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Forsmark site investigation

Hydrochemical logging in KFM09A

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May 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 author and do not necessarily coincide with those of the client.

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Abstract

Hydrochemical logging or so called tube sampling has been performed in the core drilled borehole KFM09A. The method is a fast and simple sampling technique to obtain information about the chemical composition of the water column along an open borehole. The equipment consists of an approximately 800 m long polyamide tube divided into units of 50 m.

The water content in each tube unit constituted one sample. Every second sample was analysed according to SKB chemistry class 3 (isotope options excluded). However, electrical conductivity and Uranine concentration were determined in all samples. The content of flushing water remaining from the core drilling was low (< 20%) below 500 m borehole length. Therefore, the SKB chemistry class 3 isotope options and also uranium and thorium determinations were included for the three deepest samples. The flushing water content in the groundwater was relatively high in the mid part of the borehole, the highest amount being 53% in the tube unit from section 245–295 m borehole length.

The indication of presence of highly saline water from the borehole radar logs in the deepest part of the borehole was confirmed. The highest electrical conductivity value was 3,710 mS/m and the highest chloride concentration was 14,300 mg/L in the bottom part of the borehole at approximately 620 m vertical depth.

The relative charge balance error did not exceed the acceptable level of $\pm 5\%$ in any of the eight samples analysed. The remaining flushing water content in the three deepest samples was low and there are evenly distributed water bearing fractures in this part of the borehole. Consequently, the water composition of the last sample (flushing water content 4%) can be regarded as fairly representative for the groundwater chemistry in the fractures in the bottom part of the borehole.

Sammanfattning

Hydrokemisk loggning, eller så kallad slangprovtagning, har utförts i det kärnborrade borrhålet KFM09A. Metoden är snabb och enkel att använda för att erhålla information om den kemiska sammansättningen hos grundvattenpelaren längs ett öppet borrhål. Utrustningen består av en cirka 800 m lång polyamidslang uppdelad i enheter om vardera 50 m.

Innehållet i en slangenheter utgjorde ett prov varav vartannat prov analyserades enligt SKB kemiklass 3 (exklusive tillval). Elektrisk konduktivitet och Uranin bestämdes emellertid i samtliga prov. Halten kvarvarande spolvatten från kärnboringen var låg (< 20 %) från 500 m och nedåt i borrhålet. Därför inkluderades isotoptillvalen enligt SKB klass 3 samt uran- och thoriumanalyser för de tre nedersta proverna. I den mellersta delen av borrhålet var spolvattenhalten relativt hög, med ett högsta värde på 53 %, erhållet från sektionen 245–295 m.

Indikationen från borrhålsradarloggningen på hög salinitet i vattnet i den djupaste delen av borrhålet konfirmerades. Den elektriska konduktiviteten var som högst 3 710 mS/m och den högsta kloridhalten var 14 300 mg/L i botten på borrhålet vid cirka 620 m vertikaldjup.

Det relativa jonbalansfelet överskred inte den accepterbara gränsen på $\pm 5\%$ i något av de åtta analyserade proverna. Spolvattenhalten i de tre djupaste proven var relativt låg och det finns vattenförande sprickor jämnt fördelade i denna del av borrhålet. Därför kan vattensammansättningen i det sista provet (spolvattenhalt 4 %) anses vara någorlunda representativt för grundvattenkemin i de vattenförande sprickorna i botten av borrhålet.

Contents

1	Introduction	7
2	Objective and scope	11
3	Sampling equipment	13
4	Performance	15
4.1	Hydrochemical logging	15
4.2	Sample treatment and chemical analysis	16
4.3	Data handling	17
4.4	Nonconformities	17
5	Results	19
5.1	Chemical analyses	19
6	Summary and conclusions	21
7	References	23
Appendix 1	Design of the telescopic borehole KFM09A	25
Appendix 2	Sampling and analytical methods	27
Appendix 3	Water composition including Uranium and Thorium	33
Appendix 4	Isotopes I, compilation of H- and O-isotopes	35

1 Introduction

This document reports the performance and the results of the activity “Hydrochemical logging” in KFM09A within the site investigation programme at Forsmark /1, 2/. The controlling documents for the activity are listed in Table 1-1. Both activity plan and method description are SKB’s internal controlling documents. The field work was carried out on the 7th of March 2006. The obtained data from the activity are reported to the database SICADA, where they are traceable by the activity plan number.

Borehole KFM09A is a deep core drilled borehole /3/. The location of KFM09A and the other current deep boreholes within the investigation area are shown in Figure 1-1. Figure 1-2 shows a zooming in towards drilling site DS9 with KFM09A and nearby situated percussion drilled boreholes. The borehole KFM09A is inclined 59° from the horizontal plane in the direction towards south-west. The borehole is core drilled with a diameter of 77.3 mm. The design of borehole KFM09A is presented in Appendix 1.

KFM09A is a non-chemistry type core drilled borehole, see method descriptions MD 620.003 (Method description for drilling cored boreholes). Even if not required, the cleaning procedures of all equipment used in the borehole, during and after drilling, were performed according to level 2 in the cleaning instructions in MD 600.004 (Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning). The activities/investigations performed in KFM09A prior to the hydrochemical logging are listed in Table 1-2.

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

Activity Plan	Number	Version
Hydrokemisk loggning i KFM09A	AP PF 400-06-016	1.0
Method Descriptions	Number	Version
Metodbeskrivning för hydrokemisk loggning	SKB MD 422.001	2.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0

Table 1-2. Activities performed in KFM09A prior to the hydrochemical logging.

