4 GEOCHEMICAL ATLAS OF NORTHERN EUROPE

All the maps included in the Atlas were prepared in Arc/Info format and visualized in Arc/View 3.3 projects. The data of these maps are presented using the geographical coordinate system (longitude/latitude), the visualization of the maps is based on Lambert conformal conic projection with metres as the measurement unit, the map projection is WGS-84 spheroid, the main meridian is 24°, the width of the zone of true coordinates is 62°, and the main parallels are 52° and 72°.

A geographical base map compiled from different source materials was prepared for use together with the geochemical maps. For the Russian territory, a digital geographical map was prepared at the scale of 1:1,000,000 based on the geographical map of NW Federal Okrug of Russia from the GIS Atlas of Geological Maps (VSEGEI 2003). For Fennoscandia, the geographical base map from the geological map of the Fennoscandian Shield (Koistinen et al. 2001) was used. The geographical map of the territory of the Baltic countries was compiled by the Geological Survey of Lithuania. For the final geographical map of the project area, the data from these maps were generalized and harmonized to the scale of 1:5,000,000.

The digital model of the geographical base map includes the following layers: the sea shoreline (sea_land cover), state borders (border cover), linear and polygonal objects (lake and river cover), roads (roads cover), railways (railway cover), population centres (city cover), and a geographical grid (grid_1000 cover).

4.1 Accessory maps

4.1.1 Map of landscape zoning

The aim of this map is to show the taxons of natural landscapes that are characterized by homogeneous conditions for the migration of elements. This map allows background concentration levels of elements in different sample media to be reliably estimated. It also gives an opportunity for proper interpretation of geochemical anomalies and an estimation of the resistance of the environment to anthropogenic impacts.

The map of landscape zoning was compiled from published cartographic geological and physiographic materials (ESRI 1996, Koistinen et al. 2001, Kolosova 1980, Reimann et al. 1998, Salminen et al. 2004, WRB 1998, ESRI 2002). Instructive Russian ecogeochemical documents (IMGRE 1999, IMGRE 2001) were also taken into account in the composition of this map.

The following taxon categories were used in compiling the map of landscape zoning:

- types, showing latitudinal and high-altitude climatic and vegetation zonality (veget cover);
- rows, corresponding to large structural geological territories (megablocks and blocks) with different neotectonic movements, including blocks of prevailing rising, stabilization or slightly rising and prevailing depression (geol. cover);
- classes, reflecting the main soil types (soil cover);
- families, showing the genetic types of relief (relief cover);
- kinds, showing the main paragenetic (allochthonous or autochthonous) groups of Quaternary deposits (landscape cover).

Landscape types. A clear latitudinal zonality prevails in the study area, which is caused by the north-to-south increase in moisture rotation, evaporation and pedogenesis. The biological productivity and the diversity of flora and fauna also increase from north to south. The northernmost subarctic zone includes subzones of tundra, forest-tundra and mountain tundra. The majority of the study area is situated in the boreal zone. From north to south the boreal zone is divided into the northern taiga, middle taiga and southern taiga subzones. In the southernmost part of the boreal zone, the subzones of mixed and deciduous forests prevail.

Landscape rows. Three large structural geological megablocks are defined in the study area: (i) the Caledonian folded belt forms a region of prevailing rising, (ii) the Fennoscandian Shield belongs to a stabilized territory with slight rising and (iii) the Russian Plate is a region of prevailing depression. The Fennoscandian Shield and the Russian Plate are divided into second-order structures: Kola, Belomorian, Lapland-Karelian, Svecofennian and Sveco-Norwegian blocks are separated within the Fennoscandian Shield, and the Russian plate is divided into Mezen-Moscowian and Baltic syneclises, and the Lithuanian-Belarusian anticlise.

Table 6. List of integrated AGF maps and the element associations in different sample media included in each map. SSE=stream sediment, CHO$_{ar}$= aqua regia extractable concentration of the <2 mm fraction of the soil C-horizon, till= aqua regia leachable part of the <0.06 mm fraction of till, CHO$_{tot}$=total concentration of the <2 mm fraction of the soil C-horizon, SW=stream and lake water.

Name (index) of integrated map	Composition of integrated map (elements associations and sampling media)
M1all_an	M_1(Co,Cr,Ni,Cu,V)$_{sse}$, M_1(Co,Cr,Ni,Cu,V)$_{till,}$ M_1(Co,Cr,Ni,Cu,V)$_{CHOar}$, M_1(Co,Cr,Ni,Cu,V)$_{CHOtot}$ for Estonia and Latvia only
M1all-1_an	M_1(Co,Cr,Ni,Cu,V)$_{sse}$, M_1(Co,Cr,Ni,Cu,V)$_{till,}$ M_1(Co,Cr,Ni,Cu,V)$_{CHOar}$, M_1(Co,Cr,Ni,Cu,V)$_{CHOtot}$ for Estonia and Lithuania only, M_1(Co,Cr,Ni,Cu,V)$_{sw}$
M2all_an	M_2(Fe,Mn)$_{sse}$, M_2 (Fe,Mn)$_{till}$, M_2 (Fe,Mn)$_{CHOar}$, M_2(Fe,Mn)$_{CHOtot}$ for Estonia and Latvia only
M3all_an	M_4(Cd,Mo,Pb,Zn,As)$_{sse}$, M_4(Zn,Pb,Mo)$_{till}$, M_3(Cd,Mo,As,Sb,Bi)$_{CHOar}$, M_4(Pb,Zn)$_{CHOar}$, M_4(Mo,Pb,Zn)$_{CHOtot}$ for Estonia and Lithuania only
M3all-1_an	M_4(Cd,Mo,Pb,Zn,As)$_{sse}$, M_4(Zn,Pb,Mo)$_{till}$, M_3(Cd,Mo,As,Sb,Bi)$_{CHOar}$, M_4(Pb,Zn)$_{CHOar}$, M_4(Mo,Pb,Zn)$_{CHOtot}$ for Estonia and Lithuania only, M_4(Zn,Pb,Cd)$_{sw.}$
.M4all_an	M_5(Ce,La,Nb,Th,Y)$_{sse}$, M_7(Be,Zr,Ti,Sc)$_{sse}$, M_{11}(Al,Ba)$_{sse}$, M_9(P,U,Sr)$_{sse}$, M_5(Zr,Sr,Ti,P,La)$_{till}$, M_9(Be,P,Sr)$_{CHOar}$, M_{11}(B,Al,Ba)$_{CHOar}$, M_5(Ce,La,Sn,U,Y)$_{CHOtot}$, M_6(Zr,Nb,Th)$_{CHOtot.}$
M4all-1_an	M_5(Ce,La,Nb,Th,Y)$_{sse}$, M_7(Be,Zr,Ti,Sc)$_{sse}$, M_{11}(Al,Ba)$_{sse}$, M_9(P,U,Sr)$_{sse}$, M_5(Zr,Sr,Ti,P,La)$_{till}$, M_9(Be,P,Sr)$_{CHOar}$, M_{11}(B,Al,Ba)$_{CHOar}$, M_5(Ce,La,Sn,U,Y)$_{CHOtot}$, M_6(Zr,Nb,Th)$_{CHOtot.}$, M_{14}(Mo,U)$_{sw.}$
M4all-2_an	M_5(Ce,La,Nb,Th,Y)$_{sse}$, M_7(Be,Zr,Ti,Sc)$_{sse}$, M_{11}(Al,Ba)$_{sse}$, M_9(P,U,Sr)$_{sse}$, M_5(Zr,Sr,Ti,P,La)$_{till}$, M_9(Be,P,Sr)$_{CHOar}$, M_{11}(B,Al,Ba)$_{CHOar}$, M_5(Ce,La,Sn,U,Y)$_{CHOtot}$, M_6(Zr,Nb,Th)$_{CHOtot.}$, M_{14}(Mo,U)$_{sw,}$ M_{16}(Al,V,Th)$_{sw.}$
M(1_2)all_an	M1all_an, M2all_an.
M(1_3)all_an	M1all_an, M2all_an, M3all_an.
Mall_an	M1all_an, M2all_an, M3all_an, M4all_an.
Mall-1_an	M1all_an, M2all_an, M3all_an, M4all_an, M_{14}(MoU)$_{sw.}$
Mall-2_an	M1all_an, M2all_an, M3all_an, M4all_an, M_{14}(Mo,U)$_{sw}$, M_4(Zn,Pb,Cd)$_{sw.}$
Mall-3_an	M1all_an, M2all_an, M3all_an, M4all_an, M_{14}(Mo,U)$_{sw}$, M_4(Zn,Pb,Cd)$_{sw}$, M_1(Ni,Cu,Co,Cr)$_{sw.}$
Mall-4_an	M1all_an, M2all_an, M3all_an, M4all_an, M_{14} (Mo,U)$_{sw}$, M_4(Zn,Pb,Cd)$_{sw}$, M_1(Ni,Cu,Co,Cr)$_{sw}$, M_{16}(Al,V,Th)$_{sw.}$
Mallsse_an	M_1(Co,Cr,Ni,Cu,V)$_{sse}$, M_2(Fe,Mn)$_{sse}$, M_4(Cd,Mo,Pb,Zn,As)$_{sse}$, M_5(Ce,La,Nb,Th,Y)$_{sse}$, M_7(Be,Zr,Ti,Sc)$_{sse}$, M_{11}(Al,Ba)$_{sse}$, M_9(P,U,Sr)$_{sse.}$
Mallchoar_an	M_1(Co,Cr,Ni,Cu,V)$_{CHOar}$, M_2(Fe,Mn)$_{CHOar}$, M_3(Cd,Mo,As,Sb,Bi)$_{CHOar}$, M_4(Pb,Zn)$_{CHOar}$, M_9(Be,P,Sr)$_{CHOar}$, M_{11}(B,Al,Ba)$_{CHOar}$
Mallchotot_an	M_1(Co,Cr,Ni,Cu,V)$_{CHOtot}$ for Estonia and Latvia only, M_2(Fe,Mn)$_{CHOtot}$ for Estonia and Latvia only, M_4(Mo,Pb,Zn)$_{CHOtot}$ for Estonia and Lithuania only, M_5(Ce,La,Sn,U,Y)$_{CHOtot}$, M_6(Zr,Nb,Th)$_{CHOtot.}$
Malltill_an	M_1(Co,Cr,Ni,Cu,V)$_{till,}$ M_2 (Fe,Mn)$_{till}$, M_4(Zn,Pb,Mo)$_{till,}$ M_5(Zr,Sr,Ti,P,La)$_{till.}$

Landscape classes. The main genetic types and sub-types of zonal soils are Regosols, Gleysols, Cryosols, Podzoluvisols, Podsols, Eutric Podzoluvisols and Luvisols. In the mountain areas, Fluvisols, Lithosols, Leptosols, Cambisols, Rendzinas belong to the azonal types of soil.

Landscape families. There are four main genetic types of relief, including accumulative plains, accumulative-denudation plains, weakly dissected hills and plateaus, and strongly dissected low and middle mountains.

Landscape kinds. Both autochthonous and allochthonous Quaternary deposits are characteristic for the project area. The autochthonous formations include eluvial and deluvial deposits, and also areas with outcrops of bedrock. The allochthonous formations are divided into two groups according to their composition. The first and the most widespread group is glacial deposits. The second group includes different combinations of glaciofluvial, lacustrine, alluvial and marine deposits.

4.1.2 Zoning according to the natural geological and bio-climatic conditions

For the assessment of mineral potential and environmental status, the study area was divided according to the main natural geological and bio-climatic conditions (landscape types and rows) into sub areas. Consequently, 41 regions including different combinations of physiographic and geological conditions were identified. Selected areas (and in some cases more detailed districts in accordance with classes, families and kinds of landscapes) were used for the primary data processing, including the calculation of statistical parameters for element distribution, and also for the interpretation of the defined geochemical anomalous fields.

