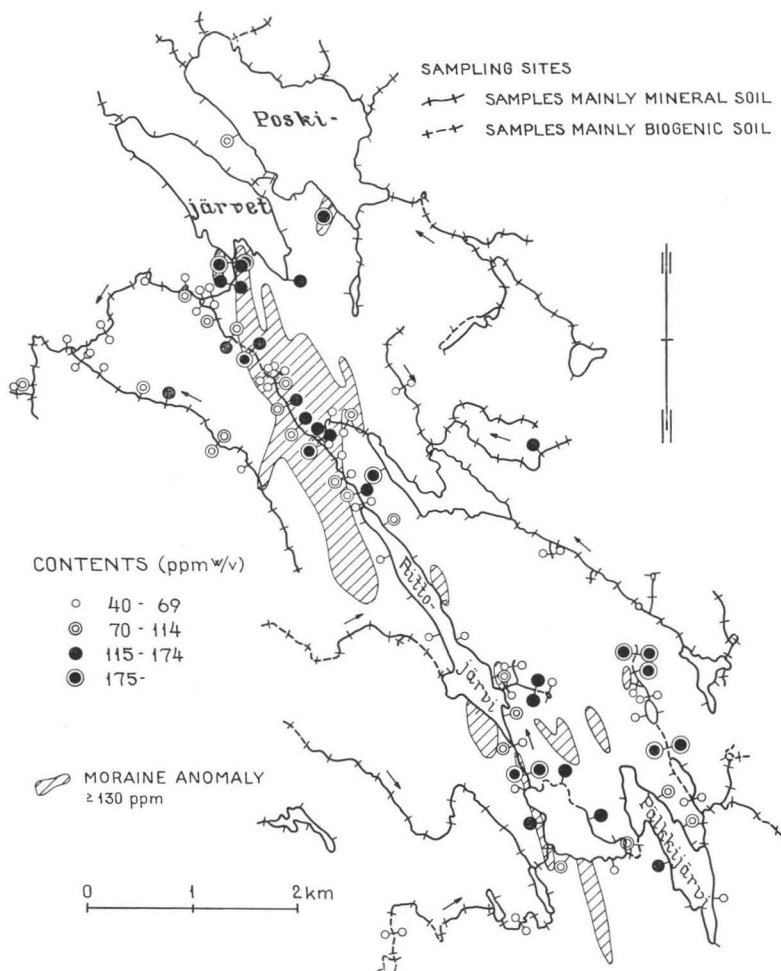


FIG. 19. The nickel anomalies in the stream sediments. Losonmäki area, Säyneinen.

and the small nickel-bearing skarn mineralizations appearing sporadically at the margins of the serpentinite.

Both the stream sediment and the soil investigations produced very similar results. The discovered anomalies have been explained as being caused chiefly by the skarn mineralizations and to a less degree by the serpentinite bodies. The result, however, is not detailed. Neither can it be expected that detailed investigations would have altered the result to any degree worth mentioning. The reason for this is the transport of soil under the influence of the glacier.

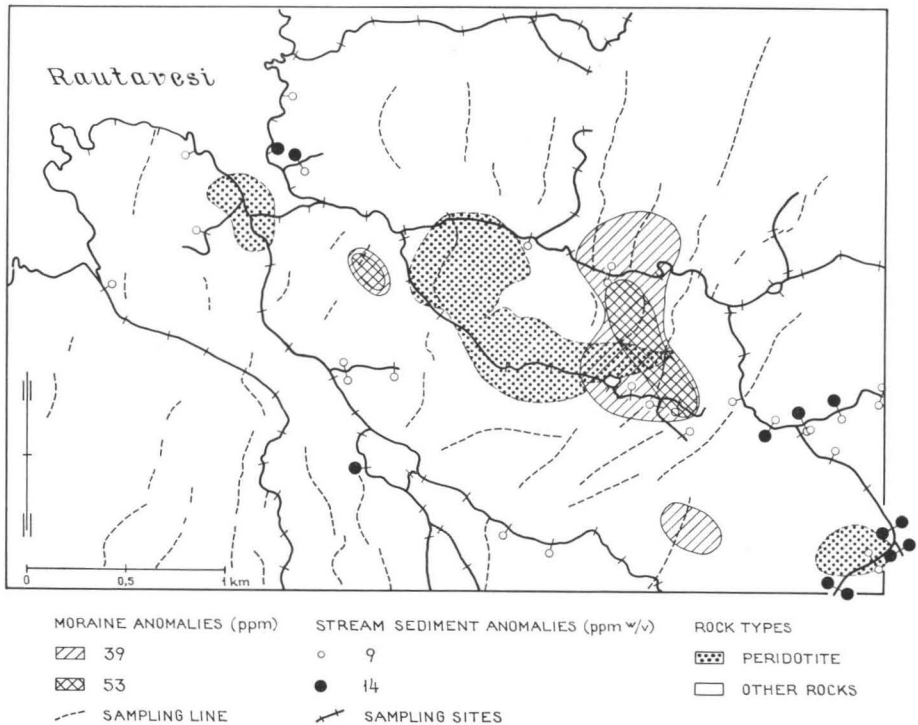


FIG. 20. Copper anomalies in the moraine and stream sediments. Stormi area, Tyrvää.

Case history 2

Stream sediment and moraine study

Stormi, Tyrvää

The investigated area is situated on map sheet 2121 of Finland, in the commune of Tyrvää in the province of Turku and Pori. The area is part of a larger area of investigation, but data obtained from it contain all the essential information of the study. In the following, a comparison between the moraine and stream sediment studies under the conditions of South and Southwest Finland is presented.

Physiographic features

The surface of the area has a low relief. The greater part of it is cultivated clay interrupted by small woods. The small hills are barren in places, but for the most part the bedrocks is covered by ground moraine with an outwashed surface. There are no swamps. The waterways consist of small ponds and brooks which are often ditched. The direction of the movement of the glacier can be determined from the striations in the exposures. The main direction is about 120° .

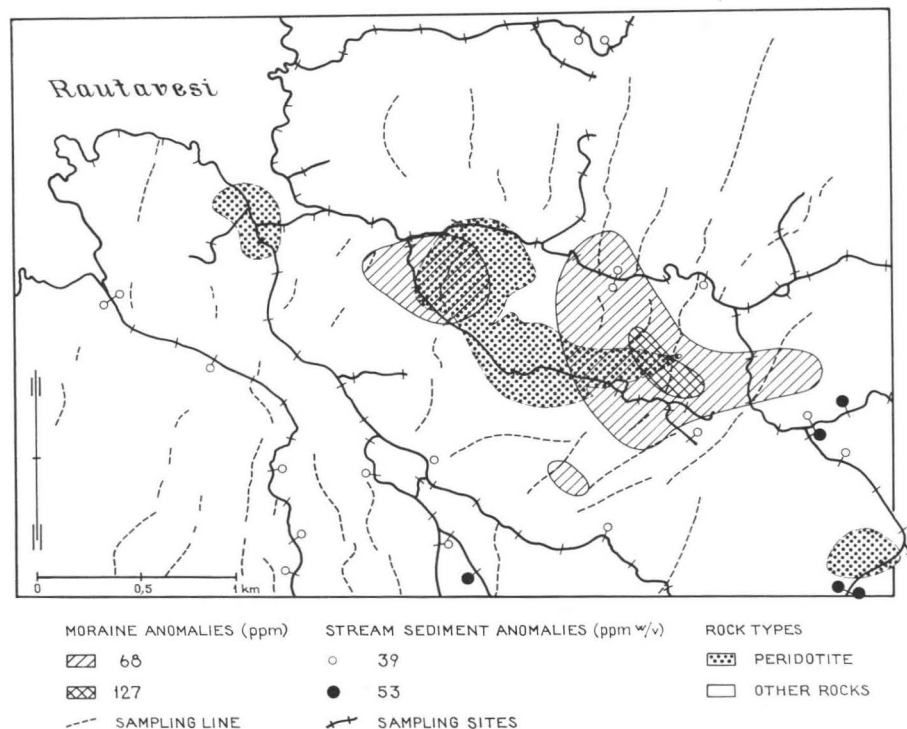


FIG. 21. Nickel anomalies in the moraine and stream sediments. Stormi area, Tyrvää.

Bedrock

The bedrock is strongly migmatic and the dominating rock type is vein gneiss. Black schist is found in places in vein gneiss as layers parallel to the schistosity. Granodiorite is sometimes encountered as lens-shaped bodies. The chief trend of the schistosity is, on an average, E—W and the dip is generally steep. The bedrock contains peridotite as irregular-shaped bodies (Fig. 20). In the peridotite bodies the following sulphides are occasionally encountered: pyrrhotite, pentlandite and chalcopyrite. The mineralizations are usually small in size. The copper and nickel concentrations are low, but have given rise to exploration in the area. One of the most remarkable sulphide mineralizations was encountered at the eastern tip of the tongue-like peridotite seen in the middle of Fig. 20.

Moraine study

Deviating from usual practice, samples were taken from the hills covered by ground moraine. In this way, a complete but somewhat irregular sample net was obtained for the area. The samples were taken by auger from a depth of one metre.

The samples were prepared as described previously (p. 16) and were analysed colorimetrically for copper and nickel soluble in boiling concentrated hydrochloric acid.

The anomaly limits were determined from the frequency distribution and the following concentration ranges were established:

Σ % limits	..... 90	98
Cu (ppm)	..... 39	53
Ni (ppm)	..... 68	127

There was no need to take the sample error into consideration.

The anomalies are relatively clear and they are depicted with contours (Figs. 20 and 21). A copper-nickel anomaly is seen at the eastern edge of the peridotite body in the centre of Figure 20. On the other hand, no definitive information was obtained concerning the shape of the anomaly due to the irregular sample net. A reliable picture of the maximum part of the anomaly was obtained later by taking samples in a regular net from under the layer of clay (Fig. 1, anomaly 4). A second copper-nickel anomaly was encountered on the banks of Lake Rautavesi ESE of the peridotite body. The anomalies are indisputably glaciogenic in type and caused by the sulphide mineralization in the peridotites.

Stream sediment study

Stream sediment samples were taken according to the method described on page 10. The samples were analysed for copper and nickel soluble in boiling concentrated hydrochloric acid.

The anomaly limits were formed on the basis of the frequency distribution and the following concentration ranges were distinguished:

Σ % limits	..... 90	98
Cu (ppm w/v)	..... 9	14
Ni (ppm w/v)	..... 39	53

The result has been depicted point by point with concentration symbols (Figs. 20 and 21). The anomalous points are scattered except at the southeastern edge of the area where both copper and nickel anomalies are concentrated. The variation in the copper and nickel concentrations of the bedrock or the moraine does not appear to correlate with the variation of copper and nickel concentrations in the stream sediments. On the basis of a terrain reconnaissance the results have been explained thus: the stream sediment copper and nickel anomalies formed where the stream sediments had obtained material directly from the moraine. In those parts of the investigated area where the formation of the stream sediments had taken place from sorted, fine-grained deposits, there are no anomalies.

Evaluation of the results

The results of the moraine study are important for exploration, whereas the stream sediment study did not produce any positive results. Directly interpreted, the results are misleading. The reason for the negative outcome of the stream sediment study is the lack of connection between the waterways, the bedrock and the ground moraine from which indications might have arisen.

Case history 3

Stream sediment, soil and moraine study

Kalliokylä, Kiuruvesi

The project is situated on map sheet 3323 of Finland, in the southern part of the commune of Kiuruvesi, in the province of Kuopio. It is a part of a larger object of study, but contains, however, the data which demonstrate most clearly the problems and possibilities of geochemical areal prospecting.

Thorough ore exploration had been carried out in the area earlier using a variety of methods. Copper- and zinc-bearing pyrrhotite-pyrite ore was discovered. The ore and its vicinity is still in a natural state and uncontaminated. The geochemical studies were made after the discovery of the orebody and the aim was to investigate what indications could be obtained from the ore. The stream-sediment method was used in the study, and the B and C horizons of the moraine in the area were mapped.

Physiographic features

The terrain is gently undulating and in the process of becoming gradually more swampy. The relief is very low. Dry land appears as islets amidst the swamps. The ground water table is high and the flow of water is slow. There are few rock exposures.

Bedrock

The bedrock is strongly metamorphosed. Its chief rock types are different gneisses, gneissose granites, granite gneisses and gabbros. Cordierite-antophyllite rocks are encountered with amphibolites. They seem to be connected with a sulphide mineralization. This mineralization was described by Helovuori (Laurila, 1963) thus (p. 18): »The mineralizations lie in the contact zones of a garnet-cordierite-antophyllite rock and granitized mica gneisses. Other surrounding rocks are gneissose granites in the south and amphibolites and gabbros in the north and northwest. The western shoots belong to the same synclinal formation, the structural conditions of the eastern shoots being unclear. The ore consists of brecciated pyrrhotite-pyrite material containing some chalcopyrite. The western ore bodies contain some sphalerite.»

Moraine and soil study

The sampling from the ground moraine was done by hand auger from a depth of about 1 metre in the C horizon of the moraine. Soil samples were taken by trowel from the same points in the B horizon of the moraine from a depth of about 20 cm to 40 cm. Moraine samples were also taken from under the swamp, where no soil samples could be collected, so that the sample grid in the soil mapping is incomplete. The spacing between lines and points, with the exception of the outmost lines, was $D = 250$ metres and $H = 50$ metres. The samples were prepared and analysed by the method explained previously. The samples were analysed by the atomic absorption method for cobalt, copper, nickel and zinc.

The anomaly limits were obtained on the basis of the calculated frequency distributions (Figs. 23 and 24). Since the distributions are partly very narrow, the sample error also has an effect on the anomaly threshold. The anomaly limits in which both the distributions and the sample errors are considered can be seen in Table 15.

It can be observed from the table that especially the variation of cobalt and nickel is very limited in the anomalous areas. This, of course, means that these metals are more or less meaningless as far as their indicativeness is concerned.

The result of the moraine study can be seen as a multi-metal map (Appendix I), on which the anomalies of certain metals have been marked at points within the limits of the anomaly classification. Since the concentrations differ rather much from the limits of the high anomalies at several points, also the actual concentrations are marked with numbers at those points in order to clarify the picture. For the sake of comparison, the Kalliokylä ore outcrop has also been drawn in on the map.

It can be seen from the map that the geochemical pattern of the area is clear and is divided on the basis of the anomaly types into two parts. Towards the centre of the area a fairly strong copper-zinc anomaly is closely connected with the ore outcrop. This continues clearly but more weakly to the northwest. This anomaly seems to be caused not only by the Kalliokylä ore exposure but also by the rock complex to which the ore is connected. Thus, one can presume — even though the matter has not been proved — that the whole rock complex serves as a carrier of metals which have been concentrated in the ore. From the point of view of geochemical exploration it is important to note that the anomaly is local. Thus, the ore anomaly is hydromorphic,

TABLE 15

The anomaly limits (ppm) for the analysed metals determined on the basis of the cumulative frequency distributions and the sample errors in the B and C horizons of the moraine. Kalliokylä area, Kiuruvesi.

