METALS IN THE SEDIMENTS OF THE EUTROPHIC LAKE ÅRUNGEN, NORWAY

Horizontal distribution and association with clay

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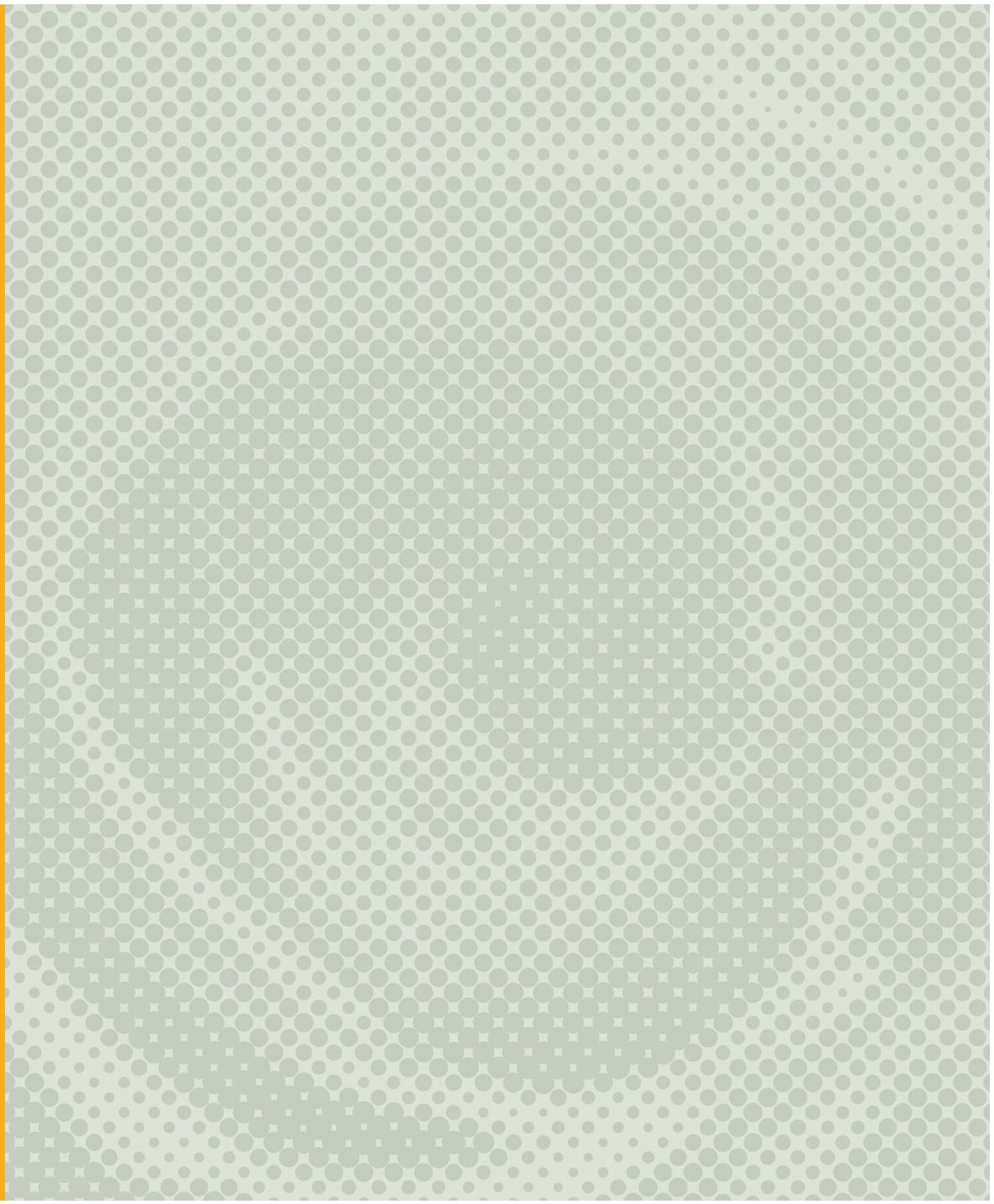

Preface and Acknowledgments

This thesis is written within the project ”Accumulation of Environmental Pollutant in Lake Sediments – Importance of Areal Use and Sediment Properties”. The project a cooperation between the Department of Plant and Environmental Sciences at the Norwegian University for Life Sciences and the PURA-project (Water Area Bunnefjorden with the Årungen and Gjersjøen Water Courses). The project started in 2008 with fieldwork and was finished in spring 2010. Four different theses were produced on the basis of the same set of samples, but with different objectives related to content and distribution of: a) phosphorus and phosphorus fractions, b) nitrogen, carbon and organic matter, c) mineralogy and grain size and d) metals.

This present thesis aims to assess and map the content of trace metals in Lake Årungen, classified among the most polluted lakes in Norway.

I would like to thank my supervisors Gunnhild Riise and Tore Krogstad. Further a lot of thanks are due co-supervisors associate professor Ingaard Arne Blakar, associate professor Elin Lovise Gjengedal and associate professor Leif Ståle Haaland. Thanks to Ingaard for many hours of constructive talks and useful advice, and to Elin for introducing me to the intricacies of sorting out and interpreting the data sets and feedback. Thanks also to Ståle for helping me during the initial stages of the thesis, for guiding me in choosing a direction and for giving advice in the concluding phase. I am also grateful to Johnny Christensen for helping me during the wet period in the laboratory, and to Solfrid Lohne and Karl Andreas Jensen for giving me training and support in the decomposition process and for carrying out the ICP-OES and ICP-MS analyses.

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Abstract

The later years European Union has introduced the Water Framework Directive (WFD) in many countries in Europe. Also in Norway the process for reaching the goals of the directive has been started. Lake Årungen is a lake that has been picked out to be fully characterised in the first phase of the directive. Increased metal concentrations in lakes have been recorded since the beginning of the Industrial Age. In this context, sediment analysis might be of great interest to better understand associations between various metals and other constituents within the sediments, which might have an affect on the water quality of lakes.

Lake Årungen is located in Akershus County, about 25 km south of Oslo, Norway. The catchment area is 52 km^2, and more than 50% of the area is cultivated field. The lake changed its trophic state from mesotrophic to eutrophic in the mid-seventies, due to runoff from agricultural areas and from savage. Today, the lake is affected by severe blue green bacterial blooms during summer and early autumn.

In spring 2009, while the lake was still covered with ice, 122 sediment cores were collected. Samples from two layers (0 - 2.5 cm and 2.5 - 5.0 cm) were analysed for metals (macro components and trace elements), nutrients, organic matter, sedimentation characteristics, grain size distribution and clay mineralogy. In this thesis the data from the metal analysis are presented and discussed. The metals which have been analysed are: Al, As, Ba, Ca, Cd, Co, Cr, Cs, Cu, Fe, K, Hg, Mg, Mn, Na, Ni, Pb, Sr, V and Zn. The aims have been to study the association between metals and the clay and organic matter content within the sediments, to map these relationships spatially, and to compare the results with results from similar previous studies.

Most of the metals were closely associated with clay content and depended on the sedimentation patterns. Al, Fe and Mn were closely associated to clay because these are metals present within clay particles, while other metals were closely associated to clay since they were bound to clay particles. Just a few metals, like Ca, Cd, Hg and Sr, were similarly associated to organic matter. Compared to measurments from the end of the seventies, Ni and Cr had an increased, while the opposite were the case for Cd, Hg and Pb had decreased.

Sammendrag

De senere årene har den Europeiske Unionen satt i gang Vannrammedirektivet i mange europeiske land. Årungen er en innsjø som har blitt valgt ut til å bli karakterisert i sin helhet i den første fasen av direktivet. Helt siden starten av den industrielle revolusjonen har det blitt registrert en økning i konsentrasjon av diverse metaller i innsjøer. På grunn av dette vil en sedimentundersøkelse være av stor interesse for å øke kunnskapen om sammenhengene mellom ulike metaller og andre parametere i sedimentene som kan være med å påvirke innsjøens vannkvalitet.

Årungen er en innsjø som ligger i Akershus fylke, ca 25 km sørøst for Oslo. Nedbørfeltet er 52 km^2, og mer enn 50 % av arealet er dyrket mark. På midten av syttitallet forandret innsjøen trofigrad, fra mesotrof til eutrof, på grunn av avrenning fra jordbruksarealene og utslipp fra avløp. Per dags dato er innsjøen sterkt påvirket av oppblomstringer av blågrønne bakterier om sommeren og tidlig på høsten.

I løpet av våren 2009, ble 122 sedimentkjerner samlet, mens vannet fortsatt var dekket med is. Prøvene fra to lag (0 - 2,5 cm og 2,5 - 5 cm) ble analysert for metaller (makrokomponenter og spormetaller), næringsstoffer, organisk materiale, sedimentasjonsegenskaper, kornstørrelsesfordeling og leiremineralogi. Resultatene er presentert i fire uavhengige mastergradsoppgaver. Denne oppgaven er basert på dataene fra spormetallanalysen, og resultatene er presentert og diskutert. Metallene som ble analysert er: Al, As, Ba, Ca, Cd, Co, Cr, Cs, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, Pb, Sr, V og Zn. Formålet med oppgaven har vært å undersøke sammenhengene mellom metallene og leire og organisk materiale, kartlegge den horisontale fordelingen og sammenligne resultatene med andre lignende studier

De fleste metallene viste seg å ha nær sammenheng med leirekonsentrasjonen og sedimentasjonsmønsteret. Metaller som Al, Fe og Mn hadde nær sammenheng med leire, siden de er en del av leirepartiklene, mens andre metaller var nært korrelert til leire siden de er bundet til leirepartiklene. Bare noen få grunnstoff, som Ca, Cd, Hg og Sr, viste knyttet til organisk materiale. Konsentrasjonen til disse var høyest i littoralsonen, der organisk materiale er tilstede i større grad. I forhold til målingene på slutten av 70-tallet, hadde Ni og Cr nå høyere konsentrasjoner, mens Pb, Cd og Hg hadde en markert nedgang.

Abbreviations

Bø	Bølstadbekken
CCA	Copper, Chromium and Arsenic
CRM	Certified Reference Material
CV-AAS	Cold vapour atomic absorption
DW	Dry weight
E6	Europe road 6
Eh	Red-ox potential
GIS	Geographical information system
ICP-OES	Inductive coupled plasma optical emission spectrometry
ICP-MS	Inductive coupled plasma mass spectrometry
LOI	Loss on Ignition
No	Norderåsbekken
Sm	Smedbølbekken
St	Storgrava
Vo	Vollebekken
UMB	Norwegian University for Life Sciences
WFD	Water frame Directive

Contents

1 Introduction

Since the beginning of the industrial age, an increase in the concentration of metals in air and water systems has been recorded. The sources for this increase are mostly anthropogenic contamination by metal industries, power industries, transport, waste management and fertilizers (Steinnes *et al.* 1989; Szyczewski *et al.* 2009). In particular, lake pollution has been investigated throughout the world, with many studies focusing on water, how pollution influences the quality of water, vegetation, ecosystems and food chains. Sediment studies are more demanding than water analysis both in costs and time, but they are able to give answers to important issues such as the state of pollution, spread patterns and their changes in time (Håkanson&Jansson, 1983). Several sediment studies have been carried out, but they have usually been based on just a few samples, generally taken from the deepest area of the studied lake. The vertical distribution of the pollution has been considered, to see how and when the changes happened (e. g. Skogheim, 1978; Rognerud *et al.* 2001). It has also been possible to reconstruct past environmental history, because lakes and other water ecosystems retain eroded soil and organic matter (Smol, 2008). Sediments can provide valid information of past environmental changes due to the Law of Superposition that states that the deepest deposits are the oldest. Differently from water analysis, sediment studies are more accurate with respect to concentration of metals, because the sediments often represent a longer time span (Smol, 2008).

Trace metals are defined as metals that in nature are present at relatively low concentrations, where some may be essential to growth, other may not (Pierzynski *et al.* 2000). Some of these metals, like iron (Fe), copper (Cu), zinc (Zn), are necessary for physiological processes in living organisms (Smol, 2008), but can become toxic in higher concentrations. Other metals, like cadmium (Cd) and lead (Pb), are non-essential and toxic even in low concentrations and can be toxic to aquatic biota. These elements bind with organic matter or allogenic minerals, which is material that originates from outside the lake, as from the catchment area and the air shed. Trace metals provide information of the composition of the soil, but also of anthropogenic supplies from the surroundings. The most important transport pathways of trace metals are surface runoff and atmospheric deposition (Håkanson&Jansson, 1983).

Norway has been heavily affected by atmospheric long-transported pollution and the highest concentrations have been registered when air masses move from the southeast to the southwest (Steinnes, 2001). Metal concentrations in the sediments are often several orders of magnitude higher than those in the overlaying water (Rognerud&Fjeld, 2001). Mapping the concentration and distribution of trace metals like Cd, Cr, Cs, Cu, Hg, Fe, Mg, Mn, Zn and Pb can give important information about how pollution enters the ecosystems, where the sources and sinks are and if the concentrations related to geochemical composition of the bedrock.

Our object of research, Lake Årungen, located southeast of Oslo in Norway, has been studied throughout the last decades due to its state of pollution and poor water quality but most of the research projects have focused on water quality, algae production, ecosystems, sources and sinks for pollutants (Ensby, 1984; Skogheim 1978). Agricultural runoff and sewage that entered directly into Lake Årungen, without any treatment, considerably degraded and polluted the lake. In the mid-seventies the lake went from being mesotrophic to hypertrophic (Skogheim, 1984). Algae blooming, for the most cyan bacteria – blue green bacteria, between July and September every year, affect the lake and the Secchi-depth is low (Løvstad&Krogstad, 1996; Romarhein&Riise, 2009).

This master thesis aims to get increased information on processes taking place in Lake Årungen, which has been picked out to be full characterized in the first phase of EU's Water Framework Directive (WFD). This information is very important for environmental authorities in order to reach the goals of the WFD, which has as general aim to re-establish good water quality in all water systems, as close as possible to their original state. It is probably the first time that such an extensive mapping study of sediments in one single lake has been done in Norway. In four different theses, this project have analysed the sediments for the content of nitrogen (N), phosphorus (P) and phosphorus fractions, sulphur (S), trace metals and physical characteristics of the sediments. Finally, these theses can give a complete overview on quality of sediments and can be used as a tool for future work in the lake.

The major aim of this present thesis is to map the horizontal distribution of trace metals in lake sediments of a eutrophic lake in southern Norway and investigate

sediment properties that influence the concentration of trace metals, with special focus on the content of clay in the sediment.

The aim of the present work can be decomposed in the following independent objectives:

1) Establishing the relation between metal concentration and lake basin morphometry (depth) and grain size distribution (clay).
2) Quantifying the horizontal distribution of trace metals at a high-resolution scale.
3) Investigating the enrichment of metals in relation to specific inlet brooks or areal use in the catchment.
4) Comparing the results with data from other Norwegian lakes.
5) Evaluating the developments in time, by comparing with previous studies done in Lake Årungen.

To discuss the data in some context three studies have been used as background literature: Ottesen *et al.* (2000), Rognerud *et al.* (2008) and Skogheim (1984).

Ottesen *et al.* (2000) made a national geochemical atlas determining the concentration of different elements. By comparing the values from the bedrock in the region to the concentrations of the metals in the sediments of Lake Årungen, it will be possible to see if there are any elements that have a higher accumulation than natural concentration. The analytical method that has been used in their research was different from the one used in this study. This means that the results of the concentrations from Lake Årungen should be higher than the one for the acid soluble part from Ottesen et el. (2000), because the decomposition method in this study is stronger. In proportion to the values for the total content the values from this present thesis should be close to the results here (appendix 9). If the values are higher than the bedrock values it may be a sign of pollution.

Between 2004 and 2006, a national research study on water and sediments in Norway was performed to map the distribution of metals, PAH and PCB in 274 lakes throughout the country (Rognerud *et al.* 2008). The concentration of metals (Hg, Pb, Sb, Bi, Sn, Te, Se, Ag, Tl, Au, V, Cr, Cd, Zn, Ni, Cu, Co, Ga, W, I, Mn and Fe) were analysed only for sediment cores taken from the deepest part of lakes. Comparing

them with the results from the deepest sample group (11.3 - 13.4m) in Lake Årungen (Figure 3), it will be possible to see how the situation in Lake Årungen, a lake that was not included in the national study, ranges on a national scale.

Skogheim (1978; 1984) presented two studies on the sediments of Lake Årungen: the first one did not consider trace metals and looked at the horizontal distribution of some elements like phosphorus, nitrogen and carbon, whereas the second took some metals into consideration, but this study was based on just one sampling site from the deepest area. The results from the metal study are presented in Skogheim (1984). One sediment core from the profoundal zone of Lake Årungen was analysed for the following metals: Mn, Zn, Fe, Hg, Cu, Pb, Cd and Cr. It is possible to compare the results from Skogheim (1984) with the average of the samples collected in the deepest group (11.3 - 13.4m) in this present thesis (Figure 3), in which the standard variation was relatively small. The results from the present study can give new information on changes in metal concentrations with time and whether the concentration of these metals has become more or less pronounced throughout these years.

2 Materials and methods

2.1 Study area

Lake Årungen and its catchment area are located in the municipalities of Frogn, Ski and Ås, in Akershus County (59° 40' N, 10° 44' E), about 25 km southeast of Oslo. The area is dominated by agricultural fields, with some urban areas and forested areas (Picture 1).

Picture 1. Aerial photo of Lake Årungen and parts of the catchment area. The picture is taken towards northwest (photo: Mapaid A/S).

2.1.1 Catchment area

The catchment area is 52 km^2 (Figure 1). 53% of it consists of agricultural areas, 34% are forests and outfields, 10% consists of buildings and 3% is water surfaces (Borch *et al.* 2007). The area has its highest altitude at 166 meters above sea level and the whole catchment is situated beneath the marine level from last ice age. The bedrock consists of gneisses covered by marine clay from last ice age (Skogheim, 1978). In the catchment area there are three small cities Ski, Drøbak and Ås, which are the areas with the highest amount of inhabitants. The runoff from the Norwegian University of Life Sciences, which is located in the municipality of Ås, enters the southern part of the lake. Along the west side of Lake Årungen passes the Europe road 6 (E6) a four-lane highway.

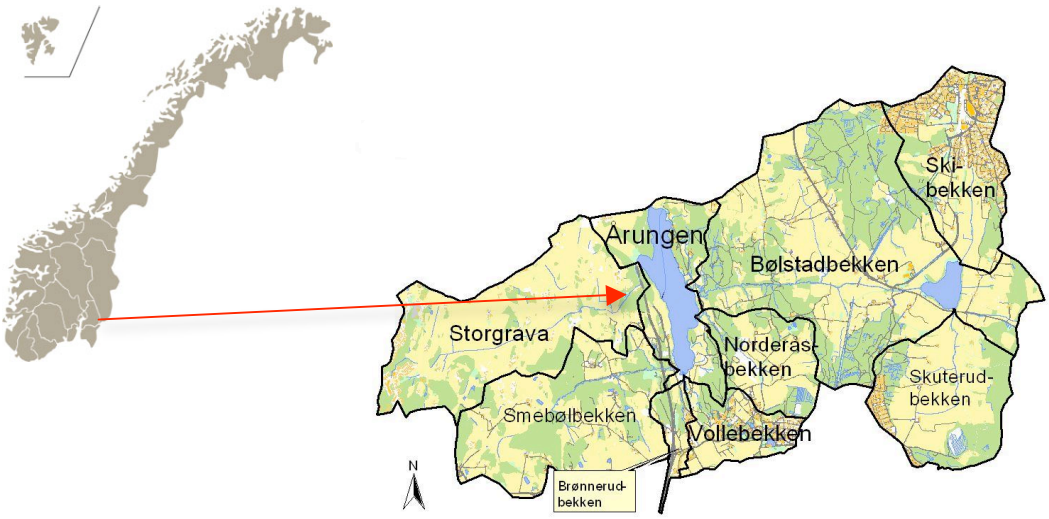


Figure 1. Catchment area of Lake Årungen (Borch *et al.* 2007).

There are 5 inlets to the lake with separate sub catchments. Table 1 shows their drainage area and runoff. The most important are Storgrava drains a part of the city of Drøbak through large cultivated areas and flows from the west into Lake Årungen. Vollebekken has its catchment area where the University is located. Bølstadbekken drains parts of the city Ski through the small lake Østensjøvannet and also run close to a dismantled waste disposal site. The outlet, Årungselva, is located at the north end of the lake and enters Bunnefjorden in the Oslofjord (Figure 1) (Ensby, 1984).

Table 1. Sub catchment areas and discharge, in proportion to figure 1 (Borch *et al.* 2007).

Inlet / area	Catchment area (km^2)	Discharge (mill. m^3/yr)
Bølstadbekken (Bø)	25.5	12.6
Storgrava (St)	8.4	4.2
Smedbølbekken (Sm)	7.3	3.6
Vollebekken (Vo)	2.1	1.0
- Brønnerudbekken	0.8	0.4
Norderåsbekken (No)	2.7	1,3
Remaining areas	4.2	2.1
-Lakes Årungen and Østensjøvannet		
Total	51.0	25.3

2.1.2 Lake Årungen

Lake Årungen has a north – south direction and is exposed to wind that generally blows in this direction. It is located at 33 meters above sea level.

Table 2 shows the morphometrical data for Lake Årungen and Figure 2 the depth characteristics.

Table 2. Morphometrical data of Lake Årungen (Skogheim&Abrahamsen, 1979; Skogheim 1984; Lilleberg *et al.* 2009).

Surface area	1.2 km^2
Volume	9.7 *10^6 m^3
Maximal deep	13.4 m
Mean deep	8.1 m
Maximal length	3 km
Maximal width	0.63 km
Mean width	0.4 km
Retention time	4.5 months
Mean sedimentation rate*	8,4 ± 0,4 mm/yr
Mean sedimentation rate**	7 mm/yr

*= in the period 1954-1978 (12.8 m)

**= measured in Lilleberg *et al.* (2009) (13.2 m)

2.2 Field method

Sediment cores were collected from Lake Årungen, in a grid of 100 X 100 m (n=122) (Figure 2). The UMT UPS coordinates were recorded in a GPS (Garmin, Colorado 300) (appendix 1). The sampling was conducted during March and April 2009 (week 13 and 14) while the ice covered the lake surface and it was still possible to walk on it to reach each sampling site. A Rapala ice drill (ϕ = 155 mm) was used. The depth was measured (appendix 1) and then the sediment cores were collected with an Uwitec Corer (60 cm long core acrylic tube, 5.95 cm inner diameter). After collecting the sample and removing the water at the top of the cores, the cores were sectioned in

situ, from 0 - 2.5 cm (sample nr 1 - 122) and from 2.5 - 5.0cm (sample nr 1001 - 1122) (appendix 2). The samples were stored dark in polypropylene (PP) cups at 2 - 4°C in a fridge. The instrument used are presented in Table 3.

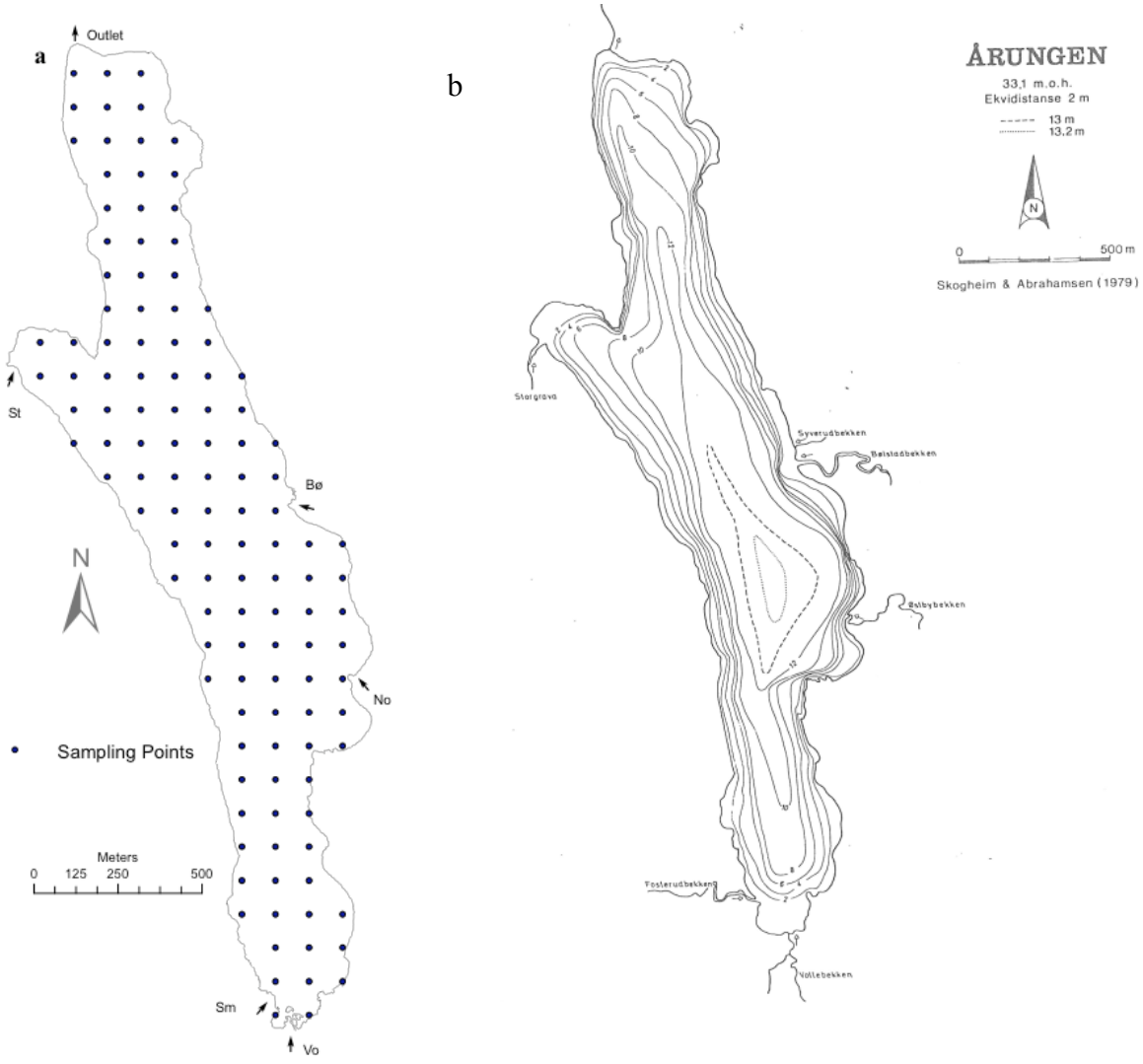


Figure 2. Map of Lake Årungen with sampling points, in a 100 X 100 m grid, for a total of 122 sampling points (a). Depth map with inlets and outlet of Lake Årungen – equipotential lines 2 m (Skogheim&Abrahamsen, 1979) (b).

Table 3. Equipment used during field work for collecting sediment cores.

Equipment in field	**Producer**
GPS – Colorado 300	Garmin
Sediment Corer	Uwitec
Measuring tape	
Polypropylene cups 125 and 180 ml	VWR
Plastic spoons	

2.3 Laboratory work

2.3.1 Dry weight

After removing surplus water, the sediment samples were homogenised and weighed on a three decimal laboratory scale (Sartorius, L420P). Depending on the depth of sampling, shallower than 4 m or deeper, approximately 15 or 13.5 gram respectively was weighed for drying. The samples were dried at 105°C for one night and after cooling for 30 minutes in a desiccator they were weighed again. Finally, the dry weight (DW) was calculated (appendix 3).

2.3.2 Analytical methods

The samples were analyzed during fall 2009. The instruments, equipment and reagents used are presented in Table 4, Table 5 and Table 6.

Table 4. Instruments used for the decomposition and analytical analysis.

Instrument	Producer
UltraClave 3	Milestone
Position rack with 40 positions	Milestone
Auto sampler AU 90	Perkin Elmer
Optima 5300 DV	Perkin Elmer
Sciex Elan 6000	Perkin Elmer
Auto sampler AS 93 Plus	Perkin Elmer

Table 5. Equipment used in laboratory.

Equipment in lab	Producer
Weight – 3 decimals – L420P	Sartorius
Electric Drying cabinet U 30	Memmeret
Agat mortar	Retsch
Electrical pipettes 10-300 µl, 50-1000 µl	Biohit
Polypropylene tubes 15 and 50 ml	Greiner bio-one
Teflon vials 18 ml	Milestone
Pasteur pipette 5 ml	VWR
Plastic spoons	
Glass rod and steel spatulas	

Table 6. Reagents and gases used in the decomposition process and for the analytical analysis. The reagents used for the instrumental analysis are not given in the table, method kap: 2.3.2-ICP-Analysis is followed.

Reagent/ gas	Chemical formula	Concentration	Quality	Producer
Nitric acid	HNO_3	65 % (V/V)	Ultra pure	UMB, distilled from Merck
Sulphuric acid	H_2SO_4	96 % (V/V)	Pro analysis	Merck
Hydrogen peroxide	H_2O_2	30 % (V/V)	Pro analysis	Merck
Potassium permanganate	$KMnO_4$	5 % (w/V)	Pro analysis	Merck
Argon gas (to FIMS)	Ar	Compressed	5.0	Yara
Nitrogen gas (to decomposition)	N_2	-Compressed	2.6	Yara
MilliQ water	H_2O			Barnstead
Internal Standard	Te, In, Tl, Rh	4 mg/l		UMB, from Spectrapure Standards

Weighing process

Between 0.3 - 0.5 g DW, was weighed from wet homogenous sediment into 18 ml Teflon tubes, dried at 75°C for 24 hours and then weighed again. Great effort was made to ensure that the whole process was as clean as possible. All the equipment used to extract the sediments from the cups to the Teflon tubes, like plastic spoons and pipette tips, were cleaned with a 5 M solution of HNO_3. The tubes were cleaned in an 8M HNO_3 acid bath.

20 samples were particularly difficult to homogenize, because they contained too much organic matter; these samples were dried and then grinded to a fine powder with a Retsch Agat mortar and then weighed. The Agat mortar was thoroughly cleaned with brush and paper tissues between each subsample.

Sample decomposition

All 269 subsamples were subjected to acid decomposition: 242 sediment samples, corresponding to 122 samples for the upper layer and 120 for the lower layer, in addition to 12 certified sediments (5 River Sediment, 2 Estuarine sediment, 2 Mess-1, 2 Best-1, and 1 BCSS-1) and 14 blank samples. Each sample was added 250 µl internal standard and decomposed in 5 ml concentrated 69% HNO_3 (sub boiled ultrapure quality). The internal standard consisted of 4 mg/l tellurium (Te), indium (In), thallium (Tl) and rhodium (Rah) diluted in 2% HNO_3. 40 samples per batch were

processed in a Milestone UltraClave 3, using standard Teflon vials. The samples were placed in a position rack and mounted in the reaction chamber inside the UltraClave. The position rack is submerged in a container with deionised water, hydrogen peroxide (H_2O_2) and sulphuric acid (H_2SO_4). Sulphuric acid is added to the load in order to avoid that the solute loses the polarity when the water gets warmer. Hydrogen peroxide prevents uncontrolled increase of pressure due to its ability to oxidise nitrous gasses to nitrate. The system was put under pressure with nitrogen gas up to 50 bars. In the pressurized chamber an antenna sent microwaves in order to get polar molecules to rotate and ions to migrate in an alternating electromagnetic field. Collision between molecules or ions produces friction that increases the temperature in the water load and thus the samples. The high pressure makes it possible to get up to very high temperature without reaching boiling point (Gjengedal, 2009). When the temperature reaches 260°C it is held at this level for 10 minutes (Lohne, 2010).

After one night of sedimentation the samples were diluted to a final volume of 50 ml with deionised water and then put away for another grace period allowing particles to settle.

ICP-analysis

Before determining the concentrations of the different elements each digested sample was diluted 10 times.

Concentrations of Al, Ba, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Sr and V were determined by ICP-OES, whereas the concentrations of As, Cd, Co, Cs, Pb, Zn were determined by ICP-MS (appendix 4 - 5). The ICP-OES instrument measures the total concentration of the elements by using the intensity of light emitted by excited atoms in proportion to known standards (Lohne, 2010) In comparison an ICP-MS instruments has much lower detection limit than an ICP-OES, and are hence better suited for more accurate trace metal analysis. The metals are here analysed based on their mass to charge ratios (Harris, 2007).

Determination of mercury

The samples selected for determination of mercury (Hg) using a cold vapour atomic absorption technique (CV-AAS) were analysed the same day as the decomposition process was finished, to avoid evaporation of Hg^{2+}.

Potassium permanganate ($KMnO_4$) was used for preservation purposes, avoiding loss of mercury prior to analysis; it avoids reduction of Hg^{2+} to Hg^0. Both digested samples and synthetic standard solutions were added a droplet of 5% (v/v) $KMnO_4$. Finally the total content of mercury was determined with a Perkin Elmer FIMS400, which is based on the fact that Hg adsorbs light (λ=253.7 nm). In this way it is possible to determinate how much Hg there is in the sample comparing it with known standards (Lohne, 2010) (appendix 4 - 5).

Certified reference material and blank samples

5 different types of certified reference material (CRM) were used: River Sediment (LGC, 2000), Estuarine Sediment (National Bureau of Standards, 1982) and marine sediment reference materials Mess-1, Best-1 and BCSS-1 (National Research Council, 1990). It was important to use standard material in order to secure the traceability in addition to assess the accuracy in the method (appendix 6). The blank samples were used to detect possible contaminations.

2.4 Data analysis

The data set consists on the values of Al, Ba, As, Ca, Cd, Cr, Cs, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, Pb, Sr, V and Zn obtained in the present work. The results for the two layers are treated as separate data sets and can give a picture on how the development has been during the recent period of time (6 - 8 years).

2.4.1 Statistical Analysis

The statistical analysis was carried out with Minitab (edition 15.1.0.0). The two sediment layers were assumed to be independent variables and each sample was considered independently and was found to be normally distributed with conditional expectation $(0, \sigma^2)$. Pair-t-test was used to see if the concentrations of the elements in the two layers were significantly different ($p < 0.05$). Correlation (r) was also used to check if there was any element that was significantly related with each other. Regression analyses were done to find out if the metal distribution increased with the content of clay and whether it was less dependent to the depth or not, with a 95% confidence interval. Backward elimination analysis with $\alpha = 0.15$ was performed to each element proportionally to clay content, depth and loss on ignition (LOI)

(Mendenhall&Sincich, 2003). Cluster analyses were also used to assess similarities among the elements in relation to each other (Johnson&Wichern, 2002). Box-and-whisker plots were used to display the data in the four depth groups (Figure 3). In this way it is possible to see the distribution of the data. In the box, 50% of the data are presented. The bottom line shows 25% of the data that have this value or less, the upper line shows 75% of the data that have an equal or smaller value. The middle line corresponds to the median value. The upper and lower whisker line extends respectively to the maximum and minimum data point within 1.5 box height, from respectively the top and the bottom of the box. The arrows (*) shows values that are out of this range (outliers) (Minitab HELP, 2010). Only 60 samples of the second layer were analyzed for grain size, so the boxplot has five categories depending on percent of clay content (<50%, 50-60%, 60-68%, >68%).

2.4.2 Map Presentation

ESRI ArcMap GIS-tool (version 9.3.1) was used to present horizontal distribution of the elements. Data are presented visually in maps with graduated colours depending on the value. Final the maps in this thesis are presented with an interpolation of the data collected. The program made all the calculation to establish which value to give to the different points in the area of the lake. “The interpolation of a variable value can be extracted from the give spatial distribution because the value at any specific location is related to the values of surrounding locations” (Chou, 1997). Maps with a colour scale (from green to red, depending on the concentration, low to high) show how the concentration of a certain element changes in distribution in the lake basin. In addition to the area of the sample uptake, a background map of Lake Årungen is shown with inlets and the outlet marked with arrows. Each inlet is identified with the first two letters of its name: Bø: Bølstadbekken, No: Norderåsbekken, Sm: Smedbølbekken, St: Storgrava and Vo: Vollebekken.

3 Results

The accuracy in the determination of trace metals was checked by concurrent analysis of certified reference materials. The average value and standard deviation for the different CRM samples was calculated where it was possible (n ≥ 3). The results are given in appendix 6 and the data are presented in proportion to how the certified limits were to the analyses values.

It is not possible to say anything about the precision of the analysis because no parallel analysis of the same sample was done.

A paired-t-test with a 95% confidence interval showed that the two layers (0 - 2.5 cm and 2.5 - 5 cm) where not significantly different (p-value > 0.05). This means that the metals in the two layers apparently are similar and for this reason the data that are analysed here are based just on the data for the second layer (2.5 - 5 cm), because this layer was analysed also for clay content and other grain sizes.

3.1 Depth groups

The data were divided into four groups (each on 25% of the total surface area) depending on the bathigraphical curve: shallower than 4 m, between 4 m and 8.5 m, between 8.5 m and 11.3 m and deeper than 11.3m (Figure 3).

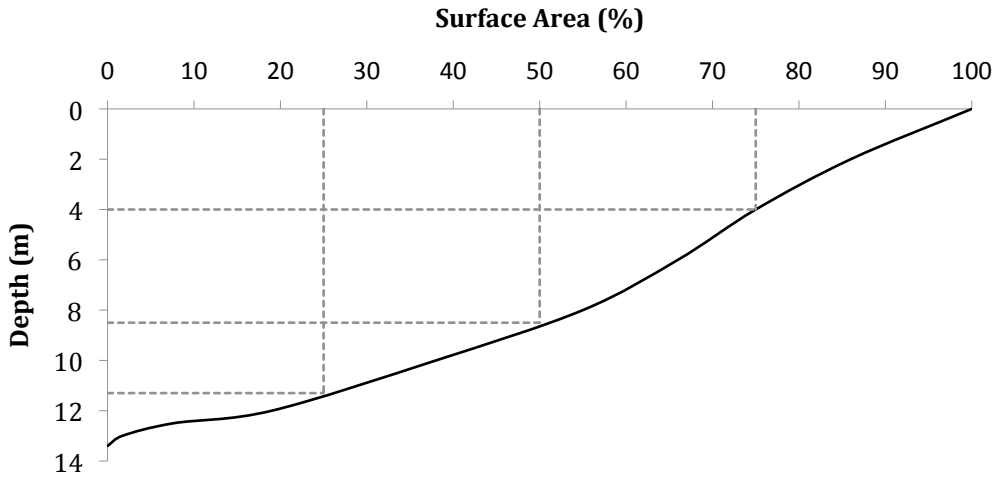


Figure 3. Bathigrafical curve of Lake Årungen. Modified from Hexum (1963).

The data were analysed with the help of a boxplot. Since there were clay data just for 61 of 122 samples it was important to find out that these samples were representative for the whole study area. A two-sample-t-test with a 95% confidence interval was used. The test results were given in Table 7. The values in the column "estimated difference" gave an indication if the group with clay data was representative or not. This test showed that the two groups were not significantly different ($p > 0.05$). In this way it was possible to show that the samples chosen for the grain size analysis were representative also for the samples that did not get analyzed for clay content.

Table 7 Results from the two-sample-t-test between the samples that were analysed for clay content and those that were not, to see if the one with clay content analysis were representative for the whole dataset.

Element	Estimated difference	p-values	Element	Estimated difference	p-values
Al	1.45	0.553	Fe	1.17	0.520
As	0.009	0.977	K	0.448	0.544
Ca	-0.150	0.585	Mg	0.272	0.564
Cd	-0.0443	0.159	Mn	0.0580	0.233
Co	0.095	0.863	Ni	0.84	0.694
Cr	1.80	0.583	Pb	0.000	1.000
Cs	0.159	0.568	Zn	2.47	0.763
Cu	-0.24	0.873	Hg	0.00118	0.827

For the maps the histograms and the scatterplot of depth and concentration of the metal the total amount of samples was 120, while for the boxplot and the scatterplot of clay content and concentration of the metal the total amount was 59, because two of the samples analysed for clay were not analysed for content of metals (sample 1069 and 1098). The linear regression with the variables depth and clay content is also based on $n = 59$ (appendix 7).

