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Abstract

The Swedish Nuclear Fuel and Waste Management Company (SKB) carries out site investigations for a final repository for spent nuclear fuel in the Oskarshamn community, located at the Baltic coast in the south of Sweden. Soil and groundwater samples from the Laxemar area have been collected and characterised, as have previously been reported /1/.

Batch experiments with sorption of radiotracers of I, Cs, Sr, Ni, Eu, U and Np have been made with eight selected soil samples and one natural groundwater. The solid:liquid ratio in the experiments was 1:48 and sampling were made at 3 hours, 1 day, 7 days, 14 days, 40 days and finally 130 days. Phase separation was made by centrifugation field > 20 kG. Experiments were made in an inert-gas glove-box (O_2 < 1 ppm).

The same type of batch sorption experiments was also made with a synthetic groundwater. The recipe for the synthetic groundwater was based on the analyses of the natural groundwater, except for dissolved organic matter, which were omitted.

A separate series of supporting experiments, without radionuclide tracers, were made for the measurement of the evolution of pH and Eh.

Another series of supporting experiments were made for a number of chemical analyses, where samples were taken at 14 and 130 days only: anion and cation chromatography, alkalinity titrations, total organic carbon (TOC), inorganic carbon, pH and Eh measurements, ICP-MS and -OES analyses of background radiotracer elements and a number of other elements.

The general trend of the batch sorption results show specific surface corrected distribution coefficients, R_a (m) that increase with time, but the trend is a levelling out to limiting values. Iodine sorption is generally below the lower detection limit and very few data could be collected for this tracer. Eu generally shows the strongest sorption and some measurements at the later samplings are above the upper detection limit.

Results from the batch experiments with peat and natural groundwater at 130 days give R_a values that ranges from $5 \cdot 10^{-5}$ (Sr) to $3 \cdot 10^{-4}$ m (Cs). The order of increasing sorption is: Sr, Ni, Np, Eu, U and Cs.

For synthetic groundwater Eu and U sorption is stronger, at least initially, compared with the natural groundwater, but for Cs the sorption is weaker over the whole sampling period.

Results from the batch experiments with gyttja and natural groundwater at 130 days give R_a values that ranges from $3 \cdot 10^{-5}$ (Sr) to $1 \cdot 10^{-2}$ m (Eu). The order of increasing sorption is: Sr, Cs, U, Ni, Np and Eu.

For synthetic groundwater the sorption of U is stronger and comparable with Eu.

Results from the batch experiments with clay gyttja, type I and natural groundwater at 130 days give R_a values that ranges from $1 \cdot 10^{-5}$ (Sr) to > $1 \cdot 10^{-3}$ m (Eu). The order of increasing sorption is: Sr, Cs, Ni, U, Np and Eu.

For synthetic groundwater the sorption of U is stronger, at least initially, comparable with Eu. For Np, on the other hand, the sorption is weaker and comparable with Sr over the whole sampling period.

Results from the batch experiments with sand and natural groundwater at 130 days give R_a values that ranges from $1 \cdot 10^{-4}$ (Sr) to $2 \cdot 10^{-1}$ m (Eu). The order of increasing sorption is: Sr, U, Cs, Ni, Np and Eu.

For synthetic groundwater, U and Ni sorption is stronger. For Np the sorption is weaker.

Results from the batch experiments with clay and natural groundwater at 130 days give R_a values that ranges from $4 \cdot 10^{-7}$ (U) to > $1 \cdot 10^{-3}$ m (Eu). The order of increasing sorption is: U, Sr, Np, Ni, Cs and Eu.

For synthetic groundwater, U and Ni sorption is stronger. For Cs the sorption is weaker.

Results from the batch experiments with till, type I and natural groundwater at 130 days give R_a values that ranges from $2 \cdot 10^{-6}$ (U) to > $1 \cdot 10^{-2}$ m (Eu). The order of increasing sorption is: U, Sr, Np, Ni, Cs and Eu.

For synthetic groundwater, Ni sorption is stronger.

Results from the batch experiments with till, type II and natural groundwater at 130 days give R_a values that ranges from $4 \cdot 10^{-7}$ (U) to > $1 \cdot 10^{-2}$ m (Eu). The order of increasing sorption is: U, Np, Sr, Ni, Cs and Eu.

For synthetic groundwater, Ni sorption is stronger.

Results from the batch experiments with clay gyttja, type II and natural groundwater at 130 days give R_a values that ranges from $5 \cdot 10^{-6}$ (Sr) to > $2 \cdot 10^{-3}$ m (Eu). The order of increasing sorption is: Sr, U, Cs, Np, Ni and Eu.

For synthetic groundwater Eu and U sorption is stronger, at least initially, while Np sorption is weaker over the whole sampling period.

pH show an increase over the sampling period by about 0.5 units in all experiments, while Eh decrease from about 0.3–0.4 V to 0–0.1 V.

Tracer element analyses show no Eu or Cs background concentration, while U, Sr and Ni were of about the same concentration as tracer levels. Iodine background concentration levels ($1 \cdot 10^{-5}$ M) were several magnitudes higher than added tracer.

TOC concentration is clearly higher in natural groundwater (~ 1 mM), while it was not detected in the synthetic groundwater (< 0.2 mM). However, TOC contributions from the solid phases complicate the pattern.

Sammanfattning

Svensk Kärnbränslehantering AB (SKB) genomför platsundersökningar för ett slutförvar av använt kärnbränsle i Oskarshamns kommun, som ligger vid Östersjökusten i södra Sverige. Jord och grundvattenprover från området runt Laxemar har insamlats och karaktäriserats, vilket också nyligen har rapporterats /1/.

Så kallade batchförsök med sorption av radioaktiva spårämnen av I, Cs, Sr, Ni, Eu, U och Np har genomförts med åtta utvalda jordprover och ett naturligt grundvatten. Viktsförhållandet mellan fast och flytande fas var 1:48 och provtagning skedde vid 3 timmar, 1 dag, 7, 14, 40 och slutligen 130 dagar. Fas separation gjordes med centrifugering där fältets styrka var > 20 kG. Experimenten genomfördes i en handskbox med inert atmosfär (O_2 < 1 ppm).

Samma typ av batchsorptionsförsök gjordes också med ett syntetiskt grundvatten . Receptet för det syntetiska grundvattnet baserades på analyser av det naturliga grundvattnet, förutom att lösta organiska ämnen inte ingår.

En separat serie med understödjande experiment, utan tillsatta spårämnen, gjordes för att mäta utvecklingen av pH och Eh.

Ytterligare en serie med understödjande experiment gjordes för ett antal kemiska analyser, där provtagning skedde endast vid 14 och 130 dagar: an- och katjoner, alkalinitet, totalt organiskt kol (TOC), oorganiskt kol, pH, Eh, samt ICP-MS och -OES analyser av bakgrundshalter av spårämnesgrundämnen och ett antal andra grundämnen.

Generellt visar resultaten för batchförsöken att de uppmätta specifik-yta-korrigerade fördelningskoefficienterna R_a(m) ökar med tiden, men att de tycks plana ut mot ett gränsvärde. Sorptionen av jod är generellt under den undre detektionsgränsen och få data kunde bestämmas för detta spårämne. Eu visar generellt mycket stark sorption och vissa mätningar vid senare provtagningar är övre den övre detektionsgränsen.

Resultaten från batchförsök med torv och naturligt grundvatten vid 130 dagar ger R_a värden inom området $5 \cdot 10^{-5}$ (Sr) till $3 \cdot 10^{-4}$ m (Cs). Ordningen för ökande sorption är: Sr, Ni, Np, Eu, U and Cs.

För syntetiskt grundvatten så är sorptionen av Eu och U starkare, åtminstone initialt, jämfört med naturligt grundvatten, medan sorptionen av Cs är svagare över hela försöksperioden.

Resultaten från batchförsök med gyttja och naturligt grundvatten vid 130 dagar ger R_a värden inom området $3 \cdot 10^{-5}$ (Sr) till $1 \cdot 10^{-2}$ m (Eu). Ordningen för ökande sorption är: Sr, Cs, U, Ni, Np and Eu.

För syntetiskt grundvatten så är sorptionen av U starkare och jämförbar med Eu.

Resultaten från batchförsök med lergyttja typ I och naturligt grundvatten vid 130 dagar ger R_a värden inom området $1 \cdot 10^{-5}$ (Sr) to > $1 \cdot 10^{-3}$ m (Eu). Ordningen för ökande sorption är: Sr, Cs, Ni, U, Np and Eu.

För syntetiskt grundvatten så är sorptionen av U starkare, åtminstone initialt, och jämförbar med Eu. För Np däremot så är sorptionen svagare och jämförbar med Sr över hela försöksperioden.

Resultaten från batchförsök med sand och naturligt grundvatten vid 130 dagar ger R_a värden inom området $1 \cdot 10^{-4}$ (Sr) to $2 \cdot 10^{-1}$ m (Eu). Ordningen för ökande sorption är: Sr, U, Cs, Ni, Np and Eu.

För syntetiskt grundvatten så är sorptionen av U och Ni starkare. Np däremot, har svagare sorption.

Resultaten från batchförsök med lera och naturligt grundvatten vid 130 dagar ger R_a värden inom området $4 \cdot 10^{-7}$ (U) to > $1 \cdot 10^{-3}$ m (Eu). Ordningen för ökande sorption är: U, Sr, Np, Ni, Cs and Eu.

För syntetiskt grundvatten så är sorptionen av U och Ni starkare, medan Cs visar svagare sorption.

Resultaten från batchförsök med morän typ I och naturligt grundvatten vid 130 dagar ger R_a värden inom området $2 \cdot 10^{-6}$ (U) to > $1 \cdot 10^{-2}$ m (Eu). Ordningen för ökande sorption är: U, Sr, Np, Ni, Cs and Eu.

För syntetiskt grundvatten så är sorptionen av Ni starkare.

Resultaten från batchförsök med morän typ II och naturligt grundvatten vid 130 dagar ger R_a värden inom området $4 \cdot 10^{-7}$ (U) to > $1 \cdot 10^{-2}$ m (Eu). Ordningen för ökande sorption är Sr, U, Cs, Np, Ni and Eu.

För syntetiskt grundvatten så är sorptionen av Ni starkare.

Resultaten från batchförsök med lergyttja typ II och naturligt grundvatten vid 130 dagar ger R_a värden inom området $5 \cdot 10^{-6}$ (Sr) to > $2 \cdot 10^{-3}$ m (Eu). Ordningen för ökande sorption är: Sr, U, Cs, Np, Ni and Eu.

För syntetiskt grundvatten så är sorptionen av U och Eu starkare, åtminstone initialt, medan sorptionen av Np är svagare över hela försöksperioden.

pH visar en ökning över hela försöksperioden med ungefär 0,5 enheter i alla experiment, medan Eh sjunker från cirka 0,3–0,4 V ned till 0–0,1 V.

Spårämnesanalys visar att bakgrundshalter av Eu och Cs var under detektionsgräns medan halterna av Sr, Ni och U var ungefär samma som tillsatt spårämne. Bakgrundshalt jod ($1 \cdot 10^{-5}$ M) var flera magnituder över tillsatt spårämne.

Koncentration TOC är klart högre i naturligt grundvatten (~ 1 mM) än i det syntetiska, där det var under detektionsgräns (< 0,2 mM). TOC bidrag från de fasta faserna komplicerar emellertid bilden.

Contents

1 Introduction

This document reports the results from the batch sorption experiments with eight selected soil samples and one natural groundwater from the Laxemar area in the community of Oskarshamn. In addition, experiments were carried out with a synthetic groundwater, based on the analyses of the natural one except for the omission of dissolved organic constituents.

The investigation is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-07-019. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

A description of the sampling site in the Laxemar area (Figure 1-1), sampling procedures and results of characterization and analyses of soil and groundwater samples have already been reported /1/.

A detailed experimental plan for the execution of the batch sorption measurements with soil have been documented separately /2/.

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	Number	Version
Batchsorptionsmätningar på jord från Laxemarsområdet	AP PS 400-07-019	1.0
Method descriptions	**Number**	**Version**
Batchsorptionsmätning	SKB MD 540.002	3.0

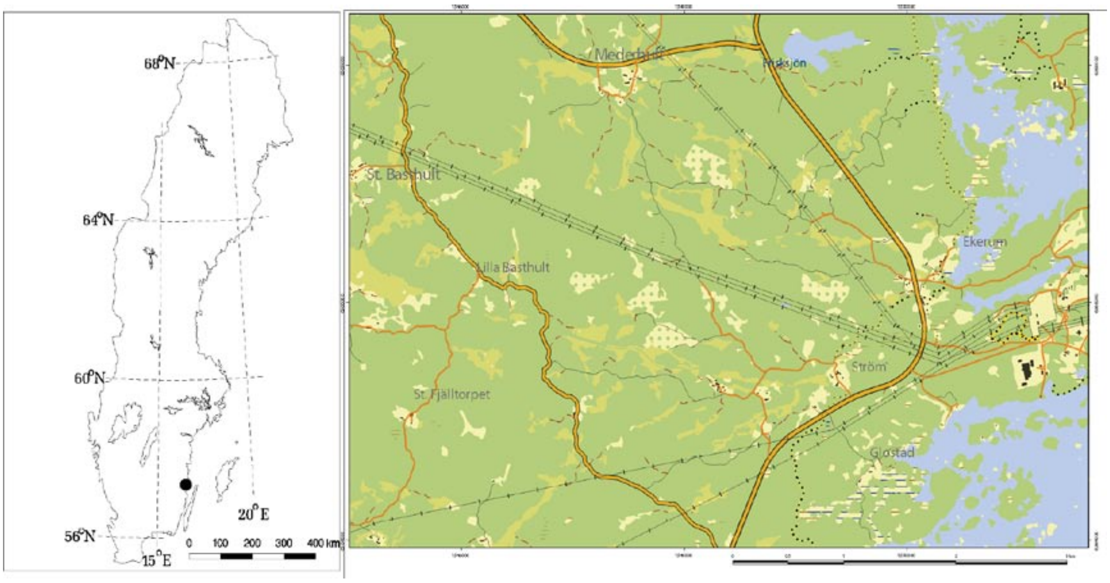

Figure 1-1. Overview from the three valleys where soil- and groundwater monitoring samples were taken for characterization. 1: Valley Mederhultsån, 2: Valley Ekerumsbäcken and 3: Valley Laxemarån.

2 Objective and scope

The purpose of this work is to measure partitioning coefficients (R_d, R_a) as a function of time for a number of radiotracers, I, Cs, Sr, Ni, Eu, U and Np, which are representative of different oxidation states and typical elements constituents in nuclear waste, by their sorption on different types of soil samples, collected in autumn 2006 in the Laxemar area.

As described in the report on characterization of the samples /1/, the soil samples were originally 17 but were later pooled into 8 composite samples for the subsequent analyses. These 8 samples were delivered to Chalmers University for the execution of batch sorption experiments. Pictures of the soils can be found in Appendix 4.

An overview of the eight soil samples are given in Table 2-1.

From Table 2-1 the soil types can be ordered in depth of sampling section: peat (2T), gyttja (GI), clay gyttja I (2LGI), sand (SI), clay (LI), clay gyttja II (LGII), till I (3MI) and till II (MII).

Note, however, that sand and clay sample sections are located in between the sample sections of the pooled samples of clay gyttja I.

The depth of the sample section is one parameter of interest when comparing results for sorption.

For shorthand notation of the eight soils in legends, tables and figures in the following sections, the respective labels T, G, LGI, S, L, LGII, MI and MII are used.

The natural groundwater used in the experiments (SSM000260, SKB nr: 011779, sample date 070320), was one of four that were sampled in the Laxemar area /1/. The selection was made after about 6 months of storing in a fridge at Chalmers University. The water which had least precipitations and discolouring after this period was selected.

Moreover, a synthetic groundwater was used in a similar series of batch experiments. The recipe was based on the analysis of the natural groundwater /1/, except for the omission of dissolved organic content. The primary interest was to compare sorption results for the synthetic groundwater with the natural groundwater, i.e. to detect possible effects of the dissolved organic content.

Apart from the main series of experiments with radionuclide tracers, two supporting series, without tracer, were also made. In the first of these, the evolution of pH and Eh was measured at the same sampling periods as for the tracer experiments.

Table 2-1. Overview of the eight soil samples /1/.

ID	Label	Pooling	Ratio wet weight	Ratio dry weight	Secup-seclow (m)
ASM000124	2T	PSM001477:1	57%	80%	0–0.9
		PSM001479:1	43%	20%	0–0.7
ASM000125	2LGI	PSM001477:3	60%	52%	2.6–3
		PSM001472:3	40%	48%	6–7.2
ASM000126	3MI	PSM001477:6	2.5%	1%	8–9
		PSM001477:7	12.5%	8%	9–10
		PSM001479:6	85%	91%	12–13
PSM001472:7	MII				12–12.5
PSM001472:3	LGII				6–7.2
PSM001477:2	GI				0.9–2.6
PSM001477:4	SI				3–5.3
PSM001477:5	LI				5.3–6.5

In the second supporting series, the evolution of a number of concentrations of so-called Main elements /2/ was made, apart from pH and Eh: major an- and cations, alkalinity, total organic carbon (TOC), dissolved inorganic carbon (DIC), concentrations of the 14 elements Cs, Sr, Eu, I, U, Ni, Si, P, Fe, Mn, Al, Ti, Cd and Co. Due to the volumes needed for the analyses, this series were run as single sample experiments. Sampling was also restricted to 14 and 130 days only due to limited space in the glove-box fridge used for storage.

The purpose of the series of Main elements analyses was to monitor any changes in elements that may explain changes of sorption and pH/Eh in the other series of experiments.

3 Equipment

3.1 Description of equipment

3.1.1 Equipment used in batch sorption experiments

For the batch sorption experiments centrifugation tubes of the type Nalge 3139-0016, with a nominal capacity of 16 mL, were used. The experiments, except for the synthetic water preparation, the tracer stock solution preparation, the phase separation step and radiotracer measurements, were made in a N_2-atmosphere glove-box of the type MBraun UNIlab. The glove-box was equipped with a fridge, set at 5°C which was used for storing the tubes between samplings. The oxygen level (~ 1 ppm) inside the box was constantly monitored during the experiments. Before using the waters (natural and synthetic) in the experiments, they were filtered through a Sartorius 0.20 µm particle filter, attached to a syringe. For the phase separation, a Beckman J2-21 centrifuge, equipped with a JA20.1 rotor, was used. The temperature control of the rotor was set to 5±3°C. For sampling, Gilson pipettes were used as well as a Mettler-Toledo PE160 balance (1 mg precision). The functioning of the balance was checked periodically with calibration weights. For radiotracer measurements of ^{125}I, ^{63}Ni and ^{152}Eu a Liquid Scintillation Counter (LSC) of the type LKB Wallac Rackbeta 1219 was used and samples dissolved in Packard Emulsifier-Safe cocktail. For measurements of ^{85}Sr and ^{134}Cs a High-Purity Germanium detector (HPGe) of the type Canberra Gamma Analyst with Genie 2000 software was used and instrument stability was checked by running standard samples at each measurement of a sampling series. For measurements of ^{233}U and ^{237}Np an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) of the type PerkinElmer Elan 6000 was used. Pure water in all applications was produced by running double-distilled water through a Milli-Q 185 Plus.

3.1.2 Equipment used in pH and Eh measurements

The pH and Eh–measurements of the experimental series dedicated for this purpose were made inside the glove-box, using electrodes of the type Radiometer pHC3006-9 and Mettler-Toledo Inlab Redox Micro, respectively, with a Radiometer PHM 240 pH/voltmeter. No stirrer was used in the actual measurements.

3.1.3 Equipment used in analyses of Main elements

The pH and Eh-measurements of this experimental series were made the same way as described in previous section. The other analyses (ion chromatography, alkalinity, ICP-MS, -OES, and TOC) were made outside the glove-box. For the analyses of major an- and cations, a Dionex DX-100 4 mm ion chromatography system, equipped with IonPac AS4A and CS12A columns, ASRS and CSRS Ultra II suppressors and conductivity detector, was used. Eluent solutions were 1.8 mM Na_2CO_3/ 1.7 mM $NaHCO_3$ and 20 mM methanesulfonic acid, respectively. For alkalinity titrations a Radiometer ABU91/TIM90/SAM90 titration system was used together with a Radiometer pHC3009-9 electrode. The pH reading stability condition was set to 1 mpH/s. A stirrer was used in the titrations. For measurement of Total Organic Carbon (TOC) and Dissolved Inorganic Carbon (DIC) an instrument of the type Shimadzu TOC-5000A was used with carrier gas of purified air, AGA Instrument 50. TOC measurements were made in the Non-Purgeable Organic Carbon (NPOC) mode, where volatile compounds are bubbled away from the acidified samples together with CO_2 before the measurement. The NPOC mode is generally recommended for measurement of low level of organics because TOC is measured as the difference between Total Carbon and DIC and the measurement error is larger than in NPOC which is a single analysis. The measurement of Cs, Sr, Eu, U, Ni, Mn, Al, Ti, Cd and Co was made with ICP-MS, as described in 3.1.1. The analyses of Si, P, Fe and I was made with an Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) of the type Thermo Scientific iCAP 6000. Pure water in all applications was produced by running double-distilled water through a Milli-Q 185 Plus.

3.2 Description of interpretation tools

3.2.1 Evaluation of sorption coefficients

The evaluation of sorption coefficients R_d(m^3/kg) was made by a methodology which is largely identical with the SKB standard methodology for evaluating batch sorption measurements with minerals.

The only deviation from the standard method is how wall sorption data is interpreted and used for correcting results for the actual batch measurements. Wall sorption is the amount of tracer that sorbs on the walls of the container used in the batch sorption experiments. In the modified evaluation method R_d-values for the wall is extracted from the wall sorption measurements and this is subsequently used for correcting the batch sorption results. The equation for calculating R_d that was used is:

$$R_d = \left(\frac{\overline{C} \cdot V_{stam} \cdot V_{utt,n}}{A_{utt,n}} - \left(V_0 - \sum_{i=1}^{n-1} V_{utt,i} \right) - L_d - \frac{V_{utt,n} \cdot \sum_{i=1}^{n-1} A_{utt,i}}{A_{utt,n}} \right) \cdot \frac{1}{10^6 \cdot m} \qquad (3\text{-}1)$$

The parameters are:

$\overline{C}$: mean concentration of the radiotracer stock solution (in cpm/mL), as measured in separate acidic reference experiments

V_{stam}: the volume of tracer initially added (mL)

$V_{utt,\,n}$: volume of sample taken at sampling n (mL)

$A_{utt,\,n}$: counting rate or mass of sample, taken at sampling n (cpm)

V_0: volume at start of experiment (mL)

L_d: R_d for wall times the mass of the tube involved in wall sorption (mL), as measured in separate wall sorption experiments

m: dry mass of soil (kg)

A detailed deduction of (3-1) can be found elsewhere /3/. In the standard methodology the wall sorption correction is instead made by assuming that the measured amount tracer sorbed in the reference experiments is the same in the batch experiments, without assuming R_d values for wall sorption, which means that any feedback on wall sorption from batch sorption onto the solid phase is omitted.

R_a(m) values were also calculated by taking the R_d values and divide them by the measured specific surface area for the soils. These have been measured in a previous work /1/.

3.2.2 Evaluation of detection levels for sorption coefficients

The methodology for calculating theoretical detection levels for radiometric measurements is based on counting statistics only, where the error associated with the number of counts is the square root of this value. Measurement errors associated with volume and mass measurements are not considered.

When measuring of R_d coefficients with the batch method there are actually no less than five detection levels (DL) to consider: upper and lower DL for the supporting L_d experiment, the “critical” value of L_d beyond where no R_d values can be evaluated and finally, upper and lower DL for R_d itself.

Starting with L_d, it is clear that there is an upper DL when the counting rate in the sample approaches background values, due to strong sorption onto the tube wall. At the one sigma confidence level, the criterion for detection is here taken as

$$P = B + \sqrt{B} + \sqrt{P} \qquad (3\text{-}2)$$

P is the number of counts in the sample and B is the corresponding value for the background.

This L_d upper DL is then calculated as

$$L_d = \left(\frac{R_0 - P}{P - B} \right) \cdot V_{0,ref} \qquad (3\text{-}3)$$

Where

$$R_0 = \frac{V_{utt,ref} \cdot \overline{C} \cdot V_{stam,ref} \cdot t_{count}}{V_{0,ref}} \qquad (3\text{-}4)$$

R_0 is the number of counts in the acidic reference, t_{count} is the counting time, and the other parameters $V_{0,ref}$, $V_{utt,ref}$, $V_{stam,ref}$ have the same meaning as defined in the previous section, but are now with respect to a wall sorption reference experiment (without solid phase). The sample volume $V_{utt,ref}$ taken from acidic and wall sorption tubes is assumed to be the same.

However, although this upper level of L_d do have importance for judging how strong wall sorption that can be detected, it will not have any importance if a R_d value shall be calculated as well.

To be able to calculate R_d, the acidic reference must first be corrected for wall sorption

$$R = R_0 - L_d \cdot (P - B)/V_0 \qquad (3\text{-}5)$$

Here R is used for the corrected value.

In addition, the criteria for detection are now chosen as

$$\begin{aligned} P &= B + \sqrt{B} + \sqrt{P} \\ R &= P + \sqrt{R} + \sqrt{P} \end{aligned} \qquad (3\text{-}6)$$

Solving the equation system for L_d yields the “critical” L_d, the largest value where R_d values can be calculated.

Turning now to the other end of the measurable range, it is also clear that there is a lower DL for L_d, where the difference between acidic reference and wall sorption reference is small.

The criteria for detection is then taken as

$$P = R_0 - \sqrt{R_0} - \sqrt{P} \qquad (3\text{-}7)$$

The L_d lower DL can then be calculated with the expression for L_d, above.

The upper and lower DL of R_d will depend on which L_d that is measured, as long as this value is below the “critical” L_d.

The detection levels are calculated as

$$R_d = \frac{(R - P) \cdot V_0}{(P - B) \cdot m} \qquad (3\text{-}8)$$

For upper DL the criterion for detection is the same as for L_d, that is (3-2). However, for the lower DL the criterion is now

$$P = R - \sqrt{R} - \sqrt{P} \qquad (3\text{-}9)$$

For non-radiometric measurements (i.e. ICP-MS), the method described above was used but the number of counts is replaced by the measured mass intensity and the error associated with that measurement. The error was taken as 1% of the measured mass intensity, as a typical value.

For results of DL calculations, see Results Section 5.1.1.

3.2.3 Evaluation of errors in the sorption coefficients

Since only random and uncorrelated errors caused by fluctuations in radiometric measurements are considered here, this section is an exercise in the application of the error propagation formula on a function F(x,y...)

$$\sigma_F^{\,2} = \sigma_x^{\,2} \cdot \left(\frac{\partial F}{\partial x} \right)^2 + \sigma_y^{\,2} \cdot \left(\frac{\partial F}{\partial y} \right)^2 + ... \tag{3-10}$$

The function *F*(x,y...) to apply the formula on is (3-1). Since L_d and C (i.e. the parameters for wall sorption and concentration of the acidic reference), are used as mean values, the measured standard deviation of the replicates are taken as errors for these parameters.

Furthermore, the relative errors in the measured volumes and solid mass are judged to be small in comparison, since they were weighed with a laboratory balance.

Therefore, weighing errors were *not* considered. Only errors in number of counts of the radioactive tracer for $A_{utt,n}$, the last sampling, and $A_{utt,i}$, the previous samplings were considered, together with the standard deviations for L_d and C.

The error in $R_{d,g}$ is therefore calculated as

$$\sigma_{Rd} = \frac{1}{m} \cdot \sqrt{\sigma_C^{\,2} \cdot \left(\frac{V_{stam} \cdot V_{utt,n}}{A_{utt,n}} \right)^2 + \sigma_{A_{utt,n}}^{\,2} \cdot \left(\frac{V_{utt,n}}{A_{utt,n}^{\,2}} \cdot \left(\sum_{i=1}^{n-1} A_{utt,i} - C \cdot V_{stam} \right) \right)^2 + \sigma_{L_d}^{\,2} + \left(\frac{V_{utt,n}}{A_{utt,n}} \right)^2 \cdot \sum_{i=1}^{n-1} \sigma_{A_{utt,i}}^{\,2}} \tag{3-11}$$

By analysing the results, it was found that the last two terms were insignificant compared with the first two terms and they can safely be omitted in the calculation of the error for R_d.

For non-radiometric measurements (i.e. ICP-MS), the method described above was used but where the number of counts is replaced by the measured mass intensity and the error associated with that measurement. The error was taken as 1% of the measured mass intensity, as a typical value.

4 Execution

4.1 General

The method used in the experiments /2/ is based on SKB MD 540.002, but adapted for soil samples.

Batch sorption experiments were made with 0.25 g samples of soil suspended in 12 mL of natural groundwater with dissolved radiotracers of ^{125}I, ^{134}Cs, ^{90}Sr, ^{63}Ni, ^{152}Eu, ^{233}U and ^{237}Np. Reference experiments for wall sorption measurements were also made, where no solid phase was added to the experimental vessels. The vessels used were centrifugation tubes and phase separation was accomplished by centrifuging the tubes immediately before withdrawing a sample of the liquid phase for radiotracer concentration measurements. Samples were taken at 3 hours, 1 day, 7, 14, 40 and 130 days. The experiments were made in inert-gas glove-box and the tubes stored in a fridge at 5°C between the sampling occasions. The batch experiments were repeated with a synthetic groundwater, based on the analysis of the natural groundwater, except for the dissolved organic content, which was omitted.

Parallel experiments without radiotracers were made for measuring pH and Eh evolution and so-called Main elements /2/: major an- and cations, alkalinity, total organic carbon, dissolved inorganic carbon and the elements Cs, Sr, Eu, I, U, Ni, Si, P, Fe, Mn, Al, Ti, Cd and Co.

4.2 Preparations

4.2.1 Preparations for batch sorption experiments with natural groundwater

The eight soil samples (Table 2-1) and four natural groundwater in sealed containers arrived at Chalmers in April 2007. These were stored in a normal fridge until the instalment of a fridge inside the glove-box was ready, in November 2007. Then, the soil samples were stored in the glove-box fridge. However, due to space limitations, the groundwater had still to be stored in the normal fridge.

Before weighing soil samples for batch sorption, the soils were lightly homogenised by shaking and mixing in moisture that had stuck on the container walls. 0.25 g samples of the wet soils were than weighed in centrifugation tubes. The tare weight of the tubes was also recorded. The dry weights of the soils were measured separately (see 4.2.3).

The stored natural groundwater was inspected in January 2008 for precipitations and discolouring. It was then decided to select the water SSM000260 (11779), which showed the least of such effects, for the batch experiments. A thorough chemical analysis of this groundwater have been made and is reported/1/. The water was taken inside the glove-box and filtrated before 12 mL was added to the tubes with soil, the exact amount was weighed.

Five radiotracer cocktails were prepared, according to Table 4-1.

Table 4-1. Overview of tracer cocktails used in batch experiments.

Cocktail	Tracer	Concentration[1] (M) incl. carrier isotopes	Concentration[1] (Bq/L) at start	pH	Detection method used
1	^{63}Ni	$5.3 \cdot 10^{-6}$	$1.1 \cdot 10^{8}$	5	LSC
2	^{125}I	$4.5 \cdot 10^{-7}$	$5.3 \cdot 10^{9}$	5	LSC
3	^{85}Sr	$2.3 \cdot 10^{-4}$	$5.9 \cdot 10^{8}$	5	HPGe
	^{134}Cs	$4.8 \cdot 10^{-7}$	$9.6 \cdot 10^{5}$		HPGe
4	^{233}U	$2.0 \cdot 10^{-5}$	$1.7 \cdot 10^{6}$	5	ICPMS
	^{237}Np	$7.5 \cdot 10^{-6}$	$4.6 \cdot 10^{4}$		ICPMS
5	^{152}Eu[2]	$5.5 \cdot 10^{-6}$	$3.3 \cdot 10^{7}$	5	LSC
		$2.8 \cdot 10^{-5}$	$1.7 \cdot 10^{8}$		

1) based on the supplier specification sheet.

2) first concentration values for natural groundwater series, second values for synthetic groundwater series.

It was originally intended to use only three cocktails, mixing ^{125}I and ^{152}Eu with the other gamma emitters ^{85}Sr and ^{134}Cs. However, initial tests with this mixture showed that the most important gamma lines of the two former were too weak to be detected with HPGe in the Compton continuum of the latter two nuclides. Therefore, ^{125}I and ^{152}Eu had to be measured individually, using beta particle counting with LSC. The far better counting efficiency of LSC over HPGe also facilitated detection.

The concentrations of the nuclides, including any carrier isotopes, were adjusted to avoid precipitations or, if this was no issue, to be comparable to expected background levels in the natural groundwater or, if that was also no issue, never exceed 1 μM after final dilution /2/. The pH of the tracer cocktails was adjusted to 5 before they were taken into the glove-box. On basis of the results from the ^{152}Eu batch sorption series with natural groundwater, were there was problems with detection due to the strong sorption of Eu onto soil, it was decided to increase the concentration of Eu five times for the series with synthetic water.

The LSC measurements were made without any preparations. The HPGe instrument was checked for energy calibration. For ICP-MS measurements standard solutions of 0.1, 1, and 5 ppb U and 0.113, 0.63 and 1.89 ppb Np were made by diluting standards of U (natural) High-Purity Standard and a ^{237}Np stock solution, respectively, in an internal standard solution of 2.5 ppb Bi and In in 1M HNO_3. The acid was a dilution of concentrated Merck Suprapur quality HNO_3.

Tubes without any soil added were also prepared for reference (wall sorption) experiments.

4.2.2 Preparations for batch sorption experiments with synthetic groundwater

The batch experiments with synthetic groundwater were prepared exactly the same way as those with the natural groundwater, except for the preparation of the water. The recipe for this was based on the analyses of the natural groundwater, which have previously been reported /1/. The constituents considered to be of most importance are shown in Table 4-2, column 1.

The data of the analyses was put into the PHREEQC geochemical speciation program /4/, a speciation was calculated for T = 5°C and then allowed to equilibrate with the low concentration of O_2 expected in glove-box atmosphere. pO_2 =–31 was selected on the basis of the initial Eh measurements in natural groundwater in the box, which gave pe = 6.89 (Table 4-2, column 2).

