Geological report of the Paz River basin

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Table of contents

1. Introduction

As commissioned by the Lapland Environment Centre, the Northern Finland Office of the Finnish Geological Survey (GTK) prepared a report of the bedrock and soil of the Paatsjoki catchment area. The sensitivity of the soil in the area to acidification was also assessed on the basis of the chemical properties of the mineral soil. The report on the geological and chemical properties of the soil is based on survey and research data owned by GTK. The capacity of the surface waters to neutralize possible increases in acidic inputs was assessed on the basis of water quality data provided by the Lapland Environment Centre. The rectangular-shaped area in the northern parts of Finland, Norway and Russia has a surface area of 243 x 186 km, and covers the whole of the Paatsjoki catchment area and its surroundings.

2. General

The geological bedrock map material

A simplified bedrock map that includes the primary rock types in the area is given in Appendix 1. The map is based on bedrock survey material from several projects carried out by GTK and other surveys at a number of different scales. GTK's 1:1 000 000 bedrock map provides an overall picture of the bedrock occurring in Finland. The map shows the types of rock and the stratigraphic and structural properties of the bedrock. The most recent map was published in 1997. Survey data have been collected in northern Finland during two separate bedrock survey projects. The 1:1 000 000 bedrock map from the Nordkalott Project (1987) covers both northern Finland and northern Norway. The bedrock material (numerical bedrock data for Northern Finland) from the Lapland Vulcanite Project, which is at a scale of 1: 400 00, covers the whole of the Näätämö area. The 1:1 000 000 bedrock map of the Fennoscandian Shield, which was produced as a joint project between Finland, Norway, Sweden and Russia, has been used in identifying the major types of bedrock and rock types in that part of the area located in Norway and Russia. The most accurate bedrock survey from Finland is from 1994, at a scale of 1:1 000 000, and covers map pages 3934, 4912 and 4914.

Geological soil mapping material

The most comprehensive soil map covering Finland, the northern part of Norway and the north-western part of Russia is from 1993 and is at a scale of 1:1 000 000. The soil map of the catchment area is a part of this map (Appendix 2). The map provides a general picture of the geological formations and the proportions of different soil types in the region. The most accurate soil data for the part of Finland in the region is at a scale of 1:400 000. The data provide a good overall picture of the distribution of different soil types, the soil structure and different types of soil formation such as hummocky moraine areas, peat and clay deposits and eskers.

Geochemical research material

The geochemical soil research material of the Pasvik catchment area consists of data from 176 points sampled in connection with the Barents Eco-geochemical project, the Lapland Forest Damage Project and a joint project carried out together with the Lapland Environmental Centre (Appendix 3). The results of the Barents Eco-geochemical Project are from subsoil (C horizon) samples taken from below the podzol profile. Aqua regia extraction was used in analyzing the samples, and the results are of indicative use when assessing the sensitivity to acidification. In addition, geochemical mapping data from 51 points in different parts of northern Finland sampled in 1995 in connection with the Lapland Forest Damage Project, and 45 points sampled in 1990 - 1992 in connection with the joint project carried out together with the Lapland Environmental Centre, were also used in this investigation. Three separate extraction methods were used in the Lapland Forest Damage Project: aqua regia extraction, ammonium acetate extraction and ammonium nitrate extraction. However, only the results of aqua regia and ammonium nitrate extraction have been used in this report. The samples from the Lapland Forest Damage Project are primarily from five depths in till soil. For the sake of consistency, the resulys covered by this report are for the C horizon. In the joint project with the Lapland Environmental Centre, samples were taken from the humus layer and from four depths in the till. The results of Aqua regia extraction on C horizon samples are presented in this report.

In the Barents Eco-geochemical Project the analyses were carried out on mineral soil material with a particle size of less than 2 mm, while in the Lapland Forest Damage Project and the joint project together with the Lapland Environmental Centre the analyses were performed on material with a size of less than 0.5 mm. As mafic minerals have a greater effect on the results when they occur in the sand and silt fractions, the results for the < 2 mm samples may give a more reliable picture of the occurrence of easily weatherable minerals and cation exchange capacity. The Ca concentrations are higher in the silt and sand fractions than in the clay fractions, especially in samples from the A and B horizons of the soil.