3.2 Sediment properties

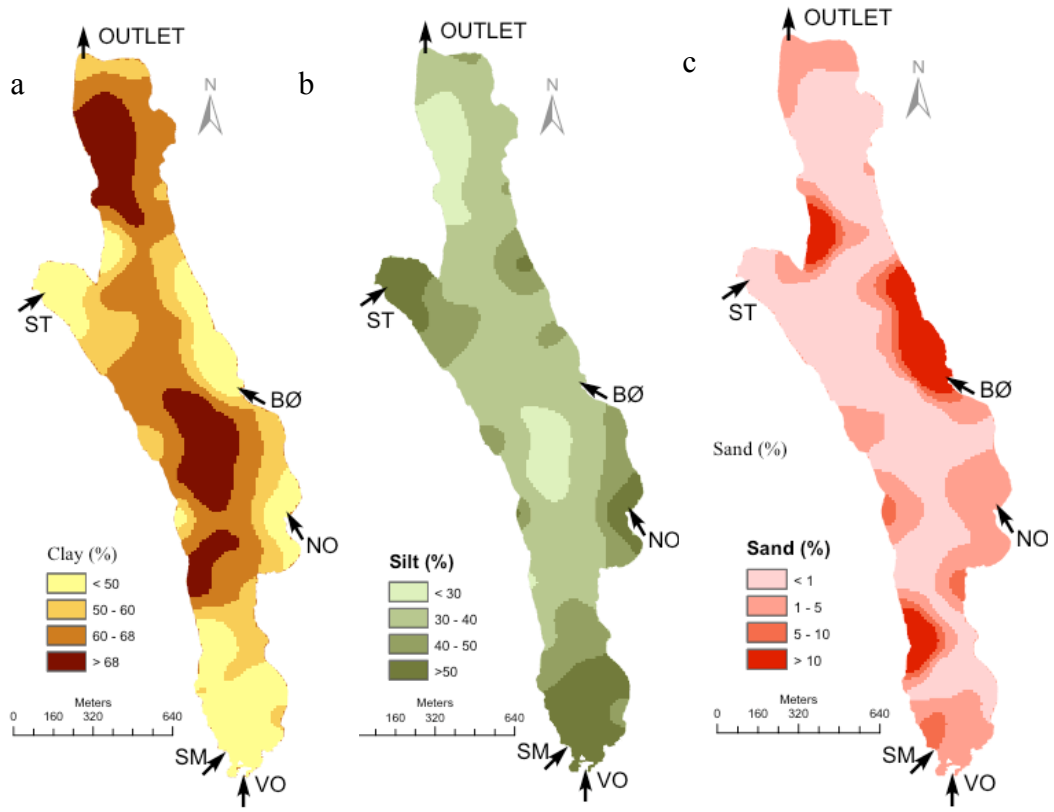


Figure 4. Distribution of clay (a), silt (b) and sand (c) in Lake Årungen (Rutsinda, 2010).

The grain size analyses were done by Rutsinda (2010) and the results are presented in an independent thesis. The distribution of sand particles was greatest in the area near the inlets of Bølstadbekken and Smedbølbekken and in the proximity of sample point 33 and 95, while there was a low accumulation in the deeper zones. A high amount of silt was settled near the inlets Norderåsbekken, Storgrava and Vollebekken and was quite high around sample point 36. Also for this grain size there was not a high accumulation in the deeper part of the lake basin. The opposite trend was valid for the distribution of clay. There was less accumulation in the shallow parts and there was an increase of clay with increasing depth (Figure 4). In the four depth groups the distribution was systematic: in the shallowest group (0 - 4m) there were many samples that had a low amount of clay (<50 %) and no samples in this group had a content of clay higher than 68%. The opposite scenario was shown in the deepest group (11.3 - 13-4 m) where no samples had a clay percent lower than 50% and many had an accumulation that was higher that 68%.

The analysis of organic matter content in the sediment samples was done by Naas (2010) and the results are presented in an independent thesis. The distribution of organic matter shown as loss on ignition (LOI) is shown in Figure 5.

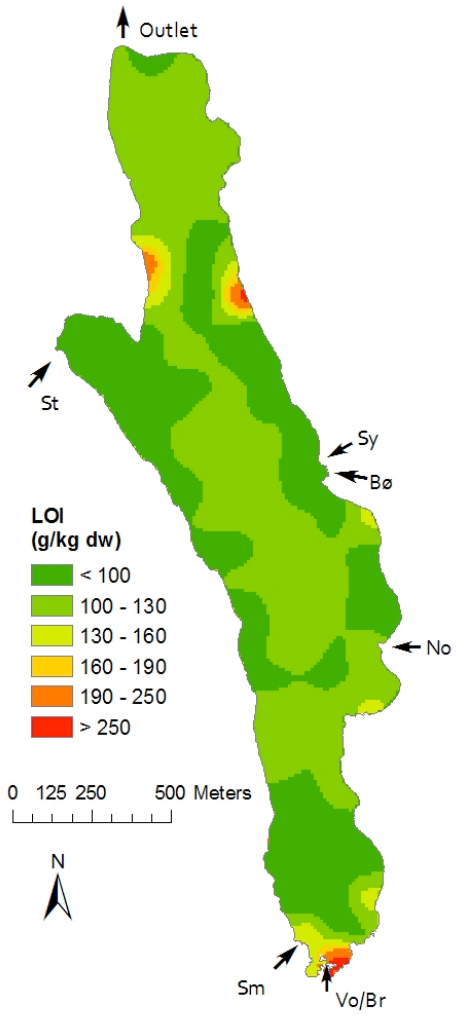


Figure 5. Map with the distribution of organic matter (LOI) in Lake Årungen (Naas, 2010).

3.3 Element composition of the lake sediment

All the raw data are presented in appendix 5 and the principal values are gathered in Table 8. The data are divided in two groups: metals that are present in soil in large quantities and trace metals. The order in which they are presented follows the median value of each element, from the one with highest concentration to the one with less. The first group comprehends Al>Fe>K>Mg >Ca>Mn>Na in decreasing order (Figure 6). These metals are naturally present in the soil crust and in rocks in high concentrations. For this reason the concentration of these is high and can be referred with g/kg DW.

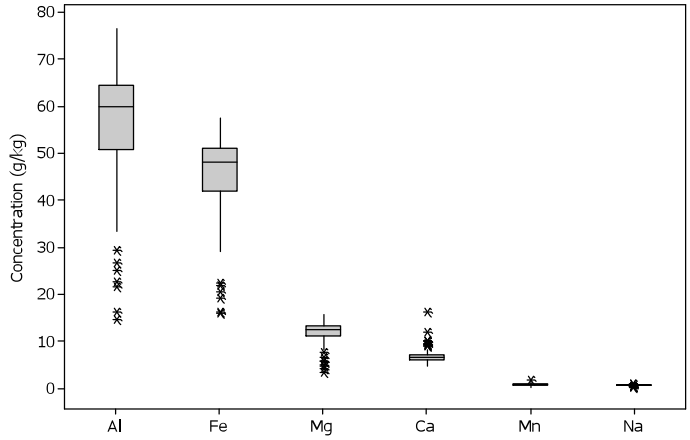


Figure 6. Boxplot for the concentrations of macro components in decreasing order.

The second group contains the elements that occur in relatively lower concentrations and that can be toxic if the accumulation is too high. In decreasing order these are: Ba>Zn>V>Cr>Sr>Ni>Cu>Pb>Co>As>Cs>Cd>Hg (Figure 7).

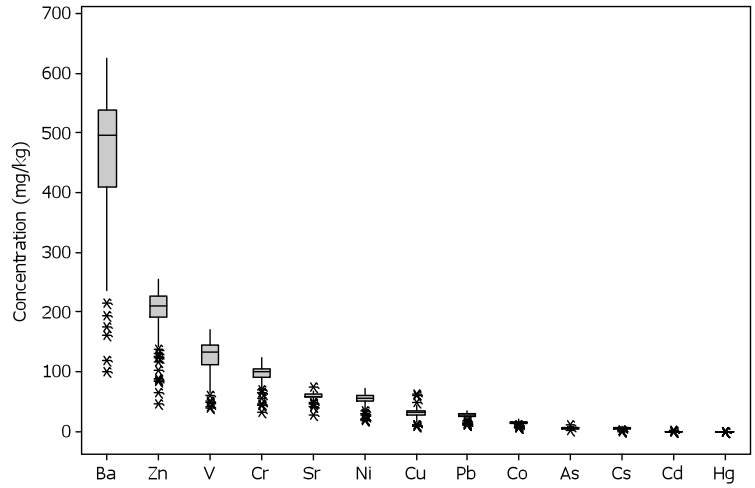


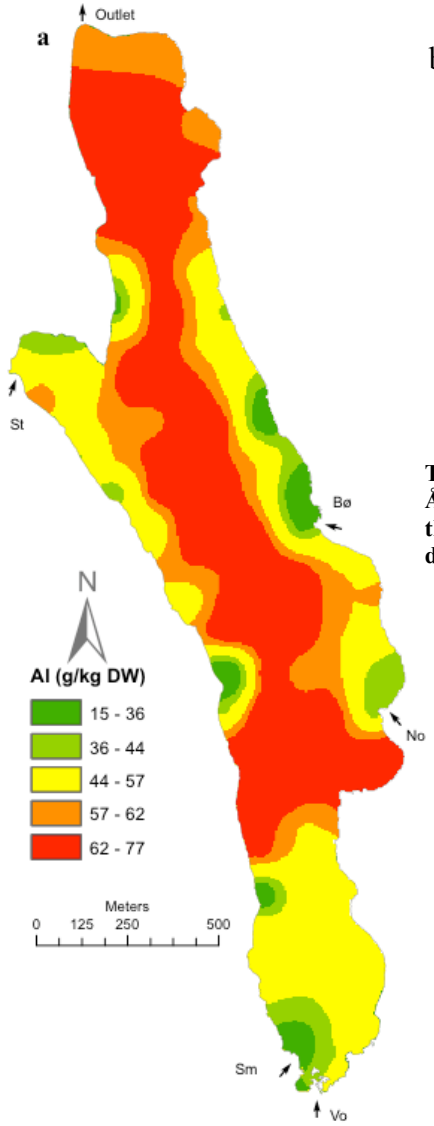
Figure 7. Boxplot for the concentrations of trace metals in decreasing order.

Table 8. Principal values of the studied trace elements. N= total number of samples, Min: minimum value, Max= maximum value, St. Dev= Standard deviation.

Element	N	Min	Average	Median	Max	St. Dev
Al (g/kg)	120	15	60	60.0	77	12
Fe (g/kg)	120	16	45	48	58	8.8
K (g/kg)	120	4.4	17	18	23	3.7
Mg (g/kg)	120	3.5	12	13	16	2.2
Ca (g/kg)	120	4.8	7.0	6.7	16	1.4
Mn (g/kg)	120	0.30	0.91	0.87	1.9	0.26
Na (g/kg)	120	0.33	0.73	0.75	1.2	0.11
Ba (mg/kg)	120	100	460	500	630	110
Zn (mg/kg)	120	46	200	210	260	40
V (mg/kg)	120	40	130	130	170	26
Cr (mg/kg)	120	33	96	100	120	15
Sr (mg/kg)	120	29	59	60	75	5.4
Ni (mg/Kg)	120	18	54	57	72	10
Cu (mg/kg)	120	9.1	31	33	63	7.6
Pb (mg/kg)	120	11	27	28	36	4.7
Co (mg/kg)	120	6.9	16	17	21	2.5
As (mg/kg)	119	1.9	6.4	6.4	11	1.6
Cs (mg/kg)	119	1.1	5.8	6.2	8.3	1.4
Cd (mg/kg)	119	0.15	0.56	0.5	1.5	0.17
Hg (mg/kg)	120	0.020	0.10	0.10	0.27	0.028

3.4 Macro components

3.4.1 Aluminium (Al)



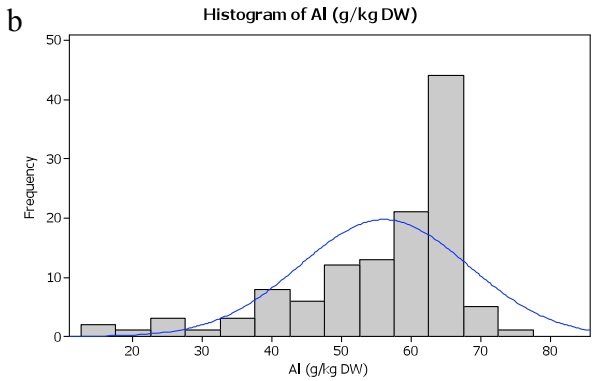


Table 9. Concentration of Al (g/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Al	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	15	15	22	41	51
Average	56	50	56	59	63
Median	60	43	60	62	64
Max	77	60	67	77	70
St.Dev	12	13	12	8.6	4.0

Figure 8. Horizontal distribution of Al (a). The arrows (↑) mark inlets and the outlet. The histogram shows the distribution of Al (g/kg DW), with a trend line for normal distribution (b).

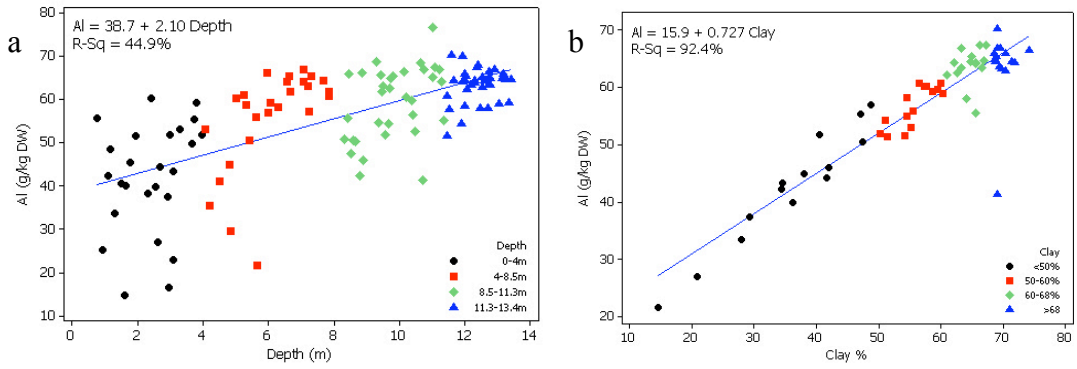


Figure 9. Scatterplot of Al concentration with depth (n=120) (a) and with clay content (n=59) (b).

The horizontal distribution of Al is shown in Figure 8. The concentration has an increasing trend with increasing depth. It seems that the concentration of Al has low values near the inlets Bølstadbekken, Norderåsbekken and Smedbølbekken; it is however higher near the inlets Storgrava and Vollebekken. The map indicates an accumulation of Al near the outlet (Figure 8).

The concentration of Al in the lake shows a sharp increase, with increasing percentage of clay (Figure 9). The variation in spreading decreases with increasing depth (Figure 10). The regression analysis shows that clay is the significant predictor in proportion to depth (appendix 7).

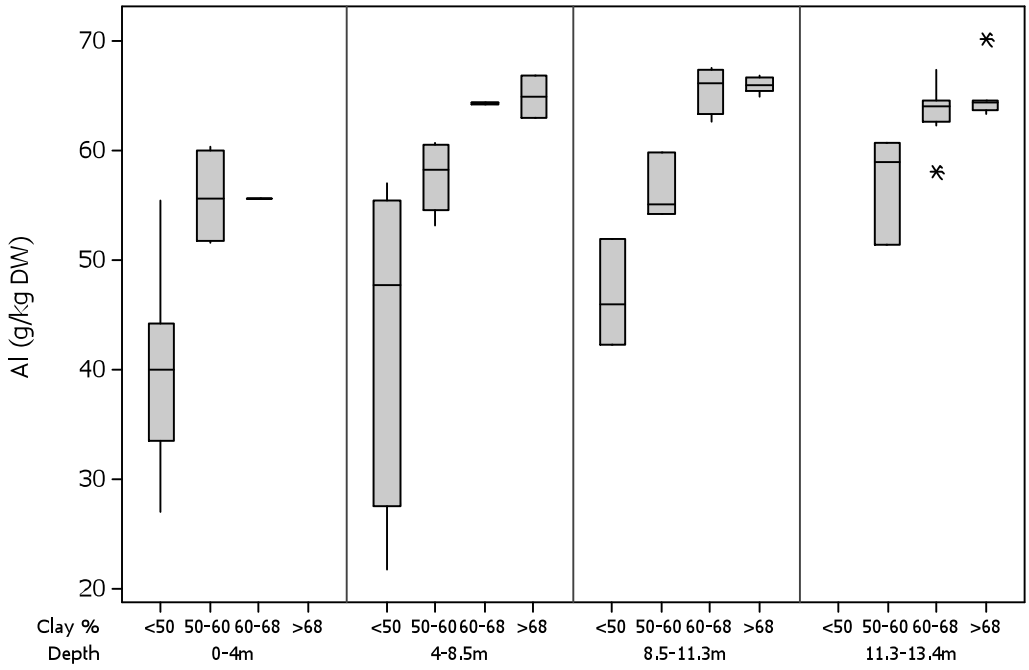


Figure 10. Concentration of Al sorted by depth groups and clay content (n=59).

3.4.2 Iron (Fe)

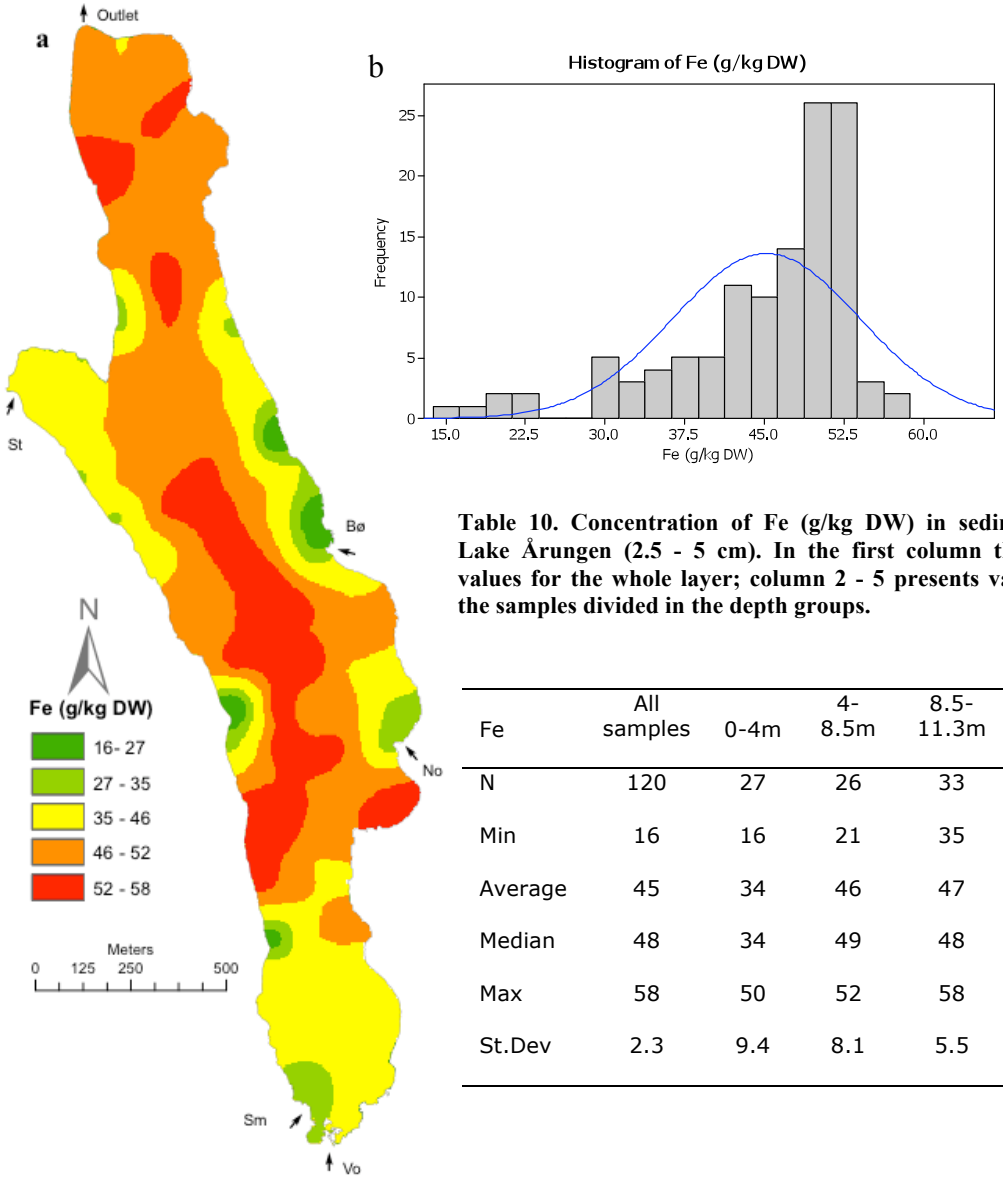


Figure 11. Horizontal distribution of Fe (a). The arrows (↑) mark the inlets and the outlet. The histogram shows the distribution of Fe (g/kg DW), with a trend line for normal distribution (b).

Table 10. Concentration of Fe (g/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Fe	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	16	16	21	35	43
Average	45	34	46	47	51
Median	48	34	49	48	52
Max	58	50	52	58	57
St.Dev	2.3	9.4	8.1	5.5	3.2

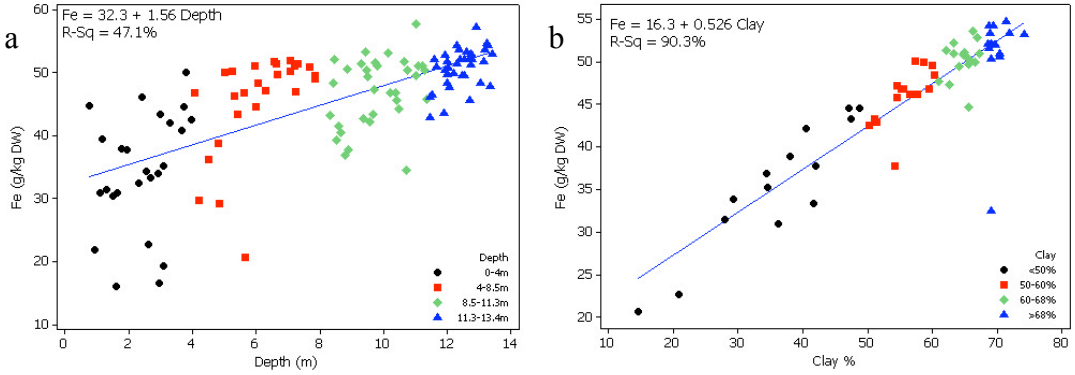


Figure 12. Scatterplot of Fe concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Fe fluctuates between 16 and 58 g/kg DW, with a median of 48 g/kg DW (Table 10).

Figure 11 shows a clear trend on the distribution of Fe in Lake Årungen. The highest accumulation is recorded in the deeper part of the lake. Near the inlets Bølstadbekken, Norderåsbekken and Smedbølbekken the accumulation is not as high as it is near the inlets Storgrava and Vollebekken.

The linear regression analysis shows that clay content in the sediment is the most influential variable in the system (appendix 7). It is quite clear in the boxplot that the content of iron increases with clay content (Figure 12; Figure 13). Also the variation in the different depth groups gets smaller with the increase of clay content, but also with increasing depth.

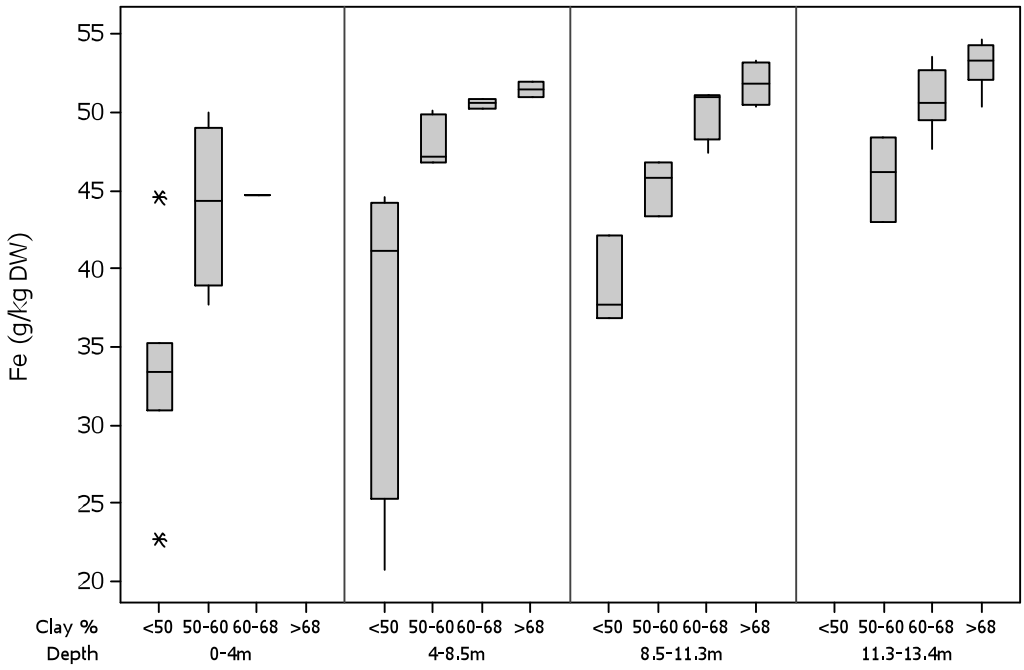


Figure 13. Concentration of Fe sorted by depth groups and clay content (n=59).

3.4.3 Potassium (K)

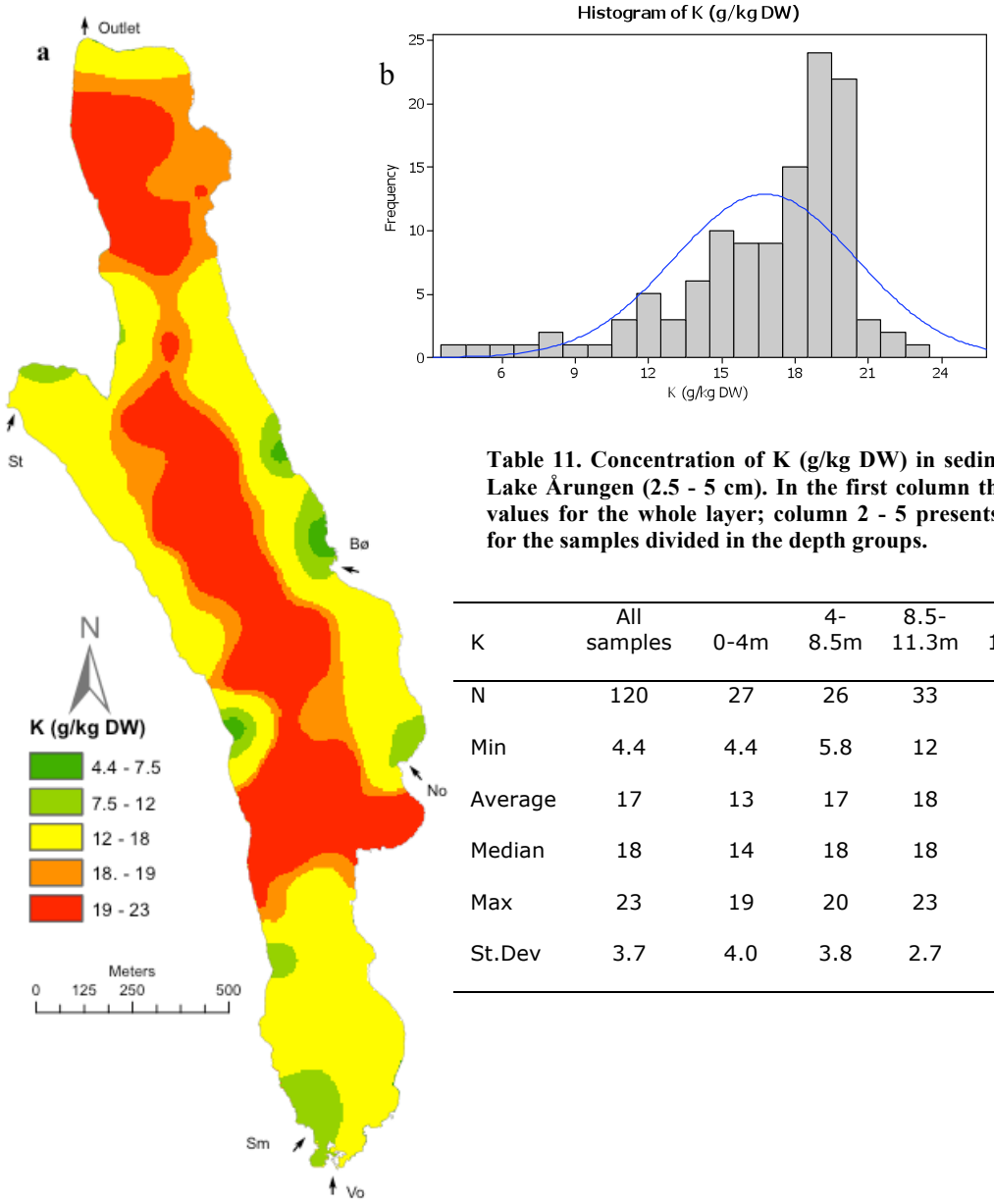


Table 11. Concentration of K (g/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

K	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	4.4	4.4	5.8	12	15
Average	17	13	17	18	19
Median	18	14	18	18	19
Max	23	19	20	23	22
St.Dev	3.7	4.0	3.8	2.7	1.4

Figure 14. Horizontal distribution of K (a). The arrows (↑) mark the inlets the outlet. The histogram shows the distribution of K (g/kg DW), with a trend line for normal distribution (b).

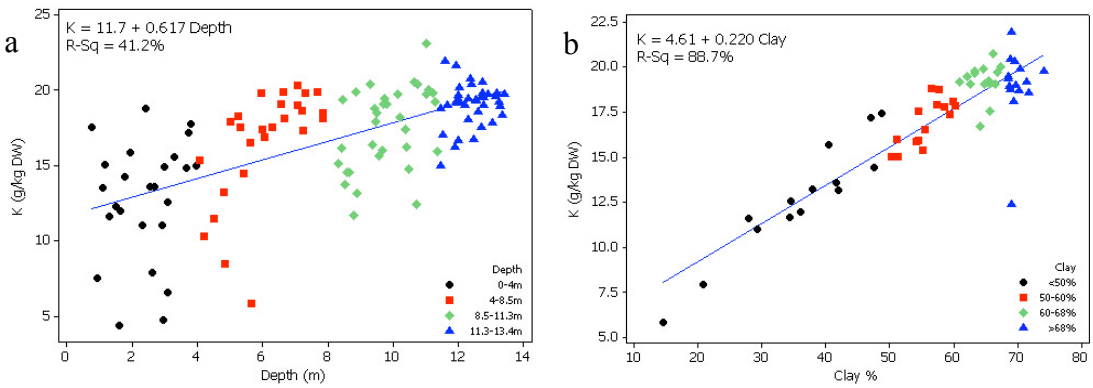


Figure 15. Scatterplot of K concentration with depth (n=120) (a) and with clay content (n=59) (b).

The accumulation of K varies between 4.0 and 23 g/kg DW, with a median of 18 g/kg DW (Table 11).

The spatial distribution of K has a clear pattern: in the deeper zones there is a higher concentration, while near the inlets and in the littoral zone there are lower concentrations (Figure 14).

The linear regression analysis shows that clay is the dominant variable, while depth is not significant (appendix 7). With help of backward elimination it is possible to see that LOI should be taken in consideration together with clay content, while depth can be omitted. The scatterplot shows a clear increasing trend, where clay content in the sample and the accumulation of the element has a tight connection (Figure 15). In the shallowest groups (0 - 4 m and 4 - 8.5 m) the variation is relatively big, but it also increases between the different clay content groups. The variation of concentration between the samples gets smaller in the deeper groups (8.5 - 11.3 m and 11.3 - 13.4 m) (Figure 16).

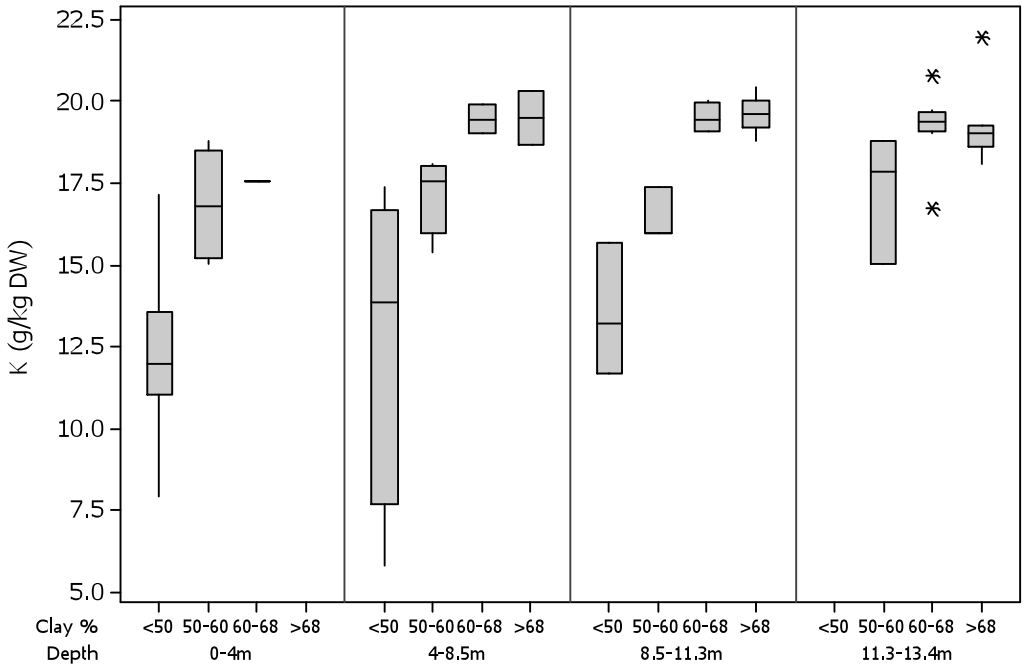


Figure 16. Concentration of K sorted by depth groups and clay content (n=59).

3.4.4 Magnesium (Mg)

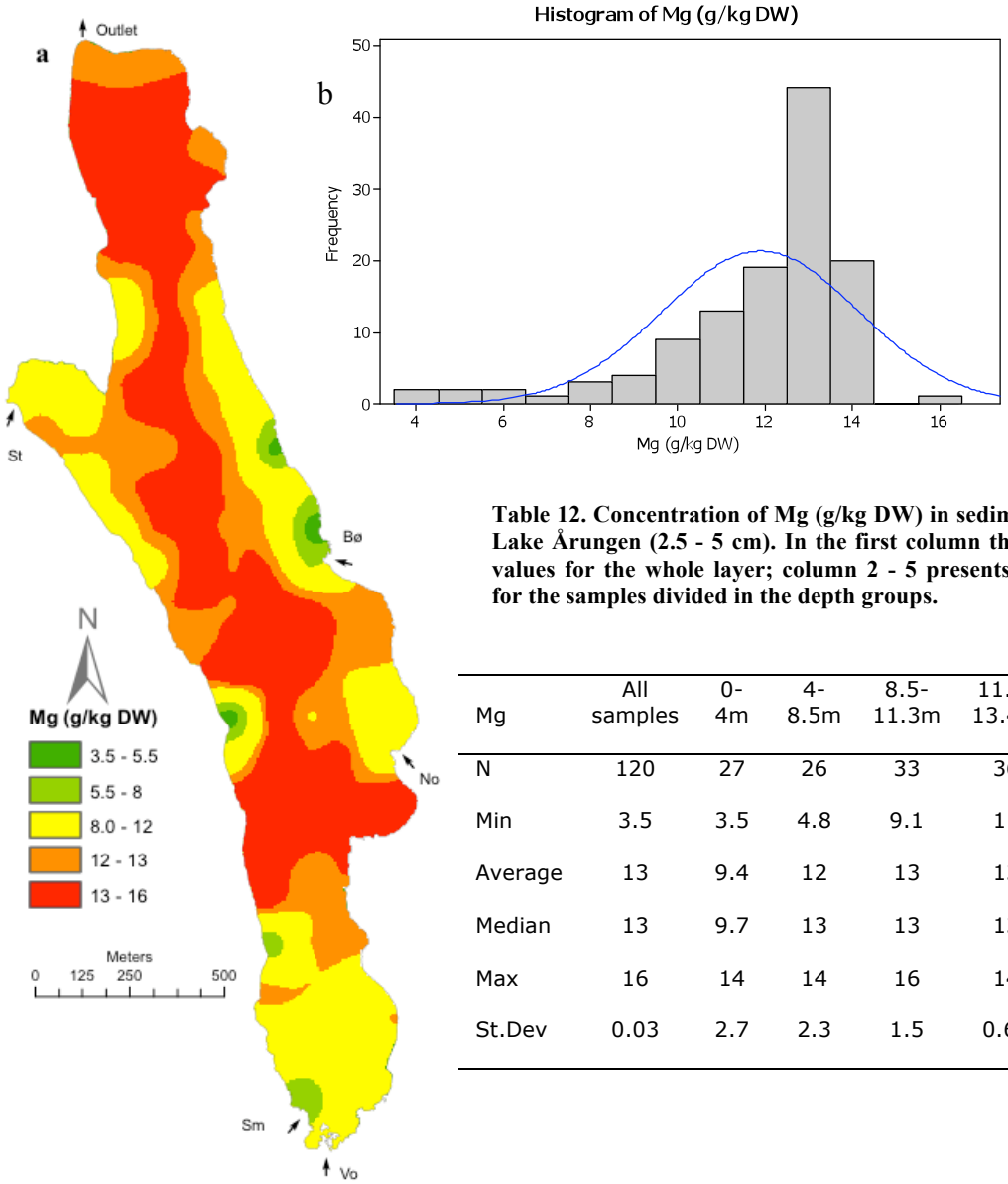


Table 12. Concentration of Mg (g/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Mg	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	3.5	3.5	4.8	9.1	11
Average	13	9.4	12	13	13
Median	13	9.7	13	13	13
Max	16	14	14	16	14
St.Dev	0.03	2.7	2.3	1.5	0.68

Figure 17. Horizontal distribution of Mg (a). The arrows (↑) mark inlets and the outlet. The histogram shows the distribution of Mg (g/kg DW), with a trend line for normality distribution (b).

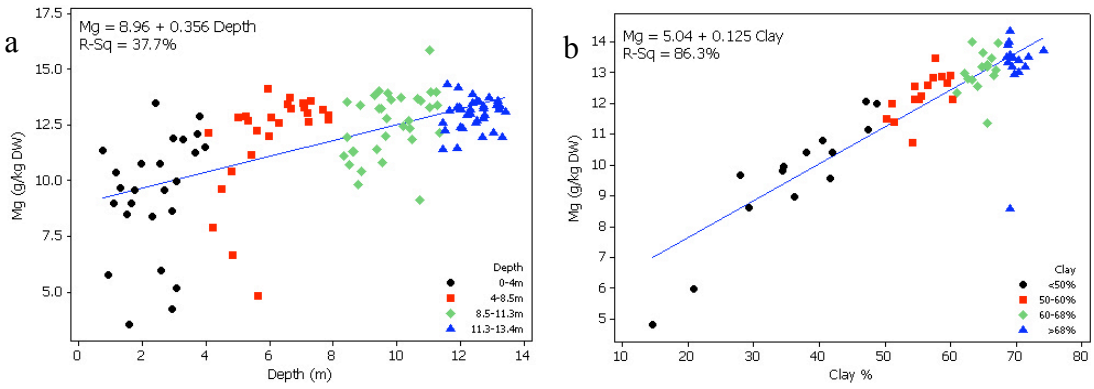


Figure 18. Scatterplot of Mg concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Mg in Lake Årungen varies between 4.0 and 16 g/kg DW, with a median of 13 g/kg DW (Table 12).

The horizontal distribution of Mg is shown in Figure 17. The highest concentrations are accumulated in the deeper area. The contribution of Mg from the inlets Bølstadbekken, Norderåsbekken and Smedbølbekken seems to be less important compared with the other two inlets, Storgrava and Vollebekken.

The regression analysis tells that clay is the dominant variable (appendix 7). A backward elimination test shows that the best regression system for Mg is when clay content, depth and LOI are analysed together. Figure 18 and Figure 19 show the same trend as the regression, i.e. that the concentration of Mg increases with increasing content of clay in the sediment. For the depth groups 0 - 4 m and 4 - 8.5 m and 11.3 - 13.4 m is this increase very evident, while for the deepest group the variation is not so large.

