Geochemical Provinces in the Northern Parts of the Baltic Shield and Caledonides: Preliminary Results

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The geochemistry of the continental crust of the northern part of the Baltic Shield and adjoining Caledonides has been investigated by analysis of till and stream sediment samples collected at a density of 1 sample per c. 50km². Relative to the average crustal composition, the tills of the northern part of the Baltic Shield are enriched in Ba, Cs, La, Sc, U and V and depleted in Cr, Cu, Mg, Mn, Ni and Zn. Several geochemical provinces have been found, of which a belt of high contents of Cr, Mg, Ni and Sc within the Svecokarelian block is prominent. This geochemical structure follows a zone which possibly marks the border between the pre-Karelian basement and the Svecokarelian blocks. There seems to be a trend of decreasing contents of mafic elements and increasing contents of felsic elements from this border towards the southwest. This pattern is in agreement with an earlier contention that the continental crust of the Central Baltic Shield evolved by westward accretion. Another striking geochemical pattern in the Svecokarelides is that of high contents of Ag, Fe, Mn and Mo in stream sediments due to the formation of oxidates over certain types of acidic rocks. Samples taken north of the Trollfjord-Komagelv Fault on the Varanger Peninsula have a different chemical character to those south of the fault, thus supporting an earlier theory about a remote origin for the Barents Sea Group. Some of the geochemical provinces which have been found may indicate primary enrichment zones of the crust. If appropriate ore-forming processes have taken place within these zones, then the latter may become hosts for ore deposits. It is concluded that regional multi-element geochemical mapping with low sampling density can delineate areas favourable for exploration.

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Introduction

Following a programme initiated by the Nordic Council of Ministers the Geological Surveys of Finland, Norway and Sweden are carrying out an extensive mineral resource assessment project ('The Nordkalott-project') in the northern part of the Baltic Shield (Figs. 1 and 2). The project involves the collection of geological, geophysical and geochemical data from the area north of 66°N in the three countries.

The geochemical subproject comprises a low-density multi-media (stream water, stream sediments, stream organic matter, stream moss, soil organic matter and till) sampling programme. The samples are analysed by various techniques such as emission spectrometry, X-ray fluorescence and neutron activation spectrometry. The total or acid/extractable parts of altogether 46 elements have been determined.

In this paper examples of some preliminary results from the analysis of till and stream sediments are given and discussed in relation to the main features of the regional geology. Other examples have been published by Bergström et al. (1980), Björklund & Lummaa (1981), Lehmuspelto (1981), Bølviken et al. (1982), Björklund & Bølviken (1983), Björklund (1984), Bølviken & Ottesen (1984, 1985) and Ottesen & Bølviken (1984).

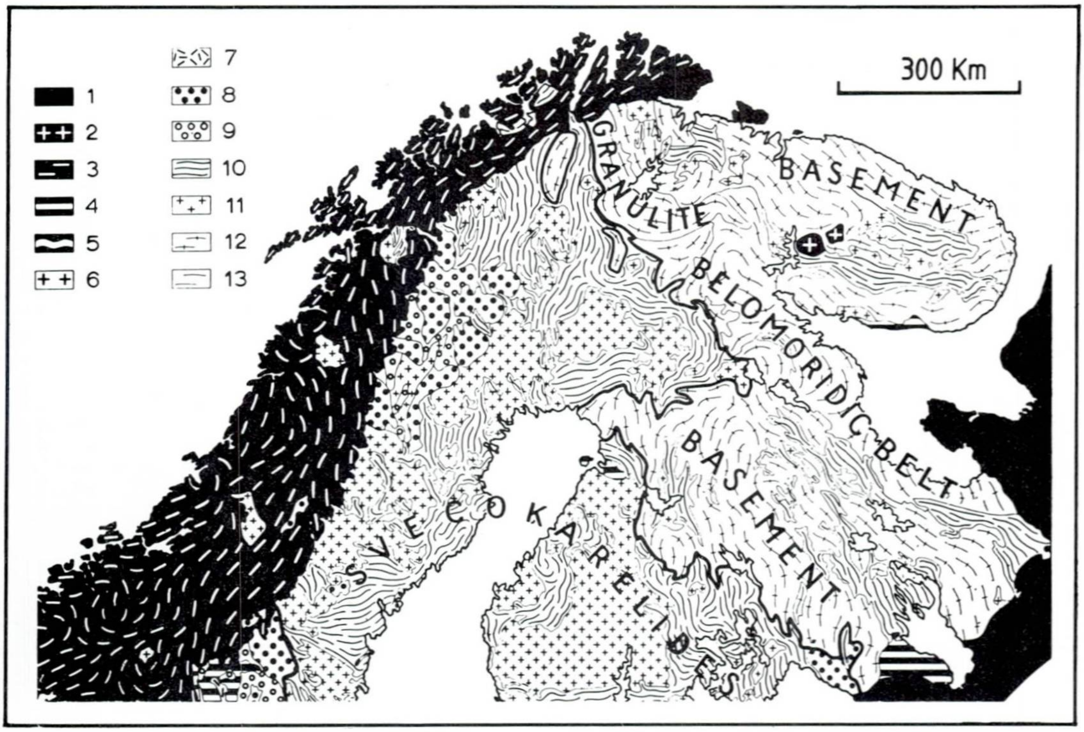

Fig. 1. Survey area with main geological units taken from Simonen (1980)*11. 1, Palaeozoic and younger sedimentary rocks. 2, Palaeozoic igneous rocks. 3, Caledonides. 4, Jotnian formations. 5, Folded Dalslandian formations. 6, Dalslandian granites. Precambrian igneous rocks, representing the time of cratonization after the Svecokarelidic orogeny. 7, Diabases. 8, Gothian and rapakivi granites. 9, Volcanic rocks. Svecokarelidic folded area. 10, Schists and gneisses. 11, Plutonic rocks. 12, Pre-svecokarelidic basement. 13, Basement of unknown age.*

