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Interaction between geosphere and biosphere in lake sediments

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1990-12-18

ABSTRACT

One main issue in the safety assessment of nuclear repositories, is which processes influence the distribution pattern of radionuclide elements in the biosphere when released radioactivity is carried with groundwater that penetrates through the bottom sediment of a lake.

To be able to evaluate the transport of elements such as thorium, uranium, and rare earth elements (REE), sampling of lake sediment cores at different Swedish sites with different degrees of groundwater leakage was performed.

Different lake sediment fractions have been identified. One fraction is related to aluminosilicates (clay and sand contents), while the other major fraction containS organic material.

Enrichment of uranium is observed in areas of groundwater seepage, and U-contents is correlated to the levels of organic matter. Besides a higher mobility and enrichment of uranium compared to thorium is observed.

Chondrite normalised REE sediment contents have been found higher in the most reducing sediments.

The weathering and deposition processes are discussed in connection with the degree of mobility of elements. Elements as titanium, zirconium and hafnium are nearly insoluble in aqueous solutions. The immobility of these elements have been confirmed by this study.

Hafnium is selected to study the differentiation of the sediment fraction originating from refractory and other physically weathered minerals.

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APPENDICES

1 INTRODUCTION

The main object of this project is to assess the long-term distribution and turnover of radionuclides within a lake and to identify any conceivable zones within the ecosystem where enrichment of nuclides in due time may become hazardous to the human population.

According to the most probable scenario, radioactivity from a nuclear waste repository will be transported by groundwater, which will reach the biosphere in discharge areas (through wells, springs, bogs, etc). Radioactive compounds will eventually be transported through water courses and reach a lake, whereupon further dispersion to other parts of the ecosystem will occur. However, one main issue is how the distribution pattern will be changed if the released radioactivity is carried with groundwater that penetrates through the bottom sediment of a lake. In order to provide information on this processes, a preliminary study was performed in a number of lakes where a more or less distinct groundwater flow through the bottom was identified (Sundblad and Evans 1987). The preliminary investigation was focused on recording element distribution in sediment profiles from areas in which such a groundwater seepage occurred, compared to areas in which no flow was detectable. Some of the conclusions reached by Sundblad and Evans (1987) are: U and Ce enrichment in areas of groundwater seepage, a correlation between organic matter (in the sediment materials) and trace element contents, etc.

Studies of the transfer of radionuclides within lake ecosystems have been performed by SKB. Reports from these studies are e.g. Tham et al (1985), Evans (1986), Sundblad (1986) and Sundblad et al (1988). Furthermore, the Cs-137 contents of the sediments in lake Hillesjön, which are reported in these studies, have been used in two different scenarios in the BIOMOVS project (Smith, 1989 and Sundblad, 1990).

The present report will discuss the observed content of about 25 different elements in different types of sediments. Most of the discussion will deal with results from two sites, the springs of Täckhammar and Lake Hillesjön, see Figure 1.1.

The importance of different parameters as pH, redox, water and organic content on the mobility of the elements are discussed.

The use of chondrite normalised REE-pattern as indicator of the sorption/desorption in the sediment is also presented.

The differences in weathering, transport and sorption of elements are discussed outgoing from ratios with elements with very low solubility as e.g. Hf, Zr, Ti and Ta.

Radionuclides carried by the groundwater and penetrating the sediment due to different processes as diffusion or resuspension can be transported from the lake ecosystem. Examples of this kind of turnover are shown in the report.

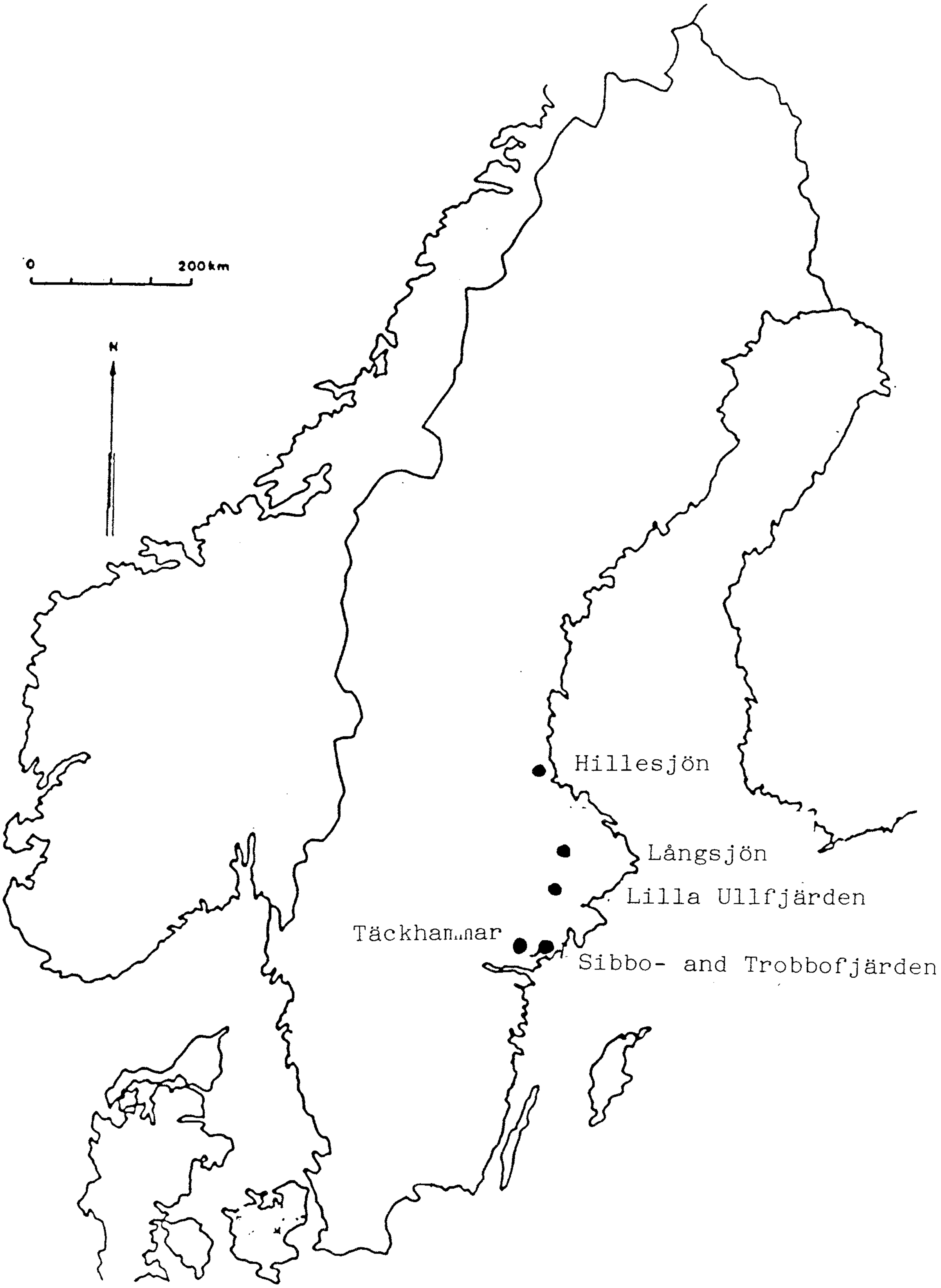

Figure 1.1 Location of the investigated lakes.

2 INTERACTION BETWEEN GROUNDWATER AND SURFACE WATER

Usually a lake is thought of as a part of a surface water ecosystem. However, there is some evidence indicating that groundwater can interact with surface water in lakes by seepage through the sediments. The groundwater flow in the vicinity of a lake can take different paths. This is described by Vanek (1985) and is summarised in Figure 2.1. The lake can either be a discharge lake or a flow-through lake. There is also a third type, called recharge lake, where the lake is drained through the lake bottom. However, this is not applicable to this study.

Other findings from the literature review of Vanek (1985), is that the degree of water exchange between lake and aquifer is primarily determined by geology and hydrogeology. The nature of the lake sediments is usually of minor importance.

Most of the groundwater seepage usually occurs in the near-shore areas and decreases exponentially towards the middle of the lake. This pattern can be changed if there are fracture zones in contact with the bottom sediments.

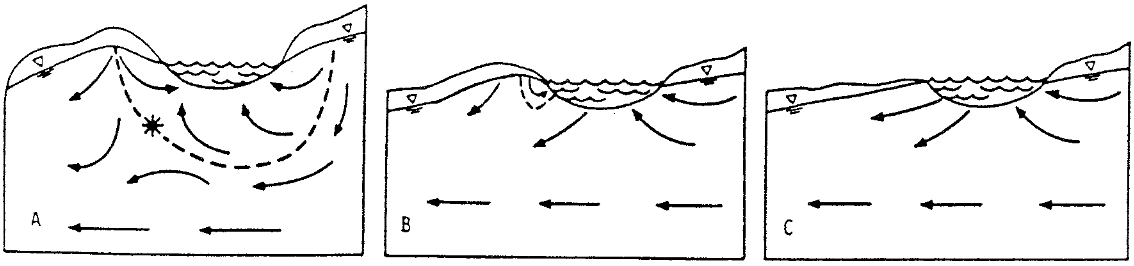

Figure 2.1 Groundwater flow path in the vicinity of a discharge lake (A) and flow-through lake (B, C). Asterisk shows the location of the stagnation point and the dashed line shows the location of the groundwater divide separating the shallow flow system from a deeper system (from VANEK, 1985).

3.5 SITE DESCRIPTIONS

3.1 LAKE HILLESJÖN

In the semi-eutrophic Lake Hillesjön, the temperature recordings showed (Sundblad and Evans, 1987) that a pronounced groundwater flow occurred through the bottom close to the shore-line, where an esker limits the lake's further extension westwards (Figure 3.1). The bottom consists of loose sediments rich in organic matter. Sediment cores were taken in the region where groundwater seepage was observed as well as in non-seepage areas, see Figure 3.1. Groundwater discharges in the shore of lake Hillesjön in several places. Spring A is enclosed in a cement pipe, and shows clear signs of human influence. The water flow is localized and allowed a water sample to be taken (Table B.4). Spring B consists of a diffuse discharge of groundwater into the surface of the lake shore. Brown precipitates appear in the surface of locations where the groundwater flow is higher and locally limited. A sample of such precipitate was taken and analysed (Table A.6). These are situated on the shore where the groudwater penetrates the sandy esker material.

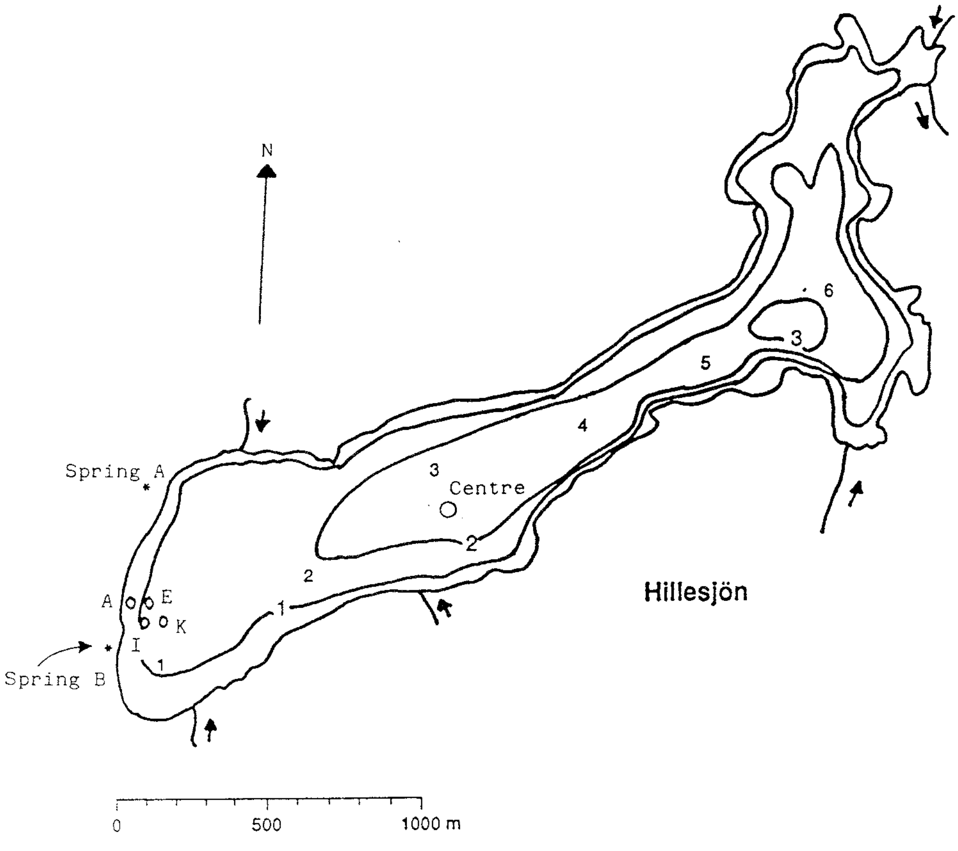

Figure 3.1 Map of Lake Hillesjön with sampling sites A, E, I and K.

3.2 LAKE LÅNGSJÖN

Lake Långsjön, see Figure 3.2, is supported with groundwater to about 50 %. This groundwater emanates from a boulder-ridge which is in direct communication with the lake. Some groundwater veins are also supposed to exist at the edge of the shore, according to Forsberg and Ryden (1979).

The two sampling sites are shown in Figure 3.2. The site L1/2 is the reference site with no observed groundwater seepage. The other site L3/4 is situated in the area were groundwater seepage i detected. However the seepage through the sediment is patchy.

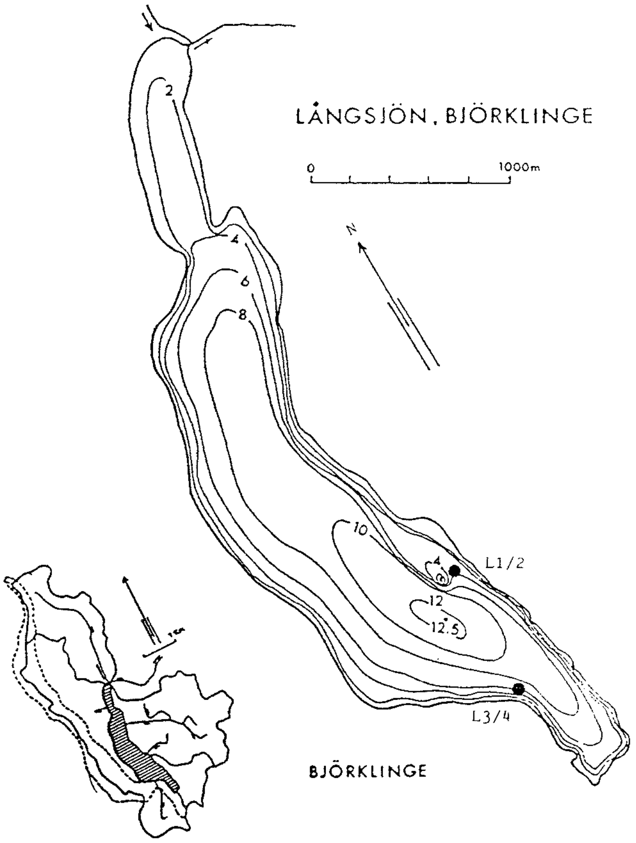

Figure 3.2 Map of Lake Långsjön.

3.3 LAKE ULLFJÄRDEN

Lake Ullfjärden constitutes the southernmost part of system of bays which is connected to Lake Mälaren (Figure 3.3). An increased eutrophication during the past 80 years has caused a change towards seasonal oxygen depletions and the subsequent formation of laminated bottom sediments. Enrichments of P, Fe and Mn occur in the sediment within a depth interval of 5 - 20 m, indicating a discharge of oxygen-poor groundwater from the boulder that runs parallel to the western edge of the lake. No sediment profiles have been collected by us in this area; analyses have instead been performed on material collected earlier by the Department of Physical Geography, Uppsala University.

The site 1265 is situated in the seepage zone, while site 1263, see Figure 3.3, is in the non-seepage part of the lake.

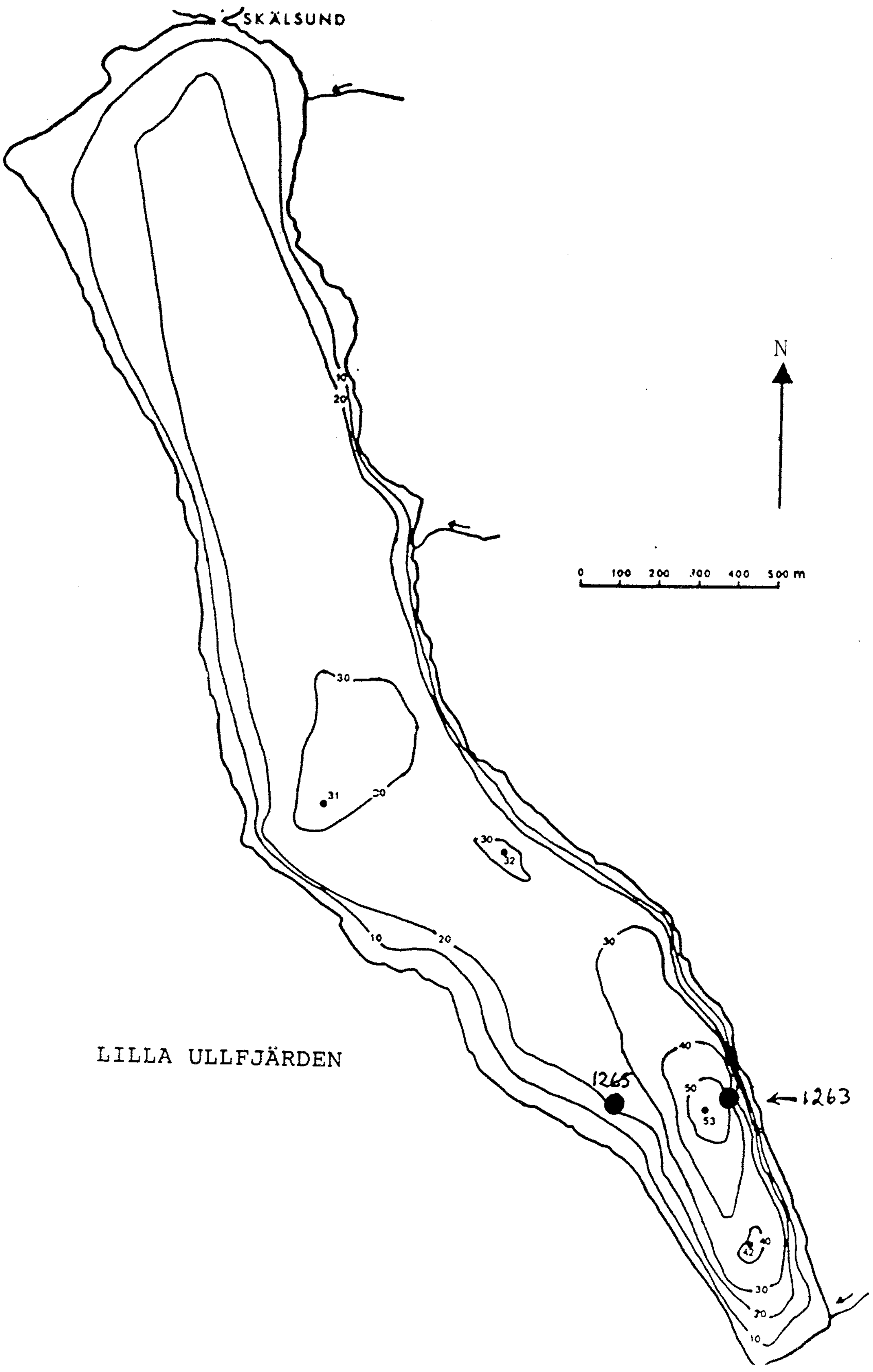

Figure 3.3 Map of Lake Lilla Ullfjärden with sampling sites Nos. 1263 and 1265.

3.4 TÄCKHAMMAR

Täckhammar is situated at the southern shore of Lake Långhalsen, see Figure 3.4. This lake belongs to the drainage area of Nyköpingsån, with an outlet about 10 km north of the town of Nyköping.

In 1858 the threshold of the outlet of the lake was lowered about two meters. Thus, former lake bottom became land area. The area at Täckhammar is partly a discharge area with springs. Thus these springs earlier had their outlet at the lake bottom. Nowadays there are two main springs in Täckhammar, called in this report "oxic" and "anoxic" spring, respectively. The "oxic" spring is located near the mansion, it consists of groundwater discharging in several holes in the bottom of a kidney-shaped pond (about 10x15 m in diameter and a depth of 1 m). The bottom of the pond is made up by loose gray clay, with no vegetation or organic material. The water is discharged through a small waterfall into another pond, and finally through a small creek into the lake Långhalsen.

The "anoxic" spring is located nearer to the lake (about 100 m North-East of the "oxic" spring). It is formed by groundwater emanating through a hole in the bottom of a little pond (about 2 m wide, 0.2 m deep). The sediment in the pond is completely covered by dark coloured algae, occasionally coloured brown or orange (suggesting Fe/Mn-hydroxide precipitation). The pond is discharged through a small creek that joins the creek originating from the "oxic" spring, before the waters reach lake Långhalsen.

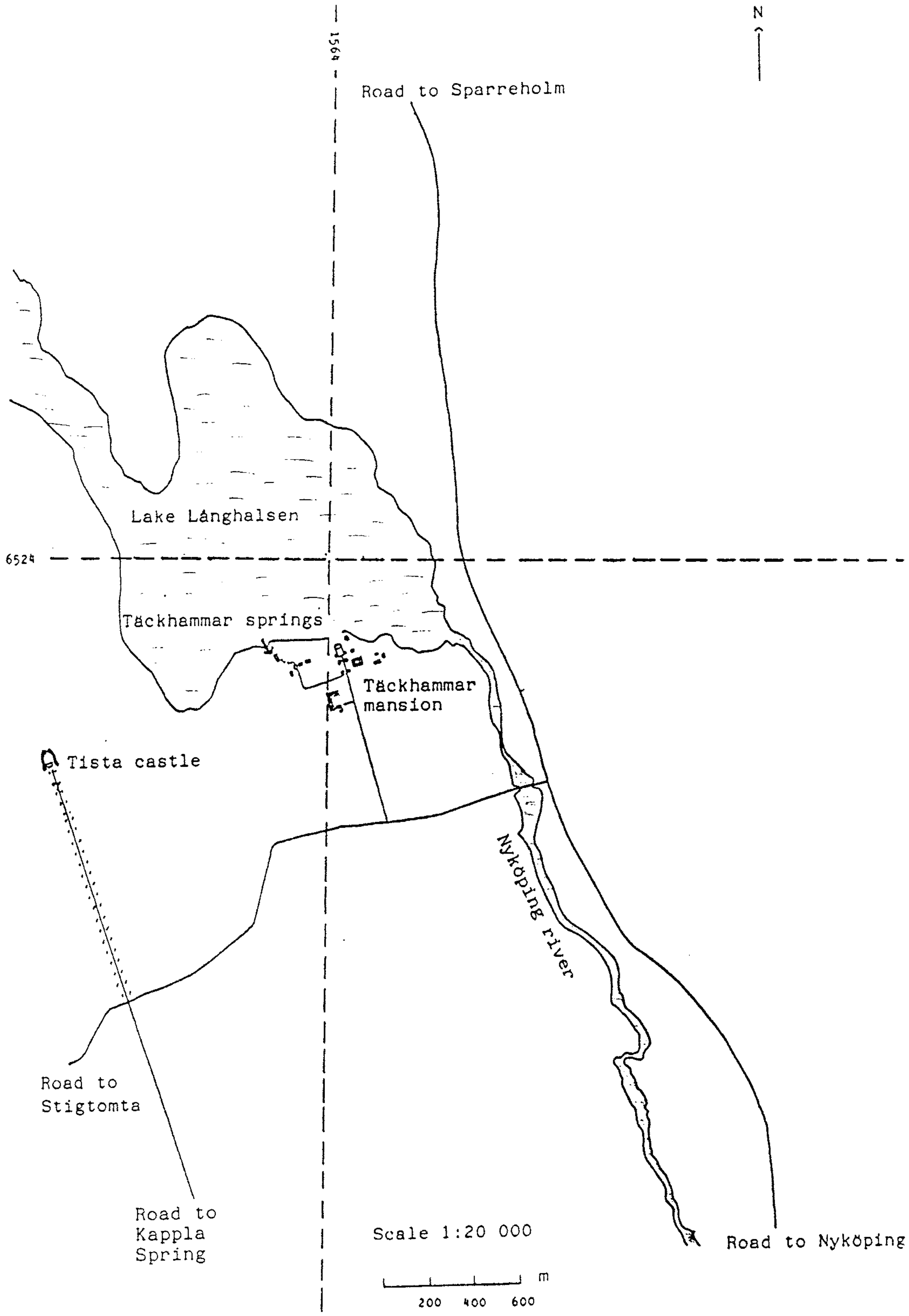

Figure 3.4 Map of Täckhammar.

3.5 OTHER LAKES

The data collected in this study are compared with sediment analysis from lakes in the Studsvik area (c.f. Section 5.4). These lakes (Sibbo- and Trobbofjärden, Stora Frillingen, Käxlan) do not show any evidence of groundwater discharge. Sediment and water analysis from these lakes are reported by Sundblad (1986) and Andersson (1987).

3.6 GEOLOGY

3.6.1 The Lake Hillesjön

The description following below is taken from a SGU publication (Lundqvist, 1963) which includes both map-sheet 98 Gävle and 97 Falun.

Topography

Below the highest coastline young sediments (clay and silt) exist. The coastal plain is of precambrian age (probably prejotnian age), about 1200 millions years old.

Bedrock

The most common bedrock within the county of Gävleborg is gneissic granite. The structure of the rock is often characterised of sediment gneiss rich in mica.

The basin of the bay of Gävle consists mainly of precambrian rocks. Younger bedrock is represented of sandstone, diabase, eruptive rocks and young breccias with cement of quarts.

Quaternary deposits - Moraine

The most common type of soil within the county of Gävleborg is moraine. Normally, the blocks are made up of normal size. They are irregular and not assorted.

Within the map-sheet of Gävle the moraine is sandy (sandy-silty towards the west). In the coastal area it is swelled and rinsed out. Normal size of the blocks is most common. The composition of the stones and blocks in the moraine varies. Locally the Dala sandstone may constitute up to 89 %, and amphibolite up to 57 %.

Glacifluvial sediments

Boulder ridges, glacifluvial deltas and kames occur within the map-sheet. The material in the glacifluvial sediments varies from big boulders to medium-sized sand, and it has been stratified several times.

Within the map-sheet three boulder ridges occur; namely the ridge of Möklinta (Möklintaåsen), the ridge of Gävle (Gävleåsen) and the ridge of Enköping (Enköpingsåsen).

Swelled gravel and sand

The swelled gravel and sand above the highest coastline is less rinsed compared with the material below the highest coastline.

Below the highest coastline swelled moraine and gravel occur. The swelled gravel is similar to the glacifluvial gravel, it consists mainly of sand and gravel, and occurs everywhere below the highest coastline.

Within the map-sheet most of the material is swelled.

Fine-grained sediments

The soil-types that occur within the county are sandy soil, silt and clay. Sandy soil is found in association with glacifluvial sand. Silt is not so common in the coastal area as in the inland. Clay is found throughout the county at lower levels, but it dominates in the coastal area.

Within the map-sheet clay dominates, but silt and sandy soil may as well be found. In the south-east area of the map clay dominates, and in the south-west area clay and sandy soil are most common. Sandy soil and silt are more common in the inland than in the coastal regions. Sandy soil is the most widespread find-grained sediment within the map-sheet. Fine-grained sediments may as well be glacial as postglacial.

Summary - Lake Hillesjön

The bedrock around the lake Hillesjön is made up of grey gneiss rich in mica and garnet, altered schist, greywackes and tuff. South of the lake quartzite and feldspar-quartzite occur together with altered sandstone and arkoses. The bedrock north and west of the lake consists of rocks similar to arkoses (probably altered acid gneissic granite). The quaternary deposits consist of sandy moraine with bigger blocks, peat and marsh-land. Southwest of the lake clay dominates and in the west a boulder ridge, which consists of glacifluvial gravel, defines the extension of the lake.

3.6.2 Täckhammar and Långhalsen

The following description is taken from SGU publications (Lundström, 1974, with map-sheet; SGU, 1972).

Bedrock

The bedrock at the springs of Täckhammar and south-east of the lake Långhalsen consists of red and grey, strongly deformed gneissic granite. Homogenously distributed quartz-feldspar material with biotite strings is common as well as strings of gneiss of sedimentary origin.

The area south of the lake is covered with soil, and the bedrock is poorly known.

At the south-east corner of the lake the bedrock is made up of deformed gneiss with biotite strings. Quartz and feldspar are common minerals. Minor occurrence of gneissic granite has been found. The components of the bedrock are strongly mixed and recrystallised.

The bedrock south-west of the lake consists of leptite, limestone and skarn. The rocks show decimetre to metre-thick layers of amphibolites. Dikes of gneissic granite are common. The area is characterised of massive granite.

Quaternary deposits

The area around the springs of Täckhammar is made up of postglacial fine sand.

Varved clay dominates south-west of the springs, and towards the east the soil is composed of varved silt with layers of clay and varved clay with layers of silt, postglacial coarse-grained clay and, further east, varved silt with layers of clay and varved clay with layers of silt. To the west of the springs slimy clay dominates.

The area east of the springs consists of varved silt with layers of clay and varved clay with layers of silt. Further east postglacial coarse grained clay occurs abundantly.

4 SAMPLES AND METHODS

4.1 SEDIMENTS

The sediment core sampler used had a diameter of 69 mm. Immediately after collection of the sediment core, it was sliced into different layer thicknesses of one to five centimetres. The collected cores from the three sites are listed in Table 1 below.

Table 1 Core characteristics.

Lake	Site	Water depth m	Core length m
Hillesjön	A	1.25	0.35
"	E	0.80	0.50
"	I	1.50	0.25
"	K	0.95	0.35
"	Middle	1.85	0.45
"	Spring B	-	0.01
Långsjön	L1/2	7.5	0.35
"	L3/4	4.5	0.35
Lake Ullfjärden	1265	22	0.20
"	1263	48	0.45
Täckhammar	Oxic spring, centre	-	0.25
"	Oxic spring, border	-	0.15
"	Oxic spring, soil	-	0.10
"	Anoxic, North	-	0.15
"	Anoxic, South	-	0.20
"	Oxic spring	-	0.15
"	Anoxic spring	-	0.15
"	Lake	1	0.15

The samples were dried at 75 °C and ashed at 450 °C. These analyses gave the water and the organic content.

By gamma-ray spectrometry measurements K-40, Ra-226, Ra-228 and Th-228 have been determined in Studsvik. These measurements gave also radionuclide contents from the Chernobyl fallout such as Ru-106, Ag-110m, Sb-125, Cs-134, Cs-137 and Ce-144. These were mainly found in the top layers of the cores.

The concentration of Th, U and an additional number of elements were analysed by Instrumental Neutron Activation

Analysis (INAA) in Studsvik. The elements were Al, As, Ba, Br, Ca, Co, Cr, Cs, Fe, Hf, Mg, Mn, Mo, Na, K, Rb, Sc, Ta, Te, Th, U, Zn and Rare Earth Elements as La, Ce, Nd, Sm, Eu, Tb, Dy, Yb and Lu.

Sediment pore waters were sampled after centrifugation (90 minutes at 17000 rpm) and send for ICP analysis to Lennart Månson International (Helsingborg).

