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Forsmark site investigation

Drilling of the telescopic borehole KFM07A at drill site DS7

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September 2005

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Keywords: AP PF 400-04-53, Percussion drilling, Core drilling, Telescopic borehole, Drilling site DS7.

Abstract

The major part of the deep boreholes drilled within the scope of the Forsmark site investigations are performed with so called telescopic technique. The upper 100 m are percussion drilled in two drilling sequences, pilot drilling with a diameter of about 160 mm, respectively reaming to a diameter of c 200–250 mm. Below 100 m the borehole is core drilled with a diameter of approximately 76–77 mm to full drilling length, which normally is c 1,000 m.

Performance of and results from drilling and measurements during drilling of the seventh deep borehole drilled by applying telescopic technique are presented in this report. The borehole, which is denominated KFM07A, is 1,001.55 m long and reaches almost 600 m horizontally (inclined 59.22° from the horizon at the starting point but flattens out towards depth). KFM07A is of so called SKB chemical type, intended for detailed hydrogeochemical and microbiological investigations.

During percussion drilling of section 0–100 m with the diameter Ø 163 mm, an unstable, fractured section was encountered at about 59–65 m, interpreted as a gently dipping fracture zone. This zone was heavily water-yielding, and an inflow of c 200 L/min was measured. Due to the high water capacity and unstable borehole wall, the borehole was reamed to Ø 251 mm, whereupon a stainless steel casing was installed, and the gap between the borehole wall and the casing was grouted. These measures resulted in that all inflow of groundwater to the percussion drilled part of the borehole ceased.

A relatively complicated flushing water/return water system is applied for core drilling of the telescopic boreholes. The flushing water is prepared in several steps before use, and the return water is taken care of, as to permit drill cuttings to settle before the water is conducted to an approved recipient. During drilling, a number of technical and flushing water/return water parameters are registered in order to obtain a good control of the drilling process and to permit an estimation of the impact on the rock aquifer penetrated by the borehole of flushing water and drilling debris. Because high-conductive fractures were encountered in the section 100–200 m, probably significant amounts of drill cuttings and flushing water have been forced into the formation.

A sampling- and measurement programme for percussion drilling and another 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. For example, the drill cores from the core drilled part and samples of drill cuttings from the percussion drilled section, together with later produced video images of the borehole wall (so called BIPS-images), served as a basis for the borehole mapping (so called Boremap mapping) performed after drilling. A diagram of the Boremap mapping results from KFM07A is presented in this report.

After completion of 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.

One experience from drilling of KFM07A is that the quartz-rich bedrock in Forsmark is hard to drill, entailing rapid wearing of drill bits. However, technical development of drill bits has improved the life-time by c 25% compared to drilling of the first deep boreholes at Forsmark. Other lasting impressions from the drilling are the water-yielding sub-horizontal fracture zone encountered in the shallow part of the bedrock and the, on the other hand, very low fracture frequency and low water-yielding capacity of the major part of the core drilled section of KFM07A.

Sammanfattning

De flesta djupa borrhål inom Forsmarks platsundersökning utförs som teleskopborrhål. Det innebär att de övre 100 metrarna hammarborras med ca 200–250 mm diameter, medan avsnittet 100–1 000 m kärnborras med diametern 76–77 mm. Resultaten från det sjunde djupborrhålet i Forsmark som har borrats med denna teknik redovisas i denna rapport. Borrhålet, som benämns KFM07A, är 1001.55 m långt och når cirka 600 m horisontellt (är ansatt med 59,22 ° lutning från horisontalplanet men flackar ut mot djupet). KFM07A är ett så kallat kemiprioriterat borrhål, vilket innebär att det planeras att nyttjas för detaljerade hydrokemiska och bakteriologiska undersökningar, varför all utrustning som används i borrhålet, både vid borrning och mätning, måste rengöras och desinficeras enligt speciella instruktioner.

Vid hammarborrning av avsnittet 0–100 m med diametern Ø 163 mm påträffades ett instabilt, sprucket avsnitt vid ca 59–65 m, vilket tolkades som en flackt stupande spricKzon. Zonen hade en betydande vattenkapacitet och ett inflöde på ca 200 L/min uppmättes. Eftersom borrhålet var instabilt och kraftigt vattenförande, rymdes det upp till 251 mm och kläddes in med rostfritt foderrör, varefter spalten mellan borrhålsvägg och foderrör cementinjekterades, så att allt vatteninflöde i denna del av hålet upphörde.

För kärnborrningen av avsnittet 100–1 001.55 m användes ett relativt komplicerat spol- och returvattensystem, där spolvattnet preparerades i flera moment före användning. Returvattnet leddes till ett system av containrar, så att borrkaxet kunde sedimentera i tre steg innan returvattnet pumpades vidare till recipient.

Under kärnborrningsfasen vid utförandet av teleskopborrhål används ett relativt komplicerat spol- och returvattensystem, där spolvattnet prepareras i olika steg före användning. Returvattnet leds till ett system av containrar, där borrkaxet sedimenterar i tre steg innan returvattnet pumpas vidare till godkänd recipient. Under borrningen registreras ett antal borr- och spolvattenparametrar, så att god kontroll uppnås dels avseende borrningens tekniska genomförande, dels beträffande den påverkan av spolvatten och borrkax som grundvattenakvifären i anslutning till borrhålet utsätts för. Främst p.g.a. högkonduktiva sprickor som påträffades i avsnittet 100–200 m borrlängd har sannolikt relativt stora mängder borrkax och spolvatten trängt ut i formationen runt borrhålet.

Ett mät- och provtagningsprogram för hammarborrningen och ett annat program 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 från den kärnborrade delen av borrhålet och borrkaxproverna från den hammarborrade delen, tillsammans med videofilm av borrhålsväggen (s k BIPS-bilder), underlaget för den borrhålskartering (s k Boremap-kartering) som utförs efter borrning. Ett resultatdiagram från Boremap-karteringen av KFM07A 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.

En erfarenhet från borrningen av KFM07A är att den kvartsrika berggrunden i Forsmark är svårborrad och att borrkroneslitaget är högt. Den tekniska utvecklingen av borrkronor har dock medfört att livslängden nu är ca 25 % högre än jämfört med vid projektets början. Andra intryck är dels de flacka, delvis kraftigt vattenförande strukturer i den ytliga delen av berggrunden, dels att, omvänt, sprickfrekvensen och vattenföringen i större delen av det kärnborrade partiet av borrhålet visade sig vara mycket låga.

Contents

1 Introduction

Site investigations are currently being performed by SKB for location and safety assessment of a deep repository for high level radioactive waste /1/. The investigations are carried out in two Swedish municipalities: Östhammar and Oskarshamn. The investigation area in Östhammar is situated close to the Forsmark nuclear power plant /2/, see Figure 1-1.

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 boreholes drilled through 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, three sub-vertical and five inclined, approximately 1,000 m long, cored boreholes have been drilled within the investigation area. One deep borehole is also currently being drilled at drill site DS8. The locations of the eight drill sites in question, DS1–DS8, are illustrated in Figure 1-1.

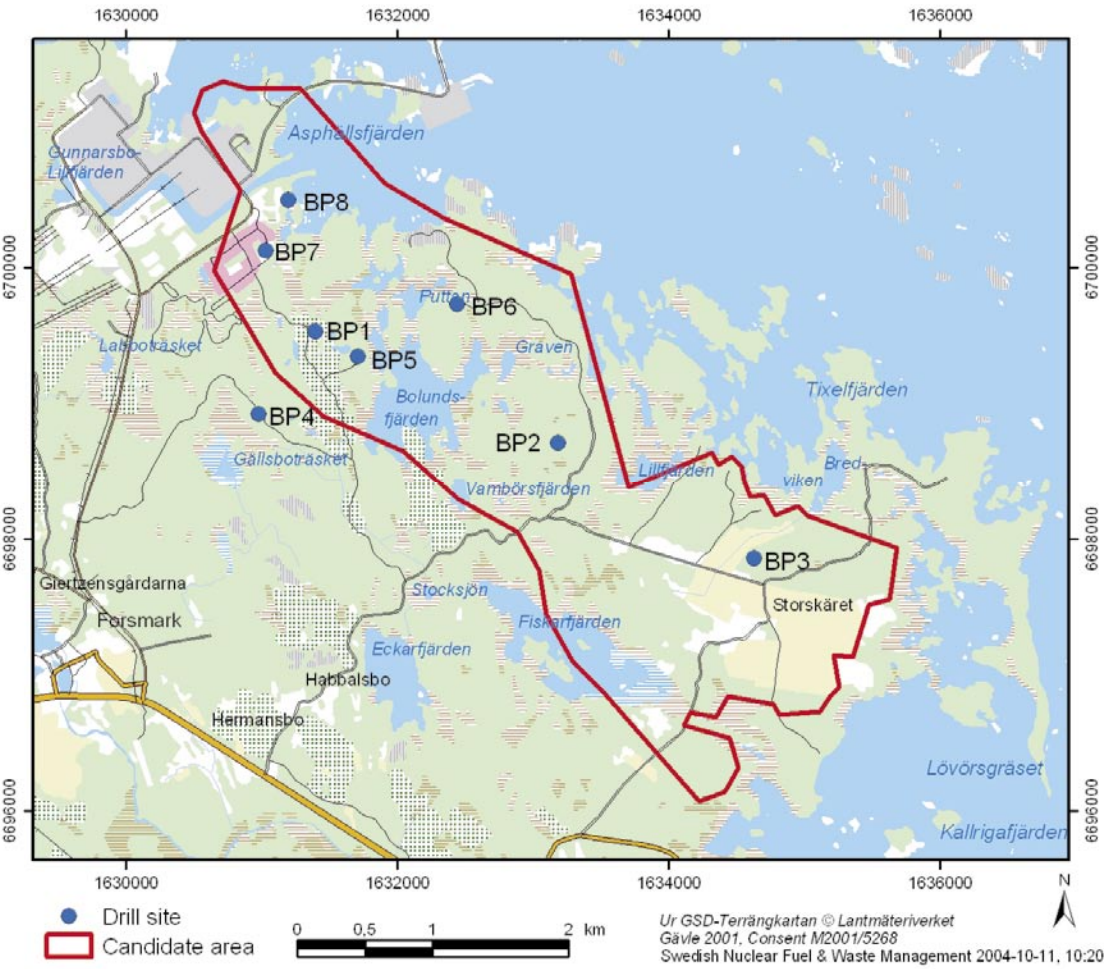


Figure 1-1. *The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drill sites DS1–8 are marked with blue dots.*

This document reports the data and other results gained by the drilling of the telescopic borehole KFM07A at drill site DS7, which is part of the activities performed within the site investigation at Forsmark. The work was carried out in compliance with activity plan AP PF 400-04-53.

In Table 1-1 controlling documents for performing this activity are listed. Both activity plans and method descriptions are SKB's internal controlling documents.

By drilling the deep boreholes, so called telescopic drilling technique is applied, entailing that the upper 100 m of the borehole is percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section 100–1,000 m is core drilled with a diameter of approximately 76–77 mm. This technical approach was put into practise also when drilling the borehole presented in this report, KFM07A, which has a total drilling length of 1,001.55 m. Besides, borehole KFM07A is of the so called SKB chemical type, implying that the borehole is prioritized for hydrogeochemical, including microbiological, investigations. A practical consequence of this is that all DTH (Down The Hole) equipment used during and/or after drilling must undergo severe cleaning procedures, see Chapter 4.

In order to compensate for the missing core in the borehole section 0–100 m, a shorter borehole, KFM07B, will soon be drilled from the same drill site, in which drill core will be retrieved all the way from the rock surface to c 500 m vertical depth.

Close to the deep borehole at drill site DS7, 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 202 m. The locations of all boreholes at drill site DS7 are shown in Figure 1-2.

Drill site DS7 is located in the north-western part of the candidate area, c 700m from the Forsmark power facilities. The site is built on the ground belonging to the accommodation facilities for the power station (Figure 1-2).

The drilling operations were performed during two periods between June7th, 2004 and December 9th, 2004. Drillcon Core AB, Nora, Sweden, was engaged for the drilling commission. Two different drilling equipments were employed, a percussion drilling machine for drilling the upper c 100 m, whereas core drilling of the remaining part (section 100.40–1,001.55 m) was carried out with a wireline core drilling system.

In the present report, performance of and results from drilling of KFM07A are presented. The report also treats investigations made during and immediately after drilling. All data from this activity are stored in the SICADA database and are traceable by the activity plan number.

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

Activity plan	Number	Version
Borrning av teleskopborrhål KFM07A	AP PF 400-04-53	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för hammaborrning	SKB MD 610.003	1.0
Metodbeskrivning för kärnborrning	SKB MD 620.003	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

Figure 1-2. *Borehole locations at and near drill site DS7. Besides the core drilled borehole KFM07A, the area comprises a monitoring well in bedrock (HFM21), and a monitoring well in soil (SFM0076). The projection of inclined boreholes on the horizontal plane at the ground surface (top of casing) is shown in the figure.*

2 Objective and scope

The main objectives of drilling deep telescopic boreholes at the site investigation are the following:

- To provide rock samples from the ground surface to the borehole bottom. Percussion drilling through the overburden produces soil samples recovered to the surface by compressed air. These samples are collected with a frequency of one sample per metre. The same sampling frequency is applied for the drill cuttings produced when percussion drilling the upper c 100 m of the solid rock. Below 100 m, the core drilling provides (in principle) continuous drill cores down to the borehole bottom. In order to compensate for the missing drill core in borehole section 0–100 m in KFM07A, a second borehole, KFM07B, will be drilled from the drill site and drill core will be retrieved from the rock surface to approximately 500 m vertical depth. The rock samples collected during drilling are used for 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 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.
- To make water sampling possible down to and below repository depth. High-class hydrogeochemical sampling/analysis demands special measures during and after drilling in order to keep the borehole clean. When these measures have been taken, the borehole is categorized as a borehole of chemical type. Only boreholes of this category are approved for advanced hydrogeochemical and microbiological characterization.
- To enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

During drilling, a number of drilling related parameters are monitored by a drilling monitoring system. Part of these data sets, in this report called DMS (Drilling Monitoring System) data, which after drilling are transferred to SICADA, may be used as supplementary data for geological and hydraulic characterization as well as for assessment of technical aspects of the drilling operations. DMS-data are described in this report.

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

Two types of drilling machines were employed for drilling borehole KFM07A. The upper c 100 m were drilled with a percussion drilling machine of type Comacchio 1500 S. For core drilling of section 100.40–1,001.55 m, a Wireline-76 core drilling system, type Onram 2000 CCD, was engaged.

3.1 Percussion drilling equipment

The Comacchio percussion machine is equipped with separate engines for transportation and power supplies. Water and drill cuttings were discharged from the borehole by an Atlas-Copco XRVS 466 Md 27 bars diesel compressor. The DTH drill hammer was of type Secoroc 8", operated by a Driconeq 76 mm pipe string. All DTH-equipment was cleaned with a Kärcher HDS 1195 high-capacity steam cleaner.

At drill site DS7, the bedrock is covered by approximately one metre of landfill (coarse gravel) underlain by a few metres of quaternary deposits. Due previous experience that the bedrock could be highly fractured in the shallow part, a decision was made to drive a casing through the regolith and some metres into the bedrock. To obtain a borehole as straight as possible in this type of overburden, the choice of technique is important. In this case the NO-X technique was applied, dimension NO-X 280, with a non-stainless casing, following the principles and dimensions presented in Figure 3-1 (a stainless steel casing was later driven inside the non-stainless casing, see Figure 3-1, C2). The NO-X technique is described in more detail in SKB MD 610.003 (Method Description for percussion drilling). Figure 3-1 is a schematic diagram where the drilling depths presented are approximate. The true depths in the respective drilling sequences carried out in KFM07A are presented in Section 5.2.

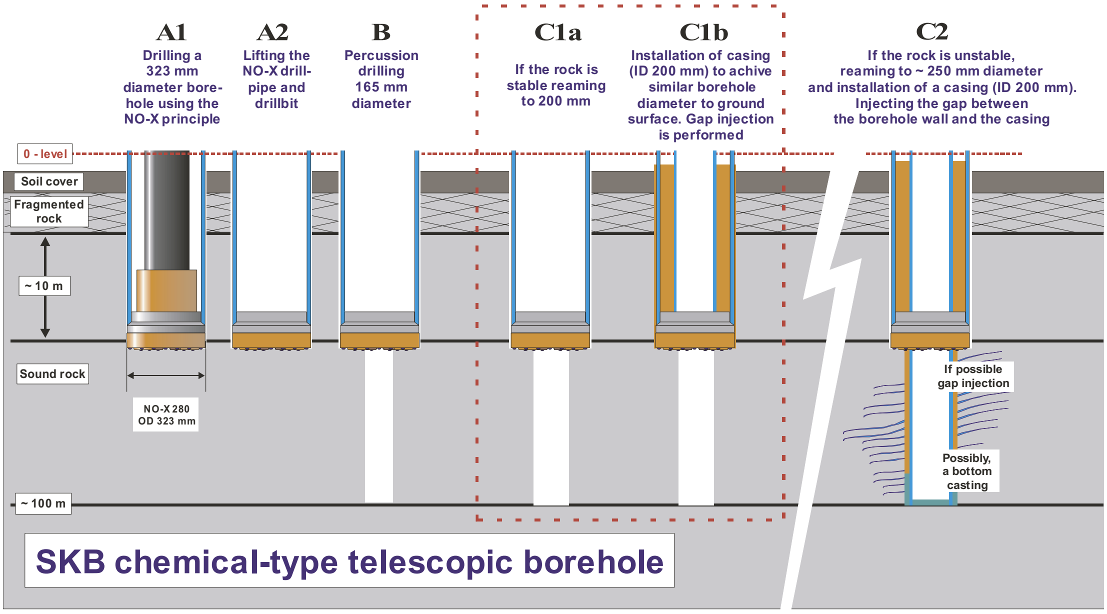


__Figure 3-1.__ Schematic diagram showing the various stages of drilling the 0-100 m section of an SKB chemical-type telescopic borehole. The letters and numerals above each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB MD 620.003, Version 1.0.

3.2 Injection technique

For investigation of the groundwater conditions, especially the hydrogeochemical characteristics, of the cored part of a telescopic borehole, it is essential that the deeper groundwater is not mixed with surface water or groundwater from the shallow parts of the bedrock. Instabilities in the upper part of a borehole is another feature which may cause severe problems during continued drilling and during measurements after drilling. Therefore, if groundwater and instabilities are encountered in the percussion drilled part of a telescopic borehole, it is essential to forestall the described potential problems by expedient measures. Heavy groundwater inflow is for example often efficiently prevented by casing the borehole, succeeded by cement grouting of the gap between the borehole wall and the casing, whereas borehole sections or sometimes the entire borehole have to be cement grouted when severe instabilities occur.

Borehole KFM07A was gap grouted after installation of the $Ø_i$ 200 mm, 100 m long casing (C2 in Figure 3-1). Application of cement in the gap between the borehole wall and the casing pipe can be performed according to different techniques. Two variants are illustrated in Figure 3-2. In KFM07A injection through a packer was applied.

