P-04-302

Forsmark site investigation

Drilling of borehole KFM01B at drilling site DS1

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March 2005

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Keywords: AP PF 400-03-41, Core drilling, Overcoring, Drilling site DS1.

Abstract

The major part of the deep boreholes drilled within the scope of the Forsmark site investigations are performed as telescopic boreholes, entailing that no drill core is received from the upper 100 m. To compensate for this deficiency, a conventional core drilling borehole to 100 m is normally drilled.

At drilling site DS1 within the Forsmark investigation area, a 1,000 m deep telescopic borehole, KFM01A, was initially drilled, indicating low-fractured and low-conductive rock at depth, whereas the shallow parts were fractured and in to some extent highly water-yielding. In the course of the site investigations a decision was made to prolong the planned borehole KFM01B from 100 m to 500 m, in order also to permit rock stress determinations by overcoring measurements down to repository depth.

This borehole, which is denominated KFM01B, is 500.52 m long and reaches about 480 m in vertical distance from the ground surface (inclined 79.04° from the horizon). Overburden drilling with the core drilling machine failed due to occurrence of a boulder rich till. Instead, a percussion drilling machine performed the soil drilling and installed a stainless steel casing to 9.17 m before core drilling commenced.

When performing core drilling in the upper part, unstable and fractured rock was hit. In section 28–46 m a major pressure loss was observed and a hydraulic transmissivity of 2E–3 m^2/s was measured. No return water was recovered and increased pressure levels were observed in surrounding boreholes, which indicated that the flushing water and drill cuttings were injected into the formation. During drill stops, return water and cuttings refilled the borehole making rock stress measurements impossible to perform. The entire section down to 235 m therefore had to be sealed, and after three grouting attempts the flushing water was retrieved to the ground surface and overcoring measurements could start. The overcoring campaign was carried out in sections 235–242 m and 404–475 m.

A sampling- and measurement programme for core drilling provided preliminary but current information about the geological and hydraulic character of the borehole directly on-site. It also served as a basis for extended post-drilling analyses. E.g. the drill cores together with later produced video images of the borehole wall (so called BIPS-images), were used as working material for the borehole mapping (so called Boremap mapping) performed after drilling. Results of the Boremap mapping of KFM01B are presented in this report.

After completed drilling, grooves were milled into the borehole wall at certain intervals as an aid for length calibration when performing different kinds of borehole measurements after drilling.

By the drilling of KFM01B, a drill core was obtained for better characterization of the sub-horizontal structures encountered in the shallow part of the bedrock at DS1 than is possible by only using BIPS-images. The activity also demonstrated that, by conducting overcoring stress measurements in dimension Ø 76 mm, an increased rock stress field, like the one prevailing in the Forsmark investigation area, may corrupt part of or all measurement results due to microfracturing, sometimes resulting in core discing.

Sammanfattning

De flesta djupa (0–1 000 m) borrhål inom Forsmarks platsundersökning utförs som teleskopborrhål, varför borrkärna saknas mellan 0–100 m. För att kompensera för den uteblivna borrkärna i övre delen borras vanligen ett konventionellt kärnborrhål till 100 m.

På borrplats BP1 i Forsmarks undersökningsområde borrades först ett 1 000 m djupt teleskopborrhål, KFM01A. Borrhålet uppvisade ett sprickfattigt och lågkonduktivt berg mot djupet, medan de övre partierna hade förhöjd sprickfrekvens och i vissa sektioner hög vattenföring. Under platsundersökningens gång beslutades att det planerade 100 m-borrhålet KFM01B skulle förlängas till 500 m borrlängd för att även möjliggöra bergspänningsmätningar med överborrningsmetoden ner till förvarsdjup.

Borrhålet, som benämns KFM01B, är 500,52 m långt och når cirka 480 m vertikalt (är ansatt med 79.04° lutning från horisontalplanet). Försök till jordborrning med kärnborrmaskin misslyckades på grund av förekomst av storblockig morän, varför en hammarborrmaskin utförde jordborrningen och drev ett rostfritt foderrör till 9,17 m innan kärnborrning kunde påbörjas.

Vid kärnborrningen av den övre delen påträffades instabilt och sprucket berg. I sektionen 28–46 m noterades stora tryckförluster och en hydraulisk transmissivitet av 2E–3 m^2/s uppmättes. Returvattnet upphörde samtidigt som högre trycknivåer observerades i intilliggande borrhål, vilket indikerade att spolvatten och borrkax blivit kvar i formationen och sannolikt trängt ut i spricksystemet. Vid borruppehåll återfylldes borrhålet med vatten och borrkax, vilket omöjliggjorde bergspänningsmätningar. Därför måste hela sektionen ner till 235 m avtätas. Efter en tredje injekteringsomgång återvände returvattnet, varpå bergspänningsmätningarna kunde inledas. Dessa utfördes i sektionerna 235–242 m samt 404–475 m.

Ett mät- och provtagningsprogram för kärnborrningen gav preliminär information om borrhålets geologiska och hydrauliska karaktär direkt under pågående borrning samt underlag för fördjupade analyser efter borrning. Bland de insamlade proverna utgör borrkärnorna tillsammans med videofilm av borrhålsväggen (s k BIPS-bilder), arbetsmaterialet för den borrhålskartering (s k Boremapkartering) som utförs efter borrning. Även resultaten från Boremapkarteringen av KFM01B finns redovisad i föreliggande rapport.

Efter avslutad borrning frästes referensspår in i borrhålsväggen med syftet att användas för längdkalibrering i samband med olika typer av borrhålsmätningar som senare utförs i det färdiga borrhålet.

Borrningen av KFM01B gav en borrkärna som ger bättre möjligheter till karaktärisering av de subhorisontella strukturer som tidigare påvisades vid borrplats BP1 än vad enbart BIPS-bilder kan ge. Av bergspänningsmätningarna framkom att höga bergspänningar, vilket förekommer i Forsmarks undersökningsområde, kan göra metodens tillämpning osäker, åtminstone vid överborrning i dimension Ø 76 mm. Orsaken är mikrouppsprickning av den överborrade kärnan, som ibland även leder till core discing.

Contents

1 Introduction

This document reports the results gained by core drilling of borehole KFM01B, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-03-41. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB internal controlling documents.

Drilling is one important activity within the scope of the site investigations. Three main types of boreholes are produced: core drilled respectively percussion drilled boreholes in solid rock and short boreholes drilled through unconsolidated soil. The last type may be accomplished by different drilling techniques, e.g. percussion drilling and auger drilling.

The deepest boreholes drilled at the site investigation are core drilled boreholes in hard rock. So far (March 2005), three sub-vertical and four inclined, approximately 1,000 m long, cored boreholes have been drilled within the investigation area. One deep borehole is also underway at DS8. The locations of the eight drilling sites in question, DS1, DS2, DS3, DS4, DS5, DS6, DS7 and DS8 are illustrated in Figure 1-1.

By drilling the deep boreholes, so called telescopic drilling technique is applied, entailing that the upper c 100 m section of the borehole is percussion drilled with a large diameter (≥ 200 mm), whereas the borehole interval 100–1,000 m is core drilled with a diameter of approximately 76–77 mm.

In order to compensate for the missing core in the borehole section 0–100 m, a shorter core drilled borehole might be drilled all the way from the rock surface.

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

Activity plan	**Number**	**Version**
Kärnborrning och överborrningsmätningar i KFM01B.	AP PF 400-03-41	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för kärnborrning.	SKB MD 620.003	1.0
Metodbeskrivning för genomförande av hydrauliska enhålspumptester.	SKB MD 321.003	1.0
Metodbeskrivning för registrering och provtagning av spolvattenparametrar samt borrkax under kärnborrning.	SKB MD 640.001	1.0
Metodbeskrivning för pumptest, tryckmätning och vattenprovtagning i samband med wireline-borrning.	SKB MD 321.002	1.0
Method description for in-situ stress measurements by means of overcoring using the Borre probe.	SKB MD 181.001	1.0