Bedrock Geology

The survey area covers the northern parts of the Baltic Shield and the Caledonian fold belt. The geological history of the northern parts of the Baltic Shield is still a matter of controversy (see e.g. Gaal et al. 1978, Oftedahl 1980, Simonen 1980, Barbey et al. 1980, Gaal 1982, Bernard-Griffiths et al. 1984, Witschard 1984 and Papunen & Gorbunov 1985). We have based the following account on the overviews given by Oftedahl (op.cit.) and Simonen (op.cit.) (see Figs. 1 and 2).

The shield area can be subdivided into 2 blocks: (1) the pre-Karelian basement with the Granulite Complex, and (2) the Svecokarelian schist and greenstone belt. Rocks of the Caledonian orogen occur above the older Precambrian complexes in the northwestern parts of the survey area.

The oldest part of the Baltic Shield in the east is composed of granites, gneisses and supracrustal rocks with U-Pb zircon ages of generally typical feature of the Svecokarelian orogeny, (Pharaoh et al. 1982). Some recent radiometric data are presented by Krill et al. (1985, this volume).

The Caledonian fold belt can be broadly subdivided into (1) metamorphic nappe complexes composed mainly of metasediments, and (2) autochthonous to parautochthonous very low grade sediments of late Precambrian to Cambrian age. A review of the Caledonides in Finnmark is given in an accompanying article in this volume (Roberts 1985).

Quaternary Geology

The Pleistocene ice sheet covered the whole of the Baltic Shield, and the rocks are generally poorly exposed due to extensive deposits of till and other glacial sediments. There have been at least five episodes of glacial transport that differ in age and direction of ice flow (Hirvas 1977).

The transport distance of the till appears to have been short. Kauranne (1975) reported that the Geological Survey of Finland is carrying out an extensive geochemical mapping programme, in which the fine fraction (-0.06 mm) of several hundred thousand till samples have been analysed. The till samples were taken at an average depth of 1.8 m. The geochemical anomalies found during this programme generally seem to be displaced in the direction of the ice movement less than a few hundred metres from the bedrock source. Hirvas (1977) found that in Finnish Lapland the glacial transport distance of the stone fraction (20-200 mm) of till from 2-5 m depth is 1-4 km, in one case 10 km from the bedrock source.

Pulkkinen et al. (1980) have studied the transport distance of the finest grain-size fraction (-0.06 mm) at various depths in the till in two areas in the Finnish part of the survey area using magnetic susceptibility measurements and chemical analysis. Both methods gave similar distances, approximately 300 metres in one area and 50 metres in the other.

The data reported above indicate that even for samples taken at a depth of 60 cm the glacial displacement of geochemical patterns is generally negligible at the sampling distances and