		Co		Cu		Ni		Zn	
		B	C	B	C	B	C	B	C
		low anomaly	n = 1	15	16	19	26	22	26	46	48
	2	14	14	19	24	19	23	43	43
	3	14	14	19	24	18	23	43	43
high anomaly		22	18	29	34	23	26	64	58

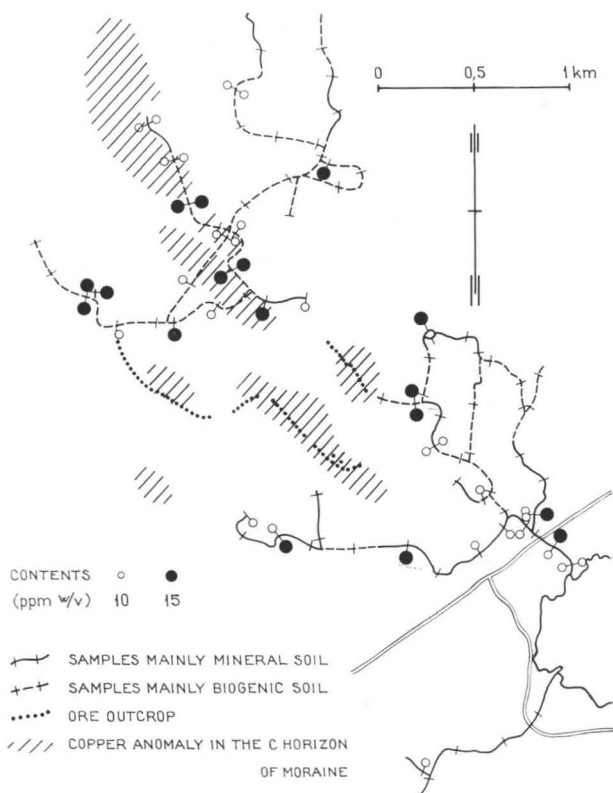


FIG. 22. Variations of copper concentration in the stream sediments. Kalliokylä area, Kiuruvesi.

possibly partly sedentary, and there do not seem to be any glaciogene features connected with it.

In the southern part of the area, to the west of Lake Kalliojärvi, there are two weak anomalies, both of them differing in type from the ore anomalies. One of the anomalies, which is relatively wide-spread, is characterised by a cobalt-nickel combination and the other, an apparently narrow anomaly, by a combination of all the determined metals. It is not quite clear what has caused these low anomalies, but one can presume that the cobalt-nickel anomaly points to mafic or ultramafic rocks, gabbros or hornblendites which have been encountered in several exposures of corresponding anomalies on the northern border of the area. The anomaly in common to all the metals was determined on the basis of geophysical measurements and one diamond drillhole as belonging to the black schist sequence.

Although the three typical anomalies in the moraine were also encountered in the soil investigation, they appeared as sparser and more isolated points. This was caused chiefly by the fact that the sample grid was incomplete due to the lack of samples from the swamp areas.

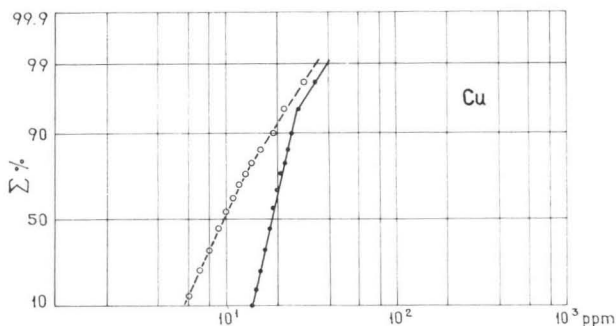
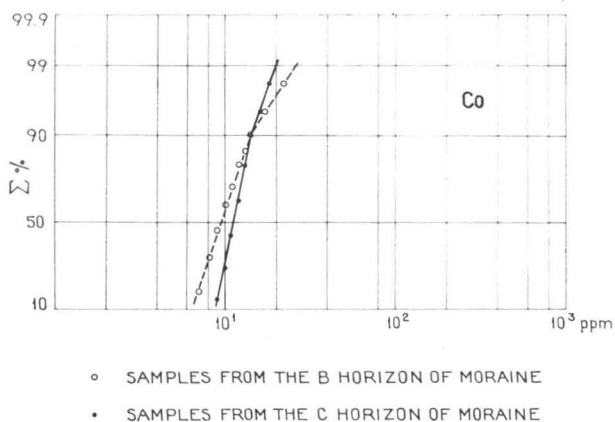


FIG. 23. The cumulative frequency distributions of the cobalt and copper concentrations in samples taken from the B and C horizons of the moraine. Kalliokylä area, Kiuruvesi.

Stream sediment study

Stream sediment samples were taken according to the method described on page 10. They were prepared in the same way as explained in Case History 1. The samples were analysed colorimetrically for copper and zinc soluble in boiling, concentrated hydrochloric acid. Only the variations in copper concentration in the area under discussion are presented, because the colorimetric method for zinc proved later to be very unreliable. The anomaly limits were determined also in this case on the basis of the frequency distribution. The following concentration limits were established.

Σ % limits	80	95
Cu (ppm w/v)	10	15

Since there are only slight variations in the concentrations of copper in the stream sediments, a more accurate concentration classification was unnecessary.

The results have been depicted on a map (Fig. 22), employing symbols for the concentrations. Wherever the sample was of biogenic matter, the shore was drawn with

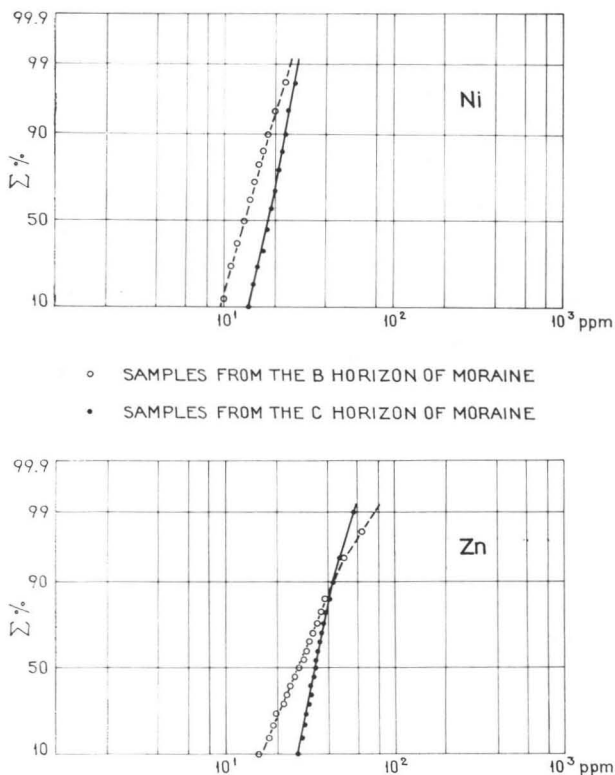


FIG. 24. The cumulative frequency distributions of the nickel and zinc concentrations in samples taken from the B and C horizons of the moraine. Kalliokylä area Kiuruvesi.

a broken line. As can be observed from the map, many samples contain abundant biogenic matter.

Fluctuations in concentration are small and the anomalies are not clearly grouped. A considerable part of the anomaly maxima are to be found in samples containing abundant biogenic matter. No connection can be observed in the anomalies with an ore outcrop or the copper anomalies detected in the moraine study. The small concentration variations give none of the indications expected in areal geochemical studies. Since the result does not indicate ore nor even put a limit to the object of study, it is negative.

Statistical results

Distribution data

Distribution data from the results are depicted on a probability paper (Figs. 23 and 24). The distribution data represent the whole explored area, of which only a part is to be found in this Case History.

TABLE 16

The linear and logarithmic coefficients of correlation between different metals in the B and C horizons of the moraine and the coefficients of correlation of the same metals between the B and C horizons of the moraine. The three pairs of metals with the highest numerical values of correlation coefficient are listed in the lower part of the table. Kalliokylä area, Kiuruvesi.

	B horizon		C horizon		Correlations between B and C horizons		
	lin.	log.	lin.	log.			
Co/Cu	0.46	0.44	0.20	0.28		lin.	log.
Co/Ni	0.60	0.68	0.47	0.53	Co	0.42	0.40
Co/Zn	0.40	0.46	0.21	0.32	Cu	0.29	0.33
Cu/Ni	0.26	0.53	0.38	0.46	Ni	0.27	0.26
Cu/Zn	0.39	0.33	0.59	0.64	Zn	0.48	0.38
Ni/Zn	0.48	0.54	0.36	0.52			
I	Ni/Co	Ni/Co	Cu/Zn	Cu/Zn			
II	Ni/Zn	Ni/Zn	Ni/Co	Ni/Co			
III	Cu/Co	Cu/Ni	Cu/Ni	Ni/Zn			

The plot of the distributions onto a probability paper reveals them to be almost lognormal and to represent mainly one population. Rare high concentrations, however, form their own group, whose slope of the graph differs that of the usual population.

Correlation coefficients

The correlation coefficients were calculated using the conventional equations. The coefficients are presented in Table 16.

With regard to the numerical values of the coefficients, it must be noted that they are relative values, regulated mainly by the rare large concentrations. Moreover, they are probably always positive, as far as the variations in the concentration of the trace metals in moraine and stream sediments are concerned. They are of significance when comparing coefficients with each other in the same area and when comparing their mutual order in different areas.

When examining the correlation coefficients one notices that the coefficients between the same metals in different podzolic horizons are small and show dissimilarity of distribution. The mutual coefficients of different metals in the B horizon of the moraine are in the following order: Ni/Co, Ni/Zn and Cu/Ni, whereas in the C horizon of the moraine the order is: Cu/Zn, Ni/Co and Ni/Zn. It should be noted in the grouping that the Cu/Zn and Ni/Co appear in the C horizon of the moraine with the highest numerical values of the coefficient, because the same combinations have also been observed following each other closely in the anomaly pattern.

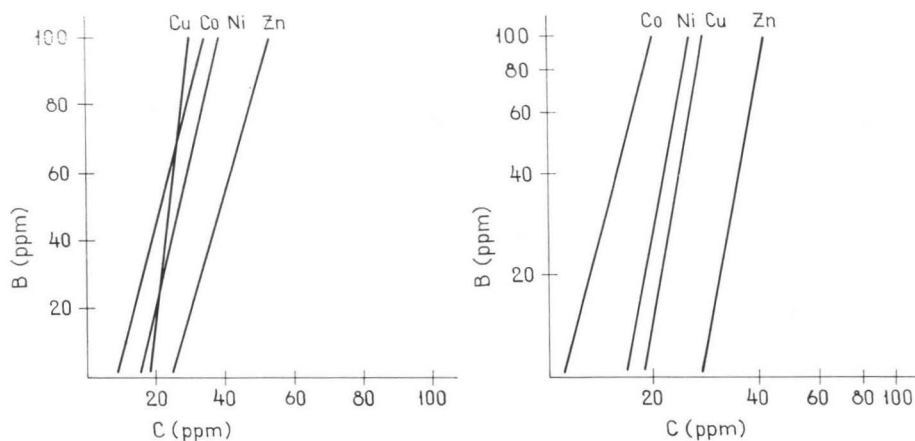


FIG. 25. The linear and logarithmic regression lines of the cobalt, copper, nickel and zinc concentrations between the B and C horizons of the moraine. Kalliokylä area, Kiuruvesi.

Regression analysis

Simple regression models were computed between the concentrations:

$$y = a + bx$$

$$\ln(y) = a + b \ln(x)$$

The calculations follow the normal procedure. The regression models were used especially for distinguishing between samples taken from different moraine horizons at the same site and for clarifying the relationships between the trace metal concentrations. In this study the behaviour of the trace metals in the B and C horizon of the podzol profile was studied. The outcome is given in Fig. 25.

The study shows that in the small concentrations, the concentrations for all the determined metals are greater in the C horizon of the podzol profile than in the B horizon, but that as the concentrations increase all the metals are inclined to become enriched in the B horizon of the podzol profile. The tendency to enrichment varies among the metals. A linear model shows that it increases in the order Cu, Ni, Co, Zn, but according to the logarithmic model the order is: Cu, Ni, Zn, Co.

The data available is not sufficient to draw a generalizing conclusion. In Survey Areas 3 and 9 (see p. 73) the regression models show that in low concentrations, the concentrations of the trace metals in the C horizon of the podzol profile are higher than the corresponding concentrations in the B horizon, but that the inclination towards enrichment as the concentrations increase is greater in the B horizon of the podzol profile than in the C horizon. The order of enrichment at Area 3 in the linear model is Ni, Zn, Co, Cu and in the logarithmic model Ni, Cu, Zn, Co, respectively. At Area 9 the corresponding order in the linear and logarithmic models is Zn, Co, Cu, Ni.

Evaluation of the results

Three methods of geochemical exploration were tested in the Kalliokylä area: moraine, soil and stream sediment methods.

The moraine investigation gave the best results of all the methods. A local hydro-morphic anomaly, which is in part possibly sedentary, is connected to the well-known ore outcrop. The anomaly is distinct but not especially large. The rocks belonging to the ore complex are depicted in the data, the reason for which is probably that copper and zinc occur also in these rocks as anomalous concentrations. The result of the soil investigations shows that in very swampy areas the sample grid might be too sparse and irregular just at the critical points. Thus, when carrying out the soil investigation it would have been advisable to complete the sample grid with samples taken from under the swamps. If soil material that could stand comparison were desired, then the sampling should have been transferred from the B horizon of the moraine to e.g. the upper part of the C horizon. The result of the stream-sediment investigation is negative and shows that in areas where the stream sediments have no close connection with the moraine or bedrock due to stagnant water or soil impervious to water, the method will not give results of any practical value.

Case history 4

Stream sediment and moraine study; Geochemical study of the bedrock

Haukijärvi, Enontekiö

The exploration area is situated on map sheet 1834 of Finland, in the northwestern part of Enontekiö commune, about 70 km to the southeast of Kilpisjärvi. The area is a part of the much larger Lätäseno area. The area in question was chosen on the basis of stream sediment studies carried out in the Lätäseno area. The aim of the results given is chiefly to explain the anomalous concentration of copper and nickel in the bedrock, moraine and stream sediments appearing in the area.

Physiographic features

The nature of the area is entirely different from those described in Case Histories 1, 2 and 3, being typical only of North Lapland. Characteristic are the barren fells rising above the timber line; however, the actual area now under discussion is completely covered by a thick forest of small birch trees. Biological activity is slow in the soil and the humus layer is thin in the podzol profile. The elevation of the area above sea-level is 405 metres at Lake Haukijärvi. The highest point is in the northwest corner where it is 569 metres above sea-level. Due to the considerable local differences in elevation the terrain is relatively dry. The direction of movement of the glacier is

roughly 20° and the moraine cover is unbroken. In places, exposures are encountered abundantly, as are also the mounds of rubble typical of Lapland, in which the boulders are often local and reflect the bedrock.

Bedrock

According to K. Vormisto (personal communication) the main rock unit of the area is a shuttle-shaped massif of gabbro, which strikes roughly N—S. The massif, called the Haukijärvi gabbro, is about 15—20 km long and, near Lake Haukijärvi, about 3 km wide. It seems to have intruded the surrounding volcanic amphibolites and quartzites almost concordantly.

The main part of the Haukijärvi massif is made up of medium-grained hornblende gabbro with hornblende and plagioclase as chief constituents. Some more basic variants encountered indicate that the massif has been differentiated. At the eastern contact, the rock approaches peridotite in composition. The strip-like pyroxene gabbro horizon almost in the centre of the massif is also comparatively distinct. Alongside the pyroxene gabbro there is olivine-rich gabbro. The sulphide mineralization, which is capricious and weak, is concentrated mainly along the eastern contact zone of the Haukijärvi massif.

The geochemical investigation of the bedrock

The purpose of the investigation was to establish the distributions of cobalt, copper, nickel and zinc occurring as sulphides in the gabbro. Attempts were made to carry out the sampling over the whole area with the most regular sample grid possible. But since there was a lack of outcrops this was not quite successful.

