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Bedrock and Quaternary sediment geochemistry and biodiversity in Eastern Fennoscandia and Estonia

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Abstract. Crystalline bedrock and Quaternary sediments are the parent materials for soil, which is a substrate for plant roots and also a supplier of nutrients. Through interactions within the bedrock–soil–plant–animal–human beings system, bedrock geology and geochemistry influence all forms of life on the planet. There are 11 major elements or macronutrients that are nutritionally essential for plants and animals in constructing and maintaining cells and tissues, and up to 43 trace elements or micronutrients involved in the regulation of metabolic processes. Element concentrations in soils reflect those of parent rocks, but for healthy growth and development of plant and animal tissues there are very strict constraints on trace element concentrations. Chemical analysis of different organic materials shows that all forms of life, marine and terrestrial plants and animals, and bacteria consist of comparable proportions of the of macronutrients: O, H, C, N, P, S, Ca, Mg, K, Na, Cl , as well as trace elements. Some differences are noted in elements that are more available in sea water (Mg, I, Br, Sr, Fe, Pb) or are essential for life outside of water (terrestrial animals need more Ca and P for stronger skeletons, etc.). Limestone and dolostone of northern and central Estonia are rich in Ca and Mg, whereas the sandstones that predominate in southern Estonia consist mainly of quartz (SiO_2) and contain very few nutrients. Glacial activity in Fennoscandia transported predominantly Si-rich granite rock material to Estonia, in which trace element concentrations are very low, as in the local bedrock. The bedrock geochemistry, Quaternary cover and their influence on vegetation in some selected areas in Fennoscandia and Estonia are discussed.

Key words: geochemistry, soils, chemical elements, macronutrients, micronutrients, biodiversity, elements in plants and animals.

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Introduction

The distribution of chemical elements in the Earth crust is controlled by their physical and chemical properties, which are becoming progressively better understood with progress in geochemistry and laboratory study methods. Of the 90 (Albarède, 2009) naturally occurring stable elements, only 9 have abundances (in atomic weight) exceeding 1% (Table 1). The first 14 elements in order of the abundance comprise 99.81% of the earth's crust in terms of atomic weight. The remaining 76 elements, also known as trace elements, thus represent only 0.19%, with a mean abundance of only 0.025 atomic weight per cents; some of them are also therefore referred to as rare earth elements. Zinc, copper, and nickel, which are commonly found in everyday use, are included in these trace elements.

Table 1. Distribution of most abundant chemical elements in Earth crust, in atomic weight% (after Bulakh, 2002).
Tabel 1. Peamiste keemiliste elementide sisaldus maakoores, aatomkaalu%-des (Bulakh, 2002 järgi).

No	Element	a.w.%	No	Element	a.w.%	No	Element	a.w.%
1	O	53.39	6	Mg	1.72	11	Ti	0.22
2	H	17.25	7	Ca	1.41	12	Cl	0.10
3	Si	16.11	8	Fe	1.31	13	F	0.07
4	Al	4.80	9	K	1.05	14	S	0.05
5	Na	1.82	10	C	0.51		Total	99.81

All plants and animals need a range of different chemical elements as nutrients for normal and healthy growth and development (Thornton, 1983b). However, not all of the most widely distributed elements are needed in large amounts. Of these, 11 elements, which occur throughout the atmosphere, water, bedrocks and soils, are essential for plants and animals, namely O, H, C, N, Ca, Mg, Na, K, P, S and Cl. These are also known as macronutrients or macro-biogenic elements, of which the first four can be easily obtained from air or water, while the remaining 7 elements are more common in bedrock or are present in limited concentrations in groundwater. These elements are needed every day and the daily intake of an adult human daily intake may be 100 mg or more (Crounse *et al.*, 1983). The sources of mineral elements are soils, drinking water and food – each kind of food has its own distinct composition of macro- and micronutrients. Phosphorus, calcium, potassium, sodium and magnesium are present in every kind of food, but sulfur is usually absent from dried produce (Food and Nutrition III, 1997).

The abundances of the main macronutrients in marine and terrestrial animals, marine and terrestrial plants, and in bacteria are remarkably similar to one another, which mean that all forms of living life require the same macro-elements (Table 2). Macro-biogenic elements are very important for normal life functions and are vital for manufacturing cells and tissues in plants and animals.

There is some variation in actual element abundances according to specific environmental conditions and requirements of plants and animals. For example, terrestrial animals need stronger skeletons than marine organisms and their phosphorus content is about 3 times higher. Potassium, sodium, sulfur and magnesium are more readily available in marine environments than on land and their concentrations in marine plants and animals are accordingly higher. Bacteria do not differ very strongly from other groups, indicating that all life forms on the Earth are composed mostly from the same chemical elements. A typical 70 kg human body consists of the major elements as follows : O – 43 kg, C – 23 kg, H – 7 kg, N – 1.8 kg, Ca – 1.0 kg, P – 0.78 kg, K and S both – 140 g, Na – 100g, Cl – 95 g and Mg – 19 g (after Emsley, 1998, 2003; Uthman, 2000).

Despite numerous studies of macro- and micronutrients in soils, plants and animals, there is no consensus on the exact abundances of essential trace element concentrations (Koval'skij, 1982; Thornton, 1983a; Emsley, 1998, 2003; Trofimov *et al.*, 2000; Kabata-Pendias, Pendias, 2001; Merian *et al.*, 2004 *etc.*). The reason for this is that micronutrients are present and needed in very small amounts. For example, the normal human daily intake of selenium must not exceed 28-55 µg (Himeno & Imura, 2002). The most complete list of micronutrients is given by Emsley (1998, 2003), which was published on the Internet by Uthman (2000). For an average 70 kg human

Table 2. Average content of major elements in marine and terrestrial plants and animals, and bacteria (in g to 100 g dry matter, modified after Bowen, 1966 and Barabanov, 1985).
Tabel 2. Keskmine makroelementide sisaldus mere ja maismaa loomades, taimedes ja bakterites (g-des 100 g kuivaine kohta, modifitseeritud Bowen'i, 1966 ja Barabanovi, 1985 järgi).

Macronutrients, grams in 100 g *Makroelemendid, g-des 100 g kohta*	Marine plants *Meretaimed*	Terrestrial plants *Maismaa taimed*	Marine animals *Mereloomad*	Terrestrial animals *Maismaa loomad*	Bacteria *Bakterid*
Carbon – C	34.5	45.4	40.0	46.6	54.0
Oxygen – O	47.0	41.0	40.0	18.6	23.0
Hydrogen – H	1.5	3.0	7.5	10.0	9.6
Nitrogen – N	4.1	5.5	5.2	7.0	7.4
Calcium – Ca	1.0	1.8	0.15–2.0	0.02–8.5	0.51
Magnesium – Mg	0.52	0.32	0.5	0.1	0.7
Sodium – Na	3.3	0.12	0.4–4.8	0.4	0.46
Potassium – K	5.2	1.4	0.5–3.0	0.74	11.5
Phosphorus – P	0.35	0.23	0.4–1.8	1.7–4.4	3.0
Sulphur – S	1.2	0.34	0.5–1.9	0.5	0.53
Chlorine - Cl	0.47	0.2	0.5–9.0	0.28	0.23

body mass the 59 elements have been determined, including 11 major elements. Of 48 trace elements 43 are considered essential. Only four elements exceed the 1.0 g level: Fe (4.2g), F (2.6 g), Zn (2.3 g) and Si (1.0 g), and another four have levels greater than 0.1 g: Rb (0.68 g), Sr (0.32 g), Br (0.26 g) and Pb (0.12 g). The amounts of the remaining elements fall within the interval between 72 – 0.11 mg (after Emsley, 1998; Uthman, 2000). Table 3 shows trace element concentrations in marine and terrestrial plants and animals, and also in bacteria for some elements.