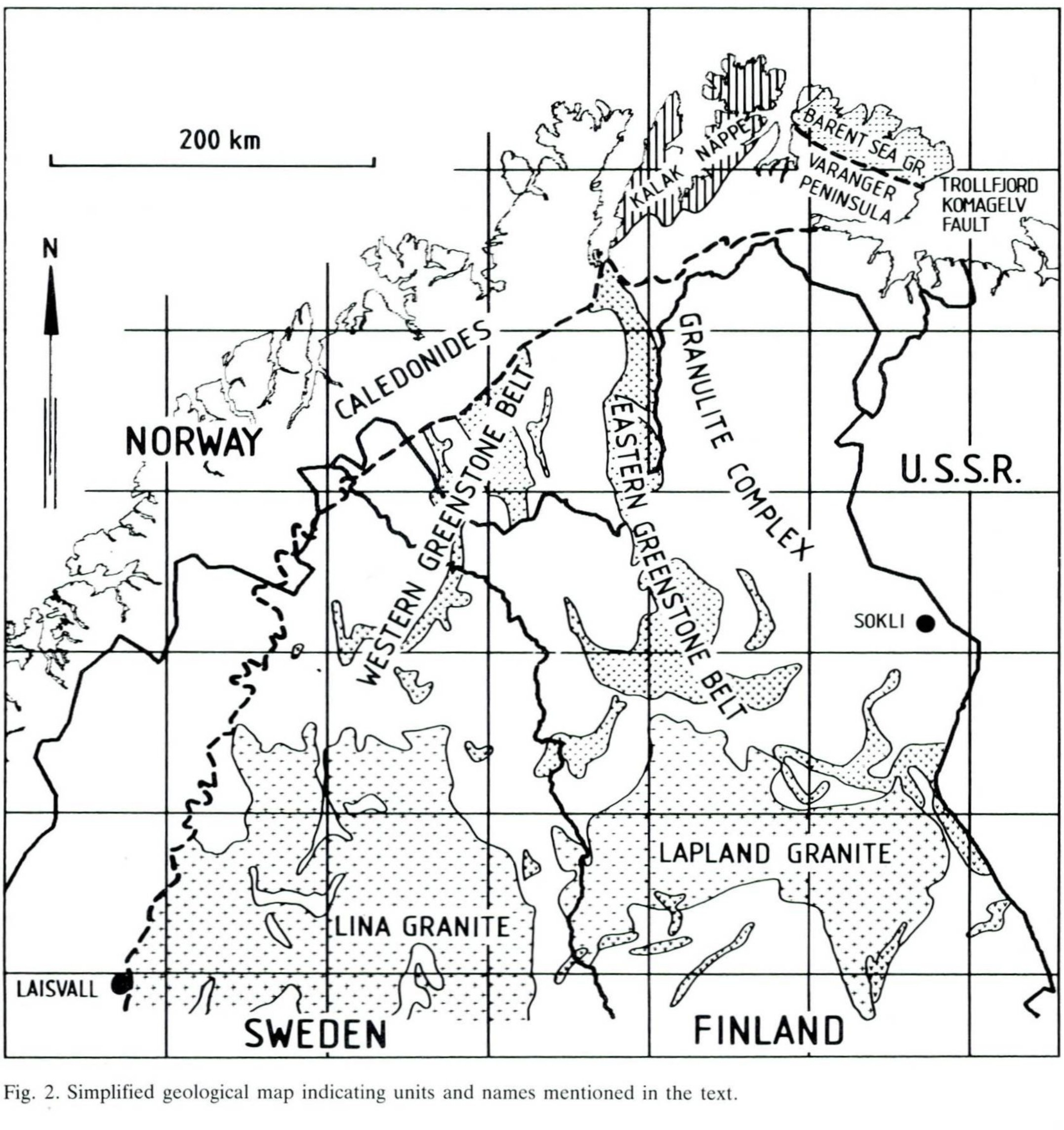

Fig. 2. Simplified geological map indicating units and names mentioned in the text.

map scales used in our survey.

In some areas products of preglacial weathering have survived the glaciation, forming up to several tens of metres thick deposits of unconsolidated residual material under the glacial sediments (Bjørlykke 1966, Hirvas 1977). The extension of these areas of presumably Tertiary weathering is not completely known.

Podzolization is common. Other types of postglacial weathering are also taking place, especially in the northern coastal districts of Norway like the Varanger Peninsula where there is a considerable frost action. In such areas there are deposits of glacial sediments as well as deposits of recent weathering products which are both heavily eroded by surface run off (J. Bogen, in prep.).

Methods

7,267 drainage areas ranging from 5 to 20 km^2 in size were selected within the approximately 250,000 km^2 survey area. A sampling station was defined at the apex (lowest point) of each drainage area. Till and stream sediments were sampled at all stations where material was available. Till was found at 5,400 stations and stream sediments at 5,773.

The analytical methods which have been applied, are summarized in Table 1. Methods of sampling and sample preparation are briefly described below.

Till

At each station, a few tens of metres away from the stream, one 60 cm-deep hole was dug with a spade. The till (preferably basal, but sometimes ablation) was taken in the C-horizon of the soil in the bottom of the hole. After drying, the samples were sieved through nylon cloths and two grain-size fractions 0.0062–0.0500 mm and -0.062 mm) were obtained.

Stream Sediments

Stream sediments consisting of mixtures of inorganic active sediments and inactive stream-bank (floodplain) deposits were collected from 5-10 substations within a 50 m section of each stream. The samples were wet-sieved in the field to obtain two grain-size fractions, 0.18 + 0.6 mm and -0.18mm.

Table 1. THE NORDKALOTT PROJECT. ANALYTICAL METHODS USED AND ELEMENTS DETERMINED IN SAMPLES OF TILL AND STREAM SEDIMENTS.

(C=composite samples, HM=heavy mineral concentrate)

Method (laboratory)	Sample type	Grain size (mm)	Elements	Total/acid--soluble contents
X-ray fluorescence(3)	Stream sediments (C, HM) Till (C, HM)	0.18-0.6 0.062-0.5	Al,Ba,Ca,Cl,Co,Cr,Cu, Fe,K,Mg,Mn,Mo,Na,Nb,Ni, P,Pb,Rb,S,Sn,Sr,Ti,V,Y, Zn,Zr	Total
ICP emission spectrometry(2)	Stream sediments	-0.18	Ag,Al,Ba,Ca,Ce,Co,Cr,Cu,Fe, K,La,Li,Mg,Mn,Mo,Na,Ni,P, Pb,Sc,Sr,Ti,V,Zn,Zr	Acid soluble
Emission spectrometry (Tape machine)(1)	Till	-0.062	Ca,Co,Cr,Cu,Fe,K,Mg,Mn,Na Ni,Pb,Ti,V,Zn	Total
Neutron activation(4)	Till	-0.062	Ba,Br,Cr,Cs,Fe,La,Lu,Mo, Na,Rb,Sb,Sc,Sm,Ta,Th,W,Zn,U	Total

Laboratory: 1 Geological Survey of Finland
2 Geological Survey of Norway
3 Swedish Geological Company
4 Technical Research Centre of Finland

Composite samples

In order to reduce costs, samples from neighbouring sample stations were mechanically mixed into composites before applying the most expensive methods of chemical analysis. Approximately 1000 composite samples represent the survey area.