4.2 WATER CHEMISTRY

Water samples from the Täckhammar area were taken March 17 and 29, 1988, and from the Hillesjön site on April 18, 1989. These samples were send for analysis both to Lennart Månson International (Helsingborg), for ICP analysis (inductively coupled plasma spectrophotometry), and to Statens Lantbrukskemiska Laboratorium (Upp~~sa~~la) in bottles supplied (and prepared) by that laboratory.

Another sampling was performed in the Täckhammar area on May 5, 1989. The water samples where this time filtered in the field through 0.4µm filters, and immediately introduced in plastic bottles. The samples that had to be analysed for Fe^{2+} and metal contents where introduced into plastic bottles that already contained HCl in order to prevent Fe(II) oxidation, and metal precipitation. Samples to be analysed for sulphide were introduced in glass bottles, zinc acetate and sodium hydroxide was added, and air excluded. Samples were sent the same day to be analysed the next day for Fe-tot, Fe(II) (ferrozine colorimetry), and anions in SKB's mobile laboratory (Almén et al, 1986). Other samples were send to the Department of Inorganic Chemistry of the Royal Institute of Technology at Stockholm for analysis with inductively coupled plasma spectrophotometry (ICP) for Na, Ca, Mg, Fe-tot, Mn, Si, Al, Sr, K, Li and rare earths, and uranium analysis with fluorimetric spectrophotometry (Scintrex).

4.3 pH AND REDOX FIELD MEASUREMENTS

A mobile, battery operated, equipment from Swedish Geological Co. was tested for the field measurements. This equipment is designed to be used at a depth of several hundred meters in SKB's boreholes in granitic bedrock. During our field measurements, it was found that due to its size and special design the equipment is not convenient for pH and Eh monitoring in shallow lakes and springs.

After some search, it was decided to use a portable, battery operated pH meter (Radiometer PHM29), together with combination pH and Pt electrodes (Sensorex, Stanton, California). These electrodes where mounted at the end of plastic tubes, which protected a coaxial cable and connections. This made possible both to submerge the electrodes a couple of meters into the emerging water flow of the springs, as well as into sediments. Before each field measurement, the electrodes where calibrated with standard pH-buffers (from Radiometer) and saturated benzoquinhydrone solutions (Bates, 1964).

The difficulties associated with redox measurements of natural systems are well known (Stumm, 1984; Lindberg and Runnells 1984). In sulphidic or iron rich environments, the Eh values reflect redox properties of the natural waters. In diluted, poorly poised, and oxygen contaminated samples, the Eh values drift for long periods of time. The Eh measured in this work have therefore the uncertainties which are normally associated with this type of studies, and should be regarded as qualitative indicators.

5 RESULTS

The preliminary study (Sundblad and Evans, 1987) was mainly focused on how the element composition of the solid sediment was affected by discharging groundwater. Totally 55 sediment samples were studied and for each sample about 35 parameters were analysed. Comparison was made with sediment that was not or to a very little extent influenced by groundwater seepage.

In this study, more sediment samples have been collected, and sediment pore waters have been extracted. Furthermore, water samples have been analysed, and both pH, and Eh measured in the field. Most of the data collected in this study (as well as in the preliminary work, Sundblad and Evans 1987) are included in Appendices A and B.

5.1 LAKE HILLESJÖN

5.1.1 Water temperature

Temperature profiles were obtained from the western part of Lake Hillesjön both during winter and summer conditions in order to locate groundwater seepage through the bottom sediments. Some profiles from the summer survey are shown in Figure 5.1. The variations of conductivity and pH were also measured. These variables can be used for location of seepage of groundwater when the seepage is relatively strong.

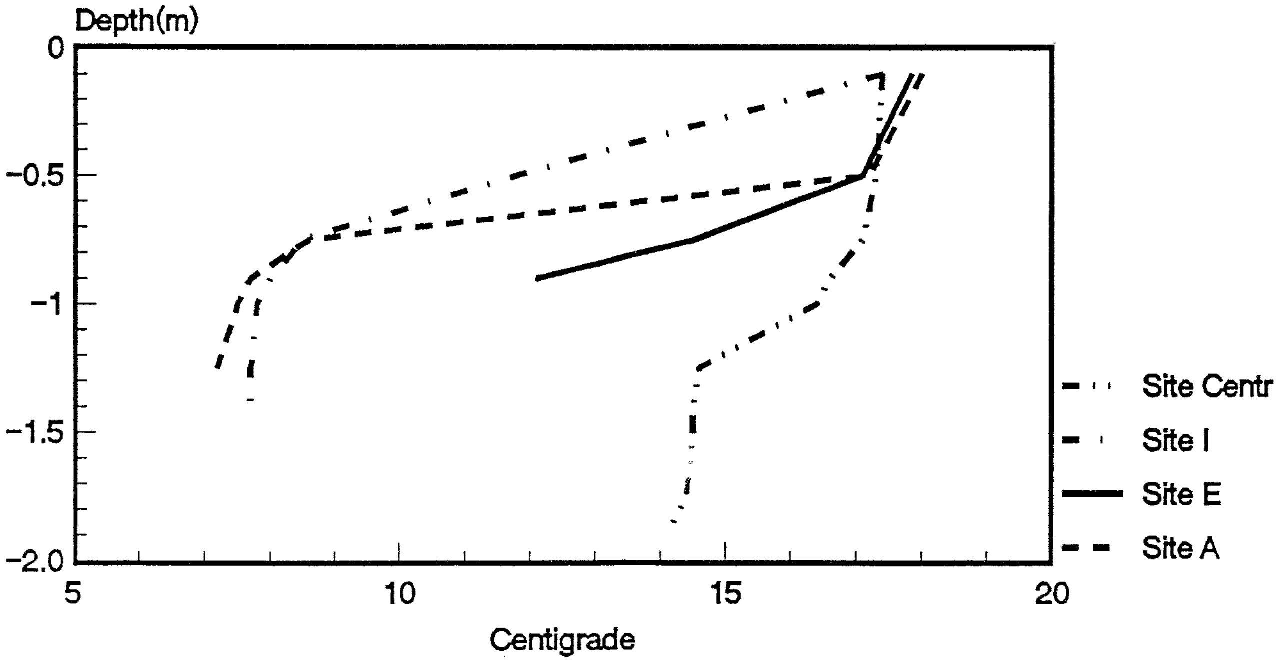

Figure 5.1 Temperature versus depth for Lake Hillesjön, 870624.

5.1.2 Thorium and uranium

The total amount of U and Th in the sediment is presented in Figures 5.2 and 5.3 and the Th/U-ratio is shown in Figure 5.4. There is a tendency of lower Th-content in the discharge areas of Lake Hillesjön, compared to the sediments in the middle of the lake. No direct trends with changing depths are found.

The concentration of U in the sediment varies to a greater extent than that of Th. A strong enrichment is observed at the E-site in the sediment of Lake Hillesjön. Seepage of groundwater through the bottom sediment occurs at this site, but this seepage is smaller than that of the A-, I- and K-sites. The top layer of the E-core, 0 - 20 cm, has a high organic content of about 35 to 45 %. There is a sharp transition zone just below the depth of 20 cm, where the organic content drops to about 10 %. This can explain the strong enrichment of U in the top layer. The site in the middle of the lake (centre) has somewhat higher U-values in the upper layers, with a slow decrease towards deeper layers.

The difference in the Th/U-ratio is very clear for the different sites in Lake Hillesjön, see Figure 5.4. Low values are observed throughout the whole core profiles. However, in the middle of the lake, at levels below 20 cm, the ratio is around 3, a value which corresponds to the composition of the suspended material introduced from the surroundings.

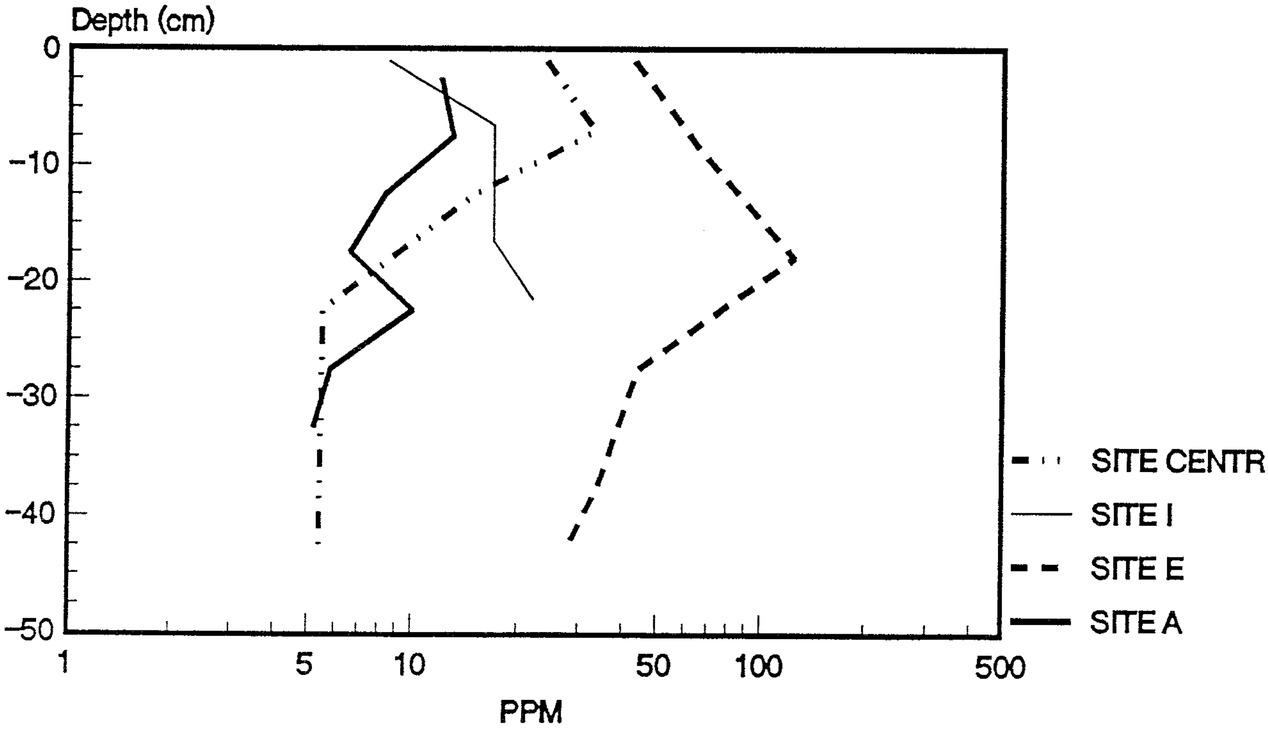

Figure 5.2 Uranium contents for sediment samples from Lake Hillesjön, 870624.

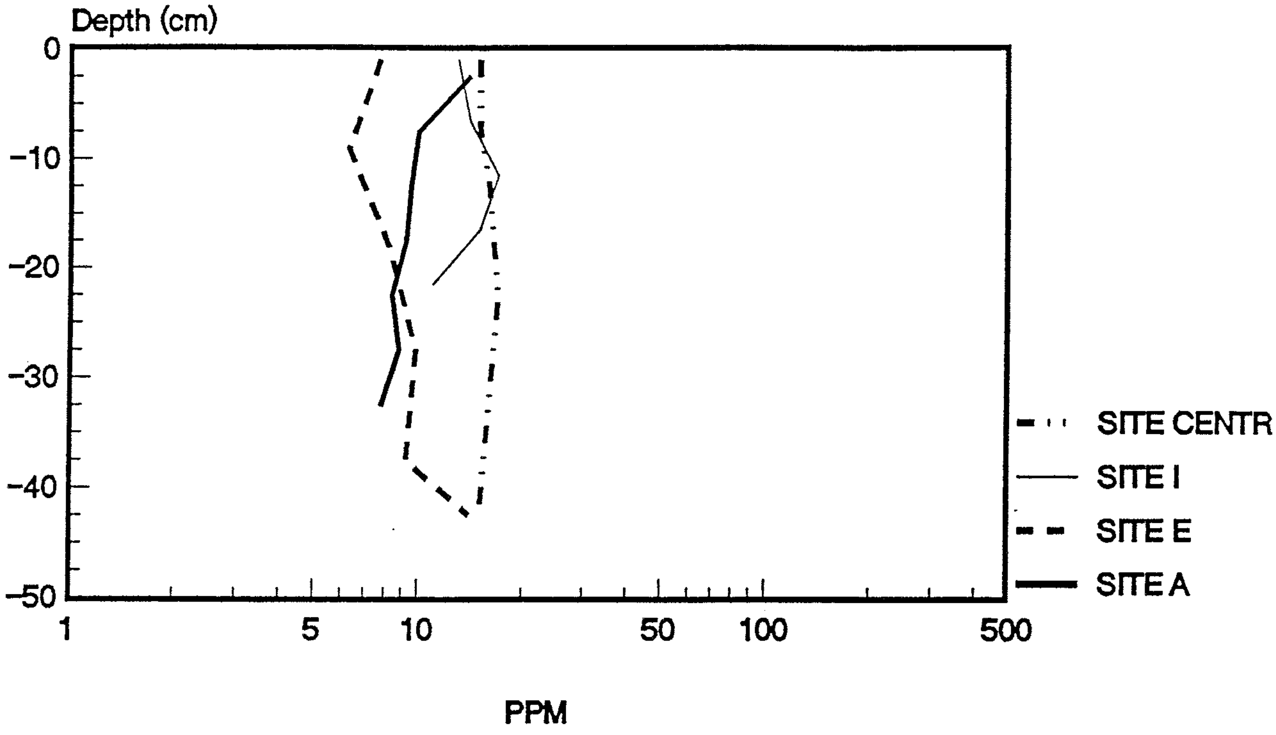

Figure 5.3 Thorium contents for sediment samples from Lake Hillesjön, 870624.

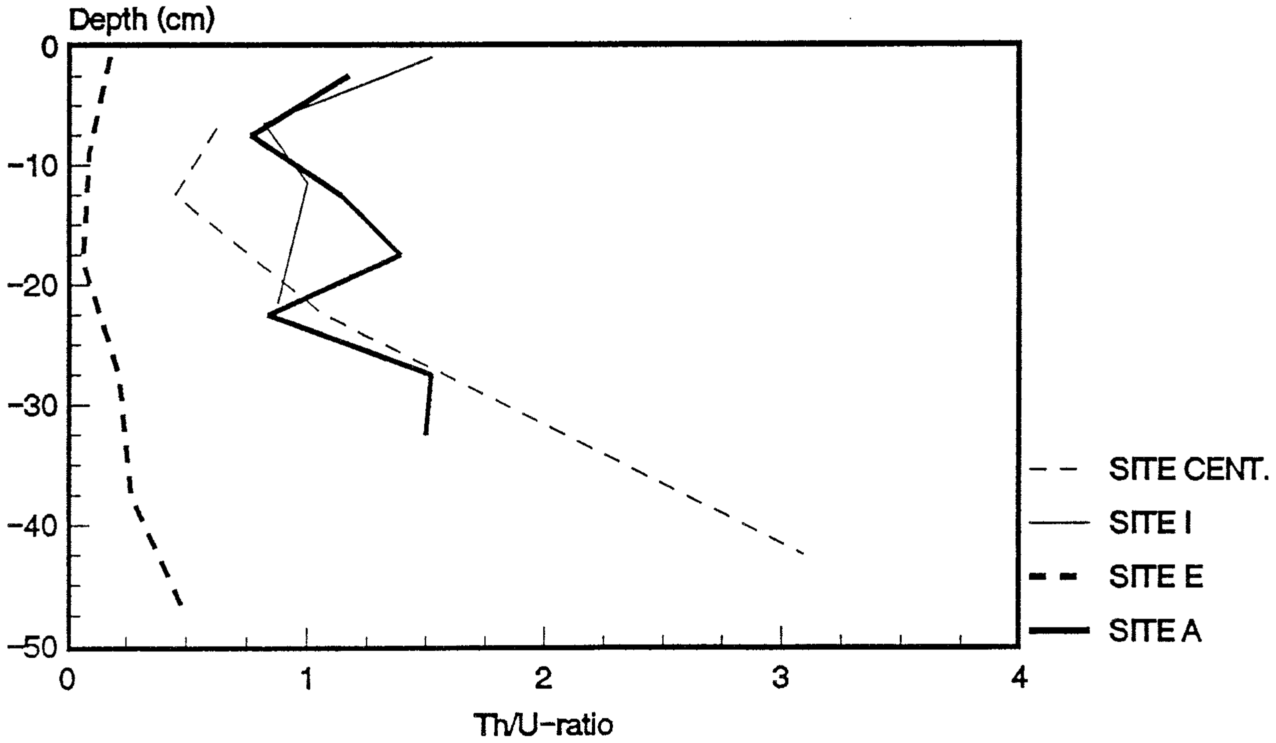

Figure 5.4 Thorium/Uranium ratio for sediment samples from Lake Hillesjön, 870624.

5.1.3 Iron

Fe is included as an example of elements with different oxidations states which can be affected by different redox conditions. There is a clear tendency for higher Fe values the more distant the sediment is from the shore line of Lake Hillesjön, Figure 5.5. The precipitate sample from "Spring B" has the highest iron contents.

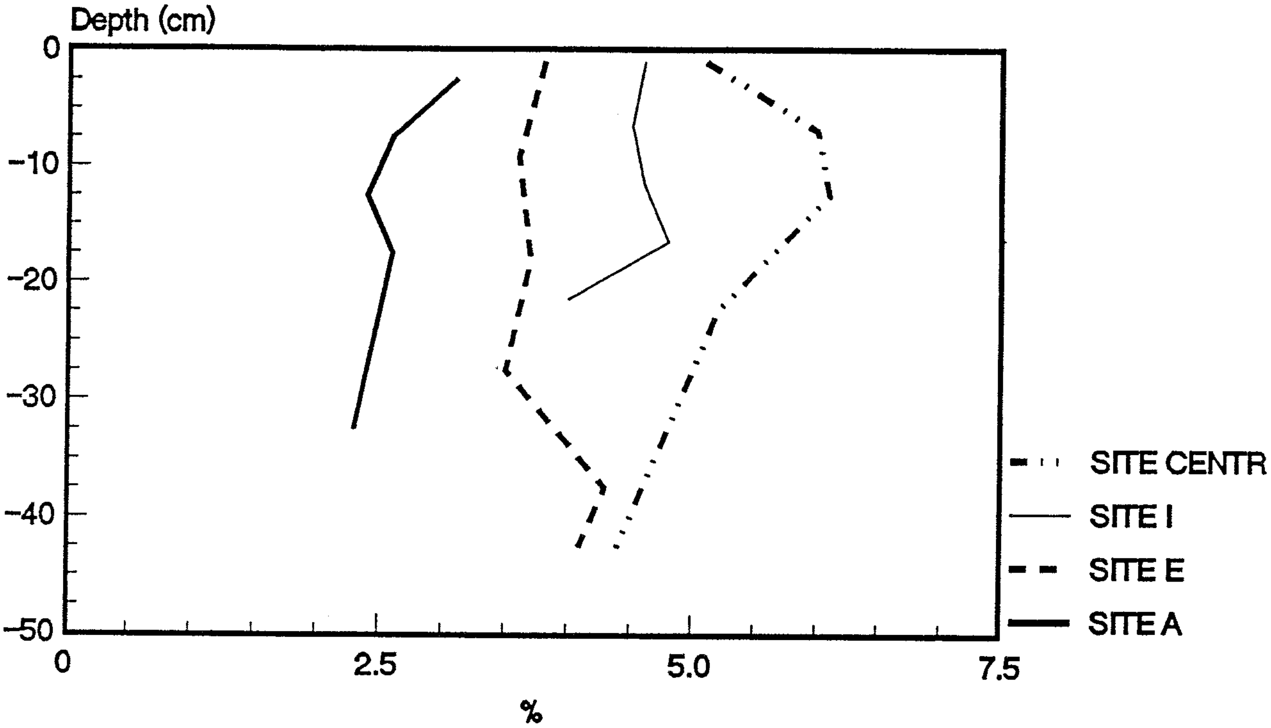

Figure 5.5 Iron contents for sediment samples from Lake Hillesjön, 870624.

5.1.4 Cesium

There is no tendency of enrichment zones of stable cesium, see Figure 5.6. The fluctuations are small, between 2 and 7 ppm.

The Chernobyl fallout in the Gävle area (where Lake Hillesjön is located) was highest in Sweden. The deposition of Cs-137 was in the order of 100 kBq/m². The Cs-137 profiles in lake sediments are presented in Figure 5.7. There are large differences between the different sites in Lake Hillesjön. The surface activity in the area most affected by discharging groundwater is about 900 Bq/kg dw. This may be compared with the activity of 50 000 Bq/kg dw in the middle of the lake. These differences are caused by the quite high outflow of groundwater which affects the sedimentation and migration of Cs-137.

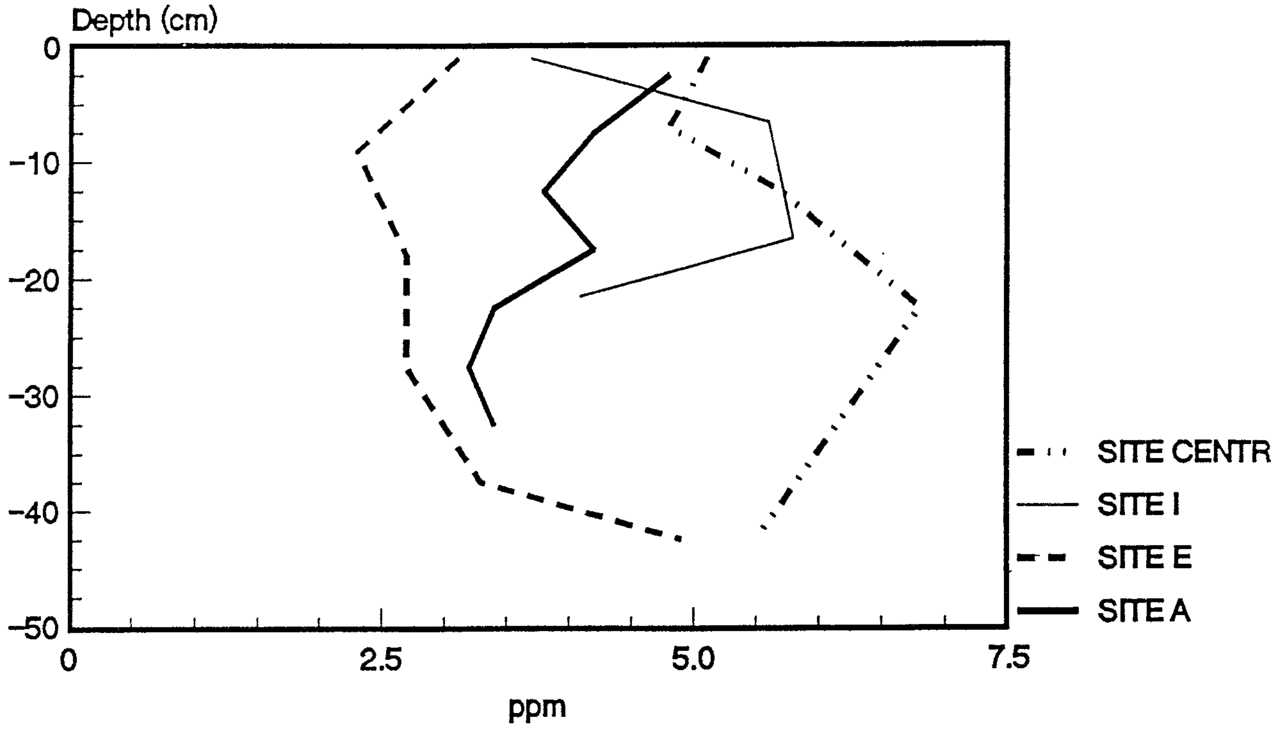

Figure 5.6 Cesium contents for sediment samples from Lake Hillesjön, 870624.

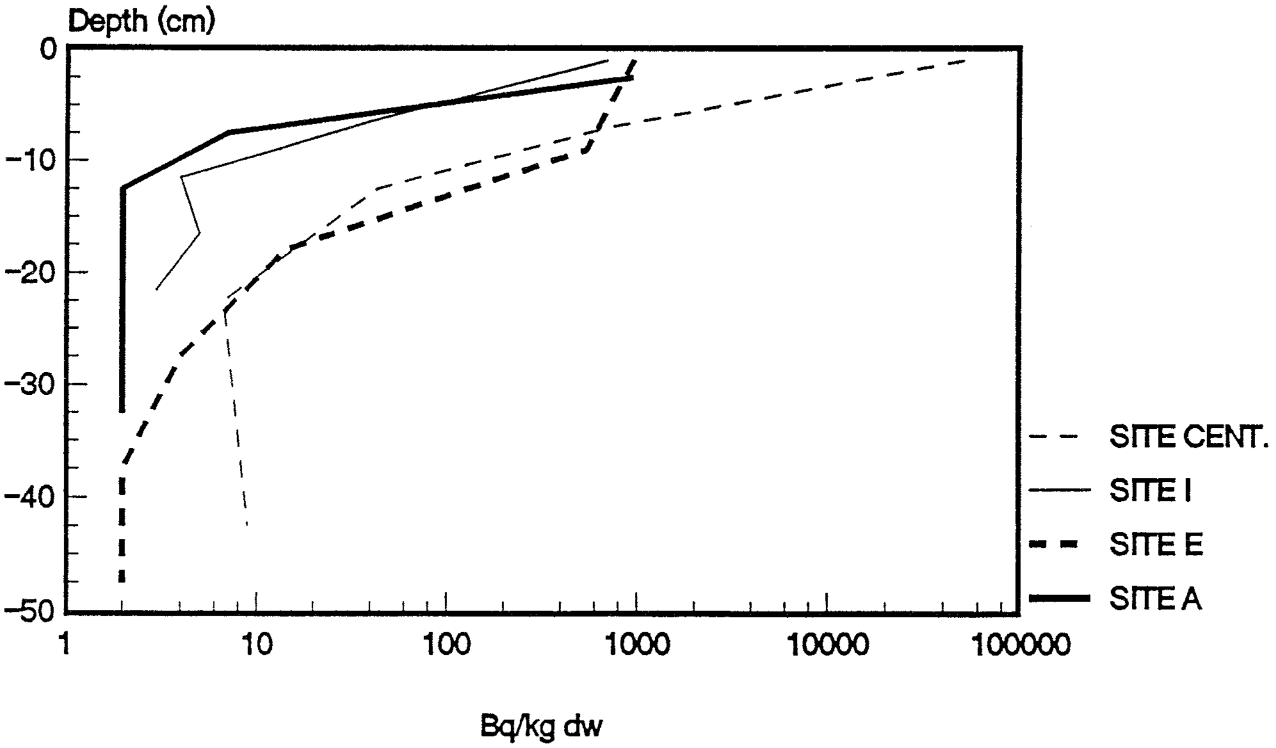

Figure 5.7 Cs-137 contents for sediment samples from Lake Hillesjön, 870624.

5.1.5 Rare Earth Elements (REE)

Cerium belongs to the rare earth elements (REE) and will be presented as an example of the distribution of these elements. The lowest values are found in the A-profile and the highest values in the centre of Lake Hillesjön, see Figure 5.8. The other sites are between these two.

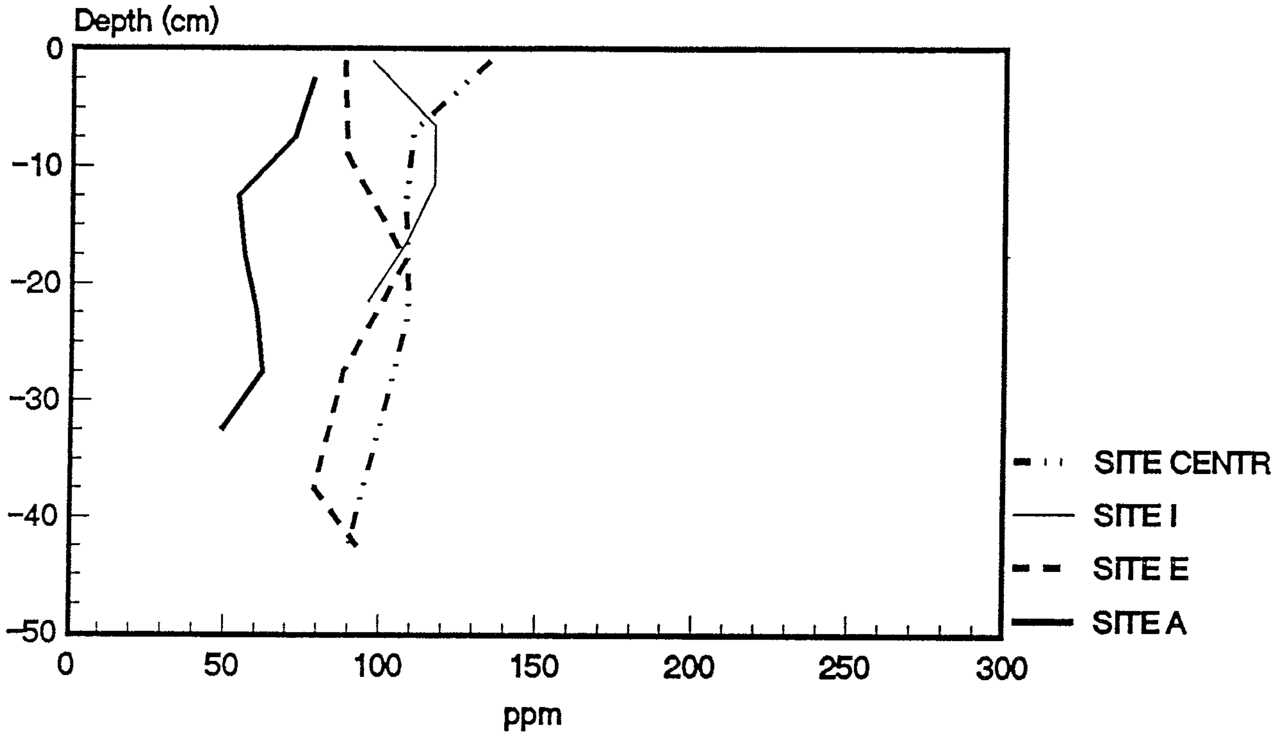

Figure 5.8 Cerium contents for sediment samples from Lake Hillesjön, 870624.

5.1.6 Activity ratios

Activity ratios were also calculated for members of the U-238 and Th-232 chains. Uranium and thorium series isotopic disequilibrium can be used as an indicator of actinide migration under natural conditions.

Activity ratios of Ra-226/U-238, Ra-228/Th-232 and Th-228/Th-232 were calculated. The Ra-226/U-238 ratios are given in Figure 5.9. Disequilibrium is found more or less in all profiles which is to be expected due to the long half-life times of these elements, because the sediments are young compared to the half-lives. However, there are interesting features of the profiles which show that there are different migration patterns.

It is easier to interpret the ratios of Ra-228/Th-232 due to their shorter half-lives which are comparable to the age of the sediment, as equilibrium may be reached in about 30 years, and should be expected in a closed sediment system. The ratios are shown in Figure 5.10. The Ra-228/Th-232 ratio recorded in the sediment core collected in the middle of Lake Hillesjön is close to 1.0 and can thus be looked upon as a sediment in which no or very slow migration of nuclides occurs. The other profiles from the discharge zones show ratios greater than 1.0 indicating an open system, with higher ratios of Ra-228/Th-232.