The situation with respect to microelements is the same as for major elements. The content of Zn, Rb, and Si in each group is quite comparable, although some other elements show greater differences in concentration than in the case of major elements. The abundances of Sr, I, Pb, B, Ba and Fe are highest in marine plants, which is to be expected given that ocean water contains more of these elements and that uptake from solution is relatively easy.

In excess concentrations many of the trace elements present in soils, including: As, B, Cd, Cu, F, Pb, Hg, Mo, Ni, Se and Zn, may be toxic to plants and animals or may affect the quality of foodstuff for human consumption (Thornton, 1983b). They are potentially toxic to plants and animals, but can also have adverse effects at relatively low level (Plant & Raiswell, 1983). In many countries, including Estonia, there are regulations concerning maximum permitted concentrations for poisonous and dangerous chemical elements in agricultural lands, urban and industrial environments and in drinking water.

The role of chemical elements in the natural environment began to be more understood during the early decades of the twentieth century, with the first significant findings emerging in the middle of the century. In some countries, as in Great Britain, the importance of geochemical investigations has been recognized and has been supported by government. The discovery of irregularities in the distribution of diseases regularities in the early 1960's, in particular with respect to the incidence of cancer in southwest England, initiated a special geochemistry study of Britain by multi-disciplinary team (Webb, 1983). Some 20 years later, following numerous international

Table 3. Average content of trace elements in marine and terrestrial plants, animals and bacteria (modified after Bowen, 1966 and Barabanov, 1985).
Tabel 3. Keskmine mikroelementide sisaldus mere ja maismaa loomades, taimedes ja bakterites (modifitseeritud Bowen'i, 1966 ja Barabanovi, 1985 järgi).

Microelements, mg in 100 g dry matter *Mikroelemendid, mg 100 g kuivaine kohta*	Marine plants *Mere-taimed*	Terrestrial plants *Maismaa-taimed*	Marine animals *Mere-loomad*	Terrestrial animals *Maismaa-loomad*	Bacteria *Bakterid*
Arsenic – As	3	0.02	0.0005–0.03	≤ 0.02	–
Aluminum – Al	6	50 (0.05–400)	1.5	0.4–10	–
Barium – Ba	3	1.4	0.02-0.3	0.075	–
Boron – B	12	5	2-5	0.05	–
Bromine – Br	74	1.5	6-100	0.6	–
Cadmium – Cd	0.04	0.06	0.015–0.3	≤ 0.05	–
Chromium – Cr	0.1	0.023	0.02–0.1	0.0075	–
Cobalt – Co	0.07	0.05	0.05–0.5	0.003	–
Copper – Cu	1	1.4	0.4–5	0.24	4.2
Fluorine – F	0.45	0.005-4	0.2	15–50	–
Iodine – I	3–150	0.042	0.1–15	0.043	–
Iron – Fe	70	14	40	16	25
Manganese – Mn	5.3	63	0.1–6	0.02	–
Mercury – Hg	0.003	0.0015	–	0.0046	–
Molybdenum – Mo	0,045	0.09	0.06–0.25	0.02	–
Nickel – Ni	0.3	0.3	0.04–2.5	0.08	–
Lead – Pb	0.84	0.27	0.05	0.2	–
Rubidium – Rb	0.74	2	2	1.7	–
Selenium – Se	0.08	0.02	–	0.17	–
Silicon – Si	150–2000	20–500	7–100	12–600	18
Tin – Sn	0.1	< 0.03	0.02– 2	< 0.015	–
Strontium – Sr	26–140	2.6	2–50	1.4	–
Vanadium – V	0.2	0.16	0.014–0.2	0.015	–
Tungsten – W	0.0035	0.007	0.00005	?	–
Zinc – Zn	15	10	0.6–150	16	–

conferences and workshops in environmental geochemistry and health, the main results of investigations were published in a special book (Thornton, 1983a), which presented for the first time, information concerning all aspects of environmental geochemistry and pollution in the environment in which people live (Webb, 1983). This geochemical study is an important component of the environmental and geological research programs in USA, Canada, Australia, China, Japan, Poland, Germany, Sweden, Finland, Norway, Russia and many other countries.

Material and Methods

Detailed geochemical studies of bedrock and soil, and their influence on biodiversity, were initiated in 1997–2000 within the Russian-Finnish project of the Russian Academy of Sciences, Karelian Research Centre "Inventory and studies of biological diversity in Republic of Karelia". These investigations included parallel studies of bedrock geology and Quaternary sediments, soils, climate, vegetation, fish, bird, mammals and insect population in different environments in the Republic of Karelia, with particular emphasis on areas of high nature conservation value

(Gromtsev *et al*., 2003). The author of the current paper was involved as a geologist in a research group mapping the geological complexes of Russian Karelia and as a result of 30 years experience, is familiar with bedrock composition and geochemistry in all kinds of terrain. Fieldwork throughout the years from 1962–1984 in North Karelia principally comprised many thousand kilometers of geological traverses on foot, from the White Sea to Russian-Finnish border. During all this time, the spectacular plant *Cypripedium calceolus* L. was only found in one location, covering an area of about a hectare on the Tiksozero alkali-carbonatite massive. Later, however, further occurrences were discovered throughout the entire zone of Paleoprotreozoic bedrock between Kukasozero and Paanajärvi. Geological reviews of the Karelian Region have been published in Systra (1991, 2004a). The research group at the Karelian Research Center of the Russian Academy of Sciences was characterized by close collaboration between specialists in different fields, including forestry, vascular plants, mosses, lichens, mammal species, bird fauna, insects, algal flora, periphyton, zooplankton, macrozoobenthos, and fish communities. This interaction between these specialists during field studies resulted in much new information being obtained.

Detailed fieldwork was done in the Onega Synclinorium, in the Paanajärvi National Park, and along the western and northwestern shore of Lake Ladoga. The results of previous research also facilitated characterization of the Western White Sea area and Central Karelia (Fig. 1). Later, in 2002–2003 and 2008–2009, LAPBIAT and LAPBIAT-2 financial support made it possible to visit key areas for studying the influence of bedrock geochemistry on vegetation in subarctic Lapland in Finland, in the surroundings of Kilpisjärvi and Kevo, and in the Oulanka National Park, Kuusamo. The influence of carbonate rocks on vegetation in the Kilpisjärvi Region in Lapland, at latitude 69º N, was noted by V.A. Pesola in the beginning of the last century (1928) which led to the creation in 1916 of the first protected area in Finland (now Malla Strict Reserve). Subsequently, in 1956, parts of the Oulanka River valley near the Arctic Circle, were protected within the Oulanka National Park. On the Russian side of the border the Paanajärvi National Park is larger still (1040 sq. km) and was created in 1992. There are distinct correlations between geochemistry and vegetation type, especially in the old-growth forests, which are in near pristine condition and where the chemical composition of bedrock is well studied.

In all of the areas studied, we had access to the necessary data concerning chemical composition of the bedrock. In the Onega region some 20 reduced soil profiles were analyzed specifically for major and trace element contents in soil horizons and bedrock, in order to quantitatively assess the influence of bedrock on soil composition.