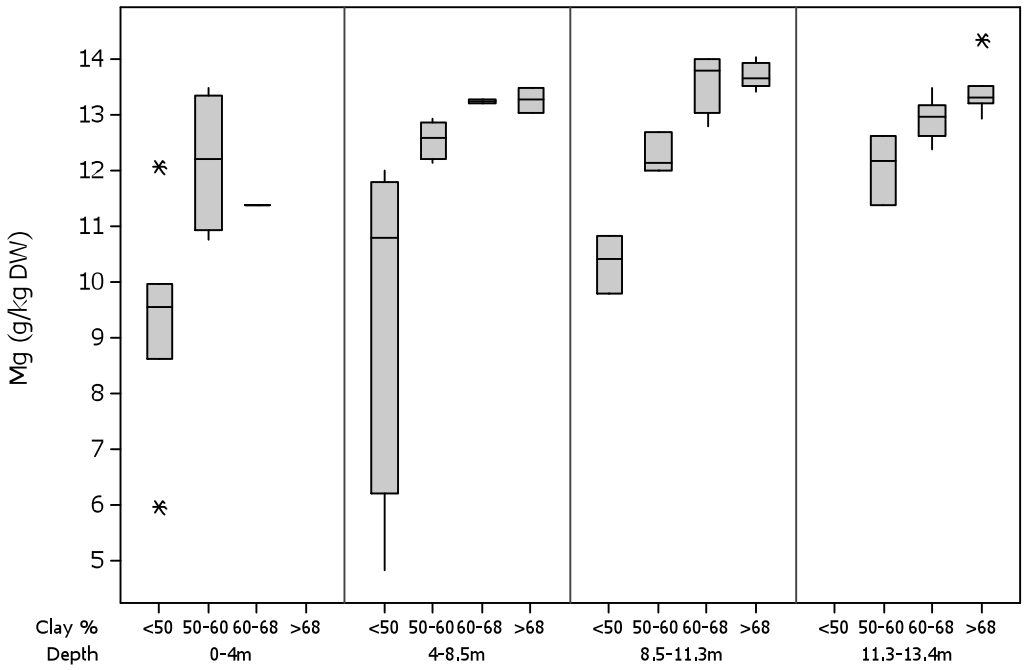


Figure 19. Concentration of Mg sorted by depth groups and clay content (n=59).

3.4.5 Calcium (Ca)

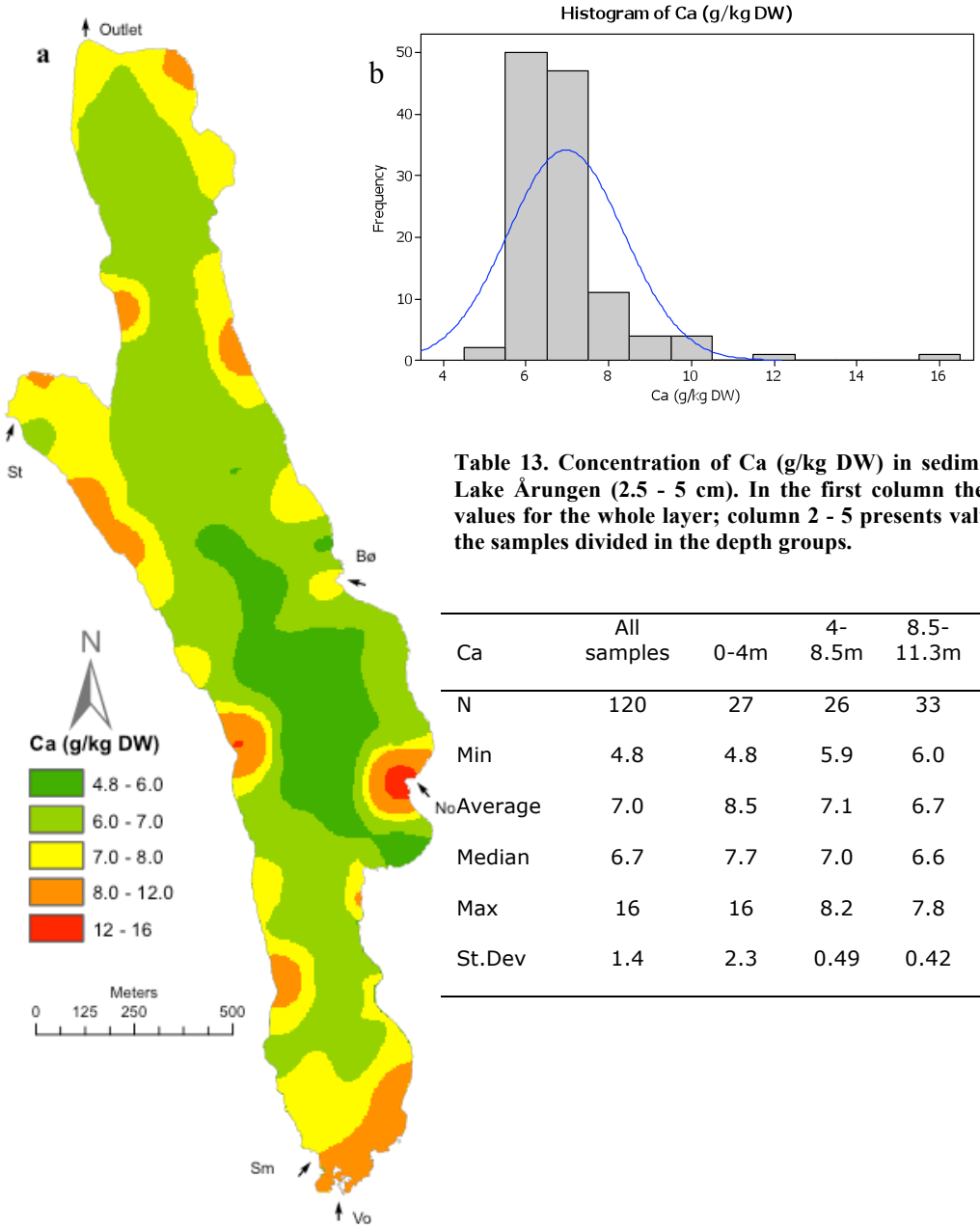


Table 13. Concentration of Ca (g/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Ca	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	4.8	4.8	5.9	6.0	5.2
Average	7.0	8.5	7.1	6.7	6.0
Median	6.7	7.7	7.0	6.6	6.0
Max	16	16	8.2	7.8	6.6
St.Dev	1.4	2.3	0.49	0.42	0.26

Figure 20. Horizontal distribution of Ca (a). The arrows (↑) mark the inlets and the outlet. The histogram shows the distribution of Ca (g/kg DW), with a trend line for normal distribution (b).

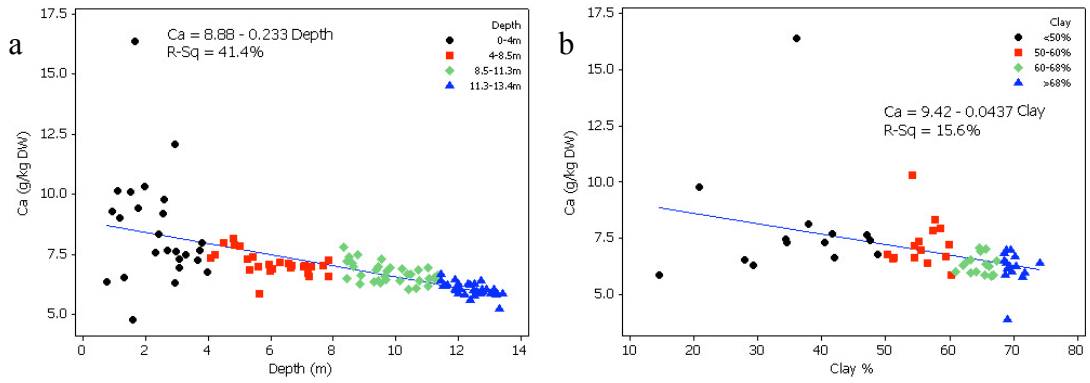


Figure 21. Scatterplot of Ca concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Ca covers values between 4.8 and 16 g/kg DW with a median of 6.7 g/kg DW (Table 13).

The horizontal distribution shows visually that the concentration of clay decreases with depth. There is a high accumulation at the inlet Norderåsbekken, where the highest values were measured. Also in the area of Bølstadbekken high values were measured (Figure 20).

The amount of Ca is inversely proportional to the depth of the lake and clay content in the sediment (Figure 21). The highest concentration of Ca is in the shallowest group (0 - 4 m); in the remaining groups there is most Ca in the group with less clay (<50%) (Figure 22). The regression analysis confirms that depth is the dominating variable, while clay is not significant in the analysis (appendix 7). Also the backward elimination test confirms this: depth gives the best result. As depth increases, the concentration decreases.

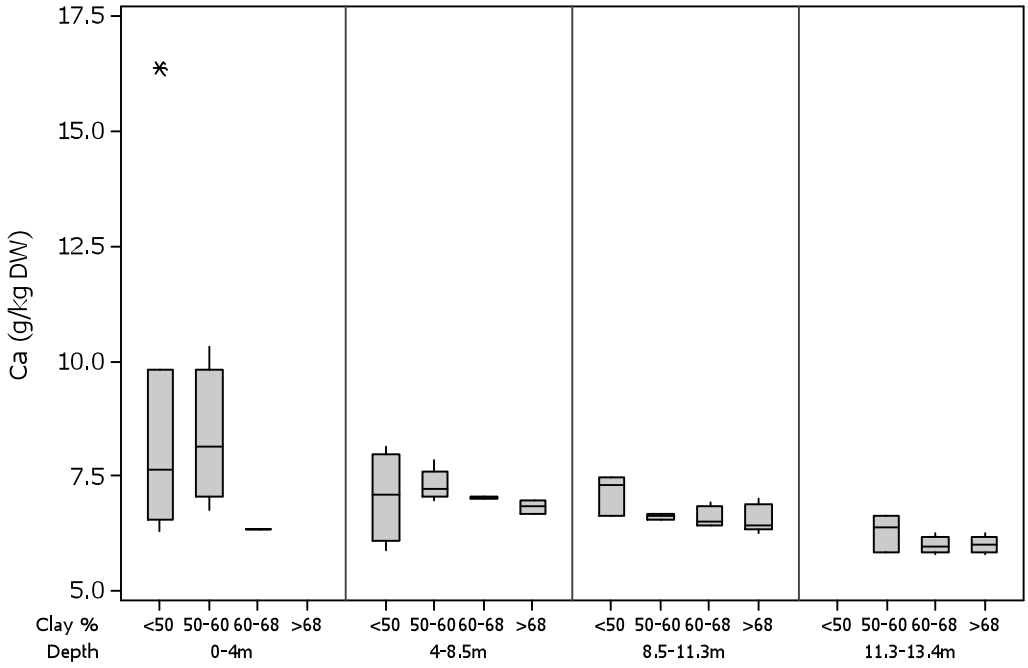


Figure 22. Concentration of Ca sorted by depth groups and clay content (n=59).

3.4.6 Manganese (Mn)

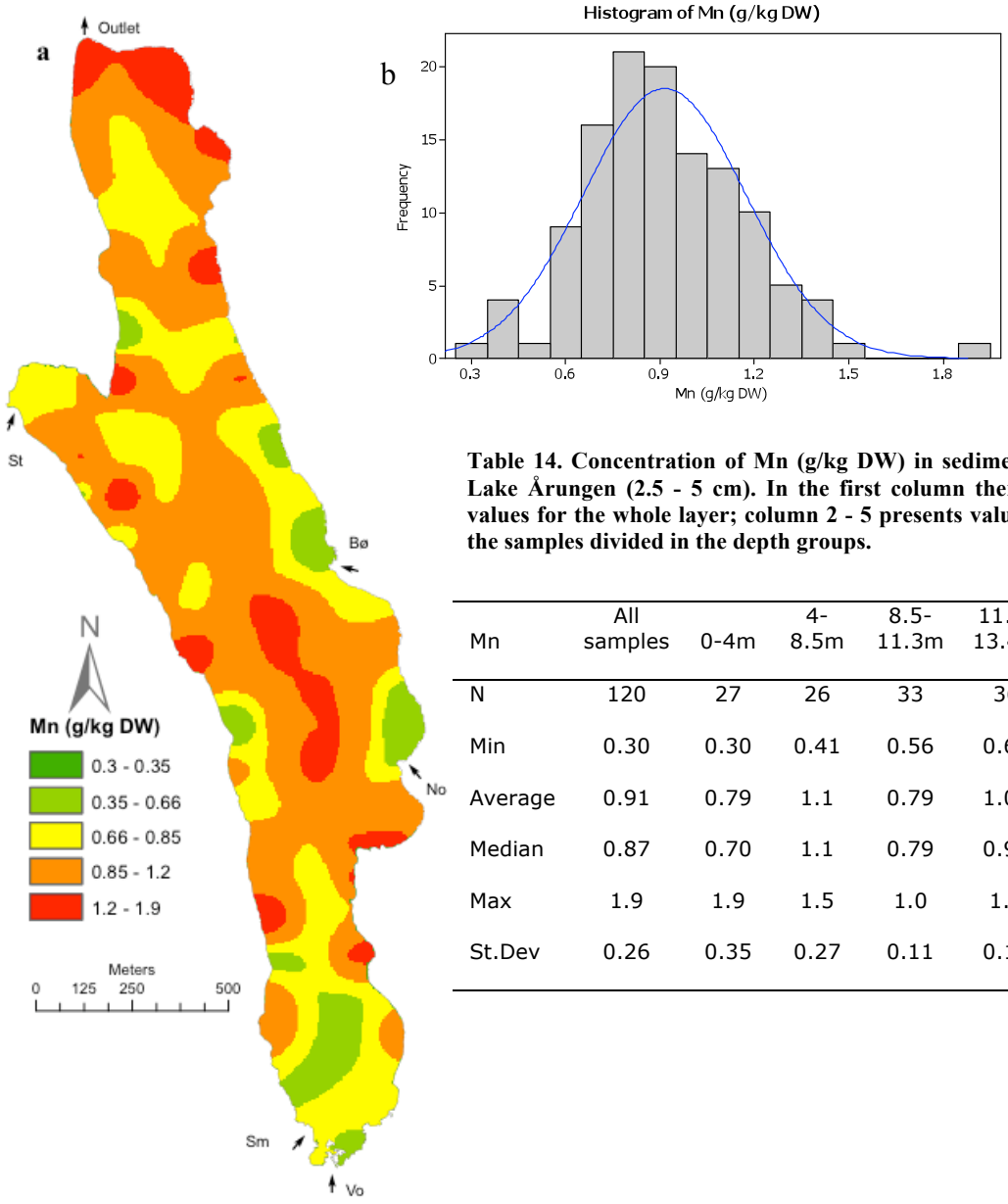


Table 14. Concentration of Mn (g/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Mn	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	0.30	0.30	0.41	0.56	0.67
Average	0.91	0.79	1.1	0.79	1.00
Median	0.87	0.70	1.1	0.79	0.99
Max	1.9	1.9	1.5	1.0	1.3
St.Dev	0.26	0.35	0.27	0.11	0.17

Figure 23. Horizontal distribution of Mn (a). The arrows (↑) mark inlets and the outlet. The histogram shows the distribution of Mn (g/kg DW), with a trend line for normal distribution (b).

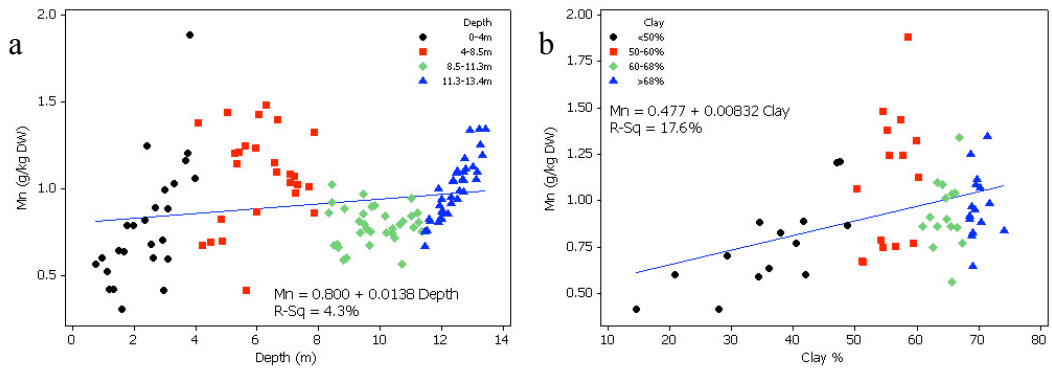


Figure 24. Scatterplot of Mn concentration with depth (n=120) (a) and with clay content (n=59) (b).

Mn ranges between 0.3 and 1.9 g/kg DW, with a median of 0.87 g/kg DW (Table 14).

The horizontal distribution seems to follow a particular pattern, different from the other elements, but there is an increase with the depth and an accumulation in the outlet area. There are low concentrations near the inlets Bølstadbekken, Norderåsbekken and Vollebekken, while the concentration is higher in the area under the influence of Storgrava and Smedbølbekken (Figure 23).

Manganese is the only element that has high correlation with the depth in the shallowest group and in the sedimentation area in the deep (appendix 8). The regression analysis on the other hand shows that clay is still the most dominant variable and that depth is inverse proportional to the accumulation of Mn in the sediments (Figure 24) (appendix 7). The backward elimination test presents that the best system for regression is the one where clay content, depth and organic matter are included. The boxplot visualises that there are trends for increasing concentration with increasing clay content, but it is not as conspicuous as it is for the other macro elements (Figure 25).

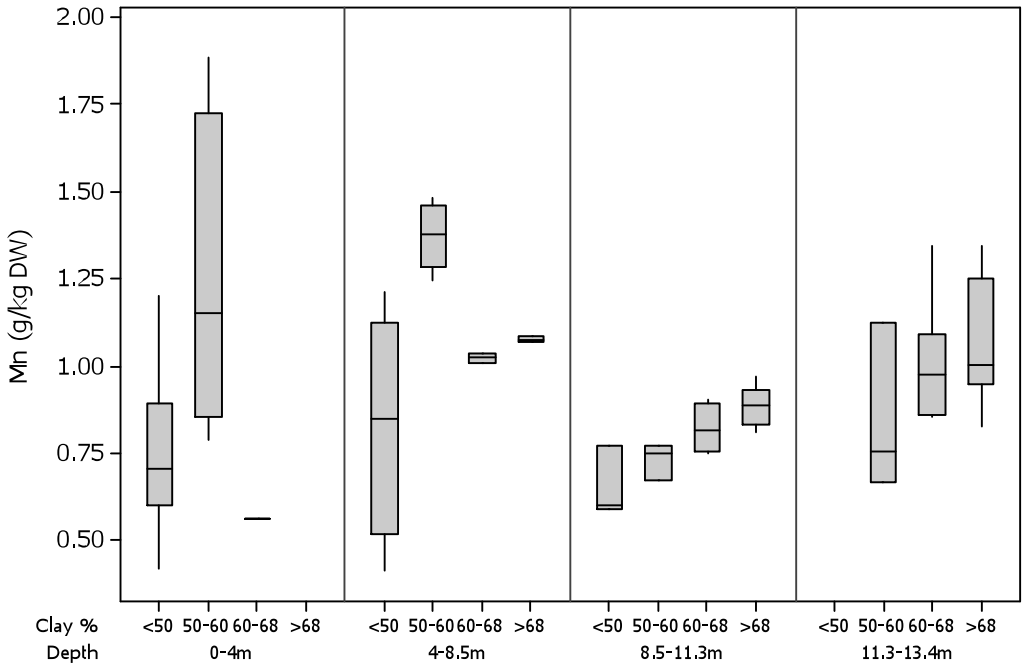


Figure 25. Concentration of Mn sorted by depth groups and clay content (n=59).

3.4.7 Sodium (Na)

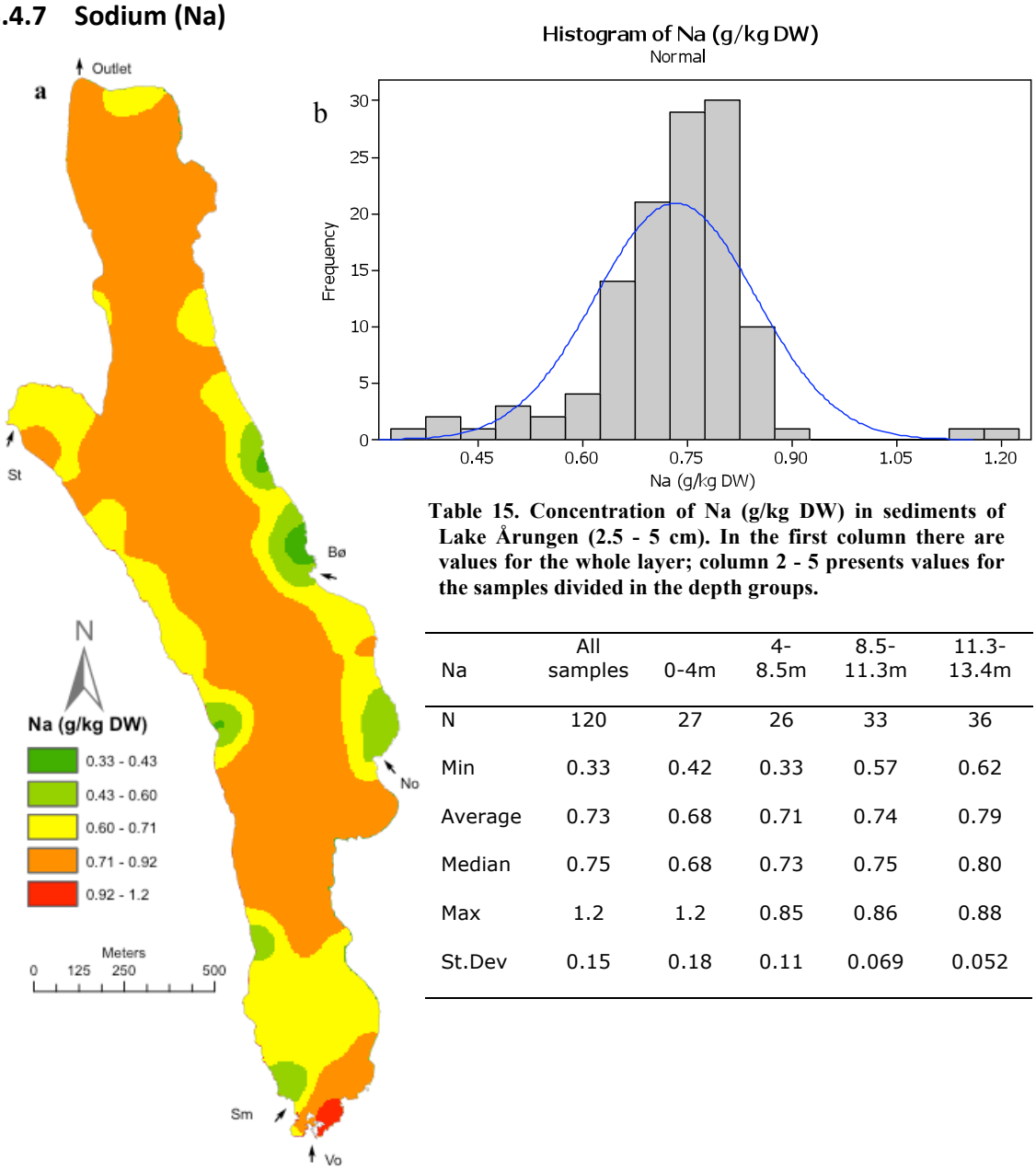


Table 15. Concentration of Na (g/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Na	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	0.33	0.42	0.33	0.57	0.62
Average	0.73	0.68	0.71	0.74	0.79
Median	0.75	0.68	0.73	0.75	0.80
Max	1.2	1.2	0.85	0.86	0.88
St.Dev	0.15	0.18	0.11	0.069	0.052

Figure 26. Horizontal distribution of Na (a). The arrows (↑) mark inlets and the outlet. The histogram shows the distribution of Na (g/kg DW), with a trend line for normal distribution (b).

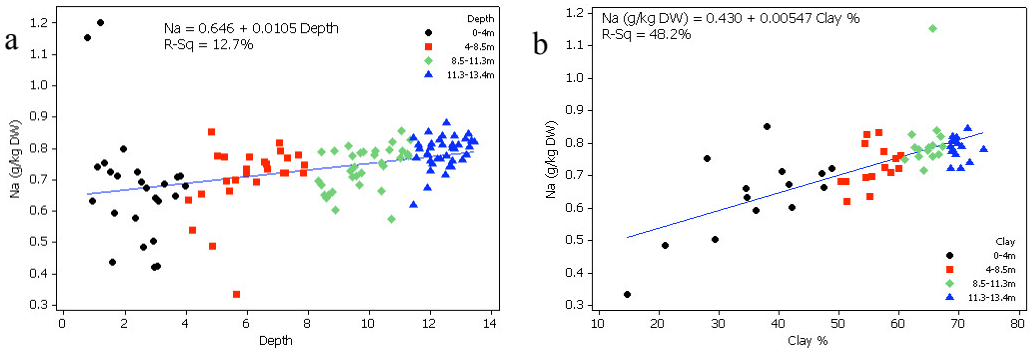


Figure 27. Scatterplot of Na concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Na is measured to be between 330 and 1200 mg/kg DW, with a median of 750 mg/kg DW (Table 15).

Figure 26 displays the accumulation of Na in the lake basin. A clear trend can be seen: the concentration is highest in the deeper part, while near the inlets of Bølstadbekken and Norderåsbekken the concentration is quite low. The opposite is for Vollebekken, where the highest values are measured.

The scatterplots illustrate the pattern for accumulation; there is an increase with increasing depth and increase in clay content (Figure 27). In Figure 28 the trend is not so clear, but the variation decreases with increasing depth. The regression analysis shows that depth is inverse proportional, while clay is the dominant component and that the best regression system is the one with clay depth and LOI (appendix 7).

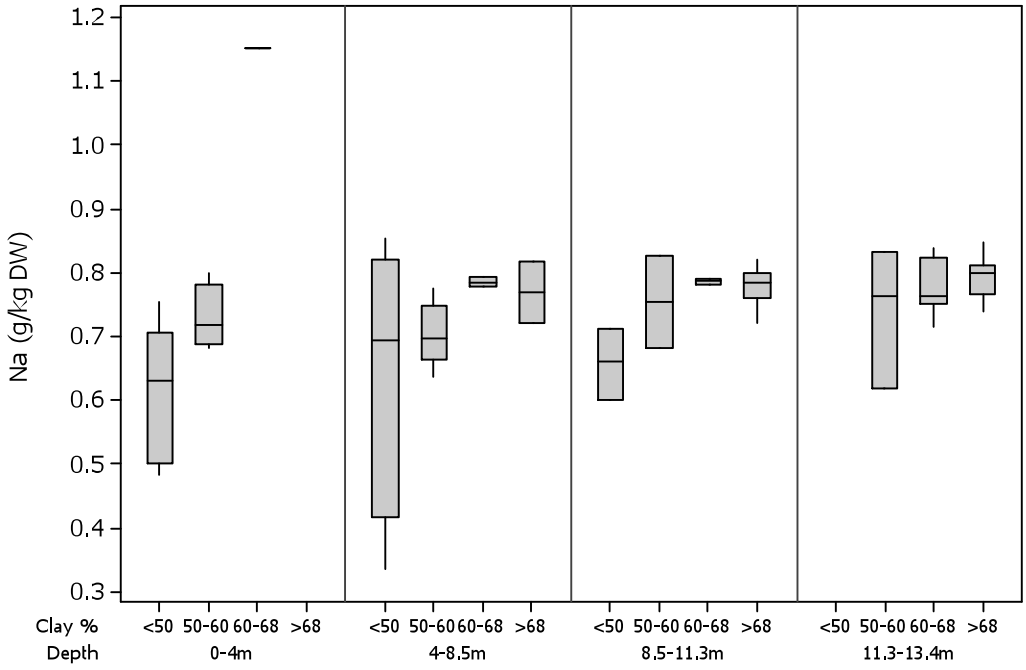


Figure 28.Concentration of Na sorted by depth groups and clay content (n=59).

3.5 Trace metals

3.5.1 Barium (Ba)

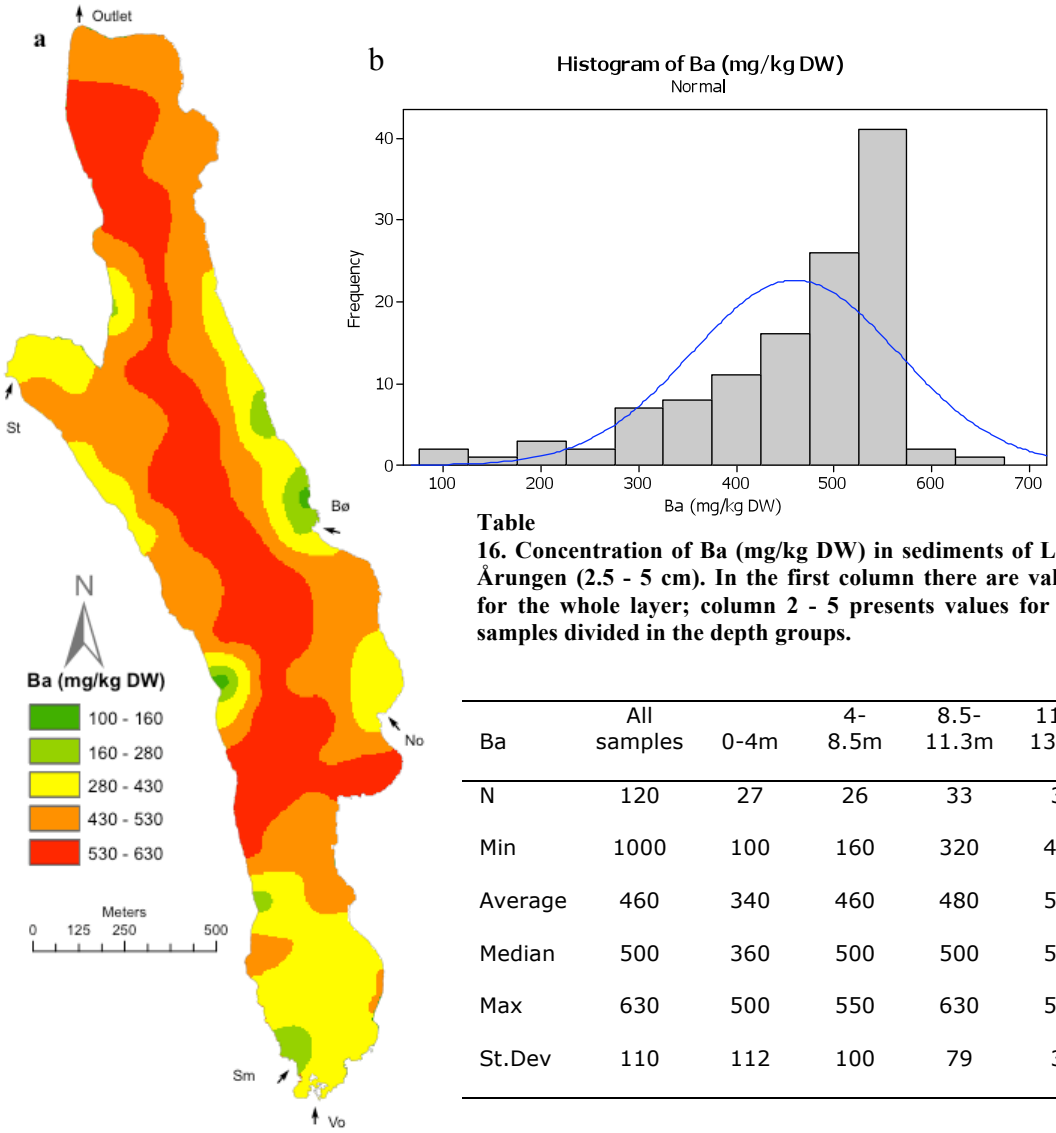


Figure 29. Horizontal distribution of Ba (a). The arrows (↑) mark inlets and the outlet. The histogram shows the distribution of Ba (mg/kg DW) with a trend line for normal distribution (b).

Table 16. Concentration of Ba (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Ba	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	1000	100	160	320	410
Average	460	340	460	480	530
Median	500	360	500	500	540
Max	630	500	550	630	590
St.Dev	110	112	100	79	38

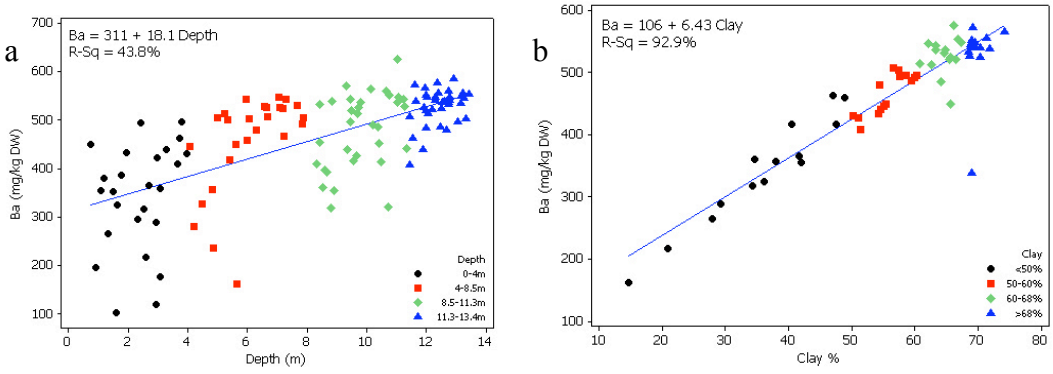


Figure 30. Scatterplot of Ba concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Ba varies between 100 and 630 mg/kg DW, with a median value of 500 mg/kg DW (Table 16).

The horizontal distribution of Ba follows the accumulation pattern of clay. This means that there is a higher accumulation where the concentration of clay is high, as in the deep part of the lake basin (Figure 29).

The plots show a clear pattern of increased concentration of Ba as higher the amount of clay is (Figure 30; Figure 31). Also the regression analysis tells that clay is the dominant variable in the system and that there is less of this metal with increasing LOI (appendix 7).

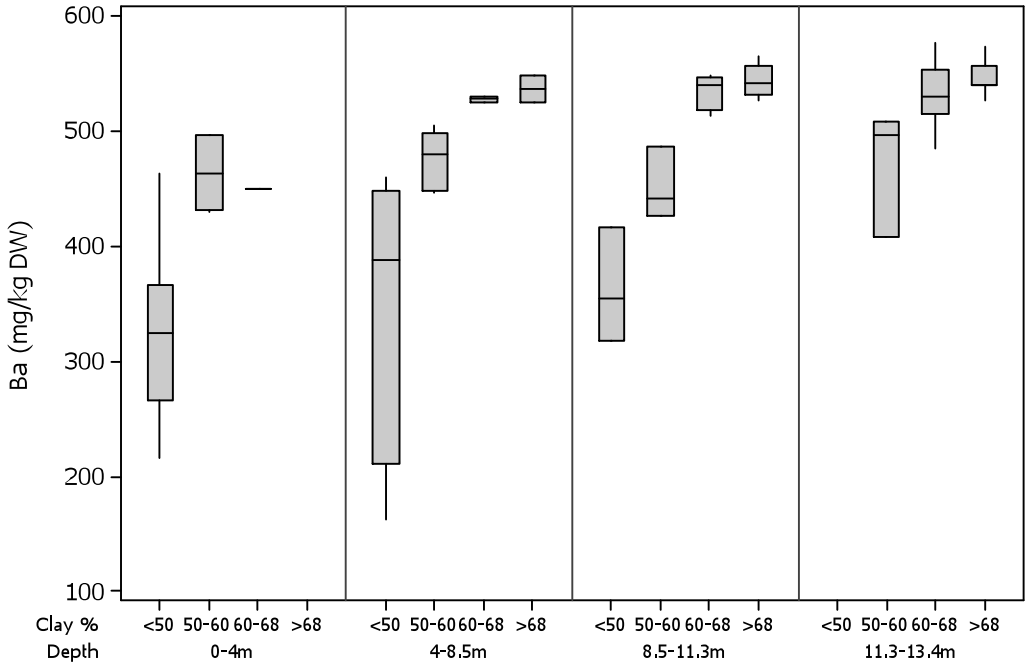


Figure 31. Concentration of Ba sorted by depth groups and clay content (n=59).

3.5.2 Zinc (Zn)

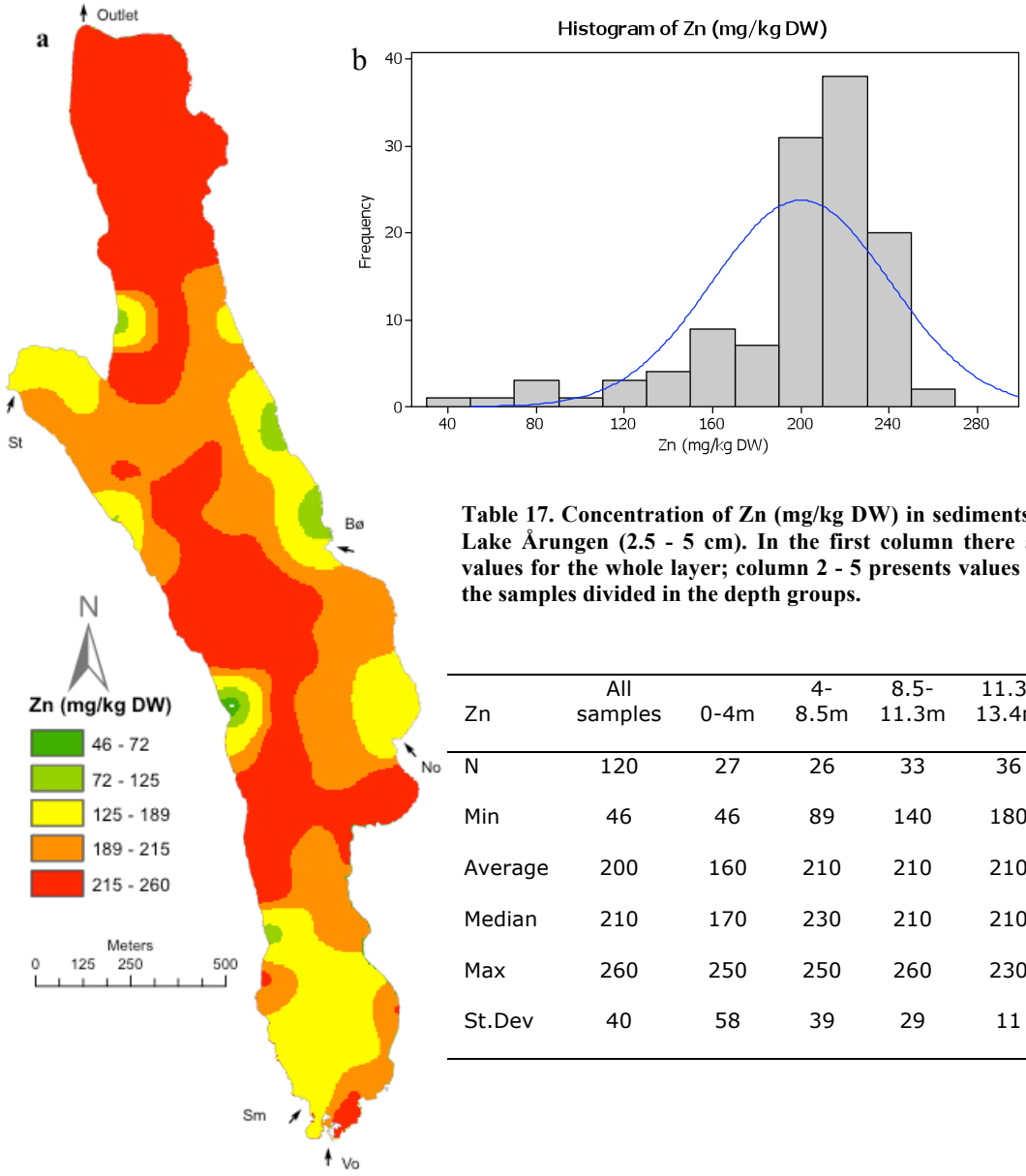


Table 17. Concentration of Zn (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Zn	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	46	46	89	140	180
Average	200	160	210	210	210
Median	210	170	230	210	210
Max	260	250	250	260	230
St.Dev	40	58	39	29	11

Figure 32. Horizontal distribution of Zn (a). The arrows (↑) mark the inlets the outlet. The histogram shows the distribution of Zn (mg/kg DW), with a trend line for normal distribution (b).