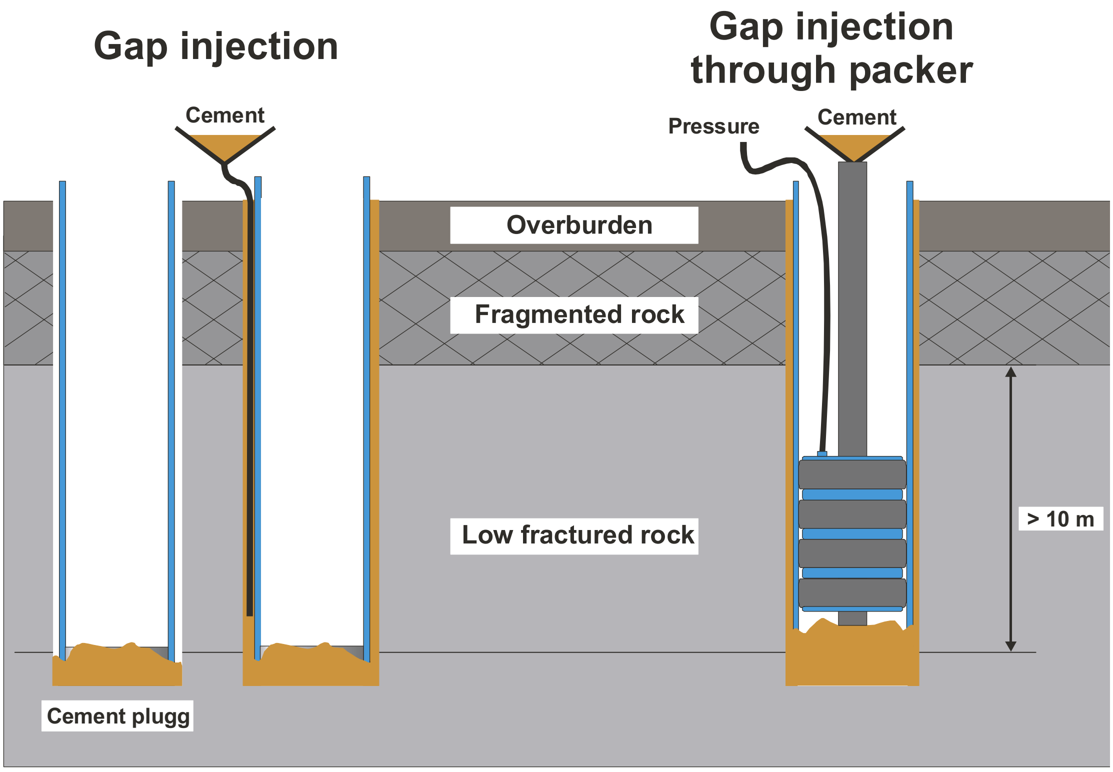


Figure 3-2. *Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer.*

3.3 Core drilling equipment

3.3.1 The wireline-76 system

For drilling the cored part of borehole KFM07A, a wireline-76 system, type Hagby Bruk Onram 2000 CCD, was employed. The drilling process is operated by an electrically-driven hydraulic system supplied with a computer control. The drilling capacity for 76–77 mm holes is maximum c 1500 m. The drill pipes and core barrel used belong to the Hagby WL76 triple-tube system. Technical specifications of the drilling machine with fittings are given in Table 3-1.

Table 3-1. Technical specifications of the Onram 2000 CCD-system from Hagby-Asahi with appurtenances.

Unit	Manufacturer/Type	Specifications	Remarks
Onram 2000	Hagby-Asahi	Capacity for 76–77 mm holes maximum approx. 1,500 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	
Mobile electrical plant	P250HE with diesel engine Perkins GCD 325	250 KVA, 200 kW, 360 A.	
Compressor	Atlas Copco GA75P-13	Max pressure: 12 bars Flow: > 5 L/sec	Electrically supplied
CCD-system	Dunfoss		Standard system modified for core drilling by the manufacturer

3.3.2 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 drill pipes. However, if the borehole has penetrated water conductive rock fractures, part of, and sometimes all of the return water from the borehole, including drill cuttings, may be forced into these fractures. This renders a correct characterization of the in situ hydraulic and hydrogeochemical conditions more difficult, due to partial or complete clogging by drill cuttings and due to the contribution of 'foreign' flushing water in the fracture system.

In order to reduce these negative effects, SKB has developed a specially designed flushing water and return water system. The equipment consists of the components shown in Figure 3-3. The system includes equipment for pumping, transport and storage of water. The flushing/return water system may be divided into:

- equipment for preparing the flushing water,
- equipment for measuring flushing water parameters (flow rate, pressure, electrical conductivity and dissolved oxygen),
- equipment for airlift pumping while drilling,
- equipment for storage and discharge of return water.

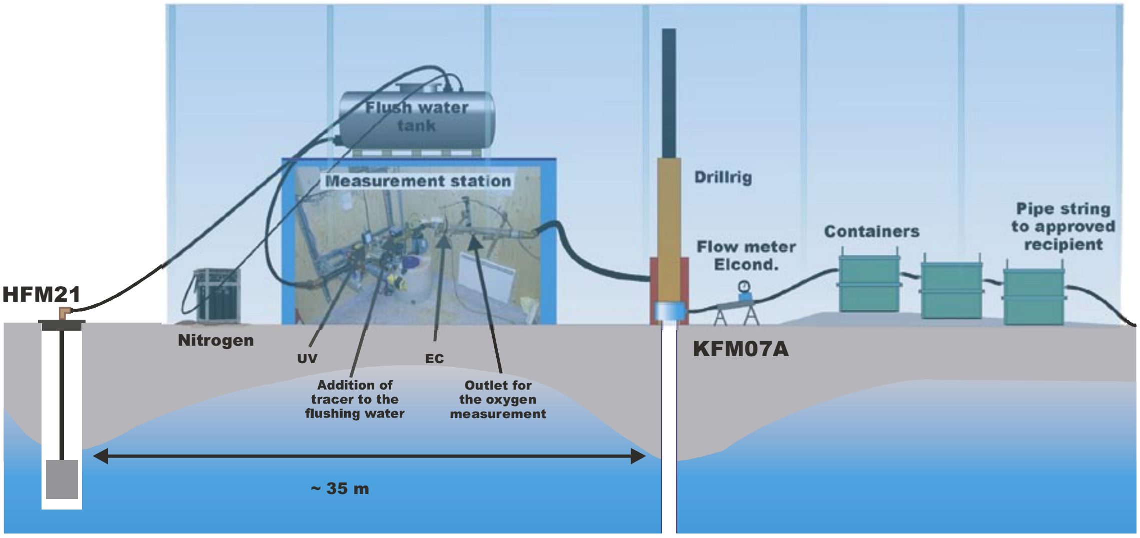


Figure 3-3. *Schematic illustration of the flushing/return water system when drilling KFM07A at DS7. The measurement station included the logger units and an UV-radiation unit. For flushing water flow rate and pressure measurements, the drilling machine gauges were applied.*

Preparation of the flushing water

The quality of the flushing water must fulfil specific demands, which are especially important when drilling telescopic boreholes of SKB chemical type. The water needs to be almost biologically clean, i.e. the content of microbes and other organic constituents needs to be low. The chemical composition should be similar to that which is to be expected in the aquifer penetrated by the telescopic borehole itself. Foreign substances, like oil and chemicals, must be avoided.

The water well used for the supply of flushing water for core drilling of KFM07A was a percussion drilled well in hard rock, HFM21, situated at DS7 approximately 35 m from KFM07A. The water quality was analysed and considered as good enough to serve as flushing water for KFM07A.

In addition to the basic quality demands on the flushing water well, the flushing water was prepared in three steps before use, in accordance with SKB MD 620.003 (Method description for core drilling).

1) Water from the flushing water well was pumped into the flush water tank (see Figure 3-3).
2) Nitrogen was bubbled through the water in the tank in order to expel oxygen, which might be dissolved in the water (see Figure 3-3). Expelled oxygen was discharged through a pressure reducing valve. Oxygen must be avoided in the flushing water because it is a critical parameter in the programme for hydrogeochemical characterization of the groundwater. The water was then kept continuously under a positive nitrogen pressure (about 1 bar) until pumped down into the borehole.
3) After leaving the tank the water was conducted into the measurement station, where it was exposed to UV-radiation before entering the doser equipment for tracer labelling illustrated in Figure 3-3. The microbe content in the water was radically reduced by the UV-radiation.
4) An organic tracer dye, Uranine, was added by the tracer doser at a concentration of 0.2 mg/L before the water was pumped into the borehole, see Figure 3-3. 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 following flushing water parameters were measured on-line when pumping the flushing water into the borehole:

- flow rate,
- pressure,
- electrical conductivity,
- dissolved oxygen.

Data were stored in a drilling monitoring system, see Section 3.3.3. Technical specifications of the measurement instruments are presented in Table 3-2.

The total quantity of water supplied to the borehole, used as a double-check of the flow measurements, was acquired by counting the number of filled water tanks used, multiplied by the tank volume.

Table 3-2. Technical specifications of instruments used for measurement of flushing water parameters.

Instrument	Manufactorer/type	Range of measurement	Remarks
Flow meter	Krohne IFC 010-D	1 – 350 L/min	Inductive
Electrical Conductivity	Kemotron 2911	1 mS/cm–200 mS/cm 0.1 mS/m–20 S/m	
Oxygen	Orbisphere model 3600		

Air-lift pumping while drilling

Airlift pumping during core drilling involves pumping of compressed air into the percussion drilled portion of the telescopic borehole, so that the air emerges at a depth of about 80–100 m. As it expands in rising out of the borehole, it forces the water upwards, to produce the air-lift pumping effect. The resulting groundwater draw-down entails transport of much of the mixture of water and drill cuttings from the bottom of the hole up to the surface, see Figure 3-4. The resulting return water is a mixture of flushing water, groundwater from fracture zones in the rock and drill cuttings. Some of the flushing water and drill cuttings will, however, be forced into the local fracture systems and a minor part will be left in the borehole. The air-lift pumping is continued throughout the drilling period.

The air-lift pumping equipment in KFM07A consisted of the following main components, see Figure 3-4:

- Compressor, 12 bars/10 m^3/min.
- 100 m outer support casing, 98/89 mm diameter.
- 100.5 m inner support casing, 84/77 mm diameter.
- PEM hose: 20 bars, 22 mm diameter, 400 m.
- PEM hose: 20 bars, 28 mm diameter, 200 m.
- Expansion vessel (= discharge head).
- Pressure sensor, 10 bars, instrumentation and data-logging unit.
- Electrical supply cubicle, at least 16 A.
- Ejector tube.
- Two - 22 mm diameter hoses at about 90 m.

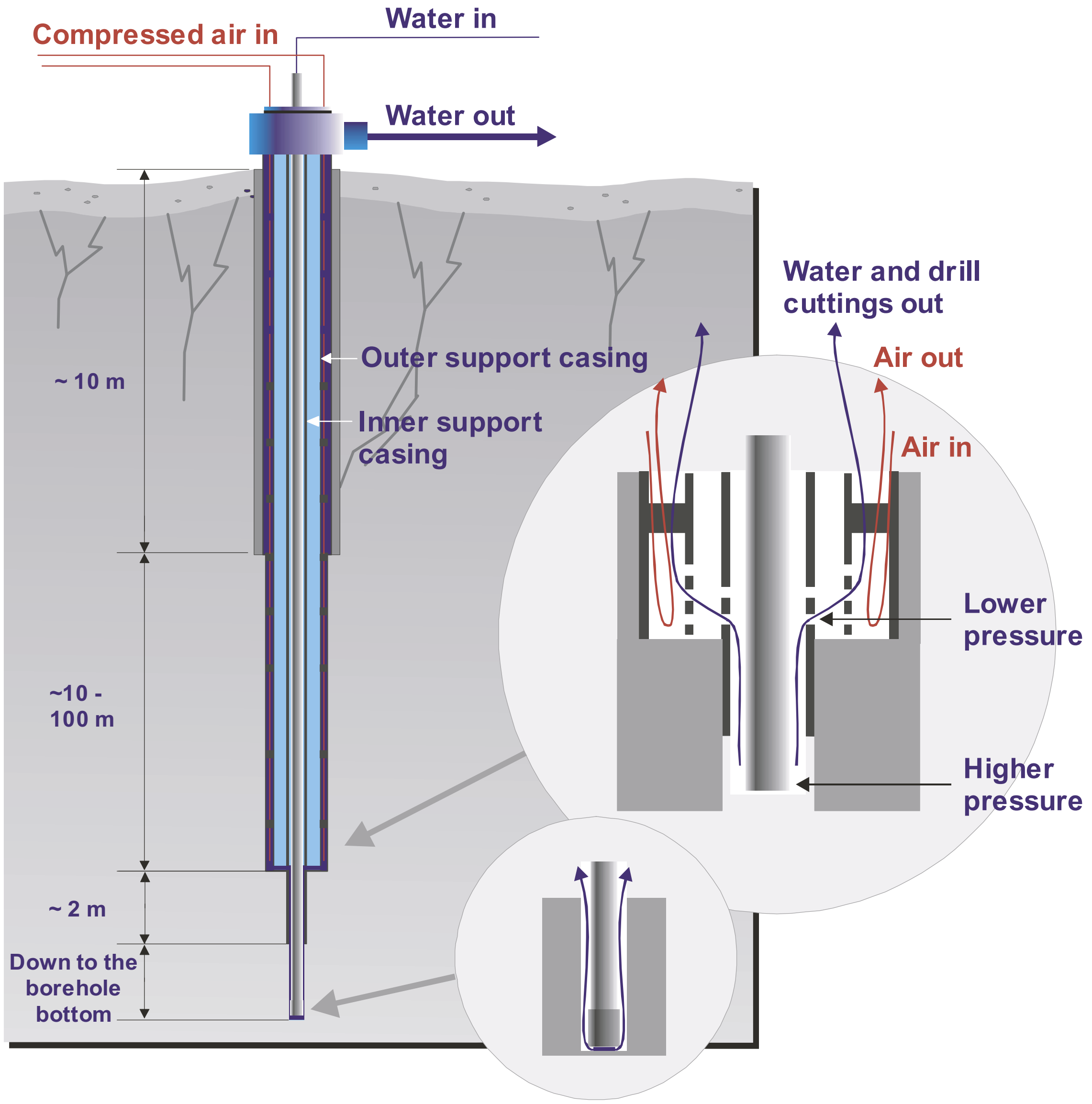


Figure 3-4. *Airlift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole. Return water flows between the borehole wall and the drill pipe string and then through holes in the support casing before being transported up to the surface.*

- One - 22 mm diameter hose at about 100 m.
- Two - 28 mm diameter hoses at about 100 m.

Core drilling beneath the large-diameter percussion drilled part of the borehole demands installation of a support casing, in order to avoid vibrations of the drill pipe string. This is accomplished by an inner support casing, which is further stabilized by an outer support casing supplied with steel "wings" resting against the borehole wall, see Figure 3-4. When installing the outer support casing, it was lowered into the borehole together with the hoses for air-lift pumping with a mobile crane. The ejector tube was fit to the outer support casing, about 200 mm above the bottom of the telescopic borehole. A 22 mm supply hose and a 28 mm return hose were connected to the ejector tube as shown in Figure 3-5. With this construction, the air leaving the ejector rose, reducing the pressure in the lower part of the ejector tube, helping to lift drill cuttings from the bottom of the hole.

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 Figures 3-3 and 3-6. The return water was discharged from the borehole via the expansion vessel and a flow meter to three containers, in which the drill cuttings separated out in three sedimentation steps. The cuttings were preserved in the containers for later weighing. Due to environmental restrictions, the return water was, after separation of drill cuttings, pumped directly to the Baltic Sea.

The flow rate and electrical conductivity of the return water was measured and data stored in the data-logging system. Technical specifications of the measurement instruments are given in Table 3-3.

Flow rate data and other flushing water data were continuously stored in an automatic data-logging system, see Section 3.3.3. As a back-up and double-check, 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.

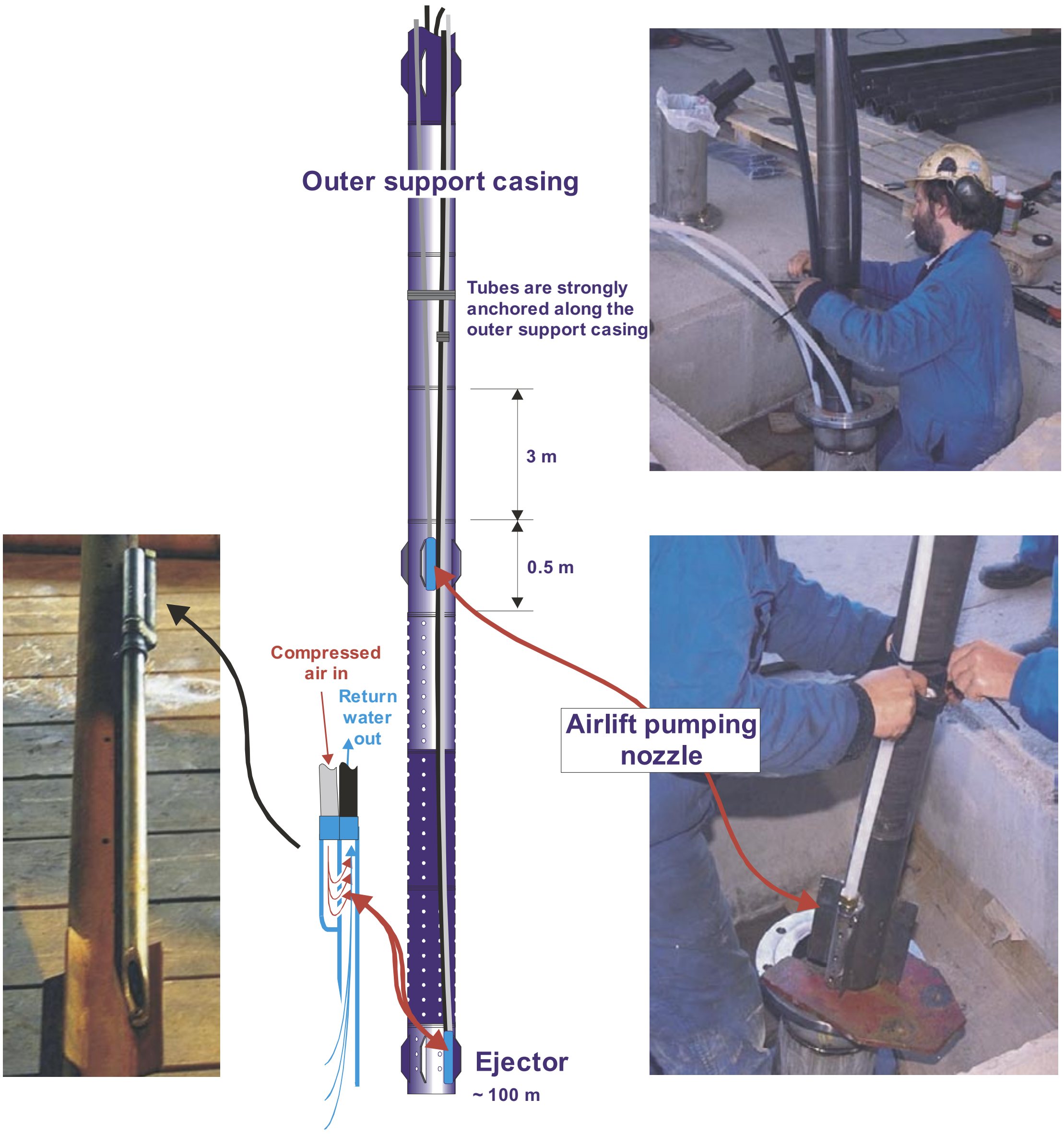


Figure 3-5. *Schematic representation of connection and installation of the air-lift pumping nozzle and ejector on the outer protective casing.*

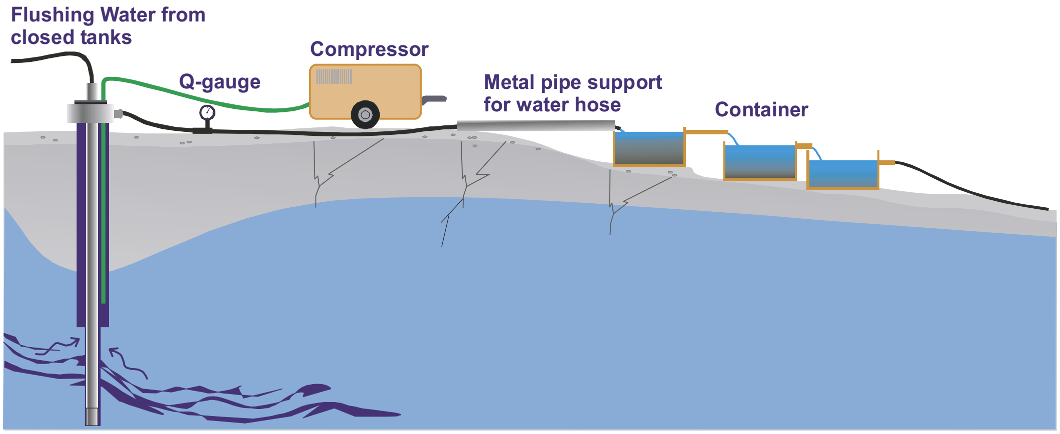


Figure 3-6. Return water system. Air-lift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in three steps in the containers (where they are preserved for later weighing), after which the water is pumped to an approved recipient.