Surface water analysis data collected by the Finnish Game and Fish Research Institute and INEP (Apatity, Russia) from areas in Finland, Norway and Russia, provided by the Lapland Environmental Centre, have been used as source material in the part of the report covering the geochemical properties of surface waters. The report focuses primarily on the results for pH, alkalinity and electrical conductivity.

Bedrock

The area contains early proterozoic mafic and felsic granulites, which stretch from the western part of the Kola Peninsula, through Finland, into Norway. A large granite-gneiss complex extends from the Kola Peninsula through the northern Inari and eastern Utsjoki area, and continues into Norway. The complex primarily consists of granites, granodiorites, amphibolites, gneisses of varying composition, and a greenstone zone of volcanic origin. The greenstone zones in both countries consist of basaltic and komatitic vulcanites, which include multiple ore deposits such as the nickel ore deposit at Zapoljarny. The northern parts of Norway and Russia have late proterozoic and paleozoic sedimentary rocks, such as sandstones and conglomerates.

There is considerably variation in the composition of the bedrock at the local level. The geochemical and mineralogical composition of the bedrock affects the chemical properties of the soil. The occurrence of even small areas of special rock types can affect the composition of the till and, consequently, its sensitivity to acidification and the composition of the ground water in the area.

Soil

The dominant mineral soil type in the area is till. Only 10 % of the surface area consists of sorted soil formation such as eskers, shore deposits or dunes. The mineralogical composition of till mainly reflects the local bedrock, and the particle size of the material ranges from boulder to clay fractions. The material in the moraine formations is primarily gravel and sand till. The types of moraine formation in the area also include hummocky moraines and drumlins, in which lenses of sorted material are more common than in areas with ground moraines. The average thickness of the till soil in the valleys, on the lower slopes of hills and in flat areas is a few metres. There is no soil at all on the hill and fell tops.

Especially large amounts of material weathered before the last Ice Age have been found in the soil in Lapland, and this may be reflected in certain areas in the geochemical properties of till. Weathered material contains large amounts of easily soluble elements which, however, have been leached out of the surface layers of the soil. Sorted mineral soil deposits, such as eskers and shore depsoits, have low proportions of fine material and easily soluble elements. Approximately 10 % of the surface area is peatland. The peat bogs in northern areas are usually aapa, palsa and hilltop bogs.

Geochemical effects of the bedrock

Magma rocks are alkaline rock types that contain relatively small amounts of silicate, SiO_2. The most typical alkaline rock types are gabros and basalts, which consist of dark minerals and feldspar in which SiO_2 is bound. Alkaline rock types contain large amounts of iron and easily soluble base cations, especially magnesium and calcium. Komatic vulcanites are especially rich in magnesium. The proportion of heavy metals, such as chromium and nickel in alkaline rocks is relatively high, and their effect is further enhanced in the soil because these rock types of rock readily disintegrate into fine particles.

Acidic rock types contain more SiO_2. The most typical acidic rock type is granite. The primary minerals in granite, quartz and feldspar, do not decompose easily and they therefore have a reducing effect on the amount of soluble elements in the soil. However, if these rock types contain relatively large proportions of mica, then they liberate potassium, iron and aluminium into the soil. Till formed from acidic rock types usually contains a low proportion of fine material.

Gneisses are medium- or coarse-particled, structurally aligned metamorphic rocks. The catchment area contains several types of gneiss of different composition. Bottom gneisses usually have the same composition as granites and mica gneisses. Mica gneiss can also be found in the northern part of the Paatsjoki catchment areas that extends into Norway. Soluble elements in the soil in gneiss areas are, depending on the chemical composition of the gneiss, primarily aluminium and potassium.

Granulites differ from gneiss in that the mica is either partially or wholly replaced by granates. The composition of the rocks in granulate areas varies between dark (mafic) and light minerals (felsic). Depending on the mineral composition, soluble aluminium or iron, or base cations, heavy metals and sulphur, may occur in the soil. The rocks in the Lapland granulate area are coarse and easily disintegrate.

In addition to mafic vulcanites, black schists and mica schists also occur in the greenstone zone. Mica schists with a high aluminium concentration also occur in the northern part of the zone in Russia that extends into Norway. The composition of the schists varies, although they mainly release soluble aluminium, potassium and magnesium into the soil. Of the schist rocks, quartzite usually has a reducing effect on the amount of soluble elements in the soil.