A number of phases were found to be oversaturated (Table 4-2, column 3). A recalculation was thereafter done, where most of the oversaturated phases were selected for equilibration with the water. This gave a new set of over-saturated phases with Al, Fe and Mn (Table 4-2, column 4). On the basis of this Al and Fe was excluded from the recipe, since if they would equilibrate with the water, the Al and Fe concentrations would be insignificant anyway while leaving them in the recipe was considered to be a potential problem with precipitations during the course of the experiment. The oversaturated $MnHPO_4$ phase was considered to be of minor importance.

The next step was to construct a recipe based on these calculations and this is shown in Table 4-3.

The first two calculations (Table 4-3, columns 1 and 2) for room temperature and atmosphere show the equilibrium solution from natural groundwater before and after equilibration with O_2.

Since it was not possible to add carbonate by means of dissolving a salt (too much of the counter-ion would then be added), CO_2 had to be bubbled in the preparation of the synthetic water. Column two in Table 4-3 therefore shows the composition of the "proto-"synthetic water that should be used before the CO_2 bubbling step. A number of Mn and Mg phases are oversaturated.

The next two calculations (Table 4-3, columns 3 and 4) show the solution after the addition of carbonate by bubbling at room temperature and atmosphere, before and after equilibrium with O_2 and CO_2. $CaCO_3$ and a number of Mn and Mg phases are oversaturated.

The final two calculations (Table 4-3, columns 5 and 6) show the solution before and after equilibrium with inert-box atmosphere and at 5°C. Here only $MnHPO_4$ is oversaturated, but was again considered to be of minor importance.

For the preparation of the "proto"-synthetic water, it was therefore decided to have the target concentrations of major constituents as shown in Table 4-4, which is based on the water in Table 4-3, column 3.

Table 4-2. Major constituents of natural groundwater SSM000260, analysed /1/ and calculated equilibrium concentrations in inert atmosphere. Concentrations in mM.

Parameter	Analysed	Calculated at exp. T	Calculated at phase equilibrium	Calculated at phase equilibrium
T	9	5	5	5
pH	7.45	8.4	7.98	7.63
pe	–(1	6.89(2	6.88	6.98
Ca	1.72	1.72	1.72	1.57
Na	0.892	0.892	0.892	0.892
Mg	0.457	0.457	0.457	0.457
Si	0.385	0.385	0.385	0.0506
Cl	0.336	0.336	0.336	0.336
K	0.0908	0.0908	0.0908	0.0908
Mn(2)	0.00683	0.00683	0.00683	0.00683
Mn(6)	0	0	0	0
Mn(7)	0	0	0	0
Sr	0.00289	0.00289	0.00289	0.00289
Al	0.00745	0.00745	0.00745	0
Li	0.00141	0.00141	0.00141	0.00141
Fe(2)	0.0202	0.0202	0	0
Fe(3)	0.0032	0.0032	0.234	0
F	0.0942	0.0942	0.0942	0.0942
PO_4	0.00197	0.00197	0.00197	0.00197
SO_4	0.541	0.541	0.541	0.541
NO_3	0.028	0.028	0	0
NO_2	0.002	0.002	0	0
NH_4	0.0624	0.0624	0	0
C	3.92	3.92	3.92	3.77
Oversaturation phases			SiO_2,Fe_3O_4, Fe_2O_3,FeOOH $Al(OH)_3$,$CaCO_3$	$MnHPO_4$ Fe_2O_3 AlOOH
Equilibrium phases			pO_2=–31	pO_2=–31, SiO_2, FeOOH $Al(OH)_3$,$CaCO_3$

1)not reported.

2)measured value in glove-box.

Table 4-3. Recipe of synthetic groundwater, calculated equilibrium concentrations in ordinary and inert atmosphere. Concentrations in mM.

Parameter	Calculated at room T	Calculated at phase equilibrium	Calculated at room T	Calculated at phase equilibrium	Calculated at exp. T	Calculated at phase equilibrium
T	25	25	25	25	5	5
pH	8.4	11.5	8.4	8.7	8.4	7.6
pe	7.0	9.2	7.0	12	7	7.2
Ca	1.57	1.57	1.57	1.57	1.57	1.57
Na	0.892	0.892	0.892	0.892	0.892	0.892
Mg	0.457	0.457	0.457	0.457	0.457	0.457
Si	0.0506	0.0506	0.0506	0.0506	0.0506	0.0506
Cl	0.336	0.336	0.336	0.336	0.336	0.336
K	0.0908	0.0908	0.0908	0.0908	0.0908	0.0908
Mn(2)	0.00683	0	0.00683	0.00166	0.00683	0.00683
Mn(6)	0	0.00466	0	0	0	0
Mn(7)	0	0.00217	0	0.00515	0	0
Sr	0.00289	0.00289	0.00289	0.00289	0.00289	0.00289
Al	0	0	0	0	0	0
Li	0.00141	0.00141	0.00141	0.00141	0.00141	0.00141
Fe(2)	0	0	0	0	0	0
Fe(3)	0	0	0	0	0	0
F	0.0942	0.0942	0.0942	0.0942	0.0942	0.0942
PO_4	0.00197	0.00197	0.00197	0.00197	0.00197	0.00197
SO_4	0.541	0.541	0.541	0.541	0.541	0.541
NO_3	0.028	0.0924	0.028	0.0924	0.028	0
NO_2	0.002	0	0.002	0	0.002	0
NH_4	0.0624	0	0.0624	0	0.0624	0
C	0	0	3.77	3.24	3.77	3.77
Oversaturation phases		MnO_2,$MnHPO_4$ Mn_2O_3,$Mg(OH)_2$ MnOOH		$CaCO_3$,MnO_2, $MgCO_3$, MnOOH $MnCO_3$		$MnHPO_4$
Equilibrium phases		pO_2=–0.7		pO_2=–0.7, pCO_2=–3.4		pO_2=–31

Table 4-4. Target concentrations of components for the synthetic groundwater.

Component	Concentration (M)
Sr	2.89E–06
Si	5.06E–05
SO_4	5.41E–04
PO_4	1.97E–06
Na	8.92E–04
Mn[1]	6.83E–06
Mg	4.57E–04
Li	1.41E–06
K	9.08E–05
F	9.42E–05
Cl	3.36E–04
Ca	1.57E–03
CO_3[2]	3.77E–03
NO_3	0.000028
NO_2	1.98E–06
OH	3.47E–03
NH_4	6.24E–05

[1] added last, in glove-box.

[2] added by bubbling of CO_2 gas.

A number of salts were designated for this composition and as the final regulating component NaOH was included in recipe for compositional balance. A carbonate salt was excluded since CO_2 bubbling have to be used for the addition of this component.

The amount of bubbling that was required was therefore judged by the change in pH from the theoretical values of 11.5 of the "proto-"synthetic water down to 8.7 (or 8.4 when cooled) in the final synthetic water.

The preparation procedure was as follows:

- A 500 times pre-concentrate was prepared by dissolving 0.1537 g $NaH_2PO_4{\cdot}2H_2O$, 0.0299 g LiCl, 0.0683 g $NaNO_2$, 0.0714 g NaF and 0.116 g 1 M NaOH in 1 L of Milli-Q water.
- A 50 times pre-concentrate was prepared by dissolving 0.0385 g $SrCl_2{\cdot}6H_2O$, 0.5966 g Na_2SO_4, 0.2638 g KF, 0.119 g $NaNO_3$, 0.1669 g NH_4Cl and 0.7393 g NaCl in 1 L of Milli-Q water.
- To a 1 L measuring flask, half-filled with Milli-Q water, was added: 0.1162 g $CaOH_2$, 0.1126 g $MgSO_4{\cdot}7H_2O$, 0.27 mL of a 34.1 g/L Na_4SiO_4 solution, 20 mL and 2 mL of the 50X and 500X pre-concentrates, respectively.
- The solution was then diluted to the mark. pH measurements on this slightly hazy solution gave values about 11.3.
- The solution was transferred to an E-beaker with magnetic stirrer and cooled on ice-bath.
- CO_2 was bubbled while pH was monitored. When pH went below about 8.5 the bubbling was stopped and the solution allowed to stand overnight, sealed and with continued stirring. pH measurements the next day gave values about 7–8 for different batches and the solution was completely clear.
- The water was then taken into the glove-box and 0.068 g $MnCl_2{\cdot}4H_2O$ was added.

The solution was allowed to stand for several days with stirring. pH measurements then usually gave values about 8.5 for different batches at 5°C, to be compared with the theoretical 8.4. A very small amount of white precipitation had then developed and the water was therefore filtrated before it was used in the batch sorption experiments.

4.2.3 Determination of soil dry weigths

The dry weight of the soil samples were determined by weighing in about 3 grams of soil samples in dried and constant-weighed E-flasks. The samples were then dried at about 80°C in an oven, cooled and re-weighed with repetitions until the weight was constant.

4.2.4 Determination of densities of solutions

Since all amounts of solution in the batch experiments were weighed, the densities of the solutions used were measured separately, using a pychnometer. The densities of natural and synthetic groundwater, 1 M HCL and 1 M NaOH , the latter two used in reference experiments, were determined at 5 and 20°C.

4.2.5 Preparations for analyses of pH and Eh

The series of experiments designated for pH and Eh measurements were prepared as the batch experiments described in Section 4.2.1, except that no radiotracers were to be used in this series of experiments. Instead a "tracer dummy" solution was prepared with the approximate same ionic strength and same pH, to be added at the start of the experiments.

At each measurement, the pH electrode was two-point calibrated with Radiometer IUPAC pH buffers immediately before measurement of a series. The function of the Eh electrode was checked with a Mettler-Toledo 220 mV buffer. The reference value was extrapolated to 253 mV at 5°C and if the measured value was within ±5 mV of this it was considered to be in working order. All buffers were cooled to 5°C before using them.

4.2.6 Preparations for analyses of Main elements

The series of experiments designated for Main elements analyses were prepared as the batch experiments described in Section 4.2.1, except that no radiotracers were to be used in this series of experiments. Instead a “tracer dummy” solution was prepared with the approximate same ionic strength and pH, to be added at the start of the experiments.

pH and Eh measurements

The measurements were prepared as in Section 4.2.5.

Ion chromatography

For the measurement of anions F^-, Br^-, NO_3^- and I^- standard solutions of pro Analysis (p.A.) quality salts were prepared to 0.001, 0.01, 0.05 and 0.1 mM. For Cl^- and SO_4^{2-} the concentrations 0.01, 0.1, 0.5 and 1 mM were used.

For the measurement of cations Li^+ and NH_4^+ standard solutions of p.A. quality salts were prepared to 0.001, 0.01, 0.05 and 0.1 mM. For Na^+, K^+, Mg^{2+} and Ca^{2+} the concentrations 0.01, 0.1, 0.5 and 1 mM were used.

Alkalinity titrations

For the titrations of alkalinity, HCl solutions of two different strengths were used, 0.01 and 0.002 M, prepared from 0.01 mol Fluka FIXANAL HCl ampoules. The titer concentrations were determined with triplicate titrations on a freshly prepared solution of 0.1 mol Fluka FIXANAL NaOH ampoule.

ICP-MS measurements

For the measurement of the elements Sr, Mn, Al, Ti, U, Ni, Eu, Cs, Co, and Cd standard solutions of 0.05, 0.1, 0.5, 1 and 5 ppb were prepared by diluting 10 ppm High-Purity Standards in a solution of 1M HNO_3 with 2.5 ppb internal standards of Bi, In and Y. The latter acidic internal standard solution was prepared from Merck Suprapur concentrated HNO_3.

ICP-OES measurements

For the measurement of the elements Fe, Si, I, and P standard solutions of 0.05, 0.1, 0.5 and 1 ppm were prepared by diluting 10 ppm High-Purity Standards in a solution of 1 M HNO_3. The latter acidic solution was prepared from Merck Suprapur concentrated HNO_3.

TOC and DIC measurements

For the measurement of Non-Purgeable Organic Carbon (NPOC) standard solutions of 1, 5, 10 an 15 ppm C, diluted in 0.01M HCl, were prepared from a stock solution of 1,000 ppm C solution of p.A. quality sodium hydrogen ftalate. For the measurement of Dissolved Inorganic Carbon (DIC) standard solutions of 0.05, 0.1, 0.5 and 1.0 mM sodium hydrogen carbonate was prepared from a stock solution of 10 mM dissolved p.A quality salt. All carbonate solutions were prepared the same day as the analyses.

4.3 Execution of work

4.3.1 Time schedule

The time schedule of the different experimental series is shown in Table 4-5. Each experimental series were made in duplicates.

Table 4-5. Time schedule of start and sampling of the different experiment series (3 hours and 1 day are not shown).

Water	Experiment	Start	7 days	14 days	40 days	130 days
Natural	Ni, pH, ME(1	2008-02-06	2008-02-13	2008-02-20	2008-03-17	2008-06-15
	I	2008-03-10	not measured	2008-03-24	2008-04-19	2008-07-18
	Sr, Cs	2008-03-27	2008-04-03	2008-04-10	2008-05-06	2008-08-04
	U, Np	2008-04-18	2008-04-25	2008-05-02	2008-05-28	2008-08-26
	Eu	2008-06-24	2008-07-01	2008-07-08	2008-08-03	2008-11-01
Synthetic	Ni, pH, ME(1	2008-07-23	2008-07-30	2008-08-06	2008-09-01	2008-11-30
	I	2008-09-11	2008-09-18	2008-09-25	2008-10-21	2009-01-19
	Sr, Cs	2008-09-17	2008-09-24	2008-10-01	2008-10-27	2009-01-25
	U, Np	2008-08-29	2008-09-05	2008-09-12	2008-10-08	2009-01-06
	Eu	2008-08-29	2008-09-05	2008-09-12	2008-10-08	2009-01-06

1) Main elements. Samples were taken only at 14 and 130 days.

4.3.2 Batch sorption experiments

The batch sorption experiments were started by adding 50 μL of the appropriate radiotracer cocktail to the centrifugation tubes with soil and water. Reference experiments without solid were also started, these were of two kind: one with groundwater and one with 1 M HCl or 1 M NaOH (only for iodine tracer). The amount added was weighed. The samples were then stored inside the fridge. On the prescribed intervals 3 hours, 1 day, 7, 14, 40 and 130 days samples were taken with the following procedure:

- The whole series (experiments with one tracer cocktail and one groundwater) were taken outside the glove-box and centrifuged for half an hour.
- The tubes were returned inside the glove-box, weighed, 0.1 mL samples were withdrawn and the tubes weighed again.
- The tubes were then lightly shaken, in some cases (clay samples) a vibrating pad had to be used for mixing the phases and the tubes were returned to storage.
- For LSC measurements, 20 mL of LSC cocktail were added to the samples and then allowed to stand for at least one hour before measurement. The counting limit was 1 hour or 900,000 counts. Individual beta energy windows were set for each nuclide.
- For HPGe measurements, 0.5 mL 0.1M HCl was added to the samples before measurement. The counts (peak area) at gamma energies 514 keV and 605 keV were selected for ^{85}Sr and ^{134}Cs, respectively. The counting time was 1 hour. All radiometric analyses were corrected for background counts.
- For ICP-MS measurements, 5 mL of internal standard solution was added to the samples (see ICP-MS Preparations sections above). At least five measurements were made of the solution at the appropriate mass number and measurement statistics computed from this.

4.3.3 pH and Eh measurements

The series designated for pH and Eh-measurements were started the same way as the batch sorption experiments, except that the “tracer dummy” solution was added instead. At the prescribed sampling time the tubes were taken from the fridge. Phase separation was accomplished as in the batch sorption experiments, the tubes returned inside the glove-box and pH and Eh was consecutively measured in the supernatant. Stable pH readings were usually quickly established, for Eh readings the stabilisation was considerably longer (several minutes). If no stabilisation could be achieved, the samples were returned to fridge and Eh re-measured some hours or one day after the first measurement.

4.3.4 Analyses of Main elements

The series designated for Main elements analyses were started the same way as the batch sorption experiments, except that the "tracer dummy" solution was added instead. The sampling intervals prescribed were 14 and 130 days, and one series of tubes were made for each occasion. On the sampling time, phase separation was accomplished as with batch sorption experiments. Samples of 5 mL were then taken to separate tubes, stored in glove-box, awaiting further analyses. The reminding solution was used for pH and Eh measurements.

Two types of samplings were made for analyses of groundwater without contact with soil: one from a reference series of centrifugation tubes, sampled at the same time as the other series, and one taken directly from the filtrated water container. The latter were taken at the end of the experiments to give an indication of any contributions from the centrifugation tubes to main elements. pH and Eh were, however, not measured in these direct-from-the-bottle samples.

pH and Eh measurements

These measurements were made as described in Section 4.3.3.

Ion chromatography

For the measurement of anions and cations, samples of 1–2 mL were transferred to glass vials. A typical analysis would consist of one standard series measurement followed by blank samples and then the samples to analyse. Double injections of 20 µL each were made and mean value and standard deviation calculated.

Alkalinity titrations

For the titrations of alkalinity 0.2 or 0.4 mL samples were taken and transferred to a vessel with magnetic stirrer. 5 mL of Milli-Q water was added and the solution titrated for inflexion point.

ICP-MS measurements

For the measurement of the elements Sr, Mn, Al, Ti, U, Ni, Eu, Cs, Co and Cd 10 mL of internal standard solution (see ICP-MS Preparations sections above) was added to 0.6 mL samples. At least five measurements were made of the solution at the appropriate mass number and measurement statistics computed from this. The standard series, including blanks, were measured thrice during one run.

ICP-OES measurements

For the measurement of the elements Fe, Si, I, and P 5 mL 1M HNO_3 (see ICP-OES Preparations sections above) was added to 0.4 mL samples. Three measurements were made of the solution at an appropriate emission line and measurement statistics computed from this. The standard series, including blanks, were measured twice during one run.

TOC and DIC measurements

For the measurement of Non-Purgeable Organic Carbon (NPOC) 4–5 mL 0.01M HCl was added to 0.1 mL samples. For the measurement of Dissolved Inorganic Carbon (DIC) 0.1 mL samples were diluted in 4–5 mL water that had been stored in inert atmosphere. A typical analysis consisted of one standard series, several blanks and 20 samples, interspaced by two blanks each.

4.4 Data handling

Raw data in the form of paper print-outs were collected and stored, raw data in the form of data files were transferred immediately to a computer. All raw data were transferred to computer files. Back-up copies of files on a remote server were made regularly.

4.5 Analyses and interpretations

Experimental raw data of the batch sorption experiments was interpreted with the model for R_d values, described in Section 3.2 above. Radiometric data was not processed further, while ICP-MS data was first evaluated, using the measured standard curves.

Raw data from the pH measurements was not processed further. Eh raw data were corrected to Standard Hydrogen Electrode (SHE) values, by adding 221 mV (extrapolated value for 5°C) to the voltage readings.

Raw data from the analyses of Main elements were evaluated with the measured standard curves, where appropriate.

4.6 Nonconformities

A detailed methodology for the soil and water sampling, treatment, characterization, analyses and their use in subsequent batch sorption experiments have been written /2/.

However, since there was no previous reference case or standard methodology to fall back onto for the batch sorption experiments with soil (the SKB standard methodology is for crushed rock) some modifications to the prescribed methodology /2/ had to be done *ad hoc* basis.

Deviations from the prescribed methodology are:

- Originally three radionuclide cocktails were prescribed. Due to measurement difficulties this had to be expanded to five. This also gave consequences to the time schedules for the batch experiments since the amount of work involved was almost doubled.
- Due to space limitations the total liquid volume of each batch experiment was decreased from the stipulated 25 mL to 12 mL. To maintain the solid to weight ratio the size of solid phase was also changed from 0.5 to 0.25 g.
- Acidified reference samples were prepared by using acidified pure water and not acidified groundwater. Since these samples are only for reference measurement of added radiotracer, the inclusion of groundwater was considered unimportant.
- Centrifugation was made with a centrifugation field of > 20 kG, which is considerable stronger than the stipulated (approx. 800 G). This precautionary change of method mitigates potential phase separation problems due the lower gravity of the soil compared with crushed rock.
- The method prescribes washing out of the pore-water of the soil, but only when using a synthetic groundwater. This was not done. The methodology assumes in the case with natural groundwater that this water would be identical to the pore-water and such washing is unnecessary, while the pore-water need to be replaced when using synthetic water. However, measurements show an initial impact on pH for the natural groundwater in contact with soil. This indicates that the selected natural groundwater is not representative for the individual pore-waters in each soil type. Then, to facilitate the comparative study between natural groundwater and synthetic water, it was judged to be best to keep experimental conditions as close as possible between the two cases.
- The prescribed sampling at 4 days was changed to 7 days. Due to practicalities, for the longer sampling periods (14, 40 and 130 days) the exact sample period was usually within ±5 days of the prescribed.
- Due to space limitations, the number of samples for Main Elements was restricted from four to two, which also compensated for, to a certain extent, the increased amount of work with the additional batch sorption experiments (see point one, above). This restriction may however make the interpretation of changes in results for sorption/pH/Eh more difficult.

5 Results

5.1 Results for the batch sorption experiments

5.1.1 Detection limits

The theoretical detection limits of R_d values for each radiotracer was calculated according to the methods described in Section 3.2.2, for the particular wall sorption coefficient L_d that was measured in each batch sorption experimental series. The results are presented in Table 5-1 below.

The far better dynamical range (i.e. difference between background and max value) of the ICP-MS measurements over the radiometric methods is obvious from $R_{d,max}$ values.

The resolution (i.e. statistical error, which affects the ability to resolve two values) is, however, somewhat better for the radiometric methods, as the $R_{d,min}$ values show.

Note that these are detection levels based on measurement statistics, in practice the limits may be narrower due to errors in volume measurements, hence the appearance of negative or not calculable values in the sections below.

In the following sections, all R_d values that are below the calculated lower detection limit are put between ( ) and all R_d values that are above the calculated upper detection limits are marked with *.

5.1.2 Sorption onto peat

The results of the batch sorption measurements of ^{63}Ni onto peat in natural and synthetic groundwater are shown in Tables 5-2 and 5-3, respectively. R_d was converted to R_a(m) by utilizing the measured BET-area of 12.42 m^2/g /1/. The R_a values for tracer sorption onto peat are plotted as function of time in Appendix 1.

The results of the batch sorption measurements of ^{125}I onto peat in natural and synthetic groundwater are shown in Tables 5-4 and 5-5, respectively. Most measurements are clearly below the lower detection limit since they yield negative R_d values and can therefore not be used. The calculated values are nevertheless presented here to give an indication of how close to zero they are. R_a values were not calculated for this tracer.

Table 5-1. Results of measurements of wall sorption coefficients, L_d(mL) and calculated detection levels of soil sorption coefficients R_d(m^3/kg).

Series	Average experimental L_d (mL)	$R_{d,max}$(m^3/kg)	$R_{d,min}$(m^3/kg)
Natural groundwater			
^{134}Cs	1.0	11	0.001
^{125}I	0.3	75	0.0002
^{90}Sr	1.0	7	0.0009
^{63}Ni	0.4	21	0.0005
^{152}Eu	1.8	9	0.0003
^{233}U	0.5	430	0.001
^{237}Np	0.4	1,370	0.001
Synthetic groundwater			
^{134}Cs	0.8	11	0.001
^{125}I	1.8	75	0.0002
^{90}Sr	0.6	7	0.0009
^{63}Ni	3.0	21	0.0005
^{152}Eu	1.7	47	0.0003
^{233}U	0.4	300	0.001
^{237}Np	0.3	2,200	0.001

Table 5-2. Results of batch sorption of ^{63}Ni onto peat in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.15 ±0.00	0.12 ±0.00	1.2E–05	9.3E–06
1	0.41 ±0.01	0.37 ±0.01	3.3E–05	3.0E–05
7	0.83 ±0.01	0.79 ±0.01	6.7E–05	6.3E–05
15	1.0 ±0.0	0.95 ±0.02	8.1E–05	7.7E–05
48	1.0 ±0.0	1.0 ±0.0	8.2E–05	8.1E–05
130	0.76 ±0.01	0.81 ±0.01	6.1E–05	6.5E–05

Table 5-3. Results of batch sorption of ^{63}Ni onto peat in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.038 ±0.002	0.069 ±0.002	3.1E–06	5.6E–06
1	0.20 ±0.00	0.23 ±0.00	1.6E–05	1.8E–05
7	0.52 ±0.01	0.59 ±0.01	4.2E–05	4.7E–05
15	0.73 ±0.01	0.78 ±0.01	5.9E–05	6.3E–05
41	0.92 ±0.01	0.94 ±0.01	7.4E–05	7.6E–05
130	0.74 ±0.01	0.73 ±0.01	6.0E–05	5.9E–05

Table 5-4. Results of batch sorption of ^{125}I onto peat in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.001	(–0.008)	–	–
1	(–0.005)	(–0.002)	–	–
7	not measured	not measured	–	–
14	0.035	0.038	–	–
42	(–0.000)	(–0.003)	–	–
133	0.005	0.004	–	–

Table 5-5. Results of batch sorption of ^{125}I onto peat in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.0002	(–0.001)	–	–
1	(–0.002)	(–0.004)	–	–
7	(–0.005)	(–0.005)	–	–
21	(–0.005)	(–0.006)	–	–
40	(–0.000)	(–0.001)	–	–
133	0.002	0.0004	–	–

The results of the batch sorption measurements of ^{85}Sr onto peat in natural and synthetic groundwater are shown in Tables 5-6 and 5-7, respectively.

The results of the batch sorption measurements of ^{134}Cs onto peat in natural and synthetic groundwater are shown in Tables 5-8 and 5-9, respectively.

Table 5-6. Results of batch sorption of ^{85}Sr onto peat in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.066 ±0.008	0.077 ±0.008	5.3E–06	6.2E–06
1	0.17 ±0.01	0.25 ±0.02	1.3E–05	2.0E–05
7	0.31 ±0.02	0.36 ±0.02	2.5E–05	2.9E–05
15	0.50 ±0.03	0.45 ±0.03	4.1E–05	3.6E–05
41	0.55 ±0.03	0.67 ±0.03	4.4E–05	5.4E–05
131	0.61 ±0.03	0.67 ±0.03	4.9E–05	5.4E–05

Table 5-7. Results of batch sorption of ^{85}Sr onto peat in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.054 ±0.005	0.081 ±0.005	4.4E–06	6.5E–06
1	0.25 ±0.01	0.34 ±0.01	2.0E–05	2.7E–05
7	0.49 ±0.01	0.47 ±0.01	4.0E–05	3.8E–05
15	0.56 ±0.02	0.61 ±0.02	4.5E–05	4.9E–05
48	0.57 ±0.02	0.72 ±0.02	4.6E–05	5.8E–05
130	0.52 ±0.01	0.51 ±0.01	4.2E–05	4.1E–05

Table 5-8. Results of batch sorption of ^{134}Cs onto peat in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.14 ±0.01	0.14 ±0.01	1.1E–05	1.1E–05
1	0.43 ±0.02	0.56 ±0.03	3.5E–05	4.5E–05
7	1.1 ±0.1	1.2 ±0.1	9.2E–05	1.0E–04
15	1.8 ±0.1	1.5 ±0.1	1.5E–04	1.2E–04
41	2.2 ±0.1	2.6 ±0.1	1.8E–04	2.1E–04
131	3.8 ±0.2	3.6 ±0.2	3.0E–04	2.9E–04

Table 5-9. Results of batch sorption of ^{134}Cs onto peat in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.063 ±0.005	0.068 ±0.005	5.0E–06	5.4E–06
1	0.27 ±0.01	0.31 ±0.01	2.2E–05	2.5E–05
7	0.68 ±0.02	0.49 ±0.02	5.5E–05	4.0E–05
15	0.93 ±0.03	0.78 ±0.02	7.5E–05	6.3E–05
48	1.3 ±0.0	1.2 ±0.0	1.0E–04	9.3E–05
130	2.3 ±0.1	1.9 ±0.1	1.8E–04	1.5E–04

The results of the batch sorption measurements of ^{152}Eu onto peat in natural and synthetic groundwater are shown in Tables 5-10 and 5-11, respectively.

The results of the batch sorption measurements of ^{233}U onto peat in natural and synthetic groundwater are shown in Tables 5-12 and 5-13, respectively.

The results of the batch sorption measurements of ^{237}Np onto peat in natural and synthetic groundwater are shown in Tables 5-14 and 5-15, respectively.

Table 5-10. Results of batch sorption of ^{152}Eu onto peat in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.041±0.008	0.070 ±0.008	3.3E–06	5.6E–06
1	0.42 ±0.01	0.38 ±0.01	3.4E–05	3.0E–05
8	1.0 ±0.0	0.99 ±0.02	8.1E–05	8.0E–05
14	1.4 ±0.0	1.6 ±0.0	1.1E–04	1.3E–04
43	1.4 ±0.0	1.8 ±0.0	1.1E–04	1.5E–04
132	1.6 ±0.0	1.9 ±0.0	1.3E–04	1.5E–04

Table 5-11. Results of batch sorption of ^{152}Eu onto peat in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.91 ±0.01	0.83 ±0.01	7.3E–05	6.7E–05
1	3.3 ±0.0	4.1 ±0.0	2.6E–04	3.3E–04
7	6.4 ±0.0	7.2 ±0.0	5.1E–04	5.8E–04
14	7.8 ±0.0	10 ±0	6.3E–04	8.1E–04
40	6.4 ±0.0	5.1 ±0.0	5.2E–04	4.1E–04
136	2.0 ±0.1	2.3 ±0.1	1.6E–04	1.8E–04

Table 5-12. Results of batch sorption of ^{233}U onto peat in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.14 ±0.01	0.19 ±0.01	1.1E–05	1.6E–05
1	0.32 ±0.01	0.46 ±0.01	2.6E–05	3.7E–05
7	1.6 ±0.0	1.7 ±0.0	1.3E–04	1.3E–04
17	2.7 ±0.1	2.5 ±0.1	2.1E–04	2.0E–04
42	3.5 ±0.1	2.8 ±0.1	2.8E–04	2.3E–04
130	2.4 ±0.1	2.3 ±0.0	1.9E–04	1.8E–04

Table 5-13. Results of batch sorption of ^{233}U onto peat in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.53 ±0.01	0.19 ±0.00	4.3E–05	1.5E–05
1	2.0 ±0.0	0.93 ±0.01	1.6E–04	7.5E–05
7	5.5 ±0.0	3.2 ±0.0	4.5E–04	2.6E–04
14	7.2 ±0.0	3.8 ±0.0	5.8E–04	3.1E–04
40	3.9 ±0.0	3.4 ±0.0	3.1E–04	2.8E–04
133	2.0 ±0.0	2.3 ±0.0	1.6E–04	1.8E–04

Table 5-14. Results of batch sorption of ^{237}Np onto peat in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.057 ±0.003	0.047 ±0.002	4.6E–06	3.8E–06
1	0.10 ±0.00	0.10 ±0.00	8.3E–06	8.2E–06
7	0.19 ±0.01	0.16 ±0.00	1.5E–05	1.3E–05
17	0.25 ±0.01	0.23 ±0.01	2.0E–05	1.8E–05
42	0.45 ±0.01	0.38 ±0.01	3.6E–05	3.1E–05
130	1.1 ±0.0	0.93 ±0.02	8.7E–05	7.5E–05

Table 5-15. Results of batch sorption of ^{237}Np onto peat in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.049 ±0.001	0.028 ±0.001	3.9E–06	2.3E–06
1	0.071 ±0.001	0.046 ±0.001	5.7E–06	3.7E–06
7	0.14 ±0.00	0.10 ±0.00	1.1E–05	8.1E–06
14	0.17 ±0.00	0.14 ±0.00	1.3E–05	1.1E–05
40	0.35 ±0.00	0.30 ±0.00	2.8E–05	2.4E–05
133	0.80 ±0.01	0.90 ±0.01	6.5E–05	7.3E–05

5.1.3 Sorption onto gyttja

The results of the batch sorption measurements of ^{63}Ni onto gyttja in natural and synthetic groundwater are shown in Tables 5-16 and 5-17, respectively. R_d was converted to R_a(m) by utilizing the measured BET-area of 10.18 m^2/g /1/. The R_a values for tracer sorption onto gyttja are plotted as function of time in Appendix 1.

The results of the batch sorption measurements of ^{125}I onto gyttja in natural and synthetic groundwater are shown in Tables 5-18 and 5-19, respectively. Most measurements are clearly below the lower detection limit because they yield negative R_d values and can therefore not be used. The calculated values are nevertheless presented here to give an indication of how close to zero they are. R_a values were not calculated for this tracer.

Table 5-16. Results of batch sorption of ^{63}Ni onto gyttja in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.67 ±0.00	1.2 ±0.0	6.5E–05	1.1E–04
1	1.8 ±0.0	2.2 ±0.0	1.7E–04	2.2E–04
7	3.8 ±0.0	4.8 ±0.0	3.7E–04	4.7E–04
15	6.0 ±0.0	5.7 ±0.0	5.9E–04	5.6E–04
48	8.8 ±0.1	9.0 ±0.1	8.7E–04	8.8E–04
130	7.7 ±0.1	7.7 ±0.1	7.6E–04	7.6E–04

Table 5-17. Results of batch sorption of ^{63}Ni onto gyttja in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.81 ±0.01	1.0 ±0.01	8.0E–05	1.0E–04
1	1.6 ±0.0	1.7 ±0.01	1.6E–04	1.7E–04
7	3.9 ±0.0	3.8 ±0.0	3.9E–04	3.8E–04
15	6.4 ±0.1	5.4 ±0.0	6.3E–04	5.3E–04
41	9.2 ±0.1	8.0 ±0.1	9.1E–04	7.8E–04
130	5.0 ±0.0	4.3 ±0.0	4.9E–04	4.2E–04

Table 5-18. Results of batch sorption of ^{125}I onto gyttja in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	(–0.016)	0.002	–	–
1	(–0.013)	0.002	–	–
7	not measured	not measured	–	–
14	(–0.013)	0.006	–	–
42	(–0.009)	0.003	–	–
133	(–0.014)	(–0.004)	–	–

Table 5-19. Results of batch sorption of ^{125}I onto gyttja in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.008	0.008	–	–
1	0.003	0.006	–	–
7	(–0.004)	(–0.0004)	–	–
21	0.004	0.006	–	–
40	0.002	0.003	–	–
133	(0.0001)	0.003	–	–

The results of the batch sorption measurements of ^{85}Sr onto gyttja in natural and synthetic groundwater are shown in Tables 5-20 and 5-21, respectively.

