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Forsmark site investigation

Hydrochemical logging in KFM09B

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September 2006

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Keywords: Core drilled borehole, Groundwater, Hydrochemical logging, Tube sampling, Water sampling, Chemical analyses, AP PF 400-06-048.

Abstract

Hydrochemical logging or so called tube sampling has been performed in the core drilled borehole KFM09B. 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 600 m long polyamide tube divided into units of 50 m.

The water volume 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 remaining flushing water from the core drilling was high (20–59%) in all samples except the three first samples at the top (borehole length 10–160 m). Therefore the SKB chemistry class 3 isotope options were not included. The planned uranium and thorium analyses were omitted for the same reason.

The high salinity found in the groundwater at the bottom of KFM09A, a previous and adjacent borehole, justified sampling also in KFM09B which is inclined towards southeast into the tectonic lens. The report presents a comparison between chloride concentrations in KFM09A and KFM09B and it is observed that the chloride concentrations are higher along KFM09A directed out from the lens than along KFM09B. The most saline water was found in the bottom part of the borehole at 560 to 610 m borehole length (approx. 480 m vertical depth) where the chloride concentration was 8,350 mg/L and the electrical conductivity reached 2,210 mS/m.

Sammanfattning

Hydrokemisk loggning, eller så kallad slangprovtagning, har utförts i kärnborrhålet KFM09B. Metoden är snabb och enkel att använda för att erhålla information om den kemiska sammansättningen hos grundvattnet längs ett öppet borrhål. Utrustningen består av en cirka 600 m lång polyamidslang uppdelad i enheter om vardera 50 m.

Vattenvolymen i varje slangenhet utgjorde ett prov varav vartannat prov analyserades enligt SKB kemiklass 3 (exklusive tillval). Elektrisk konduktivitet och spolvattenhalt bestämdes emellertid i samtliga prov. Halten kvarvarande spolvatten från kärnborrningen var hög (20–59 %) i samtliga prov utom i de tre övre proven (10–160 m borrhålslängd). Därför analyserades inte isotoptillvalen enligt SKB klass 3. Även de planerade analyserna av uran och torium uteslöts av samma orsak.

Den höga salthalten som upptäcktes i grundvattnet i botten av KFM09A, ett tidigare och näraliggande borrhål, motiverade provtagning också i KFM09B som är vinklat mot sydost in i den tektoniska linsen. Rapporten presenterar en jämförelse mellan kloridkoncentrationerna i KFM09A och KFM09B och det kan observeras att kloridkoncentrationen är högre längs KFM09A som är riktat ut från linsen än längs KFM09B. Det saltaste vattnet i KFM09B upptäcktes i botten på borrhålet vid 560–610 m borrhålslängd (ca 480 m vertikalt djup) där kloridkoncentrationen uppgick till 8 350 mg/L och den elektriska konduktiviteten nådde 2 210 mS/m.

Contents

1 Introduction

This document reports the performance and the results of the activity “Hydrochemical logging” in KFM09B 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 30th of May 2006. The obtained data from the activity are reported to the database SICADA, where they are traceable by the Activity Plan number.

The core drilled borehole KFM09B is about 600 m long /3/. Its location together with the other current deep boreholes within the investigation area is shown in Figure 1-1. Figure 1-2 shows a zooming in towards drill site DS9 with KFM09B and nearby situated boreholes in rock. The borehole KFM09B is inclined c. 55° 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 KFM09B is presented in Appendix 1.

KFM09B is a non-chemistry type core drilled borehole, see method descriptions MD 620.003 (Method description for drilling cored boreholes). The cleaning of the equipment was performed according to level 1 in the cleaning instructions in MD 600.004 (Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning). The activities/investigations performed in KFM09B 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 KFM09B	AP PF 400-06-048	1.0
Method Documents	**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

Figure 1-1. *The investigation area at Forsmark (approximately the area inside the black square) including the candidate area selected for more detailed investigations.*

Figure 1-2. *Location and projection on the horizontal plane of the cored borehole KFM09B and the surrounding boreholes at drill sites DS9 and DS7.*

Table 1-2. Activities performed in KFM09B until and including the hydrochemical logging.