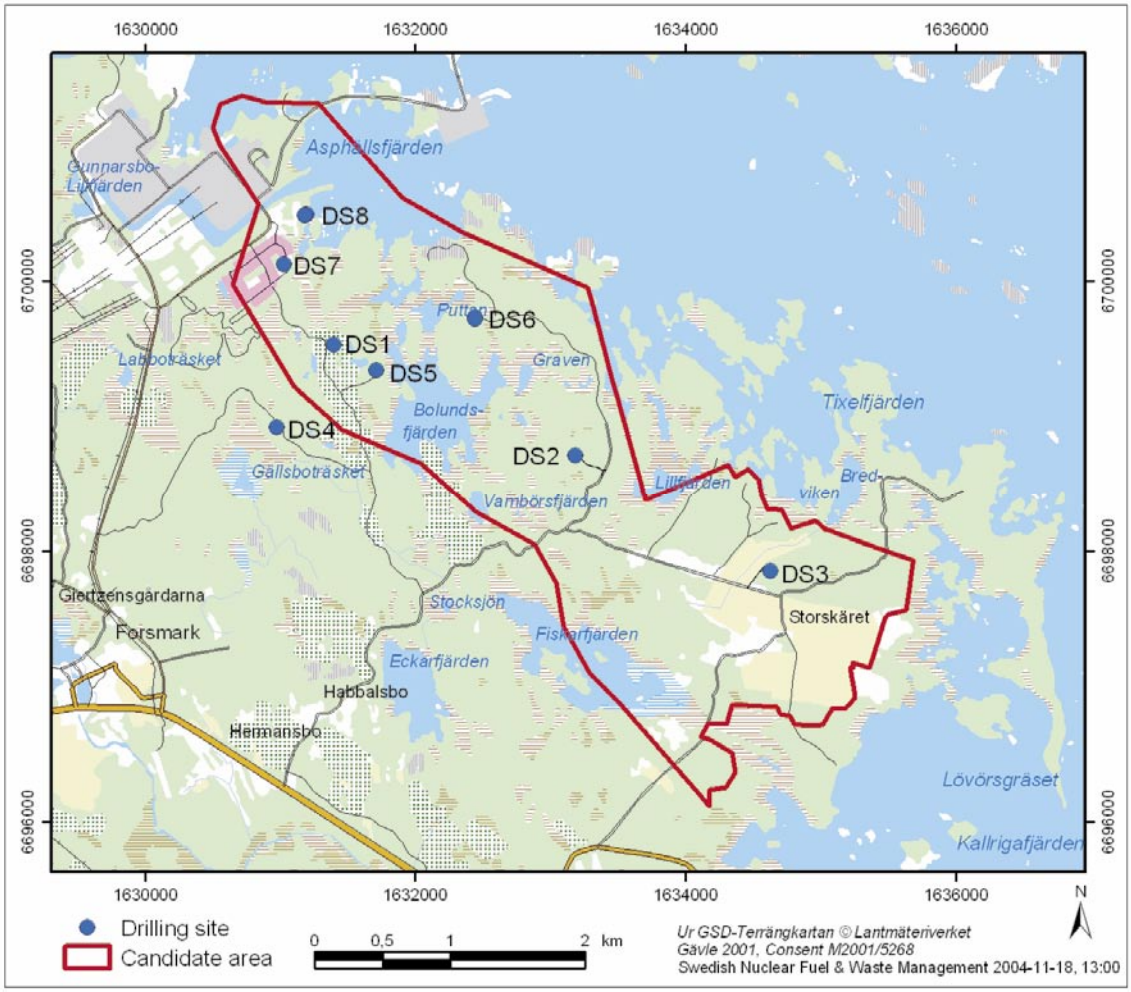


Figure 1-1. *The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drilling sites DS1–8 are marked with blue dots.*

Such a shorter borehole was drilled at drilling site DS1 and is called KFM01B, whereas the 1,000 m deep borehole is called KFM01A. Borehole KFM01B was, however, prolonged from the planned length of 100 m to 500 m because a decision was made to perform rock stress measurement by overcoring (Decision 1032375 /1/). KFM01B was drilled between June 27th 2003 and January 15th 2004 and was used for a combined investigation of geological features and rock mechanical properties. The final borehole length was 500.52 m.

Close to the two deep/semi-deep boreholes at drilling site DS1, also percussion drilled boreholes in soil and solid rock have been drilled for different purposes. The lengths of these boreholes vary between a few metres to approximately 200 m. The locations of all boreholes at drilling site DS1 are displayed in Figure 1-2.

Results from drilling of the flushing water well HFM01 and the two monitoring wells in hard rock, HFM02–03, have been reported separately /2/. So have the results from drilling of the three monitoring wells in regolith, SFM0001–03, /3/. Results from geological mapping of borehole KFM01A (so called Boremap mapping) are treated in /4/. Finally, the overcoring measurements in borehole KFM01B were presented in /5/ and the Boremap mapping of KFM01B in /6/.

Data from drilling of KFM01B are stored in SKB's database SICADA (cf Table 1-2).

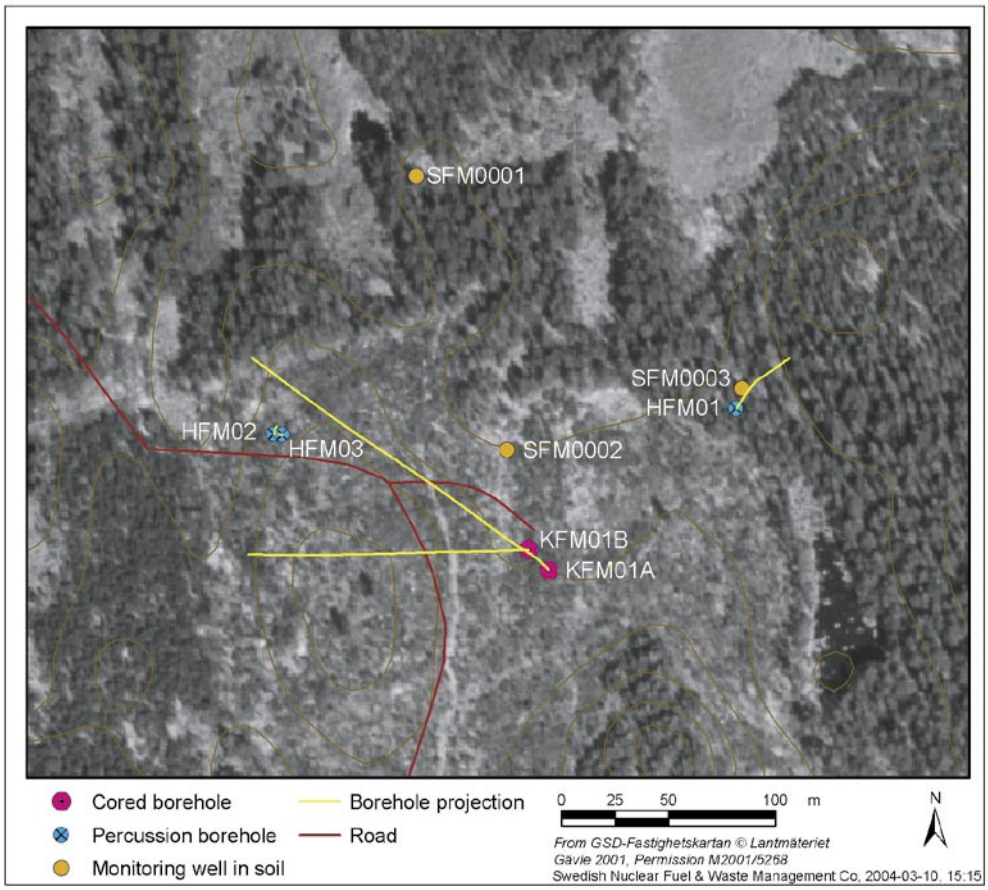


Figure 1-2. *Borehole locations at drilling site DS1. Besides the core drilled boreholes KFM01A and KFM01B, the drilling site incorporates a flushing water well (HFM01), two monitoring wells in solid rock (HFM02 and HFM03), and three monitoring wells in the unconsolidated overburden (SFM0001–03). The projection of inclined boreholes on the horizontal plane at the ground surface (top of casing) is shown in the figure.*

Table 1-2. Data references.

Subactivity	Database	Identity number
Utsättning av KFM01B	SICADA	Field note 148
Borrning, provtagning och mätning KFM01B	SICADA	Field note 172
Bergspänningsmätningar i KFM01B (överborrningar)	SICADA	Field note 292

2 Objective and scope

The main objectives of drilling borehole KFM01B at the site investigation were the following:

- To compensate for the missing drill core in borehole section 0–100 m in KFM01A. The rock samples collected during drilling are used for a lithological, structural and rock mechanical characterization as well as determination of the transport properties of the bedrock from the rock surface to the full drilling depth.
- To improve the poor hydraulic characterization (due to rock instabilities) performed in KFM01A of the shallow part of the bedrock (0–100 m).
- To enable rock stress measurements to repository depth. In this particular borehole, overcoring rock stress measurements were performed during drilling and later, after completion of drilling, a stress measurement campaign by hydraulic fracturing (HF) and hydraulic testing of pre-existing fractures (HTPF) was carried out.
- To render geophysical borehole investigations possible, e.g. TV logging, borehole radar logging and conventional geophysical logging as an aid for the geological/rock mechanical characterization.
- To allow hydraulic borehole tests (single hole tests as well as interference tests, in some cases performed as tracer tests) for characterization of the hydrogeological conditions of the bedrock.
- To enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

Furthermore, a number of hydraulic tests and water samplings are normally performed during the drilling process, whereby a specifically designed test system, a so called wireline probe, is utilized.

3 Equipment

A wireline-76 core drilling system, type Onram 1000/3 without CCD, see Figure 3-1, was engaged for the core drilling and a percussion drilling machine, type Nemek 407 RE DTH, for the short soil drilling. Descriptions of the latter machine are given e.g. in /2/. A short presentation of the core drilling equipment is provided below.

3.1 Drilling equipment

3.1.1 Core drilling equipment

The drilling process is operated by an electrically-driven hydraulic system. The drilling capacity for 76 mm holes is maximum c 700 m. The drill pipes and core barrel used belong to the Hagby WL76 triple-tube system. A photo of the Onram WL76-system is displayed in Figure 3-1. Technical specifications of the drilling machine with fittings are given in Table 3-1.

Figure 3-1. *The Onram 1000 core drilling machine in operation on drillhole KFM01B.*

Table 3-1. Technical specifications of the Onram 1000-system from Hagby-Asahi with appurtenances.

Unit	Manufacturer/Type	Specifications	Remarks
Onram 1000	Hagby-Asahi	Capacity for 76 mm holes maximum approx. 700 m	
Flush water pump	Bean	Max flow rate: 170 L/min Max pressure: 103 bars	
Submersible pump	Grundfos SQ	Max flow rate: 200 L/min	

Core drilling with a wireline system entails recovery of the core barrel via the drilling pipe string, inside which it is hoisted up with the wireline winch. During drilling of borehole KFM01B, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 76.3 mm part of the borehole is 50.8 mm. Minor deviations from this diameter may however occur.

3.1.2 Flushing/return water system – function and equipment

Core drilling involves pumping of flushing water down the drill string, through the drill bit and out into the borehole in order 1) to conduct frictional heat away from the drill bit, and 2) to enhance the recovery of drill cuttings to the ground surface. The cuttings, suspended in the flushing water (in general mixed with groundwater), are forced from the borehole bottom to the ground surface via the gap between the borehole wall and the drilling pipes. A schematic illustration of the flushing/return water system when drilling KFM01B at DS1 is shown in Figure 3-2. Below, the following equipment systems and their functions are briefly described:

- equipment for preparing the flushing water,
- equipment for storage and discharge of return water.

Preparing the flushing water

The water well used for the supply of flushing water for core drilling of KFM01B was a percussion drilled well in hard rock, HFM01 (see Figure 1-2), situated approximately 110 m from KFM01B. Since borehole KFM01B was not prioritized for hydrogeochemical investigations, the groundwater from HFM01 was used without the carbon filter earlier installed (during drilling of KFM01A) for reduction of the organic content.