The results of the batch sorption measurements of ^{134}Cs onto gyttja in natural and synthetic groundwater are shown in Tables 5-22 and 5-23, respectively.

Table 5-20. Results of batch sorption of ^{85}Sr onto gyttja in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.10 ±0.01	0.028 ±0.006	9.5E–06	2.8E–06
1	0.17 ±0.01	0.11 ±0.01	1.7E–05	1.1E–05
7	0.19 ±0.01	0.16 ±0.01	1.9E–05	1.6E–05
15	0.21 ±0.01	0.19 ±0.01	2.1E–05	1.9E–05
41	0.19 ±0.01	0.19 ±0.01	1.9E–05	1.9E–05
131	0.27 ±0.01	0.31 ±0.01	2.6E–05	3.0E–05

Table 5-21. Results of batch sorption of ^{85}Sr onto gyttja in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.062 ±0.004	0.11 ±0.01	6.1E–06	1.0E–05
1	0.18 ±0.01	0.18 ±0.01	1.8E–05	1.8E–05
7	0.24 ±0.01	0.25 ±0.01	2.3E–05	2.4E–05
15	0.26 ±0.01	0.26 ±0.01	2.5E–05	2.5E–05
48	0.33 ±0.01	0.29 ±0.01	3.2E–05	2.9E–05
130	0.24 ±0.01	0.30 ±0.01	2.4E–05	2.9E–05

Table 5-22. Results of batch sorption of ^{134}Cs onto gyttja in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.30 ±0.01	0.14 ±0.01	2.9E–05	1.4E–05
1	0.53 ±0.02	0.41 ±0.01	5.2E–05	4.0E–05
7	0.82 ±0.03	0.72 ±0.02	8.1E–05	7.1E–05
15	0.97 ±0.03	0.85 ±0.02	9.5E–05	8.4E–05
41	1.1 ±0.0	1.0 ±0.0	1.1E–04	9.6E–05
131	1.4 ±0.0	1.3 ±0.0	1.3E–04	1.3E–04

Table 5-23. Results of batch sorption of ^{134}Cs onto gyttja in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.11 ±0.00	0.20 ±0.01	1.1E–05	1.9E–05
1	0.31 ±0.01	0.33 ±0.01	3.0E–05	3.2E–05
7	0.48 ±0.01	0.56 ±0.01	4.7E–05	5.5E–05
15	0.53 ±0.01	0.56 ±0.01	5.2E–05	5.5E–05
48	0.74 ±0.01	0.69 ±0.01	7.2E–05	6.8E–05
130	0.68 ±0.01	0.74 ±0.01	6.7E–05	7.3E–05

The results of the batch sorption measurements of ^{152}Eu onto gyttja in natural and synthetic groundwater are shown in Tables 5-24 and 5-25, respectively. For both groundwater, sorption went above the upper detection limit (values marked with *) in the middle of the sampling series.

The results of the batch sorption measurements of ^{233}U onto gyttja in natural and synthetic groundwater are shown in Tables 5-26 and 5-27, respectively. For synthetic groundwater, sorption went above the upper detection limits at last samplings.

The results of the batch sorption measurements of ^{237}Np onto gyttja in natural and synthetic groundwater are shown in Tables 5-28 and 5-29, respectively. For one series of synthetic groundwater, sorption went above the upper detection limit at last samplings.

Table 5-24. Results of batch sorption of ^{152}Eu onto gyttja in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	3.6 ±0.0	6.0 ±0.0	3.6E–04	5.9E–04
1	14*±0	20*±0	1.3E–03	1.9E–03
8	27*±0	58*±1	2.7E–03	5.7E–03
14	35*±1	113*±3	3.4E–03	1.1E–02
43	not detected	not detected	–	–
132	not detected	not detected	–	–

Table 5-25. Results of batch sorption of ^{152}Eu onto gyttja in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	12 ±0	19 ±0	1.2E–03	1.9E–03
1	30 ±0	29 ±0	3.0E–03	2.8E–03
7	44 ±0	35 ±0	4.3E–03	3.4E–03
14	63* ±1	51* ±1	6.2E–03	5.0E–03
40	97* ±1	77* ±1	9.5E–03	7.6E–03
136	38 ±0	21 ±0	3.7E–03	2.0E–03

Table 5-26. Results of batch sorption of ^{233}U onto gyttja in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.36 ±0.01	0.35 ±0.01	3.5E–05	3.4E–05
1	0.81 ±0.01	0.77 ±0.01	8.0E–05	7.6E–05
7	2.2 ±0.0	2.1 ±0.0	2.2E–04	2.1E–04
17	3.6 ±0.0	3.0 ±0.0	3.5E–04	3.0E–04
42	3.9 ±0.0	3.4 ±0.0	3.8E–04	3.3E–04
130	6.7 ±0.1	5.1 ±0.0	6.6E–04	5.0E–04

Table 5-27. Results of batch sorption of ^{233}U onto gyttja in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	3.6 ±0.0	4.2 ±0.0	3.6E–04	4.1E–04
1	8.7 ±0.0	8.6 ±0.0	8.5E–04	8.5E–04
7	68 ±0	56 ±0	6.7E–03	5.5E–03
14	188 ±1	81 ±0	1.8E–02	7.9E–03
40	not detected	not detected	–	–
133	not detected	not detected	–	–

Table 5-28. Results of batch sorption of ^{237}Np onto gyttja in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.11 ±0.00	0.14 ±0.00	1.0E–05	1.4E–05
1	0.22 ±0.00	0.26 ±0.00	2.1E–05	2.6E–05
7	0.52 ±0.01	0.60 ±0.01	5.1E–05	5.9E–05
17	1.0 ±0.0	1.0 ±0.0	9.8E–05	1.0E–04
42	6.8 ±0.1	8.8 ±0.1	6.7E–04	8.6E–04
130	22 ±0	28 ±0	2.2E–03	2.7E–03

Table 5-29. Results of batch sorption of ^{237}Np onto gyttja in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.13 ±0.00	0.15 ±0.00	1.3E–05	1.5E–05
1	0.22 ±0.00	0.21 ±0.00	2.2E–05	2.1E–05
7	0.78 ±0.00	0.86 ±0.00	7.7E–05	8.4E–05
14	2.0 ±0.0	2.0 ±0.0	1.9E–04	2.0E–04
40	not detected	27 ±0	–	2.6E–03
133	not detected	30 ±0	–	3.0E–03

5.1.4 Sorption onto clay gyttja type I

The results of the batch sorption measurements of ^{63}Ni onto clay gyttja type I in natural and synthetic groundwater are shown in Tables 5-30 and 5-31, respectively. R_d was converted to R_a(m) by utilizing the measured BET-area of 19.61 m^2/g /1/. The R_a values for tracer sorption onto clay gyttja type I are plotted as function of time in Appendix 1.

The results of the batch sorption measurements of ^{125}I onto clay gyttja type I in natural and synthetic groundwater are shown in Tables 5-32 and 5-33, respectively. Most measurements are clearly below the lower detection limit because they yield negative R_d values and can therefore not be used. The calculated values are nevertheless presented here to give an indication of how close to zero they are. R_a values were not calculated for this tracer.

The results of the batch sorption measurements of ^{85}Sr onto clay gyttja type I in natural and synthetic groundwater are shown in Tables 5-34 and 5-35, respectively.

Table 5-30. Results of batch sorption of ^{63}Ni onto clay gyttja type I in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.17 ±0.00	0.11 ±0.00	8.5E–06	5.6E–06
1	0.34 ±0.00	0.28 ±0.00	1.7E–05	1.4E–05
7	1.3 ±0.0	1.0 ±0.0	6.8E–05	5.3E–05
15	3.1 ±0.0	2.4 ±0.0	1.6E–04	1.2E–04
48	4.8 ±0.0	4.3 ±0.1	2.4E–04	2.2E–04
130	4.2 ±0.0	3.7 ±0.0	2.1E–04	1.9E–04

Table 5-31. Results of batch sorption of ^{63}Ni onto clay gyttja type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.12 ±0.00	0.16 ±0.00	6.0E–06	8.2E–06
1	0.24 ±0.00	0.27 ±0.00	1.2E–05	1.4E–05
7	0.96 ±0.01	1.0 ±0.0	4.9E–05	5.2E–05
15	1.9 ±0.0	1.7 ±0.0	9.8E–05	8.9E–05
41	4.8 ±0.1	3.6 ±0.0	2.4E–04	1.8E–04
130	5.0 ±0.1	3.6 ±0.0	2.5E–04	1.8E–04

Table 5-32. Results of batch sorption of ^{125}I onto clay gyttja type I in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	(–0.006)	(–0.003)	–	–
1	0.004	(–0.003)	–	–
7	not measured	not measured	–	–
14	(–0.004)	(–0.006)	–	–
42	(–0.003)	(–0.007)	–	–
133	(–0.002)	(–0.002)	–	–

Table 5-33. Results of batch sorption of ^{125}I onto clay gyttja type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.005	0.001	–	–
1	0.004	(–0.001)	–	–
7	0.001	(–0.003)	–	–
21	0.005	0.001	–	–
40	0.006	(0.000)	–	–
133	0.005	0.001	–	–

Table 5-34. Results of batch sorption of ^{85}Sr onto clay gyttja type I in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.030 ±0.006	0.022 ±0.006	1.5E–06	1.1E–06
1	0.055 ±0.007	0.049 ±0.007	2.8E–06	2.5E–06
7	0.048 ±0.006	0.061 ±0.007	2.4E–06	3.1E–06
15	0.076 ±0.008	0.11 ±0.01	3.9E–06	5.4E–06
41	0.10 ±0.01	0.075 ±0.007	5.0E–06	3.8E–06
131	0.25 ±0.01	0.20 ±0.01	1.3E–05	1.0E–05

Table 5-35. Results of batch sorption of ^{85}Sr onto clay gyttja type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.008 ±0.004	0.051 ±0.004	4.2E–07	2.6E–06
1	0.051 ±0.004	0.086 ±0.004	2.6E–06	4.4E–06
7	0.065 ±0.004	0.10 ±0.01	3.3E–06	5.1E–06
15	0.050 ±0.004	0.088 ±0.004	2.5E–06	4.5E–06
48	0.10 ±0.01	0.10 ±0.01	5.0E–06	5.1E–06
130	0.095 ±0.01	0.15 ±0.01	4.8E–06	7.6E–06

The results of the batch sorption measurements of ^{134}Cs onto clay gyttja type I in natural and synthetic groundwater are shown in Tables 5-36 and 5-37, respectively.

The results of the batch sorption measurements of ^{152}Eu onto clay gyttja type I in natural and synthetic groundwater are shown in Tables 5-38 and 5-39, respectively. For both groundwater, sorption went above the upper detection limit from the middle of the sampling series (values marked with*).

Table 5-36. Results of batch sorption of ^{134}Cs onto clay gyttja type I in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.36 ±0.01	0.39 ±0.02	1.8E–05	2.0E–05
1	0.97 ±0.03	0.86 ±0.03	4.9E–05	4.4E–05
7	1.5 ±0.1	1.5 ±0.1	7.4E–05	7.8E–05
15	1.8 ±0.1	2.1 ±0.1	9.2E–05	1.1E–04
41	2.2 ±0.1	2.2 ±0.1	1.1E–04	1.1E–04
131	3.3 ±0.1	3.0 ±0.1	1.7E–04	1.5E–04

Table 5-37. Results of batch sorption of ^{134}Cs onto clay gyttja type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.21 ±0.01	0.34 ±0.01	1.1E–05	1.7E–05
1	0.53 ±0.01	0.69 ±0.02	2.7E–05	3.5E–05
7	1.1 ±0.0	1.3 ±0.0	5.7E–05	6.5E–05
15	1.1 ±0.0	1.4 ±0.0	5.4E–05	7.1E–05
48	1.6 ±0.0	1.6 ±0.0	8.3E–05	8.3E–05
130	1.4 ±0.0	1.8 ±0.0	7.2E–05	9.2E–05

Table 5-38. Results of batch sorption of ^{152}Eu onto clay gyttja type I in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	6.4 ±0.1	0.57 ±0.01	3.3E–04	2.9E–05
1	16* ±0	7.3 ±0.1	(8.3E–04)	3.7E–04
8	not detected	33* ±1	–	(1.7E–03)
14	not detected	not detected	–	–
43	not detected	not detected	–	–
132	not detected	not detected	–	–

Table 5-39. Results of batch sorption of ^{152}Eu onto clay gyttja type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	3 ±0	4 ±0	1.7E–04	1.9E–04
1	14 ±0	11 ±0	7.0E–04	5.5E–04
7	32 ±0	29 ±0	1.6E–03	1.5E–03
14	142* ±3	206* ±6	7.2E–03	1.0E–02
40	142* ±3	409* ±17	7.2E–03	2.1E–02
136	141* ±3	208* ±6	7.2E–03	1.1E–02

The results of the batch sorption measurements of ^{233}U onto clay gyttja type I in natural and synthetic groundwater are shown in Tables 5-40 and 5-41, respectively. For synthetic groundwater, sorption went above the upper detection limit for the middle of the samplings.

The results of the batch sorption measurements of ^{237}Np onto clay gyttja type I in natural and synthetic groundwater are shown in Tables 5-42 and 5-43, respectively.

Table 5-40. Results of batch sorption of ^{233}U onto clay gyttja type I in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.40 ±0.01	0.34 ±0.01	2.0E–05	1.7E–05
1	0.92 ±0.01	0.77 ±0.01	4.7E–05	3.9E–05
7	2.8 ±0.0	2.7 ±0.0	1.4E–04	1.4E–04
17	4.6 ±0.1	5.1 ±0.1	2.4E–04	2.6E–04
42	4.6 ±0.1	5.3 ±0.1	2.3E–04	2.7E–04
130	7.2 ±0.1	8.9 ±0.1	3.6E–04	4.5E–04

Table 5-41. Results of batch sorption of ^{233}U onto clay gyttja type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	2.3 ±0.0	4.0 ±0.0	1.2E–04	2.1E–04
1	6.5 ±0.0	12 ±0	3.3E–04	6.0E–04
7	not detected	not detected	–	–
14	not detected	not detected	–	–
40	not detected	not detected	–	–
133	not detected	not detected	–	–

Table 5-42. Results of batch sorption of ^{237}Np onto clay gyttja type I in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.036 ±0.002	0.038 ±0.002	1.8E–06	1.9E–06
1	0.051 ±0.002	0.057 ±0.002	2.6E–06	2.9E–06
7	0.14 ±0.003	0.15 ±0.003	7.0E–06	7.5E–06
17	0.39 ±0.01	0.42 ±0.01	2.0E–05	2.1E–05
42	2.6 ±0.0	2.1 ±0.0	1.3E–04	1.1E–04
130	24 ±0	27 ±0	1.2E–03	1.4E–03

Table 5-43. Results of batch sorption of ^{237}Np onto clay gyttja type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.010 ±0.001	0.018 ±0.001	5.3E–07	9.1E–07
1	0.015 ±0.001	0.018 ±0.001	7.6E–07	9.0E–07
7	0.034 ±0.001	0.042 ±0.001	1.7E–06	2.1E–06
14	0.068 ±0.001	0.065 ±0.001	3.5E–06	3.3E–06
40	0.18 ±0.00	0.20 ±0.00	9.0E–06	1.0E–05
133	0.54 ±0.01	0.48 ±0.00	2.8E–05	2.5E–05

5.1.5 Sorption onto sand

The results of the batch sorption measurements of ^{63}Ni onto sand in natural and synthetic groundwater are shown in Tables 5-44 and 5-45, respectively. R_d was converted to R_a(m) by utilizing the measured BET-area of 0.15 m^2/g /1/. The R_a values for tracer sorption onto sand are plotted as function of time in Appendix 1.

The results of the batch sorption measurements of ^{125}I onto sand in natural and synthetic groundwater are shown in Tables 5-46 and 5-47, respectively. Most measurements are clearly below the lower detection limit because they yield negative R_d values and can therefore not be used. The calculated values are nevertheless presented here to give an indication of how close to zero they are. R_a values were not calculated for this tracer.

The results of the batch sorption measurements of ^{85}Sr onto sand in natural and synthetic groundwater are shown in Tables 5-48 and 5-49, respectively. Some of the initial measurements were below detection limit, since they yield negative values.

Table 5-44. Results of batch sorption of ^{63}Ni onto sand in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.033 ±0.002	0.030 ±0.002	2.2E–04	2.0E–04
1	0.056 ±0.002	0.057 ±0.002	3.7E–04	3.8E–04
7	0.14 ±0.00	0.15 ±0.00	9.5E–04	9.8E–04
15	0.19 ±0.01	0.23 ±0.01	1.3E–03	1.6E–03
48	0.28 ±0.01	0.33 ±0.01	1.8E–03	2.2E–03
130	0.27 ±0.01	0.36 ±0.01	1.8E–03	2.4E–03

Table 5-45. Results of batch sorption of ^{63}Ni onto sand in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.019 ±0.002	0.015 ±0.002	1.3E–04	1.0E–04
1	0.053 ±0.003	0.049 ±0.003	3.5E–04	3.3E–04
7	0.22 ±0.01	0.20 ±0.01	1.5E–03	1.3E–03
15	0.45 ±0.01	0.43 ±0.01	3.0E–03	2.8E–03
41	0.78 ±0.02	0.89 ±0.02	5.2E–03	6.0E–03
130	0.85 ±0.02	0.99 ±0.02	5.7E–03	6.6E–03

Table 5-46. Results of batch sorption of ^{125}I onto sand in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.005)	(–0.003)	–	–
1	(–0.002)	(–0.001)	–	–
7	not measured	not measured	–	–
14	(–0.003)	(–0.003)	–	–
42	(–0.003)	(–0.003)	–	–
133	(–0.002)	(–0.003)	–	–

Table 5-47. Results of batch sorption of ^{125}I onto sand in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.001)	(–0.001)	–	–
1	(–0.001)	(–0.001)	–	–
7	(–0.003)	(–0.003)	–	–
21	(–0.001)	(–0.001)	–	–
40	0.0004	0.001	–	–
133	(0.0001)	(0.000)	–	–

Table 5-48. Results of batch sorption of ^{85}Sr onto sand in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.000)	(–0.006)	–	–
1	(–0.003)	(–0.001)	–	–
7	0.004 ±0.006	(–0.003)	2.7E–05	–
15	0.007 ±0.006	(–0.001)	4.4E–05	–
41	0.003 ±0.006	0.016 ±0.007	1.7E–05	1.1E–04
131	0.013 ±0.006	0.015 ±0.007	8.8E–05	9.9E–05

Table 5-49. Results of batch sorption of ^{85}Sr onto sand in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.005 ±0.004	(–0.011)	3.5E–05	–
1	0.006 ±0.004	0.006 ±0.004	4.2E–05	4.1E–05
7	0.006 ±0.004	0.004 ±0.004	4.3E–05	2.5E–05
15	0.009 ±0.004	0.009 ±0.004	5.9E–05	6.0E–05
48	0.004 ±0.004	0.011 ±0.004	2.6E–05	7.3E–05
130	0.015 ±0.004	0.020 ±0.004	9.9E–05	1.3E–04

The results of the batch sorption measurements of ^{134}Cs onto sand in natural and synthetic groundwater are shown in Tables 5-50 and 5-51, respectively.

The results of the batch sorption measurements of ^{152}Eu onto sand in natural and synthetic groundwater are shown in Tables 5-52 and 5-53, respectively. For both series, sorption went above the upper detection limit from the middle of the samplings (values marked with*).

Table 5-50. Results of batch sorption of ^{134}Cs onto sand in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.014 ±0.005	0.010 ±0.005	9.5E–05	6.7E–05
1	0.020 ±0.006	0.023 ±0.006	1.3E–04	1.5E–04
7	0.044 ±0.007	0.030 ±0.006	2.9E–04	2.0E–04
15	0.056 ±0.009	0.03 ±0.008	3.7E–04	2.6E–04
41	0.051 ±0.008	0.065 ±0.009	3.4E–04	4.3E–04
131	0.076 ±0.010	0.067 ±0.010	5.1E–04	4.5E–04

Table 5-51. Results of batch sorption of ^{134}Cs onto sand in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.019 ±0.004	0.0001 ±0.003	1.3E–04	4.6E–07
1	0.027 ±0.004	0.028 ±0.004	1.8E–04	1.8E–04
7	0.030 ±0.004	0.033 ±0.004	2.0E–04	2.2E–04
15	0.038 ±0.005	0.037 ±0.005	2.6E–04	2.5E–04
48	0.035 ±0.005	0.046 ±0.005	2.4E–04	3.1E–04
130	0.051 ±0.005	0.059 ±0.006	3.4E–04	3.9E–04

Table 5-52. Results of batch sorption of ^{152}Eu onto sand in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	3.7 ±0.2	4.3 ±0.3	2.5E–02	2.9E–02
1	8.6 ±0.6	8.7 ±0.6	5.7E–02	5.8E–02
8	26* ±3	not detected	1.7E–01	–
14	not detected	not detected	–	–
43	not detected	not detected	–	–
132	not detected	not detected	–	–

Table 5-53. Results of batch sorption of ^{152}Eu onto sand in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	1.7 ±0.0	1.7 ±0.0	1.1E–02	1.1E–02
1	3.6 ±0.1	2.4 ±0.1	2.4E–02	1.6E–02
7	7.4 ±0.2	2.4 ±0.1	4.9E–02	1.6E–02
14	70* ±5	48* ±3	4.7E–01	3.2E–01
40	not detected	not detected	–	–
136	not detected	not detected	–	–

The results of the batch sorption measurements of ^{233}U onto sand in natural and synthetic groundwater are shown in Tables 5-54 and 5-55, respectively.

The results of the batch sorption measurements of ^{237}Np onto sand in natural and synthetic groundwater are shown in Tables 5-56 and 5-57, respectively.

Table 5-54. Results of batch sorption of ^{233}U onto sand in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.027 ±0.003	0.034 ±0.003	1.8E–04	2.2E–04
1	0.030 ±0.003	0.030 ±0.003	2.0E–04	2.0E–04
7	0.030 ±0.003	0.036 ±0.003	2.0E–04	2.4E–04
17	0.026 ±0.003	0.033 ±0.003	1.7E–04	2.2E–04
42	0.023 ±0.003	0.027 ±0.003	1.6E–04	1.8E–04
130	0.013 ±0.003	0.016 ±0.003	8.7E–05	1.1E–04

Table 5-55. Results of batch sorption of ^{233}U onto sand in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	1.6 ±0.0	1.2 ±0.0	1.1E–02	7.8E–03
1	4.6 ±0.1	4.2 ±0.1	3.0E–02	2.8E–02
7	12 ±0	7.3 ±0.1	8.1E–02	4.9E–02
14	52 ±1	9.1 ±0.2	3.4E–01	6.1E–02
40	16 ±0	5.2 ±0.1	1.1E–01	3.5E–02
133	3.8 ±0.1	1.9 ±0.0	2.6E–02	1.3E–02

Table 5-56. Results of batch sorption of ^{237}Np onto sand in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.030 ±0.002	0.030 ±0.003	2.0E–04	2.0E–04
1	0.071 ±0.004	0.064 ±0.004	4.7E–04	4.3E–04
7	0.48 ±0.02	0.46 ±0.02	3.2E–03	3.1E–03
17	1.2 ±0.0	1.2 ±0.0	8.0E–03	8.1E–03
42	1.8 ±0.1	1.7 ±0.1	1.2E–02	1.1E–02
130	1.7 ±0.1	2.1 ±0.1	1.1E–02	1.4E–02

Table 5-57. Results of batch sorption of ^{237}Np onto sand in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.009 ±0.001	0.006 ±0.001	6.1E–05	3.8E–05
1	0.010 ±0.001	0.011 ±0.001	6.6E–05	7.4E–05
7	0.053 ±0.002	0.059 ±0.002	3.5E–04	3.9E–04
14	0.16 ±0.00	0.21 ±0.00	1.1E–03	1.4E–03
40	0.60 ±0.01	0.66 ±0.01	4.0E–03	4.4E–03
133	6.4 ±0.1	6.3 ±0.1	4.2E–02	4.2E–02

5.1.6 Sorption onto clay

The results of the batch sorption measurements of ^{63}Ni onto clay in natural and synthetic groundwater are shown in Tables 5-58 and 5-59, respectively. R_d was converted to R_a(m) by utilizing the measured BET-area of 27.12 m^2/g /1/. The R_a values for tracer sorption onto clay are plotted as function of time in Appendix 1.

The results of the batch sorption measurements of ^{125}I onto clay in natural and synthetic groundwater are shown in Tables 5-60 and 5-61, respectively. Most measurements are clearly below the lower detection limit because they yield negative R_d values and can therefore not be used. The calculated values are nevertheless presented here to give an indication of how close to zero they are. R_a values were not calculated for this tracer.

The results of the batch sorption measurements of ^{85}Sr onto clay in natural and synthetic groundwater are shown in Tables 5-62 and 5-63, respectively. One of the initial measurements was below detection limit.

Table 5-58. Results of batch sorption of ^{63}Ni onto clay in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.093 ±0.003	0.091 ±0.003	3.4E–06	3.4E–06
1	0.12 ±0.00	0.11 ±0.00	4.4E–06	4.0E–06
7	0.28 ±0.01	0.28 ±0.01	1.0E–05	1.0E–05
15	0.43 ±0.01	0.44 ±0.01	1.6E–05	1.6E–05
48	0.78 ±0.01	0.84 ±0.02	2.9E–05	3.1E–05
130	1.2 ±0.0	1.3 ±0.0	4.4E–05	4.7E–05

Table 5-59. Results of batch sorption of ^{63}Ni onto clay in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.71 ±0.01	0.27 ±0.01	2.6E–05	1.0E–05
1	1.2 ±0.0	0.47 ±0.01	4.4E–05	1.7E–05
7	2.4 ±0.1	1.3 ±0.0	8.8E–05	4.8E–05
15	2.6 ±0.1	1.8 ±0.0	9.5E–05	6.6E–05
41	5.0 ±0.2	4.0 ±0.1	1.8E–04	1.5E–04
130	7.5 ±0.3	5.5 ±0.2	2.8E–04	2.0E–04

Table 5-60. Results of batch sorption of ^{125}I onto clay in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	(–0.004)	(–0.001)	–	–
1	(–0.003)	(–0.003)	–	–
7	not measured	not measured	–	–
14	0.005	0.002	–	–
42	0.003	0.003	–	–
133	0.002	0.002	–	–

Table 5-61. Results of batch sorption of ^{125}I onto clay in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.003)	(–0.002)	–	–
1	(–0.003)	(–0.002)	–	–
7	(–0.002)	(–0.002)	–	–
21	0.002	(–0.000)	–	–
40	(–0.000)	0.001	–	–
133	(–0.001)	0.0005	–	–

Table 5-62. Results of batch sorption of ^{85}Sr onto clay in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(0.0003)	0.013 ±0.006	1.1E–08	4.9E–07
1	0.023 ±0.005	0.036 ±0.007	8.5E–07	1.3E–06
7	0.041 ±0.007	0.038 ±0.008	1.5E–06	1.4E–06
15	0.044 ±0.008	0.061 ±0.009	1.6E–06	2.2E–06
41	0.032 ±0.007	0.071 ±0.010	1.2E–06	2.6E–06
131	0.052 ±0.008	0.071 ±0.010	1.9E–06	2.6E–06

Table 5-63. Results of batch sorption of ^{85}Sr onto clay in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.022 ±0.004	0.022 ±0.004	8.0E–07	8.3E–07
1	0.048 ±0.005	0.047 ±0.005	1.8E–06	1.7E–06
7	0.070 ±0.005	0.054 ±0.005	2.6E–06	2.0E–06
15	0.057 ±0.005	0.059 ±0.005	2.1E–06	2.2E–06
48	0.079 ±0.006	0.071 ±0.005	2.9E–06	2.6E–06
130	0.084 ±0.006	0.077 ±0.005	3.1E–06	2.9E–06

The results of the batch sorption measurements of ^{134}Cs onto clay in natural and synthetic groundwater are shown in Tables 5-64 and 5-65, respectively.

The results of the batch sorption measurements of ^{152}Eu onto clay in natural and synthetic groundwater are shown in Tables 5-66 and 5-67, respectively. For both series, sorption went above the upper detection limit from the middle of the sampling series (values marked with *).

Table 5-64. Results of batch sorption of ^{134}Cs onto clay in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.048 ±0.007	0.072 ±0.009	1.8E–06	2.6E–06
1	0.23 ±0.02	0.21 ±0.02	8.4E–06	7.9E–06
7	1.0 ±0.1	1.3 ±0.1	3.7E–05	4.8E–05
15	2.1 ±0.1	2.6 ±0.2	7.6E–05	9.7E–05
41	2.8 ±0.2	3.5 ±0.3	1.0E–04	1.3E–04
131	3.8 ±0.3	4.7 ±0.4	1.4E–04	1.7E–04

Table 5-65. Results of batch sorption of ^{134}Cs onto clay in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.073 ±0.004	0.10 ±0.01	2.7E–06	3.5E–06
1	0.21 ±0.01	0.27 ±0.01	7.7E–06	1.0E–05
7	0.82 ±0.04	0.85 ±0.04	3.0E–05	3.1E–05
15	1.1 ±0.1	1.3 ±0.1	4.0E–05	4.7E–05
48	1.8 ±0.1	1.8 ±0.1	6.5E–05	6.6E–05
130	1.9 ±0.1	2.0 ±0.1	7.1E–05	7.5E–05

Table 5-66. Results of batch sorption of ^{152}Eu onto clay in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.53 ±0.02	0.29 ±0.01	2.0E–05	1.1E–05
1	1.8 ±0.1	3.2 ±0.1	6.5E–05	1.2E–04
8	11* ±1	31* ±3	4.1E–04	1.1E–03
14	not detected	not detected	–	–
43	not detected	not detected	–	–
132	not detected	not detected	–	–

Table 5-67. Results of batch sorption of ^{152}Eu onto clay in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	2.4 ±0.0	1.9 ±0.0	8.7E–05	6.9E–05
1	5.3 ±0.1	4.9 ±0.1	2.0E–04	1.8E–04
7	15 ±0.4	8.0 ±0.2	5.4E–04	2.9E–04
14	48* ±2	91* ±6	1.8E–03	3.3E–03
40	94* ±6	62* ±3	3.5E–03	2.3E–03
136	not detected	not detected	–	–

The results of the batch sorption measurements of ^{233}U onto clay in natural and synthetic groundwater are shown in Tables 5-68 and 5-69, respectively.

The results of the batch sorption measurements of ^{237}Np onto clay in natural and synthetic groundwater are shown in Tables 5-70 and 5-71, respectively.

Table 5-68. Results of batch sorption of ^{233}U onto clay in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.0070 ±0.0023	0.0061 ±0.002	2.6E–07	2.3E–07
1	0.0067 ±0.0024	0.011 ±0.002	2.5E–07	4.0E–07
7	0.011 ±0.002	0.0083 ±0.0024	4.2E–07	3.1E–07
17	0.011 ±0.002	0.0084 ±0.0024	4.1E–07	3.1E–07
42	0.011 ±0.002	0.013 ±0.002	3.9E–07	4.7E–07
130	0.011 ±0.002	0.010 ±0.002	4.2E–07	3.9E–07

Table 5-69. Results of batch sorption of ^{233}U onto clay in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.003)	0.0014 ±0.0014	–	5.0E–08
1	0.010 ±0.001	0.013 ±0.002	3.7E–07	4.9E–07
7	0.030 ±0.002	0.032 ±0.002	1.1E–06	1.2E–06
14	0.038 ±0.002	0.041 ±0.002	1.4E–06	1.5E–06
40	0.037 ±0.002	0.038 ±0.002	1.4E–06	1.4E–06
133	0.029 ±0.002	0.030 ±0.002	1.1E–06	1.1E–06

Table 5-70. Results of batch sorption of ^{237}Np onto clay in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.013 ±0.002	0.012 ±0.002	4.8E–07	4.4E–07
1	0.022 ±0.002	0.032 ±0.002	8.0E–07	1.2E–06
7	0.059 ±0.003	0.059 ±0.003	2.2E–06	2.2E–06
17	0.085 ±0.004	0.084 ±0.004	3.1E–06	3.1E–06
42	0.11 ±0.00	0.12 ±0.01	4.1E–06	4.3E–06
130	0.16 ±0.01	0.16 ±0.01	5.9E–06	5.8E–06

Table 5-71. Results of batch sorption of ^{237}Np onto clay in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.0072 ±0.0008	0.014 ±0.001	2.7E–07	5.0E–07
1	0.019 ±0.001	0.021 ±0.001	6.9E–07	7.6E–07
7	0.066 ±0.001	0.061 ±0.001	2.4E–06	2.3E–06
14	0.10 ±0.00	0.090 ±0.002	3.5E–06	3.3E–06
40	0.15 ±0.00	0.15 ±0.00	5.6E–06	5.6E–06
133	0.21 ±0.00	0.21 ±0.00	7.6E–06	7.8E–06

5.1.7 Sorption onto till type I

The results of the batch sorption measurements of ^{63}Ni onto till type I in natural and synthetic groundwater are shown in Tables 5-72 and 5-73, respectively. R_d was converted to R_a(m) by utilizing the measured BET-area of 1.18 m^2/g /1/. The R_a values for tracer sorption onto till type I are plotted as function of time in Appendix 1.

The results of the batch sorption measurements of ^{125}I onto till type I in natural and synthetic groundwater are shown in Tables 5-74 and 5-75, respectively. Most measurements are clearly below the lower detection limit because they yield negative R_d values and can therefore not be used. The calculated values are nevertheless presented here to give an indication of how close to zero they are. R_a values were not calculated for this tracer.