Activities performed	Date of start-date of completion	Length or section [m]	Comment
Core drilling	2005-08-31–2005-10-27	0–799.67	Drinking water from tap served as the source of flushing water for the core drilling of KFM09A /3/
Flushing water treatment	2005-09-12–2005-10-27	47.08–799.67	Automatic dosing of Uranine was used during drilling of KFM09A. In this way no in-line storage tank was needed after the UV-system /3/
Microbe control was not preformed	–	–	–
Sampling of flushing water and returned water	2005-09-12–2005-10-27	47.08–799.67	–
Water sampling SKB class 3	2005-10-05	100.00–515.00	Sample no. 8972 /3/
Geophysical logging	2005-11-05–2005-11-11	0–799.18	/4/
BIPS-logging	2005-11-06	7.00–792.00	/5/
Injection tests	2005-11-17–2005-12-21	7.80–791.00	/6/
Hydrochemical logging	2006-03-07	0–795	Presented in this report

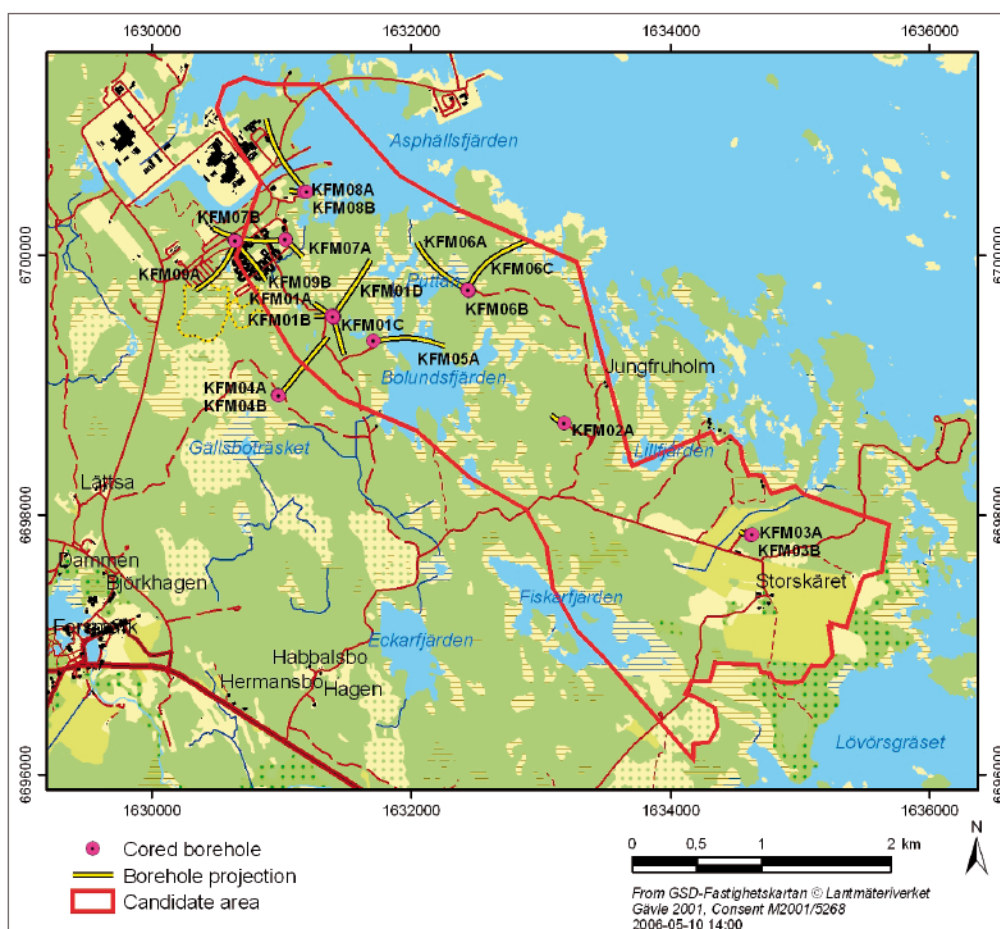


Figure 1-1. The investigation area at Forsmark (approximately the area inside the black square) including the candidate area selected for more detailed investigations with the currently completed core drilled boreholes.

