Distribution of silicon in soils and sediments of a small catchment area: similarities and differences

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Abstract

The uptake and transformation of silicon (Si) by terrestrial plants is of importance for both the plants themselves and for the transport of Si from the watershed. The occurrence and transport of potentially bio-available Si pools from soil in the drainage area to rivers, lakes and the sea may significantly influence the phytoplankton composition and ecological state of the receiving water body due to complicated ecological interactions. The distribution of biogenic Si in soil, seston (suspended particles), and sediment in samples from a small watershed in Southern Finland was studied and the different compartments compared to each other and to environmental variables. The biogenic Si content in the different parts of the watershed varied, and biogenic Si produced by diatom algae in the aquatic part of the watershed appeared to be more important than the transformation of dissolved Si into phytoliths by terrestrial plants in the soil. More information on the variability of the biogenic Si (phytolith) content in different types of soil and on the differentiation between diatom and phytolith Si in waters are needed.

Key Words

Silicon, Soil, sediment, seston, catchment, watershed

Introduction

Although silicon (Si) is one of the most abundant elements on earth in general (Wollast and McKenzie, 1983) and in soil in particular (see Sommer *et al*., 2006), most of this Si is inert on the time-scales relevant when short-term chemical and biological processes involving the element are concerned. Such processes of ecological relevance are, for example, Si uptake by plants and the transport of Si from soil to adjacent water bodies (leaching). Although Si is not considered an essential element for plant growth, its role as an important ameliorative factor has recently been more and more widely recognized (e.g. Ma and Yamaji, 2006; Vaculik *et al*., 2009). The Si taken up by terrestrial plants is transformed into silica bodies known as phytoliths or plant opal (bio-opal), which are relatively resistant to dissolution and remain in the soil upon the decay of the plant (see e.g. Alexandre *et al*., 1997).

Leaching of Si from soil in the watershed to the receiving water bodies is, also, a major qualitative factor which affects the constitution of the food web in the water body concerned (Smayda, 1990; Humborg *et al*., 2000). Some algae, mainly the diatoms, have a high and absolute requirement for Si, and the supply of Si from the watershed thus affects the composition of the phytoplanktonic community responsible for the primary production in lakes and oceans drastically (e.g. Reynolds, 1980). A decrease in the supply of Si may e.g. cause a shift in the planktonic community from the often relatively benign diatoms to e.g. toxic cyanobacteria or dinoflagellates (which do not require Si at a macronutrient level). Silicon may be transported into the waters in dissolved, biogenic or particulate form, with phytoliths playing a so-far relatively little known role (e.g. Alexandre *et al*., 1997). In order to understand the processes that affect the transport of Si from the watershed to lakes, rivers and oceans, a better understanding of the distribution of potentially mobile forms of Si in soil and the processes affecting them is needed. In this study, the distribution of one of the main potentially mobile forms of Si (biogenic Si) in soil, seston and sediment samples from a small watershed in Southern Finland was studied. Two different methodologies developed for biogenic Si analysis were used and their comparability estimated.

Methods

Study area

Samples were taken from the Vikträsk sub-catchment (a sub-area of the Siuntionjoki River catchment) situated in Southern Finland in the boreal vegetation zone (Figure 1). The soil in the study area consists predominantly of glacial clay and silt deposits, with some sand eskers and moraine deposits. The bedrock in the area consists of granite. Most of the catchment is covered by forest (ca 60%, coniferous and mixed deciduous/coniferous, mostly pine, spruce and birch), with 30% cultivated fields (wheat, cultivated lawn) and the rest mainly urban areas.