Activities performed	Start date and date of completion	Length or section [m]	Comment
Percussion drilling	2005-11-15	0–9.12	
Core drilling	2005-11-16–2005-12-19	9.12–616.45	Drinking water from the tap served as the source of flushing water for the core drilling of KFM09B /3/
Flushing water treatment	2005-11-15–2005-12-21	10.70–616.45	/3/
Sampling of drilling water and returned water (Microbe control was not performed)	2005-11-15–2005-12-21	13.21–616.45	–
Injection tests	2005-11-23–2005-11-25	10.5–57.75	The injection tests were carried out during two different field campaigns /4/
BIPS-logging	2006-01-24	80.0–610.70	/5/
Geophysical logging	2006-01-25–2006-01-31	0.0–613.80	/6/
Injection tests	2006-02-09–2006-03-13	55.0–605.5	/4/
BIPS-logging	2006-03-16	440.00–605.00	/5/
Hydrochemical logging	2006-05-30	10–610	Presented in this report

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 unusual high salinity of the water in the adjacent borehole KFM09A, discovered during the hydrochemical logging in March 2006 /7/. Borehole KFM09B is drilled in another direction (see Figure 1-2) than KFM09A, and may therefore show a different ground0water character.

The analysis program is carried out according to SKB chemistry class 3. However, if the content of flushing water remaining from core drilling exceeds 20% in a sample, which was the case in KFM09B, the isotope determinations are omitted.

3 Sampling equipment

For the hydrochemical logging an approximately 600 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 assembled 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.

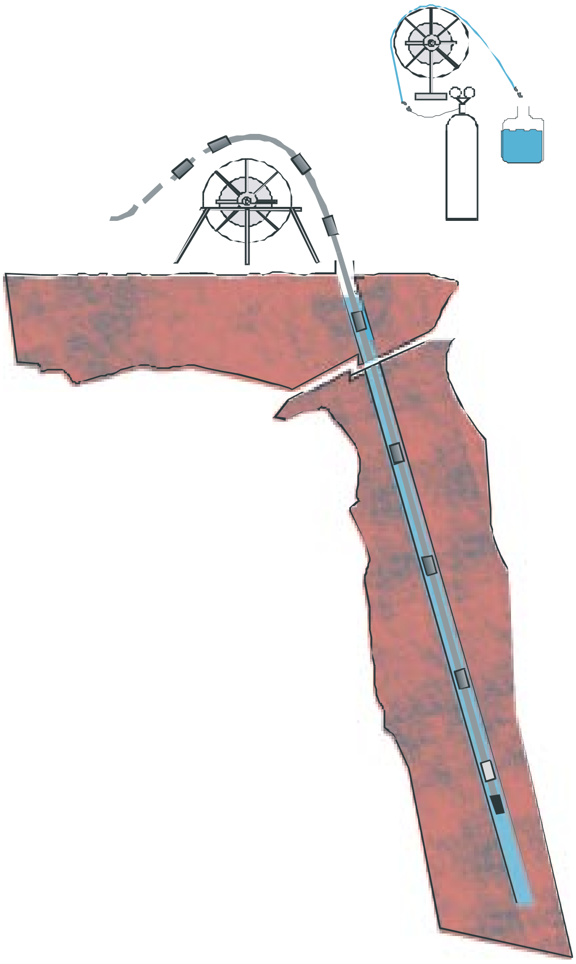


Figure 3-1. *Equipment for hydrochemical logging in boreholes. At the lower end of the tube array there is a non-return valve and a weight connected. Each tube unit is 50 m long.*

4 Performance

4.1 Hydrochemical logging

Sampling of the telescopic borehole KFM09B was performed on the 30th of May 2006 according to the activity plan AP PF 400-06-048 and in compliance with the method description SKB MD 422.001 (Table 1-1).

The hydrochemical logging was carried out to 610 m borehole length. The lowering of the tubes started at 09:57 and the retrieval at 12:30. The tube units were emptied using pressurised 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 5.60 m, from the top of the casing. The upper tube unit was therefore not completely filled with sample water, and this water was not analysed. The twelve samples analyzed represent borehole interval 10–610 m.

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 KFM09B were assigned SKB numbers 12267 to 12278. The flushing water content in all the samples except sample number 12267 was above 20%, and no samples were sent to laboratories for isotope determination. Also, the planned uranium and thorium determinations were omitted due to the high flushing water content. A scheme showing the filled sample portions at the logging occasion is given in Table 4-1.

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).

Table 4-1. Overview of samples collected at the hydrochemical logging in KFM09B. Filled blue cells represent collected samples. Striped cells represent collected reserve samples.