4.1.3 Map of human activity at the scale of 1:5,000,000

The map (Fig. 10) describes the location of different types of industry and intensity of land use in the project area. It was prepared on the basis of the analysis and generalization of graphical and factual materials published by ESRI (1996), Kolosova (1980), Kozlovsky (1981), Salminen et al. (2004) and Salminen et al. (2005). The map includes information on human activities in the form of local (dotted), linear and areal elements.

Local (dotted) objects include:

- population centres ranked according to the number of inhabitants, and including a circle diagram that shows the main types of industry *(techno cover)*;
- objects of the mining industry *(mining cover)*;
- power production objects *(energ. cover)*;
- sea and river ports *(seaport cover)*.

The power production objects are divided to three different types (hydro-, heating and nuclear power plants) because of their ecological importance. An attribute table contains additional information about electrical power plants including year of installation, location and Russian and English name (altogether 362 objects).

Linear objects include roads *(road cover)*, railways *(railway cover)*, sea, lake and river transport ways *(seaway cover)*, oil and gas pipelines *(oilpipe and gaspipe covers)*, and the contour of the Barents Sea oil- and gas-bearing province *(oilbase cover)*.

Areal objects show the location of agricultural land *(agricult. cover)* and nature protection areas (PNCT) *(protec_area cover)*. According to the intensity of agricultural use, the project area is divided to 6 districts. The attribute table of PNCT include additional information on their size (in hectares), name, location and territorial status.

Intensity of anthropogenic activities

A map layer describing anthropogenic activities was created by summarizing two factors, population density and the development of transport networks. Both of these factors have a strong positive correlation with the level of economic development of the territory. Four levels of territorial development are shown on the map, including predominately non-utilized areas and weakly, moderately and intensively utilized areas.

The highest population density and the greatest diversity of industry are situated in the southern regions of Norway, Sweden, Finland and NW Russia (Leningrad and Vologda regions). A high level of economic activity is typical for the Baltic countries and some northern districts (the Norrbotten province in Sweden, and the Murmansk and Arkhangelsk regions in NW Russia). Different enterprises based on metal products (machinery), black and colour metallurgy, the chemical industry, large shipyards and sea ports are concentrated in the big industrial centres and play an important role in the economic development of these regions.

Refining and transportation of oil and gas products with the necessary wide network of different services such as energy and food production, building, agriculture and transport contribute significantly to the economic activity in the large megapolises and numerous middle- and small-sized industrial centres.

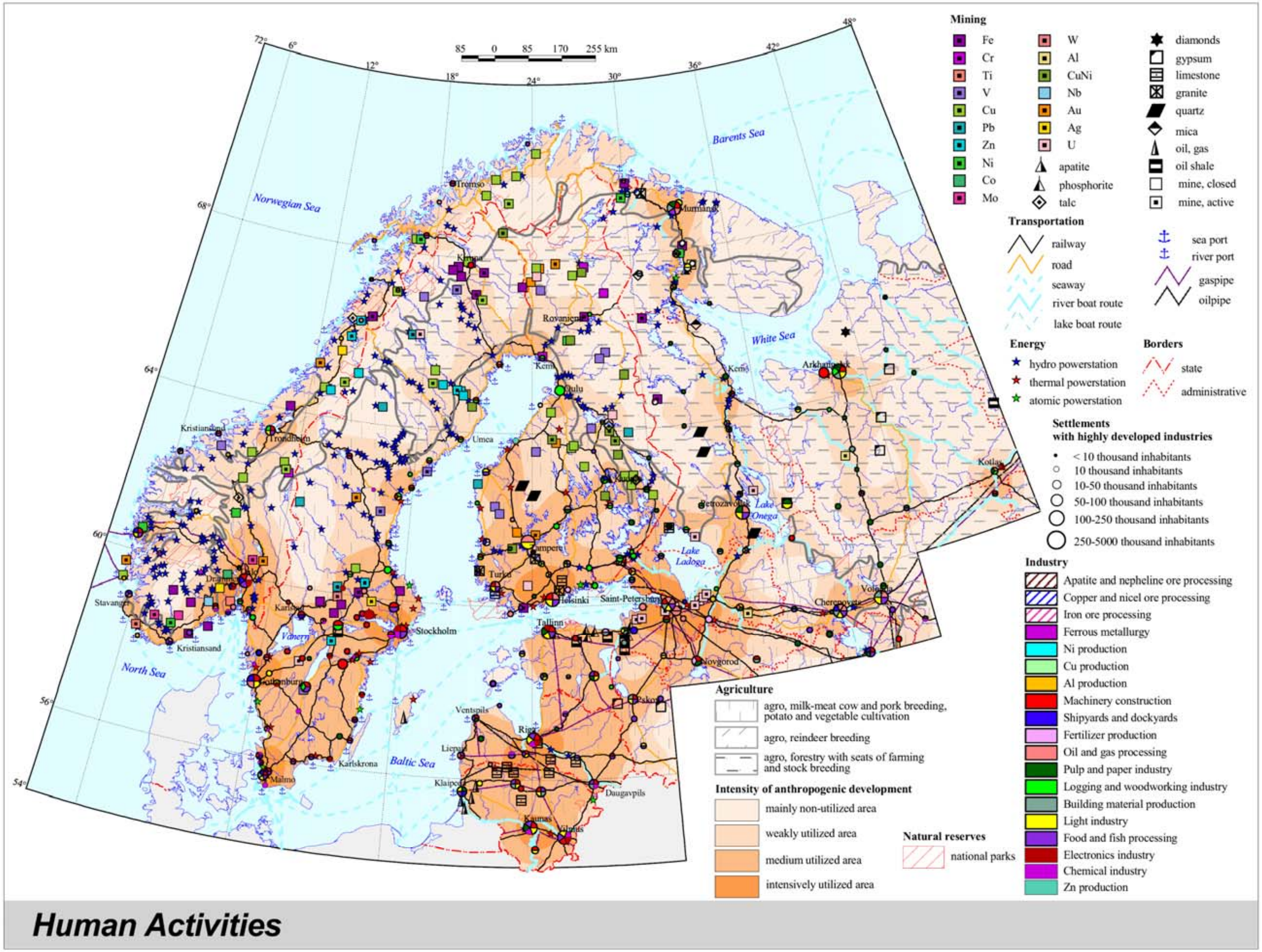

Figure 10. Map of human activities.

A large part of energy production is based on a wide network of thermal electric power plants using coal, gas, heavy oil products, peat and oil shales. These thermal power plants are distributed in both big industrial centres and numerous small settlements. Their emissions cause constant atmospheric pollution by dust containing a wide spectrum of elements.

Numerous large centres of mining and metallurgy, including extraction, refining and processing of different ore types are located in the study area. The most important of these are:

- iron and black metallurgy (Olenegorsk, Kostamuksha and Cherepovets in Russia, Kiruna in Sweden, Raahe in Finland);
- copper, nickel and cobalt (Nikel and Monchegorsk in the Murmansk region of Russia, Hitura and Harjavalta in Finland);
- chromium (Kemi and Tornio in Finland);
- copper, lead and zinc (Pyhäsalmi, Kokkola in Finland, Skellefte and Bergslagen ore districts in Sweden, Bruvann, Rana, Trondheim and Oslo graben in Norway);
- aluminium (Kandalaksha, Nadvoithy and Tihvin in Russia);
- raw materials for fertilizers (Apatity-Kirovsk and Kingisepp in Russia, Siilinjärvi and Kokkola in Finland, and some other districts of Sweden and Finland round the Gulf of Bothnia).

Large pulp and paper production enterprises are situated in the Arkhangelsk region (Solombola), the Republic of Karelia (Segezhda, Kondopoga, Pitkaranta) and in the Leningrad region (Svetogorsk, Sjas'stroi) in Russia, and also in Finland and Sweden, mainly along the coast of the Gulf of Finland and the Gulf of Bothnia (Imatra, Lappeenranta, Kouvola, Oulu, Kemi, Kaskinen, Piteå, Gävle, and others).

The dense network of highways in the southern regions of the study area is a source of pollution by various components (lead, chlorine, methane, oxides of nitrogen and carbon and sulphuric anhydride).

The types and areas of agricultural production vary. The southern regions of NW Russia, the Baltic countries and the southern parts of Scandinavian countries have the most intensively developed livestock farming. In these regions, various fertilizers are also widely used, which cause an environmental problem for these areas. Sewage waters need cleaning before release into the river systems and large water reservoirs, which are sources of drinking water for communities. This introduces a high contamination risk.

4.1.4 Map of Major Mineral Deposits

The map of the major mineral deposits is based on information collected from published summary reviews (Beljaev et al. 1991, Frietsch et al. 1979 and Korovkin et al. 2003). Additional analogous data and other additional information for the area outside Russia were collected by the project team members from different national sources. The attribute table of the mineral deposits also contains additional information including the size of deposits and estimations of their economic value and element composition. Because of the large number (174) of ore objects, only the most important deposits (88) are shown on the map. The final map was combined with the simplified geological map. This map was used for interpretation of the geochemical information and classification of the anomalous geochemical fields in accordance with known or predicted ore formation types.

Ore mineral deposits

Metallogenic features of the Fennoscandian Shield were caused by the dominance of endogenous magmatic and metamorphogenic mineralization of Precambrian and Palaeozoic ages. In the Precambrian period, this region was characterized by formation of pyrite ores. The accumulation of nickel, copper, cobalt, chromium and platinum group elements (PGE) was connected with mafic-ultramafic magmatism. Iron ores are common in acid and intermediate volcanites, and within thick ferruginous quartzites. Stratified volcanogenic-sedimentary deposits of polymetallic ores, also including molybdenum and gold, were associated with granite formation processes. Some of the largest iron ore deposits in the Archaean rocks are the ferruginous quartzites of the Kola province, the Kostamuksha deposit in Lapland-Karelian province and the Björnevann deposit, associated with medium and acid metavolcanites in northern Norway.

Many ore formations of Proterozoic age occur in the Fennoscandian Shield and are of great economic value. Among them should be mentioned the copper-nickel deposits of Pechenga, Monchegorsk, and some other districts in the Kola Peninsula, Vetrjany Belt in Karelia, and Hitura, Kotalahti, and Vammala in the southern part of Finland.

Deposits of copper, nickel, vanadium, chromium and PGE are connected with the layered mafic and ultramafic intrusions in the Kola and Lapland-Karelian blocks. Between them are large resources of chromium ores (Kemi and Koitelainen in Finnish

Lapland, and Aganozero in the south-eastern part of the Republic of Karelia).

Large pegmatite fields with deposits of rare alkaline elements are known in the Kolmozero-Voronja volcanogenic-sedimentary structure in the eastern part of the Kola Peninsula. Copper-molybdenum deposits and numerous occurrences of gold mineralizations that are connected with processes of postorogenic granitization are also met in this structure.

The Outokumpu ore district in eastern Finland includes deposits (Vuonos, Outokumpu, Luikonlahti, Hammaslahti, and others) of massive copper-cobalt-zinc ores in the association of serpentines, skarns, quartzites and black graphite bearing schists.

The Kittilä ore district in Finnish Lapland encompasses several deposits (Pahtavaara and Suurikuusikko are the biggest of them) of gold, copper-cobalt sulphides and uranium oxide occurrences. In their close vicinity lies the Kolari skarn ore district, which is a continuation of the Pajala iron ore district in northern Sweden.

The Vihanti and Pyhäsalmi polymetallic deposits in Finland, confined to metamorphozed sediments and acid volcanites, have some similar features to the Skellefte ore district in Sweden. Sulphide ore deposits of the Skellefte district (Petiknäs, Kristineberg and others) belong to the most important areas for metal production in Sweden. The Arjeplog ore district, with molybdenum (Björntjärn, Munka) and uranium (Pleutajokk) deposits in acid volcanites, is located northwest of the Skellefte district.