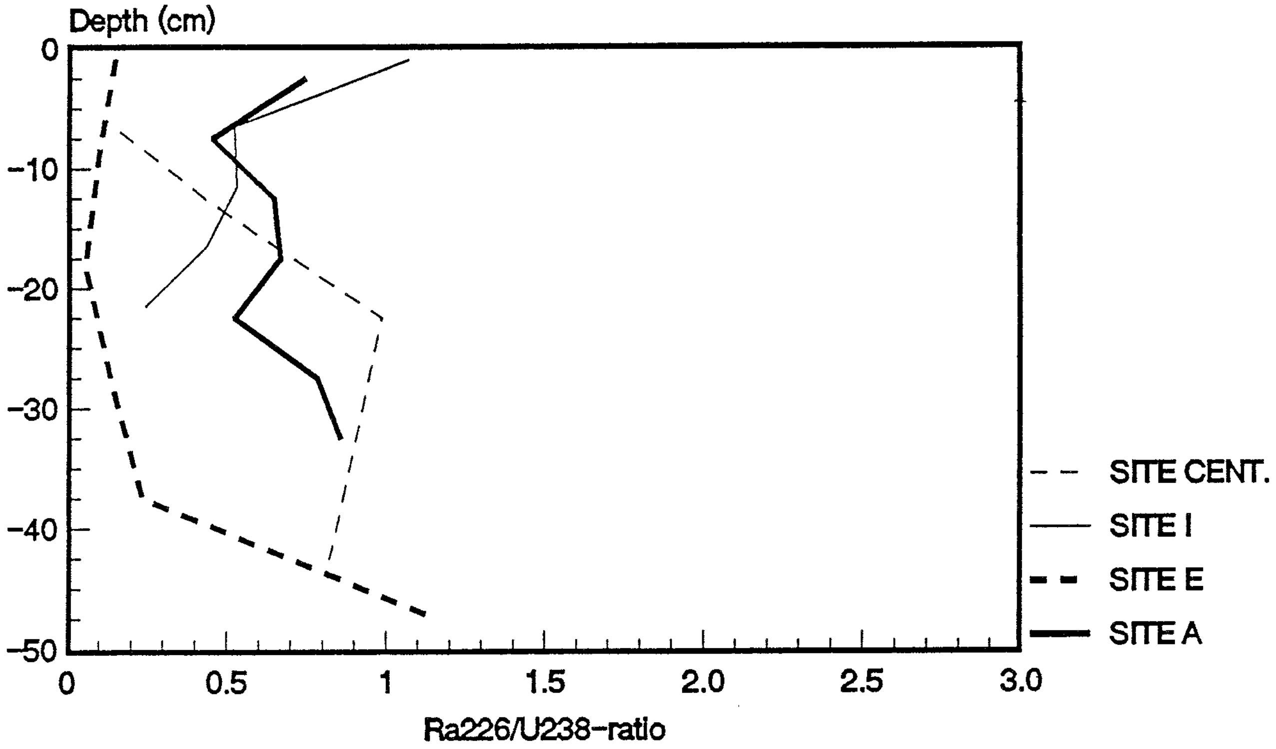

Figure 5.9 Ra-226/U-238 ratio for sediment samples from Lake Hillesjön, 870624.

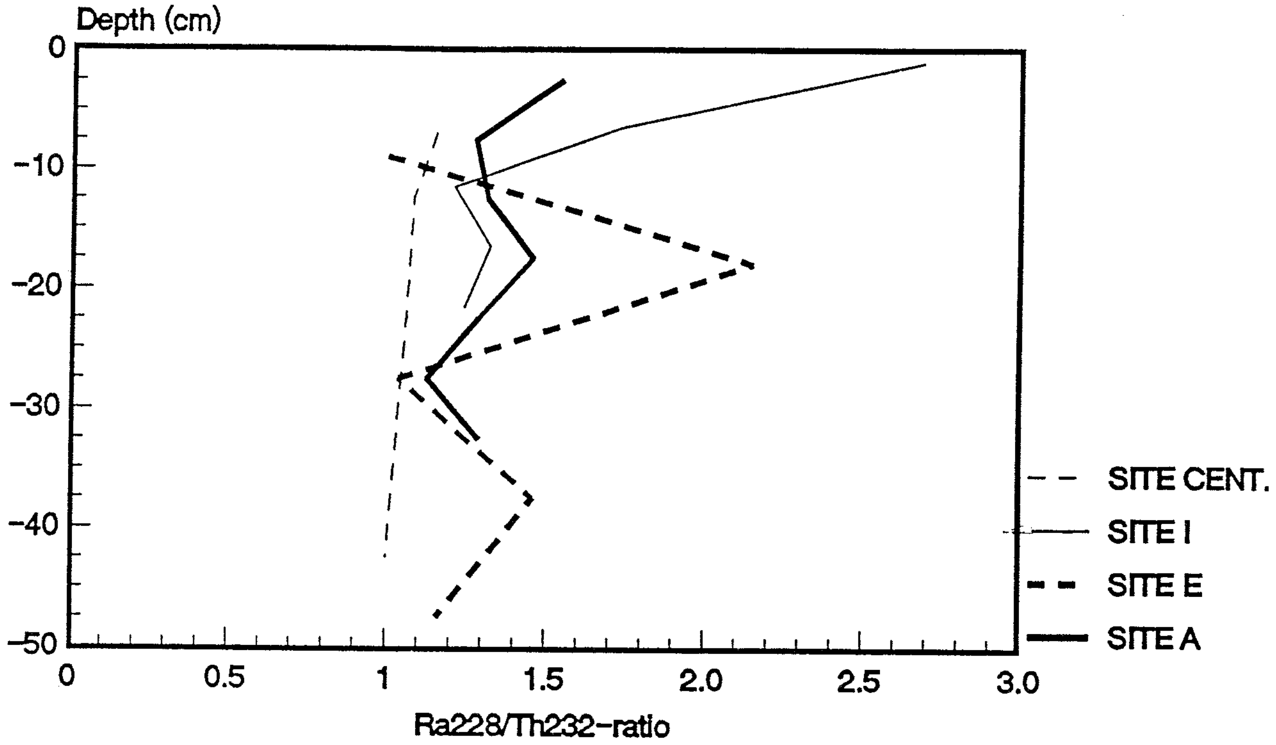

Figure 5.10 Ra-228/Th-232 ratio for sediment samples from Lake Hillesjön, 870624.

5.1.7 Factor analysis

A factor analysis was performed on 18 elements at four sites (A, E, I and Centre). A factor analysis can be used to group the data and to reduce the data to a few major axes to explain most of the variation in the sediment concentrations.

There are different types of factor analyses, R-mode and Q-mode (Davis, 1973). The interrelations between variables are investigated by a R-mode factor analysis, while the Q-mode analysis gives the interrelations between samples.

The Q-mode analysis for the sediment sites in Lake Hillesjön shows that the centre site of the lake (C1 - C5), see Figure 5.11. The other sites (A, E and I) are more grouped together. The two groups also show different gradients between the two Factors I and II. There is a decreasing value of Factor I for increasing Factor II values of site C (the centre of the lake). The loadings are presented in Table 2 below.

The R-mode analysis, presented in Figure 5.12, for the whole sediment material, gives some outliers among the 18 elements, such as Br and As. Most of the other elements group close to origo, with Rb, Ce, Cr, La and U falling on a line that goes through origo.

Table 2 The varimax rotated loadings for 18 elements (23 samples). Loadings <0.50 are not quoted.

	Factor		
Element	I	II	III
As	<	-0.83	0.39
Br	<	<	0.72
Ce	0.94	<	<
Cs	<	0.79	<
Cr	<	0.83	<
Co	0.81	<	<
Eu	0.78	<	<
Hf	<	<	<
Fe	0.82	<	<
La	0.94	<	<
Lu	0.82	<	<
Rb	<	0.78	
Sc	<	0.85	<
Tb	0.64	<	<
Th	0.59	0.78	<
U	<	-0.77	<
Yb	0.86	<	<
Zn	0.66	<	-0.51
Eigenvalue	7.1	5.6	1.3
% of variance	40	30	7
Cumulative %	40	70	77

As can be seen in Table 2, Factor I is dominated by the REE (like La and Ce), Co, Fe, and Zn, while Factor II is constituted mainly by As, Rb, Cs, Sc, Cr, U and Th. Factor III is mainly described by As and Br (the outliers in Figure 5.12). The significance of these Factors is further discussed in Section 5.4.

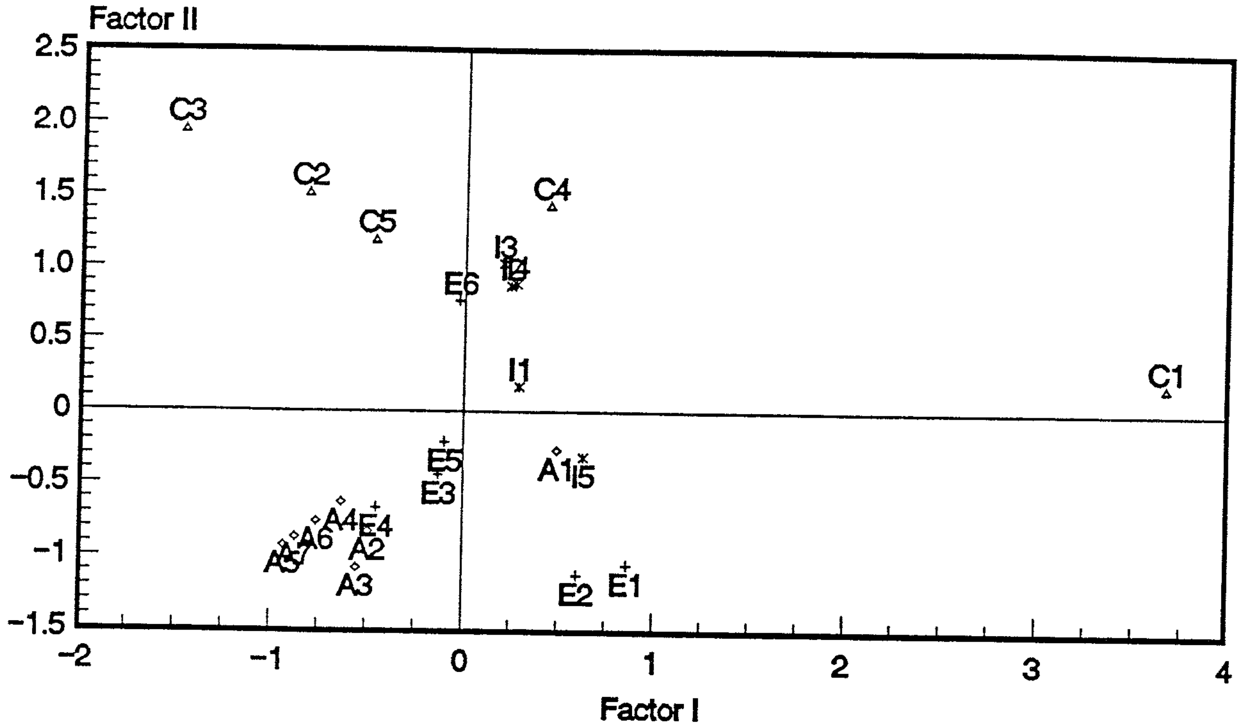

Figure 5.11 Q-mode Factor Analysis for sediment samples from Lake Hillesjön, 870624.

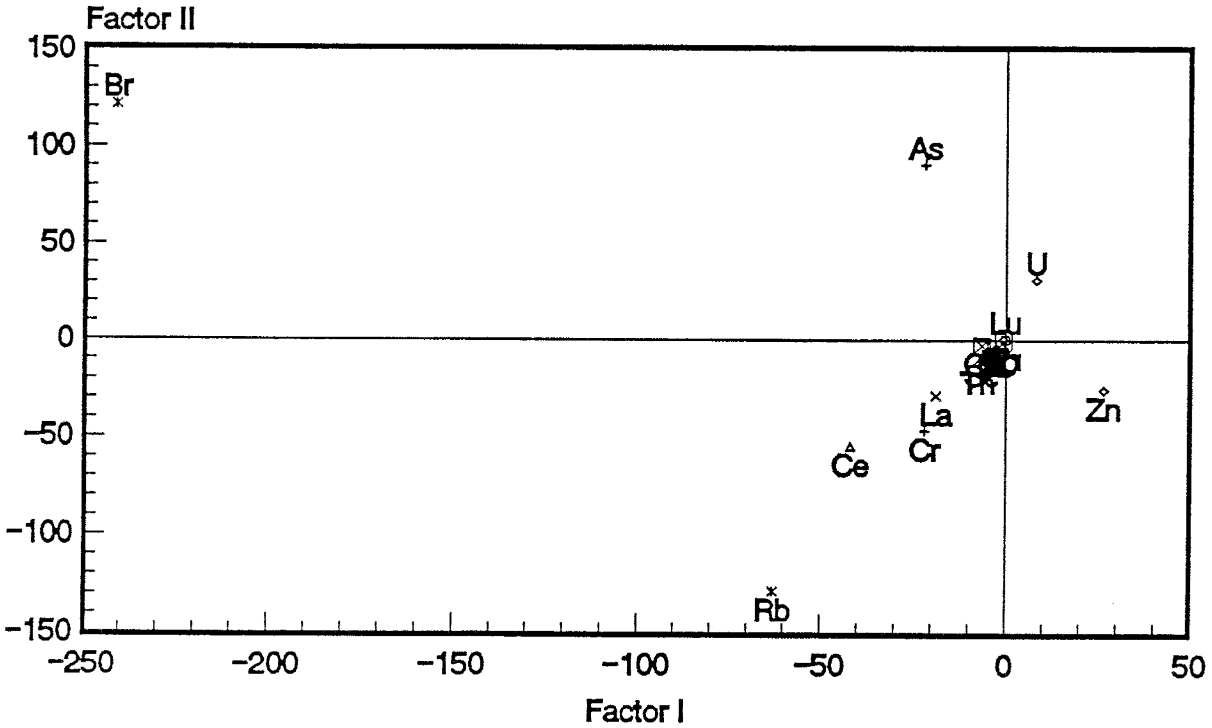

Figure 5.12 R-mode Factor Analysis for sediment samples from Lake Hillesjön, 870624.

5.1.8 K-40, U-238, Fe, Ce and organic content

A strong negative correlation exists between K-40 and organic contents of the sediments, see Figure 5.13. Thus sediment with high mineral content has high content of K-40 that originates from different minerals.

On the contrary, for U-238 a positive correlation is found with organic content, see Figures 5.14 and 5.35.

Elements like for example Fe and Ce do not show a correlation with organic content except for organic content below 10 % where a slight increase is found.

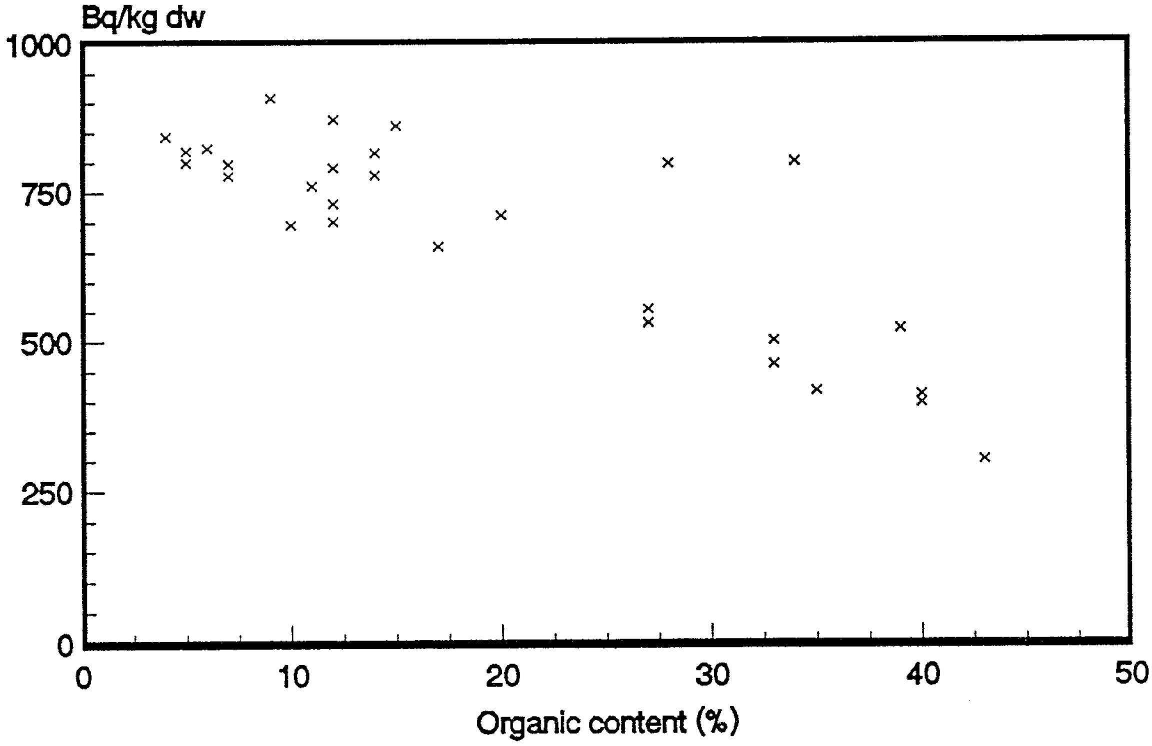

Figure 5.13 Correlation between K-40 and organic contents for sediment samples from Lake Hillesjön, 870624.

5.1.9 The precipitate from Spring B

Analysis for this sample is reported in Appendix A, Table A.6. This sample has a high arsenic contents (1.7 %-As dry weight, equivalent to 2.2 % As_2O_3), the highest lanthanum concentration (116 ppm), and its composition is mainly hydroxides of iron (32 %, equivalent to 61 % $Fe(OH)_3$) and manganese (2.7 % MnO_2). Actinide levels (U and Th) are not specially high.

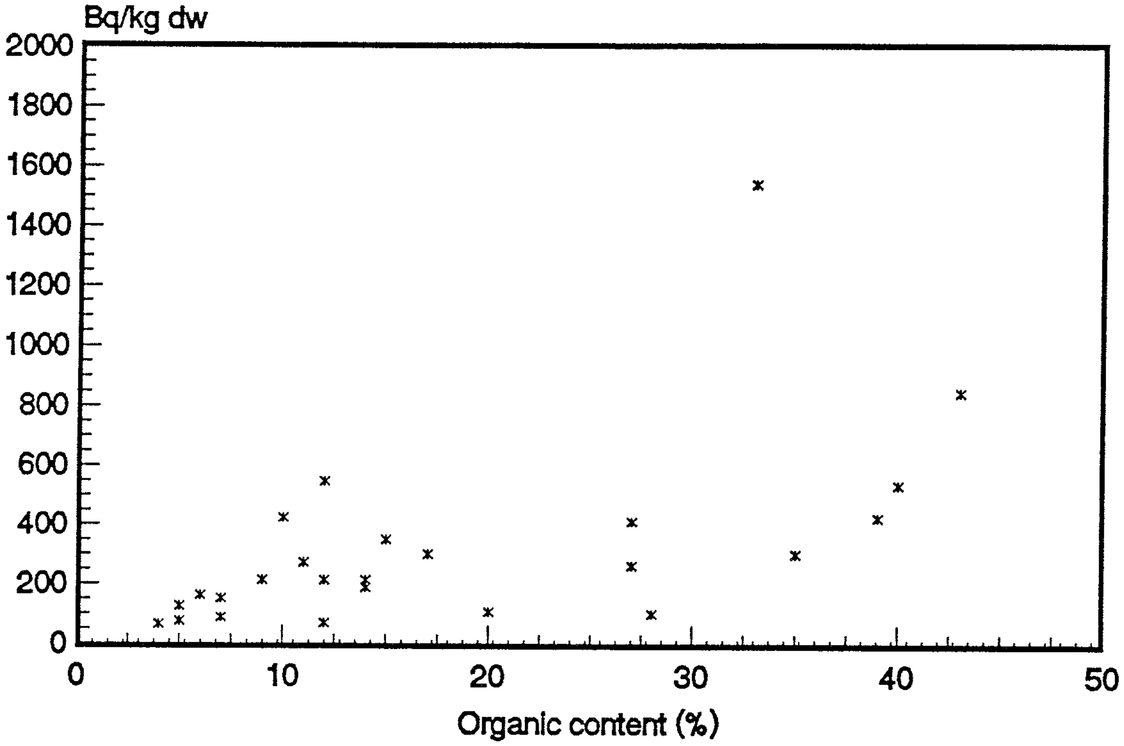

Figure 5.14 Correlation between U-238 and organic contents for sediment samples from Lake Hillesjön, 870624.

5.2 THE TÄCKHAMMAR AREA

The springs of Täckhammar and the area of lake Långhalsen which is just outside the shore where the springs are located, were studied during a two-year period. Measurements of the water and sediments in the two springs called "oxic" and "anoxic", as well as in the surrounding discharge area were performed.

Water quality sampling of the oxic spring as well as another spring (Kappla) and lake water from Lake Långhalsen was carried out in March 1988, Table B.3. Sampling and direct measurements were performed at some occasions during 1989 - 1990.

5.2.1 Water temperature

The water temperature was measured at the different sites at different occasions. The mean temperature in the oxic spring was around 7 centigrades, while the mean temperature in the anoxic spring was about one degree higher. No seasonal variations were observed. The mean annual mean temperature of the topmost layer of the groundwater in Södermanland is about 5.7 centigrades (SGU 1984). This means that the water in the oxic spring originates from a depth of about 100 meters below ground, because the temperature gradient is about 1 centigrade/100 m (SGU 1984). Thus the water in the anoxic spring comes from a depth of about 200 meters below the ground and probably from a different aquifer.

The temperature measurements in the lake bottom sediment have not given any evidence of groundwater discharge of major importance.

5.2.2 Thorium and Uranium

There is a strong tendency of uranium enrichment in the layer about 5 cm from the sediment surface in the anoxic spring, see Figure 5.15, 5.32 and 5.33. The content reaches about 500 ppm, while the oxic and lake sediment are around 10 ppm. The pattern is almost the opposite for thorium, see Figures 5.16, 5.32 and 5.33, with contents of 10 - 20 ppm for all three sites.

On the other hand, the Th/U-ratio indicates a slight enrichment in the oxic spring sediment and in the lake top sediment (above 7 cm), see Figure 5.17. A value of the Th/U-ratio of around 3 is similar to the rock composition. The same result was obtained for Lake Hillesjön, see Figure 5.4. The Th/U-ratios for lakes with no discharge as for example Lake Sibbo- and Trobbofjärden (Sundblad et al, 1987) were above 3 for all depths.

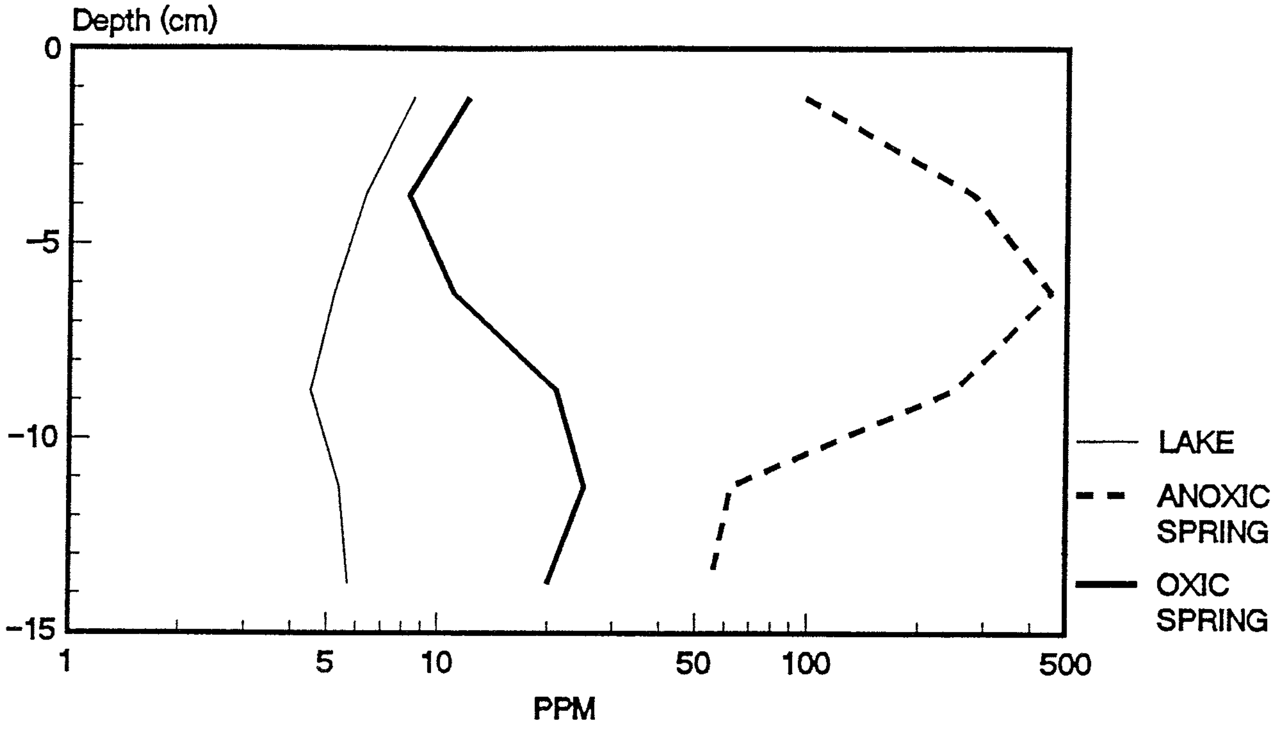

Figure 5.15 Uraniun contents for sediment samples from Täckhammar springs and Lake Långhalsen, 890929.

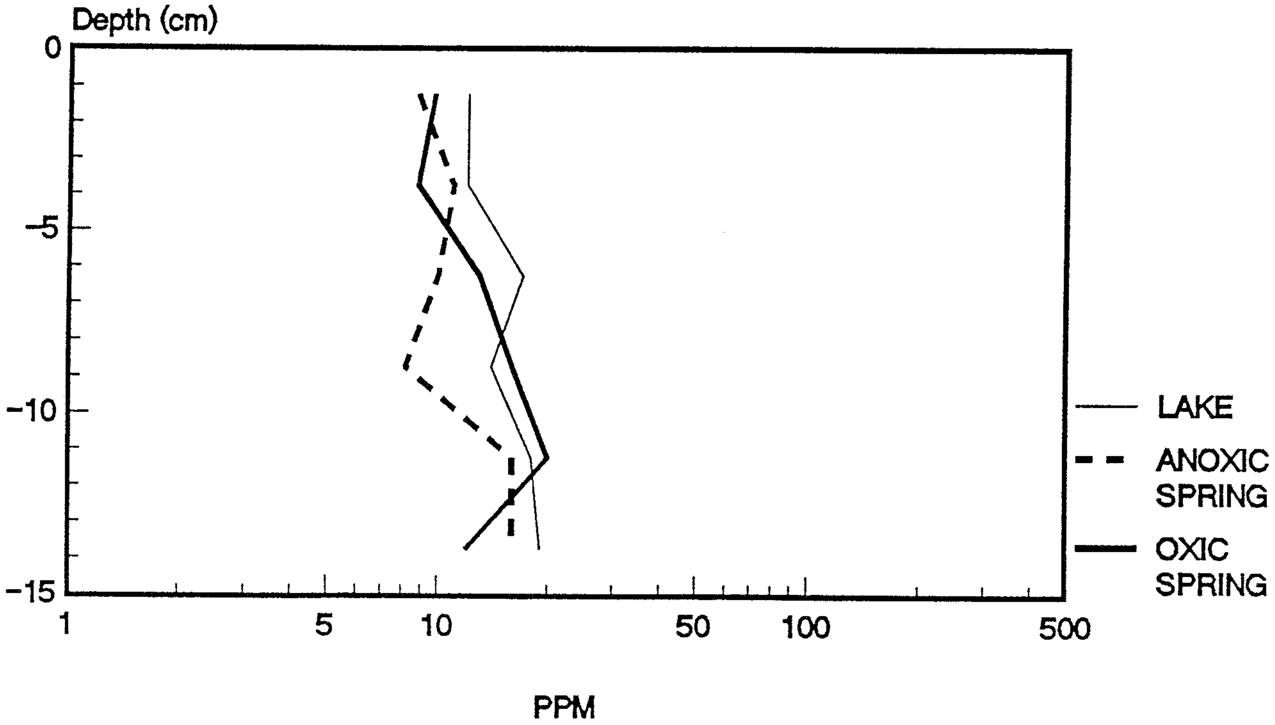

Figure 5.16 Thorium contents for sediment samples from Täckhammar springs and Lake Långhalsen, 890929.

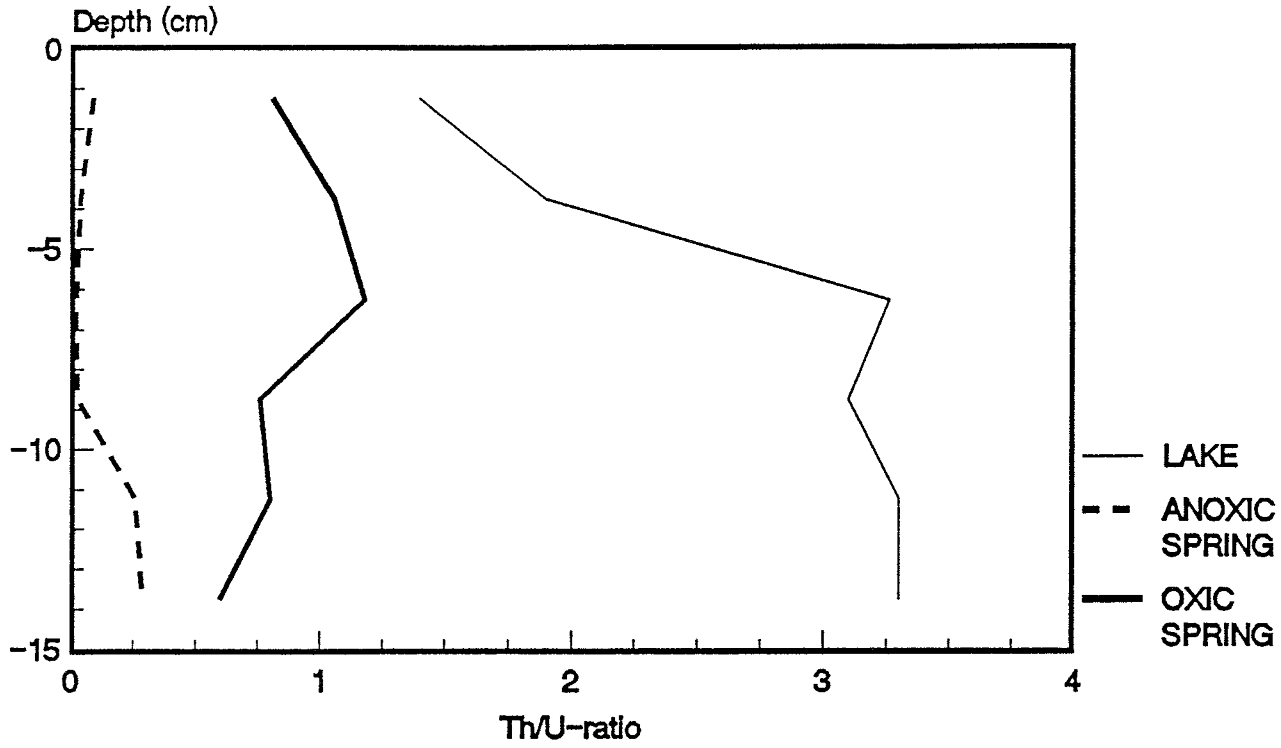

Figure 5.17 Thorium/Uranium concentration ratio for sediment samples from Täckhammar spring and Lake Långhalsen, 890929.

