P-05-50

Forsmark site investigation

Drilling of the telescopic borehole KFM06A and the core drilled borehole KFM06B at drill site DS6

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

April 2005

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-05-50

Forsmark site investigation

Drilling of the telescopic borehole KFM06A and the core drilled borehole KFM06B at drill site DS6

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

April 2005

Keywords: AP PF 400-03-80, AP PF 400-04-52, AP PF 400-04-108, Percussion drilling, Core drilling, Telescopic borehole, Drill site DS6, Stabilization with PLEX system.

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 sixth borehole, KFM06A, drilled at Forsmark by applying telescopic technique are presented in this report. KFM06A is 1,000.64 m long, at its starting point inclined 60.25° from the horizon, and reaches about 500 m in horizontal distance. The borehole is of so called SKB chemical type, intended for detailed hydrogeochemical and microbiological investigations.

During pilot drilling of section 0–100 m with the diameter 164 mm, an unstable, fractured section, interpreted as a gently dipping fracture zone, was encountered at about 51 m. This zone has a relatively low water-yielding capacity of about 10 L/min. After completed pilot drilling, the borehole was filled with cement in order to stabilize the borehole wall. Pilot drilling was repeated after setting of the cement, followed by reaming to Ø c 250 mm. Finally, the percussion drilled part was cased with a stainless steel casing, and the gap between the borehole wall and the casing was grouted. These measures entailed 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. The conclusion after drilling of KFM06A was that only relatively small amounts of flushing water and drill cuttings penetrated the fracture system.

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 the samples of drill cuttings from the percussion drilled section, together with later produced video images of the borehole wall (so called BIPS-images), were used for mapping of the borehole (so called Boremap mapping) performed after drilling. A diagram of the Boremap mapping results is included 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. However, the reference grooves below 600 m length are weak, probably due to high leakage in the drill string threads. These grooves are therefore difficult to detect.

One experience from drilling of KFM06A is that the quartz-rich bedrock in Forsmark is hard to drill, entailing rapid wearing of drill bits. Other lasting impressions from the drilling are the water-yielding gently dipping fracture zones 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 KFM06A.

In order to compensate for the missing drill core in the percussion drilled part of KFM06A from the upper rock formation, a short borehole was drilled all the way from the ground surface to 100.33 m drilling length. KFM06B is subvertical (inclined 83.52° from the horizon). By drilling KFM06B, the existence of the flat laying fracture zone at c 51 m in KFM06A was verified.

Sammanfattning

De flesta djupa borrhål inom Forsmarks platsundersökning utförs som s k teleskopborrhål. Det innebär att de övre 100 m hammarborras i två steg, pilotborrning med dimensionen ca 160 mm följd av upprymning till ca 200–250 mm diameter. Avsnittet därunder, dvs sektionen ca 100–1 000 m, kärnborras med 76–77 mm diameter. Resultaten från det sjätte djupborrhålet i Forsmark som har borrats med teleskopborrningsteknik redovisas i denna rapport. Borrhålet, som benämns KFM06A är ansatt med en lutning av 60.25° från horisontalplanet, är 1 000.64 m långt och når cirka 500 m i horisontell riktning. KFM06A är ett så kallat kemiprioriterat borrhål, vilket innebär att det planeras att utnyttjas för detaljerade hydrogeokemiska 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 164 mm påträffades ett instabilt, sprucket avsnitt vid ca 51 m, vilket tolkades som en flackt stupande sprickzon. Zonen hade en relativt blygsam vattenkapacitet och ett inflöde på ca 10 L/min uppmättes. Pilotborrningen fortsatte därefter till fullt djup, ca 100 m. För att stabilisera borrhålet fylldes det sedan med cement. Efter att cementen brunnit, upprepades pilotborrningen, varefter borrhålet upprymdes till Ø ca 250 mm. Därefter kläddes det in med rostfritt foderrör. Slutligen cementinjekterades spalten mellan borrhålsvägg och foderrör, så att allt vatteninflöde i den hammarborrade delen av teleskopborrhålet upphörde.

Under kärnborrningsfasen vid utförandet av teleskopborrhål används ett relativt komplicerat spol- och returvattensystem, där spolvattnet prepareras i olika moment före användning. Returvattnet leds till ett system av containrar, där borrkaxet sedimenterar i tre steg innan returvattnet leds 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 grundvatten-akviféren i anslutning till borrhålet utsätts för. Slutsatsen efter borrningen av KFM06A var att endast relativt små mängder spolvatten och borrkax har trängt ut i spricksystemet.

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 Boremapkarteringen av KFM06A finns redovisad i denna 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. På grund av läckage i borrsträngen blev spåren under 600 m svaga och därigenom svåra att detektera.

En erfarenhet från borrningen av KFM06A är att den kvartsrika berggrunden i Forsmark är svårborrad och att borrkroneslitaget är högt. Andra bestående intryck är dels de flacka, vattenförande zoner som påträffades i den övre delen av KFM06A, dels att, omvänt, sprickfrekvensen och vattenföringen i större delen av det kärnborrade partiet av borrhålet visade sig vara mycket låga.

För att kompensera för den uteblivna borrkärnan från den ytliga berggrunden borrades ett kort kärnborrhål, KFM06B, 5 m söder om KFM06A. Borrhålet är subvertikalt, lutar 83.52° från horisontalplanet och har en längd av 100.33 m. Vid borrningen av KFM06B kunde förekomsten av den flacka sprickzonen som påträffades vid 51 m i KFM06A verifieras.

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 site investigation area in Östhammar is situated close to the Forsmark nuclear power facilities /2/, see Figure 1-1.

Drilling is one important activity within the scope of the site investigations. Three main types of boreholes are produced, 1) core drilled respectively 2) percussion drilled boreholes in solid rock and 3) boreholes drilled through regolith. 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 three inclined, approximately 1,000 m long, cored boreholes have been drilled within the investigation area. One deep borehole is also underway. The locations of the seven drill sites in question, DS1, DS2, DS3, DS4, DS5, DS6 and DS7, are illustrated in Figure 1-1. Also three shorter (c 100–500 m) core boreholes have been drilled, at drill sites DS1, DS3 and DS6.

This document reports the data and results gained by drilling of the telescopic borehole KFM06A and the core drilled borehole KFM06B at drill site DS6, which is one of the activities included in the site investigations at Forsmark. The work was carried out in compliance with activity plans AP PF 400-03-80 and AP PF 400-04-52. Because an instable section in borehole KFM06B was encountered, the borehole wall had to be stabilized with a newly developed stabilization system, the so called PLEX system. This work was performed in accordance with activity plan AP PF 400-04-108.

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

By drilling the deep boreholes, so called telescopic drilling technique is applied, meaning 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 applied also when drilling KFM06A, which has a total drilling length of 1,000.64 m. The borehole is inclined c 60 degrees from the horizontal plane, entailing that the horizontal extension of the borehole is approximately 500 m. Borehole KFM06A is of the so called SKB chemical-type. This implies that the borehole is prioritized for hydrogeochemical and microbiological investigations, prompting that all DTH (Down The Hole) equipment used during and/or after drilling must undergo special cleaning procedures, see Chapter 4.

In order to compensate for the missing core in borehole section 0–100 m, a shorter, near-vertical core drilled borehole, KFM06B, was drilled from the surface to 100.33 m borehole length.

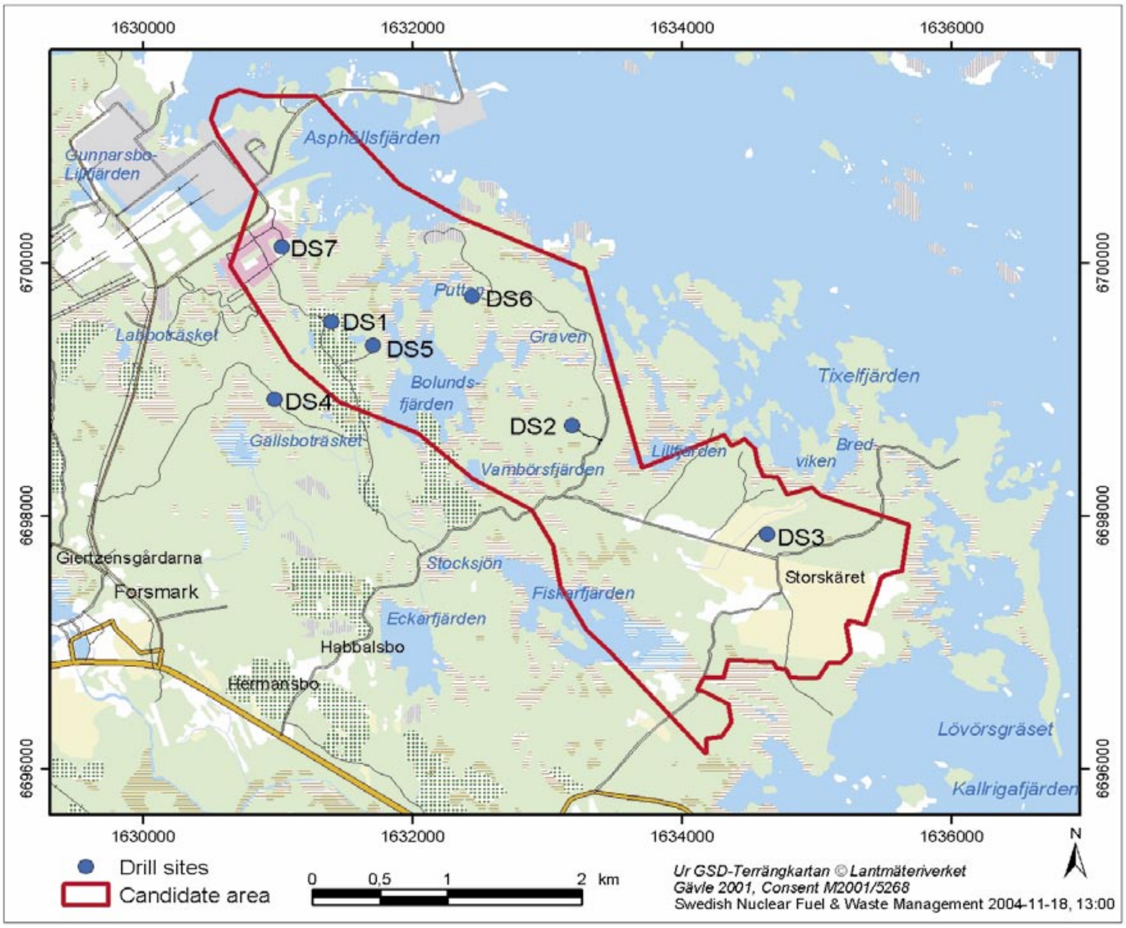


Figure 1-1. *The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drill sites DS1–7 are marked with blue dots.*

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

Activity plan	**Number**	**Version**
Borrning av teleskopborrhål KFM06A.	AP PF 400-03-80	1.0
Kärnborrning av KFM06B.	AP PF 400-04-52	1.0
Stabilisering av sprickzon I borrhål KFM06B.	AP PF 400-04-108	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för hammarborrning.	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
Method instructions	**Number**	**Version**
Rengöring av borrhålsutrustning och viss markbaserad utrustning.	SKB MD 600.004	1.0
Användning av kemiska produkter och material vid borrning och undersökning.	SKB MD 600.006	1.0
Analys av injektions- och enhålspumptester.	SKB MD 320.004	1.0

Close to the deep borehole at drill site DS6, 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 132 m. The locations of all boreholes at drill site DS6 are shown in Figure 1-2.

Drill site DS6 is located in the northern part of the candidate area, c 2 km from the Forsmark power facilities. The area is covered by forest and is characterized by small lakes tied off from the nearby Baltic Sea in, from a geological point of view, recent times. The present coastline is situated about 500 m north-east of the drill site (Figure 1-1).

The drilling operations were performed during two periods between November 11th 2003 to October 5th 2004. Drillcon Core AB, Nora, Sweden, was engaged for the drilling commission. Two different drilling equipments were employed for drilling KFM06A, a percussion drilling machine for drilling the upper c 100 m, whereas core drilling of the remaining part (section 100.64–1,000.64 m) was carried out with a wireline core drilling system. Borehole KFM06B was drilled with the same core drilling system.