The lithological composition and ore types (complex Cu-Pb-Zn sulphide ores in metavolcanites, iron-bearing skarns and Ti-Fe mineralization in gabbro intrusions) of the Aijala-Orijärvi-Metsämonttu zone in the south-western part of Finland are analogous to the Bergslagen district in Sweden. The ore deposits of the Bergslagen district, predominantly built by acid volcanites and metasediments, include apatite-bearing iron-ore skarns (Grängesberg), manganese-silica ores (Långban), sulphide Cu-Zn-Pb ores (Falun, Zinkgruvan) and also occurrences of wolframite and molybdenum ores (Yxsjöberg, Wigström, Baggetorp).

Iron-ore skarns, ferruginous quartzites and apatite-bearing magnetite-hematite ores (Kirunavaara, Malmberget) in a volcanogenic-sedimentary complex are the typical ore types in the Kiruna ore district in the northern part of the Norrbotten province in Sweden. They are comparable with the Lapponium complex in the Karelids of northern Finland. Several deposits (Aitik and others) with large resources of chalcopyrite ores are located in the mafic metavolcanites of this district.

In the Sveco-Norwegian megablock of the Fennoscandian Shield, the most typical and widely spread are magmatic iron-titanium (Tällnes) and copper-nickel (Flat, Softestad, Brested, Lengo) deposits, metamorphosed sedimentary iron-ore skarns and epigenetic vein type deposits of copper, copper-molybdenum and molybdenum (Knaben, Flottorp) sulphide ores. A niobium deposit situated west from Oslo graben, in alkaline-carbonatite complex Fen of Late Proterozoic age, is also worth mentioning.

The economically most important mineralizations of the Caledonian folded belt can be divided into three main types:

- sulphide deposits of lead and zinc in sandstones of Late Proterozoic and Early Cambrian ages,
- deposits of massive and impregnated polymetallic (Zn, Cu, Fe, less Pb) sulphide ores in the volcanites and volcanogenic-sedimentary complexes of Lower Palaeozoic (mainly Ordovician) age,
- stratified deposits of iron oxides (magnetite and/or hematite) in the sedimentary rocks of Early Palaeozoic age.

Sulphide deposits are found throughout the Caledonian folded belt and they form groups of ore districts such as Trondheim (Løkken, Tverrfjell, and Killingdal), Rana (Bleikvassli, Mofjell), Sulitjelma (a group of deposits in northern Norway), and Grong-Västerbotten (Scorovas, Grong, Gjersvik, Laisvall and Stekenjokk). Iron-ore deposits are known in the Rana (Storforsby, Salten, and Mosjaen), Tromsö and Trondheim (Fosdalen) districts. Copper-nickel sulphide deposits in association with mafic-ultramafic intrusive complexes are known in the different parts of the Caledonian folded belt. They do not play any significant economic role, but are evidence of the opportunity to discover new ore objects in this belt. Vanadium-bearing magnetite-ilmenite deposits in association with metabasalts (Rodsan, Meisingset) are specific to the tectonic windows of the Precambrian bedrock in the central part of Norway. Iron-titanium oxide ores are connected with the anorthosite-gabbro complex of Precambrian age in the east of the Caledonian folded belt in Sweden.

In the Kola Peninsula, ore mineralizations connected with the Palaeozoic magmatic formations include the rare earth metals deposits of Khibiny and Lovozero and also the iron and titanium deposits of the Kovdor and Gremjaha-Vyrmes alkaline massifs. Large deposits of aluminium, phosphorus, titanium, iron and rare earth metals are connected with alkaline magmatism of Palaeozoic age.

Numerous polymetallic occurrences containing copper, molybdenum and silver are situated within different intrusive complexes in the Palaeozoic rocks of the Oslo graben (Norway).

There are abundant occurrences of different ores in the sediment cover of the Russian and Timan-Pechora Plates (East-European and Malozemelsko-Pechorskaja metallogenic provinces). However, the majority of these occurrences have very limited size. Bauxite deposits in Carboniferous residual soil of the Tihvin-Onega bauxite zone (Moscovskaja-Mezenskaja sub province) are economically important and the ores of these deposits are processed in the Kandalaksha and Nadvoithy aluminium plants and Boksitogorsk argil enterprise.

Non-metallic mineral deposits

The largest apatite-nepheline deposits in the Khibiny mountain ridge are universally known. There are numerous apatite-rare metal ore occurrences in the Palaeozoic alkaline intrusive rocks in different parts of this region. Organogenic phosphorite deposits (e.g. Kingisepp) in Lower Ordovician sandstones are widely spread in the southern slope of the Fennoscandian Shield.

The Archaean pegmatite veins of the Fennoscandian Shield are targets of economic mica and feldspar mining. Different intrusive, metamorphic and sedimentary rocks are widely used for the production of building materials. Nepheline syenites of the Caledonian belt (Sterny Island in the Finnmark province of Norway) are used in the production of nepheline-feldspar concentrate for the glass and ceramic industry.

Within the sedimentary cover of the Russian plate, numerous small and middle-size deposits of clay, sands, limestone and dolomites are mined for the local needs of building, chemical and metallurgical industries. Occurrences of white clays (for example, deposits near Borovichi, Russia) have a special value for ceramic production.

Precious stones

The Arkhangelsk diamondiferous district is well known nowadays. A group of diamond-bearing large kimberlites is situated there and two of them (the pipes named after V.P. Grib and M. Lomonosov) are being prepared for industrial production. Some other districts containing diamond-bearing kimberlites are situated in different parts of the Belomorian and the Lapland-Karelian Archaean blocks of the Fennoscandian Shield. Some of them (Kuopio in Finland, Kostamuksha and Lake Onega in Russia) may have economic value.

4.2 Maps of the spatial distribution of elements and their associations

The Geochemical Atlas of Northern Europe includes 233 single element maps, giving an overview of the spatial distribution of 48 elements in eight components of natural geological media. These are terrestrial moss, the organic soil horizon, the mineral soil C-horizon (total content and aqua regia leachable mobile forms of elements), surface (stream and lake) water, stream sediments, the fine fraction of till and the upper (0-5 cm) soil layer.

The best coverage of data (from 5 or more sample media) was available for 28 elements (Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, La, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, Sr, Th, Ti, Tl, U, V and Zn). Data from 3-4 sample media was available for 10 elements (Ag, B, Bi, Ce, Cs, Nb, Sb, Sc, Sn and Zr, and data from only 1 or 2 sample media was available for Br, Cl, F, Ga, S, Se, Si, Te, Y, Yb. The reason for missing data was most often a high detection limit in analysis or simply that certain elements did not belong to the analytical programme of a particular project.

The element associations are presented on 44 maps, prepared for 6 media (Table 7)). The element associations for moss, the C-horizon of soil and surface water are presented as multiplicative coefficients, calculated by the multiplication of their real concentrations (in mg/kg or µg/l). The additive coefficients, calculated by the summation of relative element concentrations (concentration divided by the geometric mean), were used for drawing maps of stream sediments and the fine fraction of till. The element association maps for the organic soil horizon and the upper (0-5 cm) soil layer were not compiled because of the strong heterogeneity of sample composition due to the wide variation in the amount of organic and mineral matter in samples, which significantly distorts the natural features of the element distributions in multiplication.

A review of the prepared single and poly element maps shows that for every sampled medium, all analyzed elements can be combined into certain groups or associations, which have similar spatial element distributions and can be explained by specific natural geochemical processes or can be connected with a significant impact of anthropogenic pollution.

Table 7. List of element association maps prepared for each sample media.

Map index	Element association in different sample media					
	Soil C-horizon, total concentration, CHO_{tot}	Soil C-horizon, aqua refia extraction, CHO_{ar}	Moss	Surface water, sw	Sream sediment, normalized concentration, sse norm	Till <0.06 mm, normalized concentration, till norm.
M_1	Co,Cr,Cu,Ni,V	CoCrCuNiV	CoCrCuNi	CoCrCuNi	CoCrCuNiV	CoCrCuNiV
M_2	FeMn	FeMn	FeMn		FeMn	FeMn
M_3	AsBiCdSbMo	AsSbBi			CdMoPbZn	
M_4	MoPbZn	PbZn	CdSbMoPbSnZn	CdPbZn	CdMoPbZnAs	ZnPbMo
M_5		CeLaSnUY			CeLaNbThY	ZrSrTiPLa
M_6		ZrNbTh				
M_7					BeZrTiSc	
M_8	CaMg	CaMg	CaMg	CaMg	CaMg	
M_9	PSr				PUSr	
M_{10}			ThV			
M_{11}	AlBa	AlBa			AlBa	
M_{12}		GaKRbTl	RbTl		KRbTl	
M_{13}	NaK					KNaCaBaAl
M_{14}				MoU		
M_{15}				BrClNa		
M_{16}				VAlTh		
M_{17}				Sr/Ca		

4.2.1 Terrestrial moss

B, Na, Ca, Mg, Sr. High concentration levels of this group of elements are connected with the influence of marine aerosols and they are typical found on the Arctic coast of the Barents Sea. Local anthropogenic anomalies were mapped in the areas surrounding the large industrial centres (Khibiny-Lovozero in the Kola Peninsula, Petrozavodsk, Kondopoga, Medvezhegorsk, Belomorsk and Kem in Republic of Karelia, and also St.-Petersburg and Arkhangelsk regions). Many local anomalies with low background contrast are in the eastern part of the region, where they are caused by geogenic dust connected with soil erosion and weathering of the Permian carbonate rocks of the Russian Plate.

K, Rb, Tl, P. The dominating feature for the distribution of these elements is their zonal spatial distribution in accordance with the climate and vegetation zonality. In the tundra and northern taiga zones, median values of element concentrations are significantly lower than in the middle and southern taiga zones. Inside this regularly changing background level there are large anomalies with high background contrast in the southern parts of Finland and the adjacent territory of Russia (Leningrad region and the southern part of the Republic of Karelia). The main source of these local anomalies is geogenic dust from cultivated fields (soils within the Svecofennian mega-blocks of the Fennoscandian Shield). To a minor extent, anthropogenic contamination from numerous sources of this large and highly industrialized region increases the element concentrations in mosses. Estimation of the share of natural and anthropogenic components in this area is not possible without additional investigations.

Co, Cr, Cu, Fe, Ni, V. High values of this group of elements are connected with practically all larger industrial centres. The concentration of this group of elements varies strongly in different parts of the region, but generally they reflect contamination from the most urbanized and highly industrialized areas. The largest anomaly with a very high contrast to the background is connected with the metallurgic production of colour metals in the Kola Peninsula. The anomaly continues from Northern Karelia in the south to Murmansk, Nickel/Zapoljarny and to the coast of the Barents Sea. Anomalies with a rather high contrast to the background are located in the areas surrounding St. Petersburg, Petrozavodsk and Arkhangelsk industrial districts. The main transport route from St. Petersburg to Murmansk and the neighbouring industrial centres is clearly seen in the maps for this group of elements. Anomalies of these elements are also common along the Gulf of Bothnia in the south-western part of Finland and southern Sweden, and around the Oslo industrial district.

Ag, As, Mo, Sb, Th, U, Ba, Cd, Pb, Zn. The spatial distribution of these elements, including a number of strongly toxic elements, shows features that are very similar to the distribution of the above-mentioned elements. Clear zonality of the regional background level follows changes in the climate and vegetation zones. Most probably, the sources of these elements are both natural geogenic dust and anthropogenic emissions, but this is a subject for more detailed study. Special attention should be paid to the highly anomalous concentrations of such toxic elements as cadmium in the areas surrounding St. Petersburg. The main probable source of this contamination is the unusually high density of traffic, which releases mobile forms of cadmium from car tires on hard roads (Salminen et al. 2004).

4.2.2 Organic soil horizon

Because the organic soil layer contains varying amounts of mineral matter, the heterogeneity of sample material causes “random noise” in the data and creates undesirable variation in the natural spatial distribution of some elements and their associations. Therefore, special attention should be paid to this lack of homogeneity in the interpretation of these maps.