5.2.3 Iron

There is a marked difference between the anoxic-spring sediment profile and lake as well as oxic-spring profiles, see Figures 5.18, 5.32 and 5.33. The big differences are found in the uppermost 10 cm where the concentration of iron is about three times higher in the anoxic-spring sediment. On the other hand, the concentration in the deeper sediment layers is somewhat lower. One explanation is that when the anoxic groundwater enters the spring, oxidation of ferrous iron, Fe(II), into ferric iron, Fe(III), resulting in precipitation in the top sediment.

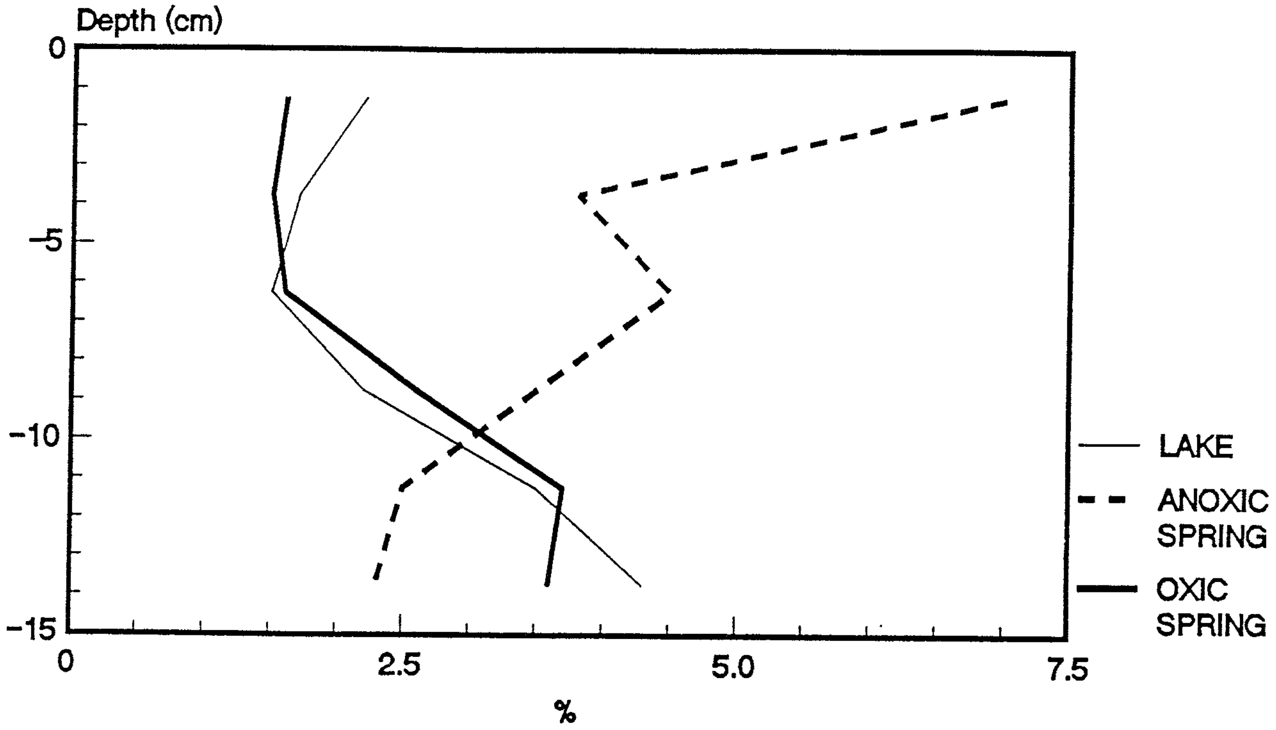

Figure 5.18 Iron contents for sediment samples from Täckhammar spring and Lake Långhalsen, 890929.

5.2.4 Sodium, Potassium, Rubidium and Cesium

The stable cesium profiles are similar for oxic and anoxic springs as well as for the lake with a decrease with depth, see Figure 5.19. This is in contrast with the iron profiles for example. Cesium has only one oxidation state (+I) and thus can not undergo oxidation or reduction.

Na, K and Rb belong to the same group of the periodic system, with monovalent oxidation state (+I). The content of the sediments of these elements is the same with lower values for the anoxic spring, see Figure 5.20. These results are comparable with the cesium results.

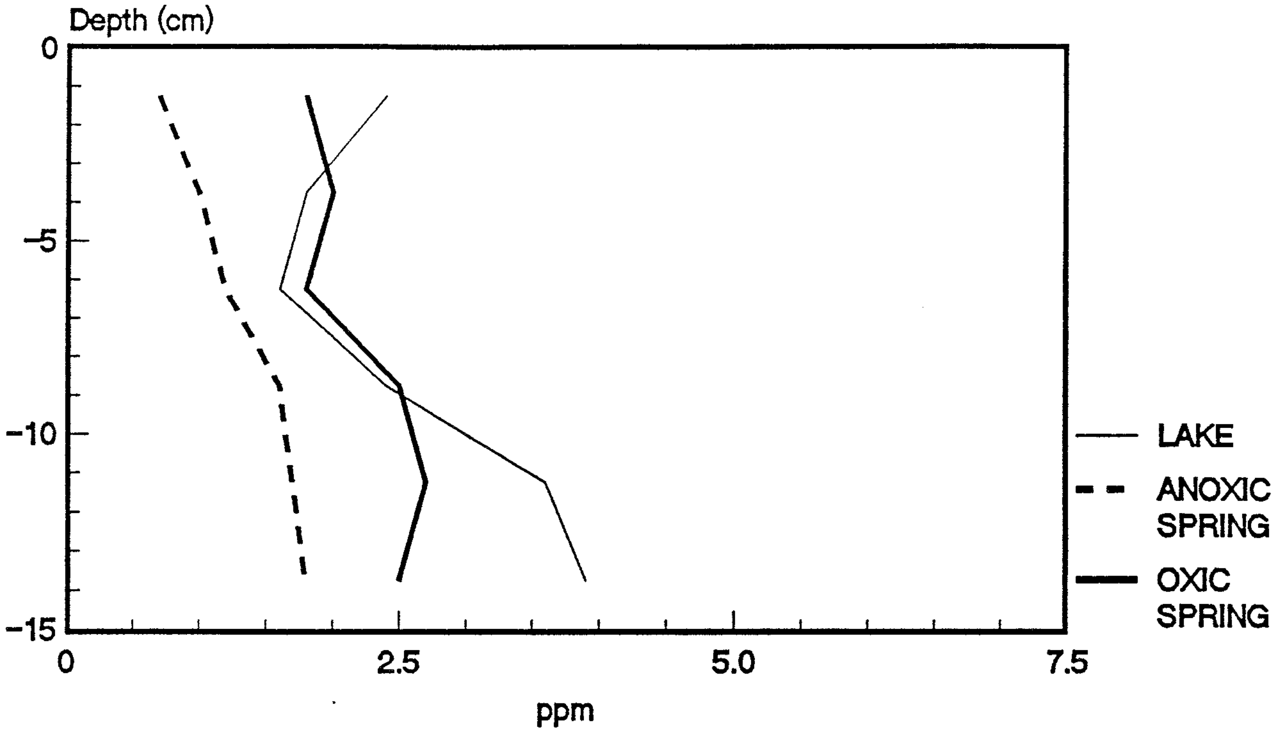

Figure 5.19 Cesium contents for sediment samples from Täckhammar spring and Lake Långhalsen, 890929.

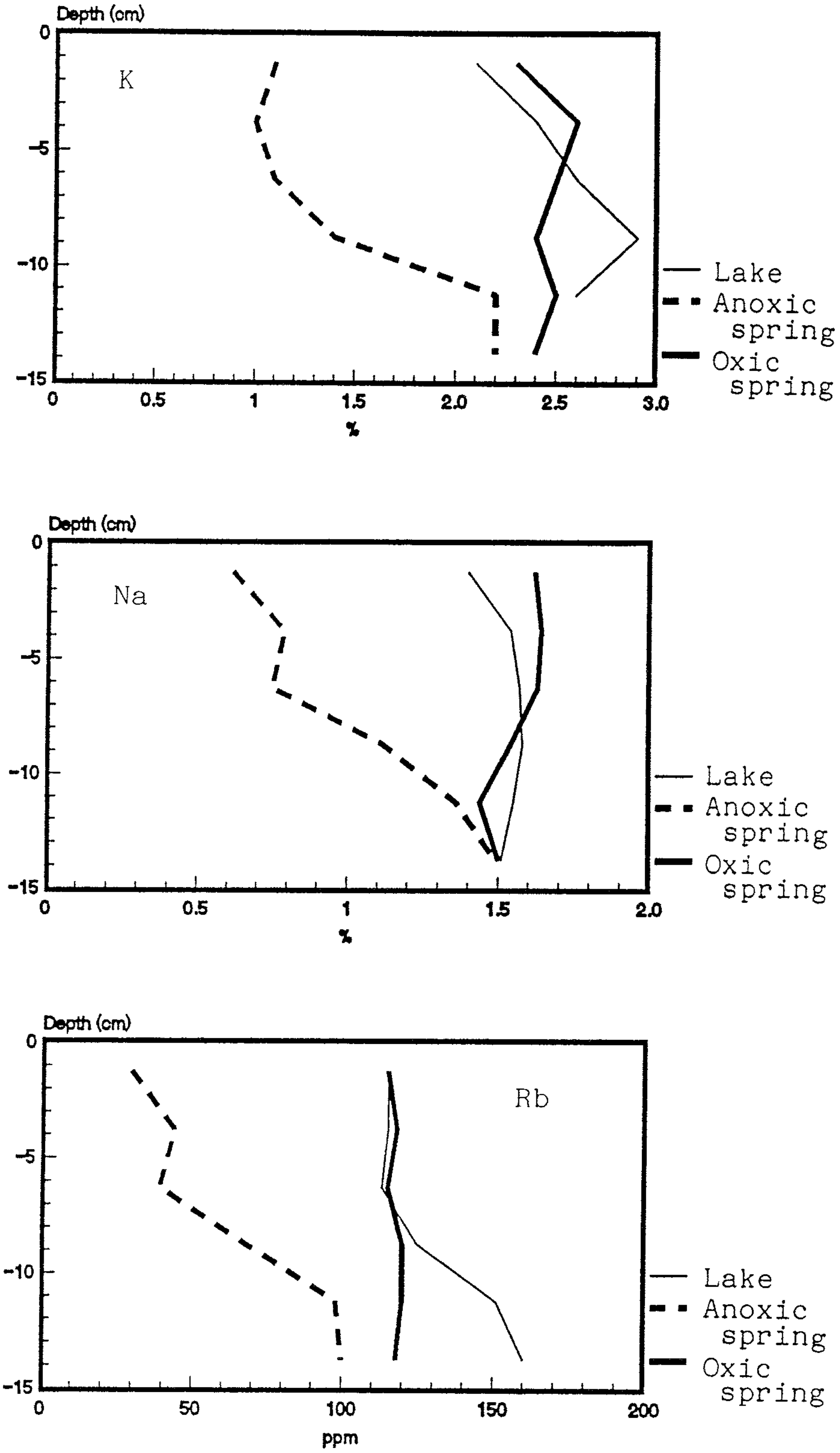

Figure 5.20 Potassium, Sodium and Rubidium contents for sediment samples from Täckhammar springs and Lake Långhalsen, 890929.

5.2.5 Zinc, Scandium and Hafnium

The main oxidation states for these elements are Zn(II), Sc(III) and Hf(IV). The behaviour of scandium and hafnium resemble that of the alkaline elements, see Figure 5.21 while zinc has a somewhat different concentration gradient. However, the upper sediment values of zinc are missing for the anoxic spring.

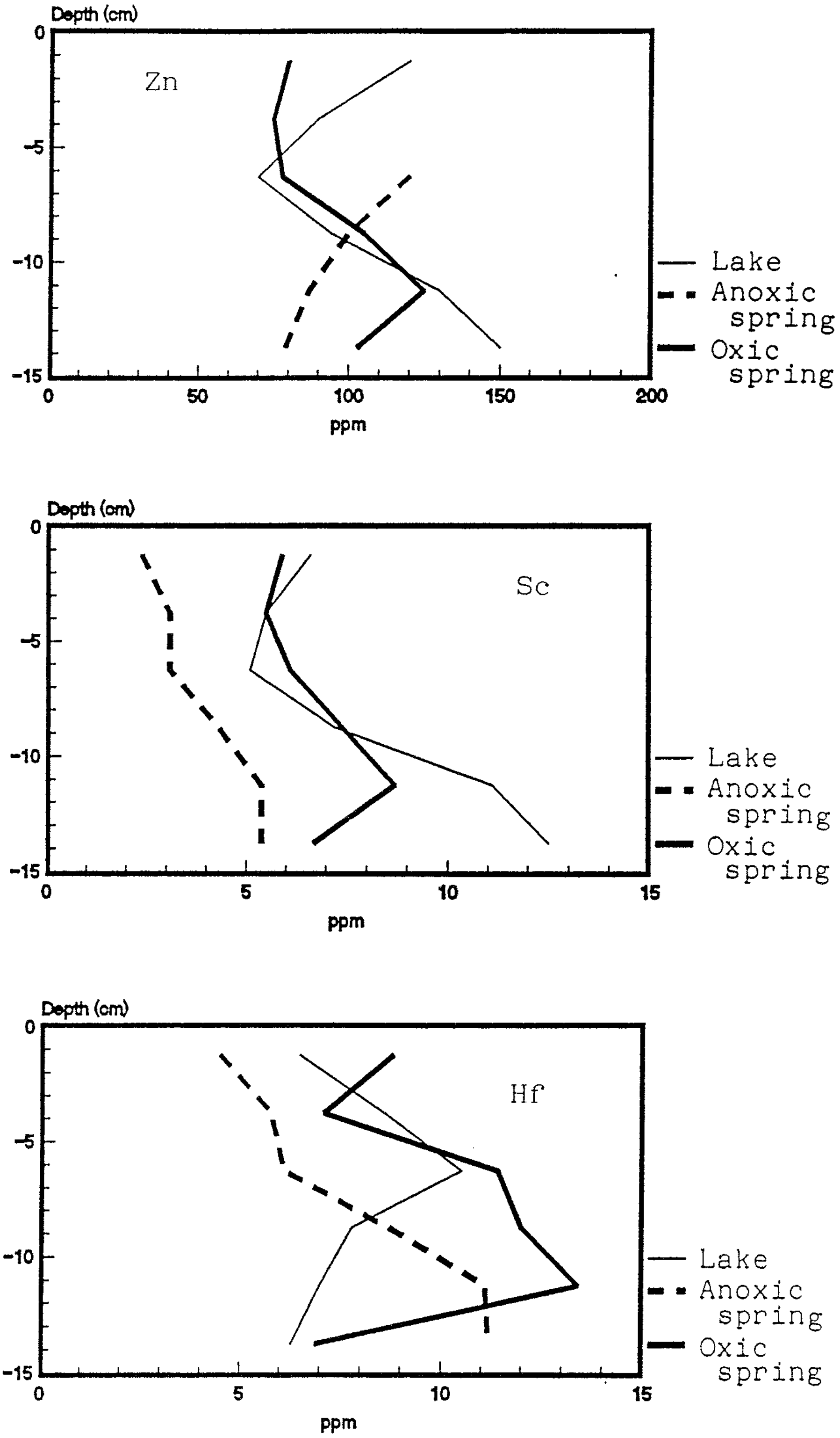

Figure 5.21 Zinc, Scandium and Hafnium contents for sediment samples from Täckhammar springs and Lake Långhalsen, 890929.

5.2.6 Rare Earth Elements (REE)

All rare earth elements (REE) show the same concentration gradients despite of different oxidation states and valence conditions. The concentration pattern is similar for both La, Sm and Lu with (+III)-state and Ce, Tb and Eu, that may be divalent (Eu(II)) or tetravalent (Ce(IV) and Tb(IV)). This is easily seen in Figures 5.22 and 5.23. The anoxic sediments are enriched in the top sediments, while the lake and oxic spring sediments have similar concentration levels. These conditions are in agreement with the uranium results (section 5.2.2)

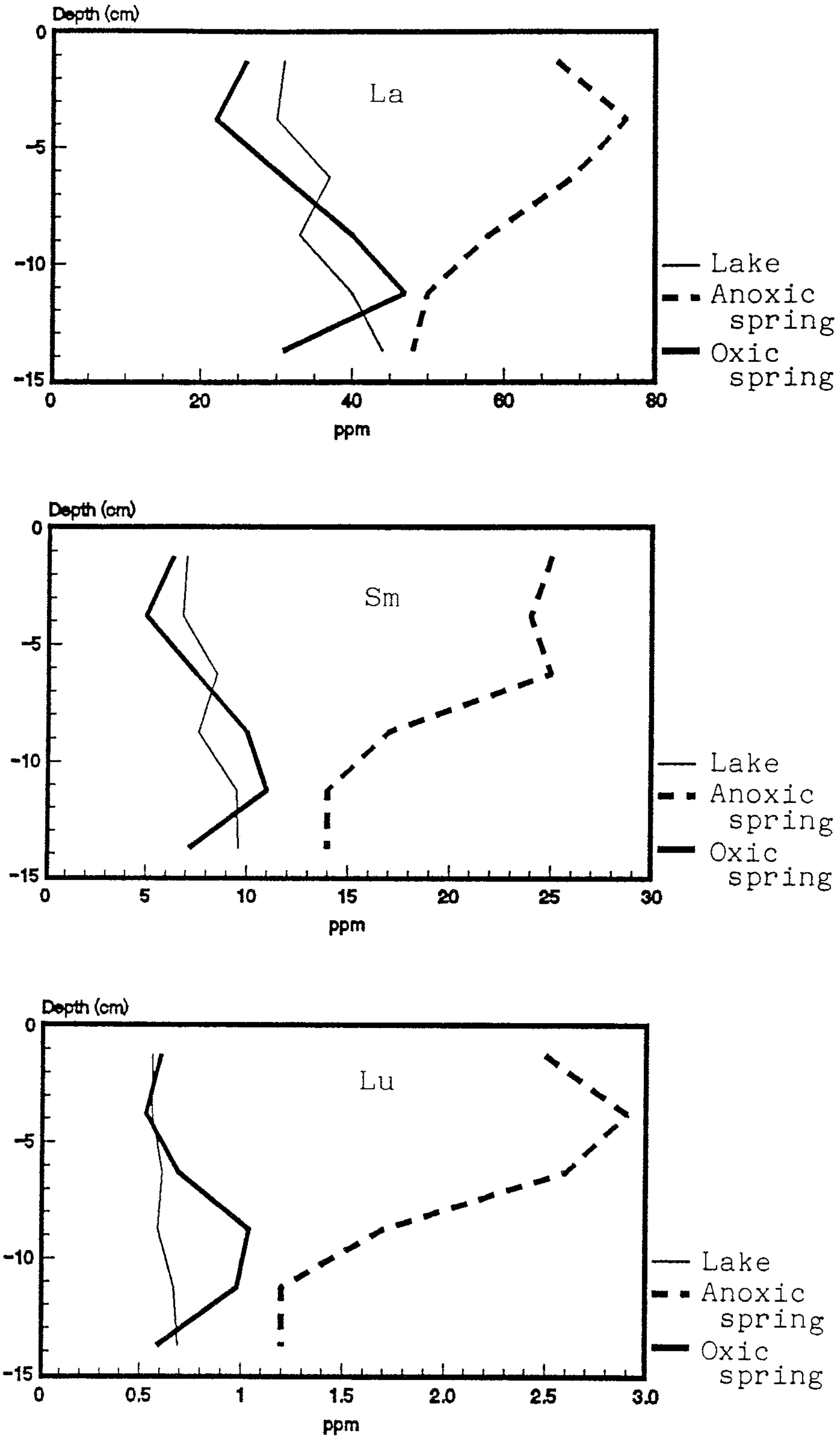

Figure 5.22 Lanthanum, Samarium and Lutetium contents for sediment samples from Täckhammar springs and Lake Långhalsen, 890929.

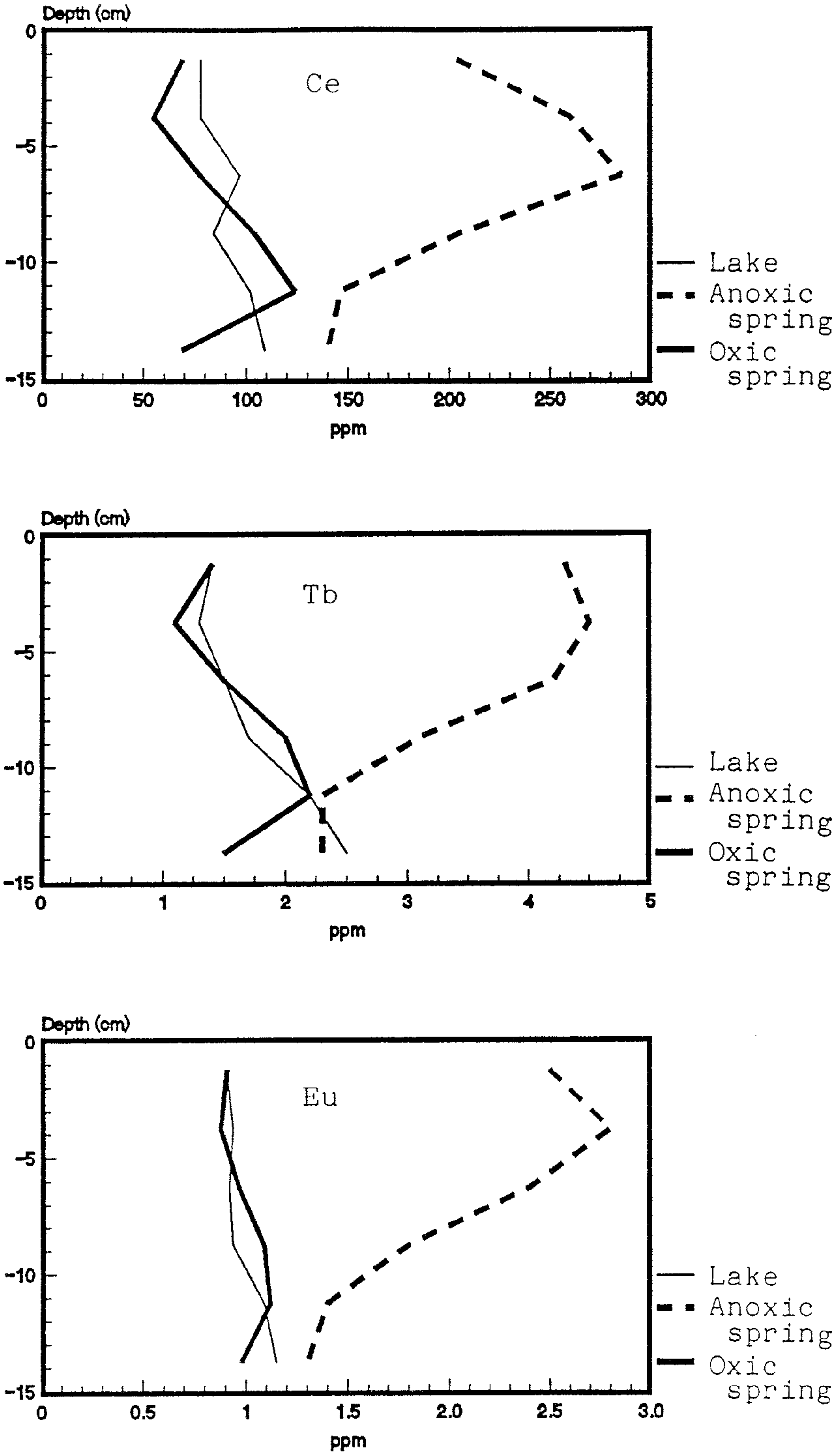

Figure 5.23 Cerium, Terbium and Europium contents for sediment samples from Täckhammar spring and Lake Långhalsen, 890929.

Chondrite-normalised patterns (for sediments sampled 890829) have also been calculated according to Wakita et al (1971), see Appendix A.19. The results are presented in Figures 5.24 to 5.26. There are some striking things worth mentioning.

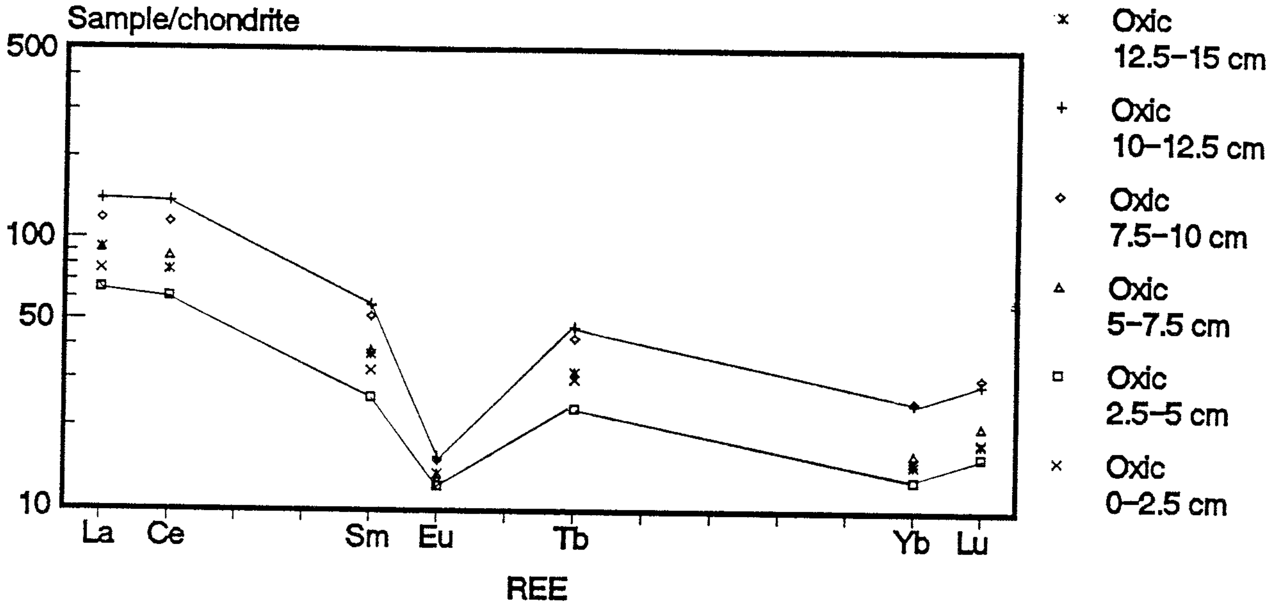

Figure 5.24 Chondrite-normalised rare earth element patterns for sediment samples at different depths. Sediment from Täckhammar oxic spring, 890929.

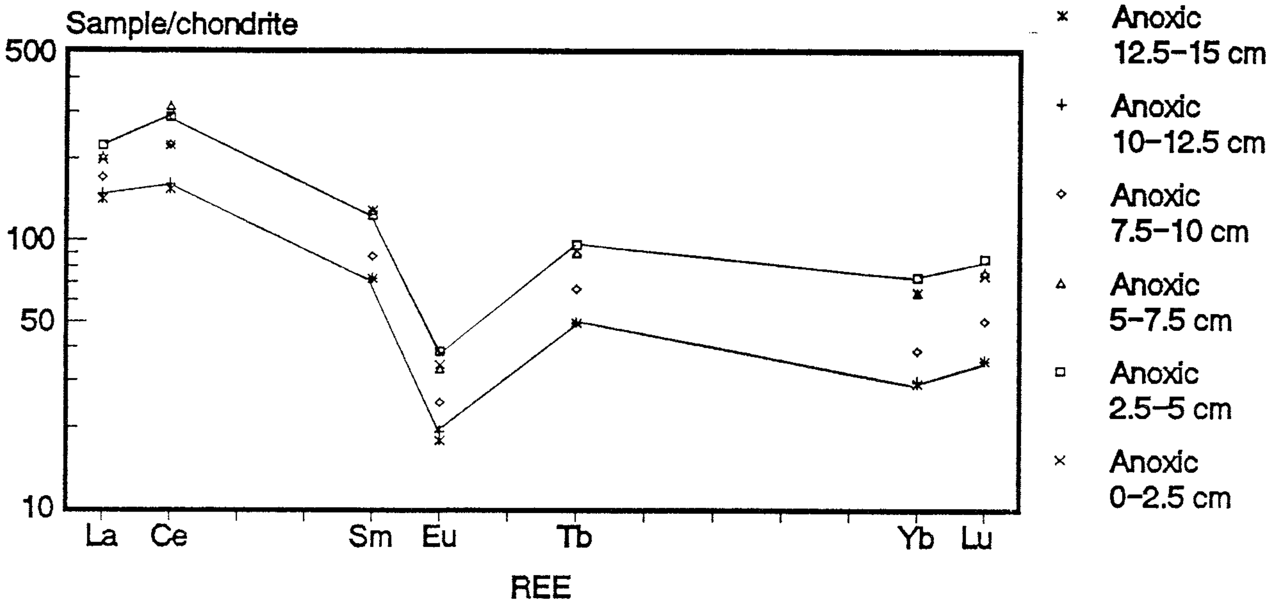

Figure 5.25 Chondrite-normalised rare earth element patterns for sediment samples at different depths. Sediment from Täckhammar anoxic spring, 890929.

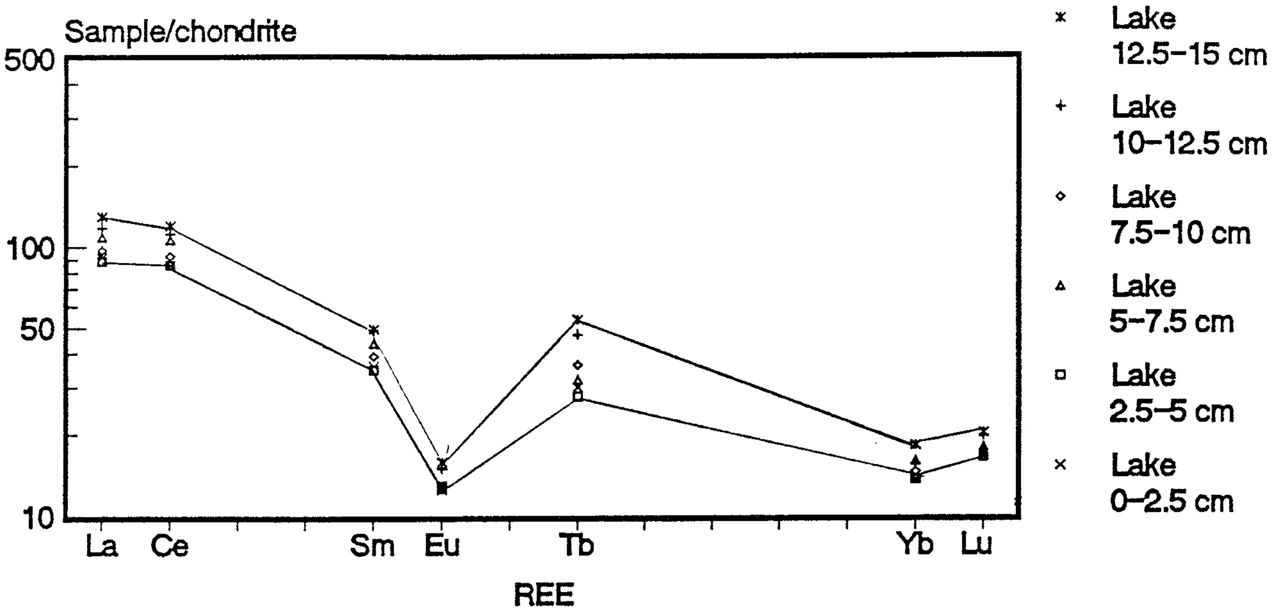

Figure 5.26 Chondrite-normalised rare earth element patterns for sediment samples as a function of depth. Sediment from Lake Långhalsen, Täckhammar site, 890929.