Sample information			Collected sample portions							
Tube unit	Length [m]	SKB No.	Cond.	pH, alk.	Major constit.	Anions	Uranine	^3H	δ^2H / $\delta^{18}O$	U, Th
12	10 60	12267	🟦	▨	▨	▨	🟦			▨
11	110	12268	🟦	🟦	🟦	🟦	🟦	x	x	x
10	160	12269	🟦	▨	▨	▨	🟦			▨
9	210	12270	🟦	🟦	🟦	🟦	🟦	x	x	x
8	260	12271	🟦	▨	▨	▨	🟦			▨
7	310	12272	🟦	🟦	🟦	🟦	🟦	x	x	x
6	360	12273	🟦	▨	▨	▨	🟦			▨
5	410	12274	🟦	🟦	🟦	🟦	🟦	x	x	x
4	460	12275	🟦	▨	▨	▨	🟦			▨
3	510	12276	🟦	🟦	🟦	🟦	🟦	x	x	x
2	560	12277	🟦	▨	▨	▨	🟦			▨
1	560 610	12278	🟦	🟦	🟦	🟦	🟦	x	x	x

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

x = samples were collected but not analysed.

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 ± 5% are considered acceptable (in surface waters ± 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 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.

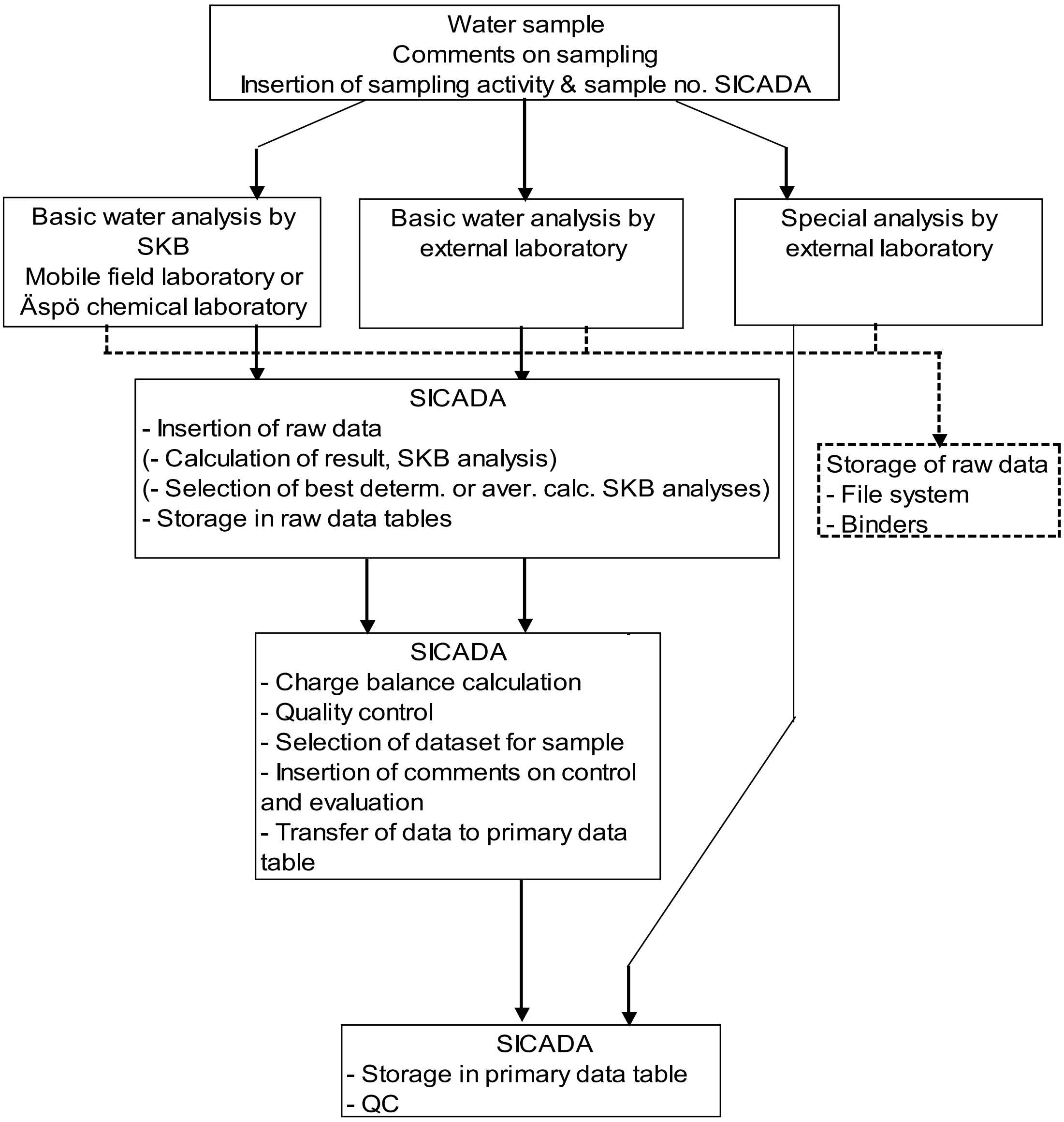


Figure 4-1. *Overview of data management for hydrogeochemical data.*

4.4 Nonconformities

