

Forsmark site investigation

Hydrochemical characterisation in borehole KFM01D

Results from seven investigated borehole sections:

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314.5–319.5 m, 354.9–355.9 m

369.0–370.0 m, 428.5–435.6 m

568.0–575.1 m

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November 2006

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

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Abstract

Complete chemical characterisation is the most extensive chemical investigation method performed in core drilled boreholes. The method entails pumping, measurements on-line and regular water sampling for chemical analyses in isolated borehole sections during approximately three weeks per section at a flow rate of between 50 and 200 mL/min.

The method has been used in two sections from borehole KFM01D at 428.5–435.6 m borehole length (vertical depth 340 m) and 568.0–575.1 m borehole length (vertical depth 445 m). The results include on-line measurements of redox potential, pH, dissolved oxygen, electrical conductivity and water temperature in the borehole sections, together with chemical analyses of major constituents, trace metals and isotopes as well as gas content and composition. Furthermore, inorganic and organic colloids (humic and fulvic acids) were investigated both by fractionation and laser-induced breakdown colloid detection (LIBD).

In addition, an SKB class 5 sample was collected in the borehole section at 314.5–319.5 m borehole length (vertical depth 253 m) using the equipment for injection tests (PSS) and four fractures with low transmissivity ($\leq 1\text{E}-8 \text{ m}^2/\text{s}$) were sampled using special equipment (sampling equipment for low transmissivity fractures, SLT). The latter samples were collected in sections at 194.0–195.0 m, 263.8–264.8 m, 354.9–355.9 m and 369.0–370.0 m borehole lengths (vertical depths 156, 211, 282 and 293 m respectively) and analysed according to SKB class 3 including isotope options and uranium.

The water compositions in sections 428.5–435.6 m and 568.0–575.1 m were close to stable during the pumping and sampling periods. The chloride concentrations amounted to 5,500 mg/L and 6,000 mg/L while the flushing water contents were 6% and < 1%, respectively. The occasionally difficult redox potential measurements were successful and stabilised at close to –260 mV in both sections. The colloid content measured by Laser Induced Breakdown Detection (LIBD) amounted to 4–10 $\mu\text{g}/\text{L}$ in section 428.5–435.6 m but was as high as 110–190 $\mu\text{g}/\text{L}$ in section 568.0–575.1 m, probably due to contamination by drilling debris. The organic constituents were present mainly as fulvic acids or other low molecular weight acids (citric acid, oxalic acids, etc). A summary of results from colloid filtration and LIBD in groundwaters from KFM01D and previously investigated boreholes is given in this report.

Sammanfattning

Fullständig kemikaraktisering är den mest omfattande kemiska undersökningsmetoden för kärnborrhål. Metoden innebär pumpning, mätning on-line och regelbunden vattenprovtagning för kemiska analyser i avgränsade borrhålssektioner under cirka tre veckor per sektion med ett pumpflöde på mellan 50 och 200 mL/min.

Metoden har utförts i två sektioner av borrhålet KFM01D vid 428,5–435,6 m borrhålslängd (vertikalt djup 340 m) och vid 568,0–575,1 m borrhålslängd (vertikalt djup 445 m). Resultaten omfattar mätningar on-line av redoxpotential, pH, löst syre, elektrisk konduktivitet och vatten temperatur i borrhålssektionen liksom kemiska analyser av huvudkomponenter, spårelement, isotoper samt bestämning av gasinnehåll och sammansättning. Vidare undersöktes oorganiska och organiska kolloider (humus och fulvosyror) med fraktioneringsteknik och detektering genom laserinducerad nedbrytning (LIBD).

Dessutom togs ett SKB klass 5 prov i borrhålssektionen vid 314,5–319,5 m borrhålslängd (vertikalt djup 253 m) med hjälp av utrustningen för injektionstester (PSS) och fyra ytterligare prov från sprickor med låg transmissivitet ($\leq 1E-8$ m²/s). För de senare proven användes en nyligen framtagen specialutrustning (provtagningsutrustning för sprickor med låg hydraulisk konduktivitet, SLT) och sektionerna som undersöktes omfattade 194,0–195,0 m, 263,8–264,8 m, 354,9–355,9 m och 369,0–370,0 m borrhålslängd (vertikaldjup 156, 211, 282 och 293 m). Vattenproverna från dessa sektioner analyserades enligt SKB klass 3 med tillval av isotoper och uran.

Vattensammansättningen i sektionerna 428,5–435,6 m och 568,0–575,1 m var nära nog stabil under pump/provtagningsperioderna och kloridkoncentrationerna uppgick till 5 500 mg/L respektive 6 000 mg/l medan spolvattenhalterna var 6 % och < 1 %. De emellanåt besvärliga redox-potentialmätningarna var lyckade och stabiliserade sig på ungefär –260 mV i båda borrhålssektionerna. Kolloidkoncentrationen mätt med *Laser Induced Breakdown Detection* (LIBD) uppgick till 4–10 µg/L i sektionen 428,5–435,6 m men var så hög som 110–190 µg/L i sektionen 568,0–575,1 m, förmodligen beroende på kontaminering av borrhax. De organiska komponenterna förelåg huvudsakligen som fulvosyror eller andra lågmolekylära syror (citronsyra, oxalsyra etc). En sammanställning av resultat från kolloidfiltrering och LIBD i grundvatten från KFM01D och tidigare undersökta borrhål presenteras i denna rapport.

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1 Introduction

This document reports performance and results of the activity Complete Chemical Characterisation in borehole KFM01D within the site investigation programme at Forsmark /1/. The work was conducted according to the activity plan AP PF 400-06-053. The report presents hydrogeochemical data from fieldwork carried out during June to August 2006 and includes also sampling from low transmissive fractures using a new downhole unit. Details on the technical performance are given in PIR-06-32.

The controlling documents for the activity are listed in Table 1-1. The activity plan, the method description and the measurement system descriptions constitute SKB's internal controlling documents. The obtained data from the activity are reported to the SICADA database and are traceable by the activity plan number. Sampling for microbe studies, based on the activity plan AP PF 400-05-66, was also performed within the present activity. The microbe investigations will be reported in a separate primary data report /2/.

Borehole KFM01D is a telescopic borehole /3/ and its location together with other current deep telescopic and conventional core drilled boreholes within the investigation area is shown in Figure 1-1. Figure 1-2 presents a detailed map of drill site DS1 with KFM01D and nearby situated boreholes indicated. KFM01D is inclined at 55°, dipping northwest. The borehole section between 0–89.5 m is percussion drilled and has a stainless steel casing with an internal diameter of 200 mm, whereas the 89.8–800.2 m interval is core drilled with a diameter of 75.8 mm. The design of the borehole is presented in Appendix 1. The borehole is one of the so-called SKB chemical-type; see the SKB method descriptions MD 620.003 (Method description for drilling cored boreholes) and MD 610.003 (Method description for percussion drilling). An SKB chemical-type borehole requires cleaning procedures to be carried out on all equipment used in the borehole, both during and after drilling, according to level 2 in the cleaning instructions outlined in MD 600.004 (Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning).

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

Activity plan	Number	Version
Fullständig kemikaraktärisering med mobilt fältlaboratorium i KFM01D.	AP PF 400-06-053	1.0
Method descriptions and documentations	Number	Version
Metodbeskrivning för fullständig kemikaraktärisering med mobilt fältlaboratorium.	SKB MD 430.017	2.0
Enkel provtagning i hammarborrhål och kärnborrhål.	SKB MD 423.002	2.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning.	SKB MD 600.004	1.0
Mätsystembeskrivningar för mobil kemienhet allmän del, slangvagn, borrhålsutrustning, mobil ytChemmac och dataapplikation.	SKB MD 434.004 SKB MD 434.005 SKB MD 434.006 SKB MD 434.007 SKB MD 433.018	1.0 1.0 1.0 1.0 1.0
Mätsystembeskrivning för fraktionering av humus- och fulvosyror.	SKB MD 431.043	1.0
Provtagning och analys-kemilaboratorium.	SKB MD 452.001–019	–

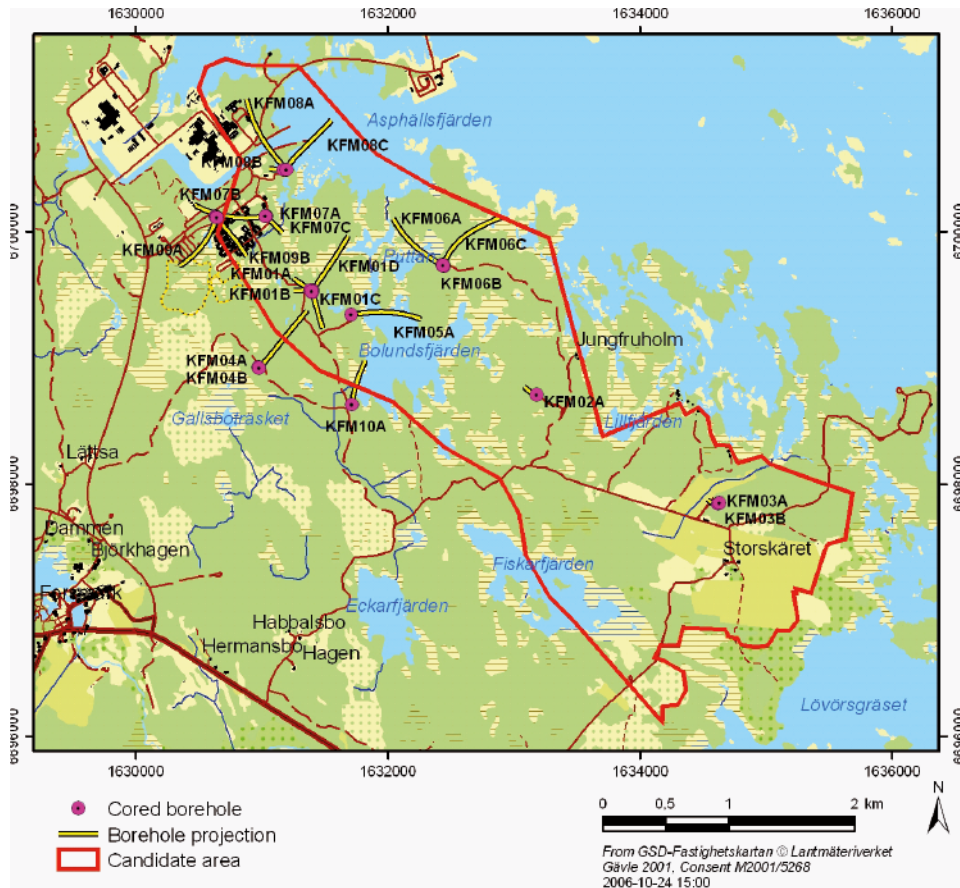


Figure 1-1. The investigation area at Forsmark (approximately the area shown) with the candidate area selected for more detailed investigation. The current telescopic and conventional core drilled boreholes are marked with pink infilled circles.

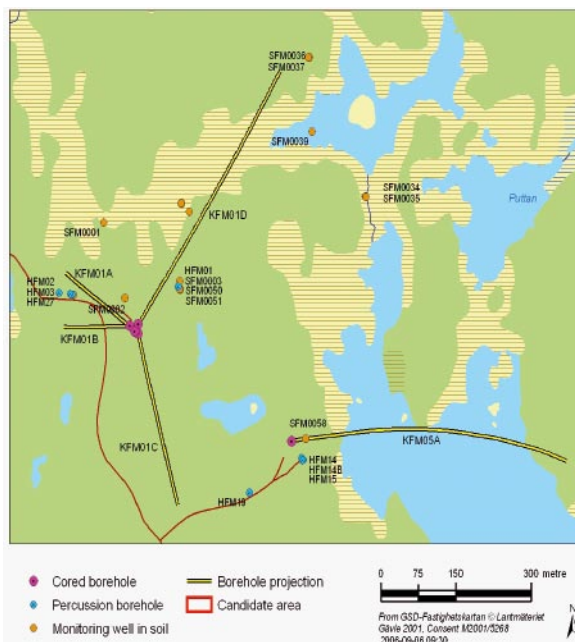


Figure 1-2. Locations and projections on the horizontal plane of the telescopic boreholes KFM01A and KFM01D, the core drilled boreholes KFM01B and KFM01C, percussion boreholes and monitoring soil pipes at drill site DS1 as well as the boreholes at drill site DS5.

2 Objectives and scope

Complete chemical characterisation is the most extensive chemical investigation method performed in core drilled boreholes. The method is carried out in order to achieve as much information as possible about the chemical conditions in the groundwater from individual water-bearing fractures or fracture zones. Considerable effort is put into obtaining representative samples from a limited rock volume. Careful pumping and continuous control of the pressure in the sampled borehole section, as well as above the section, is maintained in order to minimise the risk of mixing with groundwaters from other fracture systems.

It has been decided to prioritise the north-western part of the Forsmark candidate area for the continuing investigations /4/. Besides the fact that borehole KFM01D is located in the centre of this prioritised part, hydrochemical investigations in this borehole are especially interesting for the following reasons; 1) sampling of drill core material for matrix pore water investigations has been performed during drilling and the water composition of “fracture” groundwaters along the borehole is important in order to allow comparison, 2) the borehole yields relatively little water and intersects a bedrock volume relatively free from large fractures and fracture zones, i.e. the type of bedrock conditions that will prevail at the location of a future repository for spent nuclear fuel, 3) the water composition of the groundwater represents modelled fracture domains in the bedrock and not deformation zones which is usually the case, and 4) the presence of fractures suitable for testing a new sampling equipment specially designed for low transmissive fractures, the so called SLT equipment.

The analytical programme was carried out according to SKB chemistry class 3 (SLT), class 4 and class 5 including all options /1/. In the two deepest sections pH, redox potential (Eh) and water temperature were measured in flow-through cells downhole as well as at the ground surface. The flow-through cell at the surface also measured electrical conductivity and dissolved oxygen. Furthermore, samples were collected in situ in the borehole sections for determination of gas content and composition, microbe content and their characterisation as well as for determination of colloid content by the LIBD technique. Fractionation of organic acids and inorganic species were performed in order to investigate size distribution (DOC and ICP analyses), and enrichment of organic acids was conducted in order to determine $\delta^{13}\text{C}$ and pmC in organic constituents.

3 Background

3.1 Flushing water history

The percussion drilled borehole HFM01 /5, 6/ served as a supply well for the flushing water used to drill borehole KFM01D and the chemical composition of the flushing water was checked twice during use /3/. The core drilling of the 800.24 m long borehole consumed 772 m³ of flushing water and the volume of returned water pumped from the borehole by air-lift pumping during drilling was 1,080 m³. The difference in volume is rather small and indicates that the borehole itself yields little water. After drilling, nitrogen flushing was carried out three times from the bottom of the borehole which exchanged an additional volume of 15 m³ borehole water.

Automatic dosing equipment to introduce Uranine was installed in the water line which supplies flushing water to the drilling head. The Uranine concentration in the flushing water and returned water was checked regularly and a total of 108 samples of each sample type were analysed. By mistake, a number of the flushing water samples below 560 m borehole length were collected close to where the dosing takes place and not at the drilling machine. These samples showed much too low concentrations due to insufficient mixing and are therefore not included in the calculation of the average Uranine concentration which amounts to 0.214 ± 0.017 mg/L. The Uranine concentrations in the flushing water and in the returned water are presented in Figure 3-1. A water budget, presenting the amount of Uranine added to the borehole via the flushing water and the estimated amount recovered in the return water, is given in Table 3-1.

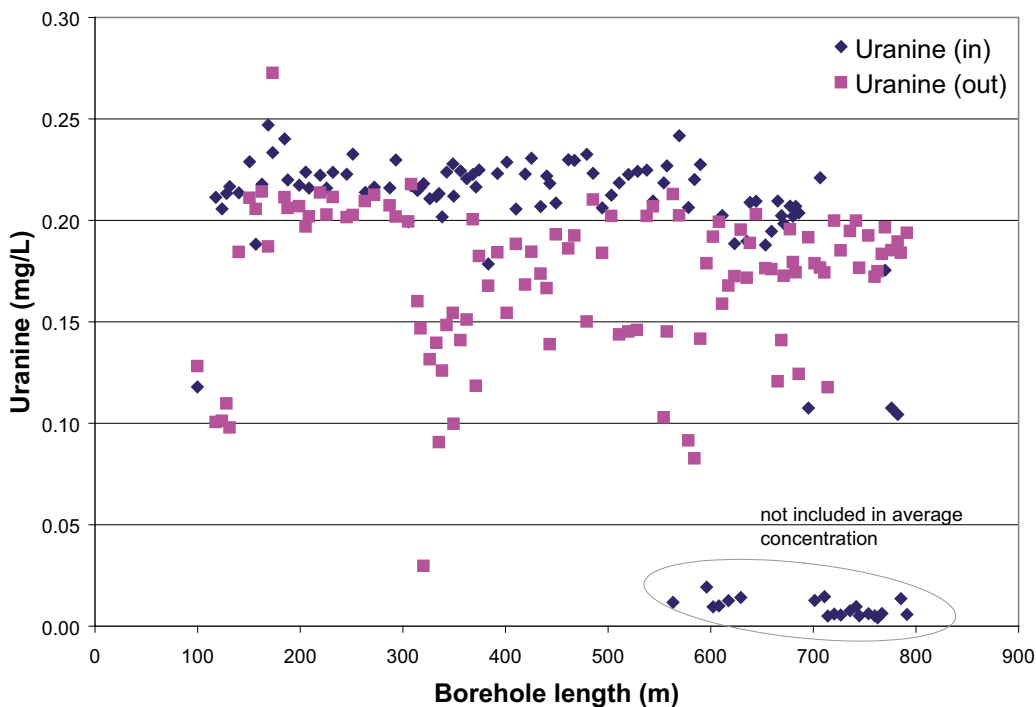


Figure 3-1. Uranine concentrations in the flushing water and in the recovered water versus borehole length.

Table 3-1. Amount of Uranine added to KFM01D via the flushing water during core drilling and the amount recovered from the contemporary air-lift pumping.

Uranine	(g)
Added, according to the log book.	177
Added, calculated from the average Uranine concentration and the total volume of flushing water.	165
Recovered, estimated from the average Uranine concentration and the total volume of returned water.	185

The Uranine budget in Table 3-1 suggests that only a few cubic metres (corresponding to the error in the budget calculation) of the flushing water might have been lost to the borehole and the adjacent host bedrock during drilling. Additional cleaning was also obtained by nitrogen flushings after the drilling. However, no Uranine analyses were performed on these exchanged water volumes.

As borehole KFM01D is of SKB chemical-type, the following special precautions were taken in order to minimise contamination via the flushing water:

- The supply well was also of SKB chemical-type.
- Borehole HFM01 was selected to supply flushing water although the concentration of total organic carbon (TOC) was somewhat too high. The TOC concentration should preferably be below 5 mg/L but the concentration in the two most recent samples collected in HFM01 was in the range 7.4–7.9 mg/L.
- Dosing equipment for Uranine was installed, thereby removing the need for an in-line flushing water storage tank placed after the UV-system.
- In order to minimise oxygen contamination, pressurised nitrogen gas was passed through the water storage tank placed before the UV-system in the flushing water line.

The microbe content in the flushing water was not determined during drilling of this borehole. The results from the preceding borehole KFM06A /7/ showed convincingly that the cleaning procedure works well and it was concluded that to check for microbes at all drilling occasions was no longer necessary.

3.2 Previous events and activities in the borehole

KFM01D is an SKB chemical-type core borehole placed within the demarcated repository area and thus specially intended for complete hydrochemical characterisation. Only those borehole activities that are necessary in order to select borehole sections for groundwater sampling are carried out in the borehole prior to the chemistry campaign. The more downhole equipment used in the borehole, the greater is the risk of contamination and mixing effects on, for example the in situ microbiological conditions. The activities/ investigations performed in KFM01D prior to the chemistry campaign are listed in Table 3-2 below.

Table 3-2. Activities performed in KFM01D prior and in connection to the chemical characterisation.

Activities performed	Date of completion	Length or section (m)	Comment
Percussion drilling	2005-12-05	0–89.77	
Core drilling	2006-02-18	0–800.24	HFM01 was the source of flushing water for drilling the cored part of KFM01D. HFM01 is an SKB chemical-type borehole /3, 5, 6/. Flushing water volume = 772 m ³ . Return water volume 1,080 m ³ .
Flushing water treatment	–	–	Automatic dosing of Uranine was used during drilling of KFM01D. In this way there was no need for an in-line storage tank placed after the UV-system /3/.
Geophysical logging	2006-03-14	89–800	/8/
BIPS-logging	2005-03-14	91–796	/9/
Differential flow logging	2006-06-01	78–795	/10/
Microbe investigation	2006-07-04	428.5–435.6	/2/
Microbe investigation	2006-08-14	568.0–575.1	/2/

3.3 Choice of borehole sections

The differential flow logging /10/ prior to the chemical investigation revealed several water-bearing single fractures. These were well spread along the strategically located borehole and for several reasons, for example its central location within the proposed repository area, it was important to investigate as many sections as possible within the time available. Figure 3-2 presents the determined hydraulic transmissivities. The two deepest fractures at repository depth and with high enough hydraulic transmissivity to allow pumping were selected for chemical characterisation. Furthermore, a highly transmissive fracture at 314.5–319.5 m was selected for complementary sampling in connection to the subsequent injection tests. The injection test equipment is especially suitable for sampling from this kind of fractures, with expected high flushing water contents, due to the efficient pumping. In addition, four one-metre sections were selected to test the new sampling equipment for low transmissive fractures. These fractures fulfilled the equipment requirements: a) well-defined single water-bearing fractures ($T \geq 1E-9$ m²/s) that can be identified from flow logs and BIPS images, and b) an adjacent bedrock of good quality. The selected fractures for investigation and the sampling methods are indicated by coloured arrows in the transmissivity diagram in Figure 3-2. Section limits, vertical depths and hydraulic transmissivity values are given in Table 3-3.

The differential flow logs for relevant parts of the borehole are given in Appendix 2 and the corresponding images from BIPS-logging (Borehole Image Processing System) are presented in Appendix 3. A certain similarity in direction between the different water yielding fractures can be observed from the BIPS images.

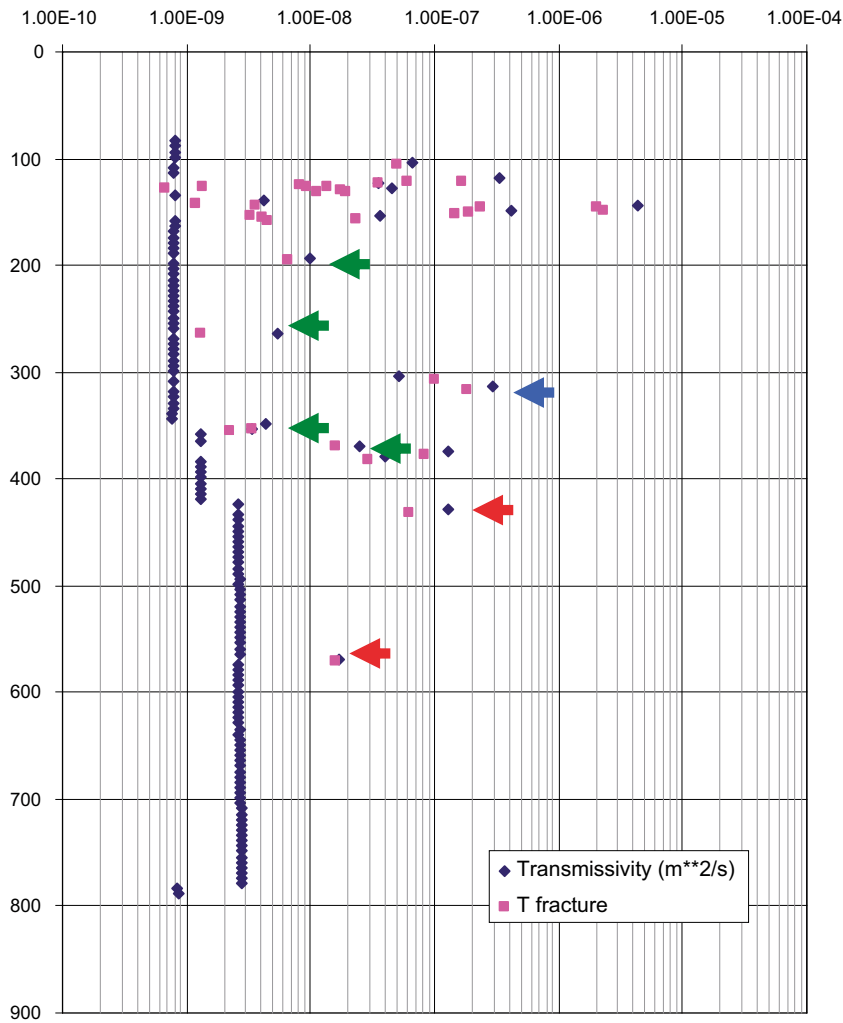


Figure 3-2. Hydraulic transmissivity along borehole KFM01D. Selected fractures for investigation are indicated with arrows; red = hydrochemical characterisation, green = sampling of low transmissive fractures, blue = sampling in connection with injection tests.

Table 3-3. Selected borehole sections for hydrochemical sampling and hydraulic transmissivity calculated from differential flow logging (T_D).

Section (m)	Elevation mid sect. (m.b.s.l)	T_D (m^2/s) /10/	Comments
194.0–195.0	156	6.5E–9	T (fracture), SLT equipment
263.8–264.8	211	1.3E–9	T (fracture), SLT equipment
314.5–319.5	253	2.9E–7	T (5 m), sampling in connection to injection tests
354.9–355.9	282	2.2E–9	T (fracture), SLT equipment
369.0–370.0	293	1.6E–8	T (fracture), SLT equipment
428.5–435.6	340	1.3E–7	T (5 m), hydrochemical characterisation (MFL*)
568.0–575.1	445	1.6E–8	T (5 m), hydrochemical characterisation (MFL*)

* Mobile Field Laboratory

4 Equipment

4.1 The mobile field laboratory

The mobile field laboratories used by SKB for water sampling and downhole measurements consist of a laboratory unit, a separate computer unit (MYC), a hose unit with downhole equipment and a Chemmac measurement system. The equipment setup is presented in Figure 4-1. The different parts of the system are described in the SKB internal controlling documents SKB MD 434.004, 434.005, 434.006, 434.007 and SKB MD 433.018 (Mätsystembeskrivningar för mobil kemienhet allmän del, slangvagn, borrhålsutrustning, mobil ytChemmac och dataapplikation).

The Chemmac measurement facilities include communication systems, measurement application and flow-through cells with electrodes and sensors at the ground surface (surface Chemmac) and downhole (borehole Chemmac).

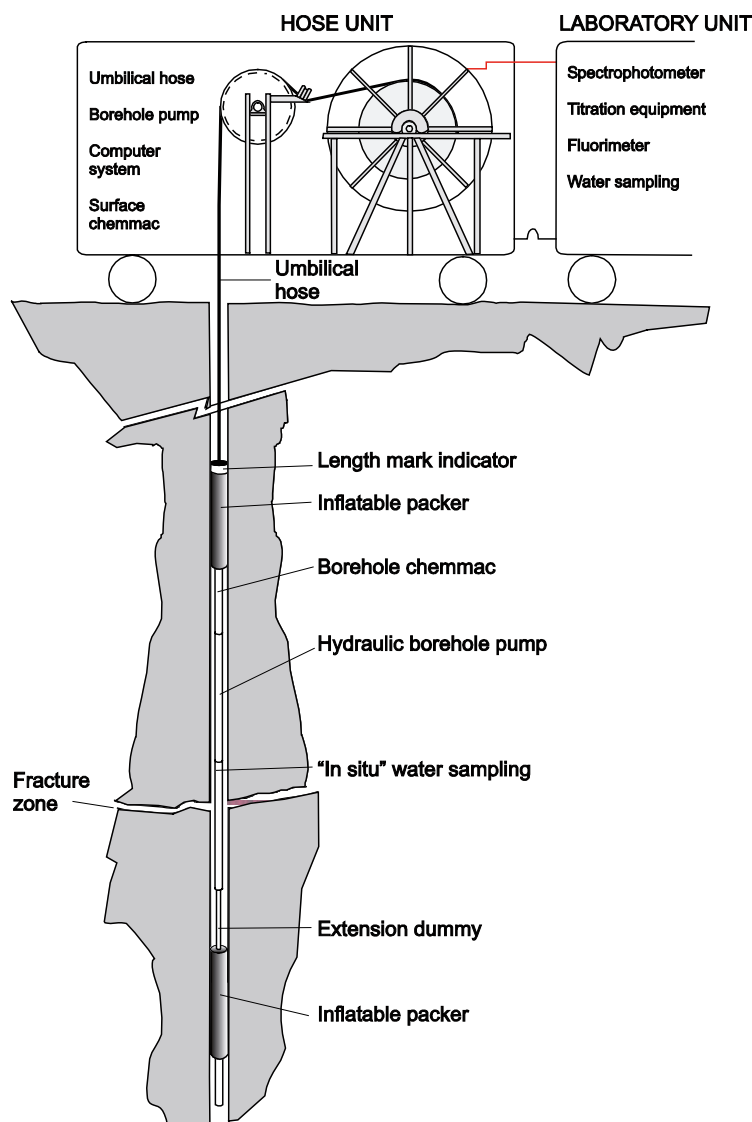


Figure 4-1. The mobile laboratory including laboratory unit, hose unit and downhole equipment. The configuration of the downhole units in the borehole can be varied depending on desired section length. However, the in situ water sampler must always be positioned first in the sample water path.

The downhole equipment comprises inflatable packers, pump, borehole Chemmac and the in situ sampling unit (PVP), allowing measurement (borehole Chemmac) and sampling in situ in the borehole section (PVP sampling unit). The four sampled portions of groundwater collected with the PVP sampling unit maintain the pressure from the borehole section when raised to the surface. The portions are used for colloid and gas analysis and microbe investigations.

The mobile units used for the investigation of borehole KFM01D consisted of the hose unit S3 together with the computer unit MYC 3 including surface Chemmac. The laboratory unit L3 was employed for analytical work but was located close to the core mapping facility and not at drill site DS1.

4.2 Sampling equipment for low transmissive fractures

The new unit, SLT, for sampling of groundwater in low transmissive fractures consists of upper and lower inflatable packer delimiting a borehole section of one metre length. Furthermore, a dummy is mounted in between the packers to reduce the water volume in the section to 0.3 L. The surface of the dummy is coated with Teflon. The sample container (1.2 L), which is in hydraulic connection with the section, is placed above the upper packer. The different parts of the system are presented in Figure 4-2 and described in PIR-06-32 (Test av provtagningsutrustning för sprickor med låg hydraulisk transmissivitet i KFM01D).

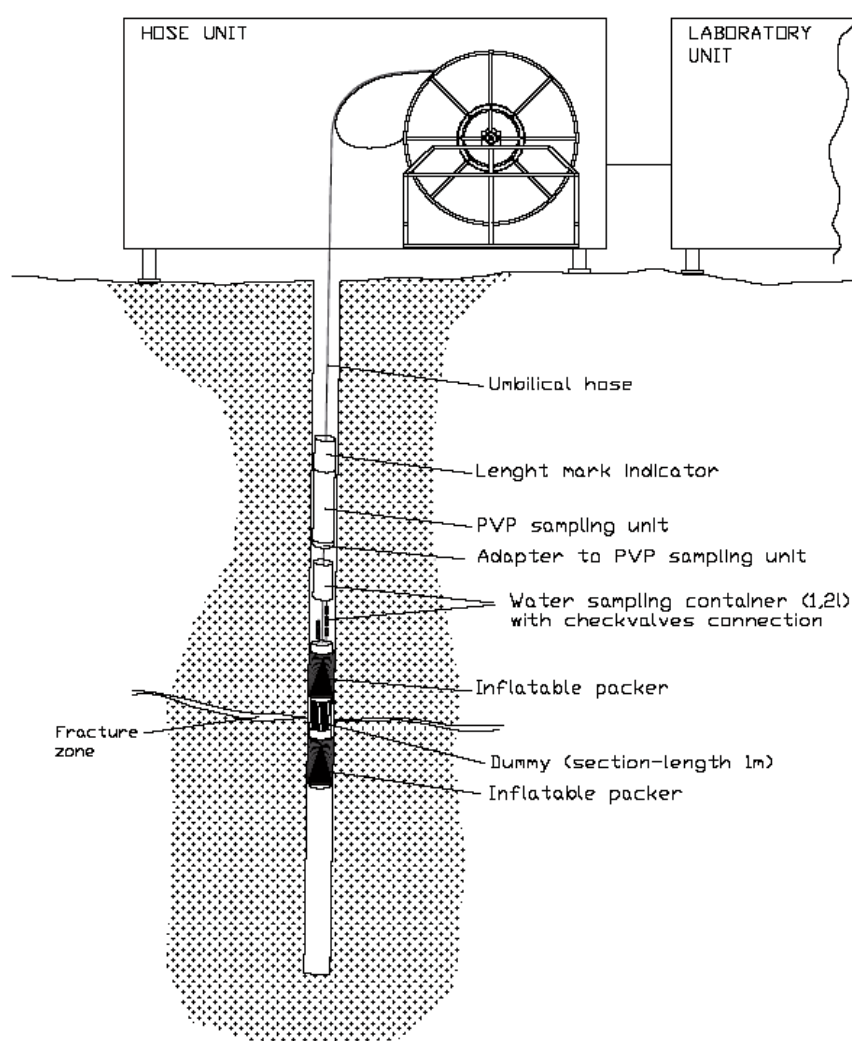


Figure 4-2. Outline of the sampling equipment for low transmissive fractures (SLT).

The sample container is filled with nitrogen gas, to a raised pressure compared to the hydrostatic pressure in the section, during lowering of the equipment to the sampling depth. Prior to sampling, the entire system including the sampled section, the sample container and tubings are flushed with nitrogen gas. The flushing may be repeated to exchange several system volumes of water. Nitrogen gas is then slowly evacuated to decrease the pressure in the system to 200 kPa below the natural pressure, resulting in an inflow of water into the section, the sample container and the tubing up to the ground surface. The filling of water is recorded by a pressure sensor. After sampling is completed, the equipment is raised to the ground surface and the water is portioned into bottles and sent to laboratories for analysis.

4.3 Colloid filtering equipment

The colloid filtering equipment is adapted to the sample containers (PVB) from the PVP water sampling unit and consists of holders for two PVB-containers, a separated tube and valve system for water and gas, a filter holder package for five filters, and a collecting container. The pore sizes of the five connected filters are 0.4, 0.4, 0.2, 0.05 and 0.05 μm . The equipment is described in SKB MD 431.045 (Mätssystembeskrivning för kolloidfiltreringssystem, handhavandedel, SKB internal controlling document to be published). Figure 4-3 shows the equipment set up.

The major equipment features are:

- Filtering is performed in a closed system under an argon atmosphere, thus avoiding the risk of iron precipitation due to contact between the groundwater sample and air.
- Filtering is performed at a pressure similar to that of the groundwater in the borehole section. The system is adjusted to create a pressure difference between the inlet of the filter package and the outlet side. The pressure difference drives the sample water through the filters.
- The design of the sample containers and the mounting with the outlet at the top prevents migration of larger particles which may clog the filters. Furthermore, clogging is prevented by the first two filters with pore sizes 0.4 μm which are mounted parallel to each other.

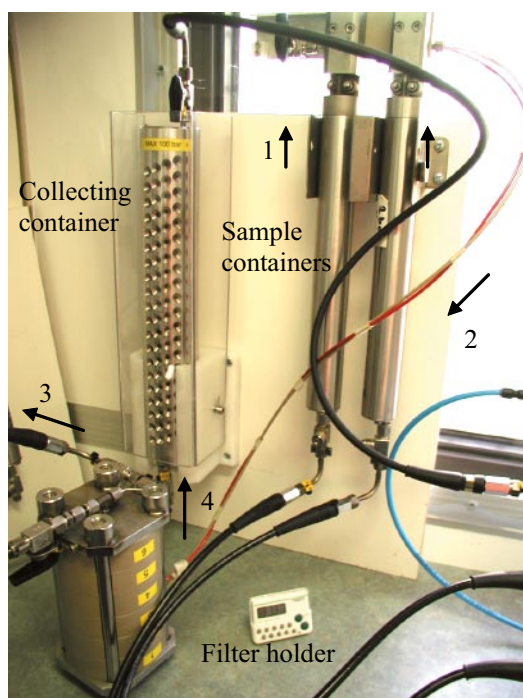


Figure 4-3. The colloid filtering equipment including the sample containers, the filter holder package and the collecting container. The black arrows, 1 to 4, show the flow direction of the sample water through the system.