Table 5-72. Results of batch sorption of ^{63}Ni onto till type I in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.015 ±0.002	0.015 ±0.002	1.2E–05	1.3E–05
1	0.018 ±0.002	0.017 ±0.002	1.5E–05	1.4E–05
7	0.035 ±0.002	0.027 ±0.002	2.9E–05	2.3E–05
15	0.043 ±0.002	0.042 ±0.002	3.7E–05	3.6E–05
48	0.073 ±0.002	0.071 ±0.002	6.2E–05	6.0E–05
130	0.11 ±0.00	0.097 ±0.003	9.6E–05	8.2E–05

Table 5-73. Results of batch sorption of ^{63}Ni onto till type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.070 ±0.002	0.076 ±0.003	5.9E–05	6.4E–05
1	0.14 ±0.00	0.14 ±0.00	1.2E–04	1.2E–04
7	0.28 ±0.01	0.23 ±0.01	2.4E–04	2.0E–04
15	0.39 ±0.01	0.29 ±0.01	3.3E–04	2.4E–04
41	0.65 ±0.01	0.43 ±0.01	5.5E–04	3.6E–04
130	1.2 ±0.0	0.70 ±0.01	1.0E–03	6.0E–04

Table 5-74. Results of batch sorption of ^{125}I onto till type I in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.006)	(–0.001)	–	–
1	(–0.004)	0.002	–	–
7	not measured	not measured	–	–
14	(–0.004)	0.002	–	–
42	(–0.001)	0.0003	–	–
133	0.002	0.008	–	–

Table 5-75. Results of batch sorption of ^{125}I onto till type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.003)	(–0.002)	–	–
1	(–0.004)	(–0.002)	–	–
7	(–0.003)	(–0.001)	–	–
21	(0.000)	0.001	–	–
40	(–0.000)	0.0004	–	–
133	(–0.001)	0.0004	–	–

The results of the batch sorption measurements of ^{85}Sr onto till type I in natural and synthetic groundwater are shown in Tables 5-76 and 5-77, respectively. Several of the measurements were below detection limit.

The results of the batch sorption measurements of ^{134}Cs onto till type I in natural and synthetic groundwater are shown in Tables 5-78 and 5-79, respectively.

Table 5-76. Results of batch sorption of ^{85}Sr onto till type I in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.0042 ±0.0054	(–0.004)	3.6E–06	–
1	(–0.001)	(–0.008)	–	–
7	0.0047 ±0.0054	0.0063 ±0.0054	4.0E–06	5.3E–06
15	0.0080 ±0.0060	0.0051 ±0.0059	6.8E–06	4.3E–06
41	(–0.005)	0.011 ±0.006	–	9.1E–06
131	0.0080 ±0.0058	0.021 ±0.006	6.8E–06	1.8E–05

Table 5-77. Results of batch sorption of ^{85}Sr onto till type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.014 ±0.004	0.0019 ±0.0036	1.2E–05	1.6E–06
1	0.012 ±0.004	0.020 ±0.004	1.0E–05	1.7E–05
7	(–0.000)	0.015 ±0.004	–	1.3E–05
15	0.0038 ±0.0034	0.0074 ±0.0036	3.2E–06	6.3E–06
48	0.013 ±0.004	0.018 ±0.004	1.1E–05	1.5E–05
130	0.020 ±0.004	0.0061 ±0.004	1.7E–05	5.2E–06

Table 5-78. Results of batch sorption of ^{134}Cs onto till type I in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.032 ±0.006	0.029 ±0.006	2.7E–05	2.5E–05
1	0.041 ±0.006	0.036 ±0.006	3.5E–05	3.0E–05
7	0.084 ±0.008	0.072 ±0.008	7.1E–05	6.1E–05
15	0.11 ±0.01	0.085 ±0.009	9.0E–05	7.2E–05
41	0.094 ±0.009	0.11 ±0.01	7.9E–05	9.0E–05
131	0.14 ±0.01	0.12 ±0.01	1.2E–04	1.0E–04

Table 5-79. Results of batch sorption of ^{134}Cs onto till type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.036 ±0.004	0.031 ±0.004	3.1E–05	2.6E–05
1	0.056 ±0.005	0.063 ±0.005	4.8E–05	5.3E–05
7	0.057 ±0.005	0.077 ±0.005	4.8E–05	6.5E–05
15	0.068 ±0.05	0.082 ±0.005	5.8E–05	6.9E–05
48	0.089 ±0.006	0.11 ±0.01	7.6E–05	9.0E–05
130	0.12 ±0.01	0.10 ±0.01	1.0E–04	8.2E–05

The results of the batch sorption measurements of ^{152}Eu onto till type I in natural and synthetic groundwater are shown in Tables 5-80 and 5-81, respectively. For both series sorption went above the upper detection limit for the last of the samplings (values marked with *).

The results of the batch sorption measurements of ^{233}U onto till type I in natural and synthetic groundwater are shown in Tables 5-82 and 5-83, respectively. For synthetic groundwater, several measurements are clearly below detection level, since they yield negative values and therefore cannot be used.

The results of the batch sorption measurements of ^{237}Np onto till type I in natural and synthetic groundwater are shown in Tables 5-84 and 5-85, respectively. One single measurement of the synthetic groundwater series is below detection level, yielding a negative value.

Table 5-80. Results of batch sorption of ^{152}Eu onto till type I in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.24 ±0.01	0.40 ±0.01	2.1E–04	3.4E–04
1	1.3 ±0.0	1.6 ±0.1	1.1E–03	1.4E–03
8	4.0 ±0.1	4.4 ±0.1	3.4E–03	3.7E–03
14	6.6 ±0.2	5.3 ±0.2	5.6E–03	4.5E–03
43	not detected	20* ±1	–	1.7E–02
132	not detected	not detected	–	–

Table 5-81. Results of batch sorption of ^{152}Eu onto till type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.95 ±0.01	1.6 ±0.0	8.0E–04	1.3E–03
1	2.2 ±0.0	3.2 ±0.0	1.8E–03	2.7E–03
7	4.7 ±0.1	4.5 ±0.1	3.9E–03	3.8E–03
14	6.7 ±0.1	7.6 ±0.1	5.7E–03	6.4E–03
40	8.0 ±0.1	8.9 ±0.2	6.8E–03	7.6E–03
136	39 ±1	58* ±2	3.3E–02	4.9E–02

Table 5-82. Results of batch sorption of ^{233}U onto till type I in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.0045 ±0.0022	0.010 ±0.002	3.8E–06	8.4E–06
1	0.0014 ±0.0022	0.0020 ±0.0022	1.2E–06	1.7E–06
7	0.0007 ±0.0022	0.0038 ±0.0022	5.7E–07	3.2E–06
17	(–0.001)	0.0055 ±0.0023	–	4.7E–06
42	0.0005 ±0.0023	0.0067 ±0.0024	4.4E–07	5.7E–06
130	0.0026 ±0.0024	0.0044 ±0.0024	2.2E–06	3.7E–06

Table 5-83. Results of batch sorption of ^{233}U onto till type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.010)	(–0.003)	–	–
1	(–0.001)	0.0048 ±0.0014	–	4.0E–06
7	(0.000)	0.0015 ±0.0015	–	1.3E–06
14	0.0027 ±0.0015	0.0036 ±0.0015	2.3E–06	3.1E–06
40	(–0.001)	0.0027 ±0.0016	–	2.3E–06
133	(–0.003)	0.0065 ±0.0017	–	5.5E–06

Table 5-84. Results of batch sorption of ^{237}Np onto till type I in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.0051 ±0.0018	0.013 ±0.002	4.3E–06	1.1E–05
1	0.0059 ±0.0018	0.0055 ±0.0022	5.0E–06	4.6E–06
7	0.0070 ±0.0018	0.011 ±0.002	5.9E–06	9.3E–06
17	0.0072 ±0.0019	0.015 ±0.002	6.1E–06	1.2E–05
42	0.0083 ±0.0020	0.017 ±0.002	7.0E–06	1.4E–05
130	0.019 ±0.002	0.025 ±0.002	1.6E–05	2.1E–05

Table 5-85. Results of batch sorption of ^{237}Np onto till type I in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.002)	0.0047 ±0.0008	–	4.0E–06
1	0.0018 ±0.0008	0.0073 ±0.0009	1.5E–06	6.2E–06
7	0.0057 ±0.0009	0.0073 ±0.0009	4.9E–06	6.2E–06
14	0.010 ±0.001	0.010 ±0.001	8.3E–06	8.3E–06
40	0.013 ±0.001	0.013 ±0.001	1.1E–05	1.1E–05
133	0.022 ±0.002	0.033 ±0.002	1.9E–05	2.8E–05

5.1.8 Sorption onto till type II

The results of the batch sorption measurements of ^{63}Ni onto till type II in natural and synthetic groundwater are shown in Tables 5-86 and 5-87, respectively. R_d was converted to R_a(m) by utilizing the measured BET-area of 1.01 m^2/g /1/. The R_a values for tracer sorption onto till type II are plotted as function of time in Appendix 1.

The results of the batch sorption measurements of ^{125}I onto till type II in natural and synthetic groundwater are shown in Tables 5-88 and 5-89, respectively. Almost all measurements are clearly below the lower detection limit because they yield negative R_d values and can therefore not be used. The calculated values are nevertheless presented here to give an indication of how close to zero they are. R_a values were not calculated for this tracer.

The results of the batch sorption measurements of ^{85}Sr onto till type II in natural and synthetic groundwater are shown in Tables 5-90 and 5-91, respectively. Some of the measurements were clearly below detection limit, since they yield negative values.

Table 5-86. Results of batch sorption of ^{63}Ni onto till type II in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.0013 ±0.0016	0.0032 ±0.0016	1.3E–06	3.1E–06
1	0.0046 ±0.0017	0.0077 ±0.0016	4.6E–06	7.7E–06
7	0.0067 ±0.0017	0.011 ±0.002	6.6E–06	1.1E–05
15	0.011 ±0.002	0.016 ±0.002	1.1E–05	1.6E–05
48	0.020 ±0.002	0.027 ±0.002	1.9E–05	2.7E–05
130	0.026 ±0.002	0.038 ±0.002	2.6E–05	3.8E–05

Table 5-87. Results of batch sorption of ^{63}Ni onto till type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.039 ±0.002	0.024 ±0.002	3.8E–05	2.3E–05
1	0.081 ±0.003	0.076 ±0.003	8.0E–05	7.5E–05
7	0.16 ±0.01	0.12 ±0.00	1.6E–04	1.2E–04
15	0.21 ±0.01	0.17 ±0.01	2.1E–04	1.7E–04
41	0.35 ±0.01	0.28 ±0.01	3.5E–04	2.8E–04
130	0.74 ±0.02	0.53 ±0.02	7.3E–04	5.2E–04

Table 5-88. Results of batch sorption of ^{125}I onto till type II in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.006)	(–0.002)	–	–
1	(–0.003)	(–0.001)	–	–
7	not measured	not measured	–	–
14	(–0.003)	(–0.001)	–	–
42	(–0.003)	(0.000)	–	–
133	(–0.001)	0.001	–	–

Table 5-89. Results of batch sorption of ^{125}I onto till type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.001)	(–0.001)	–	–
1	(–0.002)	(–0.002)	–	–
7	(–0.001)	(–0.002)	–	–
21	(0.0001)	(–0.000)	–	–
40	0.0003	(0.000)	–	–
133	(–0.000)	(–0.001)	–	–

Table 5-90. Results of batch sorption of ^{85}Sr onto till type II in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.0034 ±0.0055	(–0.001)	3.3E–06	–
1	0.015 ±0.006	0.0056 ±0.0057	1.5E–05	5.6E–06
7	0.0039 ±0.0056	(–0.001)	3.8E–06	–
15	0.016 ±0.007	0.0005 ±0.0058	1.5E–05	5.0E–07
41	0.019 ±0.007	0.0023 ±0.0058	1.9E–05	2.3E–06
131	0.019 ±0.007	0.024 ±0.008	1.9E–05	2.3E–05

Table 5-91. Results of batch sorption of ^{85}Sr onto till type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	(–0.002)	0.0018 ±0.0034	–	1.8E–06
1	0.0050 ±0.0036	0.0034 ±0.0035	4.9E–06	3.4E–06
7	0.010 ±0.004	0.011 ±0.004	1.0E–05	1.0E–05
15	0.0009 ±0.0035	0.0073 ±0.0036	9.1E–07	7.3E–06
48	(–0.001)	0.0010 ±0.0035	–	9.6E–07
130	0.0018 ±0.0035	0.0074 ±0.0036	1.8E–06	7.3E–06

The results of the batch sorption measurements of ^{134}Cs onto till type II in natural and synthetic groundwater are shown in Tables 5-92 and 5-93, respectively.

The results of the batch sorption measurements of ^{152}Eu onto till type II in natural and synthetic groundwater are shown in Tables 5-94 and 5-95, respectively. For both series sorption went above the upper detection limit for the last of the samplings (values marked with *).

Table 5-92. Results of batch sorption of ^{134}Cs onto till type II in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.024 ±0.006	0.020 ±0.006	2.3E–05	1.9E–05
1	0.058 ±0.009	0.039 ±0.008	5.7E–05	3.8E–05
7	0.060 ±0.009	0.051 ±0.009	5.9E–05	5.0E–05
15	0.088 ±0.012	0.063 ±0.010	8.7E–05	6.2E–05
41	0.10 ±0.01	0.070 ±0.011	1.0E–04	6.9E–05
131	0.11 ±0.01	0.12 ±0.02	1.1E–04	1.2E–04

Table 5-93. Results of batch sorption of ^{134}Cs onto till type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.0093 ±0.0035	0.015 ±0.004	9.2E–06	1.5E–05
1	0.026 ±0.004	0.027 ±0.004	2.6E–05	2.7E–05
7	0.041 ±0.005	0.046 ±0.005	4.0E–05	4.5E–05
15	0.031 ±0.005	0.043 ±0.005	3.1E–05	4.2E–05
48	0.036 ±0.005	0.040 ±0.005	3.5E–05	3.9E–05
130	0.041 ±0.005	0.052 ±0.006	4.1E–05	5.1E–05

Table 5-94. Results of batch sorption of ^{152}Eu onto till type II in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.15 ±0.01	0.17 ±0.01	1.5E–04	1.7E–04
1	0.54 ±0.03	0.61 ±0.03	5.3E–04	6.0E–04
8	1.2 ±0.1	2.2 ±0.1	1.2E–03	2.2E–03
14	2.2 ±0.1	3.5 ±0.2	2.2E–03	3.4E–03
43	11* ±1	22* ±3	1.1E–02	2.1E–02
132	not detected	not detected	–	–

Table 5-95. Results of batch sorption of ^{152}Eu onto till type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.58 ±0.02	0.60 ±0.02	5.7E–04	5.9E–04
1	1.2 ±0.0	1.3 ±0.0	1.2E–03	1.3E–03
7	3.0 ±0.1	2.3 ±0.1	3.0E–03	2.2E–03
14	4.1 ±0.1	5.0 ±0.2	4.0E–03	4.9E–03
40	6.2 ±0.2	5.5 ±0.2	6.2E–03	5.4E–03
136	120* ±15	45 ±3	1.2E–01	4.4E–02

The results of the batch sorption measurements of ^{233}U onto till type II in natural and synthetic groundwater are shown in Tables 5-96 and 5-97, respectively. For both groundwater, several measurements are below detection levels.

The results of the batch sorption measurements of ^{237}Np onto till type II in natural and synthetic groundwater are shown in Tables 5-98 and 5-99, respectively.

Table 5-96. Results of batch sorption of ^{233}U onto till type II in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.0038 ±0.0023	0.0043 ±0.0023	3.8E–06	4.2E–06
1	0.0013 ±0.0023	(0.0005)	1.2E–06	5.2E–07
7	(0.0005)	(0.0006)	4.7E–07	6.0E–07
17	(0.0009)	(0.0002)	9.1E–07	2.0E–07
42	(0.0007)	0.0022 ±0.0024	6.8E–07	2.2E–06
130	(0.0004)	0.0030 ±0.0025	3.6E–07	3.0E–06

Table 5-97. Results of batch sorption of ^{233}U onto till type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	(–0.0032)	(–0.0023)	–	–
1	(0.0008)	(–0.0007)	8.1E–07	–
7	0.0015 ±0.0014	0.0005 ±0.0014	1.5E–06	4.6E–07
14	0.0017 ±0.0015	(–0.0001)	1.7E–06	–
40	(0.0009)	(–0.0003)	9.2E–07	–
133	0.0030	(0.0008)	3.0E–06	8.0E–07

Table 5-98. Results of batch sorption of ^{237}Np onto till type II in natural groundwater.

Sample time (days)	R_d(m³/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.0040 ±0.0018	0.0047 ±0.0018	3.9E–06	4.6E–06
1	0.0030 ±0.0019	0.0025 ±0.0018	3.0E–06	2.5E–06
7	0.0047 ±0.0019	0.0047 ±0.0019	4.7E–06	4.7E–06
17	0.0062 ±0.0020	0.0050 ±0.0019	6.1E–06	4.9E–06
42	0.0078 ±0.0021	0.0091 ±0.0022	7.7E–06	9.0E–06
130	0.013 ±0.002	0.016 ±0.002	1.3E–05	1.5E–05

Table 5-99. Results of batch sorption of ^{237}Np onto till type II in synthetic groundwater.

Sample time (days)	R_d(m³/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.0031 ±0.0008	0.0041 ±0.0009	3.1E–06	4.1E–06
1	0.0028 ±0.0009	0.0009 ±0.0009	2.8E–06	9.1E–07
7	0.0051 ±0.0010	0.0042 ±0.0010	5.0E–06	4.2E–06
14	0.0058 ±0.0011	0.0042 ±0.0011	5.8E–06	4.2E–06
40	0.0086 ±0.0013	0.0071 ±0.0012	8.5E–06	7.1E–06
133	0.029 ±0.002	0.11 ±0.00	2.9E–05	1.1E–04

5.1.9 Sorption onto clay gyttja type II

The results of the batch sorption measurements of ^{63}Ni onto clay gyttja type II in natural and synthetic groundwater are shown in Tables 5-100 and 5-101, respectively. R_d was converted to R_a(m) by utilizing the measured BET-area of 19.16 m²/g /1/. The R_a values for tracer sorption onto clay gyttja type II are plotted as function of time in Appendix 1.

Table 5-100. Results of batch sorption of ^{63}Ni onto clay gyttja type II in natural groundwater.

Sample time (days)	R_d(m³/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.32 ±0.00	0.95 ±0.01	1.7E–05	4.9E–05
1	0.78 ±0.01	2.2 ±0.0	4.0E–05	1.1E–04
7	2.3 ±0.0	3.1 ±0.0	1.2E–04	1.6E–04
15	3.9 ±0.0	4.3 ±0.0	2.0E–04	2.2E–04
48	5.4 ±0.1	5.8 ±0.1	2.8E–04	3.0E–04
130	7.7 ±0.1	7.1 ±0.1	4.0E–04	3.7E–04

Table 5-101. Results of batch sorption of ^{63}Ni onto clay gyttja type II in synthetic groundwater.

Sample time (days)	R_d(m³/kg) Series 1	 Series 2	R_a(m) Series 1	 Series 2
0.125	0.73 ±0.01	0.73 ±0.01	3.8E–05	3.8E–05
1	1.3 ±0.0	1.3 ±0.0	6.6E–05	6.7E–05
7	3.6 ±0.0	4.0 ±0.0	1.9E–04	2.1E–04
15	6.2 ±0.1	5.7 ±0.1	3.2E–04	3.0E–04
41	12 ±0	13 ±0.2	6.4E–04	6.8E–04
130	5.5 ±0.1	7.4 ±0.1	2.9E–04	3.9E–04

The results of the batch sorption measurements of ^{125}I onto clay gyttja type II in natural and synthetic groundwater are shown in Tables 5-102 and 5-103, respectively. Some measurements for natural groundwater are clearly below the lower detection limit because they yield negative R_d values and can therefore not be used. The calculated values are nevertheless presented here to give an indication of how close to zero they are.

The results of the batch sorption measurements of ^{85}Sr onto clay gyttja type II in natural and synthetic groundwater are shown in Tables 5-104 and 5-105, respectively. Some of the measurements were clearly below detection limit, since they yield negative values.

Table 5-102. Results of batch sorption of ^{125}I onto clay gyttja type II in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.004	(–0.010)	–	–
1	0.007	(–0.006)	–	–
7	not measured	not measured	–	–
14	0.001	(–0.007)	–	–
42	0.007	(–0.003)	–	–
133	0.019	0.004	–	–

Table 5-103. Results of batch sorption of ^{125}I onto clay gyttja type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.005	0.006	2.7E–07	3.0E–07
1	0.004	0.005	2.1E–07	2.7E–07
7	0.002	0.002	8.6E–08	1.1E–07
21	0.006	0.008	3.4E–07	4.0E–07
40	0.001	0.002	5.9E–08	7.9E–08
133	0.003	0.004	1.6E–07	1.9E–07

Table 5-104. Results of batch sorption of ^{85}Sr onto clay gyttja type II in natural groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.049 ±0.006	0.045 ±0.006	2.5E–06	2.3E–06
1	0.037 ±0.006	0.072 ±0.007	1.9E–06	3.7E–06
7	0.040 ±0.006	0.11 ±0.01	2.1E–06	5.5E–06
15	0.044 ±0.007	0.082 ±0.008	2.3E–06	4.3E–06
41	0.054 ±0.007	0.090 ±0.008	2.8E–06	4.7E–06
131	0.088 ±0.007	0.15 ±0.01	4.6E–06	7.9E–06

Table 5-105. Results of batch sorption of ^{85}Sr onto clay gyttja type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg) Series 1	Series 2	R_a(m) Series 1	Series 2
0.125	0.028 ±0.004	0.038 ±0.004	1.5E–06	2.0E–06
1	0.075 ±0.004	0.071 ±0.004	3.9E–06	3.7E–06
7	0.081 ±0.004	0.069 ±0.004	4.2E–06	3.6E–06
15	0.084 ±0.004	0.091 ±0.004	4.4E–06	4.8E–06
48	0.15 ±0.01	0.11 ±0.01	7.6E–06	5.9E–06
130	0.14 ±0.01	0.15 ±0.01	7.0E–06	7.6E–06

The results of the batch sorption measurements of ^{134}Cs onto clay gyttja type II in natural and synthetic groundwater are shown in Tables 5-106 and 5-107, respectively.

The results of the batch sorption measurements of ^{152}Eu onto clay gyttja type II in natural and synthetic groundwater are shown in Tables 5-108 and 5-109, respectively. For both series, sorption went above the upper detection limit for the middle of the samplings (values marked with *).

Table 5-106. Results of batch sorption of ^{134}Cs onto clay gyttja type II in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.78 ±0.03	0.56 ±0.02	4.1E–05	2.9E–05
1	0.90 ±0.03	1.1 ±0.03	4.7E–05	5.7E–05
7	1.3 ±0.0	1.7 ±0.1	6.6E–05	8.7E–05
15	1.4 ±0.0	1.7 ±0.1	7.2E–05	8.8E–05
41	1.8 ±0.1	2.0 ±0.1	9.5E–05	1.0E–04
131	1.8 ±0.1	2.5 ±0.1	9.4E–05	1.3E–04

Table 5-107. Results of batch sorption of ^{134}Cs onto clay gyttja type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.39 ±0.01	0.40 ±0.01	2.0E–05	2.1E–05
1	0.82 ±0.02	0.88 ±0.02	4.3E–05	4.6E–05
7	1.3 ±0.0	1.2 ±0.0	6.8E–05	6.2E–05
15	1.4 ±0.0	1.5 ±0.0	7.5E–05	7.6E–05
48	2.0 ±0.0	1.7 ±0.0	1.0E–04	8.9E–05
130	2.0 ±0.0	2.2 ±0.1	1.0E–04	1.1E–04

Table 5-108. Results of batch sorption of ^{152}Eu onto clay gyttja type II in natural groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	1.1 ±0.0	1.2 ±0.0	6.0E–05	6.1E–05
1	7.4 ±0.1	14* ±0	3.8E–04	7.5E–04
8	34* ±1	not detected	1.8E–03	–
14	not detected	not detected	–	–
43	not detected	not detected	–	–
132	not detected	not detected	–	–

Table 5-109. Results of batch sorption of ^{152}Eu onto clay gyttja type II in synthetic groundwater.

Sample time (days)	R_d(m^3/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	9.3 ±0.1	7.8 ±0.1	4.8E–04	4.1E–04
1	45 ±1	35 ±0	2.4E–03	1.8E–03
7	136* ±3	104* ±2	7.1E–03	5.4E–03
14	not detected	not detected	–	–
40	not detected	not detected	–	–
136	not detected	not detected	–	–

The results of the batch sorption measurements of ^{233}U onto clay gyttja type II in natural and synthetic groundwater are shown in Tables 5-110 and 5-111, respectively. For synthetic groundwater, the last measurements are above detection level.

The results of the batch sorption measurements of ^{237}Np onto clay gyttja type II in natural and synthetic groundwater are shown in Tables 5-112 and 5-113, respectively.

Table 5-110. Results of batch sorption of ^{233}U onto clay gyttja type II in natural groundwater.

Sample time (days)	R_d(m³/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.19 ±0.00	0.17 ±0.00	9.7E–06	8.7E–06
1	0.44 ±0.01	0.70 ±0.01	2.3E–05	3.6E–05
7	0.39 ±0.01	0.37 ±0.01	2.1E–05	1.9E–05
17	0.46 ±0.01	0.44 ±0.01	2.4E–05	2.3E–05
42	0.29 ±0.01	0.26 ±0.01	1.5E–05	1.4E–05
130	0.26 ±0.01	0.26 ±0.01	1.4E–05	1.3E–05

Table 5-111. Results of batch sorption of ^{233}U onto clay gyttja type II in synthetic groundwater.

Sample time (days)	R_d(m³/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.34 ±0.00	0.52 ±0.00	1.8E–05	2.7E–05
1	0.92 ±0.01	1.4 ±0.0	4.8E–05	7.5E–05
7	10 ±0	14 ±0	5.3E–04	7.1E–04
14	28 ±0	47 ±0	1.5E–03	2.5E–03
40	532* ±3	2,955* ±18	2.8E–02	1.5E–01
133	not detected	not detected	–	–

Table 5-112. Results of batch sorption of ^{237}Np onto clay gyttja type II in natural groundwater.

Sample time (days)	R_d(m³/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.084 ±0.003	0.072 ±0.002	4.4E–06	3.8E–06
1	0.14 ±0.00	0.16 ±0.00	7.3E–06	8.4E–06
7	0.12 ±0.00	0.13 ±0.00	6.5E–06	6.8E–06
17	0.22 ±0.00	0.22 ±0.00	1.2E–05	1.1E–05
42	0.44 ±0.01	0.47 ±0.01	2.3E–05	2.5E–05
130	8.6 ±0.1	6.4 ±0.1	4.5E–04	3.3E–04

Table 5-113. Results of batch sorption of ^{237}Np onto clay gyttja type II in synthetic groundwater.

Sample time (days)	R_d(m³/kg)		R_a(m)	
	Series 1	Series 2	Series 1	Series 2
0.125	0.011 ±0.001	0.032 ±0.001	5.9E–07	1.6E–06
1	0.031 ±0.001	0.054 ±0.001	1.6E–06	2.8E–06
7	0.16 ±0.00	0.17 ±0.00	8.3E–06	8.9E–06
14	0.31 ±0.00	0.30 ±0.00	1.6E–05	1.6E–05
40	1.6 ±0.0	1.8 ±0.0	8.3E–05	9.1E–05
133	not detected	165 ±1	–	8.6E–03

5.1.10 Comparison of batch sorption results

A brief comparison of the batch sorption results will be given here, an interpretation of the results is beyond the scope of this report. The results are most easily compared using the plots provided in Appendix 1.

The general trend of the batch sorption results show specific surface corrected distribution coefficients, R_a (m) that increase with time, but the trend is that they level out to limiting values. Iodine sorption is generally below the lower detection limit and very few data could be collected for this tracer. Eu generally shows the strongest sorption and many measurements at the later samplings are above the upper detection limit.

Results from the batch experiments with peat and natural groundwater at 130 days give R_a values that ranges from $5 \cdot 10^{-5}$ (Sr) to $3 \cdot 10^{-4}$ m (Cs). The order of increasing sorption is: Sr, Ni, Np, Eu, U and Cs.

For synthetic groundwater Eu and U sorption is stronger, at least initially, compared with the natural groundwater, but for Cs the sorption is slightly weaker over the whole sampling period.

Results from the batch experiments with gyttja and natural groundwater at 130 days give R_a values that ranges from $3 \cdot 10^{-5}$ (Sr) to $1 \cdot 10^{-2}$ m (Eu). The order of increasing sorption is: Sr, Cs, U, Ni, Np and Eu.

For synthetic groundwater the sorption of U is stronger and comparable with Eu.

Results from the batch experiments with clay gyttja, type I and natural groundwater at 130 days give R_a values that ranges from $1 \cdot 10^{-5}$ (Sr) to $> 1 \cdot 10^{-3}$ m (Eu). The order of increasing sorption is: Sr, Cs, Ni, U, Np and Eu.

For synthetic groundwater U sorption is stronger, at least initially, comparable with Eu. For Np, on the other hand, sorption is weaker and comparable with Sr over the whole sampling period.

Results from the batch experiments with sand and natural groundwater at 130 days give R_a values that ranges from $1 \cdot 10^{-4}$ (Sr) to $2 \cdot 10^{-1}$ m (Eu). The order of increasing sorption is: Sr, U, Cs, Ni, Np and Eu.

For synthetic groundwater, U and Ni sorption is stronger. For Np the sorption is weaker.

Results from the batch experiments with clay and natural groundwater at 130 days give R_a values that ranges from $4 \cdot 10^{-7}$ (U) to $> 1 \cdot 10^{-3}$ m (Eu). The order of increasing sorption is: U, Sr, Np, Ni, Cs and Eu.

For synthetic groundwater, U and Ni sorption is stronger. For Cs the sorption is weaker.

Results from the batch experiments with till, type I and natural groundwater at 130 days give R_a values that ranges from $2 \cdot 10^{-6}$ (U) to $> 1 \cdot 10^{-2}$ m (Eu). The order of increasing sorption is: U, Sr, Np, Ni, Cs and Eu.

For synthetic groundwater, Ni sorption is stronger.

Results from the batch experiments with till, type II and natural groundwater at 130 days give R_a values that ranges from $4 \cdot 10^{-7}$ (U) to $> 1 \cdot 10^{-2}$ m (Eu). The order of increasing sorption is: U, Np, Sr, Ni, Cs and Eu.

For synthetic groundwater, Ni sorption is stronger.

Results from the batch experiments with clay gyttja, type II and natural groundwater at 130 days give R_a values that ranges from $5 \cdot 10^{-6}$ (Sr) to $> 2 \cdot 10^{-3}$ m (Eu). The order of increasing sorption is: Sr, U, Cs, Np, Ni and Eu.

For synthetic groundwater Eu, U sorption is stronger, at least initially, while Np sorption is weaker over the whole sampling period.

The measured effects on R_a from switching between natural and synthetic groundwater can be shown in one diagram (Appendix 1, Figure A1-9), showing the ratio of limiting values of sorption coefficients for natural groundwater to synthetic groundwater, $R_{a,\ nat}$: $R_{a,syn}$.

Here it is important to notice that R_a values for the same sampling time (the latest available for both waters) must be used for calculating the ratios. The diagram clearly shows the lower sorption of U, Ni and Eu on some type of soils when the natural groundwater is used.

There are also some effects of stronger sorption with the natural groundwater. Such effects are generally marginal, except for the case with Np and clay gyttja I.

5.2 Results from pH and Eh analyses

This section accounts for the results for the separate series of experiments, made in parallel to the batch sorption experiments, were pH and Eh evolution were followed.

5.2.1 Evolution of pH and Eh

Results for the pH and Eh measurements in the separate series of experiments, were no radiotracer has been added, for peat in natural and synthetic groundwater, are shown in Tables 5-114 and 5-115, respectively. The evolution of pH and Eh is also shown in diagrams in Appendix 2.

Results for the pH and Eh measurements in the separate series of experiments, were no radiotracer has been added, for gyttja in natural and synthetic groundwater, are shown in Tables 5-116 and 5-117, respectively.

Table 5-114. Results of pH and Eh measurements of peat in natural groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	6.74	6.51	417	407
1	6.87	6.67	409	400
9	7.09	6.92	451	448
16	7.27	6.91	338	304
63	7.08	6.76	217	212
132	7.06	7.03	90	82

Table 5-115. Results of of pH and Eh measurements of peat in synthetic groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	6.54	6.5	412	369
1	6.71	6.63	405	327
8	6.81	6.7	307	302
14	7.11	6.99	271	267
42	6.78	6.76	260	257
133	7.12	7.08	1	–3

Table 5-116. Results of pH and Eh measurements of gyttja in natural groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	6.89	6.85	377	368
1	7.03	7.11	302	299
9	7.26	7.2	428	424
16	7.56	7.45	269	256
63	7.8	7.86	23	24
132	8.04	8.07	30	20

Table 5-117. Results of of pH and Eh measurements of gyttja in synthetic groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	6.76	6.78	219	216
1	7.06	7.06	252	249
8	7.14	7.12	251	250
14	7.44	7.4	223	217
42	7.58	7.58	101	96
133	7.82	7.86	67	63

Results for the pH and Eh measurements in the separate series of experiments, were no radiotracer has been added, for clay gyttja type I in natural and synthetic groundwater, are shown in Tables 5-118 and 5-119, respectively.

Results for the pH and Eh measurements in the separate series of experiments, were no radiotracer has been added, for sand in natural and synthetic groundwater, are shown in Tables 5-120 and 5-121, respectively.

Table 5-118. Results of pH and Eh measurements of clay gyttja type I in natural groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	6.47	6.47	380	384
1	6.55	6.58	367	367
9	6.66	6.74	419	408
16	7.08	7.04	307	313
63	7.42	7.36	76	108
132	7.8	7.74	56	57

Table 5-119. Results of of pH and Eh measurements of clay gyttja type I in synthetic groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	6.3	6.36	270	269
1	6.42	6.44	273	266
8	6.52	6.58	285	284
14	6.76	6.82	275	270
42	7.01	7.04	169	178
133	7.64	7.64	125	126

Table 5-120. Results of pH and Eh measurements of sand in natural groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	6.94	6.81	298	287
1	7.28	7.21	247	263
9	7.67	7.7	398	385
16	7.97	8	306	317
63	8.27	8.37	125	117
132	8.56	8.58	37	38

Table 5-121. Results of of pH and Eh measurements of sand in synthetic groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	7.3	7.35	121	115
1	7.56	7.68	253	251
8	7.9	8.01	250	251
14	8.23	8.33	257	258
42	8.46	8.55	158	152
133	8.57	8.8	81	79

Results for the pH and Eh measurements in the separate series of experiments, were no radiotracer has been added, for clay in natural and synthetic groundwater, are shown in Tables 5-122 and 5-123, respectively.