The first one is that the oxic spring and lake curves are quite similar, while the anoxic spring curves are on a higher level. Secondly, the oxic spring and lake values are highest in the deeper sediment layers, while on the contrary, the highest values in the anoxic spring sediment are found in the layer 0 - 2.5 cm. Thirdly, a positive Ce-anomaly is found in the anoxic spring sediment, see Figure 5.25. This type of anomaly is explained by Landström and Tullborg (1989), which assume an oxidation of Ce(III) to less mobile Ce(IV) in connection with mobilisation and removal of the trivalent REEs. While this was observed in fracture coatings, this study concerns sediment with high content of organic material. However, oxidation takes place in this sediment.

Sediment samples from Täckhammar were also sampled on 890317 in five sites. These sites are as follows,
site 1 = oxic spring, centre of the pond, site 2 = oxic spring, border, site 3 = oxic spring, near-by soil,
site 4 = anoxic spring, part north of the pond, and
site 5 = anoxic spring, south. See Appendices A.11 to A.15.

Bedrock samples were taken (and later analysed for REE contents) within 20 km radius from Studsvik, mainly in west-north direction of Studsvik. All samples have granite or granodioritic origin.

The chondrite normalised values of La, Ce, Sm, Eu, Tb, Dy, Yb and Lu are shown in Figures 5.27 to 5.29.

The sediment concentration of REE from site 1 and 3 (the oxic spring) almost exclusively increase with depth while those from site 2 (also the oxic spring) show no distinct trend (Figure 5.27). Sites 4 and 5 (the anoxic spring) show the opposite trend from sites 1 and 3, i.e., the concentration of REE is decreasing with depth.

In Figure 5.28 it can be seen that the chondrite normalised values from the springs and the bedrock may be divided into two main groups of elements, one group consisting of Ce and La and one group consisting of Eu, Tb, Yb, Dy, Lu and Sm. Cerium and lanthanum (the "first" group) have consistent higher chondrite normalised values than the "second" group.

Samarium (from the "second" group) has throughout higher chondrite normalised values than the other elements in the "second" group.

Generally the top sediment from the oxic spring has lower chondrite normalised values than the top sediment from the anoxic spring (in particular 0-5 cm depth), see Figures 5.27 to 5.29, and Tables A.20 to A.21. However, the deeper sediments of the oxic spring have higher chondrite normalised values than the anoxic spring.

The bedrock samples generally have somewhat low REE contents, and thereby slightly low chondrite normalised values (ΣREE=34.5 to 389.3 ppm, except one sample which has 685.8 ppm), compared to ordinary granitic bedrock (granites and granodiorites, ΣREE=8 to 1977 ppm, according to Cullers and Graf, 1984).

Compared to the top sediment samples (0-5 cm) from the Täckhammar springs, the chondrite normalised values for Ce and La (the "first" group) from the bedrock samples have higher values than the oxic spring, and lower values than the anoxic spring.

For the elements in the "second" group (Eu, Tb, Yb, Dy, Lu and Sm) the sediment samples from the oxic spring and the bedrock samples have generally values in the same range, while the sediment samples from the anoxic spring have higher values for the top layer (0-5 cm), and about the same values as the bedrock for deeper sediment layers.

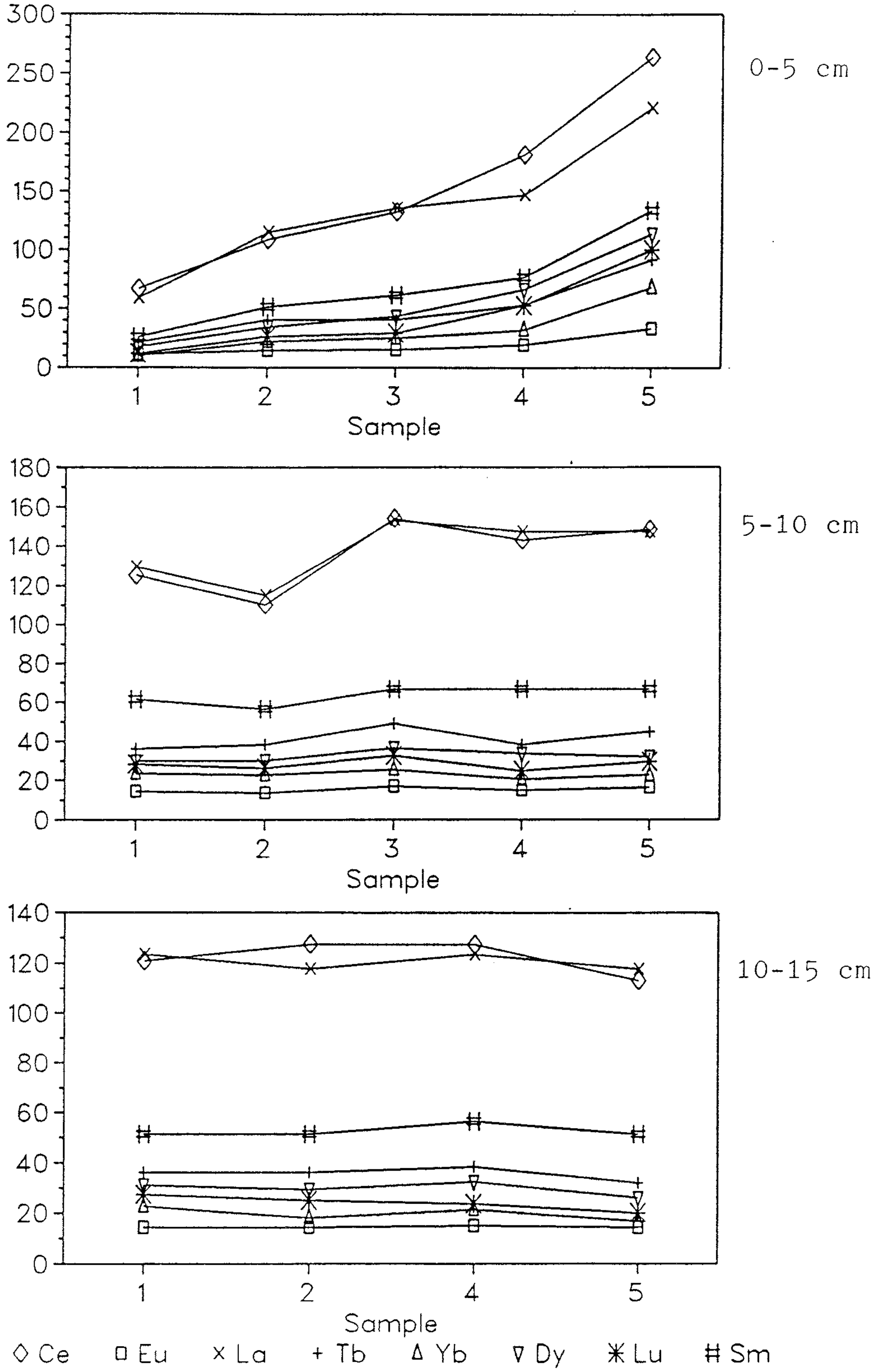

Figure 5.27 Chondrite-normalised rare earth element patterns for sediment samples as a function of depth. Sediments from Täckhammar site, 890929. Samples: 1 - oxic spring, centre; 2 - oxic spring, border; 3 - oxic spring, soil; 4 - anoxic spring, north; and 5 - anoxic spring south.

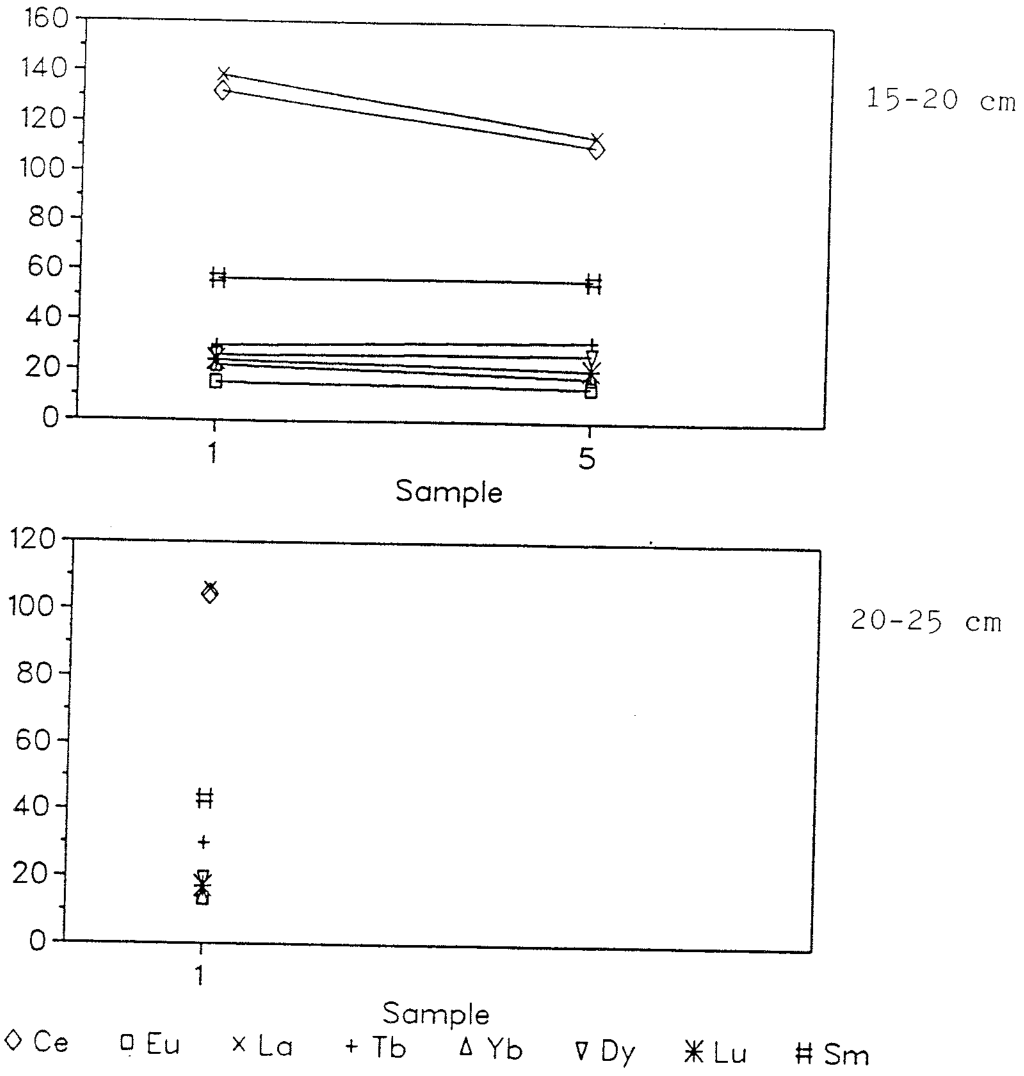

Figure 5.27 (Continued).

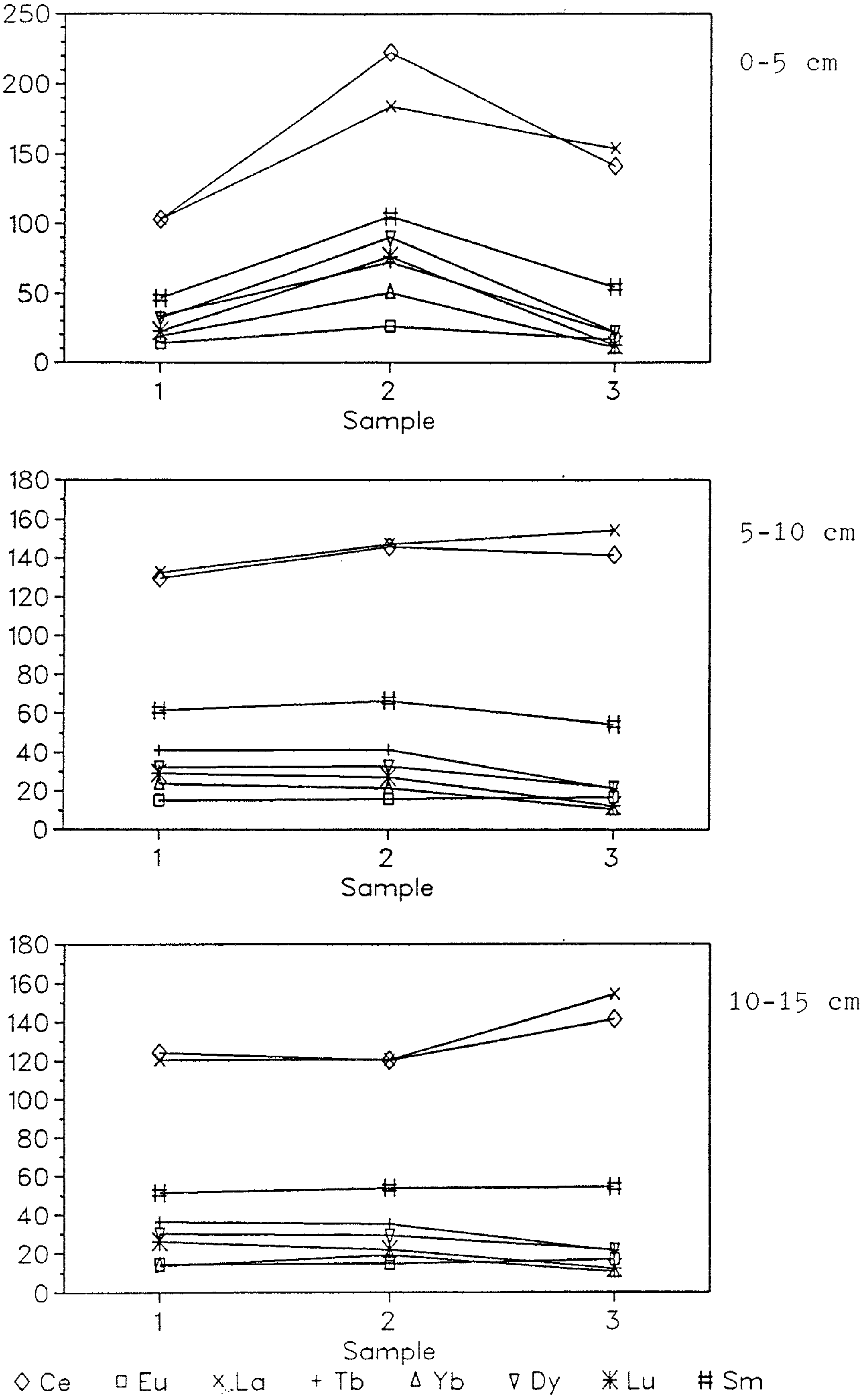

Figure 5.28 Chondrite-normalised rare earth element patterns for sediment samples as a function of depth. Mean values for samples from Täckhammar site, 890929. Samples: 1 - oxic spring; 2 - anoxic spring; 3 - granodioritic bedrock.

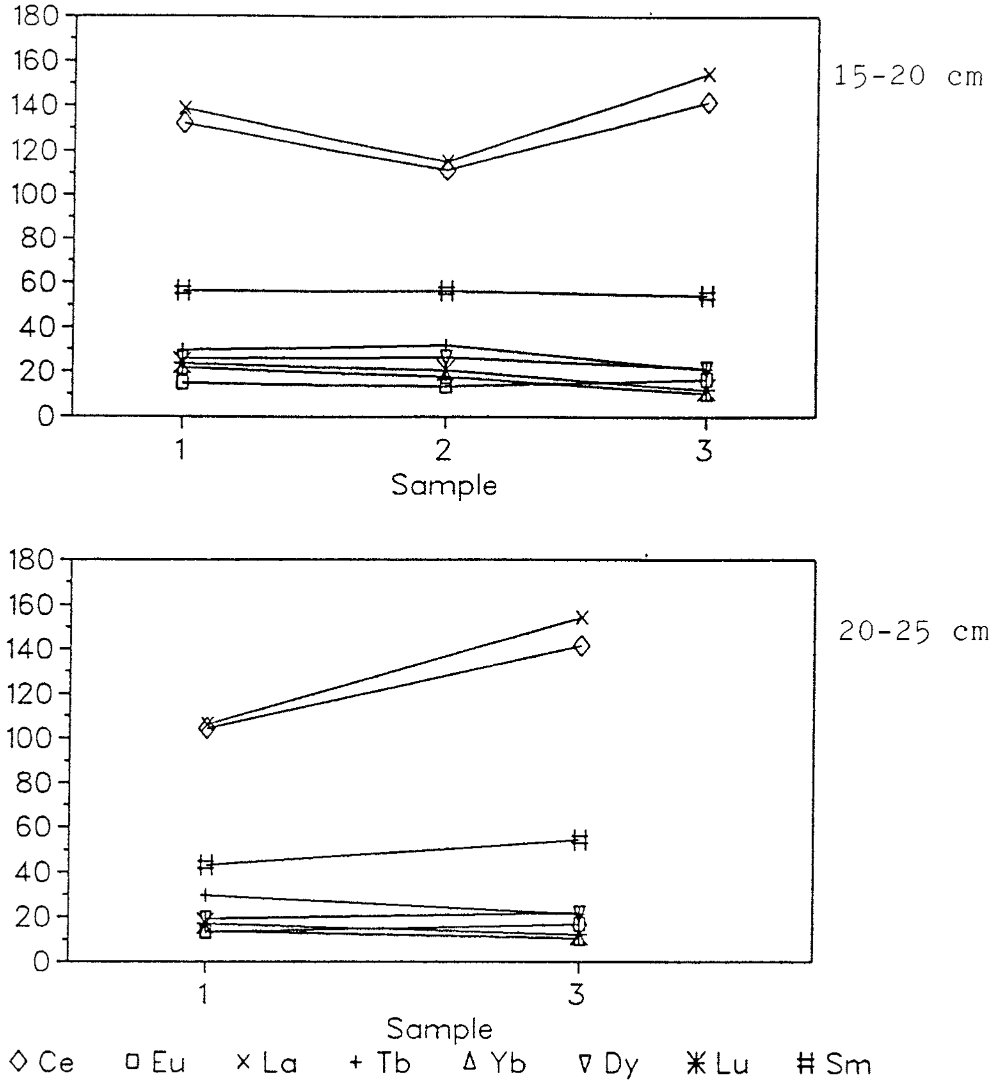

Figure 5.28 (Continued).

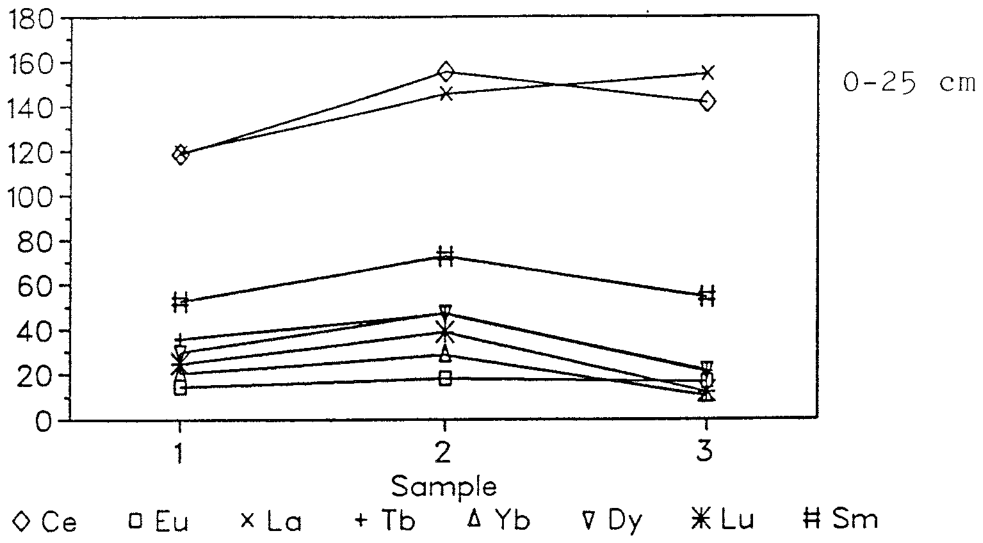

Figure 5.29 Mean values (for depths 0-25 cm) of chondrite-normalised rare earth element patterns for sediment samples. Mean values for samples from Täckhammar site, 890929. Samples: 1 - oxic spring; 2 - anoxic spring; 3 - granitic bedrock.

Differentiation ratio

A measure of the differentiation ratio between light and heavy REE can be obtained by the ratio (La/Lu)cn. The higher the value of the ratio, the steeper the slope of the REE chondrite normalised curve, indicating a higher differentiation i.e. a higher contents of the LREE compared to heavier ones (HREE).

The ratio increases with increasing depth in the sediments of the oxic spring, see Table A.24. On the other hand the ratio is either unchanged or decreasing for the top sediment. The conditions are the opposite for the anoxic spring, with decreasing ratios with increasing depth, and increasing ratio with increasing depth for the top sediment. These conditions seem to indicate an enrichment in the top sediment of the anoxic spring.

Eu-anomalies

The size of the Eu-anomalies is calculated according to (Eu/Eu*), where Eu* = (2 Sm+Tb)/3 (see Table A.22). Small values for this ratio correspond to high Eu-anomalies. The smallest ratios (i.e. the biggest Eu-anomalies) are obtained for the anoxic spring, while the highest ratios (i.e. the smallest Eu-anomalies) are found in the oxic sediments.

The bedrock samples generally show smaller Eu-anomalies, between 0.19 to 0.97, than the sediment samples(0.10 to 0.19), see Table A.23. The bedrock (granite and granodiorite) has somewhat small, or medium-sized, Eu-anomalies compared to ordinary granitic bedrock (Cullers and Grat, 1984).

5.2.8 Factor analysis

Factorial analysis was also performed for the sediment samples from the Täckhammar area. The site analysis is shown in Figure 5.30. The anoxic spring constitutes one group while the oxic and lake sites group relatively well together. The factorial analysis for the different elements is presented in Figure 5.31. The outliers are Rb, La, Ce and U. The material has also been divided into three groups according to the three different sites. It can be concluded that the U in the anoxic sediment contributes to the common pattern as shown in Figure 5.31.

The factor loadings for the three first factors are presented in Table 3. It is obvious that the positive loadings of Factor I are dominated by monovalent elements like Na, K and Rb as well as Al. On the other hand, U and REE have highly negative values. Correlation analysis also shows very high correlations between U and REE. Factor II has positive loadings mainly from Co, Sc, and Th. It is not quite clear from this analysis what the different factors stand for. However, their significance is further discussed in Section 5.4.

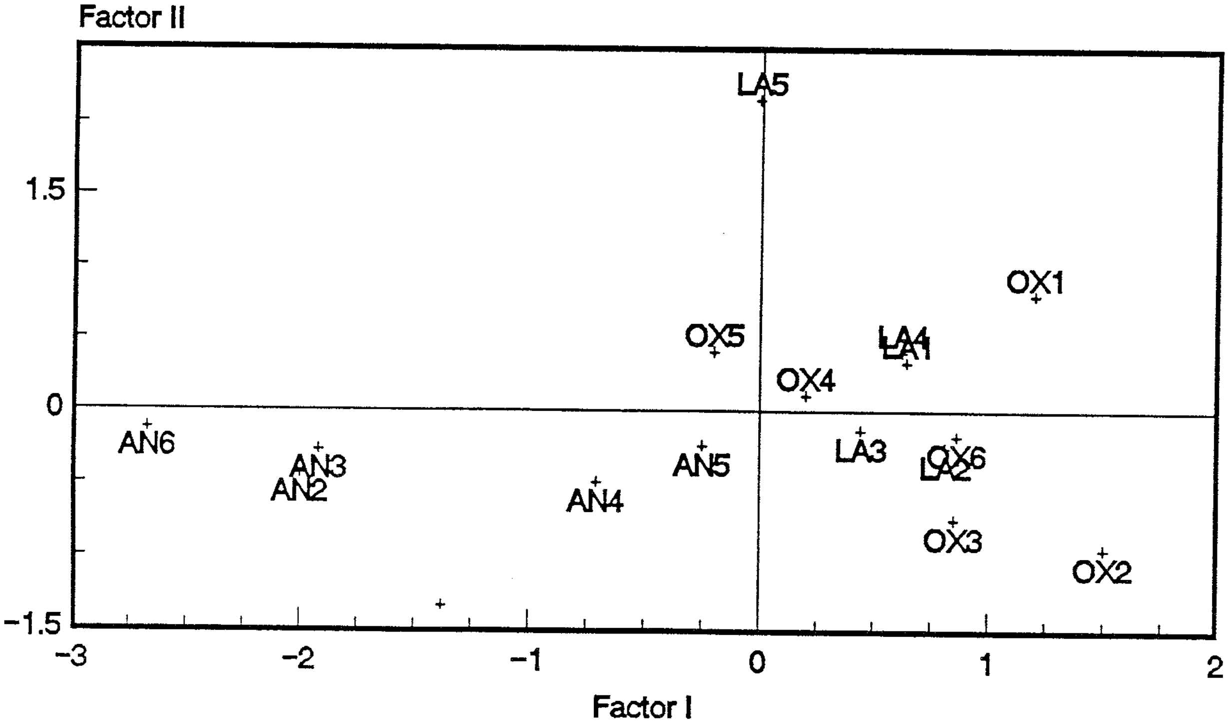

Figure 5.30 Q-mode Factor Analysis for sediment samples from Täckhammar.

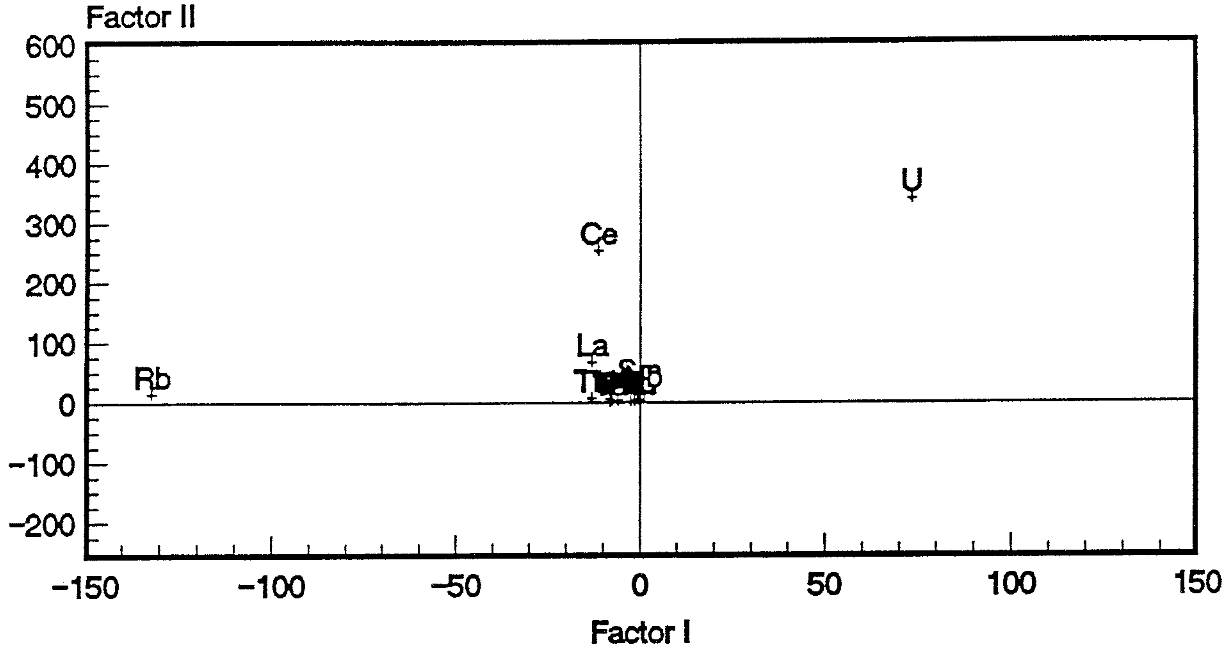

Figure 5.31 R-mode Factor Analysis for sediment samples from Täckhammar.

Table 3 The varimax rotated loadings for 20 elements (18 samples). Loadings <0.50 are not quoted.

Element	Factor I	Factor II	Factor III
Al	0.97	<	<
Ce	-0.93	<	<
Co	<	0.70	<
Cs	0.76	0.59	<
Eu	-0.96	<	<
Fe	-0.63	0.57	<
Hf	0.41	<	-0.84
K	0.97	<	<
La	-0.88	<	<
Lu	-0.97	<	<
Mn	<	<	-0.67
Na	0.96	<	<
Rb	0.97	<	<
Sc	<	0.63	<
Sm	-0.96	<	<
Ta	0.77	0.58	<
Tb	-0.91	<	<
Th	0.54	0.62	<
U	-0.85	<	<
Yb	-0.97	<	<
Eigenvalue	13.5	3.2	1.6
% of variance	67	16	8
Cumulative %	67	83	91

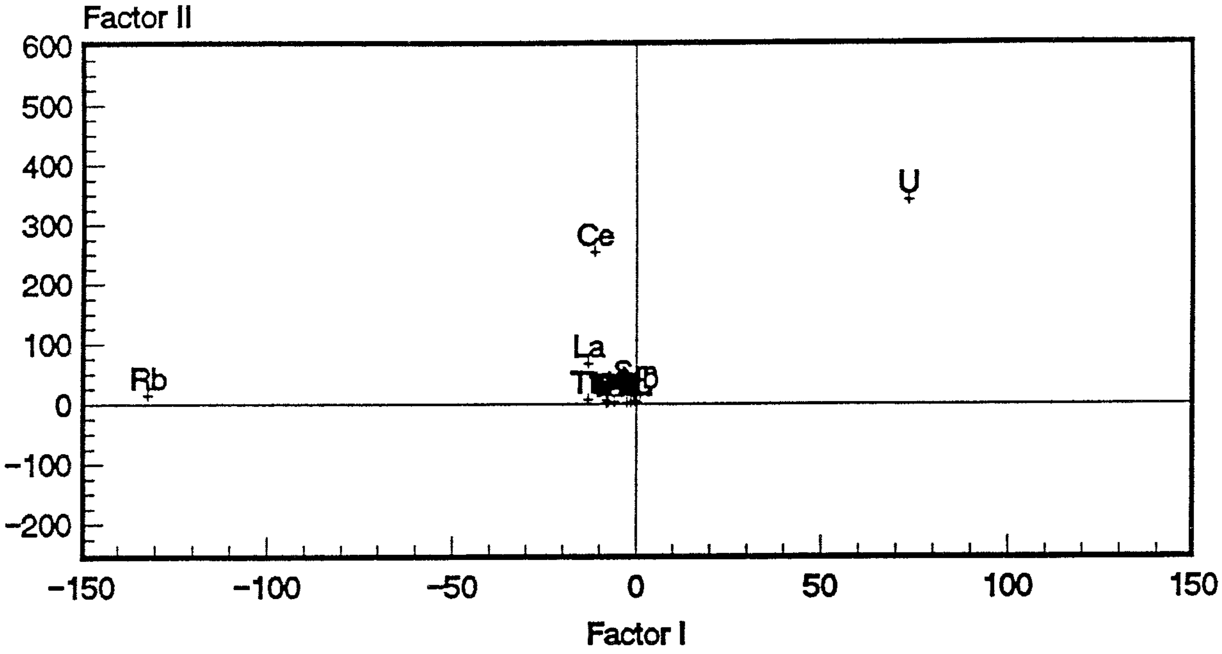

Figure 5.31 R-mode Factor Analysis for sediment samples from Täckhammar.

Table 3 The varimax rotated loadings for 20 elements (18 samples). Loadings <0.50 are not quoted.