Table 3-3. Technical specifications for instruments used for measurement of return water parameters.

Instrument	Manufactorer/type	Range of measurement	Remarks
Flow meter	Krohne IFC 010-D	1–350 L/min	Inductive
Electrical Conductivity	Kemotron 2911	1 mS/cm–200 mS/cm 0.1 mS/m–20 S/m	

3.3.3 Drilling monitoring system

The ONRAM 2000-CCD drilling machine is supplied with a computer based logging kit integrated in the steering system (cf Section 3.3.1). The parameters logged are those used for automatic operation of the drilling machine. During drilling of the earlier telescopic boreholes, KFM01A to KFM04A, quality problems with the core and the borehole wall were observed from time to time. Therefore an upgraded software and same components of the steering system were installed prior to drilling borehole KFM05A and has been used since then, i.e. for drilling KFM06A and B as well as KFM07A.

A log-file name, a time- or depth-interval and parameters to be logged are selected from a menu. The system produces files in ASCII format, which can be transferred into several Windows programs for further analyses.

The following parameters are automatically registered: date, time, mode, status, rotation pressure (bar), feed force on drill bit (kp), feed force on cylinder (kp), feed pressure (bar), flushing water flow rate (L/min), flushing water pressure (bar), rotation speed (rpm), penetration rate (cm/min), drill length (cm), bit position (cm), feed position (1/10 mm), rod weight (kg) and rod pressure (bar). The parameter "mode" represents the current activity in the drill cycle, whereas "status" gives an explanation to drill stops and also indicates when a drilling sequence is finished.

For the geoscientific data acquisition, the following technical parameters are of primary interest:

- time,
- drill bit position,
- penetration rate,
- feed force,
- rotation speed.

However, during drilling of the telescopic boreholes at Forsmark, the registration is extended to include also the following flushing water parameters:

- electric conductivity,
- dissolved oxygen.

as well as the return water parameters:

- flow rate,
- electric conductivity.

The system is also equipped with devises for convenient sampling of flushing water and return water for analysis of the Uranine content.

Finally, the level of the groundwater table in the borehole is registered during drilling.

3.3.4 Equipment for deviation measurements

During drilling of borehole KFM07A, deviation measurement were made at two occasions in order to check the straightness of the borehole. One measurement was made after approximately 518 m and then the final deviation measurement was carried out. Both measurements were performed 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.

As a quality check of the deviation measurements, a second method for deviation measurements was applied. The control measurements were performed with a Reflex Multishot instrument, which is a magnetic measurement system. Measurements were carried out in the entire part of the borehole below casing. Azimuth and dip are measured at every third metre.

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

In SKB MD 620.003 (see Table 1-1) 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 named "the wireline probe" or "WL-probe", is described in SKB MD 321.002, Version 1.0, see Table 1-1.

4 Execution

4.1 Percussion drilling of borehole section 0–100 m in KFM07A

Performance of the percussion drilling followed Activity Plan AP PF 400-04-53, which refers to SKB MD 610.003, see Table 1-1. The percussion drilling operations included the following parts:

- preparations,
- mobilization, including lining up the machine and measuring the position,
- drilling, measurements, and sampling during drilling,
- finishing off work,
- data handling,
- environmental control.

The four first items are treated in the present section (Section 4.1), whereas the last two activities, together with the corresponding ones for core drilling, are presented in Sections 4.3 and 4.4.

4.1.1 Preparations

The preparation stage included the contractor's service and function control of his equipment. The machinery was obliged to be supplied with fuel, oil and grease exclusively of the types stated in SKB MD 600.006, Version 1.0, cf Table 1-1. Finally, the equipment was cleaned in accordance with the cleaning instruction in SKB MD 600.004, Version 1.0 (Table 1-1), for boreholes of SKB chemical type. Both instructions are SKB internal controlling documents.

4.1.2 Mobilization

Mobilization onto and at the site included preparation of the drill site, transport of drilling equipment as well as of sampling pots for soil and drill cuttings, hand tools and other necessary outfit. Furthermore, the mobilization included cleaning of all in-the-hole equipment at level two in accordance with SKB MD 600.004, lining up the machine and final function control.

4.1.3 Drilling, measurements and sampling during drilling

The percussion drilling started with drilling through the overburden during simultaneous casing driving and subsequent gap injection. These activities followed the principles described in Sections 3.1 and 3.2 (corresponding to A1–A2 in Figure 3-1). The length of the NO-X 280 casing was 9.14 m.

The continued percussion drilling through solid rock was performed with a drill bit of nominal diameter 164 mm, providing a borehole with the end diameter 162.7 mm, to 100.40 m drilling length (corresponding to B in Figure 3-1). The borehole was then reamed to Ø c 251 mm, whereupon an SS2333 stainless steel $Ø_i$ 200 mm casing was installed.

Prior to that, the borehole was though cleaned from drill cuttings by a "blow out" with the compressor working at maximum capacity during 30 minutes. This also served as a hydraulic capacity test of the borehole, since the recovery of the groundwater table was registered after the compressor had been turned off. The results were used as a rough capacity test of the percussion drilled part of the borehole, used on-site, i.e. for preparation of the gap injection of the casing, see below.

In order to prevent rock outfall from the fractured bedrock, the gap between the wall and the casing was grouted using the packer technique illustrated in Figure 3-2. After grouting, the recharge of water into the borehole ceased completely.

Measurements and sampling while percussion drilling (and immediately after drilling) were performed according to a specific measurement/sampling programme. Concerning the section below the casing through the overburden down to 100.40 m, the measurements and sampling during and immediately after drilling were carried out in association with the Ø 162.7 mm drilling sequence. The measurement/sampling programme performed was in accordance with SKB MD 610.003, see Table 1-1, and included:

1) Sampling of drill cuttings at every third metre. Each sample consists of three individual samples collected one per metre. The samples were stored in a plastic bottle marked with a sample number. Ocular inspection and a preliminary description of the mineral content was made on-site as a basis for classification of the rock type.
2) Manual measurements of the penetration rate at every 20 cm.
3) Observation of the flow rate (if any) at every 20 cm. When a significant increase of the flow rate was noticed, it was measured using a graduated vessel and a stop-watch.
4) Observation of the water colour at every 20 cm.
5) Measurement of the electric conductivity of the groundwater at every three metres.

Results from the remaining measurements and observations are presented in Chapter 5.

4.1.4 Finishing off work

Finishing off work included measurements of the final diameter of the drill bit after reaming to Ø 251 mm. The borehole was secured with a lockable stainless steel flange. The drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

4.1.5 Nonconformities

The activity was performed without nonconformities.

4.2 Core drilling of KFM07A

Also performance of the core drilling followed Activity Plan AP PF 400-04-53, which refers to SKB MD 620.003, cf Table 1-1. The core drilling operations included:

- preparations,
- mobilisation, including lining up the machine and measuring the position,
- drilling, measurements, and sampling during drilling,
- finishing off work,

- data handling,
- environmental control.

The four first items are presented in Section 4.2, while the last two activities are referred to in Sections 4.3 and 4.4.

4.2.1 Preparations

As for percussion drilling, 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.

4.2.2 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, hand tools etc. Furthermore, the mobilization included cleaning of all in-the-hole equipment at level two in compliance with SKB MD 600.004, lining up the machine and final function control of all equipment.

4.2.3 Drilling, measurements and sampling during drilling

Core drilling of borehole KFM07A was performed with two borehole dimensions. Section 100.40–101.95 m was drilled with a borehole diameter of 86.0 mm, whereas the main part of the borehole, section 101.95–1,001.55 m, was drilled with Ø 77.3 mm. The inner Ø 84/77 mm support casing was fitted into the short Ø 86 mm borehole. In this way the casing was centralized in the borehole and fixed laterally. (The outer Ø 98/89 mm support casing is resting on the bottom of the percussion drilled borehole, see Figure 3-4).)

Core drilling with Ø 77.3 mm of the main part of the borehole serves many purposes, cf Chapter 2. One of the most essential objectives is to provide (in principle) continuous rock samples, i.e. drill cores, down to the borehole bottom, which allows lithological, structural and rock mechanical characterization of the bedrock. The drill cores may also be used for determination of transport properties of the rock and, sometimes, for the study of chemical characteristics of the pore water in the rock matrix.

Core drilling with a wireline system involves recovery of the core barrel via the drill pipe string, inside which it is hoisted up with the wireline winch. During drilling of borehole KFM07A, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 77.3 mm part of the borehole is 50.8 mm. Minor deviations from this diameter may though occur.

Like the percussion drilling, 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 KFM07A some deviations from this programme could not be avoided. In order to elucidate the nonconformities, the programme according to the Method Description is presented in Section 4.2.5, Table 4-1, together with the actual performance when drilling KFM07A.

Results of drill core logging (Boremap mapping) are presented in /3/, whereas the remaining measurements and registrations during core drilling are presented in Chapter 5.

Besides the activities mentioned in Table 4-1, cleaning of the flushing water system using 2% (by volume) Sodium Hypochlorite solution (by volume) was performed before drill start.

The concluding work included the following items:

1) The borehole was flushed for about 10 hours during simultaneous air-lift pumping in order to clean it from drilling debris adhered to the borehole walls, settled at the bottom of the hole or suspended in the water. After finished flushing/air-lift pumping, the recovery of the groundwater table was registered as an estimate of the hydraulic conditions of the entire borehole. The results are presented in Chapter 5.
2) The drill string was pulled.
3) The inner support casing was removed with aid of a crane lorry.
4) The outer support casing was removed with the same crane lorry.
5) The discharge head was removed.
6) Using the drill rig, a stainless steel transition cone was installed between the reamed and cased percussion drilled, respectively the cored part of the borehole, as shown in Figure 4-1. The cone is located at 96.04–101.70 m.

Figure 4-1. *Schematic illustration of the transition cone between the upper, wide section and the lower, slim part of a telescopic borehole. In KFM07A, the entire upper, percussion drilled part was cased.*

7) The borehole was again secured with the lockable stainless steel flange.

8) The core drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

4.2.4 Nonconformities

The core drilling operation resulted in a number of nonconformities with the Method Description. These deviations 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 compared to the actual performance during drilling of borehole KFM07A.

Activity	Performance and frequency according to SKB MD 620.004	Performance and frequency during drilling of KFM07A
Registration of drilling- and flushing water parameters.	Described in Section 3.3.2. Registration during the entire drilling.	According to programme.
Registration of the groundwater level in the borehole during drilling.	Every 10th second.	According to programme.
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 during drilling and one measurement after completion of drilling with the Maxibor system. One measurement with Reflex Multishot after drilling.
Measurements of the difference in length between the compressed drill pipe string and as extended by its own weight.	Normally performed every 100 m.	Values presented in Figure 5-17 are from material properties of the drill pipe string.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drill pipe string should be controlled before each test.	No pumping tests was made due to malfunctioning of the WL-sond.
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drill pipe string should be controlled before each test.	One sample was collected by using the ejector pump due to malfunctioning of the WL-sond.
Absolute pressure measurements.	Normally during natural pauses in drilling.	No measurements performed.
Groove milling in the borehole wall, normally at each 100 m.	Normally performed after completion of drilling.	Eighteen grooves performed after drilling. Three grooves not detectable.
Collecting and weighing of drilling debris.	Drilling debris settled in containers and weighed after finished drilling.	Not carried out for the percussion drilled part of the borehole. According to programme for the core drilled part.
Flushing of the entire borehole.	After completion of drilling and groove milling.	Ordinary water flushing combined with nitrogen gas flushing.

The next last item in Table 4-1 may be commented on. All drilling debris produced during drilling (percussion drilling as well as core drilling) was collected in the sedimentation containers of the return water system, see Figures 3-7 (except the finest fractions which stayed suspended in the discharge water from the third container). The collected drill cuttings from the core drilled part were weighed after completed drilling in order to obtain an estimate of the drill cuttings recovery.

4.3 Data handling

4.3.1 Performance

Minutes for several items with the following headlines: Activities, Cleaning of the equipment, Drilling, Borehole, 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 and are traceable by the activity plan number.

4.3.2 Nonconformities

None.

4.4 Environmental programme

4.4.1 Performance

A program according to SKB's routine for environmental control was followed throughout the activity. A checklist was filled in and signed by the Activity Leader, who also filed it in the SKB archive.

4.4.2 Nonconformities

None.

5 Results

An overview of the drilling progress of borehole KFM07A 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 (percussion drilling)
- Section 5.4 (core drilling).

Well Cad-presentations of borehole KFM07A are shown in:

- Appendix A (percussion drilled part)
- Appendix B (the complete drilled borehole). 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
- Appendix C (chemical analyses from flushing water).

5.1 Drilling progress

Drilling of borehole KFM07A was carried out during two separate periods, see Figure 5-1. As preparation of drill site DS7 was finished before schedule and since the drilling rig was available on site, the percussion drilling of KFM07A was brought forward to mid June 2004. After the summer holidays, core drilling of KFM06A was completed during August and the first half of September, whereupon the Onram rig was transferred to and installed on drill site DS7. Core drilling of KFM07A started on October 19, 2004, and drilling was completed on December 9, after a drilling period of less than 2 months, see Figure 5-1.

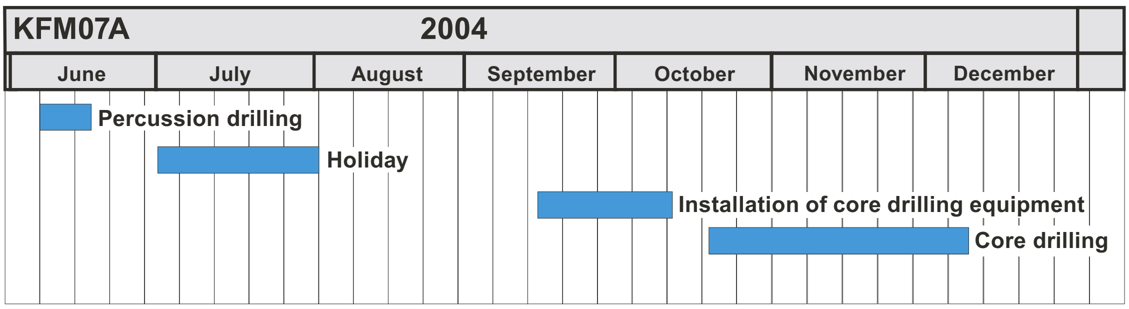


Figure 5-1. *Overview of the drilling performance of borehole KFM07A.*

5.1.1 Percussion drilling period

Percussion drilling is a rapid drilling method. Although a relatively complex approach is applied when drilling telescopic boreholes with two drilling sequences, casing driving and gap injection, drilling of KFM07A could be completed after a rather short total working period of about ten days.

The durations of the different sub-operations included in the percussion drilling from 2004-06-07 to 2004-06-16 are presented in Figure 5-2.

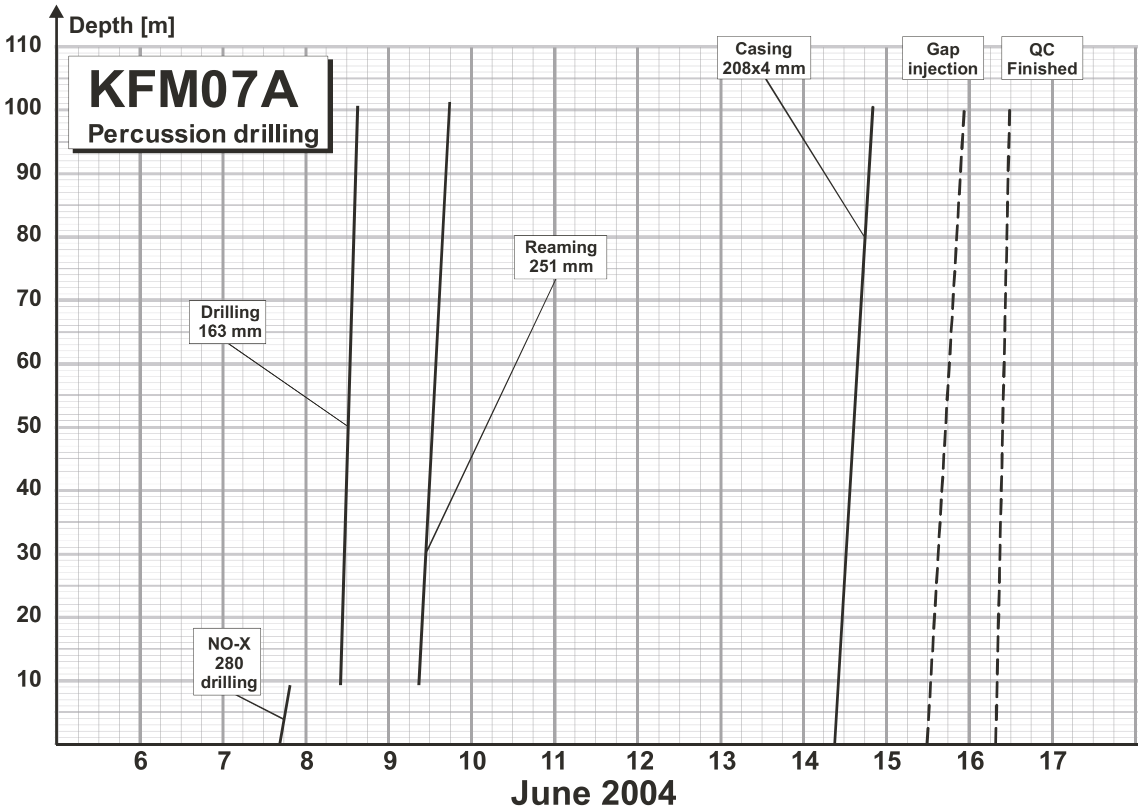


Figure 5-2. *Percussion drilling progress (depth and activity versus calendar time).*

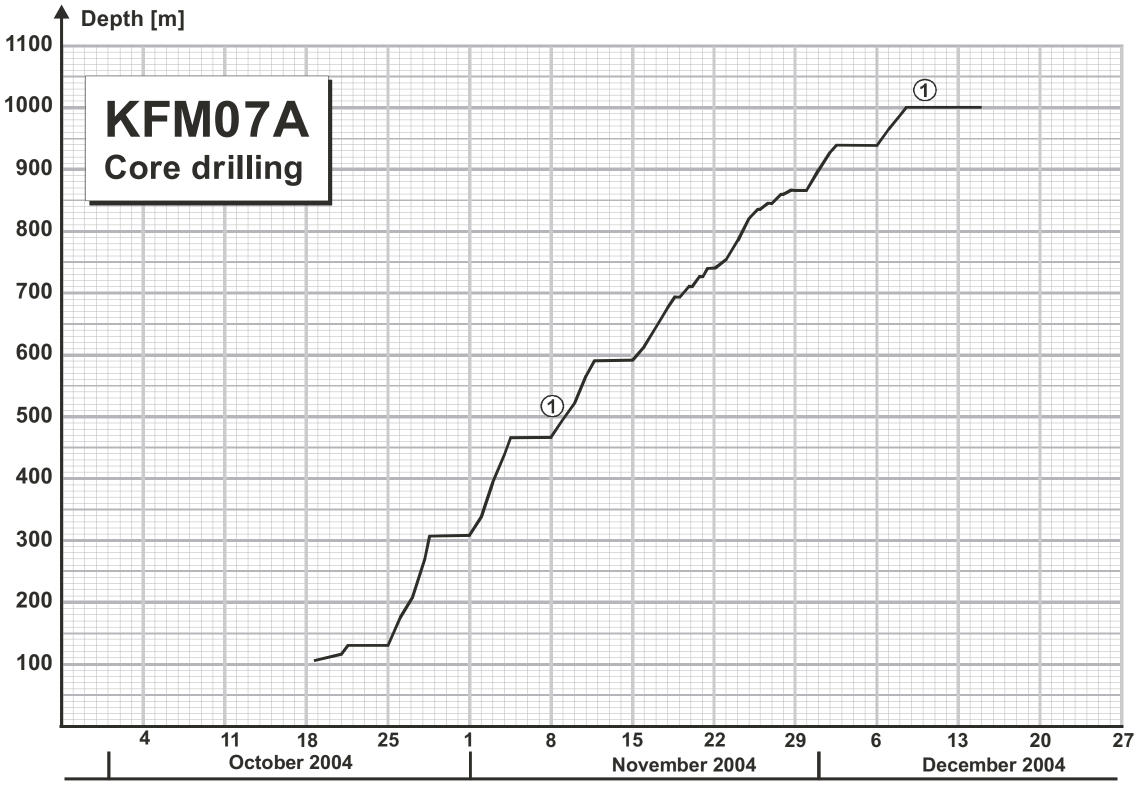


Figure 5-3. Core drilling progress (depth versus calendar time). ① Deviation measurement (Maxibor).