Heavy Mineral Fraction

Heavy mineral fractions of specific gravity greater than 2.96 g/cm^3 were produced from the 0.062–0.5 mm fraction of tills and from the 0.18–0,6 mm fraction of stream sediments using a heavy liquid and equipment described by Brundin & Bergström (1977).

Results

Average Chemical Composition of The Till in The Survey Area

Since basal till constitutes a mixture of crushed and ground bedrock that has not been extensively washed with water, its general chemical composition would be expected to approach that of the bedrock source. The contents of Ba, Br, Cs, La, Sc, V and U in the till of the survey area are enriched, and the contents of Cr, Cu, Mg, Mn, Ni and Zn are depleted in relation to the Clarke values taken from Mason (1966); see Table 2. The values found for As, Au, Co, Fe, Pb, Rb and Th are similar to those given by Mason (op.cit.) as crustal averages.

TABLE 2. Average contents of 24 elements in till from the northern part of the Baltic Shield-(X) compared with accepted Clarke values for crustal abundance (Mason 1966).

Element	$\overline{X}$	Crustal abundance	Enrichment factor
As	2.4	2	1.2
Au	0.005	0.005	1
Co	26	23	1.1
Cr	138	200	0.7
Cs	21.9	1	1.9
Cu	17	45	0.38
Fe	48 000	50 000	0.96
La	37	18	2.0
Mg	14 700	20 900	0.70
Mn	605	1 000	0.6
Na	24 000	28 300	0.84
Ni	41	80	0.51
Pb	17	15	1.1
Rb	64	75	0.85
Sb	0.4	0.2	2
Sc	20	05	4
Th	10	10	1
V	224	110	2
Zn	30	65	0.46
Br	11	03	3.7
U	3	2	1.6
Ba	635	400	1.6
Sm	6	7	0.86

Geochemical Characterization of The Main Bedrock Units

The pre-Karelian Basement and Granulite Complex

Rather uniform and low concentrations of most of the analysed elements is a striking feature of tills and stream sediments from the pre-Karelian basement and Granulite Complex (Fig. 1), Cr (Fig. 3) being a typical example. Contents of Ba (Fig. 4), La and Th form exceptions to this rule, showing a geochemical province of high values in parts of the Granulite Complex and surrounding gneisses including the area of the Sokli Carbonatite (Fig.2).

This is in agreement with the findings of Hörmann et al. (1980), who showed that parts of the Granulite Complex in Finland are enriched in Ba and REE. However, Sheraton (1970) and Tarney et al. (1972) consider that the granulite facies metamorphism generally has been responsible for a major depletion of elements like Cs, K, La, Pb, Th, U and Y.

The Svecokarelian Schist and Greenstone Belts

There seems to be a main SW-NE trend in the chemical composition of tills and stream sediments from the Svecokarelian block (Fig. 1). In many cases this trend overshadows differences in lithology and age of the bedrock. Examples are provided by southwestward increases in the contents of felsic elements such as Al (Fig. 6) and the ratio K/Na and a corresponding decrease in the contents of mafic elements like Cr (Fig. 3).

There are also SW-NE differences between units of similar rock types. Samples taken over the eastern greenstone belt (Fig. 2) show generally 3-10 times as much Cr (Fig. 3), Mg, Ni, Sc and V as those taken over the greenstones further west. Samples over the granites in the western part of the survey area have contents of As, Fe, Mo (Fig. 7), Pb,Sb, Ta, V, W and Zn which on the whole are 2-10 times higher than those over the granites in the eastern part. Furthermore, the SW-NE trend also seems to be apparent within separate bedrock units; see for example the distribution of Cr (Fig. 3) over the southern part of the western greenstone belt (Fig. 2) and the distribution of Nb (Fig. 6) over the Lapland granite (Fig. 2).

These geochemical trends in tills and stream sediments seem to support Gaals' (1982) contention that the continental crust of the central Baltic Shield evolved by westward accretion during the Svecokarelian orogeny, as well as Witschard's (1984) findings of E-W differences in the major composition of the greenstones of northern Sweden.

Striking geochemical patterns within the Svecokarelides are those of Fe and Mn and associated metals such as Ag and Mo (Fig. 7) in the stream sediments. The high Ag and Mo values are considered to be associated with Fe and Mn precipitates (oxidates) in the stream channels. Oxidates seem to develop mainly in streams draining from certain acidic rocks. Similar observations have been made in southern Norway (Ottesen & Volden 1983).