The activity was performed according to the controlling documents for the activity without any deviations that can affect the quality of the data. The only exception was that the planned uranium and thorium determinations were omitted due to the high flushing water content.

5 Results

5.1 Chemical analyses

The results from the chemical analyses performed on samples from the hydrochemical logging in KFM09B are presented in Appendix 3. No isotope determinations were made since the flushing water content exceeds 20% in all samples except the three samples representing borehole interval 10–160 m. Diagrams showing the flushing water content, the electric conductivity and the concentration of Cl^-, Na^+ and Ca^{2+} along the borehole at the time of the sampling are presented in Figures 5-1 to 5-3; concentrations are plotted versus borehole length. The data are plotted at the mid-length of each tube unit.

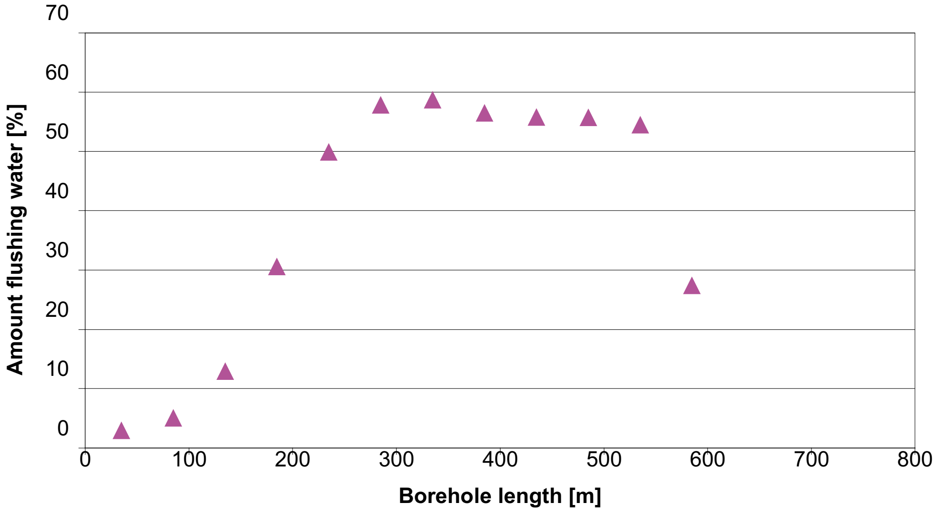


Figure 5-1. *Amount of remaining flushing water versus borehole length in KFM09B.*