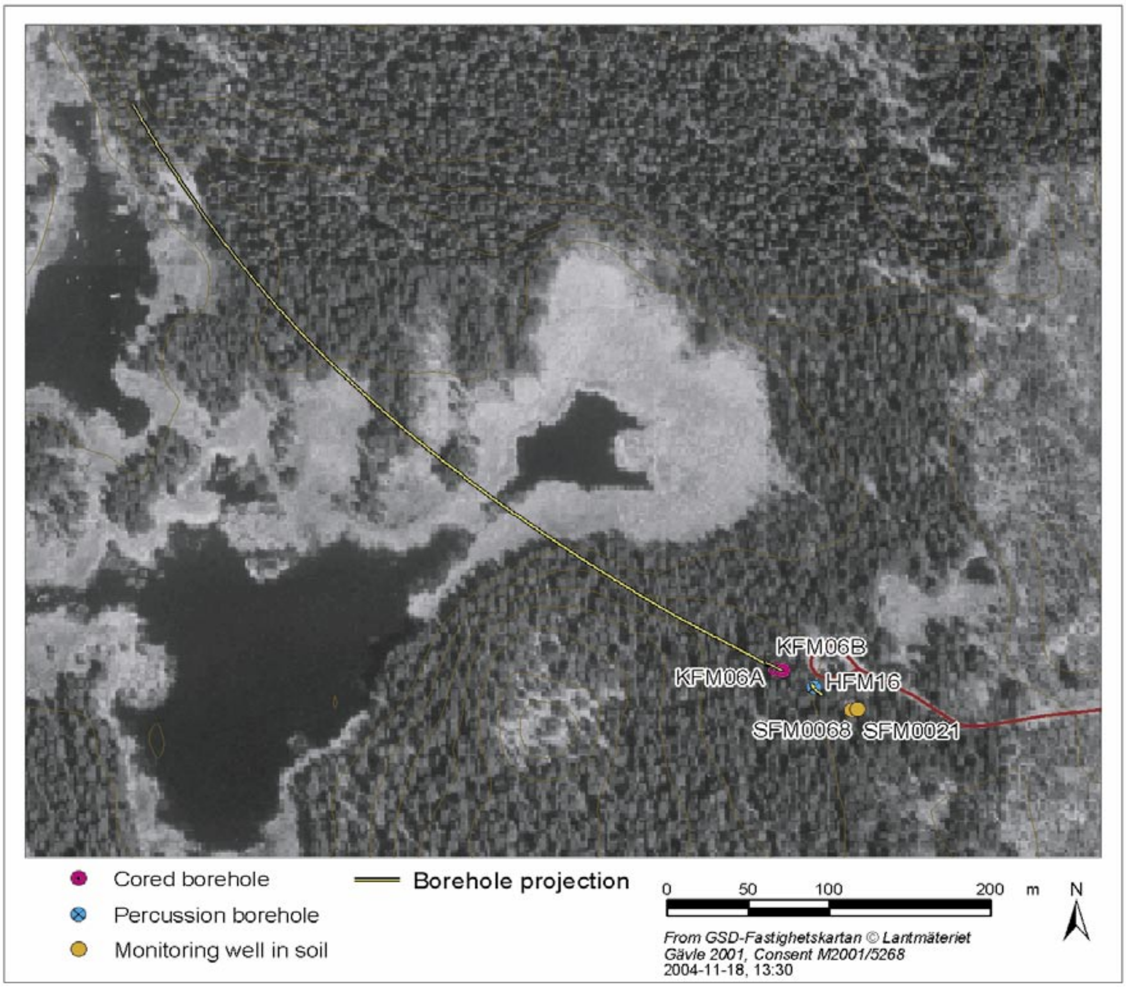


Figure 1-2. *Borehole locations at and near drill site DS6. Besides the core drilled boreholes KFM06A and KFM06B, the area incorporates a monitoring well in bedrock (HFM16), and two monitoring wells in the unconsolidated overburden (SFM0021 and SFM0068). The projection of inclined boreholes on the horizontal plane at the ground surface (top of casing) is shown in the figure.*

In the present report, performance of and results from drilling of KFM06A and KFM06B, are presented. The report also treats investigations made during and immediately after drilling. All data are stored in the SICADA database, and are tradeable by the activity plan number.

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 KFM06A, a short core borehole, KFM06B, was also drilled from the drill site. The rock samples collected during drilling are used for lithological, structural and rock mechanical characterization as well as for determination of retention 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 KFM06A. The upper c 100 m were drilled with a percussion drilling machine of type Puntel MX 1000. For core drilling of section 100.64–1,000.64 m, a Wireline-76 core drilling system, type Onram 2000 CCD, was engaged. Drilling of borehole KFM06B was performed with the same Wireline-76 core drilling system.

3.1 Percussion drilling equipment

The Puntel percussion machine is equipped with separate engines for transportation and power supplies. Water and drill cuttings were retrieved from the borehole by a 27 bars air-compressor, type Atlas-Copco XRVS 455 Md.

At drill site DS6, the bedrock is covered by approximately one metre of gravel. This part had to be cased off with a solid pipe (NO-X 365). During pilot drilling, highly fractured and unstable rock was observed. Due to this, a decision was made to use a NO-X 280 system (not stainless casing) for penetration of the gravel and fractured bedrock. To obtain a borehole as straight as possible in this type of soil, the choice of technique is important. In this case the NO-X technique was applied, following the principles and dimensions presented in Figure 3-1. The NO-X technique is described more in 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 performed in KFM06A are presented in Section 5.2.

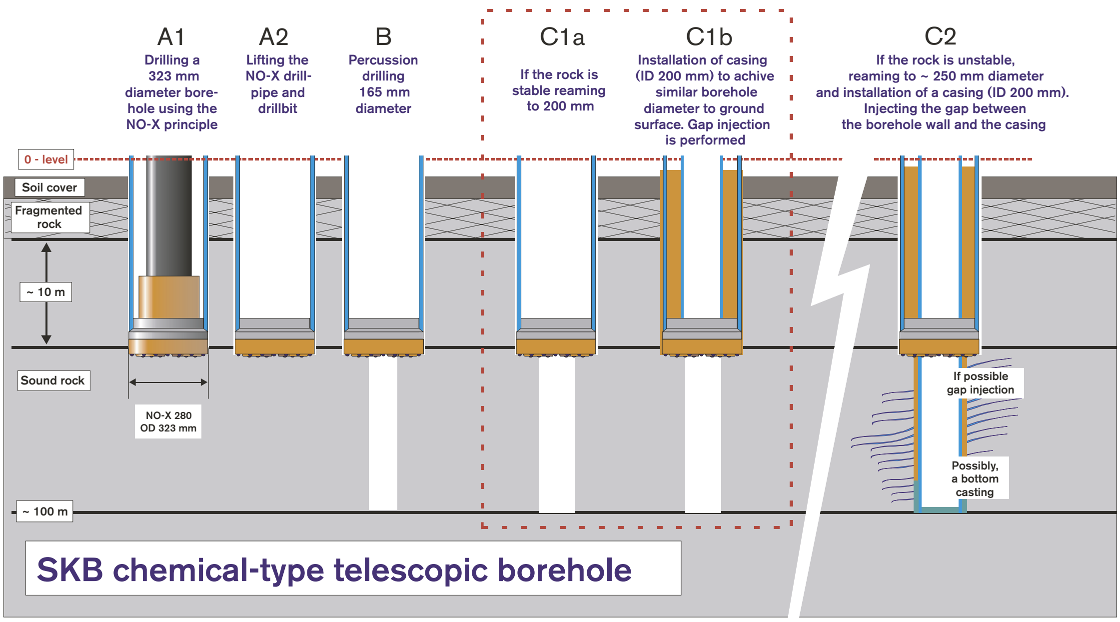


Figure 3-1. *Schematic diagram showing the various stages of drilling the 0-100 m section of an SKB chemical-type telescopic borehole. The letters and numerals above each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB MD 620.003, Version 1.0.*

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 shallow parts of the bedrock. Therefore, if large inflows of groundwater are met with during percussion drilling of a telescopic borehole, it is essential to prevent it from permeating into deeper parts of the bedrock. This is achieved by cement grouting of water-yielding fractures or fracture zones, as they come across. The simplest method is to fill part of the borehole with cement and to continue drilling after setting of the cement. This is also an effective method to stabilize the borehole wall as well, e.g. if a highly fractured and unstable section is penetrated.

If the percussion drilled part of a telescopic borehole is fractured and water-yielding, it is normally cased to the full drilling length. The gap between the borehole wall and the casing is then cement grouted, which further decreases or, often, completely prevents, inflow of shallow groundwater to the borehole. 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.

Borehole KFM06A was grouted at three occasions: 1) the entire borehole after pilot drilling to 12 m, 2) the entire borehole after pilot drilling to 100.64 m, and 3) after installation of the $Ø_i$ 200 mm, 100 m long casing (C2 in Figure 3-1). After installation of the casing, gap injection through a packer was applied.

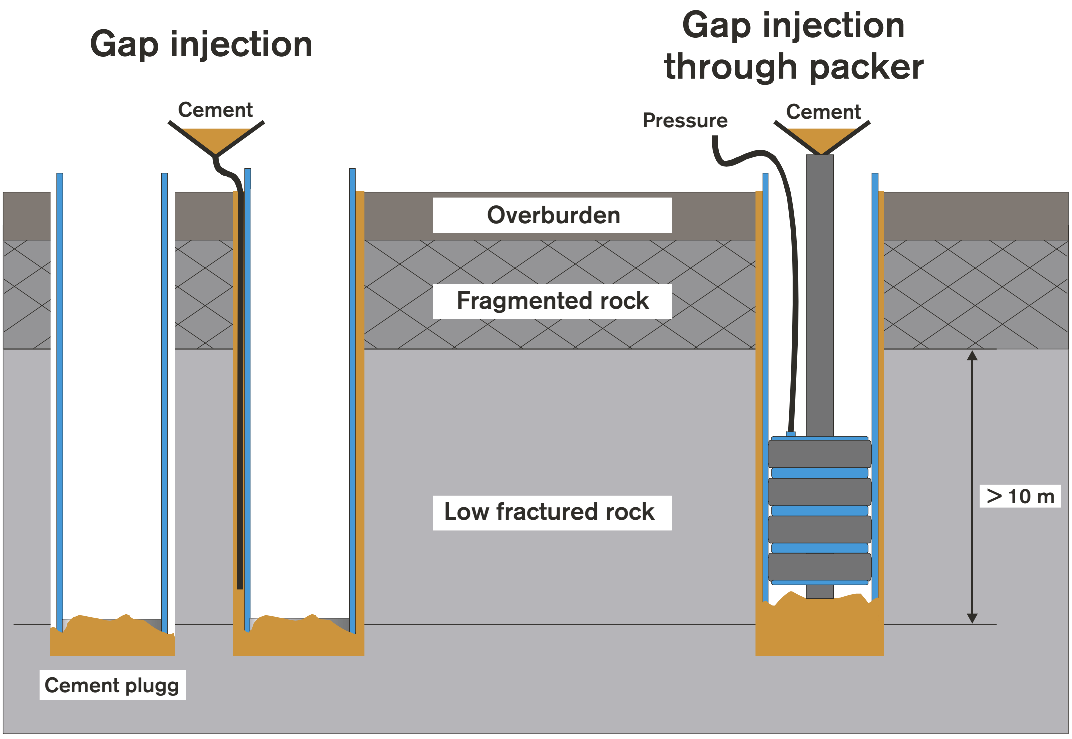


Figure 3-2. *Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer.*

3.3 Core drilling equipment

3.3.1 The wireline-76 system

For drilling the cored part of boreholes KFM06A and KFM06B, 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 1,500 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.

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 air-lift pumping while drilling,
- equipment for storage and discharge of return water.

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

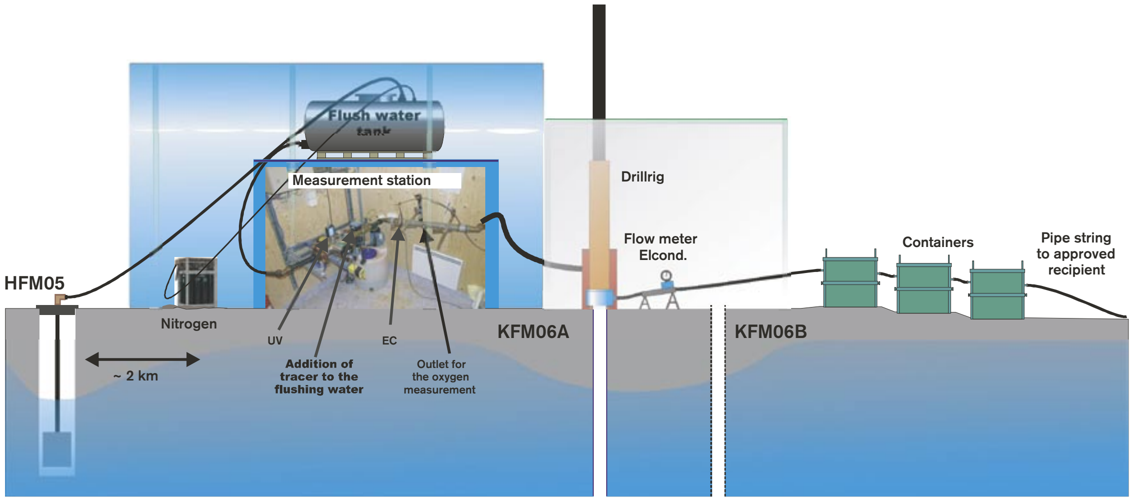


***Figure 3-3.** Schematic illustration of the flushing/return water system when drilling KFM06A and KFM06B at DS6. The measurement station included logger units and an UV-radiation unit. For flushing water flow rate and pressure measurements, the drilling machine gauges were applied.*

Preparing 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 KFM06A was a percussion drilled well in hard rock, HFM05, situated at DS2 approximately 1.5 km from KFM06A. Water from the percussion drilled well HFM16 sited on DS6 did not meet with the quality needed. The HFM05 well had earlier been used for flushing water supply for drilling of KFM02A, and the water quality was analysed and considered as sufficiently good to serve as flushing water for KFM06A and KFM06B.

Besides these basic demands on the flushing water quality, which were fulfilled when drilling KFM06A, the flushing water was also prepared in three steps before use, in accordance with SKB MD 620.003 (Method description for core drilling).

1) Incoming water from the 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) The incoming water from the tank was exposed to UV-radiation (inside the measurement station) before entering the tracer doser equipment, illustrated in Figure 3-3. The microbe content in the water was thereby radically reduced.