Results for the pH and Eh measurements in the separate series of experiments, were no radiotracer has been added, for till type I in natural and synthetic groundwater, are shown in Tables 5-124 and 5-125, respectively.

Table 5-122. Results of pH and Eh measurements of clay in natural groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	7.63	7.68	435	424
1	7.94	7.98	262	279
9	8.09	8.14	382	381
16	8.24	8.3	356	339
63	8.46	8.49	209	216
132	8.77	8.76	79	79

Table 5-123. Results of of pH and Eh measurements of clay in synthetic groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	7.95	7.93	223	224
1	8.13	8.21	280	284
8	8.29	8.27	277	279
14	8.42	8.47	284	295
42	8.53	8.5	158	157
133	8.91	8.78	101	96

Table 5-124. Results of pH and Eh measurements of till type I in natural groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	7.95	7.84	412	407
1	8.23	8.15	411	413
9	8.49	8.47	377	375
16	8.69	8.6	331	334
63	8.71	8.72	221	223
132	8.89	8.92	86	93

Table 5-125. Results of of pH and Eh measurements of till type I in synthetic groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	8.62	8.64	220	224
1	8.65	8.66	290	293
8	8.73	8.79	283	286
14	8.86	8.92	297	311
42	8.71	8.66	155	154
133	8.87	8.85	103	99

Results for the pH and Eh measurements in the separate series of experiments, were no radiotracer has been added, for till type II in natural and synthetic groundwater, are shown in Tables 5-126 and 5-127, respectively.

Results for the pH and Eh measurements in the separate series of experiments, were no radiotracer has been added, for clay gyttja type II in natural and synthetic groundwater, are shown in Tables 5-128 and 5-129, respectively.

Results for the pH and Eh measurements in the separate series of reference experiments, where no radiotracer or solid phase has been added, in natural and synthetic groundwater, are shown in Tables 5-130 and 5-131, respectively.

Table 5-126. Results of pH and Eh measurements of till type II in natural groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	7.94	7.91	400	404
1	8.23	8.18	410	405
9	8.49	8.43	374	368
16	8.6	8.57	328	325
63	8.68	8.68	229	233
132	8.92	8.92	114	110

Table 5-127. Results of of pH and Eh measurements of till type II in synthetic groundwater.

Sample time (days)	pH		Eh	
	Series 1	Series 2	Series 1	Series 2
0.125	8.62	8.64	226	228
1	8.72	8.74	303	301
8	8.77	8.77	291	294
14	8.82	8.86	321	320
42	8.69	8.65	157	154
133	8.64	8.67	100	100

Table 5-128. Results of pH and Eh measurements of clay gyttja type II in natural groundwater.

Sample time (days)	pH Series 1	 Series 2	Eh Series 1	 Series 2
0.125	not measured	not measured	416	405
1	7.01	7.07	421	416
9	7.3	7.33	370	366
16	7.65	7.74	341	337
63	7.96	8.04	243	247
132	8.39	8.41	106	95

Table 5-129. Results of of pH and Eh measurements of clay gyttja type II in synthetic groundwater.

Sample time (days)	pH Series 1	 Series 2	Eh Series 1	 Series 2
0.125	6.96	6.92	171	152
1	7.08	7.15	256	253
8	7.27	7.32	276	269
14	7.53	7.62	264	263
42	7.73	7.73	99	86
133	8.4	8.4	71	64

Table 5-130. Results of pH and Eh measurements of natural groundwater (reference).

Sample time (days)	pH Series 1	 Series 2	Eh Series 1	 Series 2
0.125	8.17	8.08	373	370
1	8.4	8.36	380	380
9	8.62	8.59	362	357
16	8.72	8.77	323	326
63	8.72	8.81	254	261
132	8.95	9.01	121	122

Table 5-131. Results of of pH and Eh measurements of synthetic groundwater (reference).

Sample time (days)	pH Series 1	 Series 2	Eh Series 1	 Series 2
0.125	8.65	8.76	193	195
1	8.7	8.76	279	281
8	8.8	8.79	381	355
14	9.03	9.04	289	290
42	8.93	8.95	177	170
133	9.14	8.9	50	63

5.2.2 Comparison of pH and Eh results

The results are most easily compared using the plots provided in Appendix 2.

pH show an increase over the sampling period by about 0.5 units in all experiments, while Eh decrease from about 0.3–0.4 V to 0–0.1 V.

The impact of the different soils on initial pH is obvious, both for natural and synthetic groundwater experiments and the effects are, in most cases, sustained to the last measurement at 130 days. While reference experiments start at about pH 8.5, the most acidic soils, peat and clay gyttja type I, start at pH 6.5. The order of decreasing acidity is: peat/clay gyttja I, gyttja, clay gyttja II, sand, clay, till I/II. This order roughly corresponds to increasing sampling depth (Table 2-1).

The Eh measurements generally show a decreasing trend, probably reflecting the slow equilibration of each experiment with the inert glove-box atmosphere. In this process excess O_2 and CO_2 is probably driven off. This should affect both pH (increasing) and Eh (decreasing).

Although pH values generally show a levelling out to constant values, most Eh values are still decreasing between the last measurements.

Any differences between natural and synthetic groundwater with respect to pH can only be discerned for the low-acidic soils and references, where pH is slightly higher for synthetic than for natural groundwater. For the acidic soils, these obviously buffer pH.

For the Eh measurements, differences seem to be a quicker decrease of Eh in the synthetic water than in natural. Possible exceptions are the samples with gyttja and sand, where the final values for natural groundwater are below the values for synthetic groundwater.

5.3 Results from analyses of Main elements

This section accounts for the results of the two separate series of experiments that were prepared for measuring so-called Main elements /2/. Only two sampling intervals were designed, 14 and 130 days, using one series for each sampling occasion. In addition, samples were also taken directly from the filtrated water, stored in sealed bottles (but not in glove-box). These were also analysed for all main elements, except pH and Eh.

5.3.1 pH and Eh

The results of pH and Eh measurements in the Main elements series with natural and synthetic groundwater are shown in Tables 5-132 and -133, respectively. The results are also shown as single points in the diagrams in Appendix 2.

Table 5-132. Results of of pH and Eh measurements of natural groundwater (reference).

Soil	pH		Eh	
	19 days	132 days	20 days	134 days
peat	7.04	7.26	273	48
gyttja	7.54	8.02	258	20
clay gyttja I	7.1	7.75	306	146
sand	8.1	8.56	303	134
clay	8.24	8.64	305	156
till I	8.56	8.92	309	134
till II	8.71	8.91	310	137
clay gyttja II	7.8	8.47	325	149
reference	8.72	8.97	319	130

Table 5-133. Results of of pH and Eh measurements of synthetic groundwater (reference).

Soil	pH		Eh	
	23 days	134 days	16 days	140 days
peat	6.77	7.04	279	0
gyttja	7.59	7.71	218	53
clay gyttja I	6.87	7.65	275	154
sand	8.26	8.35	255	82
clay	8.49	8.67	291	100
till I	8.86	8.84	302	101
till II	8.8	8.74	304	99
clay gyttja II	7.88	8.35	264	66
reference	8.87	8.7	287	74

5.3.2 Major ionic constituents

The results of the ion chromatography measurements of major ionic constituents in the series of Main elements experiments with peat are shown in Table 5-134. The results are also presented as diagrams in Appendix 3.

The results of the ion chromatography measurements of major ionic constituents in the series of Main elements experiments with *gyttja* and *clay gyttja I* are shown in Table 5-135 and 5-136, respectively.

Table 5-134. Results of analyses of major ionic constituents (mM) in groundwater in contact with peat.

Ion	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
F^-	0.05	0.07	0.04	0.06
Cl^-	0.36	0.36	0.41	0.37
Br^-	0.003	0.003	0.001	0.001
NO_3^-	0.001	< 0.001	0.001	0.002
SO_4^{2-}	0.82	0.67	0.80	0.71
Li^+	< 0.0004	< 0.0004	< 0.0003	< 0.0005
Na^+	0.95	0.92	0.63	0.84
NH_4^+	0.038	0.078	0.060	0.120
K^+	0.051	0.047	0.099	0.098
Mg^{2+}	0.32	0.84	0.38	0.35
Ca^{2+}	0.73	0.63	0.66	0.84

Table 5-135. Results of analyses of major ionic constituents (mM) in groundwater in contact with gyttja.

Ion	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
F^-	0.10	0.12	0.08	0.10
Cl^-	0.36	0.36	0.41	0.36
Br^-	0.010	0.015	0.009	0.010
NO_3^-	0.002	0.006	< 0.001	0.002
SO_4^{2-}	2.35	2.39	2.26	2.07
Li^+	< 0.0004	< 0.0004	< 0.0003	< 0.0005
Na^+	0.99	0.97	0.67	0.96
NH_4^+	0.043	0.061	0.081	0.093
K^+	0.062	0.056	0.115	0.153
Mg^{2+}	0.84	0.69	1.06	0.97
Ca^{2+}	1.66	1.44	1.53	1.89

Table 5-136. Results of analyses of major ionic constituents (mM) in groundwater in contact with clay gyttja type I.

Ion	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
F^-	0.09	0.11	0.06	0.07
Cl^-	0.37	0.36	0.42	0.38
Br^-	0.004	0.007	< 0.0003	0.002
NO_3^-	0.002	0.005	0.001	0.001
SO_4^{2-}	3.07	3.20	2.83	2.84
Li^+	< 0.0004	< 0.0004	< 0.0003	< 0.0005
Na^+	1.07	1.05	0.77	0.99
NH_4^+	0.097	0.110	0.127	0.182
K^+	0.053	0.038	0.087	0.109
Mg^{2+}	0.93	0.75	1.23	1.07
Ca^{2+}	1.52	1.29	1.62	1.79

The results of the ion chromatography measurements of major ionic constituents in the series of Main elements experiments with *sand* and *clay* are shown in Table 5-137 and 5-138, respectively.

The results of the ion chromatography measurements of major ionic constituents in the series of Main elements experiments with *till type I* and ***II*** are shown in Table 5-139 and 5-140, respectively.

The results of the ion chromatography measurements of major ionic constituents in the series of Main elements experiments with *clay gyttja type II* and *references* are shown in Table 5-141 and 5-142, respectively.

The results of the ion chromatography measurements of major ionic constituents in *groundwater* is shown it Table 5-143. Unlike the reference samples, these waters have not been transferred to, and sampled from, centrifugation tubes but directly from containers with filtrated water, at the end of the experimental period.

Table 5-137. Results of analyses of major ionic constituents (mM) in groundwater in contact with sand.

Ion	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
F^-	0.14	0.16	0.11	0.11
Cl^-	0.36	0.37	0.44	0.37
Br^-	0.003	0.002	0.001	0.002
NO_3^-	0.002	0.001	0.002	0.034
SO_4^{2-}	2.35	2.57	1.76	1.68
Li^+	< 0.0004	< 0.0004	< 0.0003	< 0.0005
Na^+	1.01	1.00	0.70	0.93
NH_4^+	0.024	0.027	0.046	0.056
K^+	0.079	0.065	0.13	0.18
Mg^{2+}	0.73	0.63	0.90	0.88
Ca^{2+}	1.62	1.70	1.33	2.24

Table 5-138. Results of analyses of major ionic constituents (mM) in groundwater in contact with clay.

Ion	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
F^-	0.10	0.12	0.09	0.10
Cl^-	0.36	0.38	0.47	0.39
Br^-	0.003	0.003	< 0.0003	0.002
NO_3^-	0.002	< 0.001	< 0.001	0.061
SO_4^{2-}	0.81	0.82	0.79	0.71
Li^+	< 0.0004	< 0.0004	< 0.0003	< 0.0005
Na^+	1.04	1.01	0.71	0.98
NH_4^+	0.022	0.027	0.041	0.048
K^+	0.109	0.095	0.156	0.136
Mg^{2+}	0.80	0.65	0.90	0.84
Ca^{2+}	1.18	1.40	0.83	1.74

Table 5-139. Results of analyses of major ionic constituents (mM) in groundwater in contact with till type I.

Ion	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
F^-	0.10	0.10	0.08	0.08
Cl^-	0.37	0.37	0.41	0.38
Br^-	0.002	0.003	< 0.0003	0.001
NO_3^-	0.001	< 0.001	0.002	0.002
SO_4^{2-}	0.79	0.81	0.75	0.69
Li^+	< 0.0004	< 0.0004	< 0.0003	< 0.0005
Na^+	1.04	1.01	0.69	0.93
NH_4^+	0.023	0.024	0.045	0.048
K^+	0.079	0.077	0.136	0.178
Mg^{2+}	0.68	0.61	0.82	0.79
Ca^{2+}	1.00	1.12	0.85	1.23

Table 5-140. Results of analyses of major ionic constituents (mM) in groundwater in contact with till type II.

Ion	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
F^-	0.10	0.10	0.08	0.08
Cl^-	0.37	0.36	0.41	0.38
Br^-	0.003	< 0.001	< 0.0003	0.001
NO_3^-	0.002	< 0.001	0.001	< 0.001
SO_4^{2-}	0.79	0.80	0.74	0.70
Li^+	< 0.0004	< 0.0004	< 0.0003	< 0.0005
Na^+	1.04	1.01	0.69	0.92
NH_4^+	0.023	0.024	0.044	0.047
K^+	0.080	0.076	0.134	0.176
Mg^{2+}	0.67	0.58	0.82	0.79
Ca^{2+}	0.99	1.09	0.82	1.18

Table 5-141. Results of analyses of major ionic constituents (mM) in groundwater in contact with clay gyttja type II.

Ion	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
F^-	0.10	0.11	0.08	0.09
Cl^-	0.38	0.38	0.43	0.41
Br^-	0.003	0.002	0.002	0.001
NO_3^-	0.001	< 0.001	< 0.001	< 0.001
SO_4^{2-}	3.02	3.02	2.56	3.02
Li^+	< 0.002	0.002	< 0.0003	< 0.0005
Na^+	1.20	1.16	0.90	1.21
NH_4^+	0.118	0.129	0.158	0.147
K^+	0.093	0.074	0.131	0.180
Mg^{2+}	1.04	0.84	1.25	1.13
Ca^{2+}	1.90	1.54	1.61	1.85

Table 5-142. Results of analyses of major ionic constituents (mM) in groundwater references.

Ion	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
F^-	0.10	0.10	0.09	0.08
Cl^-	0.36	0.37	0.39	0.37
Br^-	0.003	< 0.001	< 0.0003	0.001
NO_3^-	0.001	< 0.001	0.027	0.014
SO_4^{2-}	0.78	0.81	0.73	0.71
Li^+	< 0.0004	< 0.0004	< 0.0003	< 0.0003
Na^+	1.03	1.00	0.69	0.92
NH_4^+	0.021	0.023	0.045	0.051
K^+	0.071	0.069	0.125	0.165
Mg^{2+}	0.68	0.60	0.86	0.82
Ca^{2+}	1.01	1.14	1.05	1.27

Table 5-143. Results of analyses of major ionic constituents (mM) in prepared groundwater.

Ion	Natural groundwater	Synthetic groundwater
F^-	0.10	0.10
Cl^-	0.42	0.39
Br^-	0.003	0.001
NO_3^-	0.112	0.030
SO_4^{2-}	0.75	0.77
Li^+	< 0.0004	< 0.0004
Na^+	0.94	0.62
NH_4^+	0.020	0.046
K^+	0.110	0.103
Mg^{2+}	0.58	0.59
Ca^{2+}	1.36	0.45

5.3.3 Alkalinity

The results from the alkalinity titrations in the series of Main elements are shown in Table 5-144. The analyses are also shown as diagrams in Appendix 3.

Inflexion points were measured in the pH interval 5.3–5.9.

5.3.4 Trace elements

The results of the analysis of trace elements in the groundwater in contact with peat are shown in Table 5-145. The analyses are also shown as diagrams in Appendix 3.

The results of the analysis of trace elements in the groundwater in contact with gyttja are shown in Table 5-146.

Table 5-144. Results of alkalinity titrations (mM) on the Main elements series of experiments.

Soil	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
peat	1.06	< 0.20	0.34	< 0.20
gyttja	1.85	1.15	1.01	0.58
clay gyttja I	0.91	0.29	< 0.20	< 0.20
sand	1.41	1.52	1.04	1.45
clay	2.69	2.87	1.37	2.20
till I	2.31	2.31	1.44	1.90
till II	2.18	2.28	1.33	1.69
clay gyttja II	1.99	1.51	1.09	0.68
reference	2.46	2.37	1.76	1.73
filtrated water[1]	1.18		0.85	

[1] sampled directly from container

Table 5-145. Results of analyses of trace elements (M) in groundwater in contact with peat.

Element	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
U	$5.5\cdot10^{-9}$	$2.0\cdot10^{-8}$	$5.5\cdot10^{-9}$	$2.4\cdot10^{-8}$
Ni	$1.7\cdot10^{-7}$	$3.8\cdot10^{-7}$	$1.6\cdot10^{-7}$	$3.5\cdot10^{-7}$
Cd	$2.4\cdot10^{-9}$	$2.9\cdot10^{-9}$	$2.4\cdot10^{-9}$	$3.0\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$
Eu	$1.5\cdot10^{-9}$	$5.7\cdot10^{-9}$	$1.6\cdot10^{-9}$	$5.7\cdot10^{-9}$
Co	$1.9\cdot10^{-8}$	$3.9\cdot10^{-8}$	$2.4\cdot10^{-8}$	$4.2\cdot10^{-8}$
Al	$7.9\cdot10^{-6}$	$4.2\cdot10^{-5}$	$1.3\cdot10^{-5}$	$4.0\cdot10^{-5}$
Ti	$1.9\cdot10^{-7}$	$2.0\cdot10^{-6}$	$2.6\cdot10^{-7}$	$1.7\cdot10^{-6}$
Mn	$7.6\cdot10^{-7}$	$1.4\cdot10^{-6}$	$1.1\cdot10^{-6}$	$1.8\cdot10^{-6}$
Sr	$1.5\cdot10^{-6}$	$1.4\cdot10^{-6}$	$1.3\cdot10^{-6}$	$1.3\cdot10^{-6}$
Fe	$3.9\cdot10^{-6}$	$1.6\cdot10^{-4}$	$1.3\cdot10^{-5}$	$1.6\cdot10^{-4}$
I	$9.2\cdot10^{-6}$	$5.9\cdot10^{-6}$	$6.7\cdot10^{-6}$	$9.4\cdot10^{-6}$
P	$< 2.8\cdot10^{-6}$	$1.0\cdot10^{-5}$	$1.2\cdot10^{-5}$	$2.0\cdot10^{-5}$
Si	$3.3\cdot10^{-4}$	$4.6\cdot10^{-4}$	$1.8\cdot10^{-4}$	$2.6\cdot10^{-4}$

Table 5-146. Results of analyses of trace elements (M) in groundwater in contact with gyttja.

Element	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
U	$1.1\cdot10^{-8}$	$1.5\cdot10^{-8}$	$2.3\cdot10^{-9}$	$3.1\cdot10^{-9}$
Ni	$7.4\cdot10^{-8}$	$7.7\cdot10^{-8}$	$4.7\cdot10^{-8}$	$7.4\cdot10^{-8}$
Cd	$3.0\cdot10^{-9}$	$2.4\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$
Eu	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$
Co	$6.2\cdot10^{-9}$	$< 5.6\cdot10^{-9}$	$1.1\cdot10^{-8}$	$< 5.6\cdot10^{-9}$
Al	$6.7\cdot10^{-7}$	$3.0\cdot10^{-7}$	$6.2\cdot10^{-7}$	$8.6\cdot10^{-7}$
Ti	$9.5\cdot10^{-8}$	$1.0\cdot10^{-7}$	$1.2\cdot10^{-7}$	$1.4\cdot10^{-7}$
Mn	$2.6\cdot10^{-6}$	$1.4\cdot10^{-6}$	$3.1\cdot10^{-6}$	$2.6\cdot10^{-6}$
Sr	$3.4\cdot10^{-6}$	$3.1\cdot10^{-6}$	$3.1\cdot10^{-6}$	$2.9\cdot10^{-6}$
Fe	$< 4.6\cdot10^{-7}$	$7.8\cdot10^{-6}$	$5.3\cdot10^{-5}$	$4.9\cdot10^{-5}$
I	$7.9\cdot10^{-6}$	$7.5\cdot10^{-6}$	$7.3\cdot10^{-6}$	$9.4\cdot10^{-6}$
P	$< 2.8\cdot10^{-6}$	$8.5\cdot10^{-6}$	$1.8\cdot10^{-5}$	$3.2\cdot10^{-5}$
Si	$4.0\cdot10^{-4}$	$4.0\cdot10^{-4}$	$2.0\cdot10^{-4}$	$2.4\cdot10^{-4}$

The results of the analysis of trace elements in the groundwater in contact with clay gyttja I are shown in Table 5-147.

The results of the analysis of trace elements in the groundwater in contact with sand are shown in Table 5-148.

The results of the analysis of trace elements in the groundwater in contact with clay are shown in Table 5-149.

Table 5-147. Results of analyses of trace elements (M) in groundwater in contact with clay gyttja I.

Element	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
U	$1.3\cdot10^{-9}$	$1.0\cdot10^{-9}$	$4.0\cdot10^{-10}$	$3.8\cdot10^{-10}$
Ni	$1.4\cdot10^{-7}$	$5.8\cdot10^{-8}$	$1.4\cdot10^{-7}$	$3.8\cdot10^{-8}$
Cd	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$
Eu	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$
Co	$4.3\cdot10^{-8}$	$5.7\cdot10^{-9}$	$5.9\cdot10^{-8}$	$2.7\cdot10^{-8}$
Al	$4.4\cdot10^{-7}$	$1.9\cdot10^{-7}$	$2.0\cdot10^{-7}$	$1.0\cdot10^{-6}$
Ti	$9.9\cdot10^{-8}$	$1.0\cdot10^{-7}$	$1.2\cdot10^{-7}$	$1.2\cdot10^{-7}$
Mn	$6.8\cdot10^{-6}$	$3.5\cdot10^{-6}$	$8.5\cdot10^{-6}$	$7.3\cdot10^{-6}$
Sr	$3.1\cdot10^{-6}$	$2.5\cdot10^{-6}$	$3.0\cdot10^{-6}$	$2.3\cdot10^{-6}$
Fe	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$8.8\cdot10^{-6}$
I	$7.8\cdot10^{-6}$	$7.4\cdot10^{-6}$	$8.9\cdot10^{-6}$	$2.1\cdot10^{-5}$
P	$3.1\cdot10^{-6}$	$1.2\cdot10^{-5}$	$1.6\cdot10^{-5}$	$2.8\cdot10^{-5}$
Si	$4.3\cdot10^{-4}$	$4.4\cdot10^{-4}$	$2.6\cdot10^{-4}$	$3.7\cdot10^{-4}$

Table 5-148. Results of analyses of trace elements (M) in groundwater in contact with sand.

Element	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
U	$1.1\cdot10^{-8}$	$1.8\cdot10^{-8}$	$3.6\cdot10^{-9}$	$6.2\cdot10^{-9}$
Ni	$2.1\cdot10^{-7}$	$6.1\cdot10^{-8}$	$1.1\cdot10^{-8}$	$1.8\cdot10^{-8}$
Cd	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$
Eu	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$
Co	$2.0\cdot10^{-8}$	$<5.6\cdot10^{-9}$	$<5.6\cdot10^{-9}$	$<5.6\cdot10^{-9}$
Al	$9.8\cdot10^{-7}$	$1.0\cdot10^{-6}$	$8.7\cdot10^{-7}$	$2.6\cdot10^{-6}$
Ti	$8.4\cdot10^{-8}$	$8.4\cdot10^{-8}$	$9.1\cdot10^{-8}$	$9.0\cdot10^{-8}$
Mn	$1.5\cdot10^{-6}$	$1.6\cdot10^{-6}$	$1.7\cdot10^{-8}$	$2.0\cdot10^{-6}$
Sr	$2.9\cdot10^{-6}$	$2.7\cdot10^{-6}$	$2.5\cdot10^{-6}$	$2.3\cdot10^{-6}$
Fe	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$
I	$7.4\cdot10^{-6}$	$7.9\cdot10^{-6}$	$9.0\cdot10^{-6}$	$1.1\cdot10^{-5}$
P	$3.5\cdot10^{-6}$	$1.3\cdot10^{-5}$	$1.7\cdot10^{-5}$	$2.1\cdot10^{-5}$
Si	$2.8\cdot10^{-4}$	$2.4\cdot10^{-4}$	$1.6\cdot10^{-4}$	$1.8\cdot10^{-4}$

Table 5-149. Results of analyses of trace elements (M) in groundwater in contact with clay.

Element	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
U	$1.1\cdot10^{-8}$	$1.5\cdot10^{-8}$	$1.0\cdot10^{-8}$	$1.2\cdot10^{-8}$
Ni	$3.9\cdot10^{-8}$	$1.5\cdot10^{-8}$	$< 1.0\cdot10^{-8}$	$< 1.0\cdot10^{-8}$
Cd	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$
Eu	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$
Co	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$
Al	$1.8\cdot10^{-7}$	$1.4\cdot10^{-7}$	$2.1\cdot10^{-7}$	$2.4\cdot10^{-7}$
Ti	$4.5\cdot10^{-8}$	$4.6\cdot10^{-8}$	$6.3\cdot10^{-8}$	$5.6\cdot10^{-8}$
Mn	$1.3\cdot10^{-7}$	$3.5\cdot10^{-7}$	$8.4\cdot10^{-9}$	$8.6\cdot10^{-7}$
Sr	$2.8\cdot10^{-6}$	$2.8\cdot10^{-6}$	$2.5\cdot10^{-6}$	$2.6\cdot10^{-6}$
Fe	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$
I	$6.6\cdot10^{-6}$	$6.9\cdot10^{-6}$	$8.3\cdot10^{-6}$	$9.5\cdot10^{-6}$
P	$4.4\cdot10^{-6}$	$1.6\cdot10^{-5}$	$1.7\cdot10^{-5}$	$2.2\cdot10^{-5}$
Si	$2.7\cdot10^{-4}$	$2.3\cdot10^{-4}$	$1.1\cdot10^{-4}$	$1.3\cdot10^{-4}$

The results of the analysis of trace elements in the groundwater in contact with till type I are shown in Table 5-150.

The results of the analysis of trace elements in the groundwater in contact with till type II are shown in Table 5-151.

The results of the analysis of trace elements in the groundwater in contact with clay gyttja type II are shown in Table 5-152.

The results of the analysis of trace elements in groundwater in reference experiments are shown in Table 5-153.

The results of the analysis of trace elements in groundwater are shown in Table 5-154. Unlike the reference samples, these waters have not been transferred to, and sampled from, centrifugation tubes but are sampled directly from containers with filtrated water, at the end of the experimental period.

Table 5-150. Results of analyses of trace elements (M) in groundwater in contact with till type I.

Element	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
U	$2.7\cdot10^{-8}$	$2.7\cdot10^{-8}$	$2.1\cdot10^{-8}$	$3.2\cdot10^{-8}$
Ni	$5.5\cdot10^{-8}$	$3.0\cdot10^{-8}$	$< 1.0\cdot10^{-8}$	$< 1.0\cdot10^{-8}$
Cd	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$3.7\cdot10^{-9}$	$4.2\cdot10^{-9}$
Eu	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$
Co	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$
Al	$1.6\cdot10^{-6}$	$1.9\cdot10^{-7}$	$4.3\cdot10^{-7}$	$5.8\cdot10^{-7}$
Ti	$1.2\cdot10^{-7}$	$4.8\cdot10^{-8}$	$9.3\cdot10^{-8}$	$5.9\cdot10^{-8}$
Mn	$8.6\cdot10^{-8}$	$2.5\cdot10^{-8}$	$9.1\cdot10^{-9}$	$6.8\cdot10^{-8}$
Sr	$2.7\cdot10^{-6}$	$2.7\cdot10^{-6}$	$2.6\cdot10^{-6}$	$2.6\cdot10^{-6}$
Fe	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$
I	$6.6\cdot10^{-6}$	$6.7\cdot10^{-6}$	$7.6\cdot10^{-6}$	$9.4\cdot10^{-6}$
P	$4.8\cdot10^{-6}$	$1.3\cdot10^{-5}$	$1.8\cdot10^{-5}$	$2.0\cdot10^{-5}$
Si	$3.9\cdot10^{-4}$	$4.2\cdot10^{-4}$	$2.2\cdot10^{-4}$	$1.4\cdot10^{-4}$

Table 5-151. Results of analyses of trace elements (M) in groundwater in contact with till type II.

Element	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
U	$1.3\cdot10^{-8}$	$2.0\cdot10^{-8}$	$2.1\cdot10^{-8}$	$1.3\cdot10^{-8}$
Ni	$6.1\cdot10^{-8}$	$2.0\cdot10^{-8}$	$< 1.0\cdot10^{-8}$	$< 1.0\cdot10^{-8}$
Cd	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$3.7\cdot10^{-9}$	$< 2.4\cdot10^{-9}$
Eu	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$
Co	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$
Al	$9.9\cdot10^{-7}$	$3.3\cdot10^{-7}$	$< 6.0\cdot10^{-8}$	$4.0\cdot10^{-7}$
Ti	$5.2\cdot10^{-8}$	$6.2\cdot10^{-8}$	$2.3\cdot10^{-7}$	$6.1\cdot10^{-8}$
Mn	$1.6\cdot10^{-8}$	$2.5\cdot10^{-8}$	$3.2\cdot10^{-8}$	$3.5\cdot10^{-8}$
Sr	$2.7\cdot10^{-6}$	$2.8\cdot10^{-6}$	$2.7\cdot10^{-6}$	$2.7\cdot10^{-6}$
Fe	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$
I	$7.7\cdot10^{-6}$	$7.6\cdot10^{-6}$	$9.5\cdot10^{-6}$	$8.5\cdot10^{-6}$
P	$5.3\cdot10^{-6}$	$1.3\cdot10^{-5}$	$1.8\cdot10^{-5}$	$2.1\cdot10^{-5}$
Si	$4.0\cdot10^{-4}$	$4.1\cdot10^{-4}$	$1.2\cdot10^{-4}$	$1.4\cdot10^{-4}$

Table 5-152. Results of analyses of trace elements (M) in groundwater in contact with clay gyttja type II.

Element	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
U	$8.1\cdot10^{-9}$	$2.0\cdot10^{-8}$	$1.5\cdot10^{-9}$	$2.9\cdot10^{-9}$
Ni	$8.2\cdot10^{-8}$	$4.0\cdot10^{-8}$	$3.9\cdot10^{-8}$	$1.1\cdot10^{-8}$
Cd	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$3.7\cdot10^{-9}$	$< 2.4\cdot10^{-9}$
Eu	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$
Co	$1.6\cdot10^{-8}$	$< 5.6\cdot10^{-9}$	$1.9\cdot10^{-8}$	$< 5.6\cdot10^{-9}$
Al	$1.4\cdot10^{-7}$	$< 6.0\cdot10^{-8}$	$2.5\cdot10^{-7}$	$4.8\cdot10^{-7}$
Ti	$9.5\cdot10^{-8}$	$9.9\cdot10^{-8}$	$1.2\cdot10^{-7}$	$1.0\cdot10^{-7}$
Mn	$5.2\cdot10^{-6}$	$1.7\cdot10^{-6}$	$6.3\cdot10^{-6}$	$3.5\cdot10^{-6}$
Sr	$4.0\cdot10^{-6}$	$3.4\cdot10^{-6}$	$3.5\cdot10^{-6}$	$3.0\cdot10^{-6}$
Fe	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$2.1\cdot10^{-6}$	$< 4.6\cdot10^{-7}$
I	$7.7\cdot10^{-6}$	$8.9\cdot10^{-6}$	$9.1\cdot10^{-6}$	$8.6\cdot10^{-6}$
P	$7.3\cdot10^{-6}$	$1.8\cdot10^{-5}$	$2.0\cdot10^{-5}$	$2.7\cdot10^{-5}$
Si	$4.1\cdot10^{-4}$	$3.9\cdot10^{-4}$	$2.3\cdot10^{-4}$	$2.6\cdot10^{-4}$

Table 5-153. Results of analyses of trace elements (M) in groundwater in reference experiments.

Element	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
U	$7.9\cdot10^{-10}$	$7.9\cdot10^{-10}$	$5.1\cdot10^{-10}$	$6.5\cdot10^{-10}$
Ni	$3.4\cdot10^{-8}$	$< 1.0\cdot10^{-8}$	$< 1.0\cdot10^{-8}$	$< 1.0\cdot10^{-8}$
Cd	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$
Eu	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$
Co	$1.6\cdot10^{-8}$	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$
Al	$3.2\cdot10^{-7}$	$1.3\cdot10^{-7}$	$9.7\cdot10^{-7}$	$1.0\cdot10^{-6}$
Ti	$4.2\cdot10^{-8}$	$4.1\cdot10^{-8}$	$5.6\cdot10^{-8}$	$5.5\cdot10^{-8}$
Mn	$1.9\cdot10^{-8}$	$4.1\cdot10^{-8}$	$3.2\cdot10^{-8}$	$3.0\cdot10^{-8}$
Sr	$2.7\cdot10^{-6}$	$2.7\cdot10^{-6}$	$2.7\cdot10^{-6}$	$2.7\cdot10^{-6}$
Fe	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$
I	$7.5\cdot10^{-6}$	$7.7\cdot10^{-6}$	$9.2\cdot10^{-6}$	$8.3\cdot10^{-6}$
P	$6.6\cdot10^{-6}$	$1.5\cdot10^{-5}$	$1.9\cdot10^{-5}$	$2.2\cdot10^{-5}$
Si	$4.1\cdot10^{-4}$	$4.4\cdot10^{-4}$	$1.2\cdot10^{-4}$	$1.3\cdot10^{-4}$

Table 5-154. Results of analyses of trace elements (M) in groundwater.

