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The characteristics of mineral subsoils of Finnish cut-away peatlands related to different geological areas

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In Finland, the whole peat layer of a peat production area is used due to the value of the basal peat as energy peat. In this situation the properties of the mineral subsoil below the peat layer are significant when choosing the form of after-use. The geochemical provinces are based on the chemical features of the fine material in till, related to differences found in the bedrock, defined by Geological Survey of Finland. The study of peat production areas (1998–1999, covering 9800 ha) shows that the characteristics of the provinces affects the subsoil sediments. In Lake Ladoga–Bothnian Bay zone subsoils were rich in sulphur and iron. The amount of water soluble sulphur was 3–6 times higher than that in the Granitoid area of Central Finland and the Archaean gneiss areas (calculated as mg/kg). Below the highest shoreline of the ancient Litorina Sea the average content of the water soluble sulphur in subsoil sediments was ca. seven fold compared to the content found above the highest shoreline, (calculated as mg kg^{-1}). There was also a difference in soil acidity between these areas. Nutrient content varied between sediments, which have the same fine material percentage. In the Lake Ladoga–Bothnian Bay geological zone and in the zones of Svecocarelian schists and gneisses, natural nutrient levels are high when compared to the Granitoid areas.

Key words: cut-away peatlands, after-use, mineral subsoil, geochemical province, Litorina zone

Introduction

Finnish peat production for energy uses reached its current extent just after the energy crises in the 1970's. The first sites prepared for peat production in the 70's are now becoming exhausted and it is now the time to plan the after-use for many abandoned peat production areas i.e. cut-away areas. In Finland, the whole peat layer of a peat production area is used because of the value of the basal peat as energy peat. The remaining peat layer is generally thin, and consequently, the properties of the mineral subsoil are important when choosing the after-use of cut-away peatlands.

In planning the after-use of the cut-away areas, the beneficial chemical characteristics must be taken into account. This is most important when the applied after-use is forestry, agriculture or energy crop production.

The location of the peatlands in relation to geological areas became an interesting issue, because an area called Litorina Zone (covered once by the Litorina sea) has been for a long time known to be a geochemically hazardeous area, “area of acidic clays”. The sulphur rich soils of this area have been studied for example by Purokoski (1959). Yli-Halla (2003) has pointed out that leaving acidic sulphate soils undrainded can prevent further oxidation of sulphides and acidity. Litorina-zone is a band-formed area close to coastline. This area was covered by sea during a Baltic Sea period called Litorina, when the sea was at high level and the water quality was closer to the ocean waters. Because of land uplift and a cooling climate, Litorina sediments are now on dry land. Close to the current coastline, Litorina sediments are already covered by younger sediments. As it is important to pay specific attention to the effects of the Litorina zone in reletion to the other geological areas, the locations of the bogs in this study are checked against the Litorina shoreline 7500–700 years ago as described by Eronen & Haila (1990).

Geochemical provinces defined by the Geological Survey of Finland are based on chemical studies of fine material in till. Their chemical differences in till are mostly related to differences in the bedrock (Koljonen 1992). The knowledge of the differences of the subsoil between areas could be used as a tool to predict the suitability of the cut-away areas for different purposes such as afforestation.

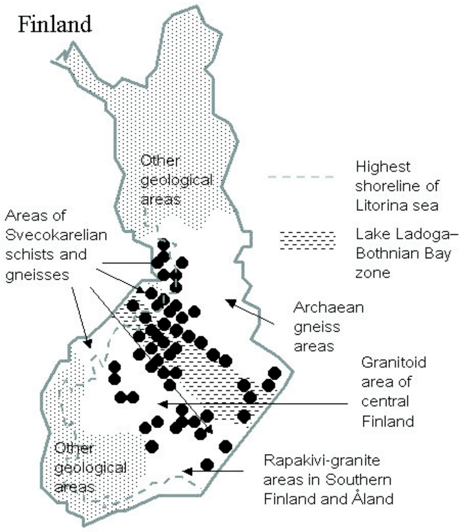

Fig. 1. The location of the study sites (black circles) in relation to the geochemical provinces in Finland. The dashed line depicts the highest previous shoreline of Litorina sea. TheGeological information is illustrated according to Geochemical Atlas of Finland, Part 2 (Koljonen 1992).

Kuva 1. Tutkittujen suonpohjien sijainti (mustat ympyrät) ja geokemialliset alueet. Katkoviiva osoittaa Litorina-meren korkeimman rannan sijaintia. Kartta on piirretty Koljosen (1992) mukaan.