The flushing water was, however, prepared before use, in accordance with SKB MD 620.003 (Method description for core drilling), with an organic tracer dye, Uranine, which was added to the flushing water at a concentration of 0.2 mg/L before the water was pumped into the borehole, see Figure 3-2. The tracer was thoroughly mixed with the flushing water in the tank. Labelling the flushing water with the tracer aims at enabling detection of the flushing water content in groundwater samples collected in the borehole during or after drilling.

Measurement of flushing water parameters

The total quantity of water supplied to the borehole was acquired by counting the number of filled water tanks used, multiplied by the tank volume.

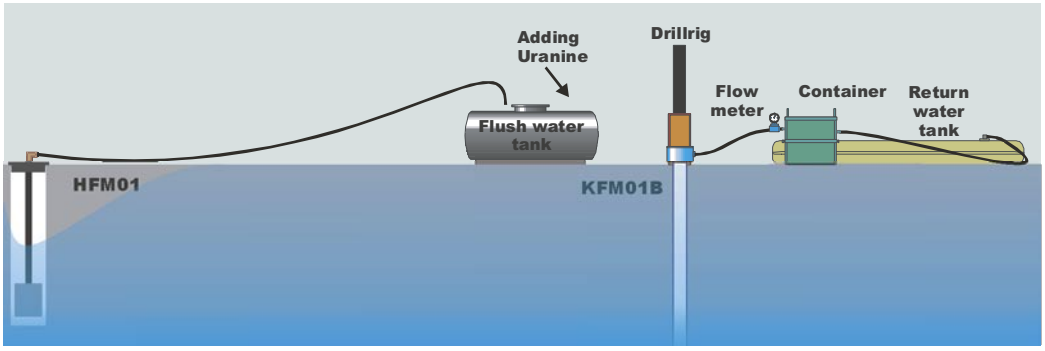


Figure 3-2. *Schematic illustration of the flushing/return water system when drilling KFM01B at DS1. For measurements of the accumulated return water volume, a mechanical water gauge were used.*

Storage and discharge of return water

At the surface level, the return hose was connected to a return pipe between the discharge head and the first return water container, see Figure 3-2. The return water was discharged from the borehole via an expansion vessel and a flow meter to three containers, in which the drill cuttings separated out in the sedimentation container. Since the return water had an increased salt content, it could not, for environmental reasons, be discharged into any fresh water recipient, but had to be pumped from the container via a 1 km long pipe string to the Baltic Sea. Intermittently, the return water was, after separation of drill cuttings, stored in one elastic water tank with an expansive capacity of up to 40 m^3, see Figure 3-2.

3.1.3 Equipment for deviation measurements

After completion of drilling, a deviation measurement was carried out with a Reflex MAXIBOR™ system, which is an optical, i.e. non-magnetic measurement system. Azimuth and dip are measured at every third metre. The collaring point coordinates and the measured values are used for calculating the coordinates of the position of the borehole at every measurement point.

3.1.4 Equipment for hydraulic tests, absolute pressure measurements and water sampling during drilling

In SKB MD 620.003 it is stated that hydraulic tests, absolute pressure measurements and water sampling should be performed at certain intervals using a down-hole tool specially designed for the wireline-76 system. The tool, which is denominated “the wireline probe” or “WL-probe”, is described in SKB MD 321.002, Version 1.0 (Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wireline-borrning), which is an SKB internal controlling document.

4 Execution

4.1 General

The activity was conducted in compliance with Activity Plan P PF 400-03-41, which refers to SKB MD 620.003 (Method description for core drilling). The drilling operations included the following parts:

- preparations,
- mobilisation, including lining up the machine and measuring the position,
- drilling, measurements, over-coring and sampling during drilling,
- finishing off work,
- data handling.

The items are presented more in detail in Sections 4.2–4.5.

4.2 Preparations

The preparations included the contractor's service and function control of his equipment. The machinery was supplied with fuel, oil and grease entirely of the types stated in SKB MD 600.006. Finally, the equipment was cleaned in accordance with SKB MD 600.004.

4.3 Execution of field work

4.3.1 Mobilization

Mobilization onto and at the site included preparation of the drilling site, transport of drilling equipment, flushing water equipment, sampling boxes for drill cores, as well as hand tools etc. Furthermore, the mobilization consisted of cleaning of all in-the-hole equipment at level one in accordance with SKB MD 600.004, lining up the machine and final function control of all equipment.

4.3.2 Drilling of section 0–9.17 m

The soil depth in KFM01A was about nine metres. This part of the borehole has to be cased and cement grouted to prevent groundwater inflow. Soil drilling started with the Onram 1000 machine, but a large boulder at 3 m depth caused difficulties and obstructed continued the drilling. As a percussion drilling machine (Nemek 407 RE DTH) was available, the overburden drilling was instead performed with this machine, using ODEX 115 (Øy/Øi 150/139.7 mm) down to 9.17 m.

4.3.3 Core drilling, measurements and sampling during drilling

By core drilling of borehole KFM01B, two borehole dimensions were applied. Section 9.17–15.56 m was drilled with a borehole diameter of 101.0 mm, whereas the main part of the borehole, section 15.56–500.52 m, was drilled with Ø 76.3 mm. The inner Ø 90/78 mm support casing was fitted into the short Ø 101 mm borehole and cement grouted.

Core drilling is associated with a programme for sampling, measurements and other activities during and immediately after drilling, cf SKB MD 620.003. However, for different reasons, during drilling of KFM01B some deviations from this programme could not be avoided. The major discrepancy compared to SKB MD 620.003 was the overcoring rock stress measurements during drilling. In order to elucidate the nonconformities, the programme according to the Method Description is presented in Section 4.6, Table 4-1, together with the actual performance when drilling KFM01B.

Results from mapping the drill core samples are presented in /6/, and results from the overcoring rock stress measurements are reported in /5/. The remaining measurements and registrations during core drilling are presented in Chapter 5.

4.4 Finishing off work

The concluding work included the following items:

1) The borehole was flushed for about 10 hours in order to clean it from drilling debris adhered to the borehole walls, sedimented at the bottom of the hole or suspended in the water.
2) The drill string was pulled.
3) The borehole was secured with a lockable stainless steel flange.
4) The core drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

4.5 Data handling/post processing

Minutes for several items with the following headlines: Activities, Cleaning of the equipment, Drilling, Drillhole, Core drilling penetration rate, Deliverance of field material and Discrepancy report were filled in by the field crew, and collected by the Activity Leader, who made a control of the information and had it stored in the SKB database SICADA /7/. Field note numbers are presented in Chapter 5.

4.6 Nonconformities

Drilling through the overburden with the Onram 1000 machine failed due to occurrence of large boulders in the soil layer. Therefore soil drilling was performed with a percussion drilling machine (Nemek 407 RE DTH) applying ODEX 115.

No computer controlled drilling rig was available and therefore an Onram 1000 without computer based logging system was used during drilling of KFM01B.

Nitrogen air flushing 0–500 m was performed in order to improve cleaning of the borehole from drilling debris.

The core drilling operation resulted in a number of nonconformities with the Method Description. These are presented in Table 4-1 below.

Table 4-1. Programme for sampling, measurements, registrations and other activities during and immediately after core drilling according to SKB MD 620.003 and AP PF 400-03-41, and the actual performance during drilling of borehole KFM01B.

Activity	Performance and frequency according to SKB MD 620.004 and, for the last item, AP PF 400-03-41	Performance and frequency during drilling of KFM01B
Registration of drilling- and flushing water parameters.	Registration during the entire drilling.	Described in Section 3.1.2. No registration system was available.
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	One measurement after completion of drilling.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drilling pipe string should be controlled before each test.	One measurement performed due to extremely high inflow of groundwater (known from KFM01A).
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drilling pipe string should be controlled before each test.	One measurement performed at the section with a high groundwater inflow.
Absolute pressure measurements.	Normally during natural pauses in drilling.	No measurements performed.
Groove milling in the borehole wall, normally at each 50 m.	Normally performed after completion of drilling.	Nine grooves performed.
Over-coring rock stress measurements.	Measurements at 236 m, 430 m and 500 m.	Performed at 235–242 m and 404–475 m.

5 Results

All data were stored in the SICADA database. Field note numbers are Forsmark 148, 172 and 292 /7/. An overview of the drilling progress of borehole KFM01B is given in Section 5.1, whereas geometrical data and technical design are presented in Section 5.2.

Results from drilling and measurements during drilling are accounted for in:

- Section 5.3 (drilling 0–15.56 m)
- Section 5.4 (drilling 15.56–500.52 m)
- Section 5.5 (measurements while drilling)
- Section 5.6 (hydrogeology)

Well Cad-presentations of borehole KFM01B are shown in:

- Appendix A

The Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling.

5.1 Drilling progress

Borehole KFM01B was drilled during a period of slightly less than 8 months including Summer and Christmas holidays, see Figure 5-1. The prolonged drilling period was mainly due to the much time consuming overcoring rock stress measurements, but partly also to the drilling performance with only one shift/day.