Disadvantages/drawbacks, which may cause subsequent modifications of the equipment, are:

- The sample volume is limited to a maximum of 2×190 mL.
- The PVB sample containers are made of stainless steel which may contaminate the samples. An improvement could be to use Teflon coating on the insides of the cylindrical containers.

4.4 Equipment for enrichment of humic and fulvic acids

Enrichment of humic and fulvic acids is conducted in order to collect enough material to determine $\delta^{13}\text{C}$ and pmC (percent modern carbon) on organic constituents in the groundwater. The equipment for enrichment includes a porous column filled with an anion exchanger (DEAE-cellulose) and a textile filter with a well-defined pore size. The textile filter is placed inside the column in order to prevent the ion exchange resin from diffusing through the column. The equipment and performance is described in SKB MD 431.044 (Mätssystembeskrivning för uppkoncentrering av humus- och fulvosyror). Figure 4-4 shows the equipment setup. Since the ion exchange resin in the column creates a counter-pressure, which disturbs the water flow through the surface Chemmac, a pump was used for pumping a portion of the outlet water through the column (approximately 1.8 L/hour).

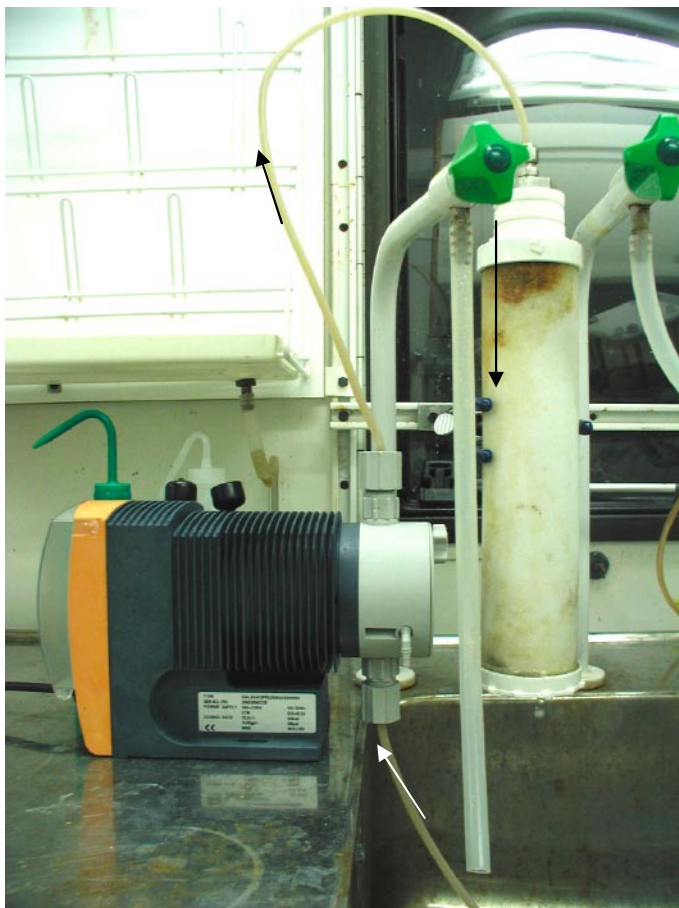


Figure 4-4. The ion exchange column. The arrows show the water flow direction.

4.5 Equipment for fractionation of humic and fulvic acids

The equipment consists of membrane filters with a defined cut-off (pore size), a membrane pump, flexible tubing and vessels. Generally, two sample portions from each section are filtered through filters with cut offs of 1,000 D and 5,000 D, respectively ($D = \text{Dalton}$, $1D = 1 \text{ g/mol}$). The equipment and performance are described in SKB MD 431.043 (Mätssystembeskrivning för fraktionering av humus- och fulvosyror). Figure 4-5 describes schematically the function of a membrane filter and Figure 4-6 shows the equipment setup.

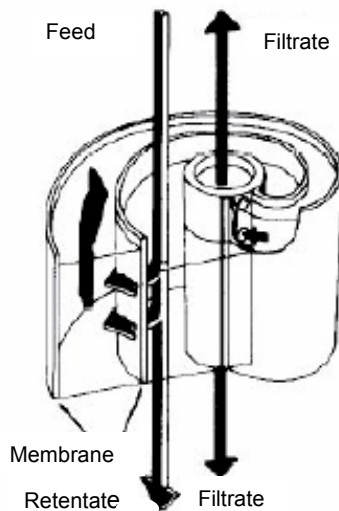


Figure 4-5. Outline of membrane filter with water flow directions.

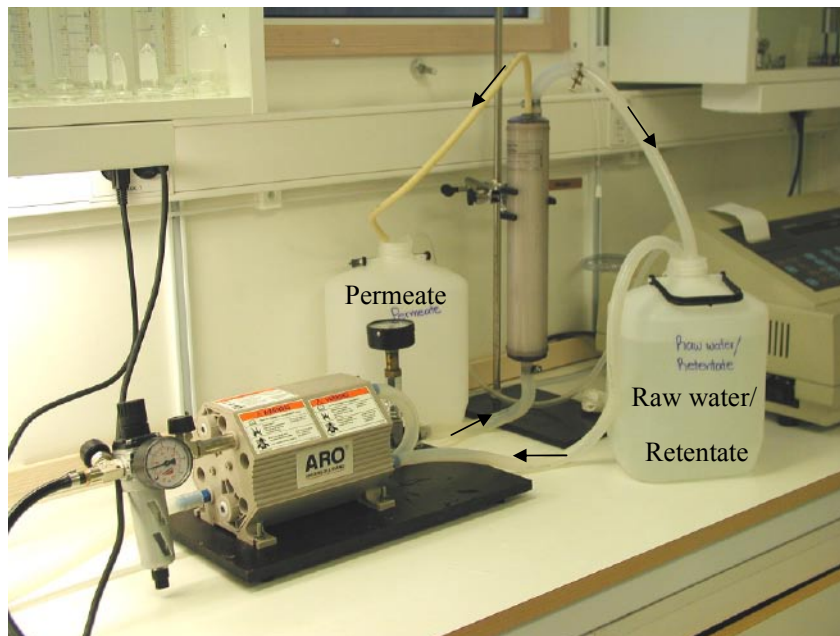


Figure 4-6. Equipment for fractionation of humic and fulvic acids.

5 Performance

5.1 General

Chemical characterisation in borehole KFM01D was conducted according to activity plan AP PF 400-06-053 following the method described in SKB MD 430.017 (Metodbeskrivning för fullständig kemikaraktisering med mobilt fältlaboratorium). Table 5-1 gives an overview of the investigation sequence in KFM01D.

5.2 Chemical characterisation

5.2.1 Overview of field work procedure

A short chronological summary of the different steps that constitute chemical characterisation of groundwater in one borehole section is given below. The preparations conducted before the downhole equipment is lowered in the borehole include:

- Cleaning the inside of the umbilical hose (the sample water channel) with de-ionised and de-oxygenated water. Finally, the sample water channel is filled with de-ionised and de-oxygenated water prior to lowering.
- Cleaning and preparation of the four sample containers (PVB) belonging to the in situ water sampling unit (PVP). The containers/vessels are cleaned on the outside using 70% denatured ethanol and on the inside using chlorine dioxide. One of the containers is used for microbe sampling and sterile conditions are desirable. The containers are purged with nitrogen or argon gas and a small gas pressure is maintained in the containers. The magnitude of the pressure depends on the depth of the section to be sampled and in this case an overpressure of 5 bars was used.
- Calibration of the pH and redox electrodes in the downhole Chemmac equipment.

Table 5-1. Investigation sequence in KFM01D.

Start date/ Stop date	Investigation	Section	Comment
2006-06-05/ 2006-07-04	Complete chemical characterisation	428.5–435.6	Pumped volume = 6.8 m ³ . Flow rate approx. 200 mL/min.
2006-07-04/ 2006-08-01	Complete chemical characterisation	568.0–575.1	Pumped volume = 0.54 m ³ . Flow rate approx. 0–25 mL/min.
2006-08-03/ 2006-08-04	Sampling of low transmissive fractures	369.0–370.0	–
2006-08-06/ 2006-08-07	Sampling of low transmissive fractures	194.0–195.0	–
2006-08-08/ 2006-08-09	Sampling of low transmissive fractures	354.9–355.9	–
2006-08-09/ 2006-08-10	Sampling of low transmissive fractures	263.8–264.8	–
2006-08-14/ 2006-08-22	Sampling with Pipe String System (PSS), equipment for injection tests.	314.5–319.5	Pumped volume = 10.1 m ³ . Flow rate approx. 2–6 L/min. SKB class 5 (12366) without Fe(tot) Fe(II) and ammonium.

The different downhole units are assembled during lowering of the equipment down the borehole and the following steps are taken:

- The outside of the umbilical hose is cleaned with 70% denatured ethanol (SKB MD 600.004).
- Calibration of the umbilical hose length is conducted at least once for each borehole. For this purpose, a length mark detector unit (caliper) is mounted together with the regular downhole equipment. The length mark detector indicates length calibration marks milled into the borehole wall at almost every 50 m along the borehole /3/. At each indication, a reading is made of the corresponding length mark on the umbilical hose. The correct distance to each length mark is obtained from the SICADA database.

When the pump is started and the packers are inflated at the desired positions in the borehole, a pumping and measurement period begins. Typical measures taken and activities carried out during this period are:

- Calibration of the pH and redox electrodes as well as the electrical conductivity and oxygen sensors in the surface Chemmac is conducted when the pumped water from the borehole section has reached the surface.
- Careful attention is paid in order to ensure that the packed-off section is well isolated from the rest of the borehole. A significant drawdown in the section during pumping is one indication that the section is properly sealed off. Leakage would cause pumping of water from the borehole column above and/or below the packers and not only from the fracture zone of interest. However, the drawdown in the borehole section must not be too large, because the greater the drawdown, the larger the bedrock volume affected by the pumping, and the risk of mixing with groundwater from other shallower and/or deeper fracture systems increases. The pumping flow rate is adjusted depending on the flow yield from the fracture or fracture zone (to between 50 and 200 mL/min) and maintained more or less constant during the pumping and measurement period.
- Water samples are collected regularly once or twice a week during the pumping period. Changes in water composition are monitored by conductivity measurements and by immediate analyses (pH, Uranine, chloride, alkalinity, ferrous and total iron, and ammonium) at the site.
- Enrichment of humic and fulvic acids is conducted for as long a time as possible in each section. The time needed depends on the organic carbon concentration in the water and the flow rate through the ion-exchanger. Generally, a period of at least two weeks is needed to collect the amount of carbon required to determine $\delta^{13}\text{C}$ and pmC.
- Fractionation of humic and fulvic acids, as well as inorganic species to determine the size distribution, is performed at the end of the pumping period.
- A decision when to terminate the sampling work in the section is made during a suitable stage of the pumping and measurement period. The investigation might be prolonged if the concentration of flushing water exceeds 1% or if the redox potential measurements have not reached stable values. A final SKB Class 5 sample including options is collected the day before termination.

Completion of the investigation in the section and lifting of the downhole equipment entails:

- Collection of in situ samples prior to lifting the equipment. The valves to the PVB sampling containers in the borehole section are opened from the surface in order to rinse the system and fill the containers. After some hours the valves are closed and the water sample portions for analyses of colloids, dissolved gases and microbes are secured.
- Following stopping of the borehole pump and deflation of the packers, the equipment is lifted and the different downhole units are dismantled.
- Calibration of the electrodes in the downhole Chemmac and surface Chemmac.

5.2.2 Performance in section 428.5–435.6 m

The chemical characterisation in section 428.5–435.6 m was performed using the following configuration of the downhole equipment in the borehole. From the top: umbilical hose, length mark detector, borehole Chemmac, upper packer, borehole pump, in situ water sampler (PVP), and lower packer, see Appendix 4. The pressures above and within the section were measured by the borehole Chemmac unit and the PVP water sampling unit, respectively.

The pumping flow rate was about 200 mL/min and the drawdown approximately 13–14 m at the end of the measurement period. Diagrams showing the pressures above and within the borehole section and the flow rate during the pumping/measurement period are presented in Appendix 5. The events during the investigation are listed in Table 5-2.

5.2.3 Performance in section 568.0–575.1 m

The chemical characterisation in section 568.0–575.1 m was performed using the following configuration of the downhole equipment in the borehole. From the top: umbilical hose, length mark detector, borehole Chemmac, upper packer, borehole pump, in situ water sampler (PVP), and lower packer, see Appendix 4. The pressures above and within the section were measured by the borehole Chemmac unit and the PVP water sampling unit, respectively.

The estimated average pumping flow rate was 10 mL/min and the drawdown approximately 45–50 m at the end of the measurement period. Diagrams showing the pressures above and within the borehole section and the flow rate during the pumping/measurement period are presented in Appendix 5. The events during the investigation are listed in Table 5-3.

Table 5-2. Events during the complete chemical characterisation pumping/measurement period in section 428.5–435.6 m.

Date	Event	Sample no.
060605	Calibration of borehole Chemmac. <i>Lowering of downhole equipment S3 (428.50–435.64 m).</i>	
060607	Calibration of surface Chemmac, MYC3. <i>Start of Chemmac measurements.</i>	
060607	The length mark detector is non operational.	
060612	Water sampling: SKB class 4.	12307
060614	Leakage in driving pump.	
060619	Fluctuating flow and pressure from the driving pump.	
060620	Water sampling: SKB class 5.	12314
060622	Water sampling: SKB class 4.	12315
060626	Water sampling: SKB class 5.	12316
060629	Water sampling: SKB class 4.	12326
060629	Humic and fulvic acids; fractionation 1 kD.	12316
060630	Humic and fulvic acids; fractionation 5 kD	12316
060703	Lost contact with the borehole chemmac.	
060703	Water sampling: SKB class 5, all options. Humic and fulvic acids; enrichment stop. PVP-sampler: opening of valve at 16:15.	12316
060704	PVP-sampler: closure of valve at 05:11. Sampling for colloids, microbes and dissolved gases. <i>End of Chemmac measurements.</i> <i>Raising equipment.</i> Calibration of borehole Chemmac. Calibration of surface Chemmac.	12316

Table 5-3. Events during the *complete* chemical characterisation pumping/measurement period in section 568.0–575.1 m.

Date	Event	Sample no.
060704	Calibration of borehole Chemmac.	
060706	<i>Lowering of downhole equipment S2 (568.00–575.14 m).</i>	
060707	Calibration of surface Chemmac. <i>Start of Chemmac measurements.</i>	
060710	Water sampling: SKB class 2.	12331
060713	Water sampling: SKB class 5. The water sampling is performed without filtering on-line due to the low water flow (20 mL/min)	12343
060714	Humic and fulvic acids; enrichment start.	
060718	Water sampling: SKB class 5.	12350
060724	Water sampling: SKB class 5.	12351
060725	Humic and fulvic acids; fractionation 1 kD.	12354
060726	Humic and fulvic acids; fractionation 5 kD.	12354
060728	PVP-sampler: opening of valve at 12:45.	
060730	Water sampling: SKB class 5, all options.	12354
060801	Humic and fulvic acids; enrichment stop. PVP-sampler: closure of valve at 06:00. Sampling for colloids and dissolved gases. <i>End of Chemmac measurements.</i> <i>Raising equipment.</i> Calibration of borehole Chemmac. Humic and fulvic acids; enrichment eluation.	12354
060811	PVP-sampler: opening of valve at 08:58.	12364
060814	PVP-sampler: closure of valve at 05:49.	

5.2.4 Water sampling, sample treatment and analyses

The pumped water from the borehole section is led from the hose unit into a container furnished with a sink and a tank for collecting the outlet water. Filtration of sample portions is performed on-line by connecting the filter holders directly to the water outlet. A water sample is defined as groundwater collected during one day and consists of several sample portions, labelled with the same sample number.

An overview of sample treatment and analysis methods is given in Appendix 6. The routines are applicable independently of sampling method or type of sampling object.

5.2.5 Collection of in situ water samples

The in situ water sampling in the borehole section was conducted successfully in both bore hole sections. In section 428.5–435.6 m the filtration of colloids was cancelled due to time constraints and a limited number of sample portions, while in section 568.0–575.1 m the in situ sampling was repeated in order to obtain a sufficient number. The purpose of each sample portion is given in Table 5-4. Colloid determinations using laser-induced breakdown detection, LIBD, see Appendix 7, were performed in both sections.

The PVB-containers were all quality controlled before use; this procedure includes disassembling of the container, thorough cleaning, reassembling and measurement of piston friction. The filled PVB-containers were packed together with ice packs in insulated bags and sent to the laboratories by express delivery service immediately after sampling.

Table 5-4. Collection and purpose of in situ water sample portions.

Sample portion no.	Section 428.5–435.6 m 2006-07-04	Section 568.0–575.1 m 2006-08-01	Section 568.0–575.1 m 2006-08-14
1	Dissolved gas (Lab 1), Ar	Dissolved gas (Lab 1), N ₂	Dissolved gas (Lab 2)*, Ar
2	Dissolved gas (Lab 1), N ₂	Colloids (LIBD)	Dissolved gas (Lab 2)*, N ₂
3	Microbes	Colloids	Microbes
4	Colloids (LIBD)	Colloids	Microbes

* Results rejected, faulty sample container or handling mistake.

5.2.6 Colloid filtration

The method for sampling of colloids in groundwater entails filtering the groundwater through a series of connected filters in a closed system under an argon atmosphere. The pressure in the system is maintained at the same level as the pressure in the sampled borehole section. The intention is that colloids should be collected on the different filters (descending pore sizes) according to their sizes. Two out of the four sample portions collected in situ in section 568.0–575.1 m were used for colloid filtration. Data on performance of the filtration run are given in Table 5-5.

A leak test of the system at 10 bars was also done prior to the sampling in order to eliminate the risk of leakage.

Each filtration results in five filter samples (two 0.4 µm, one 0.2 µm and two 0.05 µm filter pore sizes) and two water samples (water in and water out). All samples were sent for ICP analyses (major constituents and common trace metals).

5.2.7 Enrichment of humic and fulvic acids

Enrichment of humic and fulvic acids was conducted in order to collect enough material to determine δ¹³C and pmC in organic constituents in the groundwater. The method is described in SKB MD 431.044 (Mätssystembeskrivning för uppkoncentrering av humus- och fulvosyror). The enrichment method entails collection of organic acids on an ion exchanger, elution of the resin and evaporation of the resulting solution. The dry residue is used for isotope determination and a minimum amount of 10 mg organic carbon is needed. In addition to organic material, the residue also contains sodium hydroxide from the elution. The sample is acidified in order to prevent the formation of carbon dioxide.

Estimations of total duration time and water volume through the ion exchanger are given in Table 5-6.

Table 5-5. Colloid filtration, data on performance.

Section/ date	Entering pressure [bars]	Max. differential pressure over filter package [bars]	Temp. [°C]	Filtering time [min]	Filtered volume [ml]	Comments
568.0–575.1/ 20060801	~30	3.3 (during most of the filtration the diff. pressure was 3 ± 0.2 bars)	~18	24	306.0	Leakage test prior to filtration. No leakage was noticed. No broken filters.

Table 5-6. Enrichment time and water volume through the ion exchanger.

Borehole section (m)	Duration of enrichment (days)	Volume through ion exchanger (L)
568.0–575.1	18	20

5.2.8 Fractionation of organic and inorganic species

Humic and fulvic acids were fractionated with respect to molecular weight using an ultra-filtration technique. The method is described in SKB MD 431.043 (Mätssystembeskrivning för fraktionering av humus- och fulvosyror).

Sampled water from the investigated section was first filtered through a 0.40 µm filter and then through special membrane filters with cut-off sizes of 1,000 D and 5,000 D, respectively. The initial water volume, prior to filtration, was approximately 5 litres. The final retentate and permeate volumes following the filtration runs were approximately 1 and 4 litres, respectively, which gave an enrichment factor of five in the retentate.

Water samples were collected from the retentate and permeate as well as from the untreated groundwater. Each sample was analysed for dissolved organic carbon (DOC), major constituents, common trace metals and uranium. The analyses of metal ions indicate if metals such as Al, Si, Mn, Fe and U exist as colloidal species.

5.3 Sampling of low transmissive fractures (SLT)

The equipment for sampling of groundwater in low transmissive fractures (SLT) was used in sections 369.0–370.0 m, 194.0–195.0 m, 354.9–355.9 m and 263.8–264.8 m.

The performance is discussed thoroughly in PIR-06-32 (Test av provtagningsutrustning för sprickor med låg hydraulisk konduktivitet i KFM01D) and summarised in Table 5-7. The table also compares theoretical filling times calculated from hydraulic transmissivity values with real filling times. In PIR-06-32 it is suggested that the observed discrepancy is due to the transmissivity being determined after a relatively long time of pumping, while the flow usually is larger in the beginning of a pumping period.

Registrations of the hydrostatic pressure as well as the pressure in the sample container make it possible to follow the course of sampling. Examples of resulting pressure curves during flushing, and sampling as well as lifting the equipment, are presented in Figures 5-1 to 5-3 below.

Table 5-7. Summary of SLT performances in sections 369.0–370.0 m, 194.0–195.0 m, 354.9–355.9 m and 263.8–264.8 m.

Section (m)	Mid.section elevation (mbsl)	Transmissivity (m ² /s)	Number of nitrogen flushings	Theoretical filling time (min)	Real filling time (min)	Sample no
369.0–370.0	293	2.5×10 ⁻⁸	2	67	20 (first flush) 90 (second flush)	12360 SKB class 3
194.0–195.0	156	1.8×10 ⁻⁸	1	82	95	12361 SKB class 3
354.9–355.9	282	3.4×10 ⁻⁹	1	524	184	12362 SKB class 3
263.8–264.8	211	5.4×10 ⁻⁹	1	264	8	12363 SKB class 3

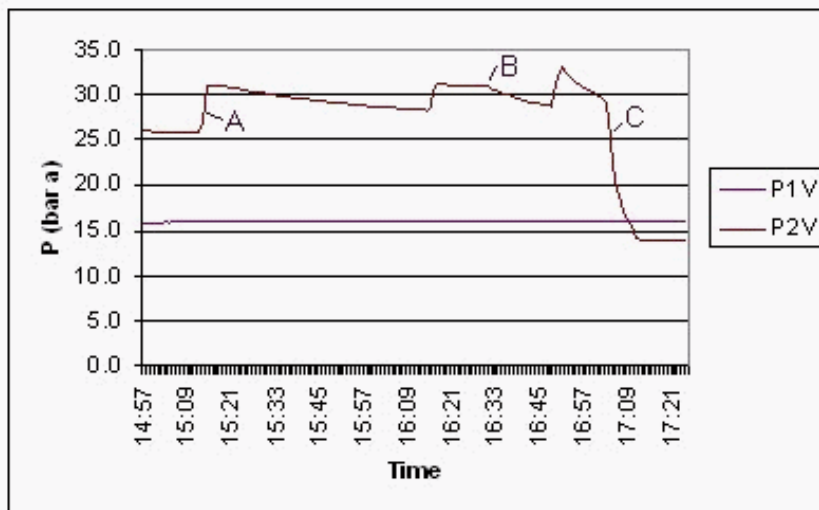


Figure 5-1. Registration of pressures during flushing, section 194.0–195.0 m. P1V (hydrostatic pressure), P2V (pressure in sample container), A (nitrogen flushing), B (all the water in the borehole section is pressed out after the second flushing), C (lowering of the pressure (P2V compared to the hydrostatic pressure (P1V))).

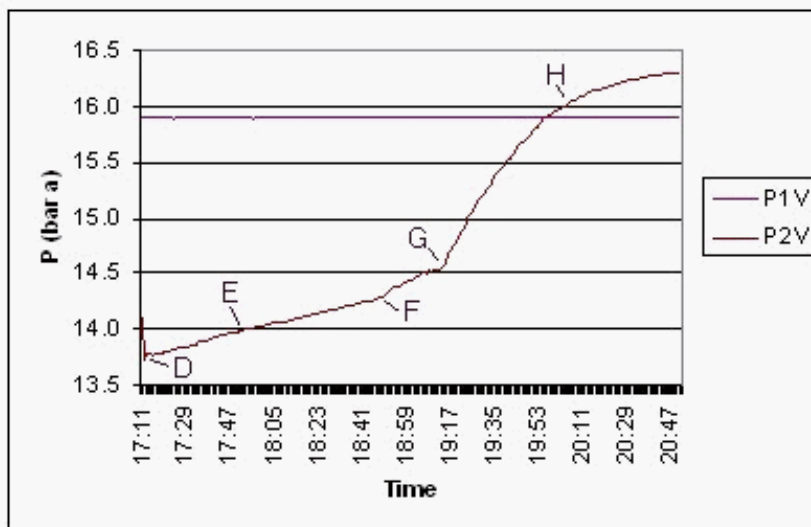


Figure 5-2. Registration of pressures during filling, section 194.0–195.0 m. P1V (hydrostatic pressure), P2V (pressure in sample container), the desired underpressure of two bars is reached (D) and the section and the sample unit are being filled. When the section is filled (E) the pressure is raising faster for a short while before the filling of the sample unit starts. After the sample unit is filled (F) the pressure increases faster as the narrow tubing in the PVP unit is being filled. The water reaches the umbilical hose (G). At (H) the pressures are equal and no more water enters the system.

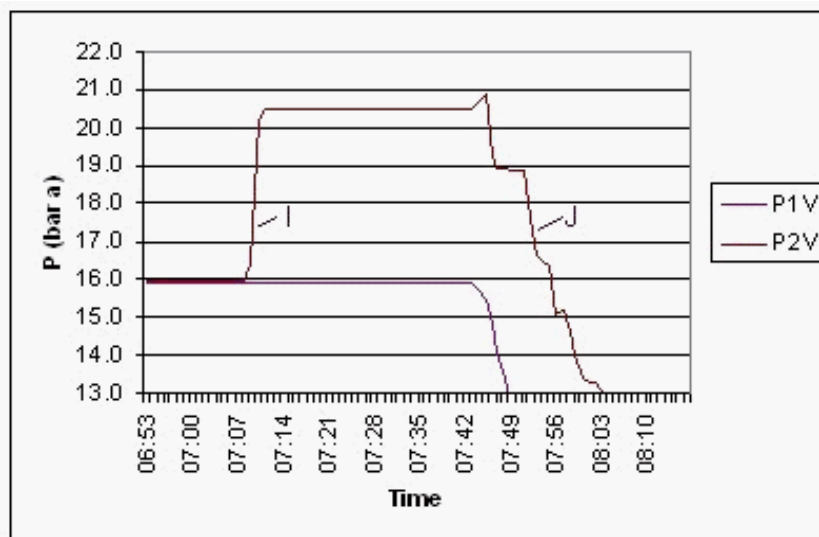


Figure 5-3. Registration of pressures while raising the equipment, section 194.0–195.0 m. P1V (hydrostatic pressure), P2V (pressure in sample container), increase of pressure in sample container (P2V) to 4–5 bars over the hydrostatic pressure P1V (I), the pressure difference is maintained (J).

6 Nonconformities

The hydrochemical characterisation in KFM01D has been conducted according to the SKB internal controlling documents AP PF 400-06-053 and SKB MD 430.017 with the following deviations and remarks:

- No enrichment of humic and fulvic acids was performed in section 428.5–435.6 m since the flushing water content was too high.
- The repeated in situ sampling in section 428.5–435.6 m (four extra sample containers (PVB)) was cancelled due to time constraints and therefore the colloid filtration was cancelled as well.
- A repeated in situ sampling to obtain samples for microbial analysis from section 568.0–575.1 m (four extra sample containers (PVB)) was delayed two weeks due to closure for summer vacation at the commercial laboratory.
- The allowed upper limit for flushing water content, 1%, was exceeded in sections 428.5–435.6 m (6–7%), 369.0–370.0 m (4%), 194.0–195.0 m (4%), 354.9–355.9 m (5%), 263.8–264.8 m (5%) and 314.5–319.5 m (9%).

7 Data handling and interpretation

7.1 Chemmac measurement data

The processing of Chemmac data is described in SKB MD 434.007, version 2 (Mätsystem-beskrivning för Chemmac mätsystem, SKB internal controlling document, in progress).

7.1.1 Data file types and calculation software

The on-line measurements in a borehole section produce the following types of raw data files:

- Calibration files from calibration measurements (*.CRB) and corresponding comment files (*.CI). The files are used for calculation of calibration constants (pH and Eh) and the calibration factor (electrical conductivity). For surface Chemmac ten *.CRB and ten *.CI files are produced, and for borehole Chemmac six *.CRB and six *.CI files.
- Raw data file containing the logged measurements from the borehole section and the surface (*K.MRB) as well as a corresponding comment file (*.MI). The logged voltage values need to be converted to pH and Eh values (also in mV) using the calibration constants obtained from calibration.
- Measurement file including equipment and environment parameters (*O.MRB), such as power consumption in the downhole Chemmac unit and temperature inside the hose unit.

The original raw data files listed above are stored in the SICADA file archive. Furthermore, the files are re-calculated and evaluated to obtain pH and redox potential values and to correct the electrical conductivity values using the specially designed calculation software (Hilda). The resulting files containing calculated and evaluated values as well as comments on the performance are:

- A file **constants.mio* containing all the calculated calibration constants (one constant for each electrode in each buffer solution). The file is stored in the SICADA file archive and is useful in order to follow the development of single electrodes.
- A file **measurements.mio* containing the calculated and evaluated measurement values (pH, redox potential, electrical conductivity and water temperature). The data from the file are exported to the data tables “redox” and “ph_cond” in SICADA. As the file also contains some measured parameters that are not included in the tables mentioned above (e.g. pressure registrations), the complete file is also stored in the SICADA file archive.
- A file **comments.mio* containing comments on the fieldwork and the calculation/evaluation. The comments in the file are imported as activity comments in SICADA.

7.1.2 Calculations and evaluation of redox potential and pH

The redox potential is measured by three electrodes at the surface and three downhole in the borehole section. In addition, pH is measured by two electrodes at the surface and two downhole in the borehole section. The registrations by the redox and the pH electrodes are logged each hour during a measurement period of approximately three weeks and a calibration is performed before and after the measurement period. The treatment of the raw data includes the following steps:

- Calculation and choice of calibration constants.
- Calculation of one pH and one redox potential sequence for each electrode (i.e. three or six redox electrodes and two or four pH electrodes).
- Determination of representative pH and redox potential values as well as estimated measurement uncertainties for the investigated borehole section.

One calibration constant is selected for each electrode using one of the following alternatives:

- Case 1: Calculation of the average calibration constant value and the standard deviation. The initial and the final calibration measurements result in four constants for each redox electrode (in pH 4 and pH 7 buffer solutions) and six constants for each pH electrode (in pH 4, 7 and 10 buffer solutions).
- Case 2: The calibration constant obtained from the initial calibration measurement at pH 7 is selected since it is closest to the pH of the borehole water. This alternative is chosen if the calibration constants obtained in the different buffers show a large variation in value (generally a difference larger than 20 mV between the highest and the lowest value). The standard deviation is calculated in the same way as in Case 1.
- Case 3: If the final calibration constants turn out to be very different (more than 20 mV) from the initial constants, a linear drift correction is needed. The reason for this is most often a drift in the reference electrode. The values and standard deviations are calculated for the initial and the final calibration constants separately, and a linear correction is made between the selected initial and the selected final constant. The higher of the two standard deviation values is used in the estimation of the total measurement uncertainty.

The values in the measurement raw data file are converted to pH and Eh measurement sequences for each pH and redox electrode using the calibration constant selected as stated above.

The next step is to choose a logging occasion in a stable part of the measurement period and select a representative result for each electrode. The average values are calculated for each electrode group in order to obtain one representative value of redox potential, pH (borehole Chemmac) and pH (surface Chemmac), respectively. Obviously erroneous electrodes are omitted. The corresponding total measurement uncertainties are estimated using the standard deviations of the calibration constants and the standard deviations of the Eh and the pH values obtained by the different sets of electrodes. It is useful to evaluate pH at the surface and pH in the borehole section separately, since pH in the pumped water might differ from the pH measured in the borehole section. This is due to changing gas pressure conditions and their effects on the carbonate system.

Factors considered when evaluating the measurement uncertainties in pH and redox potential (Eh) values are:

- Difference in calibration constants for each electrode and calibration/buffer solution.
- Drift in calibration constants between the initial and the final calibration.
- Stability in voltage value during the final part of the on-line measurement. A successful measurement shows no tendency of a slope.
- Agreement between the different pH and redox electrodes on the surface and in the downhole Chemmac.
- Number of electrodes showing reasonable agreement. Obviously erroneous electrodes are excluded from the calculation.

7.2 Water analysis data

The following routines for quality control and data management are generally applied for hydrogeochemical analysis data, independently of sampling method or sampling object.

Several components are determined by more than one method and/or laboratory. Moreover, duplicate analyses by an independent laboratory are performed as a standard procedure on every fifth or tenth collected sample. All analytical results are stored in the SICADA database. The applied hierarchy path "Hydrochemistry/Hydrochemical investigation /Analyses/Water in

the database” contains two types of tables, raw data tables and primary data tables (final data tables).

Data on *basic water analyses* are inserted into the raw data tables for further evaluation. The evaluation results in a final reduced data set for each sample which are compiled in a primary data table named “water composition”. The evaluation is based on:

- Comparison of the results from different laboratories and/or methods. The analyses are repeated if a large disparity is noted (generally more than 10%).
- Calculation of charge balance errors according to the equation below. Relative errors within $\pm 5\%$ are considered acceptable (in surface waters $\pm 10\%$).

$$\text{Relative error (\%)} = 100 \times \frac{\sum \text{cations}(\text{equivalents}) - \sum \text{anions}(\text{equivalents})}{\sum \text{cations}(\text{equivalents}) + \sum \text{anions}(\text{equivalents})}$$

- General expert judgement of plausibility based on earlier results and experience.

All results from *special analyses* of trace metals and isotopes are inserted directly into primary data tables. In those cases where the analyses are repeated or performed by more than one laboratory, a “best choice” notation will indicate those results which are considered most reliable.

An overview of the data management is given in Figure 7-1.

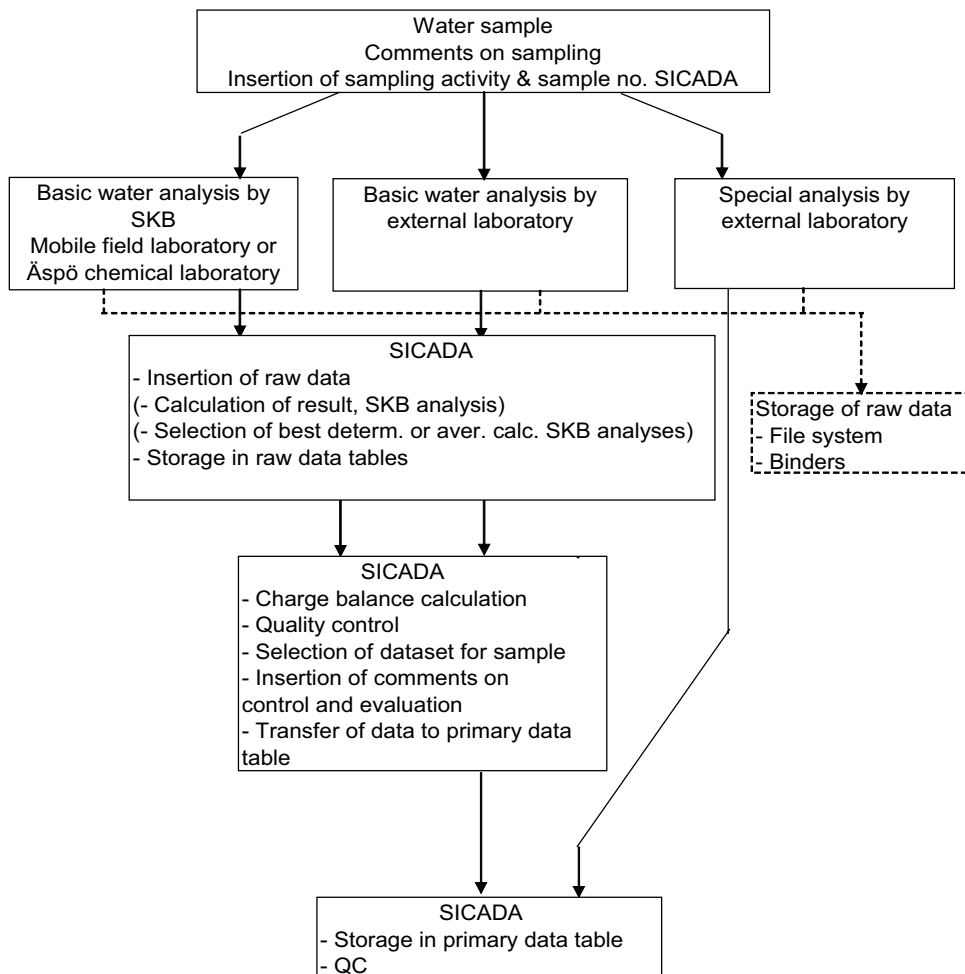


Figure 7-1. Overview of data management for hydrogeochemical data.