Material and methods

Subsoils of 54 peatland areas recently released from peat production in Finland were studied in 1998–1999 (Fig. 1, Tables 1 and 2). The total area was 9800 ha.

The criteria for choosing the cut-away areas for this study were based on the amount of released area and their ownership. All peat production areas owned by Vapo Oy, where production had ended or was ending within next few years either entirely or in some part of the area, were included in the object list. From this list, areas with largest proportion owned by the producer were sampled to this study. In these areas the producer was most likely to be able to choose the after-use form based on the mineral subsoil quality. The whole production area was included in the study material.

Fieldwork methods were chosen to cover the variation in the geological environments. Research lines chosen were in an orientation that would most likely cross all the geological formations in the mineral subsoil lying under peat. Glacial flow directions (known earlier) during last ice age gave a good base for locating the studied traverses. In most of the areas, the research line orientation was crossing the latest glacial flow direction. However, close to the end moraines or other ice edge formations, the research line orientation coincided with the latest glacial flow direction. The information of the glacial flow directions were obtained from Geochemical Atlas of Finland (Koljonen 1992). The number of sampling points was 25–50 / 100 ha that were sampled from 3–5 research lines / 100 ha. This sampling density gave enough material for creating the maps of the coarse scale subsoil types. The lowest sampling densities were used in areas studied earlier with ground radar. In contrast, the highest sampling densities were used in the areas, where only poor background information was available or where the subsoil combinations varied considerably. All sampling points were studied in the field and about 20% of the samples were also studied in the laboratory. The field studies included classifying the soil texture to tills and other sorted sediments and making other visual observations like the colour and roundness of the stones and the boulders (made in order to estimate the distance to original bedrock). Laboratory studies included the analysis of grain size distribution and chemical features of the subsoil. Grain size distribution was tested by dry sieving and areometer analysis. The concentrations of P, NO_3-N, NH_4-N S and Fe were analysed from the water solution and Ca, Mg and K as exchangeable elements. The nutrient analysis was carried out with atomic absorption spectrophotometer. The grain size distribution was studied because it is in relation to both cation exchange (nutrient retention) capacity and water permeability in the soil. This information could also provide information on the usefulness of the mineral soil as material, for example for construction purposes. Natural nutrient contents were studied mainly for possible agriculture or forestry needs. Possibly harmful elements were studied to predict water quality in case of building artificial lakes or planning deeper ditches for cut-away areas. The study material included the topmost 50 cm of the mineral subsoil.

For this study (except for comparison of the Litorina area sulphur comparison) the samples were selected by discarding the samples from the cut-away areas, which were already in any after-use, because of the possible fertilisation treatments or other treatments, which could have disturbed the subsoil. In the relatively sulphur rich areas, all the results represents the real surface area as a percentage of hectares. In other chemical comparisons results are averages, medians and standard deviations calculated from all the samples taken. These samples do not represent exactly the equal amount of hectares because some extra samples were taken in areas where are unusually large selection of different subsoil types.

In order to make comparisons considering the nutrient retention capacity, very coarse grained samples were analysed as a separate group. Very coarse samples in this study are samples having less than 15% of the weight of the fine material (<0.06 mm grains). This principle is based on observations in previous forest experiments. Tree's growth in sites, where the mineral subsoil includes more than 15–20% <0.06 mm grains is significantly better than in the sites having coarser soil texture (Aro & Kaunisto 1998).

A specific classification of the soil acidity was developed for categorizing the results. "Relatively sulphur rich" sediments in this study are defined in a statistical way based on the categorization of subsoil sediments to acidic sediments or sediments that have potential to produce significant acidity. Sediment sample was classified to acidic if its pH value was below the standard error of the overall mean pH value in the data, and

Table 1. The surveyed cut-away peatlands and their proportion of the total surveyed cut-away area presented by the geochemical provinces.

Taulukko 1. Tutkittujen suonpohjien pinta-ala ja niiden osuus kokonaissuonpohja-alasta eri geokemiallisilla alueilla.

	Cut-away peatland	
Geochemical province	studied, ha	% of the total area
Archaean Gneiss areas	859	9
Areas of Svecocarelian schists and gneisses	3286	34
Lake Ladoga– Bothnian Bay zone	3332	34
Granitoid area of Central Finland	1668	17
Rapakivi-granite areas in Southern Finland and Åland	651	7

simultaneously, if the concentration of the soluble sulphur in the sample was larger than the overall mean soluble sulphur concentration.