5.1.2 Core drilling period

After percussion drilling of section 0–100.40 m, followed by a four months break, core drilling commenced, see Figure 5-1. The progress of the core drilling from 2004-10-19 to 2004-12-09 is presented in Figure 5-3. The pace of the drilling progress decreases slightly versus time, due to that with increasing borehole length, retrieval of the core barrel, e.g. for change of drill bit, becomes more and more time consuming. To ensure that the drilling was to be completed before Christmas, six extra shifts during two weekends were claimed. Due to low fractured rock, longer lift-time of drill bits than previously and a minimum of disturbances, drilling of KFM07A could be completed within the shortest time for all telescopic boreholes drilled so far in Forsmark.

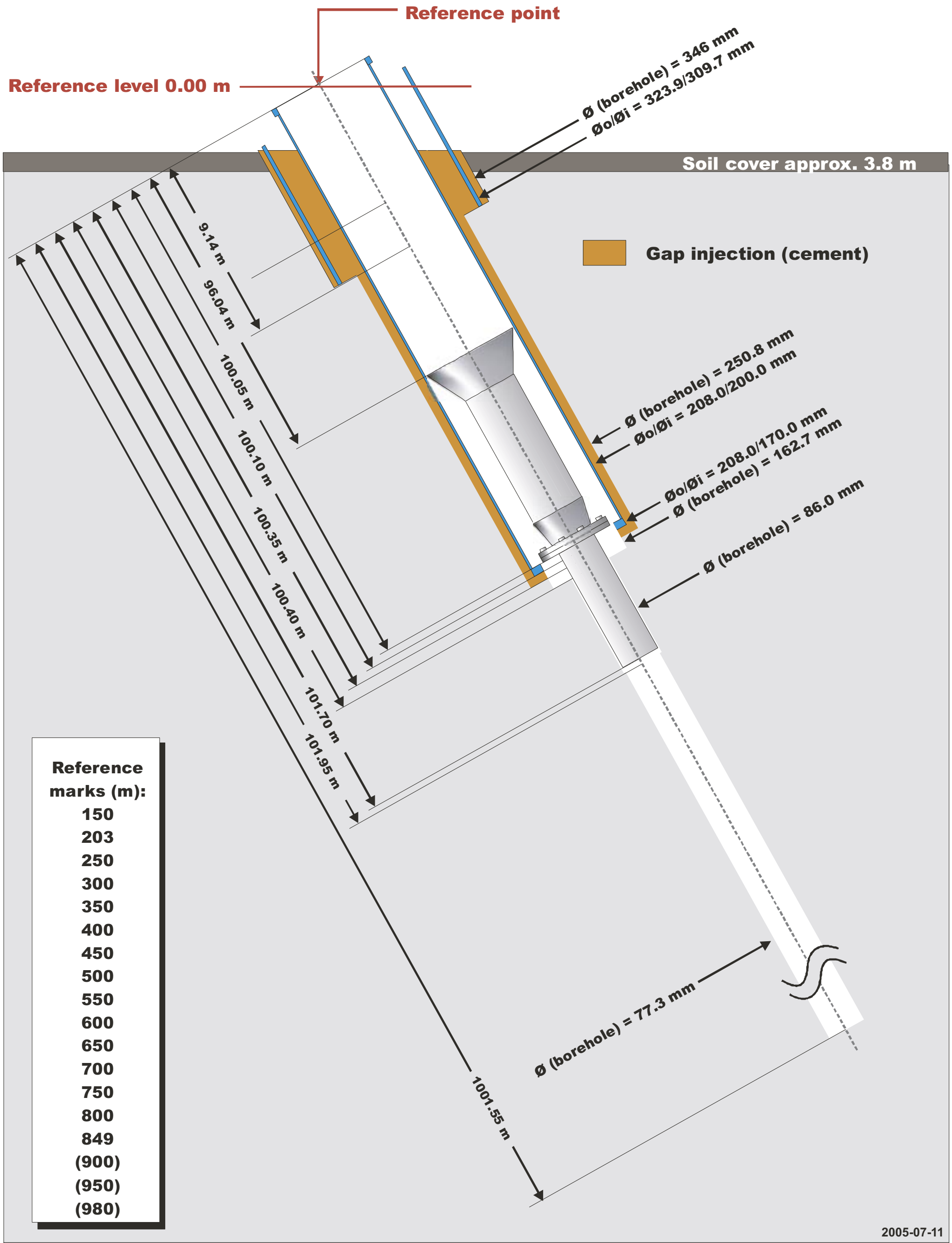
5.2 Geometrical and technical design of borehole KFM07A

Administrative, geometric and technical data for the telescopic borehole KFM07A are presented in Table 5-1. The technical design is illustrated in Figure 5-4.

Table 5-1. Administrative, geometric and technical data for borehole KFM07A.

Parameter	KFM07A
Borehole name	KFM07A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	June 7, 2004
Completion date	December 9, 2004
Percussion drilling period	2004-06-07 to 2004-06-16
Core drilling period	2004-10-19 to 2004-12-09
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Sven Andersson i Uppsala AB
Percussion drill rig	Commachio 1500
Core drill rig	ONRAM 2000 CCD
Position KFM07A at top of casing (RT90 2.5 gon V 0:–15 / RHB 70)	N 6700127.08 E 1631031.57 Z 3.32 (m a s l)
	Azimuth (0–360°): 261.47°
	Dip (0–90°): –59.22°
Position KFM07A at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6700210.10 E 1630476.37 Z –816.33 (m a s l)
	Azimuth (0–360°): 298.31°
	Dip (0–90°): –46.07°
Borehole length	1001.55 m
Borehole diameter and length	From 0.00 m to 9.14 m: 0.346 m From 9.14 m to 100.35 m: 0.251 m From 100.35 m to 100.40 m: 0.163 m From 100.40 m to 101.95 m: 0.086 m From 102.10 m to 1,001.55 m: 0.077 m
Casing diameter and drilling length	$Ø_o/Ø_i$ = 324 mm/310 mm to 9.14 m $Ø_o/Ø_i$ = 208 mm/200 mm to 100.05 m
	Casing shoe $Ø_i$ = 170 mm between 100.05 and 100.10 m
Transition cone inner diameter	At 96.04 m: 0.195 m
	At 101.70 m : 0.080 m
Drill core dimension	100.40 –1,001.55 m/Ø 51 mm
Core interval	100.40–1,001.55 m
Average length of core recovery	2.78 m
Number of runs	324
Diamond bits used	23
Average bit life	37.63 m

Technical data
Borehole KFM07A



Drilling reference point

Northing:	**6700127.08 (m), RT90 2,5 gon V 0:-15**
Easting:	**1631031.57 (m), RT90 2,5 gon V 0:-15**
Elevation:	**3.32 (m), RHB 70**

Orientation

Bearing (degrees):	**261.47°**
Inclination (degrees):	**-59.22°**

Borehole

Length:	**1001.55 m**

Percussion drilling period

Drilling start date:	**2004-06-07**
Drilling stop date:	**2004-06-16**

Core drilling period

Drilling start date:	**2004-10-19**
Drilling stop date:	**2004-12-09**

Figure 5-4. *Technical data of borehole KFM07A.*

5.3 Percussion drilling 0–100.40 m

5.3.1 Drilling

As mentioned in Section 4.1.3, the upper section to 9.14 m of the borehole was drilled and cased with NO-X 280. During pilot drilling to 100.40 m a water inflow of 200 L/min was encountered at 59 m (drilling length). Highly fractured rock was observed in section 63–65 m. Due to heavy groundwater inflow and instabilities in the borehole wall, the borehole section 9.14–100.40 was reamed to 251 mm, and a 200 mm stainless steel casing was installed. The gap between the casing and borehole wall was cement grouted, thereby sealing the gap completely so that the water inflow ceased.

5.3.2 Measurements while drilling

During, and immediately after drilling, a program for sampling and measurements was applied, cf Section 4.1.3. Below, the results of the deviation measurements made after completed percussion drilling of KFM07A (also displayed in the Well Cad-presentation in Appendix A) are commented on.

Borehole deviation

The end (bottom) point of the percussion borehole deviates approximately 0.3 m upwards and 0.5 m to the right compared to an imagined straight line following the dip and strike of the borehole collaring point (inclination –59.22° and bearing 261.47°).

5.4 Core drilling 100.40–1,001.55 m

5.4.1 Drilling

Drill site DS7 is located within the tectonic lens, and the borehole KFM07A is drilled through the so called rock domaine 29 /4/, the rock types of which completely dominate the tectonic lens. However, the bottom section of KFM07A probably reaches the north-western limit of the lens. This part of the borehole, below c 800 m drilling length, is characterized by increased fracturing compared to the rest of the borehole below the shallow, fractured part.

The major part of the borehole, section 200–800 m, is very low-fractured. In total 75 unbroken 3 m long drill cores were recovered from that part, which is also characterized by a very low hydraulic conductivity, as could be observed during drilling.

The drillability of the Forsmark bedrock, especially within the tectonic lens, has appeared to be relatively low, probably to a large extent depending on the high quartz content. This has been a challenge for the drill bit manufactures, and when drilling KFM07A a series of modified drill bits was applied. These drill bits appeared to be more successful than previously tested bits, and resulted in the longest life-time so far. In average, the life-time was 37.6 drilled metres per drill bit, which is 4 m more than for example in KFM04A.

During, and immediately after drilling, a program for sampling, measurements, registration of technical and geoscientific parameters and some other activities was applied, as described in Section 4.2.3. The results are presented in Sections 5.4.2–5.4.13 below.

Mapping of the drill core samples from KFM07A is presented in /3/.

5.4.2 Registration of drilling parameters

A selection of results from drilling parameter registration is presented in diagrams below. As regards the complete dataset of drilling parameters, it is referred to SICADA, were it can be traced by the activity plan number.

Drill bit position versus time

Figure 5-5 illustrates how drilling proceeded versus time. Generally, drilling ran 24 hours a day from Monday to Thursday with a weekend stop from Thursday night to Monday morning. Furthermore, drilling was performed during two weekends, see Section 5.1.2. Figure 5-5 serves as a basis for Figure 5-3, with which it should be compared.

Penetration rate, rotation speed and feed force

As borehole KFM07A was the seventh drilled telescopic borehole within the scope of the Forsmark site investigation, the experience of the behaviour of drill bits in the Forsmark rock types has increased much since the first boreholes were drilled. Several types of drill bits from different manufacturers have been tested, mainly as an attempt to obtain longer drill bit life-times. Some of the drill bits used for drilling KFM07A seem to have been successful, as the obtained life-times are the longest observed so far during the project.

The penetration rate, see Figure 5-6, was in average almost the same as during drilling of KFM01A /5/, indicating that longer life-time of drill bits does not necessarily affect penetration rate. Initially, the penetration rate was unstable. From about 150 m it stabilized at c 10 cm/min for a short period and increases after 200 m to 14 cm/min, a level which was maintained almost to 500 m. In section 500–700 m the penetration rate fell back to c 10 cm/min, probably caused by a change to a more quartz-rich rock type.

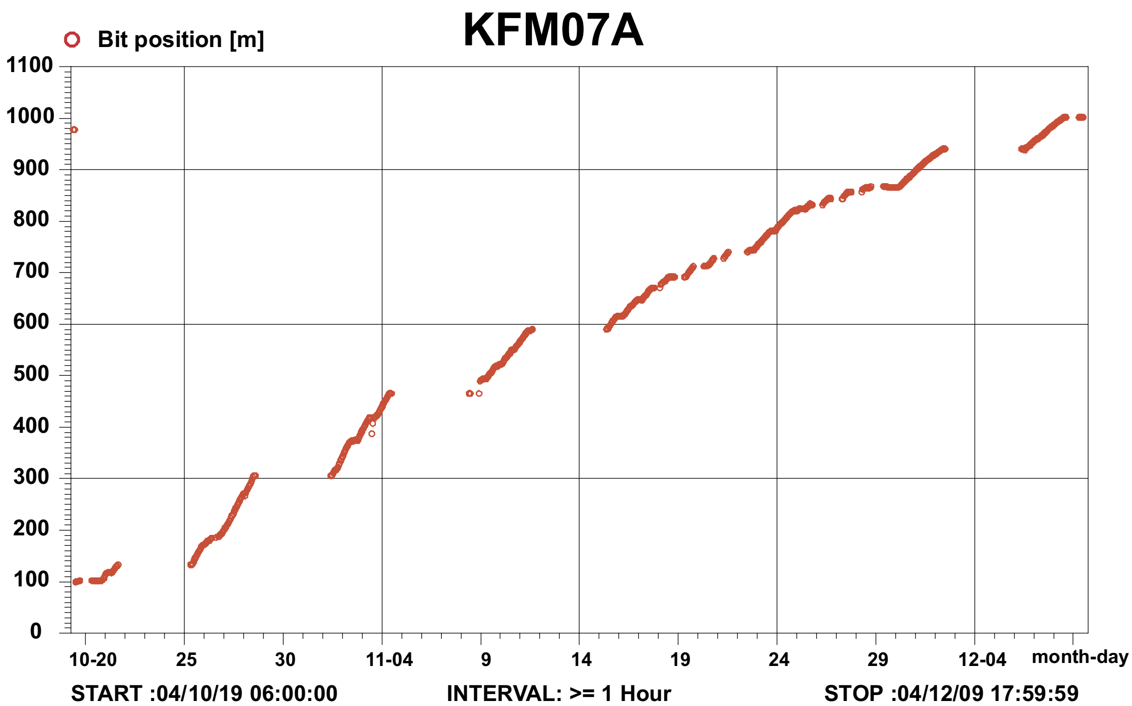


Figure 5-5. *Drill bit position versus time.*

When reaching the more fractured bedrock at c 800 m, penetration rate again decreased to 10 cm/min with a slightly declining trend towards the end of the borehole. However, although the decreased penetration rate in the bottom section of the borehole to some degree may be due to lithological and structural changes of the rock, it seems more probable that the phenomenon is related to the corresponding decreases in rotation speed and feed force observed in Figures 5-7 and 5-8.

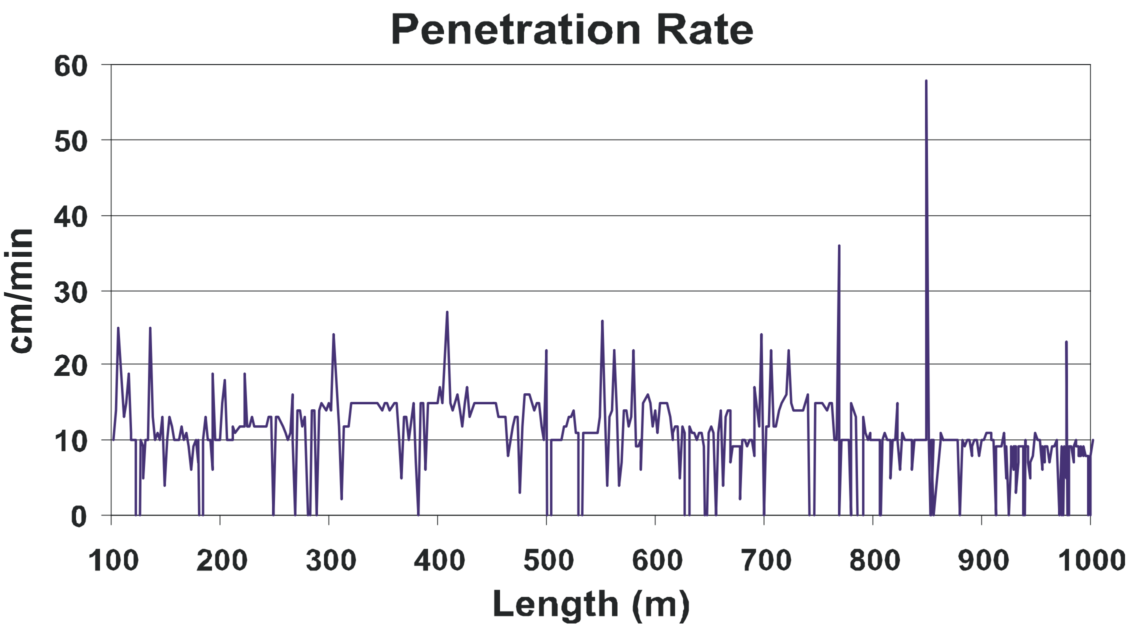


Figure 5-6. *Penetration rate during core drilling of KFM07A.*

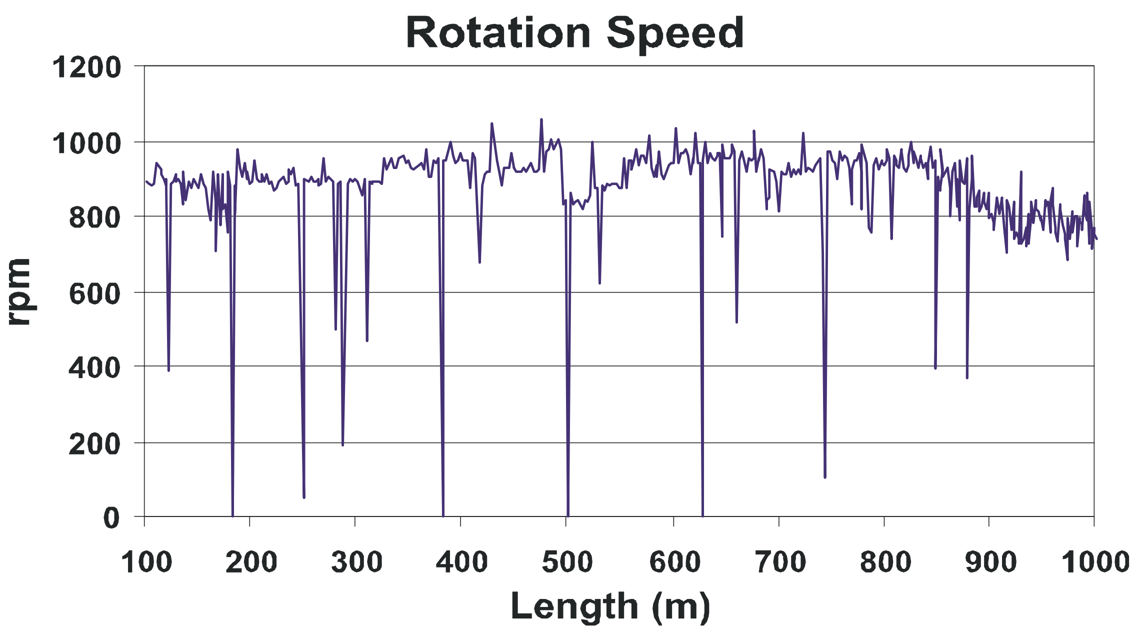


Figure 5-7. *Rotation speed versus borehole length during drilling of borehole KFM07A.*

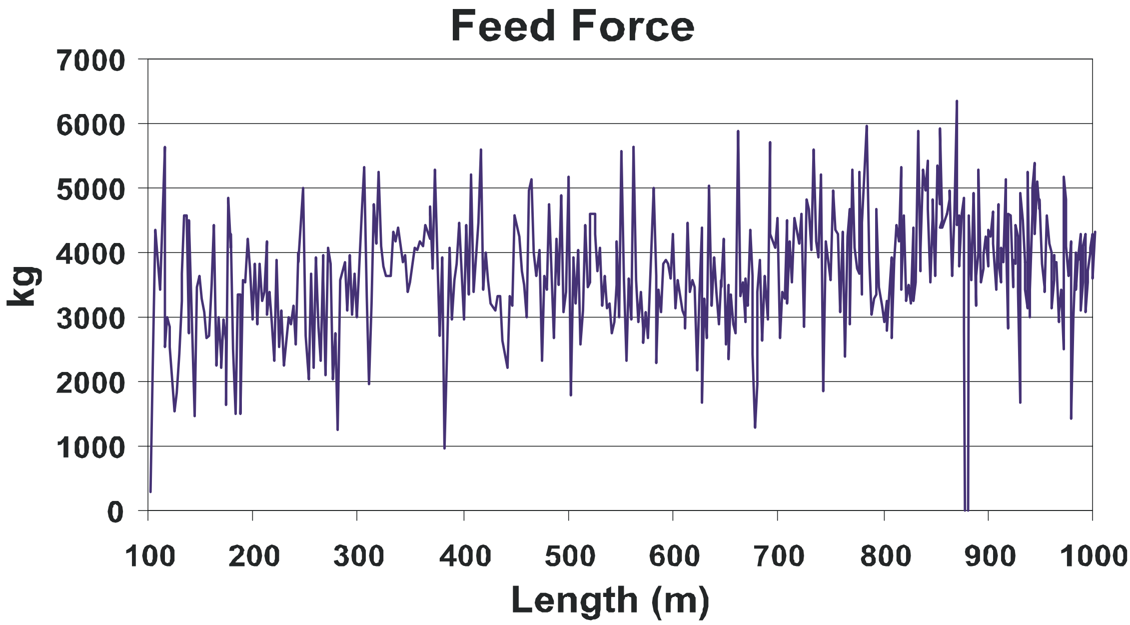


Figure 5-8. *Feed force versus borehole length during drilling of borehole KFM07A.*

Figure 5-7 displays a relatively constant rotation speed within the span c 900–950 rpm, although a sudden drop is observed at c 500 m, coinciding with a decreased penetration rate. (The sudden drops in the curve represent drilling shut off.) From c 800 m the rotation speed slowly drops to 750 rpm. This is interpreted as a result of increased friction between the borehole wall and drill rods due to the strong borehole deviation, see Section 5.4.8.