7.3 Data from special sampling methods

Special sampling methods include collection of in situ samples (dissolved gases and colloids) and enrichment and fractionation of humic and fulvic acids.

Separate activities, methods and sample numbers are defined in SICADA for data on dissolved gases, colloids, fractions of humic and fulvic acids as well as $\delta^{13}\text{C}$ and pmC determined on organic constituents. All data are subjected to quality control.

7.3.1 Colloid filtration

The concentration of the colloid portion caught on each filter is calculated with the assumption that the water volume coming out in the collecting container is equal to the volume going into the system. This is not quite true as up to ten millilitres will be left in cavities in the filter holder package, in the tubing and in valves. A small volume of about 0.01 to 0.06 mL is left in each filter after the filtration and its content of the different elements is included in the analysis. The measurement uncertainty of each colloid concentration is calculated according to the equation below.

$$U = \sqrt{\left(\frac{1}{V^2} \cdot (\Delta m)^2 + \frac{m^2}{V^4} (\Delta V)^2 \right)}$$

where

- U = measurement uncertainty [$\mu\text{g/L}$]
- V = water volume through the system [L]
- ΔV = estimated volume error, 0.010 [L]
- m = amount on filter [μg]
- Δm = measurement uncertainty of the filter analysis, 20% [μg]

The calculated results of the colloid filtration are stored in SICADA.

7.3.2 Dissolved gases

Results from gas analyses are stored in a primary data table in SICADA without post-processing or interpretations.

7.3.3 Enrichment of humic and fulvic acids

The pmC and $\delta^{13}\text{C}$ values for enriched organic acids are stored in a primary data table in SICADA without post-processing or interpretations.

7.3.4 Fractionation of organic and inorganic species

The concentrations of organic and inorganic constituents in the retentate and permeate are recalculated to concentrations of each fraction of carbon and metal ions with molecular weight lower or higher than the cut-off size of the filter. This is done using mass balance equations as described in SKB MD 431.043 (Mätssystembeskrivning för fraktionering av humus- och fulvosyror). Comparison of the four concentration values from the two filters results in values for three fractions, i.e. < 1,000 D, 1,000–5,000 D and > 5,000 D which are stored in a primary data table in SICADA.

8 Results

8.1 Chemmac measurements

The data sequences of pH, Eh, electrical conductivity, oxygen and temperature values from the Chemmac measurements in borehole sections 428.5–435.6 m and 568.0–575.1 m are plotted versus time in Appendices 8 and 9, respectively. The measured time series of data were evaluated in order to obtain one representative value of Eh, pH, electrical conductivity and dissolved oxygen for the borehole section as described in Section 7.1. Data were selected from the last part of the measured time series sequences (where the electrodes show stable values), marked with an arrow in the diagrams in the Appendices. The evaluated results from the measurements in the investigated sections are given in Table 8-1 together with the corresponding results from the LIBD experiments.

In section 428.5–435.6 m, all six redox electrodes showed stable and coinciding values at the end of the measurement period and all of them were therefore included in the calculation of the representative Eh value. In section 568.0–575.1 m, on the other hand, the surface Chemmac electrodes stabilised at a somewhat higher level than the borehole Chemmac electrodes. This is probably due to an extremely small oxygen intrusion caused by the very low pumping flow rate and the pulsating flow. The Eh data from the surface Chemmac measurements were therefore considered to be less reliable than the data from the borehole Chemmac. Consequently, surface Chemmac redox electrodes were omitted in the evaluation.

The two surface Chemmac pH-electrodes show perfect agreement at the end of the measurement periods in both borehole sections but there is a regular temperature variation (day/night). One of the two borehole pH-electrodes was omitted in the evaluation of the representative borehole pH (both sections). This was due to diverging calibration constant values and therefore a large uncertainty in the calibration constant. The oxygen concentration readings from section 428.5–435.6 m vary more than usual. The cause may be electrical disturbances from equipment in the hose unit.

Table 8-1. Evaluated results from the Chemmac and LIBD measurements in KFM01D.

Borehole section [m]	EC* [mS/m]	pH (surface Chemmac)**	pH (borehole Chemmac)**	Eh (Chemmac)** [mV]	Dissolved oxygen*** [mg/L]
428.5–435.6	1,450 ± 40	8.1 ± 0.2	8.1 ± 0.3	-263 ± 8	0.00 ± 0.01
428.5–435.6 PVB (LIBD)****	1,397	7.97	–	-41	0.003
568.0–575.1	1,800 ± 50	8.1 ± 0.3	8.4 ± 0.3	-260 ± 40 B	0.00 ± 0.01
568.0–575.1 PVB (LIBD)****	1,574	7.91	–	-18	0.02

* The electrical conductivity is measured between 0–10,000 mS/m with a measurement uncertainty of 3%.

** Evaluated result and measurement uncertainty calculated as described in section 7.1.

*** Measuring interval 0–15 mg/L, resolution 0.01 mg/L.

**** See Appendix 7.

B = Only values from borehole Chemmac have been used in the calculation.

8.2 Water analyses

8.2.1 Basic water analyses

The basic water analyses include the major constituents Na, K, Ca, Mg, S, Sr, SO_4^{2-} , Cl^- , Si and HCO_3^- as well as the minor constituents Fe, Li, Mn, DOC, Br, F, I, HS^- and NH_4^+ . Furthermore, batch measurements of pH (lab-pH) and electrical conductivity (lab-EC) are included. Another important parameter is the flushing water content in each sample. The basic water analysis data and relative charge balance errors are compiled in Appendix 10, Table A10-1. Existing lab-pH and lab-Eh values are compared to the corresponding on-line Chemmac measurement values in Appendices 8 and 9.

The charge balance errors give an indication of the quality and uncertainty of the analyses of major constituents. The errors do not exceed $\pm 5\%$. Furthermore, the last sample in each section was also analysed by a second laboratory. A comparison between results from different laboratories and methods shows that the agreement is acceptable in most cases. Generally, the difference in concentrations between laboratories/methods for each analysed constituent is less than 10%.

The flushing water contents in the sample series collected from the two borehole sections are presented in Figure 8-1. The content should not exceed 1% in order for a sample to be considered representative for the groundwater of the sampled fracture. This condition was only achieved for the samples collected in section 568.0–575.1 m. The last sample, collected after the ordinary sampling/measurement period, recorded a higher value of 8%. The flushing water contents in the samples collected with SLT amounted to between 4 and 9%. The percentage of flushing water in the samples was calculated using the nominal Uranine concentration (0.20 mg/L).

The concentration levels of chloride, calcium and sodium are presented in Figures 8-2 and 8-3. The concentrations of all major constituents, except sulphur (section 428.5–435.6 m), remained practically constant during the entire pumping and sampling period, although a very small systematic decrease with time can be noted at the 428.5–435.6 m level.

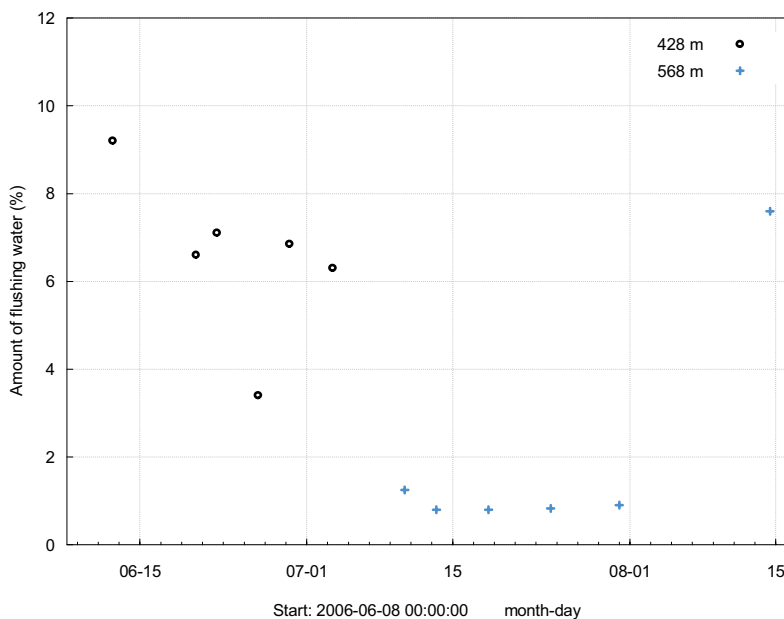


Figure 8-1. Flushing water content in the groundwater samples from sections 428.5–435.6 m and 568.0–575.1 m.

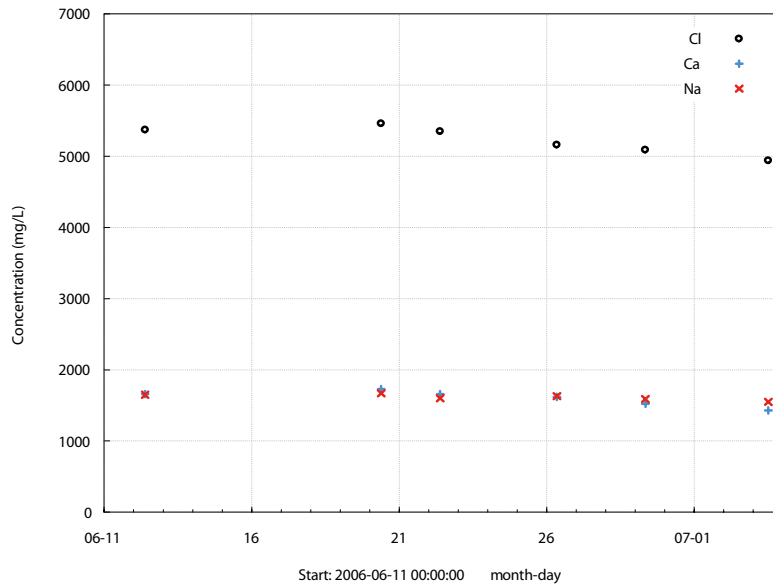


Figure 8-2. Chloride, calcium and sodium concentration from sample series at 428.5–435.6 m.

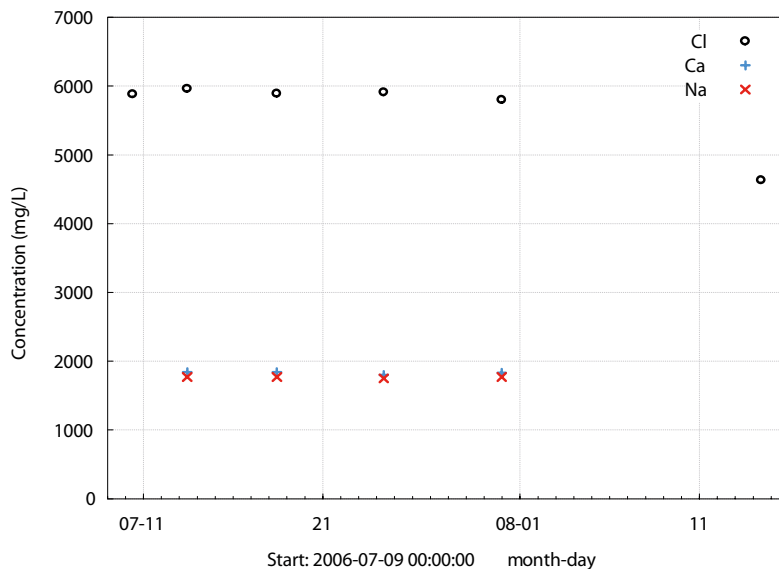


Figure 8-3. Chloride, calcium and sodium concentration from sample series at 568.0–575.1 m.

The iron concentrations determined by ICP-AES (total Fe) and by spectrophotometry (Fe(II) and Fe-tot) are compared in Figures 8-4 and 8-5. The total iron concentrations determined by ICP agree well with the results obtained by spectrophotometry. The iron concentrations are high and show an increasing trend throughout the sampling period. This may be an artefact from the drilling (material from wear of drilling equipment) or contamination from iron oxyhydroxide deposits in the water channel of the umbilical hose. However, the latter suggestion is expected to cause an opposite trend with a high initial concentration.

Sulphate analysed by ion chromatography (IC) is compared to sulphate determined as total sulphur by ICP-AES in Figures 8-6 and 8-7. As shown, there are discrepancies which might be due to some analytical error or presence of the sulphur as another species. The results from the ICP measurements are considered more reliable, by experience, since the variation in a time series often is smaller. The sulphate concentration remains relatively constant during the sampling period in section 568.0–575.1 m, whereas in section 428.5–435.6 m, the concentration is higher and increases during the period.

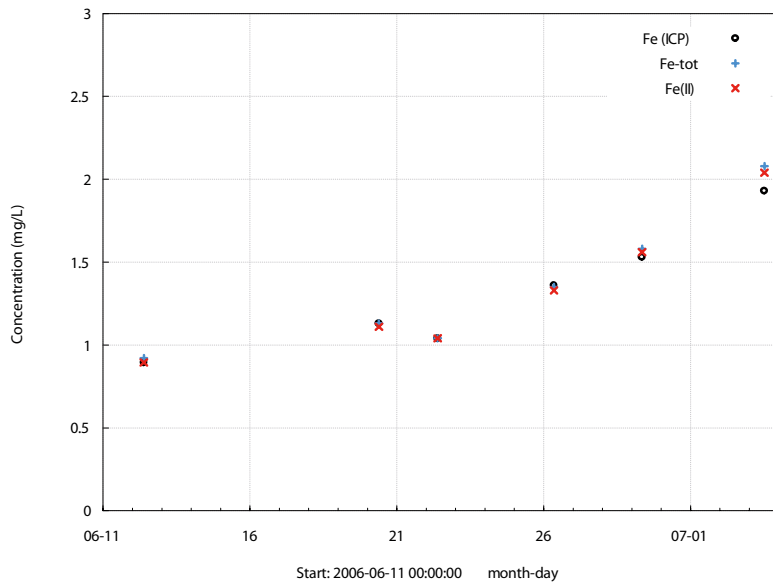


Figure 8-4. Comparison of iron concentrations obtained by ICP-AES and by spectrophotometry, borehole section 428.5–435.6 m.

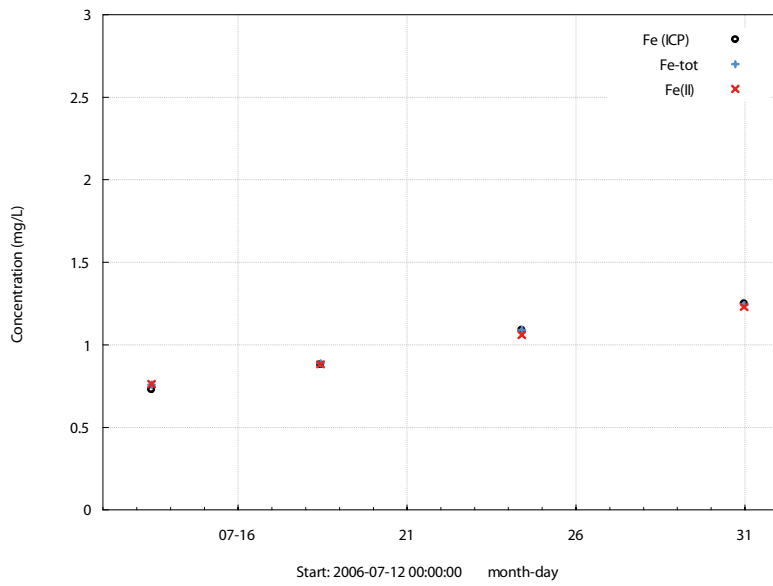


Figure 8-5. Comparison of iron concentrations obtained by ICP-AES and by spectrophotometry, borehole section 568.0–575.1 m.

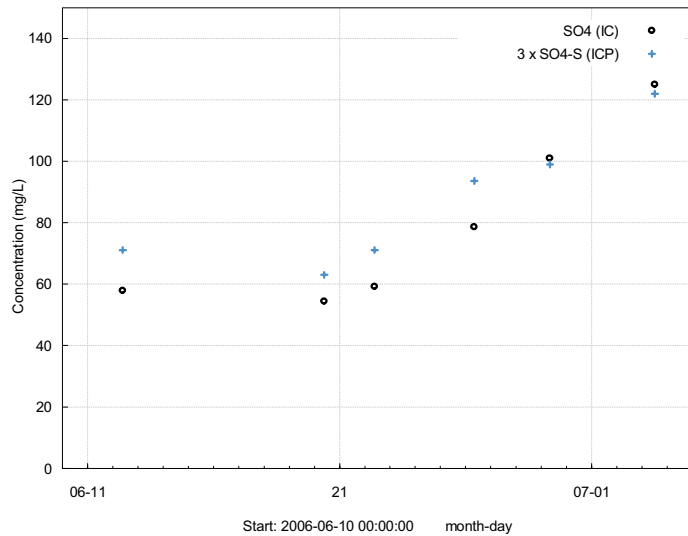


Figure 8-6. Sulphate (SO_4 by IC) to total sulphate calculated from total sulphur ($3 \times SO_4-S$ by ICP) versus date, borehole section 428.5–435.6 m.

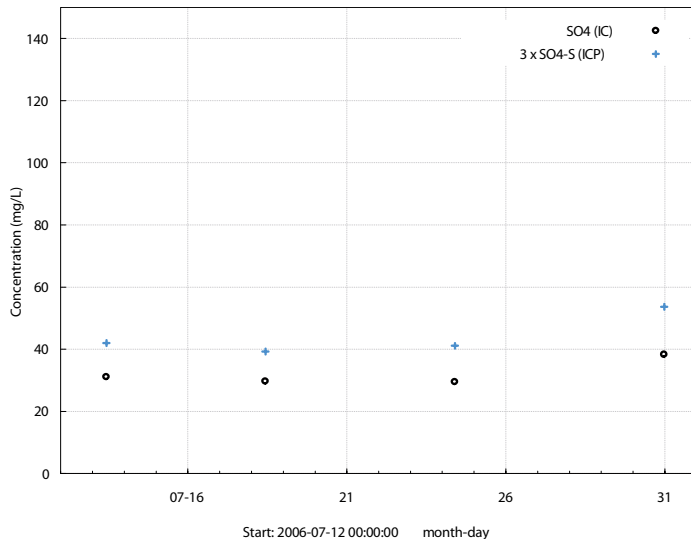


Figure 8-7. Sulphate (SO_4 by IC) to total sulphate calculated from total sulphur ($3 \times SO_4-S$ by ICP) versus date, borehole section 568.0–575.1 m.

The chloride concentrations are plotted versus the corresponding electrical conductivity values in Figure 8-8. The plot gives a rough check of both the measured EC values and the chloride concentrations. As shown, the data from the KFM01D agree well with the regression line obtained by previous data from the site investigation at Forsmark.

8.2.2 Trace elements (rare earth metals and others)

The analyses of trace and rare earth metals include Al, B, Ba, U, Th, Sc, Rb, Y, Zr, In, Sb, Cs, La, Hf, Tl, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu. Commonly occurring metals, such as Cu, Zn, Pb and Mo, are not included in the analytical programme due to contamination considerations. The risk of contamination is large also for aluminium but the aluminium concentration is still reported due to its importance for the modelling work. The trace element data are compiled in Appendix 10, Table A10-3.

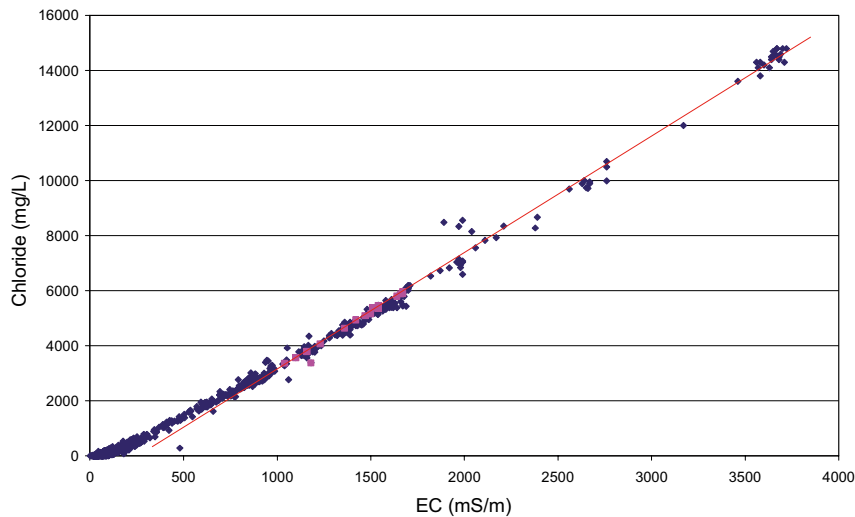


Figure 8-8. Chloride concentration versus electrical conductivity. Data from previous investigations at Forsmark are used to show the linear trend. Data from KFM01D are shown in pink.

8.2.3 Stable and radioactive isotopes

The isotope determinations include the stable isotopes δD , $\delta^{18}O$, $^{10}B/^{11}B$, $\delta^{34}S$, $\delta^{13}C$, $\delta^{37}Cl$ and $^{87}Sr/^{86}Sr$ as well as the radioactive isotopes Tr (TU), ^{14}C (pmC), ^{238}U , ^{235}U , ^{234}U , ^{232}Th , ^{230}Th , ^{226}Ra and ^{222}Rn . Available isotope data at the time of reporting are compiled in Appendix 10, Table A10-2 and Table A10-4.

The tritium and $\delta^{18}O$ results for section 428.5–435.6 m and 568.0–575.1 m are presented in Figures 8-9 and 8-10. The sample series showed more or less constant $\delta^{18}O$ values.

The carbon isotopes ($\delta^{13}C$ and pmC) were determined both in inorganic carbon (hydrogen carbonate) and in organic constituents (enriched samples) but no data were available at the time of reporting.

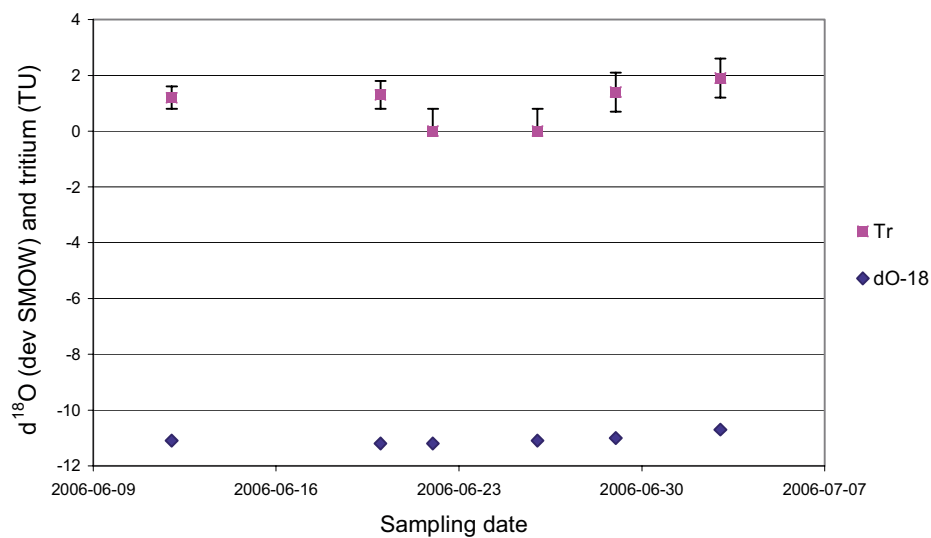


Figure 8-9. Tritium and $\delta^{18}O$ (‰ SMOW) data versus sampling date, section 428.5–435.6 m.

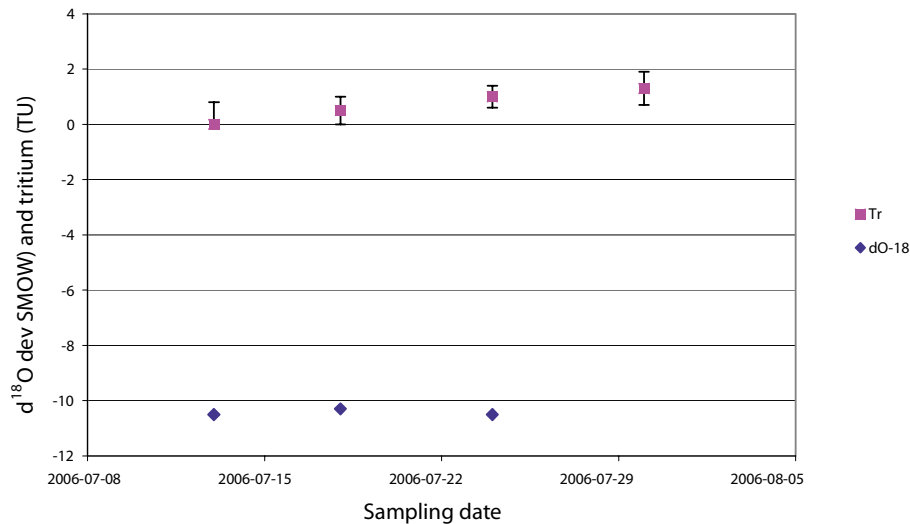


Figure 8-10. Tritium and $\delta^{18}O$ (‰ SMOW) data versus sampling date, section 568.0–575.1 m.

8.3 Dissolved gas

The analyses of dissolved gases include argon (Ar), helium (He), nitrogen (N₂), carbon dioxide (CO₂), methane (CH₄), oxygen (O₂), hydrogen (H₂), carbon monoxide (CO), ethane (C₂H₆), ethene (C₂H₄), ethyne (C₂H₂), propane (C₃H₈) and propene (C₃H₆). The gas data are compiled in Appendix 10, Table A10-5.

Total gas contents in the groundwaters as well as the detected oxygen content are given in Table 8-2.

From section 428.5–435.6 m two containers were analysed at the same laboratory using argon gas (1) and nitrogen gas (2) for purging the samples, respectively. A higher argon value could be seen in container (1), explained by leakage of argon into the PVB-container when purging the sample at the consulting laboratory.

The gas compositions of the groundwaters are presented in Figures 8-11 and 8-12.

8.4 Colloids

The presence of colloids was investigated by two or three methods: 1) filtration through a series of connected filters at argon atmosphere (only section 568.0–575.1 m), 2) fractionation/ultra filtration using two cylindrical filters with cut-offs of 1,000 D and 5,000 D, and 3) Laser-Induced Breakdown Detection, LIBD, Appendix 7.

Table 8-2. Total content of dissolved gas.

	Section 428.5–435.6 m (1)	Section 428.5–435.6 m (2)	Section 568.0–575.1 m
Total gas content [mL/L]	99	92	112
Oxygen content [mL/L]	0.032	0.062	0.014

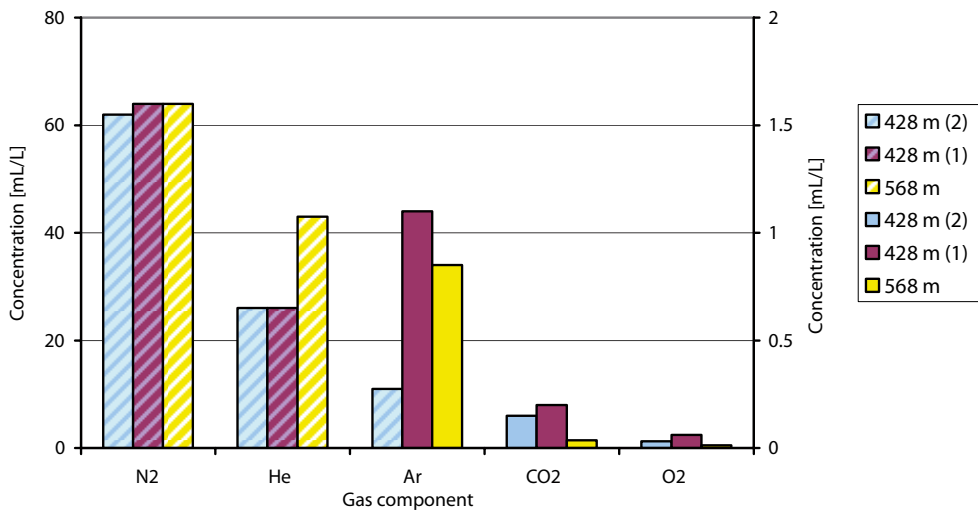


Figure 8-11. Gas components of high concentrations (N_2 , He, Ar, CO_2 , and O_2) in the sample collected in sections 428.5–435.6 m and 568.0–575.1 m using the in situ sampling equipment. Diagonally and infilled rastered columns refer to left and right axis, respectively.

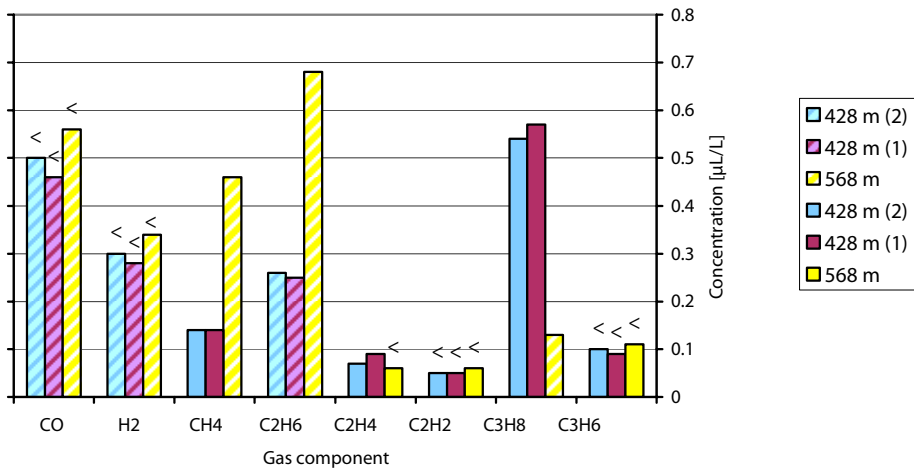


Figure 8-12. Gas components of low concentrations (CO , H_2 , CH_4 , C_2H_6 , C_2H_4 , C_2H_2 , C_3H_8 and C_3H_6), in the samples collected in sections 428.5–435.6 m and 568.0–575.1 m using the in situ sampling equipment. Diagonally and infilled rastered columns refer to left and right axis, respectively.

An overview of colloid concentrations in groundwater samples from boreholes KFM06A, KFM07A, KFM08A and KFM01D is presented in Table 8-3. The table includes results from all filtration experiments with a filtrate volume exceeding 300 mL and also the LIBD tests conducted so far. The results from the filtration runs are corrected by considering the remaining water volume in each filter (indicated by the sodium content) and excluding its corresponding amounts of the different dissolved elements. The calcium contents in the filters are significantly effected by this correction and the impact of analytical errors is very large. Furthermore, the analysed elements are recalculated to the amounts of probable mineral phases (illite, calcite, iron hydroxide and manganese hydroxide).

The table illustrates the difficulties associated with colloid determinations. Generally, it is expected that the measured colloid concentrations turn out higher than the natural amount of background colloids in the groundwater as additional colloids are easily generated by artefacts. The sources may be:

- Oxygen intrusion and formation of iron hydroxide.
- Decrease of pressure and precipitation of calcite.
- Sampling process or equipment.

Table 8-3. Compilation of colloid concentrations in samples from boreholes KFM06A-KFM08A and KFM01D. Comparison of results obtained by filtration and by LIBD technique.

Filtration through series of connected filters									LIBD	
Idcode/ secup/ filter pore size (µm)	Filtrate volume (mL)	Element content on each filter per litre of water (µg/L)				Mineral phases (µg/L)			Idcode/ secup/ run no.	Content (µg/L)
		Al	Ca	Fe	Mn	Total/ filter*	Calcite/ filter	Sum**/ three filters		
KFM06A/ 354/0.2	308.5	0.178	0.0	2.188	0	5.28	0		KFM06A/ 354/1	1.1
KFM06A/ 354/0.05	308.5	0.522	0.0	1.448	0	5.99	0			
KFM06A/ 354/0.05	308.5	0.284	29.4	0.511	0.026	76.1	73.3	14.0	KFM06A/ 354/2	1.3
KFM06A/ 768/0.2	321.5	0.237	222.4	0.648	0	557	555			
KFM06A/ 768/0.05	321.5	0.284	25.7	0.580	0	66.9	64.0			
KFM06A/ 768/0.05	321.5	0.198	17.9	0.456	0	46.7	44.6	7.66		
KFM07A/ 848/0.2	336.5	0.266	0.0	1.302	0	4.13	0			
KFM06A/ 848/0.05	336.5	0.466	47.3	0.982	0	123	118			
KFM06A/ 848/0.05	336.5	0.686	32.0	0.921	0	85.7	79.7	14.9		
									KFM08A/ 683.5/1	17.5
									KFM08A/ 683.5/2	16.8
									KFM08A / 683.5/3	5.9
									KFM08A/ 683.5/4	6.8
									KFM01D/ 428.5/1	4
									KFM01D/ 428.5/2	10
KFM01D/ 568/0.4	306	4.02	5.33	8.38	0.06	71.4	13.3		KFM01D/ 568.0/1	110
KFM01D/ 568/0.4	306	6.63	7.56	15.81	0.14	118.1	18.9		KFM01D/ 568.0/2	190
KFM01D/ 568/0.2	306	0	6.76	4.85	0	24.6	16.8			
KFM01D/ 568/0.05	306	0	29.4	3.93	0	79.6	73.3			
KFM01D/ 568/0.05	306	0	0	3.82	0	6.1	0	20		

* Total content on each filter. Aluminium is calculated as 2.3 Al in K- Mg-illite (383.9 g/mol), calcium is calculated as CaCO₃ (100.0 g/mol), iron is calculated as Fe(OH)₃ (106.8 g/mol) and manganese is calculated as Mn(OH)₂ (88.9 g/mol). The sulphur and silicon contents on the filters were below detection limit and the uranium content was also below or close to the detection limit.

** Sum of content (mineral phases) on the last three filters. Calcite is excluded.

The high element contents in the two 0.40 µm filters (Total/filter) from borehole KFM01D, section 568.0 m, indicate presence of particles and may explain the exceptional LIBD results from this borehole section. Further, the filtration results seem to be more affected by calcite precipitation than the LIBD measurements but an apparent calcite content may also arise due to analytical errors. The calcite phase is excluded from the calculated total colloid concentration (sum column in Table 8-3) obtained by the filtration method but, if present, it is included in the LIBD results.

8.4.1 Inorganic colloids – colloid filtration

The results from the colloid filtration method for section 568.0–575.1 m are presented in Figures 8-13 to 8-19.

The bars in the diagrams represent amounts (µg) of aluminium, iron, silicon, manganese, calcium, sulphur and uranium entering the filter package, incorporated on each filter and present in the collecting container. The amounts are calculated assuming that the water volume passing through the filters and into the collecting container is equal to the volume going into the system. This is not quite the case, as up to ten millilitres will be left in cavities in the filter holder package, in the tubing and in valves. Further, a small volume of about 0.01 to 0.06 mL is left in each filter after the filtration and its salt content is included in the analysis. The presented input amounts, in the diagrams below, represent the sample taken on-line at the surface just before opening the PVB-containers for sampling.

The concentrations in blank samples (rinsing water), PVB-containers, collecting container and pumped groundwater are given in Table 8-4. The remaining water in the PVB containers after filtration was in both cases contaminated by aluminium and possibly by iron. The deviating iron concentrations may also be due to precipitation followed by settling down of particles.

Analysis of blank filters showed that the contributions of aluminium, iron, silica, manganese and uranium from filters were insignificant.

The following conclusions may be drawn from the colloid filtration results:

- The amount present as colloids on the filters is generally very low, therefore analytical uncertainties are high. Especially the aluminium analyses are uncertain.
- The amount of uranium in the filters from section 568.0–575.1 m exceeded the detection limit which may indicate that colloidal uranium is present in this groundwater.

Table 8-4. Element concentrations in blank water, remaining water in PVB container, collected output water from filter system and in pumped water that has not passed the filter system.