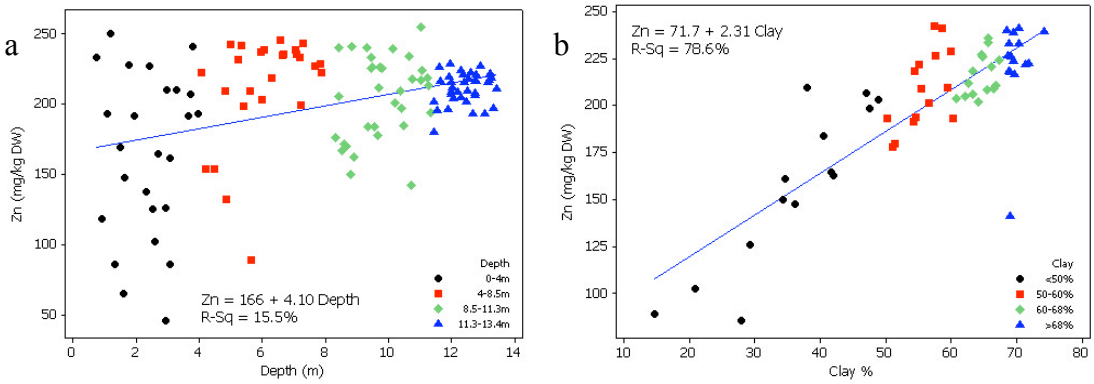


Figure 33. Scatterplot of Zn concentration with depth (n=120) (a) and with clay content (n=59) (b).

The accumulation of Zn varies between 46 and 260 mg/kg DW, with a median of 210 mg/kg DW (Table 17).

The horizontal distribution map demonstrates an accumulation of Zn in the deepest area and near the outlet. In the shallower area there are quite high values near the inlet Vollebekken and Storgrava, while near the other three inlets the concentration of Zn is lower (Figure 32).

The regression analysis shows that clay is dominant and that depth is inverse proportional to the accumulation of Zn (appendix 7). The backward elimination test shows that depth still should be taken in consideration to get the best result. The plots (Figure 33; Figure 34) show that the concentration of Zn and the amount of clay are tightly connected to each other and that the variation decreases with increasing depth, where the sedimentation is not affected by wind and stream turbulence.

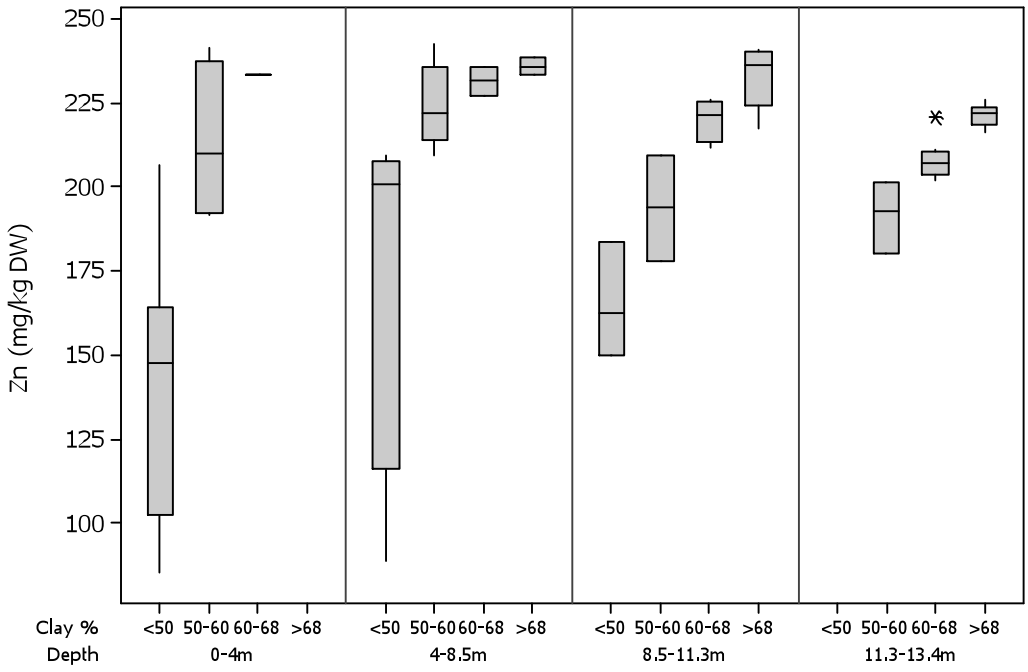


Figure 34. Concentration of Zn sorted by depth groups and clay content (n=59).

3.5.3 Vanadium (V)

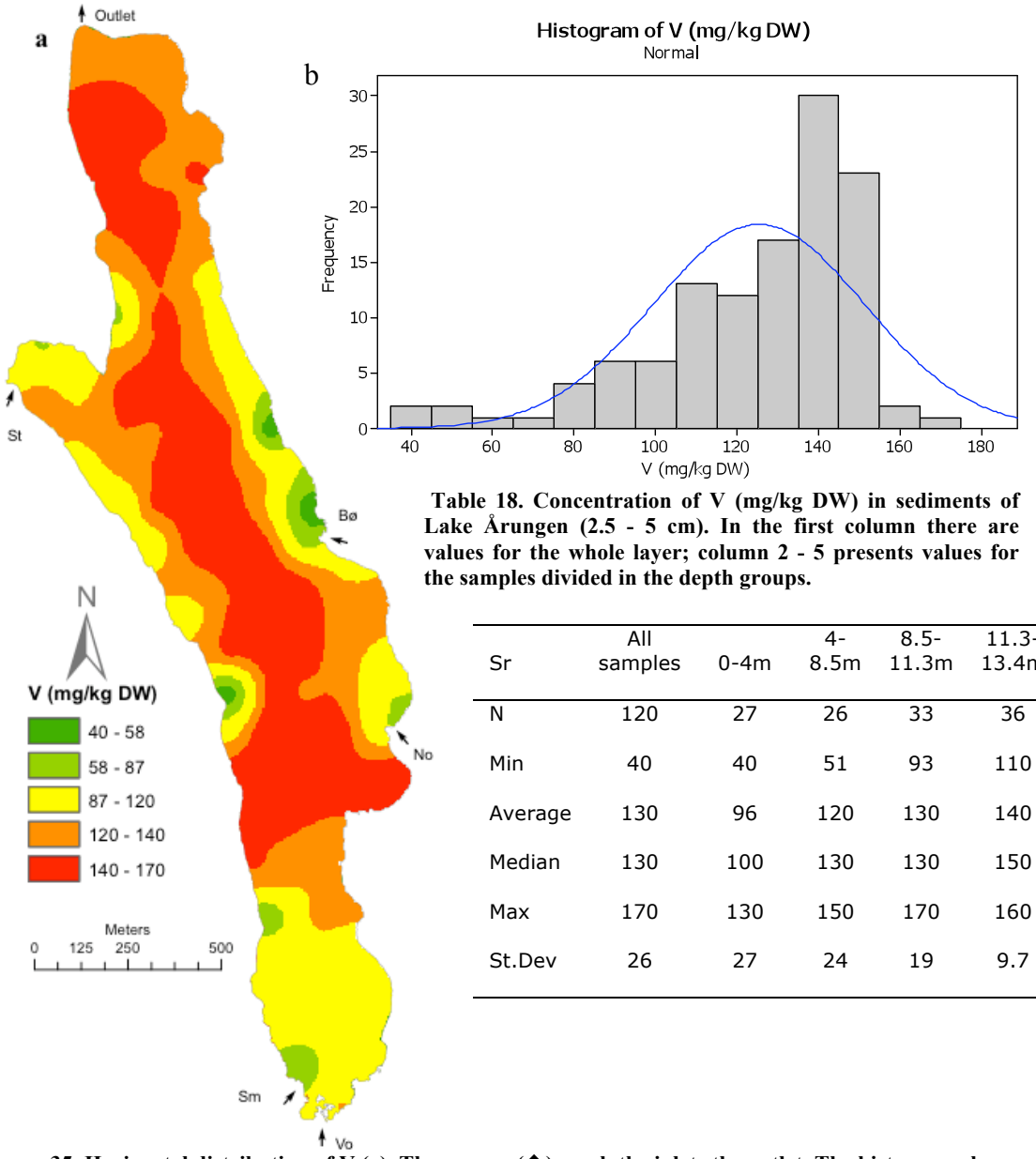


Figure 35. Horizontal distribution of V (a). The arrows (↑) mark the inlets the outlet. The histogram shows the distribution of V (mg/kg DW), with a trend line for normal distribution (b).

Table 18. Concentration of V (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Sr	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	40	40	51	93	110
Average	130	96	120	130	140
Median	130	100	130	130	150
Max	170	130	150	170	160
St.Dev	26	27	24	19	9.7

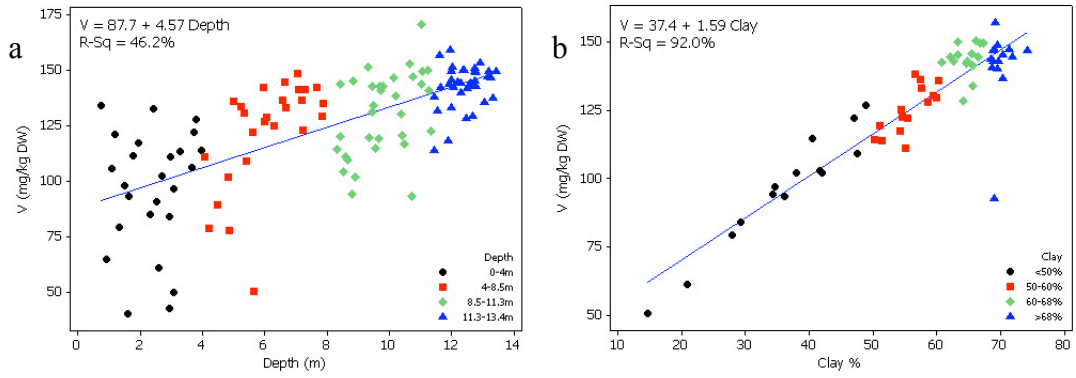


Figure 36. Scatterplot of V concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of V varies between 40 and 170 mg/kg DW, with a median value of 130 mg/kg DW (Table 18).

The horizontal distribution follows the depth and there is a high accumulation in the deep area of the lake basin where the accumulation of clay is high. Near the inlets Bølstadbekken and Smedbølbekken the concentration is not so high (Figure 35).

In the groups from 0 - 4 m and 4 - 8.5 m groups there is an increase in concentration, but the variation is high. In the deeper groups the variation decreases, but there is still an increase of concentration of V within the group with increasing amount of clay in the samples (Figure 36; Figure 37). The regression shows that clay is dominant, but in the backward elimination all three variables, clay content, depth and LOI, are present, so this is the best match (appendix 7).

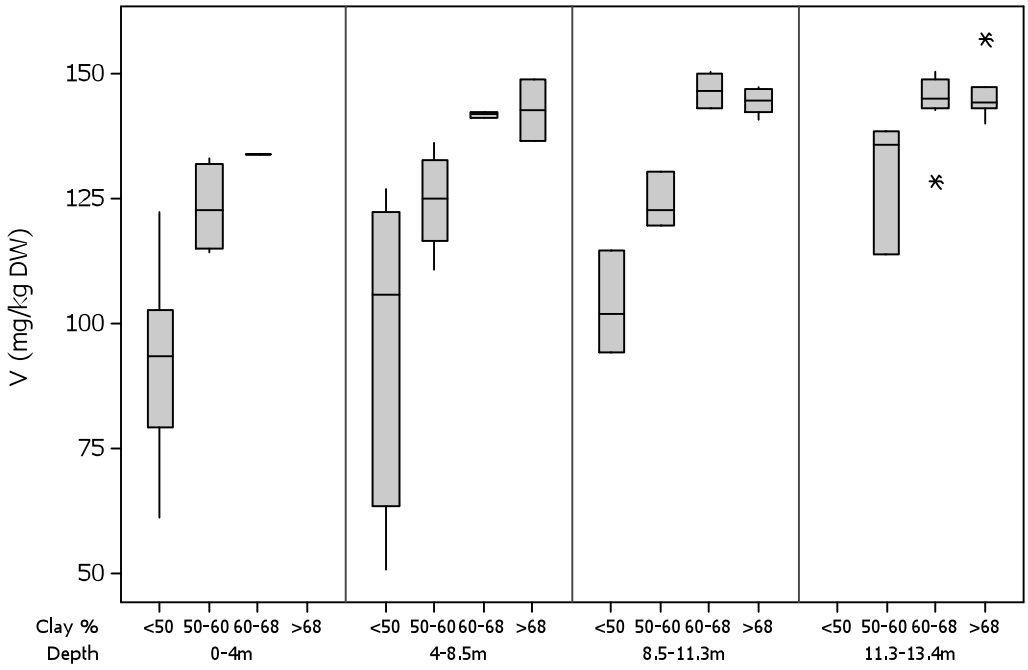


Figure 37. Concentration of V sorted by depth groups and clay content (n=59).

3.5.4 Chromium (Cr)

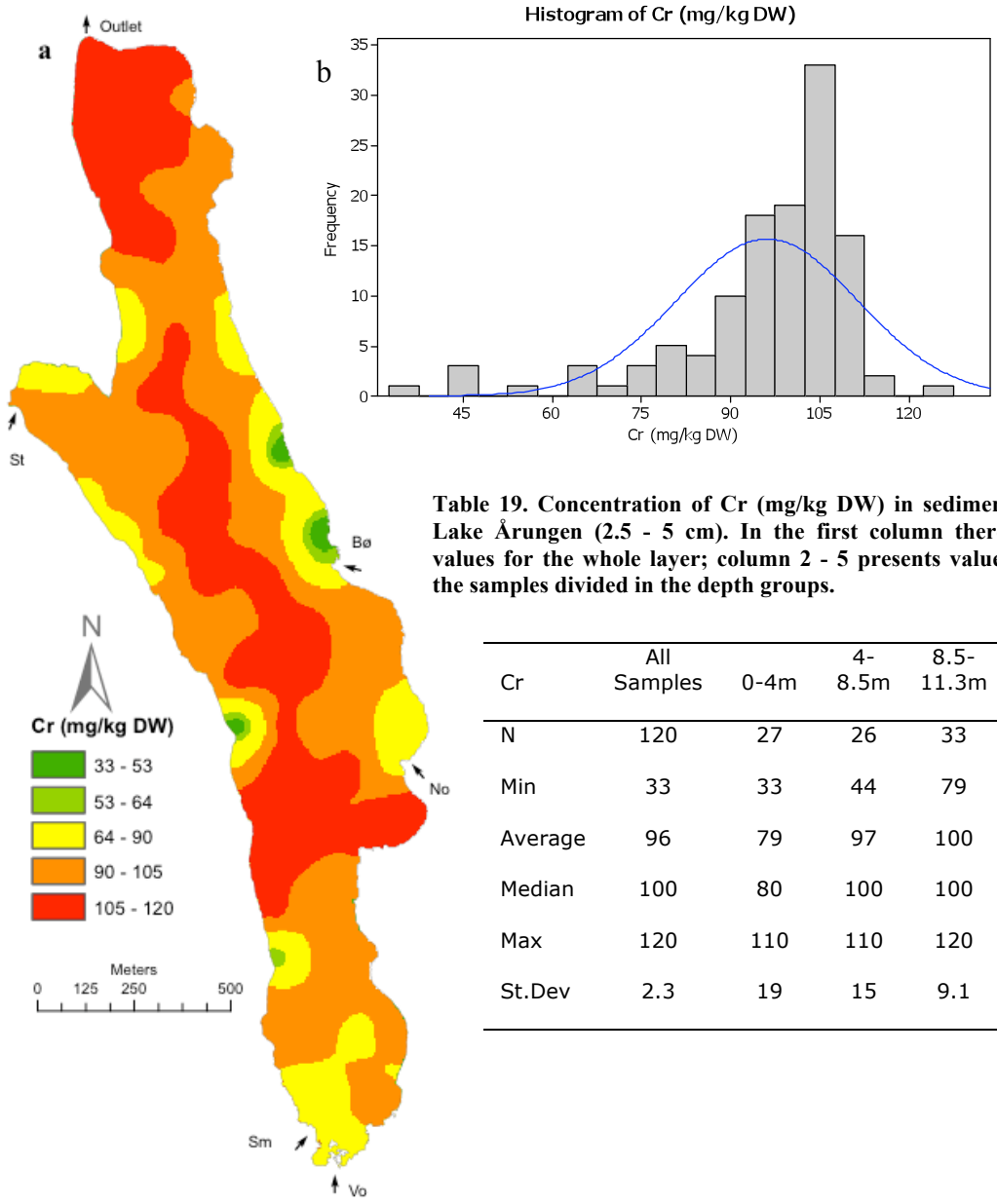


Table 19. Concentration of Cr (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Cr	All Samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	33	33	44	79	90
Average	96	79	97	100	100
Median	100	80	100	100	110
Max	120	110	110	120	110
St.Dev	2.3	19	15	9.1	5.2

Figure 38. Horizontal distribution of Cr (a). The arrows (↑) mark the inlets and the outlet. The histogram shows the distribution of Cr (mg/kg DW), with a trend line for normal distribution (b).

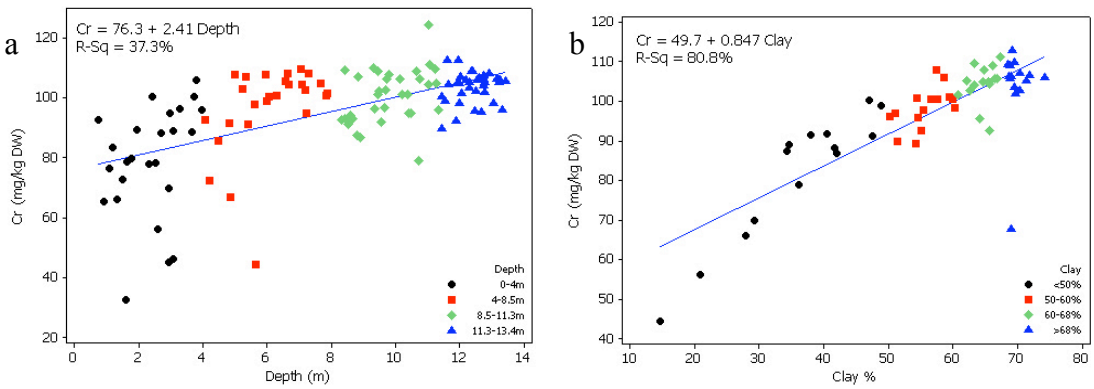


Figure 39. Scatterplot of Cr concentration with depth (n=120) (a) and with clay content (n=59) (b).

The amount of Cr range between 33 and 120 mg/kg DW and the median value is 100 mg/kg DW (Table 19).

The horizontal distribution map demonstrates that the content of Cr follows the sedimentation pattern of clay. For this reason the concentration is highest in the deeper areas of Lake Årungen, as in the area near the outlet (Figure 38).

The linear regression shows that depth is not significant and that clay is the important variable in the system (appendix 7). The backward elimination test shows that clay content and LOI should be analysed together when regression is needed. The accumulation has a very high variation in the different depth groups, most in the groups 0 - 4 m and 4 - 8.5 m (Figure 40). In the other two groups this factor is considerably reduced. It is visible that the content of chromium increases with increasing content of clay (Figure 39).

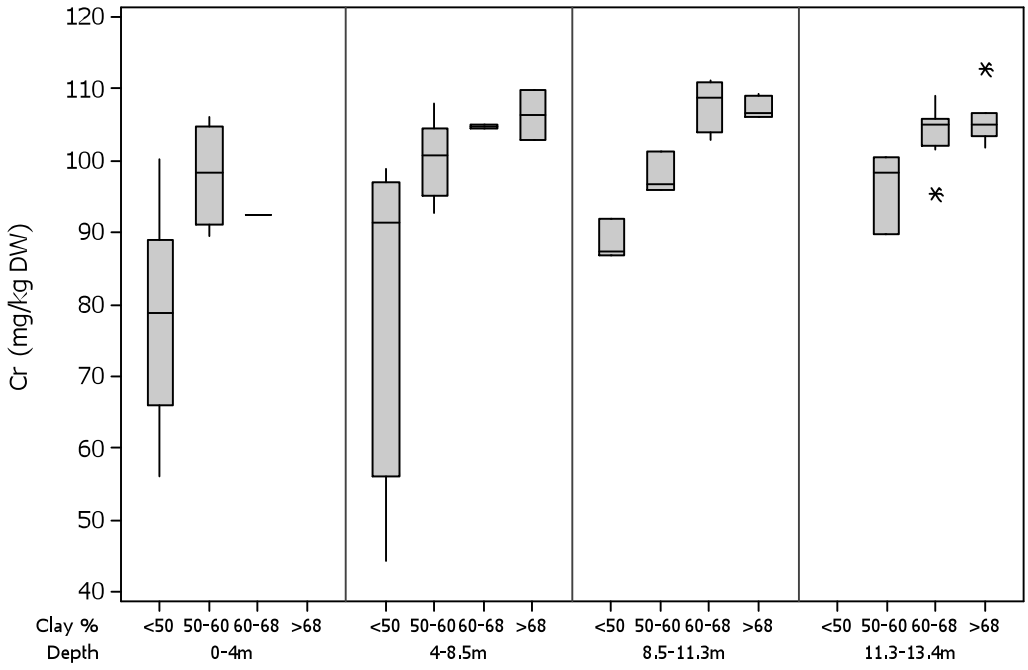


Figure 40. Concentration of Cr sorted by depth groups and clay content (n=59).

3.5.5 Strontium (Sr)

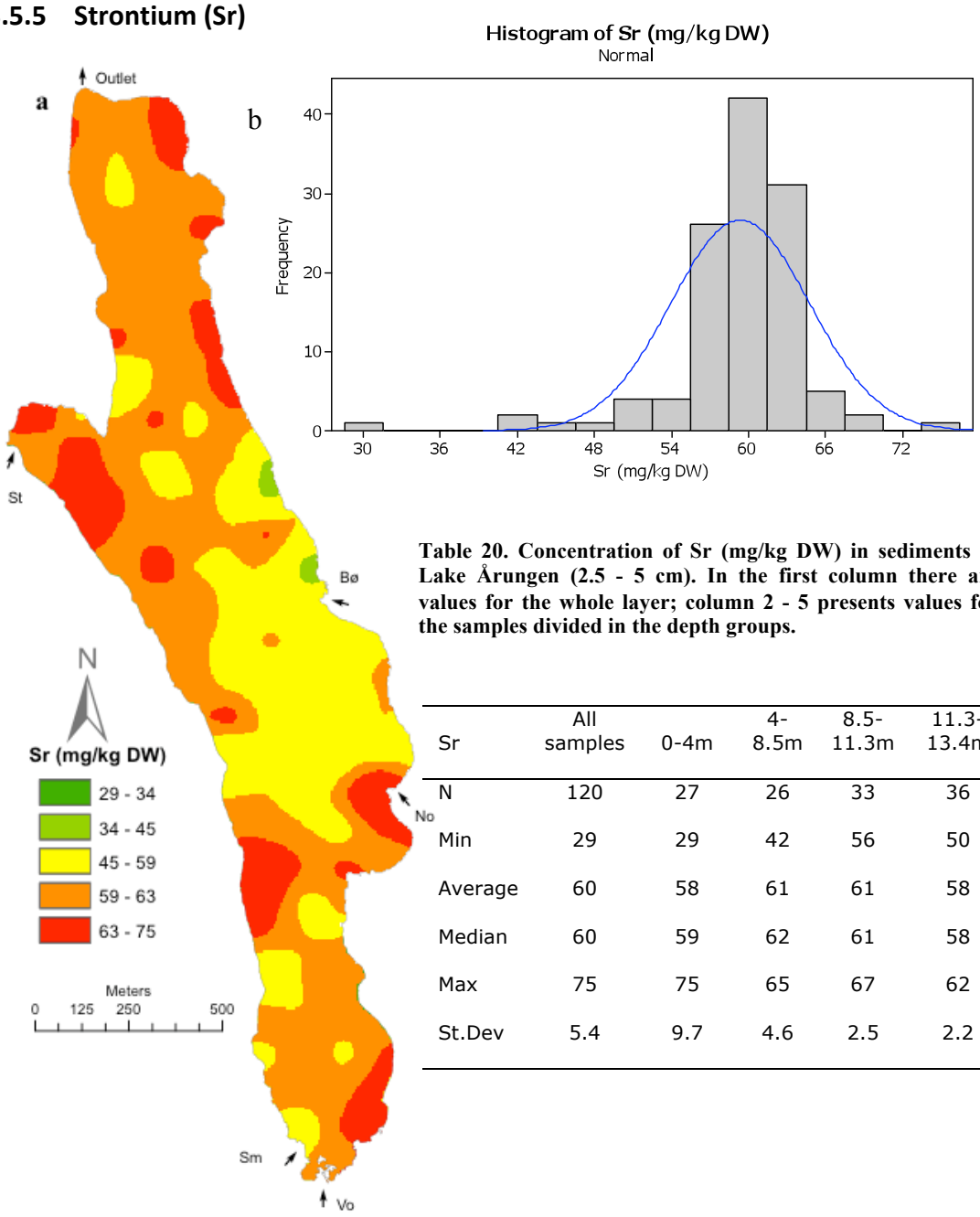


Table 20. Concentration of Sr (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Sr	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	29	29	42	56	50
Average	60	58	61	61	58
Median	60	59	62	61	58
Max	75	75	65	67	62
St.Dev	5.4	9.7	4.6	2.5	2.2

Figure 41. Horizontal distribution of Sr (a). The arrows (↑) mark the inlets and the outlet. The histogram shows the distribution of Sr (mg/kg DW), with a trend line for normal distribution (b).

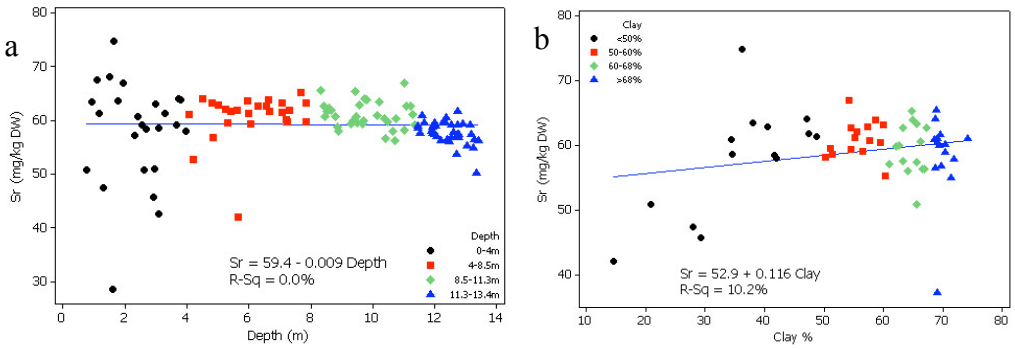


Figure 42. Scatterplot of Sr concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Sr varies between 29 and 75 mg/kg DW, with a median value of 60 mg/kg DW (Table 20).

The horizontal distribution shows an accumulation of Sr in the littoral zone and parts of the deeper areas, while in the areas that have a high content of sand the concentration is not so high. In the area near the inlet Norderåsbekken there is a relatively high amount of this metal (Figure 41).

The linear regression analysis shows that clay is the dominant factor, while depth is inversely proportional to the concentration of Sr (appendix 7). The same result is given by the backward elimination test where the program shows that clay and depth are the most important variables. The scatterplot for depth shows that there is a little negative trend, while for clay the trend is opposite (Figure 42). The boxplot illustrates that the concentration of Sr varies a lot in the two shallow groups (0 - 4 m 4 - 8.5 m) and that in the two other groups there is no clear trend. It is possible to see that there is a weak trend of decreasing accumulation with increasing depth (Figure 43).

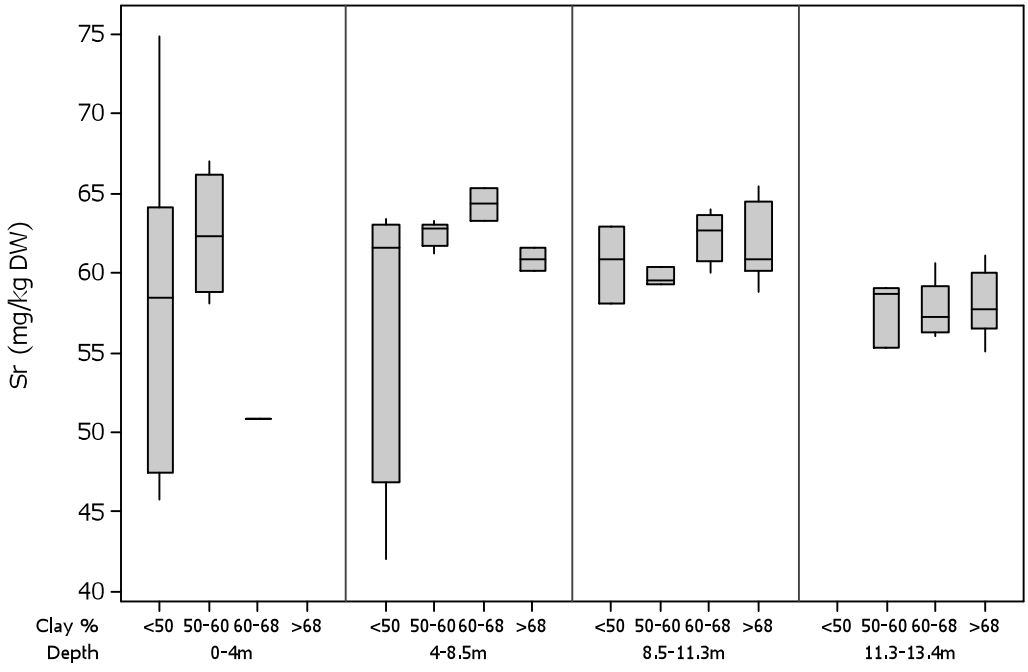


Figure 43. Concentration of Sr sorted by depth groups and clay content (n=59).

3.5.6 Nickel (Ni)

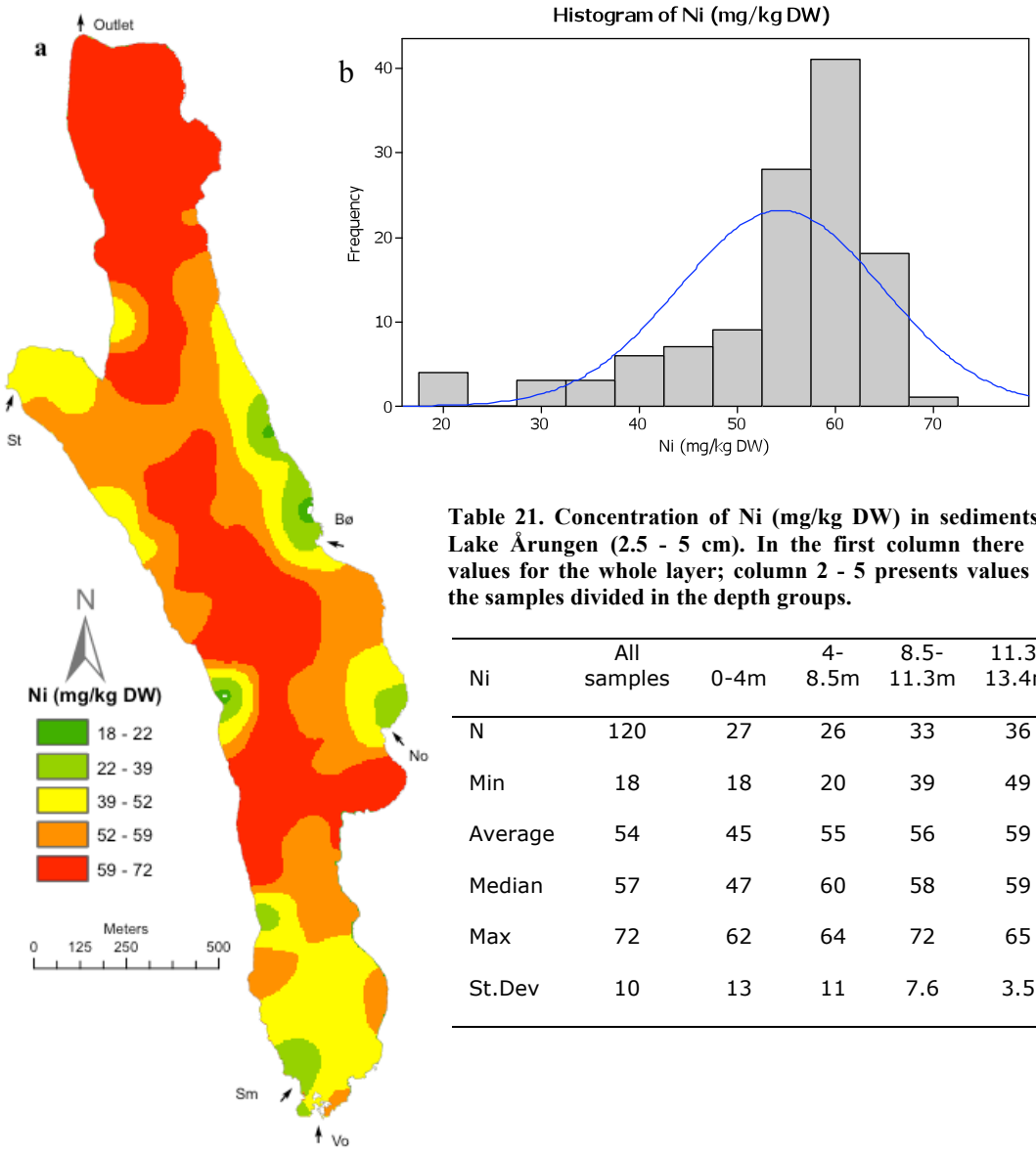


Table 21. Concentration of Ni (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Ni	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	18	18	20	39	49
Average	54	45	55	56	59
Median	57	47	60	58	59
Max	72	62	64	72	65
St.Dev	10	13	11	7.6	3.5

Figure 44: Horizontal distribution of Ni (a). The arrows (↑) mark the inlets the outlet. The histogram shows the distribution of Ni (mg/kg DW), with a trend line for normal distribution (b).

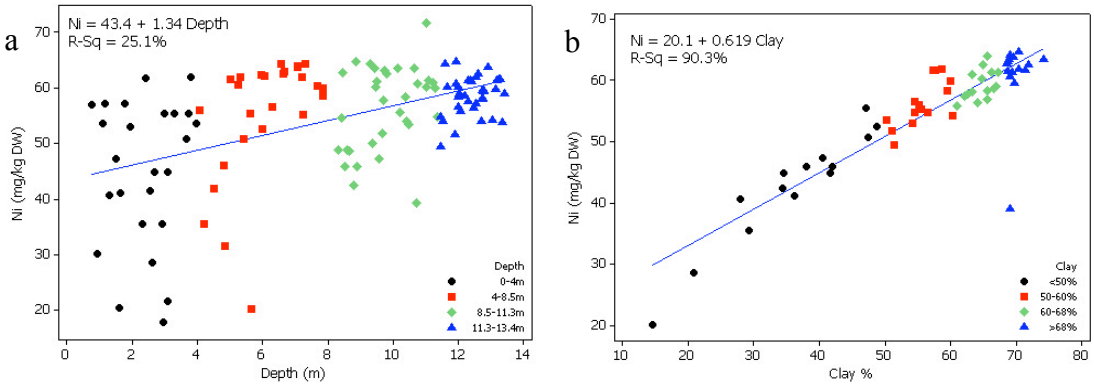


Figure 45. Scatterplot of Ni concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Ni varies between 18 and 72 mg/kg DW, with a median of 57 mg/kg DW (Table 21).

The horizontal distribution shown in Figure 44 illustrates how Ni accumulates in Lake Årungen. The highest concentration is in the deeper areas, while the concentration is quite low in the proximity of the inlets Bølstadbekken, Norderåsbekken and Smedbølbekken. The concentration is higher near the Storgrava inlet, but even higher near the inlet Vollebekken.

The regression analysis shows that clay is dominant (appendix). The backward elimination test shows in the meanwhile that also depth and LOI should be considered when Ni is statistically studied. From the boxplot it is easy to see that the content of Ni increases in each depth group with increasing clay content (Figure 45; Figure 46).

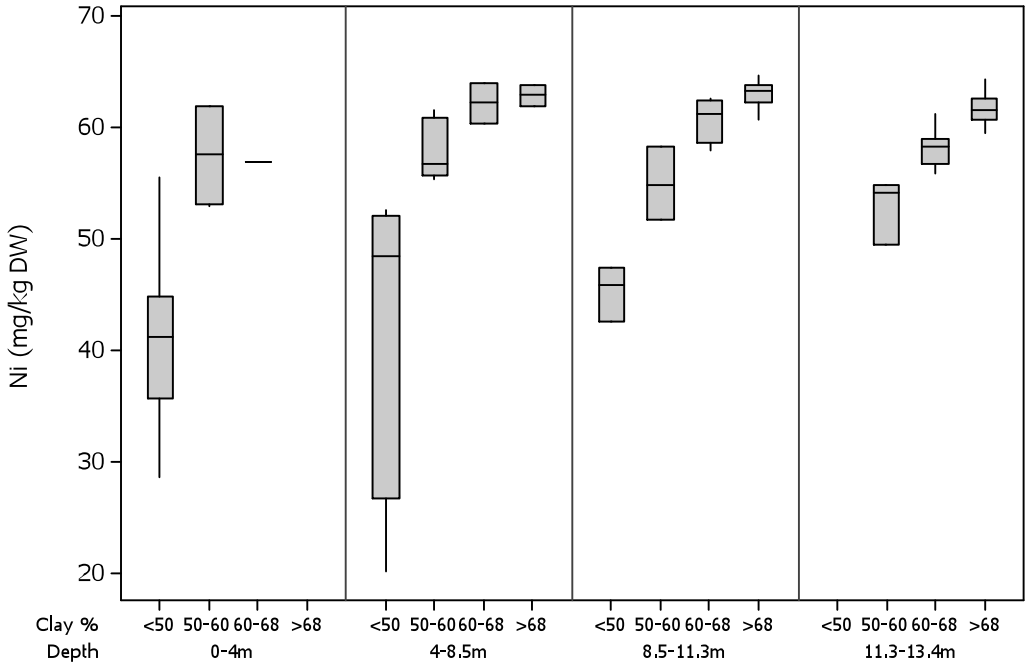


Figure 46. Concentration of Ni sorted by depth groups and clay content (n=59).