Cluster analysis of the analytical data from the organic soil horizon did not yield any additional useful information because of the heterogeneity of the sample composition (Salminen et al. 2004). Factor analysis also confirmed that more than 60% of variation was caused by variation in the amount of organic and mineral matter in the samples.

Ca, Mg, Sr, As, B, P. Regional features in the distribution patterns of these elements with well known biophile properties very much resemble the distribution maps of carbon and LOI (loss on ignition), reflecting the quantity of organic matter in the samples. The lowest concentrations of these elements are in the western part of the study area on the crystalline rocks of the Fennoscandian Shield. A low content of organic matter in the upper soil horizon and relatively weak leaching of these elements from the mineral part of the sample are typical for this area. An opposite situation is observed in the eastern part of the region (within sedimentary cover of the Russian Plate). There, the highest concentrations of these elements are found in the samples with low organic matter content and, at the same time, relatively high mobility of elements in the mineral part of the samples. Local anthropogenic anomalies are found in the areas surrounding large industrial centres.

K, Li, Rb, Ti, Al. The elevated natural concentration level of these elements is typical for the Svecofennian mega-block and the eastern part of the Kola block of the Fennoscandian Shield. Anthropogenic anomalies of this element group were found close to the cities of Arkhangelsk and St. Petersburg.

Ni, Cu, Co, Cr, V, Fe, Mn. The main features of the regional distribution of these siderophile and chalcophile elements show a clear negative correlation with the organic matter content in the areas of low background values. However, the largest technogenic anomaly of the Kola Peninsula is considerably increased by natural background levels and “noisy” variation caused by sample heterogeneity. The elevated regional level and several local anomalies of this association are located within the Svecofennian mega-block and along the slope of the Fennoscandian Shield.

Ag, Cd, Hg, Zn, Sb. This group of elements with clear biophile properties shows a strong positive correlation with the organic matter content in the samples, and the spatial distribution of these elements is very similar to that of carbon and LOI. The majority of the local anomalies of this association are probably connected with biogenic accumulation from geogenic sources, but some of them are undoubtedly anthropogenic. The anthropogenic anomalies are located in the areas surrounding industrial centres such as St. Petersburg, Monchegorsk, Kostamuksha and Belomorsk.

Mo, Th, U, Be. A rather stable background level and barely visible negative correlation with the organic matter content are characteristic for the distribution of this group of elements. Local anomalies with a strong background contrast are located over the Khibiny and Lovozero nepheline syenite massifs and Keivy granites in the Kola Peninsula, and Vyborg rapakivi granite massif in Finland. Elevated concentrations of these elements are also typical for the western part of the Fennoscandian Shield.

Br, Na. The main feature in the spatial distribution of these two elements is a strong connection of their high concentrations with coastal districts. The concentrations strongly decrease within a short distance inland. Several local areas with elevated concentrations of this element group found at a longer distance from the coast are probably connected with anthropogenic sources.

4.2.3 Surface waters

Ca, Mg, SO_4^{2-}, Sr, Ba. The distribution patterns of this element group are similar to their distribution in the organic soil horizon, despite the main factors controlling the distribution of the elements being different. A predominant controlling feature in surface waters is the dependence on regional properties such as latitudinal zonality of climate and vegetation. The relief of the landscape sharply increases the variation in element concentrations by several orders of magnitude.

The lowest concentrations of these elements are typical found on mountain ridges, highland plateaus and main watersheds with weak water mineralization. A discrete strip of points with high concentrations is generally traced within low-lying areas along the eastern part of the Barents Sea and around the Gulf of Finland and the Gulf of Bothnia.

The widest variation of element concentrations is caused by geological features of the region (Appendix B, Table B.9). For example, the territory of the Fennoscandian Shield, excluding the Svecofennian mega-block, is characterized by slightly lower concentrations than the area of sedimentary cover of the Russian and Timan-Pechora Plates. The largest regional anomalous zone with a strong background contrast is within the Mezenskaja syneclise, where it is connected with an area of sulphate-carbonate sediment deposits of Permian age. This area is actually dangerous from the ecological point of view because of naturally high element concentrations and especially because of the very high Sr/Ca ratio. The value of this ratio exceeds the permissible level 0.01 (Ivanov 1996) at many sampling sites. Elevated concentrations of this group of elements were also found in the south of the study area (Estonia and the Leningrad region) connected with the Devonian phosphorite-bearing sediments in the Slope of the Fennoscandian Shield. Local anthropogenic anomalies of these elements are found in the areas surrounding Arkhangelsk, Kovdor and Apatite-Kirovsk industrial centres.

Fe, Mn, Pb, Zn, Al. The regional relief features also influence the spatial distribution of the elements of this group. The lowest concentrations are typically found in the mountain areas of Norway and Sweden and the watershed area between the Baltic Sea and the Barents Sea basins (eastern Finland, Murmansk region and Republic of Karelia). A rather stable regional background prevails over the rest of the territory. Highly anomalous values with a wide range of variation were found in the low-laying areas of the south-western part of Finland and the Leningrad region and south-eastern Karelia in Russia. The highest concentrations of Fe and Mn are caused by reduced pH values and the high content of dissolved organic matter in surface waters of these areas. In turn, these coloured waters with a high content of colloid forms of Fe-Mn hydroxides regulate the behaviour and accumulation of Pb, Zn, Co and Ni and some other elements. Disorders of the unstable hydrochemical equilibrium and changing pH and Eh conditions can activate the desorption of hydroxides and subsequent remobilization of retained elements. In many samples Fe and Mn concentrations exceed the maximum allowed concentration (MAC) values for drinking water (Minzdrav of Russia 2002).

Co, Cr, Ni, V, Cu, Ag. The spatial distribution of this group of elements is very close to that for the previous one. A clear relation of sharp changes in concentration with latitudinal changes in the climate and vegetation zones and regional topographical features of the territory are also observed for this group. Rather large anthropogenic anomalies of these elements were found in the areas surrounding Nikel/Zapoljarny and Monchegorsk in the Kola Peninsula and nearby Arkhangelsk region in Russia, and also close to Kokkola, Oulu and Turku in Finland. The elevated values of these elements in eastern part of Russian Karelia, and in the Outokumpu (Finland), Skellefte and Bergslagen ore districts (Sweden), and Oslo graben (Norway) are most probably predominantly due to geogenic sources.

Cs, Rb, K, Cd, Th, Sb, Tl. An elevated background level and large anomalous districts of these elements are typical for the Svecofennian mega-block and the south-eastern part of the Slope of the Fennoscandian Shield. The sedimentary cover of the Russian Plate is characterized by relatively low background levels. The lowest concentrations of these elements are exclusively marked in the high mountainous areas. The weak anomalies close to Arkhangelsk and a large anomalous district in the central part of the Leningrad region are probably due to both natural geogenic and anthropogenic causes.

Mo, U, F. The spatial distribution of this element association shows some rather specific features that are very important with respect to assessment of the metallogenic specialization of frontier territory of the Fennoscandian Shield and its contact area with the Russian Plate. A stable regional background level throughout the territory with an extensive chain of large anomalies of these elements is traced with some interruptions from Finnish Lapland through the Kola Peninsula to the Arkhangelsk region, where it turns to a southern direction and finally to the southwest and west, going further through the Vologda and Leningrad regions to the territories of southern Finland, the Baltic countries and the southern parts of Sweden and Norway.

As, B, P. The distribution of these elements depends strongly on regional relief features. The lowest concentrations are situated in the northern part of Republic of Karelia along the main watershed between the Baltic Sea and Barents Sea. High mountain areas of Norway, Sweden and Kola Peninsula in Russia are also characterized by noticeably reduced concentrations compared with background levels for the whole study area. Lengthy and strong anomalies are found in the eastern part of the territory along the Timan frontier flexure of the Moskovskaja-Mezenskaja syneclise. The local anomaly in the central part of the Leningrad region south of Lake Ladoga can be explained by anthropogenic (influence of the large gas reserve and oil refining plant in Kirichi) or by geogenic sources.

Br, Na, Cl. The highest values and sharp concentration gradients of these elements are caused by the strong influence of marine aerosols. A chain of these anomalies is traced continuously along all coastal areas and especially within the most low-lying areas of the coastline. The lowest concentrations are typical for the areas with high absolute regional relief (Norway, Sweden) and for the main watershed between the Baltic Sea and Barents Sea (eastern Finland and northern and central Russian Karelia). A number of local anomalous districts, probably of geogenic origin, are situated along the frontier depression between the Timan belt and the Moskovskaja-Mezenskaja syneclise.

4.2.4 C-horizon of soil (total element concentrations)

Ca, Mg. The highest element concentrations of this group are in the north-eastern part of the Fennoscandian Shield, including Finnish Lapland, the western part of the Kola Peninsula and northern Karelia in Russia. All these areas are characterized by different rocks of mafic and ultramafic magmatic complexes. Elevated concentrations of these elements are also marked in the sedimentary cover of the Russian Plate. Large anomalous areas with unusually high background contrast were found in the south-western part of the Moskovskaja-Mezenskaja syneclise (Salminen et al. 2004). These are considered promising for prospecting of new large magnesite deposits.

Al, Na, Sr. High regional background levels of this group of elements are common within the Fennoscandian Shield, while rather low concentrations of these elements are typical for the rest of the study area. It is suggested that the areas with high concentrations of this group of elements reflect centres of granitization or the thickest sialic Earth's crust. The high anomalous values in the central part of the Kola Peninsula are connected with a vast zone of alkaline metasomatism around the Khibiny and Lovozero nepheline syenite massifs (respective anomalies are also found in aqua regia leachable results). The lowest concentrations of these elements (and also Ca, Mg and Sc) and the highest Si concentrations were detected in the south-eastern part of the Russian Plate, reflecting the prevalence of continental sedimentary rocks in the platform cover.

Fe, Ti, V, Co, Cr, Cu, Mn, Ni, Sc. A number of local anomalies in the rather even background level throughout the study area are typical for this group of elements. Within the Fennoscandian Shield the largest anomalies of this group are predominantly concentrated in the Archaean basement (Kola, Belomorian and Lapland-Karelian blocks), including Finnish Lapland, the western part of the Kola Peninsula, northern Karelia and the Finnmark province in Norway. There are some local anomalies connected with ore districts in Central Finland and southern and south-eastern parts of the Republic of Karelia. Anomalies with a rather strong contrast to the background are found inside the Russian Plate in connection with zones of pyroschists and phosphate ores in the Slope of the Fennoscandian Shield and in the Tihvin-Onega bauxite zone of the Leningrad region. Weak local anomalies are also found in the Arkhangelsk region near Onega Guba of the White Sea and in the areas along the Severnaja Dvina River.

Ag, As, Be, Cd, Mo, Sb, Th, U, K, Rb, Pb, La, Li, Zr, Cs. Rather high anomalous values of this large group of chalcophile and lithophile elements are typical for the Ladoga-Bothnian Bay ore zone and the Svecofennian and Sveco-Norwegian mega-blocks of the Fennoscandian Shield as a whole. Anomalies of this element group are spread within the Baltic and Moskovskaja-Mezenskaja syneclises of the Russian Plate. In particular, the highest anomalies of these elements are located in the Kevy rare metal ore district in the Kola Peninsula and in connection with the alkaline metasomatic rocks of the Karelian Isthmus and the southern part of Finland. This group of elements is traced as a discrete anomalous strip along the Slope of the Fennoscandian Shield, including pyroschists, phosphate ores and bauxites. Districts of the diamond-bearing kimberlites in the Arkhangelsk region are also marked by anomalies of these elements.

4.2.5 C-horizon of soil (partial extraction of elements)

Ca, Sr, Mg. The regional background level of this element group is rather stable in the Fennoscandian Shield as a whole. A number of lengthy zones and separate local anomalies are located in different parts of the Shield. The majority of them are in the Ladoga-Bothnian Bay ore zone and in some ore districts of the Kola block. In the Lapland-Karelian block, marked anomalies are situated in the Kola-Vygozero and Vygozero-Tikshozero metallogenic zones, and also in the Vostochno-Karelskaja zone and in the Onega Pt-Ti-V-U ore district. A lengthy belt of large and high anomalies is traced along the Slope of the Fennoscandian Shield from the Gulf of Finland in the southwest to the coastal areas of the White Sea in the north.