The samples were taken with a light motor-driven pneumatic drill. The sampling was carried out by drilling a row of 50—60 cm long holes across the outcrops with a hole spacing of 1 metre. When sampling, the drill was inclined, so that the combined sample series of each site form a groove sample. A total of 225 samples from 57 places was taken in the area. The drill cuttings were collected in cloth bags by means of a sample collector designed especially for this purpose, after having first removed the weathered surface of the rock by drilling. Due to the care with which the work was done, there was very little dust loss in the sampling. About 1 kg of material was taken from each hole. The sample to be analysed was obtained later in the laboratory by repeated splitting.

The drill cuttings were analysed by atomic absorption method for cobalt, copper, nickel and zinc soluble in boiling concentrated nitric acid.

The data have been presented as the average concentrations of the samples taken from the same place. The frequency distributions were calculated on the basis of the averages, and the anomaly limits in Fig. 26 determined.

When examining the variations in concentration of the analysed metals the anomalous sites can be observed more frequently on the eastern and southeastern sides of

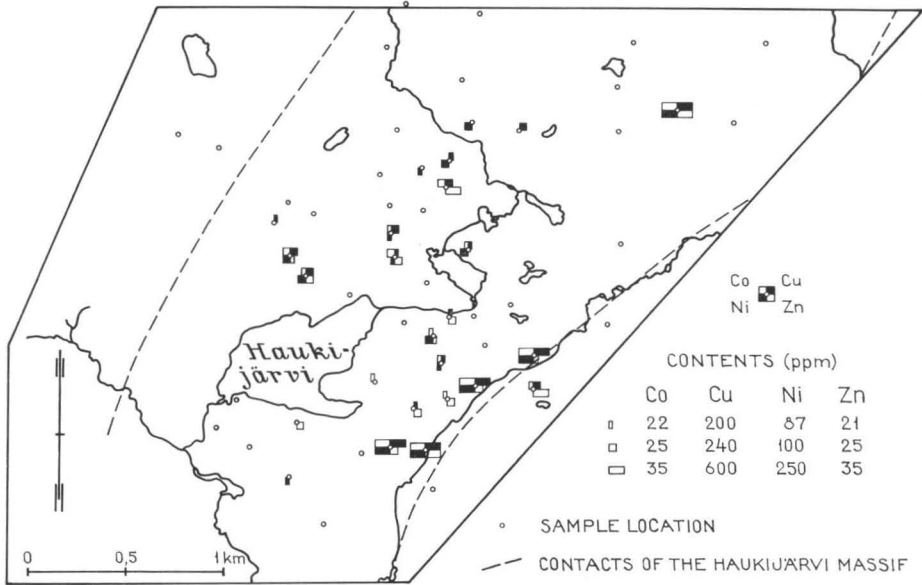


FIG. 26. Variations in the concentrations of cobalt, copper, nickel and zinc in drill cuttings from the bedrock. The concentration limits correspond to the Σ % limits of 70, 80 and 90 of the cumulative distribution. Haukijärvi area, Enontekiö.

Lake Haukijärvi at the edge of the gabbro massif. A less distinct anomaly zone appears on the northeastern side of Lake Haukijärvi. On the other hand, anomalies are missing at the northern and southern edges of the area. Further, cobalt, copper and nickel, and to a less degree zinc, can be observed to correlate with each other at the anomaly sites.

The number of samples is insufficient, so that it is possible that outcome is not correct. Since the intention of the study was to compare the concentration distributions in the bedrock with the concentration distributions in the moraine and stream sediments, the material obtained from the bedrock was also employed in connection with the statistical analysis (p. 65—71).

Moraine study

In the moraine study, the sampling was comparatively detailed, the grid being $D = 200$ m, $H = 40$ m. There were no large breaks in the sample grid. The sampling was done partly by hand auger and partly by hand-operated drill (designed by the Geological Survey of Finland). The samples were taken from the C horizon of the ground moraine, the desired depth being 1.5 metres. They were prepared in the usual way and analysed by the atomic absorption method for cobalt, copper, nickel and zinc soluble in boiling, concentrated nitric acid. On the basis of a frequency distribution, the following anomaly limits were determined.

Σ % limits	80	90	98
Co (ppm)	16	18	23
Cu »	86	118	258
Ni »	45	54	84
Zn »	40	44	62

A sampling error must be taken into account in the anomaly threshold of the zinc. Considering this error, the anomaly thresholds for $n = 1, 2$ and 3 are 48 ppm, 43 ppm and 40 ppm respectively. However, this does not have any noteworthy effect on the anomaly pattern, because the anomalous points accumulate relatively distinctly into certain places. Due to the concentrations and the difference between significant and threshold values, the most distinct anomalies in the Haukijärvi area are produced by copper and nickel.

The distribution of anomalous points is so clear that it was possible to depict the anomalies separately with contours for each determined metal (Figs. 27 and 28). The copper anomalies seen in Fig. 27 can be observed concentrating roughly in a north to south direction, in a line running from the eastern side of Lake Haukijärvi. However, the anomaly sequence is apparently not uniform. Smallish separate anomalies are to be found to the north of Lake Haukijärvi. If the distribution of the anomalies in the moraine is compared with the concentration distribution in the rock samples, the distributions look the same though rather indistinctly. For example, the copper anomaly situated at the northern edge of the area is in surroundings where the concentrations obtained from drill cuttings cannot be distinguished from the background. Similarity has been taken as evidence for the fact that both the concentration distribution in the bedrock and the copper anomalies in the moraine reveal those parts of the bedrock in which the sulphide mineralization in the gabbro massif is concentrated. This is quite certain on the eastern side of Lake Haukijärvi.

The nickel anomaly map (Fig. 27) is very similar to the copper anomaly map. The biggest difference is that the nickel anomalies are centred at the northern edge of the area, where they do, however, correlate with the copper anomalies. Also east of Lake Haukijärvi, where the strongest of the copper anomalies is to be found, there is a corresponding but weaker nickel anomaly. Separate nickel anomalies also occur north of Lake Haukijärvi in the same places as the copper anomalies. When comparing the location of the moraine nickel anomalies with the nickel distribution in the bedrock, only a faint similarity can be observed.

In the Haukijärvi area, the changes in the concentration of cobalt and zinc are less than those of copper and nickel (Fig. 28). Also the distribution of the cobalt and zinc anomalies is less uniform. The most distinct cobalt and zinc anomalies appear in the northern part of the area, in addition to which zinc anomalies in particular appear to the northeast of Lake Haukijärvi and in the southern part of the area. The cause of the anomalies has not been determined. If one compares the cobalt and zinc

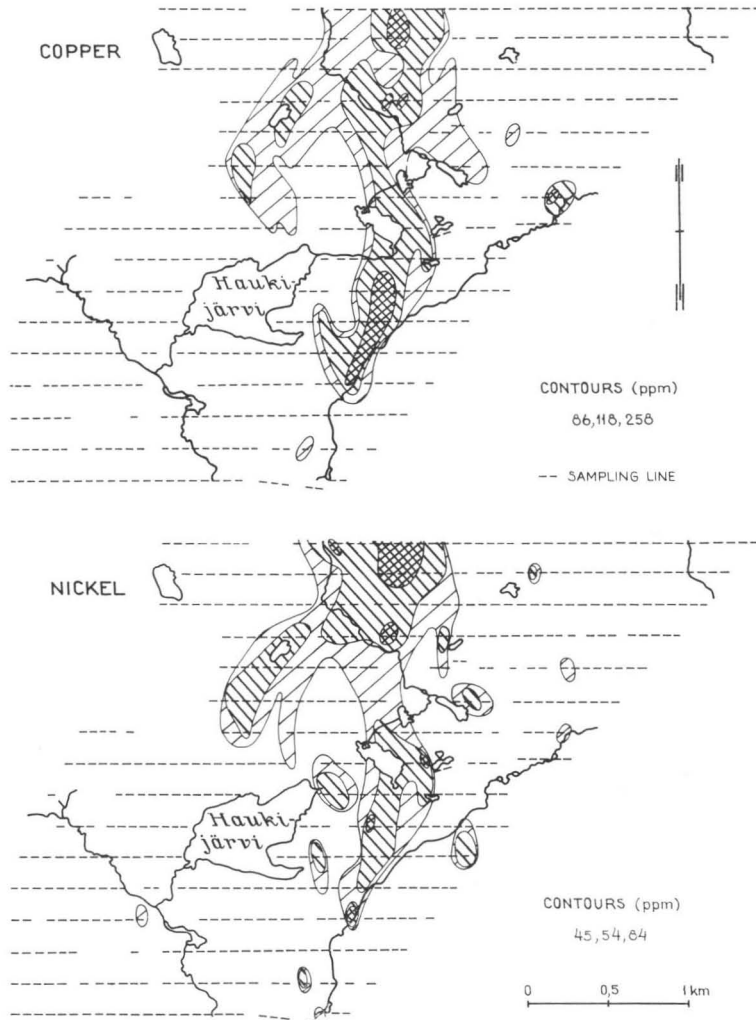


FIG. 27. Copper and nickel anomalies in the C horizon of the moraine. The anomaly limits correspond to the Σ % limits of 80, 90 and 98 of the cumulative distribution. Spacing between the lines (D) 200 m, and between the sampling sites (H) 40 m. Haukijärvi area, Enontekiö.

anomalies in the moraine with the corresponding anomalies in the bedrock, similarity is difficult to observe.

As for the anomaly types, geological observations seem to indicate that the glacier played an active part in the formation of the moraine. The stretching of some anomalies in the direction of movement of the glacier, e.g. the anomaly east of Lake Haukijärvi, supports the concept of the glaciogeneous origin of the anomalies, but, of course, there may be other types of anomaly among them.

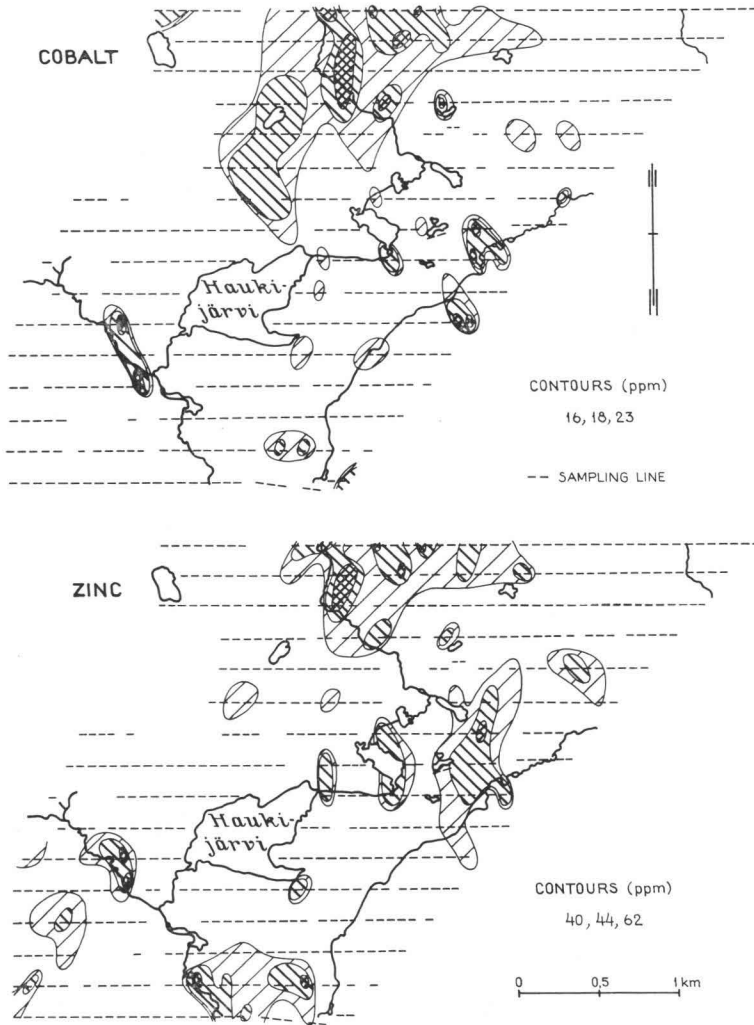


FIG. 28. Cobalt and zinc anomalies in the C horizon of the moraine. The anomaly limits correspond to the Σ % limits of 80, 90 and 98 of the cumulative distribution. Spacing between the lines (D) 200 m, and between the sampling sites (H) 40 m. Haukijärvi area, Enontekiö.

Stream sediment study

The stream sediment mapping was done over a relatively large area, the so-called Lätäseno area, of which the Haukijärvi area is only a small part. However, waterways around the Haukijärvi area have also been added to the presentation of the stream sediment study. This has been done so that the concentration variations of the metals can be seen more clearly in the actual area under discussion.

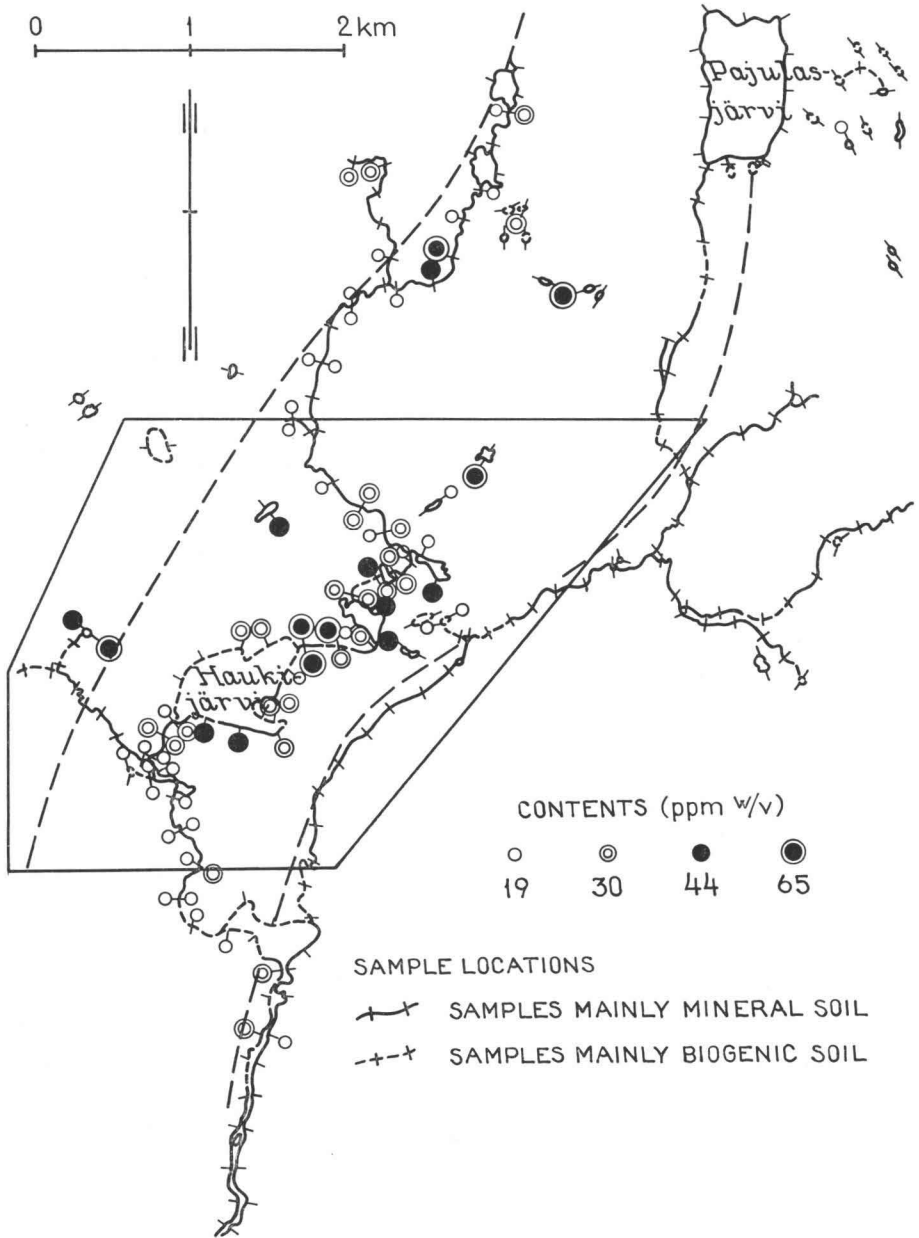


FIG. 29. Variations of copper concentration in the stream sediments. The concentration limits correspond to the $\Sigma\%$ limits of 80, 90, 95 and 98. The bedrock and moraine study area is marked on the map. Haukijärvi area, Enontekiö.