Element	Natural groundwater	Synthetic groundwater
U	$9.4\cdot10^{-10}$	$4.8\cdot10^{-10}$
Ni	$< 1.0\cdot10^{-8}$	$< 1.0\cdot10^{-8}$
Cd	$< 2.2\cdot10^{-9}$	$< 2.2\cdot10^{-9}$
Cs	$< 2.4\cdot10^{-9}$	$< 2.4\cdot10^{-9}$
Eu	$< 1.4\cdot10^{-9}$	$< 1.4\cdot10^{-9}$
Co	$< 5.6\cdot10^{-9}$	$< 5.6\cdot10^{-9}$
Al	$3.9\cdot10^{-7}$	$2.5\cdot10^{-6}$
Ti	$4.7\cdot10^{-8}$	$5.2\cdot10^{-8}$
Mn	$2.5\cdot10^{-8}$	$2.5\cdot10^{-7}$
Sr	$2.3\cdot10^{-6}$	$2.7\cdot10^{-6}$
Fe	$< 4.6\cdot10^{-7}$	$< 4.6\cdot10^{-7}$
I	$7.3\cdot10^{-6}$	$7.4\cdot10^{-6}$
P	$2.2\cdot10^{-5}$	$2.2\cdot10^{-5}$
Si	$4.3\cdot10^{-4}$	$1.5\cdot10^{-4}$

5.3.5 Carbon

The results of the Total Organic Carbon, TOC (measured as Non-Purgeable Organic Carbon, which is TOC minus volatile compounds) measurements of the Main elements series are shown in Table 5-155.

The results of Dissolved Inorganic Carbon, DIC measurements of the Main elements series are shown in Table 5-156.

Diagrams of these analyses are shown in Appendix 3.

Table 5-155. Results of Non-Purgeable Organic Carbon (NPOC) (mM) measurements of the Main elements series of experiments.

Soil	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
peat	4.12	4.65	0.82	3.73
gyttja	0.58	1.14	1.36	2.02
clay gyttja I	0.42	0.79	0.58	0.49
sand	< 0.40	0.68	< 0.22	< 0.22
clay	< 0.40	0.63	< 0.22	< 0.22
till I	< 0.40	< 0.40	< 0.22	< 0.22
till II	0.70	< 0.40	< 0.22	0.31
clay gyttja II	< 0.40	0.71	0.69	0.53
reference	< 0.40	0.49	< 0.22	< 0.22
filtrated water[1]	0.77		< 0.22	

[1] sampled directly from container

Table 5-156. Results of Dissolved Inorganic Carbon (DIC) (mM) measurements of the Main elements series of experiments.

Soil	Natural groundwater		Synthetic groundwater	
	14 days	130 days	14 days	130 days
peat	0.71	0.72	0.13	0.19
gyttja	1.13	1.05	1.09	0.70
clay gyttja I	0.63	0.56	< 0.05	< 0.05
sand	1.10	0.74	0.62	1.07
clay	1.56	2.23	0.98	2.40
till I	1.97	1.73	0.43	1.96
till II	1.44	1.58	1.45	1.21
clay gyttja II	1.64	1.57	1.40	0.48
reference	1.72	1.64	1.62	1.61
filtrated water[1]	2.30		1.10	

[1] sampled directly from container

5.3.6 Comparison of results for the Main element analyses

The most notable results of the Main element analyses will be high-lighted here. Comparisons are made regarding the development of concentrations from the in-going groundwater to the samples with increasing contact time with soils.

For major ionic constituents, it can be noted that NO_3^- is not stable in inert atmosphere conditions. All analyses show a decreasing trend compared with the original concentrations in the groundwater.

SO_4^{2-} is increasing in the water with a group of soils, sampled from neighbouring section depths: gyttja, gyttja clay I and II and sand.

NH_4^+ is also increasing in the water with a group of the shallow soils: peat, gyttja, gyttja clay I and II.

Several of the cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) increase in concentrations in almost all experiments with synthetic groundwater. With natural groundwater, the changes are smaller or even reversed, showing a decrease from original concentrations.

The alkalinity decrease for the shallow soils, while it increases for deep soils, compared with the original groundwater. The trends are the same for both types of groundwater.

For trace elements, the U concentration increases about two orders of magnitude (10^{-10} to 10^{-8} M) in most of the series, a notable exception is those with gyttja clay I.

Ni is increasing substantially (< 10^{-8} to 10^{-7} M) in the series with shallow soils peat, gyttja and gyttja clay I.

Al and Ti concentrations are increasing 1–2 orders of magnitude in waters in contact with peat.

Mn is increasing substantially (< 10^{-7} to 10^{-6} M) in the series with shallow soils peat, gyttja and gyttja clay I.

Sr shows some accumulation in all series, except peat, where it instead decrease over time.

For the tracer elements Cs and Eu, background concentrations could not be detected. For tracers U, Ni and Sr the background concentrations were lower or about the same as those added in the batch experiments (compare Table 4-1).

For I, on the other hand, the background concentration was several orders of magnitude higher than added tracer, which may explain the difficulty to obtain measurable sorption data for this tracer.

The analyses of C show that dissolved inorganic carbon is decreasing in the shallow soils. This is consistent with the decreasing trend in alkalinity for these soils. However, for the deep soils the effects is not an increase in dissolved inorganic carbon, as could be expected from increasing alkalinity in these series, but rather a moderate decrease or nearly constant concentrations.

For organic carbon, there is a significant contribution from the shallow soils peat, gyttja and gyttja clay I. The concentration in natural groundwater is also significantly higher (0.8 mM) than in synthetic water (< 0.2 mM).

5.4 Other results

5.4.1 Dry weight of soils

The results of the measurements of dry weight of the different soils are presented in Table 5-157.

5.4.2 Density measurements

The results of the measurements of densities for the different solutions used in the batch experiments are shown in Table 5-158.

Table 5-157. Results of measurements of dry weight of soils.

Soil type	Wet weight (g)	Dry weight (g)	% dry material
peat	3.072	1.346	43.82
gyttja	2.944	0.620	21.06
clay gyttja I	3.053	0.971	31.80
sand	2.978	2.453	82.35
clay	3.089	2.045	66.20
till I	2.996	1.614	53.87
till II	2.981	2.834	95.07
clay gyttja II	2.991	0.914	30.57

Table 5-158. Results of density measurements of solutions.

Solution	T = 5°C	T = 20°C
Natural groundwater	0.9997	0.9973
Synthetic groundwater	0.9988	0.9969
1M HCl(1	1.017	1.014
1M NaOH(2	1.036	1.033

1) used in acidic references for all tracers, except iodine.

2) used in alkaline references for iodine.

6 Summary and discussions

The sorption coefficients of Cs, Sr, Ni, Eu, U and Np tracer onto eight types of soils and with two types of groundwater, one natural and one synthetic, was measured over a time period up to 130 days. The measurements were successful, except for those cases that were close to either upper detection limits (late samplings of Eu and U) or close to lower limits (all I measurements, some Sr). With a single experimental configuration, R_d data could be collected in a dynamic range of 4 orders of magnitude and duplicate measurements show very good reproduction of results.

A recommendation for future studies would be to use a constant specific surface area to water mass ratio, instead of constant solid mass to water mass ratio, since this will facilitate detection of tracers. The non-measurable sorption of I tracer was, on the other hand, probably due to high background concentration of I.

If the results for surface area corrected sorption coefficients R_a for tracers and soils with synthetic groundwater are compared soil-wise, it is clear that sand generally shows the strongest sorption for the tracers, followed by a group of gyttja, clay gyttja I and II and till I and II. Trailing in sorption capacity are clay and peat. However, it should be noted that pH in the sorption experiments differs considerably for the different soils: from pH 7 (peat) to pH 9 (tills and reference without soil), which reflects the different pH buffer capacity of the soils. The pH may therefore also be a factor that contributed to the differences between soils in measured sorption.

Generally Eu and partly U show strongest sorption, while Sr shows weakest sorption. A closer study on the results of the individual tracers may however show patterns where, for example, the U sorption is very weak and comparable to Sr on clay and the tills.

The use of natural groundwater instead of the synthetic in the batch sorption of soils shows an effect where sorption is reduced considerably for U and Ni and probably also Eu, when detectable. These effects are pronounced in the experiments with soils that give a low level of background organic carbon in the contacted water. This effect of reduced sorption may then be an effect of the organics in the natural groundwater.

A complex formation of U, Ni and Eu with the organic substances (probably humic acids) in natural groundwater may be the reason for the reduced sorption that was measured, compared with synthetic groundwater.

The effect on Np sorption was not so pronounced. A literature study on the subject may confirm that the complexes of Np(V) with humic acids are comparatively weak, see for example /5/.

A separate study that evaluates the results presented here in this report, together with results from the soil characterisation /1/ and additional literature data, will be made.

References

/1/ **Lundin L, Snäll S, Jonsson E, Hannu S, Selnert E, Engdahl A, 2007.** Oskarshamn site investigation. Characterization of soil samples from three valleys in the Laxemar area. SKB P-07-222.

/2/ **Malmström M, Berglund S 2007.** Experimentell bestämning av platsspecifika K_d-värden för jord och sediment. Försöksplan för steg 1. Kapitel: Utförande. v.3.1

/3/ **Andersson M, Ervanne H, Glaus M A, Holgersson S, Laine H, Lothenbach B, Puigdomenech I, Schwyn B, Snellman M, Ueda H, Vuorio M, Wieland E, Yamamoto T, 2008.** Development of Methodology for Evaluation of Long-term Safety Aspects of Organic Cement Paste Components. POSIVA Working report 2008-28.

/4/ **Parkhurst D L, 2005.** PHREEQC, V.2.12.1. U.S. Geological Survey.

/5/ **Zhang Y J, Bryan N D, Livens, F R, Jones M N, 1997.** Selectivity in the complexation of actinides by humic substances. Environmental Pollution, 96, pp 361–367.

Diagrams of specific surface corrected partitioning coefficients as function of time

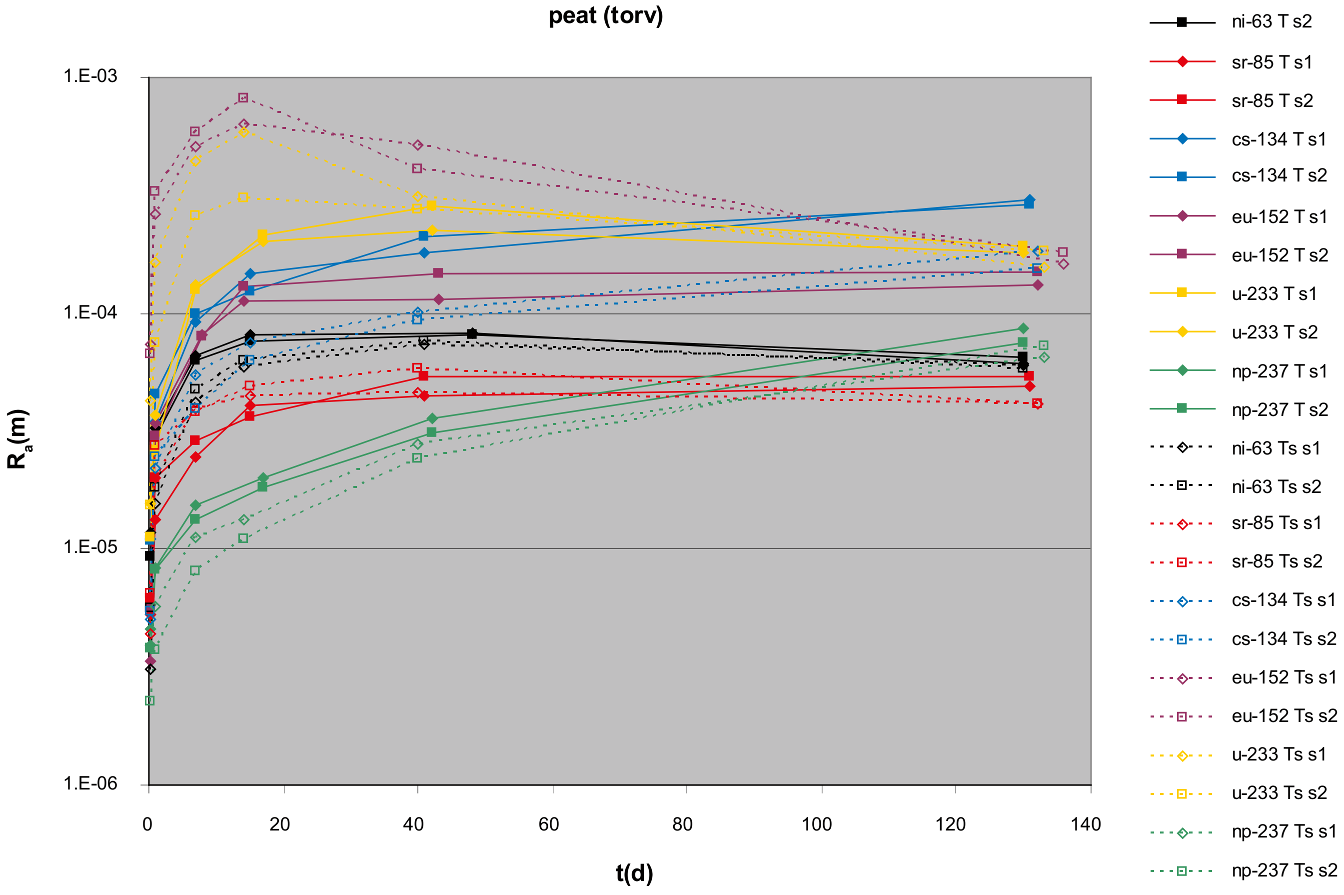

Figure A1-1. *Specific surface corrected partitioning coefficients R_a(m) for tracer sorption onto peat as function of time.*

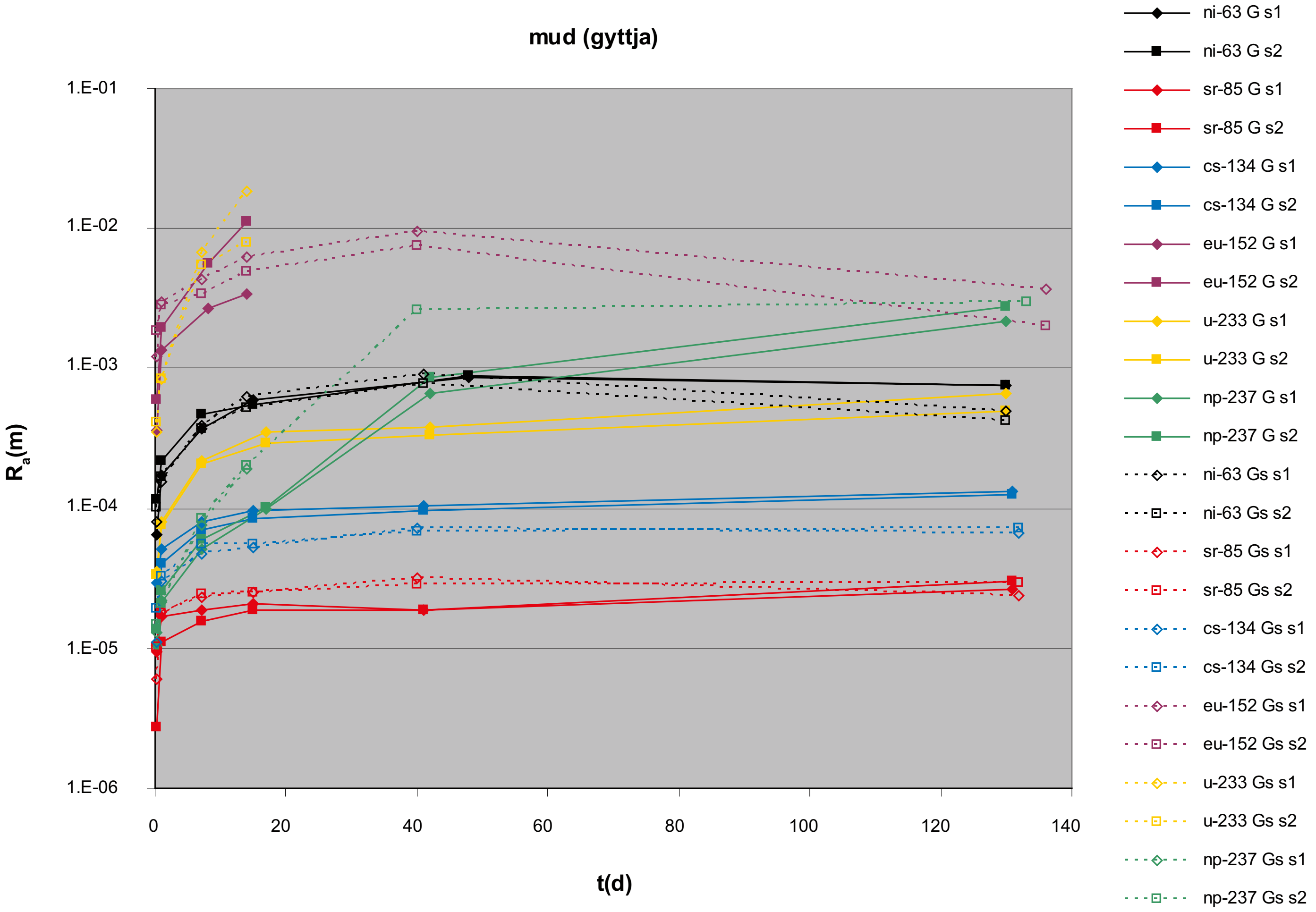

Figure A1-2. *Specific surface corrected partitioning coefficients $R_a(m)$ for tracer sorption onto gyttja as function of time.*

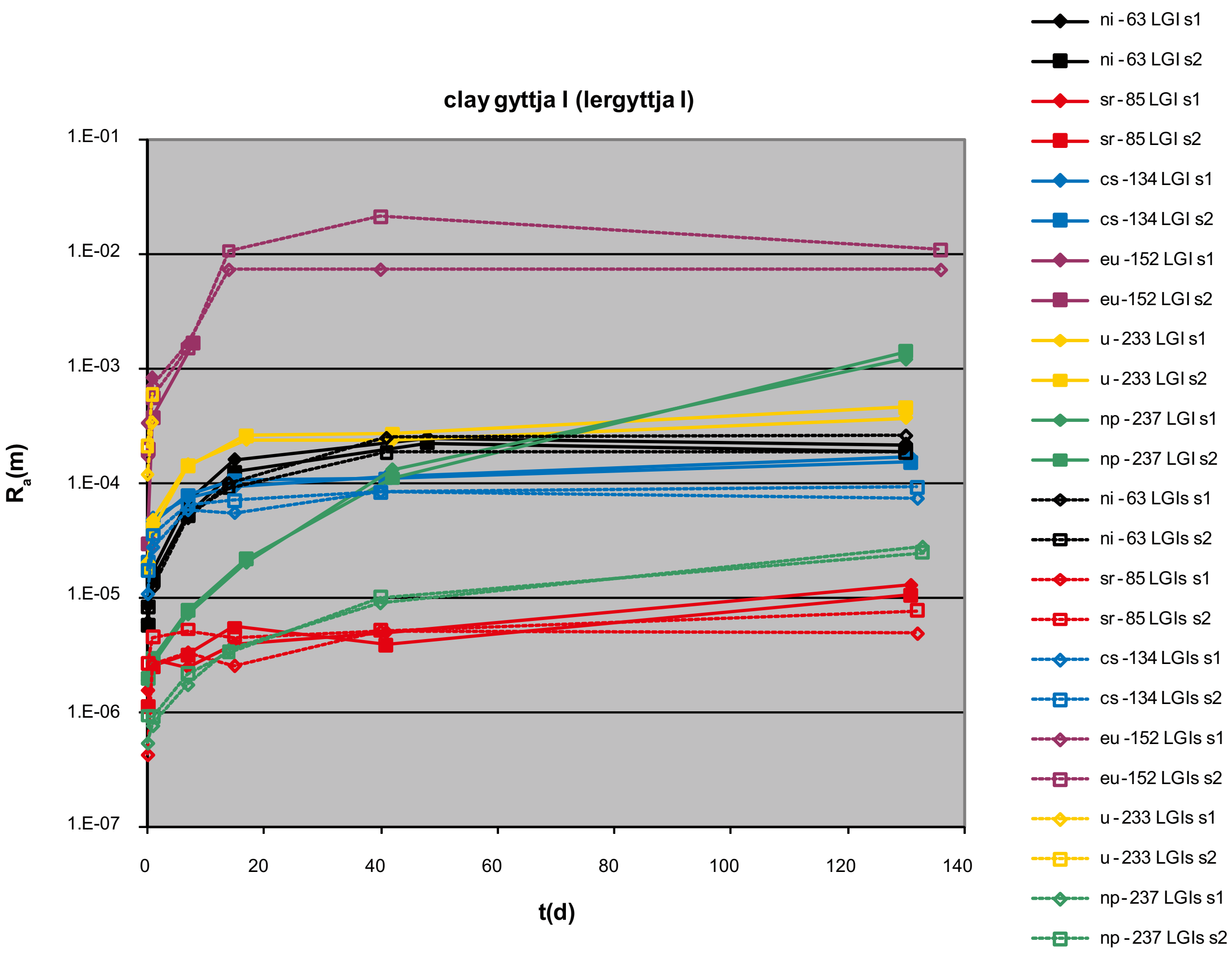

Figure A1-3. *Specific surface corrected partitioning coefficients $R_a(m)$ for tracer sorption onto clay gyttja type I as function of time.*

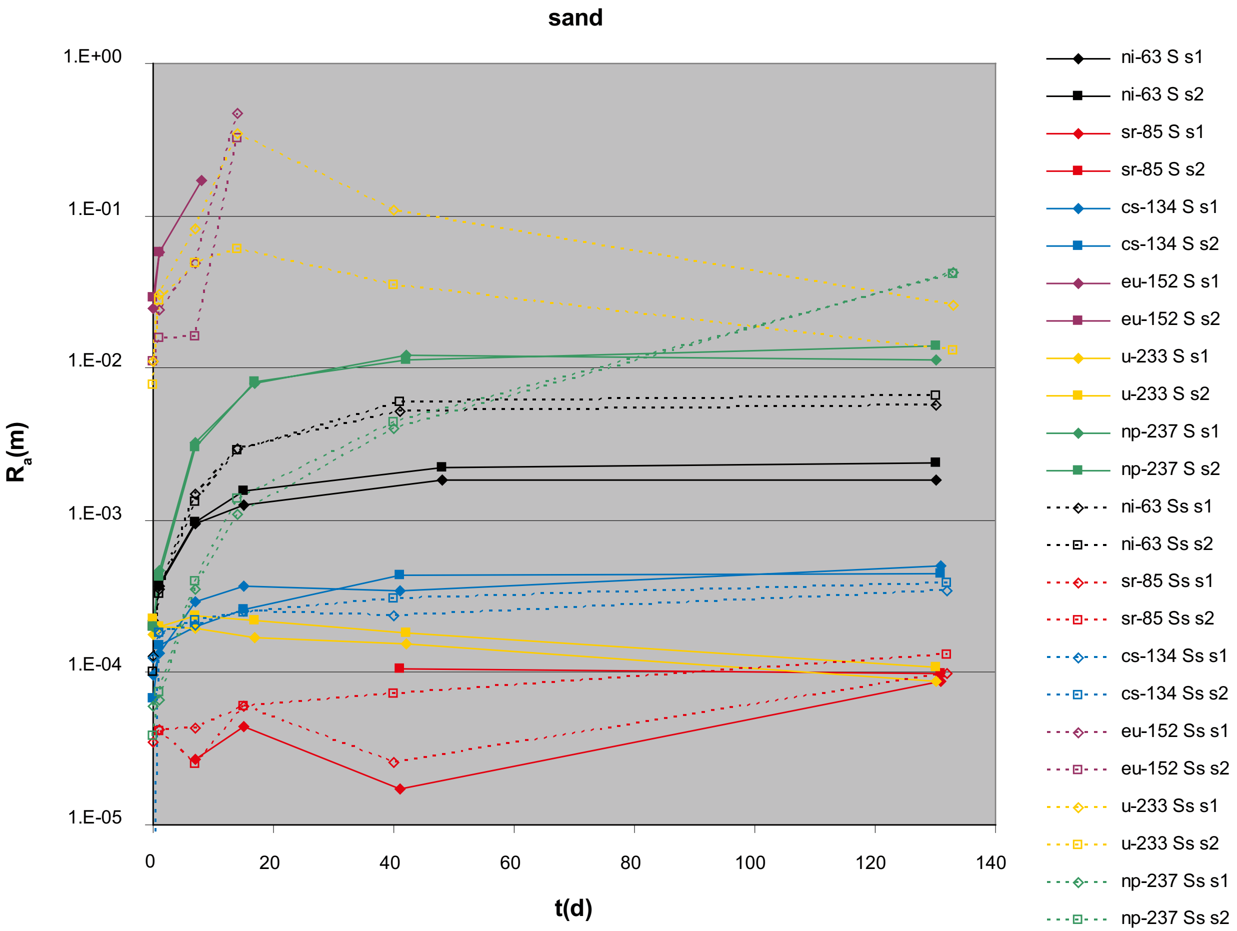

Figure A1-4. *Specific surface corrected partitioning coefficients R_a(m) for tracer sorption onto sand as function of time.*

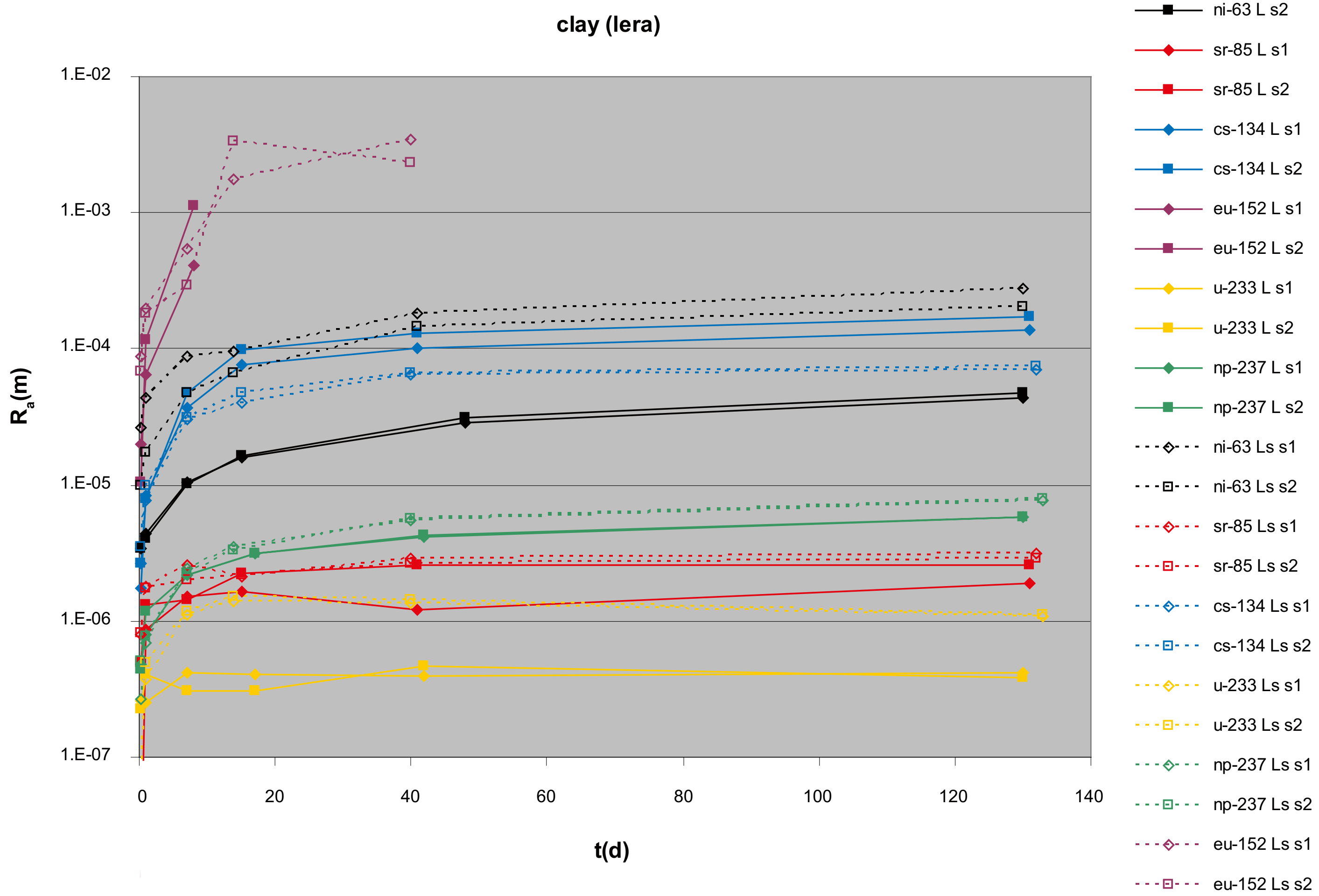

Figure A1-5. *Specific surface corrected partitioning coefficients $R_a(m)$ for tracer sorption onto clay as function of time.*

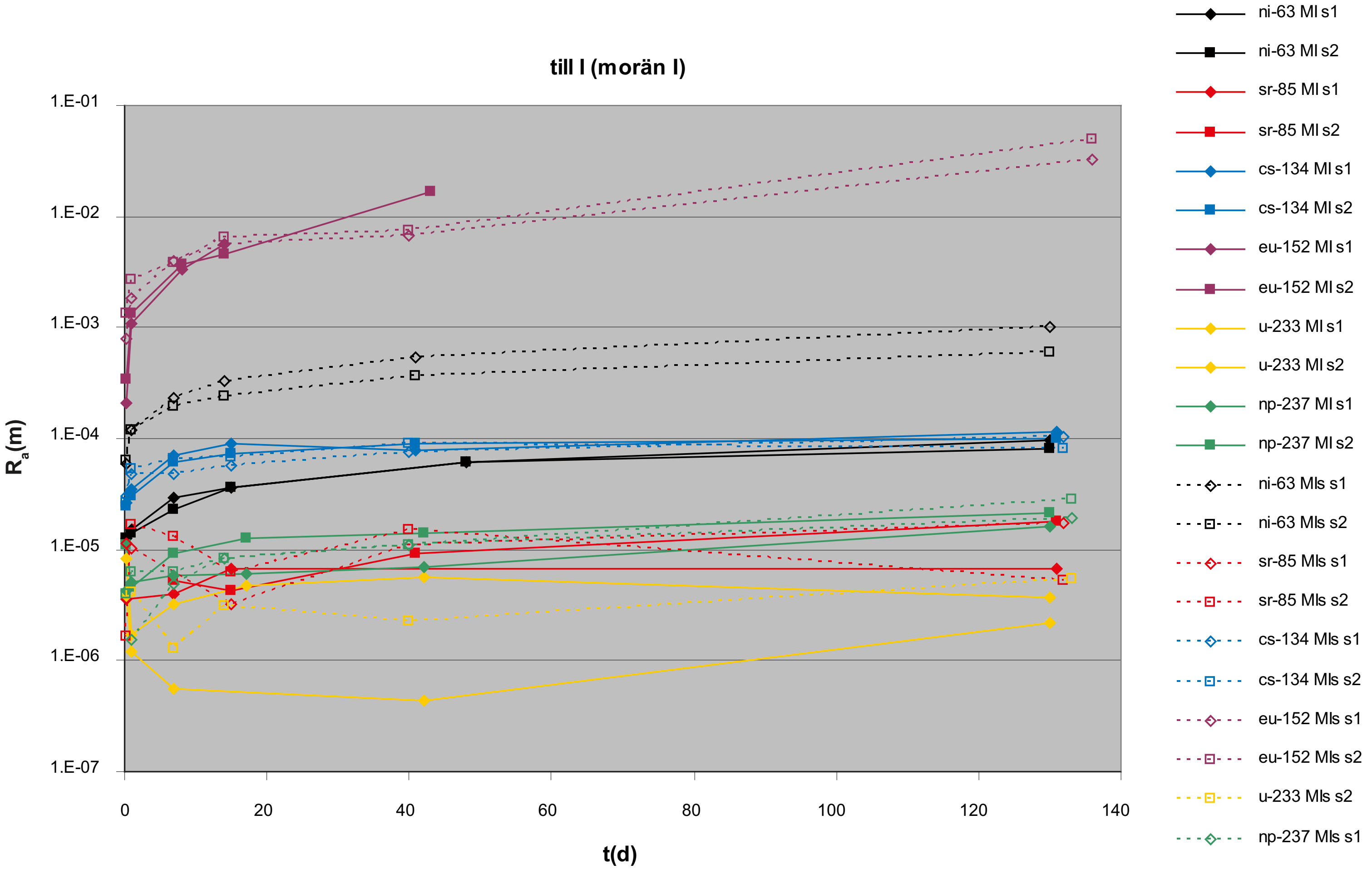

Figure A1-6. *Specific surface corrected partitioning coefficients R_a(m) for tracer sorption onto till type I as function of time.*