P, Al, Ba, B, Be, K, Na. This group of lithophile elements is characterized by rather even background levels for the whole study area. Local, but in some cases very high anomalies were found in the Kola Peninsula, in northern and south-eastern Karelia and also in Norway, southern Finland and in the south-eastern part of Sweden. A chain of high anomalies is traced along the eastern border between the Fennoscandian Shield and the Russian Plate.

Fe, Ti, V, Co, Cr, Cu, Mn, Ni. The spatial distribution of these elements is very similar to the anomalies of the total element concentrations for the same element group.

Ag, As, Cd, Mo, Pb, Sb, Zn, Bi. An elevated background level and numerous local anomalies of these elements are characteristic of the Svecofennian mega-block of the Fennoscandian Shield. The same is also typical for the northern part of the Moskovskaja-Mezenskaja syneclise and the southern part of the Slope of the Fennoscandian Shield.

4.2.6 Stream sediments and the fine fraction (<0.06 mm) of till

A complete set of single and polyelement maps for stream sediments and the fine fraction of till was prepared using only normalized relative values. These maps give an overview of spatial variation in element concentrations, predominantly connected with the main geological and structural features of the study area.

Ca, Mg, Al, Ba. Elevated relative values of these elements mark areas of alkaline magmatism and regional metasomatism for the majority of the ore districts in the Precambrian basement of the

Fennoscandian Shield. This element group is also typical for the areas of the Phanerozoic sedimentary complexes located both within the sedimentary cover of the Russian Plate and the syncline structures of the Shield.

P, U, Sr, K, Tl, Rb, Ce, La, Ti, Nb, Th, Y. This group of lithophile elements is particularly specific to areas of alkaline magmatic activity. It is most impressive in the Kola, Belomorian and Lapland-Karelian blocks of the Fennoscandian Shield (Kola Peninsula, northern Karelia and Finnish Lapland). Numerous local anomalies are also spread within the Svecofennian (southern parts of Finland and Sweden) and Sveco-Norwegian (the Oslo graben in Norway) mega-blocks and along the boundary of the Russian Plate and the Fennoscandian Shield (Arkhangelsk and Leningrad regions, Estonia and Latvia).

Cd, Mo, Pb, Zn, As, partly Cu. The highest relative values of this group of chalcophile elements are typical for the Svecofennian block (especially in its western and south-western parts) of the Fennoscandian Shield and the Caledonian folded belt. Most of the known ore districts (Pyhäsalmi, Vihanti, Outokumpu and Aijala-Orijärvi in Finland, Aitik, Skellefte and Bergslagen districts in Sweden, Bruvann, Rana, Grong and Throndheim regions in Norway) with polymetallic deposits are marked by high anomalies of these elements. Several local anomalies of this element group are traced along the border between the Russian Plate and the Fennoscandian Shield.

Co, Cr, Ni, Cu, V, Fe, Mn. High anomalies of this element group are mostly specific for the Archaean crystalline basement of the Fennoscandian Shield. A continuous strip of these anomalies are located within the Kola Archaean craton and volcanogenic-sedimentary belts with marked mafic and ultramafic magmatic processes. Analogous anomalies are present within the Svecofennian Proterozoic craton (Tampere schist belt in Finland) and in the eastern arched zones of the Archaean Lapland-Karelian block (eastern Finland and western and south-eastern Karelia). A group of anomalies connected with the areas of alkaline ultramafic magmatism has been mapped along the border between the Russian Plate and the Fennoscandian Shield. Several anomalies are also located in the Sveco-Norwegian mega-block (Bergen and Bable-Arengal ore districts) and in the Caledonian folded belt (Lofoten-Vestorolen and Brumvann ore districts).

4.2.7 Comparison of different sample media

Joint interpretation of data from several different components of the geological media allowed mapping of different types of natural and anthropogenic sources of elements, as well as accumulation of a wide spectrum of elements. By taking into account their mutual relations it was possible to assess the environmental status and mineral potential of the study area.

Terrestrial moss is a sensitive bio-indicator for contamination and a reliable method for periodical monitoring of the environment status. Anomalies reflect practically all types of industrial activity. However, in some cases the natural climate and landscape conditions and geogenic sources of elements have a marked influence on the element concentration of mosses.

The organic soil horizon (A0+A1) and the uppermost (0-5cm) soil layer are informative media for estimation of anthropogenic loadings during longer periods, especially near large industrial centres. However, it should be kept in mind that the composition of the samples from the organic soil horizon is very heterogeneous, and elements in these samples are exposed to the influence of geogenic sources much more than those in moss samples.

The background levels of major and trace elements in lake and stream water vary by several orders of magnitude within large areas, and they are primarily controlled by the climatic vegetation zones and topographical features of the territory. Most of the hydrogeochemical anomalies are connected with the composition of the tectonic blocks and properties of the ore formations. In some cases, element concentration levels due to anthropogenic or natural (landscape and geogenic) sources can cause health risks when the element concentrations exceed the MAC levels of toxic elements.

The geochemistry of the soil C-horizon is strongly controlled by the composition of the bedrock and it can be used to define whether the anomalies in moss and the organic soil horizon are of anthropogenic or geogenic origin. Data on the soil C-horizon, together with hydrogeochemical data, are also valuable in estimating the prognostic mineral potential of the territory. Data from stream sediments and the fine fraction of till include the most valuable information for mineral exploration of wide range of elements.

4.3 Maps of integrated anomalous geochemical fields (AGFs)

Maps of integrated geochemical fields (19 maps, Table 6) were drawn as a transitional cartographic tool to be used for determining complex geochemical anomalies and preparing the resulting map of ore-related geochemical anomalies.

These maps are based on different variants of the square summation of anomalous levels of element association in selected sample media (Table 6). Anomalous levels were calculated using relative element concentrations, normalized against the geometric mean separately for the most important landscape taxa (Appendix B, Tables B, 1-9). Square summation of the anomalous levels of each integrated map was carried out according to the condition of correspondence (Ki>Kj).con(Ki,Kj) (see Chapter 3.2.3) of reclassified anomalous levels Table 5) of element associations used for each specified map (Table 7). The map Mall_an was then used to contour the ore-related AGFs. The Mall_an map is the result of the square summation of sidero-chalcophile (M1all_an and M2all_an), chalcophile (M3all_an) and rare metal + rare-earth metal (Ma4all_an) groups of elements.

Additionally, particular combinations of this group and their different versions were made using corresponding element associations from surface water data and thereafter used to prepare the main resulting map of ore-related AGFs.

Separate AGF maps were prepared for each sampling medium, including stream sediments (SSE), the soil C-horizon (CHOtot and CHOar) and the fine fraction of till (Till <0.06). These maps were used to estimate the contribution of each medium to the main resulting map of ore-related geochemical anomalies.

4.4 Ecogeochemical map of Northern Europe at the scale 1:5,000,000

The ecogeochemical map was prepared with methodological help from IMGRE according to instructions for MGHM-1000 (Multipurpose Geochemical Mapping at the scale 1:1,000,000) and GHBM-1000 (Geochemical Basic Maps for the State Geological Map at the scale of 1:1,000,000) (IMGRE 1999, IMGRE 2001). The main aim of this map is to assess the status of the environment in the study area. The map contains several information blocks such as characteristics of natural landscapes, the degree of soil and vegetation damage, the intensity of developing human activities, objects of human activity and estimation of the environmental status of the territory.

The first block includes characteristic features of natural landscapes. Each type of landscape is marked by its own index.

The second block is adopted from the map of human activities and it reflects the intensity of the anthropogenic development of the area. This indicator was calculated by summation of two factors: the density of the population and consistency of the road network. Four levels of intensity of anthropogenic development of the territory were defined: (i) predominantly undeveloped, (ii) weakly developed, (iii) moderately developed and (iv) highly developed areas.

The third block shows the ecological status of the territory and the nature of the soil and vegetation damage as a result of pollution by toxic chemical agents.

The fourth block contains information about contamination sources including:

- the mining industry, classified according to the main mineral resources and indicated on the map using different colours;
- transport routes, shown on the map as linear elements or special signs including roads, railways, pipelines, water ways, and sea and river ports;
- the energy industry, including hydro-, heating and nuclear power plants;
- industrial centres, classified into six groups according to the population size and marked on the map with dots of different size. The type of industry is indicated by different colours.

The fifth block contains different types of borders, including administrative areas, landscapes and borders of areas with an unsatisfactory environmental status.

The following tasks were carried out in preparing the ecogeochemical map:

- contouring of zones polluted by defined groups of toxic elements in each sample medium;
- identification of anomalously high concentrations of toxic elements in each sample medium;

- classification of the studied area according to the level of ecological danger;
- contouring of areas with an unsatisfactory environmental status.

Analytical data from five media (terrestrial moss, the uppermost soil layer, the organic soil horizon, stream sediment and surface water) were used for contouring ecogeochemical anomalies. The level of pollution in moss cover, soil horizons and stream sediments was calculated as a summary index of pollution Z_C (IMGRE 1999, IMGRE 2001). The pollution level of surface waters was detected by means of comparing element concentrations with the MAC and was classified according to the hazard class of the components. The ratio Sr/Ca, normalized against the median value for the whole territory, was also used as an additional but important indicator of water quality.

The summary index of pollution Z_C corresponds to the sum of the concentration coefficients of elements above their background level. It was was calculated according to the formula:

$$Z_C = \sum K_C - (n-1),$$

where:

K_C is the concentration coefficient (ratio of the concentration of element i in the anomaly to its background level), and

n is the number of anomalous elements.

Matrices of normalized values were then used to contour the additive anomalies in each medium. The list of elements used for these calculations included elements of 1st to 2nd and 3rd to 4th hazard classes for surface waters and 1st to 3rd hazard classes for the other media. The generalized contours of the anomalies for all sampled media are shown on the final ecogeochemical map. The assessment of the environmental status within these areas is also shown on the map. Based on the estimated pollution levels of the environmental components the ecogeochemical status of the areas was classified, according to the Russian classification, as satisfactory, stressed, critical or hazardous on the map.

A satisfactory status was characterized by the complete absence of pollution in all sample media without any detected damage.

A stressed status corresponded to permissible pollution levels in any of the sample media. Possible damage could be compensated and self-regeneration of the landscape is possible.

A critical status was contoured by moderate levels of pollution, even if found in only one medium but absent or at low levels in the other sample media. Damage could be compensated, but landscape regeneration is only possible with technical aid.

A hazardous status was defined by highly dangerous pollution levels in one medium but, at the same time, little or no detected pollution in the other sample media. Damage could not be compensated.

The contoured anomalous areas were classified according to the probable sources of pollution as anthropogenic, natural and mixed natural/anthropogenic anomalies. In the studied area, there are large-scale zones where contamination of the environment has a natural genesis and is caused by specific landscapes. These can be classified into three types: (i) geogenic anomalies, reflecting a particular composition of bedrock, especially in areas with a thin cover of Quaternary sediments; (ii) barrier anomalies, formed in wetlands on places of sharply changing pH-Eh conditions or caused by stagnant water with a high content of organic matter and Fe - Mn hydroxides; and (iii) lengthy anomalies along sea shores, affected by the strong influence of marine aerosols.

A detailed description of the areas with a problematic ecological situation and their classification according to probable genesis are given in the cadastre “Geochemical characteristics of territories with unsatisfactory environmental status” (Appendix C). Altogether, 48 areas with an unfavourable ecogeochemical status were detected. Their total surface area is 588,300 km^2 (28.9% of the whole territory). It should be noted that many of these areas, and in some cases large ones, are connected with areas having a critical or hazardous environment status caused both by human activities and natural factors.