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.

Air-lift pumping while drilling

Air-lift pumping during core drilling involves pumping of compressed air into the percussion drilled portion of the telescopic borehole, forcing it to emerge at a depth of about 80–100 m. As the air expands in rising out of the borehole, it lifts the water up, thereby producing the air-lift pumping effect. The resulting pressure drop 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 KFM06A 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.
- One 22 mm diameter hose at about 100 m.
- Two 28 mm diameter hoses at about 100 m.

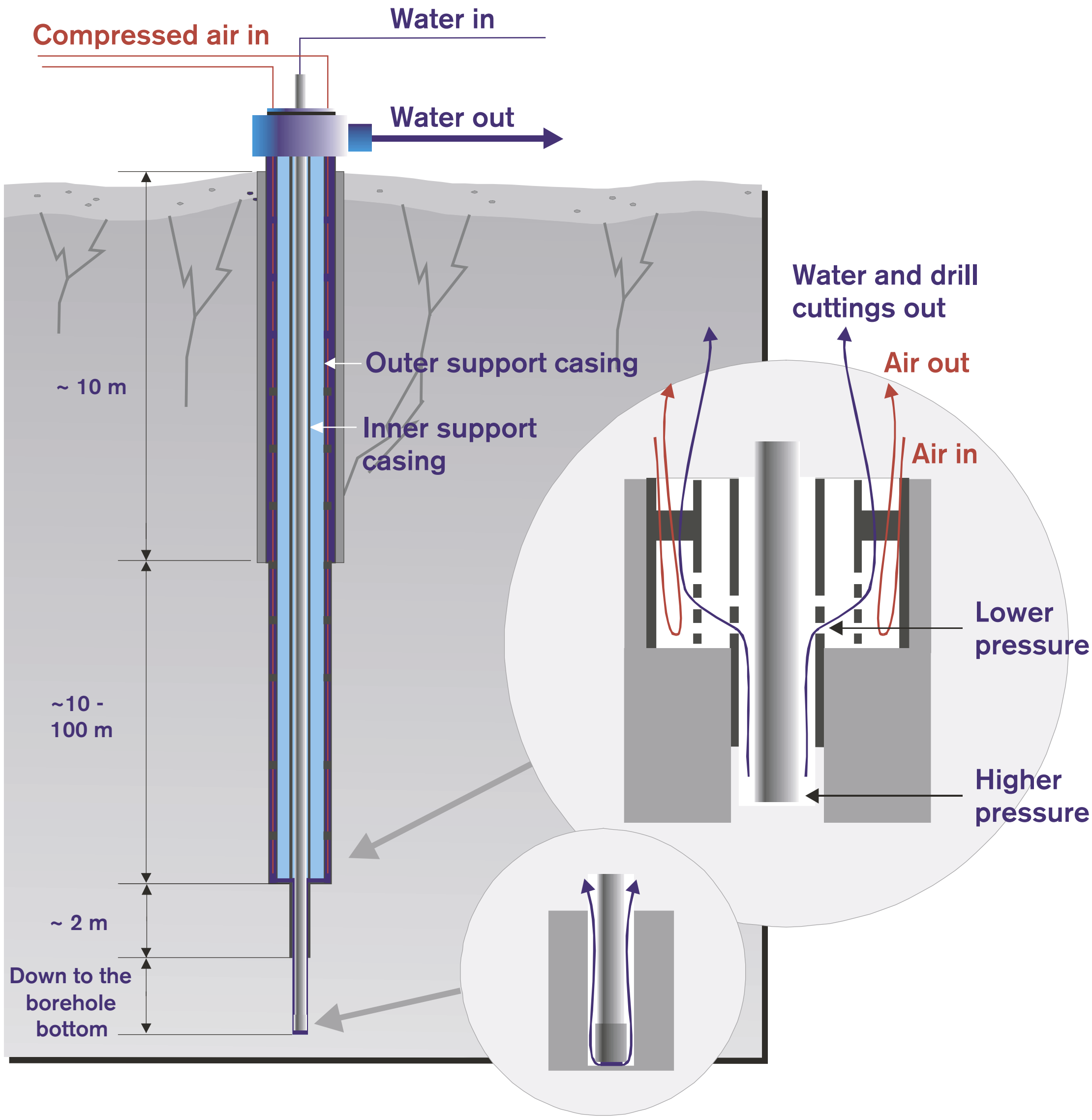


Figure 3-4. *Air-lift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole.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

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		

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.

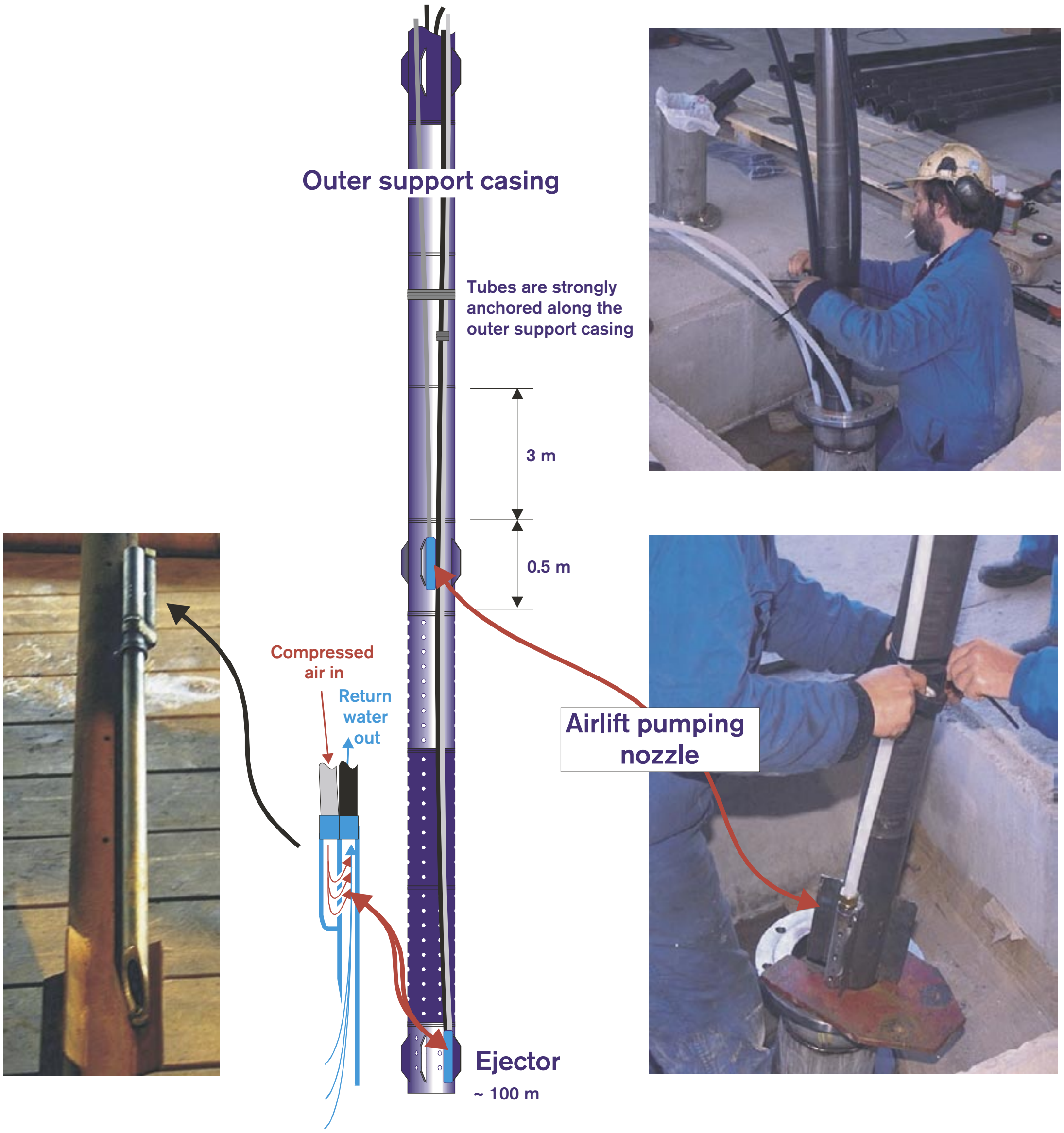


Figure 3-5. Schematic representation of connection and installation of air-lift pumping nozzle and ejector on the outer protective casing.

Storage and discharge of return water for KFM06A

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 pumped through an exit pipe string 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- 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.

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

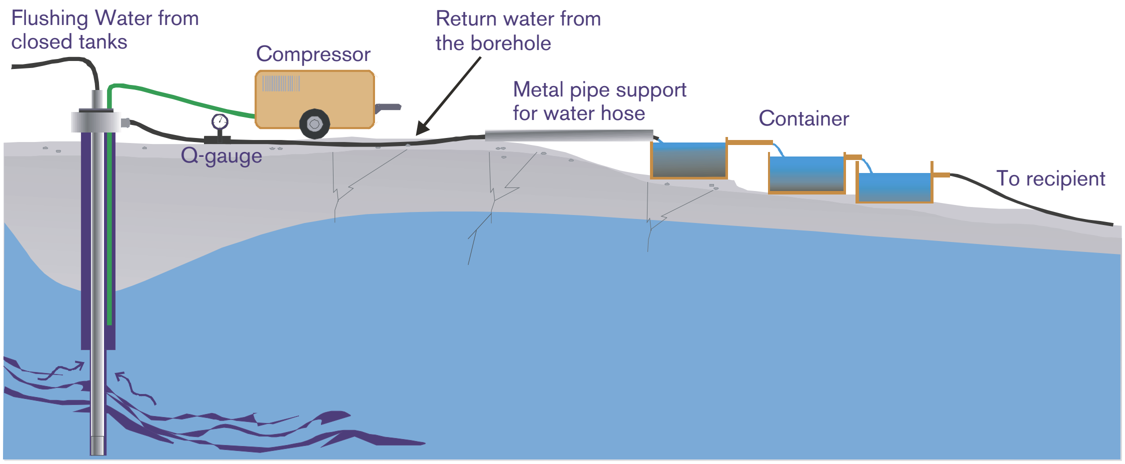


Figure 3-6. *Return water system. Air-lift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in three stages in the containers (where it is preserved for later weighing), after which the water is pumped to an approved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

were observed from time to time. Therefore an upgraded software was installed and some parts of the steering system were exchanged already prior to drilling of borehole KFM05A, which was drilled during the period Feb 10th 2004 to April 20th 2004 /3/. The new software and equipment have been in use since then.

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 drilling 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 provided 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 KFM06A, deviation measurement were made at two occasions, in order to check the straightness of the borehole. One measurement was made after approximately 450 m and then a final deviation measurement was carried out after completed drilling. 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. In KFM06B one deviation measurement with a Reflex MAXIBOR™ system was carried out after completed drilling.

3.3.5 Equipment for hydraulic tests, absolute pressure measurements and water sampling during drilling in KFM06A

It is stated in SKB MD 620.003 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, see Table 1-1.

3.3.6 Equipment for borehole stabilization in KFM06B

A new technique for stabilization of borehole walls, designated the PLEX technique, has just recently been developed and tested by SKB, see Figure 3-7. The PLEX system can be applied for mechanical stabilization of unstable parts of the borehole wall after part of or the entire borehole has been drilled. The system components, comprising a reamer, a packer with a steel plate (perforated or non-perforated) and a top valve, are assembled on top of each other in one single unit. The tool is designed for the N-dimension. By using the same pilot drill bit and ring gauge as used for drilling the borehole in question, the tool is well adjusted to the true borehole diameter. Only one rod trip is required for reaming, expanding the steel tube and verifying the inner diameter of the borehole. Using a perforated or non-perforated steel plate is optional. A perforated plate is applied if hydraulic characterization of the unstable section remains to be done.

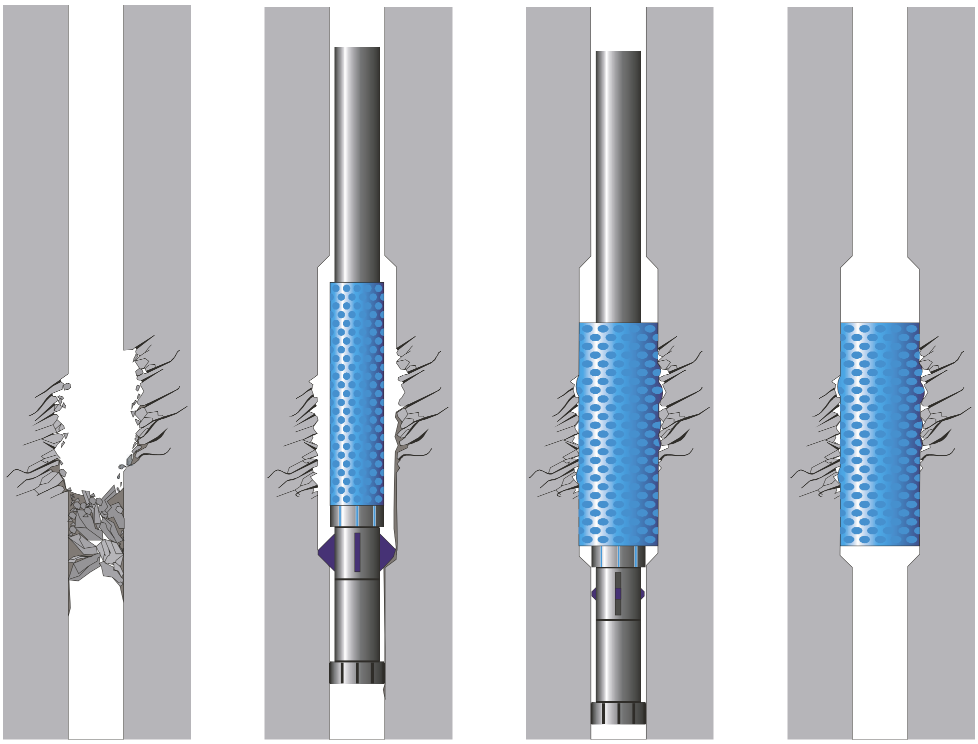


Figure 3-7. *Schematic figure illustrating the sequence of measures when stabilizing a fractured and unstable section in a core drilled borehole of N-dimension with a perforated steel plate by applying the PLEX system. The tool is descended, the 80 cm long unstable section is reamed, the packer is inflated as to expand the steel plate against the reamed part of the borehole wall, the packer is deflated and the tool is retrieved. As the steel tube is perforated, the stabilization does not prevent hydraulic testing of the stabilized section.*

4 Execution

4.1 Percussion drilling of borehole section 0–100 m in KFM06A

The percussion drilling operations included:

- 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 items 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, see Table 1-1. Finally, the equipment was cleaned in accordance with the cleaning instruction in SKB MD 600.004, see Table 1-1, for boreholes of SKB chemical type.