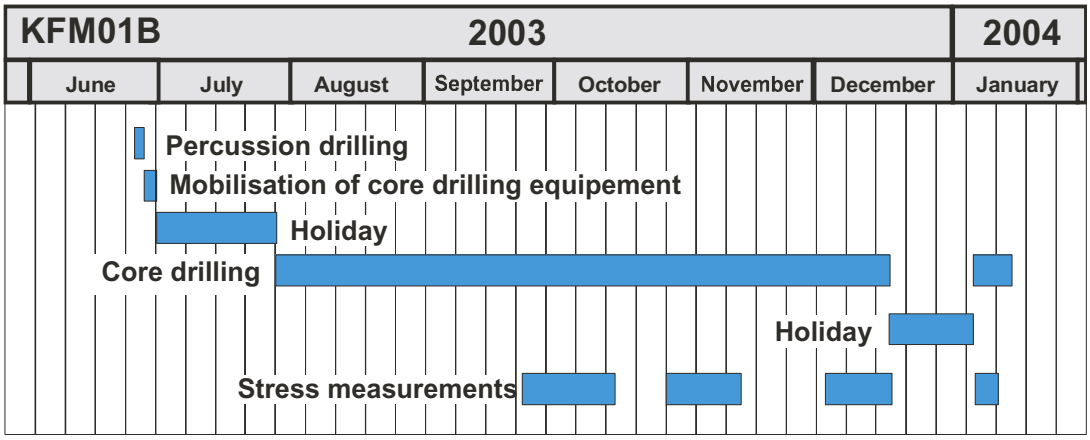


Figure 5-1. *Overview of the drilling performance of borehole KFM01B.*

5.2 Geometrical and technical design of borehole KFM01B

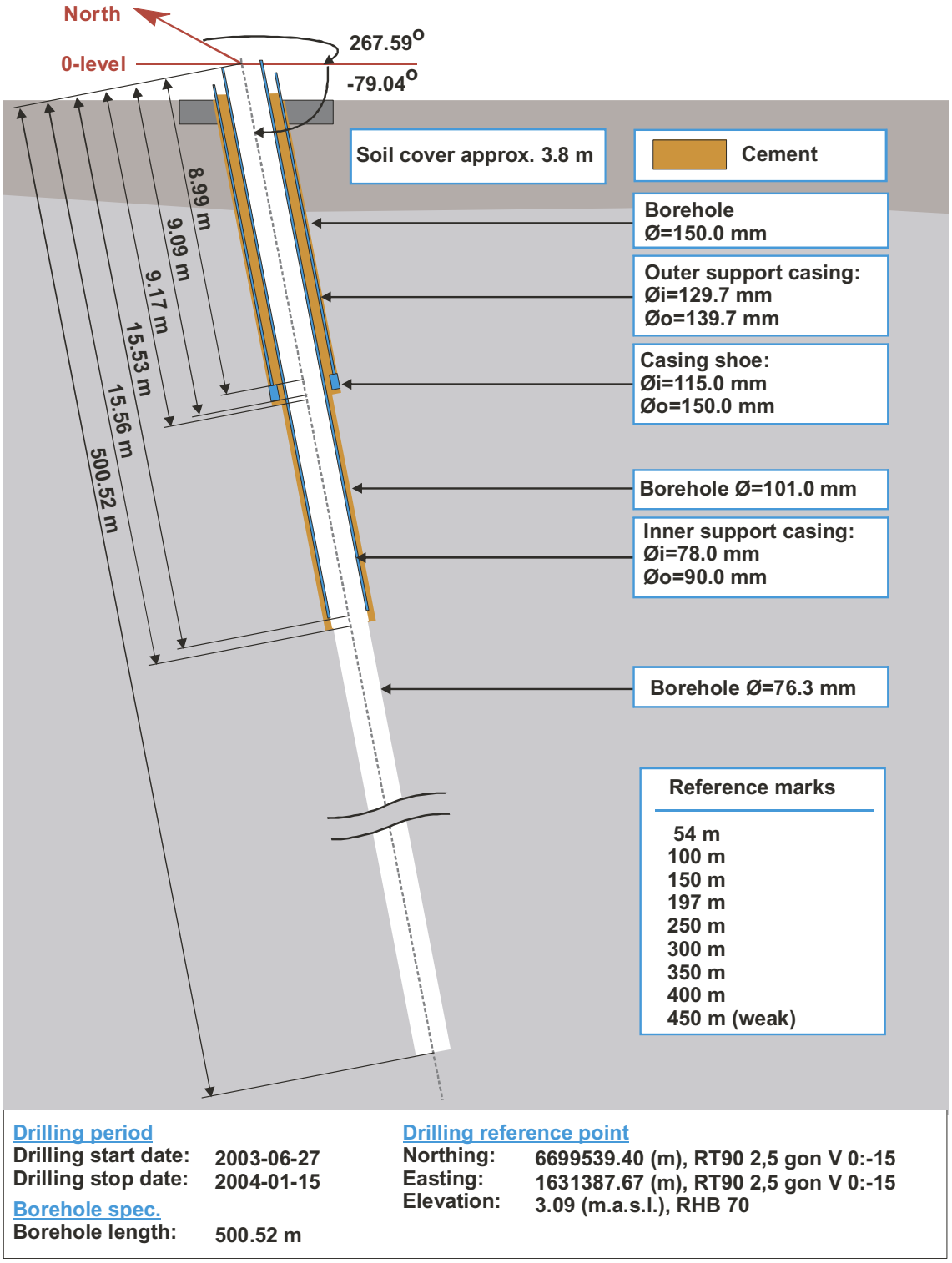
Administrative, geometric and technical data for the core drilled borehole KFM01B are presented in Table 5-1. The technical design of the borehole is illustrated in Figures 5-2 and 5-3.

Table 5-1. Administrative, geometric and technical data for borehole KFM01B.

Parameter	KFM01B
Borehole name	KFM01B
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	June 27, 2003
Completion date	January 15, 2004
Drilling period	2003-06-27 to 2003-07-01 (0–9.17 m)
	2003-07-29 to 07-31 (9.17–15.56 m)
	2003-08-05 to 2004-01-15 (15.56–500.52 m)
Contractor core drilling	Drillcon Core AB
Core drill rig	ONRAM 1000 CCD
Position KFM01B at top of casing (RT90 2.5 gon V 0:–15 / RHB 70)	N 6699539.40 E 1631387.67 Z 3.09 (m a s l)
	Azimuth (0–360°): 267.59° Dip (0–90°): –79.04
Position KFM01B at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6699537.32 E 1631256.27 Z –479.39 (m a s l)
	Azimuth (0–360°): 271.34° Dip (0–90°): –71.46°
Borehole length	500.52 m
Borehole diameter and length	From 0.15 m to 9.17 m: 150 mm
	From 9.17 m to 15.56 m: 101 mm
	From 15.56 m to 500.52 m: 76.3 mm
Casing diameter and length	$Ø_o/Ø_i$ = 90 mm/78 mm to 15.53 m
	$Ø_o/Ø_i$ = 140 mm/130 mm between 0.05 m to 9.05 m
	$Ø_o/Ø_i$ = 150 mm/115 mm between 8.99 m to 9.09 m
Drill core dimension	9.17–15.56 m/Ø 87 mm
	15.56–500.52 m/Ø 51 mm
Core interval	9.17–500.52 m

Technical data

Borehole KFM01B



Drilling period

Drilling start date:	2003-06-27
Drilling stop date:	2004-01-15

Borehole spec.

Borehole length:	500.52 m

Drilling reference point

Northing:	6699539.40 (m), RT90 2,5 gon V 0:-15
Easting:	1631387.67 (m), RT90 2,5 gon V 0:-15
Elevation:	3.09 (m.a.s.l.), RHB 70

Figure 5-2. *Technical data of borehole KFM01B.*

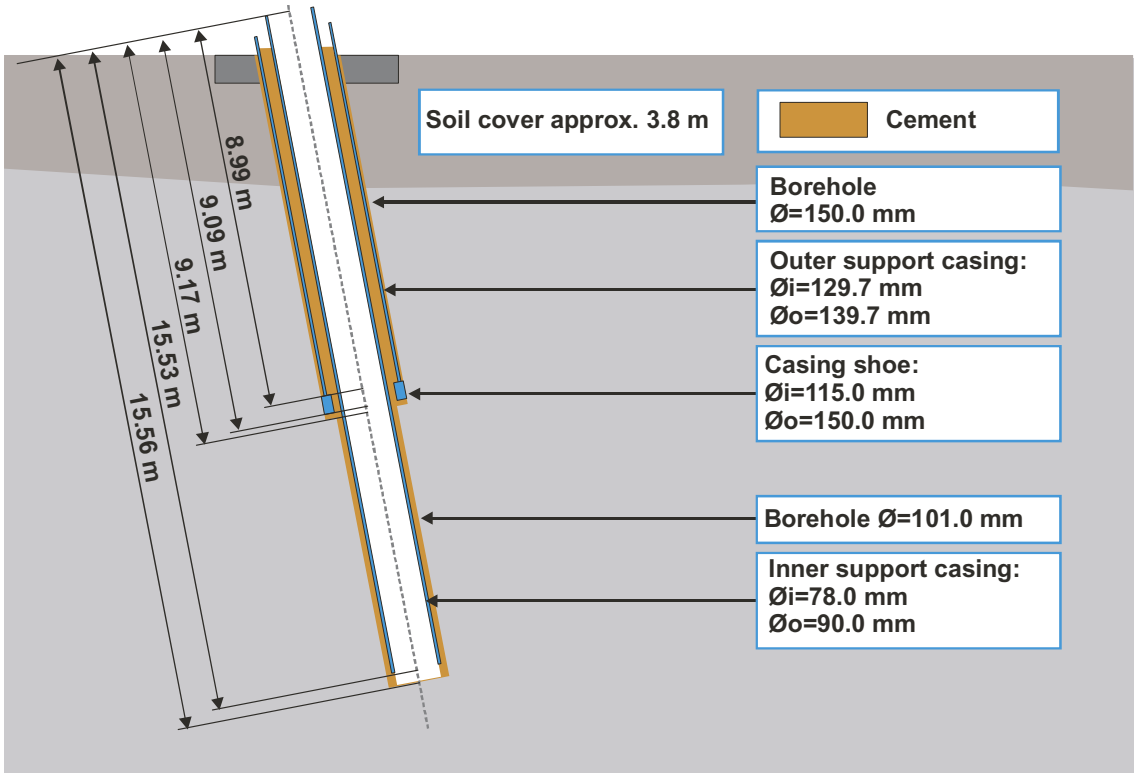


Figure 5-3. *Technical data of upper section 0–15.56 m of borehole KFM01B.*

5.3 Drilling 0–15.56 m

Drilling of the section 0–15.56 m was progressing between June 27th to July 31st 2003 (Figure 5-1). As mentioned in Section 4.3.2, the upper part down to 9.17 m of the borehole is supplied with a 139.7 mm steel casing. In Section 4.3.3 a description of the core drilled part from 9.17 to 15.56 m with a borehole diameter of 101 mm was given. Section 0–15.53 m is also supplied with a cement grouted stainless steel casing of dimension 90/78 mm (Figure 5-3).