Young sedimentary rocks, which usually have a relatively high concentration of calcium, such as sandstones, conglomerates and graywackes, occur in the northern parts of the Kola Peninsula and Norway. These rock types primarily consist of readily decomposable quartz. The particles formed in the disintegration of graywackes are usually schists or vulcanites. Calcium occurs as carbonates in the matrix of these rock types. The claystones in some parts of the Varange area have high concentrations of phosphorus.

Sensitivity of the soil to acidification

The geochemical properties of the soil are affected by thechemical and mineralogical composition of the bedrock. The geochemical properties can be used to estimate the sensitivity of the soil to acidification and the quality of the groundwater and runoff. Due to chemical decomposition and leaching, the till may contain considerably lower amounts of soluble cations than the original starting material. The minerals in the upper part of the podzol profile are more weathered and their composition is strongly dependent on the degree of weathering and on climatic and vegetation factors, as well as on the starting material. The lower part of the profile may, in some areas, have been affected by pre-glacial weathering.

Soil acidification is a process in which the hydrogen ion concentration of the soil solution increases as the base cation reserves in the soil are gradually depleted through ion exchange and the weathering of minerals. The development of a podzol profile acts as a natural buffering mechanism that prevents excessive acidification. The decomposition of organic substance, and subsequent release of weak organic acids, lowers the pH of the surface layer of the soil. Coarse-textured soil material is more sensitive to acidification then fine textured material, because the surface area of fine particles is larger and they contain relatively large amounts of exchangeable cations. As acidification increases, the dissolution of Al^{3+} as well as of base cations, is accelerated. The hydrolysis reactions of aluminium start at a pH of ca. 4.4.

The acid neutralization capacity (ANC) is a measure of how large an acid load the soil can withstand while the neutralization reactions continue to function in the soil. The regional acidification sensitivity of the soil is expressed as the sum of the equivalent concentrations of exchangeable base cations ($Ca^{2+} + Mg^{2+} + K^{+}$, expressed as meq/kg) in the mineral fraction of the soil. The risk of acidification in the mineral soil can be assessed on the basis of the dissolution of aluminium, and it is expressed as the ratio of the equivalent aluminium concentration to the sum of the equivalent base cation concentration ($Al^{3+}/ Ca^{2+} + Mg^{2+} + K^{+}$ meq/kg, Al/BC). The higher the value of the ratio, the greater is the risk of acidification.

Sensitivity of the watercourses to acidification

Watercourse acidification usually occurs in areas where the buffering capacity of the soil is low for minerological reasons or because the soil is thin or completely lacking (a high proportion of exposed bedrock). In areas with coarse-textured soils, the rate of water percolation down through the soil is high and the buffering capacity of the soil is therefore relatively unimportant. As a result, the lakes in small esker areas especially are sensitive to acidification. In soil with a low permeability, surface runoff is of more importance because there is only little chemical buffering between the water and the soil. Small lakes are more sensitive to acidification than large ones.

Conclusions

According to the results for Aqua regia extraction (HNO_3 + HCl), there are more base cations (Ca + Mg + K) in the greenstone zones and the Vaskojoki anorthosite area than in areas with granites and felsic gneisses, which are acidic rock types (Appendix 4). In the area extending from Paatsjoki to Kirkkoniemi, the occurrence of mica schists, mica gneisses, hornblende gneisses, and in some areas gabbros, increase the amounts of base cations in till. The areas with felsic gneisses also include outcrops of amfibolites and hornblende gneisses, which is reflected in the higher amounts of base cations.

The risk of acidification was estimated on the basis of the Al/BC ratio (Appendix 5). In the granite area of northern Lapland, which is a rock type that disintegrates easily, the bedrock has a reducing effect on the proportion of fine material in the till, and therefore on the amounts of base cations. As the Al/BC ratio is higher than that in the surrounding areas, the risk of acidification is higher in the granite area. No corresponding higher acidification risk was found in north-western Russia, presumably due to the too sparse sample plot network.