The study area is rather heterogeneous with respect to the level of human activity and the intensity of anthropogenic loadings. The most intensively developed districts are situated in the southern part of the region, as well as the western part of the Kola Peninsula in the north. The central districts of Scandinavia, northern Finland and the eastern part of NW Russia are categorized as weakly or moderately developed.

Within NW Russia there are 16 ecogeochemical anomalies characterized by an unsatisfactory environmental status. The total area of these anomalies is about 374,100 km^2. Anomalies of anthropogenic origin are connected with large industrial centres. The biggest of these are anomalies (No. 3 and 4) in the Kola Peninsula near the Nikel/Zapoljarny and Apatity/Kirovsk industrial districts. Anomaly No. 3 (with an area of 9,320 km^2) was detected in moss and soil horizons. It includes a range of elements, but Ni, Cu, Co, Cr and As are the most important of them. The summary index of pollution, Z_C, is 305 relative unites (r.u.) in moss cover and 542 r.u. in soil. Anomaly No. 4 (22,890 km^2) is marked in moss and soil horizons and has a similar composition to anomaly No. 3. The index ZC reaches 215 r.u. in the moss cover and 292 r.u. in soil. An elevated Sr/Ca ratio was detected in surface water samples within this anomaly. The major polluting elements are derived from mining and the metallurgical production of colour metals (Ni, Cu). The environmental status reached the hazardous level in these areas. The tundra and northern taiga landscapes of these areas are highly sensitive to anthropogenic loading and can be severely damaged by anthropogenic fallout. Technogenic wastelands, several hundreds of square kilometres in size, are formed in the areas surrounding Monchegorsk and Nikel/Zapoljarny.

Anomaly No. 10 (with an area of 4,570 km^2) is located nearby Kovdor. An elevated concentration of V, Sr and Ni in moss and a relatively high Sr/Ca ratio in surface waters are typical for this anomaly.

The large anomaly No. 5 was mapped in the eastern part of the Kola Peninsula. Its source is natural and the anomaly is characterized by elevated concentrations of Co in moss, Mn, V, Co, Mo and Sr in soil horizons and high Fe concentrations in surface waters with respect to existing MAC values (Minzdrav of Russia 2002).

Anomalies No. 18 and 19 in the Republic of Karelia are of natural origin. They have high (with respect to MAC values) concentrations of Fe and Mn in surface waters.

The largest (116,660 km^2) anomalous zone, No. 33, covers the southern part of the Republic of Karelia and most of the Leningrad and Novgorod regions. The main limiting factor for this anomaly is the very high (with respect to MAC values) concentrations of Fe and Mn in surface waters and the elevated concentration of V in terrestrial moss. This anomaly most probably has a complex origin. Within a slightly anomalous background level caused by specific landscape features are two centres with a critical environmental status. One of them appears to have a mixed natural/anthropogenic origin and is confined to St. Petersburg and the most developed areas of the Leningrad region. Elevated concentrations of Pb, Cd and V in the moss cover are typical for this centre. The second one, situated on the south-eastern shore of Lake Ladoga, is marked by maximum concentrations of Fe and Mn in surface waters. It is most likely caused by both particular landscape features and large (possibly economic) deposits of magnetite (Zandler et al. 1967) in crystalline basement rocks, partly underlying Lake Ladoga.

The small anomaly No. 32 in the Karelian Isthmus has a mixed origin. The elevated (with respect to MAC) concentrations of Fe, Mn and Al in stream water are caused by natural landscape features. At the same time, contamination by such anthropogenic elements as Pb, V and Sb is found in mosses.

Anomaly No. 44 of probably mixed origin is found to the south of Novgorod, where elevated concentrations of Pb, Zn, Cu and Mn were detected in the uppermost soil horizon.

In the Arkhangelsk region, anomaly No. 21 (12,100 km^2) also has a mixed natural/anthropogenic origin, including the Arkhangelsk and Severodvinsk industrial centres. This anomaly is characterized by a moderately hazardous content of V, B, Co, As, Ni and Cr in terrestrial moss and elevated (with respect to MAC) concentrations of Fe and Br in surface waters.

The large anomalies No. 22, 23, 34 and 35 of geogenic origin are traced as a continuous chain in the central part of the Arkhangelsk region. They include high (with respect to MAC) concentrations of Sr, Ca, Fe and Ba in surface waters. The Sr/Ca ratio indicates a very serious ecological situation in this area. The anomalous relative values of this ratio reach 0.9 r.u. The background level of the Sr/Ca ratio is 0.0045 for the whole project area, but the mean value of this ratio is 6-10 times higher within anomalous areas, thus being much higher than the value 0.01, which is considered critical for endemic osetoarthritic diseases (Ivanov 1996, Krainov 1980). Anomalies No. 6 in the Kanin Nos Peninsula and No. 20 in the border area between the Arkhangelsk region and Republic of Karelia have a similar natural origin. The main anomaly-forming factor is the strong influence of marine aerosols.

In the Baltic countries there are several small anomalies (No. 43, 45 and 46) with a total area of 3,680 km^2. Anomaly No. 43 is situated in the Kohtla Jarve-Sillamae industrial district and characterized by elevated concentrations of Mo in terrestrial moss and high Ba concentrations in surface waters. Anomaly No. 45 in Latvia contains elevated concentrations of As, V, Mn, Mo and Sr in the top soil horizon. Anomaly No. 46 includes high concentrations of a wide spectrum of polluting elements in soil and stream sediments in the area surrounding the Siauliai industrial centre in the central part of Lithuania.

Ten problematic zones of unsatisfactory environmental status with a total area of 73,000 km^2 were mapped in Finland. A number of large anomalies of mixed natural/anthropogenic origin are situated in the southern and most intensively developed areas of the country. Anomaly No. 15

stretches along the coast of the Gulf of Bothnia from Oulu in the north to Vaasa in the south. The total area of this zone is about 28,300 km^2, and the main anomalous elements include As and Co in terrestrial mosses and Fe, Mn and Al in surface waters. The highest centre of this zone is near Vaasa and is characterized by a critical environmental status. Anomaly No. 28 (with an area of 14,460 km^2), including a wide spectrum of pollutants of technogenic origin in moss and soil horizons, is traced from Turku to Tampere. At the same time, surface waters of this area have a notably high (with respect to MAC) natural concentration of Fe and Al. The small anomalies No. 29-31 have, as a rule, constant elevated levels of Fe in surface waters from one side, and a wide spectrum of technogenic elements in terrestrial moss, soil horizons and stream sediment from the other side. These differences provide evidence of the mixed nature of this group of anomalies. Anomaly No. 11 of mixed origin is situated on the northern coast of the Gulf of Bothnia in the areas surrounding the Kemi industrial centre. High concentrations of Cr and Ni in terrestrial moss, connected with the impact of open chromite mining, are followed by natural elevated levels of Fe in surface waters.

The anomalous zones No. 8-9 and No. 16-17 in Finland belong to a group with a natural origin. Their main anomaly-forming components are high concentrations of Fe, Mn and, in places, Al in surface waters.

In Sweden there are 9 small ecogeochemical anomalies contoured on the map. All these anomalies have a natural or mixed origin with moderately hazardous levels of pollutants. The total area with an unsatisfactory environmental status is about 24,450 km^2. All these anomalies include natural elevated concentrations of Fe, Mn and Al in surface waters. In some cases (anomalies No. 39-41), high concentrations of polluting elements of anthropogenic origin are found in terrestrial mosses and soil horizons.

In Norway, 8 problematic areas with an unfavourable ecological situation occupy a total area of 114,000 km^2. The largest anomalous zones were found in the southern part of the country. The anomalous zones No. 7, 36, 37 and 38 most probably have a mixed natural/anthropogenic origin. The natural component of these anomalies is caused by the influence of the geological substrate, i.e. in the areas of thin Quaternary cover the composition of these anomalies reflects the geochemical features of the underlying bedrock with ore mineralizations. In some cases, in addition to the geogenic influence, these anomalies are characterized by elevated concentrations of technophile elements in terrestrial moss.

4.5 Map of Ore-Related Geochemical Anomalies at the scale 1:5,000,000

The map of ore-related geochemical anomalies of Fennoscandia and NW Russia was prepared at the scale of 1:5,000,000. It includes a map-inset for the territory of the eastern part of the Fennoscandian Shield and its frame at the scale of 1:2,500,000. The map is based on the main results from the interpretation of previous maps and contains contoured ore-related and potentially ore-related anomalous geochemical zones and districts.

Altogether, 134 AGFs suggested to reflect known or potential ore districts were contoured on the map. Detailed information about each AGF is included in a catalogue (Appendix D) including:

- the name and number on the map;
- characteristic features of the AGF, including the size, number of anomalous points, detailed information about the composition in the order of accumulation or deficiency of elements, variation coefficients (as a superscript index) and concentration coefficients (as a subscript index) for elements within the interval $0.7>C_c>1.3$, separately for each sample medium;
- the summarized composition of the AGF arranged according to the accumulation of elements in the order of concentration coefficients in two or more sample media;
- an averaged statistical ranking of anomaly-forming elements, arranged according to the above-mentioned parameters in turn;
- mean values of variation coefficients of all elements (V%) and the summary coefficient of accumulation (ΣC_c) as acommon parameter of AGF in each of the sample media;
- predictive estimation of the AGF, including the type of ore formation, an indication of the major commercial components and ranking of the AGF according to its estimated economic value.

Technical processing of the estimation of mineral potentials and categorization of contoured AGFs were carried out in accordance with the methodological recommendations of IMGRE (IMGRE 1999), specified for the combined use of geochemical, geological and other data available from the AGF area. It included:

- the size of the AGF (km^2);
- the element composition of the AGF, including the main ore and associated elements indicating the predictable mineralization;
- the intensity of the anomalous field (ΣC_c)and variation (V %) in element concentrations;
- the presence of ore deposits or occurrences of predictive ore-formation types;
- the existence of specified (ore-bearing or potentially ore-bearing) geological complexes;
- the presence of a favourable structural and geodynamic situation;
- the presence of favourable geophysical and mineralogical indications;
- the association of the AGF with several components of natural geological media.

The estimation of prognostic resources was carried out using geological similarity. The productivity of geochemical anomalies was also used if the anomaly included direct element indicators of predictable ores. For the estimation of the mineral potential of the AGFs, ore deposits were classified according to their size ranking on the scale of small, medium or large.

Assessment of the prognostic categories (high, medium, low or unclear) of the AGFs was based on the presence of favourable pre-conditions and indications (arbitrary estimation) and the size of predictable ores.

A brief list of ore districts contoured on the map and the main results of their prognostic estimation is presented in Table 8.

The AGFs were grouped into 17 geochemical zones, having an arch-shaped system around two large mega-blocks of the Fennoscandian Shield. The predominant information on the main rock forming, ore and associated elements typical for these geochemical zones is presented in Table 9. Two zones were connected to the first of these mega-blocks (called the Kola Craton): (i) the internal Pechengsko-Allarechensko-Solozerskaja (No. 1) and (ii) the external Lapland-Kola (No. 2). Both of these have a predominantly Ni-Cr-Cu composition with an appreciable increase in chalcophile elements within the latter one.

The Bothnian (No. 9) and Central Sweden (No. 10) geochemical zones are connected to the second mega-block (Svecofennian Craton). These zones are characterized by a gradual transition from a predominantly Cu-Co-Ni composition of AGFs in the central part of the megablock (No. 9) to the prevalence of the polymetallic group of elements in the west (No. 10).

A group of linear and local syncline-formed zones was mapped in interspace between these two mega-blocks, including the Kiruna (No. 3), East Karelian (No. 4), Central Karelian (No. 5), Western Karelian (No. 6) Burakovskaya mulda (No. 7) and Onezhskaya mulda (No. 8) zones. A wide spectrum of elements is typical for the composition of all these zones.