Section m	Sample origin	Al µg/L	Ca mg/L	Fe mg/L	Mn µg/L	Si mg/L	S mg/L	U µg/L
568.0–575.1	Blank	11.6	< 0.1	0.0011	0.114	0.426	< 0.2	0.0002
	Rest volume PVB (input conc)	327	1840	2.62	120	7.86	15.0	1.65
		926	1830	4.14	140	6.89	14.8	2.30
	Collecting container after filter system	6.61	1750	1.22	93.3	4.34	14.3	0.645
	Pumped water (alt. input conc)	5.48	1830	1.25	113	4.55	17.9	0.799

Blank = rinsing water, leakage test.

Rest volume PVB = remaining water in the PVB container after filtering experiment.

Collecting container = water that has passed the filter system.

Pumped water = regular sample collected at the surface and not in situ in the borehole section.

Results of colloid filtering experiment, section 568.0–575.1 m

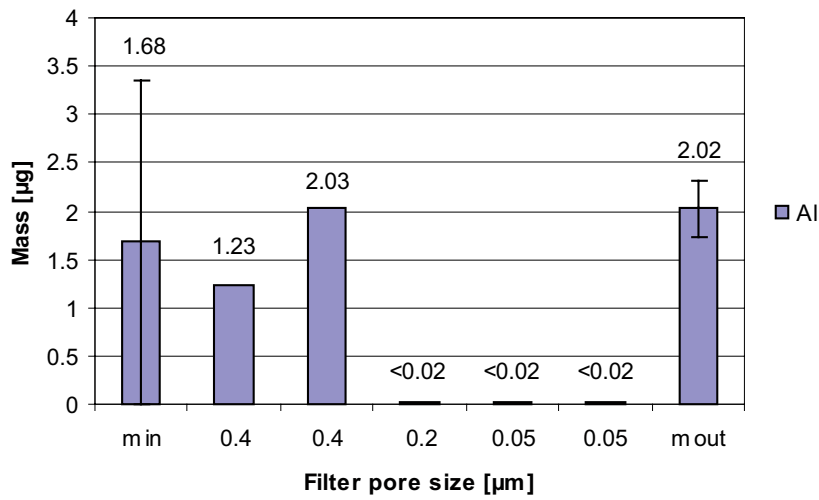


Figure 8-13. Amount of aluminium entering the filter system (m in), in the filters and in the collecting container (m out).

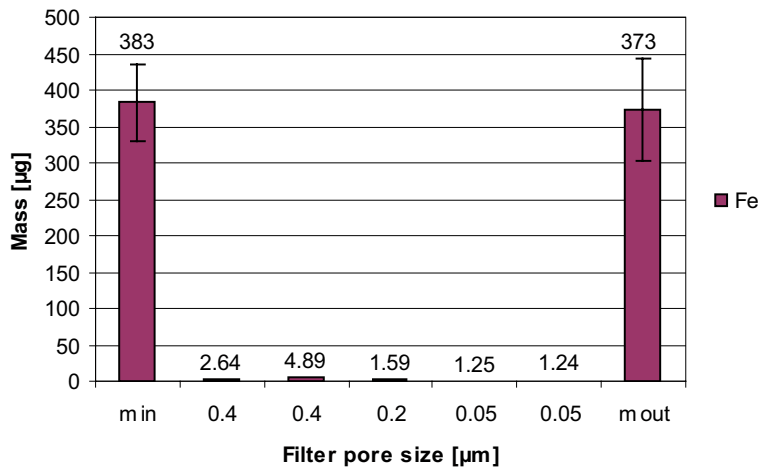


Figure 8-14. Amount of iron entering the filter system (m in), in the filters and in the collecting container (m out).

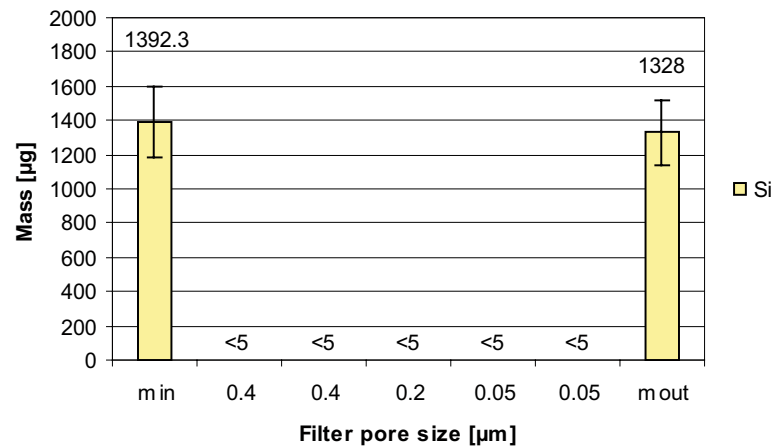


Figure 8-15. Amount of silicon entering the filter system (m in), in then filters and in the collecting container (m out).

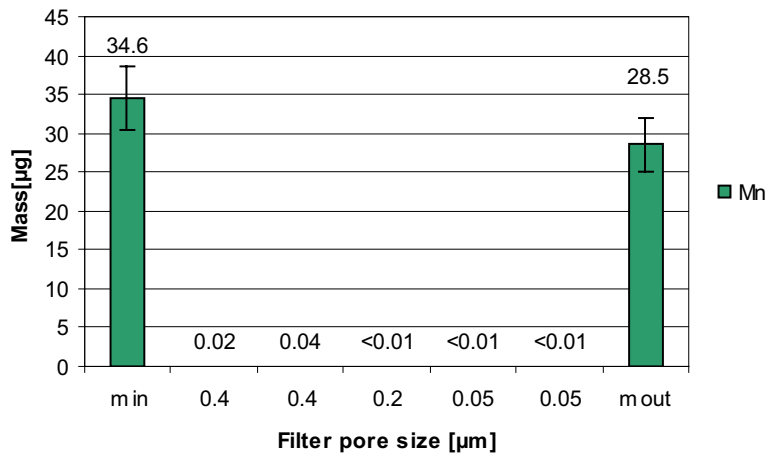


Figure 8-16. Amount of manganese entering the filter system (m in), in the filters and in the collecting container (m out).

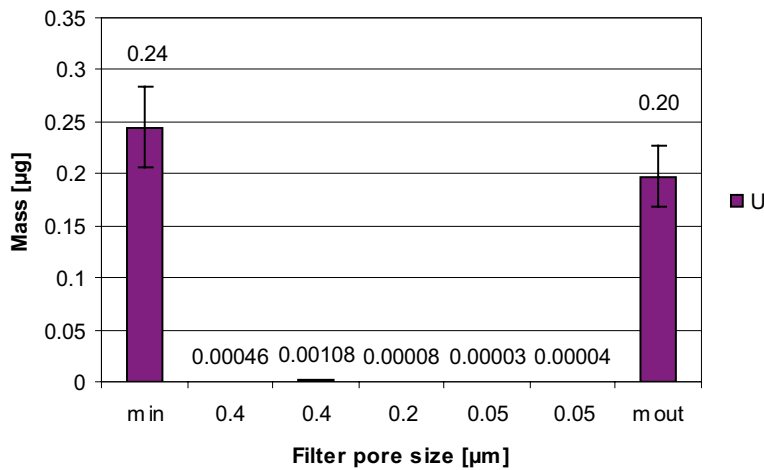


Figure 8-17. Amount of uranium entering the filter system (m in), in the filters and in the collecting container (m out).

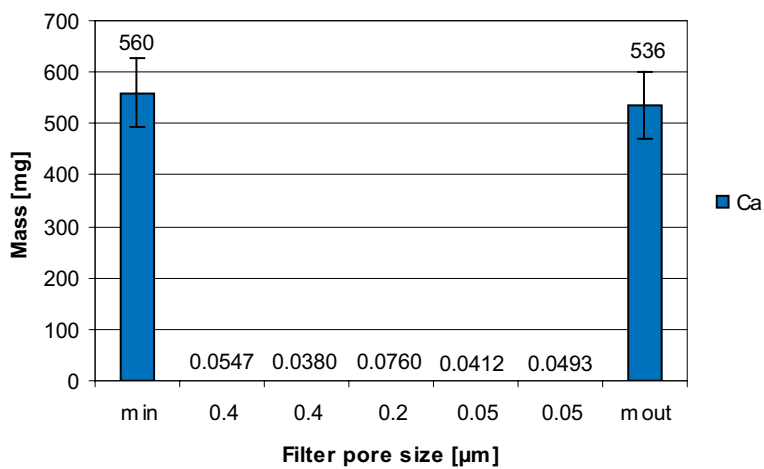


Figure 8-18. Amount of calcium entering the filter system (m in), in the filters and in the collecting container (m out).

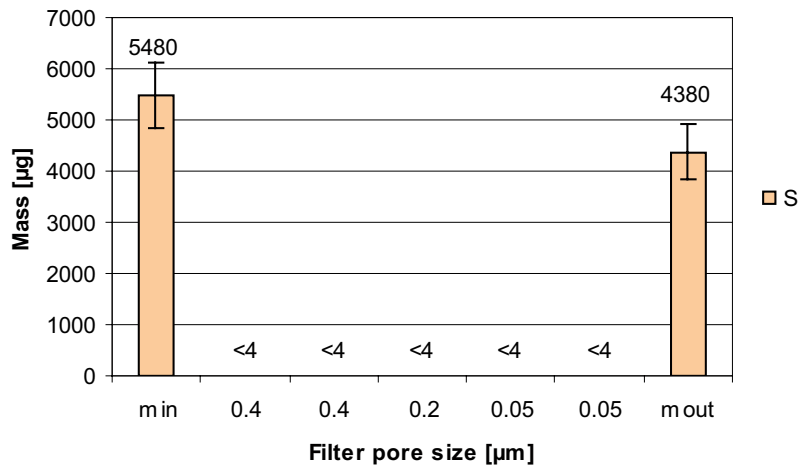


Figure 8-19. Amount of sulphur entering the filter system (*m in*), in the filters and in the collecting container (*m out*).

8.4.2 Inorganic colloids – fractionation

Fractionations were performed 2006-06-29 to 2006-06-30 (428.5–435.6 m) and 2006-07-25 to 2006-07-26 (568.0–575.1 m). The samples from the fractionation experiment were analysed by ICP and the determined elements were; Ca, Fe, K, Mg, Na, S, Si, Al, Ba, Cd, Co, Cr, Cu, Hg, Li, Mn, Mo, Ni, P, Pb, Sr, V, Zn and U. Only iron, silicon, aluminium, calcium, sulphur, manganese and uranium were considered important as colloid species. The fractionation results see Tables 8-5 and 8-6, indicate that Si, Ca, S, Mn and U exist solely as species with a molecular weight less than 1,000 g/mol. Such species are too small to be referred to as colloids. No calcite precipitation was detected.

Table 8-5. Inorganic fractions (< 1,000 D, 1,000 D to 5,000 D and > 5,000 D) in section 428.5–435.6 m.

Fraction	Fe (mg/L)	Si (mg/L)	Ca (mg/L)	S (mg/L)	Mn (µg/L)	U (µg/L)
< 1,000 D	0.209 ± 0.028	26 ± 4	1,370 ± 164	32 ± 4	164 ± 20	1.9 ± 0.3
< 5,000 D	1.16 ± 0.15	21 ± 3	1,430 ± 172	30 ± 4	162 ± 20	1.9 ± 0.3
> 1,000 D but < 5,000 D	0.121 ± 0.028	< 1	< 3	< 1	< 1	< 0.05
> 5,000 D	< 0.02	< 1	< 19	< 1	< 1	< 0.1
Adsorption 1,000 D	1.07 ± 0.19	< 7	< 108	< 2	< 1	< 0.07
Adsorption 5,000 D	< 0.3	< 3	< 91	< 4	< 1	< 0.04

Table 8-6. Inorganic fractions (< 1,000 D, 1,000 D to 5,000 D and > 5,000 D) in section 568.0–575.1 m.

Fraction	Fe (mg/L)	Si (mg/L)	Ca (mg/L)	S (mg/L)	Mn (µg/L)	U (µg/L)
< 1,000 D	0.48 ± 0.06	4.2 ± 0.6	1,750 ± 211	12.8 ± 1.6	83 ± 13	0.55 ± 0.07
< 5,000 D	0.56 ± 0.08	4.2 ± 0.6	1,800 ± 217	13.1 ± 1.6	81 ± 10	0.47 ± 0.06
> 1,000 D but < 5,000 D	0.04 ± 0.02	< 0.1	< 47	< 0.1	< 3	< 0.006
> 5,000 D	0.05 ± 0.03	< 1	< 19	< 0.2	< 1	< 0.01
Adsorption 1,000 D	0.37 ± 0.14	< 0.4	< 117	< 1.4	< 5	< 0.11
Adsorption 5,000 D	0.42 ± 0.16	< 0.3	< 90	< 0.7	< 5	< 0.05

The result for iron is uncertain since some precipitation might have occurred during or just after the filtrations. The fractions with the molecular weight corresponding to > 5,000 D may be a colloid phase present in the groundwater but it is also possible that it is precipitation caused by intrusion of oxygen in the filtering system (pump, filter, hose etc).

The aluminium concentration in the untreated groundwaters was too low to draw any conclusions regarding fractions of aluminium.

The blanks (de-ionised water after passing through the washed filters) showed insignificant concentrations of iron, silicon, calcium, sulphur, manganese and uranium.

8.4.3 Humic and fulvic acids – fractionation

The results from fractionation of organic acids in sections 428.5–435.6 m and 568.0–575.1 m are summarised in Table 8-7. The water in these sections contains mainly organic acids with a molecular weight less than 1,000 D. This means that the organic constituents are present as low molecular weight fulvic acids and possibly other low molecular weight organic acids such as citric acid and oxalic acid. The results from the 1,000 D and 5,000 D filters were consistent.

Table 8-7. Summary of fractionation results.

Fraction	DOC 428.5–435.6 m (mg/L)	DOC 568.0–575.1 m (mg/L)
< 1,000 D	2.3 ± 0.3	7.5 ± 1.0
> 1,000 D but < 5,000 D	< 0.04	< 0.6
> 5,000 D	< 0.1	< 0.4
Adsorption 1,000 D	< 0.2	< 0.4
Adsorption 5,000 D	< 0.2	< 0.03

9 Summary and discussion

The results from sampling and measurements in KFM01D add important information on groundwater composition above and at the planned repository depth in a strategically located borehole. Furthermore, the borehole yields relatively little water and intersects a bedrock volume relatively free from large fractures and fracture zones, i.e. the type of bedrock conditions that will prevail at the location of a future repository for spent nuclear fuel.

Figure 9-1 displays chloride concentrations versus depth for KFM01D together with corresponding data from other boreholes at Forsmark. A high magnesium to chloride ratio indicates a marine origin of the groundwater. Figure 9-2 shows that the magnesium concentrations in KFM01D generally are lower than in previously investigated boreholes at corresponding chloride concentrations.

The main conclusions from the experimental results in KFM01D are:

- Figures 9-1 and 9-2 suggest that the relict marine groundwater (Littorina) did not reach the same depth in the centre of the north-western part of the tectonic lens as in the south-eastern part. This might be due to the different character of the bedrock below the deformation zone A2 /11/. The gradual change from mainly Littorina type to a mixture of glacial water or diluted shallow groundwater deeper saline groundwaters commences already at 250 m depth in KFM01D compared to at approximately 550 m in all previous boreholes except KFM06A.
- The redox measurements in sections 428.5–435.6 m and 568.0–575.1 m performed well. The recorded potentials were stable and ended at more or less the same value of –260 mV, which is reasonable since the borehole sections are close to each other and the groundwater conditions are similar.
- Generally, the flushing water content in the samples was somewhat high from this borehole. However, in section 568.0–575.1 m the content was below 1% which is the accepted upper limit for a fully representative water sample.
- The quality of the water analyses is generally high, based on comparison between results from different laboratories and methods and acceptable charge balance errors. The relative errors are within $\pm 5\%$.
- The major constituents show close to stable concentrations during the pumping/sampling period, which indicate that no mixing occurred with water from other fracture systems with a different water composition.
- The LIBD results suggest a reasonable colloid concentration of approximately 4–10 $\mu\text{g/L}$ in section 428.5–435.6 m in contrast to section 568.0–575.1 m which showed a colloid concentration as high as 110–190 $\mu\text{g/L}$. The in situ sample water from section 568.0–575.1 m was muddy, most likely due to contamination from drilling debris from the borehole. This is probably why the LIBD results from this section diverge.
- The uranium concentrations in the groundwaters from KFM01D are reasonably low; 1–9 $\mu\text{g/L}$, with the lowest values ($< 1 \mu\text{g/L}$) in section 568.0–575.1 m. This is far from the concentrations reached in some of the previous borehole sections at intermediate depths in boreholes KFM02A and KFM03A (up to 90 $\mu\text{g/L}$).
- If organic constituents exist in the groundwater, they are mostly present as low molecular weight fulvic acids or other low molecular weight organic acids such as citric acid and oxalic acid with a molecular weight less than 1,000 D.

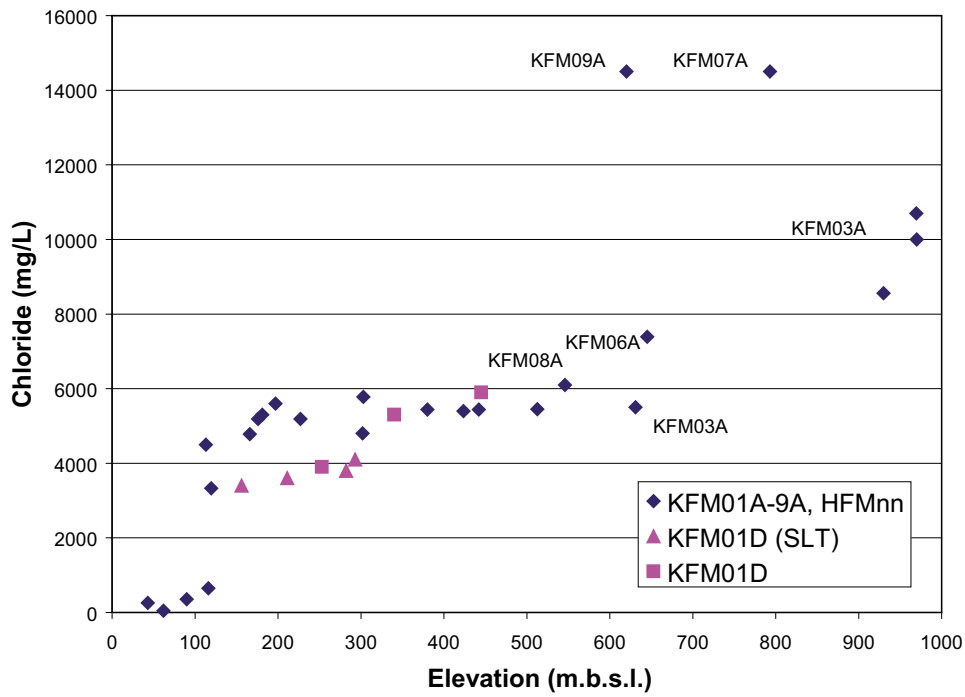


Figure 9-1. Chloride concentrations versus depth (m) at the Forsmark site.

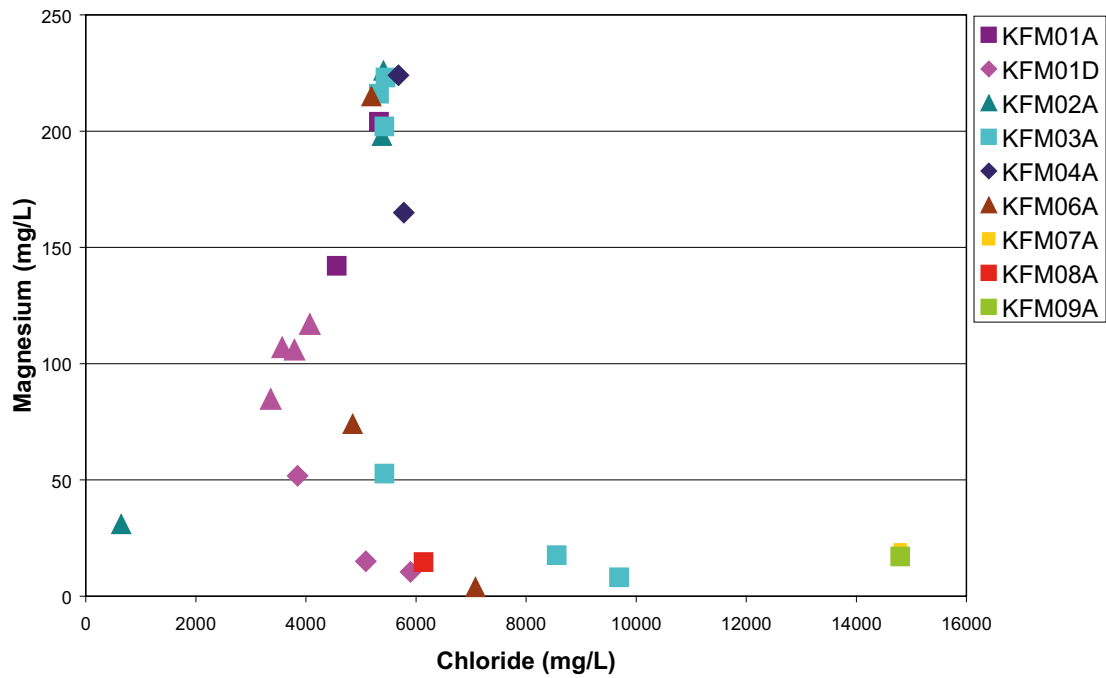


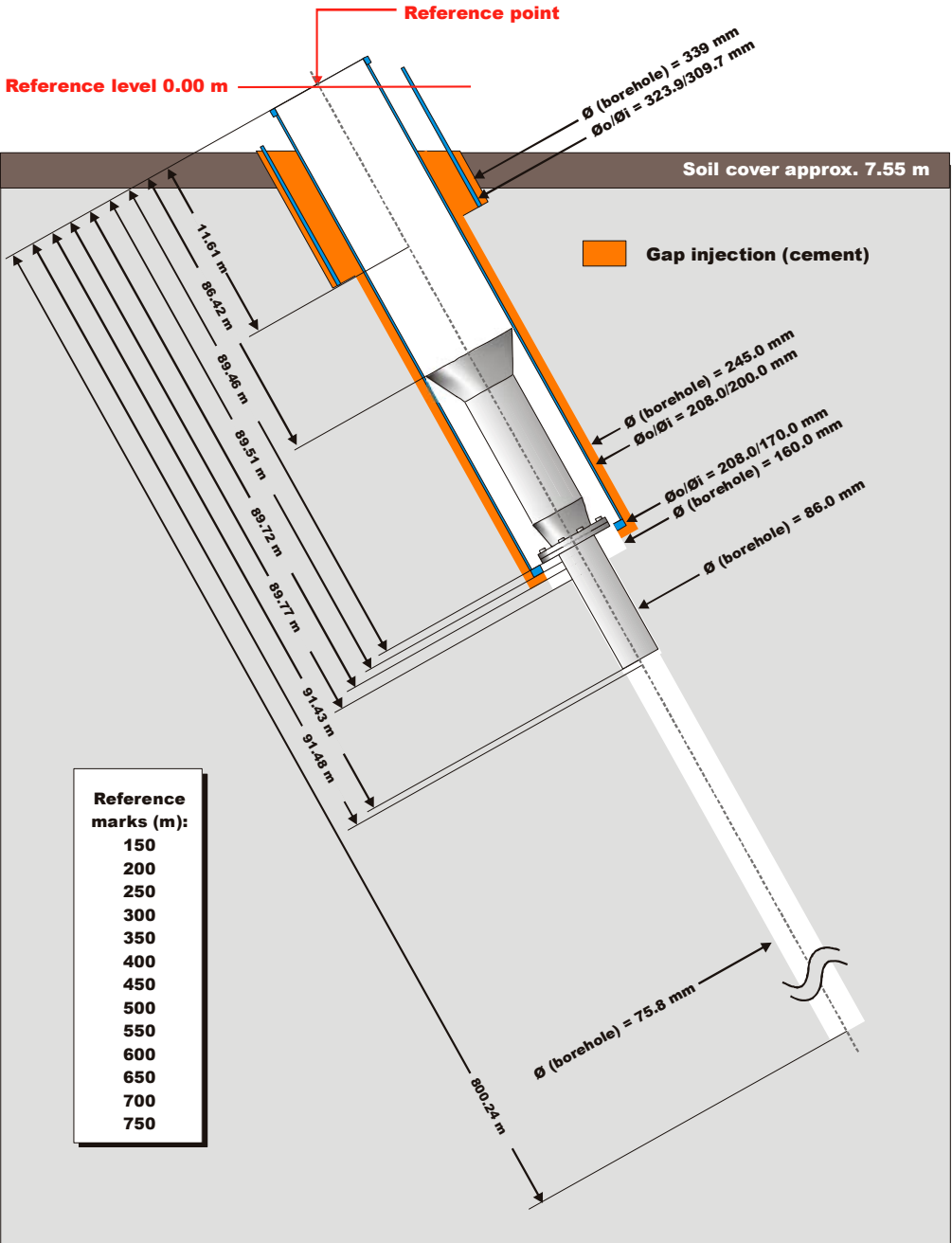
Figure 9-2. Magnesium concentrations versus chloride concentrations at the Forsmark site. Pink triangles indicate samples collected from low transmissive fractures by the SLT unit.

10 References

- /1/ **SKB, 2001.** Site investigations. Investigation methods and general execution programme. SKB R-01-29, Svensk Kärnbränslehantering AB.
- /2/ **Pedersen K, 2006.** Forsmark site investigation. Total numbers and metabolic diversity of microorganisms in boreholes KFM08A and KFM01D. P-report in progress. SKB P-06-NN, Svensk Kärnbränslehantering AB.
- /3/ **Claesson L-Å, Nilsson G, 2005.** Forsmark site investigation. Drilling of the telescopic borehole KFM01D at drill site DS1. SKB P-05-172, Svensk Kärnbränslehantering AB.
- /4/ **SKB, 2005.** Forsmark site investigation. Programme for further investigations of geosphere and biosphere. SKB R-05-14, Svensk Kärnbränslehantering AB.
- /5/ **Claesson L-Å, Nilsson G, 2003.** Forsmark site investigation. Drilling of a flushing water wells, HFM01 and two groundwater monitoring wells, HFM02 and HFM03, at drilling site DS1. SKB P-03-30, Svensk Kärnbränslehantering AB.
- /6/ **Nilsson A-C, 2003.** Forsmark site investigation. Sampling and analyses of groundwater from percussion drilled boreholes and shallow monitoring wells at drilling site DS1. Results from the percussion drilled boreholes HFM01, HFM02, HFM03, KFM01A (borehole section 0–100 m) and the monitoring wells SFM0001, SFM0002 and SFM0003. SKB P-03-47, Svensk Kärnbränslehantering AB.
- /7/ **Pedersen K, 2005.** Control of microorganism content in flushing water used for drilling of KFM06A. SKB P-05-81, Svensk Kärnbränslehantering AB.
- /8/ **Nielsen U T, Ringgaard J, and Fries Dahl T, 2005.** Forsmark site investigation. Geophysical borehole logging in the boreholes KFM01D, KFM08A and KFM08B. SKB P-05-159. Svensk Kärnbränslehantering AB.
- /9/ **Gustafsson J and Gustafsson C, 2006.** Forsmark site investigation. RAMAC and BIPS logging in boreholes KFM01C and KFM01D. SKB P-06-98, Svensk Kärnbränslehantering AB.
- /10/ **Väisäsvaara J, Leppänen H, Pekkanen J, 2005.** Forsmark site investigation. Difference flow logging in borehole KFM01D. SKB P-06-161, Svensk Kärnbränslehantering AB.
- /11/ **Platsundersökning Forsmark – Årsrapport 2005.** Svensk Kärnbränslehantering AB.

Design of cored borehole KFM01D

Technical data
Borehole KFM01D



Drilling reference point		Percussion drilling period	
Northing:	6699542.07 (m), RT90 2,5 gon V 0:-15	Drilling start date:	2005-11-21
Easting:	1631404.52 (m), RT90 2,5 gon V 0:-15	Drilling stop date:	2005-12-05
Elevation:	2.95 (m), RHB 70	Core drilling period	
Orientation		Drilling start date:	2005-12-17
Bearing (degrees):	35.04°	Drilling stop date:	2006-02-18
Inclination (degrees):	-54.90°		
Borehole			
Length:	800.24 m		

Rev 2006-05-24

Selected results from differential flow logging, KFM01D

Forsmark, borehole KFM01D
Flow rate, caliper and single point resistance

- ▲ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- ▼ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
- ▲ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- Without pumping (L=5 m, dL=0.5 m), 2006-05-24 - 2006-05-26
- With pumping (L=5 m, dL=0.5 m), 2006-05-27 - 2006-05-28
- With pumping (L=1 m, dL=0.1 m), 2006-05-28 - 2006-05-30
- Lower limit of flow rate

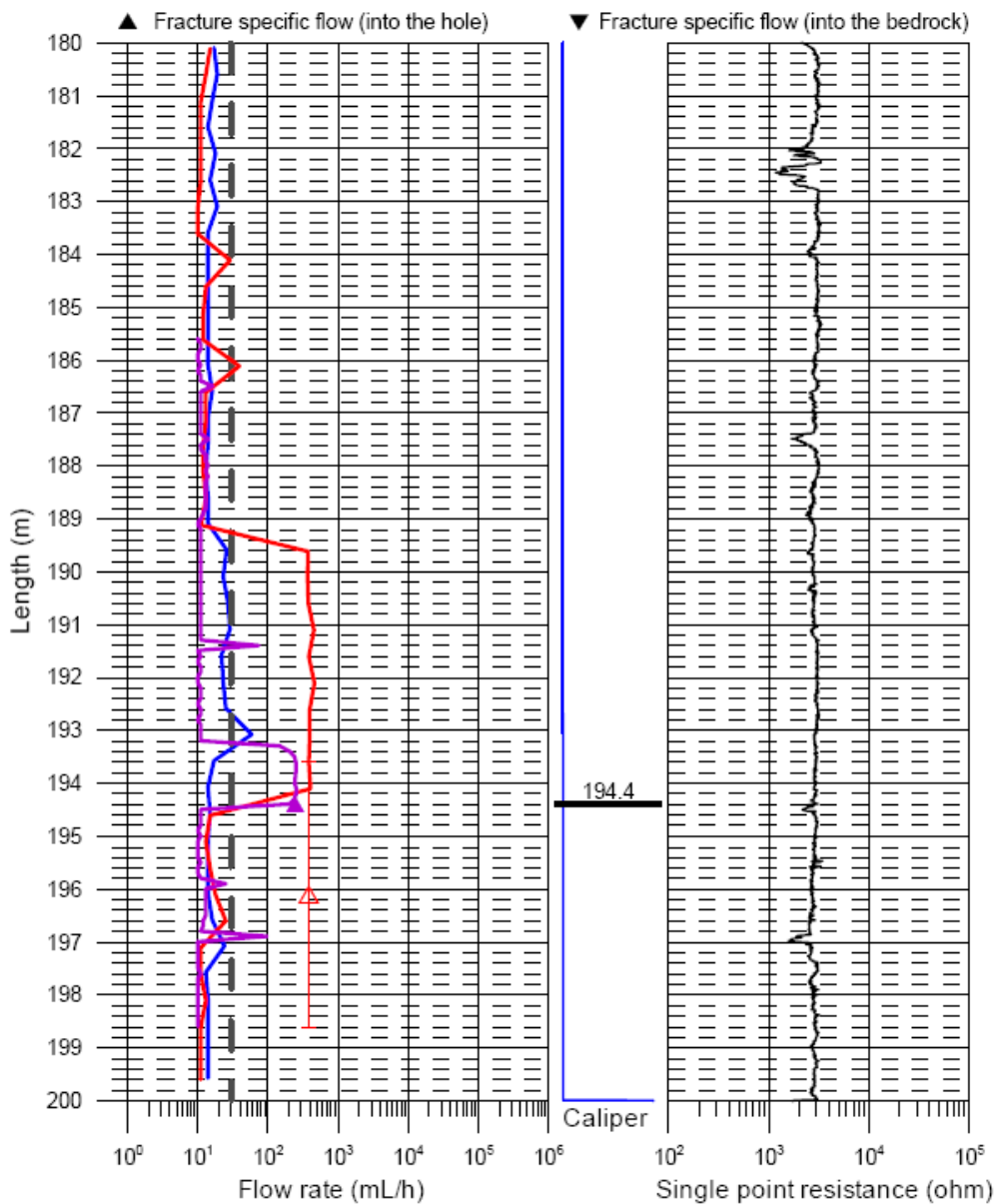


Figure A2-1. Borehole KFM01D: differential flow measurements from 180–200 m including the water bearing fracture zone at 194 m /10/.

Forsmark, borehole KFM01D
Flow rate, caliper and single point resistance

- △ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- ▽ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
- △ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- Without pumping (L=5 m, dL=0.5 m), 2006-05-24 - 2006-05-26
- With pumping (L=5 m, dL=0.5 m), 2006-05-27 - 2006-05-28
- With pumping (L=1 m, dL=0.1 m), 2006-05-28 - 2006-05-30
- Lower limit of flow rate

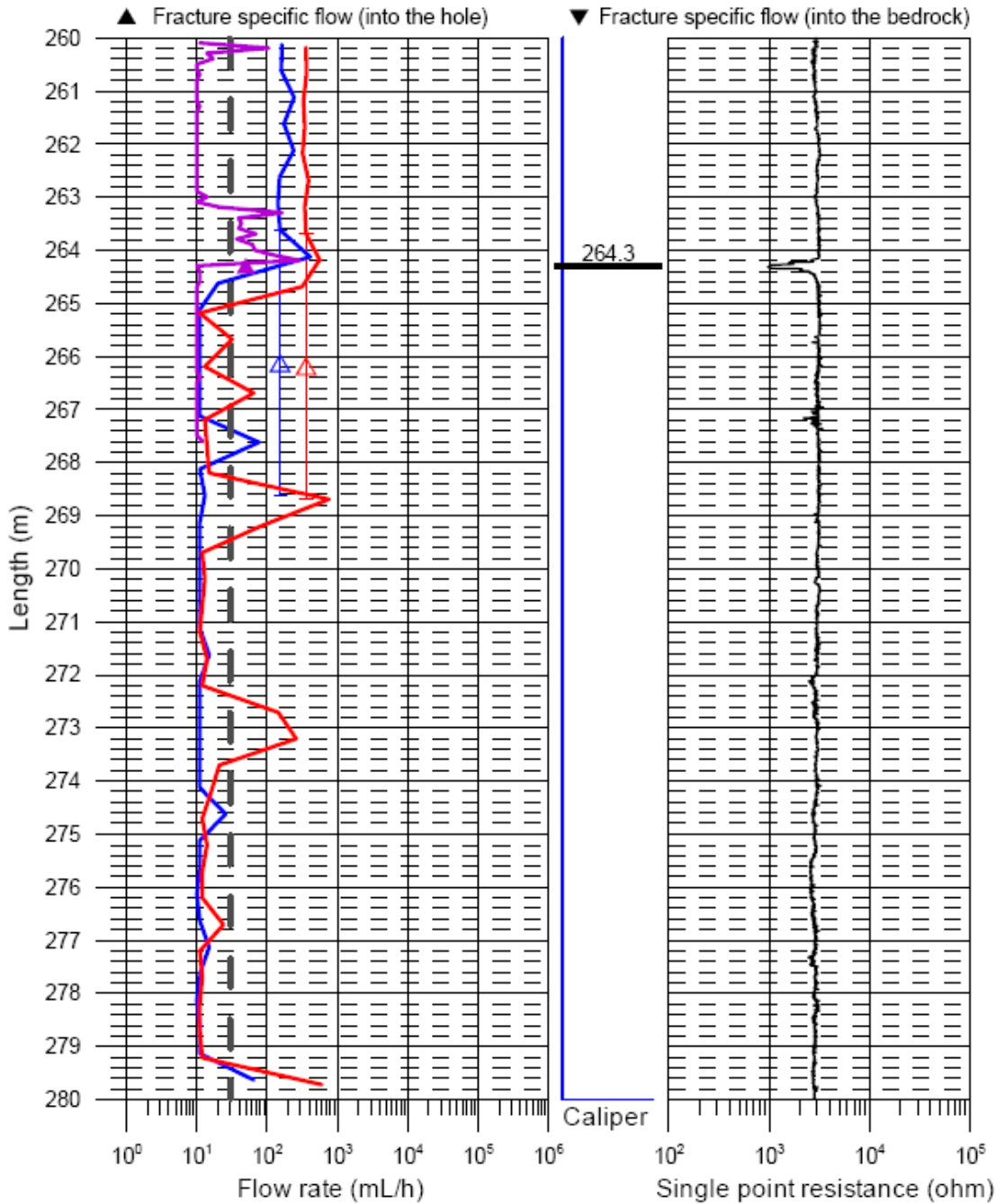


Figure A2-2. Borehole KFM01D: differential flow measurements from 260–280 m including the water bearing fracture zone at 264 m /10/.