In an earlier study (Lötjönen 1998), a subsoil was classified clearly sulphur rich if the pH value was 4.5 or less, and if the concentration of the soluble sulphur in the sample was above the standard error of the overall mean in the data.

Furthermore, another method was developed for the study: the *nutrient number* (Lötjönen 1998, Lötjönen et al. 2002). This method can be used for analysing the suitability for forestry or agriculture. The *nutrient number* is calculated from the amounts of potassium, magnesium and calcium (soluble as ammonium acetate) (equation 1). K, Mg and Ca were chosen because of their common appearance in subsoil. Nitrogen and phosphorus contents were very small because of the low decomposition of the organic biomass. K, Mg and Ca were equalized by using coefficients 1, 3 and 8 respectively based on the relations in the study results. Without coefficients subsoil nutrient characteristics would have been controlled by Ca-concentrations.

nutrient number = [Ca (mg/kg) + 3 x Mg mg/kg + 8 x K mg/kg] / 100 (1)

In final results the very coarse samples are adjusted to province characteristics. This means the minimum proportion of the fine material defined separately for each geochemical province. This was done in order to calculate the minimum nutrient number for all the areas as an average for all sediments, whose proportion of the fine material is 13–17%. The minimum province level is the minimum proportion of the fine material equivalent for minimum nutrient number inside a geochemical province.

Principal Component Analysis (PCA) was used to identify the underlying patterns in mineral subsoil features. Rotation Method Varimax was used with Kaiser Normalization. The analyses were done using the SPSS 12.0 Windows statistical tool package (SPSS 2003).

Results

Sulphur and acidity in the subsoil of cut-away areas

On average, 11% of subsoils in the cut-away areas were relatively sulphur rich and 48% of these sediments are very fine. Very fine sediment in this study means the sediment where grain size is below 0.06 mm and it is consisted by 90% or more of the dry mass. However, 29% of the relatively sulphur rich sediments were very coarse, which in this study means sediments having 15% or less of grain size <0.06 mm.

A large proportion of all the relatively sulphur rich subsoils was located in the Lake Ladoga – Bothnian Bay-zone. Some of these areas were also inside the Litorina zone. Other areas with sulphur rich subsoil are found inside the areas of Svecocarelian schists and gneisses. The bogs in this geochemical province were frequently located inside the estimated Litorina zone. A high percentage of relatively sulphur rich soils were found inside the Rapakivi-granite areas in Southern Finland and Åland. In this study, the study

Table 2. The sulphur (S) rich subsoils of the cut-away areas and their proportion of the total cut-away area by the geochemical provinces.

Taulukko 2. Rikkipitoisten suonpohjien pohjamaan ala ja niiden osuus kokonaissuonpohja-alasta eri geokemiallisilla alueilla.

Geochemical province	Relatively sulphur rich cut-away area ha	%
Archaean gneiss areas	0	0
Areas of Svecocarelian schists and gneisses	321	10
Lake Ladoga– Bothnian Bay zone	650	20
Granitoid area of central Finland	0	0
Rapakivi-granite areas in Southern Finland and Åland	176	25

area was statistically limited, because relatively sulphur rich subsoils were actually located inside only one peat production area.

Under the highest shoreline of Litorina Sea, 13% of subsoils were clearly rich in sulphur. Above the highest shoreline of Litorina Sea, clearly sulphur rich subsoils covered about 8% of the total area, and most of them above the highest shoreline were found inside the Lake Ladoga – Bothnian Bay zone (Lötjönen 1998). About 25% of the subsoils turned out to be relatively sulphur rich in Litorina zone. Under the highest shoreline of the Litorina Sea the average concentration of water soluble sulphur in subsoil sediments was 106 mg kg^{-1} and 15 mg kg^{-1} above the highest shoreline. In more uncertain "border areas" the average concentration was 28 mg kg^{-1} (Lötjönen et al. 2002). Accurate information on the location of the highest shoreline of Litorina Sea was unfortunately not available from every part of the studied areas. Therefore, some areas were classified into the border area, where the accurate location of the shoreline was not known.

The average pH of the subsoil sediments below the highest shoreline of Litorina Sea was 5.5 (standard deviation 0.5), whereas above the highest shoreline, the pH was 6.1 (standard deviation 1). This seems to be related to the previously known large content of sulphur compounds in Litorina clays that increase the soil acidity when they become oxidised (Lötjönen et al. 2002).