The large Caledonian zone (No. 11) and a small fragment of the Timan Ridge zone (No. 12) with AGFs of predominantly chalcophile elements were traced in the western and extreme northeastern parts of the study area.

A notable geochemical feature is the constant presence of a wide spectrum of rare metals, rare earth elements, Th, U, Sr, and some other lithophile elements, following the margins of the Fennoscandian Shield and its border area with the Russian Plate. These AGFs were grouped into a number of marginal zones. The most important of them are: the Oslo Rift (No. 13), the Sveco-Norwegian zone (No. 13) in the mega-block of the Shield, Belomorsko-Baltiiskaja (No. 15) in the eastern frame of the Shield, Inari-Kastojärvi (No. 16) in the northwest and the Kotlas-Kaninskaja zone (No. 17) in the Russian Plate. The main features of the mineral potential of these geochemical zones are presented in Table 10.

The highest potential of Cu-Ni ores is connected with the Pechengsko-Allarechensko-Solozerskaya zone (No. 1), situated in the western part of the Kola structural block. Surrounding this block, the Lapland-Kola zone (No. 2) is characterized by a wider spectrum of ore types. Along with Cu-Ni ores, such metals as Au, Cr, PGM and diamonds have a high potential.

Among the zones (No. 4-8) of the Lapland-Karelian block, the East Karelian zone (No. 4) has a predominantly high potential for Au, Cr, Cu-Ni, Fe and V ores and diamonds. Within the other zones of this block, the possibility of finding diamond-bearing kimberlites is limited to the areas of known ore districts, such as Hautovaara, Kostamuksha, Burakovskaja and Onezhskaja syncline structures.

Two large geochemical zones are located inside the Svecofennian block of the Fennoscandian Shield. The Bothnian circular zone (No. 9) possesses a high potential for copper and polymetallic sulphur ores and also Au and Cu-Ni ores. The maximum potential for prospecting of new polymetallic deposits and the significant expected reserves of Au, Mo and U can be connected with the arch-shaped Central Sweden zone (No. 10) in the western part of the Svecofennian structural region.

The main economic value of zone No. 11 within the Caledonian folded belt is limited to the possible discovery of new deposits of copper and, to a lesser degree, polymetallic sulphur ores. Analogous, but very restricted predictivity exists for the north-easternmost part of zone No. 12, which is a fragment of the Timan Ridge structural block.

A group of geochemical zones (No. 13-17) is exposed in a peripheral part of the Fennoscandian Shield and its fame area with the Russian plate. All of these are most probably connected with the Palaeozoic activities of the East-European platform. The Belomorsko-Baltiiskaja zone (No. 15) is the largest of them. It is set off the Shield like a continuous arch from the north-east to the south-west, and according to its size this zone corresponds to the rank of a mega-zone. The highest mineral potential of this zone is connected with diamonds (in areas with a prevalence of underlying Archaean crystal basement), rare metals, rare earth elements, apatite, uranium and bauxites.

The spatial placement and geochemical features of the zones reflect the history of the geological development of the Fennoscandian Shield. The composition of these zones and their metallogenic features are characterized by a clear spatial-temporal trend connected with the development of the Precambrian Earth's crust from the north-east to the south-west, i.e. from the Late Archaean-Early Proterozoic period (Kola and Lapland-Karelian blocks) through the Meso Proterozoic (Svecofennian block) period to the Late Proterozoic stage (Sveco-Norwegian block) and the further formation of the folded belts in the Palaeozoic.

The mineral occurrences of periodical tectonic-igneous activity from the Late Proterozoic to Palaeozoic periods are generally typical for the Fennoscandian Shield, and especially for its marginal parts and joint areas with the Russian Plate. Layered peridotite-gabbro-norite massifs, alkaline and sub-alkaline granites, unique massifs of ultramafic and alkaline rocks with carbonatites, agpaite nepheline syenites, kimberlites and large areas with dyke swarms of different composition and age are a result of metasomatic processes and the intrusion of specific types of igneous rocks.

Patterns in the spatial position of the geochemical zones and clear zonality of their composition and metallogenic features support Tihonov's (1989) concepts of the metallogenic features of annular structures. It is also the authors' opinion that they are large distinctive structural elements of all Precambrian platforms.

The total area of the 134 AGFs amounts to 679,100 km^2 (Table 9), or 31.2% of the study area. Altogether, 70 AGFs with a total area of 443,800 km^2 (20.4% of the total area) are classified in the high and medium categories of economic value. They consist of a wide range of mineral wealth, including areas favourable for prospecting of Ni-Cu (15 AGFs), MPG (5 AGFs), Au (26 AGFs), polymetallic Cu, Cu-Zn, Pb-Zn and Zn-Pb ores (13 AGFs), Mo (9 AGFs), U (6 AGFs) and U-V ores (1 AGF). There are new districts recommended for diamond exploration (12 AGFs), Cr (4 AGFs), V (1 AGFs), rare metals and rare earth elements (3 AGFs), bauxites (2 AGFs), celestine (2 AGFs) and apatite (5 AGFs) ores.

Table 8. List of districts contoured on the map of ore-related geochemical anomalies and the prognostic estimation of their economic values for mineral exploration. di=diamond.

No.	District		Prognostic estimation	
	Number on the map	Area, km^2	Main economic components and size category of deposits (S=Small, M=Medium, L=Large, n.d.=not defined)	Prognostic category
1	1-1	1,392	NiCu (L)	High
2	1-2	3,144	NiCu (M)	Medium
3	1-2-1	1,328	NiCu (M)	Medium
4	1-2-2	1,208	NiCu (S), Mo (S)	Medium
5	1-3	1,004	NiCu (S), Mo (S)	Unclear
6	1-4	2,238	Unspecified	Low
7	1-5	1,216	NiCu (M)	High
8	2-1	3,048	NiCu (S), Au (M)	High
9	2-2	3,641	NiCu (S)	High
10	2-3	9,192	Cr_2O_3 (L), PGE (L), Au (M)	High
11	2-4	1,816	NiCu (S), Au (S)	High
12	2-5	1,549	Unspecified	Unclear
13	2-6	2,472	Cu (S), Au (S)	Medium
14	2-7	2,297	PGE (M), Au (M)	High
15	2-8	2,013	R (L), Au (M)	Medium
16	2-9	1,361	NiCu (M), PGE (L)	Medium
17	2-10	1,091	Fe_2O_3 (M)	Unclear
18	2-11	2,178	NiCu (S), Au (S)	High
19	2-12	5,004	Diamond (M)	High
20	3-1	1,834	Unspecified	Unclear
21	3-2	3,337	Fe_2O_3 (n.d.)	Unclear
22	4-1	936	CuNi (S), PGE (M), di (S)	CuNi, di Low, PGE (M)
23	4-2	2,475	Unspecified	Low
24	4-3	7,484	Au (M)	High
25	4-3-1	2,995	Au (S), di (S)	High
26	4-3-2	2,659	Au (M)	High
27	4-4	1,734	Unspecified	Low
28	4-5	5,670	NiCu (M), Au (S), FeTiV (M), Cr_2O_3 (M)	Unclear
29	4-6	7,176	NiCu (M), Au (S), FeTiV (M), Cr_2O_3 (M)	High
30	5-1	1,635	Cu (S), Au (S)	Unclear
31	5-2	2,044	Unspecified	Low

32	5-3	2,963	Au (S), PbZn (S)	High
33	5-4	1,849	Unspecified	Low
34	6-1	1,345	Cr_2O_3 (n.d.), PGE (n.d.)	Unclear
35	6-2	1,495	Unspecified	Unclear
36	6-3	5,297	Au (S)	Unclear
37	6-4	1,574	NiCu (M)	Unclear
38	6-5	4,461	Au (M), di (S)	High
39	6-6	4,100	Unspecified	Unclear
40	6-7	3,905	Au (M)	High
41	7-1	2,228	PGE (M), Au (M), Cr_2O_3 (M)	High
42	8-1	9,207	V_2O_5 (M)	Medium
43	8-1-1	2,570	V_2O_5 (M)	Unclear
44	8-1-2	4,552	V_2O_5(M), Cu(M), di (S)	High
45	9-1	6,794	Cu (M), Au (S)	High
46	9-2	11,040	NiCu, ZnPb	Medium
47	9-3	14,448	Cu (M)	High
48	9-4	1,482	NiCu (M)	Medium
49	9-5	7,461	NiCu (M), Au (M)	High
50	9-6	2,927	NiCu (M), Au (M)	Medium
51	9-7	4,792	NiCu (S)	Unclear
52	9-8	2,421	Unspecified	Low
53	9-9	2,752	Unspecified	Low
54	9-10	2,587	CuNi (M), PbZn (M)	Medium
55	9-11	4,767	PbZn (M), Au (M)	High
56	10-1	5,660	Au (M), UR (M)	Unclear
57	10-2	4,145	REE, Rare metals (n.d.)	Low
58	10-3	3,000	PbZn (S)	Unclear
59	10-4	13,803	Au (M), ZnPb (M), Mo (M)	High
60	10-5	3,688	MoCu (M)	Medium
61	10-6	7,209	MoCu (M)	Medium
62	10-7	3,499	Au (S)	Medium
63	10-8	4,887	Unspecified	Unclear
64	10-9	18,232	Au (M), CuZn (M), U (M)	High
65	10-10	5,148	U(M)	Medium
66	10-11	5,865	ZnPb (M)	High

67	10-12	9,137	ZnPb (M), U (M)	High
68	10-13	1,333	PbZn (M)	Medium
69	10-14	5,601	CuNi (M), PbZn (M), U (M), Au (M)	High
70	11-1	1,363	CuNi (S)	Unclear
71	11-2	4,962	Cu (M)	High
72	11-3	19,617	Cu (M)	Medium
73	11-4	16,065	Au (S), PbZn (M)	Medium
74	11-5	6,844	CuZn (M)	High
75	11-6	18,094	Cu (M)	Medium
76	12-1	793	Cu (M), ZnPb (M)	Low
77	13-1	13,056	Au (M), PbZn (M), Mo (M), Ag (L)	High
78	13-2	853	Unspecified	Low
79	13-3	1,586	Unspecified	Low
80	13-4	7,483	Unspecified	Low
81	14-1	10,547	Unspecified	Low
82	14-2	15,648	Au (M)	Low
83	14-3	12,890	Mo (M)	Medium
84	14-4	4,610	Mo (S)	Medium
85	15-1	6,594	Apatite (M)	High
86	15-1-1	1,334	Apatite (M)	High
87	15-1-2	2,310	Apatite (S)	High
88	15-1-3	1,072	Unspecified	Low
89	15-2	1,350	Unspecified	Low
90	15-3	3,321	Rare metals (L), Apatite (L)	High
91	15-4	5,082	Apatite (M)	High
92	15-5	1,778	Au (L), Mo (L)	High
93	15-6	7,570	Rare metals (n.d.)	High
94	15-7	3,396	Diamond (S)	Medium
95	15-8	2,076	U (S)	Unclear
96	15-9	8,066	U (M)	Medium
97	15-10	5,353	U (S)	Unclear
98	15-11	3,771	U (S)	Unclear
99	15-12	1,406	Unspecified	Unclear
100	15-13	4,986	Au (M), Diamond (S)	High
101	15-14	3,086	Unspecified	Unclear

102	15-15	28,510	Diamond (L)	High
103	15-16	14,632	Diamond (L), LiBRb (L), NaCl (L),	di, LiBRb (M), NaCl (H)
104	15-17	17,800	Diamond (L), Sr(M), UV (M), Al (M)	Di (H), Sr (M), UV, Al Unclear
105	15-18	2,028	Sr (M)	Unclear
106	15-19	9,027	Sr (M), Diamond (L)	Sr Low, di Unclear
107	15-20	7,141	Au (n.d.), Diamond (n.d.), TiFe (n.d.), VCu (n.d.)	Unclear
108	15-21	5,244	U,REE (M),	Unclear
109	15-22	6,435	Diamond (n.d.), PUVAu (n.d.)	Unclear
110	15-23	2,505	Unspecified	Low
111	15-24	4,965	U (n.d), P (n.d.)	Low
112	15-25	5,776	Diamond (S)	Medium
113	15-26	3,348	U (n.d.)	Unclear
114	15-27	8,341	U (M), di (S)	Unclear
115	15-28	1,776	U (n.d.)	Unclear
116	15-29	8,589	U (L), Mo (L)	High
117	15-30	4,177	Unspecified	Low
118	15-31	9,208	Unspecified	Low
119	15-32	2,120	Unspecified	Low
120	15-33	9,303	U (S)	Unclear
121	15-34	1,455	REE (S), Diamond (n.d.)	REE (L), di Unclear
122	15-35	1,301	Sn (n.d.), U (n.d.)	Unclear
123	15-36	8,013	Al (M), Diamond (S)	Medium
124	15-37	2,904	Al (M)	Low
125	15-38	5,780	Al (n.d.)	Unclear
126	16-1	4,168	Unspecified	Low
127	16-2	2,117	U (M)	Unclear
128	17-1	2,879	Rare metals (n.d.)	Unclear
129	17-2	2,913	Rare metals, REE (S), Sr (S)	Rare metals, REE (L), Sr (M)
130	17-3	6,073	Diamond (M)	Medium
131	0-1	7,743	U (M)	Unclear
132	0-2	4,338	Unspecified	Unclear
133	0-3	1,397	Unspecified	Low
134	0-4	2,088	Unspecified	Low

Table 9. List and composition of geochemical zones contoured on the maps.