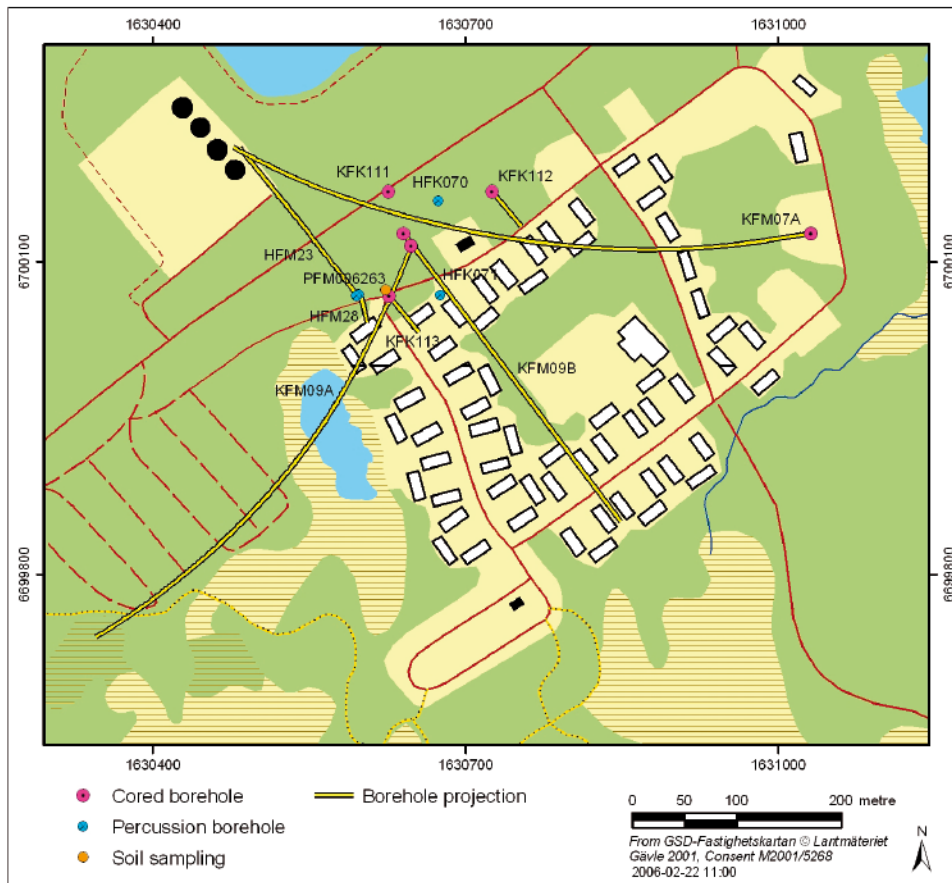


Figure 1-2. Location and projection on the horizontal plane of the cored borehole KFM09A and the surrounding boreholes at drilling sites DS9 and DS7.

2 Objective and scope

Hydrochemical logging is one of the basic investigation methods conducted in core drilled boreholes at the site investigations. The method is performed in order to obtain an overview of the initial chemical composition of the water column along an open borehole. The sampling technique is fast and simple, also for boreholes of considerable lengths. The method is normally used in chemistry prioritized boreholes, and the reason for sampling in this non-chemistry prioritized borehole is the strong attenuation of the borehole radar signal found at a borehole length below 700 m (Figure 2-1). The attenuation of the signal is a possible indication of highly saline water, and the purpose of the investigation is to confirm the assumption of presence of highly saline water in the deeper part of the borehole.

The analysis program is carried out according to SKB chemistry class 3 including isotope options, uranium and thorium. However, if the content of flushing water remaining from core drilling exceeds 20% in a sample, the isotope determinations are omitted.

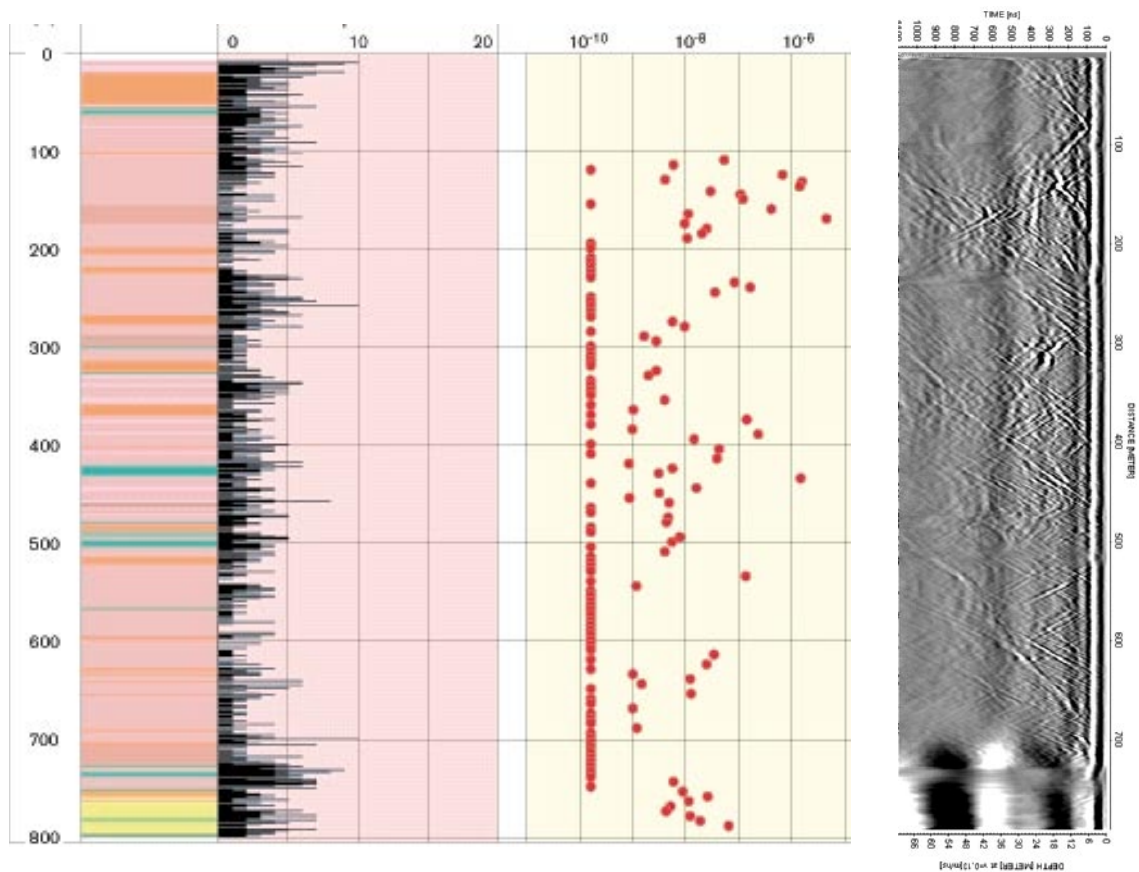


Figure 2-1. Geophysical and hydrogeological logs from KFM09A plotted versus borehole length. From left to right: Rock type, fracture frequency, hydraulic conductivity and finally the borehole radar image. In the latter, a strong attenuation of the signals is found at a borehole length below 700 m. The attenuation is a possible indication of highly saline water.