Considering the properties of subsoil, the most interesting geochemical province seemed to be the Lake Ladoga– Bothnian Bay zone. Subsoils rich in sulphur were commonly found in this area, where the average concentration of the water-soluble sulphur was 28 mg l^{-1}. This can be compared to the Granitoid area of Central Finland, where the average amount of water-soluble sulphur was 5 mg l^{-1}.

The content of the main nutrients in subsoils

The contents of calcium, magnesium and potassium were highest in Lake Ladoga – Bothnian Bay zone. These results are presented in Fig. 2. Many similar values were high in the areas of Svecocarelian schists and gneisses. High nutrient concentrations were also found in Rapakivi-granite areas in Southern Finland and Åland, but sampling was carried out in relatively limited area, and therefore, in order to get more reliable estimates, larger sample size would be evidently required.

Particle size distribution was an important characteristic when considering nutrient conditions in the soil considering e.g. afforestation. Electrical conductivity (EC) cannot be used for estimating nutrient availability in subsoil sediments. No correlation between EC and the most important nutrients was found, which means that the effect of soil nutrient content on EC was hidden behind other factors.

In the Lake Ladoga– Bothnian Bay zone, very coarse sediments (less than 15% <0.06 mm grains) were rich in nutrients compared to the granite areas and the Archaean gneiss areas. The areas of Svecocarelian schists and gneisses had very coarse sediments, which had some capacity for holding nutrients. The differences between these geochemical areas were relatively most significant considering the coarse materials and they decrease slightly towards the higher proportions of fine material in the soil.

The nutrient number was used for example for finding local limit values for afforestation use. In this study 15% of fine the material in subsoil sediments (<0.06 mm) was considered to be the average minimum level for afforestation and the whole study average *nutrient number* for this level (fine material content 13–17%) was 2.5. In the areas of Svecocarelian schists and gneisses, 15% of fine material gave a *nutrient number* very close to 2.5. In Lake Ladoga– Bothnian Bay zone *nutrient number* 2.5 was reached with 12% fine material content. In the Granitoid area of central Finland *Nutrient number* 2.5 was reached at 22% of fine material. In Archaean gneiss areas possibly approximately 25% of fine material was needed for this *nutrient number* level.

General *nutrient number*s in different geochemical provinces are presented in table 3. These *nutrient number*s were divided to categories by grain sizes. In the areas of Svecocarelian schists and gneisses the *nutrient number* (median) for very coarse sediments was 2.5 and in Archaean gneiss areas only 0.5. In Lake Ladoga– Bothnian