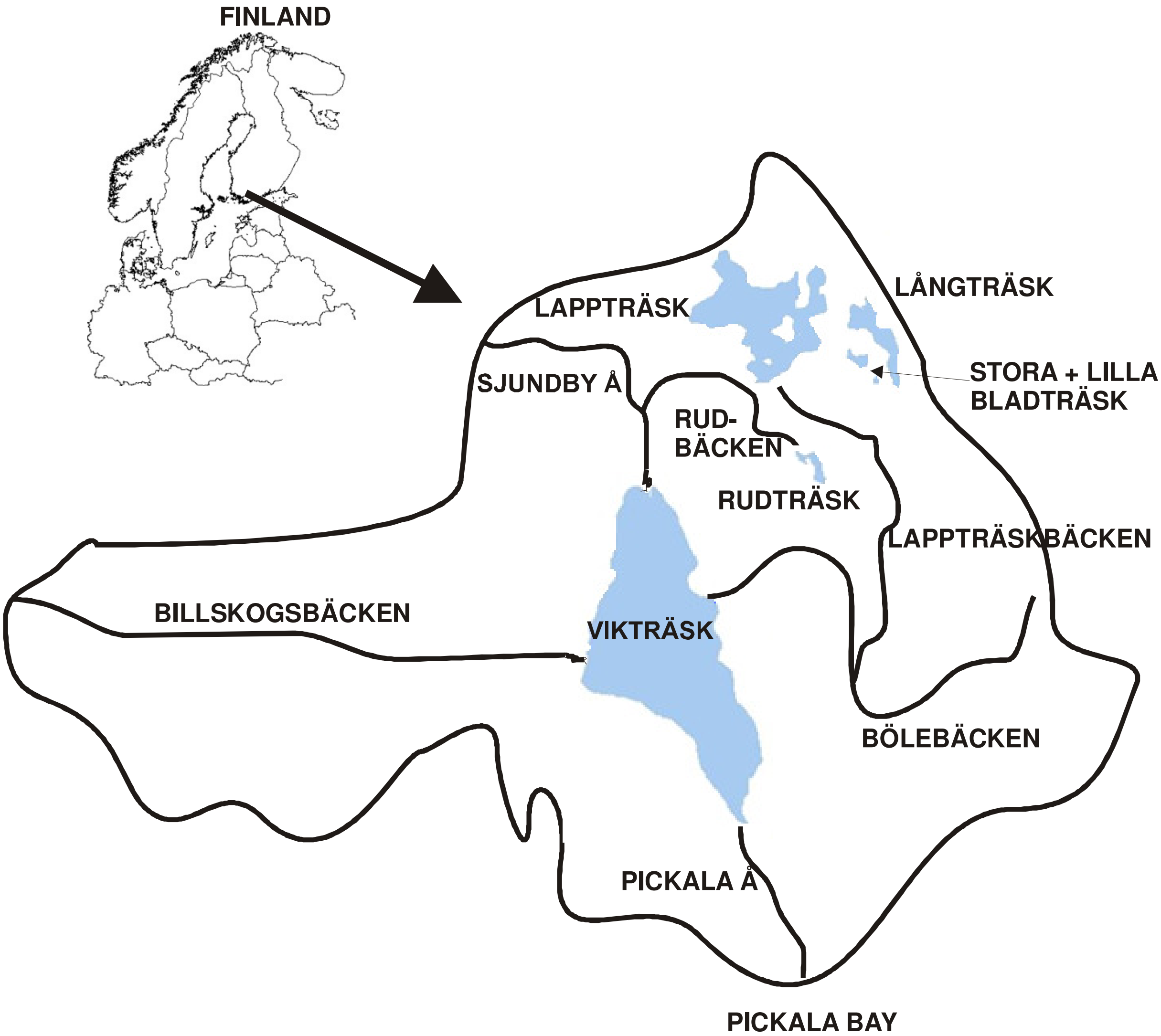

Figure 1. The study area (Vikträsk sub-catchment) in Southern Finland (1: 115 000). Samples were taken from each lake, river and from the catchment soil (see text for details).

Sampling
Topsoil samples (0-10 cm) were taken with a hand-held corer from representative sampling sites covering the main soil types and forms of land use (Figure 1). Sediment samples (0-1 cm) were taken from the rivers (including small ditches) and lakes in the study area. Samples for suspended particulate material (seston) were taken from the same water bodies using a Limnos tube sampler. Soil and sediment samples were oven-dried (+60°C) and carefully homogenized with a mortar and pestle before analysis. Seston was collected by filtering the water samples through 0.2 um polycarbonate membrane filters, which were then also oven-dried at +60°C. Flow velocity in the brooks was measured with a

Background data (soil type, vegetation and land use, physical and chemical water quality data from the studied water bodies) were obtained from the data bases at the Finnish Environment Institute.

Analyses
Dissolved Si was analysed from 0.2 µm (polycarbonate filters, Nuclepore) filtered water samples using ICP-OES (inductively coupled plasma optical emission spectrometry). From the soil and sediment samples biogenic Si was analysed using a modification of the procedure by DeMaster (1981). Thirty (+/–5) mg of dry material was weighed into polyethylene 100 ml bottles (Plastex Ltd) and extracted with 40 ml 1% sodium carbonate (Na_2CO_3) in a +85°C water bath for 5 hours.. At 3, 4 and 5 h 1 ml- samples for Si analysis (ICP-OES) were taken from each bottle and diluted with 9 ml of 0.021N HCl. The biogenic Si concentration of the sediment samples was then calculated as the intercept of the linear regression line through the 3, 4 and 5

h time points. The analysis (mineral correction) is based on the assumption that all biogenic Si in the sediment samples has dissolved during the first three hours of the extraction, while mineral-derived Si is dissolved from the sample in smaller amounts at a constant rate throughout the extraction (see e.g. Conley 1998 for a closer description).