3 Sampling equipment

For the hydrochemical logging an approximately 800 m long polyamide tube, composed of units of 50 m length, was used. The equipment is described in the method description SKB MD 422.001.

Metal couplings and manual shut off valves are mounted at both ends of each tube unit. The external and internal diameters of the tube units are 10 and 8 mm respectively. A weight and a non return valve are mounted at the lower end of the tube array to keep it stretched in the borehole and to prevent water outflow when the equipment is lifted to the ground surface. A schematic illustration of the equipment used for the hydrochemical logging is shown in Figure 3-1.

The water content in each tube unit constitutes one sample and the volume of each sample will amount to at least two litres.

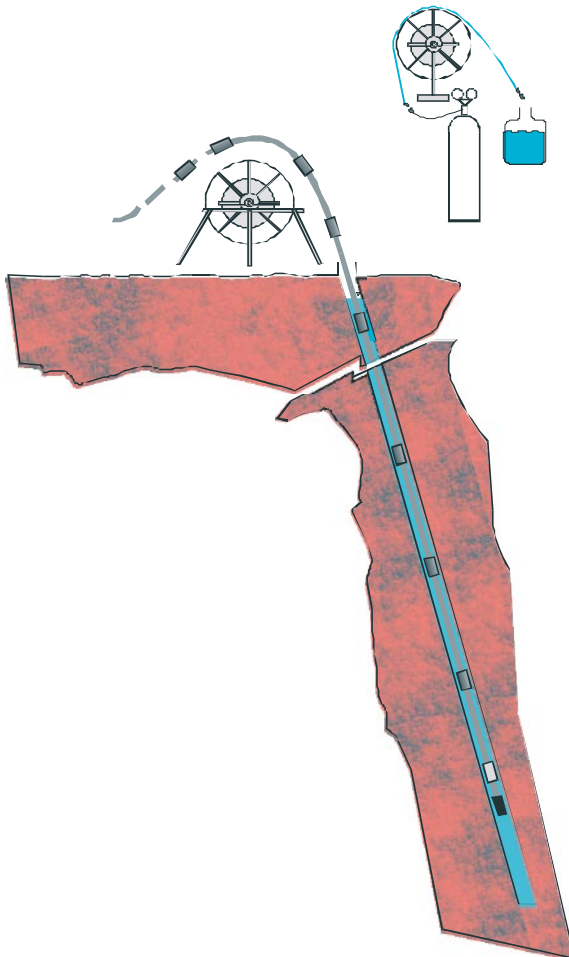


Figure 3-1. Equipment for hydrochemical logging in boreholes. At the lower end of the tube array there is a non-return valve and a weight connected. Each tube unit is 50 m long.

4 Performance

4.1 Hydrochemical logging

Sampling of the telescopic borehole KFM09A (Figure 4-1) was performed on the 7th of March 2006 according to the activity plan AP PF 400-06-016 and in compliance with the method description SKB MD 422.001 (cf Table 1-1).

The hydrochemical logging was carried out to 795 m borehole length. The lowering of the tubes started at 10:05 and the retrieval at 14:00. The tube units were emptied using pressurized nitrogen gas and the water was portioned into several plastic bottles to be analysed by different laboratories. One tube unit constituted one sample.

The ground water level measured after the hydrochemical logging was 4.11 m, below top of casing. The upper tube unit was therefore not completely filled with sample water.



Figure 4-1. Performance of the hydrochemical logging in borehole KFM09A.

4.2 Sample treatment and chemical analysis

An overview of sample treatment and analysis routines is given in Appendix 2. The routines are applicable independent of sampling object or sampling method. The samples collected from the hydrochemical logging of KFM09A were assigned SKB numbers 12201 to 12216. The flushing water content in samples number 12212 to 12216 was below 20%, and only these samples were sent to laboratories for isotope determination. No reserve sample for isotope analysis was taken from the uppermost section (0–45 m) due to lack of water in the sampling tube (no. 22). A scheme showing the filled sample portions at the logging occasion is given in Table 4-1.

Table 4-1. Overview of samples collected at the hydrochemical logging in KFM09A. Filled cells represent collected samples. Dark grey cells represent collected reserve samples.

Sample information			Collected sample portions							
Tube unit	Length [m]	SKB No.	Cond.	pH, alk.	Major constit.	Anions	Uranine	³ H	$\delta^{2}\text{H}/\delta^{18}\text{O}$	U, Th
22	0	12201						-	-	
	45									
15	95	12202						X	X	X
14	145	12203								
13	195	12204						X	X	X
12	245	12205								
11	295	12206						X	X	X
10	345	12207								
9	395	12208						X	X	X
8	445	12209								
7	495	12210						X	X	X
6	545	12211								
5	595	12212								
4	645	12213								
3	695	12214								
2	745	12215								
1	795	12216								

– = samples were not collected due to low water content in the sampling tube.

x = samples were collected but not analysed.

4.3 Data handling

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

Several components are determined by more than one method and/or laboratory. Moreover, control analyses by an independent laboratory are performed as a standard procedure on each fifth or tenth collected sample.