The reduction of the rotation speed corresponds to a decrease in feed force, cf Figure 5-8, which probably is an effect of an automatic adjustment by the drilling machine steering system. The combined effect of reduced feed force and rotation speed results most certainly in a decreased penetration rate, as observed in Figure 5-6.

5.4.3 Registration and sampling of flushing water and return water

Flushing water and return water flow rate – water balance

As borehole KFM07A is of SKB chemical type, it is important to estimate the amount of flushing water pumped into the borehole during drilling as well as the amount of return water recovered, to permit a water balance calculation. A flow gauge in the measurement station, registered the flushing water flow rate, see Figure 3-3. The return water was measured by another flow meter, mounted on-line with the discharge pipeline, see Figures 3-3 and 3-6.

However, the return water is normally a mixture of flushing water and groundwater from the formation penetrated by the borehole. In order to estimate the amount of remaining flushing water in the formation and in the borehole after the drilling operations, one must also study the content of the Uranine tracer in the flushing water and return water. This enables a mass balance calculation from which the flushing water content in the borehole can be determined.

Figure 5-9 illustrates the accumulated volume of flushing water and return water versus time during core drilling, while Figure 5-10 displays the accumulated volumes of flushing water and return water from the entire drilling period, giving a return water/flushing water quotient of 2.05 (results from Uranine measurements are presented in the next section).

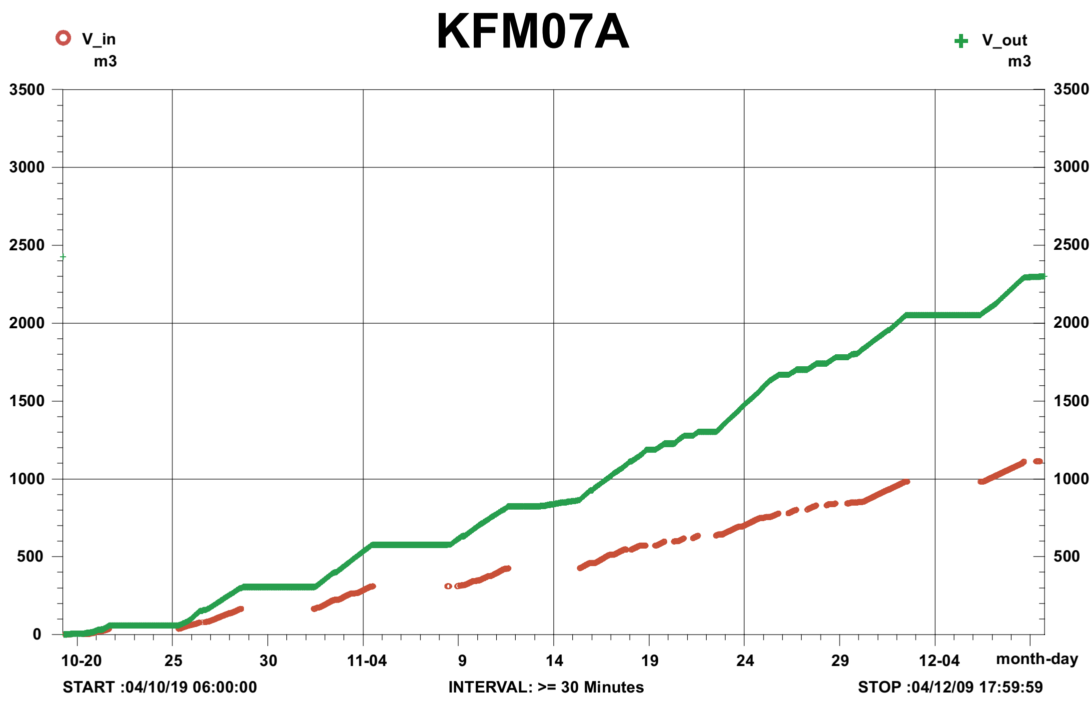


Figure 5-9. Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM07A.

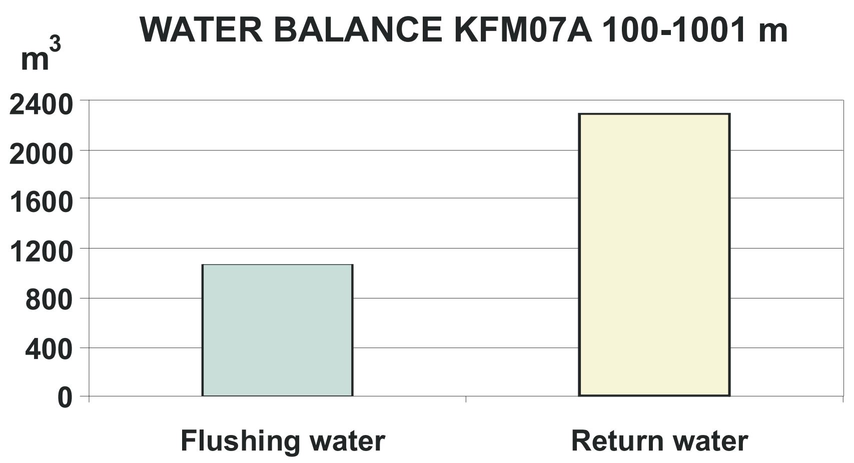


Figure 5-10. The total volume of flushing water used during core drilling was 1,121 m³. During the same period, the total volume of return water was 2,300 m³. The return water/flushing water balance is then as high as 2.05, due to the large inflow of groundwater into the upper part of the borehole during air-lift pumping.

However, in Figure 5-9 a loss of flushing water at shallow depths in the borehole is observed, as well as a significant excess of return water at depths exceeding c 200 m. This reflects the fact that when the drill bit position is close to water conductive fractures of the borehole, flushing water is forced into these fractures, because the flushing water pressure much exceeds that of the formation. After the drill bit has passed this section, the pressure gradient will eventually be reversed due to the air–lift pumping in the upper part of the borehole. If no other highly water conductive fractures are penetrated, where flushing water losses may occur, larger amounts of return water (groundwater and flushing water) are then extracted from the borehole than flushing water is supplied to it. This does not prevent certain amounts of flushing water to be forced out into the formation within the section close to the drill bit where an excess of groundwater pressure prevails.

Uranine content of flushing water and return water – mass balance

Like in boreholes KFM02A, KFM03A, KFM04A, KFM05A and KFM06A, a dosing feeder controlled by a flow meter was used for labelling the flushing water with Uranine. The feeder functioned well during the entire drilling period. Sampling and analysis of flushing water and return water was performed systematically with a frequency of approximately one sample per every fourth hour during drilling. The Uranine concentrations in the flushing water and in the return water were checked regularly by the drilling crew, and a total of 116 respectively 120 samples were analysed as an on-site test of the dosing system and of the recovery of flushing water. A selected set of 30 flushing water and 23 return water samples were also analysed in the laboratory. The laboratory results were judged as somewhat more reliable and are presented in Figure 5-11.

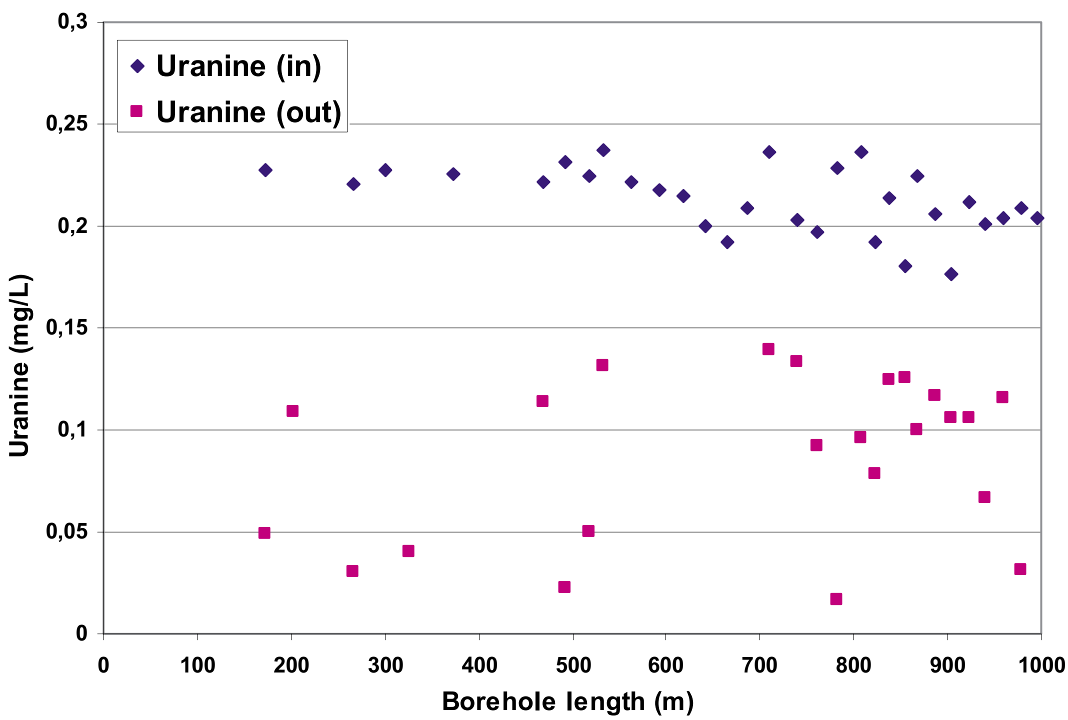


Figure 5-11. *Uranine content in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFM07A. An automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.*

The laboratory values were also used for mass balance calculations of the accumulated volumes of flushing water consumed during drilling respectively recovered from the borehole via the return water. According to notations in the log book, the amount of Uranine added to the borehole was 255 g. If the averages of the Uranine concentration values in the flushing water and in the return water are used to calculate the amount of Uranine added to and recovered from the borehole, the calculations provide 239 g respectively 181 g.

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM07A is exposed in Figure 5-12. Like in boreholes KFM02A, KFM03A, KFM04A, KFM05A and KFM06A, the borehole diameter was 77.3 mm, i.e. increased c 1 mm compared to in borehole KFM01A. This resulted in lower flushing water pressures than during drilling of KFM01A, more like in KFM04A and KFM05A. The final water pressure was for instance 10–20 bars higher than applied in KFM02A and KFM03A. One possible explanation may be that the four boreholes KFM04A, KFM05A, KFM06A and KFM07A are more inclined than the previous boreholes, which makes the recovery of drill cuttings more difficult, demanding higher water pressures and increased flow rates.

At c 500 m, there is a significant drop of the water pressure, corresponding to a section of more quartz-rich rock and decreased penetration rate, see Figure 5-6.

The decline of several drilling parameters from 800 m and downwards is also reflected in the water pressure, which probably is a result of the automatic parameter regulation.

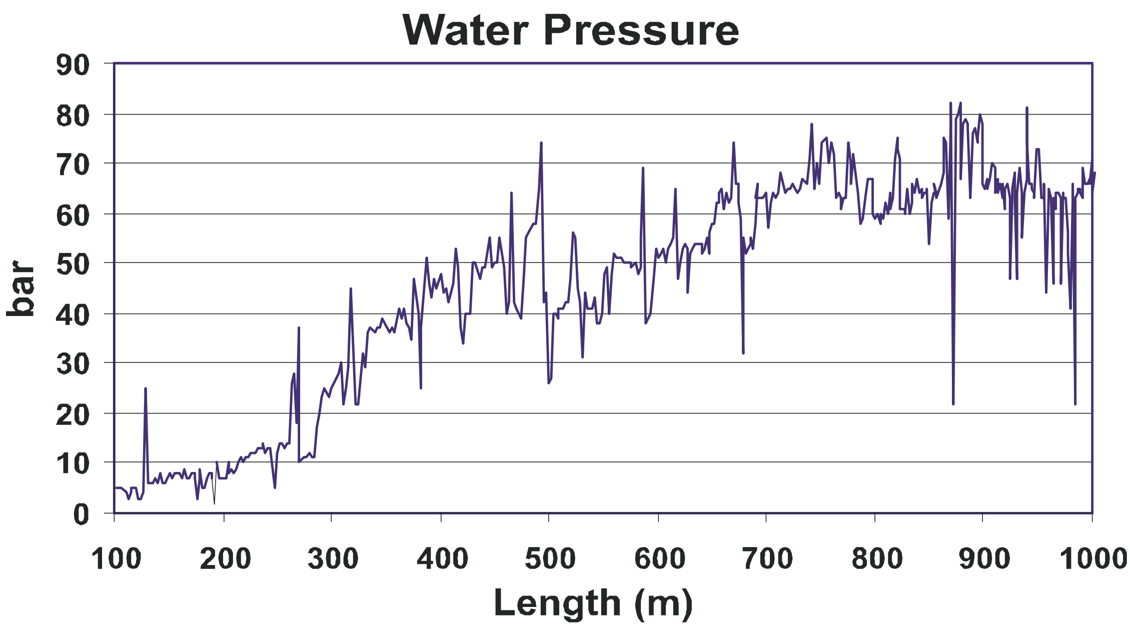


Figure 5-12. *Flushing water pressure versus drilling length when drilling KFM07A.*

Electric conductivity of flushing water

Flushing water was supplied from percussion borehole HFM21. A sensor for on-line registration of the electric conductivity (EC) of the flushing water was placed in the measurement station, before the flushing water entered the borehole, see Figure 3-3.

The sensor for registration of the electric conductivity of the return water was positioned between the surge diverter (discharge head) and the sedimentation containers see Figure 3-3.

The electrical conductivity (salinity) of the flushing water from the 202.00 m deep supply well HFM21 with its major inflow at c 162 m is presented in Figure 5-13. From start, EC displays a significantly decreasing trend during the drilling period, starting from c 1,000 mS/m and declining to 700 mS/m at the end of the 10 weeks long drilling period. This is probably due to an increased portion of shallow, low-saline groundwater recharging versus time, probably entering borehole HFM21 at c 27 m /6/.

The average electrical conductivity of the return water, follows the same decreasing trend as for the flushing water, although the EC-level is slightly higher, which though probably mostly is an illusory effect caused by the admixture of drilling debris. As return water is a mixture flushing water and groundwater from KFM07A, the results indicate that the major part of groundwater from KFM07A is of the same origin as that from HFM21. However, minor contributions of groundwater of increased salinity are known to exist from deeper levels.

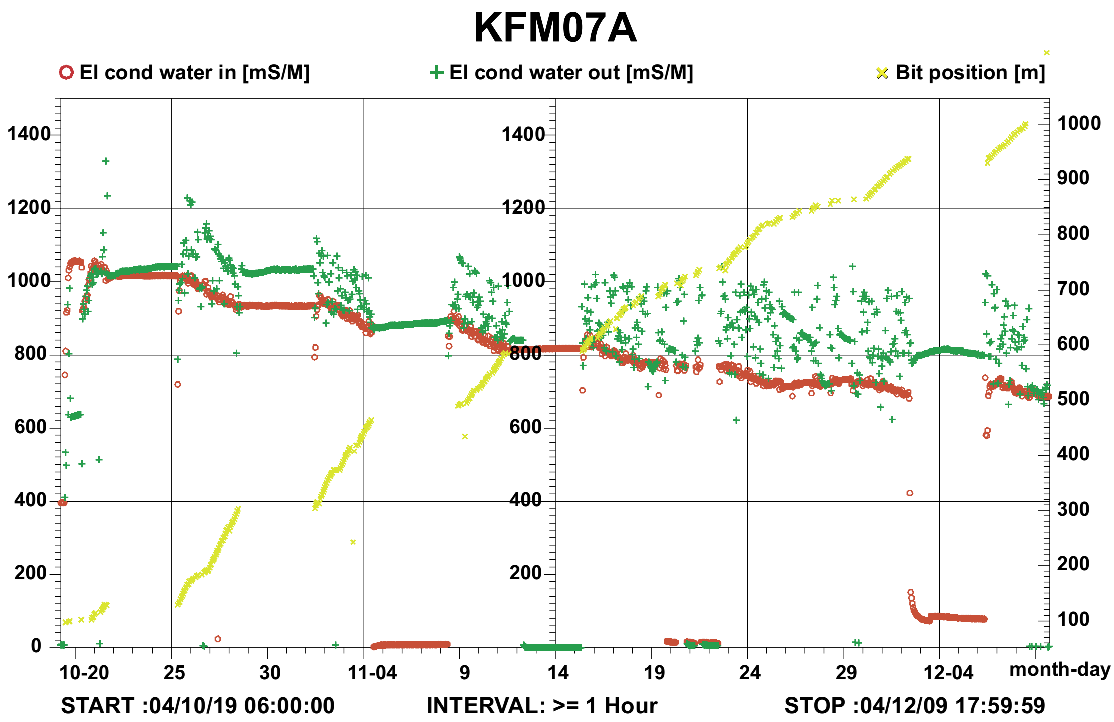


__Figure 5-13.__ Electrical conductivity of flushing water from HFM21 and return water from KFM07A.

Content of dissolved oxygen in flushing water

In Figure 5-14, the level of dissolved oxygen is plotted versus time. The amount of dissolved oxygen has generally been kept lower than 4.5 mg/L. During the first week in December 2004, the transmitter was out of function, but thereafter the amount of dissolved oxygen in the flushing water can be studied and appears to vary between, in average, 3–4.5 mg/L.

Flushing water quality

The results from chemical analyses of flushing water from the supply well HFM21 are compiled in Appendix C and /7/. The flushing water was sampled during drilling, for the following reasons:

- Initially, to check if the quality was satisfactory. The main concern is the content of organic constituents, which should be low, preferably below 5 mg/L. The reason is that introduction of hydrocarbons may affect the microbiological flora in the borehole, which would obstruct a reliable characterization of the in situ microbiological conditions.
- Generally it is useful to check also the microbe content. This was not done in this borehole.
- To monitor the water composition.