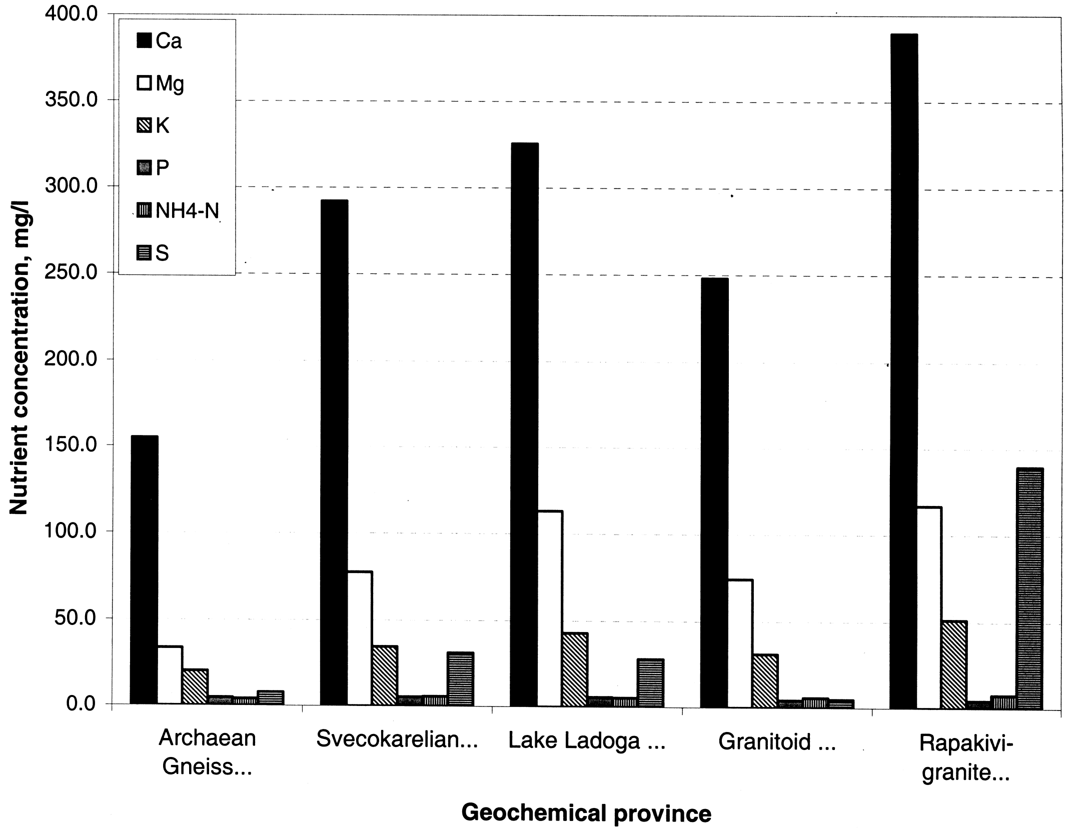

Figure 2. Some average concentrations of nutrients in the subsoil of the cut-away areas presented by the geochemical provinces. The average fine material (<0.06 mm) percentages in the samples studied were in the Archaean gneiss areas, 35%, in the areas of Svecocarelian schists and gneisses, 43%, in the Lake Ladoga– Bothnian Bay zone, 52%, in the Granitoid area of Central Finland, 39 %, and in the Rapakivi-granite areas in Southern Finland and Åland, 50 %.

Kuva 2. Keskimääräisiä eri geogemiallisten alueiden pohjamaan ravinnepitoisuuksia tutkituilla suonpohjilla. Keskimääräinen mineraalimaan hienolajiteosuus (raekoko<0.06mm) oli arkeeisten gneissien alueella 35 %, svekokarjalaisten liuskeiden ja gneissien alueella 43 %, Laatokan-Perämeren vyöhykkeellä 52 %, Keski-Suomen granitoidialueella 39 % ja Etelä-Suomen ja Ahvenanmaan rapakivi-graniitti alueella 50 %.

Bay zone the *nutrient number* (median) was 5.1 for sediments where the proportion of fine material is 15–90%, whereas in the Archaean gneiss areas it was only 2.8. There was a large variation between individual cut-away areas. Total after-use limitations calculated partly based on these factors are presented in table 4.

Ash and iron content in subsoils

The average coarseness of the sediments varied slightly between the provinces. Finer sediments with possibly higher cation exchange capacity can help to rank the provinces according to the richness of nutrients. The samples analysed in Lake Ladoga - Bothnian Bay zone were slightly finer compared to the others.

The ash content did not vary much between the provinces. The average ash content varied between 97% and 98.6% of the total weight. The lowest ash content and the highest standard deviation were found in the areas of Svecocarelian schists and gneisses.

There were large differences in the iron (water soluble) content between the provinces. The highest average iron concentration was found in the Lake Ladoga - Bothnian bay zone, 278 mg l^{-1}, whereas the lowest iron concentration, 1 mg l^{-1}, was found in the Granitoid area of Central Finland. The iron concentrations in the soil in the Rapakivi-granite area in Southern Finland and Åland were not analysed.

Factors affecting the subsoil characteristics

Factor analysis was carried out to identify the underlying factors that would explain the pattern of correlations within the mineral subsoil characteristics. Principal Component Analysis was used as the extraction method to form uncorrelated linear combinations of the observed variables. Five new components were found after this factor reduction. The rotated component matrix is presented in table 5 to inform how the original factors are represented in new components as loadings.

The first component had the maximum variance and can be called the nutrient component. Calsium, magnesium and moisture are strongly loaded in this component, which is bound to the fine material percentage. Potassium is loaded slightly only. The *nutrient number* (which actually was performed from these nutrients) naturally follows the same orientation. Other components explain smaller proportions of the variance and are all uncorrelated with each other.

The second component can be interpreted to be the sulphur compound component, because sulphur was the best explanatory factor within this component. Furthermore, both pH and EC are included in this component. The role of phosphorus has not been studied.

The third component was the iron component, the fourth one was the the bulk density component, and the fifth one was called as the nitrate component.

EC is commonly used method to measure substrate and soil nutrients. However, this analysis supported the principle of not using EC to describe nutrient levels in mineral subsoil of the cut-away areas for estimating their nutrient content and whether it is sufficient for plant production. In material studied EC had the highest correlation coefficient (0.95) with sulphur concentration and clear negative correlation (–0.83) with pH. The coefficient of the correlation between pH and sulphur was –0.77, and simultaneously, that of the correlation between pH and calcium was only 0.07. Ash content and NH_4-nitrogen was in clear negative correlation (correlation coefficient –0.72). Apparently, the ammonium form of nitrogen in the subsoil is extracted from the peat above it. Nitrate form of nitrogen had no significant correlation with any other elements. This is probably due to its very low presence in the soil. In the study material, the nitrate concentration was only seldom over the observation limit and thus difficult to study.