	Factor		
Element	I	II	III
Al	0.97	<	<
Ce	-0.93	<	<
Co	<	0.70	<
Cs	0.76	0.59	<
Eu	-0.96	<	<
Fe	-0.63	0.57	<
Hf	0.41	<	-0.84
K	0.97	<	<
La	-0.88	<	<
Lu	-0.97	<	<
Mn	<	<	-0.67
Na	0.96	<	<
Rb	0.97	<	<
Sc	<	0.63	<
Sm	-0.96	<	<
Ta	0.77	0.58	<
Tb	-0.91	<	<
Th	0.54	0.62	<
U	-0.85	<	<
Yb	-0.97	<	<
Eigenvalue	13.5	3.2	1.6
% of variance	67	16	8
Cumulative %	67	83	91

5.3 WATER ANALYSIS

Results from the water analysis are shown in Tables B.1 to B.4. Chemical equilibrium calculations have been performed with the computer program EQ3NR (Wolery, 1983) on the data of Table B.1 for the Täckhammar site. The calculated electrical imbalance is 3.7 % of the total charge for the data from the oxic spring, and 3.0 % for the anoxic spring. This indicates a good quality for the chemical analysis.

A general characteristic of the discharging groundwaters sampled here is their low redox potential. Lowest redox potentials were measured at spring A in the Hillesjön site (Table B.4). This water shows the highest ionic strength, as well as highest contents of iron and manganese contents, which is due to the lower solubility of Fe(III) and Mn(IV) hydroxides that precipitate at higher redox potentials. The dependence of metal solubility on redox potential is also reflected in the uranium concentrations in the Täckhammar area (Table B.1).

A comparison between the samples of the two Täckhammar springs taken on March and May 1989, show a 10 % dilution of the major ions due to seasonal effects, indicating that the main underground path of the discharging groundwaters has a relatively short flow-through time.

The processes of interest for this study are those taking place at the interface between the groundwater-surface water environments. Chemical processes are induced by the influence of atmospheric gases, specially CO_2 and O_2. Biologically influenced processes are the adsorption of trace metals by organic matter, which might affect the redox state of the adsorbed metal ions.

Equilibration with atmospheric carbon dioxide usually requires degassing, as the atmospheric partial pressure of CO_2 (0.00033 atm) is lower than the equilibrium CO_2 partial pressure of the groundwaters (e.g., for the oxic and anoxic springs in Täckhammar, $\log(pCO_2) = -2.84$ and -2.90 atm respectively). The degassing process is described as,

$$HCO_3^- \rightarrow CO_2(g) + OH^-$$

resulting in a pH increase. This pH change will induce the precipitation of minerals (hydroxides, carbonates, clay minerals) as they become oversaturated. Oxygen dissolution into the discharging groundwaters will cause iron and manganese hydroxide precipitation, e.g.,

$$2.5\ H_2O + Fe^{2+} + 0.25\ O_2(g) \rightarrow Fe(OH)_3(am) + 2\ H^+$$

Due to trace metal coprecipitation and adsorption on the amorphous hydroxide surface, other metal ions are as well removed from the groundwater through this process.

These processes are reflected in the water samples taken from the Täckhammar site. The iron(II) concentration, for example, varies from 0.12 mg/l in the anoxic spring water, is reduced to 0.02 mg/l at a distance of some 100 m along the discharging creek, and has a value of 0.01 mg/l at the lake shore.

Saturation states for some minerals (calculated with the EQ3NR computer program) are reported in Table 4 below for samples from the Täckhammar springs. The results show an expected small oversaturation with respect to iron and aluminium hydroxides, which is the result of insufficient filtration and slight air contamination. Uranium saturation indices show that the anoxic spring is nearly saturated with uraninite. On the other hand, the water from the oxic spring, which has a higher Eh, is undersaturated with uraninite and not oversaturated with schoepite, indicating that dissolution of U(IV) minerals (uraninite, coffinite ($USiO_4$), etc) in the bedrock is taking place along the groundwater's flow path, but that precipitation of secondary uranium(VI) minerals is yet to begin. Although soddyite oversaturation indicates that uranium(VI) silicate minerals might be precipitating from that groundwater, the uncertainty in the saturation index (±3 log-units, which originates in the uncertainty in the thermodynamic data for this mineral) is too high to draw any quantitative conclusions.

Pore water concentrations are compared with respective sediment values in Figures 5.32 and 5.33 for sediment cores from the anoxic spring and lake Långhalsen in the

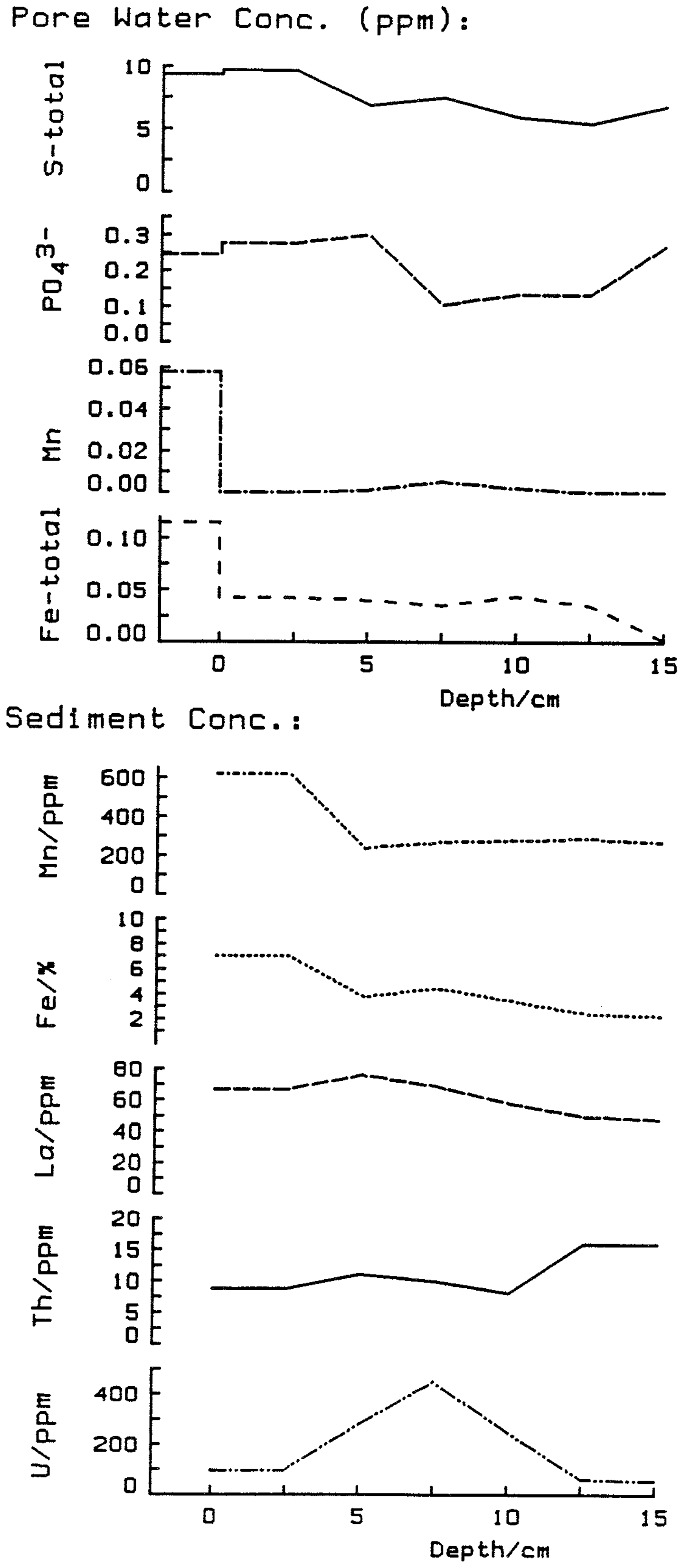

Figure 5.32 Sediment and pore water contents for Täckhammar anoxic spring, sampled 890829.

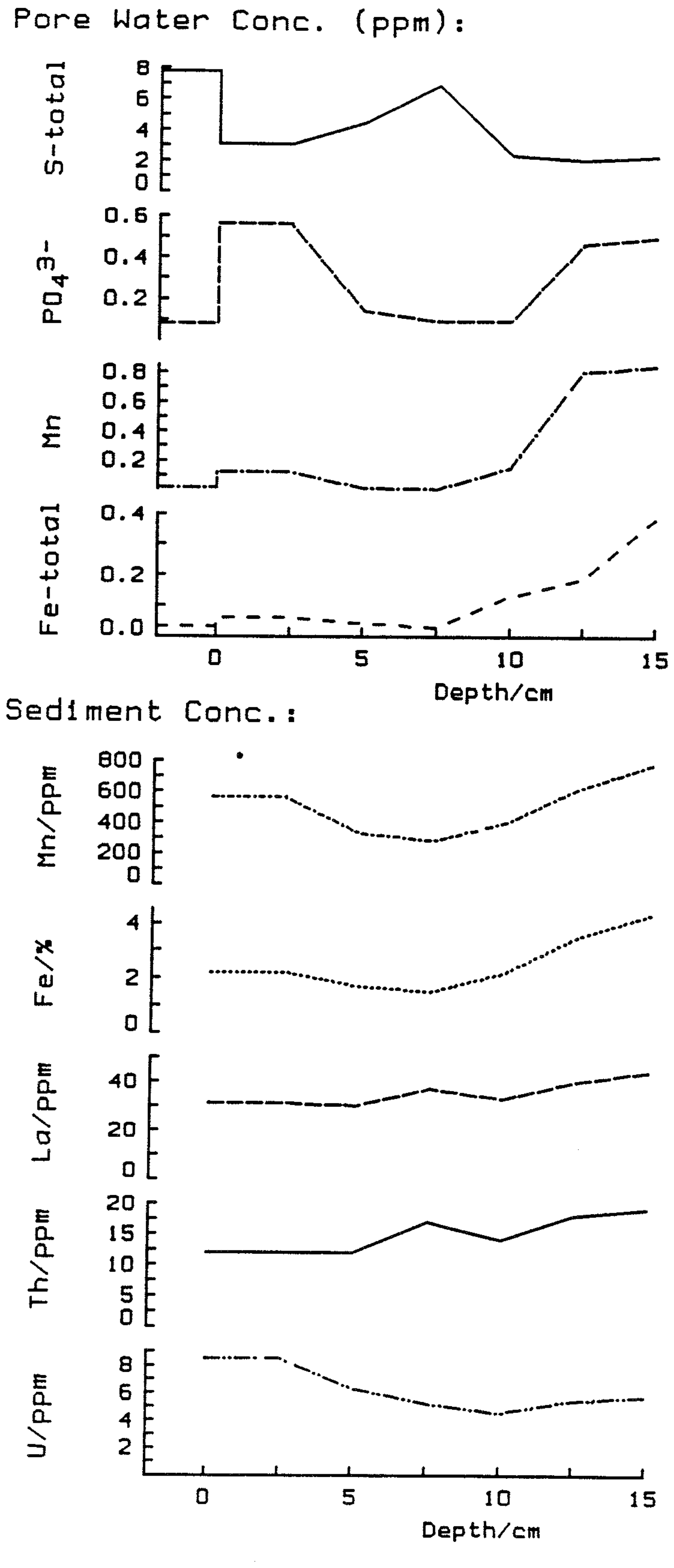

Figure 5.33 Sediment and pore water contents for Lake Långhalsen, Täckhammar site, sampled 890829.

Table 4 Calculated saturation indices for groundwaters from the Täckhammar site, sampled 1989-05-18.

Mineral	log IAP/Ksp	
	Oxic Spring	Anoxic Spring
Quartz	0.730	0.762
Calcite	-0.062	0.097
Strontianite ($SrCO_3$)	-2.543	-2.402
Rhodochrosite ($MnCO_3$)	-1.813	-0.824
Rutherfordine (UO_2CO_3)	-4.273	-4.880
Fluorite	-0.403	-0.487
Gibbsite ($Al(OH)_3$)	1.423	1.431
$Fe(OH)_3$(am)	0.569	0.436
Uraninite (UO_2)	-11.826	-0.533
Coffinite ($USiO_4$)	-11.681	-0.355
Schoepite ($UO_2(OH)_2 \cdot H_2O$)	-3.635	-4.151
Soddyite ($(UO_2)_2SiO_4 \cdot 2H_2O$)	0.983	-0.067

Täckhammar area. The sediment core from the anoxic spring shows higher contents of Fe, U and REE. On the contrary, the pore waters from the anoxic spring core, have lower concentrations of total iron, sulphur, manganese and phosphor. In the sediment core from the lake Långhalsen, the depth-dependence of the sulphur concentration of the pore waters, is inversely correlated with the phosphor contents (Figure 5.33), while aqueous manganese and iron concentrations increase with depth. A measurement of the redox potential in situ for this sediments, gave a continuous variation of Eh with depth between +100 and -50 mV.

5.4 INTER-SITE COMPARISONS

Several sediment fractions must be distinguished when a comparison between sites is made of the sediment analysis reported in the Appendix. Figures 5.34 to 5.38 show element distributions for sediment cores from all sites studied. The diagrams show for example that Co concentrations are lowest in the Täckhammar area, while Hf levels are higher in this area.

An important sediment fraction is associated with clay minerals. This is represented by the Al-contents, which is correlated with the alkaline metals. We have chosen Rb as a master variable for this fraction, see Figure 5.34.

Other chemical elements which appear to be present in this fraction are Sc, Cr, Th and Ta. Some of these elements are retained in clays by ion exchange processes, while other metals are retained through adsorption. Grains and particles originating from erosion of the bedrock, and transported by physical processes into the sediments will also be present in this Al-containing fraction (c.f. Section 5.5).

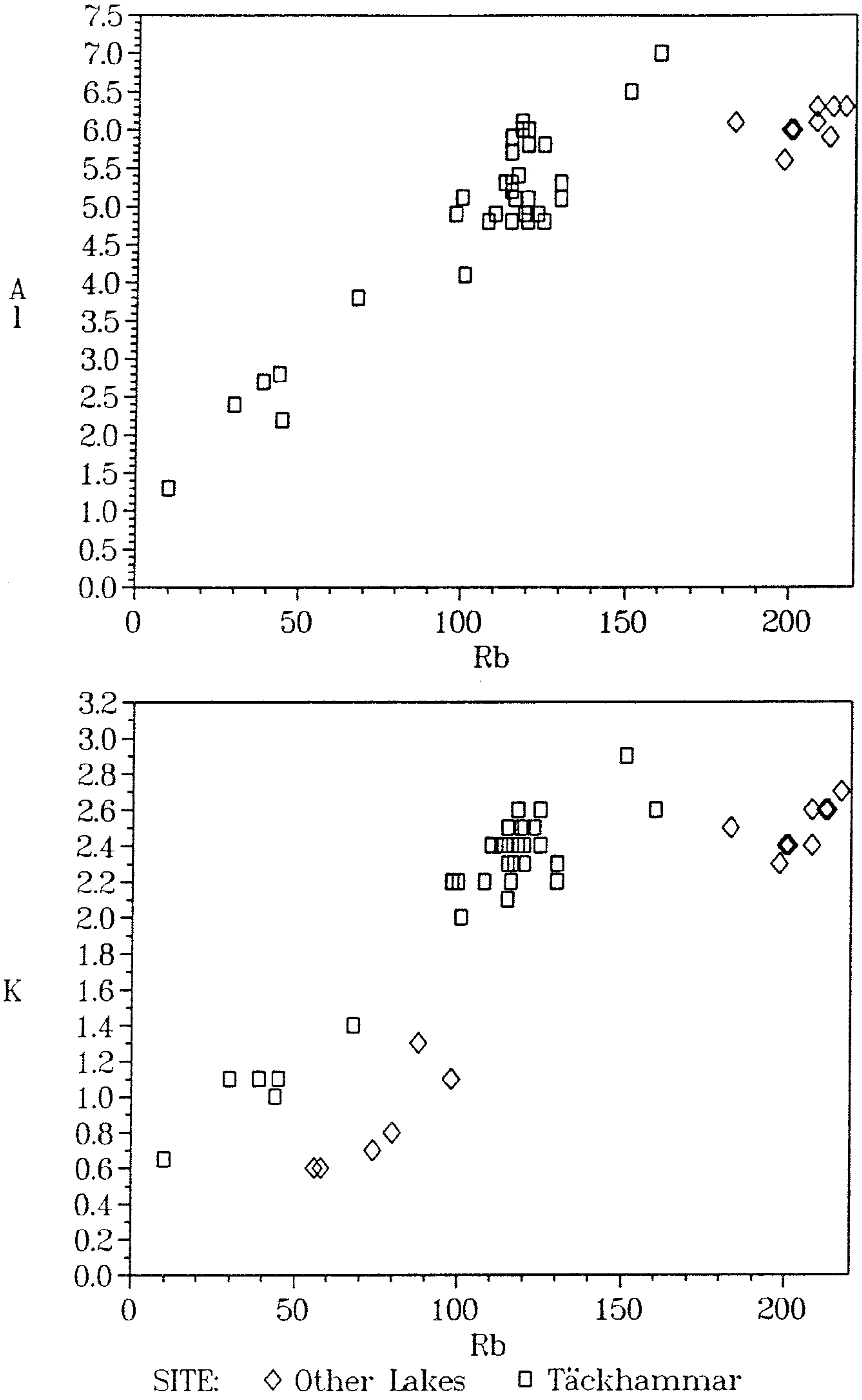

Figure 5.34 Correlations between rubidium contents (ppm dry weight) and Al, K (%) and Cs, Sc, Cr, Th and Ta (ppm) for sediment cores from the sites studied.

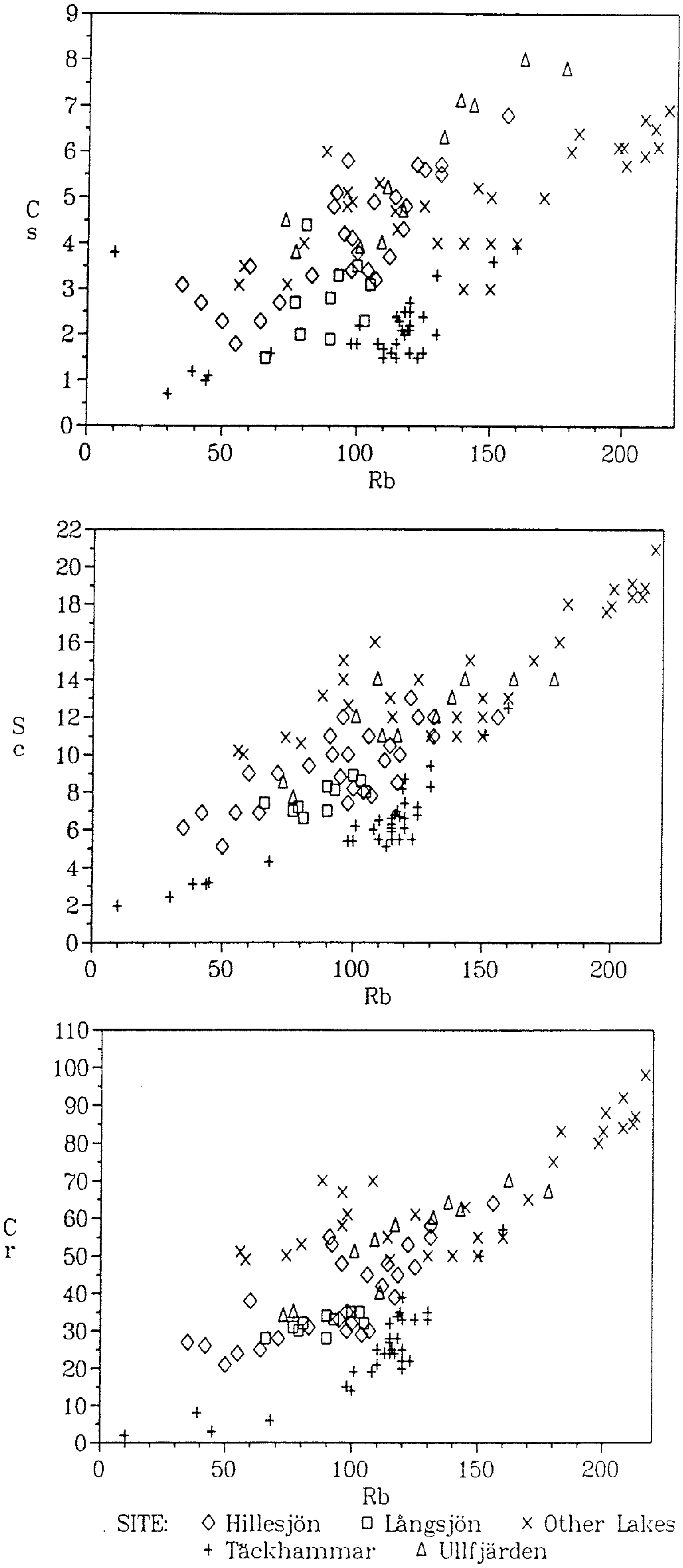

Figure 5.34 (Continued).

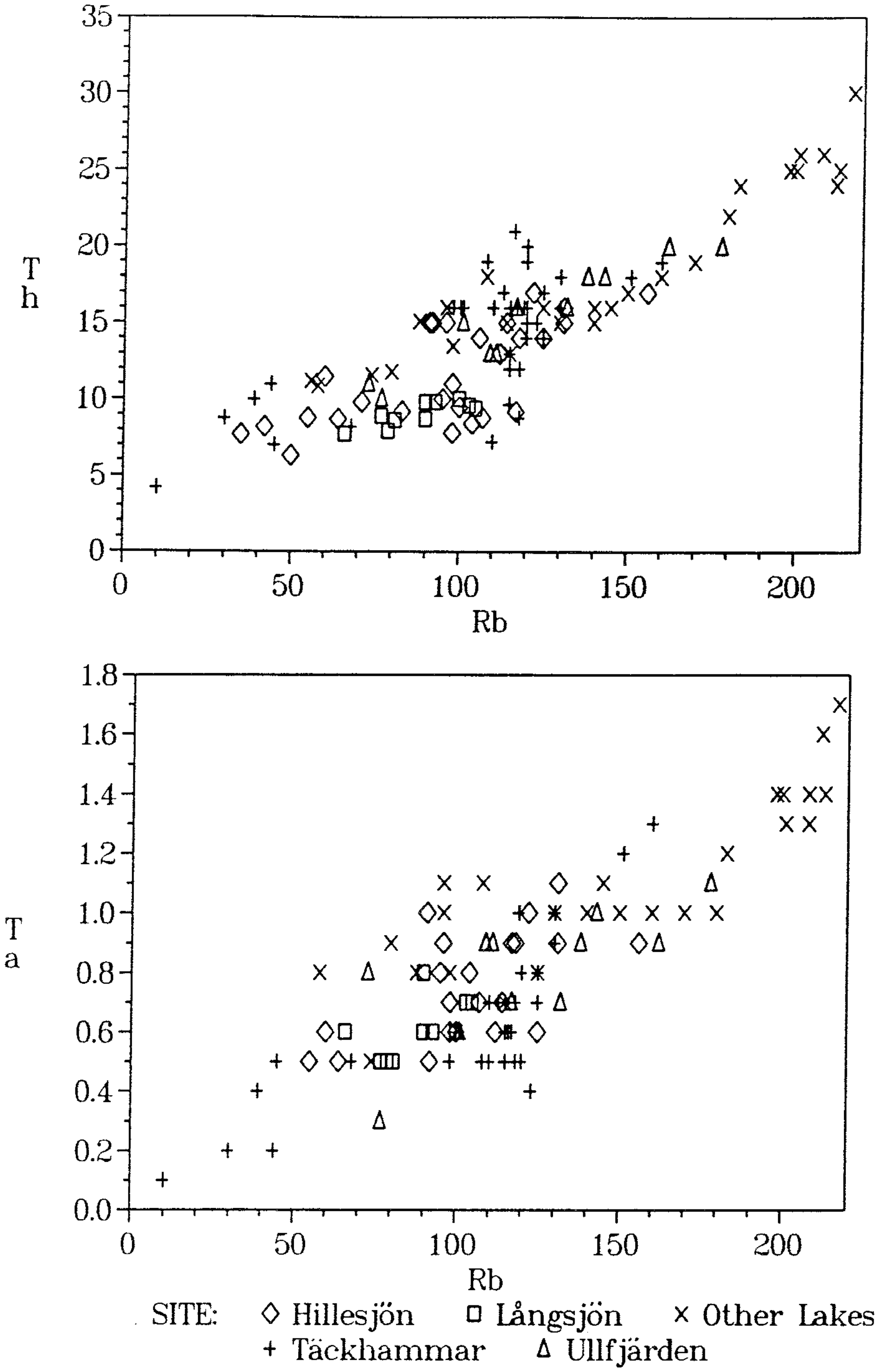

Figure 5.34 (Continued).

Other main components in the sediments studied here are organic material, Fe/Mn hydroxides, and metal sulphides. The correlation between sediment organic contents and Fe, as well as Zn and U with org. contents is shown in Figure 5.35. This relationships may be due either to a higher flora growth in reducing, trace metal rich waters, or to an increased hydroxide precipitation on the surface of decaying organic matter. Other chemical elements in this sediment fraction show weak correlations, like U/Ce, REE elements among themselves, Co/Fe, As/Fe, Mn/Fe, Ba/Fe and La/Fe (c.f. Figure 5.36).

The results from the Factor Analysis performed in the Hillesjön and Täckhammar sites (Tables 2 and 3) are in qualitative agreement with the inter-site correlations. Factor II in Table 2 (Hillesjön), has positive loadings from the alkaline metals, Cr, Sc and Th, which may be assigned to the clay fraction, while Factor I in the same Table, which corresponds to another sediment fraction, has positive loadings from Fe and REE. In Table 3 (Täckhammar) Factor I corresponds to both the clay and the Fe-Org fractions (high positive loadings of Al and alkaline metals, negative loadings of Fe, REE, U). In fact, only one Factor should be needed to describe the sediments, as both sediment fractions are complementary (high contents of clay minerals must correspond to low contents of organic-metal hydroxide materials).

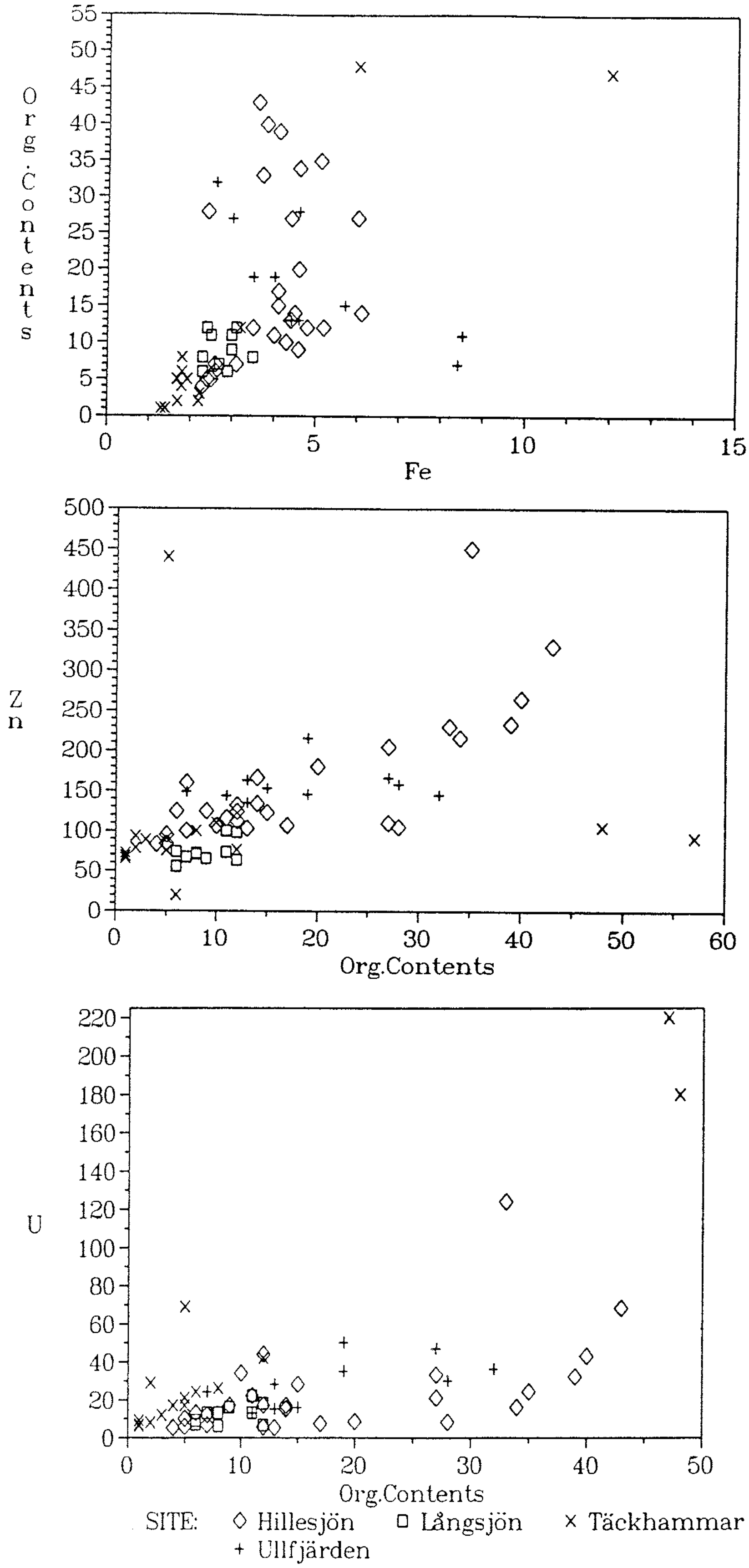

Figure 5.35 Correlations between organic contents (% dry weight) and Fe (%), Zn and U (ppm) for sediment cores from the sites studied.

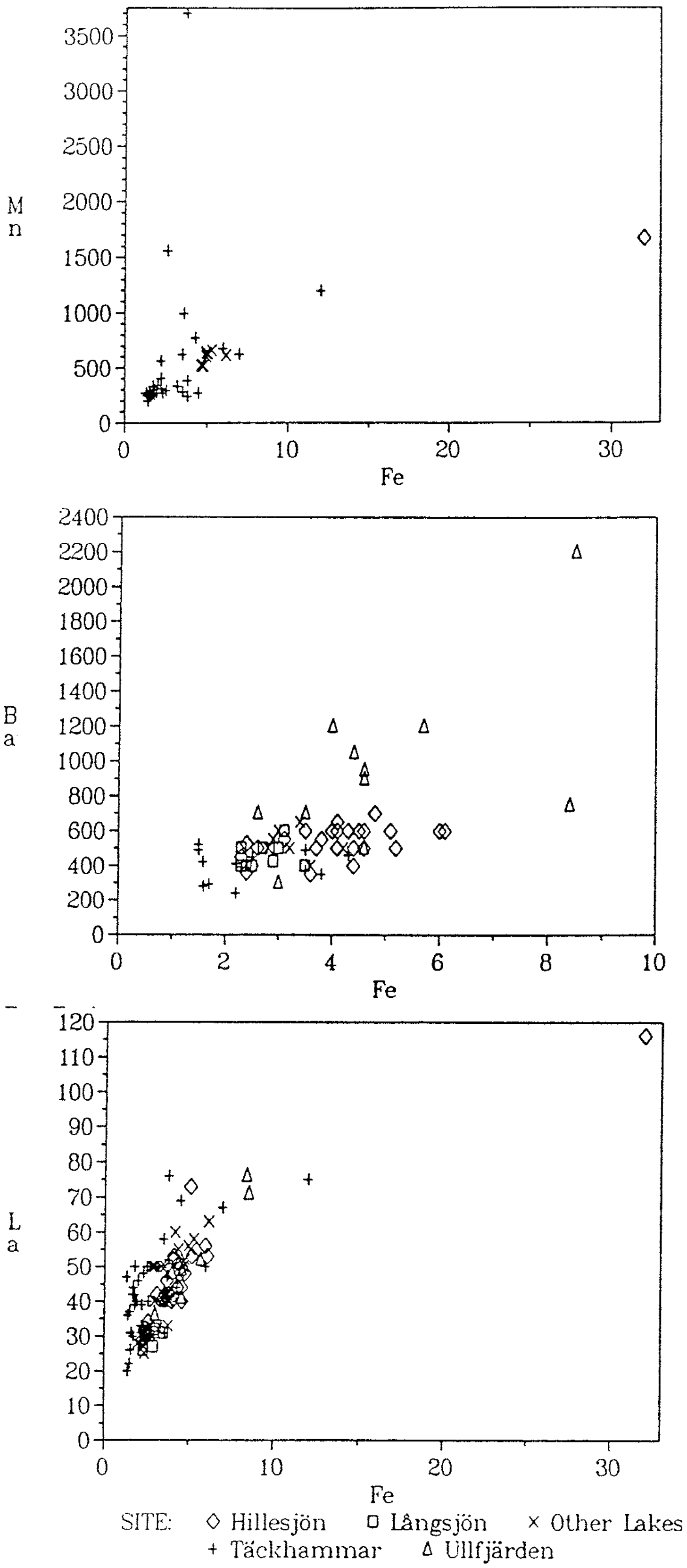

Figure 5.36 Correlations between Fe contents (% dry weight) and Mn, Ba and La (ppm) for sediment cores from the sites studied.