The Caledonides

It should be noted that the main geochemical trends in the Granulite Complex and Svecoka-

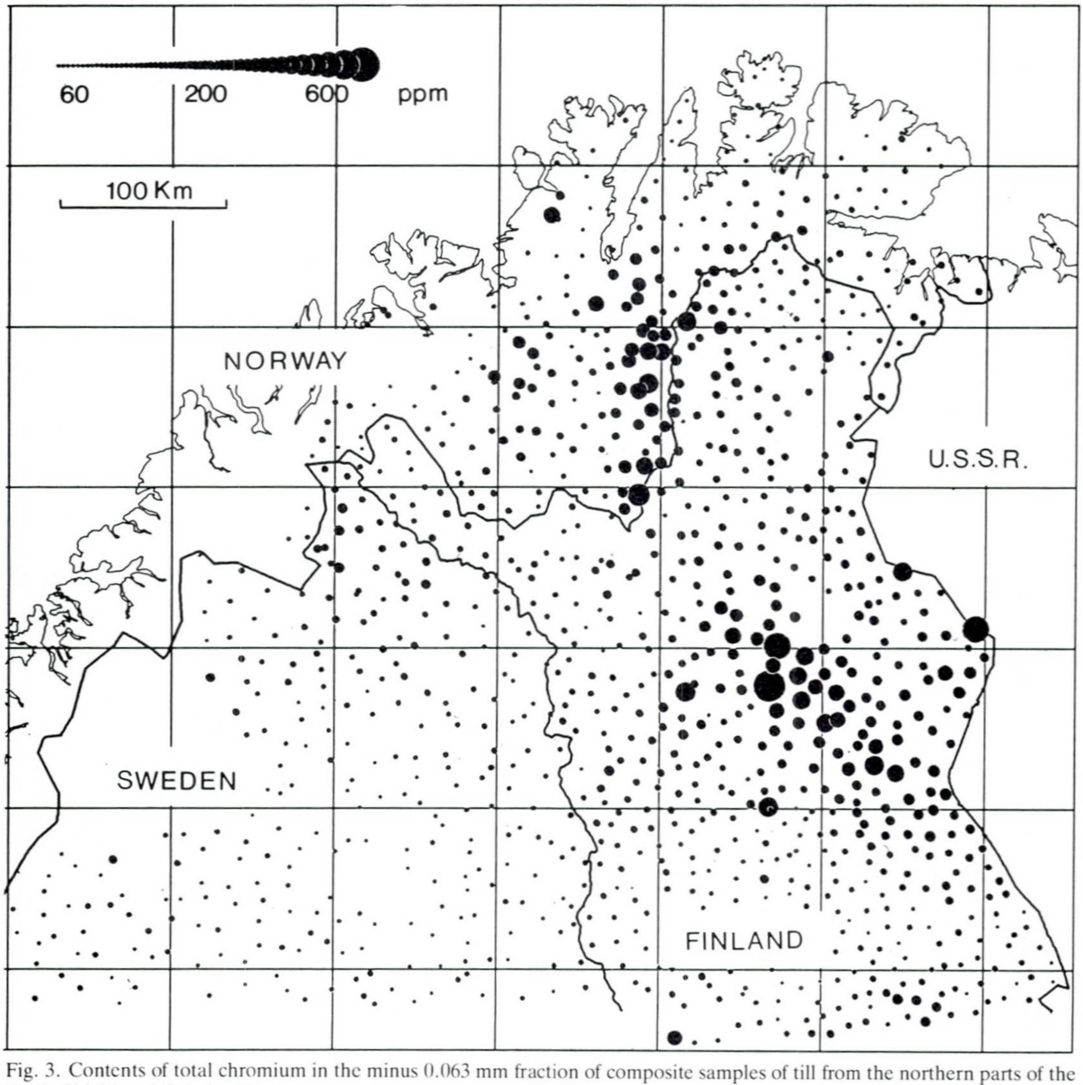

Fig. 3. Contents of total chromium in the minus 0.063 mm fraction of composite samples of till from the northern parts of the Baltic Shield and Caledonides.