The geology and composition of the sedimentary bedrock in Estonia is also well known (Raukas & Teedumae, 1997); recent studies include analysis of 20 reference samples representative of different types of bedrock (Kiipli *et al*., 2000; Kiipli, 2003, 2005). Based on the data from about 1550 analyzed samples, the geochemical atlas of the humus horizon of Estonian soil was prepared by Petersell *et al*. (1997). The 33 geochemical maps in this study, and the "Atlas of Estonian Flora" with 1353 species maps of vascular plant distribution (Kukk & Kull, 2005) were used for assessing the influence of bedrock on vegetation.

Results

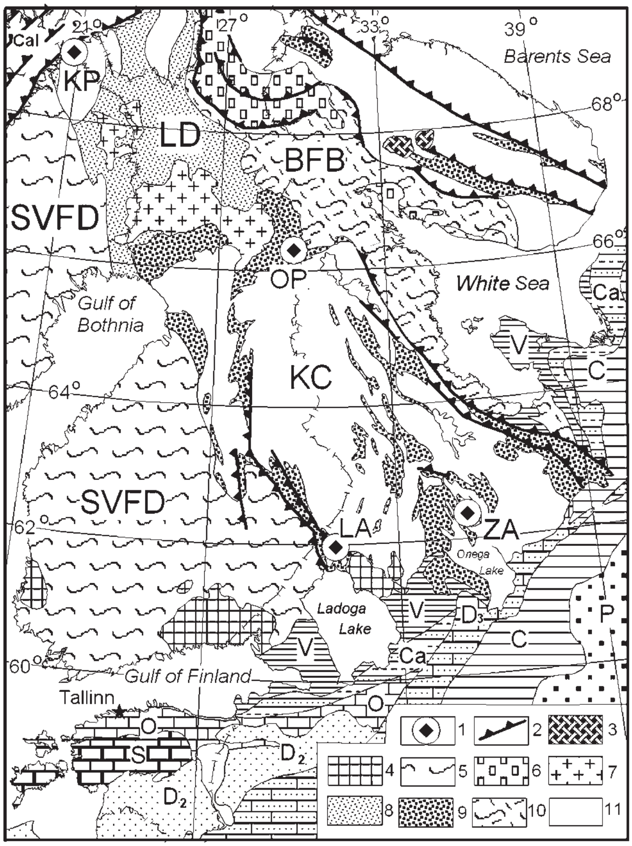
The results of study are presented separately for each region, because their geological and geochemical conditions are very different. The Republic of Karelia, in the Russian Federation, has a total area of 172 400 square kilometers, and occupies the southeastern part of the ancient Precambrian Fennoscandian Shield. The Karelian part of the Shield comprises three major northwesterly trending geological domains (Fig. 1), the Karelian Craton in the centre, the Belomorian fold belt to the northeast and the Svecofennian fold terrane to southwest (Systra, 1991, 2003, 2004a, b *etc*.). The exposed part of the Karelian Craton is 600 km long and 300 km wide, with its southeastern edge being covered by Ediacaran and Paleozoic sediments, which are contiguous with those in Estonia. The Karelian Craton formed during two distinct orogenic events, the first of which is represented by the Archean (3.8–2.5 Ga) basement, composed of Paleoarchean gneiss, gneissose diorite and migmatites, and narrow Neoarchean greenstone belts, consisting of volcanic-sedimentary rocks. The younger phase of evolution of the craton is recorded by Paleoproterozoic (2.5–1.8 Ga) volcanic-sedimentary sequences which are preserved in synclinorial structures. The Archean and Proterozoic rocks differ greatly in geochemical characteristics: basement granites and migmatites are rich in SiO_2, but contain only very small amounts of micronutrients, while Paleoproterozoic rocks are more diverse in composition, including many types of volcanic rocks, sandstone, quartzite, carbonate rocks, and shungite-bearing black schist and others. The areas selected for study were in the Onega Synclinorium and the Zaonezhje Peninsula, the Paanajärvi National Park and the northwestern shoreline of Lake Ladoga, all of which represent Paleoproterozoic bedrock with favourable rock compositions for supporting diverse vegetation (Fig. 1).

Paanajärvi – Oulanka protected reserves

Protected nature reserves near the Arctic Circle (66°10′ – 66º30′ N) are represented by two national parks across the Russian-Finnish border, one older and smaller, about 30 000 ha, in Finland (Oulanka National Park, declared in 1956) and the other, younger (Paanajärvi National Park, declared in 1992) on the Russian side of the border. Both parks have similar geological structure and vegetation. An unusually rich biodiversity characterizes the Paanajärvi–Oulanka region, with about 600 vascular plant species recorded, 67 of which have never been reported from other parts of Karelia (Systra, 1998a; Gromtsev *et al*., 2003 *etc*.). A total of 298 species of moss are known, 42 of which are listed in the Red Book of Karelia (2007). Some 443 lichen species have been recorded (Halonen, 1993), of which 10% are rare or endangered. Nearly 2000 species of fungus have been recorded from the Oulanka part of the region. In the Paanajärvi area there are 2006 insect species, 162 bird species, of which 142 nest locally and 18 of which are red-listed (Hautala, Rautiainen, 1998). This represents twice the corresponding figure for surrounding terrains and in total about 70% of the entire species diversity of Russian Karelia, where the bedrock is dominated by Archean granite gneisses. For example, the Kostomuksha Strict Nature Reserve located 250 km to south, which has an area of 47 700 ha, contains 395 vascular plant species, of which 17 are red-listed, 159 moss species, of which 6 are red-listed and 143 lichen species, of which 6 are red-listed. The Tolvajärvi Landscape Reserve, which covers 42 000 ha, some 450 km to the south of Paanajärvi contains 368 species of vascular plants, of which 9 are red-listed and 141 moss species, of which only 1 is listed in the Red Book of Karelia (2007). This difference can be primarily attributed

Figure 1. Schematic geological map of the eastern part of the Fennoscandian Shield and northwest marginal zone of the Russian Platform.

Joonis 1. Fennoskandia kilbi idaosa ja Vene platvormi loodeääre skemaatiline kaart.



Legend: 1 – Places of detail study: KP – Kilpisjärvi, OP – Oulanka-Paanajärvi region, ZA – Zaonezhje peninsula, Onega synclinorium, LA – northwestern shore of Lake Ladoga. 2 – thrusts; 3 – Devonian nepheline syenites; 4 – rabakivi granites; 5 – Svecofennian folded domain (SVFD); 6 – Lapland-Belomorian Granulite Belt; 7 – Kemijarvi granites. Early Proterozoic volcanic-sedimentary rocks: 8 – Lapland Domain (LD); 9 – cover on the Archean basement. 10 – Belomorian Fold Belt (BFB); 11 – Archean granite gneiss terrain with greenstone belts.

Late Proterozoic – Paleozoic sedimentary cover (from youngest): P – Permian and younger rocks (carbonate rocks, claystone, salt, anhydrite, sandstone); C – Carbon (carbonate rocks, claystone, coal, grewacke); D_3 – Upper Devonian (carbonate rocks, sandstone, clay); D_2 – Middle Devonian (sandstones); Cal – thrusted Scandinavian Caledonides; S and O – Silurian and Ordovician (carbonate rocks, oil shale); Ca – Cambrian (sandstone, claystone); V – Vendian (arkose, sandstone, claystones).