All analytical results are stored in the SICADA database, where they are traceable by the activity plan number. 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 raw data tables for further evaluation. The evaluation results in a final reduced data set for each sample. These data sets 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. Relative errors within $\pm 5\%$ are considered acceptable (in surface waters $\pm 10\%$).

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

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

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 4-1.

4.4 Nonconformities

The activity was performed according to the controlling documents for the activity without any deviations that can affect the quality of data. Due to problems with lack of water in sampling tube number 22 (0–45 m), no reserve sample for isotope analysis was taken in this section.

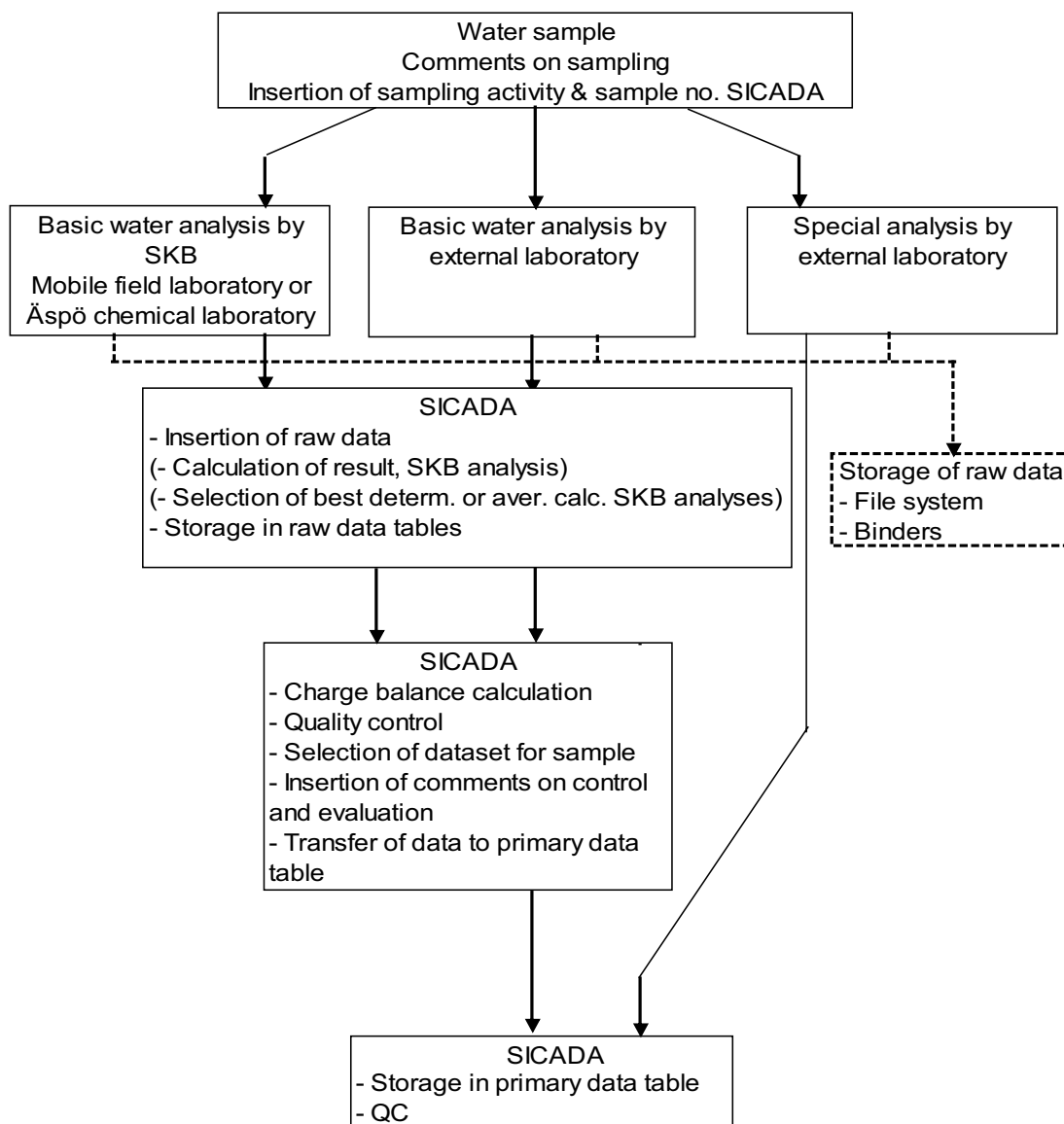


Figure 4-1. Overview of data management for hydrogeochemical data.

5 Results

5.1 Chemical analyses

The results from the chemical analyses performed on samples from the hydrochemical logging in KFM09A are presented in Appendices 3 and 4. Available isotope data at the time of printing this report are included. No isotope determinations will be available from the sections above 545 m, since the flushing water content exceeds 20%. Diagrams showing the flushing water content, the electrical conductivity and some major constituents (Na, Ca and Cl) along the borehole at the time of the sampling are presented in Figures 5-1 to 5-3. The data are plotted at the mid-length of each tube unit.