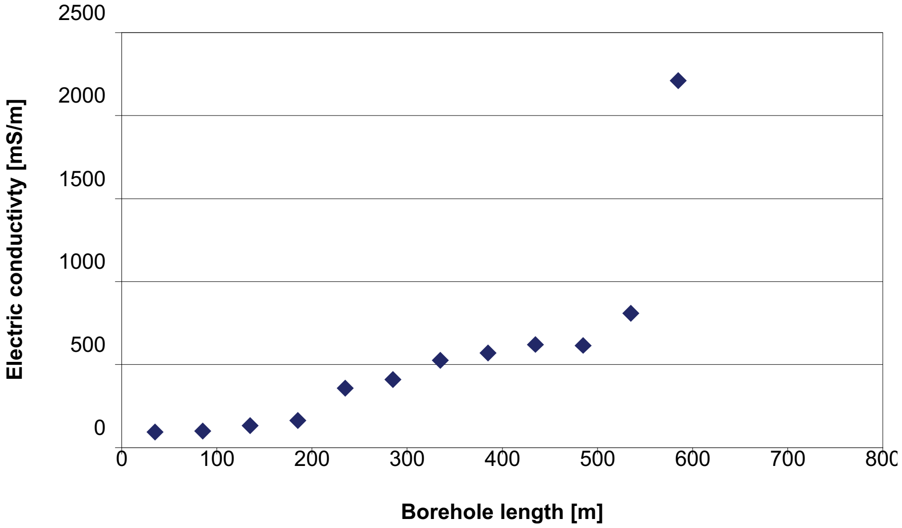


Figure 5-2. *Electrical conductivity versus borehole length in KFM09B.*

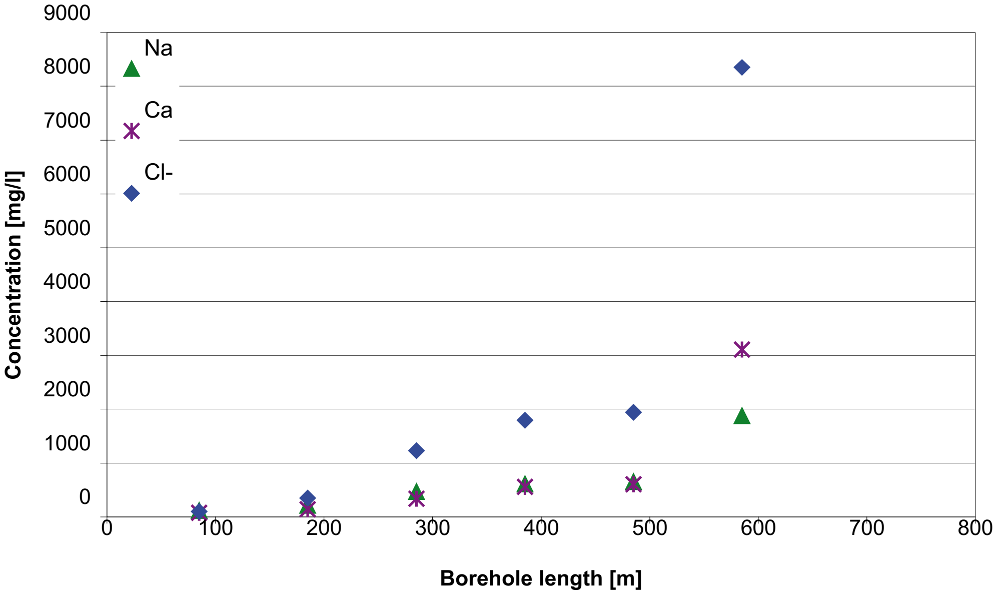


Figure 5-3. *Sodium, calcium and chloride concentrations in water samples collected from hydrochemical logging in KFM09B plotted versus borehole length.*

The charge balance errors give an indication of the quality and uncertainty of the analyses of major constituents. The relative charge balance errors are calculated for the selected sets of data, see Appendix 3. Errors within ± 5% are considered acceptable. The errors did not exceed 5% except for tube section 160–210 m, for which the charge balance error was 8%.

5.2 Comparison of salinity in KFM09A and KFM09B

The hydrochemical logging performed in the adjacent borehole KFM09A in March 2006 showed high salinity compared to most other boreholes investigated so far in the Forsmark area /7/. The two boreholes KFM09A and KFM09B are drilled in different directions. While KFM09A intersects the altered zone at the limit of the candidate area, KFM09B is directed into a fracture domain characterised by scarcity of fractures. Therefore, it is interesting to compare the distribution of the chloride concentration versus depth between the two boreholes. To make the comparison possible it is necessary to correct the chloride concentrations to account for different flushing water content. Since drinking water, which has a low salinity, was used as flushing water, the salinity of the flushing water was neglected. The calculation was made according to:

$$Cl^-_{corr} = \frac{Cl^-_{sample}}{1 - \frac{FW(\%)}{100}} \qquad (5\text{-}1)$$

Cl^-_{corr} = Chloride concentration corrected for flush water content.

Cl^-_{sample} = Chloride concentration from analyzed sample.

$FW(\%)$ = Flush water content in %.

The corrected chloride concentrations are plotted versus vertical depth in Figure 5-4. The deepest tube unit from KFM09B showed a similar concentration as the intermediate and deep part of KFM09A. Despite the uncertainty in the corrected values and also due to the open hole conditions, it is likely that the salinity distribution in KFM09B differs from that of KFM09A.