3.5.7 Copper (Cu)

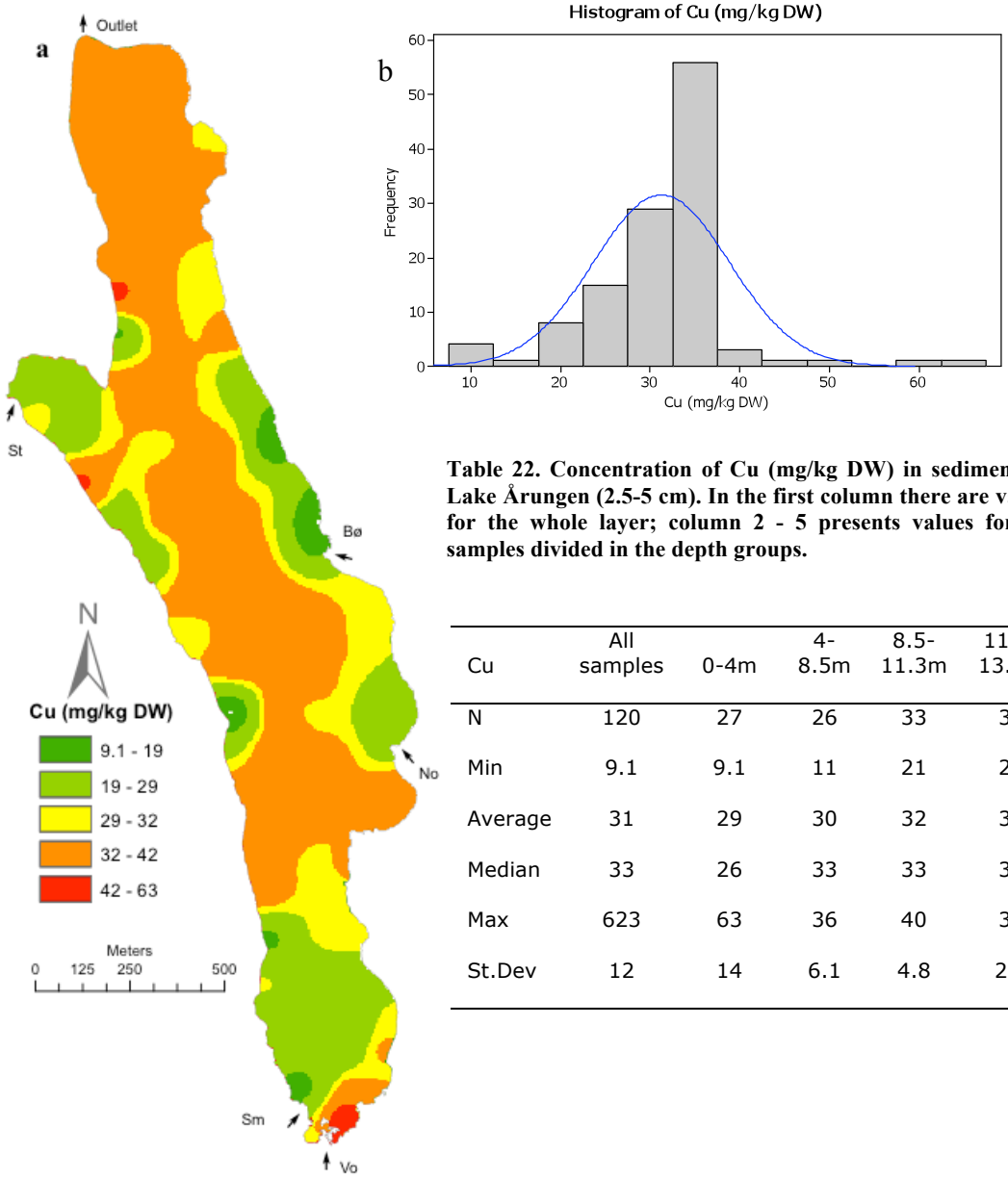


Table 22. Concentration of Cu (mg/kg DW) in sediments of Lake Årungen (2.5-5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Cu	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	9.1	9.1	11	21	28
Average	31	29	30	32	33
Median	33	26	33	33	34
Max	623	63	36	40	37
St.Dev	12	14	6.1	4.8	2.0

Figure 47. Horizontal distribution of Cu (a). The arrows (↑) mark the inlets and the outlet. The histogram shows the distribution of Cu (mg/kg DW), with a trend line for normal distribution (b).

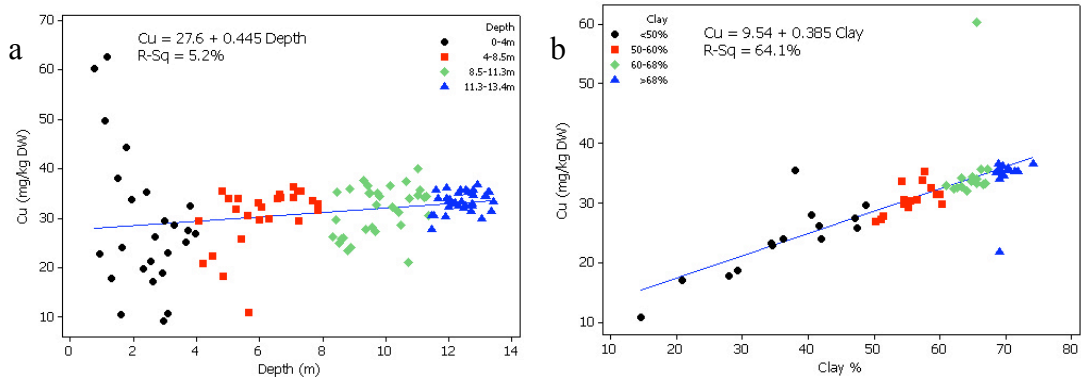


Figure 48. Scatterplot of Cu concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Cu ranges between the values 9.1 and 63 mg/kg DW, with a median of 33 mg/kg DW (Table 22).

The horizontal distribution displays an accumulation of Cu in the deeper areas. In the littoral zone there are lower values, except near the inlet Vollebekken, where the highest values were measured (Figure 47).

From the boxplot it is possible to see that in each depth group the concentration of Cu increases with increasing percent of clay; also the scatterplot shows the same trend (Figure 48; Figure 49). The regression analysis shows that clay is the dominating variable and that depth is inverse proportional to concentration (appendix 7).

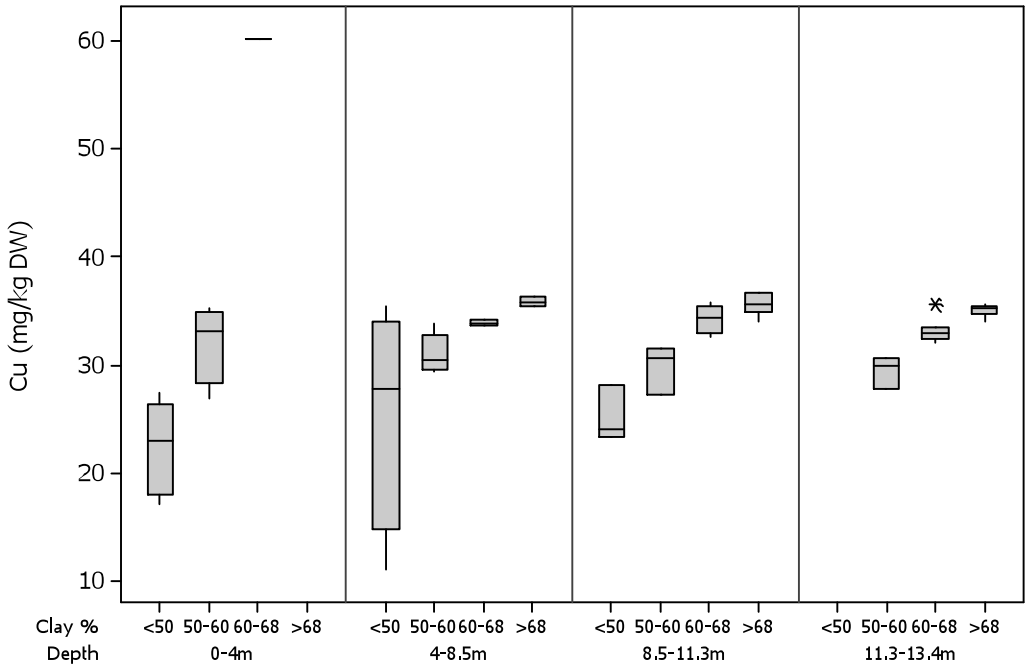


Figure 49. Concentration of Cu sorted by depth groups and clay content (n=59).

3.5.8 Lead (Pb)

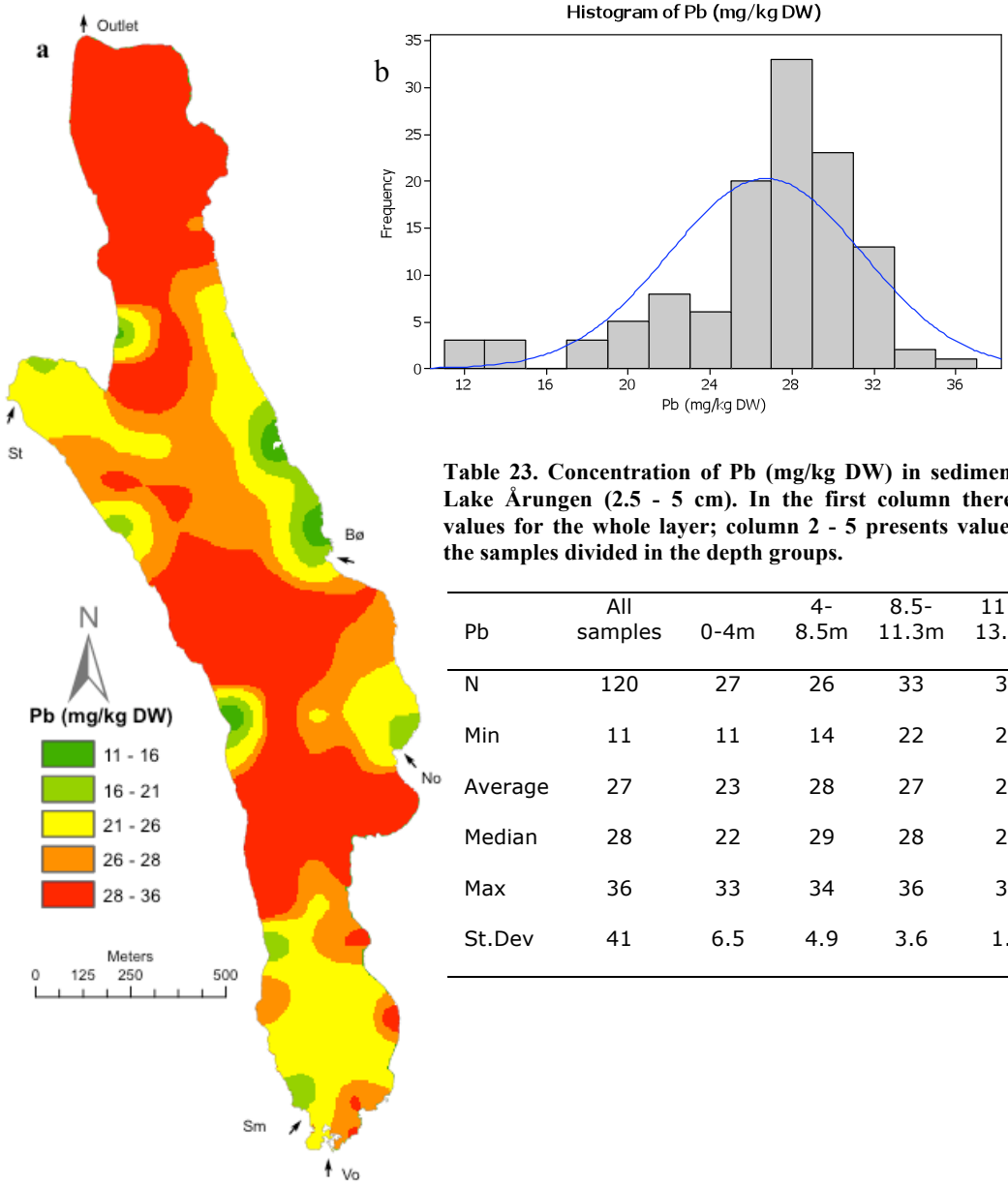


Figure 50. Horizontal distribution of Pb (a). The arrows (↑) mark the inlets and the outlet. The histogram shows the distribution of Pb (mg/kg DW), with a trend line for normal distribution (b).

Table 23. Concentration of Pb (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Pb	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	11	11	14	22	25
Average	27	23	28	27	28
Median	28	22	29	28	28
Max	36	33	34	36	32
St.Dev	41	6.5	4.9	3.6	1.6

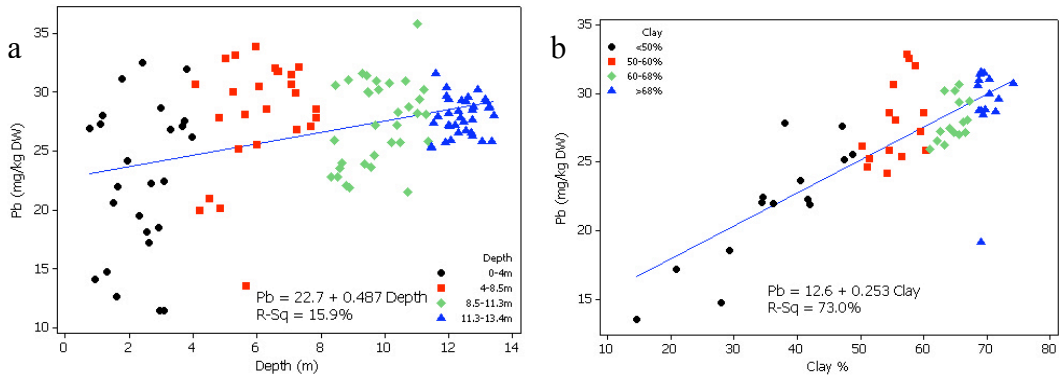


Figure 51. Scatterplot of Pb concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Pb ranges between 11 and 36 mg/kg DW with a median of 28 mg/kg DW (Table 23).

The horizontal distribution of Pb displays the highest values in the deepest area and near the outlet (Figure 50).

The statistical regression analysis tells that clay is dominant (appendix 7). Lead seems to have a connection with LOI too. This is presented by a backward elimination test, where Minitab also includes this variable in the regression to obtain the best possible result. Figure 51 shows the same information; the concentration of Pb gets more stable with higher percentage of clay. This does not occur in the deepest group (11.3 - 13.4 m) were the variation in accumulation gets higher with higher content of clay in the samples (Figure 52).

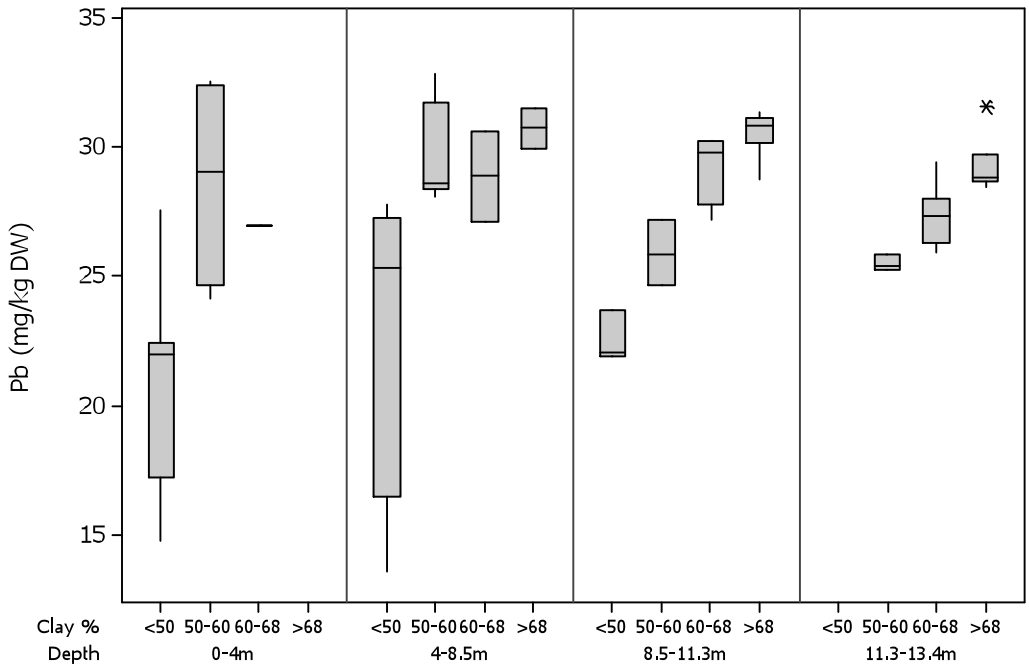


Figure 52. Concentration of Pb sorted by depth groups and clay content (n=59).

3.5.9 Cobalt (Co)

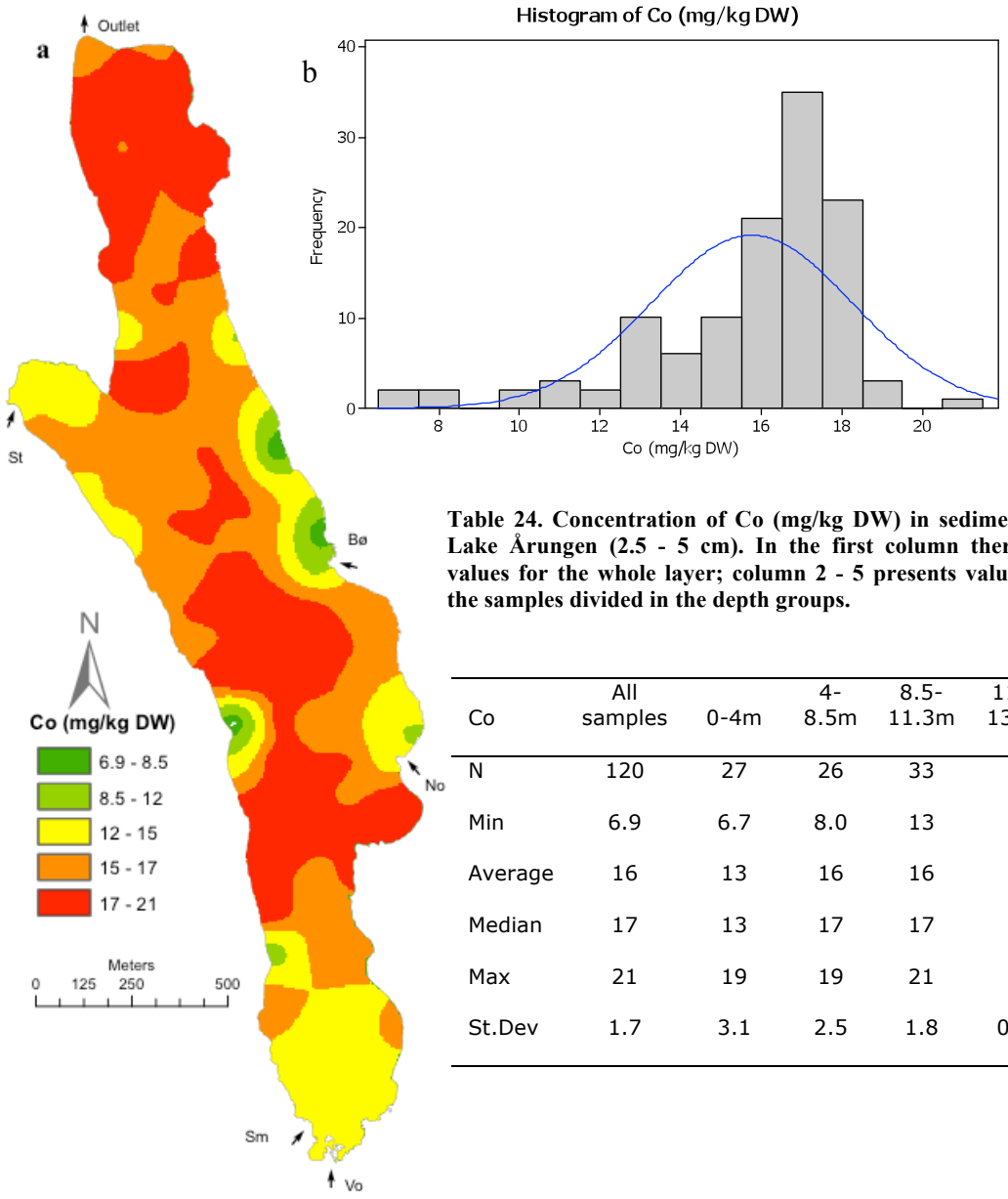


Table 24. Concentration of Co (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Co	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	6.9	6.7	8.0	13	15
Average	16	13	16	16	17
Median	17	13	17	17	17
Max	21	19	19	21	18
St.Dev	1.7	3.1	2.5	1.8	0.86

Figure 53. Horizontal distribution of Co (a). The arrows (↑) mark the inlets and the outlet. The histogram shows the distribution of Co (mg/kg DW), with a trend line for normal distribution (b).

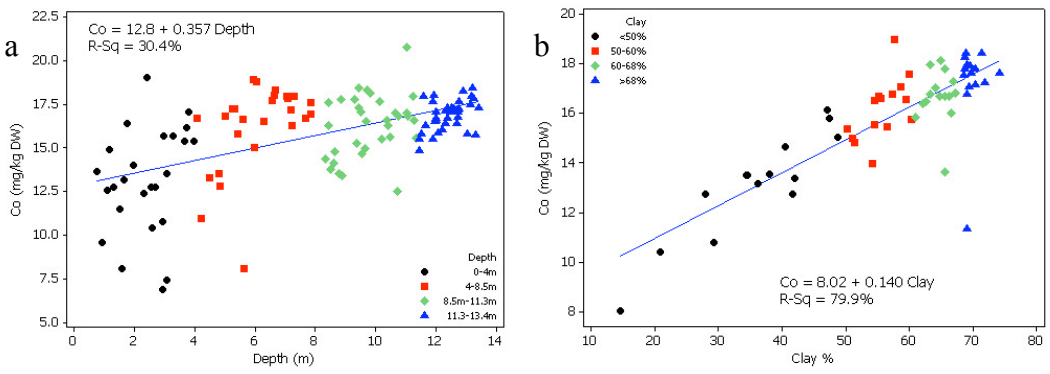


Figure 54. Scatterplot of Co concentration with depth (n=120) (a) and with clay content (n=59) (b).

Cobalt varies between 6.9 and 21 mg/kg DW with a median of 17 mg/kg DW (Table 23).

The horizontal distribution of Co is shown in figure 53.

There is a visible upswing in accumulation of Co in the different depth groups with increasing depth, especially in group of samples from 8.5 - 11.3 m (Figure 53). The regression shows that clay is the dominating factor and that depth is not significant. Depth has quite a quite little negative influence to the quantity of Co accumulated. This means that as a sample is collected from a shallower depth, the concentration of Co in the sediment is lower (Figure 54; Figure 55; appendix 7). The backward elimination test shows that the variable LOI gives the best regression result. This means that Co has connection with the content of organic matter in the sediments.

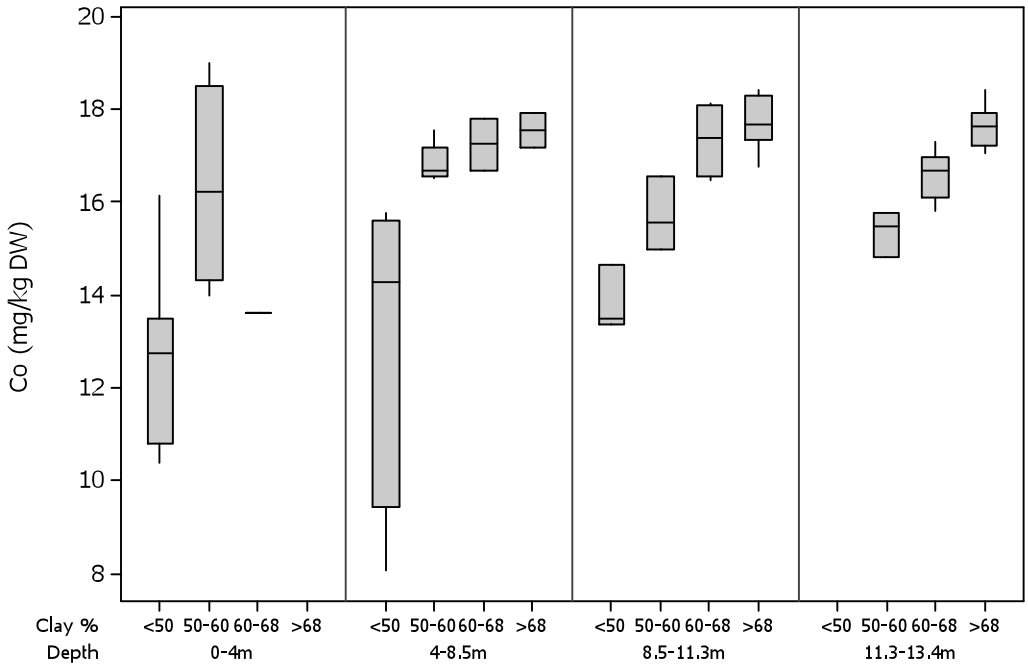


Figure 55. Concentration of Co sorted by depth groups and clay content (n=59).

3.5.10 Arsenic (As)

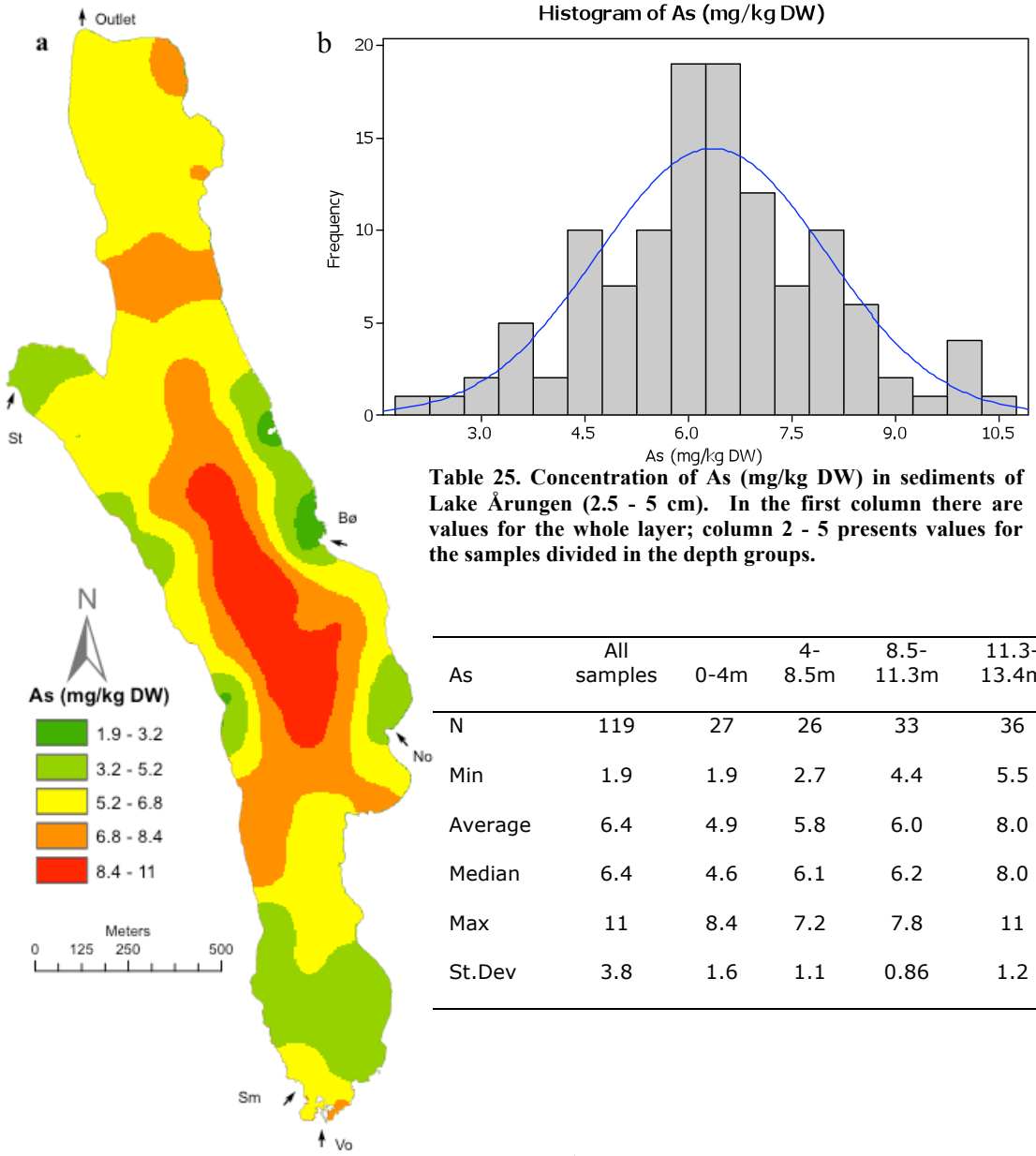


Table 25. Concentration of As (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

As	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	119	27	26	33	36
Min	1.9	1.9	2.7	4.4	5.5
Average	6.4	4.9	5.8	6.0	8.0
Median	6.4	4.6	6.1	6.2	8.0
Max	11	8.4	7.2	7.8	11
St.Dev	3.8	1.6	1.1	0.86	1.2

Figure 56. Horizontal distribution of As (a). The arrows (↑) mark inlets and the outlet. The histogram shows the distribution of As (mg/kg DW), with a trend line for normal distribution (b).

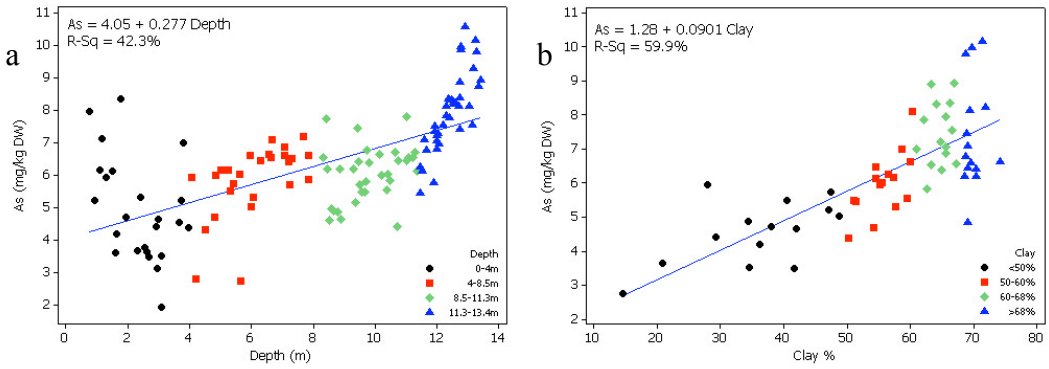


Figure 57. Scatterplot of As concentration with depth (n=119) (a) and with clay content (=60) (b).

The content of As in the sediments varies between 1.9 and 11 mg/kg DW, with a median of 6.4 mg/kg DW. The ICP-MS analysis was not performed for this element in one sample (nr. 1108) and for this reason the total amount of samples analysed is 119 (Table 25).

Figure 56 shows that most of the As is accumulated in the deepest area of the lake and there is a low accumulation in the littoral zone. The eastside inlets and the one on the west side have a low concentration of As and the inlets in the south end of the lake have a higher content of this metal.

The concentration of this metal increases with increasing depth, this is due to the increase of clay content in the sediment (Figure 57). In the group 0 – 4 m the samples that had clay content like 60 - 68% showed particularly high concentrations of As (Figure 58).

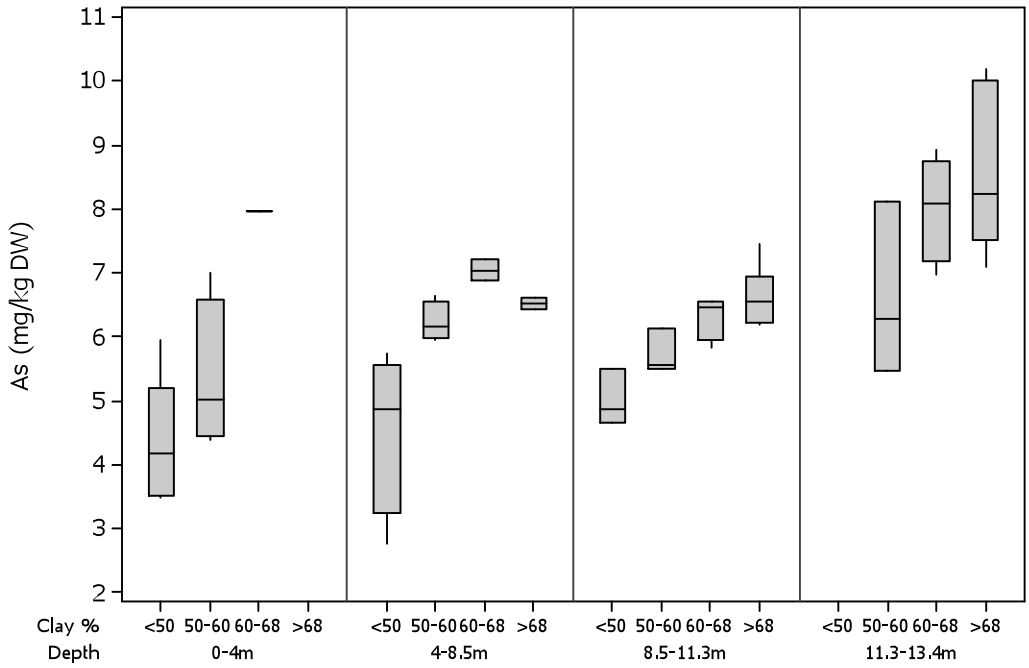


Figure 58. Concentration of As sorted by depth groups and clay content (n=59).

3.5.11 Caesium (Cs)

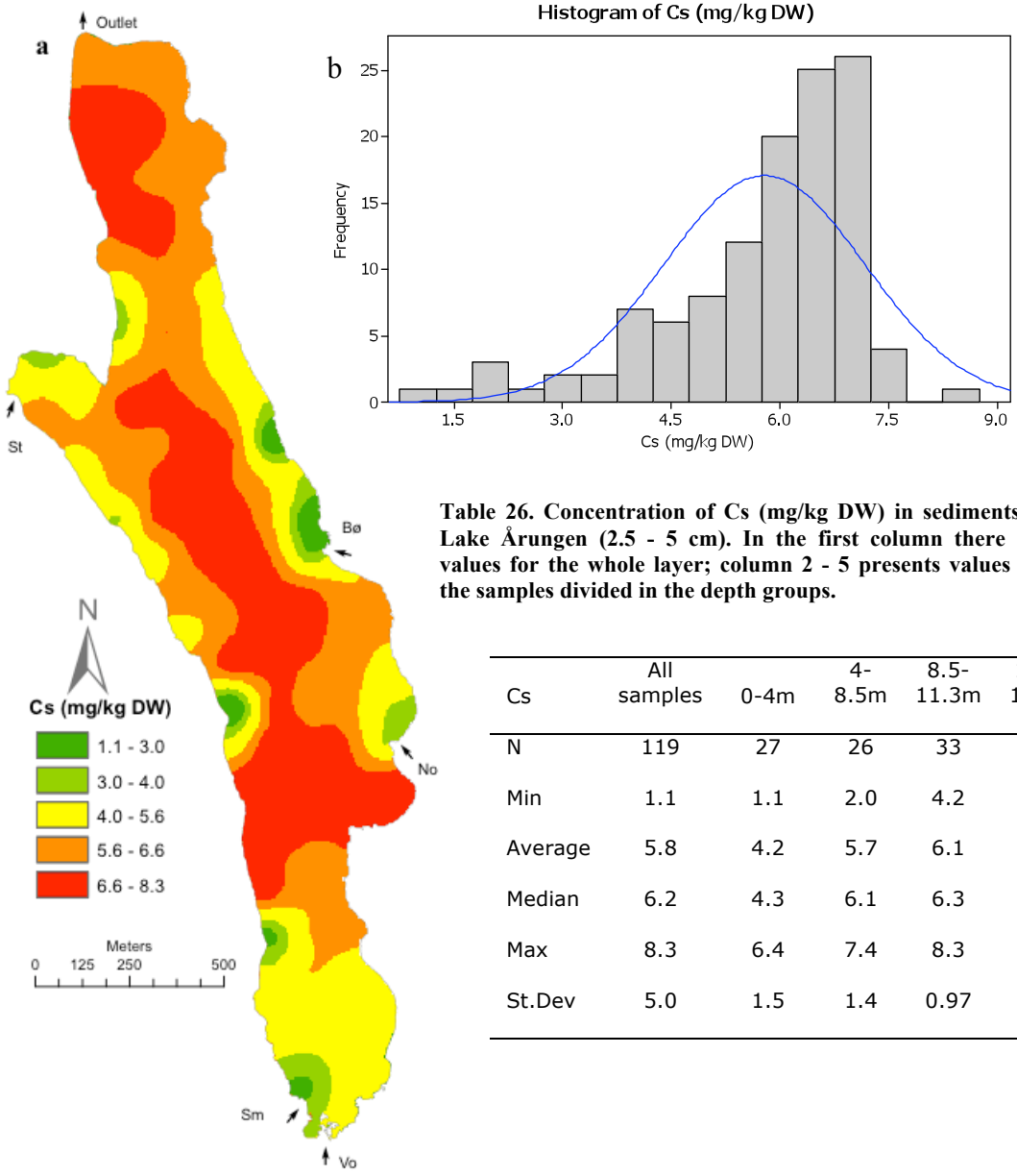


Table 26. Concentration of Cs (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Cs	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	119	27	26	33	36
Min	1.1	1.1	2.0	4.2	5.2
Average	5.8	4.2	5.7	6.1	6.6
Median	6.2	4.3	6.1	6.3	6.7
Max	8.3	6.4	7.4	8.3	7.7
St.Dev	5.0	1.5	1.4	0.97	0.50

Figure 59. Horizontal distribution of Cs (a). The arrows (↑) mark the inlets and the outlet. The histogram shows the distribution of Cs (mg/kg DW), with a trend line for normal distribution (b).

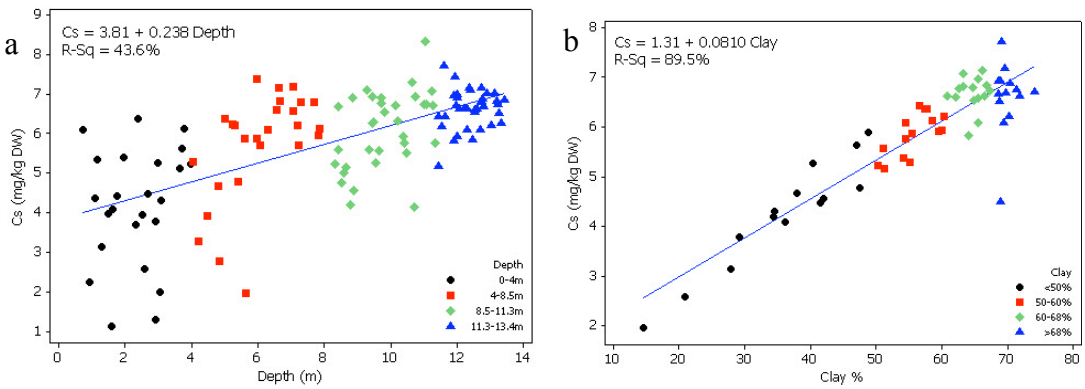


Figure 60.Scatterplot of Cs concentration with depth (n=120) (a) and with clay content (n=59) (b).

The content of Cs in the sediments varied between 1.1 and 8.3 mg/kg DW, with a median of 6.22 mg/kg DW. The ICP-MS analysis was not performed for this element in one sample (nr: 1108) and for this reason the total amount of samples analysed is 119 (Table 26).

The accumulation of Cs is connected with the content of clay (Figure 59). This element is bound to particles and this means that it follows the sedimentation pattern in Lake Årungen. Since clay settles in the areas that are not affected by wind turbation, which are located in the deeper part of the lake, it is clear that the concentration is highest in the deep area of the lake. In the proximity of Bølstadbekken, Norderåsbekken and Smedbølbekken the content is low. On the other hand the concentration is higher near the other two inlets. Also in the remaining littoral areas there is low accumulation of caesium.

The concentration of Cs is dependent on clay content in the sediment (appendix 7). The values of Cs increase for each depth group and increase as more deep the sample is taken from (Figure 60). The spreading of variation decreases with the increase of depth. In the shallowest group (0 - 4 m) there is a large variation of content for the different samples (Figure 61).

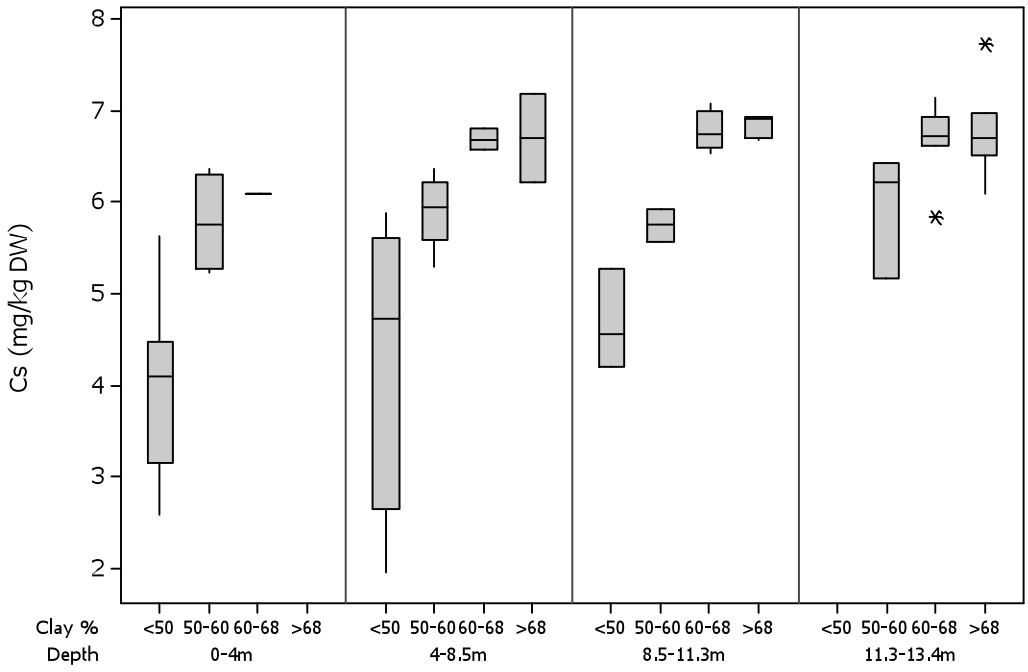


Figure 61. Concentration of Cs sorted by depth groups and clay content (n=59).