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. The borehole was drilled and cased with NO-X 365 to 2.12 m. During pilot drilling and reaming to 12.00 m, highly fractured and unstable rock was observed and the entire borehole was filled with cement. After setting of the cement, drilling and casing driving re-started from the beginning, now using NO-X 280 drilled to a length of 12.30 m.

The continued percussion drilling through solid rock was performed with a 164 mm drill bit to 100.64 m drilling length (corresponding to B in Figure 3-1). The borehole section at 51–52 m turned out to be unstable. To secure the subsequent reaming, the entire borehole was cement filled after completed pilot drilling. The pilot drilling was then repeated, after which the borehole was reamed to Ø 243 mm to 100.40 m drilling length with a special reamer bit (i.e. 0.24 m of the pilot hole was left unreamed).

An SS2333 stainless steel $Ø_i$ 200 mm casing was then installed (corresponding to C2 in Figure 3-1). Before installing the casing, the borehole was 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, as 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 seal water-yielding fractures in the percussion drilled section, the gap between the casing and borehole wall 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, which was applied in association with the Ø 164 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.

After completion of drilling with the Ø 164 mm drill bit, deviation measurements were made.

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 243 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

During pilot drilling and reaming to 12.00 m, highly fractured and unstable rock was observed and the entire borehole was cement grouted. Instead of redrilling the cement, a NO-X 280 casing was drilled to 12.30 m and left in the borehole. During pilot drilling to 100.64 m highly fractured rock was observed at c 51 m, and an again the entire borehole was cement grouted.

4.2 Core drilling of KFM06A

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 first four 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 drill 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 KFM06A was performed with two borehole dimensions. Section 100.64–102.10 m was drilled with a borehole diameter of 86.0 mm, whereas the main part of the borehole, section 102.10–1,000.64 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 a lithological, structural and rock mechanical characterization of the bedrock. The drill cores are also 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 drilling pipe string, inside which it is hoisted up with the wireline winch. During drilling of borehole KFM06A, 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, however, occur.

Like the percussion drilling, the core drilling is associated with a programme for sampling, measurements and other activities during and immediately after drilling, cf SKB MD 620.003 (Table 1-1). However, for different reasons, during drilling of KFM06A 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 4.2.4, Table 4-1, together with the actual performance when drilling KFM06A.

Results of mapping of the drill core samples are presented in /4/, 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 was performed prior to 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, sedimented 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 5-4. The cone is located at 97.28–102.05 m.
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.

The 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 3-3 and 3-6 (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 get a measure of the drill cuttings recovery.

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 KFM06A.

Activity	Performance and frequency according to SKB MD 620.004	Performance and frequency during drilling of KFM06A
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.
Measurements of the difference in length between the compressed drilling 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 drilling pipe string should be controlled before each test.	One pumping test was made.
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.	No sample was collected because the inflow of groundwater was extremely low.
Absolute pressure measurements.	Normally during natural pauses in drilling.	Two measurements were performed.
Groove milling in the borehole wall, normally at each 100 m.	Normally performed after completion of drilling.	Seventeen grooves performed. Seven grooves not detectable.
Collecting and weighing of drilling debris.	Drilling debris settled in containers 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 finishing the borehole.	Ordinary flushing combined with nitrogen flushing.

4.3 Core drilling of KFM06B

Boreholes KFM06A and KFM06B are located close to each other, on the same concrete slab at DS6. As the boreholes were drilled in sequence, KFM06B before KFM06A, the preparation and mobilization is common, see Sections 4.2.1 to 4.2.2.

4.3.1 Drilling, measurements and sampling during drilling

Soil-drilling (2.51 m) at KFM06B was performed with a B-dimension (Ø 116 mm) core barrel, after which core drilling with Ø 86 mm, entailing a core diameter of 72 mm to 6.33 m, was performed. After reaming the borehole with Ø 101 mm to 4.61 m drilling length, a stainless steel casing of 4.61 m length was installed and the entire borehole to 6.33 m was grouted. The main part of the borehole, section 6.33–100.33 m , was drilled with borehole diameter Ø 77 mm.

Core drilling with a wireline system involves recovery of the core barrel via the drilling pipe string, inside which it is hoisted up with the wireline winch. During drilling of borehole KFM06B, 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, however, occur.

Results of mapping of the drill core samples are presented in /4/, whereas the remaining measurements and registrations during core drilling are presented in Chapter 5.

The concluding work included the following items:

1) The borehole was flushed for about 1 hour in order to clean it from drilling debris adhered to the borehole walls. The results are presented in Chapter 5.
2) The core drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

4.3.2 Stabilization of drillhole KFM06B

When the BIPS video-camera, was lowered into the borehole, an outfall from c 55 m caused the instrument to get wedged in the borehole, and therefore stabilization with the PLEX system had to be made.

4.4 Data handling

4.4.1 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.

4.4.2 Nonconformities

None.

4.5 Environmental programme

4.5.1 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.

4.5.2 Nonconformities

None.

5 Results

This chapter is structured as follows:

- Section 5.1 – an overview of the drilling progress of KFM06A and KFM06B
- Section 5.2 – geometrical data and technical design of KFM06A
- Section 5.3 – results from percussion drilling of KFM06A
- Section 5.4 – results from core drilling of KFM06B
- Section 5.5 – geometrical data and technical design of KFM06B
- Section 5.6 – results from core drilling of KFM06B
- Section 5.7 – stabilization with the PLEX-system

Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling. Well Cad-presentations of boreholes KFM06A and KFM06B are shown in:

- Appendix A (percussion drilled part of KFM06A)
- Appendix B (the complete KFM06A)
- Appendix C (complete KFM06B)

5.1 Drilling progress KFM06A and KFM06B

Drilling of borehole KFM06A was carried out during three periods between November 2003 and late September 2004. KFM06B was drilled during a couple of weeks in May and June 2004. Because preparation of both drill sites DS5 and DS6 was performed simultaneously, percussion drilling of KFM05A and KFM06A was conducted in immediate succession in late 2003. During the first months of 2004, core drilling of KFM05A was accomplished, whereupon drilling of both KFM06B and KFM06A was performed during a period of approximately 4 months, including a pause during the summer holiday, see Figure 5-1.

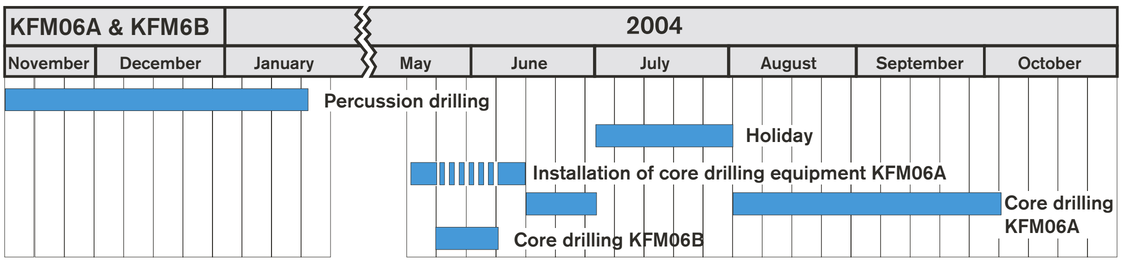


***Figure 5-1.** Overview of the drilling performance of boreholes KFM06A and KFM06B.*

5.1.1 Percussion drilling period

Percussion drilling is normally a rapid drilling method compared to core drilling. However, the relatively complex approach applied for the drilling and especially the grouting sequences when drilling KFM06A, resulted in a rather long total working period.

The durations of the different operations of the percussion drilling from 2003-11-11 to 2004-01-20, including a pause during the Christmas holiday, are presented in Figure 5-2.

5.1.2 Core drilling period

After percussion drilling of section 0–100.64 m, after which followed a break of four months, core drilling commenced. The progress of the core drilling from 2004-06-14 to 2004-10-05, including summer holidays, is presented in Figure 5-3. The pace of drilling decreases versus time, due to with increasing borehole length, retrieval of the core barrel, e.g. for change of drill bit, becomes more and more time consuming.

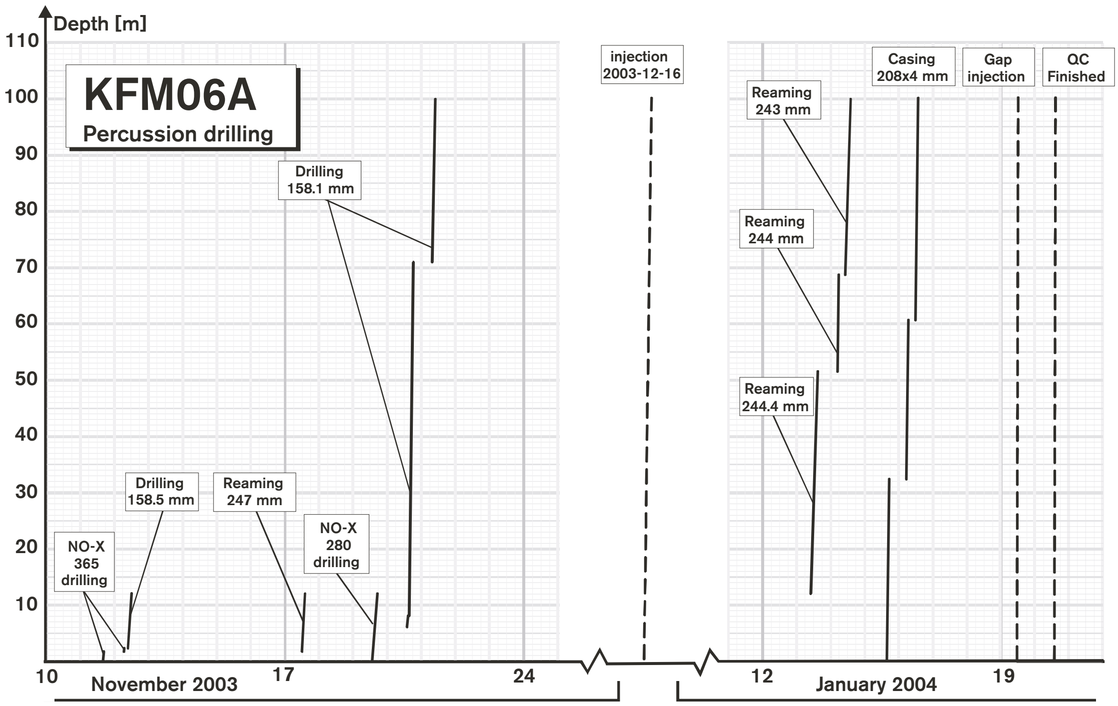


Figure 5-2. Percussion drilling progress (depth and activity versus calendar time).