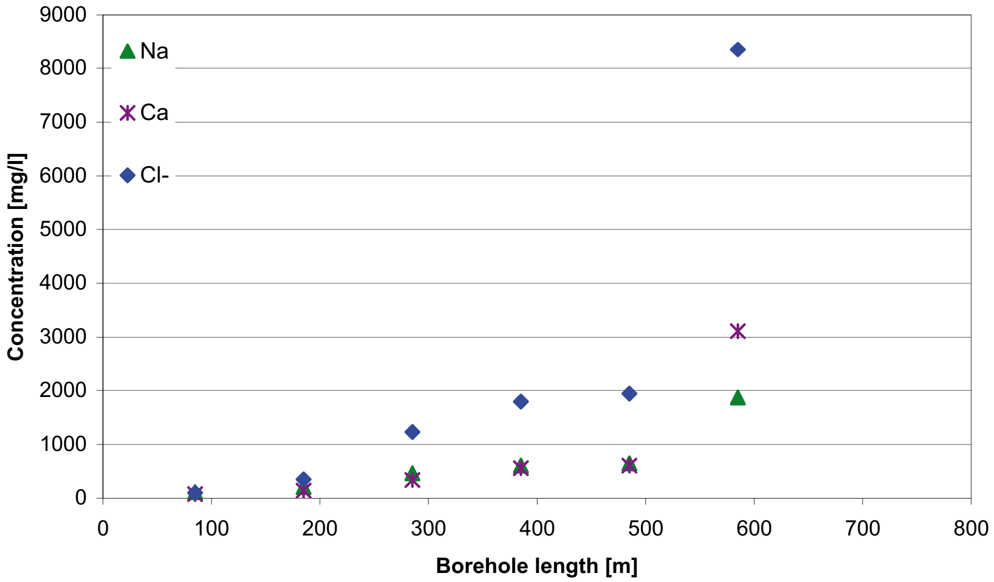


Figure 5-4. *Comparison corrected chloride concentration (Equation 5-1) from hydrochemical logging in KFM09A and KFM09B versus vertical depth. The data are plotted at the mid-length of each tube unit.*

6 Summary and conclusions

The hydrochemical logging of KFM09B was conducted successfully. The main conclusions that can be drawn from the hydrochemical logging are:

- The amount of remaining flushing water was quite high in all samples except for the ones from the three upper sections 10–160 m.
- The highest electrical conductivity (2,210 mS/m) and chloride concentration (8,350 mg/L) were found in the bottom part of the borehole at approximately 480 m vertical depth.
- The charge balance error slightly exceeded the acceptable limit of ± 5% in one of the samples.
- The salinity in the water column along the borehole was, generally, lower in KFM09B compared to the adjacent borehole KFM09A. Due to necessary corrections of chloride concentration values and also due to the open hole conditions, the interpretations are uncertain. However, the different groundwater composition in the two boreholes may reflect the difference in bedrock properties.
- Both boreholes show low magnesium – and high bromide concentrations indicating non Littorina origin.

7 References

/1/ **SKB, 2001a.** Site investigations. Investigation methods and general execution programme. SKB TR-01-29, Svensk Kärnbränslehantering AB.

/2/ **SKB, 2005.** Forsmark site investigation. Programme for further investigations of geosphere and biosphere. SKB R-05-14, Svensk Kärnbränslehantering AB.

/3/ **Claesson L-Å, Nilsson G, 2006.** Forsmark site investigation. Drilling of the cored boreholes KFM09A and KFM09B at drilling site DS9. SKB P-06-169, Svensk Kärnbränslehantering AB.

/4/ **Gustavsson E, Ludvigson J-E, Gokall-Norman K, 2006.** Forsmark site investigation. Single-hole injection tests in borehole KFM09B. SKB P-06-52, Svensk Kärnbränslehantering AB.

/5/ **Gustafsson J, Gustafsson C, 2006.** RAMAC and BIPS logging in boreholes KFM09B, HFM24, HFM26, HFM27, HFM29 and HFM32. Forsmark site investigation. SKB P-06-64, Svensk Kärnbränslehantering AB.

/6/ **Nielsen U T, Ringgaard J, Vangkilde-Pedersen T, 2006.** Geophysical borehole logging in boreholes KFM09B, KFM07B, HFM25, HFM27 and HFM28. Forsmark site investigation. SKB P-06-22, Svensk Kärnbränslehantering AB.