Forsmark, borehole KFM01D
Flow rate, caliper and single point resistance

- △ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- ▽ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
- △ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- Without pumping (L=5 m, dL=0.5 m), 2006-05-24 - 2006-05-26
- With pumping (L=5 m, dL=0.5 m), 2006-05-27 - 2006-05-28
- With pumping (L=1 m, dL=0.1 m), 2006-05-28 - 2006-05-30
- Lower limit of flow rate

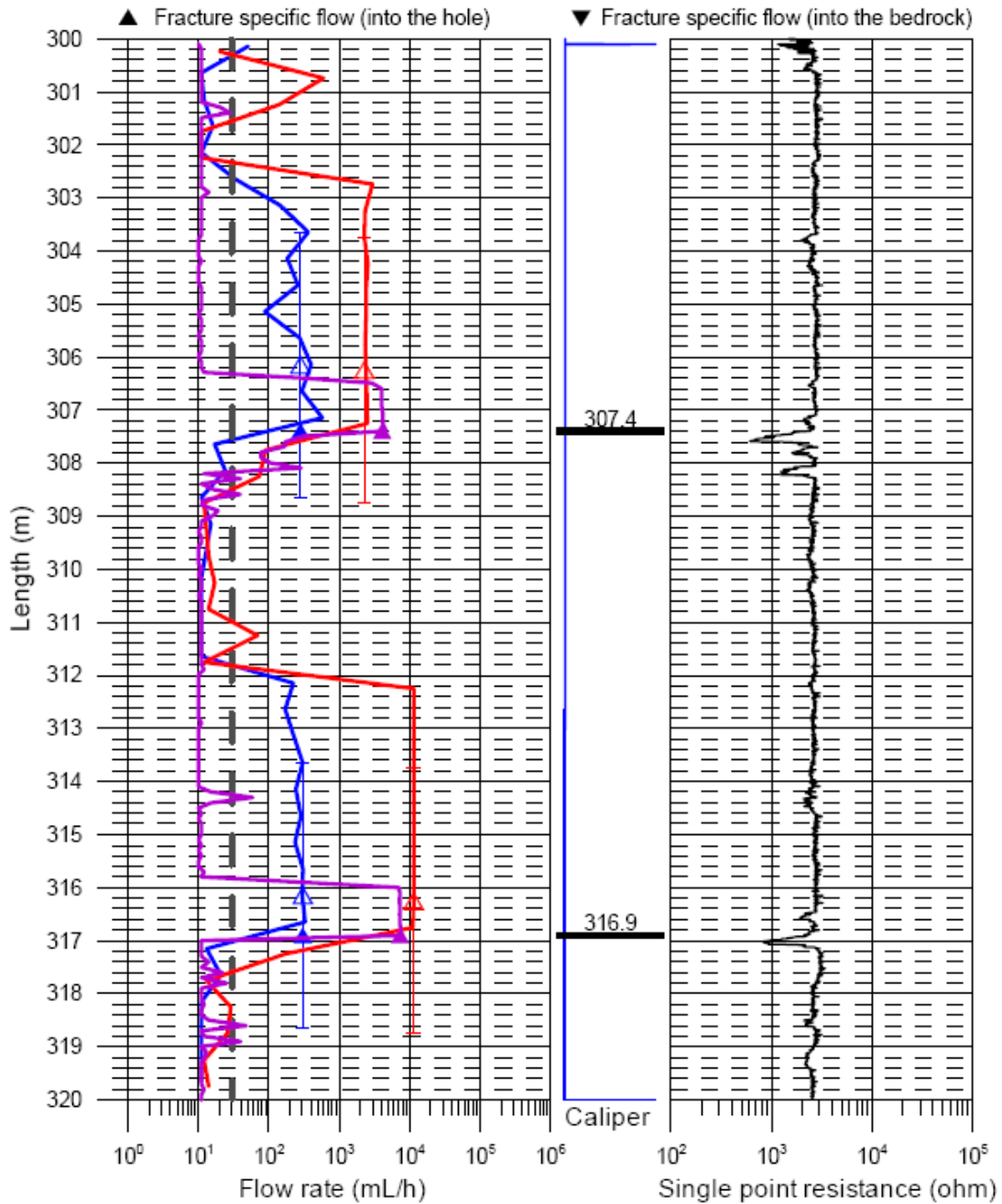


Figure A2-3. Borehole KFM01D: differential flow measurements from 300–320 m including the water bearing fracture zone at 317 m /10/.

Forsmark, borehole KFM01D
 Flow rate, caliper and single point resistance

- △ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- ▽ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
- △ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- Without pumping (L=5 m, dL=0.5 m), 2006-05-24 - 2006-05-26
- With pumping (L=5 m, dL=0.5 m), 2006-05-27 - 2006-05-28
- With pumping (L=1 m, dL=0.1 m), 2006-05-28 - 2006-05-30
- Lower limit of flow rate

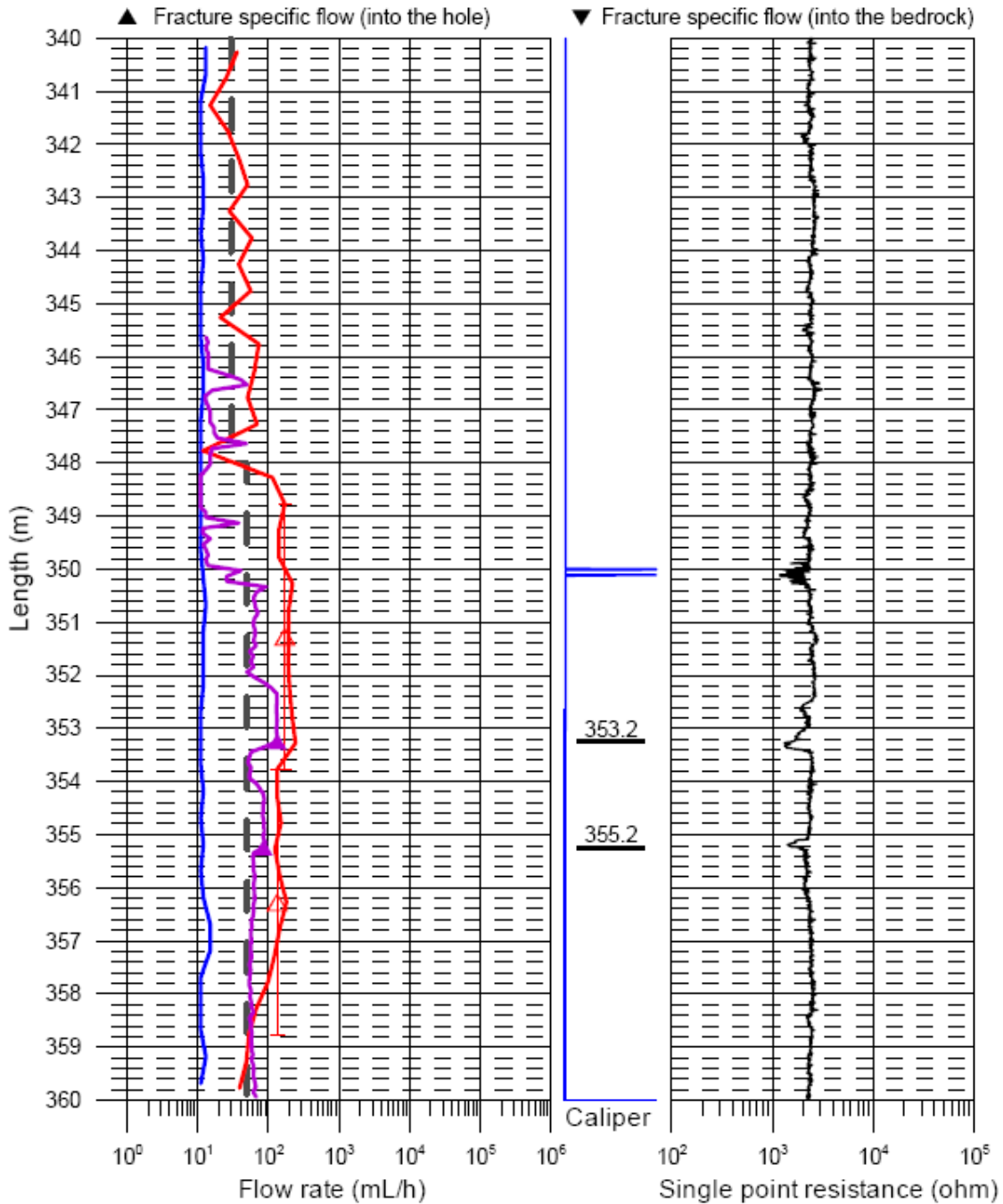


Figure A2-4. Borehole KFM01D: differential flow measurements from 340–360 m including the water bearing fracture zone at 355 m /10/.

Forsmark, borehole KFM01D
Flow rate, caliper and single point resistance

- △ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- ▽ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
- △ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- Without pumping (L=5 m, dL=0.5 m), 2006-05-24 - 2006-05-26
- With pumping (L=5 m, dL=0.5 m), 2006-05-27 - 2006-05-28
- With pumping (L=1 m, dL=0.1 m), 2006-05-28 - 2006-05-30
- Lower limit of flow rate

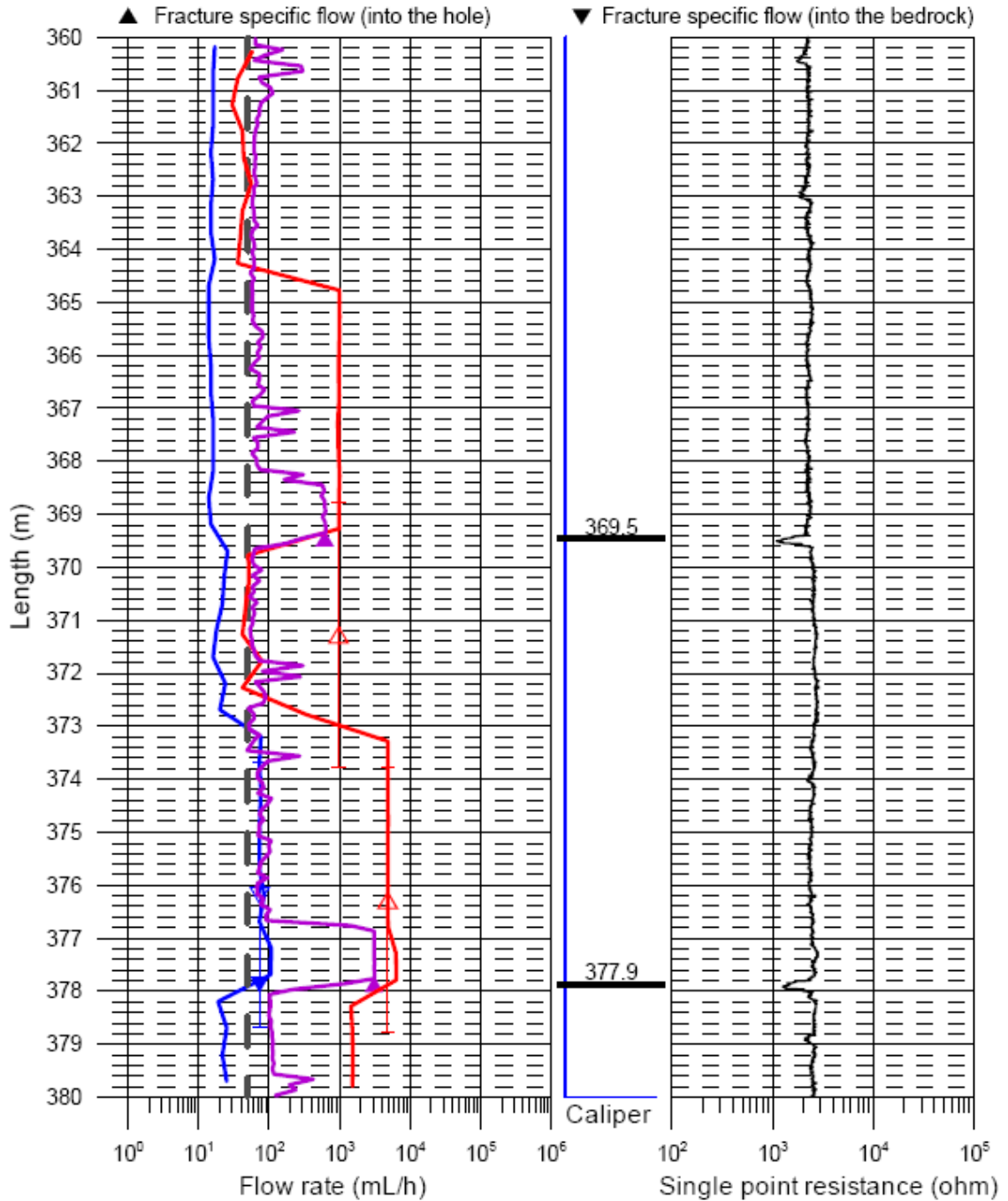


Figure A2-5. Borehole KFM01D: differential flow measurements from 360–380 m including the water bearing fracture zone at 370 m /10/.

Forsmark, borehole KFM01D
Flow rate, caliper and single point resistance

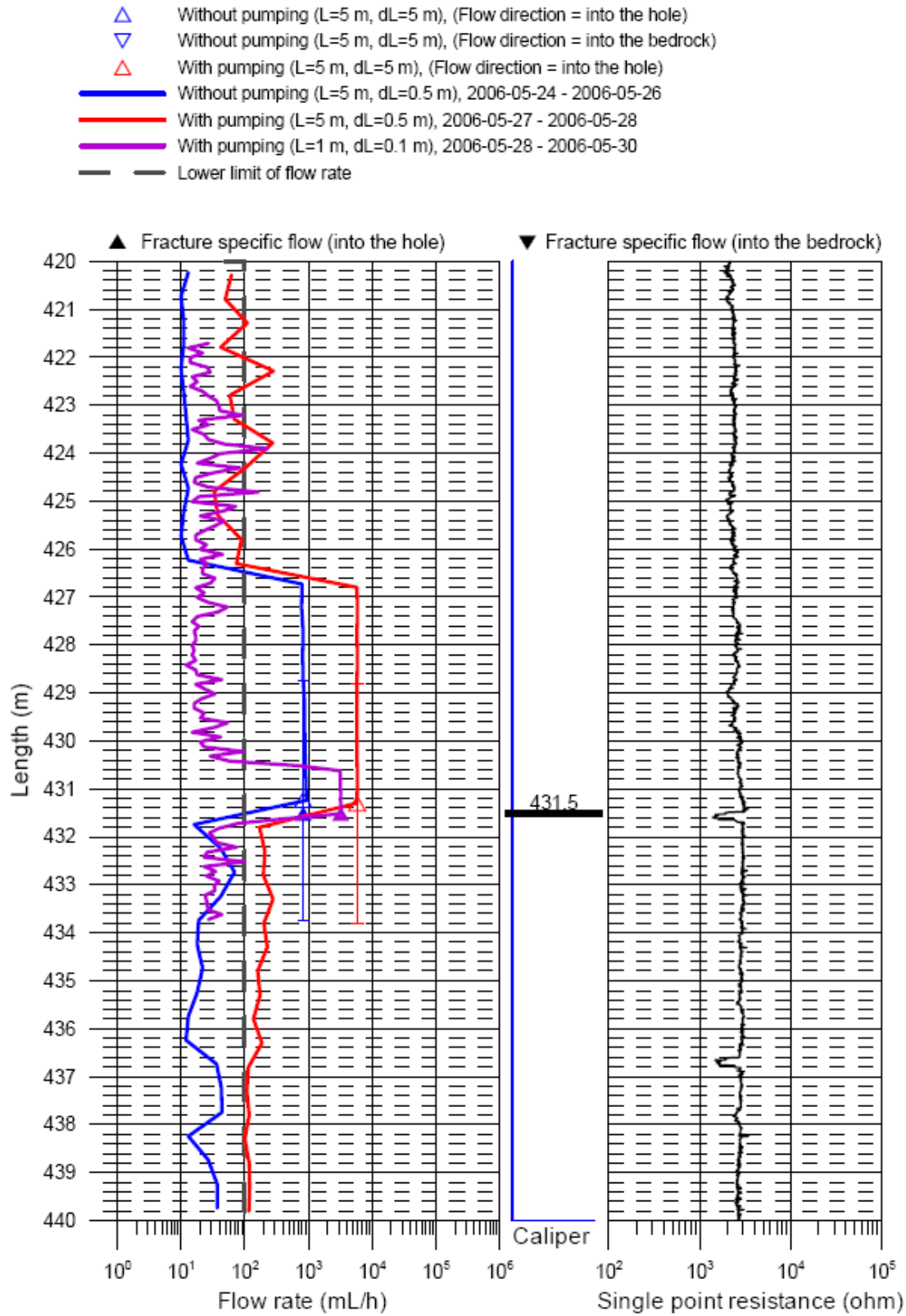


Figure A2-6. Borehole KFM01D: differential flow measurements from 420–440 m including the water bearing fracture zone at 432 m /10/.

Forsmark, borehole KFM01D
Flow rate, caliper and single point resistance

- △ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- ▽ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
- △ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- Without pumping (L=5 m, dL=0.5 m), 2006-05-24 - 2006-05-26
- With pumping (L=5 m, dL=0.5 m), 2006-05-27 - 2006-05-28
- With pumping (L=1 m, dL=0.1 m), 2006-05-28 - 2006-05-30
- Lower limit of flow rate

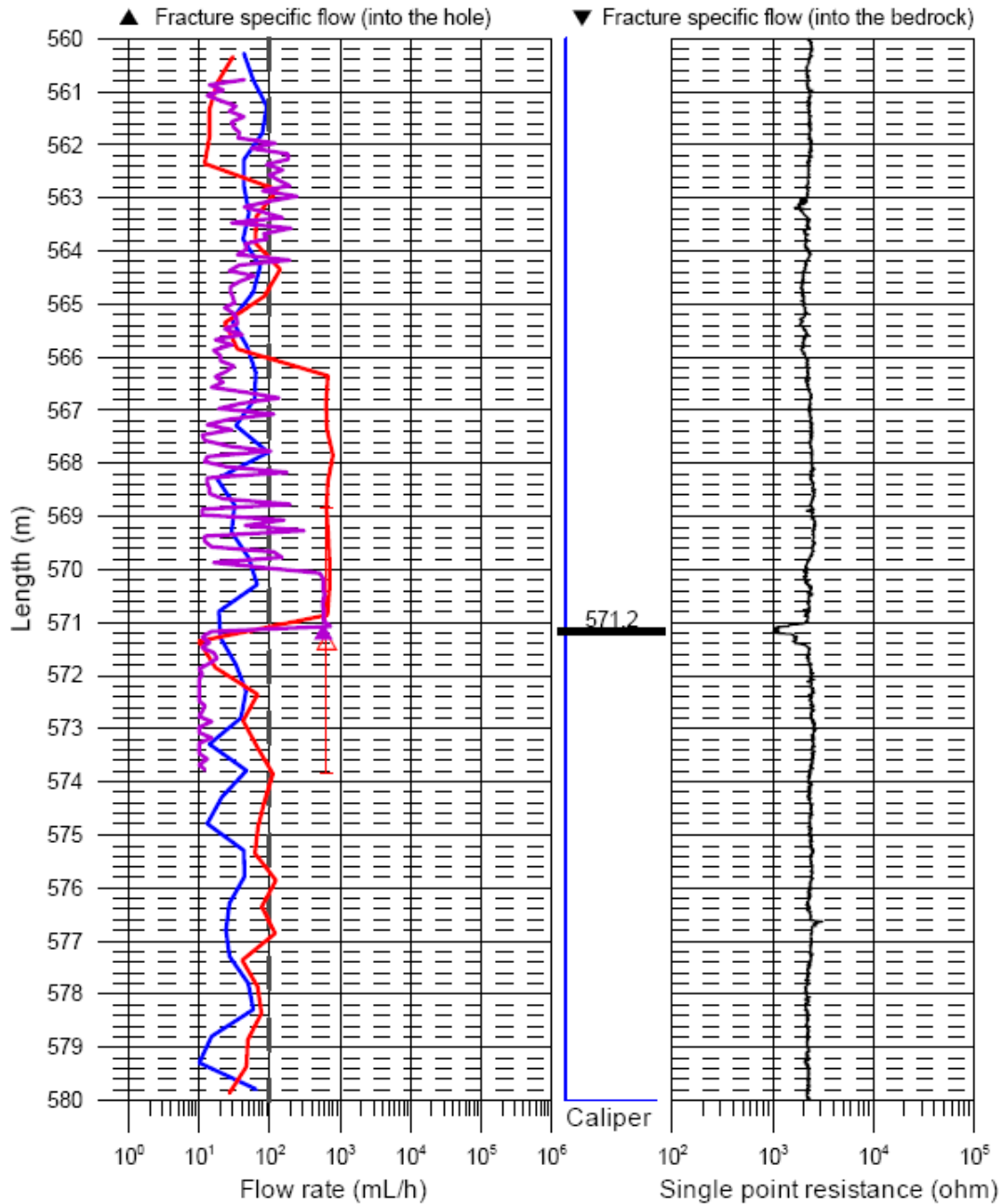


Figure A2-7. Borehole KFM01D: differential flow measurements from 560–580 m including the water bearing fracture zone at 572 m /10/.

Selected BIPS logging images, KFM01D

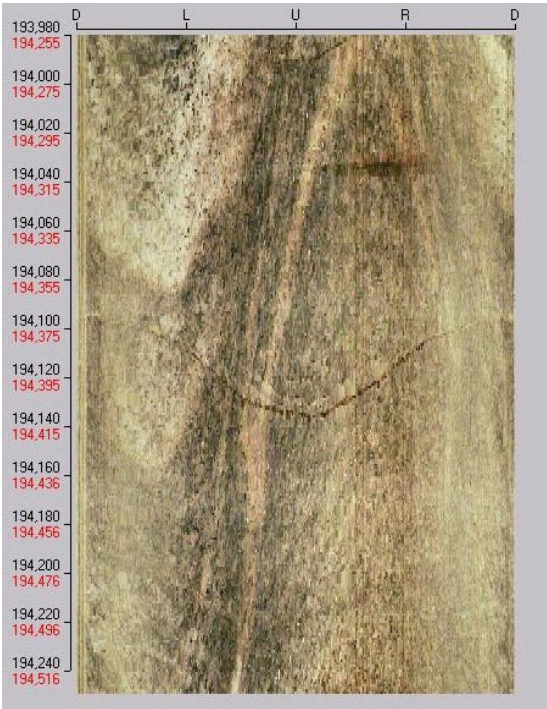


Figure A3-1. Borehole KFM01D: selected BIPS logging image from 194.3 to 194.5 m borehole length, including the water bearing fracture at 194 m. The non-adjusted length is marked with black and the adjusted true length is marked with red /9/.

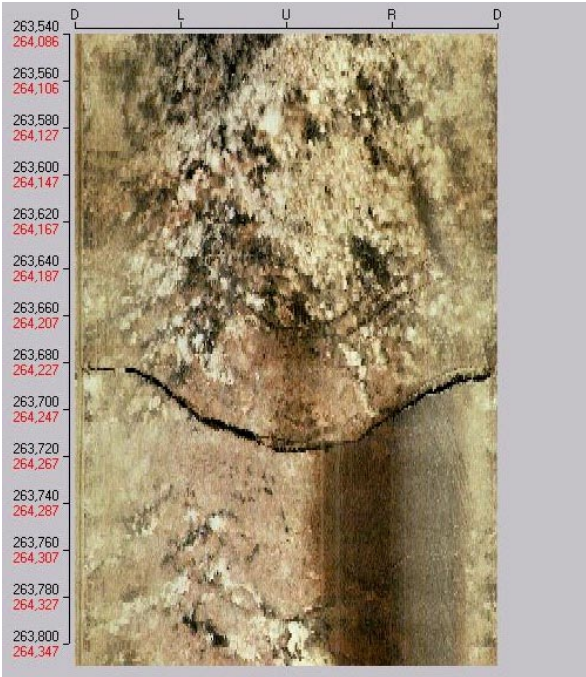


Figure A3-2. Borehole KFM01D: selected BIPS logging image from 264.1 m to 264.3 m borehole length, including the water bearing fracture at 264 m. The non-adjusted length is marked with black and the adjusted true length is marked with red /9/.

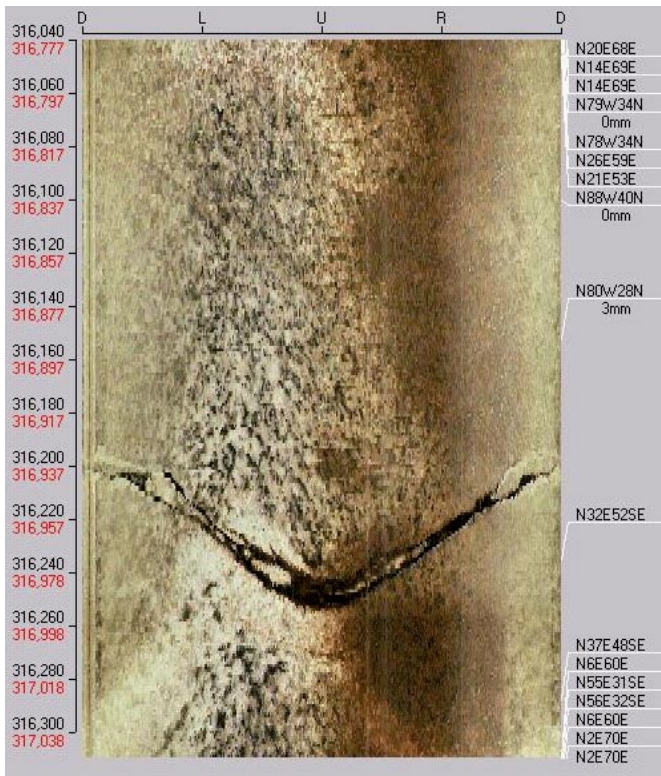


Figure A3-3. Borehole KFM01D: selected BIPS logging image from 316.8 m to 317.0 m borehole length, including the water bearing fracture at 317 m. The non-adjusted length is marked with black and the adjusted true length is marked with red /9/.

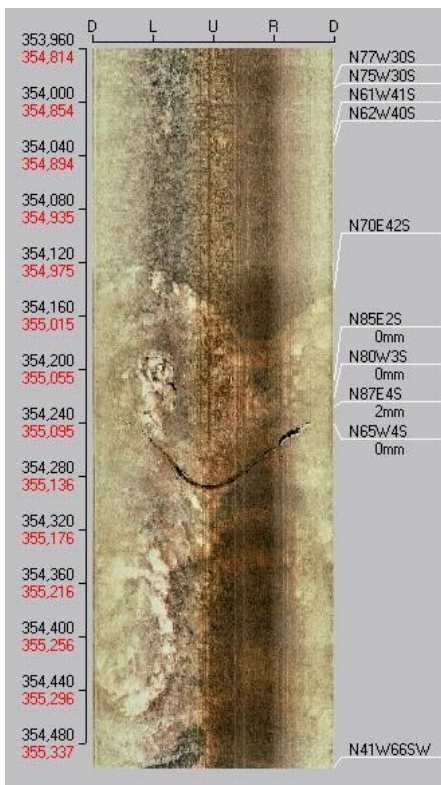


Figure A3-4. Borehole KFM01D: selected BIPS logging image from 354.8 m to 355.3 m borehole length, including the water bearing fracture at 355 m. The non-adjusted length is marked with black and the adjusted true length is marked with red /9/.

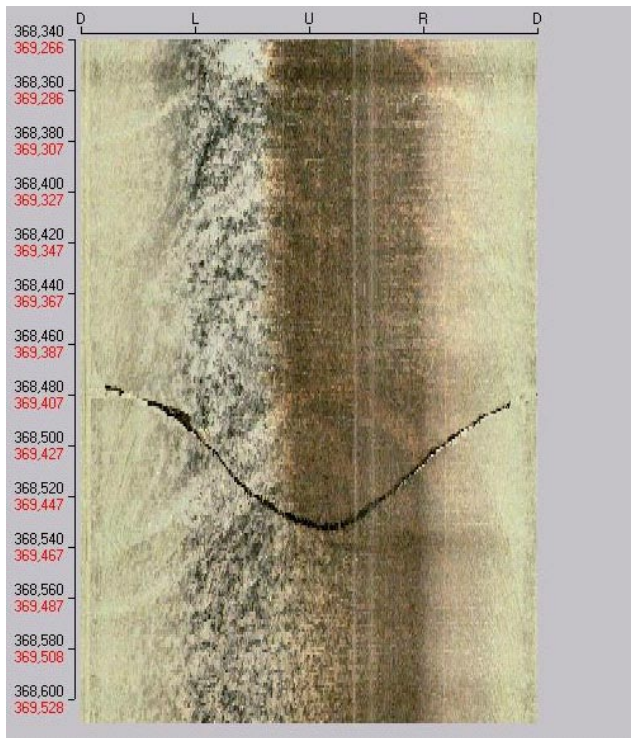


Figure A3-5. Borehole KFM01D: selected BIPS logging image from 369.3 m to 369.5 m borehole length, including the water bearing fracture at 369 m. The non-adjusted length is marked with black and the adjusted true length is marked with red /9/.

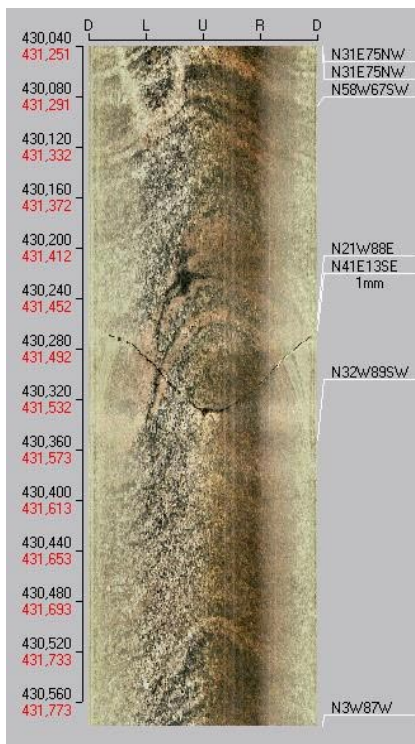


Figure A3-6. Borehole KFM01D: selected BIPS logging image from 431.3 m to 431.8 m borehole length, including the water bearing fracture at 431 m. The non-adjusted length is marked with black and the adjusted true length is marked with red /9/. This is the most well-defined fracture in the investigated section. However, several fractures are present in addition to this one, contributing to the water supply.

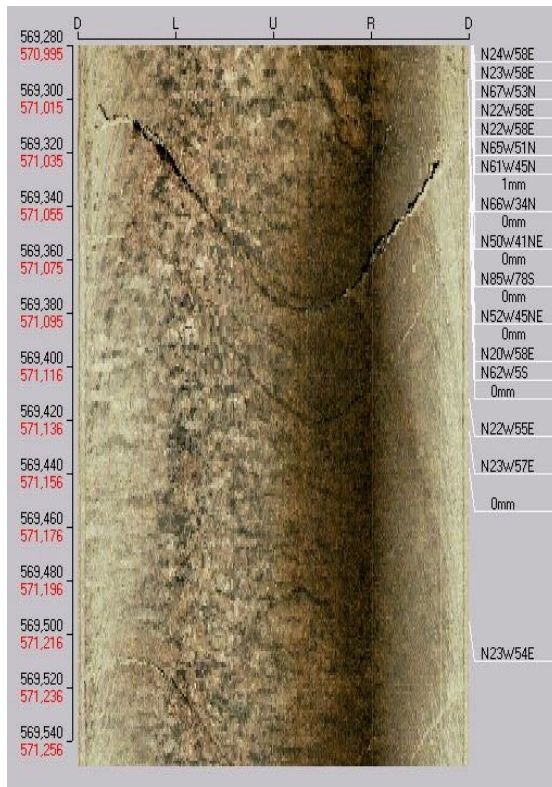


Figure A3-7. Borehole KFM01D: selected BIPS logging image from 571.0 m to 571.3 m borehole length, including the water bearing fracture at 571 m. The non-adjusted length is marked with black and the adjusted true length is marked with red /9/.

Measurement information, KFM01D

Mätapplikation Huvudmeny MATDATOR04

Administration GivarKonf. B.Utr.Konf. Mätning **Larm** Logga In

System Kemkal. LängdKal. Trend Forcerad mätning

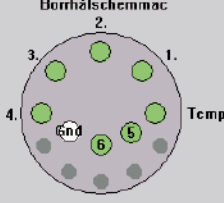
GSM-larm HistLog Till

SKB Svensk Kärnbränslehantering AB 2006-07-04 16:04:37

Givarkonfiguration - S2 Vattenprovtagare Omgivning/Process

Radera Hämta Spara

Borrhålschemmac

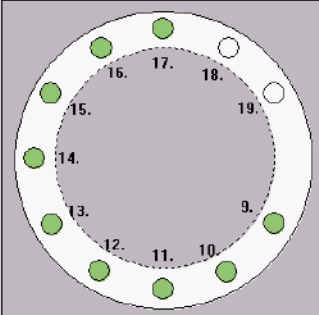


Temp

Radera Hämta Spara

Borrhålschemmac, Id	Borrhålschemmac, Typ	Borrhålschemmac, Id	Borrhålschemmac, Datum	Borrhålschemmac, Nod	Borrhålschemmac, Kanal
Temp	ETB	temp	021029	2	15
1.	EPHB	G20	021111	2	1
2.	ECB	C2-96	021111	2	2
3.	EPHIB	G21	021111	2	3
4.	EREFB	REF	021029	2	4
5.	EPTB	EG	010709	2	5
6.	EAUB	E7	010709	2	6
Gnd				0	0
-	PB		010709	2	9
-	VLARMB		010709	2	20
-	VB		010709	2	19

Ytchemmac



Radera Hämta Spara

Ytchemmac, Id	MYC3	Anm.
9.	EREFTY P9-3	021030 3 4
10.	EPHY P9-4	010925 3 2
11.	EPHY P9-4old	010925 3 7
12.	ECY C12	010925 3 3
13.	EPTY PT-1	010925 3 1
14.	EAUY P8-1	010925 3 5
15.	ETTY e15	010925 4 15
16.	EKONDY 29105	021029 4 10
17.	EOZY Syre	031007 4 17
18.		0 0
19.		0 0
-		0 0
-		0 0
-		0 0
-		0 0
-		0 0
-		0 0
-	Q 578	010925 4 9
-	VYI	3 19

Figure A4-1. Electrode configuration, section 428.5–435.6 m.

Mätapplikation Huvudmeny SKBS3

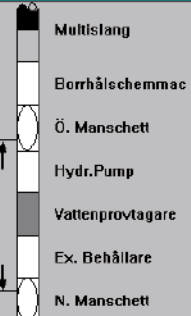
Administration GivarKonf. B.Utr.Konf. Mätning **Larm** Logga Ut

System Kemkal. LängdKal. Trend Forcerad mätning

Larmgränser Referenser **GSM-larm** HistLog Till kgn

SKB Svensk Kärnbränslehantering AB 2006-07-04 16:00:50

Konfiguration av borrhålsutrustning



Typ av enhet	Id	Längd, mm	Avstånd mellan multikoppling och tätning	Dummy Id
Multislang	Multislang S3	1		
Borrhålschemmac	KE 011	1245		ingen
Ö. Manschett	Övre mans S3	2065	500	ingen
Hydr.Pump	BHP 011	2270		ingen
Vattenprovtagare	PVP021	2495		
Ex. Behållare	PVPX011	1475		
N. Manschett	Nedre Mans S3	2065	400	ingen

Lägg till
Ta bort

Total sondlängd: 11615, mm
Längd till Övre Manschett: 2810, mm
Längd till Nedre Manschett: 9950, mm
Sektionslängd: 7140, mm

Figure A4-2. Configuration of downhole equipment, section 428.5–435.6 m.