3.5.12 Cadmium (Cd)

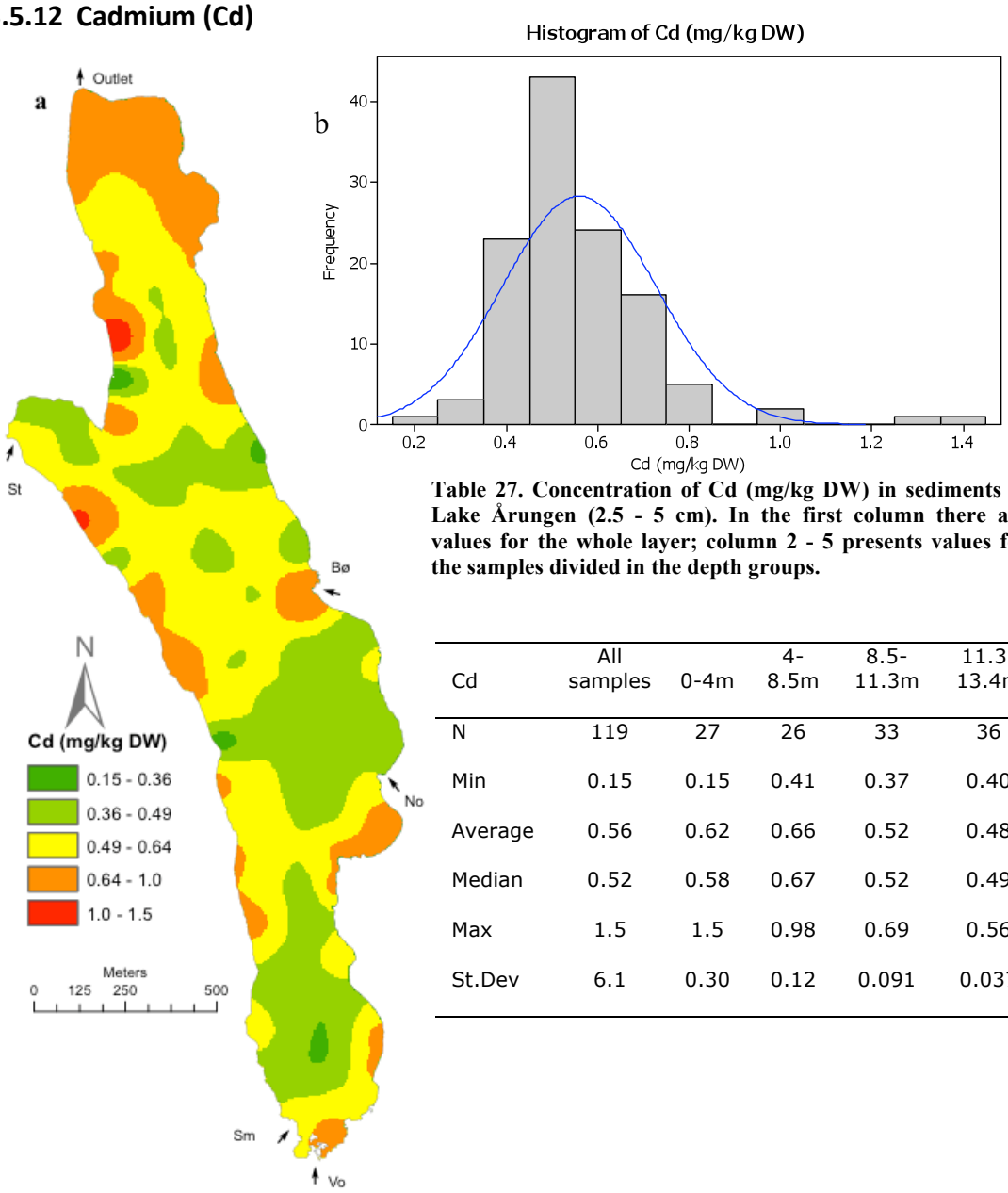


Figure 62. Horizontal distribution of Cd (a). The arrows (↑) mark the inlets and the outlet. The histogram shows the distribution of Cd (mg/kg DW), with a trend line for normal distribution (b).

Table 27. Concentration of Cd (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Cd	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	119	27	26	33	36
Min	0.15	0.15	0.41	0.37	0.40
Average	0.56	0.62	0.66	0.52	0.48
Median	0.52	0.58	0.67	0.52	0.49
Max	1.5	1.5	0.98	0.69	0.56
St.Dev	6.1	0.30	0.12	0.091	0.037

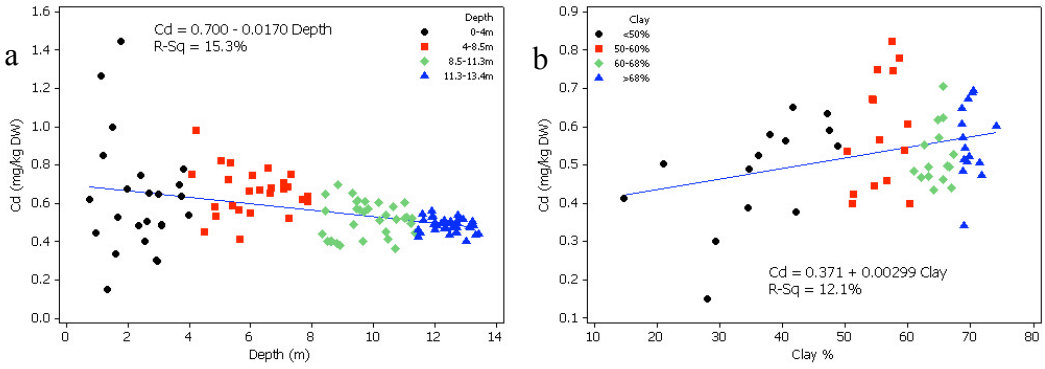


Figure 63. Scatterplot of Cd concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Cd ranges between 0.15 and 1.4 mg/kg DW with a median of 0.523 mg/kg DW. The ICP-MS analysis were not performed for this element in one sample (nr: 1108) and for this reason the total amount of sample analysed is 119 (Table 27).

The horizontal distribution shows that the highest concentration of Cd is in the littoral zone. Bølstadbekken and partly Vollebekken are sources of cadmium. The area with highest concentration in proportion to the area is near the outlet (Figure 62).

Linear regression and Figure 63 show that the concentration of Cd is inversely proportional to depth (appendix 7) and that it varies depending on clay content in the sediment in the different groups (Figure 64). The variation in diffusion decreases with increasing depth (Figure 63).

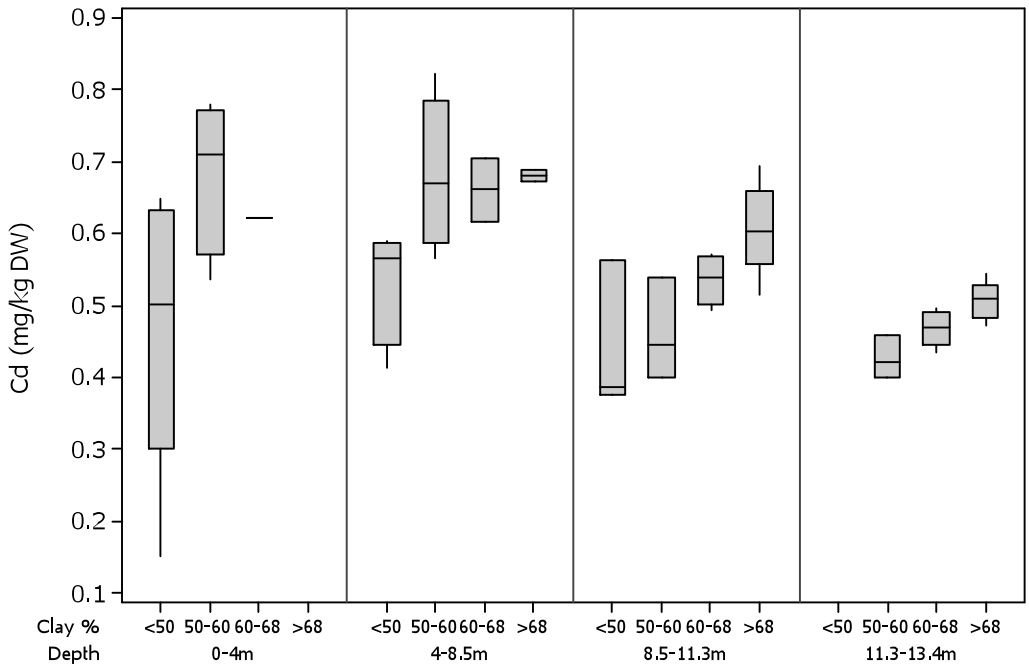


Figure 64. Concentration of Cd sorted by depth and clay content (n=59).

3.5.13 Mercury (Hg)

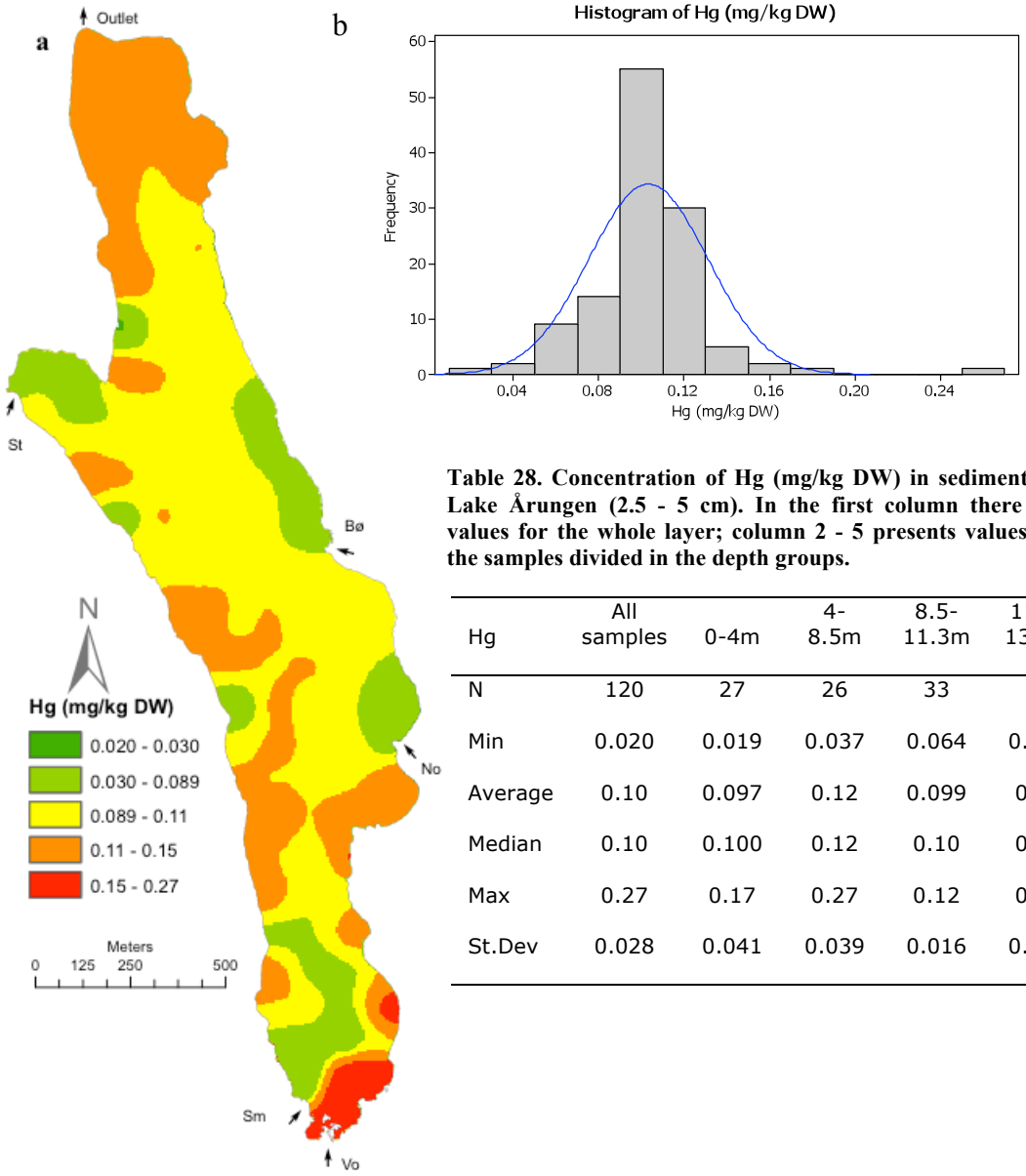


Figure 65. Horizontal distribution of Hg (a). The arrows (↑) mark and the inlets the outlet. The histogram shows the distribution of Hg (mg/kg DW), with a trend line for normal distribution (b).

Table 28. Concentration of Hg (mg/kg DW) in sediments of Lake Årungen (2.5 - 5 cm). In the first column there are values for the whole layer; column 2 - 5 presents values for the samples divided in the depth groups.

Hg	All samples	0-4m	4-8.5m	8.5-11.3m	11.3-13.4m
N	120	27	26	33	36
Min	0.020	0.019	0.037	0.064	0.085
Average	0.10	0.097	0.12	0.099	0.10
Median	0.10	0.100	0.12	0.10	0.10
Max	0.27	0.17	0.27	0.12	0.11
St.Dev	0.028	0.041	0.039	0.016	0.006

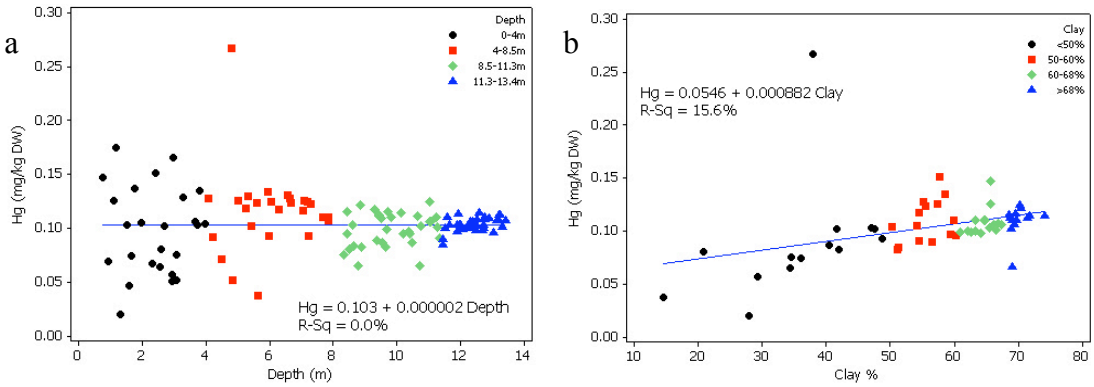


Figure 66. Scatterplot of Hg concentration with depth (n=120) (a) and with clay content (n=59) (b).

The concentration of Hg ranges between 0.020 and 0.27 mg/kg DW with a median of 0.10 mg/kg DW (Table 28).

Horizontal distribution of this element has a clear accumulation in the south end of the lake, near the inlet Vollebekken. Apart from this area with relatively high concentration, high values are measured in the littoral zone (Figure 65).

The concentration of Hg varies considerably in the two shallowest groups (0-4m and 4 - 8.5m) and depends on the content of clay (Figure 67). The less clay in these two groups, the higher is the variation in concentration. In the deeper groups (11.3 - 13.4 m) it is clear that the concentration of Hg increases with increasing clay percent in the sediment (Figure 66). The backward elimination test showed that the best representing system is the one with depth and clay content.

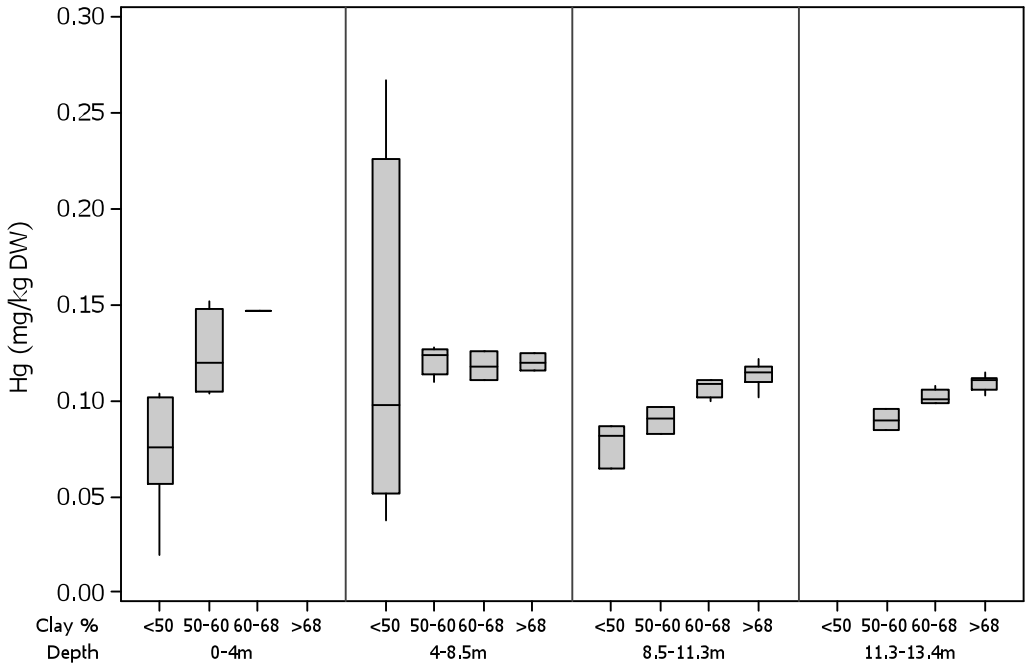


Figure 67. Concentration of Hg sorted by depth groups and clay content (n=59).

4 Discussion

The water input from the catchment area of Lake Årungen varies during the year. Spring and fall floods are most important for the variation and around 70% of the total yearly drainage happens during these two periods. Erosion from the cultivated areas is an important factor for matter transport to the lake (Ensby, 1984).

The sedimentation rate in the deep area (12.8 m) was estimated to be 8.4 ± 0.4 mm/yr in the period 1954 to 1979 (Skogheim, 1984). The sedimentation rate has not been calculated with accurate methods since Skogheim made the sediment research in 1978. In spring 2009, during the course "Limnological Methods" (VANN211) at UMB, some profound sediment cores (13.2 m) were collected. The sedimentation layers were very distinct, with alternating black and grey layers. The black layer contains a lot of organic material and iron sulphide (FeS_2), are produced during summer, while the grey one are originated in autumn and winter, and are composed by mineral material. In these cores it was possible to identify 10 layers in the upper 7 cm, which means that the sedimentation rate was about 7 mm/yr (Lilleberg *et al.* 2009). The result seems reasonable since it is not very different from the one that Skogheim calculated when he dated the sediment cores based on ^{137}Cs and ^{210}Pb analyses (Skogheim, 1984). This can mean that the sediment samples that have been collected for this study in total can represent a maximum of 7 years. It is possible that the upper layer (0 - 2.5 cm) represents less than 3 years because the sediments were not so compressed. The pair-t-test showed that the element concentration in the two layers (0 - 2.5 cm and 2.5 - 5 cm) was not significantly different. This means that there have not been significant changes in concentration of the elements in the period that this data set covers. For this reason, only the data from the second layer has been discussed in this present work, also because this layer was analysed for grain size and the content of clay was calculated.

4.1 Sediment properties

4.1.1 Sample characteristics

The sediments, as regards to the composition, showed great variation among sampling sites throughout the lake. Samples that had been collected in the shallow part of the lake (0 - 4 m) often had a high percent of organic matter due to occurrence of fragments of leaves, pieces of branches and living organisms (as mussels). Some of the other samples were influenced by human activity and had a high content of stones that possibly originated from work processes on roads and buildings (appendix 2). The samples taken from the deeper part were more homogeneous.

When the sediment cores were collected from the deep area, they often had clear signs of stratification, with alternating dark and lighter layers. These layers could give an impression of the sedimentation pattern and rate; however this variable was not quantified in the present work. On the other hand the cores that were collected from the littoral zone did not show the same pattern. The effects of wind turbation, water streams and the bioturbation by organisms can explain the lack of stratification in the shallow areas.

4.1.2 Sedimentation characteristics

The distribution of clay, silt and sand depends on the physical settling characteristics of the different grain sizes. Sediments can be divided in two groups: one with particles >0.05 mm (sand and gravel) and one with fine particles (<0.05 mm) as silt and clay (Salomons&Förstner, 1984). Sedimentation is controlled by gravity, velocity of the particle, which depends on particle shape and size, and fall velocity (Chase, 1979). Sedimentation is also influenced by vertical transport of the particles, horizontal transport by the flow and decomposition at the bottom (Raudkivi, 1990). Deposition of particles depends on the grain size and starts just when the velocity of the water flow has decreased to a certain level. Where the inlet flows into the lake basin, the velocity of the water flow decreases quickly. In this way sand and larger particles settle down first, near the inlet, while the smaller particles are held in suspension (Bogen, 1987). Clay particles are smallest (<2 μm), move slowly, remain in suspension for a longer period (Salomons&Förstner, 1984) and the sedimentation happens far from the river inlet (Bogen, 1987). The sedimentation pattern follows Stokes's law (Wetzel, 2001). Another factor that affects sedimentation is the

morphometry of the lake: wind can influence the drift of the smaller particles and the sedimentation of the particles will be delayed and will occur further away from the inlet (Bogen, 1983).

Also the sedimentation in Lake Årungen follows this pattern. Near the inlet Bølstadbekken the accumulation of sand was very high (>10%). Near the inlet area of Smedbølbekken, Vollebekken and Norderåsbekken the concentration of sand was not as high as it was for the area near Bølstadbekken, but it was still high. In the deeper area of the basin the accumulation of sand was less that 1%. Silt particles were present in the bay near Storgrava, Norderåsbekken and north of Vollebekken and Smedbølbekken. Also for this particle size there were not registered high masses in the deep part. The pattern was quite the opposite for clay: there was a low accumulation of this particle size in the littoral zone, while it was highest in the profoundal zone of the basin and in the area that was furthest away from the inlets, as the area near the outlet (Rutsinda, 2010).

4.1.3 Influence of clay and organic matter on element distribution

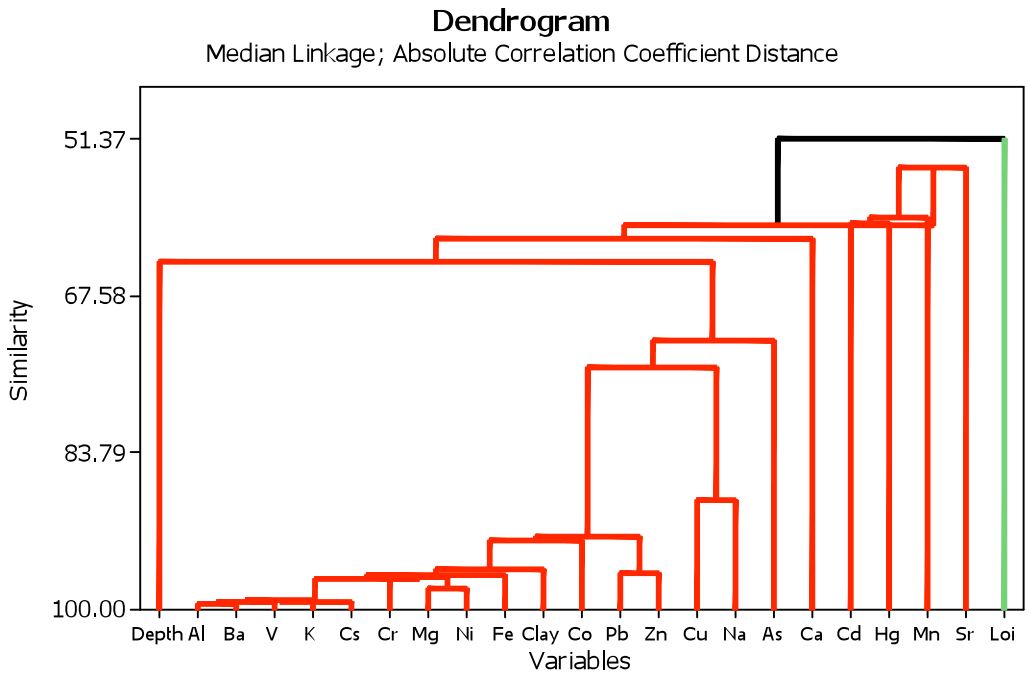


Figure 68. Cluster dendrogram shows which elements and other variables that are closely related and had high similarities (sorted by median values).

Figure 68 illustrates which elements are directly connected with clay content in the sediments and which are more connected by similarity with LOI. The cluster dendrogram summarizes how the distinct variables are grouped together and are related to the sediment properties. It is possible to see that there is a quite large group formed by Al, Ba, V, K, Cs, Cr, Mg, Ni, Fe, clay, Co, Pb and Zn. These variables are highly similar to each other. Then Cu and Na are followed by As. Depth has a marginal similarity because the accumulation of the different elements depends on clay content, which has the highest accumulation in the deeper area of the lake basin. LOI is the variable that is most dissimilar to the rest of the variables, but it seems to be related to Ca, Cd, Hg, Mn and Sr, although LOI is not significant in the linear regression for As, CD, Mn, Pb, Sr, V and Zn. The linear regression analysis, with each metal as response and clay, depth and LOI as variables, showed that clay was the dominating explaining variable. The elements in which depth was not significant were: Al, Ba, Cr, Cs, Cu, Fe, K, Na, V and Hg. Clay were not significant only for Ca (appendix 7).

The catchment area can be connected to the results for this study. The area that encompasses the lake and totally more than 50% of the catchment area, consist of fields dedicated to agricultural activity. The fields that are cultivated with grains and vegetables are easily eroded by precipitation and the particles are transported to the lake. Nutrients are supplied to the soil to increase soil productivity and become bound to the soil particles. When these undergo erosion, the nutrients and other metals follow the runoff (Sharpley, 1985). Only when the water masses are calm and not influenced by wind streams and circulation, the finest particles, like clay, will settle down to the bottom of the lake. Since the highest accumulation of clay is in the deeper part of Lake Årungen, it is expected that the highest concentration of metals will be in the same area. The fact that Ca, Cd, Hg and Sr are connected with organic matter can explain why these elements have high accumulation in the south end of Lake Årungen. In this area there is a higher concentration of organic matter in the samples that were collected.

One reason that can explain why LOI is not statistically correlated with the metals can be that the sediments consist of a mixture of allochtoneous and autochtonous produced organic matter. In an eutrophic lake such as Årungen, a fair amount of the organic matter would originate from the decomposition of dead algal biomass, which

in turn has a different composition and probably also a different association to metals when entering the sediments as compared to allochtoneous produced matter. Another possible cause can be that eutrophic lakes often have large stocks of Cyprinids. Årungen is no different and has a massive stock of roach (*Rutilus rutilus*). Roach might in this context potentially affect the metal-LOI correlation within the sediments samples through more than a simple on-site bioturbation. This is because roach and other Cyprinids have a characteristic strong horizontal food related migration pattern (Persson, L. 1983; Borgstrøm&Hansen, 2000).

4.2 Horizontal distribution

The horizontal distribution can illustrate the spatial variations of the different metals. The maps can give important information about sites with enriched accumulation of metals, if the metal that is studied is equally distributed in the whole area, or if it follows the morphological characteristics of the lake.

4.2.1 Macro components

It is interesting to see if the concentration of the metals determined in the present work is equal with the concentration of metals in the soil in the area surrounding the lake. In Ottesen *et al.* (2000) the median concentration of many metals is presented in maps with classified colours (appendix 9). It is possible to use this study to see if the accumulation of metals in the sediments of Lake Årungen depends on geological factors, or if the high concentrations are to be explained by pollution.

The elements that are present in high concentrations in the soil crust are Fe, Al and Mn. These metals are important components in clay minerals (aluminosilicates), which are the particles that often get washed from the soil by erosion and transported to e.g. water systems where they settle. Hydrous oxides of Fe, Al and Mn serve as adsorbents for P and some metals (Bowen, 1979). Al and Fe are two elements that were highly correlated ($0.643 < r < 0.995$) with As, Ba, Co, Cr, Cs, Cu, Fe, K, Mg, Na, Ni, Pb, V, Zn and clay content (appendix 8). This relationship can be explained by earlier findings by Salomon&Förster (1984) who state that the concentration of Al increases with decreasing particle size.

The horizontal distribution of Al, Fe and Mn resample each other. The accumulation followed the sedimentation pattern so, where there was a high concentration of clay,

there was also a high accumulation of these metals. The trend for Mn was not as clear as it was for the other two elements. All these elements apart from Al and Mn ranged between the total and the acid soluble concentration of those reported by Ottesen *et al.* (2000). As expected the concentration of Al was even lower than the value for the acid soluble part, while the concentration of Mn was higher than the total content.

Aluminium

Aluminium is an element that is present in the sediment as an oxide, thus it cannot be decomposed properly using HNO_3 as decomposing acid. This is showed by the insufficient accuracy of the method determined by concurrent analysis of CRM (appendix 6). The results from the analysis of MESS-1 are much lower than what is found in the certificate sheet (appendix 6). The values presented in this present work are underestimated. Most of its quantity (ca. 50%) remained in the sediments and did not undergo decomposition. For this reason the values obtained in the present work may not be compared with data from other lakes depending on which digestion method is used in the work to compare. However the values of Al can show mutual differences within sampling sites in the present work.

Iron

In this present thesis the average value from the deepest group (11.3 - 13.4 m) was 51 g/kg DW. In Skogheim (1984) the values ranged between 30 and 60 g/kg DW. Iron is an element that is red-ox sensitive. This means that the concentration of Fe in its different forms is dependent on red-ox potential (Eh). In the part of the lake where the red-ox potential is low, as in the deepest area, Fe can be reduced and thus dissolved in the water masses. In areas with higher O_2 concentration Fe will precipitate to the top sediment (Cook, 1984). Natural processes determine the high concentrations of this element in lakes (Rognerud *et al.* 2008), as in Lake Årungen. In proportion to the national scale, where the measured values of Fe had a median of ca 50 g/kg DW (Rognerud *et al.* 2008), Lake Årungen had a concentration that corresponded closely to the average.

Manganese

The accumulation of Mn in Lake Årungen was equal to the median value of 1.0 g/kg DW in the profundal area of the lake. The concentration measured by Skogheim

(1984) varied between 0.3 and 1.1 g/kg, with highest concentration in the uppermost 5 cm of the sediment. The data from this study were in accordance with measurements obtained by Skogheim apart from the fact that the maximum value was like 1.9 g/kg. On the other hand, in proportion to the national study, where most of the values were represented between 0 and 40 g/kg DW with a median value between 0-10 g/kg (Rognerud *et al.* 2008), the concentration was not so high. Manganese has a very strong correlation with depth in the shallowest and in the deepest area of the lake. Likely to Fe, Mn is an element that is very influenced by red-ox processes. If manganese is dissolved in water, it can oxide from Mn^{2+} to Mn^{4+} (from solved to solid) if there is sufficient supply of oxygen and it will then sediment to the bottom (Burns&Nriagu, 1976). Mn^{4+} occurs just in the top centimetre of the sediments (Stumm&Morgan, 1996). If the element is located deeper in the sediment and there is lack of oxygen, it goes from Mn^{4+} to Mn^{2+} and disappears from the sediments to the water (Krogstad, 2010). This can be the reason why the distribution trend for Mn is not as clear as it is for Al and Fe.

Calcium, magnesium and potassium

Calcium, Mg and K are elements that are common in the bedrock, but are also macro nutrients that are added to fertilize agricultural fields (YARA, 2009). Mg and K have the same sedimentation pattern, while Ca has an inverse trend, where the highest concentrations are detected in the shallow areas.

Calcium is an element that is supplied in cultivated areas to stabilize the pH of the soil. Photosynthetic processes can explain the high concentration in the shallow sediments. Summertime plants and algae use CO_2 in the photosynthesis (Wetzel, 2001) that will cause a local increase in pH in the water. As a consequence biogenic $CaCO_3$ will precipitate (Wetzel 2001). There is no primary production in the deeper part of Lake Årungen, so this can be an explanation to why there was not high accumulation of Ca in the profound zone.

The horizontal distribution of Mg and K was similar, with highest concentrations in the deep area and very low accumulation in the areas where there was a high percent of sand and silt, e.g. near Bølstadbekken and Smedbølbekken inlets.

4.2.2 Trace metals

Compared with the mapping reported by Ottesen *et al.* (2000) the values that had a higher concentration than the one of the total amount in Ottesen *et al.* (2000) were: Zn, V, Cr, Ni, Cu and As. The reason can be that the sediments are influenced by runoff from the fields around the lake basin and in the catchment area. The County of Akershus has the highest use of sludge as soil fertilizer. This type of fertilizer has a relatively high content of metals like Zn, Cr, Cu and Hg (Krogstad, 2010). The elements that had a middle concentration were: Sr, Pb and Co, while Ba had a lower concentration than the total. The higher values can indicate pollution, while the lower values can be caused by local differences in the geology, or by the fact that the decomposing method used in this study was not strong enough, this assertion cannot be certified because the CRM used did not have any values for Ba. Ottesen *et al.* (2000) did not register Cs, Cd and Hg.

Trace metals have their origin from combustion of fossil fuels, melting industries and combustion of waste (Klif, 2010). Also surface runoff from roads and cultivated areas are important sources (Bækken, 2006). High concentration of these elements comes to Norway as long-range transported atmospheric pollution from central Europe and Great Britain (Rognerud *et al.* 2000). Even if the concentration of many of these metals in the later years have been reduced it is still possible to find quite high concentrations in sediments.

The trend shown on the maps for the trace elements was quite similar for eight of the metals, apart for Cd and Hg that stood out. For the former eight elements the trend was higher concentration where the concentration of clay was higher; while for cadmium and mercury the trend was the opposite: increased accumulation in the shallow areas near the shore and less in the depth. As, Cu, Hg, Ni and Zn showed increased values in the south area of the lake. In this area the inlet Vollebekken flows in the lake and its water can be polluted by surface runoff from the Europe road 6 (E6) or by runoff from cultivated areas.

Zinc

The concentration of Zn in the group from 11.3 - 13.4 m had a median concentration of 210 mg/kg DW. This is in good agreement with Skogheim (1984) who reported concentrations of Zn varying between 100 and 280 mg/kg DW, with an accumulation

on 200 mg/kg DW in 1978. In the national survey, the values ranged between 0 and 150 mg/kg DW, while the highest value measured was around 700 mg/kg DW (Rognerud *et al.* 2008). This means that Lake Årungen has a concentration that reflects the national survey. In proportion to the guide for classification of environmental quality in freshwater (Bakke *et al.* 1997), Lake Årungen is in category I, "Background concentration". This class goes up to 150 mg Zn/kg (Bakke *et al.* 2007). At the same time Zn was one of the metals that showed a higher concentration compared with general observations in the region. In proportion to the bedrock concentration (between 68 and 74 mg/kg for the acid soluble part and 90.5-100.7 mg/kg for the total concentration), the values measured in Lake Årungen were quite high (median value 210 mg/kg). Zinc is an element that has its sources from long transported atmospheric pollution (Klif, 2010) and among other factors surface runoff from roads (Amundsen, 2003) and tire-tread material (Councell *et al.* 2004). The E6 passes on the west side of Lake Årungen. It can be that small pieces of tires from the wheels get eroded and later get washed out to the aquatic system.

From the map for Zn it appears that there is an accumulation in the deeper part of the lake, near the outlet where the accumulation of clay is high and near the Vollebekken inlet. The last point of high accumulation can perhaps arrive from the drainage pipes from UMB that pour into the stream.

Chromium

In the present thesis the concentration of chromium in the deeper part of the lake is about 100 mg/kg DW. In 1978 the concentration was 50 mg/kg DW and it varied between 42 and 56 mg/kg DW in the period 1955-1978 (Skogheim, 1984). This means that there has been a great accumulation the last 30 years. As a basis of comparison the national sediment study measured values between 0 and 210 mg/kg DW, with a median of ca 10 mg/kg (Rognerud *et al.* 2008). Thus Lake Årungen showed a relatively high concentration of Cr. In proportion to Bakke *et al.* (2007) the accumulation of Cr is higher than just a background concentration in the ground. In fact it corresponds to category II, "Good" that varies between 70 and 560 mg/kg. This was also confirmed by Ottesen *et al.* (2000), where the local concentrations of Cr (24.3-26.9 mg/kg for the acid soluble part and with a total concentration of 68.5 mg/kg) were lower than the one registered in Lake Årungen. Also in comparison with

Bakke (2007) it seems that Lake Årungen has relatively high median value of Cr in the samples from the deepest group.

The most important source of Cr in Norway is CCA-wood. Even if it has been prohibited to produce and sell wood impregnated with copper, chromium and arsenic since 2002, the materials that still are in use can leach to the environment (Klif, 2009 a).

Nickel

The concentration of Ni in the deepest part of the lake basin had a median value of 59 mg/kg DW. Rognerud *et al.* (2008) measured a median value in Norway corresponding to circa 18 mg/kg DW and most of the values in this study ranged between 0 and 100 mg/kg DW. The median in the whole lake was 57 mg/kg DW and corresponds to category III, "Moderate pollution" (Bakke *et al.* 2007), that has its limits on 46 and 120 mg/kg. This means that Lake Årungen has an elevated concentration.

The distribution of Ni followed the sedimentation pattern of clay, so the highest concentration was in the deeper part of the lake. There have been registered elevated values in the south end of the lake and this can be connected with surface runoff from E6.

Copper

The accumulation of copper in the deepest group ranged between 28 and 37 mg/kg DW, with a median of 34 mg/kg DW. In Skogheim (1984) the concentration varied between 25 and circa 52 mg/kg DW, with the lowest value in the deepest part of the sediment core and the highest value 9 cm from the surface of the core. In 1978 the concentration was around 38 mg/kg DW. This means that the concentration of Cu is quite the same as it was 30 years ago. In proportion to Rognerud *et al.* (2008) the median in Norway was around 30 mg/kg DW, so Lake Årungen was close to the national average. In proportion to the quality categories in Bakke *et al.* (2007), Lake Årungen has a concentration of Cu that corresponds to category I, "Background concentration". While in comparison to the bedrock concentration (Ottesen *et al.* 2000) the concentration of Cu is higher.

It was also registered that in the south end of the lake the concentration was highest. It is possible the supply of Cu had its source from surface runoff from the E6. This was the case for other lakes along the E6 in Akershus county (Bækken, 2006).

Lead

In Lake Årungen the variation of Pb was between 11 and 36 mg/kg and the median for the deepest group was 28 mg/kg DW. According to Skogheim (1984) the concentration of Pb showed a minimum of about 25 mg/kg DW and a maximum of about 55 mg/kg DW. The lowest value was measured in the deeper part of the sediment core, that deposited between year 1895 and 1925, while the highest concentration was found approximately 5 cm under the surface of the core, corresponding to accumulation in the period 1955 - 1978 (0 - 20 cm). The present concentration is comparable to the concentration from the period 1895 - 1925. The median value for the whole data set was 28 mg/kg DW and in proportion to the category table, the accumulation of Pb in Lake Årungen corresponds to category I, "Background concentration" (Bakke *et al.* 2007). Also in comparison to the national sediment study, where the concentration varied between 0 and 500 mg/kg DW, with a median of about 75 mg/kg DW (Rognerud *et al.* 2008), Lake Årungen showed relatively low values of Pb at the present. A factor that can have influenced the decline in lead concentration can be the ban of leaded petrol usage in the period from 1977 to 1995 in many countries (Steinnes, 2001). Lead is one of the metals that come to Norway by long-range atmospheric transport (Brannvall *et al.* 2001).