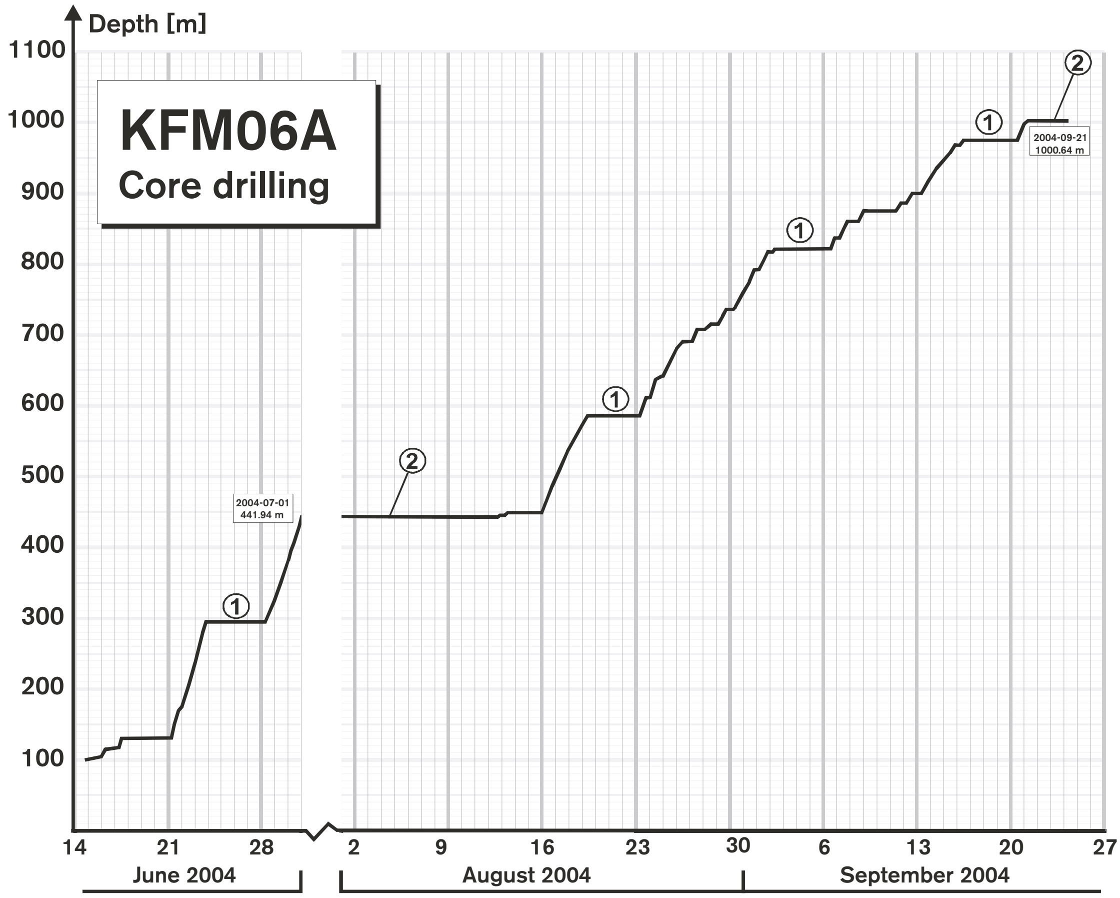


Figure 5-3. Core drilling progress (depth versus calendar time). ① WL-test, ② deviation measurement (Maxibor).

5.2 Geometrical and technical design of borehole KFM06A

Administrative, geometric and technical data for the telescopic borehole KFM06A are presented in Table 5-1. The technical design is illustrated in Figure 5-4.

5.3 Percussion drilling KFM06A 0–100.64 m

5.3.1 Drilling

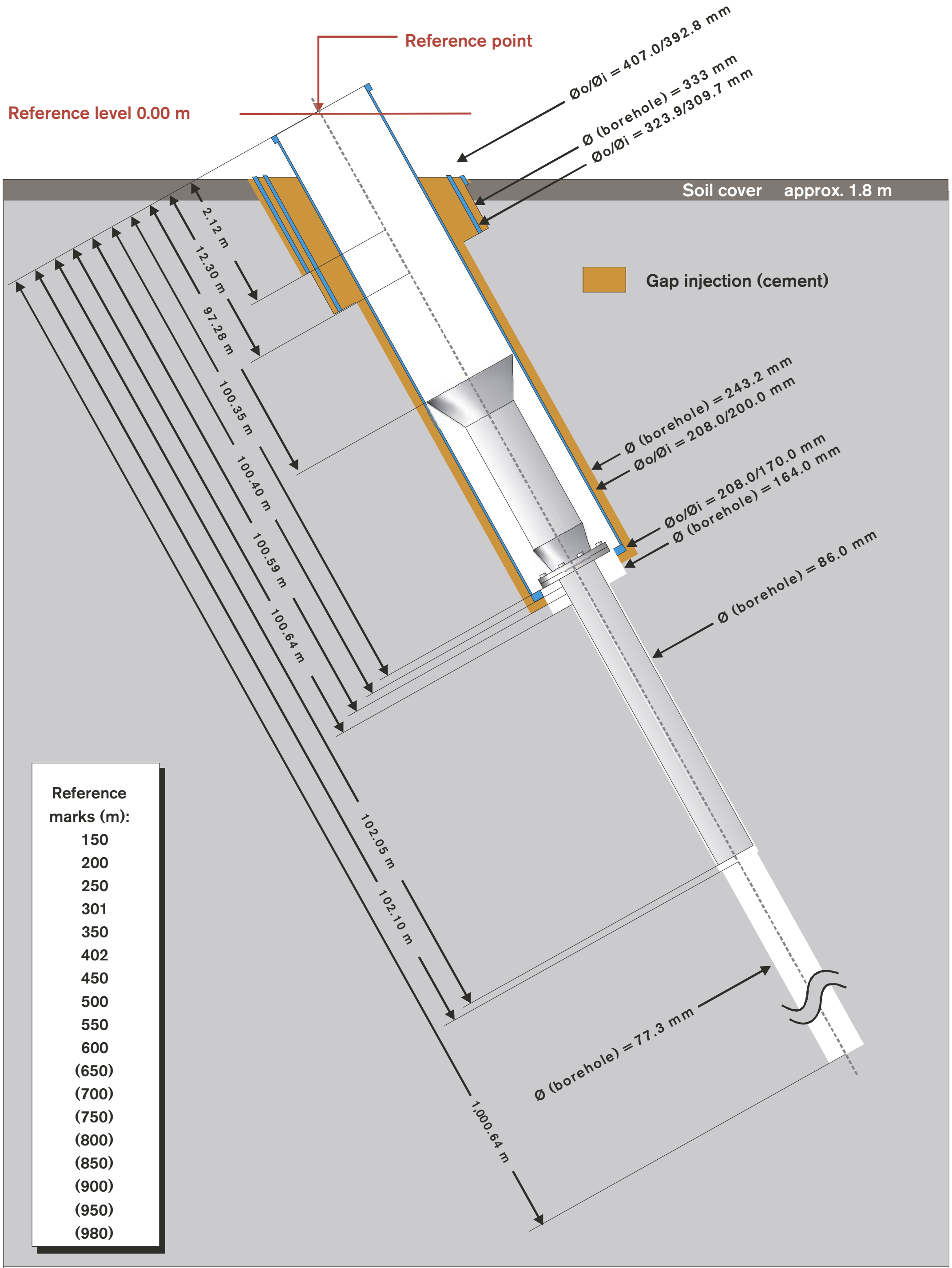
As mentioned in Section 4.1.3, the upper section to 2.12 m of the borehole was drilled and cased with NO-X 365. During pilot drilling and reaming to 12.00 m, highly fractured and unstable rock was observed and the entire borehole was filled with cement. After setting of the cement, drilling and casing driving re-started from the beginning, now using NO-X 280. The borehole was drilled and cased to 12.30 m, see Figure 5-4. During pilot drilling to 100.64 m, an unstable section with increased fracturing was again encountered, at c 51 m. After completed pilot drilling to 100.64 m, the entire borehole was cement filled. When the cement had hardened, the borehole was reamed. The reamed diameter decreases from Ø 244.4 mm at the top of the borehole to Ø 243 mm at the bottom.

Increased fracture frequencies were observed also when uncovering the bedrock surface during preparation of drill site DS6. The fracturing in the percussion drilled part of KFM06A is also well in line with the results from the nearby percussion drilled borehole HFM16. When re-drilling the cement filled borehole with the pilot bit, still some instabilities were observed. The borehole was therefore, after reaming to 243 mm, cased with a Ø 208/200 mm stainless steel casing to 100.40 m. Finally, the gap between the casing and the borehole wall was cement grouted, so that the water inflow ceased completely.

Table 5-1. Administrative, geometric and technical data for borehole KFM06A.

Parameter	KFM06A
Borehole name	KFM06A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	November 11, 2003
Completion date	October 5, 2004
Percussion drilling period	2003-11-11 to 2004-01-20
Core drilling period	2004-06-14 to 2004-10-05
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Sven Andersson i Uppsala AB
Percussion drill rig	Puntel MX 1000
Core drill rig	ONRAM 2000 CCD
Position KFM06A at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6699732.88 E 1632442.51 Z 4.10 (m.a.s.l.)
	Azimuth (0–360°): 300.92° Dip (0–90°): –60.25°
Position KFM06A at bottom of hole (RT90 2.5 gon V 0:-15 / RHB 70)	N 6700105.79 E 1632045.04 Z –828.53 (m.a.s.l.)
	Azimuth (0–360°): 301.54° Dip (0–90°): –51.82°
Borehole length	1,000.64 m
Borehole diameter and length	From 0.00 m to 12.30 m: 0.333 m
	From 12.30 m to 100.59 m: 0.243 m
	From 100.59 m to 100.64 m: 0.164 m
	From 100.64 m to 102.10 m: 0.086 m
	From 102.10 m to 1,000.64 m: 0.077 m
Casing diameter and drilling length	Ø$_o$/Ø$_i$ = 407 mm/393 mm to 2.12 m
	Ø$_o$/Ø$_i$ = 324 mm/310 mm to 12.30 m
	Ø$_o$/Ø$_i$ = 208 mm/200 mm to 100.35 m
	Casing shoe Ø$_i$ = 170 mm between 100.35 and 100.40 m
Transition cone inner diameter	At 97.28 m: 0.195 m
	At 102.05 m : 0.080 m
Drill core dimension	100.64–102.10 m/Ø 72 mm 102.10–1,000.64 m/Ø 51 mm
Core interval	100.64–1,000.64 m
Average length of core recovery	2.69 m
Number of runs	334
Diamond bits used	31
Average bit life	29.0 m

Technical data
Borehole KFM06A



Drilling reference point

Northing: 6699732.88 (m), RT90 2,5 gon V 0:-15
Easting: 1632442.51 (m), RT90 2,5 gon V 0:-15
Elevation: 4.10 (m), RHB 70

Orientation

Bearing (degrees): 300.92°
Inclination (degrees): −60.25°

Borehole

Length: 1,000.64 m

Percussion drilling period

Drilling start date: 2003-11-11
Drilling stop date: 2004-01-20

Core drilling period

Drilling start date: 2004-06-14
Drilling stop date: 2004-10-05

ver 2005-06-13

Figure 5-4. *Technical data of borehole KFM06A.*

5.3.2 Measurements while drilling

During, and immediately after drilling, a program for sampling and measurements was applied, cf Section 4.1.3. Some of the results are displayed in the Well Cad-presentation in Appendix A (deviation measurements, penetration rate and rock type distribution), whereas other results (flow data and electrical conductivity) are only used as supporting data for on-site decisions. Below, the results of the deviation measurements made after completed percussion drilling of KFM06A are commented on.

Borehole deviation

The end (bottom) point of the percussion borehole deviates approximately 3 m downwards and 1 m to the left compared to an imagined straight line following the dip and strike of the borehole collaring point (inclination –60.25° and bearing 300.92°).

5.4 Core drilling KFM06A 100.64–1,000.64 m

5.4.1 Drilling

The bedrock within the so called Forsmark tectonic lens has appeared to be relatively hard to drill, probably to a large extent depending on the high quartz content. As drill site DS6 is located in the centre of the tectonic lens, the bedrock composition was prior to drilling assumed to be of similar character. However, the upper 400 m of the bedrock at DS6 are more fractured than previously observed within the candidate area, which resulted in longer life-time of the drill bits down to c 400 m than at greater depths. However, in average, the life-time was 29.0 drilled metres per drill bit in KFM06A, which was almost exactly the same as in the previously drilled KFM01A /5/. On the whole, core drilling in both KFM01A and KFM06A was more time consuming and costly than in average granitic rocks.

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 5.4.2–5.4.14 below.

Mapping of the drill core samples from KFM06A is presented in /4/.

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 is tradeable 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, to compensate for the delayed drilling start. Figure 5-5 serves as a basis for Figure 5-3, with which it should be compared.

Penetration rate

The penetration rate, see Figure 5-6, was in average almost the same as during drilling of KFM01A /5/. Initially, the penetration rate started with a little more than c 10 cm/min, but in section 150–450 m it is increased to c 13–14 cm/min. When drilling was resumed after the summer holiday, the penetration rate started with c 12 cm/min, but fell successively back to c 10 cm/min, corresponding to the increasing frictional resistance of the return water flow, which is conducted in the narrow gap between the borehole wall and the pipe string. This reduces the retrieval of drill cuttings and slows down the penetration rate, however not as much as in KFM01A, since the borehole diameter was increased from c 76 mm in KFM01A to 77.3 mm in KFM06A.

Feed force

In Figure 5-7 the feed force is plotted versus borehole length. As the software for the steering system had been upgraded, resulting in a better control of the drilling parameters, the level of feed force when drilling KFM06A was lower compared with the feed force registered when drilling the previous boreholes KFM01A to KFM04A but higher than in KFM05A.

In section 100–400 m the feed force is significantly lower, which probably reflects the more fractured and permeable rock in the upper part of the borehole. On the other hand, the increased feed force from 400 m indicates low fractured and low permeable rock at depth.

Rotation speed

The rotation speed diagram, Figure 5-8, shows from start an almost constant rotation speed of 1,000 rpm. Between 550 and 750 m, the rotation speed was successively adjusted and varied between c 850–900 rpm with a slight decreasing trend. Finally, during the remaining drilling from 750 m the rotation speed maintained fairly constant at c 825 rpm. Sudden drops in the curve represent drilling shut off.