Tingmärgid: 1 – detailsemalt uuritud piirkonnad: KP – Kilpisjärvi, OP – Oulanka–Paanajärvi, ZA – Zaonežje poolsaar, Oneega sünklinoorium, LA – Laadoga järve loodekallas. 2 – pealenihked; 3 – Devoni nefeliinsüeniidid; 4 – rabakivi graniidid; 5 – Svekofennia kurrutatud domeen (SVFD); 6 – Lapimaa-Valgemere granuliitide vöö; 7 – Kemijärvi graniidid. Paleoproterosoikumi vulkaanilised ja settekivimid: 8 – Lapimaa domeen (LD); 9 – pealiskord Arhaikumi aluspõhjal. 10 – Valgemere kurrutusvöö (BFB); 11 – Arhaikumi rohekiltade vööde ja graniitgneissidega kaetud ala.

Neoproterosoikumi – Paleosoikumi setteline pealiskord (alates noorematest): P – Permi ja nooremad kivimid (karbonaatsed kivimid, savikivim, sool, anhüdriit, liivakivi); C – Karbon (karbonaatsed kivimid, savikivim, kivisüsi, grauvakk); D_3 – Ülem-Devon (karbonaatsed kivimid, liivakivi, savi); D_2 – Kesk-Devon (liivakivi); Cal – Skandinaavia Kaledoniidide pealenihete vöönd; S ja O – Silur ja Ordoviitsium (karbonaatsed kivimid, põlevkivi); Ca – Kambrium (liivakivi, savi); V – Vendi kompleks (arkoos, liivakivi, savi).

to bedrock geochemistry, the Oulanka and the Paanajärvi NP being underlain by Paleoproterozoic (2.5–1.9 Ga) volcanic and sedimentary rocks – including carbonates, while the bedrock in the surrounding region consists of diorites, granites and gneisses of the Karelian Craton and highly metamophosed gneisses and migmatites of Belomorian Fold Belt (Systra, 1991, 2004b).

Alpine-Arctic vegetation occurs on the highest mountains Nuorunen (576 m), Mäntytunturi (550 m) and Kivakka (499.5 m). *Loiseleuria procumbens* L., *Phyllodoce caerulea* (L.) Bab., *Diphasiastrum alpinum* L. and other species can be encountered there. Along the Kiutaköngäs rapids in the Oulanka River valley, a relict community of *Dryas octapetala* L. has survived since the Ice Age, together with *Calipso bulbosa* L. In contrast, there are no more than 30–35 species of northern aspect. On the Paleoproterozoic volcano-sedimentary rocks, soils have pH near neutral and are enriched in all necessary trace elements. Bedrock composition is the main reason for the abnormally high biological diversity here. This is principally due to the presence of carbonate rocks – dolomite marbles, which are responsible for the neutral soil composition. Most occurrences of lady's slipper (*Cypripedium calceolus* L.) are confined to carbonate rocks exposures, where up to 2000 individuals maybe found within an area of a some hundred square meters. Slope aspect and exposure also have a marked effect on microclimate. Thus, southern species inhabit south-facing slopes and deep valleys which show a greenhouse effect, whereas northern species persist under favourable conditions on cold north-facing slopes and in deep shady valleys. One cliff – Ruskeakallio (Brownrock Cliff) on the northern shore of lake, composed of an albitite dyke with numerous carbonate veins, is about 60 m high and more than 300 m long. This vertical sunny wall with hanging gardens is unique with its botanical rarities such as *Gypsophila fastigiata* L., *Aspenium ruta-muraria* L., *Draba cinerea* Adams, *D. daurica* DC, *Potentilla nivea* L., *Androsace serpentronalis* L., *Lappua deflexa* (Wahlenb.) and more than 20 additional rare plants that have been found here. During the last 150 years many generations of famous Scandinavian, and after the last war, Russian botanists have visited this locality. Now it is one of the most picturesque destinations for sightseeing in the Paanajärvi NP, although it is not permitted to set foot on the shore, in order to save the unique vegetation. The Paanajärvi National Park is also the last place where the lichen *Usnea longissima* Ach. has been recorded during the last 50 years in Eastern Fennoscandia (Kotiranta *et al*., 1998). A total of 97 vascular plants present at Paanajärvi have been listed in Red Book of Karelia (2007). One of the indications that the soils at Paanajärvi are compositionally favorable is the abundance of old spruce forest, which covers more than 60% of territory. Pine forests prevail on the glaciofluvial Quaternary coarse-grained gravels in the Oulankajoki River and Olanga River valleys, which formed through the action of very powerful melt-water streams (Systra, 1998) during melting of the last ice sheet, about 10 thousand years ago.

The deep valley of the Oulankajoki River – Lake Paanajärvi – River Oulankajoki, has been incised into the Maanselkä Uplands, the highest points of which rise up to 400–600 m above sea level. This topography has given rise to a special migration corridor at 109 m above sea level on Lake Pääjärvi to elevations of 200 m above sea level on the western side of the uplands. Lake Paanajärvi has a maximum depth of 128 m, and its deepest part is thus only 8 m above sea level. Over the last 20 years a number of new species of birds and plants have been found on both sides of the Maanselkä divide. Vegetation richness on favourable soils gives also the diversity of living nature, birds, animals, fishes and insect species.

Onega synclinorium and Zaonezhje peninsula

The Onega Synclinorium in one of the largest Paleoproterozoic structural features preserved in the Karelian Craton and covers about 10 thousand square kilometers surrounding Lake Onega (Fig. 1). The Paleoproterozoic succession in the Onega Synclinorioum usually begins with Jatulian conglomerate, sandstone and dolomite marble, and includes a remarkable salt and gypsum horizon, discovered during drilling in 2008, at a depth of about 2 km, and finishes with Ludicovian black shungite-bearing schist, mafic lava and numerous sills, of age 2.2–1.8 Ga. The metamorphic grade in these rocks is relatively low. The synclinorium represents two separate folding episodes intersected by numerous NW-trending fault zones, parallel to the axial plane of the open later generation folds. The Zaonezhje Peninsula sequence contains sandstones, carbonate rocks, mafic volcanic rocks, shungite-bearing black schists, and shungite-bearing aleurolites. The chemical composition of the main rock types and soils in reduced profiles directly overlying bedrock is given in Table 4, which shows that soil chemical composition is influenced by bedrock and Quaternary sediments. In soils overlying shungite schist (carbon rich black schist)) the concentrations of most elements are higher (Table 4, No 1, 2) than in bedrock (Table 4, No 3). This indicates that the soil has been enriched from the surrounding environment. About 70% of the Republic of Karelia is covered by granites, granite gneisses and migmatites of the Karelian Craton, which are rich in Si, Al, Ca, Na, K, but contain very low concentrations of vital micronutrients. For example chromium concentrations in soil is less than in bedrock, while Ni, Cu and S concentrations are reduced in soil lower horizons. Shungite, consisting of native carbon, is burned on ignition resulting in high weight losses (LOI). The influence of bedrock geochemistry on soils is less pronounced (Table 4, No 4, 5), when soil thickness over bedrock exceeds 0.5 m (Table 4, No 6). Soils are enriched in SiO_2, Fe_2O_3, Na_2O, K_2O and Cr from Quaternary cover sediments.