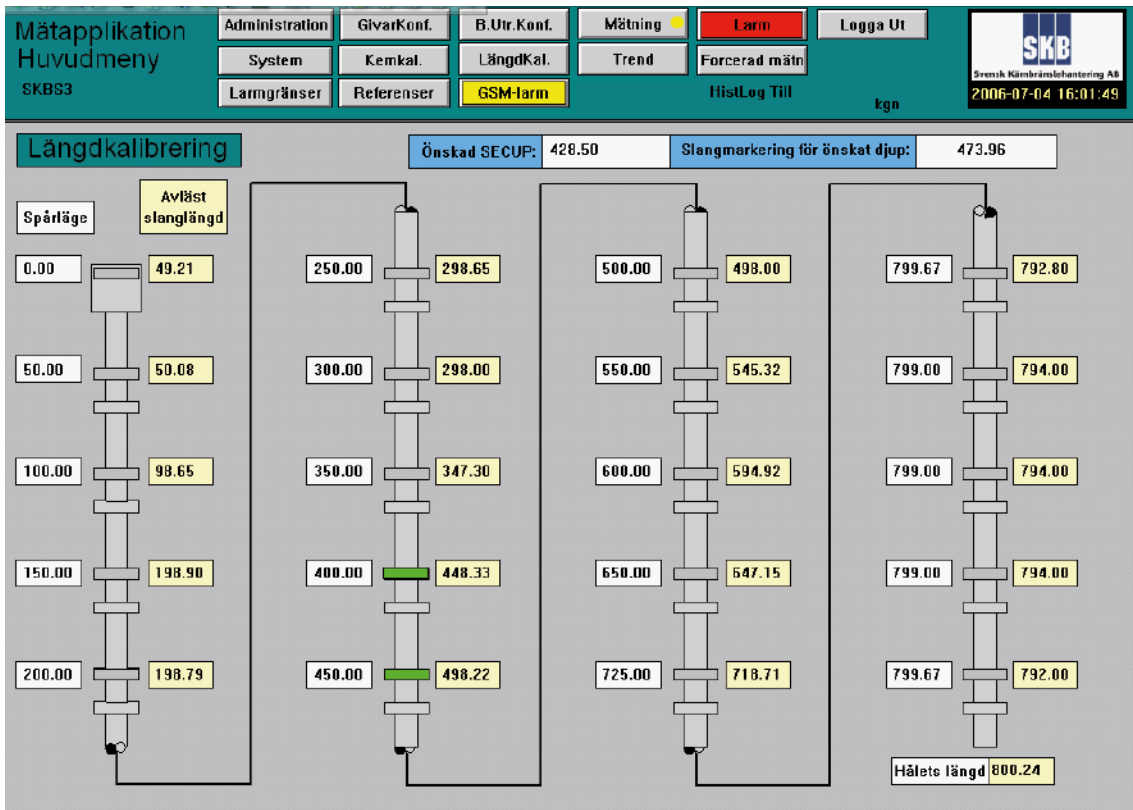


Figure A4-3. Length calibration, section 428.5–435.6 m.

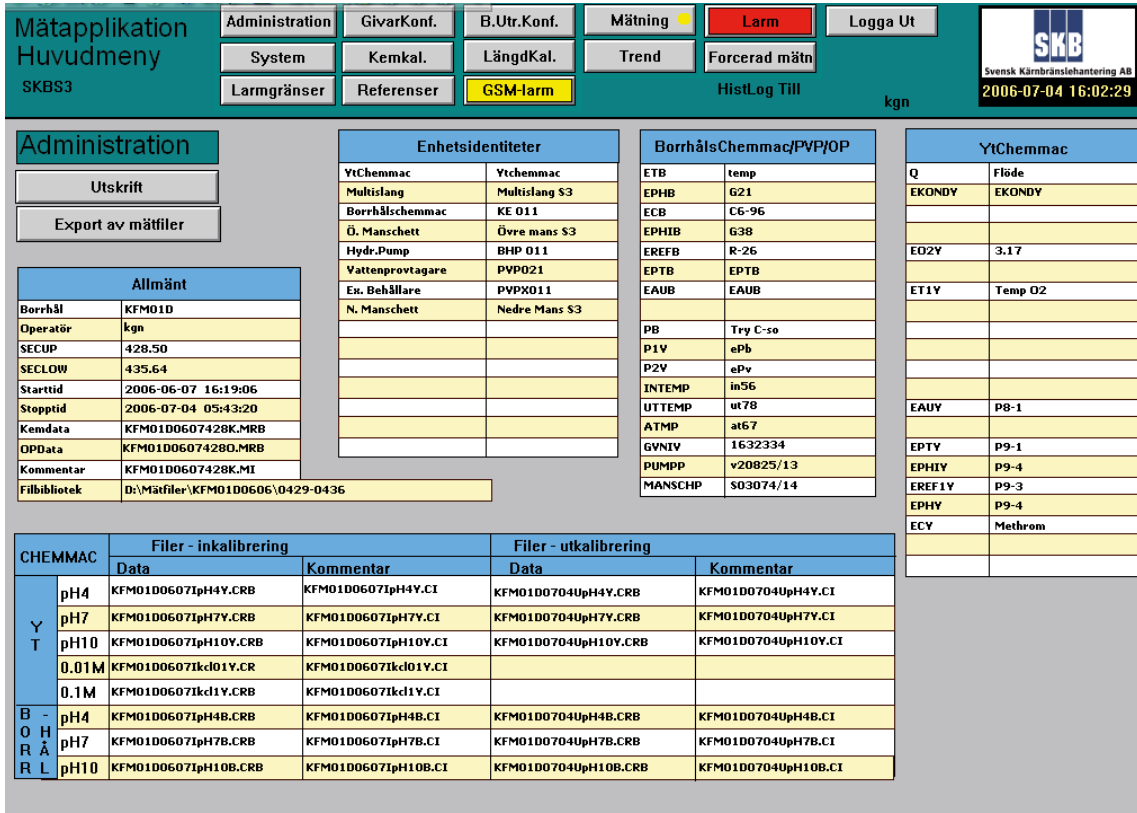


Figure A4-4. Administration, section 428.5–435.6 m.

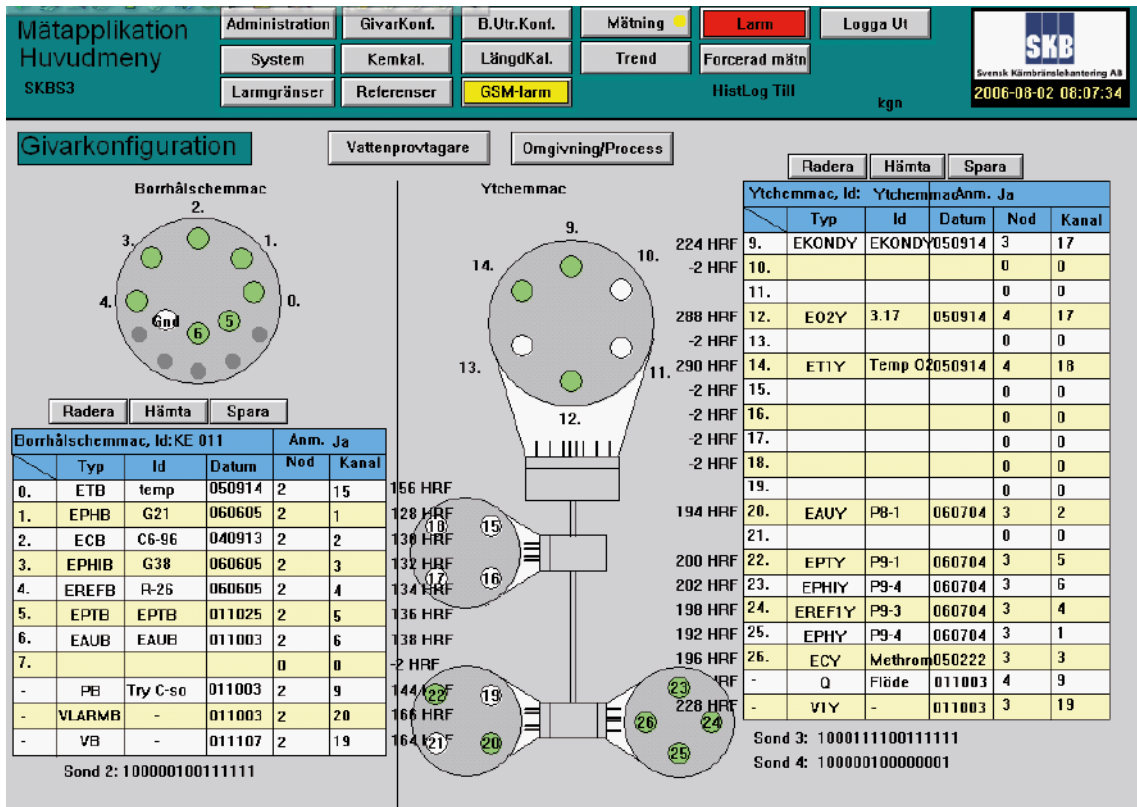


Figure A4-5. Electrode configuration, section 568.0–575.1 m.

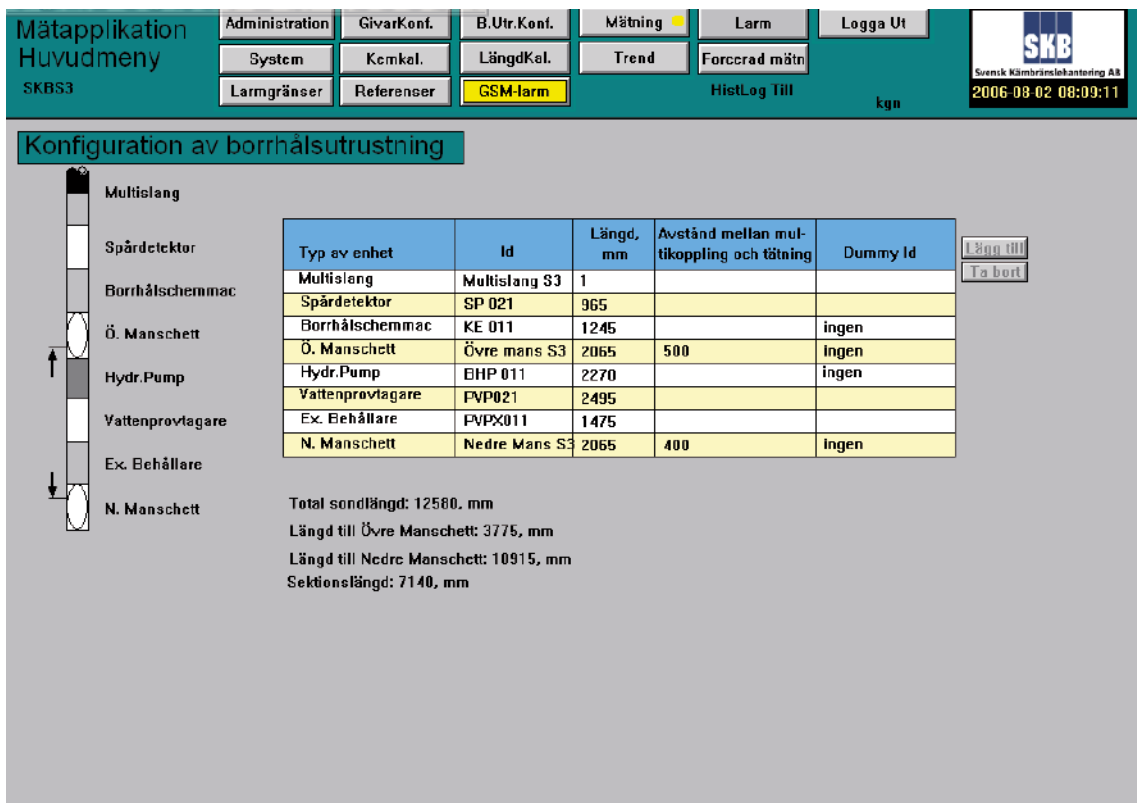


Figure A4-6. Configuration of downhole equipment, section 568.0–575.1 m.

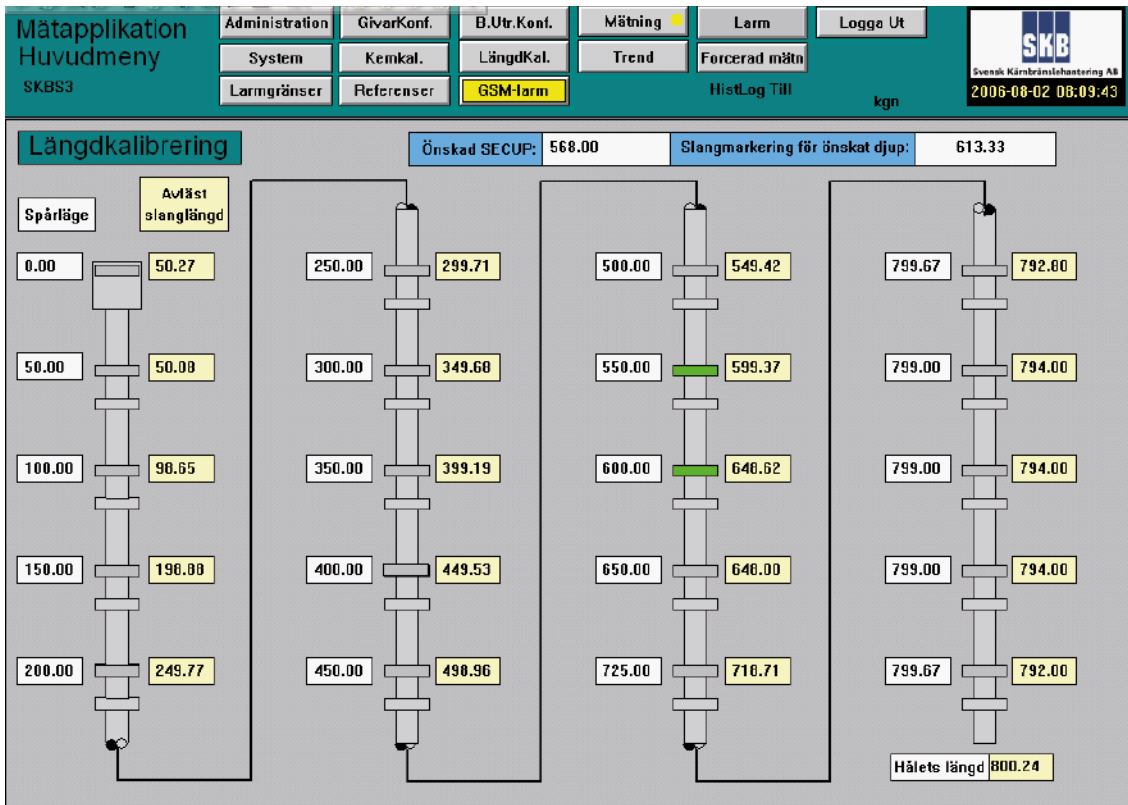


Figure A4-7. Length calibration, section 568.0–575.1 m.

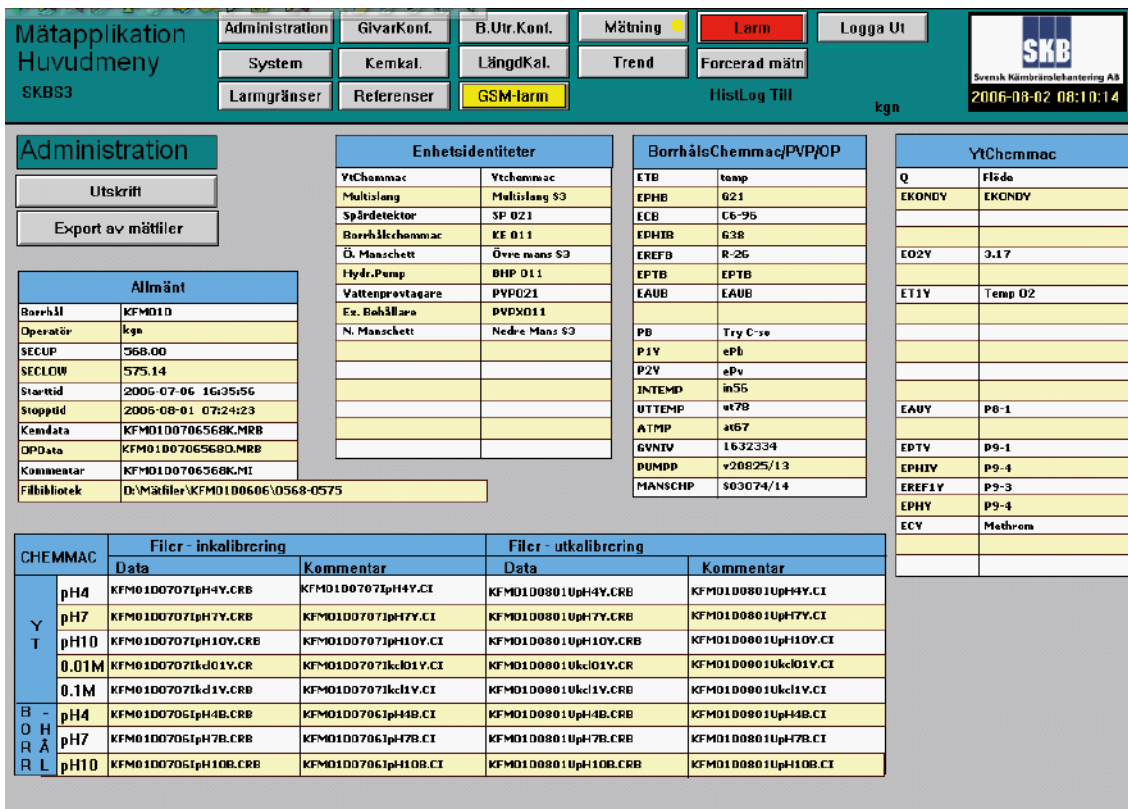


Figure A4-8. Administration, section 568.0–575.1 m.

Flow and pressure measurements, KFM01D

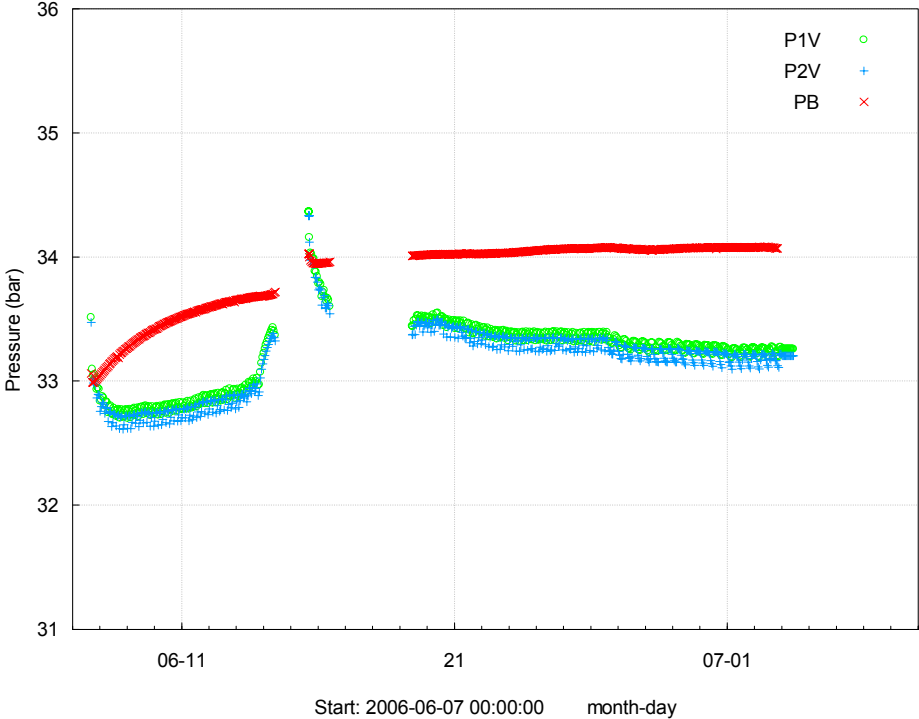


Figure A5-1. Pressure measurements (P1V, P2V and PB), section 428.5–435.6 m. The sensors P1V and P2V measure the pressure within the section and are both placed in the in situ sampling unit. The sensor PB, placed in the borehole Chemmac, measures the pressure above the section.

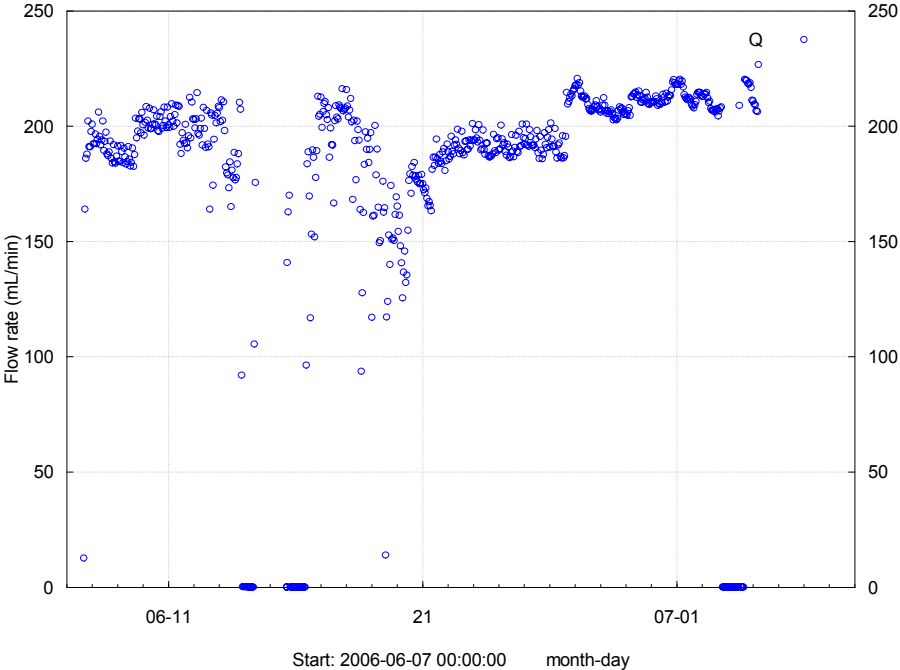


Figure A5-2. Pumping flow rate (Q), section 428.5–435.6 m

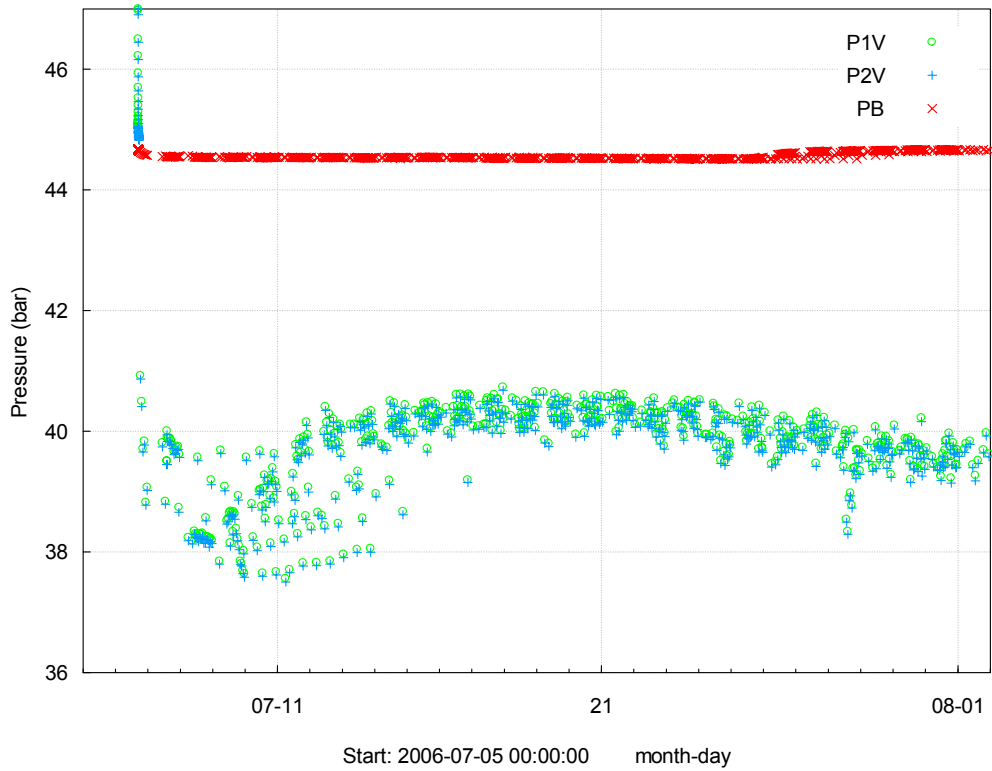


Figure A5-3. Pressure measurements (P1V, P2V and PB), section 568.0–575.1 m. The sensors P1V and P2V measure the pressure within the section and are both placed in the in situ sampling unit. The sensor PB, placed in the borehole Chemmac, measures the pressure above the section.



Figure A5-4. Pumping flow rate (Q), section 568.0–575.1 m

Sampling and analytical methods

Table A6-1. Sample handling routines and analytical methods.

Component group	Component/ element	Sample container (material)	Volume (mL)	Filtering	Preparation/ Conservation*	Analysis method	Analysis within – or delivery time to lab.
Anions 1.	HCO ₃ pH(lab) cond (lab)	Plastic	250	Yes (not in the field)	No	Titration Pot. meas, Cond. meas	The same day – maximum 24 hours
Anions 2	Cl, SO ₄ , Br ⁻ , F ⁻ , I ⁻	Plastic	100	Yes (not in the field)	No	Titration (Cl ⁻) IC (Cl ⁻ , SO ₄ , Br ⁻ , F ⁻) ISE (F ⁻)	Not critical (month)
	Br, I	Plastic	100	Yes (not in the field)	No	ICP MS	Not critical (month)
Cations, Si and S according to SKB class 3	Na, K, Ca, Mg, S(tot), Si(tot), Li, Sr	Plastic (at low conc. acid washed bottles)	100	Yes (not in the field)	Yes (not in the field, 1 mL HNO ₃)	ICP-AES ICP-MS	Not critical (month)
Cations, Si and S according to SKB class 4 and 5	Na, K, Ca, Mg, S(tot), Si(tot), Fe, Mn, Li, Sr	Plastic (Acid washed)	100	Yes (immediately in the field)	Yes (1 mL HNO ₃)	ICP-AES ICP-MS	Not critical (month)
Fe(II), Fe(tot)	Fe(II), Fe(tot)	Plastic (Acid washed)	500	Yes	Yes (5 mL HCl)	Spectrophotometry Ferrozine method	As soon as possible the same day
Hydrogen sulphide	HS ⁻	Glass (Winkler)	About 120×2	No	Ev 1 mL 1 M NaOH+ 1 mL 1M ZnAc	Spectrophotometry	Immediately or if conserved, a few days
Environmental metals	Al, As, Ba, B, Cd, Co, Cr, Cu, Hg, Mo, Ni, P, Pb, V, Zn	Plastic (Acid washed)	100	Yes	Yes (1 mL HNO ₃)	ICP-AES ICP-MS	Not critical (month)
Lantanoids, U, Th * and so on.	Sc, Rb, Y, Zr, I, Sb, Cs, La, Hf, Tl, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, U, Th	Plastic (Acid washed)	100	Yes	Yes (1 mL HNO ₃)	ICP-AES ICP-MS	Not critical (month)

Component group	Component/ element	Sample container (material)	Volume (mL)	Filtering	Preparation/ Conservation*	Analysis method	Analysis within – or delivery time to lab.
Dissolved organic Carbon, dissolved inorganic Carbon	DOC, DIC	Plastic	250 25	Yes	Frozen, transported in isolated bag	UV oxidation, IR Carbon analysator Shimadzu TOC5000	Short transportation time
Total organic Carbon	TOC	Plastic	250 25	No	Frozen, transported in isolated bag	UV oxidation, IR Carbon analysator Shimadzu TOC5000	Short transportation time
Environmental isotopes	² H, ¹⁸ O	Plastic	100	No	– –	MS	Not critical (month)
Tritium	³ H (enhanced.)	Plastic (dry bottle)	500	No	–	LSC	
Chlorine ³⁷	$\delta^{37}\text{Cl}$	Plastic	100	No	–	ICP MS	Not critical (month)
Carbon isotopes	$\delta^{13}\text{C}$, ¹⁴ C (pmc)	Plastic (HDPE)	100×2	No	–	(A)MS	A few days
Sulphur isotopes	$\delta^{34}\text{S}$	Plastic	500–1,000	Yes	–	Combustion, MS	No limit
Strontium-isotopes	⁸⁷ Sr/ ⁸⁶ Sr	Plastic	100	Yes	–	TIMS	Days or Week
Uranium and Thorium isotopes	²³⁴ U, ²³⁸ U, ²³⁰ Th,	Plastic	50 1,000	Nej	–	Chemical separat. Alfa/gamma spectrometry	No limit
Boron isotopes	¹⁰ B/ ¹¹ B	Plastic	100	Yes	Yes (1 mL HNO ₃)	ICP–MS	No limit
Radon and Radium isotopes	²²² Rn, ²²⁶ Ra	Plastic	500–1,000	No	No	EDA, RD-200	Immediate transport
Dissolved gas (content and composition)	Ar, N ₂ , CO ₂ , O ₂ , CH ₄ , H ₂ , CO, C ₂ H ₂ , C ₂ H ₄ , C ₂ H ₆ , C ₃ H ₈	Cylinder of stainless steel	200	No	No	GC	Immediate transport
Colloids	Filter series	Polycarbonate filter	0.4, 0.2 and 0.05 μm	–	Ar atmosphere	ICP-AES ICP-MS	Immediate transport
Fractionation; Humic and fulvic acids, inorganic constituents	< 1,000 D > 1,000 D but <5,000 D > 5,000 D	Fractions are collected in plastic bottles	250	–	N ₂ atmosphere	UV oxidation, IR (DOC)	Immediate transport
Archive samples with acid	–	Plast (washed in acid)	100×2**	Yes	Yes (1 mL HNO ₃)	–	Storage in freeze container
Archive samples without acid	–	Plastic	250×2**	Yes	No	–	Storage in freeze container
Carbon isotopes in humic and fulvic acids	$\delta^{13}\text{C}$, ¹⁴ C (pmc)	DEAE cellulose (anion exchanger)	–	–	–	(A)MS	A few days

Component group	Component/ element	Sample container (material)	Volume (mL)	Filtering	Preparation/ Conservation*	Analysis method	Analysis within – or delivery time to lab.
Nutrient salt + silicate	NO ₂ , NO ₃ , NO ₂ +NO ₃ , NH ₄ , PO ₄ , SiO ₄	Sample tubes, plastic	25×2 250	Yes (in the field)	No, frozen immediately***	Spectrophotometry	Short transportation time
Total concentrations of Nitrogen and Phosphorous	N-tot, P-tot	Plastic	100	No	No, frozen immediately***	Spectrophotometry	Short transportation time
Particulate Carbon, Nitrogen and Phosphorous	POC, PON, POP	Plastic	1,000	Yes (within 4 h) prepared filters. Blank filters	Filtering, the filters are frozen immediately 2 filters/sample	Elementar-analysator (N, C) own method 990121 (P)	Short transportation time
Chlorophyll	Chlorophyll a, c and pheopigment	Plastic	1,000–2,000	Yes (within 4 h)	Filtering, the filters are frozen immediately	Spectrophotometry Fluorometry	Short transportation time
Oxygen	Dissolved O ₂	Winkler, glass	2×ca 120	No	Mn (II) reagent Iodide reagent	Spectrophotometry SIS SS-EN 25813	Within 3 days
Archive samples for supplementary radio nuclides		Plastic	5,000	No	50 mL HNO ₃	–	Storage in freeze container

* Suprapur acid is used for conservation of samples.

** Minimum number. The number of archive samples can vary depending on the number of similar samples collected at the same occasion.

*** The sample is transported in frozen condition to the laboratory. It is possible that the silicate concentration can change due to polymerisation for this reason.

Abbreviations and definitions:

IC	Ion chromatograph
ISE	Ion selective electrode
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometry
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
INAA	Instrumental Neutron Activation Analysis
MS	Mass Spectrometry
TIMS	Thermal Ionization Mass Spectrometer
LSC	Liquid Scintillation Counting
(A)MS	(Accelerator) Mass Spectrometry
GC	Gas Chromatography

Table A6-2. Reporting limits and measurement uncertainties.

Component	Method	Reporting limits or range	Unit	Measurement uncertainty ²	"Total" uncertainty ³
HCO ₃	Alkalinity titration	1	mg/L	4%	< 10%
Cl ⁻	Mohr- titration	> 70	mg/L	5%	< 10%
Cl ⁻	IC	1–100		6%	10%
SO ₄	IC	1	mg/L	10%	15%
Br ⁻	IC	0.2	mg/L	9%	20%
Br ⁻	ICP	0.001		15%	
F ⁻	IC	0.1	mg/L	10%	20%
F ⁻	Potentiometric	–		–	
I ⁻	ICP	0.001	mg/L	15%	20%
Na	ICP	0.1	mg/L	4%	10%
K	ICP	0.4	mg/L	6%	15%
Ca	ICP	0.1	mg/L	4%	10%
Mg	ICP	0.09	mg/L	4%	10%
S(tot)	ICP	0.160	mg/L	21%	15%
Si(tot)	ICP	0.03	mg/L	4%	15%
Sr	ICP	0.002	mg/L	4%	15%
Li	ICP	0.2 ¹ 2	mg/L	10%	20%
Fe	ICP	0.4 ¹ 4	mg/L	6%	10%
Mn	ICP	0.03 ¹ 0.1	µg/L	8%	10%
Fe(II), Fe(tot)	Spectrophotometry	0.02 (DL=0.005 mg/L)	mg/L	15% (> 30 µg/L)	20%
HS ⁻	Spectrophotometry	SKB 0.03 (DL=0.02)	mg/L	10%	30%
NO ₂ as N	Spectrophotometry	0.1	µg/L	2%	20%
NO ₃ as N	Spectrophotometry	0.2	µg/L	5%	20%
NO ₂ + NO ₃ as N	Spectrophotometry	0.2	µg/L	0.2 (0.2–20 µg/L) 2% (> 20 µg/L)	20%
NH ₄ as N	Spectrophotometry	0.8	µg/L	0.8 (0.8–20 µg/L) 5% (> 20 µg/L)	20%
		50 (SKB)		20%	
PO ₄ as P	Spectrophotometry	0.7	µg/L	0.7 (0.7–20 µg/L) 3% (> 20 µg/L)	20%
SiO ₄	Spectrophotometry	1	µg/L	3% (> 200 µg/L)	–
O ₂	Jodometric titration	0.2–20	mg/L	5%	–
Chlorophyll a, c pheopigment ⁴	See Table A1-2	0.5	µg/L	5%	–
PON ⁴	See Table A1-2	0.5	µg/L	5%	–
POP ⁴	See Table A1-2	0.1	µg/L	5%	–
POC ⁴	See Table A1-2	1	µg/L	4%	–
Tot-N ⁴	See Table A1-2	10	µg/L	4%	–
Tot-P ⁴	See Table A1-2	0.5	µg/L	6%	–
Al, Zn	ICP	0.2	µg/L	12%	20% ⁵
Ba, Cr, Mo, Pb	ICP	0.01	µg/L	7–10%	20% ⁵
Cd, Hg	ICP	0.002	µg/L	9 resp 5%	20% ⁵
Co, V	ICP	0.005	µg/L	8 resp 5%	20% ⁵
Cu	ICP	0.1	µg/L	8%	20% ⁵
Ni	ICP	0.05	µg/L	8%	20% ⁵
P	ICP	1	µg/L	6%	10%
As	ICP	0.01	µg/L	20%	Correct order of size (low conc.)