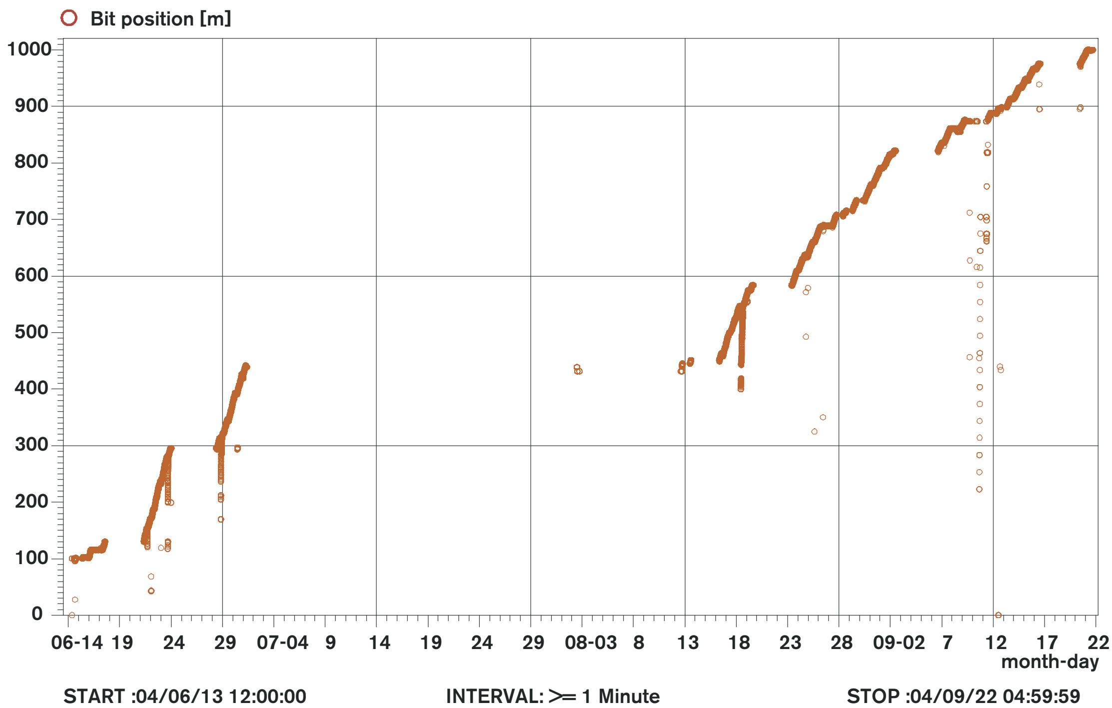


***Figure 5-5.** Drill bit position versus time.*

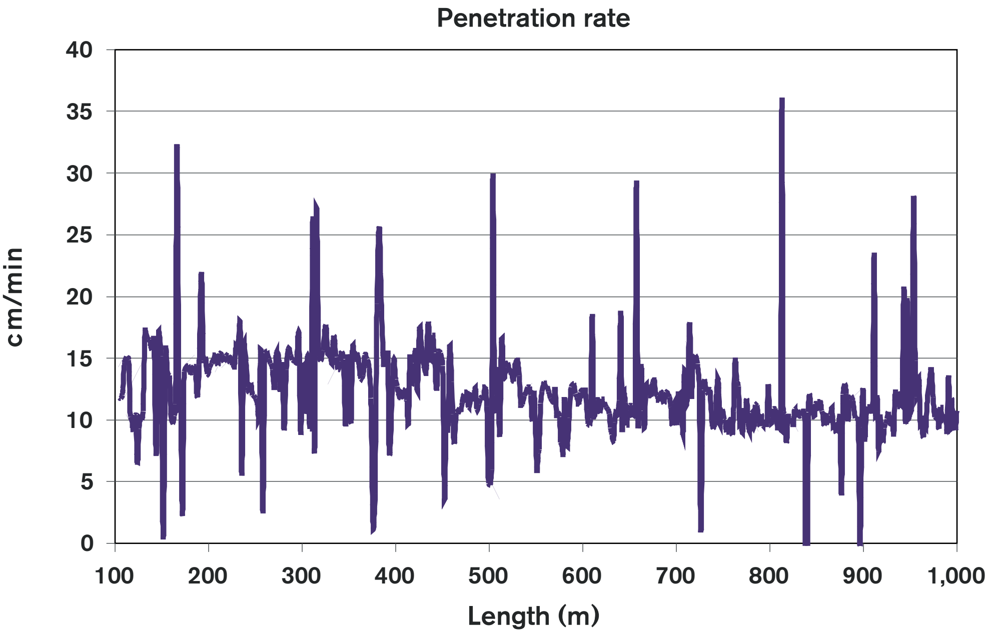


Figure 5-6. *Penetration rate during core drilling of KFM06A.*

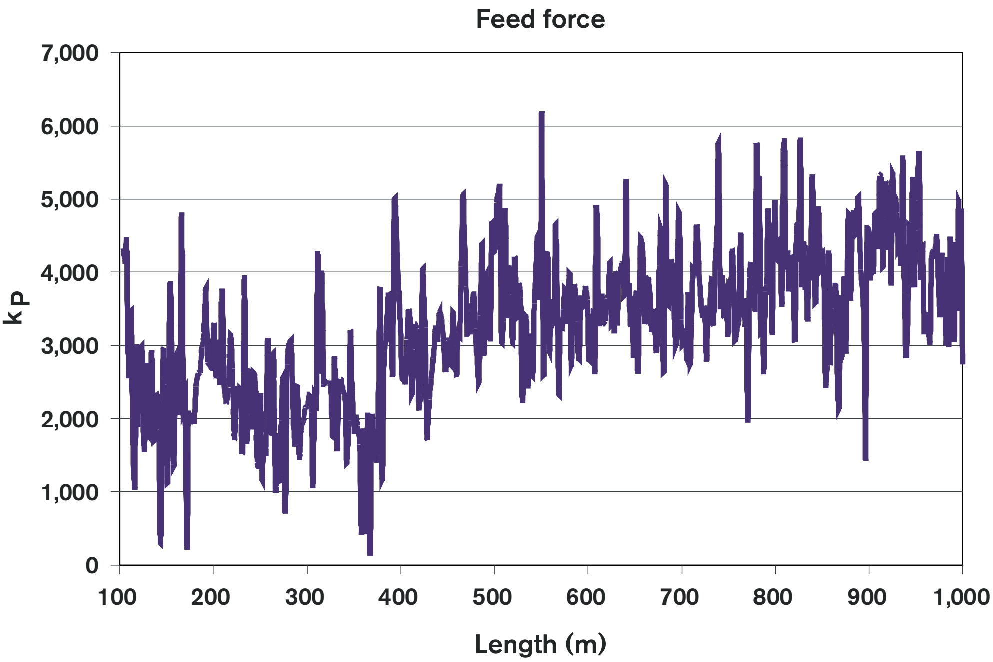


Figure 5-7. *Feed force versus borehole length during drilling of borehole KFM06A.*

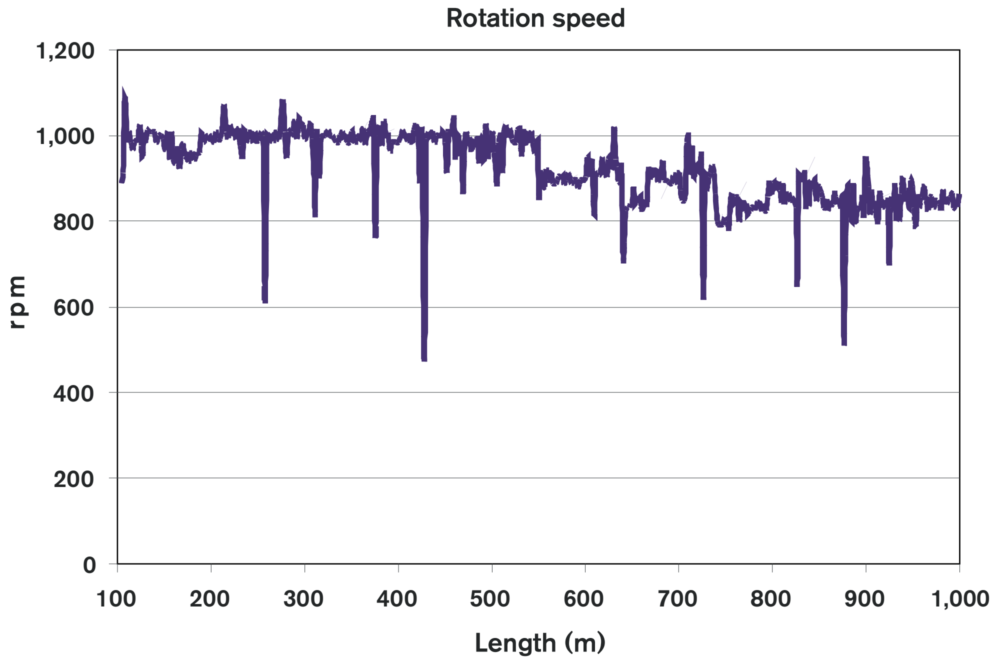


Figure 5-8. *Rotation speed versus borehole length during drilling of borehole KFM06A.*

5.4.3 Registration and sampling of flushing water and return water

Flushing water and return water flow rate – water balance

As borehole KFM06A 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 drilling, one must also study the content of the Uranine tracer dye 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 1.81 (results from Uranine measurements are presented in the next section).

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 350 m. This reflects the fact that when the drill bit position is close to water conductive fractures in the borehole, flushing water is forced into these fractures, because the flushing water pressure much exceeds that of the formation. When 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.

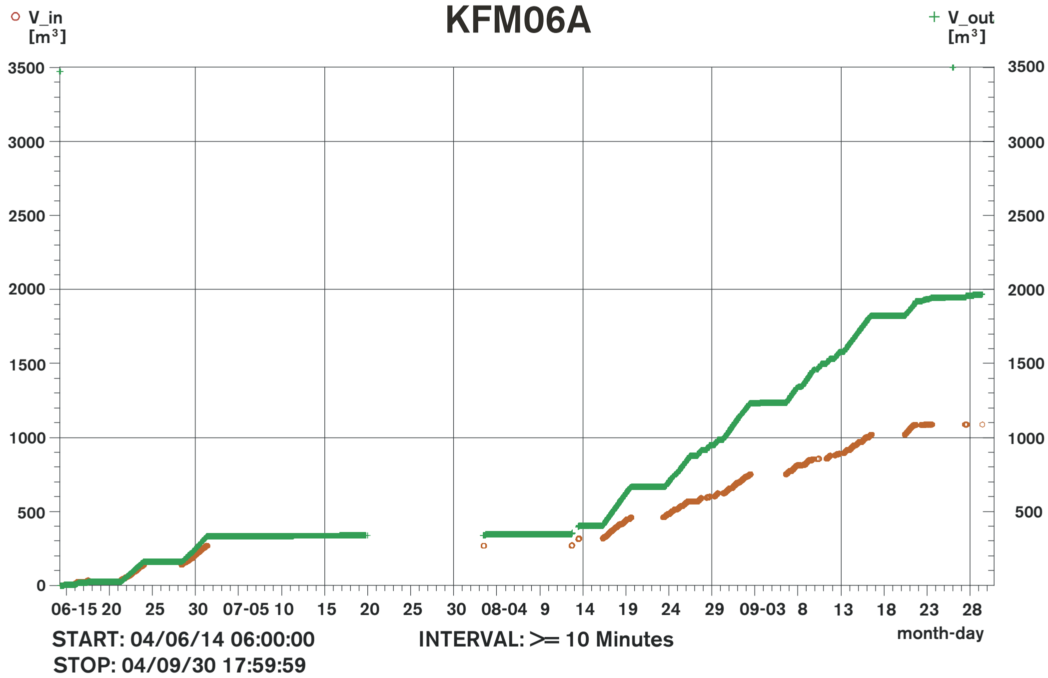


Figure 5-9. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM06A.*

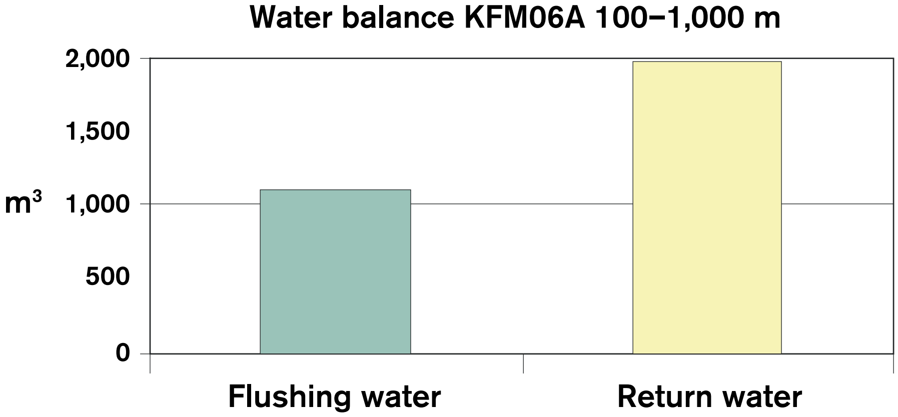


Figure 5-10. *Total amounts of flushing water and return water during drilling of borehole KFM06A. The total volume of flushing water used during core drilling amounted to 1,087 m^3. During the same period, the total volume of return water was 1,968 m^3. The return water/flushing water balance is then as high as 1.81, due to the large inflow of groundwater into the upper part of the borehole.*

Figure 5-11 illustrates the variations of flushing water and return water flow rate together with variations of the ground water table during core drilling of borehole KFM06A. The return water flow rate depends on the inflow into the borehole, as well as on the draw-down (effected by the mammoth pumping). To cool the drill bit and keep the borehole bottom clean, drilling usually requires a flushing water flow rate of c 35 L/min. However, immediately after a core recovery, a temporarily higher flushing water flow rate is often used.