The higher Al/BC ratio values observed in the granulite area may also indicate a higher risk of acidification. The tills in the granulite areas have higher aluminium concentrations than in the surrounding areas because granulite contains relatively high proportions of aluminium-rich minerals such as micas. The Al/BC ratio for the Vaskojoki aluminium-rich anorthosite area mainly indicates the natural effects of the local bedrock on the geochemistry of the area, because the anorthosite area also contains large amounts of easily soluble base cations, especially calcium. The Al/BC ratio along the Paatsjoki-Kirkkoniemi axis is low and therefore there is little risk of acidification. This is also the case in the surroundings of Zapoljarny and in the greenstone areas.

Of the results for mild chemical extractions, only the results for ammonium nitrate extraction (NH_4NO_3) are covered in this report (Appendices 6 and 7). Ammonium nitrate extraction has been carried out only on part of the samples from Finland. The results for base cations are similar to those obtained with Aqua regia, although the concentrations are much lower. In the Vakojoki anorthosite area, the Al/BC ratio values obtained with ammonium nitrate extraction are very different compared to those with Aqua regia, presumably due to the fact that the aluminium in anorthosite is in a form that is not as easily soluble as e.g. in mica. The extraction of aluminium with ammonium nitrate in the mica granulite area also gave somewhat different results from those obtained with Aqua regia, which suggests a higher capacity of the soil to buffer acidification.

The pH of surface waters in a natural state is usually slightly acid, between 6 and 7. The pH values of most of the water samples from the area settle were within in this range. pH values of below 6 occur at the sampling points on the Finnish side in the vicinity of the granite area up to the felsic gneiss area near Näätämö. According to the results of the analyses on the geochemical soil samples, there is a risk of acidification in this area. These rock types have a reducing effect on the amounts of base cations in the soil, and therefore on the buffering capacity. The pH values are also low in Dalvatn, Norway. The lowest values, below 5, occurred at Sarmitunturi in the mafic granulite area, where the Al/BC ratio values are also high.

Alkalinity is used to express the capacity of water to neutralize acids. Watercourse acidification is usually indicated by a decrease in alkalinity, even before there is a decrease in the pH. The buffering capacity of water is strongly dependent on the thickness of the soil in the catchment area. This means that small lakes in the immediate surroundings of the fells are likely to have a low acid neutralization capacity. Low alkalinity also occurs in the same areas with relatively low pH values. The lowest values occurred at sampling points in Dalvatn and Limgamb, Norway, and at points between the southern side of Näätämö and Lake Inari. Individual low values also occurred near Sarmitunturi, where the pH was also low, and in Lake Sierram which is located in an area of mafic granulates. Waters that have a low alkalinity also almost invariably have a low electrical conductivity, and low concentrations of base cations.