5.4 Drilling 15.56–500.52 m

The core drilling progress during the period from August 5th 2003 to January 15th 2004 is presented in Figure 5-4.

The ordinary drilling to the next selected rock stress measurement level was running rapidly in section 15.56–235 m. As the overcoring method is sensitive to drilling debris, the highly fractured upper part of the borehole had to be sealed in order not to function as a drill cuttings trap, from which cuttings could be sucked into the borehole for example while pulling the drill string. During the period from September 1st to October 15th 2003, several cement groutings had to bee performed before the overcoring rock stress measurements could start between 235 and 242 m. Then the ordinary core drilling commenced to the second measurement level at 404 m borehole length, whereupon a new series of overcoring rock stress measurements where attempted.

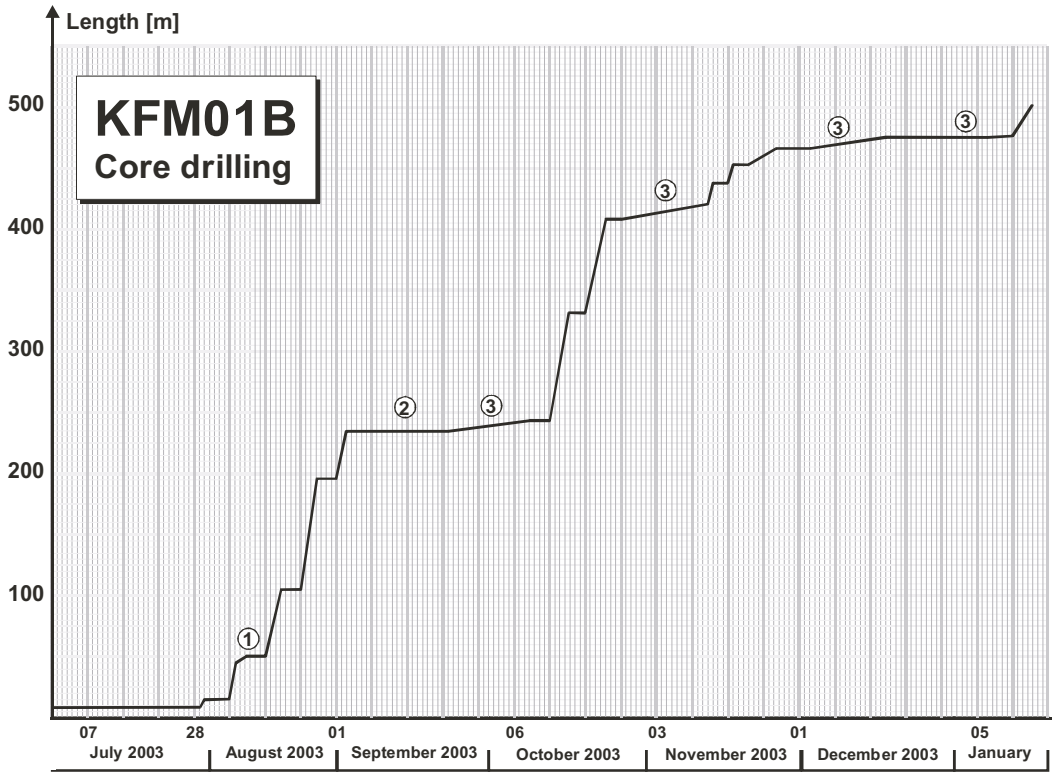


Figure 5-4. *Core drilling progress KFM01B (length versus calendar time). ① WL-test, ② Cement grouting, ③ Rock stress measurement (over-coring).*

During the period October 20th 2003 to January 12th 2004, the rock stress measurements continued, but due to the character of the stress field with high deviatoric stresses, several measurement attempts failed because of microfracturing in the overcored rock samples. More measurements than planned therefore had to be attempted. Furthermore, a section at 415–458 m of rock with increased fracture frequency caused the measurements to be more time consuming than expected, since suitable rock quality had to be found. An incident also occurred during this period. A measurement probe was dropped into the borehole, and the succeeding rescue operation caused a two weeks delay. Finally, drilling could be continued to the planned drilling length, 500.52 m.

5.4.1 Core sampling

A preliminary on-site core logging was performed continuously. Although some difficulties during the measurement campaign, cf Figure 5-5, the rock stress measurements provided stress data that have contributed to analysis and modelling of the regional stress tensor within the Forsmark area and helped reconcile results from other stress measuring techniques.

Figure 5-5. *Example of core discing after stress relief of overcored rock sample from KFM01B.*

5.5 Measurements while drilling

5.5.1 Flushing water and return water flow rate – water balance

Figure 5-6 displays the accumulated volumes of flushing water respectively return water from the entire drilling period (results from Uranine measurements are presented in the next section). From the accumulated volumes of flushing water and return water at the end of the drilling period the return water/flushing water quotient may be calculated, in this case resulting in the quotient 0.51.

Uranine content of flushing water

An organic tracer, Uranine, was manually added to the flush water tank, see Section 3.1.2. During the drilling period, sampling of flushing water and analyses of the tracer content was performed systematically with a frequency of approximately one sample per 20–30 m drilling length, see Figure 5-7. The main flushing water loss occurred into the fracture zone at c 55 m drilling length.

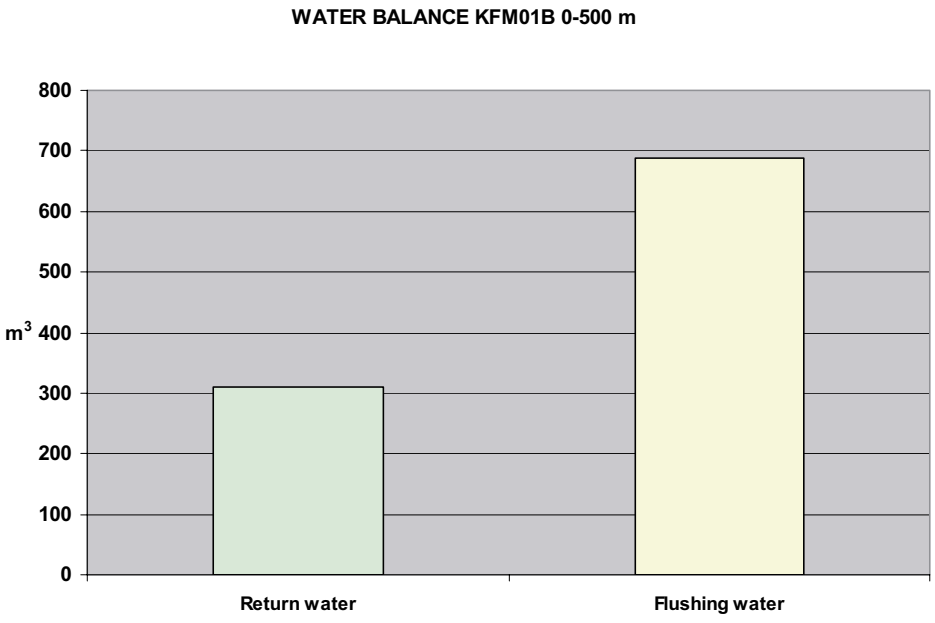


Figure 5-6. *The total volume of flushing water used during core drilling of KFM01B was 688 m³. During the same period, the total volume of return water was 309 m³. The return water/flushing water balance is then 0.51, i.e. far below 1.0 due to a major flushing water loss during drilling in the highly fractured section at 0–235 m.*

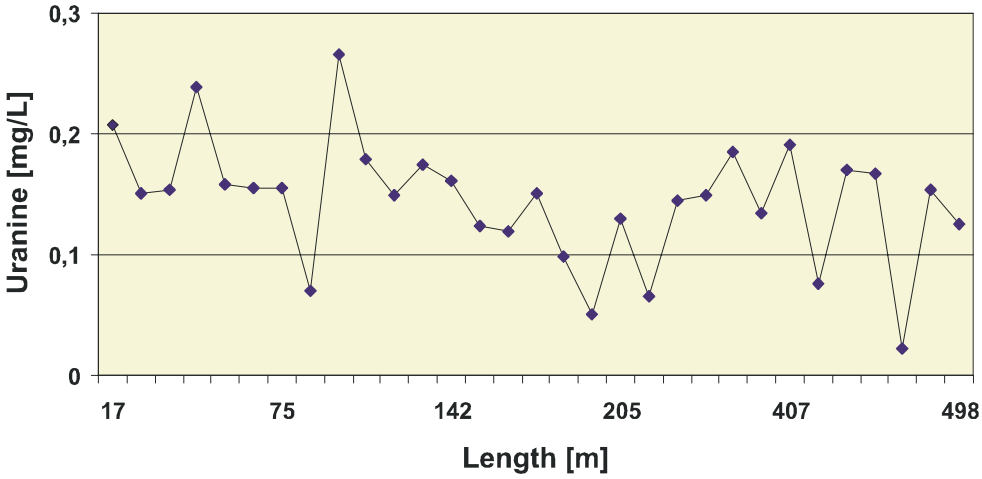


Figure 5-7. *Uranine content versus drilling length in flushing water during drilling of borehole KFM01B.*

5.5.2 Water composition

A so called first strike WL-sample was collected from section 34.74–46.24 m. The flushing water content was quite low, only 8.5%. Also isotopes were analysed and the results are presented in Appendix C.

5.5.3 Groove milling

After completion of drilling, borehole KFM01B will be used for a variety of borehole measurements, employing many types of borehole instruments with different stretching characteristics (pipe strings, wires, cables etc). In order to provide a system for length calibration in the borehole, reference grooves were milled into the borehole wall with a specially designed tool at regular levels. This was carried out after drilling, but with use of the drilling machine and pipe string.