Soils overlying Archean basement granites were studied on the northwestern limb of the Onega Synclinorium (Table 4, No 9, 11). Soils on granite (Table 4, No 9, are enriched in SiO_2, Fe_2O_3, Cr, V and Zn (Table 4, No 7–8), while on another granite (Table 4, No 11) in Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Cr, V, Zn and S (Table 4, No 10). For soils developed on diabase, peridotite and marble the organic matter content in the soil humus horizon is higher, up to 58–65%, if differences in LOI are considered, while SiO_2 content is reduced to 59–14%. Soils on gabbro-diabase in the village of Hirvas are more acid, containing 59% SiO_2 in horizons 4–16 cm and 16–45 cm, and lower abundance of macro-elements (Table 5, No 12–14) than in bedrock (Table 4, No 15). Usually the element concentration diminishes gradually from bedrock to the humus horizon: A_2O_3, FeO, MgO, K_2O, V, Cu, S, but for CaO, Co and Zn trend is opposite. Zn content increases from 104 ppm in bedrock to 473 ppm in the humus horizon (Table 4, No 12–15). On peridotite (Table 4, No 19) the tendency for decreasing concentrations of elements in soils characterizes Fe, MgO, CaO, SiO_2, Al_2O_3, Na_2O, K_2O, Ni, Cr, Cu, V, Co, whereas S and Zn show the opposite tendency (Table 4, No 16–18). The theoretical composition of dolomitic marble is CaO 30.4%, MgO 21.7%, CO_2 47.9%, which is quite close to that of these elements in dolomite – $CaMg(CO_3)_2$ – from Pyalozero Village (Table 4, No 22). In soil intervals only MgO and CaO have originated from bedrock, all other nutrients have been derived from Quaternary sediments (Table 4, No 21–22). It is likely that the abundance of CaO, MgO and necessary micronutrients has resulted in the formation of a rich humus horizon, which is the basis for biodiversity. Phosphorus and sulphur are enriched in

Table 4. Composition of reduced soil profiles on bedrocks (in italics) in Onega structure (macro-elements and LOI in wt%, microelements in ppm). Analyses made in laboratories of the Karelian Research Centre RAS, Petrozavodsk, Karelia, Russia.

Tabel 4. Mittetäielike mulla profiilide koostis erinevatel aluspõhja kivimitel (kursiivis) Oneega struktuuris. Makroelemendid ja kuumutuskaod (LOI) kaalu%-des, mikroelemendid ppm. Analüüsid teostatud Venemaa TA Karjala Teaduskeskuse laborites Petroskois, Karjalas, Venemaal.

No, soil intervals, bedrock *Nr., mulla intervallid, aluspõhja kivim*	SiO_2	Al_2O_3	Fe_2O_3 +FeO	MgO	CaO	Na_2O	K_2O	LOI	Ni	Cr	Cu	V	Zn	Co	S
1, 0-15 cm	69.29	9.05	6.35	1.56	1.15	0.90	1.99	8.58	71	96	88	302	145	8	1200
2, 15-71 cm	78.38	7.59	2.91	1.06	0.59	0.39	1.94	6.21	39	89	32	263	104	8	400
3, shungite	*59.80*	*3.80*	*1.39*	*0.60*	*0.21*	*0.05*	*1.55*	*31.86*	*40*	*102*	*40*	*225*	*16*	*8*	*7700*
4, 20-50 cm	72.77	11.25	3.66	1.07	2.30	3.02	1.57	3.13	32	34	16	67	32	12	300
5, 50-70 cm	70.09	13.35	3.18	0.63	1.90	2.67	1.83	5.45	32	55	16	100	55	8	200
6, diabase	*50.00*	*14.35*	*11.38*	*4.40*	*7.87*	*2.29*	*1.27*	*5.63*	*95*	*27*	*72*	*145*	*104*	*55*	–
7, 10-20 cm	77.23	10.74	2.33	0.94	1.44	2.77	1.95	2.17	24	27	8	39	16	8	800
8, 20-45 cm	77.20	10.05	2.44	1.06	1.56	2.97	1.86	1.38	32	41	8	61	56	8	200
9, granite	*71.38*	*14.50*	*2.19*	*1.47*	*8.87*	*3.98*	*2.85*	*1.78*	–	–	–	–	*24*	–	–
10, 12-34 cm	67.68	14.33	3.03	0.96	1,77	2.70	1.84	6.74	32	48	8	78	72	8	500
11, granite	*73.20*	*13.78*	*1.76*	*0.52*	*1.24*	*3.78*	*4.44*	*0.59*	–	–	–	–	*40*	–	–
12, 0-4 cm	22.92	5.51	2.23	1.01	2.79	0.82	0.61	62.26	32	41	7	73	473	24	300
13, 4-16 cm	59.29	11.99	5.62	1.80	2.50	2.79	1.23	12.71	79	89	24	162	264	24	800
14, 16-45 cm	59.31	11.58	5.66	1,97	2.10	2.74	1.32	13.56	24	75	24	246	225	16	1800
15, diabase	*49.20*	*12.94*	*10.45*	*9.75*	*5.39*	*3.42*	*0.80*	*4.20*	*134*	*226*	*32*	*221*	*104*	*47*	*100*
16, 0-5 cm	16.97	3.19	1.50	0.99	1.22	0.70	0.57	74.05	24	0	6	28	112	0	1200
17, 5-16 cm	44.91	8.68	3.91	2.25	3.12	2.23	1.24	31.82	71	34	72	34	104	16	1000
18, 16-32 cm	50.46	10.09	6.59	3.28	3.09	2.42	1.48	21.08	55	137	144	224	72	16	800
19, peridotite	*41.26*	*5.28*	*11.64*	*26.82*	*3.79*	*0.07*	*0.02*	*8.46*	*1493*	*1680*	*32*	*168*	*803*	*95*	*0*
20, 0-5 cm	14.22	2.10	4.16	11.76	14.55	0.43	0.42	51.35	24	27	16	34	136	16	1800
21, 5-15 cm	17.50	2.39	2.55	16.37	16.41	0.51	0.45	42.40	16	7	24	67	72	16	500
22, marble	*1.04*	*0.04*	*1.59*	*21.38*	*28.72*	*0.05*	*0.01*	*46.16*	*10*	*5*	*10*	*6*	*62*	*8*	*100*

Places of sampling: 1-3 – soil and shungite schist, Zazhogino quarry, Tolvuja; 4-6 – soil and diabase, Kumsa River; 7-9 – soil and basement granite, Kumsa River; 10-11 – soil and basement granite, 5 km to north of Kumsa Bridge; 12-15 – soil intervals and diabase, Hirvas village; 16-19 – soil and peridotite, Konchozero Lake; 20-22 – soil and dolomite marble, Pyalozero village.

Proovide võtmise kohad: 1-3 – muld ja šungiit, Zažogino karjäär, Tolvuja; 4-6 – muld ja diabaas, Kumsa jõgi; 7-9 – muld ja aluspõhja graniit, Kumsa jõgi; 10-11 – muld ja aluspõhja graniit, 5 km põhja poole Kumsa sillast; 12-15 – mulla intervallid ja diabaas, Hirvase asula; 16-19 – peridotiit, Konchozero järv; 20-22 – dolomiitne marmor, Pjälozero küla.

the humus horizon, due to the activity of animal and microbial life in the soil (Ponge, 2003; Lukina *et al.*, 2008), even if they are absent from the underlying bedrock, as for example, sulfur in the case of peridotite (Table 4, No 16–19).