3. References

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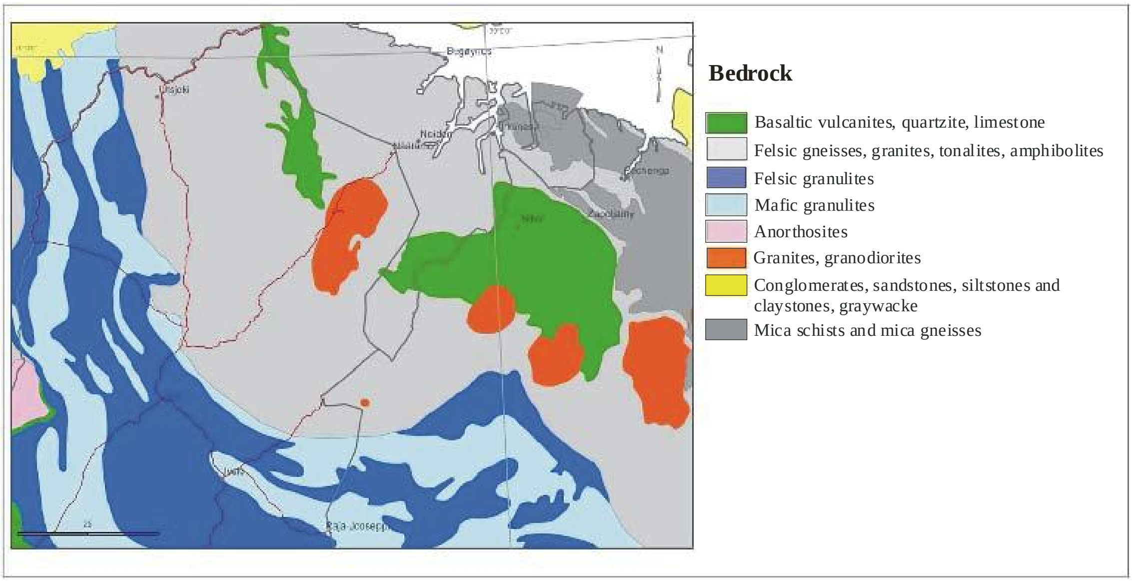
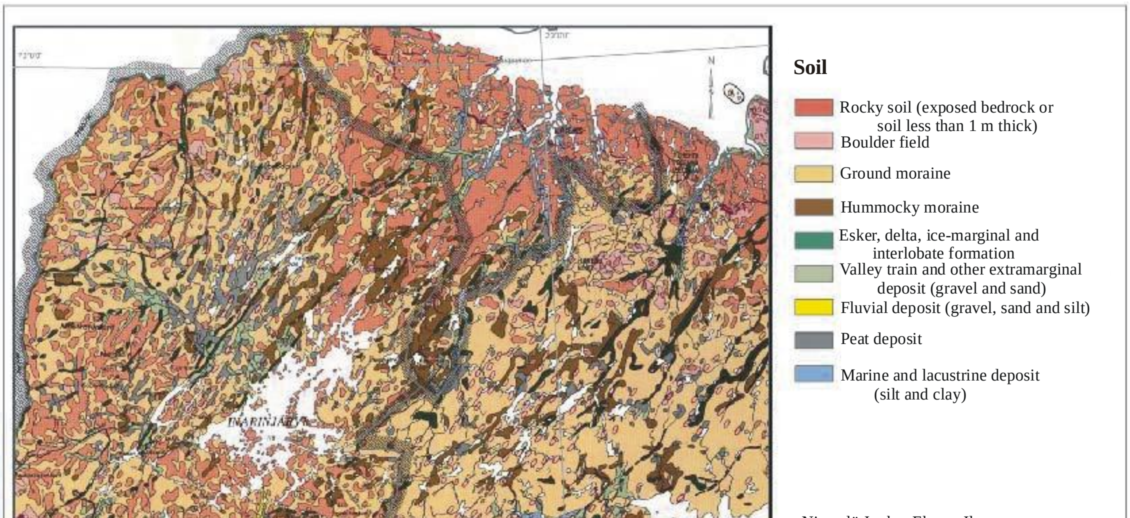
Appendix

Appendix 1.

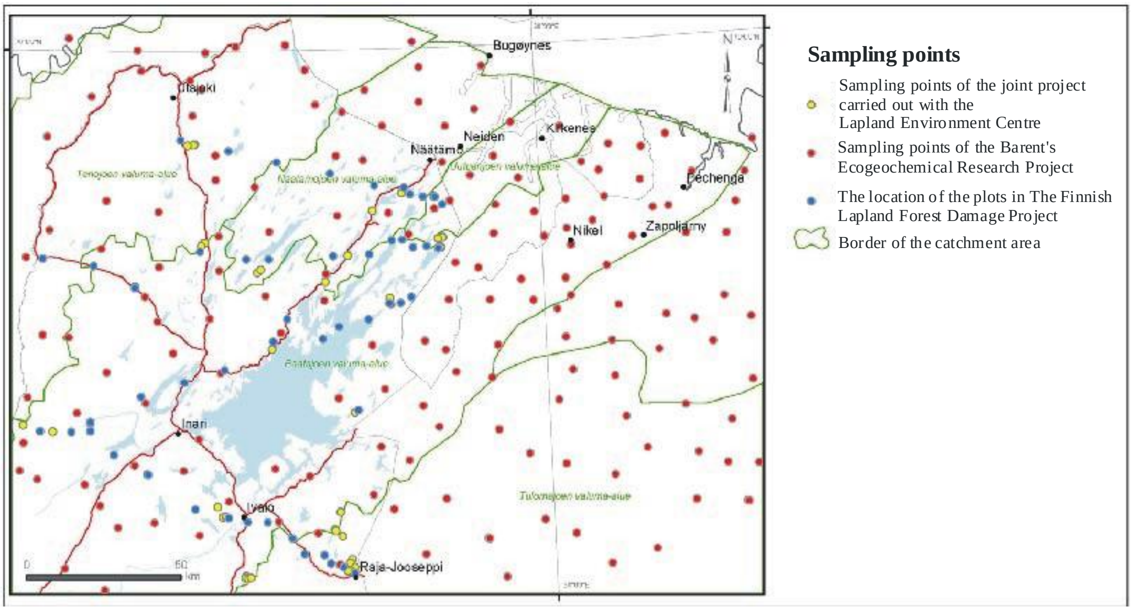


Appendix 2.