Analysing the geochemical provinces with new variables (principal components) revealed

Table 3. The *nutrient number* of subsoils within different geochemical provinces (The description of the nutrient number have been presented in the body text).

Taulukko 3. Pohjamaan ravinneluku *eri geokemiallisilla alueilla (*Ravinneluvun *johtaminen selostettu tekstissä)*

	%	Average nutrient number Grain size < 0.06mm				median		
Geochemical province		all	<15%	15–90%	>90%	<15%	15–90%	>90%
Archaean gneiss areas	35	3.1	0.5	3.9	2.1	0.5	2.8	2.1
Areas of *Svecocarelia*n schists and gneisses	43	7.7	2.7	5.1	14.1	2.5	3.7	12.4
Lake Ladoga– Bothnian Bay zone	52	7.5	3.2	6.5	12.4	2.0	5.1	12.6
Granitoid area of central Finland	39	6.6	1.3	3.7	14.6	1.3	2.3	11.9
Rapakivi-granite areas in Southern Finland and Åland	50	10.1	0.7*	7.7*	14.0	0.7*	7.7*	16.2

*Note that in the Rapakivi-granite areas the estimates of the two coarsest categories are based on the samples obtained only from only one case of cut-away peatland.

differences between the provinces. Nutrient feature gave a clear low mean (–0.60) in the Granitoid area of central Finland, Lake Ladoga - Bothnian Bay zone and the areas of Svecocarelian schists and gneisses gave slightly positive results, 0.07 and 0.09. The sulphur compound component was strongest in the areas of Svecocarelian schists and gneisses (0.16). This is probably partly due to location of these areas inside the Litorina zone. In the Granitoid area the sulphur compound feature was weakest (–0.42). However, inside the Litorina zone, the sulphur compound component was significant (0.53), whereas outside this zone, it was not (–0.35). Iron component (third component) seemed to be the strongest in the Lake Ladoga - Bothnian Bay zone (0.32) and the weakest in the Archaean gneiss areas (0.60) and (0.59) in the Granitoid area. The Rapakivi-granite areas in Southern Finland and Åland were ignored because of too small number of samples.

Discussion

The leaching of nutrients and harmful compounds from cut-away areas is particularly relevant question when building artificial lakes or ponds on the cut-away areas. Two good cases of these activities are e.g. Hirvineva, where have been built big and small ponds, and Rastunsuo, where have been built an artificial lake. In Rastunsuo, which is a "chemically safe area" no problems have occurred (Selin 1999). However, in Hirvineva, which was monitored for some years, the pH in the small ponds was observed to decrease after building, like in 1993: 4.99, in 1994: 4.52 and in 1995: 4.17 (Siira et al. 1996). However, later, the accumulation of organic material in the bottom of the pond started to repair the situation. In Hirvineva's bigger pond the bottom peat layer was successfully used as an insulating material (Selin 1999). This acidity feature in subsoils should be considered if ditches, which would extent to the subsoil, have to be dug either in the connection of after-use of the cut-away areas or in the final phases of peat production. This should be taken to account particularly when choosing places for the constructions of the water clarification systems.

Cut-away peatland areas having chemically sensitive subsoils can be recommended to use for mire restoration, because disturbing the subsoil is in many cases not necessary. Studies concerning the rewetted cut-away sites dominated cotton-grass have shown that the water table level, which raise above the soil surface helps rapid

Table 4. The proportions of subsoils of the total cut-away areas by geochemical provinces, where it is needed to set restrictions for their after-uses. The estimated proportions in the Rapakivi-granite areas in Southern Finland and Åland are based on too small sampling and thus the estimated area having restrictions for after-uses have been not presented.

Taulukko 4. Sellaisten suonpohjien osuus kokonaissuonpohja-alasta, joilla pohjamaan ominaisuuksien johdosta on tarpeen asettaa jälkikäyttörajoituksia. Käyttörajoitusalueet on esitetty geokemiallisin aluein ja maan lajitekoostumuksen mukaan. Rapakivi-alueelle ei ole esitetty arvioita jälkikäyttörajoitetusta suonpohja-alasta tutkimuksen liian pienen otoksen johdosta.