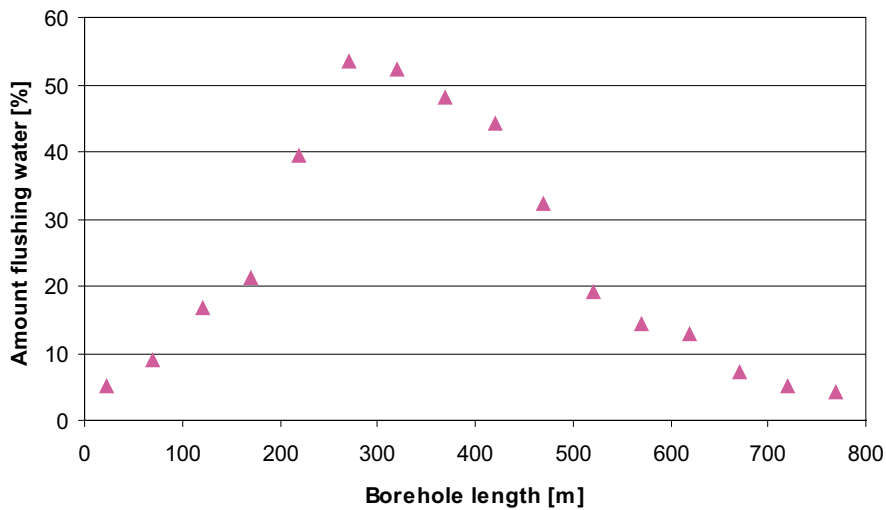


Figure 5-1. Amount of flushing water remaining versus borehole length in KFM09A.

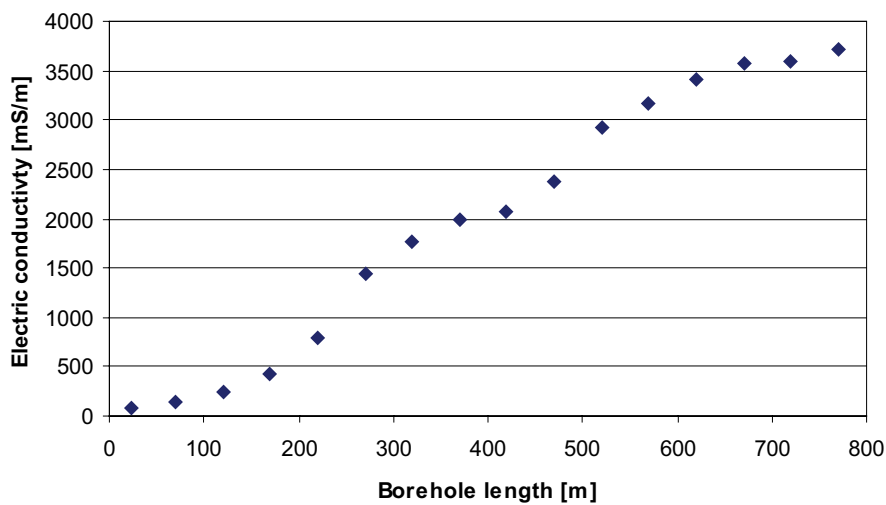


Figure 5-2. Electrical conductivity versus borehole length in KFM09A.

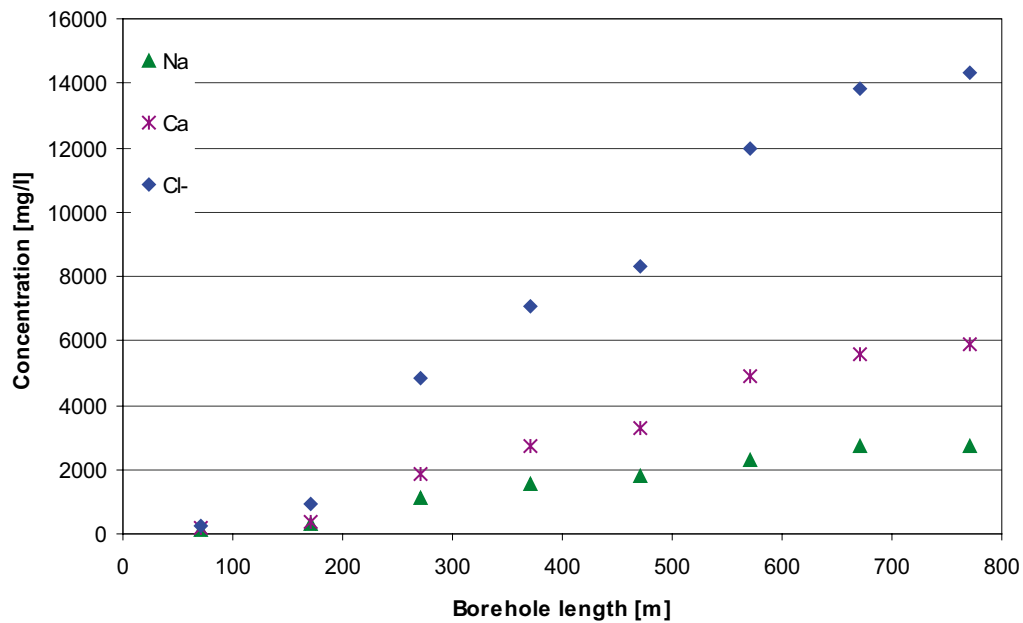


Figure 5-3. Results from analysis of the constituents Na, Ca and Cl in water samples collected from hydrochemical logging in KFM09A.

The charge balance errors give an indication of the quality and uncertainty of the analyses of major constituents. The relative charge balance error is calculated for the selected sets of data, see Appendix 3. Errors within $\pm 5\%$ are considered acceptable. This limit is not exceeded for any of the samples.