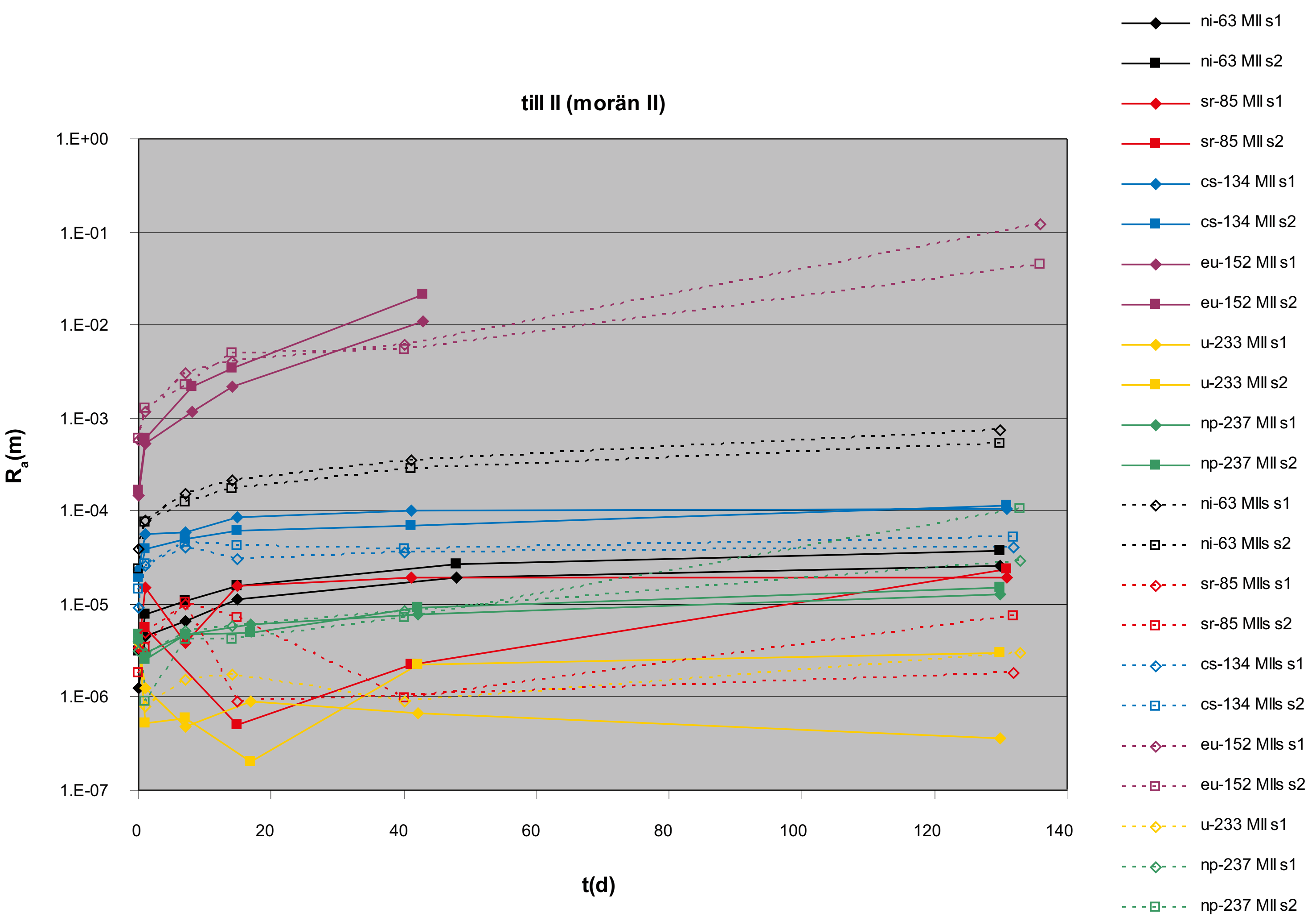

Figure A1-7. *Specific surface corrected partitioning coefficients R_a(m) for tracer sorption onto till type II as function of time.*

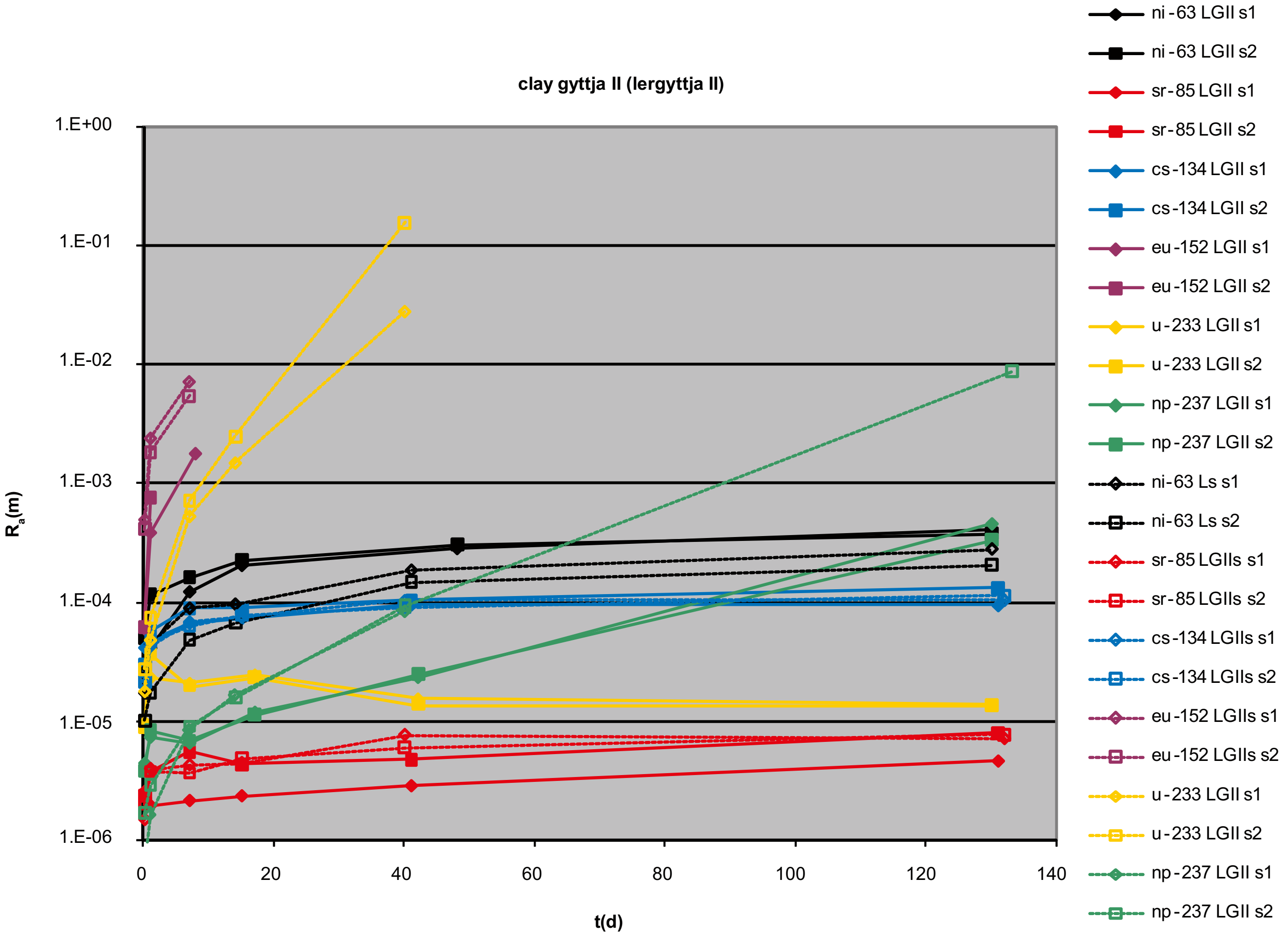

Figure A1-8. *Specific surface corrected partitioning coefficients R_a(m) for tracer sorption onto clay gyttja type II as function of time.*

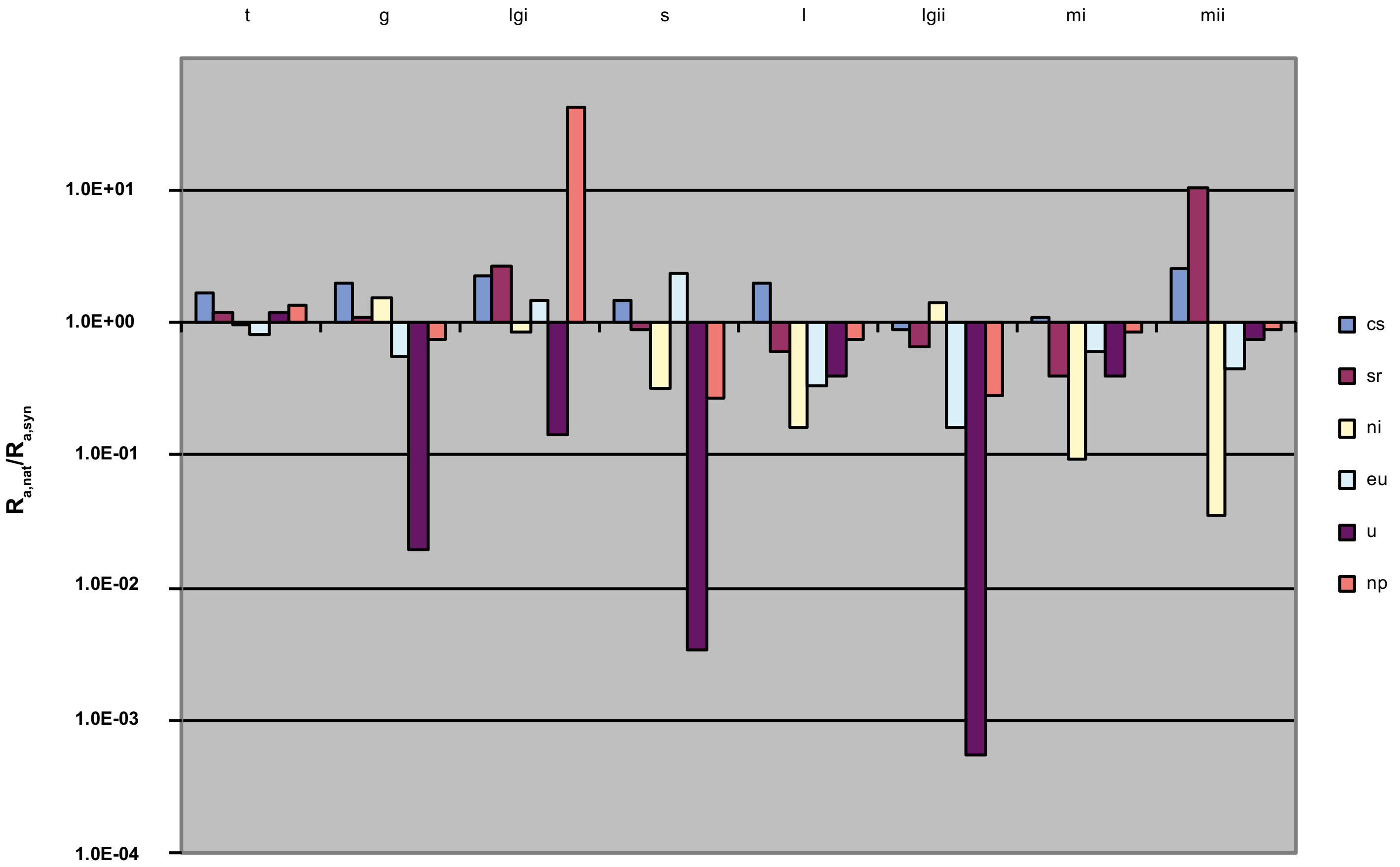

Figure A1-9. *Ratio $R_{a,nat}$:$R_{a,syn}$ of limiting surface corrected partitioning coefficients.*

Appendix 2

Diagrams of pH and Eh as function of time

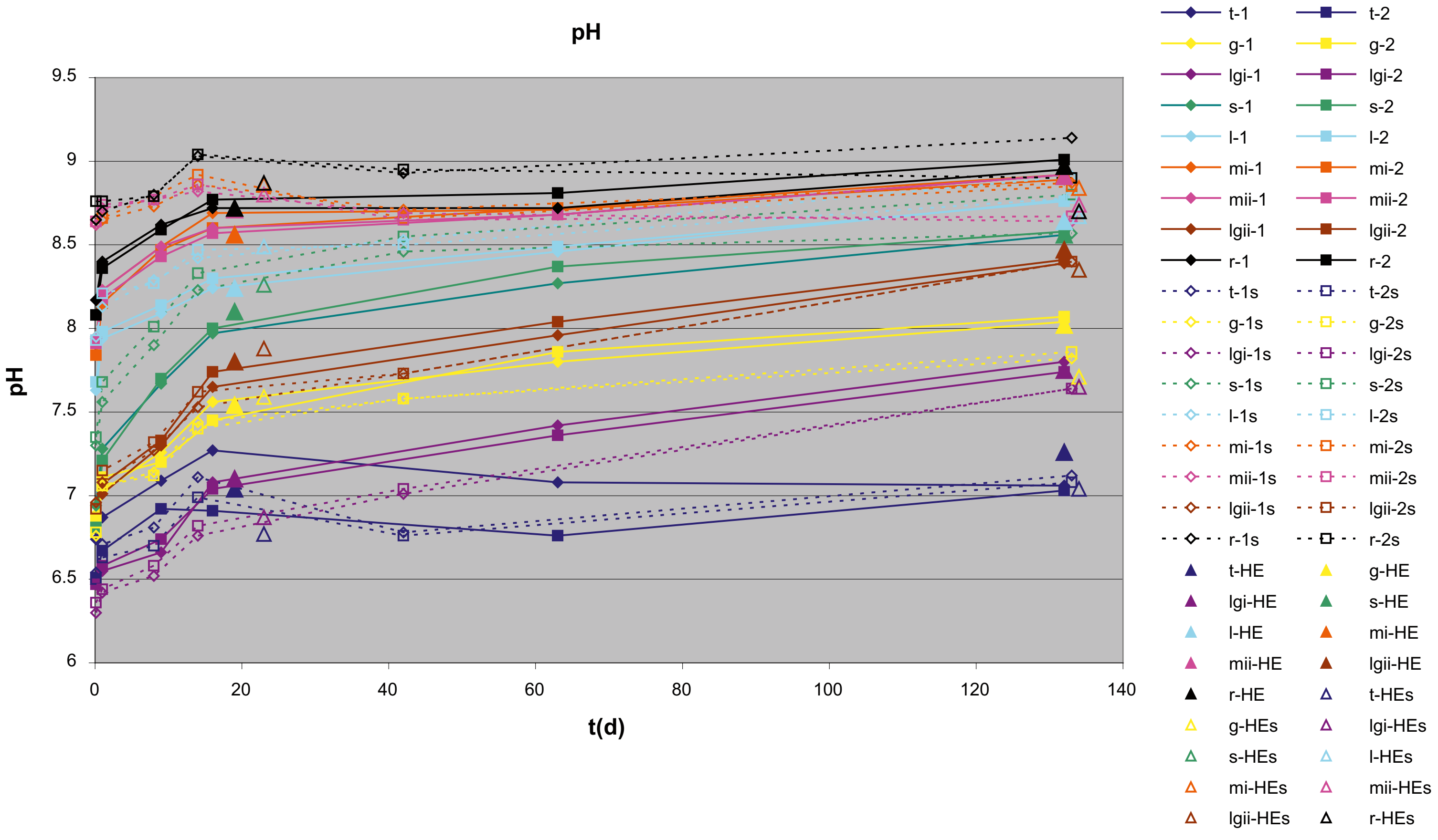

Figure A2-1. *pH as function of time. Legends ending with an "s" are synthetic groundwater experiments, HE = Huvud element (Main element) series.*

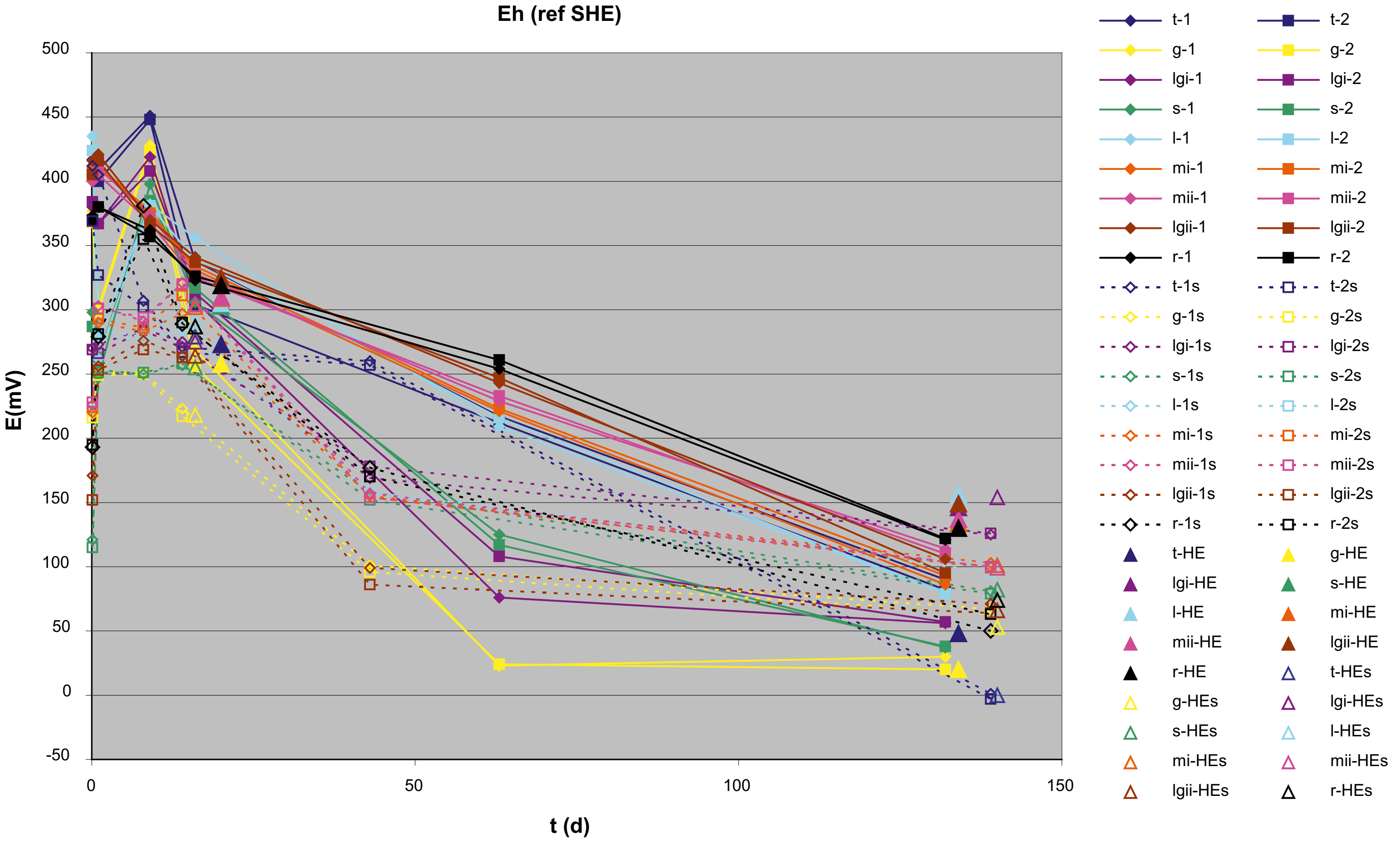

***Figure A2-2.** Eh(mV) as function of time. Legends ending with an "s" are synthetic groundwater experiments, HE = Huvud element (Main element) series.*

Appendix 3

Diagrams of Main elements analyses

Legends: nat = natural, syn = synthetic, 14d, 130d = sampling at 14 and 130 days, gv = groundwater sampled directly from container, at the end of experiments.

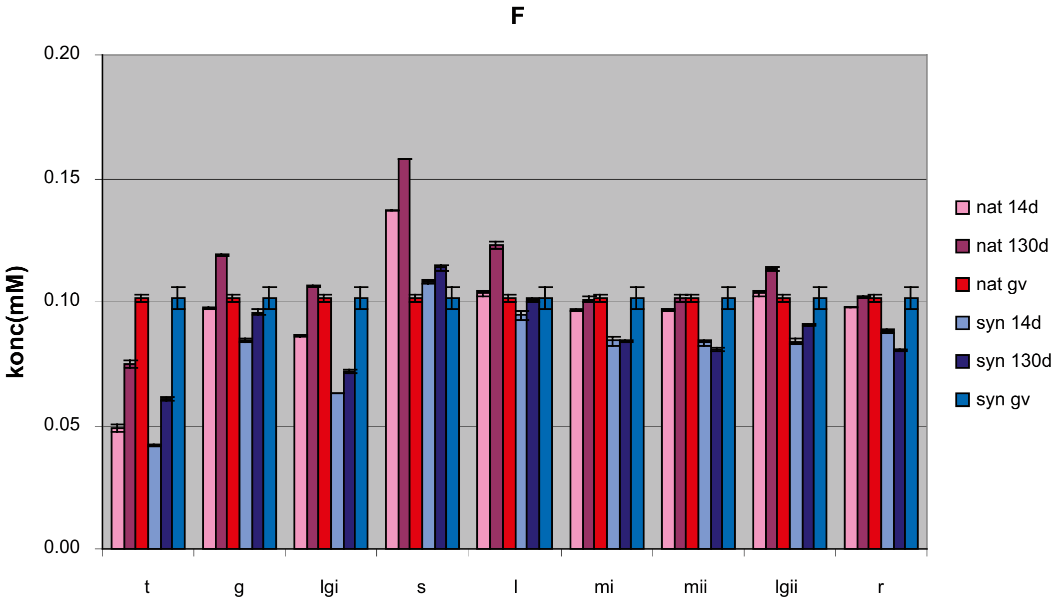

Figure A3-1. *Analysis of fluoride in Main element series.*

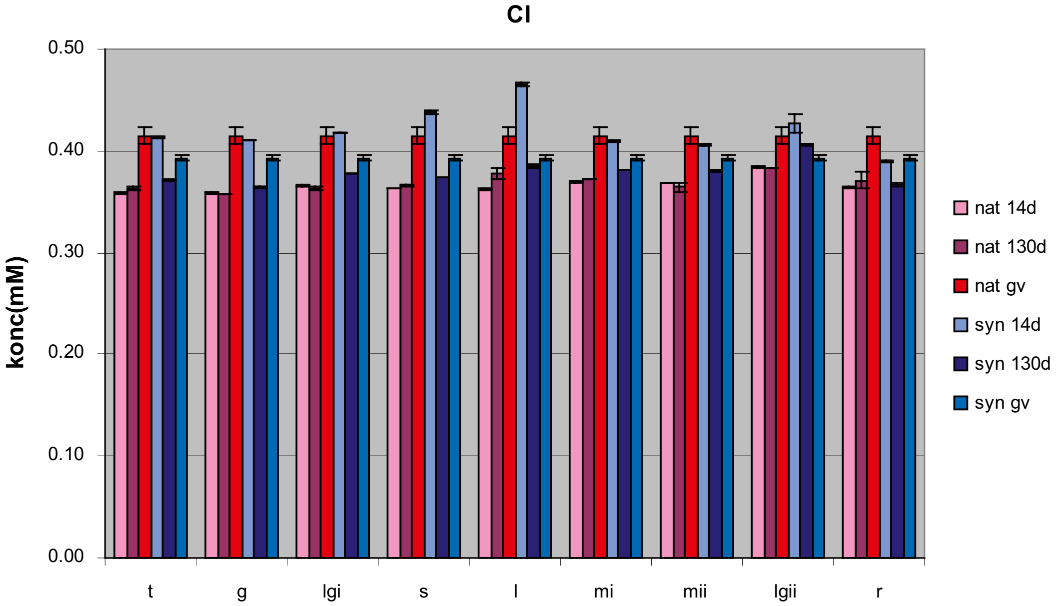

Figure A3-2. *Analysis of chloride in Main element series.*

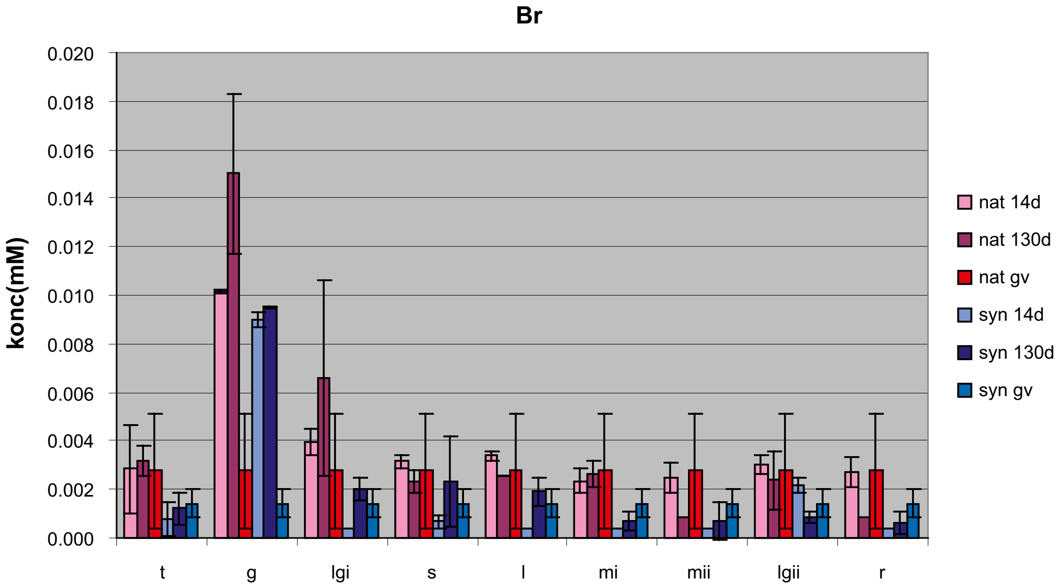

Figure A3-3. *Analysis of bromide in Main element series.*

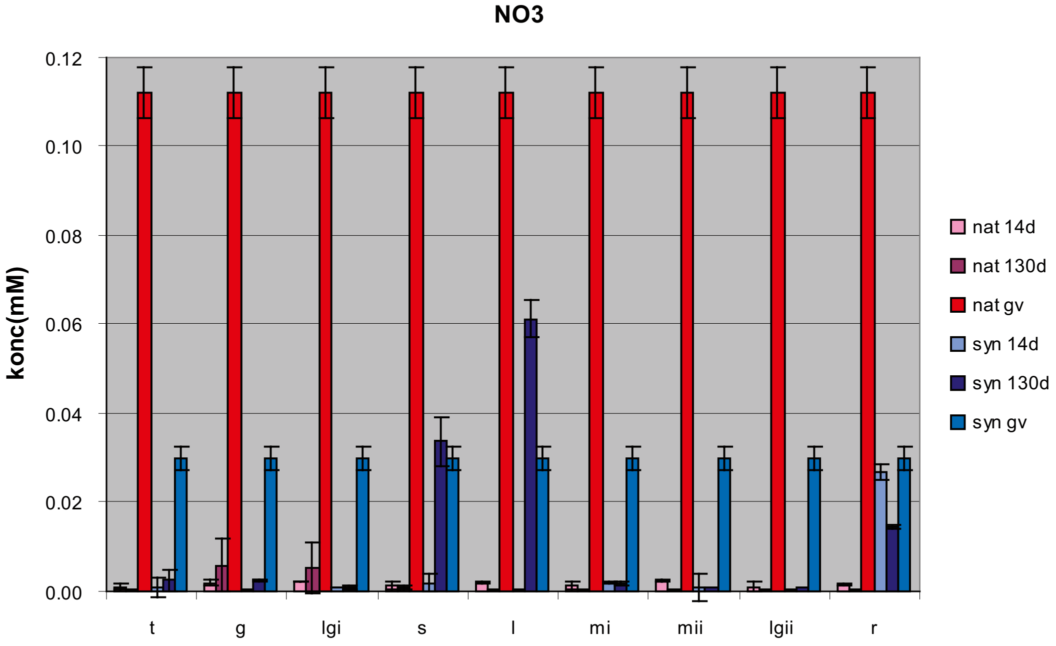

Figure A3-4. *Analysis of nitrate in Main element series.*

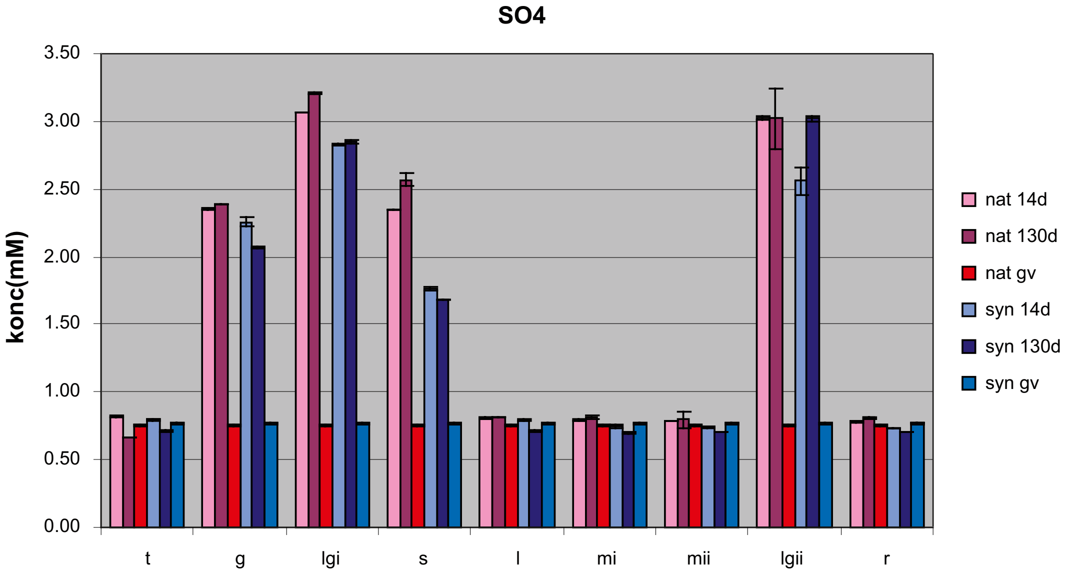

Figure A3-5. *Analysis of sulphate in Main element series.*

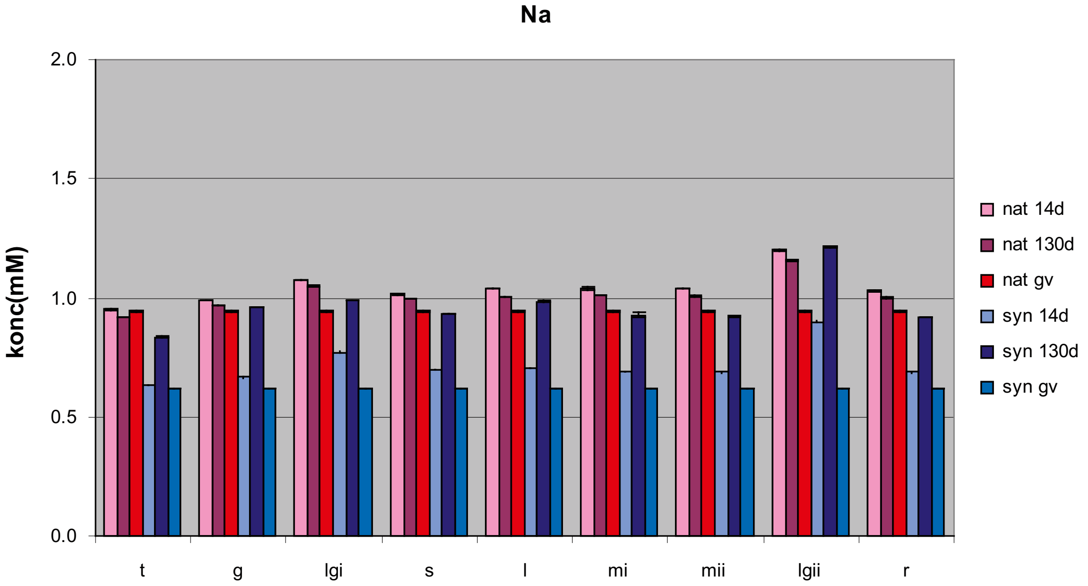

Figure A3-6. *Analysis of sodium in Main element series.*

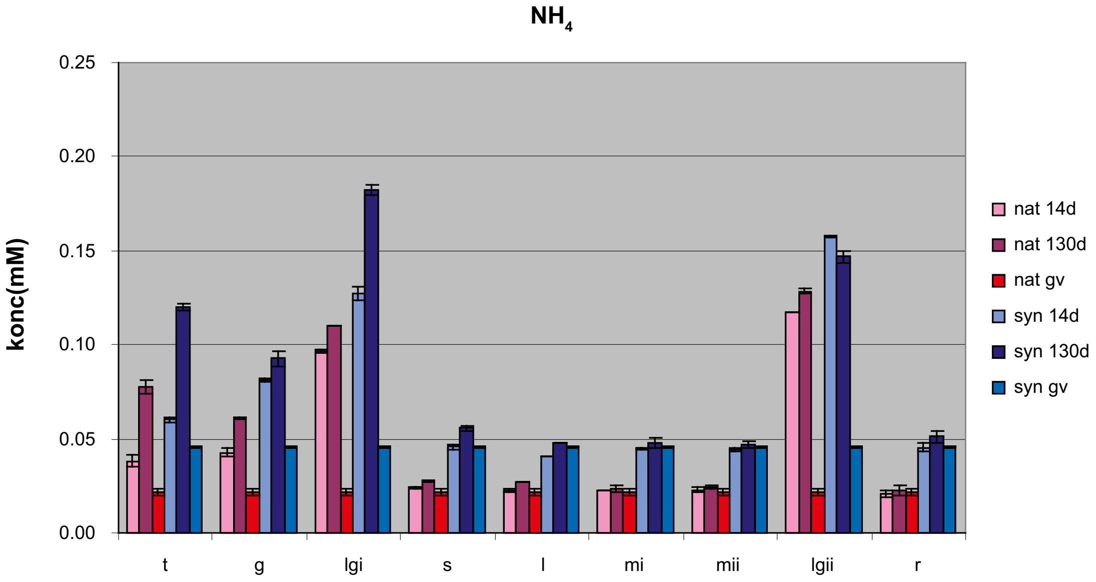

Figure A3-7. *Analysis of ammonium in Main element series.*

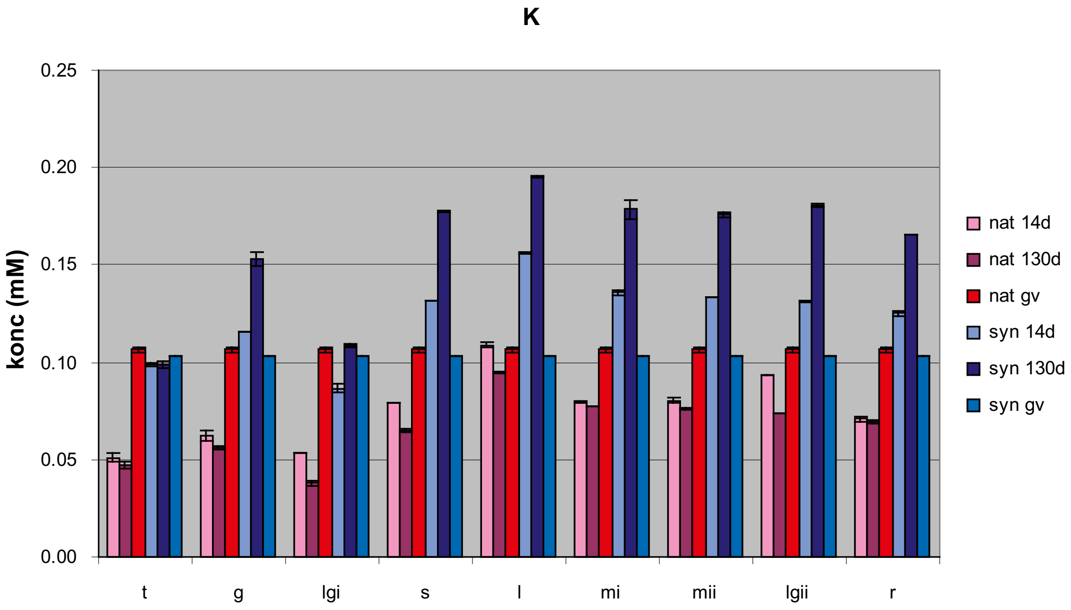

Figure A3-8. *Analysis of potassium in Main element series.*

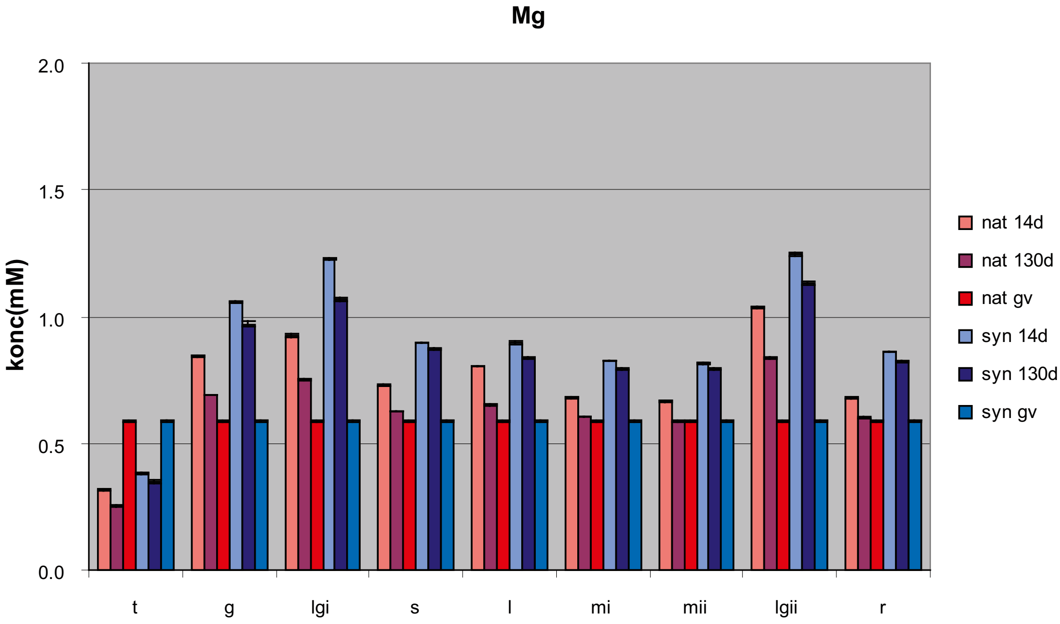

Figure A3-9. Analysis of magnesium in Main element series.