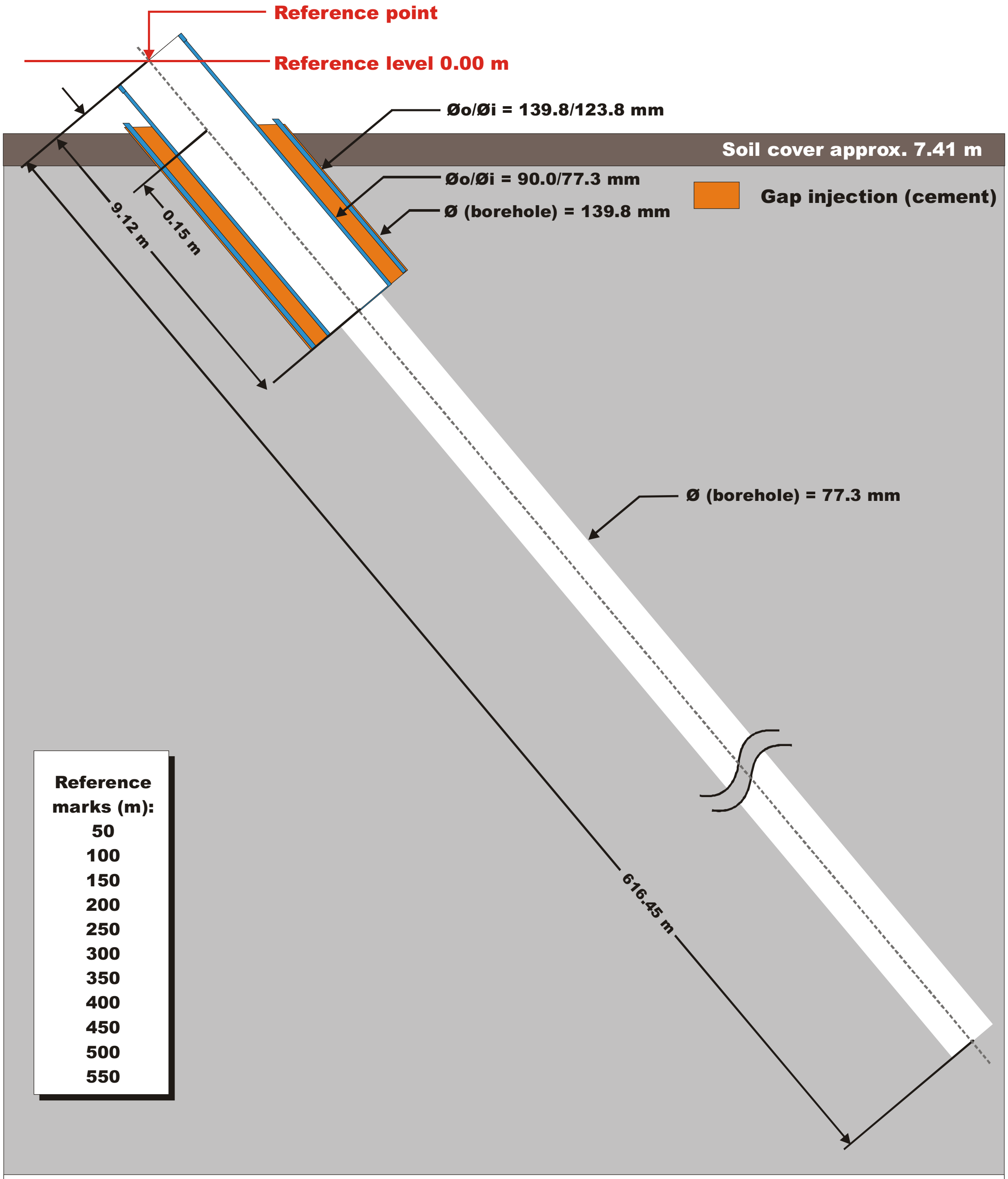
/7/ **Nilsson K, 2006.** Forsmark site investigation. Hydrochemical logging in KFM09A. SKB P-06-095, Svensk Kärnbränslehantering AB.