Arsenic

The average for the concentration of As in the deepest depth group (11.3 - 13.4 m) was 8.0 mg/kg DW. The national variation in the surface sediments is between 0 and 500 mg/kg DW, with a high frequency between 0 and 50 mg/kg DW (Rognerud *et al.* 2008). This means that Lake Årungen did not have a high concentration compared to the national survey. In proportion to the values that are given in Bakke *et al.* (2007), the concentration of arsenic is in category I, "Background concentration". In comparison to the bedrock concentrations (3 - 3.3 mg/kg) the sediments in Lake Årungen had a higher median value (6.4 mg/kg DW). The main source for As in Norway is from CCA (cupper chromium arsenic) impregnated wood and leaded ammunition. Both these two sources have been forbidden for sale lately (2002 and

2005), but are still in use and thus active sources for leakage of these elements into watercourses (Klif, 2009 b). Long range pollution is also an important source for As (Steinnes, 2001). In proportion to the concentrations measured in freshwater sediments by Bakke *et al.* (2007 b) the concentration of As in the deep area of Lake Årungen has a medium low amount of As.

Cadmium

The average concentration of Cd for the deeper sediments in Lake Årungen in this present thesis was 0.49 mg/kg DW. Skogheim (1984) reported concentrations of Cd between about 0.8 and 5.3 mg/kg DW, within the first 10 cm of the core. The highest value was situated deeper than the minimum value that was approximately 4 cm from the surface (Skogheim, 1984). The concentration that was found in 2009 was a value lower than ever measured. The lowest value in Skogheim (1984) was approximately 0.8 mg/kg. In proportion to the national study Lake Årungen did not have high concentrations. Nationally the concentrations varied between 0 and 14 mg/kg DW, with a median like 0.5 mg/kg (Rognerud *et al.* 2008). So Lake Årungen is than within the average for Norway.

This can mean that the measuring methods used in the past maybe were not as accurate as the methods are today. The detection limit is much lower today than it was before. Another fact that can indicate that there is a methodical error in Skogheim's analysis is that in the dated core the values swung up and down in just some years. Another possible explanation of the big difference in concentrations can also be that the atmospheric deposition of Cd have decreased with 95% in the period 1980-2005 in south Norway (Berg *et al.* 2008).

In proportion to the guide for classification of environmental quality in fresh water (Bakke *et al.* 2007) Lake Årungen is in category II, "Good".

There is an elevated concentration of Cd in the area near the outlet of Bølstadbekken. This can mean that the waste disposal can influence sediment quality in Lake Årungen. Since 1994 Bioforsk has monitored the runoff from a dismantled waste disposal in the catchment area of Bølstadbekken. The leakage from the waste goes through a wastewater treatment system before it flows into Bølstadbekken. Samples are collected four times a year and elements like Fe, P, N, Mn, Zn, Cu, Pb, Cd, Ni, Cr, As and Hg are monitored (Hensel *et al.* 2009). In this way it is possible to estimate if

the Bølstad waste disposal does influence the concentration of trace metals in Lake Årungen (Hensel *et al.* 2010).

It seems that the highest values of Cd are detected at the sampling points that have a low content of clay and a high content of sand (Rutsinda, 2010).

Mercury

The variation in Lake Årungen was between 0.085 and 0.11 mg/kg DW, with a median of 0.10 mg/kg DW. In Skogheim (1984) the concentration of mercury varied between 0.09 mg/kg DW, in the deeper part of the sediment core, to a maximum of 22 mg/kg DW, approximately 9 cm under the top of the core. This means that the concentration of this metal has decreased a lot over the last 30 years. The concentrations of Hg in the national sediment study fluctuated between 0.0 and 1.0 mg/kg DW, with a median of 0.2 mg/kg DW (Rognerud *et al.* 2008). This means that Lake Årungen is a little lower than the national average in mercury content. In proportion to SFT's guide the concentration of Hg in Lake Årungen corresponds to category I, "Background concentration" (Bakke *et al.* 2007). Since the concentration of mercury is not so elevated it is possible that there is a supply by long-transported atmospheric pollution.

The values from the samples in the south area of Lake Årungen were relatively high compared to the other samples from the lake. The sediments near the inlet Vollebekken were different from most of the remaining samples, with a lot of organic matter, not compacted and with high water and organic matter content. Vollebekken flows through a wetland area before it flows into the lake. This can be a reason for the higher organic content. Another possible reason for these high values in this area can be that the water in the stream get influenced by activity in the University area and can contain trace metals that can get collected with a drainage pipes for surface water. It is not possible to verify for sure, since this approach has not been investigated. Also runoff from the E6 can be a possible source.

5 Conclusion

Most of the metals were positively correlated with Al and Fe, which are present in high concentrations in clay particles in the sediment. The higher the content of clay was, the higher was the concentration of most of the elements determined. In this way the accumulation pattern for the most of the metals showed a higher accumulation in the deeper area of the lake basin and in the area with little influence from streams, like the area near the outlet, where clay particles settle down. This trend was not present for Ca, Cd and Hg. For these metals the concentration was highest in the littoral zone, where organic matter had a larger accumulation. The morphological characteristics of the lake influence the sedimentation pattern. Near the inlets a presence of coarse particles, like sand, was more common than fine particles. The smaller particles, like clay, were able to settle to the bottom in the area where the influence of external processes, as wind streams and watercourse effects, was not present. The highway that runs along the west side of the lake and the sediment composition, with a high amount of organic matter may influence the concentration of some metals in the south part, like Zn, Hg, Ni and As.

In proportion to the national survey, Lake Årungen seemed to have relatively low concentrations of As, Hg, Mn and Pb, while the opposite scenario was shown for the concentrations of Ni and Cr. The concentrations of Cd, Cu, Fe and Zn reflected the national values. The changes that have occurred the last 30 years were most pronounced for Pb, Cd and Hg, which had decreased in concentration, and for Cr that had a pronounced increase since 1978.

With respect to metals, following the current guidelines, the environmental quality in Lake Årungen may be classified as category II, “Good”. An exception was Ni that had a concentration that corresponded to category III, “Moderate pollution”. A part for Ni, these results were quite good, because it means that metals were not the principal cause to the state of pollution in Lake Årungen.

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Appendix

Appendix 1: Depth and coordinates for the sampling points in Lake Årungen.

Appendix 2: Map aver Lake Årungen with sampling points and sample number marked.

Appendix 3: Dry weight data for the samples in the second layer (2.5 - 5 cm).

Appendix 4: Raw data with the concentrations of metals for the samples in the first layer (0 - 2.5 cm).

Appendix 5: Raw data with the concentrations of metals for the samples in the second layer (2.5 - 5 cm).

Appendix 6: Table with the values for the Certified Reference Material.

Appendix 7: Table with the regression analysis.

Appendix 8: Table with the correlation analysis.

Appendix 9: Table with the concentration of the metals in the bedrock in the region of Lake Årungen.

Appendix 1: Depth and coordinates for the sampling points in Lake Årungen.

Sample nr	Depth (m)	X	Y
1	5.64	598420	6618155
2	11.90	598320	6618155
3	12.73	598220	6618155
4	12.73	598120	6618155
5	7.68	598020	6618155
6	2.54	597920	6618155
7	1.10	597820	6618255
8	6.29	597920	6618255
9	11.27	598020	6618255
10	12.38	598120	6618255
11	12.52	598220	6618255
12	9.56	598320	6618255
13	2.32	598420	6618255
14	3.07	598320	6618355
15	12.06	598220	6618355
16	12.01	598120	6618355
17	11.45	598020	6618355
18	10.20	597920	6618355
19	3.72	597820	6618355
20	5.98	597720	6618455
21	8.33	597820	6618455
22	9.70	597920	6618455
23	11.02	598020	6618455
24	12.30	598120	6618455
25	9.36	598220	6618455
26	2.93	598320	6618455
27	5.41	598220	6618555
28	11.99	598120	6618555
29	9.81	598020	6618555
30	6.06	597920	6618555
31	3.08	597820	6618555
32	4.49	597720	6618555
33	1.31	597920	6618655
34	11.64	598020	6618655
35	10.39	598120	6618655
36	1.50	598220	6618655

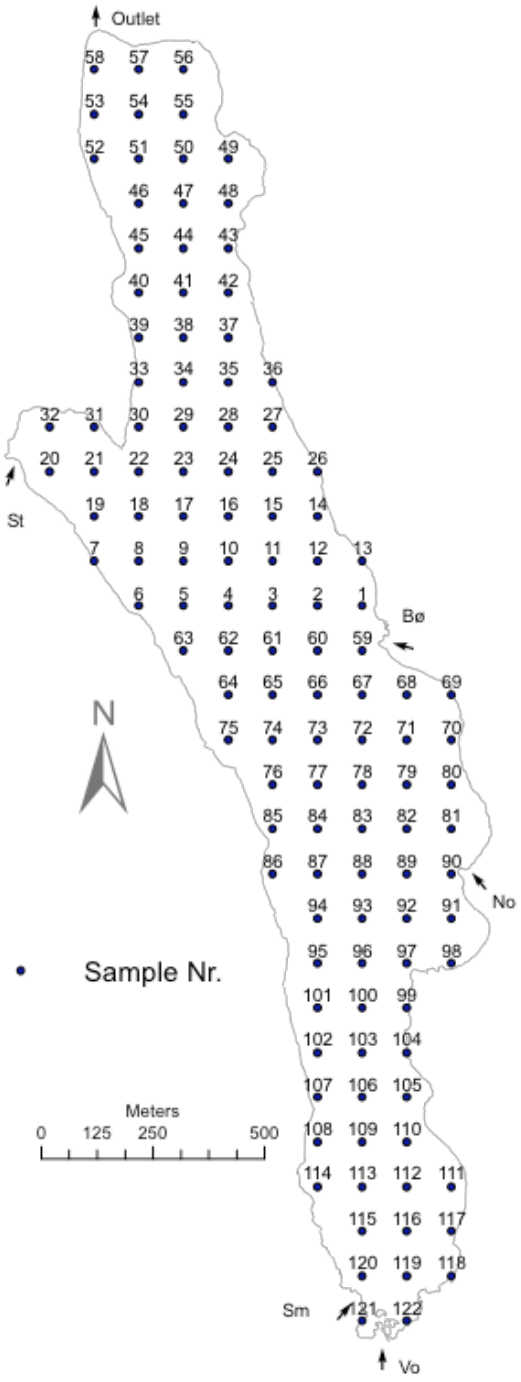
Sample nr	Depth (m)	X	Y
37	8.42	598120	6618755
38	12.31	598020	6618755
39	1.76	597920	6618755
40	7.19	597920	6618855
41	11.98	598020	6618855
42	7.84	598120	6618855
43	7.86	598120	6618955
44	10.74	598020	6618955
45	9.30	597920	6618955
46	10.15	597920	6619055
47	9.50	598020	6619055
48	7.08	598120	6619055
49	5.25	598120	6619155
50	8.44	598020	6619155
51	10.65	597920	6619155
52	7.06	597820	6619155
53	7.30	597820	6619255
54	8.84	597920	6619255
55	6.56	598020	6619255
56	3.80	598020	6619355
57	5.32	597920	6619355
58	5.01	597820	6619355
59	4.21	598420	6618055
60	12.21	598320	6618055
61	12.77	598220	6618055
62	11.08	598120	6618055
63	3.65	598020	6618055
64	9.45	598120	6617955
65	12.78	598220	6617955
66	12.91	598320	6617955
67	11.91	598420	6617955
68	10.40	598520	6617955
69	1.89	598620	6617955
70	7.23	598620	6617855
71	12.48	598520	6617855
72	12.39	598420	6617855

Sample nr	Depth (m)	X	Y
73	13.23	598320	6617855
74	12.53	598220	6617855
75	4.06	598120	6617855
76	9.73	598220	6617755
77	13.18	598320	6617755
78	13.26	598420	6617755
79	12.69	598520	6617755
80	11.45	598620	6617755
81	10.72	598620	6617655
82	13.04	598520	6617655
83	13.33	598420	6617655
84	12.60	598320	6617655
85	2.94	598220	6617655
86	2.68	598220	6617555
87	11.94	598320	6617555
88	13.42	598420	6617555
89	12.73	598520	6617555
90	1.65	598620	6617555
91	6.63	598620	6617455
92	11.99	598520	6617455
93	13.14	598420	6617455
94	11.60	598320	6617455
95	11.03	598320	6617355
96	11.23	598420	6617355
97	5.96	598520	6617355
98	1.80	598620	6617355
99	2.41	598520	6617255
100	11.53	598420	6617255
101	9.44	598320	6617255
102	6.67	598320	6617155
103	11.35	598420	6617155
104	1.59	598520	6617155
105	5.61	598520	6617055
106	10.47	598420	6617055
107	2.60	598320	6617055
108	3.28	598320	6616955
109	9.66	598420	6616955

Sample nr	Depth (m)	X	Y
110	8.65	598520	6616955
111	2.98	598620	6616855
112	8.89	598520	6616855
113	8.60	598420	6616855
114	3.98	598320	6616855
115	8.79	598420	6616755
116	8.51	598520	6616755
117	1.95	598620	6616755
118	0.93	598620	6616655
119	4.81	598520	6616655
120	4.85	598420	6616655
121	0.75	598420	6616555
122	1.18	598520	6616555

Appendix 2: Map over Lake Årungen with sampling point and sample number marked.

The map shows the sampling points with the number of the samples. In layer 1 the samples are marked 1-122, while the one from layer 2 are marked from 1001-1122. Sample nr 1007, 1013, 1036 1118, 1120, 1021 and 1122 had a high content of organic matter, while sample nr 1014 and 1033 had high content of rocks. Sample 1068 and 1098 were not analysed because there was not enough material.



Appendix 3: Dry weight data for samples in the second layer (2.5 - 5 cm).

Sample nr	Dry Weight (%)	Sample nr	Dry Weight (%)	Sample nr	Dry Weight (%)	Sample nr	Dry Weight (%)
1001	50,35	1032	36,52	1063	26,84	1094	30,11
1002	33,30	1033	70,48	1064	24,63	1095	26,56
1003	29,02	1034	29,61	1065	25,18	1096	29,60
1004	29,36	1035	30,04	1066	25,65	1097	22,61
1005	24,40	1036	14,27	1067	45,01	1098	17,37
1006	45,69	1037	24,83	1068	15,58	1099	26,29
1007	12,97	1038	29,10	1069	18,21	1100	31,99
1008	27,95	1039	15,00	1070	27,27	1101	23,88
1009	31,99	1040	19,35	1071	30,70	1102	19,78
1010	29,22	1041	29,28	1072	31,81	1103	33,33
1011	31,20	1042	24,21	1073	25,39	1104	47,90
1012	32,00	1043	22,56	1074	31,00	1105	23,82
1013	42,03	1044	29,27	1075	24,65	1106	35,42
1014	50,25	1045	22,99	1076	25,36	1107	40,08
1015	29,30	1046	24,75	1077	28,83	1108	24,97
1016	32,10	1047	27,26	1078	26,70	1109	37,21
1017	37,55	1048	21,44	1079	28,40	1110	35,48
1018	28,20	1049	22,32	1080	34,89	1111	26,22
1019	28,73	1050	24,32	1081	41,03	1112	38,60
1020	27,87	1051	27,26	1082	31,20	1113	34,52
1021	31,32	1052	19,80	1083	29,06	1114	27,43
1022	27,85	1053	19,76	1084	28,10	1115	40,59
1023	29,83	1054	23,47	1085	59,13	1116	35,76
1024	32,20	1055	20,50	1086	26,58	1117	16,58
1025	32,83	1056	21,42	1087	29,96	1118	15,93
1026	40,31	1057	25,37	1088	29,95	1119	29,11
1027	28,93	1058	21,08	1089	31,35	1120	34,94
1028	31,99	1059	34,23	1090	28,35	1121	29,02
1029	28,75	1060	29,94	1091	23,21	1122	9,74
1030	24,52	1061	25,07	1092	29,50		
1031	34,83	1062	29,44	1093	31,69		

Appendix 4: Raw data with the concentrations of metals for the samples in the first layer (0 - 2.5 cm).

The precision is probably not good enough but the values are presented with three numbers of significant figures (that means all the secure figures and 2 unsecure) to maintain the values intact.

Sample nr	Al (g/kg)	As (mg/kg)	Ba (mg/kg)	Ca (g/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cs (mg/kg)	Cu (mg/kg)	Fe (g/kg)	K (g/kg)
1	26.3	3.60	199	6.61	0.514	9.88	54.6	2.37	14.9	24.6	7.13
2	59.9	6.68	475	6.72	0.489	15.8	99.9	5.83	31.5	49.0	17.4
3	64.4	7.90	522	5.85	0.430	16.6	103	6.56	33.0	51.2	18.6
4	67.1	7.74	543	6.03	0.457	17.2	108	6.58	35.2	53.8	19.1
5	63.4	7.08	507	7.10	0.608	16.9	103	6.27	33.4	50.0	18.4
6	49.0	4.11	400	7.62	0.604	14.1	88.5	4.79	29.4	40.8	14.6
7	41.6	6.06	351	10.6	1.387	12.6	74.9	4.07	51.0	31.1	12.8
8	58.6	6.21	464	7.14	0.664	16.2	99.7	5.69	31.8	48.0	16.7
9	66.6	7.59	539	6.48	0.479	16.4	108	6.79	35.0	53.1	19.4
10	65.1	7.91	528	6.07	0.456	16.7	106	6.72	34.2	51.8	19.2
11	63.0	7.45	505	6.08	0.429	16.5	103	6.49	31.5	50.3	18.2
12	52.5	6.24	412	7.28	0.509	14.8	88.8	5.32	27.0	43.0	15.2
13	35.5	4.01	275	7.46	0.502	11.9	71.0	3.47	20.0	31.5	9.83
14	28.9	2.66	223	6.67	0.483	9.29	55.4	2.66	14.9	24.1	8.02
15	63.3	6.77	503	6.21	0.465	15.9	102	6.42	32.2	49.8	18.4
16	66.4	7.28	535	6.19	0.472	16.4	107	6.70	33.9	52.4	18.7
17	65.1	7.33	530	6.68	0.477	16.0	105	6.57	33.5	51.9	18.9
18	60.4	6.47	475	7.18	0.478	15.5	101	6.27	31.2	47.8	17.4
19	50.9	4.83	411	7.59	0.609	15.8	91.1	5.17	27.2	42.1	14.4
20	53.5	5.47	430	7.33	0.563	15.1	97.5	5.28	30.8	47.0	15.0
21	48.5	5.58	381	7.73	0.427	14.3	88.4	4.78	26.9	42.0	13.3
22	63.2	6.39	500	6.86	0.510	16.3	103	6.39	33.5	50.1	18.4
23	64.0	6.56	515	6.22	0.497	16.2	104	6.45	34.5	50.7	18.5
24	65.6	7.45	535	5.99	0.451	16.4	105	6.72	33.5	52.0	18.9
25	58.2	7.13	458	7.22	0.514	15.5	97.8	6.05	29.1	47.6	17.1
26	45.2	5.03	351	7.06	0.392	12.6	81.2	4.70	22.8	39.6	13.1
27	55.1	5.84	443	7.30	0.565	15.5	94.9	5.52	26.7	43.6	16.2
28	65.9	7.18	541	6.64	0.479	16.4	110	6.76	33.3	54.3	19.1

Sample nr	Al (g/kg)	As (mg/kg)	Ba (mg/kg)	Ca (g/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cs (mg/kg)	Cu (mg/kg)	Fe (g/kg)	K (g/kg)
29	64.2	7.25	524	6.87	0.522	16.4	105	6.65	33.3	52.7	18.7
30	64.2	5.59	529	6.71	0.658	17.4	103	6.61	32.2	49.1	19.2
31	49.4	4.67	403	7.44	0.507	14.1	93.2	4.87	26.8	40.2	14.6
32	43.7	4.88	343	7.76	0.409	12.9	88.5	4.39	23.0	37.6	12.6
33	33.9	10.36	274	8.12	0.700	10.8	65.7	3.28	28.6	29.3	10.7
34	67.3	7.30	542	6.24	0.497	16.5	107	6.85	35.0	52.1	20.2
35	61.0	6.72	483	6.79	0.485	15.9	98.7	6.08	31.5	49.5	18.0
36	37.8	5.96	337	10.4	1.03	10.6	70.1	3.91	36.0	31.5	11.3
37	58.5	7.30	467	7.14	0.535	16.6	95.6	5.86	30.7	47.7	17.0
38	65.1	7.69	527	5.93	0.487	16.6	103	6.68	35.0	53.2	18.8
39	40.4	6.01	351	10.0	1.15	14.2	74.5	4.17	38.7	33.1	12.4
40	63.9	8.04	520	6.71	0.702	17.7	103	6.45	37.2	53.1	18.3
41	64.7	7.64	527	6.22	0.506	17.2	104	6.40	35.6	53.6	18.1
42	60.3	6.65	479	7.23	0.587	17.1	98.1	6.09	32.1	48.8	17.1
43	60.0	7.15	485	6.65	0.628	16.7	98.1	6.05	33.5	50.0	17.1
44	67.2	7.70	553	6.79	0.526	17.0	114	7.05	35.1	56.5	19.6
45	68.6	7.19	548	6.79	0.606	17.2	106	7.33	36.6	52.8	20.5
46	70.5	8.23	567	6.92	0.553	18.0	110	7.31	36.7	56.8	20.6
47	68.1	7.85	544	6.56	0.523	17.1	106	7.12	34.4	53.6	20.3
48	65.3	7.63	525	7.12	0.694	17.4	105	6.91	34.0	51.9	19.2
49	60.9	6.70	504	7.39	0.682	17.1	102	6.04	33.3	51.2	17.5
50	68.7	7.54	551	6.96	0.562	17.7	108	7.12	34.4	54.0	20.2
51	70.6	7.49	567	6.21	0.532	17.2	110	7.45	37.0	54.7	21.1
52	67.2	7.10	543	7.09	0.737	17.8	111	7.10	36.7	54.3	19.7
53	68.4	7.72	560	7.44	0.690	17.9	115	7.27	35.6	56.6	19.9
54	71.6	7.80	574	7.03	0.641	18.2	113	7.55	37.4	56.5	20.8
55	65.4	7.84	528	7.01	0.700	18.2	105	6.74	34.6	52.1	19.0
56	58.9	7.36	492	7.81	0.788	18.3	102	5.89	33.0	49.8	16.9
57	61.4	6.34	516	7.01	0.705	18.3	104	6.35	35.3	50.3	17.5
58	61.1	6.94	508	7.61	0.797	16.8	107	6.47	34.0	50.5	17.6
59	41.9	4.41	339	7.66	0.851	12.1	78	4.23	22.6	34.8	12.3
60	66.0	6.91	531	5.99	0.487	16.7	106	7.00	34.2	51.4	19.5
61	67.5	7.39	548	5.66	0.423	16.9	106	7.01	33.7	52.6	19.4
62	67.4	7.51	543	6.95	0.533	16.5	109	7.06	35.4	54.7	19.2

Sample nr	Al (g/kg)	As (mg/kg)	Ba (mg/kg)	Ca (g/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cs (mg/kg)	Cu (mg/kg)	Fe (g/kg)	K (g/kg)
63	53.7	5.74	454	8.05	0.630	15.4	98.6	5.73	26.5	45.4	16.1
64	74.2	7.90	593	7.65	0.576	18.2	119	7.61	38.1	57.8	21.8
65	70.1	7.42	570	5.90	0.423	17.1	110	7.20	34.6	54.0	20.4
66	71.8	7.61	583	5.67	0.447	16.8	112	7.43	36.2	55.7	20.9
67	68.1	6.66	547	5.97	0.459	16.7	108	7.03	34.8	53.7	19.9
68	66.7	6.96	534	6.82	0.457	16.5	107	6.76	32.7	52.4	19.8
69	47.1	5.52	400	11.6	0.575	12.2	85.8	4.87	32.7	37.5	14.2
70	60.1	7.01	486	7.06	0.476	15.9	99.2	6.22	29.9	48.8	17.9
71	68.8	7.38	554	6.01	0.439	16.9	109	7.36	33.9	53.1	20.3
72	70.0	7.42	562	5.89	0.446	17.4	111	7.24	36.0	54.7	20.3
73	71.8	7.96	584	5.81	0.429	17.8	114	7.44	36.2	56.6	20.6
74	69.8	7.58	572	6.38	0.466	17.5	116	7.35	35.6	57.0	20.3
75	59.0	7.93	495	7.65	0.630	16.7	99.7	5.97	30.3	49.6	17.2
76	64.5	7.34	519	7.20	0.522	16.8	106	6.31	34.8	53.0	18.0
77	67.4	7.46	553	5.83	0.419	16.4	107	6.65	34.9	54.5	19.0
78	68.1	7.74	550	5.67	0.410	16.7	109	6.93	34.5	55.4	19.5
79	67.4	6.91	541	5.93	0.395	16.2	110	6.78	33.1	53.2	19.2
80	55.8	6.13	439	7.21	0.403	15.2	96.0	5.58	29.7	47.0	15.9
81	45.3	5.07	352	7.52	0.381	13.7	85.4	4.33	22.9	40.2	12.8
82	63.0	6.85	505	5.90	0.378	15.8	105	6.06	32.7	52.4	17.6
83	67.0	7.94	556	6.05	0.372	17.9	113	6.57	35.6	56.9	18.9
84	68.5	7.48	559	6.40	0.449	17.1	115	6.75	36.3	57.7	19.6
85	17.4	2.77	138	7.34	0.418	6.87	41.2	1.40	14.2	16.7	4.92
86	46.7	3.88	385	7.77	0.585	13.0	84.0	4.56	26.8	36.7	13.6
87	65.8	6.40	527	6.10	0.448	16.0	107	6.26	36.3	53.0	18.8
88	64.9	7.75	524	6.01	0.418	17.6	107	6.75	34.7	54.3	18.0
89	53.8	5.49	429	5.01	0.338	13.0	86.3	5.43	27.2	42.7	15.8
90	42.3	3.38	351	12.9	0.466	12.6	83.0	4.07	26.0	33.4	12.6
91	63.6	6.78	513	6.95	0.538	16.2	105	6.07	33.3	52.3	18.5
92	68.9	6.51	549	6.16	0.437	16.2	109	6.76	34.9	53.9	20.2
93	67.7	6.78	543	6.36	0.417	16.5	112	6.61	34.7	54.4	19.6
94	68.9	6.88	556	6.55	0.475	16.6	110	6.75	36.3	55.3	19.5
95	66.0	6.99	534	6.65	0.489	16.8	107	6.46	35.4	53.3	19.1
96	61.6	6.29	497	6.92	0.423	16.1	106	6.04	32.4	53.3	17.2

Sample nr	Al (g/kg)	As (mg/kg)	Ba (mg/kg)	Ca (g/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cs (mg/kg)	Cu (mg/kg)	Fe (g/kg)	K (g/kg)
97	61.6	7.02	510	7.65	0.634	17.1	107	6.07	33.2	53.0	17.3
98	44.5	4.04	357	14.1	0.525	12.0	85.4	4.44	27.4	32.7	12.9
99	69.3	6.42	580	7.42	0.636	18.4	110	7.25	37.6	52.6	20.7
100	60.5	6.54	481	6.42	0.384	15.9	102	6.12	30.2	49.3	17.5
101	68.1	7.38	547	7.04	0.493	17.6	109	6.94	34.7	53.9	19.7
102	63.9	7.28	523	7.24	0.658	17.6	105	6.24	34.7	52.6	17.8
103	59.9	6.52	471	6.76	0.386	15.4	102	6.06	29.7	48.0	17.6
104	29.7	5.45	250	8.73	0.710	11.2	52.5	2.56	25.2	27.2	8.94
105	61.7	5.55	495	7.06	0.558	16.1	102	6.29	31.6	47.9	18.3
106	59.1	6.36	465	7.07	0.389	15.3	101	5.98	29.1	48.0	17.0
107	46.9	3.65	390	8.79	0.644	12.9	82.7	4.76	28.1	34.5	14.1
108	57.2	5.99	479	7.51	0.643	15.6	98.5	6.06	29.1	45.3	17.1
109	58.1	6.19	466	7.08	0.402	15.6	104	5.96	28.6	48.5	16.9
110	56.6	5.78	439	7.75	0.426	15.3	99.9	5.74	28.5	45.6	16.5
111	51.6	5.44	423	7.45	0.632	15.4	91.0	5.42	28.2	42.5	15.3
112	46.9	5.45	359	6.84	0.335	14.0	87.9	4.63	23.7	39.9	13.5
113	55.1	6.39	430	7.13	0.387	15.2	95.8	5.64	25.9	43.5	16.4
114	53.1	5.63	437	7.00	0.520	15.4	93.9	5.41	27.9	45.3	15.4
115	43.3	5.37	329	7.14	0.317	13.2	84.1	4.22	21.4	37.3	12.3
116	44.5	5.00	342	7.35	0.346	13.9	85.1	4.54	22.8	38.5	12.6
117	49.7	4.38	412	7.82	0.585	13.3	85.3	5.09	31.5	38.0	15.1
118	26.7	5.15	205	9.19	0.441	9.12	69.2	2.43	24.1	22.5	8.03
119	47.4	5.18	375	8.03	0.591	14.2	90.4	5.09	36.4	41.2	14.0
120	27.9	6.14	237	7.96	0.614	11.5	58.3	2.61	17.4	26.4	8.57
121	55.1	7.22	441	7.31	0.682	13.9	89.7	6.21	65.4	42.1	17.4
122	47.3	6.74	377	9.66	0.849	14.0	79.0	5.43	62.3	42.1	15.2

Sample nr	Mg (g/kg)	Mn (g/kg)	Na (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Sr (mg/kg)	V (mg/kg)	Zn (mg/kg)	Hg (mg/kg)
1	5.94	0.499	419	25.1	16.2	47.9	60.4	110	0.0573
2	12.5	0.989	711	54.7	25.9	62.3	134	204	0.0955
3	13.2	1.17	730	58.3	27.9	58.3	143	209	0.0995
4	13.7	1.11	864	61.0	28.3	60.3	149	220	0.104
5	13.3	1.65	751	59.5	28.7	63.0	137	228	0.113
6	11.2	1.22	679	51.0	23.6	59.4	107	184	0.0938
7	8.98	0.576	780	52.0	28.2	70.7	102	199	0.130
8	12.8	1.39	707	59.2	28.5	61.7	124	226	0.115
9	13.6	0.956	806	59.5	28.1	62.9	147	219	0.102
10	13.2	1.06	861	59.7	27.8	58.7	148	210	0.104
11	12.8	1.14	771	55.9	27.2	58.7	141	202	0.0978
12	11.0	1.31	642	47.0	24.2	61.8	116	180	0.0843
13	7.98	1.11	502	33.9	19.4	56.5	77.4	135	0.0686
14	6.56	1.04	426	28.2	14.6	47.4	60.1	110	0.0601
15	12.9	0.941	719	56.0	26.9	59.8	140	204	0.0958
16	13.5	0.989	809	60.1	28.1	60.1	146	215	0.101
17	13.3	0.934	904	58.5	27.5	62.4	145	215	0.101
18	12.7	1.36	779	54.9	26.6	63.6	130	202	0.0941
19	11.5	1.62	647	52.8	26.6	61.6	110	195	0.0981
20	12.0	1.20	653	54.6	25.6	61.4	117	209	0.0918
21	11.1	1.27	648	49.1	23.3	62.7	106	176	0.0762
22	13.2	0.930	790	58.1	27.6	62.7	135	213	0.0991
23	13.2	0.939	752	59.1	28.4	60.2	139	217	0.101
24	13.3	0.988	857	57.8	27.9	59.3	144	209	0.0986
25	12.1	1.11	720	51.7	26.2	63.4	128	195	0.0911
26	10.2	1.19	623	42.3	23.2	53.6	102	154	0.0689
27	11.7	1.78	682	51.6	26.5	62.6	120	196	0.0995
28	13.5	1.03	764	61.6	27.7	62.5	152	220	0.101
29	13.2	1.25	742	57.5	28.0	63.3	141	216	0.105
30	13.3	1.58	778	60.4	29.3	60.7	139	226	0.109
31	10.7	1.19	681	47.3	23.5	62.7	110	182	0.0817
32	9.88	0.882	685	42.6	21.3	64.8	97.9	156	0.0662
33	7.78	0.558	963	41.9	20.5	55.7	86.0	147	0.116

Sample nr	Mg (g/kg)	Mn (g/kg)	Na (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Sr (mg/kg)	V (mg/kg)	Zn (mg/kg)	Hg (mg/kg)
34	13.5	0.990	768	60.2	28.2	61.0	147	218	0.104
35	12.7	1.05	694	55.6	26.6	62.0	129	206	0.0964
36	8.08	0.779	706	43.7	21.8	70.5	91.8	163	0.115
37	12.5	1.95	684	55.4	26.9	62.3	123	209	0.107
38	13.3	0.962	809	60.2	28.6	59.5	143	215	0.106
39	8.76	0.847	715	50.4	28.4	67.5	99.1	191	0.121
40	13.3	1.55	717	62.3	31.4	60.8	136	239	0.120
41	13.4	1.02	769	61.0	29.2	60.4	139	223	0.109
42	12.8	2.11	695	58.8	28.7	62.2	127	223	0.103
43	12.7	1.45	716	57.6	28.7	60.4	126	222	0.109
44	13.8	1.01	754	64.1	29.2	62.5	152	232	0.106
45	13.7	1.29	794	62.2	29.9	62.1	147	231	0.113
46	14.3	1.21	790	63.5	30.4	64.3	150	236	0.113
47	13.7	1.12	771	59.7	28.6	62.3	145	223	0.106
48	13.5	1.58	741	61.0	30.6	63.5	139	236	0.123
49	13.1	1.95	698	60.3	29.6	62.8	130	234	0.121
50	14.0	1.54	750	62.3	29.7	63.7	146	232	0.112
51	14.1	0.962	812	63.2	30.5	60.9	154	233	0.110
52	13.9	1.89	847	65.6	33.0	59.8	146	256	0.125
53	14.3	1.84	730	65.7	32.5	63.8	149	253	0.121
54	14.5	1.36	810	64.7	32.1	65.0	151	245	0.121
55	13.7	1.78	749	63.0	31.3	63.0	135	243	0.124
56	13.0	2.38	686	61.7	32.2	63.9	126	232	0.129
57	13.1	1.74	706	63.7	31.6	62.3	131	238	0.124
58	13.0	1.82	789	60.5	32.8	62.4	132	235	0.128
59	9.00	1.56	663	39.6	20.5	58.0	92.2	157	0.0889
60	13.3	0.985	788	59.3	28.8	58.8	146	213	0.100
61	13.6	1.22	818	58.7	28.6	57.9	147	211	0.101
62	13.7	1.15	803	62.5	29.3	63.4	149	227	0.107
63	11.8	1.98	705	54.4	26.4	63.9	122	197	0.100
64	15.0	1.48	868	67.4	31.5	70.3	160	245	0.117
65	13.9	1.20	884	61.2	29.3	60.0	153	217	0.103
66	14.1	1.21	851	63.4	29.5	59.5	157	223	0.110
67	13.7	0.993	804	61.0	28.2	59.6	149	216	0.103

Sample nr	Mg (g/kg)	Mn (g/kg)	Na (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Sr (mg/kg)	V (mg/kg)	Zn (mg/kg)	Hg (mg/kg)
68	13.6	0.943	790	58.5	27.3	65.0	146	211	0.0968
69	9.96	0.939	837	47.2	22.8	68.3	107	217	0.0813
70	12.5	1.51	724	53.8	26.3	64.7	131	198	0.0905
71	13.7	1.14	784	60.2	28.8	60.4	153	213	0.100
72	13.9	1.06	834	63.0	28.9	58.9	157	224	0.105
73	14.3	1.27	936	64.3	30.6	59.4	157	223	0.108
74	14.1	1.09	850	66.5	29.7	61.6	159	230	0.116
75	12.7	2.47	698	58.9	28.6	66.1	126	219	0.121
76	13.6	1.91	717	61.9	28.3	64.4	136	226	0.112
77	13.6	1.26	799	60.9	27.6	58.5	147	218	0.106
78	13.7	1.27	854	62.2	28.6	57.3	151	218	0.107
79	13.6	1.18	814	59.9	27.6	59.4	145	211	0.100
80	12.1	0.826	684	53.4	24.9	63.0	123	189	0.0895
81	10.1	0.819	596	43.5	21.6	62.0	98.8	154	0.0710
82	13.1	1.17	823	58.7	26.4	58.3	137	206	0.102
83	13.8	1.37	923	65.5	27.9	58.7	152	226	0.105
84	14.0	1.20	782	65.2	28.4	61.5	153	231	0.113
85	4.17	0.561	455	19.2	12.0	45.2	42.2	59.5	0.0843
86	9.99	1.34	622	46.6	21.3	61.8	101	168	0.105
87	13.6	0.975	762	62.6	27.2	60.0	142	224	0.111
88	13.5	1.32	877	60.6	28.9	59.1	141	213	0.107
89	10.9	0.834	713	48.6	21.3	49.1	118	169	0.0841
90	9.33	0.695	612	40.9	19.8	71.9	93.1	152	0.0736
91	13.4	1.66	747	59.6	26.2	62.6	136	225	0.119
92	14.0	0.966	816	61.9	26.2	61.5	150	219	0.116
93	14.0	1.04	985	62.8	26.9	61.7	149	217	0.106
94	14.1	0.937	825	62.2	28.1	63.8	145	226	0.113
95	13.8	0.931	758	62.3	27.7	63.4	142	220	0.110
96	13.3	1.00	766	60.9	25.9	62.6	136	213	0.103
97	13.6	2.09	720	63.2	29.3	64.7	133	241	0.142
98	9.5	0.636	702	42.9	22.0	76.6	98.6	146	0.0745
99	14.3	2.07	798	66.2	29.9	64.1	149	243	0.127
100	12.7	0.860	851	55.0	24.9	61.0	134	194	0.0932
101	14.0	1.74	766	62.5	28.0	64.4	144	225	0.113

Sample nr	Mg (g/kg)	Mn (g/kg)	Na (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Sr (mg/kg)	V (mg/kg)	Zn (mg/kg)	Hg (mg/kg)
102	13.6	2.13	714	63.5	30.2	63.8	135	239	0.139
103	12.5	0.953	896	54.4	24.8	61.1	132	191	0.0906
104	6.44	0.919	749	37.5	17.1	55.8	78.8	142	0.110
105	13.1	1.65	720	57.5	26.8	63.7	131	214	0.131
106	12.5	0.862	849	53.4	24.6	63.1	130	188	0.0908
107	9.64	0.842	658	45.9	21.7	57.0	104	172	0.100
108	12.0	1.68	700	54.5	27.1	64.0	125	201	0.1300
109	12.4	0.877	685	55.6	24.0	63.2	132	192	0.0909
110	12.4	1.10	729	53.2	24.6	67.6	122	185	0.0936
111	11.6	1.56	632	52.1	26.8	62.5	110	201	0.169
112	10.5	0.79	636	45.1	21.5	59.0	102	159	0.0754
113	11.8	1.23	677	50.4	23.8	61.4	118	176	0.0806
114	11.6	1.48	710	52.7	24.7	58.6	115	195	0.101
115	9.75	0.696	695	42.0	20.6	57.3	95.2	145	0.0638
116	10.3	1.01	598	43.5	21.9	59.7	96.7	154	0.0727
117	10.6	0.860	683	49.9	22.0	61.8	107	178	0.107
118	6.24	0.496	569	30.2	14.2	63.8	67.3	125	0.0654
119	10.9	1.18	826	47.3	27.2	63.2	102	213	0.246
120	6.17	0.591	624	29.7	18.3	58.0	75.1	119	0.0518
121	11.3	0.559	1282	57.9	26.4	53.6	128	236	0.146
122	10.2	0.488	1251	52.3	27.6	64.3	115	238	0.183

Appendix 5: Raw data with the concentrations of metals for the samples in the second layer (2.5 - 5 cm).

The precision is probably not good enough but the values are presented with three numbers of significant figures (that means all the secure figures and 2 unsecure) to maintain the values intact.