At each level, two 20 mm wide grooves were milled with a distance of 10 cm between them, see Figure 5-8. Table 5-2 presents the reference levels selected for milling. The table reveals that milling was totally successful. After milling, the reference grooves were detected with the SKB level indicator (a calliper). A BIPS-survey provided the final confirmation that the grooves exist.

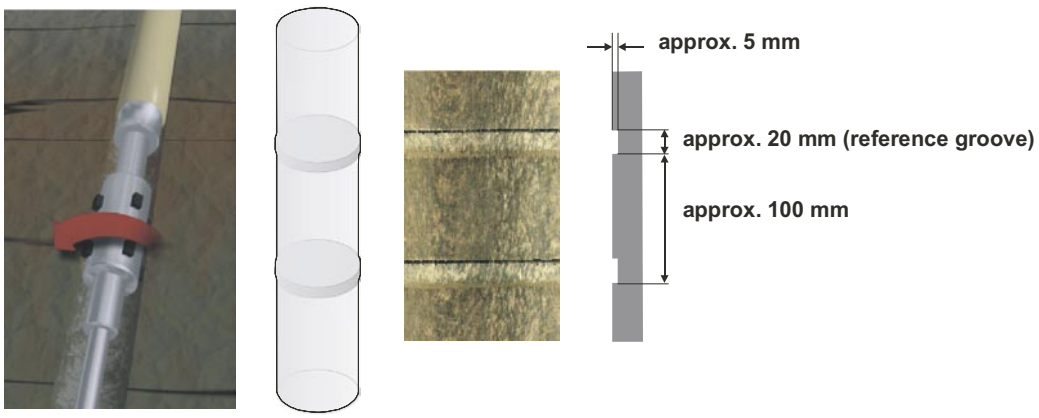


Figure 5-8. *Layout and design of reference grooves.*

Table 5-2. Compilation of length to the reference grooves. The positions of the grooves are determined from the length of the drilling pipes used at the milling process. The length is measured from the upper part of the upper two grooves.

Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS	Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS
54	Yes	Yes	300	Yes	Yes
100	Yes	Yes	350	Yes	Yes
150	Yes	Yes	400		Yes
197	Yes	Yes	450		Weak
250	Yes	Yes			

5.5.4 Deviation measurements

The deviation measurements made in borehole KFM01B with the Reflex MAXIBOR system indicate that the borehole is almost straight, however smoothly dipping upwards, ending 3 m to the right and 9 m up.

5.5.5 Consumables

The special type of thread grease (silicon based) used in this particular borehole was certified according to SKB MD 600.006, Version 1.0, Instruction for the use of chemical products and material during drilling and surveys. Oil and grease consumptions are given in Table 5-3 below.

The grout for sealing the casing and tighten the borehole are reported in Table 5-4 below.

Table 5-3. Oil and grease consumption.

Borehole ID	Thread grease (core drilling) Üni Silikon L50/2
KFM01B	6.4 kg

Table 5-4. Cement consumption.

Borehole ID	Casing length (m)	Cement volume (Portland Standard Cement)	Grouting method	Remarks
KFM01B	0.30–15.56	280 kg/225 l	Hose	2003-07-31
KFM01B	53.00–235.22	1,000 kg	Hose	2003-09-10
KFM01B	0–235.22	200 kg	Hose	2003-09-11
KFM01B	0–235.22	80 kg	Hose	2003-09-16

5.6 Hydrogeology

5.6.1 Hydraulic tests during drilling (wireline tests)

Results from pumping tests and pressure measurements from borehole KFM01B are presented in Table 5-5.

One pumping test was performed in section 34.74–46.24 m. The pumping caused almost no drawdown, less than 0.5 kPa, in the section due to a very large formation transmissivity as well as a large pressure head loss in the WL-probe. No absolute pressure measurements were performed. Test diagrams are attached in Appendix B.

For the pumping test the specific capacity (Q/s) was calculated according to SKB MD 320.004. No hydraulic transmissivity (T_M) was calculated.

Table 5-5. Pumping tests with wireline probe in KFM01B.

Tested section (m)	Q/s (m^2/s)	Comments
34.74–46.24	2E–3	A drawdown of less than 0.5 kPa was generated in the section and the pressure was very unstable. The flow rate at the end of the test was c 6.5 L/min. The estimated Q/s is very uncertain. Due to the water sampling unit, a large pressure head loss occurred in the WL-probe.

5.6.2 Hydraulic responses in surrounding boreholes at DS1

During the drilling programme at DS1, sub-horizontal extremely high-conductive fracture zones were observed at approximately 40 m depth in both the core drilled (KFM01A) and percussion drilled boreholes (HFM01–03). After finishing the measurement programme, the monitoring system was installed in the boreholes. Pressure readings during drilling of KFM01B show increased pressure levels in all surrounding boreholes. The pressure levels in boreholes HFM01–03 are presented in Figure 5-9 as well as in /8/. Almost immediately from start (15 m) of core drilling in KFM01B, a significantly increasing pressure is observed in all boreholes. These results confirm the existence of a sub-horizontal fracture zone in the upper part of the bedrock at DS1, hydraulically connecting the boreholes at the drilling site.

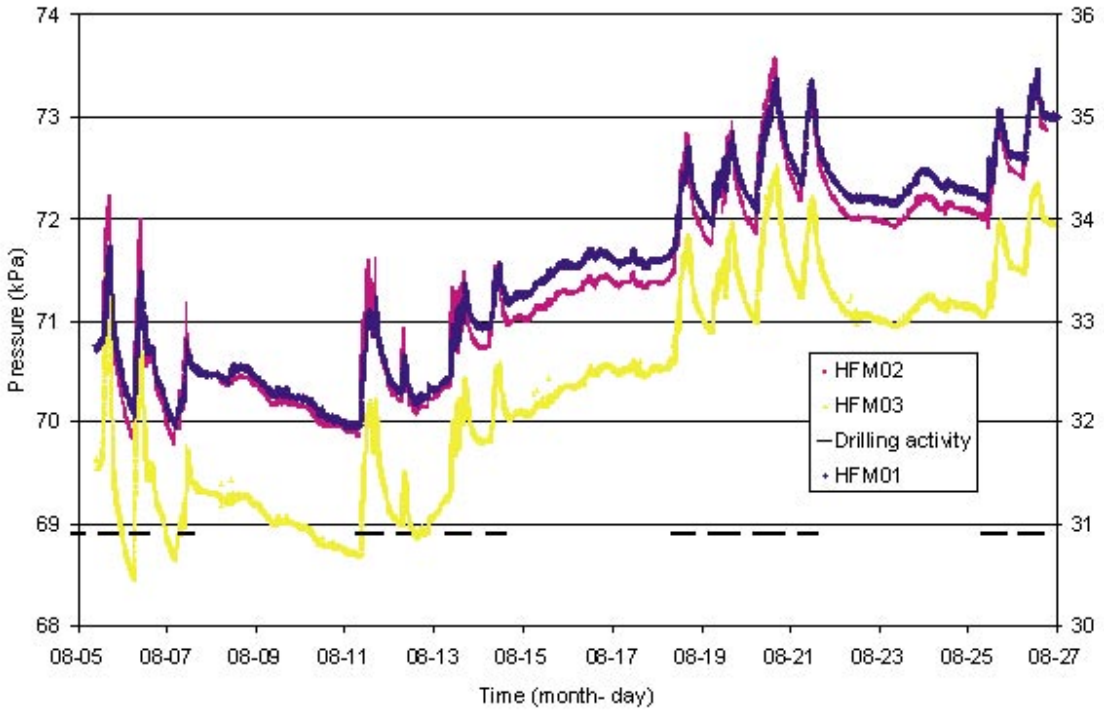


Figure 5-9. *Pressure responses in HFM01–03 during drilling of KFM01B (the drilling period in August 2003 of section 15–235 m).*

References

/1/ **Decision 1032375.** Modification of the investigation programme for boreholes KFM01 and KFM02 at Forsmark.

/2/ **Claesson L-Å, Nilsson G, 2003.** Forsmark site investigation. Drilling of a flushing water well, HFM01, and two groundwater monitoring wells, HFM02 and HFM03, at drilling site DS1. SKB P-03-30, Svensk Kärnbränslehantering AB.

/3/ **Claesson L-Å, Nilsson G, 2003.** Forsmark site investigation. Drilling of monitoring wells SFM0001–SFM0003 in soil at drilling site DS1. SKB P-03-13, Svensk Kärnbränslehantering AB.

/4/ **Petersson J, Wängnerud A, 2003.** Site investigations at Forsmark. Boremap mapping of telescopic drilled borehole KFM01A. SKB P-03-23, Svensk Kärnbränslehantering AB.

/5/ **Sjöberg J, 2004.** Forsmark site investigation. Overcoring rock stress measurements in borehole KFM01B. SKB P-04-83, Svensk Kärnbränslehantering AB.

/6/ **Berglund J, Petersson J, Wängnerud A, Danielsson P, 2004.** Boremap mapping of core drilled borehole KFM01B. Forsmark site investigation. SKB P-04-114, Svensk Kärnbränslehantering AB.

/7/ **SICADA.** Field note numbers 148, 172 and 292.

/8/ **Levén J, Ludvigson J-E, 2004.** Hydraulic interferences during the drilling of borehole KFM01B. Boreholes HFM01, HFM02, HFM03 and KFM01A. Forsmark site investigation. SKB P-04-135, Svensk Kärnbränslehantering AB.