Quaternary sediments are not usually transported by ice over distance greater than 50 km, and typically less than 5 km. For the Onega Synclinorium, this means that favorable volcanic and carbonate rock influences are present everywhere, including glaciofluvial eskers and deltas. It must be noted that the most of bedrock contains notable amounts of Mg, Ca, Na, Fe, Mn, mafic volcanic rocks and shungite (carbon)-bearing rock, in addition to essential metallic micronutrients such as Co, Cu, Cr, Ni, V, and Zr. About 800 vascular plants species have been recorded here as well as many rare plants from the Red Data Book for Fennoscandia (Kotiranta *et al.*, 1998) and Republic of Karelia (Red Book…, 2007), which is twice the number of vascular plant species (350) in the large (500 000 ha) Vodlozero National Park, which is located at the same latitude and shares the same climatic conditions, but which is situated 50 km to east, where thick Quaternary till and glaciofluvial deposits overlie Archean granites. To the east of the Vodlozero NP, in the Archangelsk Region is the Kenozero NP, which has similar physiographic conditions, but differs geologically due to the presence of Paleozoic carbonate rock and till derived from mixed sources, including granite from the Karelian Craton and local limestone. The number of vascular plant species present here is 534, of which 61 are listed in the Red Book.

Western and Northwestern Ladoga Lake area

The northeastern marginal zone of the Svecofennian Domain near Lake Ladoga is characterized by mantled granite gneiss domes. Narrow synclinal zones between basement domes comprise equivalents of the same Paleoproterozoic volcanic and sedimentary rocks, including dolomite marbles that occur in the Onega Synclinorium, which are here overlying by younger Kalevian sediments. The central part of Lake Ladoga coincides with the Mesoproterozoic Ladoga graben (aulacogene), which also includes the thick dolerite sill on outcropping on the islands of the Valaam archipelago. Lake Ladoga is the largest freshwater body in Europe and shows a significant effect on microclimate. The coastline is much more favourable for agriculture and natural vegetation compared to terrain some 100–150 m above lake level, where autumn frosts occur several weeks earlier. The Precambrian basement is divided into blocks by numerous fault zones, which are reflected topographically as deep narrow valleys in which some northern species of mosses and lichens are found. The total number of vascular plant species in the area reaches 750, of which 550 are met also in the Valaam archipelago. The number of lichens and lichenicolous fungi exceeds 800 and 269 mosses are listed here (Gromtsev *et al*., 2003; Red Book…, 2007). The main reason for such biodiversity is the wide development of carbonate and mafic volcanic rocks with their high concentrations of necessary needed nutrients.

Kilpisjärvi area, Finnish Lapland, NW Finland

This area belongs geologically to the eastern marginal zone of the Scandinavian Caledonide nappes, far to the north of Arctic Circle (69° 03'). The oldest intrusive, volcanic and sedimentary rocks belong to Neoarchean basement in an autochthonous position, cratonised 2.7–2.8 Ga ago. This deformed and metamorphosed basement is unconformably overlain by Early Cambrian basal conglomerate, with silty and quartz-rich intercalations (Lehtovaara, 1995). Dolomitic marble is typical of the Jerta Nappe, which has been thrust somewhat to the southeast and forms layer 1–40 m thick, in some places strongly folded and sometimes covering extensive parts of the hill slopes. On the upper part of the Pikku-Malla fell these dolomite outcrops coincide with most of the rare plant finds: *Erigeron acer* L., *E. uniflorus*, *Rhododendron lapponicum* L., *Polystichum lonchitis* L., *Pseudorchis albida* (Fernald), *Silene uralensis* Rupr., *Veronica fruticans* Jacq. These and other protected rare and endangered vascular plant species are only found in the presence of carbonate rocks. During the flowering of *Dryas octapetala* L. the folded dolomite layers on the hillslopes resemble natural flowerbeds. The influence of dolomite continues down slope and also in the spring waters. Numerous small springs discharge in the lower part of slopes and are associated with very diverse flora. About 470 vascular plants species are listed in the surroundings of Kilpisjärvi. The importance of carbonate rock for vegetation was first noted here by A. Pesola (1928). There are now three botanical protected areas that include all large dolomite outcrops in the Kilpisjärvi area: the Malla Strict Nature Reserve, 3000 ha, has been under protection since 1916, and was declared as a strict reserve since 1938, the Saana Protected Territory was declared in 1988, and the Anjalonja Protected Area. Although there are many other hills with the same elevation and slope aspect, most of the rare and protected species are absent where the bedrock is other than dolomite. Pelitic schists contain more microelements than quartzite and may be a more favored substrate for *Dryas octapetala* L.

Geochemistry of bedrock and Quaternary sediments in Estonia

Estonia is located along the southern shore of the Gulf Finland and the Precambrian crystalline basement is everywhere covered by Ediacaran and Paleozoic sedimentary cover. The sedimentary cover together with basement is tilted gently southwards at a gradient of nearly 3 m per 1 km and its thickness increases from 125–140 m in the north to 600 m and more in the south and southwest Estonia. Cambrian, Ordovician and Silurian bedrock are exposed in Northern Estonia as west-east belts, whereas to the south these older sequences are covered by younger rocks. The resistant Ordovician limestone forms cliffs up to 56 m high, known as the North Estonian Klint (Fig. 1).

During the last 400 000 years, the region was repeatedly covered by ice during several glacial events, which advanced towards the south or southeast from the Scandinavian Mountains, transporting metamorphic and igneous rock material to Estonia. The Svecofennian domain is covered mostly by granites, migmatites and gneisses, with mafic rocks reaching only 3.5% in till and boulder material (Pirrus, 2009). Northern Estonia belongs to the zone of glacial erosion, where the thickness of Quaternary cover seldom exceeds 5–10 m, being in many places on alvars less than 1 m thick; eskers and glaciofluvial deltas may however, exceed 20 m in thickness. Southern Estonia is in contrast characterized by moderate accumulation, with till cover in the Otepää and Haanja Uplands commonly exceeding 100 m and in the ancient buried valley of Abja attains a maximum thickness of 207 m. Local carbonate rock cobbles and pebbles are predominant in thick till sequences in Central Estonia, but near the southern border the crystalline Fennoscandian bedrock becomes prevalent. These have a strong influence on soil composition, the Ca content in the humus horizon falling to 0.2% or less, while in carbonate bedrock it is between 1–8%. The Mg content in sediments derived from carbonate rocks is usually 0.5–0.8%, whereas in southern Estonia it is commonly less than 0.09%. The minimum content of Mn in soils for healthy growth and development of plants is 400 ppm (Trofimov *et al*., 2000), but much of Estonia has Mn concentrations less than 230 ppm (Petersell *et al*., 1997).

Cambrian claystones and sandstones outcrop in the narrow zone between the klint and Baltic Sea shore. A number of micro- and macronutrients: K, Mg, P, B, Co, Cr, Cu, Ni, V and Zn have higher concentrations in these clays (Table 5, Es–1) than in carbonate rocks and sandstones. The influence of clays is however restricted to this narrow zone. The Ordovician sequence begins with the Pakerordi Stage sandstone and the kerogenous dark-brown argillite horizon, which has a thickness of 7.7 m in northwestern Estonia, diminishing to about 2.0 m in northeastern Estonia. This argillite is notable for high concentrations of U (up to 400 ppm), K As, B, Co, Cr, Cu, Hg, Mo, Ni, Pb, V and Zn (Table 5, Es–2). Soils are enriched in F, Mn. Mo, P, u and Y, but only within a zone about 10 km wide zone to south, along the klint (Petersell *et al*., 1997).