Component	Method	Reporting limits or range	Unit	Measurement uncertainty ²	"Total" uncertainty ³
La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb	ICP	0.0051 0.05	µg/L	10%	Correct order of size (low conc.)
Sc, In, Th	ICP	0.051 0.5	µg/L	10%	Correct order of size (low conc.)
Rb, Zr, Sb, Cs, Tl	ICP	0.0251 0.25	µg/L	10%	Correct order of size (low conc.)
Y, Hf	ICP	0.0051 0.05	µg/L	10%	Correct order of size (low conc.)
U	ICP	0.0011 –	µg/L	12%	Correct order of size (low conc.)
DOC	See Table A1-1	0.5	mg/L	8%	30%
TOC	See Table A1-1	0.1	mg/L	10%	30%
δ ² H	MS	2	‰ SMOW ⁵	1‰	–
δ ¹⁸ O	MS	0.1	‰ SMOW ⁵	0.2‰	–
³ H	LSC	0.8 or 0.1	TU6	0.8 or 0.1	Correct order of size
³⁷ Cl	ICP MS	0.2‰ (20 mg/L)	‰ SMOC ⁷	–	–
δ ¹³ C	A (MS)	–	‰ PDB ⁸	–	–
¹⁴ C pmc	A (MS)	–	PMC9	–	–
δ ³⁴ S	MS	0.2‰	‰ CDT ¹⁰	0.3‰	–
⁸⁷ Sr/ ⁸⁶ Sr	TIMS	–	No unit (ratio) ¹¹	–	–
¹⁰ B/ ¹¹ B	ICP MS	–	No unit (ratio) ¹¹	–	–
²³⁴ U, ²³⁵ U, ²³⁸ U, ²³² Th, ²³⁰ Th	Alfa spectr.	0.0005	Bq/L ¹³	5%	–
²²² Rn, ²²⁶ Rn	LSC	0.03	Bq/L	5%	–

1. Reporting limits at salinity ≤ 0.4‰ (520 mS/m) and ≤ 3.5‰ (3,810 mS/m) respectively.

2. Measurement uncertainty reported by consulted laboratory, generally 95% confidence interval.

3. Estimated total uncertainty by experience (includes effects of sampling and sample handling).

4. Determined only in surface waters and near surface groundwater.

5. Per mille deviation¹³ from SMOW (Standard Mean Oceanic Water).

6. TU=Tritium Units, where one TU corresponds to a Tritium/hydrogen ratio of 10⁻¹⁸ (1 Bq/L Tritium = 8.45 TU).

7. Per mille deviation¹³ from SMOC (Standard Mean Oceanic Chloride).

8. Per mille deviation¹³ from PDB (the standard PeeDee Belemnite).

9. The following relation is valid between pmC (percent modern carbon) and Carbon-14 age: pmC = 100 × e^{((1950-y-1.03t)/8274)} where y = the year of the C-14 measurement and t = C-14 age.

10. Per mille deviation¹³ from CDT (the standard Canyon Diablo Troilite).

11. Isotope ratio without unit.

12. The following expressions are applicable to convert activity to concentration, for uranium-238 and thorium-232:

$$1 \text{ ppm U} = 12.4 \text{ Bq/kg}^{238}\text{U}$$

$$1 \text{ ppm Th} = 3.93 \text{ Bq/kg}^{232}\text{Th}$$

13. Isotopes are often reported as per mill deviation from a standard. The deviation is calculated as:

$$\delta\text{‰} = 1,000 \times (K_{\text{sample}} - K_{\text{standard}}) / K_{\text{standard}}, \text{ where } K = \text{the isotope ratio and } \text{‰} = {}^2\text{H}, {}^{18}\text{O}, {}^{37}\text{Cl}, {}^{13}\text{C} \text{ or } {}^{34}\text{S} \text{ etc.}$$

Laser-induced breakdown colloid detection in natural ground water from Forsmark borehole KFM01D, section 428.5–435.6 m and 568.0–575.14 m

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Introduction

Colloid analysis has been performed in ground water samples collected during the site investigation program at Forsmark, Sweden. Two samples from the same borehole have been collected in a stainless steel cylinder each, avoiding water contact with the atmosphere. They were sent to INE for laboratory analysis. Colloid analysis was subsequently performed by the laser-induced breakdown detection (LIBD) in the laboratory using a closed flow-through detection cell again without atmosphere contact. Furthermore, a thorough chemical analysis of the water samples was performed (... not subject of this order).

It is supposed that the geological situation is similar to that found at various places in the Äspö tunnel. The aim of this study is to investigate the natural amount of background colloids in this specific borehole and to compare the data with those obtained from other sites.

Experimental

LIBD instrumentation

The principle of LIBD is based on the generation of a dielectric breakdown in the focus region of a pulsed laser beam. As the threshold energy (irradiance) to induce a breakdown is lower for solids than for liquids or gas, the breakdown can be generated selectively in particles dispersed in solution at a suitable pulse energy.

A schematic diagram of the mobile LIBD set-up used in the present work is shown Figure A7-1. A pulsed laser beam with a frequency of 15 Hz at 532 nm wavelength from a small Nd:YAG-laser (Continuum Minilite I) is focused (15 mm focal length) into the center of a flow-through detection cell, after passing through a variable attenuator and a beam splitter. The plasma generated at a breakdown event is monitored by a microscope equipped with a CCD monochrome camera triggered by the incident laser pulse and recorded by a PC controlled image processing system. A breakdown shock wave propagated in the sample solution is detected simultaneously by an acoustic sensor (piezoelectric transducer) that is connected to the surface of the cell. Both, the energy and the acoustic signal are recorded by an analog-digital converter interface in a PC. Colloid concentrations are derived from the respective breakdown probability, represented by the number of breakdown events per number of laser shots, and the range of breakdown events within the laser beam axis determined by optical inspection of the laser focus area within the flow through cell. Colloid number concentrations (Pt/L) are given relative to a calibration with polystyrene reference colloids. Mass concentrations are calculated by assuming an average colloid density of 2.7 g/ml and spherical particle shape. A more detailed description of data evaluation is given in /1/.

The mobile instrumentation of LIBD is combined with a Millipore ultra-pure water processing unit for on-line cleaning the flow-through detection cell of LIBD and to allow for the frequent control of the instrument background. The whole system, which is set up to a compact mobile unit can be transported by a van for field experiments.

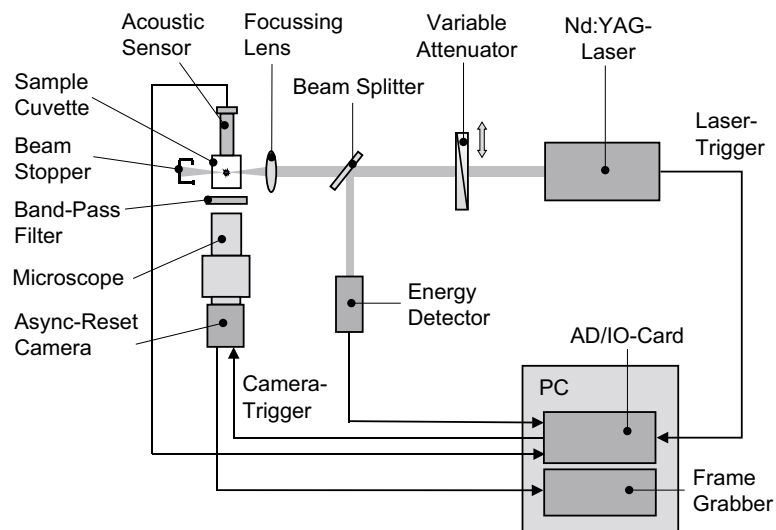


Figure A7-1. Schematic diagram of the mobile laser-induced breakdown detection system.

High-pressure flow-through detection cell

The LIBD has been operated in the CRR migration experiments (Grimsel Test-Site, Switzerland)^{1/} under low pressure conditions with commercially available quartz detection cells (fluorescence cells) for batch (laboratory experiments) or flow-through sampling. These cells have a sample volume of 3 ml at 10 mm absorption length. A new flow-through detection cell has been developed constraining water pressures of about 35 bar for in situ investigations in the Äspö Hard Rock Laboratory access tunnel (Sweden) ^{2/}, and in the Kraftwerke Oberhasli (KWO) access tunnel close to the Grimsel Test Site ^{3/}. This detection cell has also been applied in connection with a borehole sampling system for the detection of ground water colloids sampled at a natural analogue site (Ruprechtov, Czech Republic).

Figure A7-2 presents the high-pressure detection cell developed by INE. Without changing the optical path of the laser light, the detection cell fits into the same mount used for the silica cell. The new cell, fabricated from PEEK (polyether etherketone) is lined outside with a stainless steel housing (black parts in Figure A7-2). Four optical windows, one at each side are applied for the passing laser light (absorption length 12 mm), the microscope and for inspection. They consist of sapphire with 2 mm thickness. The ground water flow enters the inner cell volume of 0.8 ml from the base via a PEEK tubing. The outlet is on the top of the cell. The high-pressure detection cell is successfully tested for a water pressure up to 60 bar.

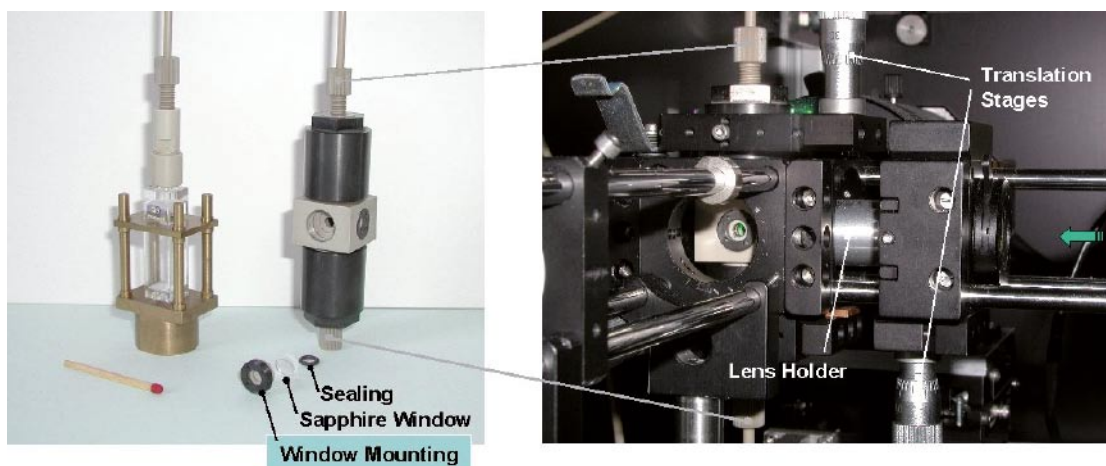


Figure A7-2. LIBD high-pressure flow-through detection cell. (left: conventional flow-through silica detection cell).

Borehole sampling

One sample (PVB 220) was taken at July 4, 2006 from Forsmark borehole KFM01D from a borehole section between 428.5–435.6 m. The vertical depth was approximately 340 m with a measured pressure in the borehole section of 33.5 bar.

At August 1, 2006 a second sample (PVB 9506-10) was taken in the same borehole but from a section between 568–575.14 m, in a vertical depth of 442 m (hydrostatic pressure 41 bar).

The stainless steel cylinders (Figure A7-3) are ground water sampling cylinders from SKB with a sample volume of about 190 ml each. They are supplied with an internal piston and 3 valves. Further information concerning the sampling procedure is given elsewhere.

At July 7 the first cooled sample (PVB 220) arrived at the INE where it has been stored in a fridge (Temp. about 10 deg. C) until colloid detection at July 11, 2006. The second sample (PVB 9506-10) arrived at August 2, was stored in the same way until colloid detection at August 7, 2006.

Configuration of laboratory experiments

Each sampling cylinder is connected with the LIBD detection cell and the detection cells for pH-, Eh-, electrical conductivity-, oxygen content-detection and for taking samples for chemical ground water analysis. A scheme of the corresponding laboratory setup is plotted in Figure A7-4 with an image of the experimental configuration in Figure A7-5.



Figure A7-3. SKB stainless steel sampling cylinder. (left: piston side, right: mounting adapter side).

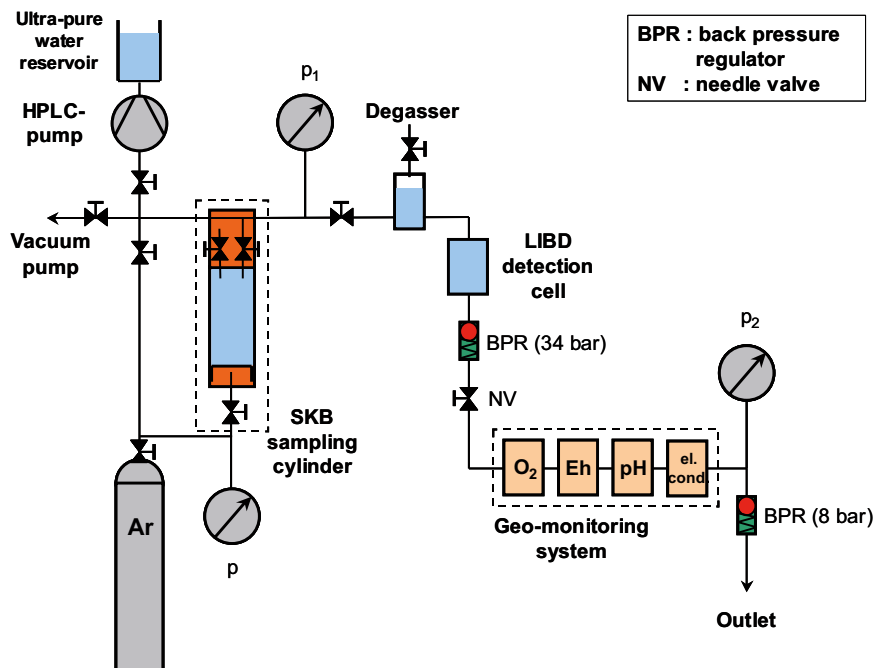


Figure A7-4. Scheme of the laboratory setup for in-line LIBD colloid analysis and ground water monitoring.



Figure A7-5. Experimental configuration.

At first the tubings around the sampling cylinder are intensively cleaned by evacuation and flushing with Argon. Then a HPLC-pump is used to fill all tubings on the water side of the sampling cylinder with ultra-pure water and to set the water pressure according the hydrostatic pressure of the samples. This was the expected water pressure in the sampling cylinder. The gas side of the sampling cylinder is then filled with the corresponding Argon gas pressure.

Now one of the top valves of the sampling cylinder can be opened without contact of the sampled ground water with atmosphere oxygen. With Argon gas the ground water is pressed out from the sampling cylinder through the LIBD detection cell via a degasser to avoid occasionally occurring gas bubbles which interfere the colloid detection. Behind the LIBD system additional detection cells with pressure resistant electrodes ($p < 15$ bar) for Oxygen, pH, Eh, a sensor for electrical conductivity and a sensor for the pressure detection are arranged downstream.

The Eh is detected with an electrode from Hamilton (Oxytrode). Before the sampling outlet a pressure regulator (PR), set to 8 bar, is installed. This overpressure in the whole system avoids further contact to oxygen. Data of this geo-monitoring system are stored on a personal computer with a data logger as a function of time. This allows to separate temporary fluctuating data, especially during the starting period when the detection cell and the geo-monitoring system are contaminated and does not contain the sampled ground water, respectively.

Ground water batch samples are collected at the outlet of the pressure regulator for chemical analysis with ICP-AES, ICP-MS and for the detection of inorganic carbon (IC) and dissolved organic carbon (DOC).

Additionally, track-etched Polycarbonate filter samples (pore size 50 nm) have been taken for colloid analysis with REM/EDX.

Results

Data from geo-monitoring as well as the chemical composition of the two ground water samples, are displayed in Table A7-1.

The detected Eh value (Table A7-1) demonstrates that reducing geochemical conditions are maintained within the sampling container during transport, storage and colloid detection. This indicates that a significant intrusion of atmosphere oxygen did not occur. In the ground water sample from container 9506-10 an oxygen concentration of 20 µg/l was detected. Though this value is higher than the sensors detection limit (0.001 ppm) it might be caused by sensor instabilities (Table A7-1) during the measurement.

The ground water pH of 7.9 is equivalent to the pH detected so far in other Forsmark (7.3–8.4) and Äspö ground water samples (7.3–7.8). The chemical composition of the ground water is characterized mainly by the high salinity with about 5,000 mg/l chloride. DOC data /5/ for other samples from Äspö with similar chloride content correspond with those detected in ground water from both sampling containers.

Table A7-1. Monitored data of pH, Eh, el. conductivity, oxygen content and chemical analysis of the ground water samples from Forsmark borehole KFM01D.

Borehole ID		KFM01D	KFM01D
Secup	m	428.5	568
Seclow	m	435.6	575.14
Sampling depth	m	340	442
Hydr. pressure	bar	33.5	41
Container ID		SKB PVB 220	SKB PVB 9506-10
Sample ID		FOR5-3	FOR6-2
<hr/>			
pH		7.97	7.91
Redox (Ag/AgCl)	mV	-255	-232
Eh (SHE)	mV	-41	-18
el. cond.	mS/m	1,397	1,574
O ₂ content	mg/l	0.003	0.02
Na ⁺	mg/l	1,387	1,523
K ⁺	mg/l	12.7	10.3
Ca ²⁺	mg/l	1,439	1,801
Mg ²⁺	mg/l	20.15	9.69
HCO ₃ ⁻ (IC)	mg/l	34.1	15.6
Cl ⁻	mg/l	4,666	5,466
SO ₄ ²⁻	mg/l	105.3	21.1
Br ⁻	mg/l	< 0.01	45,1
F ⁻	mg/l	8.3	9.3
Si ⁴⁺	mg/l	1.25	4.37
Fe-ICP	mg/l	0.53	0.37
Mn ²⁺	mg/l	0.22	0.098
Li ⁺	mg/l	0.038	0.028
Sr ²⁺	mg/l	15.32	18.5
DOC	mg/l	3.6	3.06
IC	mg/l	6.7	3.06

Data determined with the laser-induced breakdown detection system are listed in Table A7-2. The volume of the sample was sufficient to perform several colloid measurements for each container.

With image processing average colloid diameters of 170–340 nm with corresponding mass concentrations of 5–12 µg/l are calculated for the ground water sample from container PVB220. Higher colloid concentrations of 110–190 µg/l and average colloid diameters of 730–960 nm are evaluated for the ground water from sampling container PVB9506-10 (lower borehole section). Those colloid concentrations in the latter sample are more than 1 order of magnitude higher than colloid concentrations found in other Forsmark ground water. Measured concentrations are however lower than those found in water samples after intense access of oxygen.

As already mentioned above, the low redox potentials suggest that colloid generation by oxygen access is probably less relevant. Colloid sizes derived from LIBD analysis are quite high and close to the µm range. Actually such particles can hardly be assigned as ‘colloids’. Particles of this size should be subject to sedimentation and certainly not remain stable in solution. We assume that those particles might be artifacts due to oxygen access during measurement or particle impurities imported during sampling due to either insufficient flushing of the container or entrainment from the sediment. Other potential sources for artifacts are:

- corrosion of container, valve, sealing materials,
- decrease of water pressure and precipitation of calcium carbonate.

Table A7-2. LIBD data with average colloid diameter and colloid concentration of the analyzed ground water from Forsmark borehole KFM01D.

Borehole ID		KFM01D		KFM01D	
Secup	m	428.5		568	
Seclow	m	435.6		575.14	
Sampling depth	m	340		442	
Hydr. pressure	bar	33.5		41	
Container ID		SKB PVB 220		SKB PVB 9506-10	
Sample ID		FOR5b	FOR5c	FOR6a	FOR6b
BD-events		1,312	779	1,176	1,261
Trigger-pulses		20,000	20,000	8,000	8,000
BD-probability		0.066	0.039	0.147	0.158
Colloid diam.	nm	342	257	728	750
Colloid mass conc.	µg/l	12.6	4.52	108	122
<i>Sample ID</i>		<i>FOR5d</i>		<i>FOR6c</i>	<i>FOR6d</i>
BD-events		285		1,241	1,291
Trigger-pulses		9,484		8,000	8,000
BD-probability		0.03		0.155	0.161
Colloid diam.	nm	172		911	952
Colloid mass conc.	µg/l	5.9		168	189
<i>Sample ID</i>				<i>FOR6e</i>	
BD-events				1,259	
Trigger-pulses				8,000	
BD-probability				0.157	
Colloid diam.	nm			964	
Colloid mass conc.	µg/l			187	

In the Äspö colloid project /5/ a series of boreholes along the access tunnel have been sampled and their ground water was directly analyzed with the mobile LIBD system. A correlation was drawn (Figure A7-6) between the colloid concentration and the Cl⁻ concentration of the ground water. At a Cl⁻ concentration of about 4,000 mg/l a remarkable decrease of the colloid concentration over 4 orders of magnitude down to the LIBD detection limit of about 10 ng/l was observed.

The Forsmark KFM01D sample data from borehole section 428.5–435.6 m fits quite well into this correlation. According to the colloid concentration correlation with ground water salinity we should expect a lower colloid concentration for the sample from the deeper borehole section 568–575.14 m (Figure A7-6). Possible reasons for the somewhat high particle concentration are discussed above.

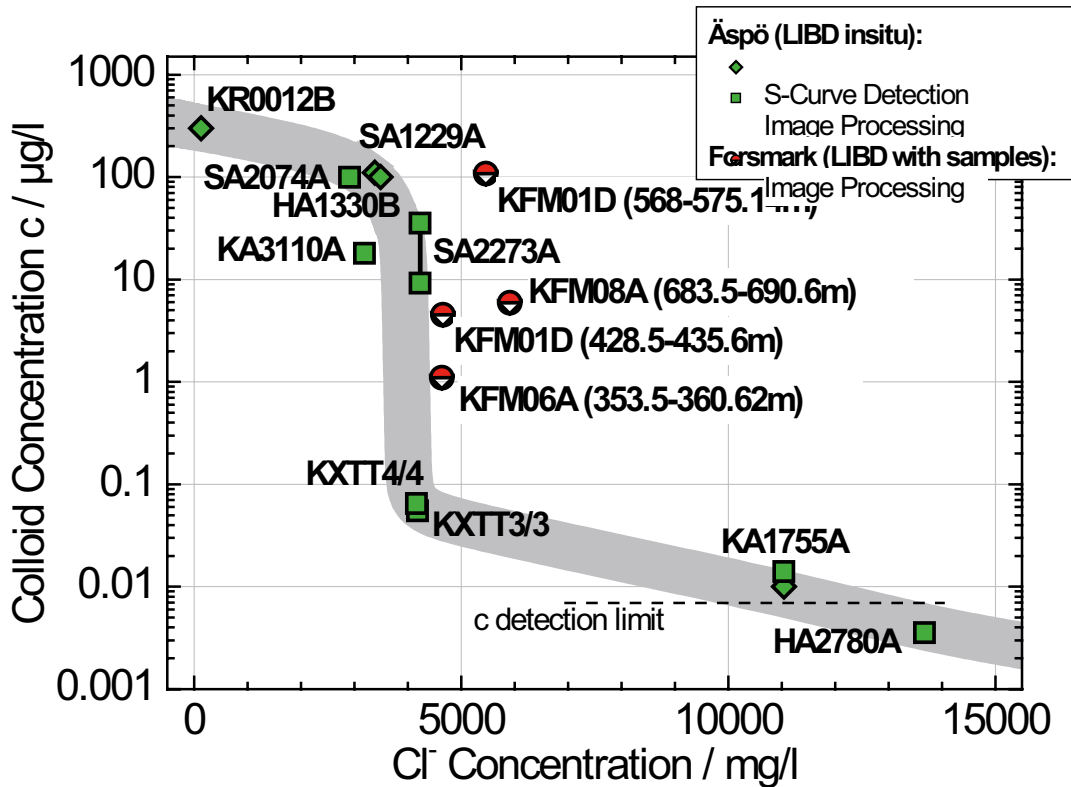
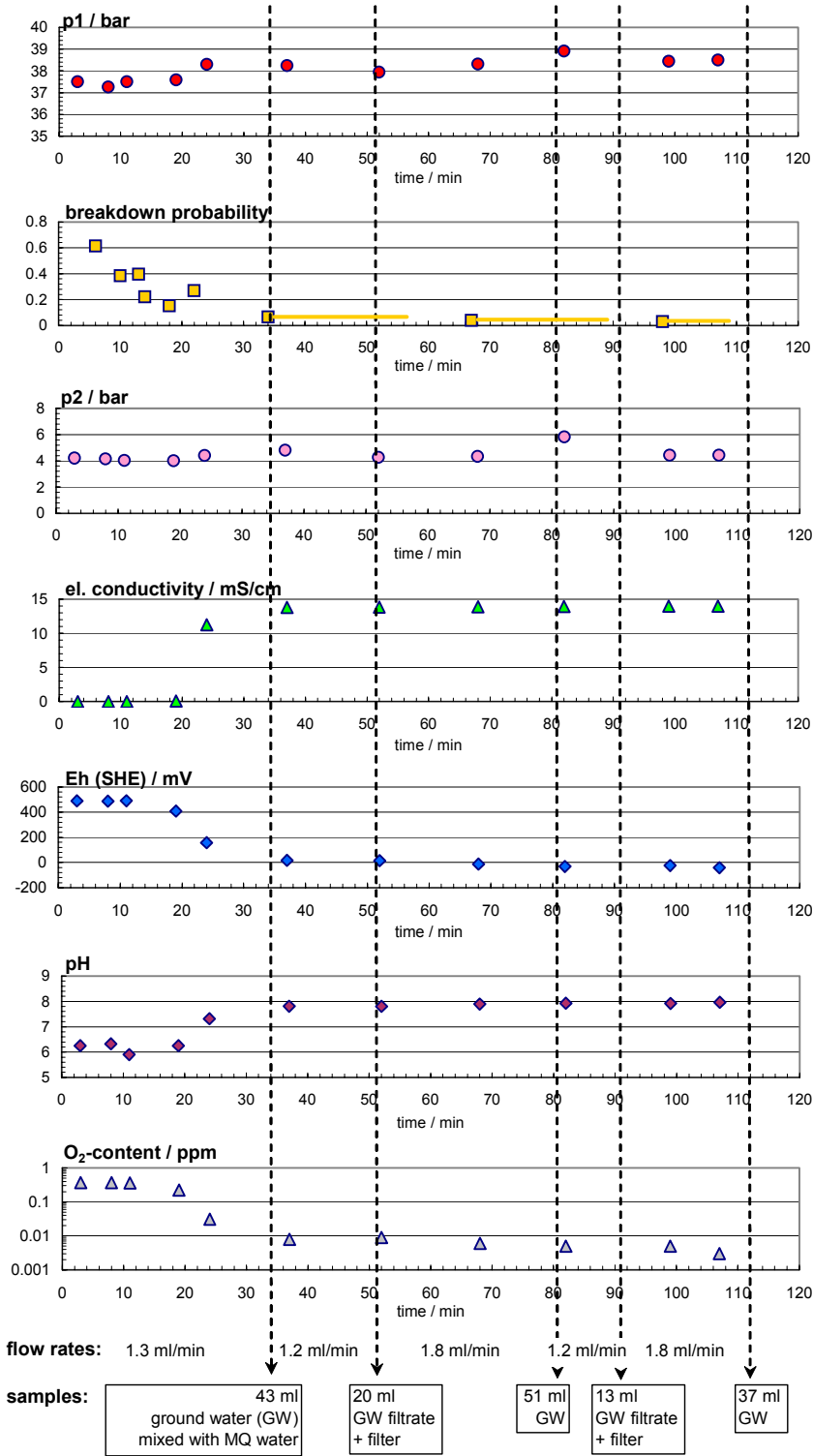


Figure A7-6. Correlation between colloid concentration and chloride concentration in different ground water from Äspö 2, 5 and in Forsmark samples.

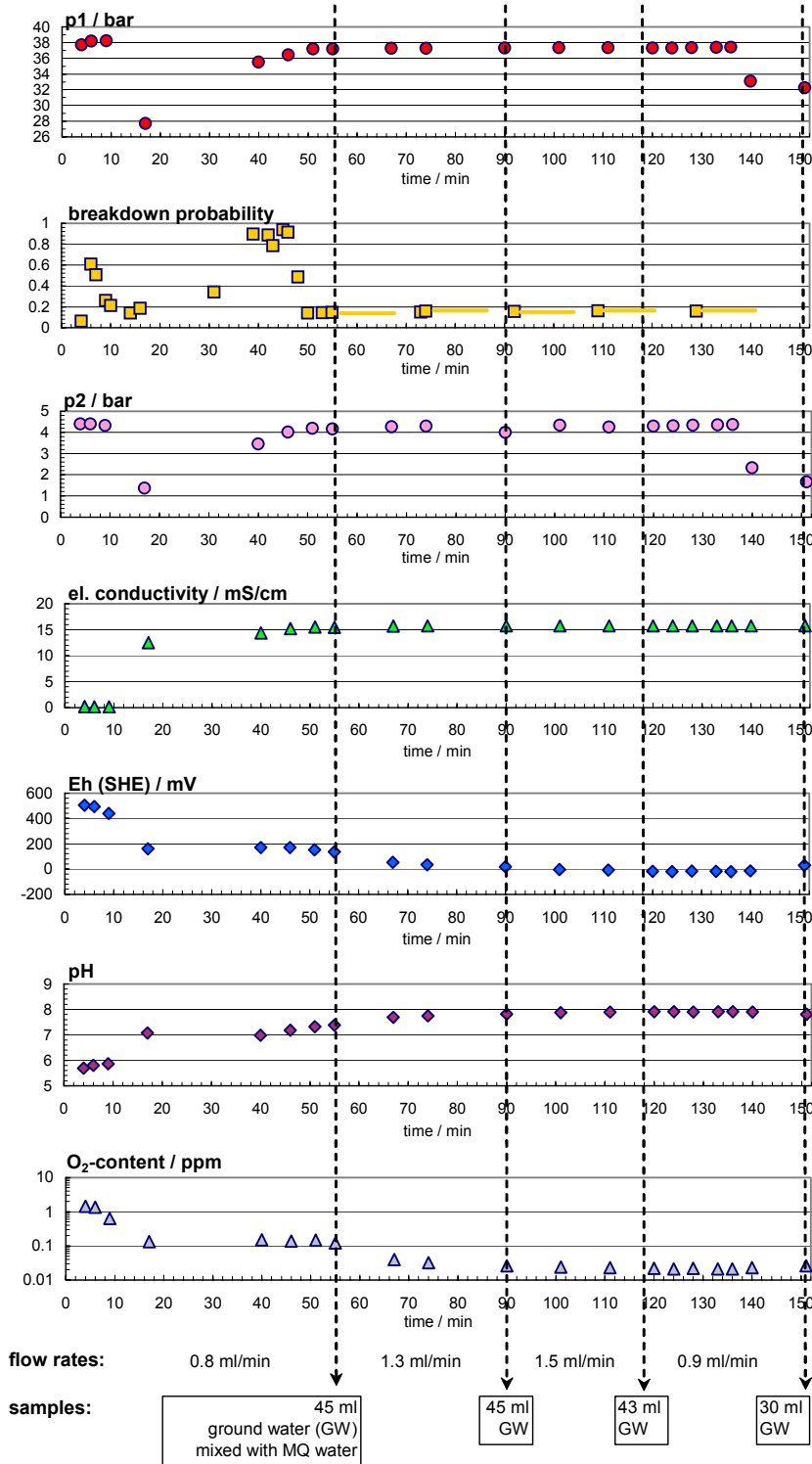
References Appendix 7

- /1/ **Hauser W, Geckeis H, Kim J I, Fierz Th, 2002.** A mobile laser-induced breakdown detection system and its application for the in situ-monitoring of colloid migration, Coll. Surf. 203, 37–45.
- /2/ **Hauser W, Geckeis H, Götz R, 2003.** In situ determination of natural ground water colloids in granite shear zones along the Äspö HRL Tunnel by LIBD, 27th Int. conf. on Scientific Basis for Nuclear Waste Management, Kalmar, S, June 15–18.
- /3/ **Geckeis H, Schäfer T, Rabung T, Hauser W, Möri A, Missana T, Eikenberg J, Degueldre C, Fierz T, Alexander W R, 2003.** Inorganic colloid borne actinide migration studied under in situ conditions at the Grimsel test site, 9th Int. conf. on Chemistry and Migration Behavior of Actinides and Fission Products in the Geosphere, Migration '03, Gyeongju, Korea, Sept. 21–26.
- /4/ **Källgarden J, Andersson P, Holmqvist M, 2001.** Äspö HRL, TRUE-1 continuation project, History and current status on flow, pressure, water chemistry and installations at the TRUE-1 site, SKB International Progress Report IPR-02-46, Svensk Kärnbränslehantering AB.
- /5/ **Hauser W, Götz R, Geckeis H, Kienzler B, 2003.** In situ colloid detection in granite groundwater along the Äspö Hard Rock Laboratory access tunnel, In Laaksoharju, M., Äspö Hard Rock Laboratory, Status report of the Colloid investigation conducted at the Äspö HRL during the years 2000-2003, SKB International Progress Report IPR-03-38, Svensk Kärnbränslehantering AB.

Plot with logged raw data from elution of sampling container SKB PVB 220 (KFM01D (428.5–435.6 m))



Plot with logged raw data from elution of sampling container SKB PVB 9506-10 (KFM01D (568.0–575.1 m))



Chemmac measurements in KFM01D, section 428.5–435.6 m

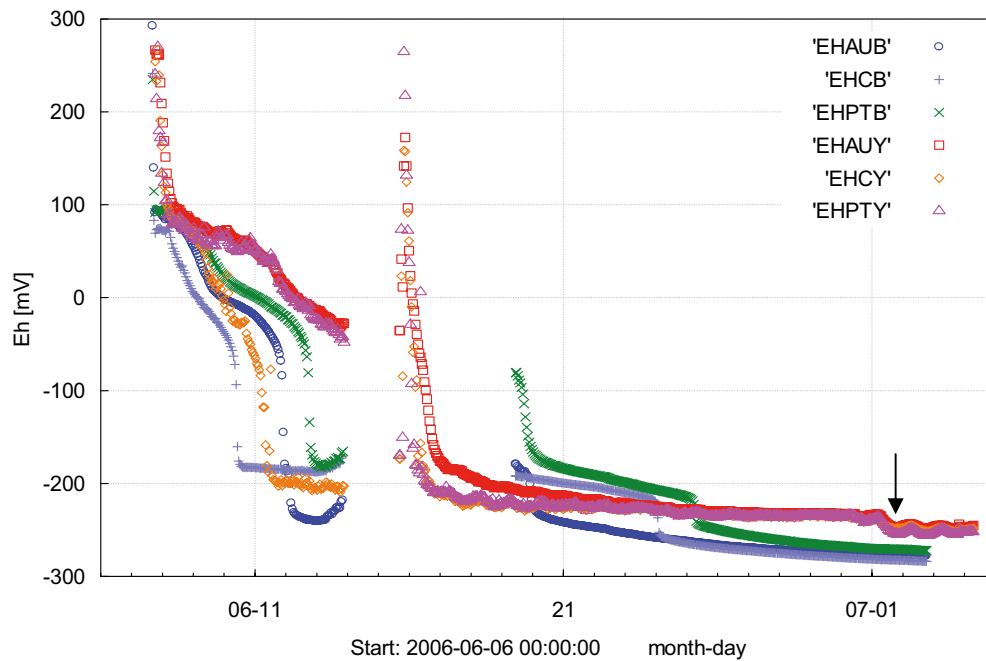


Figure A8-1. Redox potential measurements (E_h) by gold, glassy carbon and platinum electrodes in the borehole section (EHAUB, EHCB and EHPTB) and at the surface by gold, glassy carbon and platinum (EHAUY, EHCY and EHPTY). The arrow shows the chosen representative E_h values for the borehole section.

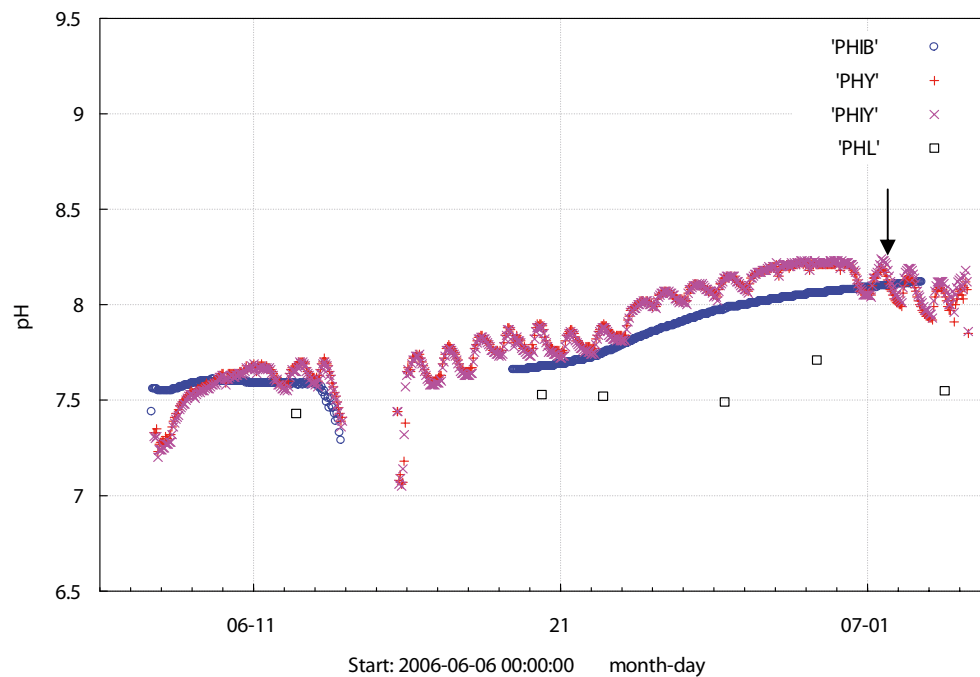


Figure A8-2. Measurements of pH by two glass electrodes in the borehole section (PHB and PHIB) and two glass electrodes at the surface (PHY and PHIY). The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the chosen representative pH values for the borehole section.