6 Summary and conclusions

The hydrochemical logging of KFM09A was conducted successfully. The main conclusions that can be drawn from the hydrochemical logging are:

- The amount of remaining flushing water was quite high at intermediate borehole lengths. Within the first 145 m, the amount was below 20%, increasing to 53% in the middle part, and from 545 m and down to the bottom of the borehole, the flushing water content again decreased to below 20%. Therefore, the water composition in the sample from the lowest section (flushing water content 4%) can be considered as fairly representative for the groundwater present in the evenly distributed water bearing fractures at the bottom part of the borehole.
- The highest electrical conductivity (3,710 mS/m) and chloride concentration (14,300 mg/L) were found in the bottom part of the borehole at approximately 620 m vertical depth. The high salinity is similar to what was found in KFM07A at 790 m vertical depth /7/.
- The charge balance error did not exceed the acceptable limit of $\pm 5\%$ for any of the eight analysed samples. This indicates that the analyses of the major components are consistent.

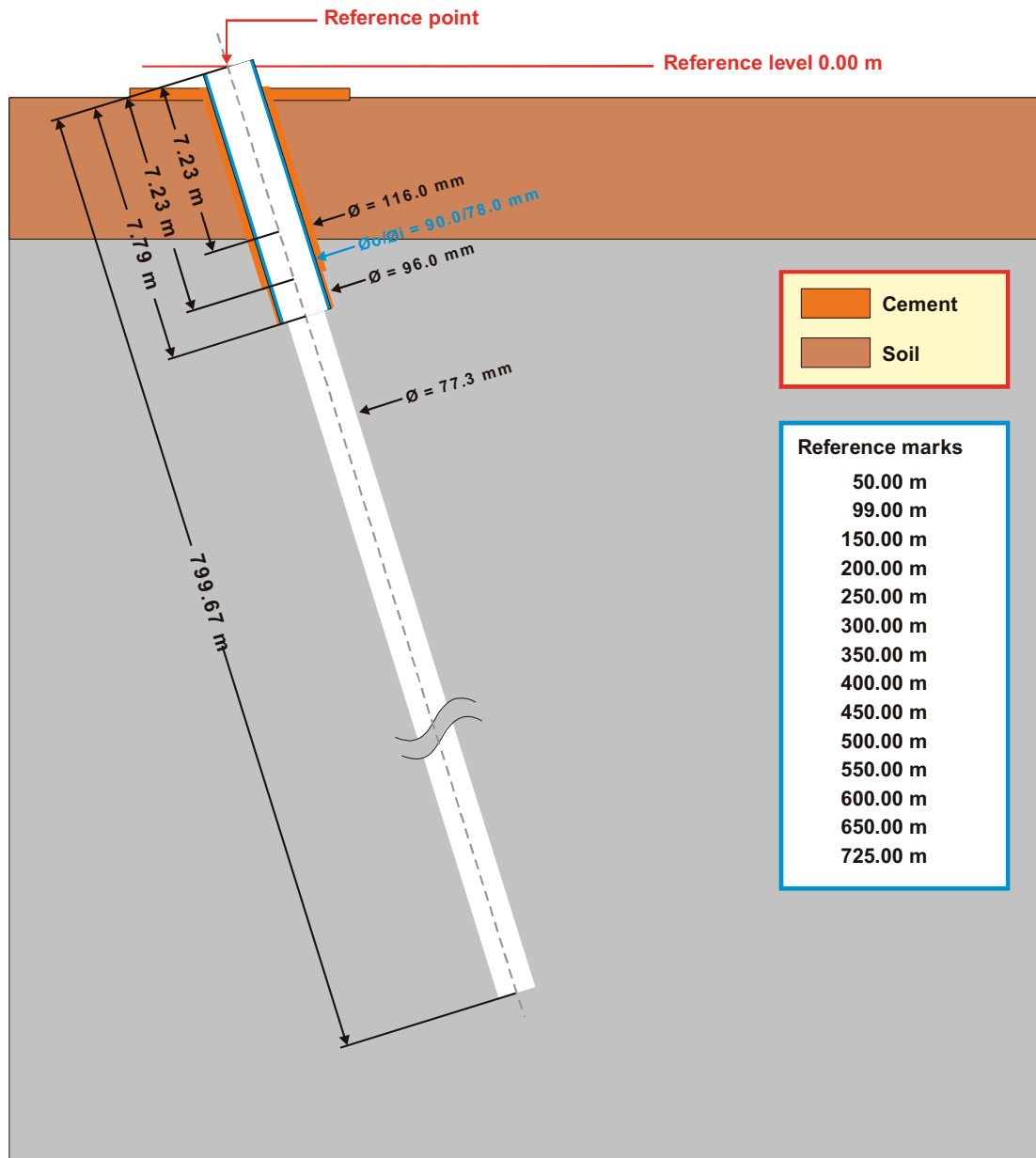
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Design of the telescopic borehole KFM09A