The chemical composition of the flushing water is important when estimating the effect, or correcting for the effect, of remaining flushing water in water samples collected from borehole KFM07A.

The results concerning organic constituents and water composition are presented and commented on below.

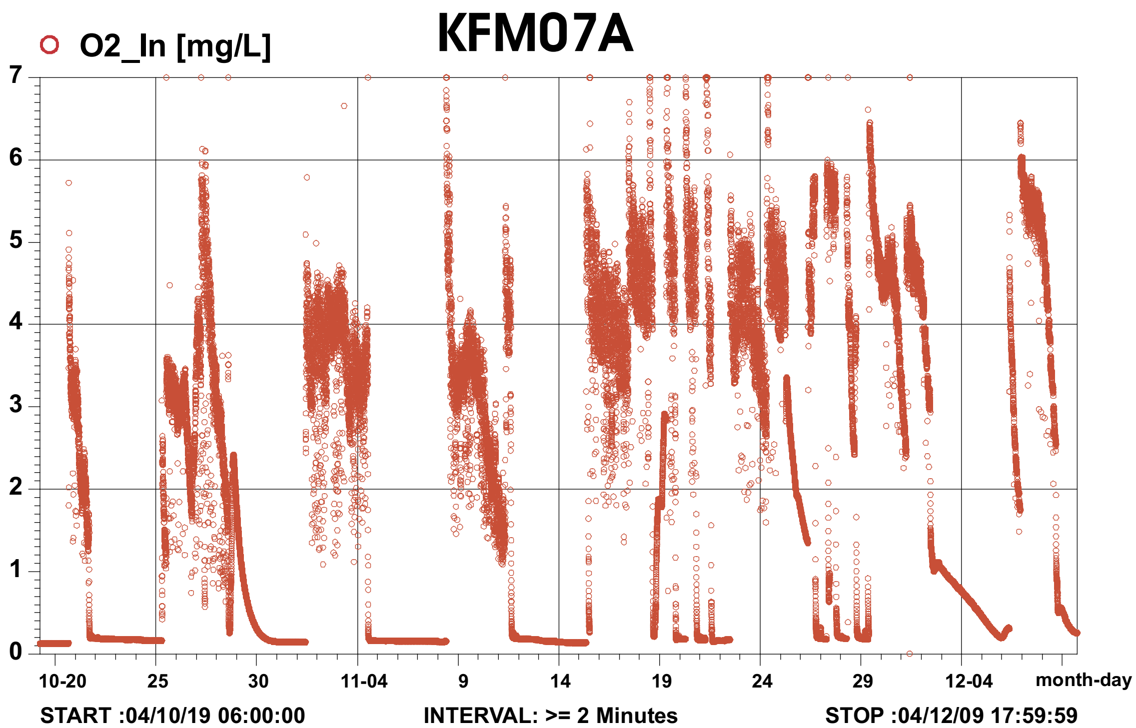


Figure 5-14. *Dissolved oxygen content in the flushing water versus time when drilling KFM07A.*

Organic constituents

The percussion borehole HFM21 has been used before as a flushing water supply well and the concentration of Total Organic Carbon (TOC) was found to be sufficiently low. Three samples were collected prior to drilling, and three additional samples were collected during the drilling period. The TOC concentration was in the range 3.9–5.8 mg/L. The flushing water well was used without further measures (e.g. using an active carbon filter system for reduction of organic substances as was applied when drilling KFM01A /5/).

Chemical composition of flushing water

The flushing water was sampled at three occasions during drilling. As shown in Appendix C, the chemical composition of the groundwater from HFM21 was relatively stable, although a minor decrease in salinity can be observed.

5.4.4 Groundwater sampling and analyses during drilling

One first strike sample was collected by using the ejector pump (see Section 4.2.4) from the return water during drilling of KFM07A (section 100.40–305.84 m). However, the flushing water content in the sample was relatively high, 9%, and therefore only a few basic analyses were performed. The results are included in Appendix C.

5.4.5 Registration of the groundwater level in KFM07A

To enhance the recovery of drill cuttings from the borehole, air-lift (mammoth) pumping was applied during the entire drilling period. The pumping capacity was checked by registration of the groundwater level in the borehole, below plotted versus borehole length (Figure 5-15).

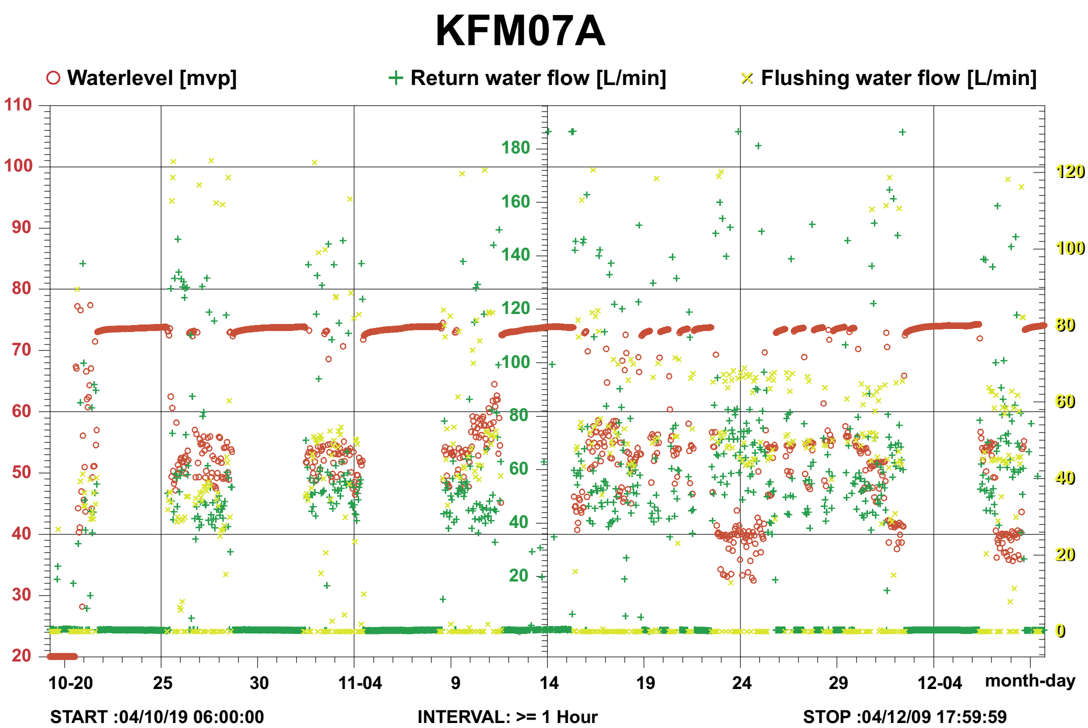


Figure 5-15. Level of the groundwater table and flushing- and return water flow rate in KFM07A during drilling.

From the beginning, the mammoth pumping was set at the maximum draw-down, but after the major inflow in the upper part, the draw-down was adjusted to approximately 25–35 m. At greater depths of drilling, the draw-down was again increased, to approximately 40–45 m. Flushing water flow rate during drilling is usually selected at a level of about 35–40 L/min, but immediately before and after drilling the borehole is flushed with higher flow rates. Drilling was performed continuously during Monday–Thursday. During the weekend stop of drilling and pumping, the groundwater table recovered rapidly due to recharge of groundwater into the borehole, resulting in the (positive) peaks in the diagram. This confirms that the total inflow of formation water in the upper part of the borehole (but below the upper cased and grouted parts) was high with only minor contributions from deeper levels. When pumping was restarted, a simultaneous draw-down occurred.

5.4.6 Core sampling

The average drill core length per run obtained from the drilling was 2.78 m. Due to the low fracture frequency between 200–800 m, in total 75 pieces of 3 m long unbroken cores were recovered. Fracture minerals were relatively well preserved. Rotation marks on the drill core occurred, but with a low frequency. A preliminary on-site core logging was performed continuously.

5.4.7 Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0–100 m) is c 5 m^3. Weighing of drill cuttings and comparison with the weight of the theoretical volume was not carried out due to the high groundwater flow from the percussion drilled part. This caused a relatively large and uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations. However, percussion drilling is associated with a constant flushing by compressed air, resulting in a groundwater table draw-down, entailing constant groundwater inflow to the borehole, which on the hole counteracts forcing of groundwater and drill cuttings into the formation. Another indication that the percussion drilled part was well cleaned from debris was that casing driving and gap grouting to full borehole length worked well, without obstruction from settled drill cuttings.

The theoretical difference in volume of the core drilled part of KFM07A and the drill core is calculated to be 2.406 m^3. This volume should correspond to the amount of drill cuttings produced during drilling. If a density of 2,650 kg/m^3 (approximate figure for granitoids in the Forsmark area) is applied, the total weight of the theoretical amount of debris is estimated at 6,376 kg. The calculated dry weight of the debris from the core drilling recovered and weighed in the containers is 3,472 kg. Hence, the difference between the theoretically produced and recovered dry weight of debris is 2,904 kg, which gives a recovery of 54%.

The recovery figure could be commented on. The dwell time in the system is too short for sedimentation of the suspended finest fractions. No estimation was made of the amount of suspended material, but the true recovery is probably somewhat higher than 54%. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

However, it seems plausible that significant amounts of drilling debris have been injected into the fracture system of the formation, especially in the permeable sections with increased fracture frequency between 100 m and c 200 m (section 0–100 m is cased and gap grouted).

5.4.8 Deviation measurements

The deviation measurements made in borehole KFM07A with the Reflex Maxibor system (Figure 5-16) show that the borehole deviates 41 m upwards and 164 m to the right compared to an imagined straight line following the dip and strike of the borehole starting point. An additional deviation measurement, using the magnetic system FLEXIT Multishot, confirm the result achieved. The radial difference between the methods is 4.2 m at 500 m borehole length and 8.7 m at 1,000 m borehole length.

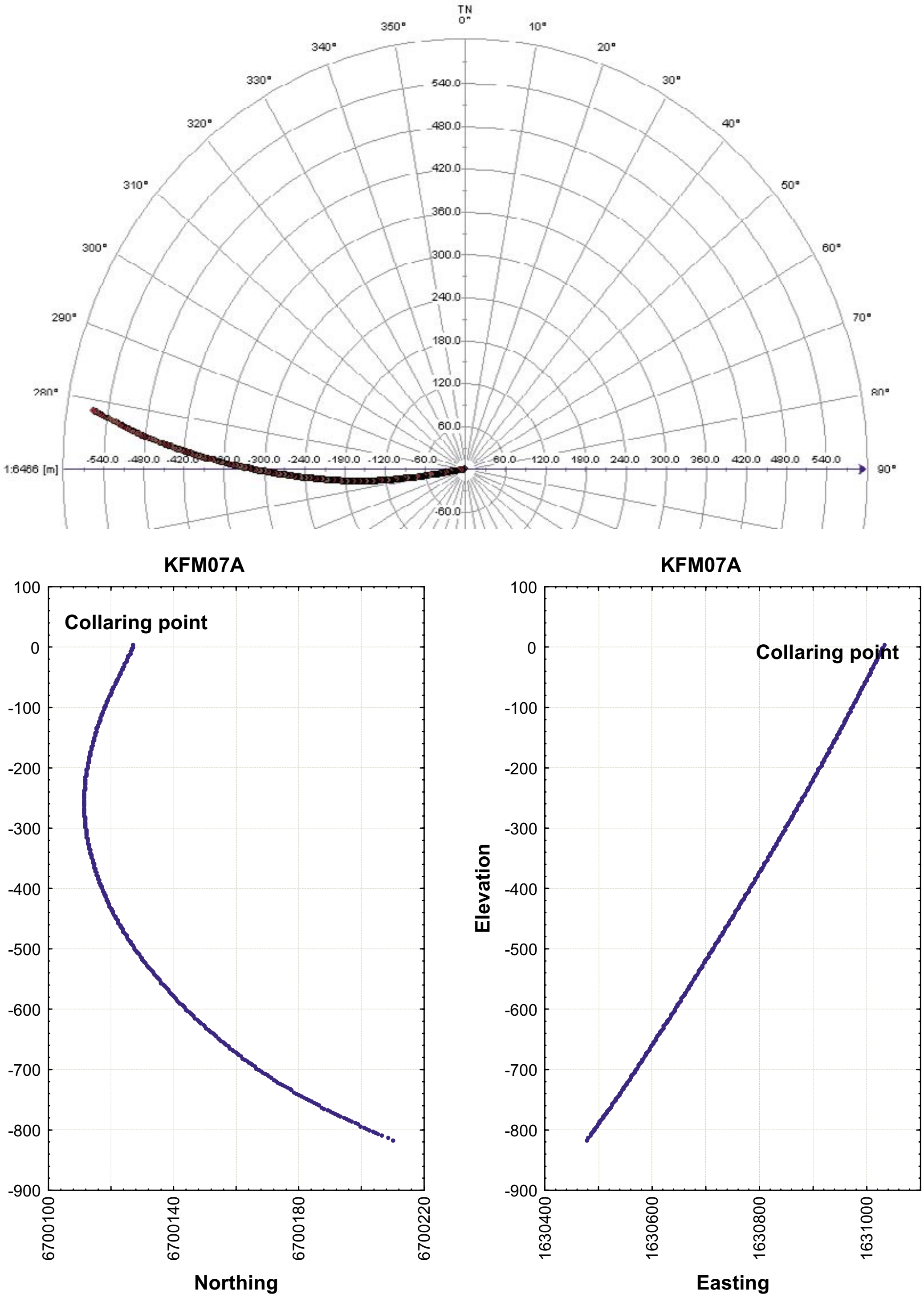


Figure 5-16. Horizontal and vertical projections of measured deviation in KFM07A.

5.4.9 Measurements of the length difference between the compressed drill pipe string and as extended by its own weight

All length values used for measurements in the borehole and of the drill core emerge from registrations of the length of the drill pipe string. However, such registrations involve a small error depending on the gravitational stretching of the pipe string when hanging freely and thus exposed to its own weight. When the pipe string is lowered to the borehole bottom, and the lifting force from the drill rig is set to zero, the pipe string will be resting on the borehole bottom and thus relieved from the previous load, and the stretching will cease. Instead, the load from the pipe string will now cause compression and, to some extent, bending of it.

By measuring the length difference between these two conditions, it was hoped that the length error could be determined for different lengths of the pipe string and for different inclinations of the borehole. The practical difficulties and uncertainties in the results however turned out to be considerable. Therefore it is recommended that the length error is determined from the diagram in Figure 5-17, which is based on load tests performed in the laboratory by the manufacturer of the drill pipes.

As seen in the diagram, the maximum elongation at 1,000 m length in a vertically drilled borehole is 180 mm. In inclined boreholes the elongation of the pipe string should theoretically be less.

5.4.10 Hydraulic tests during drilling (wireline tests)

No successful pumping test was performed during drilling of KFM07A due to equipment failure.

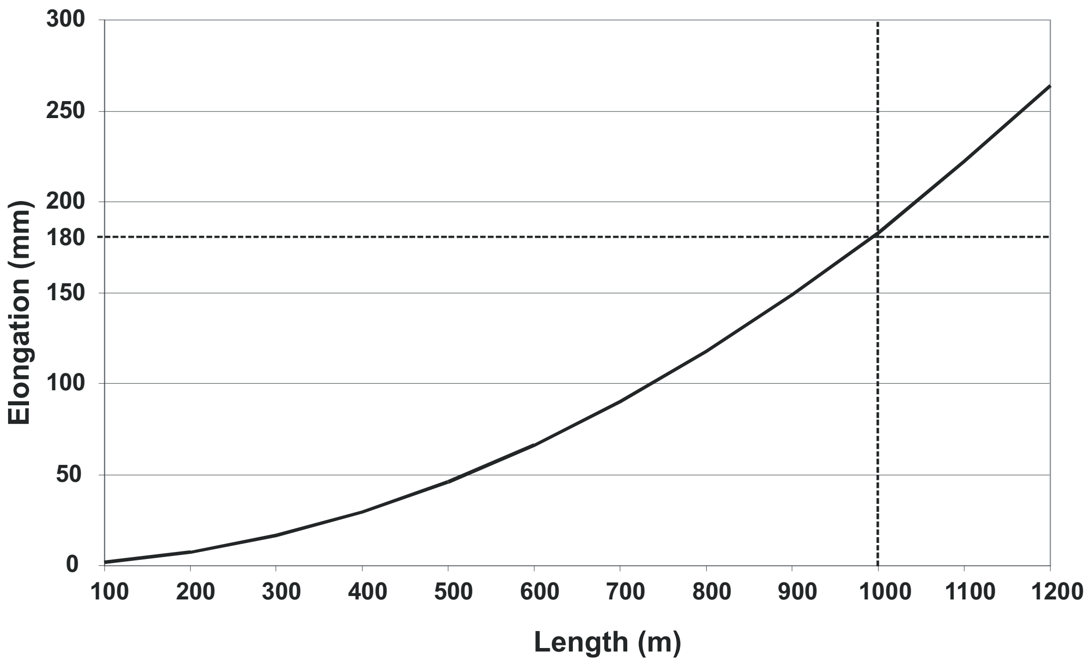


Figure 5-17. *The diagram illustrates the elongation of the WL-76 drill pipe string when hanging in a vertical water filled borehole. Values from a laboratory load tests of the drill pipe string.*

5.4.11 Groove milling

After completion of drilling, KFM07A will be used for borehole measurements, employing many types of borehole instruments with different stretching characteristics (pipe strings, wires, cables etc). In order to furnish a system for length calibration in the borehole, reference grooves were milled into the borehole wall at certain levels with a specially designed tool. This was carried out after termination of drilling, but with use of the drilling machine and drill pipe string.

At each level, two 20 mm wide grooves were milled with a distance of 10 cm between them, see Figure 5-18. Table 5-4 presents the reference levels selected for milling. The table also reveals that milling failed at certain levels. After milling, the reference grooves were detected with the SKB level indicator (a caliper). A BIPS-survey gave the final conformation of where groove milling had been successful and where it had failed.

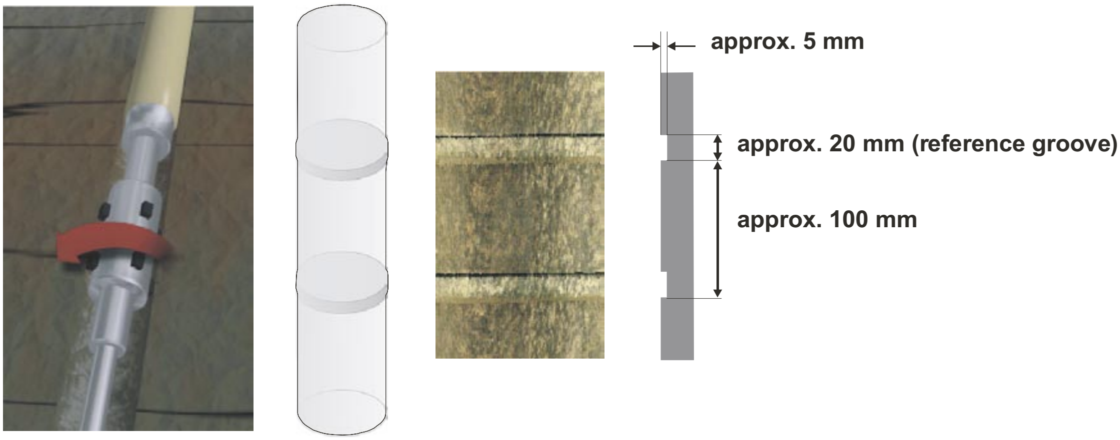


Figure 5-18. *Layout and design of reference grooves. The milling tool shown to the left.*

Table 5-4. Compilation of length to the reference grooves. The positions of the grooves are determined from the length of the drill pipes used at the milling process. The length is measured between top of casing to 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
150	Yes	Yes	600	Yes	Yes
203	Yes	Yes	650	No	Yes[1]
250	Yes	Yes	700	No	Yes[1]
300	Yes	Yes	750	No	Yes[1]
350	Yes	Yes	800	No	Yes[1]
400	Yes	Yes	849	No	Yes[1]
450	Yes	Yes	900	No	Yes[1]
500	Yes	Yes	950	No	Yes[1]
550	Yes	Yes	980	No	No

[1] Weak.