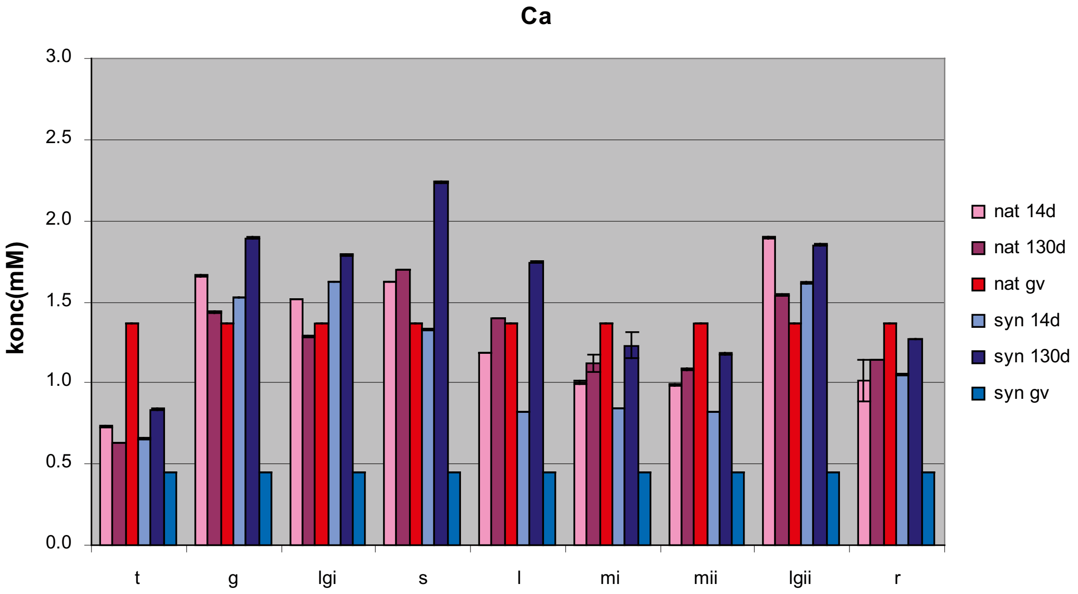

Figure A3-10. Analysis of calcium in Main element series.

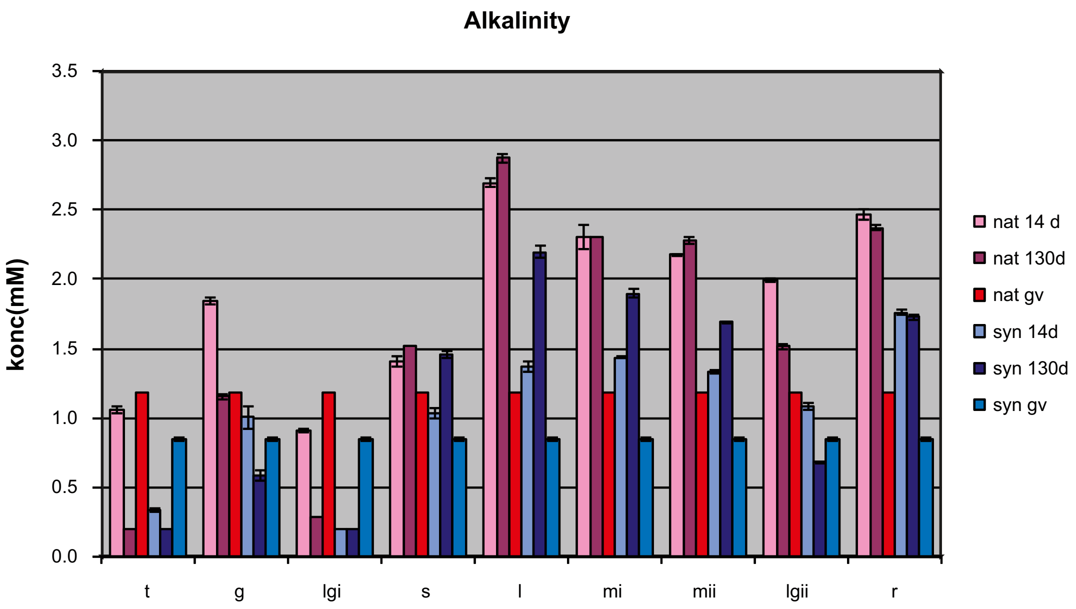

Figure A3-11. Analysis of alkalinity in Main element series.

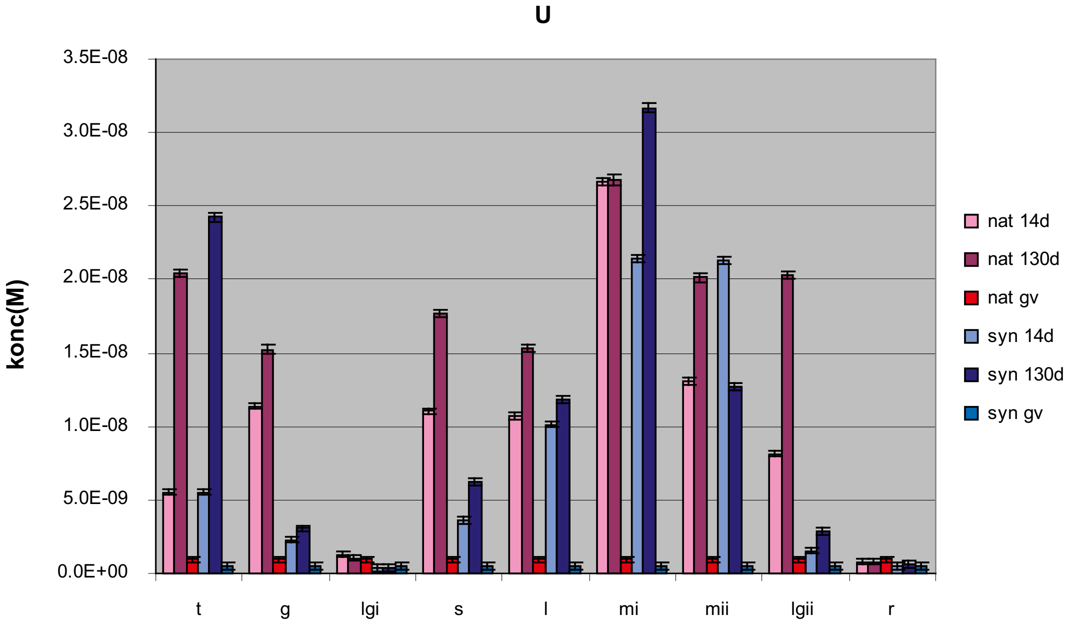

Figure A3-12. Analysis of uranium in Main element series.

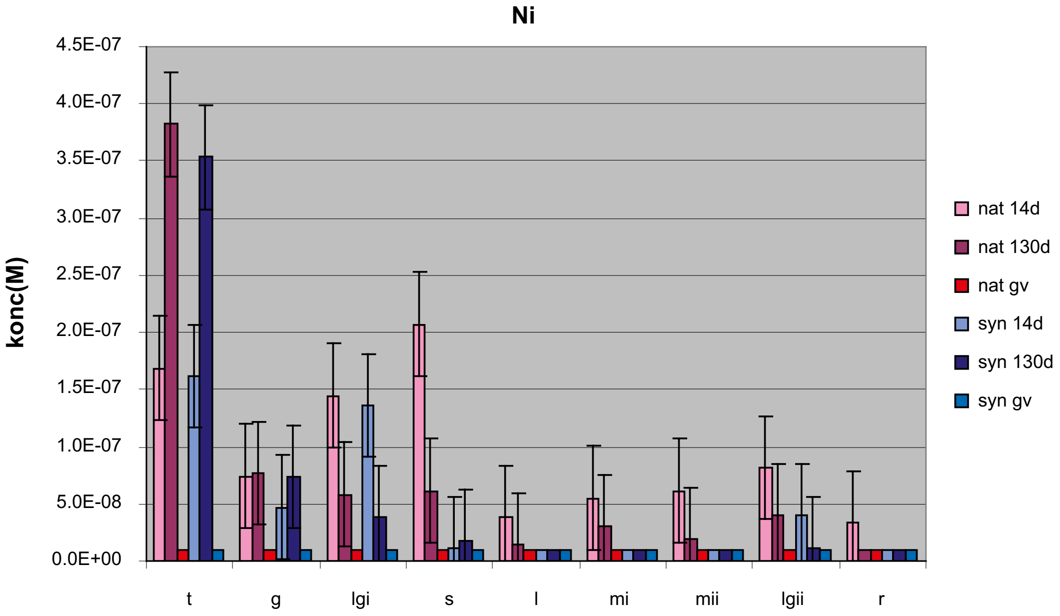

Figure A3-13. Analysis of nickel in Main element series.

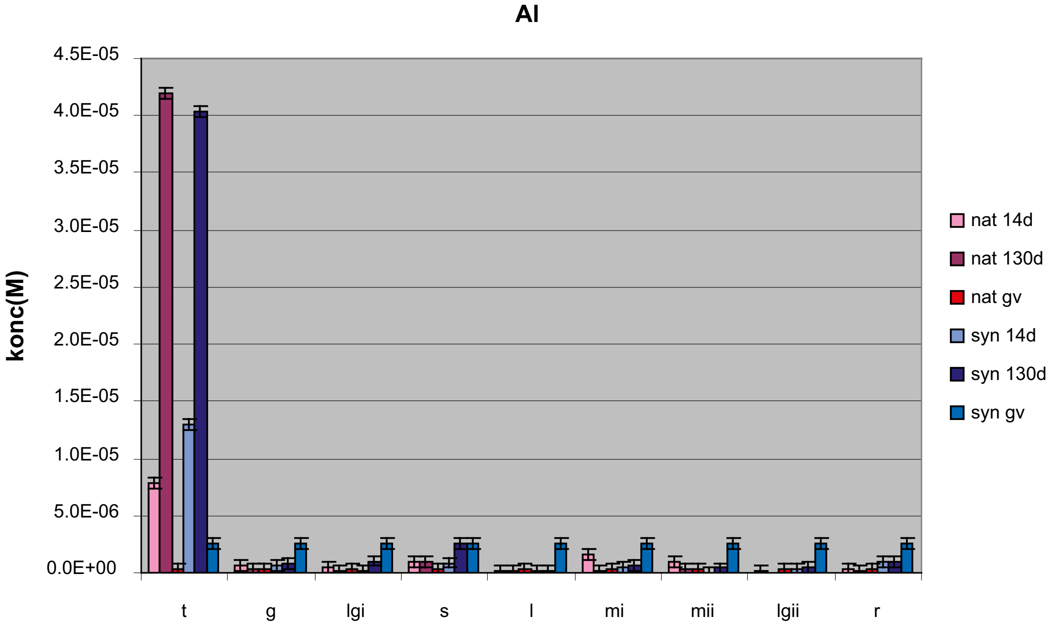

Figure A3-14. Analysis of aluminium in Main element series.

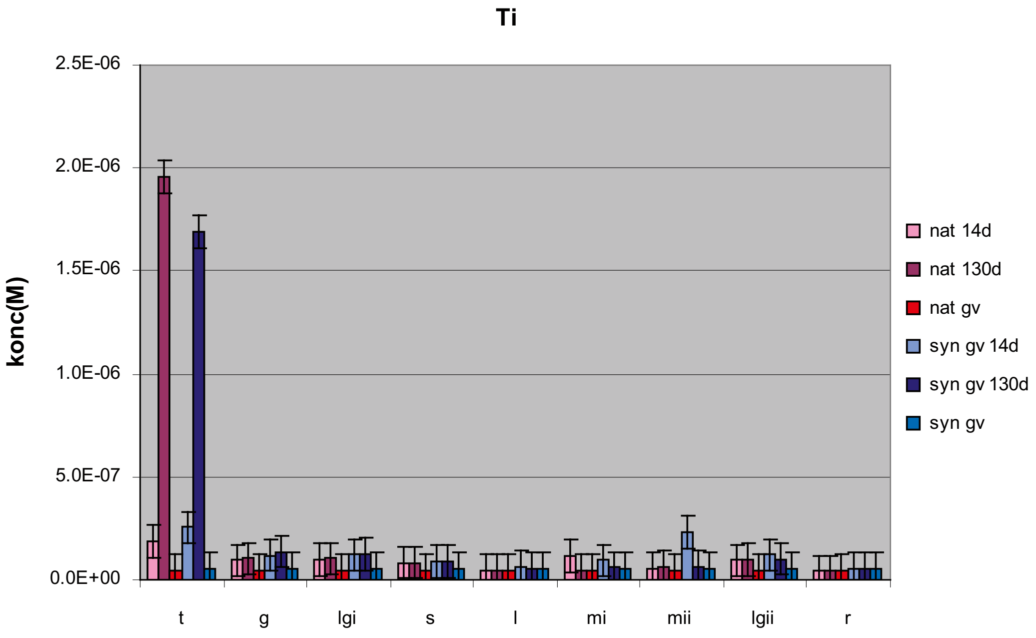

Figure A3-15. *Analysis of titanium in Main element series.*

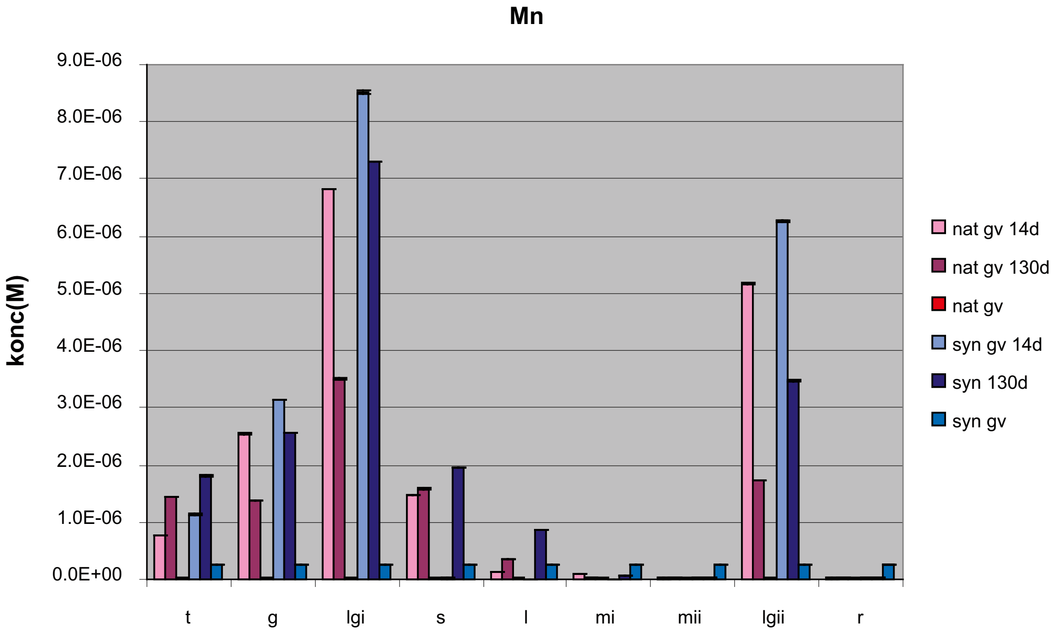

Figure A3-16. *Analysis of manganese in Main element series.*

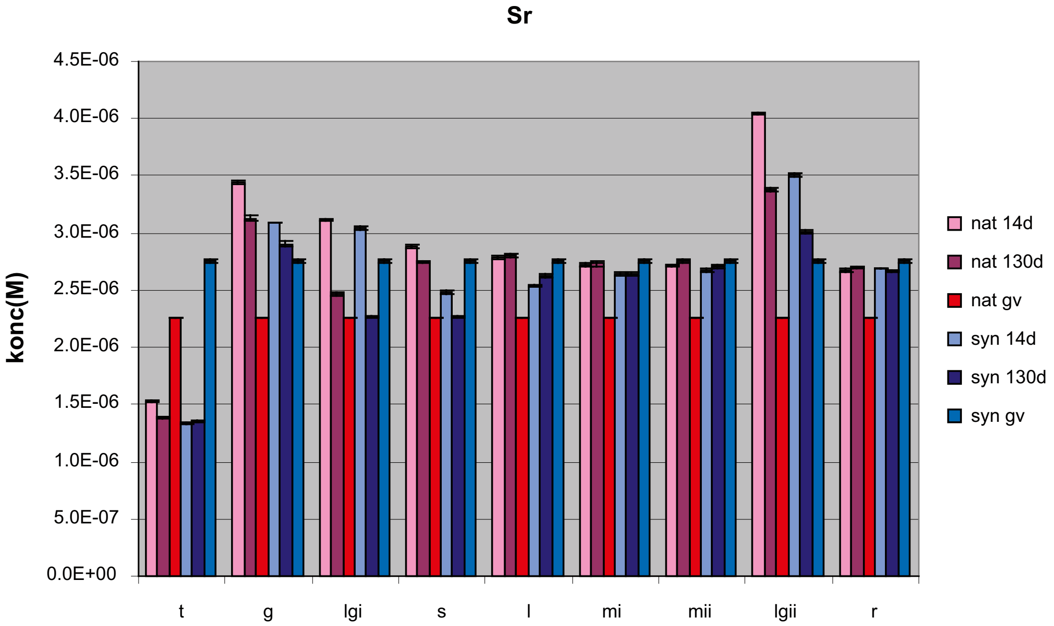

Figure A3-17. *Analysis of strontium in Main element series.*

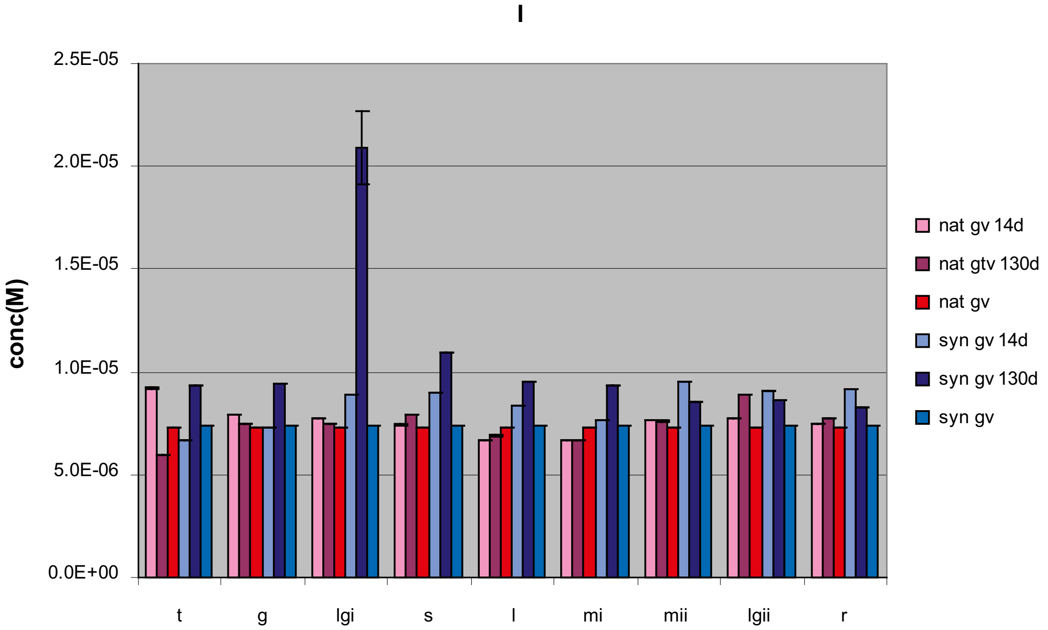

Figure A3-18. *Analysis of iodine in Main element series.*

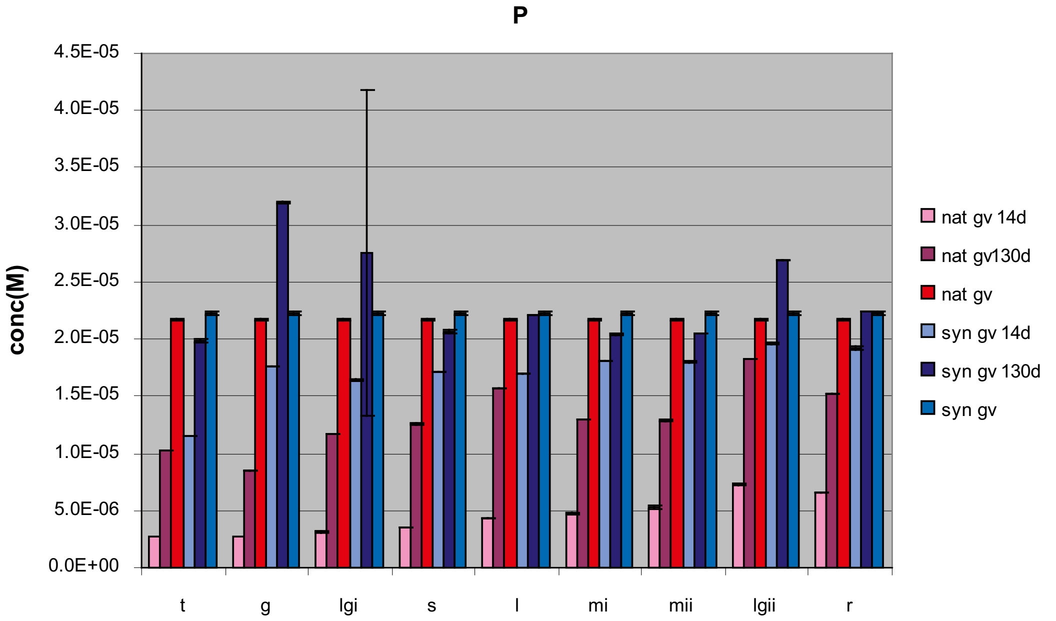

Figure A3-19. *Analysis of phosphor in Main element series.*

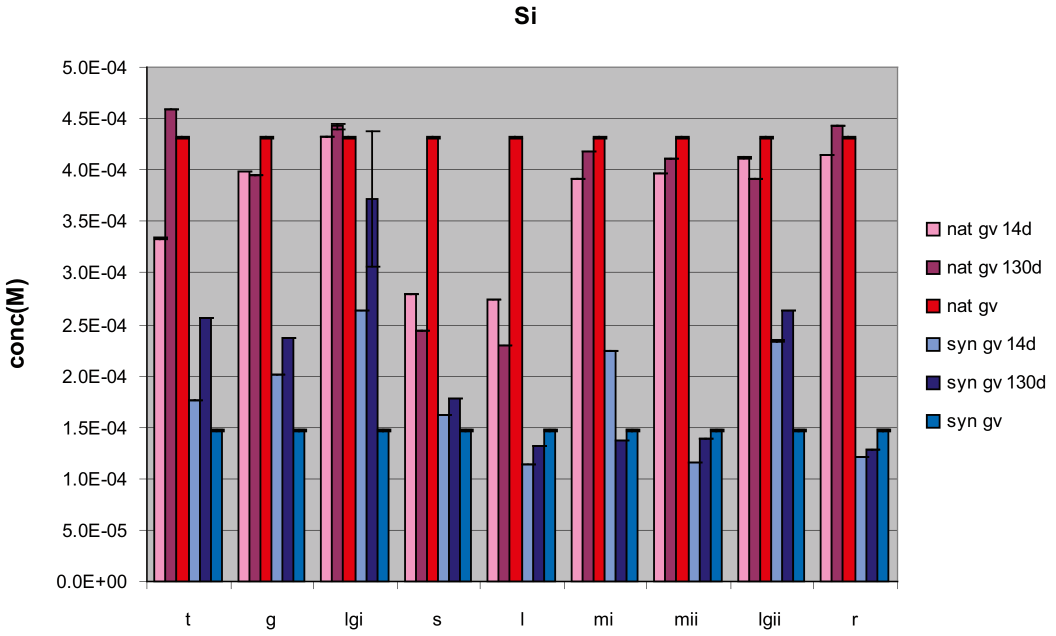

Figure A3-20. *Analysis of silica in Main element series.*

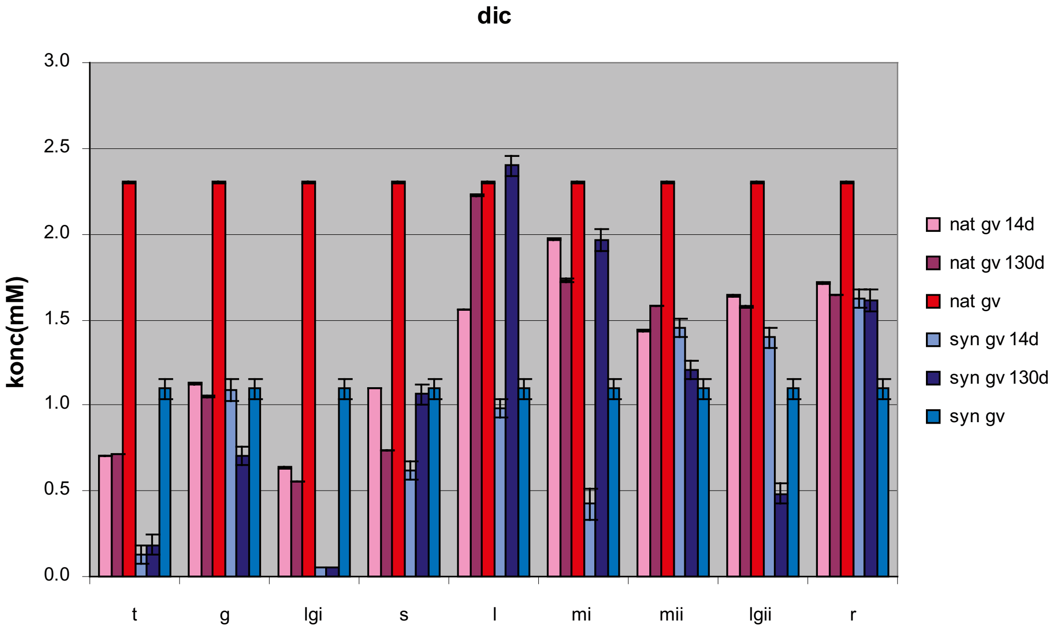

Figure A3-21. *Analysis of dissolved inorganic carbon in Main element series.*

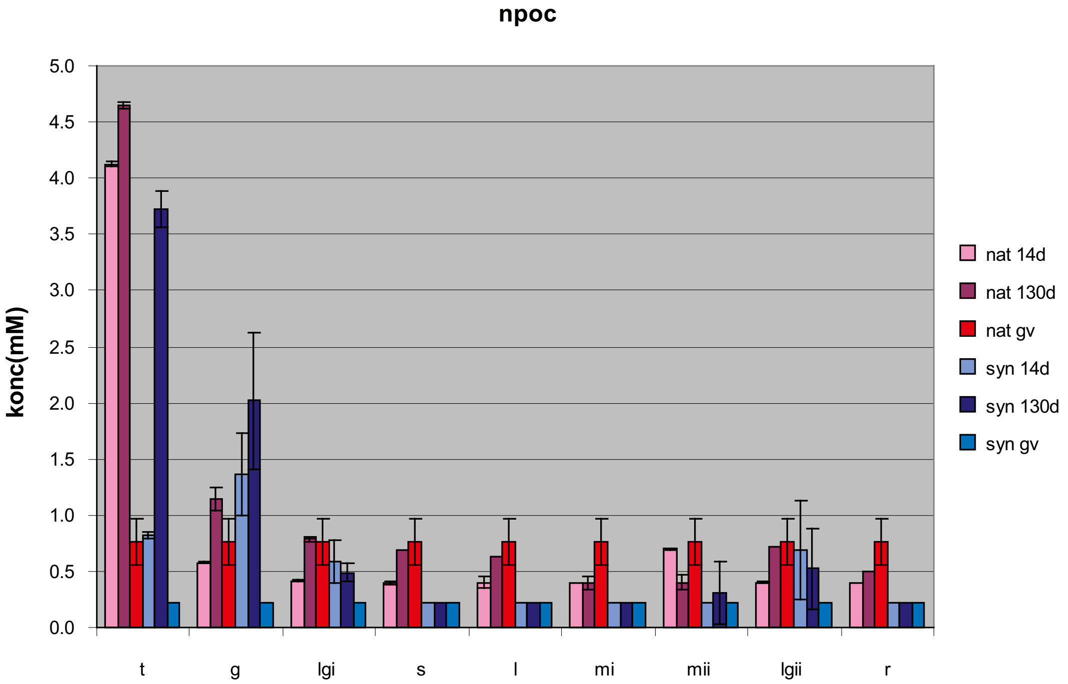

Figure A3-22. *Analysis of non-purgeable organic carbon in Main element series.*

Pictures of soil

Figure A4-1. Picture of peat sample.

Figure A4-2. Picture of gyttja sample.

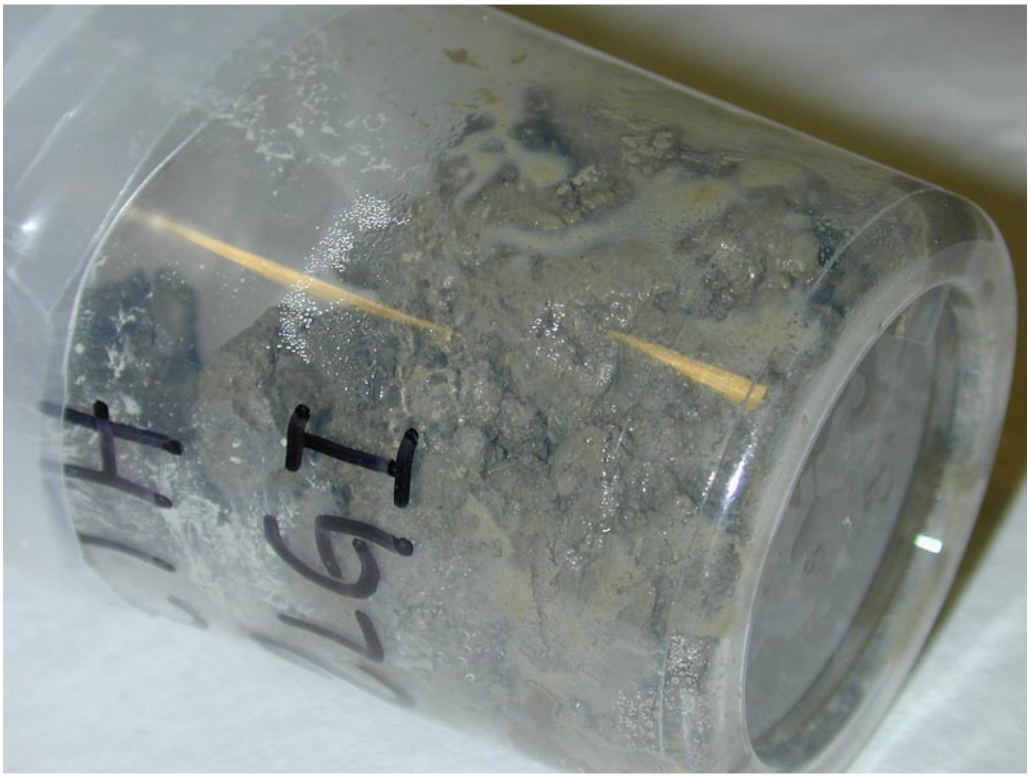

Figure A4-3. *Picture of clay gyttja type I sample.*

Figure A4-4. *Picture of sand sample.*

Figure A4-5. *Picture of clay sample.*

Figure A4-6. *Picture of till type I sample.*

Figure A4-7. *Picture of till type II sample.*

Figure A4-8. *Picture of clay gyttja type II sample.*