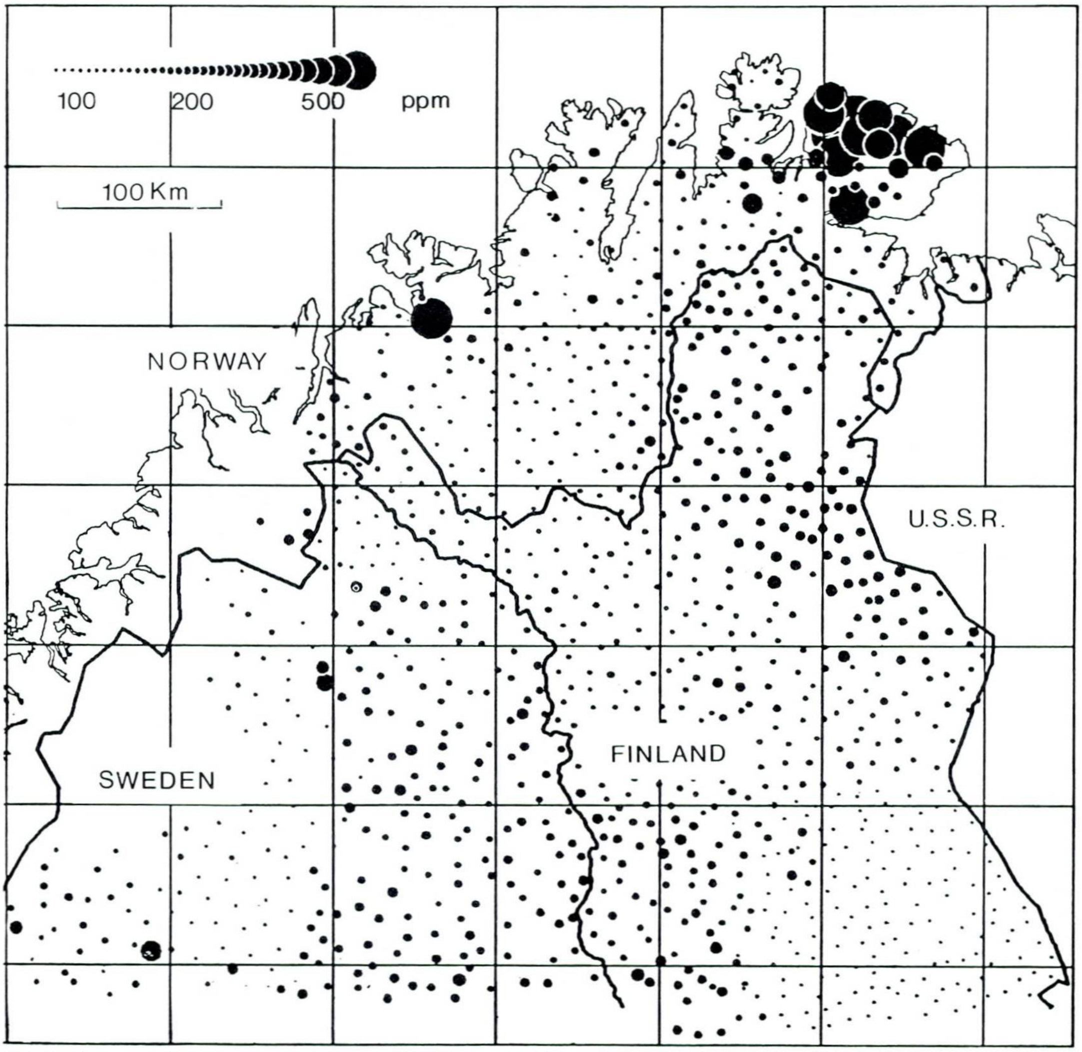

Fig. 4. Contents of total barium in the heavy mineral fraction (Sp.gr. 2.96 g/cm·3) of stream sediments from the northern parts of the Baltic Shield and Caledonides.

relian block in some cases continue into the Caledonides; see Figs. 2 and 6. Of special interest in this connection are the patterns of lead concentrations in the areas surrounding the Laisvall lead mine in the Swedish part of the Caledonides. The lead values are high even in the Precambrian areas east of the mine. The Caledonian belt is otherwise notable for its high K/Na ratios and parts of it, particularly on the Varanger Peninsula (Fig. 2), show distinct barium enrichments (Fig. 4).

The rocks north of the Trollfjord-Komagelv Fault zone (Fig. 2) on the Varanger Peninsula (see e.g. Siedlecka 1975) have several chemical characteristics which differ from those south of the fault. The distributions of Ba and Nb shown in Figs. 4 and 6, respectively, provide examples of patterns which are also similar for Fe, K, Mo, Pb, Sn, Ti, V and Zr in the heavy mineral fractions. This feature lends support to earlier suggestions that the rocks of the Barents Sea Group are a foreign element in the Caledonides of Finnmark (Siedlecka op.cit., Kjøde et al. 1978, Roberts 1985). Our data also indicate some geochemical similarities between the rocks of Barents Sea Group and those of the Kalak Nappe Complex. This last feature is less easy to explain in terms of current geological interpretations. However, the metasandstones of the Kalak Nappe in many places contain layers