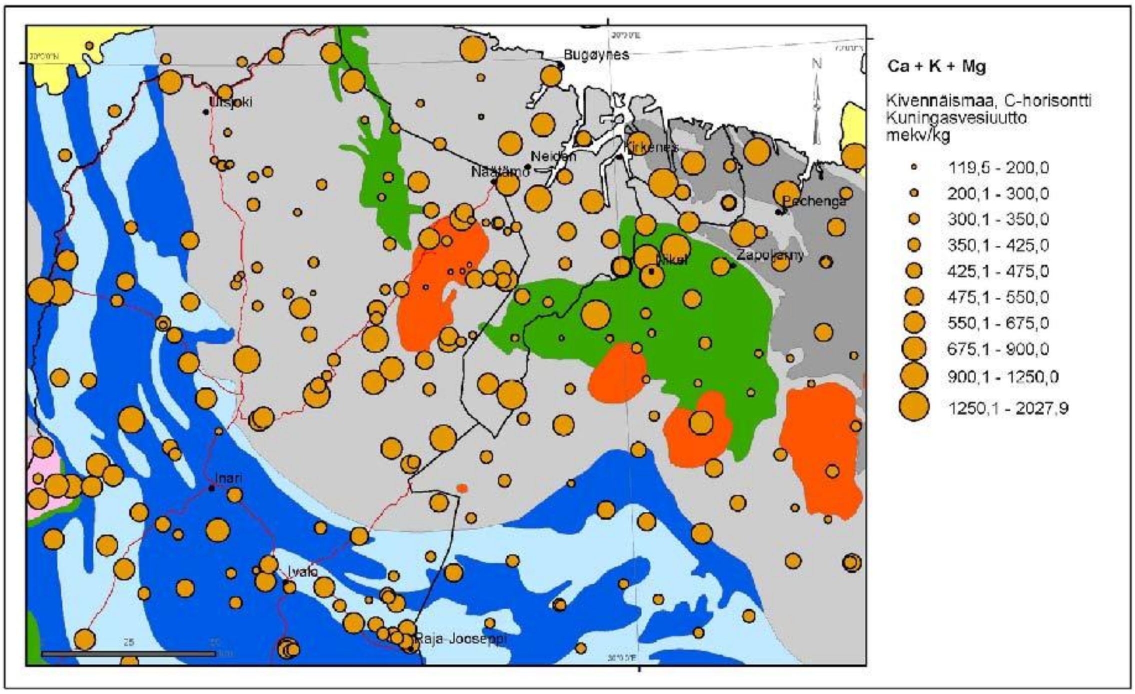


Niemelä Jouko; Ekman Ilpo; Lukashov Anatoly (eds.) 1993. (Soil and resources of Finland and Northwest part of Russian Federation, Western part)