5.4.12 Consumables

The amount of oil products consumed during drilling of the percussion drilled part of KFM07A (0–100 m), thread grease used during core drilling, and grout used for gap injections of the respective casings are reported in Tables 5-5 and 5-6. Regarding hammer oil and compressor oil, these products are indeed entering the borehole but are, on the other hand, continuously retrieved from the borehole due to the permanent air flushing during drilling. After completion of drilling, only minor remainders of the products are left in the borehole.

The special type of thread grease (silicon based) used during core drilling in this particular borehole was certified according to SKB MD 600.006 (Table 1-1). The experience from a technical point of view of the grease, is not fully satisfactory. Although expensive, the grease has a low adhesion capacity to the threads, and the lubrication characteristics are not as favourable as for conventional lubricants.

In order to estimate the amount of magnetic iron in circulation in the borehole during drilling of the telescopic boreholes, a magnetic steel plate has been installed in the first sedimentation container. Due to friction between the drill string and the support casing during drilling, iron filings are worn loose. However, due to the continuous air-lift pumping during drilling, probably most of the material is retrieved from the borehole. The outlet of the return water pipe string at the first container is placed immediately above the inclined magnetic plate, where most of the magnetic material is caught. The plate is regularly scraped, whereupon the iron filings are dried and weighed. The amount of retrieved magnetic iron filings from KFM07A is presented in Table 5-7 and compared with the amount from the previously drilled telescopic boreholes KFM05A and KFM06A.

Table 5-5. Oil and grease consumption.

Borehole ID	Hammer oil (percussion drilling) Preem Hydra 46	Compressor oil (percussion drilling) Schuman 46	Thread grease (core drilling) Unisilikon L50/2
KFM07A	Approx 15L (not exactly documented)	Not detected	8.8 kg

Table 5-6. Cement consumption when sealing the gap between the casing and the reamed borehole wall.

Borehole ID	Length (m)	Cement volume (Portland Standard Cement)	Grouting method	Remarks
KFM07A	100.10	2,520 kg/2,800 L	Gap injection	

Table 5-7. Total magnetic iron retrieved from drilling of KFM05A, KFM06A and KFM07A.

Borehole	Weight magnetic material (kg)	Comment
KFM05A	45.3	
KFM06A	36	
KFM07A	36.2	

5.4.13 Recovery monitoring after cleaning by airlift pumping

The recovery registration after the final cleaning of the borehole by airlift pumping, which caused a draw-down of 25 m, is displayed in the diagram of Figure 5-19. The recovery of the groundwater table was registered during a day and confirmed the high yielding capacity of the borehole. From the diagram an inflow of > 60 L/min can be estimated. The major part originates from above 200 m.

Prior to drilling start of KFM07A, the percussion borehole HFM21 was drilled c 35 m north-east of drill site DS7. The pumping activities in KFM07A revealed hydraulic connection between HFM21 at shallow levels.

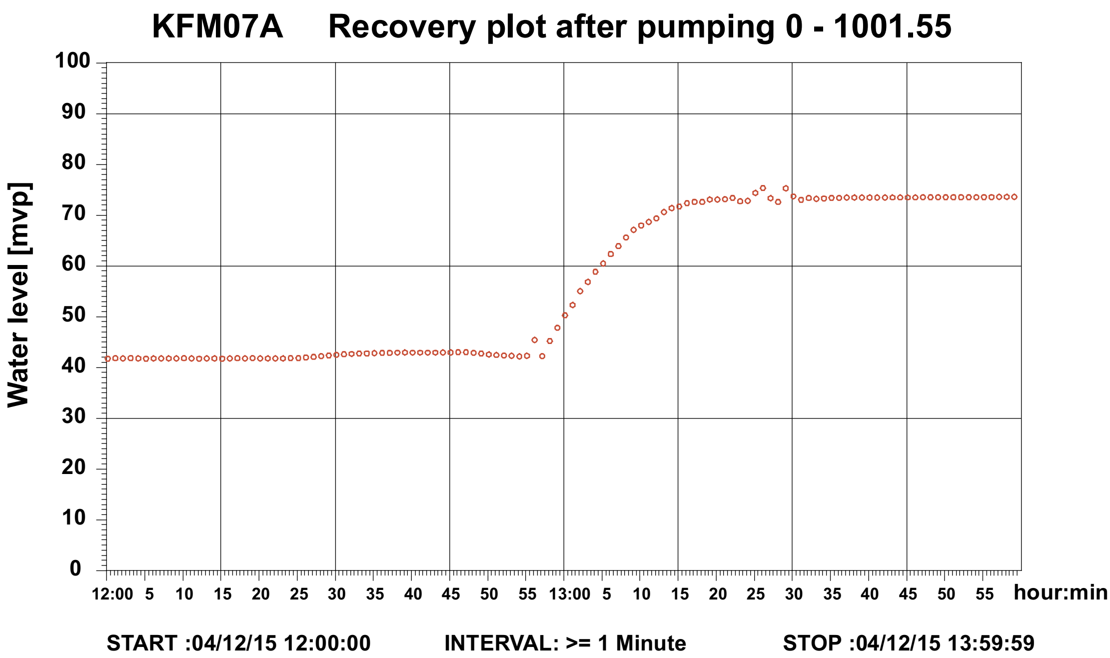


Figure 5-19. *Recovery of groundwater table in section 0–1001.55 m of KFM07A.*

6 References

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

/2/ **SKB, 2002.** Execution programme for the initial site investigations at Forsmark. SKB P-02-03, Svensk Kärnbränslehantering AB.

/3/ **SKB, 2005.** Petersson J, Skogsmo G, Wängnerud A, Berglund J, Stråhle A. Forsmark site investigation. Boremap mapping of telescopic drilled borehole KFM07A. SKB P-05-102, Svensk Kärnbränslehantering AB.

/4/ **SKB, 2005.** Preliminary site description. Forsmark area – version 1.2. SKB R-05-18, Svensk Kärnbränslehantering AB

/5/ **SKB, 2003.** Claesson L-Å, Nilsson G. Forsmark site investigation. Drilling of the telescopic borehole KFM01A at drilling site DS1. SKB P-03-32, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2005.** Claesson L-Å, Nilsson G. Forsmark site investigation. Drilling of two flushing water wells, HFM21 and HFM22, one groundwater monitoring well in solid bedrock, HFM20, and one groundwater monitoring well in soil, SFM0076. SKB P-04-245, Svensk Kärnbränslehantering AB.

/7/ **SKB, 2005.** Nilsson Daniel. Forsmark site investigation. Sampling and analyses of groundwater from percussion drilled boreholes. Results from the percussion drilled boreholes HFM20, HFM21 and HFM22. SKB P-05-48. Svensk Kärnbränslehantering AB.

Appendix A

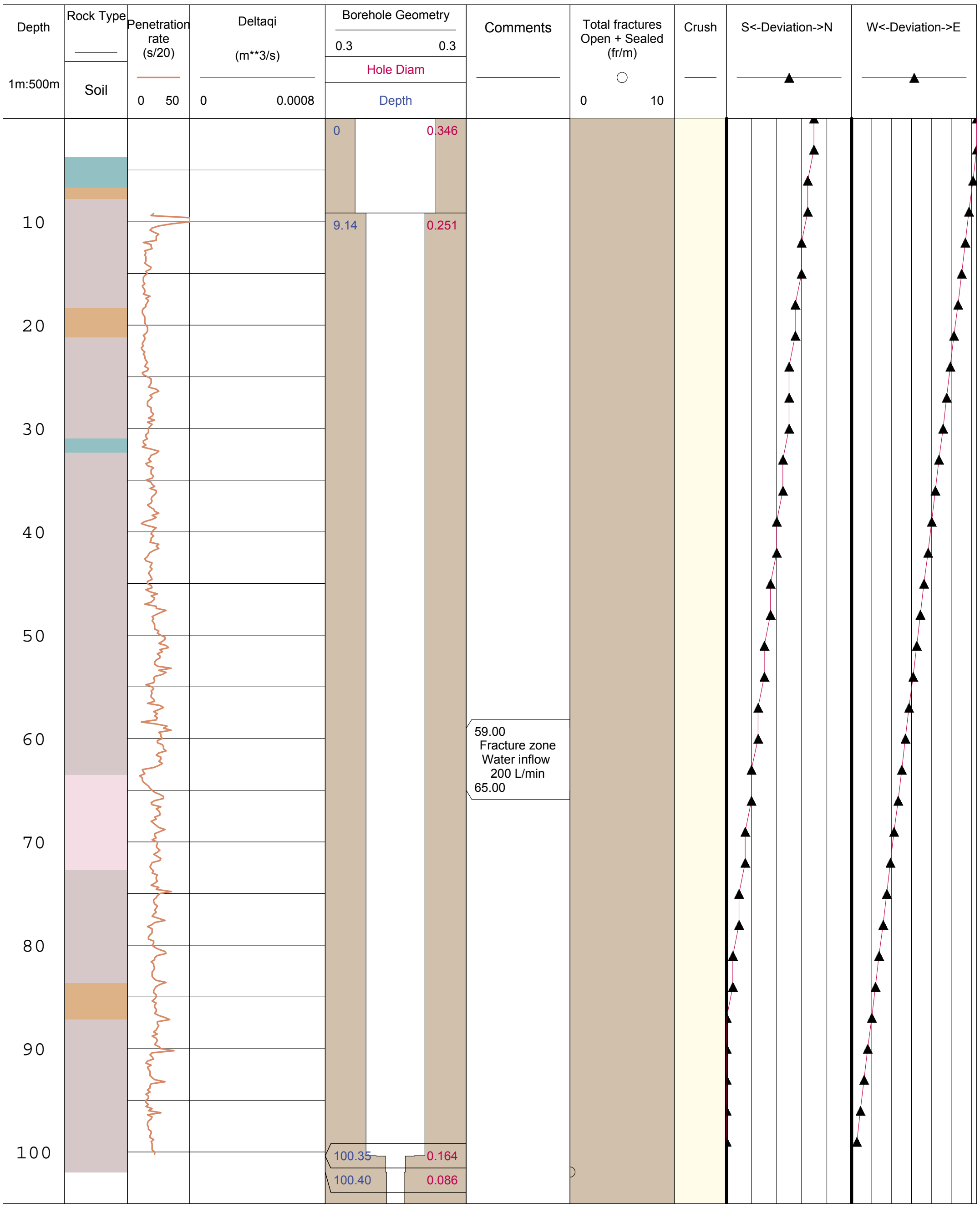
Title **PERCUSSION DRILLED BOREHOLE KFM07A**

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM07A	**Northing [m]**	6700127.08
Diameter [mm]	77	**Easting [m]**	1631031.57
Length [m]	1001.55	**Elevation [m.a.s.l.]**	3.33
Bearing [°]	261.47	**Drilling Start Date**	2004-06-07 08:00:00
Inclination [°]	-59.22	**Drilling Stop Date**	2004-06-16 11:40:00
Date of mapping		**Plot Date**	2005-09-14 00:02:30

ROCKTYPE FROM ON-SITE DESCRIPTION FORSMARK (Section 0 - 101.95 m) SOIL

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



Appendix B

Title KFM07A

Svensk Kärnbränslehantering AB

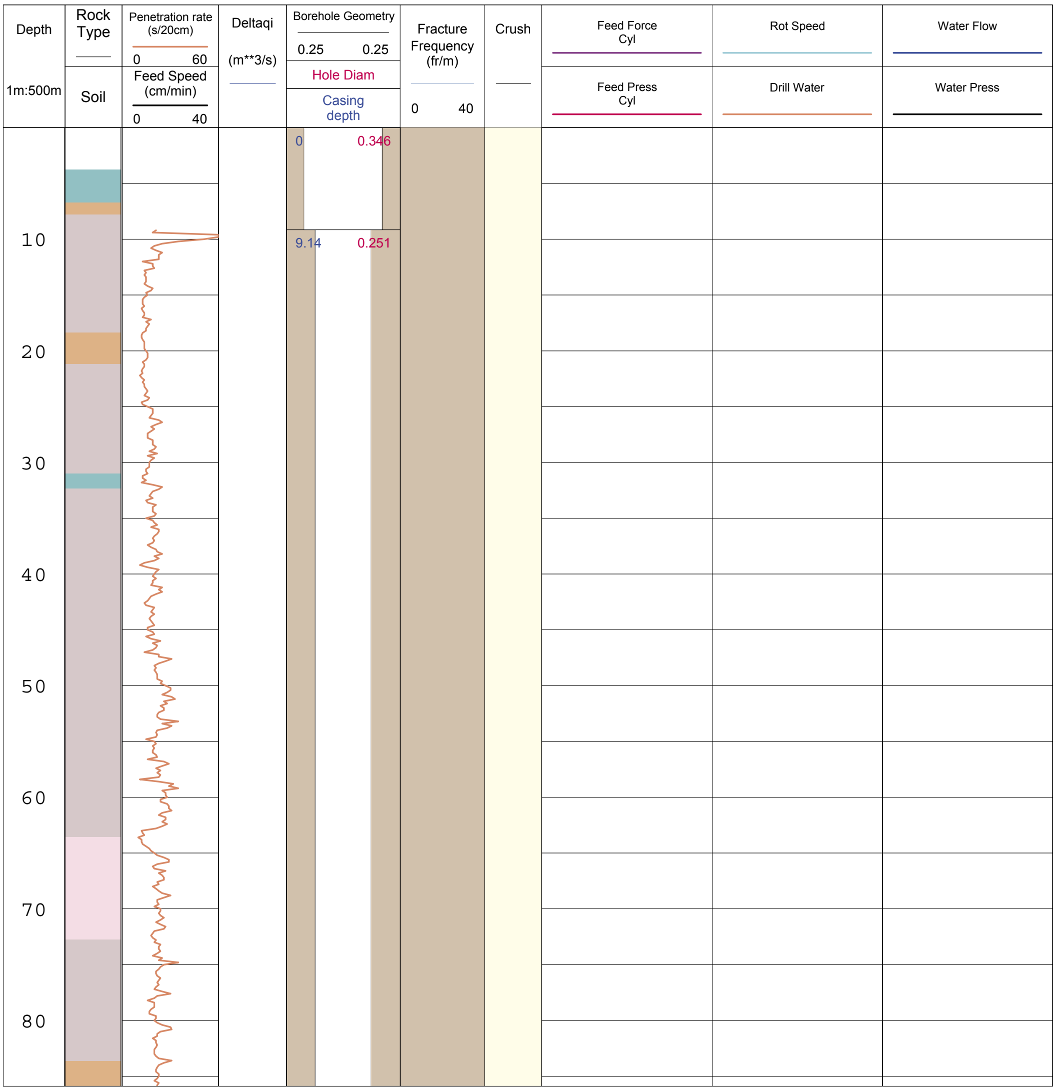
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM07A	**Northing [m]**	6700127.08
Diameter [mm]	77	**Easting [m]**	1631031.57
Length [m]	1001.55	**Elevation [m.a.s.l.]**	3.32
Bearing [°]	261.47	**Drilling Start Date**	2004-06-07 08:00:00
Inclination [°]	-59.22	**Drilling Stop Date**	2004-12-09 11:40:00
Date of mapping		**Plot Date**	2005-09-14 00:02:30

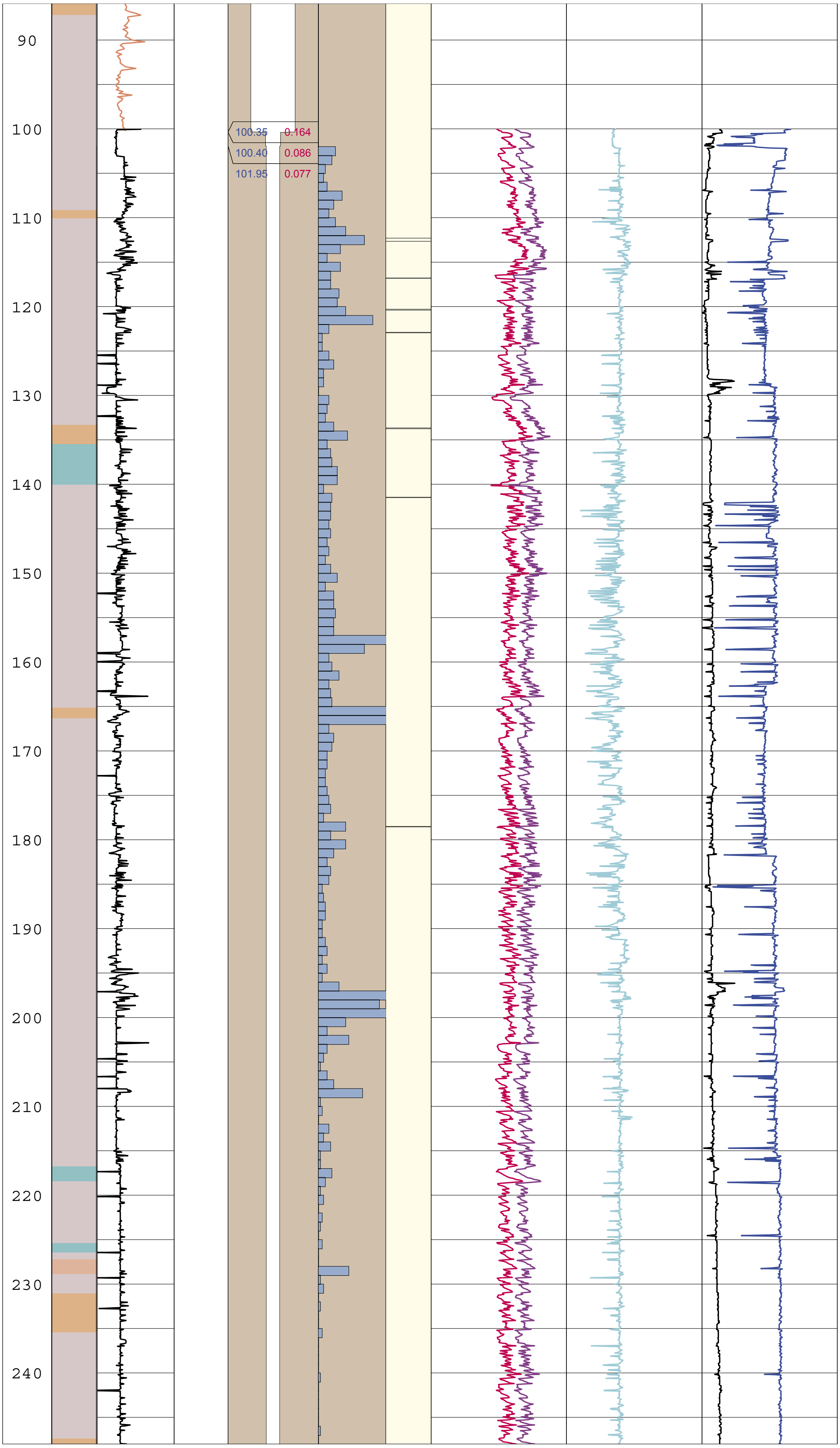
ROCKTYPE FORSMARK (Section 101.95 - 1001.55 m) SOIL

- **Granite, fine- to medium-grained**
- **Pegmatite, pegmatitic granite**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Amphibolite**
- **Felsic to intermediate volcanic rock, metamorphic**

ROCKTYPE FROM ON-SITE DESCRIPTION FORSMARK (Section 0 - 101.95 m)