5.5 WEATHERING AND DEPOSITION

Chemical weathering processes in the bedrock will dissolve mineral components and precipitate secondary minerals. Metallic elements present in the primary mineral components will be partly dissolved and transported with discharging groundwater into the biosphere, where they will be deposited, for example, they may precipitate (forming secondary minerals) or adsorb into lake sediments.

However, some of the chemical elements in granitic rocks are mainly present in minor refractory minerals (apatite ($Ca_5(PO_4)_3OH$), monazite ($CePO_4$), zircon ($ZrSiO_4$), sphene ($CaTiSiO_5$), allanite ($Ce_2(Al/Fe)_3(SiO_4)_3OH$), etc). For chemical elements present in refractory minerals, a probable transport mechanism between geosphere and biosphere is by physical weathering processes (erosion), by which particles of refractory minerals are transported, usually by superficial waters.

The group IVA elements (titanium, zirconium and hafnium) are well distributed in the geosphere, and usually present in heavy refractory minerals which often accumulate in sedimentary areas (beach deposits). Niobium and tantalum, which are group VA elements, are also nearly insoluble in aqueous solutions. In aqueous solutions they usually are present as polymeric anionic species of oxidation state +V.

The immobility of these elements is confirmed by the sediment analysis of this study. Concentrations of Hf, Ta and Th show a correlation with the aluminium-containing fraction of the sediments, which is constituted both by clay (formed by chemical weathering) and sand particles (from eroded bedrock). The correlations between sodium and hafnium, aluminium and both tantalum and thorium are shown in Figure 5.37, while the relationship between tantalum and rubidium is given in Figure 5.35.

Of these elements (Ti, Zr, Hf, Nb and Ta), hafnium and tantalum are the easiest to analyse in sediment samples by neutron activation (the analytical method used in the present work), and usually with higher precission than for example Zr or Ti. Therefore, and according to a suggestion by Landström (1990), hafnium is selected in this study to differentiate the sediment fraction originating from refractory and other physically weathered minerals.

For example, it is possible to divide the total lanthanum contents, $[La]_i^T$, of a sediment sample "i" into two parts, one proceeding from physically weathered particles (here represented by the Hf-contents), and another fraction formed by dissolved lanthanum (i.e., not bound to particles) transported by ground or superficial waters, and precipitated or adsorbed into the sediment ($[La]_i^d$),

$$[La]_i^T = [La]_i^d + A\ [Hf]_i^T \qquad (5.5.1)$$

where A is a proportionality constant, which is equal to the ratio between lanthanum and hafnium in the parent bedrock. If we have the same phenomena for iron,

$$[Fe]_i^T = [Fe]_i^d + B\ [Hf]_i^T$$

where B is also a constant, in this case equal to the ration between iron and hafnium in the parent bedrock. It is then possible to write

$$[La]_i^d/[Hf]_i^T = [La]_i^T/[Hf]_i^T - A$$

$$[Fe]_i^d/[Hf]_i^T = [Fe]_i^T/[Hf]_i^T - B \qquad (5.5.2)$$

If there is a correlation between all $[La]_i^d$ and $[Fe]_i^d$,

$$[La]_i^d/[Hf]_i^T = B°\ [Fe]_i^d/[Hf]_i^T \qquad (5.5.3)$$

where B° is again a constant. Substituting eqn. (5.5.2) in (5.5.3),

$$[La]_i^d/[Hf]_i^T = B°\ [Fe]_i^T/[Hf]_i^T - BB° \qquad (5.5.4)$$

and rearranging eqn. (5.5.1)

$$[La]_i^T/[Hf]_i^T = [La]_i^d/[Hf]_i^T + A \qquad (5.5.5)$$

and substituting eqn. (5.5.4) into (5.5.5)

$$[La]_i^T/[Hf]_i^T = (B°\ [Fe]_i^T/[Hf]_i^T - BB°) + A$$

which can be simplified to the linear relationship

$$[La]_i^T/[Hf]_i^T = A' + B°\ [Fe]_i^T/[Hf]_i^T \qquad (5.5.6)$$

Thus, with the assumptions made,

1 hafnium is present in the sediments only as particles of refractory minerals

2 La and Fe may be divided into two sediment fractions:
- chemically weathered and deposited
- "refractory fraction"

3 there is a correlation between the chemically weathered fractions of La and Fe

there should be a linear relationship between

$$[La]_i^T/[Hf]_i^T \text{ and } [Fe]_i^T/[Hf]_i^T,$$

as indicated by eqn. 5.5.6, and illustrated in Figure 5.38. Similar effects are achieved if Ta or Th are used as immobile elements.

The third assumption (correlation between the chemically weathered fractions of La and Fe) will in general not be fulfilled. Such a correlation may only be expected in certain cases, for example: a) as a result of a dilution process, b) where the deposition process (adsorption or precipitation) has the same pH-dependence for both chemical elements (i.e., for metal cations with similar characteristics), c) coprecipitation of a trace element (e.g., a rare earth) with iron or manganese oxide or hydroxide, d) adsorption (or complex formation) with organic material, etc.

The use of an immobile element to calculate the degree of chemical weathering is not an unusual concept. In a somewhat different form, it has been used by Nesbitt (1979), Middelburg et al (1988), etc.

The Hf-corrected correlations between Mn and Fe, and between Eu and La are shown in Figure 5.39 (compare with Figure 5.36 for uncorrected Mn versus Fe).

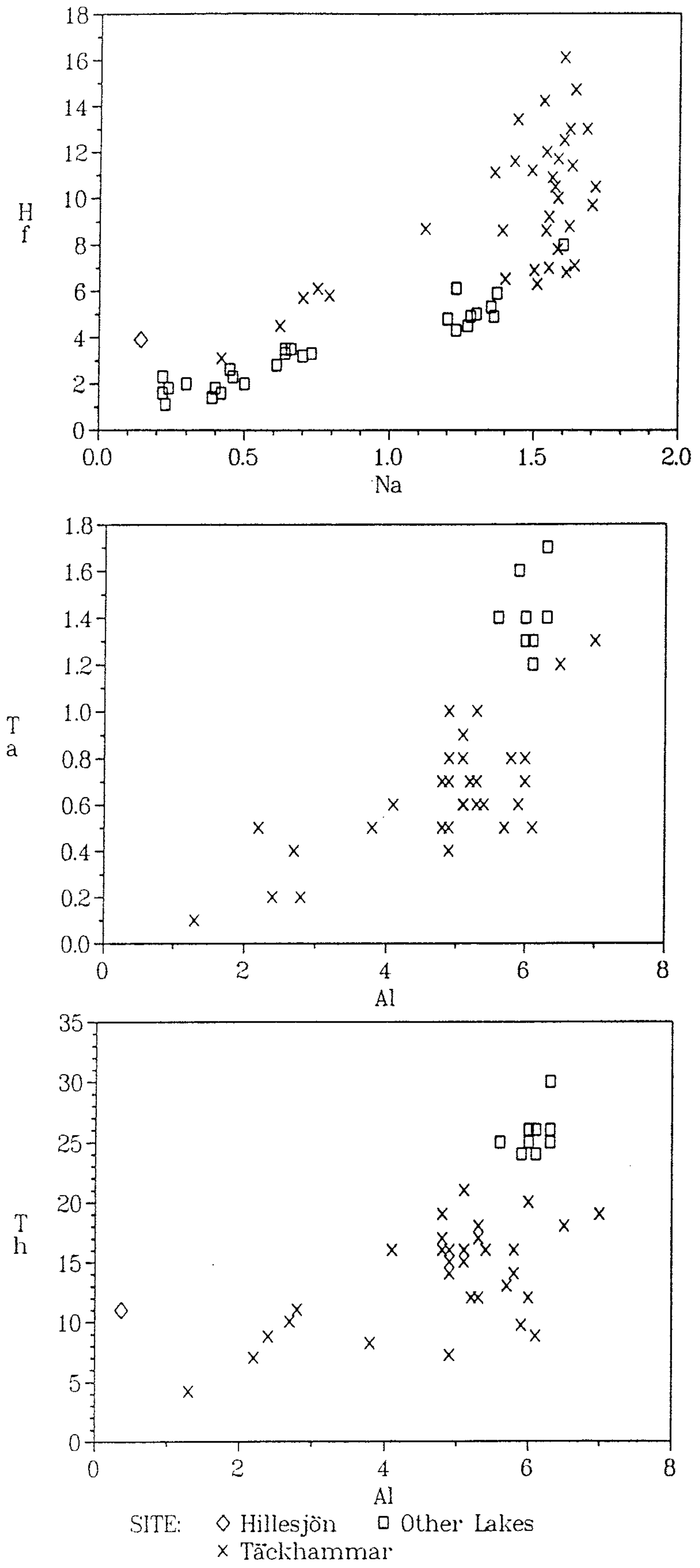

Figure 5.37 Correlations of Hf with Na (top plot), and Al with both Ta and Th, for sediment cores from the sites studied.

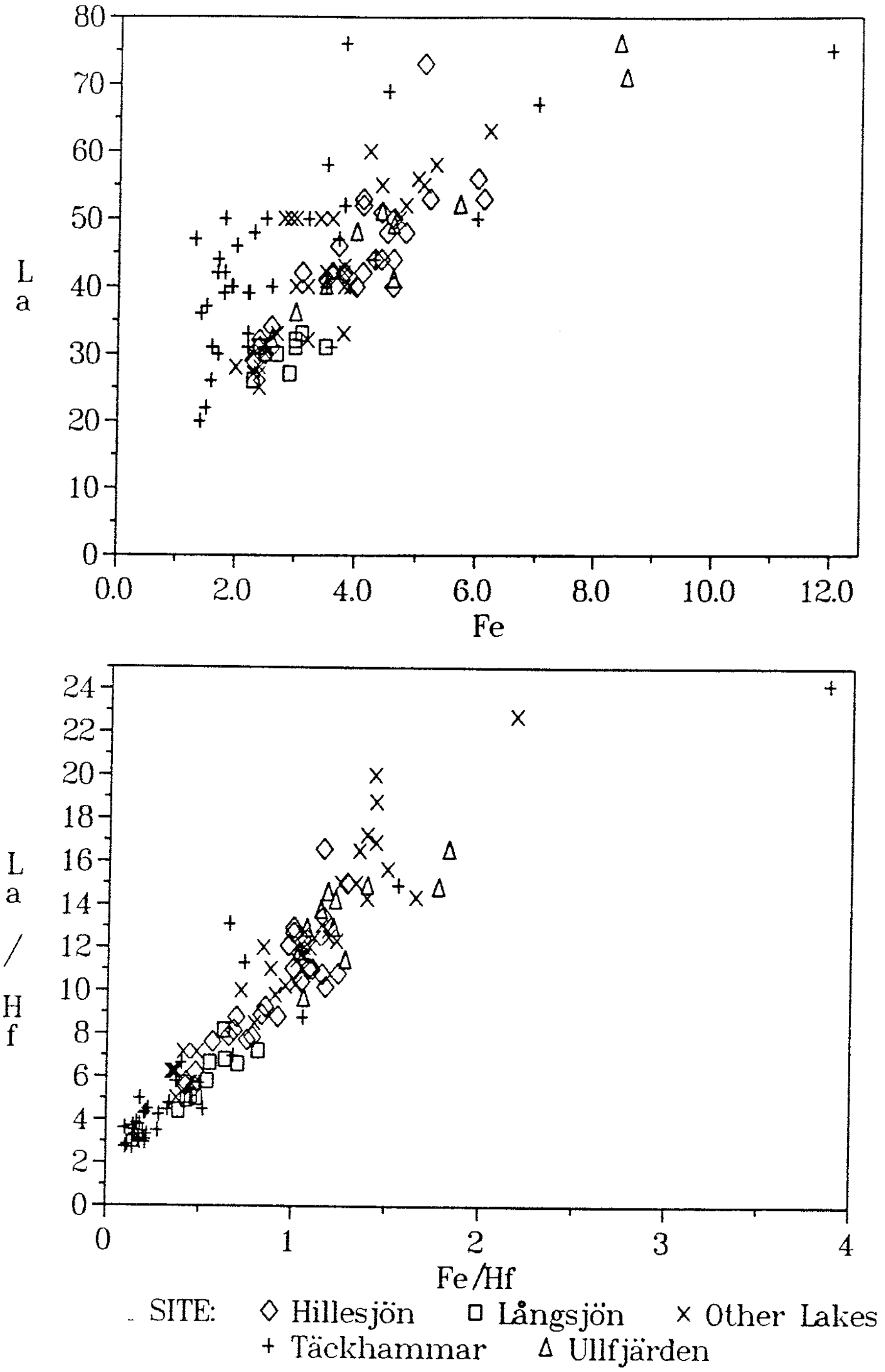

Figure 5.38 Comparison between the correlations La (ppm) versus Fe (%) and La/Hf versus Fe/Hf for sediment cores from the sites studied. To increase the detail of the plots, the sample for Spring B, Hillesjön site, has been excluded (c.f. Figure 3.36).

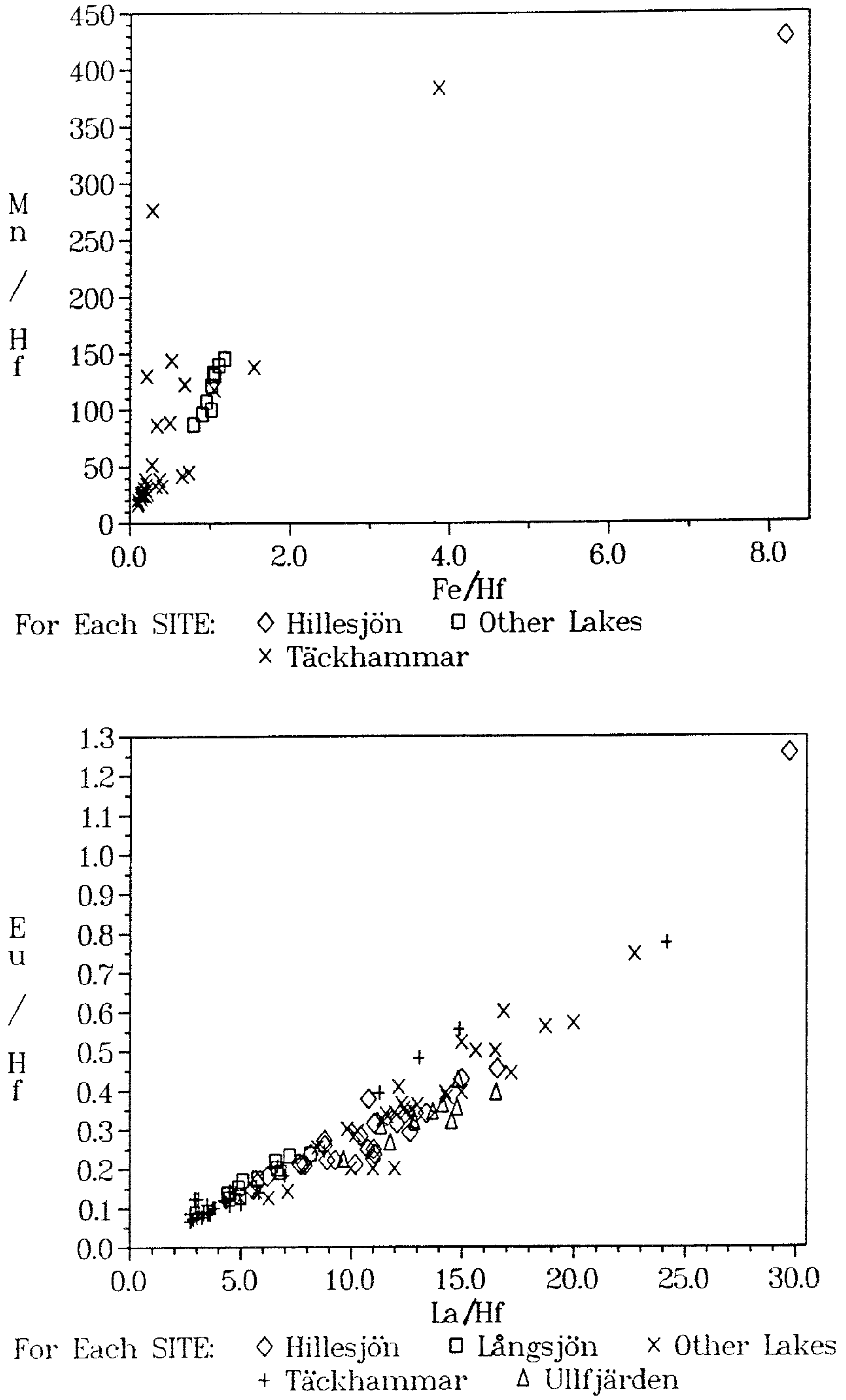

Figure 5.39 Correlations between Mn/Hf and Fe/Hf, and between Eu/Hf and La/Hf for sediment cores from the sites studied.

5.6 THE TURNOVER OF RADIONUCLIDES IN LAKE ECOSYSTEMS

One of the main aspects of this project is to study and estimate the behaviour of radionuclides in the sediment. Most of the processes are supposed to be very slow. However during some cirqumstances a rapid transfer can take place.

The study at Lake Hillesjön was initiated after the Chernobyl accident. A rapid transfer of the desposited radionuclides as Ru-103, I-131, Cs-134 and Cs-137 from the lake water to the sediment was observed (Evans et al,1988). On the other hand, a transfer in the opposite direction, i.e. seepage from the sediment to the lake water has been observed (Sundblad et al, 1990).

During the four year period 1986 to 1990 the observed net loss of Cs-137 from the sediment was about 30 % of the deposited amount. However the net loss has decreased to a level of 1 to 2 % in 1990. This result indicates that there can be a substansial transfer of radionuclides from a shallow lake ecosystem. On the other hand one has to be careful comparing the behaviour of radionuclides deposited from the water column with the radionuclides transfered by the groundwater through the sediment.

In the Sibbo- and Trobbfjärden study leakage of Cl from the sediment was observed (Sundblad 1986). On the other hand these leakage of Cl was due to the change from a brackish to a freshwater system.

However it can be possible to study the balance of for example uranium in a lake ecosystem to find out if uranium will be transfered from the sediment to the lake water lake the observed transfer of cesium.

6 CONCLUSIONS

Correlation and Factor Analysis have identified several main sediment fractions in the cores from the sites studied. One fraction is related to the clay contents, while other major fractions contain organic material, Fe hydroxides, eroded grains, etc.

The amount of organic contents of the sediment seems to be an important variable when discussing retention processes in groundwater discharge areas.

Enrichment of U is observed in areas of groundwater seepage. Uranium appears to be associated with the organic rich layers of the sediments. Comparison of Th/u ratios also shows a higher mobility and enrichment of U compared to Th.

Cs-137 from the Chernobyl fallout has been analysed and shows a clear relation between seepage velocity and the amount of activity in the sediments.

The sediment samples from the oxic and anoxic springs in Täckhammar have chondrite normalised REE-curves with distinct Eu-anomalies. These curves are also somewhat enriched in LREE relative to HREE.

The bedrock samples from the vicinity of Studsvik have low REE content (with one exception) and low chondrite normalised values. These curves are flat and somewhat enriched in LREE relative to HREE. Eu-anomalies are small to medium.

Chondrite normalised REE sediment contents at reducing conditions are higher than at oxidising condition.

The REE differentiation ratio increases with increasing depth at oxidising conditions. At reducing conditions the concentration of REE as well as the differentiation ratio decrease with increasing depth.

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Table A.1 Sediment - Hillesjön. Site A. 1987-06-24.

		Depth (cm)						
Element	Unit	0-5	5-10	10-15	15-20	20-25	25-30	30-35
Water content	%	73	56	48	59	51	48	14
As	ppm	28	21	17		14	15	7.2
Ba	ppm	550	500	525	500	400	360	450
Br	ppm	74	47	46	187	93	104	110
Ce	ppm	78	72	54	56	60	62	49
Co	ppm	14	11	9.9	9.2	9.3	8.5	7.8
Cr	ppm	45	33	32	39	29	30	30
Cs	ppm	4.8	4.2	3.8	4.3	3.4	3.2	3.4
Eu	ppm	1.2	0.9	0.9	0.9	0.8	0.9	0.9
Fe	%	3.1	2.6	2.4	2.6	2.5	2.4	2.3
Hf	ppm	7.3	6.1	5.0	3.8	3.8	4.2	3.3
La	ppm	42	34	31	31	30	32	29
Lu	ppm	0.8	0.6	0.6	0.6	0.5	0.4	0.4
Mo	ppm		15			21	20	17
Nd	ppm	44		24				
Rb	ppm	118	95	100	117	104	107	98
Sc	ppm	10	8.8	8.2	8.5	8.0	7.8	7.4
Sm	ppm							5.9
Ta	ppm	0.9	0.8	0.6	0.9	0.8	0.7	0.2
Tb	ppm	1.3	0.8	0.8	0.8	0.6	0.7	0.6
Th	ppm	14	10	9.5	9.2	8.4	8.8	7.8
U	ppm	12	13	8.3	6.6	10	5.8	5.2
Yb	ppm	4.5	3.2	3.2	2.9	2.6	2.5	2.4
Zn	ppm	160	125	105	100	95	84	82
Organic content	%	7	6	28	7	5	5	4
Nuclide	Unit							
K-40	Bq/kg dw	797	823	796	776	799	818	842
Cs-137	Bq/kg dw	944	7	< 2	< 2	< 2	< 2	< 2
Ra-226	Bq/kg dw	111	73	64	58	65	58	53
Ra-228	Bq/kg dw	85	51	46	51	45	44	40
Th-228	Bq/kg dw	90	52	49	50	48	45	46
Th-232	Bq/kg dw	55	40	35	35	35	39	31
U-238	Bq/kg dw	149	161	99	87	124	74	62

Table A.2 Sediment - Hillesjön. Site E. 1987-06-24.

		Depth (cm)					
Element	Unit	0-2	8-10	16-20	25-30	35-40	45-50
Water content	%	93	93	88	70	68	75
As	ppm	95	173	135	76	126	62
Ba	ppm	550	350	500	600	600	650
Br	ppm	104	101	92	54	145	260
Ce	ppm	88	89	108	88	79	93
Co	ppm	19	20	14	8.7	13	10
Cr	ppm	27	21	26	28	31	45
Cs	ppm	3.1	2.3	2.7	2.7	3.3	4.9
Eu	ppm	1.2	1.2	1.2	1.1	1.2	1.4
Fe	%	3.8	3.6	3.7	3.5	4.3	4.1
Hf	ppm	3.8	2.8	3.8	7.4	5.7	4.1
La	ppm	42	42	46	41	44	53
Lu	ppm	1.0	1.2	1.2	0.9	1.1	0.9
Mo	ppm	54	57	85	32	56	34
Nd	ppm		55	67	66	41	28
Rb	ppm	35	50	42	71	83	106
Sc	ppm	6.1	5.1	6.9	9.0	9.4	11
Ta	ppm				0.6	0.8	0.8
Tb	ppm	1.6	1.2	1.5	1.1	1.3	1.2
Th	ppm	7.7	6.3	8.2	9.8	9.2	14
U	ppm	43	68	124	44	34	28
Yb	ppm	5.8	6.0	5.2	4.8	5.5	4.0
Zn	ppm	265	330	230	124	106	123
Organic content	%	40	43	33	12	10	15
Nuclide	Unit						
K-40	Bq/kg dw	410	300	500	700	695	860
Cs-137	Bq/kg dw	955	540	14	4	< 2	< 2
Ra-226	Bq/kg dw	80	82	84	75	100	144
Ra-228	Bq/kg dw	-	31	43	49	51	64
Th-228	Bq/kg dw	38	73	45	52	54	74
Th-232	Bq/kg dw	35	31	20	47	35	55
U-234	Bq/kg dw			2610	750	790	760
U-235	Bq/kg dw			82	33	36	33
U-238	Bq/kg dw	533	843	1538	546	422	347

Table A.3 Sediment - Hillesjön. Site I.

		Depth (cm)				
Element	Unit	0-2	4-9	9-14	14-19	19-24
Water content	%	89	79	72	75	73
As	ppm	65	55	40	50	49
Ba	ppm	500	600	600	700	600
Br	ppm	150	196	129	184	141
Ce	ppm	97	117	117	108	96
Co	ppm	18	19	19	17	16
Cr	ppm	42	47	53	48	35
Cs	ppm	3.7	5.6	5.7	5.8	4.1
Eu	ppm	1.3	1.2	1.2	1.3	1.1
Fe	%	4.6	4.5	4.6	4.8	4.0
Hf	ppm	5.0	5.4	5.4	4.6	5.1
La	ppm	44	48	50	48	40
Lu	ppm	1.0	1.0	0.9	0.9	0.9
Mo	ppm		22	18	11	16
Nd	ppm	40	26	56	53	67
Rb	ppm	112	125	122	96	98
Sc	ppm	9.7	12	13	12	10
Sm	ppm			11		
Ta	ppm	0.6	0.6	1.0	0.9	0.7
Tb	ppm	1.4	1.8	1.3	1.6	1.5
Th	ppm	13	14	17	15	11
U	ppm	8.5	17	17	17	22
Yb	ppm	4.9	4.6	4.2	4.2	4.0
Zn	ppm	180	166	125	112	116
Organic content	%	20	14	9	12	11
Nuclide	Unit					
K-40	Bq/kg dw	710	815	907	871	759
Cs-137	Bq/kg dw	693	38	4	5	3
Ra-226	Bq/kg dw	112	110	112	92	67
Ra-228	Bq/kg dw	137	95	81	78	56
Th-228	Bq/kg dw	101	91	90	80	56
Th-232	Bq/kg dw	51	55	67	59	45
U-234	Bq/kg dw		390	540	520	290
U-235	Bq/kg dw		20	19	18	19
U-238	Bq/kg dw	105	211	211	211	272

Table A.4 Sediment - Hillesjön. Site K. 1987-06-24

		Depth (cm)					
Element	Unit	0-2	4-9	9-14	14-19	19-24	29-34
Water content	%	94	91	91	89	87	83
As	ppm	117	96			106	
Ba	ppm	500	600			500	500
Br	ppm	106	116			275	259
Ce	ppm	88	89			95	108
Co	ppm	20	20			10.8	9.5
Cr	ppm	25	24			38	48
Cs	ppm	2.3	1.8			3.5	5.0
Eu	ppm	1.4	0.9			0.9	1.2
Fe	%	4.6	4.1			4.4	4.4
Hf	ppm	3.7	3.8			4.0	4.1
La	ppm	40	42			44	52
Lu	ppm	1.3	1.3			0.9	0.8
Mo	ppm	11	23			40	21
Nd	ppm	39	25			51	41
Rb	ppm	64	55			60	114
Sc	ppm	6.9	6.9			9.0	10.5
Ta	ppm	0.5	0.5			0.6	0.7
Tb	ppm	1.5	1.3			1.5	1.6
Th	ppm	8.7	8.8			11.5	15
U	ppm	16	32			21	7.3
Yb	ppm	5.9	5.9			4.0	4.2
Zn	ppm	216	233			110	107
Organic content	%	34	39	40	33	27	17
Nuclide	Unit						
K-40	Bq/kg dw	800	520	393	461	553	658
Cs-137	Bq/kg dw	656	344	102	14	2	2
Ra-226	Bq/kg dw	96	63	57	46	57	66
Ra-228	Bq/kg dw	96	48	47	44	56	56
Th-228	Bq/kg dw	117	42	47	44	52	67
Th-232	Bq/kg dw	37	35			43	55
U-234	Bq/kg dw				290		
U-235	Bq/kg dw		25		18	21	16
U-238	Bq/kg dw		422			260	298

Table A.5 Sediment - Hillesjön. Lake Center. 1987-04-08

		Depth (cm)				
Element	Unit	0-2	6-8	10-15	20-25	40-45
Water content	%	94	89	79	74	73
As	ppm	19	20	16		5.9
Ba	ppm	600	600	600	500	400
Br	ppm	11	10	22	70	23
Ce	ppm	134	110	108	109	90
Co	ppm	28	15	12	12	11
Cr	ppm	53	55	58	64	55
Cs	ppm	5.1	4.8	5.7	6.8	5.5
Eu	ppm	2.0	1.3	1.1	1.2	1.3
Fe	%	5.1	6.0	6.1	5.2	4.4
Hf	ppm	4.4	5.2	5.2	4.8	3.8
La	ppm	73	56	53	53	51
Lu	ppm	1.2	1.0	0.8	0.8	0.7
Mo	ppm		22	22	20	
Nd	ppm	89	49	56	53	46
Rb	ppm	92	91	131	156	131
Sc	ppm	10	11	12	12	11
Ta	ppm	0.5	1.0	0.9	0.9	1.1
Tb	ppm	2.1	1.5	0.9	1.8	1.1
Th	ppm	15	15	16	17	15
U	ppm	24	33	15	5.5	5.4
Yb	ppm	4.4	6.2	4.5	3.9	3.7
Zn	ppm	450	205	134	132	103
Organic content	%	34	27	14	12	13
Nuclide	Unit					
K-40	Bq/kg dw	416	530	777	790	730
Cs-137	Bq/kg dw	50530	720	43	6.7	9
Ra-226	Bq/kg dw	-	68	80	67	55
Ra-228	Bq/kg dw	< 130	68	68	71	59
Th-228	Bq/kg dw	44	43	61	69	63
Th-232	Bq/kg dw	55	59	63	67	59
U-235	Bq/kg dw		30	16	12	8
U-238	Bq/kg dw	298	409	186	68	67

Table A.6 Gelationous brown precipitate from Hillesjön site, Spring B. 1989-04-19

		Depth (cm)
Element	Unit	0-1
Al	%	0.37
As	ppm	1710
Br	ppm	45
Ce	ppm	320
Co	ppm	8.4
Dy	ppm	75
Eu	ppm	4.9
Fe	%	32
Hf	ppm	3.9
K	%	0.2
La	ppm	116
Lu	ppm	5
Mn	ppm	1670
Na	%	0.145
Nd	ppm	160
Sc	ppm	3.3
Sm	ppm	45
Tb	ppm	9.9
Th	ppm	11
U	ppm	15
Yb	ppm	30
Zn	ppm	45

Table A.7 Sediment - Långsjön. Site L1/2. 1987-06-24.