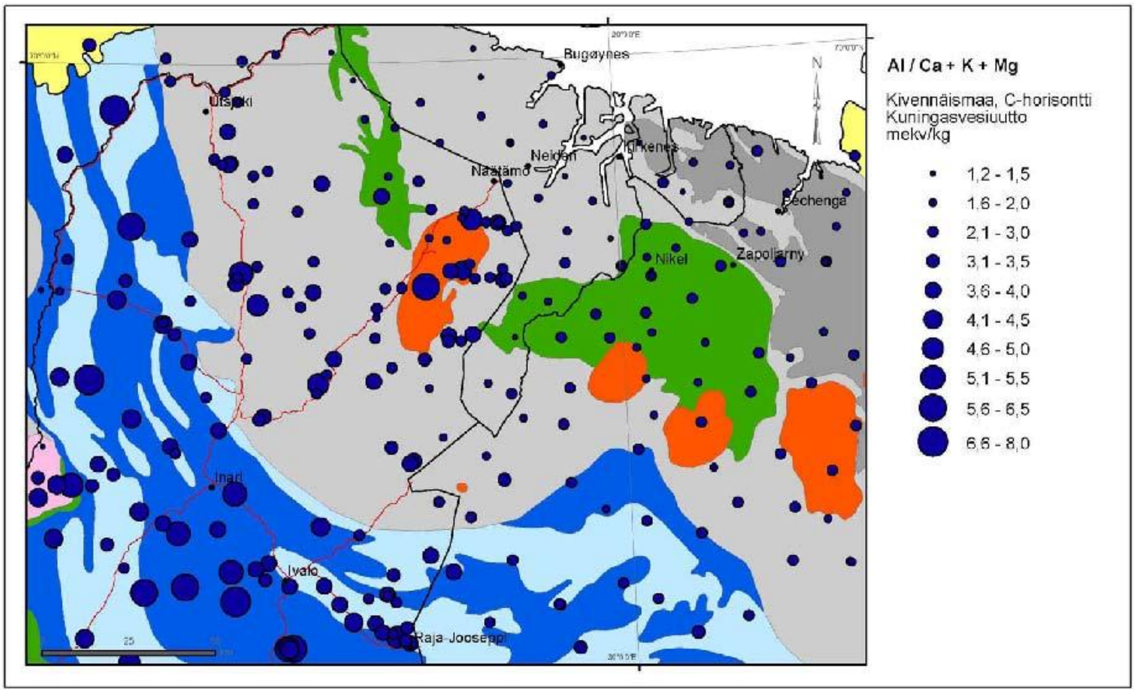
Appendix 3.



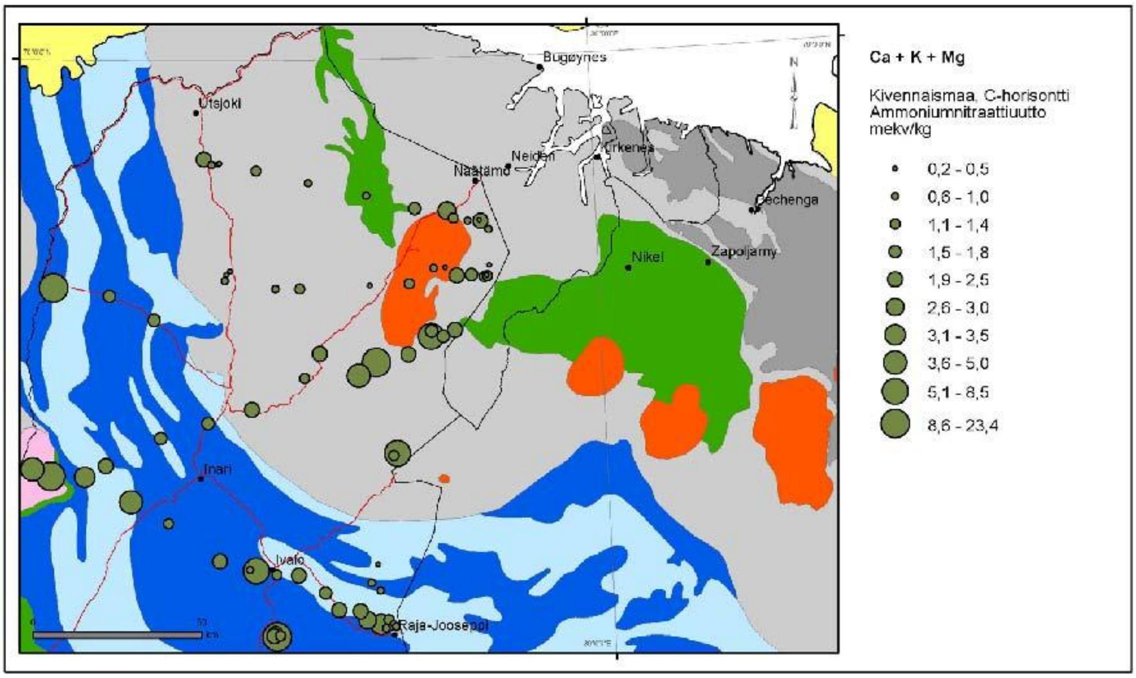
Appendix 4. Ca+K+Mg, aqua regia extraction



Appendix 5. Al/Ca+K+Mg ratio, aqua regia extraction



Appendix 6. Ca+K+Mg, ammonium nitrate extraction



Appendix 7. Al/Ca+K+Mg ratio, ammonium nitrate extraction