Table 5. Macro- and micronutrients content in the main bedrock groups of Estonia (compiled after full reference analyses of Kiipli *et al.*, 2000; Kiipli, 2003, 2005). Macro-elements and LOI in weight %, micro-components in ppm. Samples: Es-1–claystone (clay), Ca_2, Kunda; Es-2–kerogenic argillite, O_1, Tallinn; Es-3–limestone,O_2, Tallinn; Es-9–limestone, O_3, Vasalemma; Es-15–metabentonite, Kinnekulle bed, O_3, Pääsküla; Es-4–dolostone, S_1, Mündi quarry; Es-14–limestone, Lower Silurian, Taagepera drillcore; Es-5–sandstone, Middle Devonian, Suur-Taevaskoda outcrop, Ahja River.

Tabel 5. Makro- ja mikrobioelementide sisaldus peamistes Eesti aluspõhja kivimite rühmades (koostatud Kiipli et al., 2000; Kiipli, 2003, 2005 täielike etaloonanalüüside järgi), makroelemendid ja kuumuskaod (LOI) kaalu%-des, mikroelemendid – ppm. Proovid: Es-1 – savikivim (savi), Ca_2, Kunda; Es-2–kerogeenne argilliit, O_1, Tallinn; Es-3–lubjakivi,O_2, Tallinn; Es-9–lubjakivi, O_3, Vasalemma; Es-15–metabentoniit, Kinnekulle kiht, O_3, Pääsküla; Es-4–dolokivi, S_1, Mündi karjäär; Es-14–lubjakivi, Alam- Silur, Taagepera puursüdamik; Es-5–liivakivi, Kesk-Devon, Suur-Taevaskoda paljand, Ahja jõgi.

Elements	Es-1	Es-2	Es-3	Es-9	Es-15	Es-4	Es-14	Es-5
SiO_2	59.24	52.14	4.84	1,21	63.00	2.84	10.06	95.1
TiO_2	0.88	0.76	0.077	0.022	0.20	0.041	0.11	0.23
Al_2O_3	17.38	13.15	1.10	1.25	18.04	0.75	2.12	1.81
Fe_2O_3	4.29	0.85	0.06	0.5	0.59	0.1	0.28	0.11
FeO	2.60	3.02	0.44	–	0.14	0.35	0.18	1.33
MgO	2.58	1.11	0.85	1.25	0.76	20.42	1.91	0.05
CaO	0.84	0.22	50.51	52.67	0.29	29.35	45.68	0.047
K_2O	5.84	7.95	0.51	0.16	14.91	0.07	0.08	0.07
Na_2O	0.13	0.10	0.08	<0.03	0.05	0.26	0.68	1.03
P_2O_5	0.31	0.13	0.42	0.043	0.077	0.012	0.023	0.022
Cl	0.13	0.02	0.03	0.04	0.04	0.07	0.03	0.01
S	0.05	2.19	0.12	0.19	0.04	0.11	0.22	0.01
C	0.20	11.29	11.16	12.00	0.12	12.47	10.52	0.06
LOI	4.95	19.91	40.39	42.61	1.37	45.33	38.00	0.29
As	1.3	37	<1	0.80	2.6	<1	4.8	<3
B	150	53	21	8.9	40	12	20	23
Ba	420	379	29	20.09	119	14	211	147
Cd	<1	<1	<1	<5	<1	<1	8.1	<1
Co	20	12	1.8	<3	4.0	1.5	5.2	2.6
Cr	78	80	9	8.25	9	9	62	31
Cu	25	105	3	4.0	6	<4	17	10
F	1195	570	545	<100	1200	<100	350	<100
Hg	<0.01	0.162	<0.01	–	0.023	<0.01	<0.01	<0.01
Mn	320	158	460	371.4	16	214	120	98
Mo	<2	56	<2	<1	1.0	<2	0.8	<2
Ni	40	98	4	3.99	6	4	13	9
Pb	11	77	5	13.94	9	4	127	7
Rb	176	118	10	2.77	63	7	17	20
Se	<4	2.3	<6	0.50	<3	<3	4.4	<4
Sn	3,9	3.2	<1	<1	7.2	<1	20	0.73
Sr	91	53	178	113.1	10	32	492	19
V	109	509	9	3.40	14	11	12	11
Zn	176	133	4.0	8.46	38	5	32	4

The central and northern part of the Estonian mainland and the Western Islands are composed of Ordovician and Silurian carbonate rocks: marl, limestone and dolostone (Table 5, Es–3, Es–4, Es–9, Es–14). The entire region, except in areas of thick Quaternary cover, is enriched in Ca (1.25–6.06%), Mg (0.44–2.12%), and sporadically in Mn and F. High fluorine contents are typical for felsic volcanic ash (metabentonite) layers (Table 5, Es–15). All other micronutrients in carbonate rocks are present in small concentrations (Table 5) as they are in soils developed on such bedrock.

Southern Estonia is covered mostly by sandstones, which usually contain more than 95% quartz (Table 5, Es–5). As might be expected, concentrations of macro- and micronutrients in bedrock and Quaternary cover are low. The Sakala and Otepää Uplands contain material transported by ice from northern Estonia – mostly carbonate rocks – and from the Fennoscandian Shield – crystalline rock, mostly granite and migmatite. Many elements, such as B, Cd, Co, Cr, Cu, F, Hg, K, Mo, Na, Ni, Sn, Sr, U, V and Zn, occur at very low concentration in Fennoscandian bedrock and on the geochemical maps of the humus horizon of soil of Estonia they are distributed more evenly than elements derived from local bedrock. Because Estonian soils thus represent mixing of two components of differing composition, the influence of soils on vegetation is generally not so marked when compared with soils in Fennoscandia, where differences in vegetation are much greater. Nevertheless, *Asplenium ruta-muraria* L., *A. septentrionale* L., *Equisetum hyemale* L., *E.* × *moorei* Newman, *etc* grow only on the carbonate rocks of northwestern Estonia.

The most comprehensive listing of Estonian vascular plants and their distribution (Kukk & Kull, 2005), has made it possible to assess how bedrock composition influences vegetation. The list records a total of 1353 plant species, about 50 of have uncertain occurrence, while some 700 are distributed more or less evenly, with no preference for bedrock type. A further 160 rare plant species likewise show no particular correlation with rock type, while 67 species are only found in proximity to the Baltic coast. There are 55 species that are endemic to carbonate bedrock and 35 species that grow exclusively on the sandstones of southern Estonia and 76 species that are completely absent from sandstone terrain. There are 137 species that occur predominantly on carbonate rocks, compared to only 58 species that grow preferentially on sandstone. The Western Estonian Islands emerged from the Baltic Sea later than the continental part of Estonia, which is reflected in vegetation diversity: 46 vascular plant species are absent from Saaremaa, but another 50 species occur only on Saaremaa and have not been found on the mainland. The soil in Estonia has formed from two main sources, local sedimentary bedrock and crystalline material transported by glaciers from Fennoscandia. Geochemical maps of the humus horizon show that the concentrations of some elements – B, Ba, Cd, Co, Cr, K, Na, Ni, Sn, U, Th, V, Zn – show little or no influence from local bedrock. Conversely, abundances of Ca, Mg and F in soil are correlated with bedrock composition, Mo and P concentrations in particular being closely associated with the kerogenic argillite near the North Estonian Klint; bedrock controls on Fe and Hg distribution is not so evident. In summary, material derived from the Fennoscandian Shield provided most of the following microelements in Estonian soils: B, Ba, Cd, Co, Cr, K, Na, Ni, Sn, U, Th, V and Zn. Recommended maximum permissible concentrations have been legislated for most elements, but natural minimum concentrations can also be defined, below which there may be adverse influences on plant and animal health and life. For Mo this lower limit is 1.5 ppm and for Mn it is 400 ppm, but normal ecological functions require a concentration of 3000 ppm (Trofimov *et al.*, 2000). In Estonia the average Mo content 2.5 ppm, but almost a third of the country has concentrations less than 1.2 ppm, Concentrations of Mn are between 75–2400 ppm, but half of the country records concentrations less than 400 ppm.