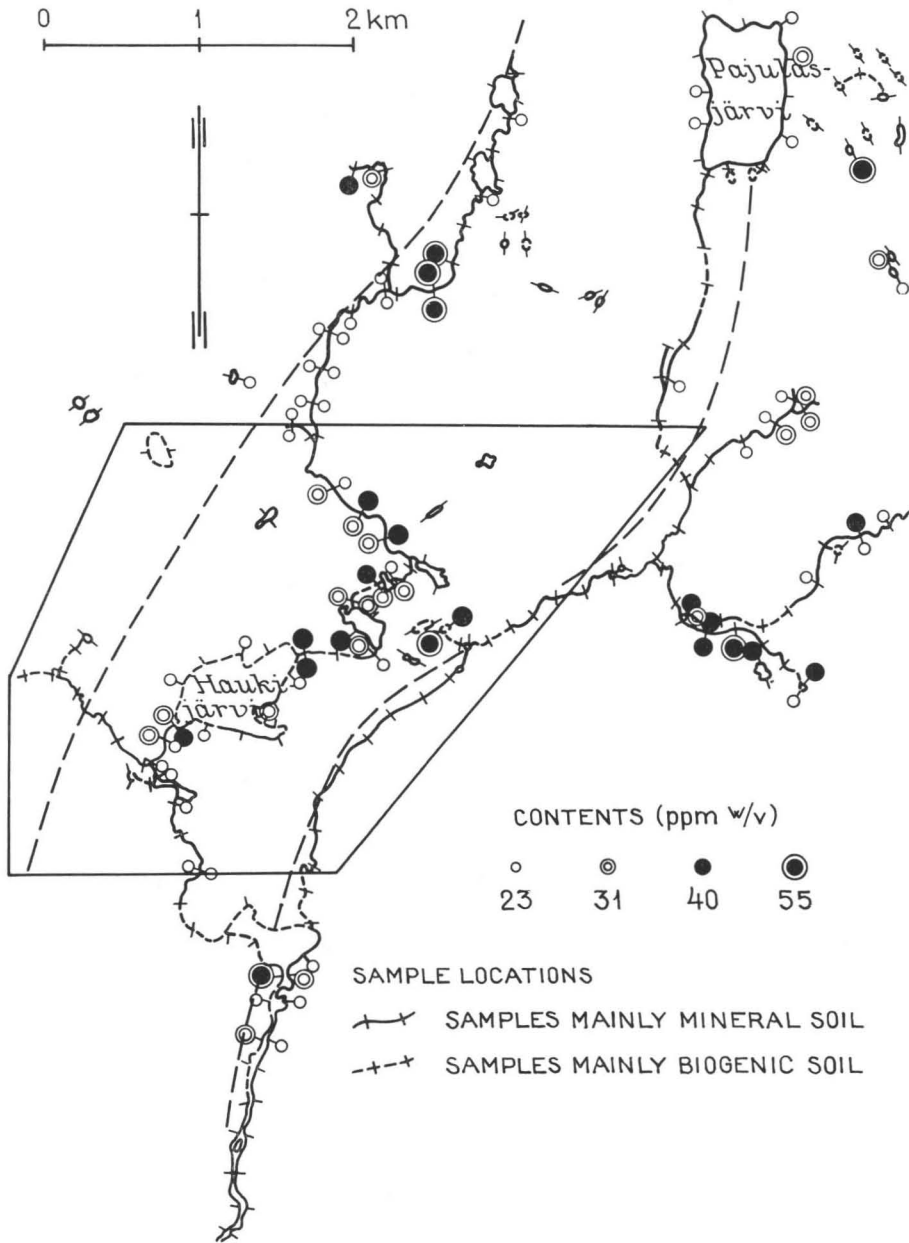


FIG. 30. Variations of nickel concentration in stream sediments. The concentration limits correspond to the Σ % limits of 80, 90, 95 and 98. The bedrock and moraine study area is marked on the map. Haukijärvi area, Enontekiö.

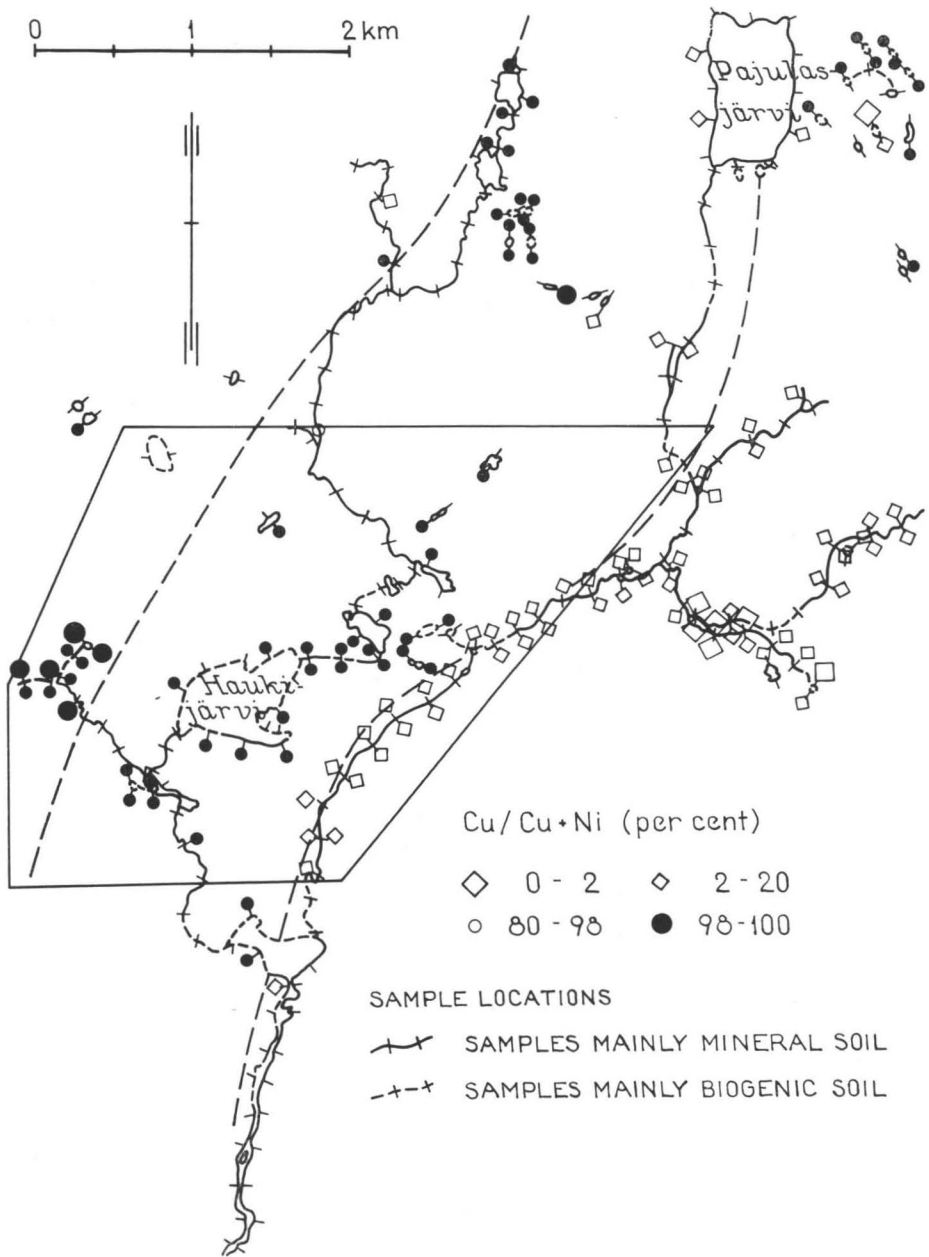


FIG. 31. The distribution of copper-nickel ratios in stream sediments. The bedrock and moraine study area is marked on the map. Haukijärvi area, Enontekiö.

Sampling was carried out using the customary methods. The material collected in the area was suitable for study, because samples containing biogenic matter only had to be taken in exceptional cases. The samples were treated as described in Case History 1, and were analyzed colorimetrically for copper and nickel soluble in boiling concentrated hydrochloric acid.

The anomalies were classified in the usual way on the basis of the frequency distributions with the following limits.

Σ % limits	80	90	95	98
Cu (ppm w/v)	19	30	44	65
Ni »	23	31	40	55

Data are presented point by point with the aid of concentration symbols.

It can be observed from the map depicting the concentrations of the copper (Fig. 29) that the anomalies are centred in the area of the Haukijärvi massif. The most considerable group of anomalies is situated around Lake Haukijärvi, especially on the northeastern side of the lake.

The concentration variations of the nickel (Fig. 30) follow the copper anomalies in the massif area, but there are also strong anomalies in the network of streams east of the massif. The causes of this anomalies are isolated serpentinite bodies.

The concentration variations of copper and nickel have been compared with each other by computing the amount of copper as percentages of the total amount of copper and nickel. The ratios between the metals show an »excess» of copper at the western edge of the area and an »excess» of nickel at the eastern edge. The distribution of the ratios (Fig. 31) indicates, that the streams coming from the eastern edge of the area transport nickel to the stream which, starting in Lake Pajulasjärvi, flows into the southern part of the area. It is probable that this stream does not collect material to any degree worth mentioning, except from the tributary coming from Lake Haukijärvi. This is indicated by the fact that on the eastern side of Lake Haukijärvi, right next to the stream, there are copper-nickel mineralizations in the exposures, the influence of which cannot be seen as corresponding anomalies in the stream sediments.

Statistical results

Distribution data

The rock, moraine and stream sediment samples analysed are from the same area. When comparing their concentrations, obvious differences can be observed. In the rock samples, the copper and nickel concentrations are on an average greater than in the moraine and stream sediment samples. At the median (Table 17), the cobalt concentration of the rock samples is almost the same as that of the moraine samples, whereas the zinc concentration of the rock samples is distinctly lower than that of the

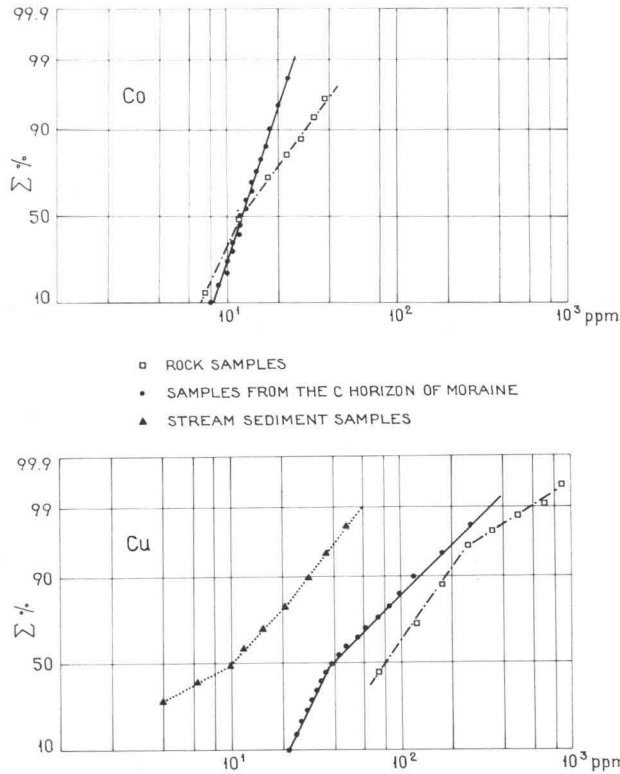


FIG. 32. The cumulative frequency distribution of the cobalt and copper concentrations in rock samples, in samples from the C horizon of the moraine and in stream sediments samples. The concentrations of the stream sediment samples in the units of volume have been converted into weight concentrations using a reduction coefficient of 0.67. Haukijärvi area, Enontekiö.

moraine samples. The metal concentrations of the stream sediments are on an average much smaller than the concentrations in the moraine samples. The reason for this is probably the mechanical and chemical dilution at the formation of the stream sediments.

TABLE 17

The median values (ppm) of cobalt, copper, nickel and zinc in rock and moraine samples. The stream sediment samples were not analysed for cobalt and zinc. The concentrations in the stream sediment samples have been converted into weight concentrations by using a reduction coefficient of 0.67. Haukijärvi area, Enontekiö.

	Co	Cu	Ni	Zn
Rock samples	13	82	42	9
Moraine samples	12	39	28	34
Stream sediment samples .		11	11	

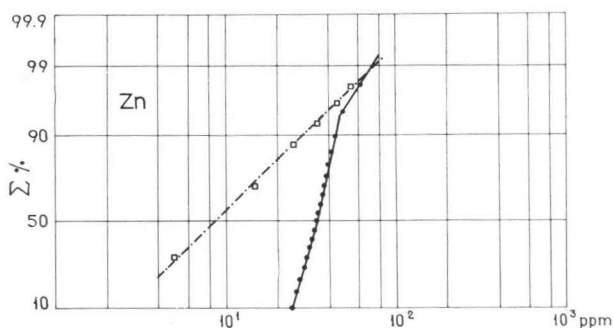
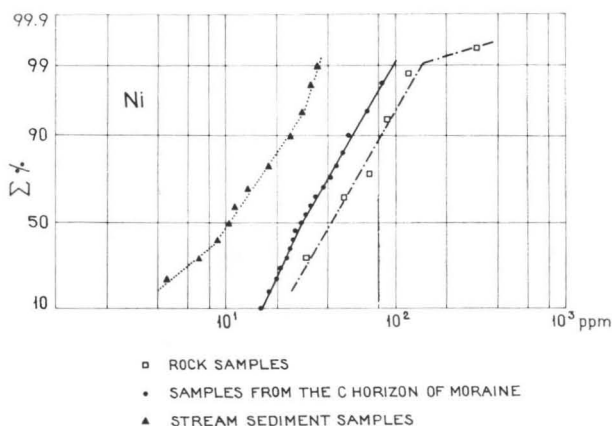


FIG. 33. The cumulative frequency distributions of the nickel and zinc concentrations in rock samples, in samples from the C horizon of the moraine and in stream sediment samples. The concentrations of the stream sediments in units of volume have been converted into weight concentrations using a reduction coefficient of 0.67. Haukijärvi area, Enontekiö.

From the point of view of geochemical exploration the contrast in anomalies is important. The numbers in Table 18 illustrate the changes in these contrasts between the rock, moraine and stream sediment samples. It can be observed that the high contrast of copper and nickel anomalies existing in the bedrock decreases in the moraine and stream sediment samples. A similar though weaker change appears in the contrast of cobalt anomalies, whereas that of zinc remains unaltered.