Well cad presentation of the core drilled borehole KFM01B

Title KFM01B

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM01B	**Northing [m]**	6699539.40
Diameter [mm]	76	**Easting [m]**	1631387.67
Length [m]	500.52	**Elevation [m.a.s.l.]**	3.09
Bearing [°]	267.59	**Drilling Start Date**	2003-06-27 07:00:00
Inclination [°]	-79.04	**Drilling Stop Date**	2004-01-15 15:00:00
Date of mapping		**Plot Date**	2004-09-22 21:01:46

ROCKTYPE FORSMARK SOIL

- **Pegmatite, pegmatitic granite**
- **Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Amphibolite**

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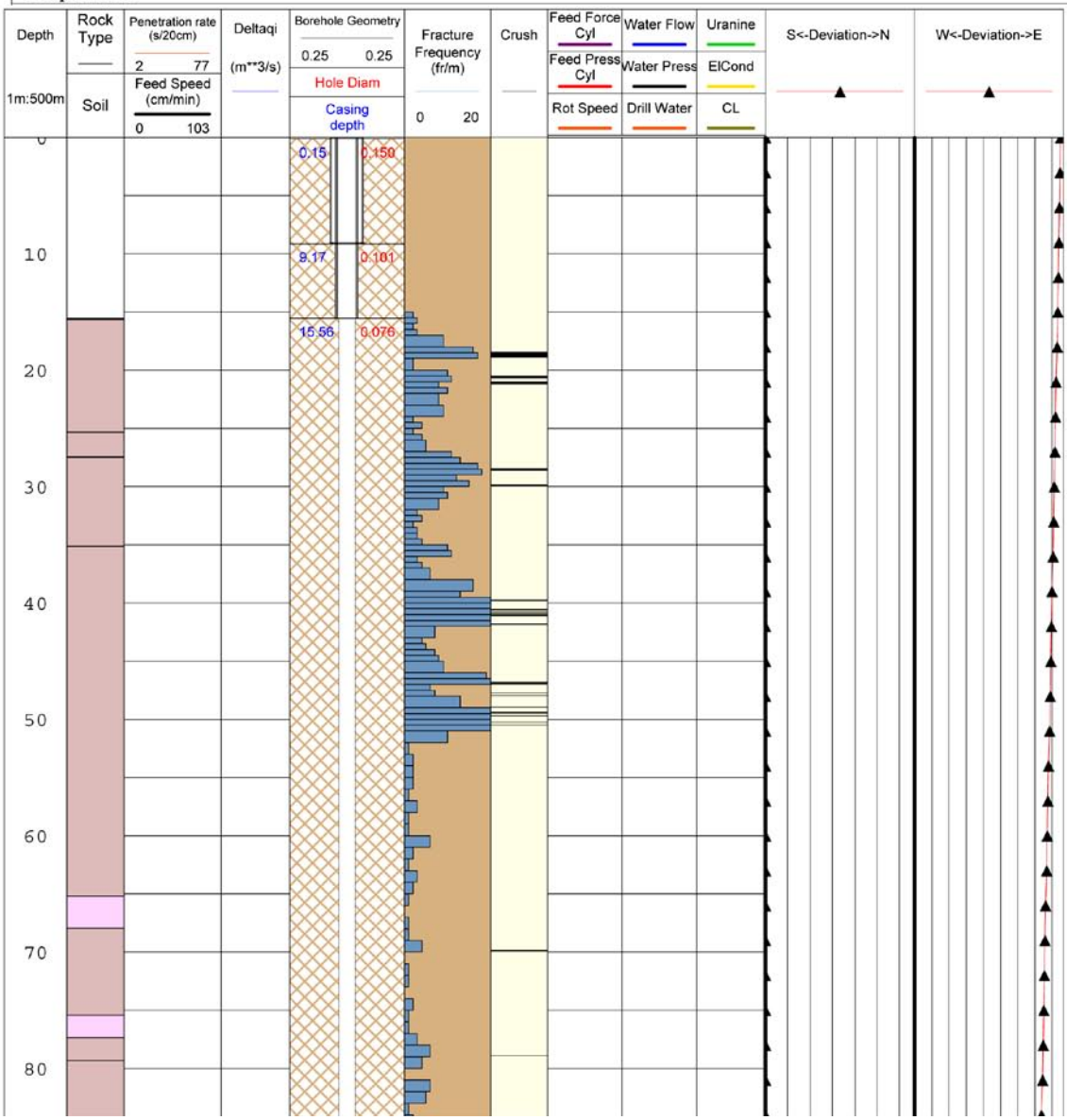

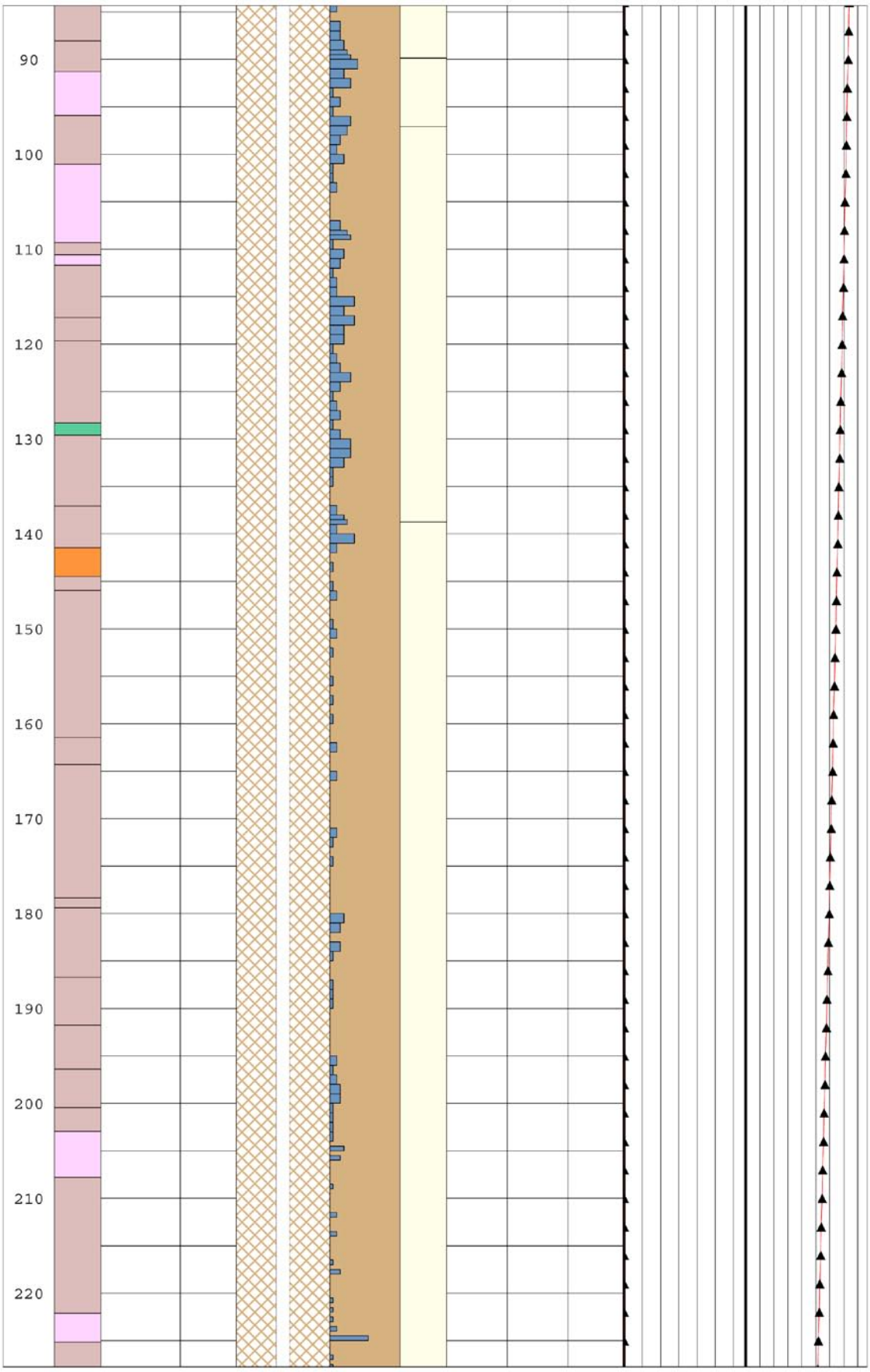
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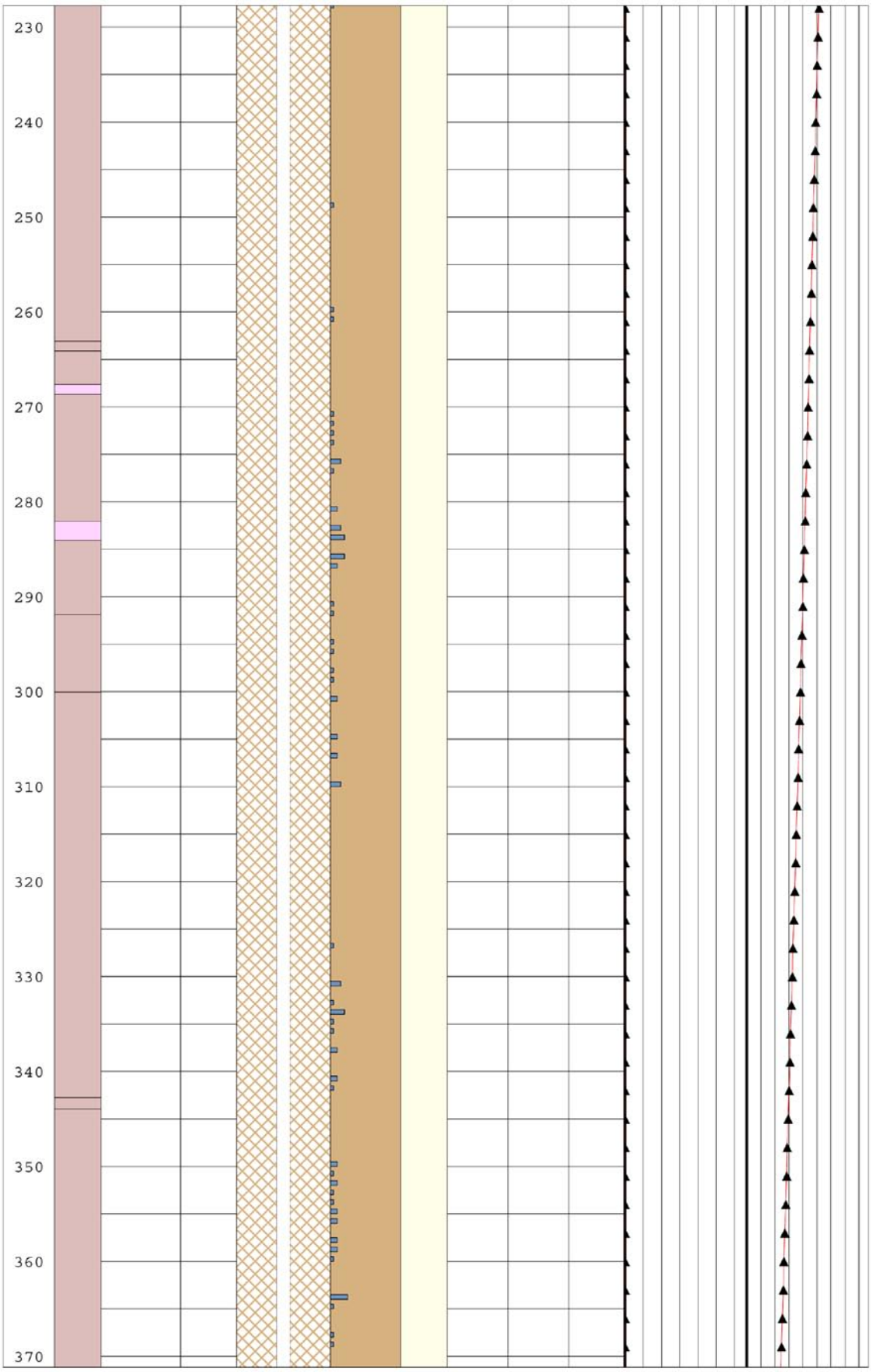
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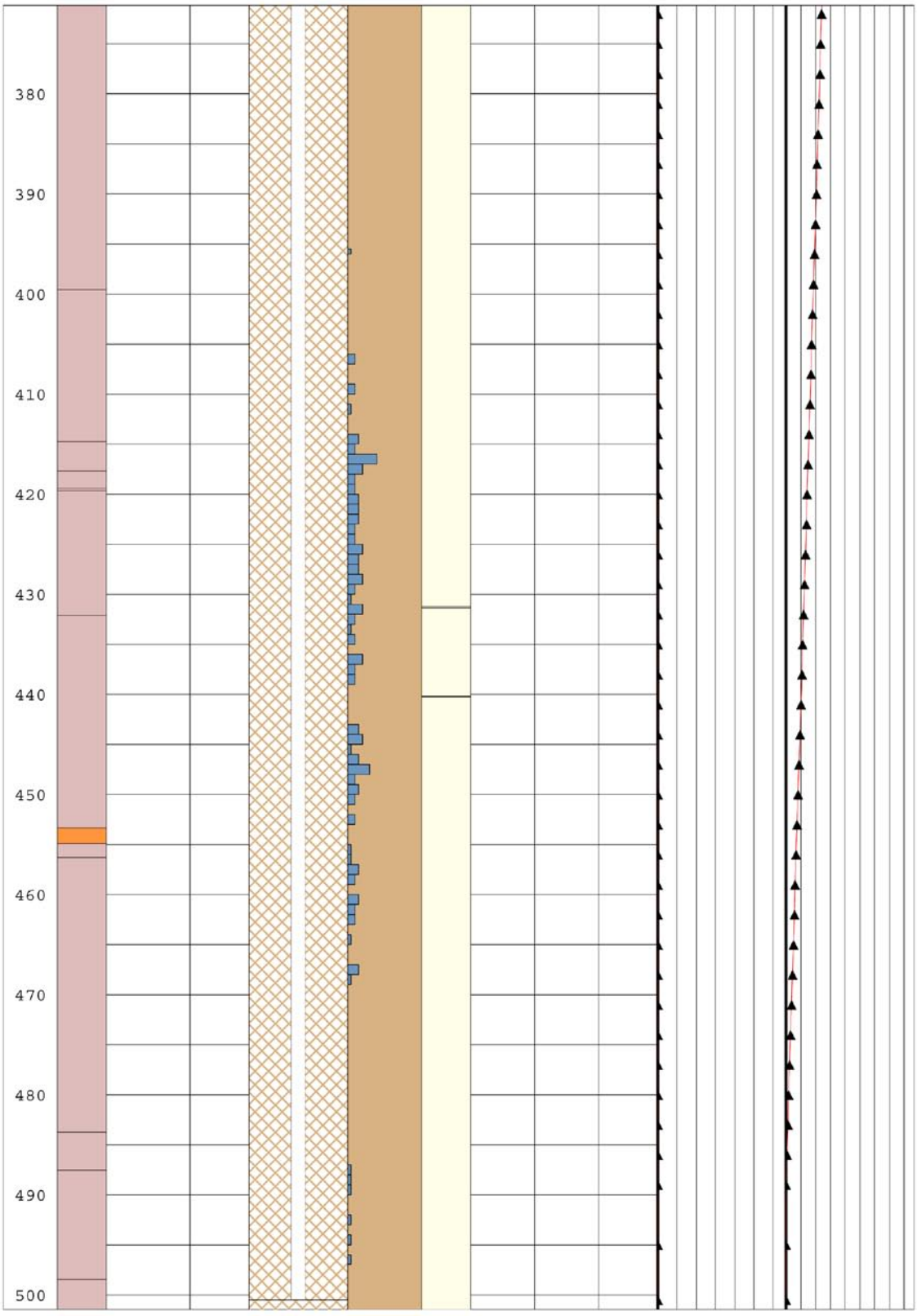
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Hydraulic test in borehole KFM01B