Sample nr	Al (g/kg)	As (mg/kg)	Ba (mg/kg)	Ca (g/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cs (mg/kg)	Cu (mg/kg)	Fe (g/kg)	K (g/kg)	Mg (g/kg)
1001	21.6	2.74	161	5.87	0.412	8.04	44.3	1.96	10.9	20.7	5.82	4.81
1002	54.4	5.77	438	6.43	0.561	15.5	92.4	5.82	30.4	43.5	16.2	11.5
1003	63.5	8.89	537	5.93	0.470	16.8	104	6.82	32.8	52.3	19.7	12.8
1004	66.3	8.40	559	5.89	0.499	17.1	106	7.17	35.1	53.0	20.5	13.2
1005	64.5	7.19	531	7.04	0.618	16.7	105	6.81	33.6	50.8	19.9	13.2
1006	39.7	3.78	316	9.19	0.403	12.8	78.3	3.95	21.2	34.4	13.6	10.7
1007	42.3	6.14	354	10.1	1.27	12.5	76.3	4.37	49.8	30.9	13.5	9.0
1008	58.3	6.46	479	7.16	0.669	16.5	101	6.10	29.8	47.2	17.5	12.6
1009	64.0	6.70	529	6.42	0.523	16.6	105	6.71	34.4	50.4	19.3	13.4
1010	67.4	8.35	576	6.22	0.496	16.7	109	7.16	35.6	53.6	20.8	13.5
1011	62.8	8.27	523	6.24	0.506	17.3	102	6.61	32.5	49.6	19.4	12.7
1012	51.9	5.49	416	7.30	0.564	14.6	91.9	5.27	28.0	42.2	15.7	10.8
1013	38.1	3.67	295	7.57	0.481	12.3	78.1	3.70	19.7	32.4	11.1	8.39
1014	22.8	1.92	175	6.95	0.480	7.39	46.1	1.99	10.7	19.2	6.60	5.18
1015	62.2	6.98	513	6.01	0.483	15.8	102	6.63	32.9	47.7	19.2	12.4
1016	65.5	7.28	547	6.11	0.489	17.0	107	6.91	33.7	50.8	20.2	13.2
1017	60.7	6.26	508	6.40	0.459	15.5	101	6.44	30.6	46.2	18.8	12.6
1018	60.4	6.00	491	6.91	0.509	15.5	101	6.33	32.3	46.8	18.2	12.4
1019	55.4	5.21	463	7.64	0.633	16.2	100	5.64	27.4	44.5	17.2	12.1
1020	56.9	5.02	459	6.79	0.550	15.0	98.8	5.89	29.6	44.6	17.4	12.0
1021	50.7	6.56	411	7.77	0.439	14.3	92.7	5.23	26.1	43.2	15.1	11.1
1022	62.6	5.81	513	6.42	0.552	16.5	103	6.77	32.6	47.4	19.1	12.8
1023	65.0	6.44	538	6.16	0.523	17.0	105	6.75	34.5	49.6	19.8	13.3
1024	64.4	7.84	547	6.27	0.468	16.4	105	6.62	32.3	51.3	19.5	13.0
1025	54.5	5.15	439	6.84	0.487	15.2	96.4	5.58	27.7	42.8	16.4	11.4
1026	37.3	4.42	289	6.29	0.300	10.8	69.9	3.78	18.8	33.9	11.0	8.62
1027	50.5	5.74	417	7.39	0.589	15.8	91.2	4.78	25.8	43.3	14.4	11.1
1028	58.5	6.81	484	6.25	0.500	16.6	98.3	5.94	32.3	48.3	16.7	12.4

Sample nr	Al (g/kg)	As (mg/kg)	Ba (mg/kg)	Ca (g/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cs (mg/kg)	Cu (mg/kg)	Fe (g/kg)	K (g/kg)	Mg (g/kg)
1029	65.4	6.38	536	6.93	0.572	18.1	108	6.55	34.5	51.1	19.1	13.6
1030	59.3	5.31	503	6.89	0.745	18.8	100	5.71	32.3	48.3	16.9	12.8
1031	43.4	3.51	360	7.31	0.488	13.5	89.0	4.31	23.0	35.2	12.5	9.95
1032	41.1	4.32	326	7.99	0.449	13.3	85.8	3.91	22.4	36.3	11.4	9.63
1033	33.5	5.94	265	6.53	0.150	12.7	66.0	3.14	17.9	31.4	11.6	9.67
1034	64.3	6.78	538	6.23	0.510	16.3	104	6.42	33.9	50.9	19.0	13.1
1035	59.8	5.54	487	6.66	0.539	16.6	101	5.92	31.4	46.8	17.4	12.7
1036	40.4	6.13	353	10.1	0.997	11.5	72.7	3.99	38.1	30.4	12.3	8.45
1037	55.6	7.76	455	7.20	0.560	16.3	93.2	5.58	29.6	48.4	16.2	11.9
1038	63.7	8.14	540	6.25	0.509	17.1	103	6.10	35.0	54.3	18.1	13.2
1039	45.3	8.36	387	9.40	1.45	16.4	79.6	4.42	44.2	37.9	14.3	9.57
1040	62.9	6.42	525	6.68	0.688	17.2	103	6.22	35.4	51.0	18.7	13.0
1041	65.9	7.23	551	6.15	0.490	16.5	105	6.70	33.6	51.7	19.7	13.3
1042	60.7	6.62	492	7.23	0.607	17.6	101	5.95	31.5	49.6	18.1	12.9
1043	61.7	5.87	505	6.59	0.636	16.9	102	6.12	33.0	49.0	18.5	12.8
1044	66.9	6.43	552	6.38	0.514	16.8	106	6.94	34.0	50.4	20.4	13.6
1045	68.6	6.18	571	6.36	0.655	17.8	110	7.12	37.6	51.4	20.4	13.8
1046	66.5	6.63	565	6.39	0.602	17.6	106	6.71	36.5	53.2	19.8	13.7
1047	63.1	5.70	519	6.30	0.616	17.0	102	6.30	35.0	49.4	18.5	13.2
1048	64.1	6.87	525	7.01	0.705	17.8	104	6.58	34.1	50.3	19.0	13.3
1049	60.9	6.16	513	7.27	0.722	17.2	103	6.25	31.9	50.3	18.3	12.9
1050	65.9	6.19	532	6.49	0.648	17.6	109	6.68	35.2	52.1	19.4	13.5
1051	68.3	6.71	560	6.08	0.583	17.0	109	7.29	37.4	51.7	20.6	13.7
1052	66.9	6.60	548	6.96	0.672	17.9	110	7.18	36.3	52.0	20.3	13.5
1053	65.5	6.50	543	6.99	0.749	17.9	108	6.80	35.4	51.5	19.8	13.6
1054	66.1	6.20	540	6.26	0.694	17.8	107	6.90	35.9	50.6	19.9	13.4
1055	64.0	6.65	529	7.12	0.783	17.7	105	6.59	33.9	51.8	19.1	13.5
1056	59.2	6.99	496	7.96	0.779	17.1	106	6.14	32.5	50.0	17.8	12.9
1057	58.7	5.51	500	6.85	0.809	17.2	107	6.21	34.0	46.2	17.5	12.7
1058	60.2	6.17	505	7.83	0.824	16.8	108	6.37	33.9	50.1	17.9	12.8
1059	35.5	2.79	280	7.47	0.978	11.0	72.5	3.28	20.8	29.8	10.3	7.86
1060	63.4	7.55	522	5.80	0.495	16.0	106	6.62	33.1	49.9	19.0	12.9
1061	64.7	9.86	547	5.95	0.540	17.2	105	6.89	35.8	52.8	19.5	12.9
1062	67.4	6.55	548	6.50	0.526	16.8	111	6.73	35.7	51.0	20.0	14.0

Sample nr	Al (g/kg)	As (mg/kg)	Ba (mg/kg)	Ca (g/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cs (mg/kg)	Cu (mg/kg)	Fe (g/kg)	K (g/kg)	Mg (g/kg)
1063	49.6	4.53	410	7.24	0.697	15.3	88.7	5.11	25.1	40.9	14.8	11.3
1064	61.7	6.41	497	6.39	0.610	17.3	101	6.26	35.1	50.4	17.9	13.2
1065	63.3	9.99	540	6.01	0.523	17.6	102	6.69	34.7	52.0	19.0	12.9
1066	66.8	10.6	585	6.04	0.516	18.2	108	7.02	36.8	57.2	19.7	13.7
1067	64.1	7.50	526	6.05	0.528	17.6	104.9	6.97	34.0	50.4	19.3	13.3
1068	56.3	6.02	451	6.02	0.449	16.3	94.8	5.77	31.2	45.6	16.3	12.4
1069												
1070	57.2	5.72	467	6.58	0.520	16.3	95.0	5.71	29.3	47.0	17.3	12.6
1071	58.1	8.32	485	5.99	0.435	17.0	95.5	5.84	32.0	49.5	16.7	12.6
1072	67.9	7.79	556	5.59	0.466	17.3	109	7.09	33.4	52.0	20.4	13.9
1073	64.6	10.2	556	5.78	0.507	18.4	105	6.75	35.4	54.7	19.2	13.2
1074	65.1	8.20	536	5.74	0.499	17.3	106	6.54	35.7	52.2	19.3	13.6
1075	53.1	5.95	446	7.34	0.749	16.7	92.7	5.30	29.4	46.9	15.4	12.1
1076	64.9	6.78	526	6.82	0.607	18.3	106	6.92	35.1	51.6	19.5	13.9
1077	66.0	9.31	549	5.85	0.473	17.9	106	6.84	34.5	53.7	19.8	13.6
1078	64.5	9.81	546	5.83	0.483	17.8	106	6.52	35.3	54.3	18.9	13.3
1079	57.9	8.12	480	5.82	0.446	16.4	95.4	6.10	31.3	45.7	17.5	11.9
1080	51.4	5.45	407	6.64	0.422	14.8	89.9	5.17	27.8	42.9	15.0	11.4
1081	41.4	4.40	321	6.83	0.365	12.5	78.9	4.15	21.1	34.5	12.4	9.13
1082	59.0	8.12	496	5.84	0.400	15.8	98.3	6.22	29.8	48.4	17.9	12.2
1083	59.3	8.75	504	5.23	0.434	15.7	96.0	6.26	31.4	47.8	18.4	12.0
1084	64.4	8.23	539	5.94	0.472	17.2	107	6.63	35.3	53.4	18.6	13.5
1085	16.4	3.13	120	12.1	0.297	6.86	45.2	1.28	9.13	16.5	4.71	4.23
1086	44.2	3.49	366	7.67	0.650	12.7	88.2	4.48	26.2	33.3	13.6	9.56
1087	70.1	7.36	567	5.97	0.531	18.0	113	7.44	36.2	52.8	21.6	14.2
1088	64.7	8.93	554	5.86	0.441	17.3	106	6.84	33.4	52.9	19.7	13.1
1089	64.9	7.43	532	6.38	0.442	17.0	108	6.80	32.5	51.3	19.8	13.3
1090	39.9	4.18	324	16.4	0.524	13.2	78.8	4.10	24.1	30.9	12.0	8.97
1091	65.4	6.54	526	6.93	0.651	18.0	108	7.16	34.8	51.4	19.9	13.7
1092	64.4	7.05	521	5.85	0.462	16.7	105	6.98	33.4	49.8	19.3	13.2
1093	65.0	7.54	536	6.02	0.475	17.4	106	7.03	34.5	51.8	19.6	13.4
1094	70.2	7.09	573	6.17	0.543	17.9	113	7.73	35.6	52.1	21.9	14.3
1095	76.8	7.82	626	6.93	0.605	20.8	124	8.34	39.9	57.7	23.1	15.9
1096	66.8	6.53	543	6.52	0.495	18.0	110	7.08	34.2	51.0	19.8	14.0

Sample nr	Al (g/kg)	As (mg/kg)	Ba (mg/kg)	Ca (g/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cs (mg/kg)	Cu (mg/kg)	Fe (g/kg)	K (g/kg)	Mg (g/kg)
1097	66.1	6.62	543	7.04	0.663	18.9	108	7.38	33.2	51.1	19.8	14.1
1098												
1099	60.3	5.31	493	8.31	0.746	19.0	101	6.36	35.3	46.2	18.8	13.5
1100	57.7	6.12	463	6.16	0.445	15.8	99.0	6.18	30.5	46.4	17.0	12.3
1101	65.5	7.45	542	6.99	0.572	18.4	109	6.93	36.7	53.4	18.8	14.0
1102	61.7	7.10	506	7.01	0.679	18.3	105	6.82	34.1	49.8	18.2	13.2
1103	55.1	6.12	441	6.61	0.445	15.6	95.9	5.77	30.5	45.9	16.0	12.1
1104	14.7	3.61	102	4.78	0.333	8.05	32.5	1.14	10.5	16.1	4.40	3.52
1105	56.0	6.01	449	6.96	0.565	16.6	97.7	5.87	30.4	46.8	16.5	12.3
1106	52.5	5.83	413	6.67	0.411	15.6	94.9	5.52	28.6	44.3	14.8	11.8
1107	26.9	3.64	216	9.79	0.502	10.4	56.2	2.59	17.0	22.6	7.91	5.98
1108	52.9		440	7.49		15.7	96.5		28.5	42.0	15.6	11.8
1109	54.3	5.49	426	6.56	0.399	15.0	96.9	5.58	27.3	43.3	16.0	12.0
1110	50.2	4.91	392	6.97	0.402	14.8	93.0	5.15	26.0	40.5	14.6	11.3
1111	51.9	4.64	423	7.60	0.649	15.7	94.9	5.26	29.4	43.4	14.9	11.9
1112	46.0	4.65	355	6.63	0.377	13.4	86.9	4.56	24.1	37.7	13.2	10.4
1113	50.6	4.96	397	7.12	0.400	14.1	94.2	5.01	25.7	41.5	14.5	11.3
1114	51.9	4.37	430	6.77	0.535	15.4	96.0	5.23	26.8	42.6	15.0	11.5
1115	42.3	4.85	318	7.46	0.387	13.5	87.5	4.20	23.3	36.9	11.7	9.80
1116	47.4	4.62	361	7.39	0.399	13.7	91.2	4.76	24.9	39.3	13.8	10.7
1117	51.6	4.69	433	10.3	0.672	14.0	89.4	5.39	33.8	37.7	15.9	10.7
1118	25.1	5.24	195	9.26	0.444	9.58	65.5	2.24	22.8	21.9	7.54	5.78
1119	44.9	4.70	357	8.15	0.580	13.5	91.5	4.67	35.4	38.8	13.2	10.4
1120	29.5	6.00	237	7.88	0.530	12.8	66.7	2.78	18.2	29.3	8.51	6.66
1121	55.5	7.96	449	6.36	0.622	13.6	92.5	6.09	60.3	44.7	17.6	11.4
1122	48.3	7.13	380	9.02	0.849	14.9	83.6	5.35	62.7	39.5	15.1	10.3

Sample nr	Mn (g/kg)	Na (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Sr (mg/kg)	V (mg/kg)	Zn (mg/kg)	Hg (mg/kg)
1001	0.412	334	20.1	13.5	42.0	50.6	88.9	0.0369
1002	0.803	672	51.7	25.8	58.0	118	196	0.0964
1003	1.10	759	58.2	26.2	57.5	145	206	0.0994
1004	1.04	809	59.6	27.6	59.1	151	217	0.0999
1005	1.01	778	60.4	27.1	65.4	142	227	0.110
1006	0.679	692	41.5	18.1	59.2	90.7	125	0.0634
1007	0.520	739	53.6	27.3	67.5	106	193	0.125
1008	1.48	694	56.6	28.6	62.7	125	219	0.117
1009	0.803	776	60.0	28.1	61.2	141	214	0.101
1010	1.04	840	61.3	27.9	60.6	150	221	0.106
1011	1.10	880	57.1	26.7	59.3	142	209	0.102
1012	0.769	712	47.3	23.7	62.9	115	184	0.0868
1013	0.815	578	35.5	19.5	57.2	85.1	138	0.0673
1014	0.590	423	21.6	11.4	42.5	50.1	85.7	0.0515
1015	0.860	749	55.9	25.9	57.1	143	204	0.0983
1016	0.936	814	59.1	27.1	59.0	151	212	0.0996
1017	0.752	834	54.8	25.4	59.0	138	202	0.0893
1018	0.746	791	55.6	25.7	63.6	138	201	0.0946
1019	1.20	707	55.4	27.6	64.1	122	207	0.103
1020	0.866	722	52.5	25.5	61.3	127	204	0.0928
1021	0.859	696	48.8	22.8	65.7	115	176	0.0750
1022	0.748	786	57.9	27.2	60.0	143	212	0.0991
1023	0.842	770	60.1	28.2	58.3	144	217	0.106
1024	0.913	826	57.5	26.6	59.8	144	205	0.0992
1025	0.745	728	50.0	23.9	59.9	120	184	0.0883
1026	0.704	502	35.6	18.5	45.7	84.1	126	0.0562
1027	1.21	663	50.7	25.2	61.8	109	199	0.101
1028	0.821	727	56.6	27.2	57.4	133	207	0.0989
1029	0.900	788	62.6	30.2	64.0	143	226	0.110
1030	1.43	772	62.2	30.5	59.4	129	239	0.124
1031	0.882	632	44.8	22.4	58.6	96.7	161	0.0751
1032	0.688	653	41.9	21.0	64.1	89.4	153	0.0706
1033	0.416	754	40.6	14.7	47.5	79.3	85.4	0.0195

Sample nr	Mn (g/kg)	Na (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Sr (mg/kg)	V (mg/kg)	Zn (mg/kg)	Hg (mg/kg)
1034	0.813	797	60.1	27.9	59.5	143	217	0.103
1035	0.770	754	58.4	27.2	60.4	130	210	0.0965
1036	0.641	724	47.2	20.6	68.3	98.3	169	0.103
1037	1.02	684	54.7	26.0	62.7	120	206	0.0950
1038	0.948	765	61.3	28.4	60.0	140	224	0.106
1039	0.789	713	57.3	31.2	63.8	112	228	0.137
1040	1.07	722	61.9	29.9	60.1	137	233	0.124
1041	0.829	801	60.2	28.2	59.5	150	216	0.103
1042	1.33	721	59.9	28.6	63.2	129	229	0.110
1043	0.860	746	58.5	27.8	59.8	135	223	0.106
1044	0.809	822	60.7	28.7	60.5	147	218	0.102
1045	0.813	808	64.4	31.6	59.4	151	241	0.117
1046	0.840	780	63.5	30.8	61.0	147	239	0.114
1047	0.791	739	61.2	29.9	59.7	134	226	0.109
1048	1.04	793	64.0	30.6	63.3	141	236	0.126
1049	1.21	773	60.6	30.1	62.2	134	232	0.118
1050	0.918	790	62.7	30.6	60.8	144	240	0.116
1051	0.794	794	63.6	31.0	58.1	153	234	0.111
1052	1.08	818	63.8	31.5	61.6	149	239	0.116
1053	1.02	768	64.2	32.1	62.0	141	244	0.122
1054	0.880	791	64.7	31.1	58.9	146	241	0.121
1055	1.15	758	64.4	32.0	62.8	136	246	0.131
1056	1.88	711	61.9	32.0	63.9	128	241	0.135
1057	1.14	695	61.9	33.1	59.7	131	242	0.129
1058	1.44	775	61.6	32.9	62.8	136	243	0.125
1059	0.669	539	35.6	20.0	52.8	78.9	153	0.0913
1060	0.855	767	58.7	27.2	56.3	145	209	0.101
1061	1.17	839	59.3	28.8	57.4	149	221	0.108
1062	0.772	791	61.4	29.4	62.7	150	225	0.106
1063	1.16	648	50.8	27.2	59.3	106	192	0.106
1064	0.856	710	60.1	30.1	60.8	131	225	0.111
1065	1.12	799	59.5	28.8	56.8	143	217	0.110
1066	1.33	812	63.8	30.2	59.3	153	227	0.109
1067	1.00	782	60.7	29.7	57.7	144	219	0.103

Sample nr	Mn (g/kg)	Na (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Sr (mg/kg)	V (mg/kg)	Zn (mg/kg)	Hg (mg/kg)
1068	0.740	663	53.9	28.3	56.6	121	197	0.0944
1069								
1070	0.974	720	55.3	26.8	59.9	123	199	0.0923
1071	1.09	715	56.4	27.5	56.0	129	202	0.0981
1072	1.05	811	61.2	29.3	56.5	150	216	0.101
1073	1.34	847	61.6	28.7	55.0	147	222	0.112
1074	0.935	775	61.9	29.2	56.8	143	218	0.108
1075	1.38	636	56.0	30.7	61.3	111	222	0.127
1076	0.897	721	63.1	31.0	64.1	141	227	0.115
1077	1.10	778	61.3	29.3	57.4	149	217	0.108
1078	1.25	804	61.5	28.8	56.4	147	219	0.112
1079	1.05	739	53.9	26.5	53.8	129	194	0.0974
1080	0.665	619	49.4	25.3	58.6	114	180	0.0848
1081	0.563	573	39.3	21.5	56.3	93	142	0.0653
1082	1.13	764	54.2	25.8	55.3	136	193	0.0952
1083	1.19	822	53.8	25.9	50.2	138	197	0.100
1084	0.986	740	62.6	29.6	57.8	144	222	0.114
1085	0.410	421	17.8	11.5	51.0	42.7	45.8	0.0507
1086	0.890	674	44.9	22.3	58.4	103	164	0.102
1087	0.900	854	64.7	30.4	58.8	159	229	0.113
1088	1.34	821	59.0	28.1	56.4	150	211	0.107
1089	0.978	803	57.9	28.5	61.8	150	208	0.103
1090	0.636	592	41.1	22.0	74.8	93.4	147	0.0737
1091	1.097	749	62.6	31.8	63.9	145	235	0.128
1092	0.862	759	58.3	29.4	57.4	146	209	0.103
1093	1.053	832	59.7	29.4	59.3	147	216	0.107
1094	0.825	812	64.3	31.6	61.1	157	226	0.110
1095	0.945	855	71.7	35.8	67.1	171	255	0.124
1096	0.858	781	61.0	30.2	62.7	150	219	0.110
1097	1.233	733	62.4	33.9	63.8	142	237	0.134
1098								
1099	1.245	725	61.7	32.5	60.7	133	227	0.151
1100	0.757	770	54.0	27.4	57.6	132	195	0.0993
1101	0.967	774	63.5	31.4	65.4	143	233	0.112

Sample nr	Mn (g/kg)	Na (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Sr (mg/kg)	V (mg/kg)	Zn (mg/kg)	Hg (mg/kg)
1102	1.399	735	63.0	31.8	61.8	133	236	0.124
1103	0.748	826	54.8	25.8	59.3	123	194	0.0902
1104	0.301	437	20.3	12.6	28.5	40.4	64.7	0.0462
1105	1.244	699	55.3	28.1	62.0	122	209	0.123
1106	0.714	745	53.4	25.7	59.7	117	184	0.0867
1107	0.600	483	28.5	17.2	50.8	61.2	102	0.0798
1108	1.027	685	55.3	26.8	61.4	113	210	0.128
1109	0.674	682	51.8	24.7	59.5	119	178	0.0825
1110	0.660	649	48.7	24.0	61.9	110	170	0.0831
1111	0.990	640	55.3	28.7	63.0	111	210	0.165
1112	0.599	602	45.9	21.9	58.0	102	163	0.0818
1113	0.678	640	48.9	23.6	62.4	111	171	0.103
1114	1.061	681	53.6	26.2	58.1	114	193	0.104
1115	0.588	661	42.5	22.1	60.8	94.2	150	0.0644
1116	0.671	651	45.9	22.8	61.7	105	167	0.0806
1117	0.788	800	53.0	24.2	66.9	118	192	0.105
1118	0.598	631	30.2	14.1	63.4	65.1	118	0.0688
1119	0.824	853	46.0	27.8	63.4	102	209	0.267
1120	0.70	489	31.5	20.1	56.8	77.9	132	0.0518
1121	0.561	1154	56.9	27.0	50.8	134	234	0.146
1122	0.416	1201	57.1	28.0	61.4	121	251	0.174

Appendix 6: Table with the values for the Certified Reference Material.

Green: the values that are within the value of the CRM and its uncertainty (good accuracy); **yellow**: the values that differs with x 2 the uncertainty (satisfying); **red**: values that are within the value were the uncertainty is x 3 or more (not satisfying). **i**= indicated value, not certified.

CRM	sediment	Al (g/kg)	As (mg/kg)	Ba (mg/kg)	Ca (g/kg)
River Sediment	Average (n=5)	33	25 ± 0.69	340 ± 10.3	23 ± 0.71
	CRM content		24 ± 3.2		
Estuarine Sediment	Average (n=2)	38	9.5	130	5.5
	CRM content	62.5 ± 2.0	11.6 ± 1.3		8.3 ± 0.3
Mess 1	Average (n=2)	33	9.4	140	3.0
	CRM content	58.3 ±20	10.6 ± 1.2		4.81 ±0.46
Best 1	Average (n=2)	64.5	19.8	740	15
Bcss 1	Amount (n=1)	38	9.5	150	4.5
	CRM content	62.6 ±2.2	211 ± 11		5.43 ±0.5

CRM	sediment	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cs (mg/kg)
River Sediment	Average (n=5)	2.9 ± 0.08	12	120 ± 3.17	5.5 ± 0.11
	CRM content	2.7 ± 0.3		84 ± 9.4	
Estuarine sediment	Average (n=2)	0.35	8.7	68	3.2
	CRM content	0.36 ± 0.07	18 ± 3	76 ± 3	3.7 i
Mess 1	Average (n=2)	0.64	10	63	3.3
	CRM content	0.59 ± 0.10	10.8 ± 1.9	71 ± 11	
Best 1	Average (n=2)	0.24	13	90.1	7.2
Bcss 1	Amount (n=1)	0,25	11	100	3,1
	CRM content	1,25 ± 0,04	17,5 ±1,1	123 ± 14	

CRM	sediment	Cu (mg/kg)	Fe (g/kg)	K (g/kg)	Mg (g/kg)
	Average (n=5)	83 ± 1.63	27 ± 0.85	7.3 ± 0.25	5.3 ± 0.076
River Sediment	CRM content	83.6 ± 4.1	23.6 ± 1.5		
	Average (n=2)	15	31	9.9	10
Estuarine Sediment	CRM content	18 ± 3	33.5 ± 10	14 i	10.9 ± 0.8
	Average (n=2)	21	28	9.3	7.7
Mess 1	CRM content	25.1 ± 3.8	30.5 ±1.7	18.5 ±0.3	8.7 ±0.5
	Average (n=2)	35	41	19	16
Best 1					
	Amount (n=1)	14	31	12	13
Bcss 1	CRM content	452 ± 16	32.9 ±0.1	18 ±0.3	15.4 ±0.14

CRM	sediment	Mn (g/kg)	Na (g/kg)	Ni (mg/kg)	Pb (mg/kg)
	Average (n=5)	1.3 ± 0.023	0.59 ± 0.018	39 ± 0.73	81 ± 3.9
River Sediment	CRM content	1.24 ± 0.06		34.7 ± 1.7	77.2 ± 4.5
	Average (n=2)	0.3	10	28	22
Estuarine Sediment	CRM content	0.375 ± 0.02	20 i	32 ± 3	28.2 ± 1.8
	Average (n=2)	0.44	6.c2	26	28
Mess 1	CRM content	0.513 ±0.025	18.7 ±1.1	29.5 ± 2.7	34 ± 6.1
	Average (n=2)	0.34	11	47.2	21
Best 1					
	Amount (n=1)	0.21	7.7	52	20
Bcss 1	CRM content	0.229 ± 0.015	20.1 ± 0.16	44.1 ± 2.0	22.7 ± 3.4

CRM	sediment	Sr (mg/kg)	V (mg/kg)	Zn (mg/kg)	Hg (mg/kg)
	Average (n=5)	120 ± 2,9	58 ± 1,8	470 ± 10	1,4 ± 0,06
River Sediment	CRM content		38.3 ± 6.5	439 ± 26	1.4 ±0.1
	Average (n=2)	44	66	127	0,089
Estuarine Sediment	CRM content		94 ± 1	138 ± 6	0.063 ± 0.012
	Average (n=2)	37	55	180	0.19
Mess 1	CRM content		72.4 ± 17	191 ± 17	
	Average (n=2)	84	190	160	0.096
Best 1					0.092 ±0.009
	Amount (n=1)	37	69	110	0.24
Bcss 1	CRM content		93.4 ± 4.9	119 ± 12	

Appendix 7: Table with the regression analysis.

The element is the response and Clay, Depth and LOI are the variables. 95 % confidence interval

El	Regression equation	R-sq	n	p	Source
Al	Al= 18.1 + 0.759 Clay - 0.143 Depth - 0.0571 LOI	93.4	59	Const=0.000 Clay=0.000 Depth=0.739 LOI=0.008	Clay=5884.1 Depth=5.6 LOI =57.2
As	As= 0.967 + 0.0615 Clay + 0.560 Depth + 0.00706 LOI	68.9	59	Const=0.099 Clay=0.000 Depth=0.000 LOI=0.316	Clay=90.227 Depth=12.547 LOI=0.874
Ba	Ba= 123 + 6.62 Clay+ 0.03 Depth - 0.458 LOI	93.8	59	Const=0.000 Clay=0.000 Depth=0.979 LOI=0.017	Clay=459273 Depth=1093 LOI=3364
Ca	Ca= 8.70 - 0.474 Depth - 0.0314 Clay + 0.0207 LOI	36.5	59	Const=0.000 Depth=0.018 Clay=0.059 LOI=0.033	Depth=40.545 Clay=1.572 LOI=7.509
Cd	Cd= 0.352 + 0.00608 Clay - 0.0753 Depth + 0.000718 LOI	53.5	59	Const=0.000 Depth=0.000 Clay=0.000 LOI=0.259	Clay=0.09915 Depth=0.33051 LOI=0.00903
Co	Co= 9.03 + 0.168 Clay % - 0.376 Depth - 0.0261 LOI	84.8%	59	Const=0.000 Clay=0.000 Depth=0.007 LOI=0.000	Clay=216.583 Depth=1.247 LOI=11.970
Cr	Cr= 53.3 + 0.941 Clay % - 1.16 Depth - 0.0914 LOI	82.4	59	Const=0.000 Clay=0.000 Depth=0.187 LOI=0.036	Clay=7983.6 Depth=8.0 LOI=146.5
Cs	Cs= 1.42 + 0.0815 Clay + 0.0180 Depth - 0.00289 LOI	89.8	59	Const=0.000 Clay=0.000 Depth=0.766 LOI=0.330	Clay=73.029 Depth=0.089 LOI=0.147
Cu	Cu= 3.39 + 0.321 Clay- 0.226 Depth + 0.166 LOI	88	59	Const=0.026 Clay=0.000 Depth=0.540 LOI=0.000	Clay=1645.95 Depth=129.90 LOI=482.46
Fe	Fe= 18.2 + 0.542 Clay+ 0.159 Depth - 0.0519 LOI	92.2	59	Const=0.000 Clay=0.000 Depth=0.643 LOI=0.003	Clay=3074.6 Depth=17.5 LOI=47.3

El	Regression equation	R-sq	n	p	Source
K	K= 5.24 + 0.235 Clay- 0.155 Depth - 0.0166 LOI	89.5	59	Cons=0.000 Clay=0.000 Dept=0.355 LOI=0.047	Clay=539.72 Depth=0.01 LOI=4.80
Mg	Mg= 5.80 + 0.144 Clay- 0.217 Depth - 0.0198 LOI	89.8	59	Const=0.000 Clay=0.000 Depth=0.025 LOI=0.000	Clay=173.533 Depth=0.134 LOI=6.87
Mn	Mn= 0.608 + 0.0148 Clay - 0.111 Depth - 0.00323 LOI	29.8	59	Const=0.000 Clay=0.000 Depth=0.004 LOI=0.076	Clay=0.77016 Depth=0.35331 LOI=0.18301
Na	Na= 361 + 4.77 Clay- 0.72 Depth + 1.82 LOI	59.0	59	Const=0.000 Clay=0.000 Depth=0.839 LOI=0.002	Clay=332410 Depth=21167 LOI=53338
Ni	Ni= 22.3 + 0.729 Clay- 1.89 Depth - 0.0546 LOI	93.5	59	Const=0.000 Clay=0.000 Depth=0.000 LOI=0.003	Clay=4260.6 Depth=102.3 LOI=52.2
Pb	Pb= 13.1 + 0.305 Clay - 1.04 Depth - 0.0115 LOI	77.7	59	Cons=0.000 Clay=0.000 Depth=0.001 LOI=0.446	Clay=713.52 Depth=44.27 LOI=2.33
Sr	Sr= 52.6 +0.199 Clay- 0.474 Depth - 0.0080 LOI	17.5	59	Const=0.000 Clay=0.004 Depth=0.047 LOI=0.831	Clay=150.32 Depth=107.99 LOI=1.02
V	V= 39.1 + 1.53 Clay + 0.448 Depth - 0.0313 LOI	92.6	59	Const=0.000 Clay=0.000 Depth=0.165 LOI=0.540	Clay=28166.3 Depth=157.5 LOI=15.7
Zn	Zn= 69.2 + 2.64 Clay- 7.99 Depth + 0.088 LOI	83.8	59	Const=0.000 Clay=0.000 Depth=0.001 LOI=0.437	Clay=59467 Depth=3804 LOI=136
Hg	Hg= 0.0400 + 0.000983 Clay - 0.00626 Depth + 0.000410 LOI	29.4	59	Const=0.020 Clay=0.006 Depth=0.135 LOI=0.047	Clay=0.0086491 Depth=0.0046855 LOI=0.0029417

Appendix 8: Table of the correlation analysis.

95 % confidence interval. In the upper line is r= Pearson correlation. Under is the p-value significant when $p < 0.05$

	Depth	Al	As	Ba	Ca	Cd	Co	Cr	Cs	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Sr	V
Al	0.670 0.000																		
As	0.651 0.000	0.703 0.000																	
Ba	0.662 0.000	0.995 0.000	0.734 0.000																
Ca	-0.644 0.000	-0.478 0.000	-0.424 0.000	-0.466 0.000															
Cd	-0.391 0.000	0.115 0.215	0.047 0.610	0.1430. 120	0.317 0.000														
Co	0.552 0.000	0.942 0.000	0.690 0.000	0.9400. 000	-0.398 0.000	0.210 0.022													
Cr	0.611 0.000	0.974 0.000	0.633 0.000	0.9640. 000	-0.408 0.000	0.115 0.211	0.935 0.000												
Cs	0.660 0.000	0.991 0.000	0.708 0.000	0.9850. 000	-0.465 0.000	0.112 0.226	0.929 0.000	0.966 0.000											
Cu	0.227 0.013	0.677 0.000	0.633 0.000	0.6820. 000	-0.132 0.150	0.507 0.000	0.000 0.644	0.642 0.000	0.693 0.000										
Fe	0.687 0.000	0.981 0.000	0.755 0.000	0.9790. 000	-0.518 0.000	0.072 0.439	0.950 0.000	0.960 0.000	0.965 0.000	0.643 0.000									
K	0.642 0.000	0.992 0.000	0.713 0.000	0.9890. 000	-0.458 0.000	0.130 0.159	0.925 0.000	0.959 0.000	0.990 0.000	0.696 0.000	0.9630. 000								
Mg	0.614 0.000	0.981 0.000	0.651 0.000	0.9710. 000	-0.450 0.000	0.092 0.320	0.956 0.000	0.977 0.000	0.970 0.000	0.642 0.000	0.9740. 000	0.970 0.000							
Mn	0.206 0.024	0.5590. 000	0.495 0.000	0.5940. 000	-0.219 0.016	0.2440. 008	0.6620. 000	0.5870.0 00	0.5500. 000	0.2560. 005	0.6230. 000	0.543 0.000	0.577 0.000						

Continuation Appendix 8

	Depth	Al	As	Ba	Ca	Cd	Co	Cr	Cs	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Sr	V
Na	0.357 0.000	0.7120. 000	0.662 0.000	0.713 0.000	-0.251 0.006	0.185 0.044	0.645 0.000	0.691 0.000	0.731 0.000	0.874 0.000	0.688 0.000	0.744 0.000	0.691 0.000	0.259 0.004					
Ni	0.501 0.000	0.9600. 000	0.692 0.000	0.961 0.000	-0.365 0.000	0.3090. 001	0.958 0.000	0.946 0.000	0.949 0.000	0.779 0.000	0.946 0.000	0.953 0.000	0.961 0.000	0.589 0.000	0.749 0.000				
Pb	0.399 0.000	0.891 0.000	0.598 0.000	0.890 0.000	-0.293 0.001	0.4260. 000	0.938 0.000	0.893 0.000	0.889 0.000	0.747 0.000	0.882 0.000	0.873 0.000	0.897 0.000	0.633 0.000	0.640 0.000	0.950 0.000			
Sr	-0.007 0.943	0.429 0.000	0.152 0.098	0.421 0.000	0.4280. 000	0.4180. 000	0.477 0.000	0.539 0.000	0.422 0.000	0.438 0.000	0.393 0.000	0.418 0.000	0.471 0.000	0.287 0.001	0.349 0.000	0.513 0.000	0.519 0.000		
V	0.679 0.000	0.989 0.000	0.755 0.000	0.9890. 000	-0.465 0.000	0.1250. 176	0.920 0.000	0.957 0.000	0.988 0.000	0.725 0.000	0.966 0.000	0.990 0.000	0.957 0.000	0.521 0.000	0.765 0.000	0.950 0.000	0.873 0.000	0.411 0.000	
Zn	0.393 0.000	0.903 0.000	0.626 0.000	0.9050. 000	-0.311 0.001	0.4470. 000	0.913 0.000	0.899 0.000	0.896 0.000	0.820 0.000	0.892 0.000	0.889 0.000	0.891 0.000	0.615 0.000	0.737 0.000	0.960 0.000	0.965 0.000	0.538 0.000	0.892 0.000
Hg	0.000 0.998	0.495 0.000	0.327 0.000	0.5000. 000	-0.012 0.893	0.5400. 000	0.537 0.000	0.525 0.000	0.511 0.000	0.705 0.000	0.486 0.000	0.490 0.000	0.502 0.000	0.443 0.000	0.577 0.000	0.608 0.000	0.711 0.000	0.438 0.000	0.493 0.000
LOI	-0.277 0.031	0.203 0.124	0.193 0.143	0.2070. 116	0.2340. 074	0.4440. 000	0.119 0.368	0.182 0.167	0.242 0.065	0.711 0.000	0.163 0.218	0.215 0.102	0.136 0.305	0.062 0.642	0.526 0.000	0.259 0.048	0.303 0.019	0.201 0.126	0.244 0.063
clay	0.6020. 000	0.961 0.000	0.774 0.000	0.9640. 000	-0.395 0.002	0.3480. 007	0.894 0.000	0.899 0.000	0.946 0.000	0.801 0.000	0.950 0.000	0.942 0.000	0.929 0.000	0.419 0.001	0.694 0.000	0.950 0.000	0.854 0.000	0.319 0.014	0.959 0.000

	Zn	Hg	LOI
Hg	0.734 0.000		
LOI	0.397 0.002	0.435 0.001	
Clay	0.887 0.000	0.395 0.002	0.247 0.055

Appendix 9: Table with the concentration of the matals in the bedrock in the region of Lake Årungen.

The total concentration was measured with X-rays, while the acid soluble part was decomposed with a 1:1 HNO_3 solution (Ottesen *et al.* 2000).

Metal	Total concentration	Acid soluble part
Al (%)	12.8 – 13.7	1.62 – 1.74
As (mg/kg)		3 – 3.3
Ba (mg/kg)	591– 624	
Ca (%)	1.57 – 1.75	0.32
Co (mg/kg)	23.8 – 26.6	9.3
Cr (mg/kg)	68.5	24.3 – 26.9
Cu (mg/kg)	16.9	13.6
Fe (%)	5.8	2.2
K (%)	2.63 –3	0.168 – 0.277
Mg (%)	1.74 – 1.91	0.49 – 0.54
Mn (%)	0.071 –0.079	0.023
Na (%)	2.04	0.017 – 0.21
Ni (mg/kg)	33.8 –36	16.1 – 20.1
Pb (mg/kg)	72 – 78	21.2
Sr (mg/kg)	218	26.9 – 29.6
V (mg/kg)	107.1 –111.5	37.9 – 40.1
Zn (mg/kg)	90.5 – 100.7	68 – 74