The frequency distributions of the concentrations are presented in Figs. 32 and 33. The examination of the cumulative distributions shows their resemblance in shape to the lognormal distributions. However, in the graph of the copper and nickel concentrations of rock samples, a distinct change of the slope can be observed in the high concentrations. In the concentration distribution of the cobalt, the truncation point is at the median, whereas the plot of the cumulative distribution of zinc is straight. In the graph of the trace metal concentrations of moraine samples the special

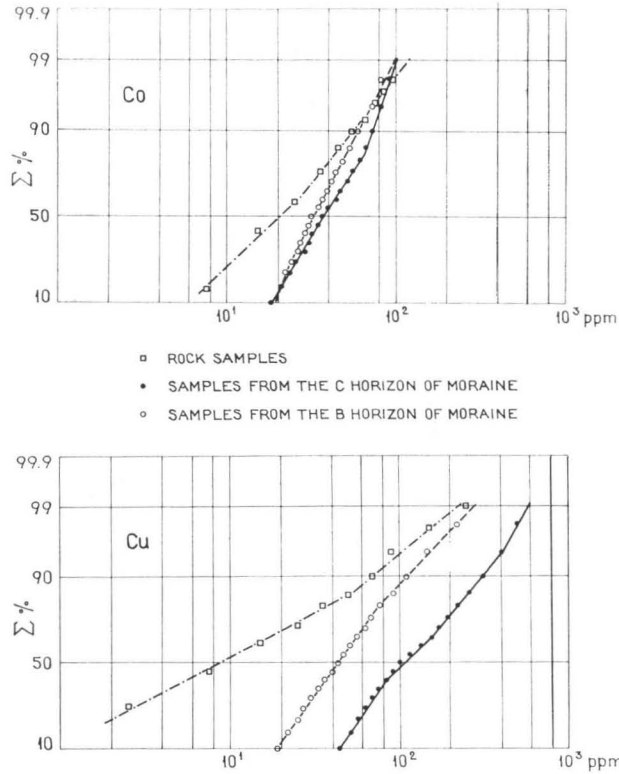


FIG. 34. The cumulative frequency distributions of cobalt and copper concentrations in rock samples and in samples from the B and C horizons of the moraine. Survey Area 3.

features of the distributions described above can be seen less clearly, obviously due to the mixing up of the material. In the cumulative concentration distribution of copper a distinct change can be observed in the slope of the graph almost at the median and a weak change in the distribution of nickel at the corresponding point.

TABLE 18

The ratios between the limit value of the high anomaly (the concentration at the 98 percentage point) and the anomaly threshold (the concentration at the 80 percentage point) for cobalt, copper, nickel and zinc concentrations in rock, moraine and stream sediment samples. The concentration ratios for the rock samples have been computed from the actual concentrations and not from the cumulative frequency distribution. The concentrations of the stream sediment samples have been converted into weight concentrations by using a reduction coefficient of 0.67. Haukijärvi area, Enontekiö.

	Co	Cu	Ni	Zn
Rock samples	3.3	8.0	8.3	1.5
Moraine samples	1.4	3.6	1.9	1.6
Stream sediment samples .		2.3	2.0	

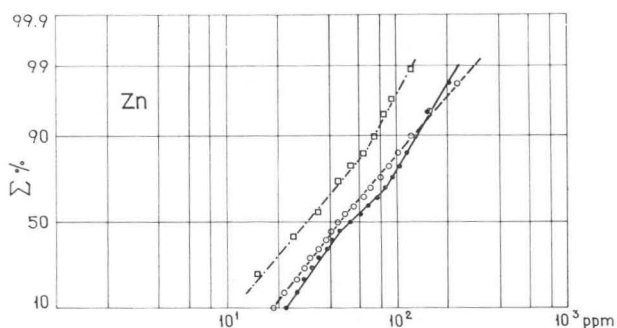
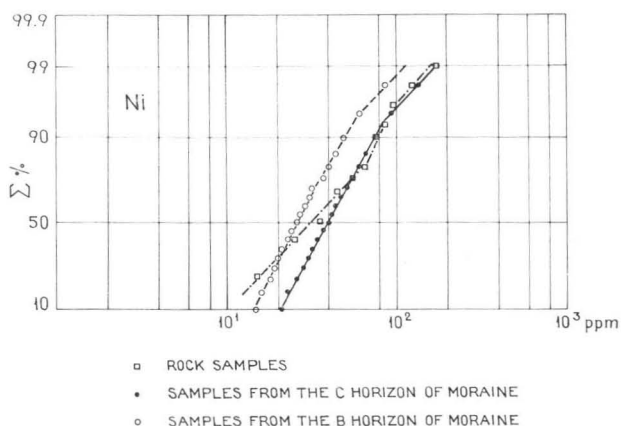


FIG. 35. The cumulative frequency distributions of the nickel and zinc concentrations in rock samples and in samples from the B and C horizons of the moraine. Survey Area 3.

In the cumulative frequency distribution of zinc the slope changes at high concentrations.

When the plots of the cumulative frequency distributions of the analysed metals are compared with each other in the rock, moraine and stream sediment samples, it can be observed that the distributions of the nickel concentrations when plotted on probability paper are sub-parallel to one another. This means that the dispersion of nickel increases with the increasing mean concentration. Also, the distributions of copper in the rock and moraine samples resemble one another. On the other hand, the distributions of cobalt and zinc are clearly different. The concentration dispersions of both metals are smaller in the moraine than in the rock samples. Since the moraine matter originates from weathered rocks and has been mixed up, the frequency distributions of cobalt and zinc are the usual ones. The frequency distributions of copper and nickel reflect the special mode of occurrence of these metals in the rock and till of the area under consideration.

Tennant and White (1959) have drawn attention to the frequency distributions when interpreting the results of geochemical exploration. Above, it has been shown

that a comparison of frequency distributions increases the information. The data of Survey Area 3 offer another example of the usage of frequency distributions for the interpretation of geochemical information.

Survey Area 3 was described on page 74. In the exploration of the area, special attention was paid to the copper mineralization. The concentration distributions of the determined metals in the rock samples and in samples from the B and C horizons of the moraine are seen in Figs. 34 and 35.

The graphs indicate that the nickel and zinc concentrations differ only slightly and follow each other almost symmetrically in the different sampling materials. This is only to be expected, since moraine is formed for the greater part from local weathered rock. The differences are also small with regard to cobalt and the concentration dispersion in the moraine is less than in the rock samples. On the other hand, in the case of copper the plots deviate from each other a great deal. It should be noted that the copper concentrations of the moraine samples are on an average much higher than those of the rock samples. The concentration dispersion of copper in the moraine samples is smaller than in the rock samples. There is a clear difference between the concentrations of the B and C horizons of the podzol profile, but the concentration dispersion is very similar.

On the basis of the distributions, it has been concluded that in the random rock samples nickel and zinc represent the bedrock of the whole area in the same way as do the moraine samples. On the other hand, in the rock samples copper, and in a less degree cobalt, do not represent the bedrock of the whole area. Since especially the copper concentrations in the moraine are higher than the copper concentrations in the rock samples, it is probable that in the covered parts of the area, there are copper concentrations in the bedrock higher than those appearing in the outcrops.

Correlation coefficients

The correlation coefficients between the metals in the rock and moraine samples in the Haukijärvi area are listed in Table 19.

The correlation coefficients of the metals in the rock samples are divided into two groups. In the first group, coefficients between cobalt, copper and nickel are high while in the second group the coefficients between these metals and zinc are noticeably lower. Since this is a copper-nickel mineralization, the coefficients show the usual grouping. In the moraine, the numerical values of the coefficients change in such a way that, in general, the high values are reduced and the low values increased. This is due, without doubt, to the fact that in moraine the concentrations tend to become homogenized.

The mutual order of the coefficients, as compared with the correlation coefficients of the trace metal concentrations in the rock samples, is also somewhat different. In particular the correlations between cobalt, copper and nickel in the moraine samples are lower than in the rock samples. The correlation between cobalt and zinc, and nickel and zinc is proportionately higher. The reason for these changes in the mutual

TABLE 19

The linear and logarithmic correlation coefficients between the metals in the drill cuttings of rock and in the C horizon of the moraine. The three pairs of metals with the highest numerical values of correlation coefficient are listed in the lower part of the table. Haukijärvi area, Enontekiö.

	Rock samples		Moraine samples	
	lin.	log.	lin.	log.
Co/Cu	0.97	0.91	0.54	0.69
Co/Ni	0.96	0.87	0.80	0.85
Co/Zn	0.54	0.70	0.70	0.73
Cu/Ni	0.98	0.85	0.84	0.88
Cu/Zn	0.44	0.58	0.23	0.42
Ni/Zn	0.40	0.39	0.50	0.59
I	Cu/Ni	Co/Cu	Cu/Ni	Cu/Ni
II	Co/Cu	Co/Ni	Co/Ni	Co/Ni
III	Co/Ni	Cu/Ni	Co/Zn	Co/Zn

order of the coefficients is not known for sure. It may be due to the fact that the rather sparse bedrock sampling does not show all the geochemical features revealed by the moraine study.

Evaluation of results

The Haukijärvi area is very suitable for a comparative investigation. A large part of the bedrock belongs to a massif in which only one rock type predominates, namely gabbro. The massif is so large, that, in the moraine and stream sediments, the concentration variations of the metals can be considered to depict the corresponding variations in the bedrock in the area of the massif.

Most attention was concentrated on the study of the changes which took place at the formation of the moraine and stream sediments. The basis of a comparative investigation is the information concerning the distribution in the bedrock of metals occurring as sulphides. Although the information is too general for a detailed comparison of the results, it is sufficient for a statistical approach.

The results can be summarised as follows:

1) The moraine was transported by the glacier, but places in the bedrock can be roughly shown which caused the anomalies in the moraine. Local conditions had an effect on the formation of the anomalies. The anomalies do not show all those places where mineralization has been encountered in the bedrock.

2) During transportation, a smoothing of concentrations has taken place in the moraine. The smoothing is the stronger, the higher is the concentration of the original material. Dilution diminishes the numerical values of the correlation coefficients of the metals, but, in the Haukijärvi area at least, there has been no obvious change in the mutual order of the correlation coefficients.

3) A comparison of the moraine and stream sediment maps shows that the stream sediment anomalies generally occur in the same places as the moraine anomalies. The stream sediment anomalies are usually local. The bedrock does not seem able directly to increase the metal concentrations in the stream sediments to any degree worth mentioning.

Conclusions

At the end of each case history there is a short evaluation of the results. If the results are considered as a whole, some more general conclusions can be drawn.

1) Methods of geochemical exploration are usually largely dependent on areal and local conditions. Due to the differences in areal conditions, the methods described are not suited to the whole of Finland, e.g. the use of the stream sediment method can reasonably be limited to Lapland and Eastern Finland. The influence of local conditions can be seen above all in the difficulty of interpreting the data.

2) The methods employed do not usually replace but rather complete one another. Consistently applied, the methods are used for setting limits to the area to be explored, e.g. the stream sediment and the soil surveys show the areas in which the moraine study is to be concentrated. However, in exploration, the choice of geochemical methods is not always clear, since the geochemical methods are often used together with other methods of exploration. A comparison of all explorational methods is the main reason for geochemical surveying having been directed from local to areal subjects.

3) A comparison of the results obtained by different methods can often be made merely by examining the geochemical maps. Frequently the comparison can be improved and made more precise by using simple statistical parameters. These are, e.g. median, anomaly contrast, and correlation coefficients. It has also proved advantageous to compare the frequency functions of the concentration distributions of the same metals in samples taken by different methods. So far, regression analysis has only been used occasionally in the interpretation of results.

4) If the results of the geochemical survey are examined in the light of the given examples, then the results can often — but not always — be observed as being of value for exploration, especially if they are used to support the results obtained by other explorational methods. However, the interpretation of the results of geochemical exploration is sometimes difficult. Moreover, cases are known in which, contrary to expectation, geochemical prospecting does not give the desired result. For these reasons, the geochemical methods described must be considered as indicative rather than eliminating methods.

COMPARISON OF THE DATA OF REGIONAL SURVEYS

Material was collected from 19 areas in different parts of Finland in order to compare the results of regional investigations. The material originates from studies carried out by the Exploration Department of the Outokumpu Co. with the exception of one area. The material for this area is composed from the data presented in Vuorimiesyhdistys, 1967. In the following, that area, the Makola area, is called Survey Area 9.

The material consists of cobalt, copper, nickel and zinc determinations solely from samples taken from the C horizon of the moraine. Since ore exploration is being carried out continually in some of the areas, neither their names nor exact locations are given and they are identified only by Survey Areas 1 to 19. An approximate location of these areas can be seen in Fig. 36. In order to compare the results of the survey areas, simple statistical parameters are used which are formed from the results of each area. These parameters are: median and average concentration, the ratios between them and the ratios between the median values of the concentrations. The ratio diagrams of Cu-Co-Ni and Cu-Zn-Ni were prepared for every point from the analytical data of Survey Areas 1, 3, 7, 9, 11 and 14. From the same data, the correlation coefficients between the concentrations of the metals were computed.

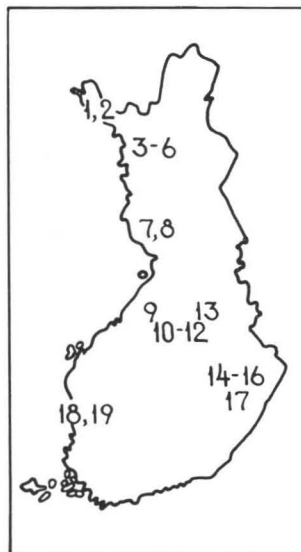


FIG. 36. The location of Survey Areas 1 to 19 employed for the comparison of areal results.

Types of rock and ore

Data concerning the bedrock of the survey areas are given in Table 20, in which the type rocks are listed with geological information. Following the stratigraphic classification presented by Simonen (1960), the survey areas can be classified into groups. Survey Areas 1 to 7 and 13 to 17 belong to the Karelidic belt. Further, Areas 3 to 6 are considered to belong to the Lapponic formation and Area 7 to the Kemi schist zone which resembles the former. Survey Areas 3 and 4 are identical with regard to their bedrock. Survey Areas 14 to 16 are located in North Karelia. The bedrock of the areas belongs to the so-called Outokumpu sequence. Survey Areas 9 to 12, 18 and 19 belong to the Svecofennidic belt. Of these areas, 10 to 12 are mutually geologically identical. The rock types predominating in Survey Areas 9, 18 and 19 resemble the rock types in Areas 10 to 12.

Survey Areas 1 and 9 are characterized by copper-nickel mineralizations. In Areas 18 and 19 local copper-nickel mineralizations are encountered. Survey Areas 3, 4, 5

TABLE 20

Geological data concerning the bedrock in the survey areas used for the comparison of the areal data.

Survey Area	Bedrock	Observations concerning mineralization
1 ...	Haukijärvi area, Enontekiö (p. 57) Gabbro	Locally feeble copper and nickel mineralization
2 ...	Various granites. Schists and amphibolites. Serpentinite bodies.	Pyrrhotite
3 ...	Almost unknown. Effusive greenstone and various schists. Black schist. Gabbro and peridotite.	Chalcopyrite as vein mineralization
4 ...	Same as area 3.	Same as area 3.
5 ...	Mainly granites. Black schist, skarn rocks.	Copper mineralization.
6 ...	Slightly known. Effusive greenstone. Black schist. Possibly peridotite.	Unknown.
7 ...	Greenstone.	Chalcopyrite as vein mineralization
8 ...	Gneiss granite with serpentinite bodies.	Pyrrhotite
9 ...	Makola area, Nivala. Gneiss granite with peridotite bodies.	Nickel ore.
10 ...	Vein gneiss. Gneiss granites. Amphibolites, quartzites. Black schists. Antophyllite-cordierite rock.	Pyrite-pyrrhotite ore with chalcopyrite and sphalerite.
11 ...	Kalliokylä area, Kiuruvesi (p. 49). Same as area 10, in addition gabbros and hornblendite.	Same as area 10.
12 ...	Same as area 10.	Unknown.
13 ...	Gneiss granite. Quartzites. Metadiabases.	Weak copper mineralization.
14 ...	Mica schists and mica gneisses. Serpentinite, quartzite and black schist, skarn rocks; rock typical of the Outokumpu sequence.	Copper mineralizations.
15 ...	Same as area 14.	Same as area 14.
16 ...	Same as area 14.	Same as area 14.
17 ...	Vein gneiss. Serpentinite, black schist, skarn rock.	Zinc mineralizations.
18 ...	Bedrock poorly known. Vein gneiss, granites, black schists. Small peridotite bodies.	Feeble nickel mineralizations.
19 ...	Same as area 18.	Same as area 18.

and 7 resemble one another in that the ore mineral is chalcopyrite, which is encountered in fracture fillings and breccias. In the bedrock of Survey Areas 10, 11 and 17 there is zinc ore. Areas 14 to 16 belong to the Outokumpu sequence famous for its copper deposits, even though ore deposits were not found in the survey areas. No mineralizations were met with in Survey Areas 2, 6, 8, 12 and 13.