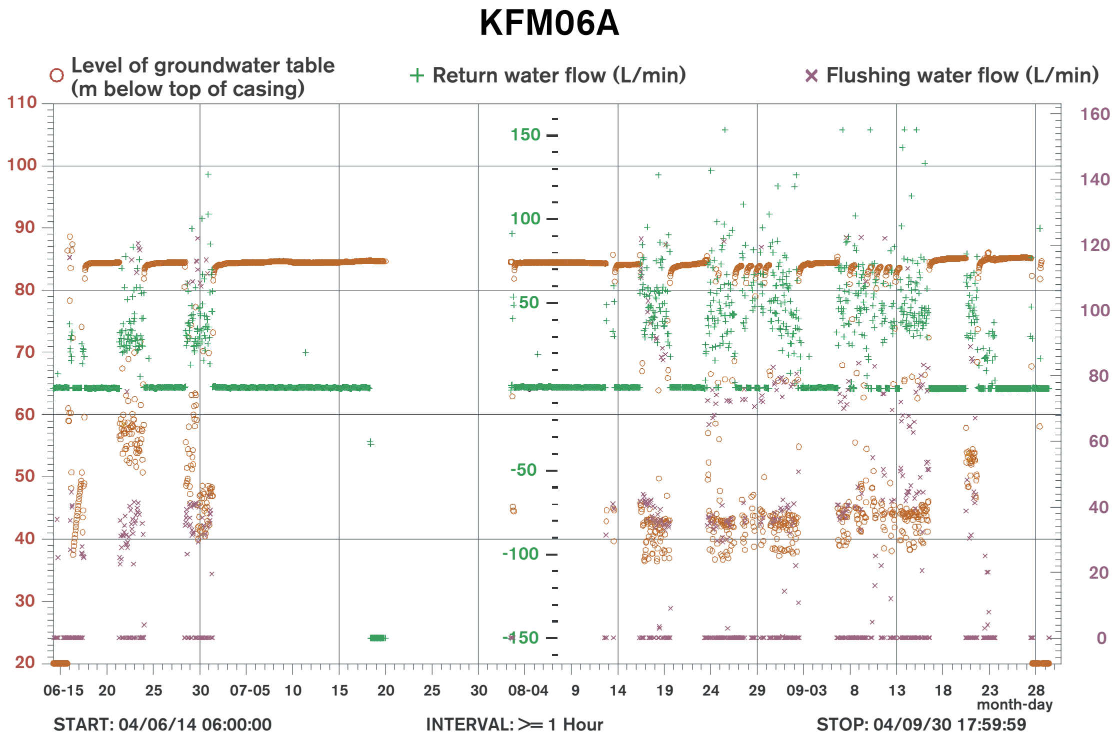


Figure 5-11. *Ground water table (red), flushing water flow rate (lilac) and return water flow rate (green) versus time during core drilling of borehole KFM06A.*

As the upper 100 m of the borehole are cased and cement grouted, there is no return water inflow above the core drilled part of the borehole. Shortly after core drilling started, the return water flow rate was c 40 L/min, indicating water yielding fractures just below 100 m. When core drilling commenced, the water inflow increased simultaneously as the groundwater table draw-down was larger. However, after the summer holidays both the return water flow rate and the draw-down stabilized. The results indicate absence of major groundwater inflows to the borehole at depth.

Uranine content of flushing water and return water – mass balance

During the drilling period, sampling and analysis of flushing water and return water for analysis of the content of Uranine was performed systematically with a frequency of approximately one sample per every fourth hour during the drilling period, see Figure 5-12. Like in boreholes KFM02A, KFM03A, KFM04A and KFM05A, a dosing feeder controlled by a flow meter was used for labelling the flushing water with Uranine to a concentration of 0.2 mg/L. The flow meter malfunctioned at a few occasions during the drilling period.

The analyses of the tracer Uranine in the flushing water and in the return water indicated a somewhat too high value due to a systematic error and have been corrected with a factor 0.7 in Figure 5-12. For this reason, it is difficult to make a reliable mass balance calculation of the accumulated volumes of flushing water and recovered flushing water in the return water. According to notations in the log book, the amount of Uranine added to the borehole was 200.5 g. If the averages of the corrected 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 give 210 g and 122 g respectively.

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM06A is exposed in Figure 5-13. Like in boreholes KFM02A, KFM03A, KFM04A and KFM05A, the borehole diameter was 77.3 mm, i.e. increased c 1 mm compared to in borehole KFM01A. This resulted in lower flushing water pressure than in KFM01A.

After an almost continuous increase of flushing water pressure versus borehole length to c 650 m, this trend was interrupted, and the system indicated difficulties in providing a sufficiently high pressure to clean the borehole from drilling debris. The problem turned out to depend on the drill pipe string being worn out, resulting in too high water leaks in the thread fittings. At c 880 m drilling length, the fittings were sealed with tape, which immediately resulted in a significantly higher (c 20 bars) flushing water pressure, whereupon the borehole could be completed. By performing groove milling after completion of drilling, it seemed as if leaking again had increased, because the seven lowermost mills were not entirely successful, see Section 5.4.12. The worn out drill string will be replaced prior to commencement of a new borehole at Forsmark.

Although the problems referred to above, the final water pressure was almost the same as in KFM02A and KFM03A, even though KFM06A is inclined.

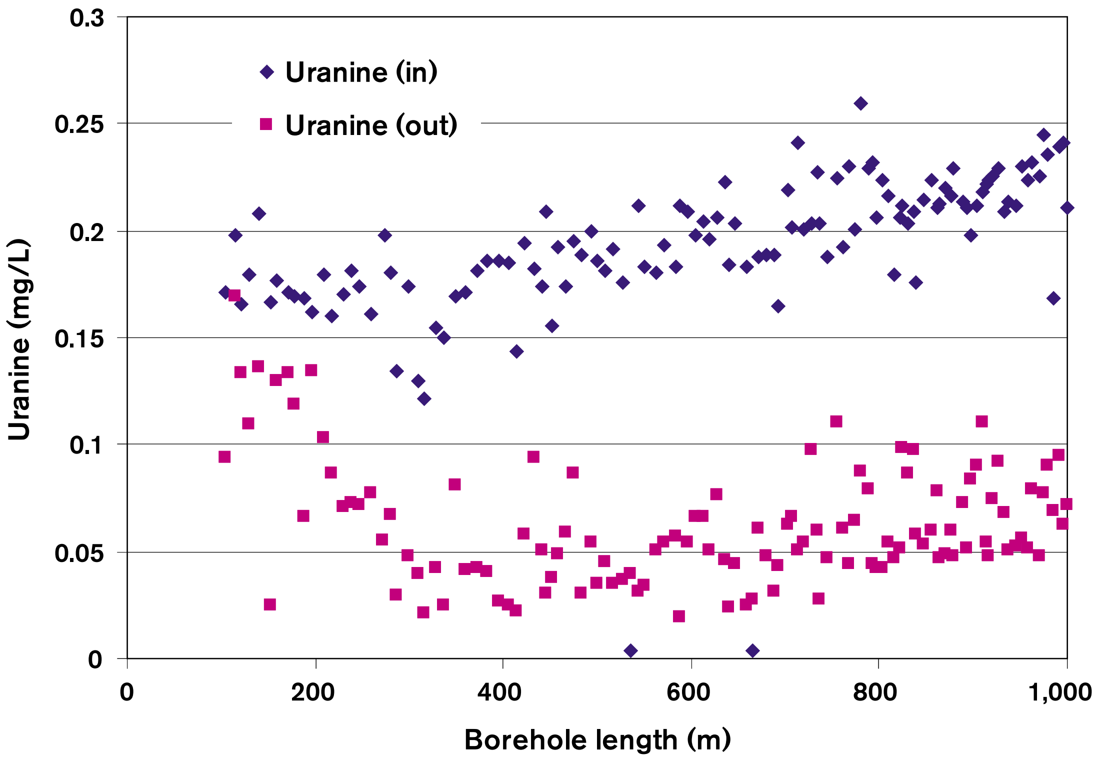


Figure 5-12. *Uranine content in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFM06A. An automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.*

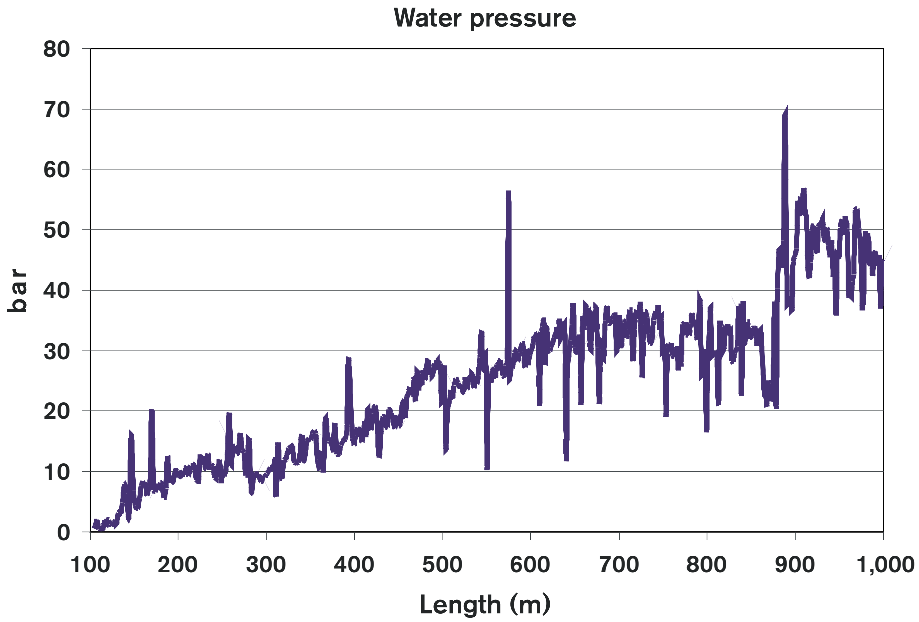


***Figure 5-13.** Flushing water pressure versus drilling length when drilling KFM06A.*

Electric conductivity of flushing water

Flushing water was supplied from percussion borehole HFM05. A sensor in the measurement station registered the electric conductivity (EC) of the flushing water on-line before the flushing water entered the borehole, see Figure 3-3.

Another sensor for registration of the electric conductivity (Figure 5-14) 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 200.10 m deep supply well HFM05 with its major inflow at c 156 m has from start a significantly decreasing trend during the weekly pumping (Monday to Thursday around the clock) of flushing water. At the beginning of the week the EC-value is c 1,000 mS/m but decreases to around 900 mS/m by the end of the week. This indicates that by increasing draw-down in HFM05A, the proportion of shallow, less saline water increases. During the week-end stops, the salinity recovers to the normal, undisturbed EC-level.

The average electrical conductivity of the return water is increasing to c 450 m but is then almost constant during the remaining drilling period. The most probable explanation is that the shallow groundwater inflow dominates completely in KFM06A.

Content of dissolved oxygen in flushing water

In Figure 5-15, the level of dissolved oxygen is plotted versus time. The content of dissolved oxygen has generally been kept lower than the approved upper limit 5 mg/L. The first week after the summer holidays, the transmitter was out of function. Thereafter, the content of dissolved oxygen in the flushing water varied between 3–4.5 mg/L.