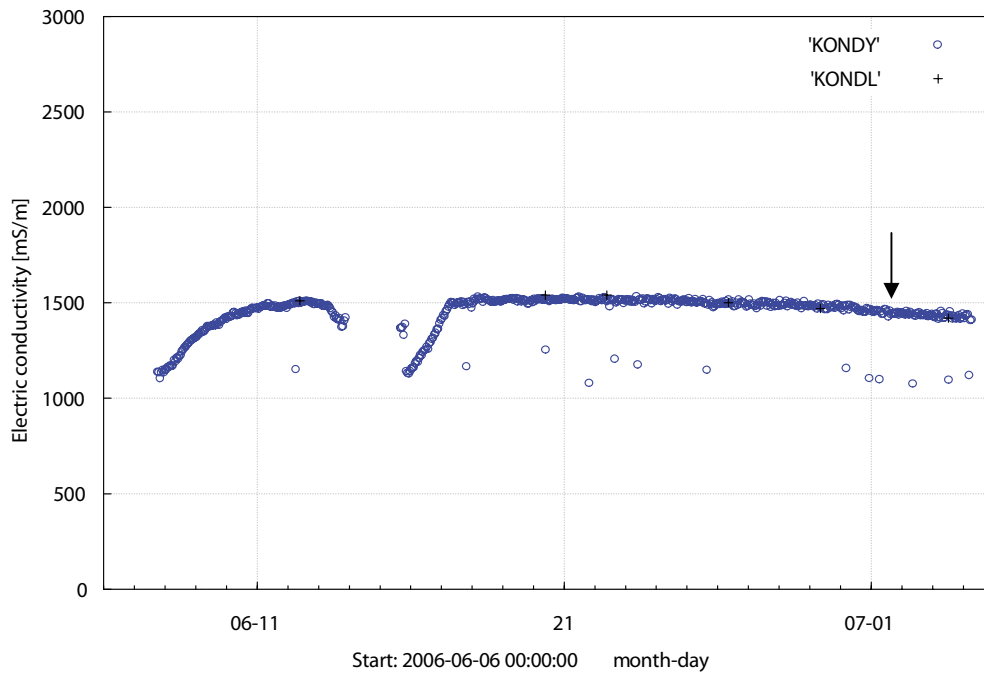


Figure A8-3. Electric conductivity measurements in the surface Chemmac cell (KONDY). The laboratory conductivity in each collected sample (KONDL) is given for comparison. The arrow shows the chosen representative electric conductivity value for the borehole section.

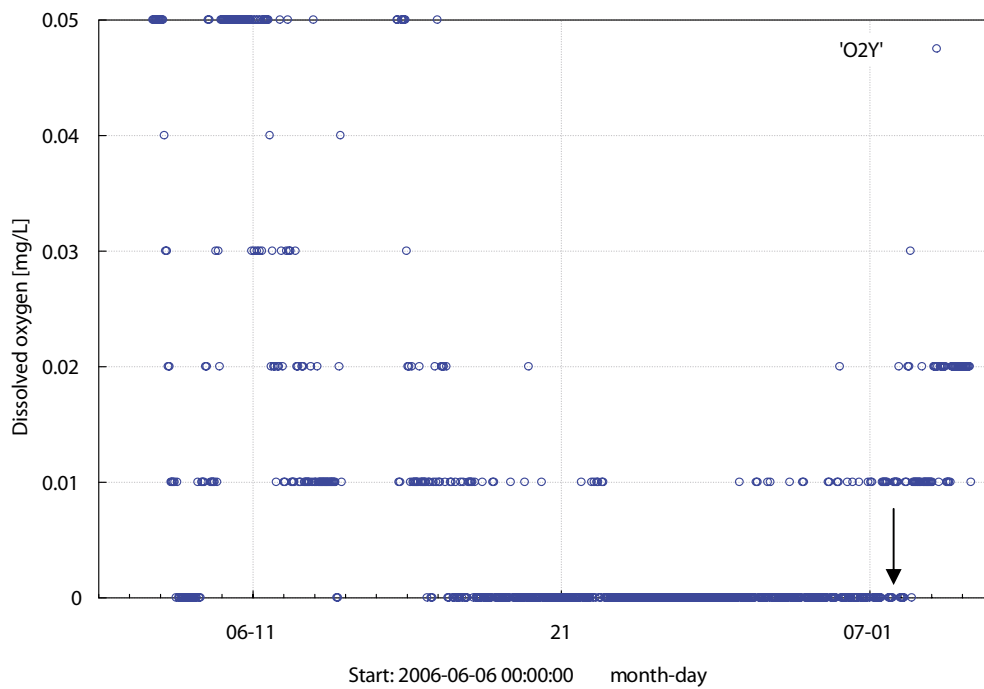


Figure A8-4. Dissolved oxygen measurements (O2Y) in the surface measurement cell. The arrow shows the chosen representative oxygen value for the borehole section.

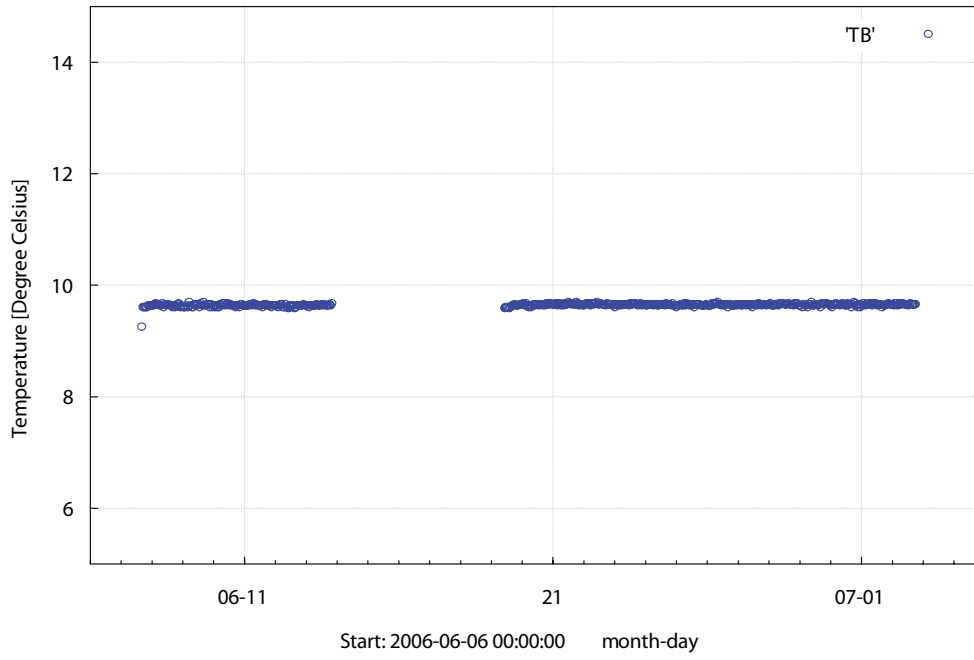


Figure A8-5. Temperature of the groundwater in the borehole section (TB).

Appendix 9

Chemmac measurements in KFM01D, section 568.0–575.1 m

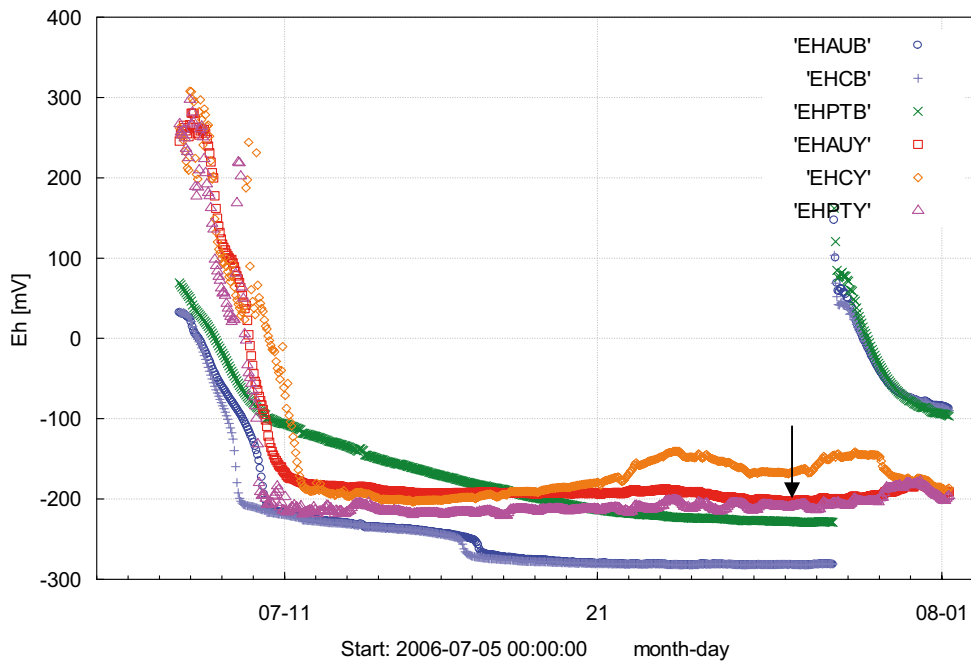


Figure A9-1. Redox potential measurements (E_h) by gold, glassy carbon and platinum electrodes in the borehole section (EHAUB, EHCB and EHPTB) and at the surface by gold, glassy carbon and platinum (EHAUY, EHCY and EHPTY). The arrow shows the chosen representative E_h values for the borehole section.

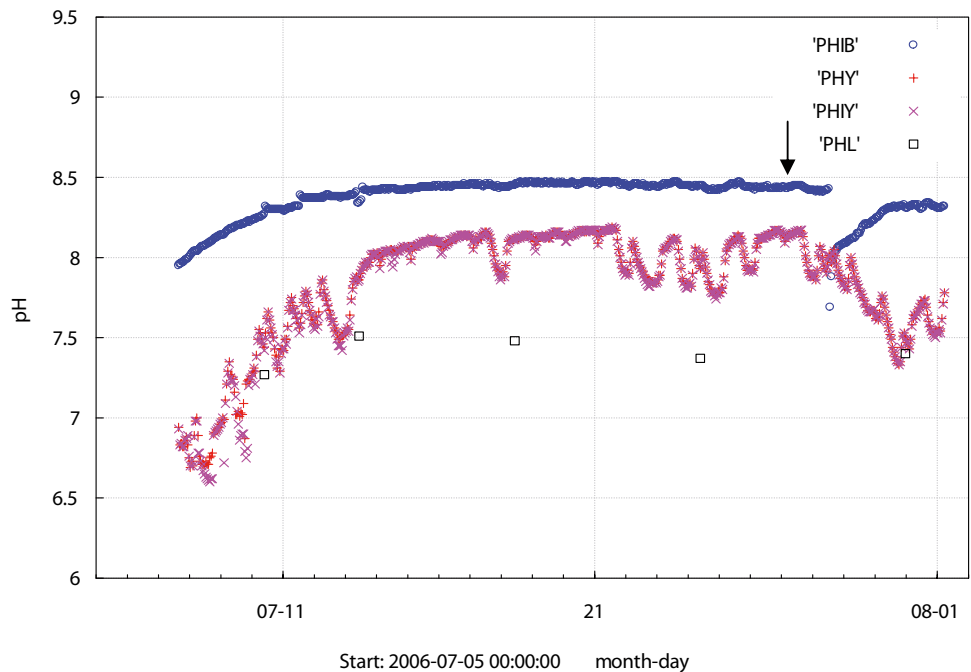


Figure A9-2. Measurements of pH by two glass electrodes in the borehole section (PHB and PHIB) and two glass electrodes at the surface (PHY and PHIY). The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the chosen representative pH values for the borehole section.

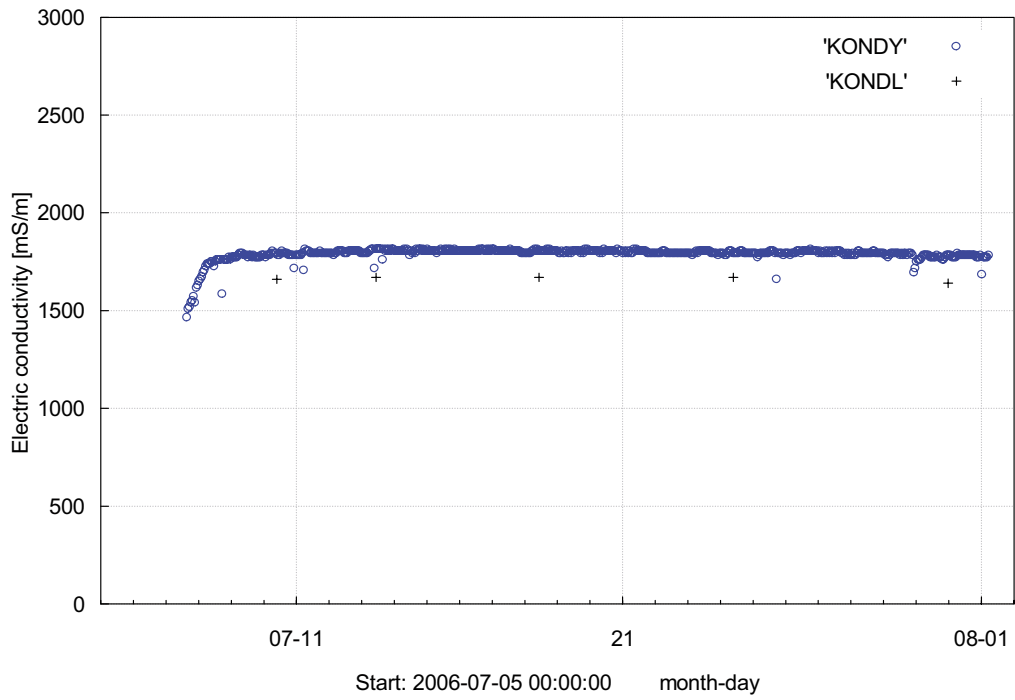


Figure A9-3. Electric conductivity measurements in the surface Chemmac cell (KONDY). The laboratory conductivity in each collected sample (KONDL) is given for comparison.

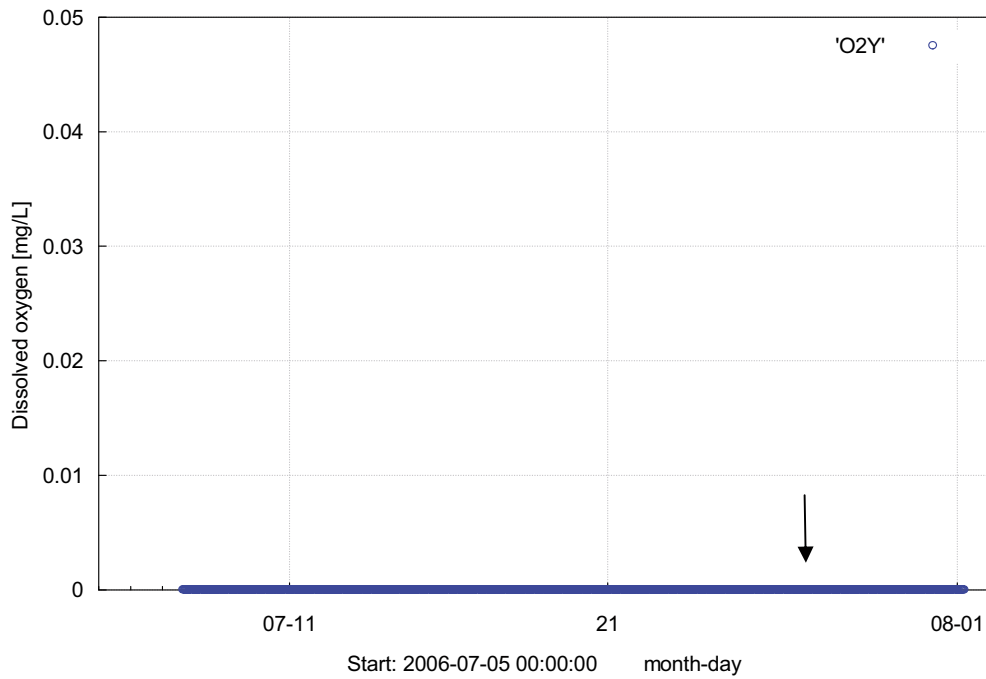


Figure A9-4. Dissolved oxygen measurements (O2Y) in the surface measurement cell. The arrow shows the chosen representative oxygen value for the borehole section.

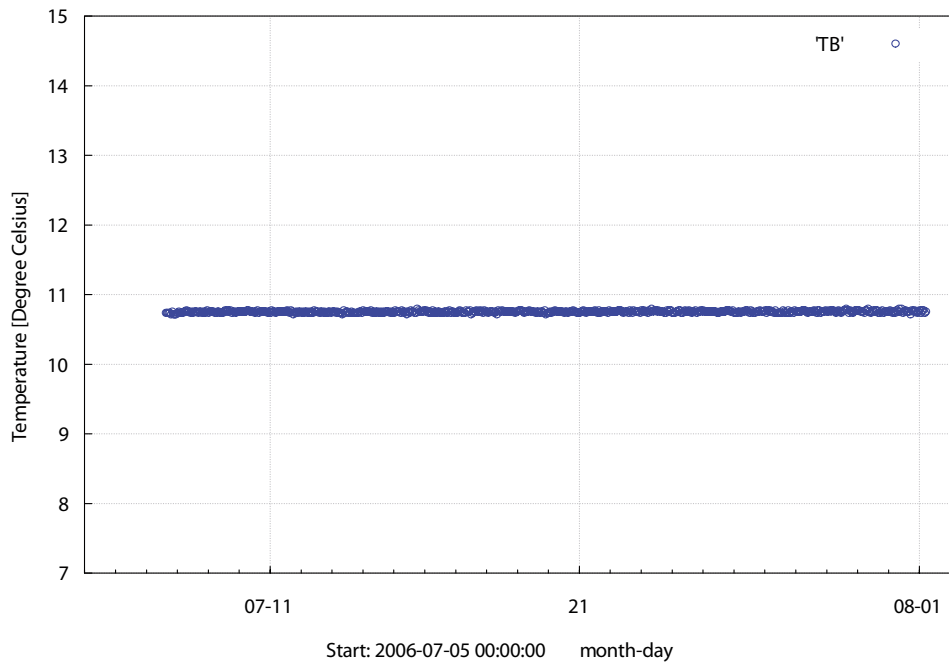


Figure A9-5. *Temperature of the groundwater in the borehole section (TB).*

Compilation of water analysis data

Compilation September 2006

Table A10-1. Water composition.

Idcode	Secup m	Seclow m	Sample no	Sampling date	RCB (%)	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO ₃ ⁻ mg/L	Cl- mg/L	SO ₄ ²⁻ mg/L	SO ₄ -S mg/L	Br mg/l	F- mg/l	Si mg/l	Fe mg/l
KFM01D	194.00	195.00	12361	2006-08-07	-0.29	1,410	25.7	684	84.8	106	3,360	302	113	14.8	1.55	10.0	-
KFM01D	263.80	264.80	12363	2006-08-10	-1.71	1,490	32.5	681	107	195	3,570	352	131	14.9	1.45	9.96	-
KFM01D	314.50	319.50	12366	2006-08-22	-1.91	1,440	24.2	866	101	131	3,890	279	117	19.0	1.14	6.86	2.48
KFM01D	354.90	355.90	12362	2006-08-09	-1.53	1,530	31.1	751	106	154	3,790	320	120	18.1	1.35	11.1	-
KFM01D	369.00	370.00	12360	2006-08-04	-1.56	1,610	32.5	796	117	144	4,070	288	107	21.1	1.43	8.63	-
KFM01D	428.50	435.64	12307	2006-06-12	1.0	1,650	12.6	1,660	21.0	22.7	5,370	57.9	23.7	39.3	1.35	7.38	0.894
KFM01D	428.50	435.64	12314	2006-06-20	1.5	1,670	10.5	1,730	14.9	20.3	5,460	54.4	21	42.2	1.47	6.69	1.13
KFM01D	428.50	435.64	12315	2006-06-22	0.3	1,600	10.0	1,660	13.4	18.5	5,350	59.2	23.7	39.5	1.51	6.65	1.04
KFM01D	428.50	435.64	12316	2006-06-26	1.7	1,630	9.41	1,620	13.7	21.5	5,160	78.6	31.2	37.9	1.41	6.85	1.36
KFM01D	428.50	435.64	12324	2006-06-29	0.1	1,590	9.47	1,520	15.0	26.2	5,090	101	33	36.3	1.29	47.3	1.53
KFM01D	428.50	435.64	12326	2006-07-03	-0.7	1,550	9.02	1,430	19.5	35.8	4,940	125	40.7	34.0	1.22	39.3	1.93
KFM01D	568.00	575.14	12331	2006-07-10		-	-	-	-	20.4	5,880	-	-	-	-	-	-
KFM01D	568.00	575.14	12343	2006-07-13	0.1	1,770	7.31	1,840	10.9	17.1	5,960	31.1	14.0	46.4	1.16	4.26	0.729
KFM01D	568.00	575.14	12350	2006-07-18	0.7	1,770	7.27	1,840	10.5	16.2	5,890	29.7	13.1	44.9	1.21	4.33	0.881
KFM01D	568.00	575.14	12351	2006-07-24	-0.3	1,750	7.26	1,800	10.7	15.7	5,910	29.5	13.7	45.6	1.15	4.34	1.09
KFM01D	568.00	575.14	12354	2006-07-30	1.4	1,770	7.67	1,830	15.2	20.0	5,800	38.3	17.9	46.2	1.20	4.55	1.25
KFM01D	568.00	575.14	12364	2006-08-14		-	-	-	-	-	4,630	-	-	-	-	-	-

- = Not analysed.

A = Results will be reported later.

X = No result due to sampling problems.

XX = No result due to analytical problems.

< value = below reporting limit.

RCB (%) = Rel. charge balance error %.

SICADA: water_composition.

Table A10-1. Continue.

Idcode	Secup m	Seclow m	Sample no	Sampling date	Fe-tot mg/l	Fell mg/l	Mn mg/l	Li mg/l	Sr mg/l	I ⁻ mg/l	pH	DOC mg/l	HS- mg/l	Drill_ water %	EiCond mS/m	NH ₄ N mg/L	P mg/L
KFM01D	194.00	195.00	12361	2006-08-07	-	-	-	0.041	6.15	0.055	7.46	-	-	3.9	1,040	-	< 0.005
KFM01D	263.80	264.80	12363	2006-08-10	-	-	-	0.044	5.52	0.043	7.47	-	-	5.3	1,100	-	< 0.005
KFM01D	314.50	319.50	12366	2006-08-22	-	-	0.584	0.042	8.33	0.061	7.56	A	0.009	9.0	1,180	-	< 0.005
KFM01D	354.90	355.90	12362	2006-08-09	-	-	-	0.044	6.72	0.059	7.35	-	-	4.6	1,160	-	< 0.005
KFM01D	369.00	370.00	12360	2006-08-04	-	-	-	0.043	6.75	0.076	7.52	-	-	3.8	1,230	-	< 0.005
KFM01D	428.50	435.64	12307	2006-06-12	0.921	0.895	0.329	0.029	17.5	-	7.43	2.7	0.006	9.2	1,510	0.305	-
KFM01D	428.50	435.64	12314	2006-06-20	1.13	1.11	0.251	0.025	19.0	0.195	7.53	3.2	0.008	6.6	1,540	0.235	< 0.04
KFM01D	428.50	435.64	12315	2006-06-22	1.04	1.04	0.205	0.027	18.3	-	7.52	2.5	0.005	7.1	1,540	0.193	-
KFM01D	428.50	435.64	12316	2006-06-26	1.35	1.33	0.171	0.028	18.1	0.175	7.49	2.3	0.009	3.4	1,500	0.166	< 0.04
KFM01D	428.50	435.64	12324	2006-06-29	1.58	1.56	0.165	0.026	18.8	-	7.71	2.3	0.008	6.9	1,470	0.171	-
KFM01D	428.50	435.64	12326	2006-07-03	2.08	2.04	0.182	0.026	17.4	0.163	7.55	3.7	0.006	6.3	1,420	0.198	< 0.005
KFM01D	568.00	575.14	12331	2006-07-10	-	-	-	-	-	-	7.27	-	-	1.3	1,660	-	-
KFM01D	568.00	575.14	12343	2006-07-13	0.759	0.763	0.0877	0.021	20.8	0.321	7.51	11	0.010	0.8	1,670	0.125	< 0.04
KFM01D	568.00	575.14	12350	2006-07-18	0.888	0.882	0.0831	0.023	20.7	0.319	7.48	6.9	0.005	0.8	1,670	0.125	< 0.04
KFM01D	568.00	575.14	12351	2006-07-24	1.09	1.06	0.0852	0.022	20.4	0.326	7.37	7.7	0.005	0.8	1,670	0.123	< 0.04
KFM01D	568.00	575.14	12354	2006-07-30	1.24	1.23	0.113	0.024	19.8	0.328	7.40	10	0.005	0.9	1,640	0.124	< 0.04
KFM01D	568.00	575.14	12364	2006-08-14	-	-	-	-	-	-	7.12	-	-	7.6	1,360	-	-

A = Results will be reported later.

X = No result due to sampling problems.

XX = No result due to analytical problems.

< value = below reporting limit.

RCB (%) = Rel. charge balance error %.

SICADA: water_composition.

Table A10-2. Isotopes I (H-, O-, B-, S-, Cl- and C-isotopes).

Idcode	Secup m	Seclow m	Sample no	Sampling date	$\delta^2\text{H}$ ‰ SMOW	^3H TU	$\delta^{18}\text{O}$ ‰ SMOW	$^{10}\text{B}/^{11}\text{B}$ no unit	$\delta^{34}\text{S}$ ‰ CDT	$\delta^{13}\text{C}$ ‰ PDB	$^{87}\text{Sr}/^{86}\text{Sr}$ no unit	^{14}C pmC	$\delta^{37}\text{Cl}$ ‰ SMOC
KFM01D	194.00	195.00	12361	2006-08-07	-76.3	2.4	-10.2	0.2377					
KFM01D	263.80	264.80	12363	2006-08-10	-71.5	1.9	-9.3	0.2374					
KFM01D	314.50	319.50	12366	2006-08-22	-72.3	1.5	-9.7	0.2388					
KFM01D	354.90	355.90	12362	2006-08-09	-71.7	1.7	-9.7	0.2380					
KFM01D	369.00	370.00	12360	2006-08-04	-70.5	2.7	-9.7	0.2373					
KFM01D	428.50	435.64	12307	2006-06-12	-75.0	1.2	-11.1	-	-	-	-	-	-
KFM01D	428.50	435.64	12314	2006-06-20	-76.0	1.3	-11.2	0.2373	25.7	A	0.720184	A	0.11
KFM01D	428.50	435.64	12315	2006-06-22	-76.7	< 0.8	-11.2	-	-	-	-	-	-
KFM01D	428.50	435.64	12316	2006-06-26	-76.9	< 0.8	-11.1	0.2392	33.8	A	0.720184	A	0.07
KFM01D	428.50	435.64	12324	2006-06-29	-74.9	1.4	-11.0	-	-	-	-	-	-
KFM01D	428.50	435.64	12326	2006-07-03	-74.9	1.9	-10.7	0.2387	26.7	A	0.720149	A	0.04
KFM01D	568.00	575.14	12343	2006-07-13	-67.5	< 0.8	-10.5	0.2408	24.0	A	0.720929	A	0.09
KFM01D	568.00	575.14	12350	2006-07-18	-65.6	1.5	-10.3	0.2401	24.4	A	0.720878	A	0.07
KFM01D	568.00	575.14	12351	2006-07-24	-65.6	1.9	-10.5	0.2458	24.5	A	0.720792	A	0.08
KFM01D	568.00	575.14	12354	2006-07-30	-64.6	1.3	-10.6	0.2395	24.7	A	0.720801	A	0.06

- = Not analysed.

A = Results will be reported later.

X = No result due to sampling problems.

XX = No result due to analytical problems.

< value = below reporting limit.

SICADA: Isotopes_1.

Table 10-3. Trace elements.

Idcode	Secup m	Seclow m	Sample no	Sampling date	Al ug/L	B ug/L	Ba ug/L	U ug/L	Th ug/L	Sc ug/L	Rb ug/L	Y ug/L	Zr ug/L	In ug/L	Sb ug/L	Cs ug/L	La ug/L
KFM01D	194.00	195.00	12361	2006-08-07	36.4	641	309	3.30	< 0.2	< 0.4	50.9	0.528	0.340	< 0.2	0.189	0.981	0.0541
KFM01D	263.80	264.80	12363	2006-08-10	282	623	157	8.86	< 0.2	< 0.4	57.5	1.32	0.430	< 0.2	0.168	1.24	0.139
KFM01D	314.50	319.50	12366	2006-08-22	432	481	826	7.38	< 0.2	< 0.4	25.2	0.551	0.314	< 0.2	0.475	0.629	0.177
KFM01D	354.90	355.90	12362	2006-08-09	53.4	679	353	8.80	< 0.2	< 0.4	52.5	1.16	0.352	< 0.2	0.164	1.18	0.0893
KFM01D	369.00	370.00	12360	2006-08-04	38.8	611	412	9.00	< 0.2	< 0.4	57.2	0.719	0.332	< 0.2	0.250	1.45	0.0837
KFM01D	428.50	435.64	12314	2006-06-20	3.83	596	896	1.35	< 0.2	< 0.5	36.9	0.184	< 0.3	< 0.5	0.273	0.534	< 0.05
KFM01D	428.50	435.64	12316	2006-06-26	29.3	655	823	1.94	< 0.2	< 0.5	34.9	0.178	< 0.3	< 0.5	0.213	0.459	< 0.05
KFM01D	428.50	435.64	12326	2006-07-03	6.21	696	807	2.15	< 0.2	< 0.4	35.3	0.162	< 0.1	< 0.2	0.203	0.432	0.0206
KFM01D	568.00	575.14	12343	2006-07-13	8.24	648	2,530	0.59	< 0.2	< 0.5	28.8	0.139	< 0.3	< 0.5	0.298	0.765	< 0.05
KFM01D	568.00	575.14	12350	2006-07-18	10.8	649	2,500	0.52	< 0.2	< 0.5	27.3	0.138	< 0.3	< 0.5	0.324	0.650	< 0.05
KFM01D	568.00	575.14	12351	2006-07-24	41.7	645	2,470	0.55	< 0.2	< 0.5	27.7	0.138	< 0.3	< 0.5	0.244	0.698	< 0.05
KFM01D	568.00	575.14	12354	2006-07-30	5.48	673	2,390	0.80	< 0.2	0.59	27.2	0.445	1.71	< 0.5	0.124	0.608	0.099

-- = Not analysed.

A = Results will be reported later.

X = No result due to sampling problems.

XX = No result due to analytical problems.

< value = below reporting limit.

SICADA: trace_elements.

Table 10-3. Continue.

Idcode	Secup m	Seclow m	Sample no	Sampling date	Hf ug/L	Tl ug/L	Ce ug/L	Pr ug/L	Nd ug/L	Sm ug/L	Eu ug/L	Gd ug/L	Tb ug/L	Dy ug/L	Ho ug/L	Er ug/L	Tm ug/L	Yb ug/L	Lu ug/L
KFM01D	194.00	195.00	12361	2006-08-07	< 0.02	0.0673	0.0562	< 0.02	0.0281	< 0.02	0.0371	< 0.02	< 0.02	< 0.02	< 0.02	0.0231	< 0.02	0.0202	< 0.02
KFM01D	263.80	264.80	12363	2006-08-10	< 0.02	0.0579	0.227	0.0266	0.0972	0.0241	0.0228	0.0386	< 0.02	0.0552	< 0.02	0.0655	< 0.02	0.0644	< 0.02
KFM01D	314.50	319.50	12366	2006-08-22	< 0.02	0.0519	0.261	0.0287	0.123	0.0203	0.0963	0.0261	< 0.02	0.0344	< 0.02	0.0253	< 0.02	0.0237	< 0.02
KFM01D	354.90	355.90	12362	2006-08-09	< 0.02	0.0606	0.105	< 0.02	0.0530	0.0203	0.0433	0.0330	< 0.02	0.0484	< 0.02	0.0536	< 0.02	0.0475	< 0.02
KFM01D	369.00	370.00	12360	2006-08-04	< 0.02	0.0880	0.0869	< 0.02	0.0392	< 0.02	0.0499	< 0.02	< 0.02	0.0277	< 0.02	0.0322	< 0.02	0.0289	< 0.02
KFM01D	428.50	435.64	12314	2006-06-20	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.058
KFM01D	428.50	435.64	12316	2006-06-26	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
KFM01D	428.50	435.64	12326	2006-07-03	< 0.02	< 0.03	< 0.02	< 0.02	< 0.02	< 0.02	0.0591	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
KFM01D	568.00	575.14	12343	2006-07-13	< 0.05	< 0.05	< 0.05	0.05	0.05	< 0.05	< 0.06	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
KFM01D	568.00	575.14	12350	2006-07-18	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.06	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
KFM01D	568.00	575.14	12351	2006-07-24	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.06	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
KFM01D	568.00	575.14	12354	2006-07-30	< 0.05	< 0.05	0.069	< 0.05	0.0532	< 0.05	< 0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

-- = Not analysed.

A = Results will be reported later.

X = No result due to sampling problems.

XX = No result due to analytical problems.

< value = below reporting limit.

SICADA: trace_elements.

Table 10-4. Isotopes II (U-, Th Ra- and Rn-isotopes).

Idcode	Secup m	Seclow m	Sample no	Sampling date	²³⁸ U mBq/L	²³⁵ U mBq/L	²³⁴ U mBq/L	²³² Th mBq/L	²³⁰ Th mBq/L	²²⁶ Ra Bq/L	²²² Rn Bq/L
KFM01D	428.50	435.64	12314	2006-06-20	A	A	A	A	A	A	A
KFM01D	428.50	435.64	12316	2006-06-26	A	A	A	A	A	A	A
KFM01D	428.50	435.64	12326	2006-07-03	A	A	A	A	A	A	A
KFM01D	568.00	575.14	12343	2006-07-13	A	A	A	A	A	A	A
KFM01D	568.00	575.14	12350	2006-07-18	A	A	A	A	A	A	A
KFM01D	568.00	575.14	12351	2006-07-24	A	A	A	A	A	A	A
KFM01D	568.00	575.14	12354	2006-07-30	A	A	A	A	A	A	A

-- = Not analysed.

A = Results will be reported later.

X = No result due to sampling problems.

XX = No result due to analytical problems.

< value = below reporting limit.

SICADA: isotopes_2.

Table A10-5. Dissolved gases.

Idcode	Secup m	Seclow m	Sample no	Sampling date	Ar mL/L	He mL/L	N ₂ mL/L	CO ₂ mL/L	CH ₄ mL/L	O ₂ mL/L	H ₂ µL/L	CO µL/L	C ₂ H ₆ µL/L	C ₂ H ₄ µL/L	C ₂ H ₂ µL/L	C ₃ H ₈ µL/L	C ₃ H ₆ µL/L	DISS_GAS mL/L H ₂ O
KFM01D	428.50	435.64	12326:1	2006-07-03	11	26	62	0.15	0.14	0.032	< 3.0	< 5.0	2.6	0.07	< 0.05	0.54	< 0.10	99
KFM01D	428.50	435.64	12326:2	2006-07-03	1.1	26	64	0.20	0.14	0.062	< 2.8	< 4.6	2.5	0.09	< 0.05	0.57	< 0.09	92
KFM01D	568.00	575.14	12354	2006-08-01	0.85	43	64	0.036	4.6	0.014	< 3.4	< 5.6	6.8	< 0.06	< 0.06	1.3	< 0.11	112

-- = Not analysed.

A = Results will be reported later.

< value = below reporting limit.

Sample 12326:1 pressurised by Ar.

Sample 12326:2 pressurised by N₂.

SICADA gas_dissolved.