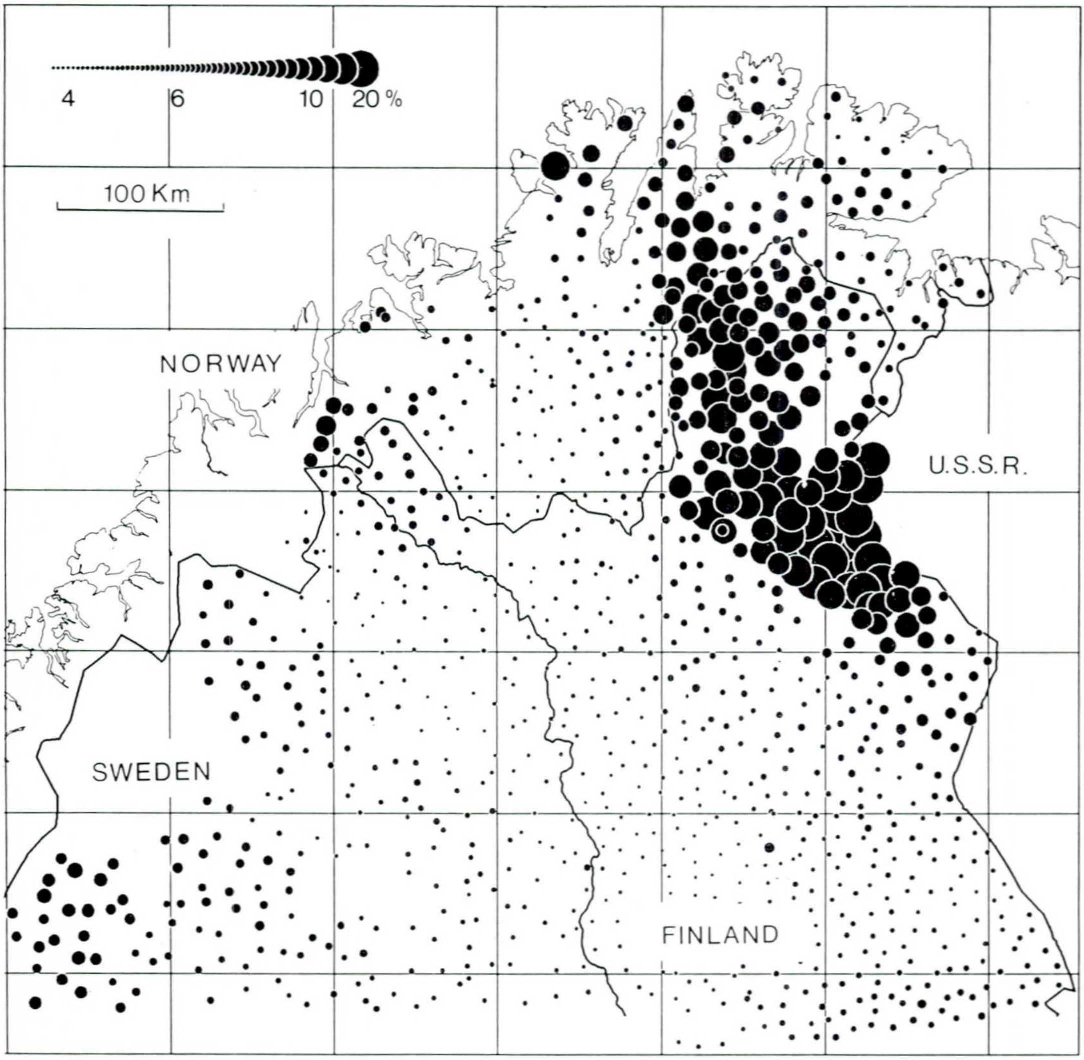

Fig. 5. Contents of total aluminium in the heavy mineral fraction (Sp.gr 2.96 g/cm·3ı) of composite samples of till from the Baltic Shield and Caledonides.

enriched in heavy minerals (Roberts & Andersen 1985) and these may contribute to the anomalies.

Conclusion

Regional geochemical mapping in the northern part of the Baltic Shield and adjoining areas of Caledonian rocks has disclosed several major geochemical provinces and trends. In some cases the distribution patterns agree with known geological domains or structural belts, whereas in others they do not. The geochemical data may, therefore, throw light upon aspects of the geological history of the region. Some of the geochemical provinces which have been found may indicate primary enrichment zones of the crust. The geochemistry of such zones could be reflected in younger formations. If appropriate ore-forming processes have taken place, then the zones may become hosts for economic deposits. It is believed, therefore, that the described type of low-density geochemical mapping is potentially of great value in exploration.

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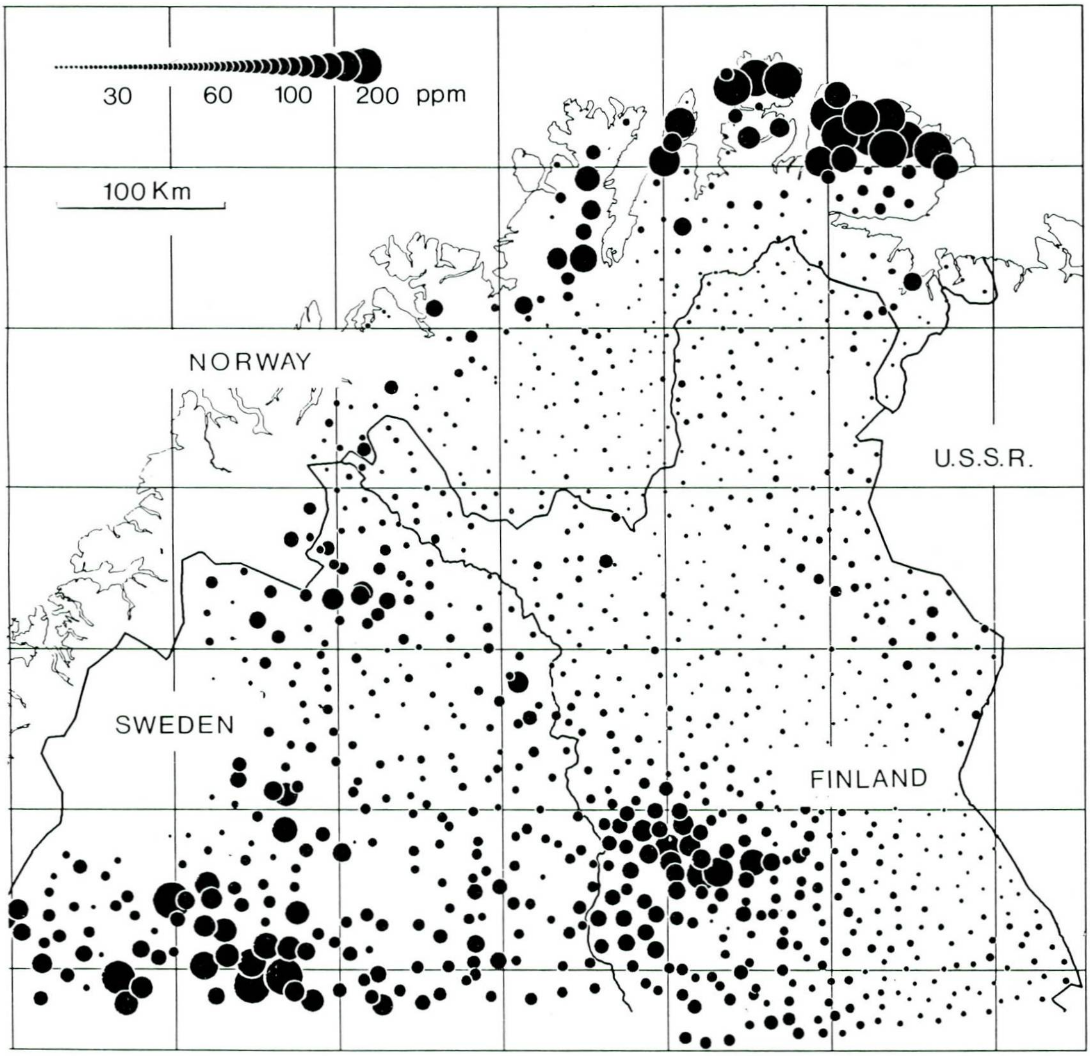