Geochemical province	very fine	very coarse	very coarse [a]	S-rich	S-rich [b]	total[c]
Archaean gneiss areas	12	20	20	0	0	32
Areas of Svecocarelian schists and gneisses	24	22	22	10	4	50
Lake Ladoga– Bothnian Bay zone	20	17	9	20	1	30
Granitoid area of central Finland	35	8	8	0	0	42
Rapakivi-granite areas in Southern Finland and Åland	61	12	25	25	too small sampling	

[a)] *adjusted to province characteristics*
[b)] *not included in very fine or very coarse material*
[c)] *areas where restrictions for after-uses*

succession of mire vegetation towards closed mire plant community (Tuittila et al. 2000). In restored mire sites in Sweden and in Estonia, the vegetation in lawns was characterized for example *Sphagnum cuspidatum* and *Sphagnum magellanicum* and on hummocks *Sphagnum fuscum* occurred (Lode et al. 2002). The observations in these studies support the possibility to restore mires without largely disturbing the subsoils. Area having too fine or too coarse subsoil can be used e.g. for artificial lake construction-mire restoration combinations. The areas having "most difficult" mineral subsoil as primary areas for rewetting also meets the socio-economical demands related to after-use: an economical use is not actually competing for the same land area with restoration.

The nutrient content and acidity of the subsoil in the cut-away areas are not any single factor affecting their suitability for wood production or field crops. In open peat field the temperature conditions can be more extreme compared to the heath areas (Saarinen 1997). The depth of the peat layer above subsoil is particularly important factor particularly for forest growth. A 15 cm peat layer is enough for nitrogen source for trees. On the other hand, a very thick peat layer makes subsoil nutrients less available for young trees, which have not extent root systems (Aro et al. 1997). Furthermore, the drainage of the site has to be adequate for wood production.

Different chemical compositions in different geochemical provinces are likely to be related to the chemical composition of the minerals themselves or the shape of the grains (related to mineralogy), which may affect the cation exchange capacity. The mass of flat grains offers more surface area than the same mass of round grains.

The features of subsoil sediments also vary in different parts of the cut-away areas, especially in the grain size (Lötjönen et al. 2002). A one way of after-use is to regenerate the original environment. According to Korhonen (1998), the areas where the terrestrialization of the lake has initiated the mire formation, the site turns quite easily back into lake. The margin areas, which have originally been forested sites, can be afforested again. These landscape characteristics can be reconstructed by the aid of geological and geometrical modelling (Korhonen 1998).

Table 5. The Rotated component matrix of the subsoil characteristics obtained from the Principal Component Analysis (PCA). Rotation Method: Varimax with Kaiser Normalization.

Taulukko 5. Pääkomponenttianalyysillä (PCA) tutkittujen pohjamaan ominaisuuksien rotatoitu pääkomponenttimatriisi. Rotaatiomenetelmä: Kaiser-normalisoitu Varimax-rotaatio.

	Component				
	1	2	3	4	5
%, <0006mm	0.728	–0.074	0.244	0.287	0.041
Bulk density	–0.071	–0.017	0.028	0.926	–0.028
Ash content	–0.962	–0.050	0.008	0.077	0.026
Moisture	0.854	0.202	0.041	–0.072	–0.136
pH	–0.053	–0.906	–0.023	–0.202	–0.120
EC, mS/m	0.116	0.957	–0.051	–0.052	–0.023
Ca, mg/kg	0.884	0.022	0.327	–0.070	0.112
Mg, mg/kg	0.793	0.046	0.508	0.019	0.170
K, mg/kg	0.573	0.021	0.643	0.029	0.088
P, mg/kg	–0.258	0.582	0.076	–0.371	–0.110
NO_3N, mg/kg	–0.003	–0.002	0.005	–0.012	0.983
NH_4N, mg/kg	0.749	0.281	–0.331	–0.006	–0.185
S, mg/kg	0.323	0.897	–0.109	–0.084	–0.053
Fe, mg/kg	0.096	–0.067	0.851	0.015	–0.062
nutrient number	0.802	0.032	0.551	–0.004	0.133

Conclusions

Using 15% of fine material (<0.06 mm) as an average minimum level for successful afforestation for the whole country, only 12–25% of cut-away sites in different geochemical areas can be considered to be suitable for wood production. Challenging areas for afforestation are, for example, the Archaean gneiss areas. The nutrient capacities, in both the Lake Ladoga - Bothnian Bay zone and in the areas of Svecocarelian schists and gneisses would be better than the Archaean gneiss areas, but the amounts of sensitive soils can be limited in the land use in these areas.