		Depth (cm)				
Element	Unit	0-5	5-10	10-15	20-25	30-35
Water content	%	84	80	75	67	56
As	ppm					
Ba	ppm	400	400	500	400	425
Br	ppm	43	40	45	41	25
Ca	%	11.0	11.7	9.3	5.2	
Ce	ppm	57	63	68	63	53
Co	ppm	11	11	10	11	9.1
Cr	ppm	32	31	33	32	28
Cs	ppm	4.4	2.7	3.3	3.1	1.9
Eu	ppm	0.9	0.9	0.9	1.0	0.9
Fe	%	2.4	2.5	3.0	3.5	2.9
Hf	ppm	3.8	4.5	4.7	4.3	4.1
La	ppm	31	30	32	31	27
Lu	ppm	0.5	0.5	0.5	0.5	0.4
Mo	ppm		10	20	10	8
Nd	ppm	17		42	33	22
Rb	ppm	81	77	93	105	90
Sc	ppm	6.6	7.0	8.1	8.0	7.0
Ta	ppm	0.5	0.6	0.7	0.6	0.5
Tb	ppm	0.5		0.6	0.9	0.5
Th	ppm	8.6	8.9	9.8	9.4	8.7
U	ppm	6.7	13	22	13	7.0
Yb	ppm	2.1	2.4	2.5	2.3	2.3
Zn	ppm	98	100	73	71	55
Organic content	%	12	11	11	8	6
Nuclide	Unit					
K-40	Bq/kg dw	539	584	630	710	685
Cs-137	Bq/kg dw	2390	940	74	9	< 2
Ra-226	Bq/kg dw	70	65	61	50	37
Ra-228	Bq/kg dw	49	56	46	46	34
Th-228	Bq/kg dw	59	56	52	44	38
Th-232	Bq/kg dw	34	35	38	37	36
U-234	Bq/kg dw		1010	340	310	260
U-235	Bq/kg dw		15	18	10	6
U-238	Bq/kg dw	83	161	273	161	87

Table A.8 Sediment - Långsjön. Site L3/4. 1987-06-24.

		Depth (cm)				
Element	Unit	0-5	5-10	10-15	20-25	30-35
Water content	%	77	66	65	65	68
As	ppm					
Ba	ppm	500	400	500	500	600
Br	ppm	29	29	46	45	58
Ca	%	9.9	8.0	8.0	5.5	5.5
Ce	ppm	55	57	63	64	67
Co	ppm	11	11	10	9.0	9.0
Cr	ppm	30	28	34	35	35
Cs	ppm	2.0	1.5	2.8	2.3	3.5
Eu	ppm	0.8	0.8	1.0	0.8	1.0
Fe	%	2.3	2.3	2.7	3.0	3.1
Hf	ppm	5.9	5.3	5.9	6.2	5.7
La	ppm	26	26	30	31	33
Lu	ppm	0.4	0.4	0.4	0.5	0.5
Mo	ppm	10	10	15	10	10
Nd	ppm	30	35			28
Rb	ppm	79	66	90	103	100
Sc	ppm	7.2	7.4	8.3	8.6	8.9
Ta	ppm	0.5	0.6	0.8	0.7	0.6
Tb	ppm	0.5	0.6	0.6	0.4	0.6
Th	ppm	7.9	7.7	9.8	9.6	10
U	ppm	6.0	9.0	13	16	18
Yb	ppm	2.3	2.2	2.3	2.8	2.5
Zn	ppm	72	74	67	65	63
Organic content	%	8	6	7	9	12
Nuclide	Unit					
K-40	Bq/kg dw	530	625	700	680	680
Cs-137	Bq/kg dw	2180	590	41	4	< 2
Ra-226	Bq/kg dw	43	49	58	47	47
Ra-228	Bq/kg dw	37	34	42	42	45
Th-228	Bq/kg dw	36	49	41	47	48
Th-232	Bq/kg dw	32	29	38	38	39
U-234	Bq/kg dw	140				
U-235	Bq/kg dw	7	9	11	8	12
U-238	Bq/kg dw	74	112	161	198	223

Table A.9 Sediment - Ullfjärden. Site 1265. Depth 22 m.

		Depth (cm)				
Element	Unit	0-3	3-6	6-12	12-15	15-20
Water content	%	97	92	87	74	50
As	ppm	25	8.3	19	32	20
Ba	ppm	500	700	1200	2200	750
Br	ppm	86	79	100	57	24
Ca	%	6.8	3.7	2.2	2.4	
Ce	ppm	88	94	102	159	167
Co	ppm	15	15	20	38	65
Cr	ppm	58	40	62	51	54
Cs	ppm	4.7	5.2	7.0	3.9	4.0
Eu	ppm	1.1	0.9	1.2	1.7	1.8
Fe	%	4.6	3.5	5.7	8.5	8.4
Hf	ppm	3.6	3.4	5.4	4.8	4.6
La	ppm	41	40	52	71	76
Lu	ppm	0.6	0.8	0.8	0.8	0.9
Mo	ppm	12	40	8		23
Nd	ppm	35	47	83	73	68
Rb	ppm	117	111	143	101	109
Sc	ppm	11	11	14	12	14
Sm	ppm	6.0	5.0	8.4	11	12
Ta	ppm	0.7	0.9	1.0	0.6	0.9
Tb	ppm	1.2	1.2	1.4	1.8	1.8
Th	ppm	16	13	18	15	13
U	ppm	30	50	16	13	24
Yb	ppm	2.7	2.5	3.3	4.0	3.8
Zn	ppm	158	146	153	144	149
Organic content	%	28	19	15	11	7
Nuclide	Unit					
K-40	Bq/kg dw	1120	1920	850	850	765
Cs-137	Bq/kg dw	290	9750	205	13	2
Ra-226	Bq/kg dw	140	118	170	177	128
Ra-228	Bq/kg dw			77	60	45
Th-228	Bq/kg dw	90	145	73	58	48
Th-232	Bq/kg dw	47	59	70	59	47
U-238	Bq/kg dw	620	372	198	161	298

Table A.10 Sediment - Ullfjärden. Site 1263. Depth 48 m.

Element	Unit	Depth (cm)					
		0-3	3-6	6-12	15-20	25-30	40-45
Water content	%	96	94	92	88	85	
As	ppm	6.6	9.4	9.0	7.3	5.3	5.3
Ba	ppm	700	300	1200	950	1050	900
Br	ppm	59	76	74	65	60	56
Ca	%	2.6	4.2				
Ce	ppm	74	76	97	105	99	100
Co	ppm	12	15	18	18	16	15
Cr	ppm	35	34	60	64	70	67
Cs	ppm	3.8	4.5	6.3	7.1	8.0	7.8
Eu	ppm	0.7	0.9	1.2	1.4	1.3	1.2
Fe	%	2.6	3.0	4.0	4.6	4.4	4.6
Hf	ppm	2.2	2.8	3.5	3.3	3.6	3.8
La	ppm	32	36	48	49	51	49
Lu	ppm	0.6	0.4	0.7	0.8	0.7	0.8
Mo	ppm	40	40	40	48		10
Nd	ppm	46	61	64	71	40	57
Rb	ppm	77	73	132	138	162	178
Sc	ppm	7.7	8.5	12	13	14	14
Sm	ppm	4.6	4.3	6.9	7.4	7.9	7.8
Ta	ppm	0.3	0.8	0.7	0.9	0.9	1.1
Tb	ppm	1.0	1.0	1.2	1.5	1.2	1.2
Th	ppm	10	11	16	18	20	20
U	ppm	36	47	35	28	15	15
Yb	ppm	1.9	2.3	2.7	3.0	3.1	2.9
Zn	ppm	145	166	215	163	135	142
Organic content	%	32	27	19	13	13	
Nuclide	Unit						
K-40	Bq/kg dw	490	1110	780	680	910	980
Cs-137	Bq/kg dw	11500	715	335	27	4	< 2
Ra-226	Bq/kg dw	120	107	70	97	78	75
Ra-228	Bq/kg dw				54	74	78
Th-228	Bq/kg dw	130	140	72	70	86	81
Th-232	Bq/kg dw	39	39	67	75	79	79
U-238	Bq/kg dw	446	583	434	347	186	186

Table A.11 Sediment - Täckhammar. Anoxic Spring, South 1989-03-17.

		Depth (cm)			
Element	Unit	0-5	5-10	10-15	15-20
Water content	%	92	62	39	39
Al	%	1.3	4.1	5.1	4.8
Br	ppm	33	12		
Ce	ppm	240	135	103	101
Co	ppm	4.1	5.5	5.7	5.3
Cr	ppm	2	19	25	24
Cs	ppm	3.8	2.2	2.2	1.5
Dy	ppm	34	9.6	7.8	8.0
Eu	ppm	2.4	1.20	1.05	1.00
Fe	%	12.0	3.2	1.94	1.79
Hf	ppm	3.1	8.6	9.2	11.7
K	%	0.65	2.0	2.3	2.4
La	ppm	75	50	40	39
Lu	ppm	3.4	1.00	0.68	0.70
Mg	%	<0.2	0.24	0.53	0.50
Mn	ppm	1190	330	270	250
Na	%	0.42	1.39	1.55	1.58
Nd	ppm	95	50	40	30
Rb	ppm	<15	101	120	115
Sc	ppm	1.95	6.2	6.6	6.3
Sm	ppm	26	13	10	11
Ta	ppm	<0.3	0.6	0.8	0.7
Tb	ppm	4.3	2.1	1.5	1.5
Th	ppm	4.2	16	15	16
U	ppm	220	42	21	17
Yb	ppm	15	5.0	3.7	3.9
Zn	ppm	<18	76	440	-
Organic content	%	47	12	5	4
Dry bulk density	kg/m^3	1010	1230	1600	1690

Table A.12 Sediment - Täckhammar. Anoxic Spring, North. 1989-03-17.

Element	Unit	Depth (cm)		
		0-5	5-10	10-15
Water content	%	86	51	42
Al	%	2.2	4.8	5.4
Br	ppm	35		
Ce	ppm	165	130	116
Co	ppm	4.2	5.5	6.2
Cr	ppm	3	19	24
Cs	ppm	1.1	1.8	2.1
Dy	ppm	20	10.1	9.7
Eu	ppm	1.40	1.10	1.10
Fe	%	6.0	1.8	1.8
Hf	ppm	5.7	10.0	10.9
K	%	1.1	2.2	2.3
La	ppm	50	50	42
Lu	ppm	1.8	0.85	0.80
Mg	%	<0.2	0.37	0.49
Mn	ppm	670	300	300
Na	%	0.70	1.58	1.56
Nd	ppm	60	50	43
Rb	ppm	45	108	117
Sc	ppm	3.2	6.0	7.0
Sm	ppm	15	13	11
Ta	ppm	0.5	0.5	0.6
Tb	ppm	2.5	1.8	1.8
Th	ppm	7.0	19	16
U	ppm	180	26	24
Yb	ppm	8.2	4.5	4.7
Zn	ppm	105	100	20
Organic content	%	48	8	6
Dry bulk density	kg/m^3	1120	1420	1530

Table A.13 Sediment - Täckhammar. Oxic Spring, Soil.

Element	Unit	Depth (cm) 0-5	5-10
Water content	%	53	8
Al	%	5.1	5.3
Br	ppm	30	70
Ce	ppm	120	140
Co	ppm	4.2	7.4
Cr	ppm	25	33
Cs	ppm	2.3	3.3
Dy	ppm	13	11
Eu	ppm	1.09	1.25
Fe	%	2.0	3.8
Hf	ppm	14.2	11.6
K	%	2.2	2.2
La	ppm	46	52
Lu	ppm	0.99	1.11
Mg	%	0.25	0.93
Mn	ppm	340	380
Na	%	1.53	1.43
Nd	ppm	50	53
Rb	ppm	116	130
Sc	ppm	6.8	9.4
Sm	ppm	12	13
Ta	ppm	0.6	1.0
Tb	ppm	1.9	2.3
Th	ppm	21	18
U	ppm	24	39
Yb	ppm	5.5	5.6
Zn	ppm	92	110
Organic content	%	57	10
Dry bulk density	kg/m^3	2260	2110

Table A.14 Sediment - Täckhammar. Oxic Spring, Border. 1989-03-17.

		Depth (cm)		
Element	Unit	0-5	5-10	10-15
Water content	%	33	39	41
Al	%	4.9	5.1	4.9
Br	ppm	5	6	3
Ce	ppm	99	100	116
Co	ppm	5.8	5.8	4.7
Cr	ppm	35	35	22
Cs	ppm	2.1	2.0	2.1
Dy	ppm	10.4	9.0	8.8
Eu	ppm	1.07	1.00	1.04
Fe	%	2.20	2.22	1.92
Hf	ppm	12.5	13.0	10.5
K	%	2.5	2.3	2.4
La	ppm	39	39	40
Lu	ppm	0.90	0.90	0.85
Mg	%	0.55	0.70	0.66
Mn	ppm	310	310	270
Na	%	1.60	1.62	1.71
Nd	ppm	33	28	40
Rb	ppm	119	130	120
Sc	ppm	8.2	8.3	6.6
Sm	ppm	10	11	10
Ta	ppm	1.0	0.9	0.8
Tb	ppm	1.9	1.8	1.7
Th	ppm	16	16	14
U	ppm	8	12	69
Yb	ppm	4.9	5.0	4.0
Zn	ppm	93	89	90
Organic content	%	2	3	5
Dry bulk density	kg/m^3	1670	1690	1510

Table A.15 Sediment - Täckhammar. Oxic Spring, Center. 1989-03-17.

		Depth (cm)				
Element	Unit	0-5	5-10	10-15	15-20	20-25
Water content	%	27	32	39	23	21
Al	%	4.9	4.8	4.9	4.8	4.9
Br	ppm		6	9		
Ce	ppm	61	114	110	120	95
Co	ppm	3.6	4.2	3.8	3.3	3.3
Cr	ppm	25	33	21	20	22
Cs	ppm	1.7	1.6	1.5	1.6	1.5
Dy	ppm	5.3	9.0	9.3	7.8	5.8
Eu	ppm	0.84	1.05	1.05	1.10	0.98
Fe	%	1.41	1.70	1.68	1.30	1.40
Hf	ppm	6.8	16.1	14.7	13.0	9.7
K	%	2.4	2.4	2.4	2.5	2.5
La	ppm	20	44	42	47	36
Lu	ppm	0.40	0.96	0.93	0.81	0.58
Mg	%	0.53	0.48	0.50	0.45	0.58
Mn	ppm	200	260	260	270	246
Na	%	1.61	1.60	1.64	1.68	1.70
Nd	ppm	23	42	40	42	30
Rb	ppm	110	125	110	120	123
Sc	ppm	5.5	6.8	6.5	6.1	5.5
Sm	ppm	5.1	12	10	11	8.4
Ta	ppm	0.5	0.7	0.7	0.5	0.4
Tb	ppm	1.0	1.7	1.7	1.4	1.4
Th	ppm	7.2	17	16	19	15
U	ppm	6	29	17	9	7
Yb	ppm	2.2	5.2	5.0	4.8	3.0
Zn	ppm	65	78	75	72	68
Organic content	%	1	2	5	1	1
Dry bulk density	kg/m^3	1890	1550	1580	1880	1980

Table A.16 Sediment - Täckhammar. Oxic Spring. 1989-08-29.

		Depth (cm)					
Element	Unit	0-2.5	2.5-5	5-7.5	7.5-10	10-12.5	12.5-15
Al	%	5.9	6.1	5.7	5.8	6.0	6.0
Ba	ppm	420	520	280			
Br	ppm	5	8	5	32	48	38
Ce	ppm	69	55	78	104	124	69
Co	ppm	3.7	3.5	3.7	5.2	6.5	5.3
Cr	ppm	28	28	28	33	39	34
Cs	ppm	1.8	2.0	1.8	2.5	2.7	2.5
Eu	ppm	0.91	0.88	0.97	1.09	1.12	0.98
Fe	%	1.58	1.50	1.59	2.6	3.7	3.6
Hf	ppm	8.8	7.1	11.4	12.0	13.4	6.9
K	%	2.3	2.6	2.5	2.4	2.5	2.4
La	ppm	26	22	31	40	47	31
Lu	ppm	0.60	0.53	0.69	1.04	0.98	0.59
Mg	%	<0.3	<0.3	0.64	<0.4	<0.5	<0.4
Mn	ppm	240	240	250	1560	3700	990
Na	%	1.62	1.64	1.63	1.54	1.44	1.50
Rb	ppm	115	118	115	120	120	118
Sc	ppm	5.9	5.5	6.1	7.4	8.7	6.7
Sm	ppm	6.3	5.0	7.5	10	11	7.2
Ta	ppm	0.6	0.5	0.5	0.8	0.8	0.7
Tb	ppm	1.4	1.1	1.5	2.0	2.2	1.5
Th	ppm	9.7	8.8	13	16	20	12
U	ppm	12	8.3	11	21	25	20
Yb	ppm	3.3	2.8	3.5	5.5	5.4	3.2
Zn	ppm	80	75	78	105	125	103
Water contents	%	30	30	28	49	51	44

Table A.17 Sediment - Täckhammar. Anoxic Spring. 1989-08-29.

		Depth (cm)					
Element	Unit	0-2.5	2.5-5	5-7.5	7.5-10	10-12.5	12.5-15
Al	%	2.4	2.8	2.7	3.8	4.9	5.11
Ba	ppm		350		370	450	390
Br	ppm	10	12	13			5
Ce	ppm	204	260	285	205	146	140
Co	ppm	3.9	5.5	4.9	5.0	5.1	5.4
Cr	ppm	-	-	8	6	15	14
Cs	ppm	0.7	1.0	1.2	1.6	1.8	1.8
Eu	ppm	2.5	2.8	2.4	1.8	1.4	1.3
Fe	%	7.0	3.8	4.5	3.5	2.5	2.3
Hf	ppm	4.5	5.8	6.1	8.7	11.1	11.2
K	%	1.1	1.0	1.1	1.4	2.2	2.2
La	ppm	67	76	69	58	50	48
Lu	ppm	2.5	2.9	2.6	1.7	1.2	1.2
Mg	%	<0.3	<0.1	0.41	<0.1	0.32	0.40
Mn	ppm	620	240	270	280	290	270
Na	%	0.62	0.79	0.75	1.12	1.36	1.49
Rb	ppm	30	44	39	68	98	100
Sc	ppm	2.4	3.1	3.1	4.3	5.4	5.4
Sm	ppm	25	24	25	17	14	14
Ta	ppm	-	0.2	0.4	0.5	0.5	0.6
Tb	ppm	4.3	4.5	4.2	3.1	2.3	2.3
Th	ppm	8.8	11	10	8.2	16	16
U	ppm	98	280	450	250	62	55
Yb	ppm	14	16	14	8.5	6.5	6.4
Zn	ppm	-	-	120	100	87	79
Water contents	%	98	93	92	84	66	59

Table A.18 Sediment - Täckhammar site. Lake Långhalsen, about 100 m North of the Täckhammar shore. Sampled 1989-08-29.

		Depth (cm)					
Element	Unit	0-2.5	2.5-5	5-7.5	7.5-10	10-12.5	12.5-15
Al	%	5.2	5.3	5.3	5.8	6.5	7.0
Ba	ppm	240	290	490	410	490	460
Br	ppm	13	6	4	16	41	53
Ce	ppm	78	78	97	84	102	109
Co	ppm	9.7	7.6	6.3	7.4	10.7	11.3
Cr	ppm	32	27	24	33	50	57
Cs	ppm	2.4	1.8	1.6	2.4	3.6	3.9
Eu	ppm	0.91	0.94	0.92	0.94	1.09	1.15
Fe	%	2.2	1.7	1.5	2.2	3.5	4.3
Hf	ppm	6.5	8.6	10.5	7.8	7.0	6.3
K	%	2.1	2.4	2.4	2.6	2.9	2.6
La	ppm	31	30	37	33	40	44
Lu	ppm	0.56	0.56	0.61	0.59	0.67	0.69
Mg	%	0.57	0.12	0.41	0.62	0.88	1.0
Mn	ppm	560	330	280	400	620	770
Na	%	1.40	1.54	1.57	1.58	1.55	1.51
Rb	ppm	115	115	113	125	151	160
Sc	ppm	6.6	5.5	5.1	7.2	11.1	12.5
Sm	ppm	7.0	6.8	8.5	7.6	9.5	9.6
Ta	ppm	0.7	0.6	0.7	0.8	1.2	1.3
Tb	ppm	1.4	1.3	1.5	1.7	2.2	2.5
Th	ppm	12	12	17	14	18	19
U	ppm	8.5	6.3	5.2	4.5	5.4	5.7
Yb	ppm	3.0	3.0	3.5	3.2	3.4	4.0
Zn	ppm	120	90	70	94	130	150
Water contents	%	75	50	32	37	47	50

Table A.19 Chondrite-normalizing factors according to Wakita & Zellmar.

La	0.340
Ce	0.910
Pr	0.121
Nd	0.640
Sm	0.195
Eu	0.073
Gd	0.260
Tb	0.047
Dy	0.300
Ho	0.078
Er	0.200
Tm	0.032
Yb	0.220
Lu	0.034

Table A.20 Chondrite-normalized values for sediments from the Täckhammar site (depth in cm).

	Eu	Sm	Tb	La	Lu
Site 1					
0- 5	11.5	26.1	21.2	58.8	11.7
5-10	14.3	61.5	36.1	129.4	28.2
10-15	14.3	51.2	36.1	123.5	27.3
15-20	15.0	56.4	29.7	138.2	23.8
20-25	13.4	43.0	29.7	105.8	17.0
Site 2					
0- 5	14.6	51.2	40.4	114.7	26.4
5-10	13.7	56.4	38.3	114.7	26.4
10-15	14.2	51.2	36.1	117.6	25.0
Site 3					
0- 5	14.9	61.5	40.4	135.2	29.1
5-10	17.1	66.6	48.9	152.9	32.6
Site 4					
0- 5	19.1	76.9	53.1	147.0	52.9
5-10	15.0	66.6	38.3	147.0	25.0
10-15	15.0	56.4	38.3	123.5	23.5
Site 5					
0- 5	32.8	133.3	91.4	220.5	100.0
5-10	16.4	66.6	44.6	147.0	29.4
10-15	14.3	51.2	31.9	117.6	20.0
15-20	13.7	56.4	31.9	114.7	20.5

Sites:
1 = Oxic spring, center
2 = -"- border
3 = -"- soil
4 = Anoxic spring, north
5 = -"- south

Table A.21 Chondrite-normalized values, bedrock, Studsvik area, sampled Oct-Nov 1987.

Site	Eu	Sm	Tb	La	Lu
RA 1	24.7	153.8	40.4	417.6	4.4
RA 2	12.9	66.7	27.7	141.2	10.9
HO 1	12.6	51.3	27.7	129.4	21.2
HA 2	5.2	4.6	6.8	19.1	7.9
ST 1	11.8	15.4	6.4	47.1	3.2
DA 1	11.4	76.9	29.8	235.3	11.8
GR 1	39.0	39.0	21.3	141.2	32.3
BJ 1	13.2	36.9	17.7	117.6	10.9
LHA 1	19.2	45.1	13.6	138.2	6.5

Samples:

RA 1	Ramsdal	(7.25 km	North-West	of Studsvik)
RA 2	-"-			
HO 1	Holmtorp	(10 km	-"-	-"-)
HA 2	Hässle	(9.75 km	-"-	-"-)
ST 1	Stensätter	(6 km	North	-"-)
DA 1	Daltorp	(7 km	North-West	-"-)
GR 1	Grinda	(8.25 km	-"-	-"-)
BJ 1	Björndal	(10.25 km	-"-	-"-)
LHA 1	L.Hamra	(8 km	-"-	-"-)

Table A.22 Eu anomalies, sediment (and soil) from Täckhammar area, sampled 890317.

(depth in cm).	
Site 1	
0- 5	0.19
5-10	0.10
10-15	0.12
15-20	0.12
20-25	0.14
Site 2	
0- 5	0.12
5-10	0.10
10-15	0.12
Site 3	
0- 5	0.10
5-10	0.11
Site 4	
0- 5	0.11
5-10	0.10
10-15	0.12
Site 5	
0- 5	0.11
5-10	0.11
10-15	0.12
15-20	0.11

Sites:

1	Oxic spring,	Center
2	-"-	Border
3	-"-	Soil
4	Anoxic spring,	North
5	-"-	South

Table A.23 Eu anomalies, bedrock, Studsvik area, sampled Oct-Nov 1987.

Site	
RA 1	0.21
RA 2	0.24
GR 1	0.42
HO 1	0.29
HA 2	0.97
ST 1	0.95
LHA 1	0.56
BJ 1	0.43
DA 2	0.19

Samples:	RA 1	Ramsdal	(7.25 km	North-West	of Studsvik)
	RA 2	-"-			
	HO 1	Holmtorp	(10 km	-"-	-"-)
	HA 2	Hässle	(9.75 km	-"-	-"-)
	ST 1	Stensätter	(6 km	North	-"-)
	DA 1	Daltorp	(7 km	North-West	-"-)
	GR 1	Grinda	(8.25 km	-"-	-"-)
	BJ 1	Björndal	(10.25 km	-"-	-"-)
	LHA 1	L.Hamra	(8 km	-"-	-"-)

Table A.24 Differentiation ratio $(La/Lu)_{cn}$, sediment (and soil) from Täckhammar area, sampled 890317.

(depth in cm).	
Site 1	
0- 5	5.0
5-10	4.5
10-15	4.5
15-20	5.8
20-25	6.2
Site 2	
0- 5	4.3
5-10	4.3
10-15	4.7
Site 3	
0- 5	4.6
5-10	4.6
Site 4	
0- 5	2.7
5-10	5.8
10-15	5.2
Site 5	
0- 5	2.2
5-10	5.0
10-15	5.8
15-20	5.5

Sites:			
	1	Oxic spring,	Center
	2	-"-	Border
	3	-"-	Soil
	4	Anoxic spring,	North
	5	-"-	South

Table A.25 Differentiation ratio $(La/Lu)_{cn}$, bedrock, Studsvik area, sampled Oct-Nov 1987.

Site	
RA 1	94.5
RA 2	13.0
GR 1	4.4
HO 1	6.1
HA 2	2.4
ST 2	14.5
L HA 1	21.4
BJ 1	10.8
DA 1	20.0

Samples:			
RA 1	Ramsdal	(7.25 km North-West of Studsvik)
RA 2	-"-	
HO 1	Holmtorp	(10 km -"- -"-)
HA 2	Hässle	(9.75 km -"- -"-)
ST 1	Stensätter	(6 km North -"-)
DA 1	Daltorp	(7 km North-West -"-)
GR 1	Grinda	(8.25 km -"- -"-)
BJ 1	Björndal	(10.25 km -"- -"-)
LHA 1	L.Hamra	(8 km -"- -"-)

Table B.1 Water quality, Täckhammar site, sampling on 1989-05-18.

Paramter*	Unit	Oxic spring	Anoxic spring	2nd Pool Oxic spring	Creek from Anoxic spring	Shore Lake Långhalsen
Temperature#	°C	6.8	7.9	6.8	7.5	5.0
pH-field#		7.75	7.92	7.80	8.03	7.6
Eh#	mV	+360	+50	+260	+205	+400
Alcalinity	mg/l	122.9	131.5	131.1	133.1	46.6
Ca	"	40.8	41.8	41.7	42.7	17.4
Mg	"	7.8	7.9	7.7	7.4	4.4
Sr	"	0.05	0.05	0.04	0.05	0.04
Na	"	9.7	8.8	9.4	9.4	6.5
K	"	3.6	3.6	3.6	3.6	2.5
Li	"	0.01	0.01	0.01	0.01	<0.01
Fe total	"	0.0165	0.123	-	0.035	0.017
Fe (II)	"	0.0085	0.116	-	0.019	0.010
Mn	"	0.01	0.07	0.01	0.04	0.01
Al	"	0.02	0.03	0.06	0.05	0.03
SiO_2	"	14.5	16.5	14.5	16.3	0.86
NO_3	"	1.3	<0.1	1.1	0.4	<0.1
F	"	1.2	1.1	1.2	1.3	0.6
Cl	"	10.9	11.3	10.5	10.3	8.0
SO_4	"	30.5	26.7	30.4	24.8	19.6
U	"	0.027	0.011	0.028	0.011	0.0022

Notes: * for all samples: Co < 0.003 ppm
Eu < 0.003 "
La < 0.004 "
Lu < 0.003 "
Th < 0.02 "
sulphide < 0.01 ppm

Temperature, pH (±0.05) and Eh (±20) measured on March 1989

Table B.2 Water quality, Täckhammar, sampling 1989-03-17.

Paramter	Unit	Oxic spring	Anoxic spring
Temperature	°C	6.8	7.8
Conductivity	mS/m	32	32
Eh-field	mV	+360	+50
pH-field		7.75	7.92
pH-lab.		7.6	7.8
Alcalinity	mg/l	127	138
Ca	"	44.2	43.0
Mg	"	8.0	8.1
Sr	"	0.04	0.045
Na	"	11.3	10.3
K	"	4.5	4.3
Fe total	"	0.04	0.10
Mn	"	<0.02	0.07
Cl	"	12	12
F	"	1.0	1.0
SO_4	"	32	27

For all samples:

$NO_2^- < 0.01$ ppm

$NO_3^- < 2$ "

$NH_4^+ < 0.05$ "

$PO_4^{3-} < 0.1$ "

Table B.3 Water quality, Täckhammar site and Kappla spring, sampling on March 1988 and average groundwaters in Södermanland (from SGU, 1984).

Parameter	Unit	Lake Lång-halsen	Lake shore	Oxic spring	Kappla spring	Dug wells	Drilled wells
Temperature	°C	1.4	5.0	6.7	6.7	5.7	7.2
Conductivity	mS/m	14	15	38	26	32	43
pH-lab		6.9	7.0	7.7	8.0	6.8	7.8
Alcalinity	mg/l	39	41	127	107	95	174
Ca	"	20	22	46	41	32	32
Mg	"	4.0	4.4	7.8	6.0	8.3	6.8
Na	"	6.6	6.7	10.0	7.4	11.0	53.0
K	"	2.7	2.7	4.1	3.6	4.8	4.0
Fe total	"	0.55	0.48	0.06	0.02	0.06	0.06
Mn	"	0.05	0.03	< 0.02	0.02		
NH_4	"	< 0.1	< 0.1	< 0.1	< 0.1	0.02	0.02
NO_2	"	0.04	0.03	< 0.01	0.03	0.01	0.01
NO_3	"	2.24	2.09	1.21	0.94	2.9	0.3
PO_4	"	0.025	0.015	0.011	< 0.010		
Cl	"	7	7	3	10	13	18
F	"	0.3	0.3	0.2	0.7	0.5	1.4
SO_4	"	21	21	8	28	30	27

Table B.4 Water quality, Hillesjön site, 1989-04-18.

Parameter	Unit	Lake water Site E	Spring A
Temperature	°C	5.7	5.9
Conductivity	mS/m	43	55
Eh-field*	mV	+140	-10
pH-field*		7.72	7.60
pH-lab.		7.5	7.4
Alcalinity	mg/l	143	208
Ca	"	62	78
Mg	"	6.0	6.1
Na	"	16	25
K	"	3.8	5.7
Fe total	"	0.19	0.91
Al	"	0.10	0.05
Mn	"	0.04	0.09
NH_4	"	0.1	<0.1
NO_2	"	0.02	<0.01
Cl	"	23	39
F	"	0.5	0.3
SO_4	"	60	44

For all samples: $NO_3^- < 2$ "

$PO_4^{3-} < 0.1$ "

Note: * field pH and Eh were measured October 10, 1989

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[2]MBT Tecnologia Ambiental, CENT, Cerdanyola, Spain
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