The average concentration and the skewness of the distributions

The concentrations are listed in Table 21 as medians and means. By combining all 19 survey areas, the following median values and average values of concentrations (ppm) are obtained:

	Co	Cu	Ni	Zn
M	10	24	18	28
\bar{X}	14	41	28	32

TABLE 21

The median and average values of the cobalt, copper, nickel and zinc concentrations (ppm) in the survey areas. The skewness of the frequency distributions is also listed expressed as a ratio of the difference between the average and median values to the average.

Survey Area	Number of samples	Cobalt		Copper		Nickel		Zinc		$\bar{x} - M/\bar{x}$			
		M	\bar{x}	M	\bar{x}	M	\bar{x}	M	\bar{x}	Co	Cu	Ni	Zn
1	760	12	13	39	62	28	33	34	35	0.1	0.6	0.2	0.0
2	862	7	8	14	16	14	24	15	17	0.1	0.1	0.7	0.1
3	597	36	42	101	148	40	46	54	69	0.1	0.5	0.2	0.3
4	250	27	42	65	130	29	69	31	37	0.4	1.0	1.4	0.2
5	285	11	13	37	48	14	19	13	18	0.1	0.3	0.4	0.4
6	777	7	8	20	21	16	21	11	13	0.1	0.1	0.3	0.2
7	820	11	13	36	63	17	18	29	29	0.2	0.8	0.1	0.0
8	817	9	9	21	23	17	18	20	21	0.0	0.1	0.1	0.1
9	223	17	20	24	38	24	38	28	29	0.2	0.6	0.6	0.0
10	4 918	10	11	18	20	16	18	37	40	0.1	0.1	0.1	0.1
11	999	11	12	18	19	18	18	34	35	0.1	0.1	0.0	0.0
12	1 096	8	9	13	14	12	13	29	30	0.1	0.1	0.1	0.0
13	963	5	6	17	21	10	11	17	20	0.2	0.2	0.1	0.2
14	1 477	9	9	33	33	22	24	39	41	0.0	0.0	0.1	0.1
15	522	9	11	30	30	27	41	39	42	0.1	0.0	0.5	0.1
16	638	10	11	28	29	23	48	39	44	0.1	0.0	1.1	0.1
17	1 581	14	14	24	25	22	23	45	48	0.0	0.0	0.0	0.1
18	2 815	12	13	26	27	22	23	56	59	0.1	0.0	0.0	0.1
19	897	7	8	15	16	16	17	43	44	0.1	0.1	0.1	0.0

The median values are presumed to correspond more or less to the cobalt, nickel and zinc concentrations of the ground moraine in Finland in that fraction from which the analyses were made. The median value of copper, however, is not similarly representative. Its actual value might be 15 ppm to 20 ppm, possibly about the same as that of nickel.

The median values of the concentrations vary among the areas in such a way that the variation in copper and cobalt is greater than in nickel and zinc:

	Co	Cu	Ni	Zn
Coefficients of variation (%)	80.2	85.8	41.1	39.4

It is probable that all the averages are slightly too high compared to the analysis fraction of the ground moraine of the whole country. The reason for this is that the studies were done in areas where exploration is being carried out. In areas such as these there are often samples whose trace element concentrations are exceptionally high.

Survey Areas 3 and 4 are distinguished by their exceptionally high metal contents in which the analysed elements are encountered in concentrations higher than normal (Table 21). Survey Areas 1, 14, 15 and 16 are anomalous with regard to copper, nickel and zinc. In addition, Areas 5 and 7 are anomalous with regard to copper alone and Area 9 is weakly anomalous to nickel. Zinc is encountered with an abundance above average in Survey Areas 14 to 19. The anomalous areas with regard to copper are

found in the region of the Lapponian and Karelian rocks. Zinc anomalies are encountered in the Karelian rocks and rocks in the Svecofennidic belt in Southwest Finland. As to nickel, the anomalous areas are distributed less evenly.

There are without doubt many reasons for the differences in median values among the areas in question. The areas whose bedrock contains more black schist than usual may be anomalous for zinc, e.g. Survey Areas 14 to 17. On the other hand, it has been observed that the zinc concentrations of the black schists do not vary merely locally but also areally. Thus, in many of the survey areas in Lapland, e.g. Areas 2, 4, 5, 6, 7 and 8 there is less zinc than average, in spite of the fact that these areas are known to contain black schists, in places even abundantly. The variations in nickel concentration are connected with the amount of ultramafic and mafic rocks as can be observed in Survey Areas 1, 9, 14, 15, 16 and 17. With regard to copper, the distinctly anomalous Survey Areas 1, 3, 4, 5 and 7 are located in Lapland and the less anomalous Areas 14, 15 and 16 in North Karelia. Since the areas in North Karelia are in the vicinity of Outokumpu and their bedrock belongs to the Outokumpu sequence, it may be that the anomalous copper concentration belongs to the bedrock of this sequence in general. The high copper concentration in Survey Areas 3, 4, 5 and 7 cannot yet be given a reliable explanation.

The concentration distributions of the metals in the moraine are often lognormal, or they resemble it. The shape of the distribution is usually skewed so that the average value of the concentration is higher than the median. In a normal distribution, the median and the average coincide and the distribution is symmetric. Although the frequency distributions may be heterogenic, e.g. produced by two or more populations, the skewness, which is the difference between the average and the median divided by the average, is regarded as describing sufficiently the symmetry of the frequency distributions. The numerical values of the skewness of the distributions are given in Table 21.

It is observed that the symmetry of the frequency distributions varies. The variation in the copper and nickel distributions is the strongest. The distributions of cobalt and zinc show a symmetry above average. There is also a distinct variation among the distributions between different survey areas. The most distinct is the asymmetry in frequency distributions of all the metals in Survey Area 4. An asymmetry in the distribution of copper, nickel and zinc can be observed in Survey Areas 3 and 5. Asymmetry in the distributions of copper and nickel is most distinct in Areas 1 to 9. As to the distributions of single metals, copper is the most asymmetric in Survey Area 7 and nickel in Areas 2, 15 and 16.

When seeking an explanation for the variations in the degree of symmetry in the frequency distributions, two basic factors must be taken into consideration: the variation in the metal concentration in the bedrock and the mode of formation of the moraine. Clearly, the greater is the metal concentration in the bedrock, the higher is the likelihood of the metal concentration varying in the moraine and the more asymmetric the frequency distributions may become. On the other hand, the stronger is the

TABLE 22

The metals whose concentration distribution shows a clear skewness, and the probable reason for it.

Survey area	Metals	Probable reason for the asymmetry of frequency distribution
1	Cu, Ni	Cu-Ni mineralization
2	Ni	Serpentinite bodies
3	Cu, Zn, Ni	Unknown. Moraine very local.
4	Ni, Cu, Co, Zn	Unknown. Moraine very local.
5	Ni, Zn, Cu	Unknown. Cu mineralization in bedrock.
6	Ni, Zn	Black schist (?)
7	Cu	Cu mineralization
9	Cu, Ni	Cu-Ni mineralization
13	Co, Cu, Zn	Black schist (?)
15	Ni	Serpentinite bodies
16	Ni	Serpentinite bodies

mixing in moraine at the time of its formation, the more the concentration variations have smoothed and the symmetry of the distributions increased. Thus, these two factors have an influence on the frequency distributions partly in opposite directions. It is probable, though, that the influential factors in the formation of moraine are reflected more strongly in the frequency distributions than in the variations in the trace element concentrations in bedrock, because in Lapland, where in many places the moraine is very local, the frequency distributions on the whole are less symmetric than elsewhere in Finland where the moraine has been more mobile. Therefore, if the frequency distributions of the metals in the moraine of a certain area are symmetric, this does not necessarily mean that the variation of trace elements in the underlying bedrock is random. It is more likely that in this case moraine is better mixed than in an area in which the distributions are more asymmetric.

When studying the information from the bedrock that the skewness may give, it is probably most important to observe the metals whose frequency distributions are asymmetric and compare the numerical values of the skewness of different metals in the same area with each other. In Table 22 the results are grouped on this basis. Those areas whose frequency distributions are more or less symmetric are omitted.

Thus, in many cases, the cause of asymmetry could be detected. The general observation is that factors reducing symmetry must be relatively common or exceptionally effective in the area in question. Compared with the size of the area, small anomalies or rare concentrations which are low compared with the background do not greatly increase the asymmetry of the frequency distribution.

Relationship between concentrations

The results obtained from different areas are compared with each other by computing the relative concentrations of each metal on the basis of the median values and the individual sample analyses. The results are presented in tables or diagrams, of

TABLE 23

The relative amounts (per cent) of the cobalt, copper, nickel and zinc concentrations from the sum of these metals and the relative amounts of the three elements: copper, nickel and zinc. The table also lists the averages of the relative concentrations (\bar{x}), the standard deviations (s) and the numerical values of the coefficients of variation (v).

Survey area	Co	Cu	Ni	Zn	Cu	Ni	Zn
1	10.6	34.5	24.8	30.1	39	34	28
2	14.0	28.0	28.0	30.0	33	32	35
3	15.6	43.7	17.3	23.3	52	20	28
4	17.8	42.8	19.1	20.4	58	22	20
5	14.7	49.3	18.7	17.3	58	22	20
6	13.0	37.0	29.6	20.4	43	34	23
7	11.8	38.7	18.3	31.2	44	21	35
8	13.4	31.3	25.4	29.9	37	29	34
9	18.3	25.8	25.8	30.1	32	21	37
10	12.3	22.2	19.8	45.7	26	23	51
11	13.6	22.2	22.2	42.0	26	25	49
12	12.9	21.0	19.4	46.8	24	22	54
13	10.2	34.7	20.4	34.7	40	21	39
14	8.7	32.0	21.4	37.9	35	24	41
15	8.6	28.6	25.7	37.1	31	28	41
16	10.0	28.0	23.0	39.0	30	26	43
17	13.3	22.9	21.0	42.9	26	25	49
18	10.3	22.4	19.0	48.3	25	21	54
19	8.6	18.5	19.8	53.1	20	22	58
\bar{x}	12.5	30.7	22.0	34.7	35.8	24.9	38.9
s	2.78	8.71	3.46	5.13	10.9	4.4	11.4
v	22.2	28.4	15.7	26.1	30.4	17.8	29.3

which the most common are the Cu-Co-Ni and Cu-Zn-Ni diagrams. In Table 23 the relative concentrations in the areas surveyed are presented.

It can be observed that, of the sum of cobalt, copper, nickel and zinc in the areas, there is on an average 12.5 % Co, 30.7 % Cu, 22.0 % Ni and 34.7 % Zn. Further, it can be seen that the most variable percentages are those of copper and zinc, whereas that of nickel is the least variable. When the relative amounts of the three most usual components i.e. copper, nickel and zinc are compared with each other the same observations can be made.

The grouping of the relative concentrations, which by and large also represents the grouping of the concentrations (see Table 21), can be clearly visualised in Table 24,

TABLE 24

The concentrations (ppm) and the relative concentrations (per cent) of the four elements, computed so that the survey areas were divided into three groups: Lapland, East Finland and the rest of Finland.

	Concentrations				Relative concentrations			
	Co	Cu	Ni	Zn	Co	Cu	Ni	Zn
Lapland	15.4	42.0	21.0	24.7	14.3	38.7	22.3	24.6
East Finland	8.3	27.0	20.5	33.5	9.4	30.8	22.6	37.2
Rest of the country	11.3	19.7	18.6	38.9	12.8	22.1	21.0	44.0

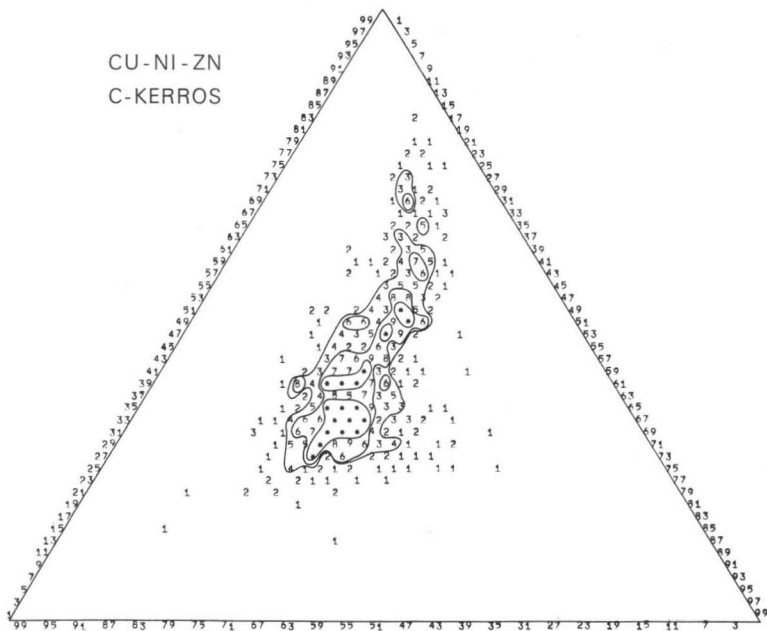


FIG. 37. An example of a triangular diagram printed out by a line printer. The numbers and symbols indicate the amount of points within the area of a sub-triangle whose area is 1/2500 of the area of the great triangle. Number zero has not been printed out. Asterisks indicate that the number of points is within the range of 10 to 20. The contours were added later by hand. (C-KERROS = C horizon).

in which the survey areas are divided into three groups: Lapland, East Finland and the rest of the country.

It can be observed that the amount of cobalt and nickel from the sum of the determined metals varies considerably less than that of copper and zinc. The variation of copper and zinc, which is observed both as a variation of concentrations as well as of relative concentrations, shows that the largest amount of copper is in the Lappish areas (Lapponian rocks), whereas zinc concentrations are highest in the areas of the rest of Finland (Central and Southwest Finland). The statistically tested differences in the concentrations and relative concentrations between the groups are highly significant. For other reasons, however, the pertinence of the observations cannot be considered as absolutely tenable. The confirmation or rejection of the observation as well as its interpretation must be left to further study.