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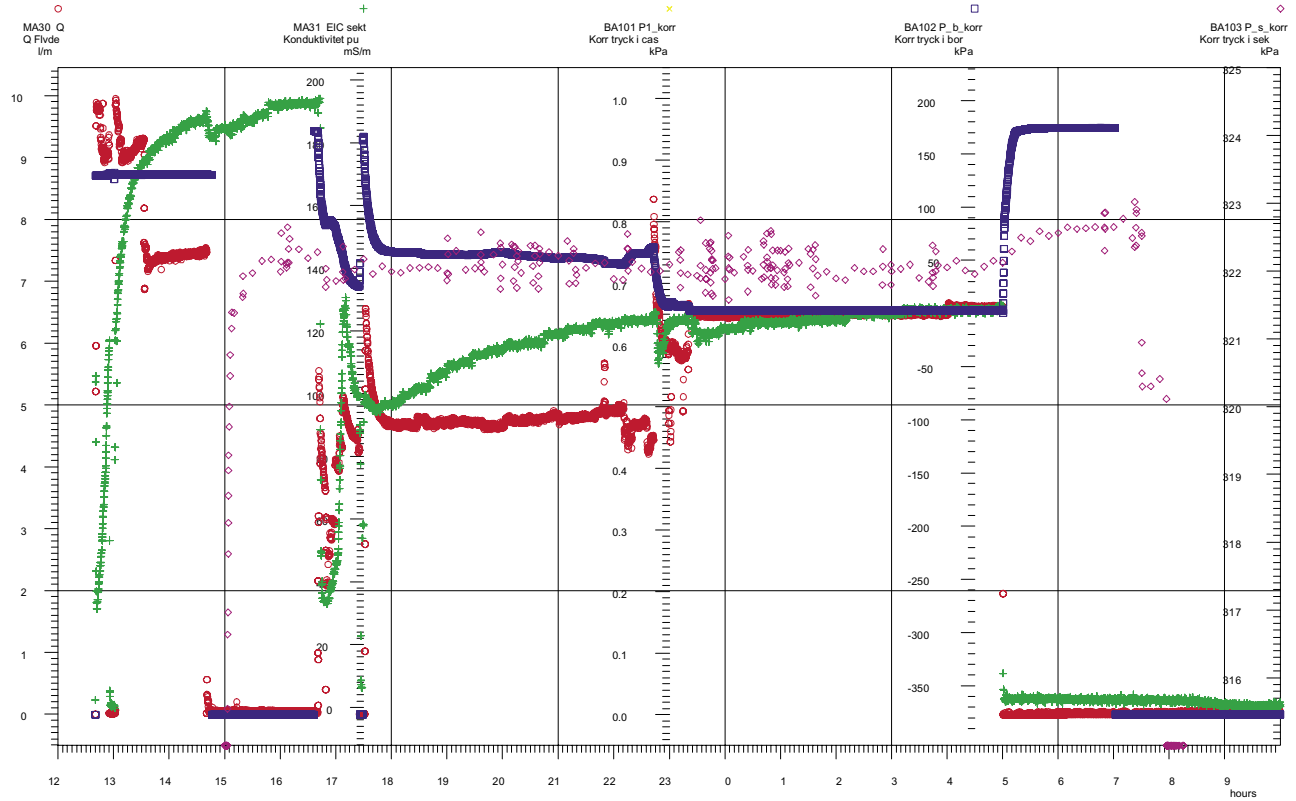
Adjusted for DST

DMS1 PF

Pumping test with wireline probe
KFM01B section 34.74-46.24 m



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STOP :03/08/07 09:59:59

Appendix C

Water composition

Date	ID code	Sample No.	Na mg/L	K	Ca	Mg	HCO_3	Cl	SO4	SO_4_S	Br	F	Si	Li	Sr	TOC	pH no unit	Cond mS/m
2003-08-07	KFM01B	4951	229	9.67	33.7	9.0	394	184	62.6	21.1	0.541	1.77	6.32	0.009	0.218		8.29	131.0

Date	IDCODE	Sample no	^{2}H dev SMOW	^{3}H(TU) Tu	^{18}O(dev) dev SMOW	^{14}C pmc	^{13}C dev PDB	Age BP year	^{10}B no unit	34S(dev) dev CDT	$^{87}SR/^{86}Sr$ no unit
2003-08-07	KFM01B	4951	–82.5	9.3	–11.1	68.41	–12.35	2997	0.2416	16.7	0.724317