From the seston (suspended particulate material) samples, biogenic Si was analysed according to Ragueneau *et al*. (2005). 40-100 ml water subsamples were filtered through 0.2 µm polycarbonate filters (Nuclepore), and the filters were dried in open test-tubes at +60°C. The dried filters were extracted with 4 ml 0.2 M NaOH in a water bath at 100C for 40 min. After this, they were acidified with 1.0 ml 1.0 M HCl, centrifuged (2500 rpm, 10 min), and a subsample for Si and Al analysis (by ICP-OES) was taken. The filter was thereafter washed three times with deionised water and dried at +60°C, whereafter the extraction and sampling was repeated. The concentration of biogenic Si in the sample was thereafter calculated as biogenic Si= Si_1-$Al_1(Si_2/Al_2)$, where Si_1 and Al_1 are the concentration of Si and Al measured after the first extraction and Si_2 and Al_2 the concentrations after the second extraction. The analysis is based on the assumption that all the biogenic Si and some of the minerogenic Si and Al is extracted in the first digestion, while the Si:Al ratio of the second digestion is characteristic of the silicate minerals in the sample.
Diatom and other phytoplankton concentrations were enumerated from all water samples using the inverted microscope technique described by Utermöhl (1958). From the seston, soil and sediment samples the organic material was removed using acid microwave digestion and samples for diatom and phytolith analysis were prepared using standard techniques (see e.g. Battarbee, 1986).

Results

Both the methods used for biogenic Si analysis worked well for the analysed samples, although in samples with high amounts of organic material the removal of the excess organic matter (by acid digestion) was needed (data not shown).

Table 1. The concentration of diatoms (mg/l water) and their percentual share of the phytoplankton biomass in the studied water bodies. Average flow velocity (Q, m^3/s) and concentration of dissolved Si (DSi, mg/l), total phosphorus (P_{tot}, µg/l) and total nitrogen (N_{tot},µg/l) is also shown when available.

	Diatoms, %	Diatoms, mg/l	Q, m^3/s	DSi, mg/l	P_{tot},µg/l	N_{tot},µg/l
River Sjundby	65	0.24	5.21	2.01	88.6	1550
Lake Rudträsk	24	0.09	-	9.30	14.0	1700
Rudbäck Brook	17	0.03	0.02	9.33	17.5	788
Billskogbäcken Brook	0.0	0.00	0.02	18.9		
Bölebäcken Brook	57	0.11	0.05			
Lake Lilla Bladträsk	35	4.33	-			
Lake Stora Bladträsk	0.3	0.03	-			
Stora Bladträsk-Långträsk Brook	0.0	0.00	0.00			
Lake Långträsk	7.3	0.04	-	3.14	15.0	570
Långträsk-Lappträsk Brook	3.9	0.01	0.00			
Mörtviken Brook	22	0.02	0.00	7.35		
Lake Lappträsk	39	0.07	-	1.03	15.0	408
Lappträskbäcken Brook	35	0.08	0.01			
Lake Vikträsk	98	11.5	-		77.7	1400
River Pikkalalanjoki	53	0.17	5.21	6.89	69.2	1370
Pikkalanlahti Bay	24	0.02	-			

Diatoms generally dominated the phytoplankton in the studied lakes, brooks and rivers, although the biomass (mg/l) was often low (Table 1). The concentration of biogenic Si was different in soils from the different parts of the watershed (Figure 2). Soil type influenced the concentration of biogenic Si both in the water and the soil, mainly through the availability of dissolved Si (Table 1 and Figure 2). In the water bodies, the BSi or diatom content was also related to the trophic state of the water body (i.e. to the availability of other main nutrients, N and P) and to the flow velocity of the water (Table 1).

Conclusion

The BSi content in the different parts of the watershed varied significantly. The transformation of dissolved Si into biogenic Si by diatom algae in the aquatic part of the watershed appeared to be more important in the studied area than the transformation of dissolved Si into phytoliths by terrestrial plants in the soil. More studies on, especially, the variability of the biogenic Si (phytolith) content in different types of soil are urgently needed.

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