The detailed distribution of the relative concentrations was studied by means of the Cu-Co-Ni and Cu-Zn-Ni diagrams. Fig. 37 depicts the principle of the construction of triangular diagrams. These diagrams were made for Survey Areas 1, 3, 7, 9, 11 and 14. In addition, in Survey Areas 1 and 3 the variations in the relative concentrations between different sampling methods were studied. This was done in such a

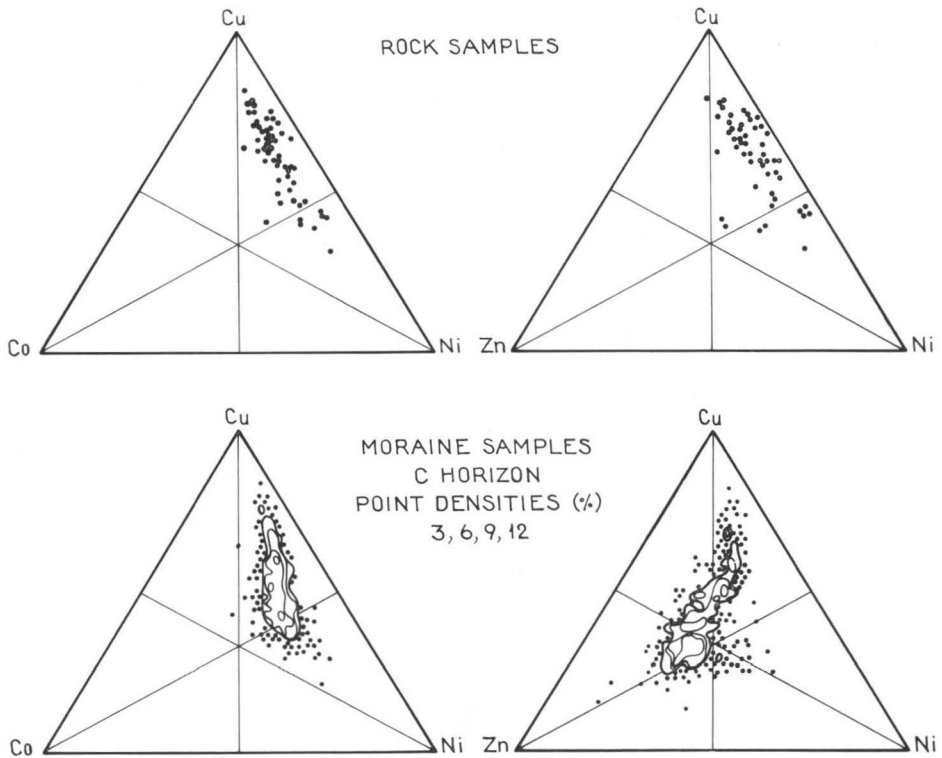


FIG. 38. The Cu-Co-Ni and Cu-Zn-Ni ratio diagrams of the concentrations in rock samples and in samples from the C horizon of the moraine. Survey Area 1; Haukijärvi area, Enontekiö.

way that in Survey Area 1 the relative concentrations of the C horizon of the moraine and of the samples taken from the rocks were compared. The same was done in Survey Area 3 but diagrams of the relative concentrations of samples taken from the B horizon of the moraine were added. The results of the comparative study are seen in Figs. 38 and 39.

The distribution of the relative concentrations in the rock and moraine samples in the Cu-Co-Ni diagrams of Survey Area 1 (Fig. 38) resemble one another. The triangular diagram of moraine, however, shows that the relative amount of copper has decreased while that of cobalt in particular, but to a less degree also that of nickel, has increased compared with the relative concentrations in the bedrock. Since in Survey Area 1 (see Case History 4; Haukijärvi area, Enontekiö) copper produces the strongest anomalies and it is known that at the formation of moraine the high concentrations in particular tend to become smoothed, the change is normal. The change is probably, however, accentuated by the fact that the number of moraine samples greatly surpasses that of the rock samples so that a smaller portion of the moraine samples than the rock samples shows typical concentration ratios for the anomaly

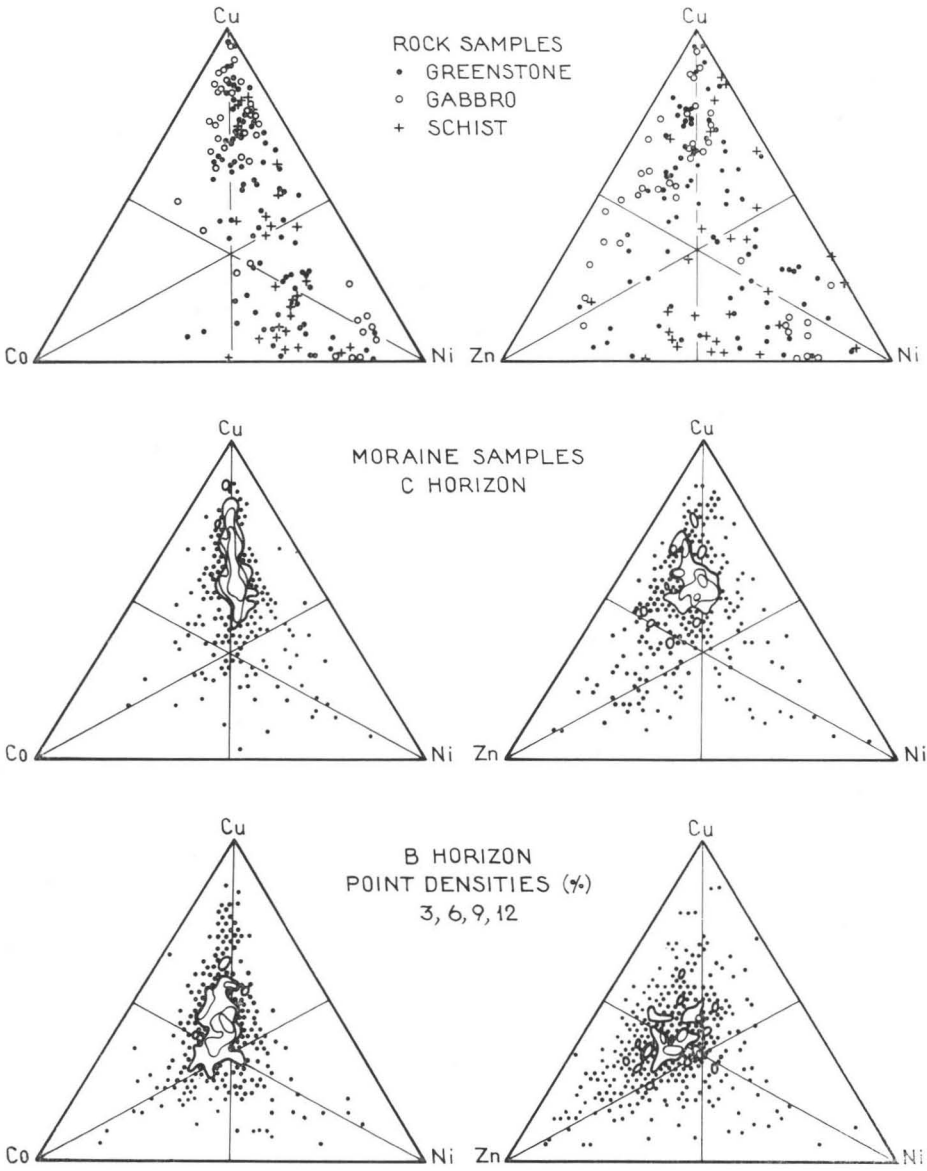


FIG. 39. The Cu-Co-Ni and Cu-Zn-Ni ratio diagrams of the concentrations in rock samples and in samples from the B and C horizons of the moraine. Survey Area 3.

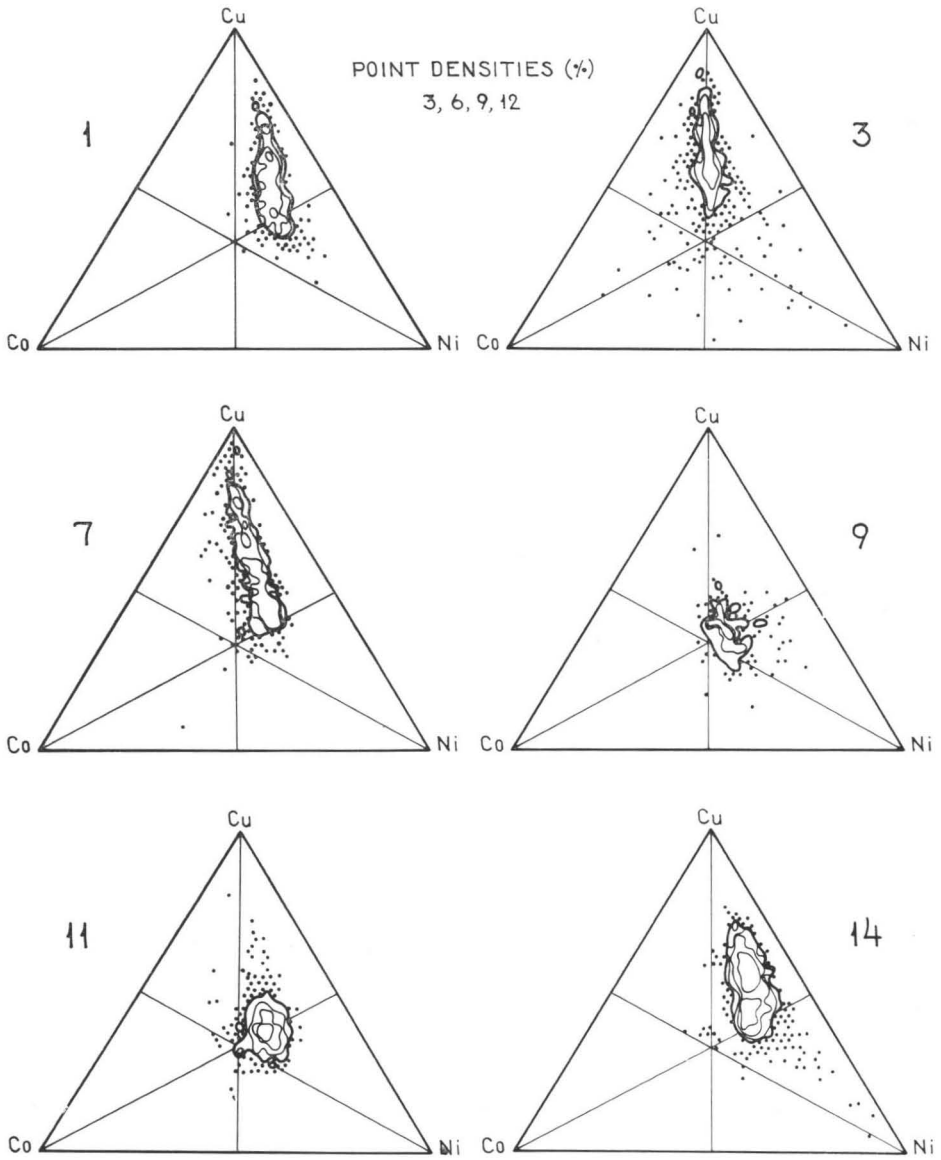


FIG. 40. The Cu-Co-Ni ratio diagrams of the concentrations in the C horizon of the moraine. Survey Areas 1, 3, 7, 9, 11 and 14.

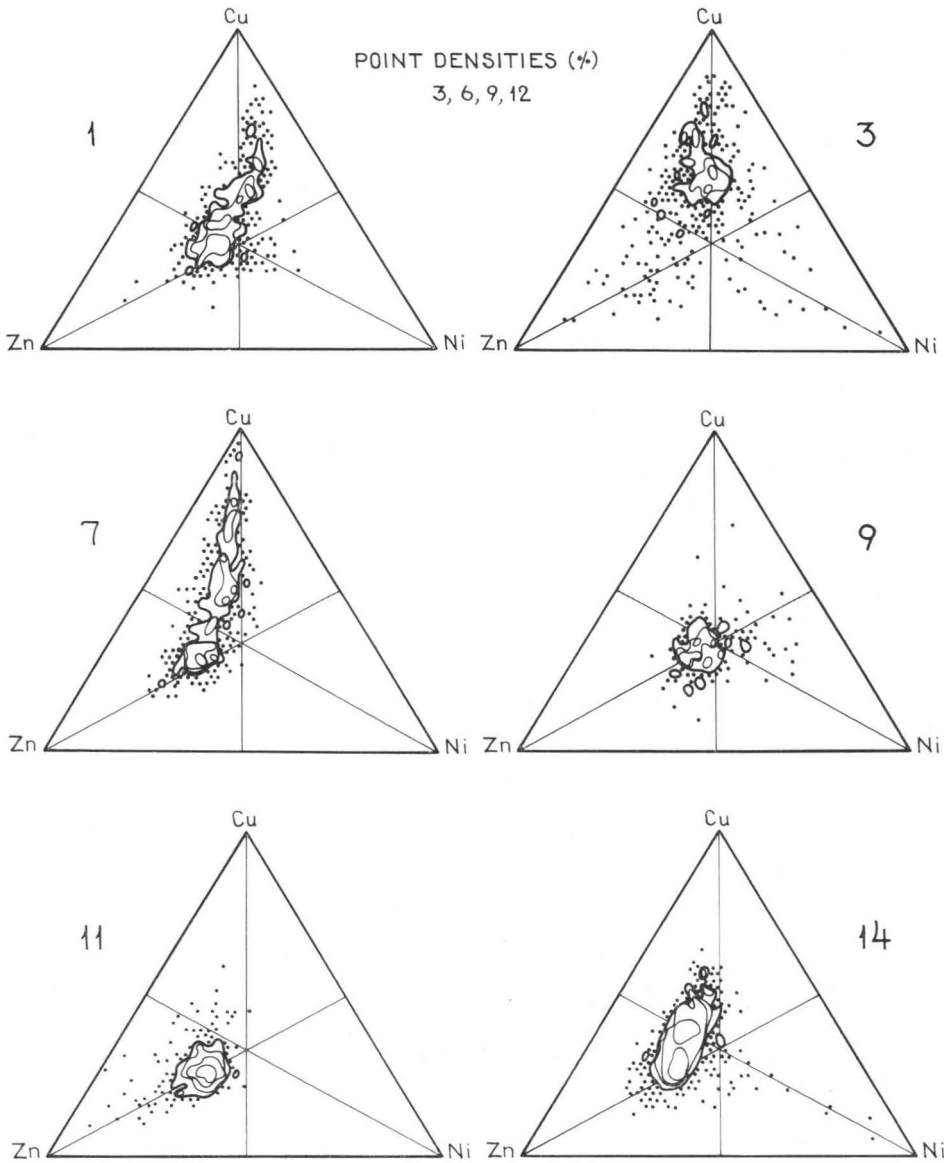


FIG. 41. The Cu-Zn-Ni ratio diagrams of the concentrations in the C horizon of the moraine. Survey Areas 1, 3, 7, 9, 11 and 14.

areas. A correspondingly larger portion of relative concentrations of the moraine samples is from those parts of the survey area where there are no anomalies.

The distribution of the relative concentrations of Cu-Zn-Ni in the rock and moraine samples (Fig. 38) differs from that of the relative concentrations of Cu-Co-Ni. Especially the relative amount of zinc from the sum of the metals has greatly increased in the moraine. From the point of view of interpretation, the same holds true as was observed in connection with the Co-Cu-Ni diagram. In addition, it is possible that primary details are reflected in the relative concentrations of the moraine samples which are not detected in the relative concentrations of the rock samples.

In Survey Area 3, the relative concentrations of the rock samples in the Cu-Co-Ni diagrams (Fig. 39) show variation in such a way that, on the whole, the varying component is copper whereas the Co-Ni ratio fluctuates considerably less. A corresponding phenomenon can also be observed in the relative concentrations of the samples taken from the C horizon of the moraine. Compared with the distribution of the relative concentrations in the rock samples, the points of these samples in the triangular diagrams accumulate more distinctly. This may be due partly to the greater amount of samples and partly to the fact that infrequent relative concentrations do not occur in the moraine. In the samples taken from the B horizon of the moraine the distribution of relative concentrations is not characteristic to the same extent as in the previous distributions. The centre of gravity of the relative concentrations shows that the percentage of copper from the sum of metals has decreased and the relative amount of cobalt in particular increased. Since the samples from the B and C horizons of the moraine were taken from the same sites, the variations depict the actual variations in the relative concentrations between the two horizons of the podzol profile.