Fig. 6. Contents of total niobium in the heavy mineral fraction (Sp.gr. 2.96 g/cm·3ı) of composite samples of till from the northern parts of the Baltic Shield and Caledonides.

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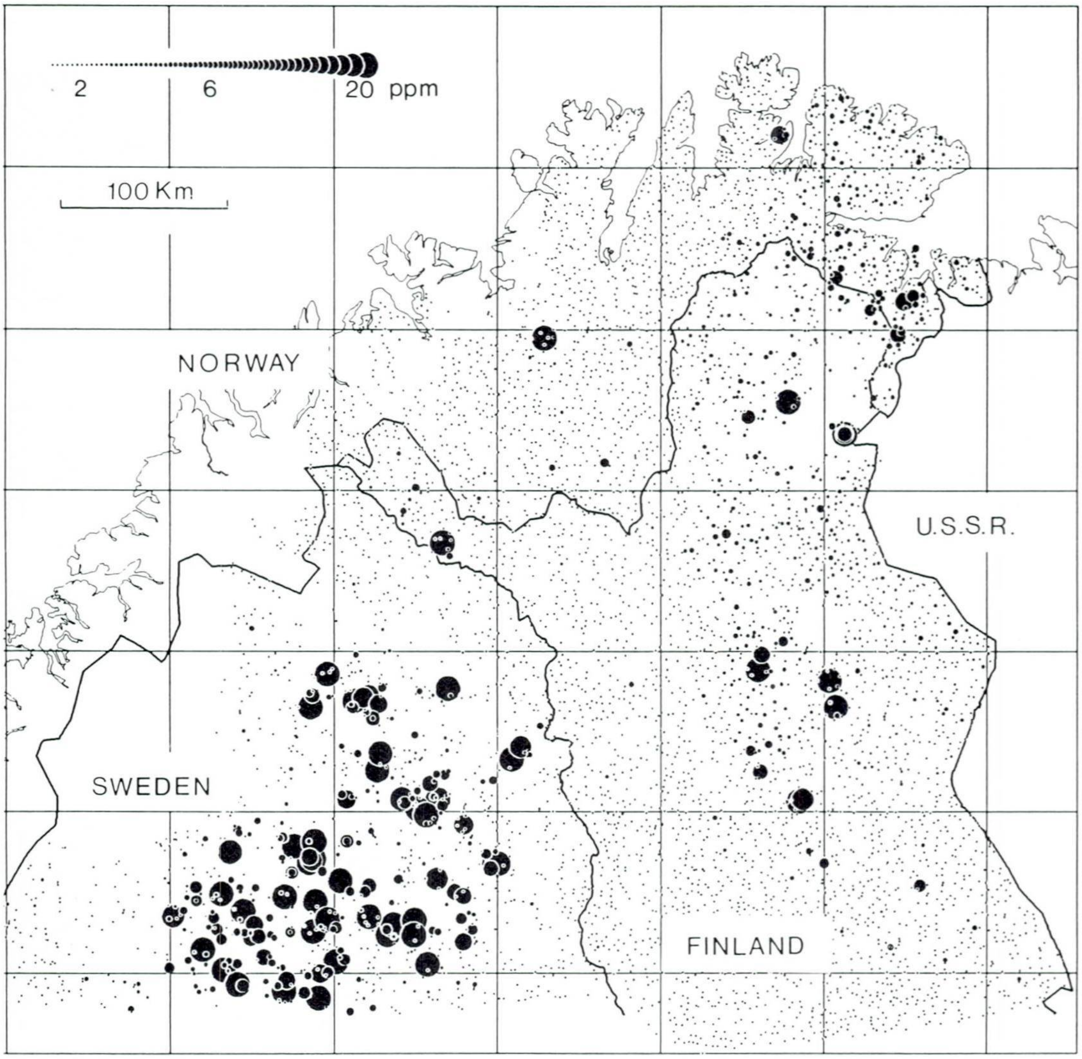

Fig. 7. Contents of acid-soluble molybdenum in the minus 0.18 mm fraction of stream sediments from the northern parts of the Baltic Shield and Caledonides.

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