Appendix 1

Design of the telescopic borehole KFM09B

Technical data

Borehole KFM09B



Drilling reference point

Northing: 6700119.89 (m), RT90 2,5 gon V 0:-15

Easting: 1630638.78 (m), RT90 2,5 gon V 0:-15

Elevation: 4.30 (m), RHB 70

Orientation

Bearing (degrees): 140.83°

Inclination (degrees): -55.08°

Borehole

Length: 616.45 m

Core drilling period

Drilling start date: 2005-11-15

Drilling stop date: 2005-12-21

Rev. 2006-01-20

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^-, SO4, 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 (1mL 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)
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

Component group	Component/element	Sample container (material)	Volume (mL)	Filtering	Preparation/ Conservation*	Analysis method	Analysis within – or delivery time to lab
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, 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_2H_2, C_2H_4, C_2H_6, C_3H_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
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

Component group	Component/element	Sample container (material)	Volume (mL)	Filtering	Preparation/ Conservation*	Analysis method	Analysis within – or delivery time to lab
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×c. 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	Jodometrisc 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%[4]
Ba, Cr, Mo, Pb	ICP	0.01	µg/L	7–10%	20%[4]
Cd, Hg	ICP	0.002	µg/L	9 resp 5%	20%[4]
Co, V	ICP	0.005	µg/L	8 resp 5%	20%[4]
Cu	ICP	0.1	µg/L	8%	20%[4]
Ni	ICP	0.05	µg/L	8%	20%[4]
P	ICP	1	µg/L	6%	10%
As	1CP	0.01	µg/L	20%	Correct order of size(low conc.)
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	0.05[1] 0.5	µg/L	10%	Correct order of size (low conc.)

Component	**Method**	**Reporting limits or range**	**Unit**	**Measurement uncertainty**[2]	**”Total” uncertainty**[3]
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‰	–
Component	Method	Reporting limits or range	Unit	Measurement uncertainty[2]	”Total” uncertainty[3]
^{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‱ (20 mg/L)	‰ SMOC[7]	–	–
δ^{13}C	A (MS)	–	‰ PDB[8]	–	–
^{14}C pmc	A (MS)	–	PMC[9]	–	–
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]	–	–
234U, 235U, 238U, 232Th, 230Th	Alfa spectr.	0.0005	Bq/L12	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 deviation[13] 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 deviation[13] from SMOC (Standard Mean Oceanic Chloride).
8. Per mille deviation[13] 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 deviation[13] 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 ppm U = 12.4 Bq/kg^{238}U
    1 ppm Th = 3.93 Bq/kg^{232}Th
13. Isotopes are often reported as per mill deviation from a standard. The deviation is calculated as:
    $\delta^{y}I = 1000\times(K_{sample}-K_{standard})/K_{standard}$, where K= the isotope ratio and ^{y}I =^{2}H, ^{18}O, ^{37}Cl, ^{13}C or ^{34}S etc.

Appendix 3

Water compostion, compilation of basic water analysis data

Table A3-1. Compilation August 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	DrillWater %
KFM09B	10	60	12267	2006-05-30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	93.6	2.85
KFM09B	60	110	12268	2006-05-30	0.19	112	7.27	74.6	23.4	380	103	57.1	23.6	0.41	1.2	9.07	0.013	0.513	7.55	99.1	4.95
KFM09B	110	160	12269	2006-05-30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	132	12.8
KFM09B	160	210	12270	2006-05-30	8.16	207	7.96	141	20	253	351	41.8	17.3	1.83	1.13	7.76	0.012	1.11	7.29	163	30.5
KFM09B	210	260	12271	2006-05-30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	358	49.8
KFM09B	260	310	12272	2006-05-30	2.2	461	10.3	337	14.7	39	1,230	51.5	20.6	7.35	0.81	4.49	0.011	3.07	6.35	409	57.7
KFM09B	310	360	12273	2006-05-30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	525	58.6
KFM09B	360	410	12274	2006-05-30	2.92	607	9.15	557	9.8	21.8	1,790	46.2	18.9	12.6	0.83	3.22	0.013	6	6.59	570	56.4
KFM09B	410	460	12275	2006-05-30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	621	55.7
KFM09B	460	510	12276	2006-05-30	2.62	649	9.06	603	8.9	21.5	1,940	44.5	18.6	13.8		3.34	0.011	6.75	7.02	615	55.6
KFM09B	510	560	12277	2006-05-30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	809	54.4
KFM09B	560	610	12278	2006-05-30	0.07	1,870	11.5	3,110	2.6	12.7	8,350	35	16.4	60.5	0.46	5.28	0.01	36.4	7.41	2,210	27.3

– = Not analysed.

ChargeBal % = Relative charge balance error %.

EC = Electrical Conductivity.