Comparison of average microelement concentrations in bedrock and humus horizons from the Zaonezhje region in Russian Karelia and Estonia (Table 6) clearly

Table 6. Comparison of average content of some micronutrients in soil and bedrock of Zaonezhje, Karelia, Russia (Table 4), and in bedrock of Estonia (Table 5), excluded are peridotite in Karelia, clay clay and kerogenous argillite in Estonia by their very high contents of micro-components and very limited development near the surface.

Tabel 6. Mõne olulise mikrobioelemendi keskmine sisaldus muldades ja aluspõhja kivimites Zaonežje poolsaarel, Karjalas, Venemaa (tabel 4) ja Eesti aluspõhja kivimites (tabel 5), analüüsidest on kõrvaldatud Karjala peridotiit, Eesti savi ja kerogeenne argilliit väga kõrge mikromponendide sisalduse ja piiratud leviku tõttu maapinna lähedases vööndis.

Component, ppm *Komponent, ppm*	Number of analyses *Analüüside arv*	Co	Cr	Cu	Ni	V	Zn
Zaonezhje soil, humus layer *Mulla huumuskiht*	5	13	141	90	34	37	21
Zaonezhje soils on bedrock Zaonežje *muld otse kivimil*	6	13	94	161	33	64	37
Zaonezhje bedrocks *Zaonežje aluspõhja kivimid*	7	43	165	155	154	408	31
Bedrock of Estonia *Eesti aluspõhja kivid*	6	4	10	12	7	27	7

shows that soils in Karelia contain more microelements than those in Estonia. At systematic geochemistry study of soil humus horizon in Zaonežje peninsula in 2000 only in single probes Cu exceeded 2-3 times highest permitted concentrations for agricultural lands.

Discussion

The geochemistry of bedrock and Quaternary sediments strongly influences soil nutrient content and at the same time biodiversity. Where beneficial nutrients are abundant in soils, southern species may spread far to the north, as *Fragaria vesca* L. and *Ribes rubrum* L. which are found near the Arctic Circle in the Paanajärvi NP. The importance of micronutrients for wild animals and birds is also well known. In Northern Karelia in autumn, when blueberries are ripe, forest birds such as the capercaillie (*Tetrao urogallus* L.), black grouse (*Tetrao tetrix* L.) and even ducks tend to be selective in feeding, preferentially choosing plants growing on gabbroic and ultramafic rock, where berries are bigger and contain more micronutrients. Larger mammals, including moose (*Alces alces* L.), brown bear (*Ursus arctos* L.), and reindeer (*Rangifer tarandus* L.) feed on mushrooms in summer and autumn time, because of the need for microelements. Animals that have access to all necessary nutrients are healthier and stronger, and hence better equipped to defend territory and offspring. Areas with abundant flowering plants are favored by insects, and therefore also by birds which then make nests in these places.

Geochemistry is therefore a valuable tool in assessing regional biodiversity in national parks, and in protection of species or areas of natural significance, or in designating areas for construction and urban development and agricultural use. A relationship between bedrock geochemistry and endemic diseases is established in many places (Thornton, 1983b; Crounse *et al.*, 1983; Golovin *et al.*, 2004 etc.). We must not forget that all life is built from the same building blocks, known as elements (Emsley, 2003).

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Aluspõhja kivimite ja Kvaternaari setete geokeemia ning bioloogiline mitmekesisus Ida-Fennoskandias ja Eestis

Ülo J. Sõstra

Kokkuvõte

Aluspõhja kivimid ja Kvaternaari setted on muldade moodustumise algallikaks, mis on substraadiks taimede juurtele ja samuti ka toiteainetega varustajaks. Läbi vastastikuse mõju süsteemis aluspõhja kivim–muld–taim–loom–inimene aluspõhja kivimite geoloogia ja geokeemia mõjutab kõiki elu vorme planeedil. Keemiliste elementide hulgas on elu jaoks 11 olulist elementi või makrobiogeenset elementi: O, H, C, N, P, S, Ca, Mg, K, Na, Cl, mis on suure tähtsusega taimede ja loomade toitumisel, sest neist moodustatakse rakud ning koed. Veel kuni 43 mikroelementi või mikrobiogeenset elementi on kaasatud ainevahetuslike protsesside reguleerimiseks. Elu kõik erinevad vormid, mere- ja maismaa taimed ning loomad, ja bakterid sisaldavad võrreldavates kogustes vajalikke makro- ja mikrobiogeenseid elemente. On mõned erinevused sõltuvalt keskkonnast, enam kättesaadavad merevees on Mg, I, Br, Sr, Fe, Pb, aga eluks maismaal on loomadel tugevama luustiku jaoks vaja enam Ca ja P jne. Muldade elementide sisaldus sõltub nende olemasolust lähtekivimis või settes. Mõne elemendi vähesus või liigne kontsentratsioon võib põhjustada kõigi elu vormide arenguhäireid või hävimist.

Venemaa Karjalas 1997–2000 läbiviidud kompleksne bioloogilise mitmekesisuse inventuur erineva geoloogilise tagapõhjaga aladel koos spetsiaalsete geokeemiliste mulla erinevate kihtide ja lähtekivimite analüüsiga näitas, et parimate toiteomadustega looduslikud mullad Karjalas moodustuvad Paleoproterosoikumi kivimitel, mis sisaldavad karbonaatseid marmoreid ja aluselisi vulkaniite. Seal on küllalt Ca, Mg ja vajalikke mikroelemente ning biioota liigirikkus võib foonilisest olla kuni 2 korda suurem ja praktiliselt kõik kaitsealused liigid esinevad ainult neil aladel.

Kesk– ja Põhja–Eesti lubja- ja dolokivid sisaldavad küllalt taimedele ja loomadele vajalikke Ca ja Mg, kuid sisaldavad suhtelised vähe metallilisi mikroelemente, mitmeid kordi vähem kui Karjala parimatel muldadel. Lõuna-Eesti liivakivid sisaldavad kuni 95% SiO_2 ja väga vähe vajalikke toiteaineid. Liustikud tõid Fennoskandiast Eesti alale peamiselt ränirikast graniitset materjali, milles mikroelemente on vähe. Soontaimede liigirikkus on karbonaatsetel muldadel suurem ja liivakividel väiksem. Geokeemiline tagapõhi mõjutab kõike elu vorme, paljud endeemilised haigused on seotud aluspõhja kivimite, muldade ja põhjavee keemilise koostisega. Sellega tuleb arvestada nii elurajoonide plaanimisel kui ka kaitsealuste liikide kaitsel ja kaitsealade piiride paikapanemisel.

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