Technical data

Borehole KFM09A



Drilling reference point

Northing: 6700115 0. 4 (m), RT90 2,5 gon V 0:-15

Easting: 1630647.50 (m), RT90 2,5 gon V 0:-15

Elevation: 4.29 (m), RHB 70

Orientation

Bearing: 200.08 °

Inclination: -59.46 °

Drilling period

Drilling start date: 2005-09-05

Drilling stop date: 2005-10-27

Appendix 2

Sampling and analytical methods

Table A2-1. 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	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	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	Chlorine-37	Plastic	100	No	–	ICP-MS	Not critical (month)
Carbon isotopes	¹³ C, ¹⁴ C	Plastic (HDPE)	100×2	No	–	(A)MS	A few days
Sulphur isotopes	³⁴ S	Plastic	500–1,000	Yes	–	Combustion, ICP MS	No limit
Strontium-isotopes	⁸⁷ Sr/ ⁸⁶ Sr	Plastic	100	Yes	–	TIMS	Days or Week
Uranium and Thorium isotopes	²³⁴ U, ²³⁵ U, ²³⁸ U, ²³² Th, ²³⁰ Th,	Plastic	50 1,000	Nej	–	Chemical separat. Alfa/ gamma spectrometry	No limit
Boron isotopes	¹⁰ 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	¹³ 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 A2-2. 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 50 (SKB)		µg/L	0.8 (0.8–20 µg/L) 5% (> 20 µg/L) 20%	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	0.005 ¹	0.05	µg/L	10%	Correct order of size (low conc.)
Sc, In, Th	ICP	0.05 ¹	0.5	µg/L	10%	Correct order of size (low conc.)
Rb, Zr, Sb, Cs, Tl	ICP	0.025 ¹	0.25	µg/L	10%	Correct order of size (low conc.)
Y, Hf	ICP	0.005 ¹	0.05	µg/L	10%	Correct order of size (low conc.)
U	ICP	0.001 ¹	–	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 eller 0.1		TU ⁶	0.8 eller 0.1	Correct order of size
³⁷ Cl	ICP MS	0.2‰ ^o (20 mg/L)		‰ SMOC ⁷	–	–
δ ¹³ C	A (MS)	–		‰ PDB ⁸	–	–
¹⁴ C pmc	A (MS)	–		PMC ⁹	–	–
δ ³⁴ S	ICP 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	–	–
234U, 235U, 238U, 232Th, 230Th	Alfa spectr.	0.0005		Bq/L ¹³	5%	–
222Rn, 226Rn	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:

$$\text{pmC} = 100 \times e^{(1950-y-1.03t)/8274}$$
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:

$$\delta y_l = 1,000 \times (\frac{\text{sample}-\text{Kstandard}}{\text{Kstandard}})$$
where K= the isotope ratio and l = ²H, ¹⁸O, ³⁷Cl, ¹³C or ³⁴S etc.

Appendix 3

Water composition including Uranium and Thorium

Compilation May 2006

Idcode	Secup m	Seclow m	Sample no.	Date	Charge Bal %	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	Li mg/L	Sr mg/L	pH	EC mS/m	Flush water%	U µg/L	Th µg/L
KFM09A	0	45	12201	2006-03-07		-	-	-	-	-	-	-	-	-	-	-	-	-	-	87.5	5.06	-	-
KFM09A	45	95	12202	2006-03-07	0.18	114	5.44	161	9.7	324	245	37.5	26.1	1.90	0.85	6.97	0.007	1.17	7.46	152	8.89	-	-
KFM09A	95	145	12203	2006-03-07		-	-	-	-	-	-	-	-	-	-	-	-	-	-	243	16.7	-	-
KFM09A	145	195	12204	2006-03-07	2.13	312	6.83	387	8.2	262	930	50.7	27.8	7.95	1.09	6.12	0.013	4.00	7.51	422	21.3	-	-
KFM09A	195	245	12205	2006-03-07		-	-	-	-	-	-	-	-	-	-	-	-	-	-	797	39.4	-	-
KFM09A	245	295	12206	2006-03-07	1.42	1,130	12.3	1,870	9.9	53.5	4,860	56.8	24.2	45.5	0.80	2.93	0.020	21.9	6.96	1,440	53.4	-	-
KFM09A	295	345	12207	2006-03-07		-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,770	52.1	-	-
KFM09A	345	395	12208	2006-03-07	0.87	1,550	13.9	2,710	10.9	7.78	7,040	59.3	24.4	66.1	0.84	2.21	0.032	31.0	5.77	1,990	48.2	-	-
KFM09A	395	445	12209	2006-03-07		-	-	-	-	-	-	-	-	-	-	-	-	-	-	2,070	44.1	-	-
KFM09A	445	495	12210	2006-03-07	1.79	1,790	14.4	3,310	12.2	3.42	8,280	76.8	32.1	78.9	0.98	1.59	0.033	39.1	5.77	2,380	32.3	-	-
KFM09A	495	545	12211	2006-03-07		-	-	-	-	-	-	-	-	-	-	-	-	-	-	2,920	19.2	-	-
KFM09A	545	595	12212	2006-03-07	0.29	2,270	14.0	4,870	16.0	10.8	12,000	102	39.6	120	1.06	0.68	0.045	56.8	7.02	3,170	14.4	1.31	<0.2
KFM09A	595	645	12213	2006-03-07		-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,420	12.8	-	-
KFM09A	645	695	12214	2006-03-07	0.91	2,710	13.4	5,610	17.1	5.28	13,800	115	44.2	141	1.24	1.86	0.057	70.2	7.61	3,580	7.28	0.556	<0.2
KFM09A	695	745	12215	2006-03-07		-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,600	5.00	-	-
KFM09A	745	795	12216	2006-03-07	1.06	2,740	17.2	5,890	24.3	6.06	14,300	118	47.9	147	0.99	37.7	0.070	68.8	7.97	3,710	4.06	85.9	9

—= Not analysed

yellow marked values are somewhat questionable and will be checked

EC = Electrical Conductivity

ChargeBal % = Relative charge balance error %

Isotopes I, compilation of H- and O-isotopes

Idcode	Secup m	Seclow m	Sample no	Date	$\delta^2\text{H}$ ‰ SMOW	^3H TU	$\delta^{18}\text{O}$ ‰ SMOW
KFM09A	545	595	12212	2006-03-07	-86.4	A	-12.2
KFM09A	645	695	12214	2006-03-07	-89.2	A	-12.9
KFM09A	745	795	12216	2006-03-07	-90.4	A	-13.1