In the Cu-Zn-Ni diagram of Survey Area 3 (Fig. 39) the relative concentrations of the rock samples are distributed irregularly in the area of the triangle. Also the result obtained from the C horizon of the moraine is irregular although there is a distinct centre of gravity in the relative concentrations. The relative quantity of copper in the samples taken from the B horizon of the moraine has decreased compared with the concentrations in the C horizon. The change is the same as in the Cu-Co-Ni ratios.

The Cu-Co-Ni and Cu-Zn-Ni diagrams of the relative concentrations in Survey Areas 1, 3, 7, 9, 11 and 14 are presented in Figs. 40 and 41. It can be observed that the diagrams differ from one another but that, by and large, they form two groups. The first is represented by figures of Survey Areas 1, 3 and 7 and the second by figures of Areas 9 and 11. The diagram of Survey Area 14 differs somewhat from both groups. Peculiar to the diagrams of Survey Areas 1, 3 and 7 is the ribbon-like shape of the relative concentrations graph. In the Cu-Co-Ni diagrams it shows, that as the relative amount of copper increases, the Co-Ni ratio remains almost stable. A different Co-Ni ratio distinguishes the diagrams from each other. In the Cu-Zn-Ni diagrams it can be seen, that the changes in the relative concentrations take place in such a way that copper and zinc replace one another while the amount of nickel varies less. The variations in the relative concentrations in Survey Area 14 show the same features

at those in Areas 1, 3 and 7 except that the points in the diagram are better concentrated. Peculiar to the diagrams of Survey Areas 9 and 11 is the strong accumulation of the relative concentrations into a small area in the triangle, that is the ratios show only a small variation.

The ratio diagrams are to be interpreted in such a way that in Survey Areas 1, 3 and 7 as well as to some degree in Area 14 the moraine is less mixed and more local than in Areas 9 and 11 where it has been more thoroughly homogenised. From the point of view of exploration, the changes in the concentration ratios of Survey Areas 1, 3 and 7 show that above all the amount of copper varies at the cost of the other components. In Survey Areas 1 and 7 this change has also been confirmed in the bedrock. In Survey Areas 9 and 11, where the diagrams have been interpreted as evidence of the homogenisation of the moraine, special observations for exploration cannot be clearly made. The copper-nickel anomaly in Survey Area 9 is probably depicted by those rare points, which, in the triangular diagrams show the quantitative abundance of copper and nickel. Correspondingly, the points depicting the copper-zinc anomalies in Survey Area 11 can be found in those parts of the triangular diagram where the relative amount of copper and zinc is the greatest.

Correlation coefficients

In conjunction with the case histories, the correlation coefficients between different metals in the same podzol profile of the moraine and the correlation coefficients between the same metals in different podzol profiles were discussed. In the following, the correlation coefficients of the metals are compared between the survey areas. The correlation coefficients were calculated from the observation material of Survey Areas 1, 3, 7, 9, 11 and 14. The coefficients and their mutual order can be seen in Table 25. It is noticed that the numerical value and order of the correlation coefficients varies. Further, it can be seen that the values of the linear and logarithmic coefficients differ from each other. The differences between the linear and logarithmic correlation coefficients are due to the fact that the linear correlation coefficients are greatly influenced by the high, rare concentrations. The logarithmic correlation coefficients are not influenced to the same extent by these scattered high concentrations. Therefore, the linear correlation coefficients are more representative of the correlations between the high concentrations of different metals than are the logarithmic correlations. When examining the results, the mutual order of the coefficients is more interesting than the numerical values of the coefficients.

When grouped according to their mutual order some basic models are formed from the areas. In Survey Areas 1 (Case History 4; Haukijärvi area, Enontekiö) and 9 the correlations Cu/Ni and Co/Ni or Co/Cu are predominant. The geochemical anomalies of these areas are caused by the Cu-Ni mineralization. Thus, the mutual correlations of the metals are as usual. In Survey Area 7 it is known that the geochemical anomalies

TABLE 25

The linear and logarithmic coefficients of correlation between the analysed metals in Survey Areas 1, 3, 7, 9, 11 and 14. The three pairs of metals with the highest numerical values of correlation coefficient are listed in the lower part of the table. As a threshold value $r = 0.50$ was employed.

The metals with values of $r = 0.50-0.70$ are in brackets.

	1		3		7	
	lin.	log.	lin.	log.	lin.	log.
Co/Cu	0.54	0.69	0.69	0.77	0.77	0.74
Co/Ni	0.80	0.85	0.63	0.82	0.31	0.52
Co/Zn	0.70	0.73	0.68	0.80	0.47	0.50
Cu/Ni	0.84	0.88	0.40	0.63	0.07	0.22
Cu/Zn	0.23	0.42	0.51	0.62	0.27	0.14
Ni/Zn	0.50	0.59	0.46	0.66	0.55	0.58
I	Cu/Ni	Cu/Ni	(Co/Cu)	Co/Ni	Co/Cu	Co/Cu
II	Co/Ni	Co/Ni	(Co/Zn)	Co/Zn	(Ni/Zn)	(Ni/Zn)
III	(Co/Zn)	Co/Zn	(Co/Ni)	Co/Cu		(Co/Ni)

	9		11		14	
	lin.	log.	lin.	log.	lin.	log.
Co/Cu	0.89	0.90	0.20	0.28	0.42	0.61
Co/Ni	0.85	0.88	0.47	0.53	0.41	0.83
Co/Zn	0.40	0.59	0.21	0.32	0.83	0.85
Cu/Ni	0.98	0.91	0.38	0.46	0.30	0.79
Cu/Zn	0.18	0.43	0.59	0.64	0.56	0.82
Ni/Zn	0.17	0.43	0.36	0.52	0.33	0.89
I	Cu/Ni	Cu/Ni	(Cu/Zn)	(Cu/Zn)	Co/Zn	Ni/Zn
II	Co/Cu	Co/Cu		(Co/Ni)	(Cu/Zn)	Co/Zn
III	Co/Ni	Co/Ni		(Ni/Zn)		Co/Ni

are caused by a copper mineralization, in which cobalt is also concentrated to a certain degree. This explains the Co/Cu correlation which has the highest value. In Survey Area 11 (Case History 3; Kalliokylä area, Kiuruvesi) copper- and zinc-rich pyrite ore is to be found in the bedrock. Geochemical anomalies in moraine connected with the orebody are hydromorphic in type and sufficient to make the numerical value of the Cu/Zn correlation highest among the correlations. Also the Co/Ni correlation indicating a rock type is depicted in the mutual order of the correlations. The cause of the high numerical values of the correlation coefficients between cobalt and other metals in Survey Area 3 is unknown.

The correlations are characteristic to such a degree that they presumably indicate the tendency of the metals to concentrate in the bedrock. Survey Area 14 is situated in the Outokumpu sequence. However, combinations with copper do not predominate among the correlations. On the contrary, the order of the correlation coefficients leads to the supposition that the geochemical anomalies are caused by serpentinites and sulphides in the black schists common in the area. Observations made in the field support this interpretation.

Conclusions

A number of statistical parameters were computed from the areal data, with the aid of which the areas were compared with one another. However, these are areas of exploration and not random areas. Neither the size of the areas, the number of samples nor the relationship between the anomalies and their surroundings has been determined. These facts have a certain influence on the parameters. There has been no attempt to test the significance of the parameters statistically, rather the following conclusions have been drawn from the evident facts.

1) There are in moraine samples differences between the average concentrations of the areas, which, together with the relative concentrations of the determined metals, perhaps show regional differences in the trace metal contents in the bedrock. However, the observation cannot yet be considered as conclusive.

The differences in the skewness of the frequency distributions of the concentrations are basically due to the distribution of the concentrations of the trace metals in the bedrock. However, more often than not, the variations in the degree of symmetry of the frequency distributions reflect the mixing up of the moraine. In these areas, where the symmetry values are of importance as an indicator of the distribution of the concentrations of the trace metals in the bedrock, a clear asymmetry shows a relatively general special feature in the bedrock or an exceptionally strong concentration.

2) It has been observed that the metal ratios indicate approximately the same geochemical features as the concentration of the metals. However, if the results given by different methods are compared with each other, it is noticed that the ratio diagrams often reveal changes in the mutual abundance of the metals which have taken place e.g. in connection with the formation of moraine or with podzolisation. Sometimes the ratio diagrams also show characteristic changes in the abundances of the metals due to the mineralization.

3) The observations concerning the coefficients of correlation seem to indicate that, in spite of the fact that during the formation of moraine the mixing of the till material naturally reduces the correlation, the mutual order of the coefficient may remain unchanged. Based on the mutual order of the coefficients of correlation computed from the metal concentration in the moraine, conclusions can be drawn, at least in some cases, as to the possible types of mineralization in the bedrock also in areas where the till is clearly mixed.

SUMMARY

The most important conclusions concerning the treated items have already been presented above. The chief aspects of the present study are as follows:

1) The study deals with some geochemical prospecting methods, special emphasis being laid upon their use as an auxiliary tool in areal prospecting. Thus, the finding of new ore indications has been taken as a goal of the areal prospecting. The purpose

of this investigation has been to develop as consequential systems as possible, for the connecting of sampling, analysing, the presentation of results and interpretation. The methods developed were tested and evaluated in connection with several case histories. On the basis of the results, a number of geochemical prospecting parameters were computed. The information useful for areal geochemical prospecting contained by the parameters was evaluated.

2) It was observed that for the presentation and interpretation of the results, the defining of a geochemical anomaly is of the utmost importance. The definition employed in this study was deduced on the basis of a statistical frequency distribution and it appears to be suitable for automatic data processing. For the most effective sampling in areal geochemical prospecting, optimal sampling grids were estimated on the basis of known anomaly models.

3) A mutual comparison of the methods shows that all of them can be used in areal studies. However, each method has its own advantages and disadvantages. The stream sediment study is not suitable for the whole of Finland. Generally, it does not provide as detailed an information as the moraine study. The slowness of sampling and the high costs are disadvantages in the moraine study. Soil survey as a geochemical method is slower than stream sediment survey and less accurate than moraine survey. It has been developed to replace the stream sediment method in large areas where the stream sediment survey is expected to fail.

4) Geochemical prospecting has revealed the following anomaly types in moraine: glaciogenic, hydromorphic, sedentary and a mixed type.

5) It is concluded that the results of geochemical prospecting are indicative rather than eliminative. This is one of the main reasons of increasing the areal use of geochemical prospecting; i.e. the aim is at the finding of new ore indications.

6) The parameters of geochemical prospecting were employed in studies within a single area as well as in the comparing of the different areas with each other. In the former case the most important statistical data are the frequency distributions, the correlation coefficients of the metals and the ratio diagrams between the concentrations of the metals. When comparing the areas with one another the most useful characteristics proved to be the median and average values of the concentrations, the degree of symmetry of the distributions and the correlation coefficients of the metals. The concentration ratios between the metals and the triangular diagrams have also proved informative.

7) Preliminary geochemical data give the impression that there are natural differences between various areas in Finland and that the statistical parameters can point to those metals to which the attention of the exploration should be directed.

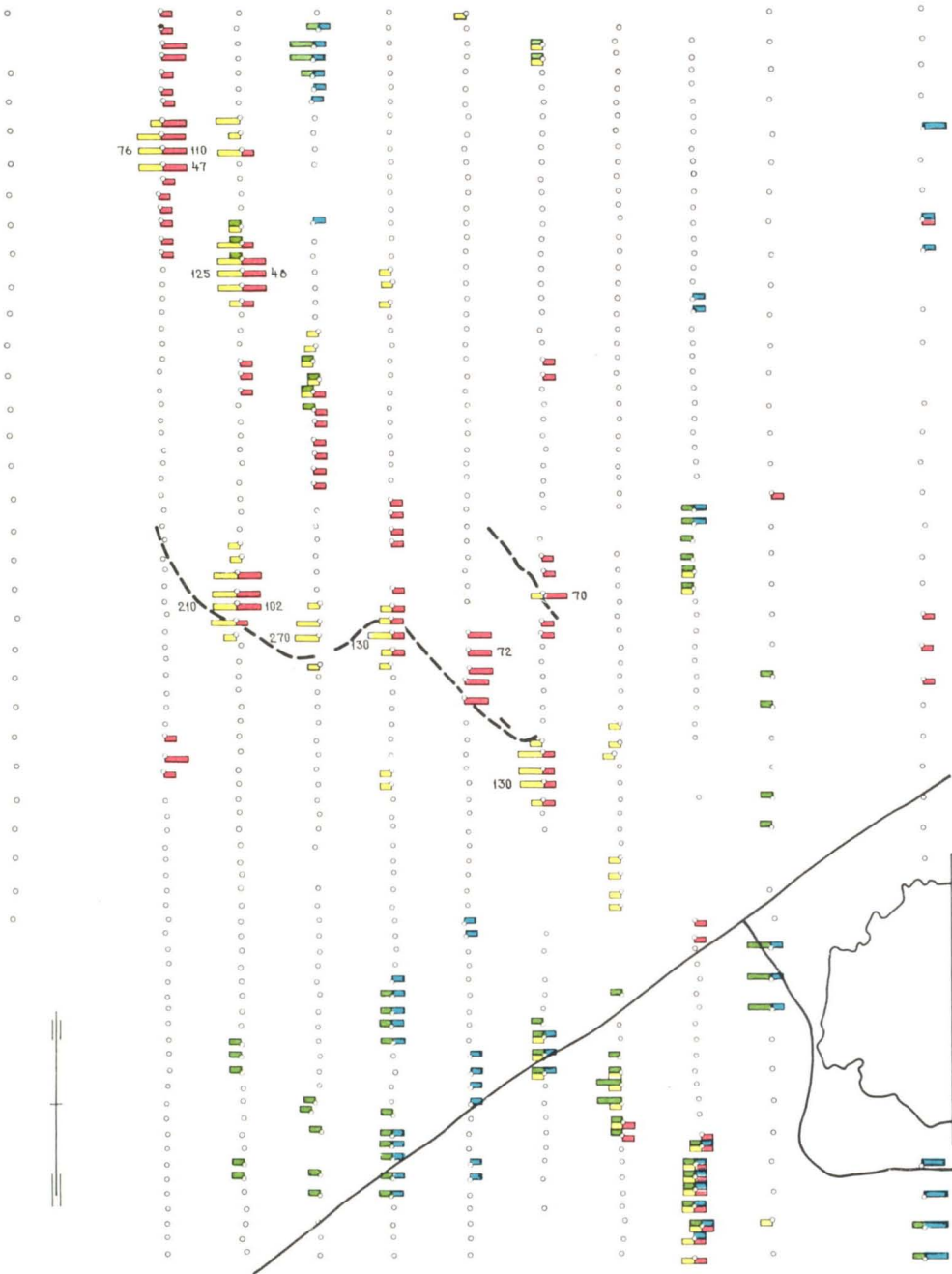
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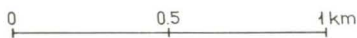




GEOCHEMICAL MAP

Trace element concentrations
in the C horizon of moraine

KALLIOKYLÄ
KIURUVESI



- Ore outcrop
- Sampling site

GEOCHEMICAL ANOMALIES (ppm)

Ni	Co	Σ%	Co	Cu	Ni	Zn
90	14	24	23	43		
98	18	34	26	58		

Anomaly limits have been determined on the basis of frequency distribution. The rare high concentrations are indicated with numbers.

by Heikki Wennervirta