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

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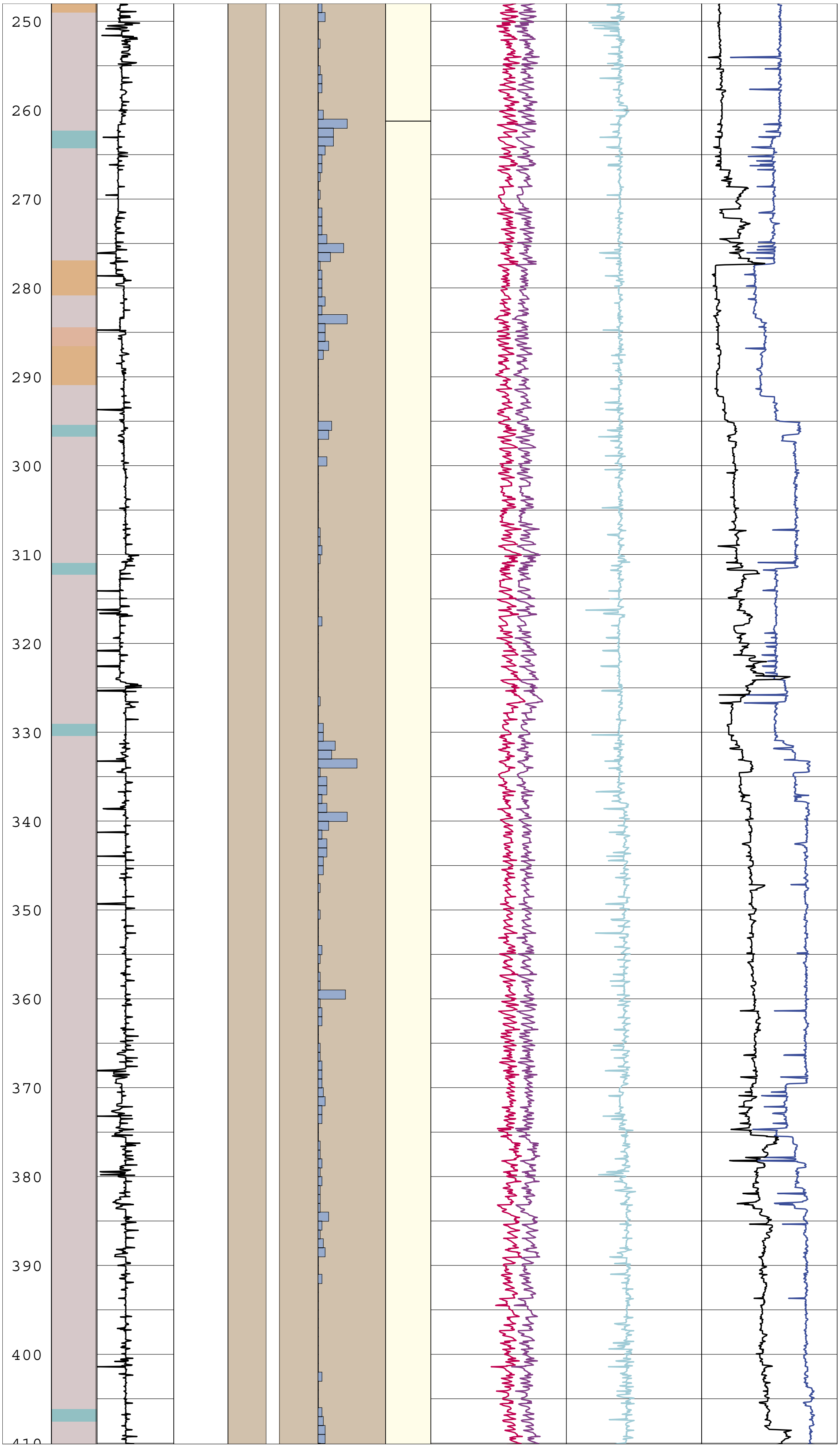
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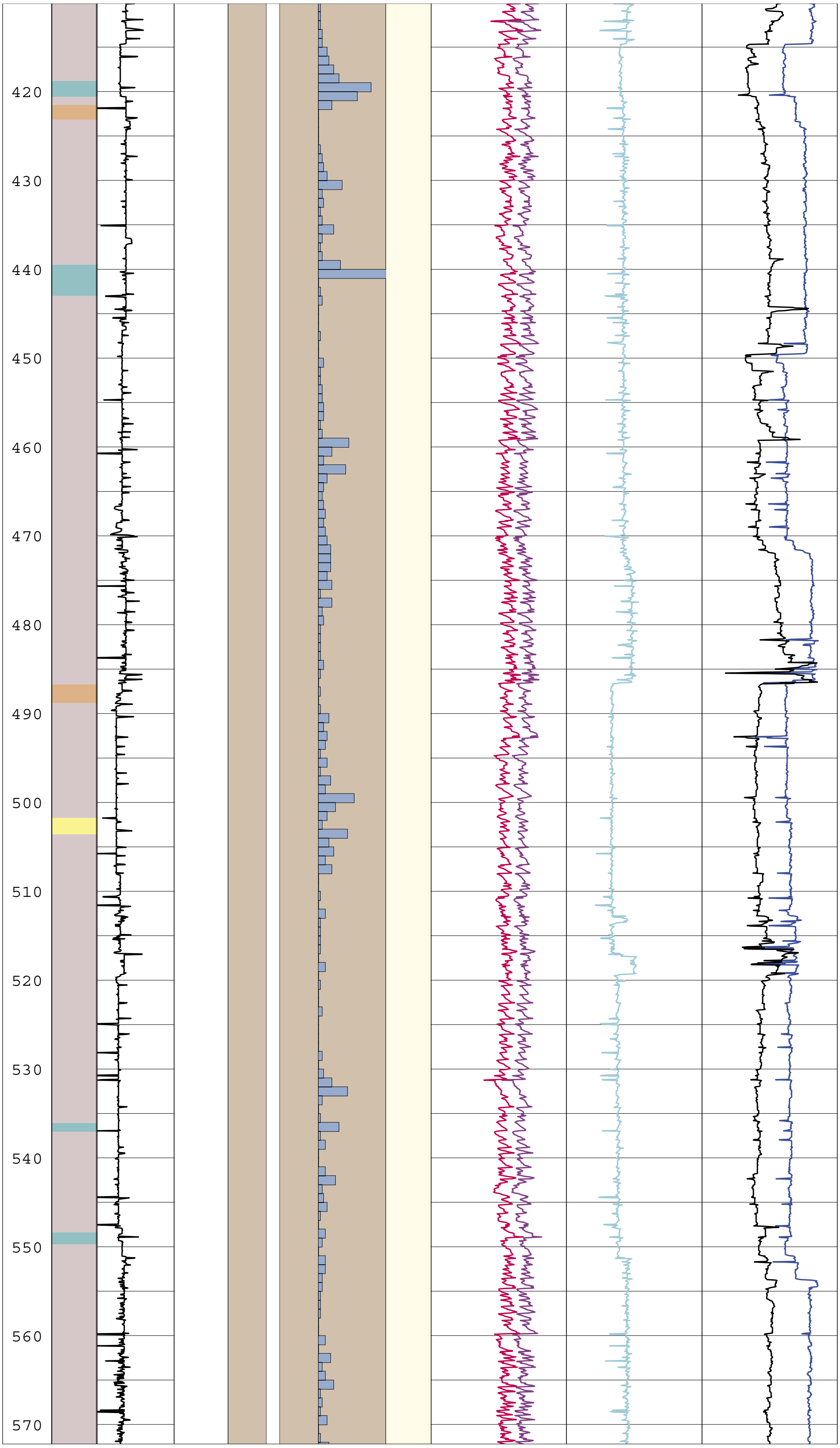
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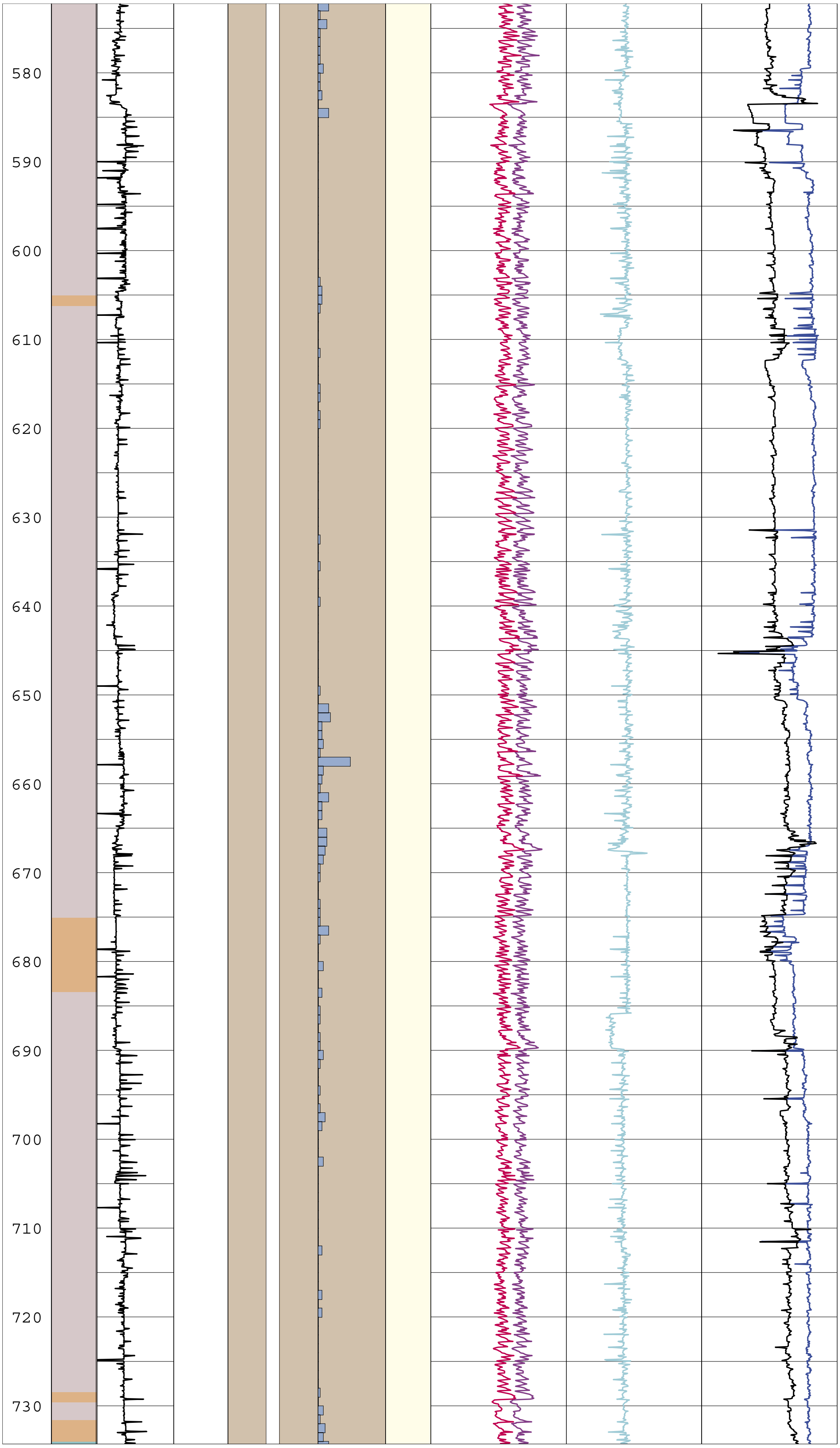
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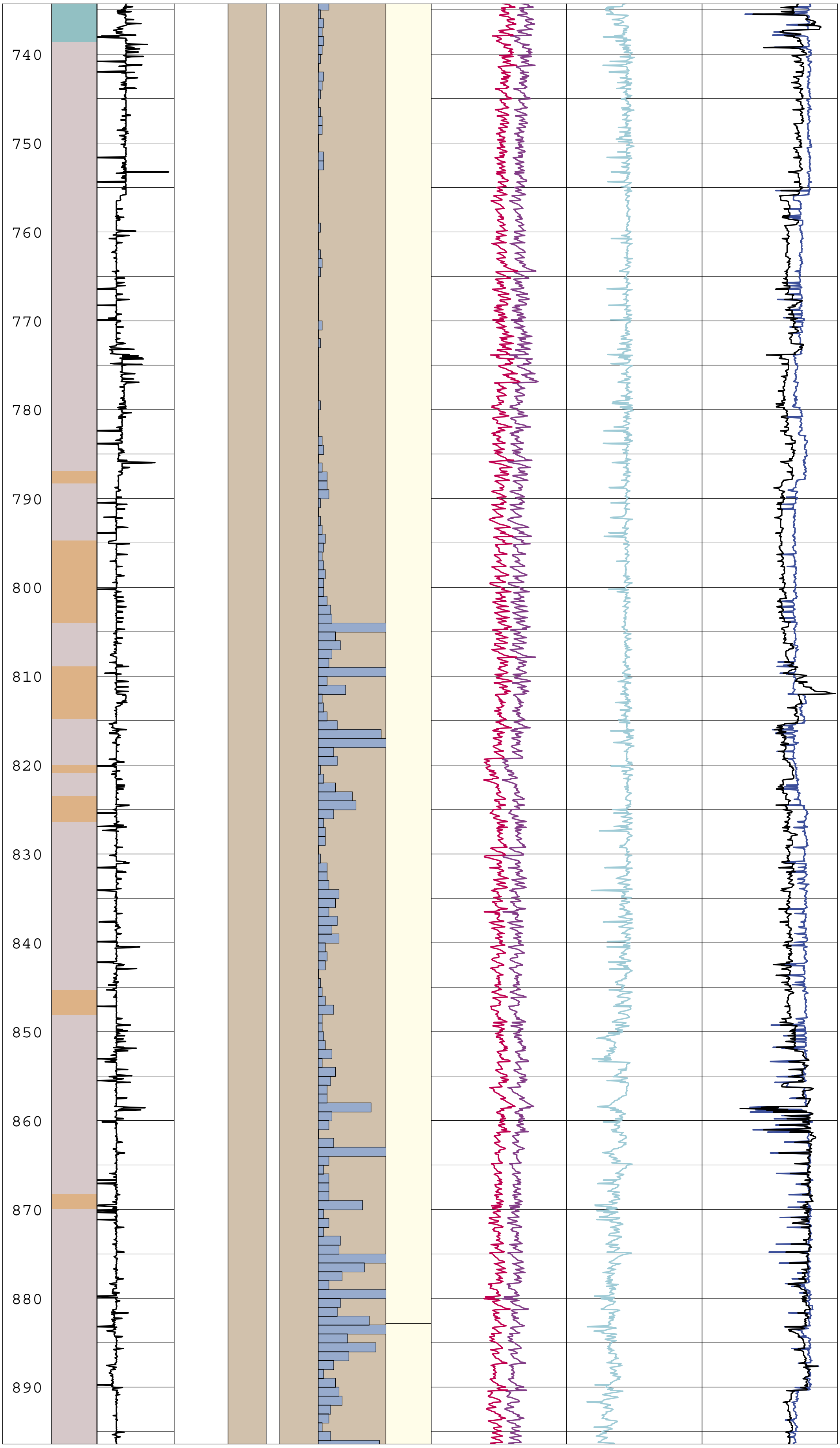
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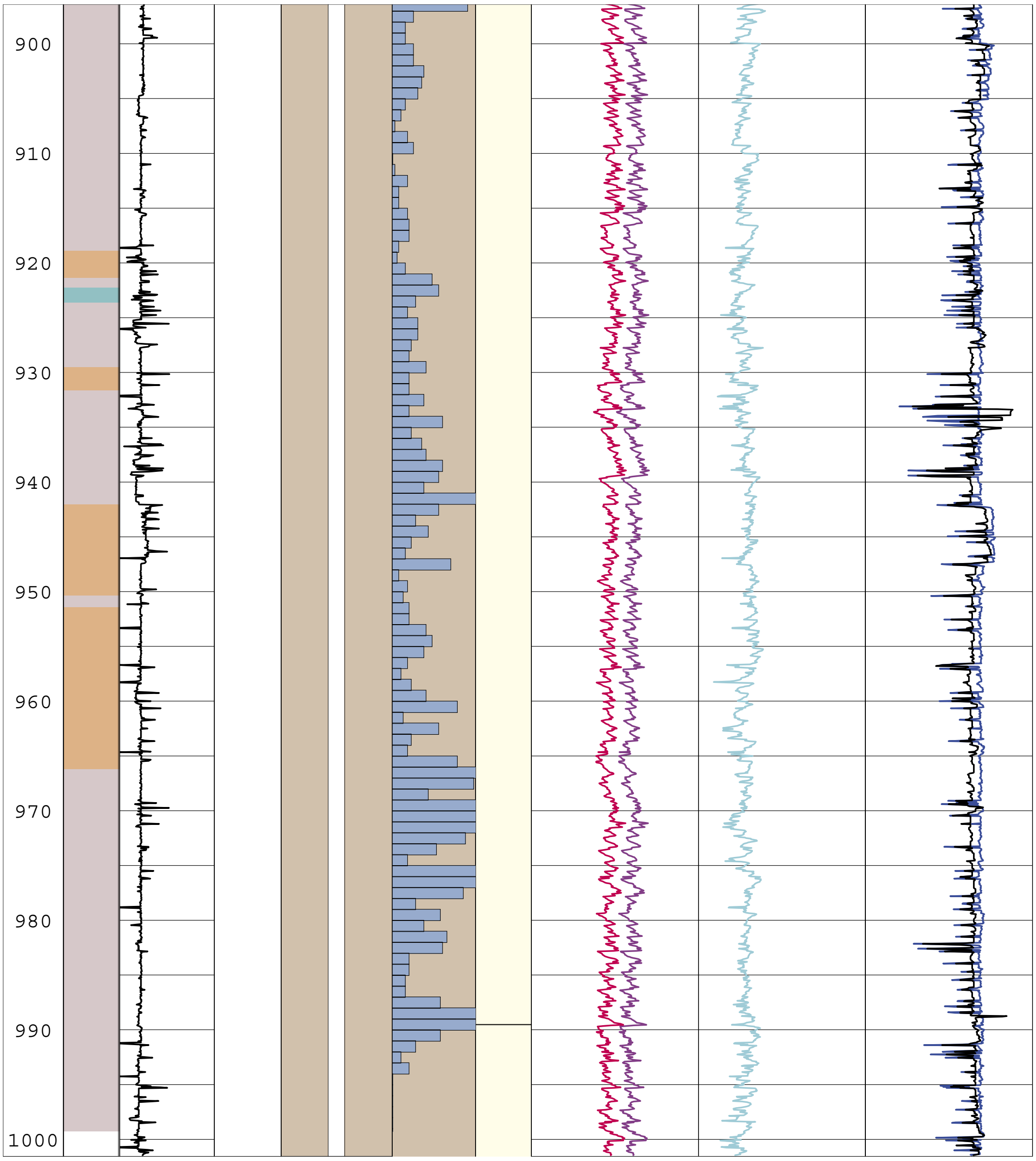
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Appendix C

Date	ID code	Sample no	Na mg/L	K	Ca	Mg	HCO_3	Cl	SO4	SO_4_S	Br	F	Si	Li	Sr	TOC	Uranine %	pH	Cond mS/m
2004-11-03	HFM21	8717	1,310	31.3	532	130	244	2,990	361	119	10.8	1.30	6.39	0.037	3.42	5.0		7.53	951
2004-11-17	HFM21	8728	1,130	28.9	415	104	277	2,480	305	105	8.86	1.30	6.40	0.033	2.61	5.8		7.54	812
2004-12-13	HFM21	8745	934	25.7	294	76.5	328	1,850	247	87.4	7.00	1.20	6.28	0.026	1.88	6.9		7.61	645
2004-10-28	KFM07A	8712	1,410	30.3	624	140	196	3,350	399	132	12.8	1.25	6.23	0.991	39.3	*	9.0	7.66	1,050

*Not analysed.

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 BPyear	$^{10}B/^{11}B$ no unit	34S(dev) dev CDT	$^{87}SR/^{86}Sr$ no unit	^{37}Cl dev SMOC
2004-11-03	HFM21	8717	–69.5	3.2	–9.3	38.58	–7.90	7,597	0.2357	*	0.722263	–0.10
2004-11-17	HFM21	8728	–70.0	3.2	–9.5	38.84	–7.92	7,544	0.2354	22.4	0.722574	–0.21
2004-12-13	HFM21	8745	–75.5	5.2	–9.5	**	**	**	0.2369	20.5	0.722864	0.08
2004-10-28	KFM07A	8712	–68.5	1.8	–9.3	22.14	–6.13	12,057	0.2361	23.3	0.721353	–0.17

*Not analysed.
**Will be reported later.