Chemically sensitive subsoil sediments are clearly common under the highest shoreline of the Litorina Sea. Relatively sulphur rich mineral subsoils are also common in the Lake Ladoga - Bothnian Bay zone where one fifth of the cut-away areas had the sensitive subsoil. This means that, in this zone at least in 20–25% of peat production areas, the mire restoration is recommended after-use. Any after-use requires careful consideration of the subsoil sediment. Sensitive subsoils do not completely dictate land-use forms, but careful activity without disturbing the subsoil is required.

Sensitive subsoils were not found in this study in the Granitoid area as well as in the Archaean gneiss areas. In this study, there were no cut-away areas in Archaean gneiss areas that would have been below the highest shoreline of the Litorina Sea. In the Rapakivi-granite areas in Southern Finland and Åland, a high percentage of the sensitive subsoils were found, but this need careful consideration, because all the sensitive subsoil sediments were in the same peat production complex.

General characteristics of the chemistry of the cut-away area can be defined on the basis of the statistical methods. The *nutrient number* can be use as a method for describing nutrient status of the mineral subsoil. In many cases, EC and pH most likely reflect the sulphur content. The availability of nitrogen (NH_4-N) relates to the organic material content (derived from the ash content). The most important factors characterizing the subsoil are the content of the main nutrients, the amount of iron, nitrate and sulphur compounds in the soil, and the soil bulk density.

The *nutrient number* could be developed further as a method for estimating the suitability of the cut-away areas for the different after-uses e.g. afforestation.. Using *nutrient number* eliminates the effects of the differences of the nutrient status in different geochemical areas having the same grain size sediments. If grain sizes are used alone, to the characteristics of geochemical provinces should be paid attention. Sulphur analysis should be always carried out on the site. Careful sulphur study (e.g. large sampling density) is needed, particularly in the Litorina zone and in the Lake Ladoga - Bothnian Bay zone.

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Tiivistelmä:

Suonpohjien turpeenalaisen mineraalimaan ominaisuudet eri geologisilla alueilla Suomessa

Suomessa turvetuotannossa hyödynnetään tavallisesti koko suon turvekerros. Tästä syystä turvekerroksen alapuolisen pohjamaan merkitys turvetuotantoalueen jälkikäyttötapaa valittaessa on suuri. Turvetuotantoalueiden pohjamaatutkimuksessa (1998–1999) tutkittiin pohjamaiden ominaisuuksia viidellä geokemiallisella alueella ja yhdellä geologisella alueella. Tarkoituksena oli selvittää näkyvätkö näiden eri alueiden kemialliset ominaispiirteet myös soiden pohjamaiden ominaisuuksissa.

Laatokan-Perämeren vyöhykkeellä vesiliukoisen rikin pitoisuudet olivat 3–6 kertaa korkeammat kuin Keski-Suomen granitoidialueella ja Arkeeisten gneissien alueella (mg/kg). Myös rautapitoisuudet olivat korkeita. Litorina-meren korkeimman rannan alapuolisilla alueilla vesiliukoisen rikin pitoisuus oli noin seitsemänkertainen ja maaperä happamampaa verrattuna korkeimman rannan yläpuolisiin alueisiin.

Pohjamaiden ravinnemäärät vaihtelivat eri geokemiallisten alueiden välillä. Niukkaravinteisimmat pohjamaat löytyivät Keski-Suomen granitoidialueelta ja Arkeeisten gneissien alueelta. Laatokan-Perämeren vyöhykkeellä ja Svekokarjalaisten liuskeiden ja gneissien alueilla ravinnepitoisuudet olivat korkeammat.

Pohjamaiden ominaisuuksista erottui kolme selkeää vaikutussuuntaa, jotka olivat maan ravinnepitoisuus, rikkiyhdistepitoisuus ja rautapitoisuus. Kalsiumin, magnesiumin ja kaliumin pitoisuuksiin perustuva *ravinneluku* laadittiin työkaluksi arvioitaessa suopohjien soveltuvuutta maa- ja metsätalouskäyttöön. Tutkimuksen perusteella pohjamaan vesiliukoisen rikin analyysiä suositellaan herkkyystestinä päätettäessä turvetuotantoalueen jatkokäytöstä varsinkin Litorina-meren korkeimman rannan alapuolisilla alueilla sekä Laatokan-Perämeren vyöhykkeellä.

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