No. on the map	Name of zone	Element composition	
		Rock forming elements	Ore and associated elements
1	Pechengsko-Allarechensko-Solozerskaja	Mg	NiCuCoCrZnPbMoCd
2	Lapland-Kola	MnMgFeCaBaNaKAlLi	CrCuMoVNiUCoTiCdZnAsSrSbBiP
3	Kiruna	MnFeBaCaKMgNa	CoCuNiVCrMoBePSr
4	East Karelian	MnFeKMgLi	ZnCoCuAsPbMoBaCrSnVNiSbUThLaTi
5	Central Karelian	MnFe	AsPbCoMoTlPAgLa
6	Western Karelian	MnFeK	ZnCdCoPbCu
7	Burakovskaja mulda	MgFeLiBaAlMnCa	AsZnVNiCuCrCdCoUBiPbSbP
8	Onezhskaja mulda	MnFeMgCaAlBa	BiAsCoVSbPbMoCuZnCdNiTi
9	Bothnian	FeMnKMgNaCaAlSLiBa	CoNiCuCrAsZnPPbVTiCdBiSbAg
10	Central Sweden	MnFeAlBa	PbMoZnAsUBeCoCdTlV
11	Caledonian	MnFeMgAlLiCa	CuCoCrNiZnPbMoVCdAsSr
12	Timan Ridge	MgKMnCaFeAlSc	ZnNiCuPbVCoCrTiAgCdBiSrBeP
13	Oslo Rift	MnNaBaKMgFeCaAlS	AsCrCoPbVZnSrNiMoCuLaUNbTiThYBeBiF
14	Sveco-Norwegian	AlBBaMnCaFe	CuMoPCoPbAsZnSrLaNiZrCe
15	Belomorsko-Baltiiskaja	MnMgCaBaFeKAl	USrPNiCoCrCuMoZnAsThCdPbTiVNbLaCs
16	Inari-Kastojarvi	KAlMgMnFeCa	UCuNiVZnCrLaRbCeThCoMoAsPbPSr
17	Kotlas-Kaninskaja	MgNaAlFeBaScMnCaKB	SrSbBeAsBiCuNiVPbNbCoZnCdCrTiPCeSnUZrTh

Table 10. Grouping of anomalous geochemical fields (AGF) according to their main components in each geochemical zone contoured on the map, and the ranked classification of the AGFs in the whole study area. PGE=platinum group elements.

Grouping of AGFs	Total area of AGFs, thousand km^2; (number of AGFs)	Share of the total study area %	Share of the total area of AGFs %	Areas (thousand km^2) and number of AGFs (in brackets) according to the main components						
				Ore type or size were not determined	Ag	Al	Apatite	Au	Cr_2O_3	Cu
Whole study area (2,175,000 km^2)										
Total	679,1 (134)	31,2	100	129,02 (38)	13,06 (1)	28,71 (3)	9,92 (5)	182,3 (31)	19,9 (4)	73,36 (9)
Unclear	125,9 (35)	5,8	18,5	55,67 (14)				16,63 (3)		1,64 (1)
Low	109,4) (29)	5,0	16,2	73,35 (24)		2,90 (1)		17,28 (2)		0,79 (1)
Medium	171,5 (28)	7,9	25,3			8,01 (1)		26,98 (5)		40,18 (3)
High	272,3 (42)	12,5	40		13,06 (1)	17,8 (1)	9,92 (5)	121,41 (21)	19,9 (4)	30,75 (4)
High+ Medium	443,8 (70)	20,4	65,3		13,06 (1)	25,88 (2)	9,92 (5)	148,39 (26)	19,9 (4)	70,93 (7)
Geochemical zones										
1	11,21 (7)	0,5	1,7	2,24 (1)						
2	35,66 (12)	1,6	5,3	155 (1)				23,02 (7)	9,19 (1)	2,47 (1)
3	5,17 (2)	0,2	0,8	5,17 (2)						
4	23,65 (8)	1,4	3,5	4,21 (2)				18,5 (4)	7,18 (1)	
5	8,49 (4)	0,4	1,3	3,89 (2)				4,6 (2)		1,64 (1)
6	22,18 (7)	1,0	3,3	5,60 (2)				13,66 (3)	1,35 (1)	
7	2,23 (1)	0,1	0,3					2,23 (1)	2,23 (1)	
8	16,3 (3)	0,8	2,4							4,55 (1)
9	61,47 (11)	2,8	9,1	5,17 (2)				21,95 (4)		21,24 (2)
10	91,21 (14)	4,2	13,5	9,03 (2)				46,80 (5)		
11	66,95 (6)	3,1	9,9					16,07 (1)		42,67 (3)
12	0.79 (1)	0,04	0,1							0,79 (1)
13	22,98 (4)	1,1	3,4	9,92 (3)	13,06 (1)			13,06 (1)		
14	43,70 (4)	2,0	6,4	10,55 (1)				15,65 (1)		
15	228,88 (41)	10,5	33,8	56,81 (15)		28,71 (3)	9,92 (5)	6,76 (2)		
16	6,29 (2)	0,3	0,9	4,17 (1)						
17	11,87 (3)	0,5	1,8	2,88 (1)						
Outside zones	15,56 (4)	0,7	2,3	7,83 (3)						

Table 10. continued.

Grouping of AGFs	Total area of AGFs, thousand km^2; (number of AGFs)	Share of the total study area, %	Share of the total area of AGFs, %	Areas (thousand km^2) and number of AGFs (in brackets) according to the main components						
				CuNi	Polymetallic ores (CuZn, PbZn, ZnPb)	Diamond	Fe_2O_3	FeTiV	LiBRb	PGE
Whole study area (2,175,000 km^2)										
Total	679,1 (134)	31,2	100	71,40 (21)	115,00 (15)	126,00 (16)	1,09 (1)	7,18 (1)	14,60 (1)	17,42 (6)
Unclear	125,9 (35)	5,8	18,5	14,40 (5)	3,00 (1)	10,73 (3)	1,09 (1)			1,35 (1)
Low	109,4 (29)	5,0	16,2	0,94 (1)	0,79 (1)	9,03 (1)				
Medium	171,5 (28)	7,9	25,3	22,54 (6)	31,03 (4)	37,89 (5)			14,60 (1)	2,30 (2)
High	272,3 (42)	12,5	40	33,52 (9)	80,23 (9)	68,36 (7)		7,18 (1)		13,77 (3)
High+ Medium	443,8 (70)	20,4	65,3	56,06 (15)	111,26 (13)	106,3 (12)		7,18 (1)	14,6 (1)	16,07 (5)
Geochemical zones										
1	11,21 (7)	0,5	1,7	6,76 (4)						
2	35,66 (12)	1,6	5,3	12,04 (5)		5,00 (1)	1,09 (1)			12,9 (3)
3	5,17 (2)	0,2	0,8							
4	23,65 (8)	1,4	3,5	13,78 (3)		3,93 (2)		7,18 (1)		0,94 (1)
5	8,49 (4)	0,4	1,3		2,96 (1)					
6	22,18 (7)	1,0	3,3	1,57 (1)		4,46 (1)				1,35 (1)
7	2,23 (1)	0,1	0,3							2,23 (1)
8	16,3 (3)	0,8	2,4			4,55 (1)				
9	61,47 (11)	2,8	9,1	30,29 (6)	18,39 (3)					
10	91,21 (14)	4,2	13,5	5,60 (1)	56,94 (7)					
11	66,95 (6)	3,1	9,9	1,36 (1)	22,91 (2)					
12	0.79 (1)	0,04	0,1		0,79 (1)					
13	22,98 (4)	1,1	3,4		13,06 (1)					
14	43,70 (4)	2,0	6,4							
15	228,88 (41)	10,5	33,8			102,0 (10)			14,60 (1)	
16	6,29 (2)	0,3	0,9	7,83 (3)						
17	11,87 (3)	0,5	1,8			6,07 (1)				
Outside zones	15,56 (4)	0,7	2,3							

Table 10. continued.

Grouping of AGFs	Total area of AGFs, thousand km^2; (number of AGFs)	Share of the total study area, %	Share of the total area of AGFs, %	Areas (thousand km^2), and number of AGFs (in brackets) according to the main components						
				Mo	NaCl	Nb, Ta REE,	Sr	V_2O_5	UV	U, Th, REE
Whole study area (2,175,000 km^2)										
Total	679,1 (134)	31,2	100	67,84 (10)	14,60 (1)	9,70 (4)	31,77 (4)	7,12 (2)	17,80 (1)	104,38 (15)
Unclear	125,9 (35)	5,8	18,5	1,00 (1)			2,03 (1)	2,57 (1)		47,53 (8)
Low	109,4 (29)	5,0	16,2			1,46 (1)	9,03 (1)			2,08 (1)
Medium	171,5 (28)	7,9	25,3	29,61 (5)	14,60 (1)	2,01 (1)	20.71 (2)			13,21 (2)
High	272,3 (42)	12,5	40	37,23 (4)		6,23 (2)		4,55 (1)	17,80 (1)	41,56 (4)
High+ Medium	443,8 (70)	20,4	65,3	66,84 (9)	14,60 (1)	8,24 (3)	20,71 (2)	4,55 (1)	17,80 (1)	54,77 (6)
Geochemical zones										
1	11,21 (7)	0,5	1,7	2,21 (2)						
2	35,66 (12)	1,6	5,3			2,01 (1)				
3	5,17 (2)	0,2	0,8							
4	23,65 (8)	1,4	3,5							
5	8,49 (4)	0,4	1,3							
6	22,18 (7)	1,0	3,3							
7	2,23 (1)	0,1	0,3							
8	16,3 (3)	0,8	2,4					7,12 (2)		
9	61,47 (11)	2,8	9,1							
10	91,21 (14)	4,2	13,5	24,70 (3)						43,78 (5)
11	66,95 (6)	3,1	9,9							
12	0.79 (1)	0,04	0,1							
13	22,98 (4)	1,1	3,4	13,06 (1)						
14	43,70 (4)	2,0	6,4	17,50 (2)						
15	228,88 (41)	10,5	33,8	10,37 (2)	14,60 (1)	4,78 (2)	28,86 (3)		17,80 (1)	50,74 (8)
16	6,29 (2)	0,3	0,9							2,12 (1)
17	11,87 (3)	0,5	1,8			2,91 (1)	2,91 (1)			
Outside zones	15,56 (4)	0,7	2,3							7,74 (1)