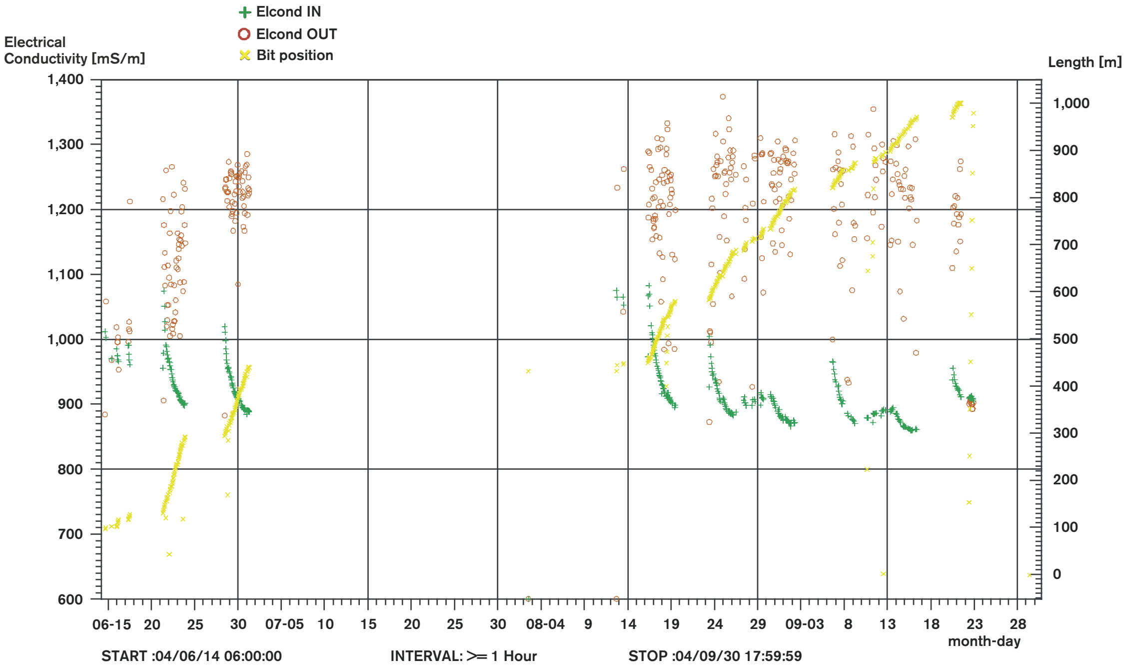


***Figure 5-14.** Electrical conductivity of flushing water from HFM05 and return water from KFM06A. The amount of values in the dataset has been reduced as well as cleaned from outliers.*

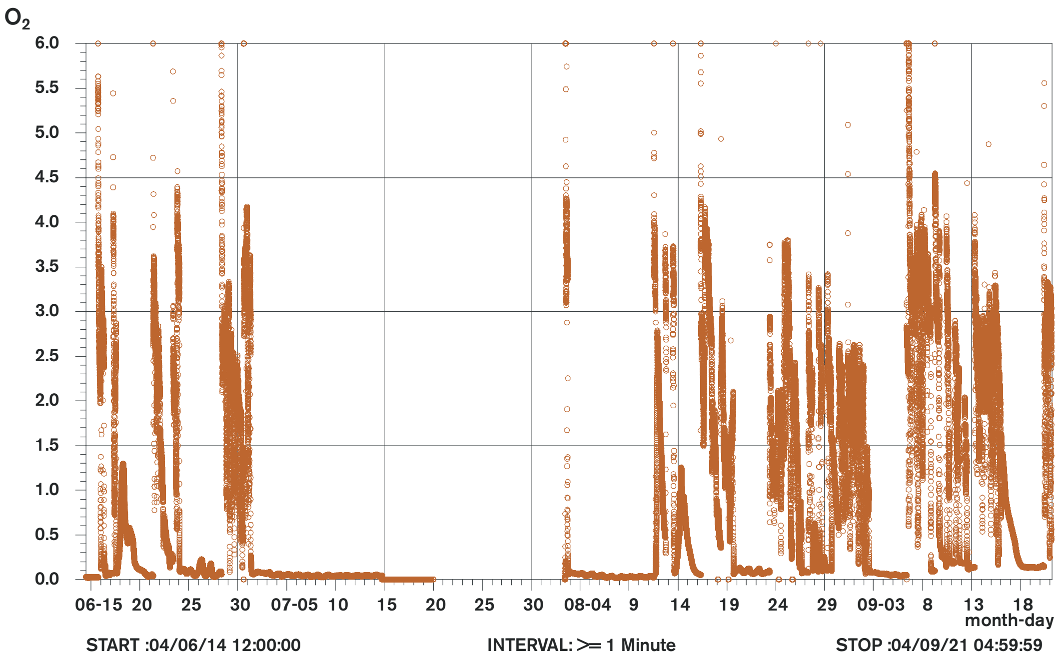


***Figure 5-15.** Dissolved oxygen content in the flushing water versus time when drilling KFM06A.*

Flushing water quality

The results from chemical analyses of flushing water from the supply well HFM05 are compiled in Appendix C and /6/. 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.
- To check the microbe content (for the same reason as the item above). Analysis of the microbe content reveals the abundance of microorganisms included in the flushing water pumped into the core drilled borehole. The microorganisms originate partly from the flushing water well and partly from the flushing water supply system between the well and the core drilled borehole. Results of the microbe analyses are presented in /6/.
- To monitor the groundwater chemical composition during drilling. 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 KFM06A.

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

Organic constituents

The percussion borehole HFM05 has been used before as flushing water supply well and the concentration of Total Organic Carbon (TOC) was known to be sufficiently low. Three samples were collected during the drilling period and the TOC concentration was in the range 5.8–6.1 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 HFM05 was relatively stable during drilling.

Sampling of return water during drilling

The return water, i.e. the water discharging from the borehole during drilling due to air-lift pumping, is a mixture of flushing water and formation water from the borehole. The return water from KFM06A was drained off to the Baltic Sea, see Figure 1-1. The return water may be of increased salinity or possibly show enhanced concentrations of other components that could have negative effects on the lake biotop. Therefore, in order to check potential environmental hazards, not only the flushing water but also the return water was sampled at three occasions during drilling. The water analysis data are compiled in Appendix C.

5.4.4 Groundwater sampling and analyses during drilling

No first strike samples were collected from packed off sections of KFM06A during the drilling period, cf Table 4-1.

5.4.5 Registration of the groundwater level in KFM06A

To enhance the recovery of drill cuttings from the borehole, air-flush (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 5-16).

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 35–45 m below top of casing. Shortly before the end of drilling, the draw-down again decreased, to approximately 35 m. 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. When pumping was restarted, a rapid draw-down occurred.

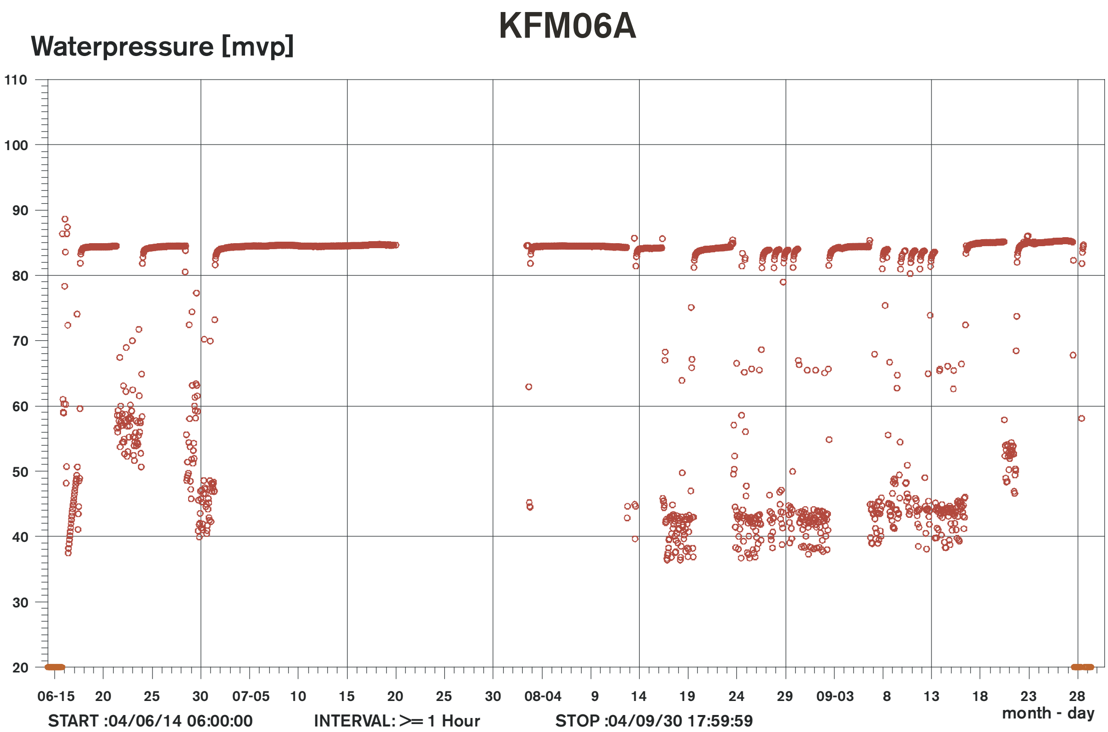


Figure 5-16. *Variation of the level of the groundwater table in KFM06A during drilling.*

5.4.6 Core sampling

The average drill core length per run obtained from the drilling was 2.69 m. Due to the low fracture frequency at depth, nine 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 relatively high water flow. This caused an uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations. However, it seems probable that the percussion drilled part was well cleaned from debris, since 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 KFM06A 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 4,064 kg. The difference between the theoretically produced and recovered dry weight of debris is 2,312 kg, which gives a recovery of 64%.

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 64%. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

However, it seems plausible that drilling debris has been injected into the fracture system of the formation, especially in the permeable sections with increased fracture frequency above c 350 m in the borehole.

5.4.8 Deviation measurements

The deviation measurements made in borehole KFM06A with the Reflex Maxibor system show that the borehole deviates 33 m upwards and 140 m to the right compared to an imagined straight line following the dip and strike of the borehole start point (Figures 5-17 and 5-18).

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

All length values used for measurements in the borehole and of the drill core originate from registrations of the length of the drilling 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 of the pipe string, and to some extent bending of it.

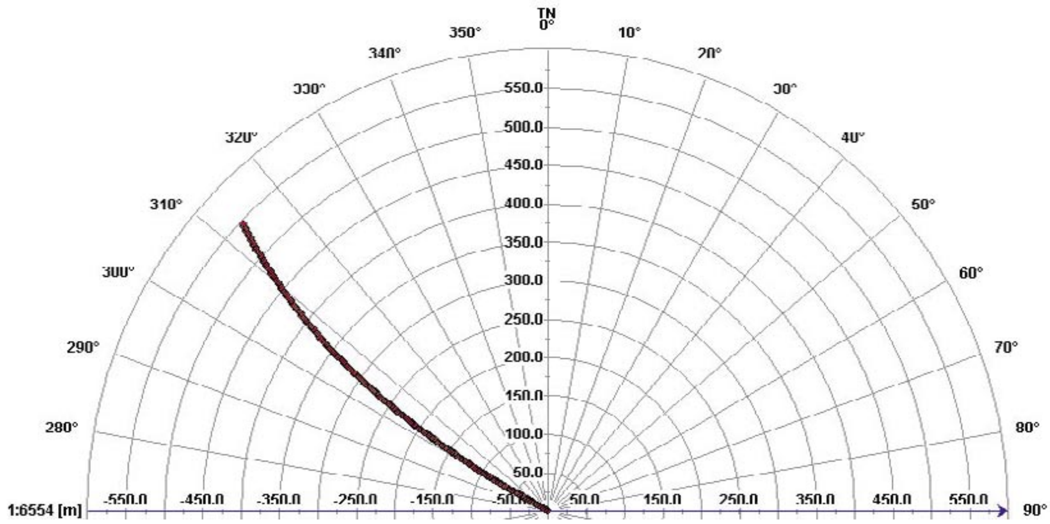


Figure 5-17. Horizontal projection of measured deviation of KFM06A.

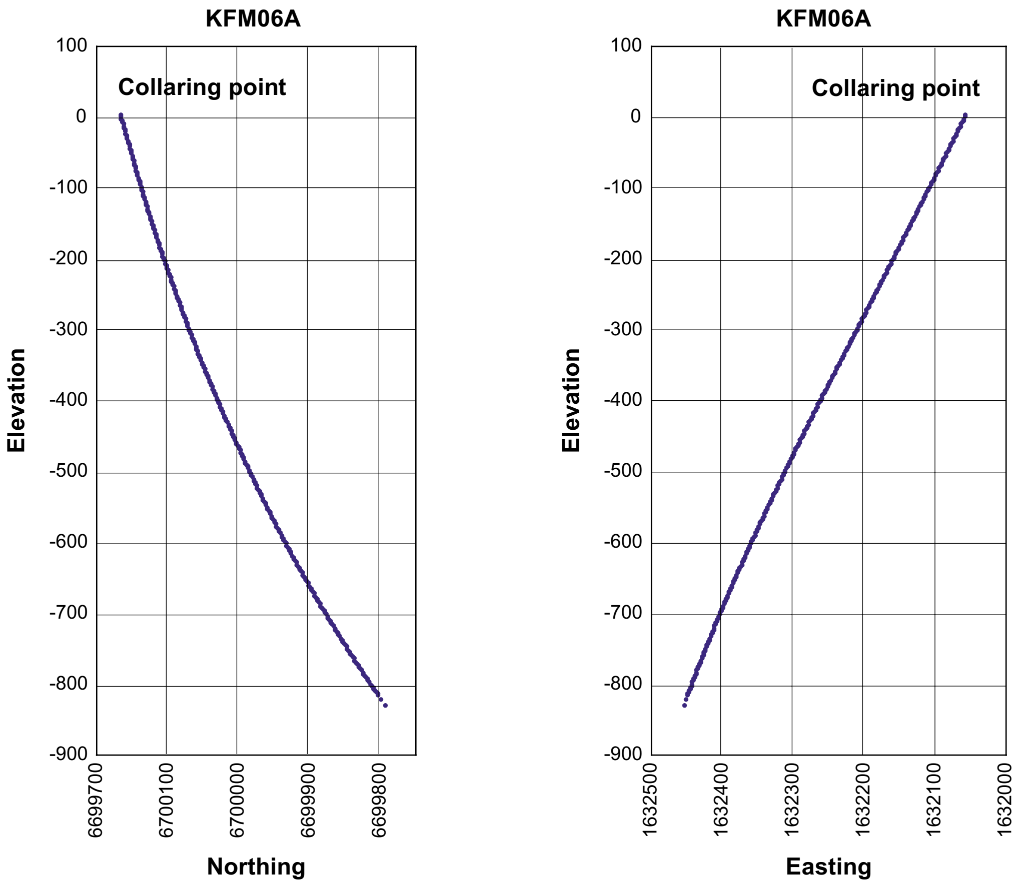


Figure 5-18. Two vertical projections of measured deviation in KFM06A.

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 5-19, which is based on load tests performed in the laboratory by the manufacturer of the drilling pipes.

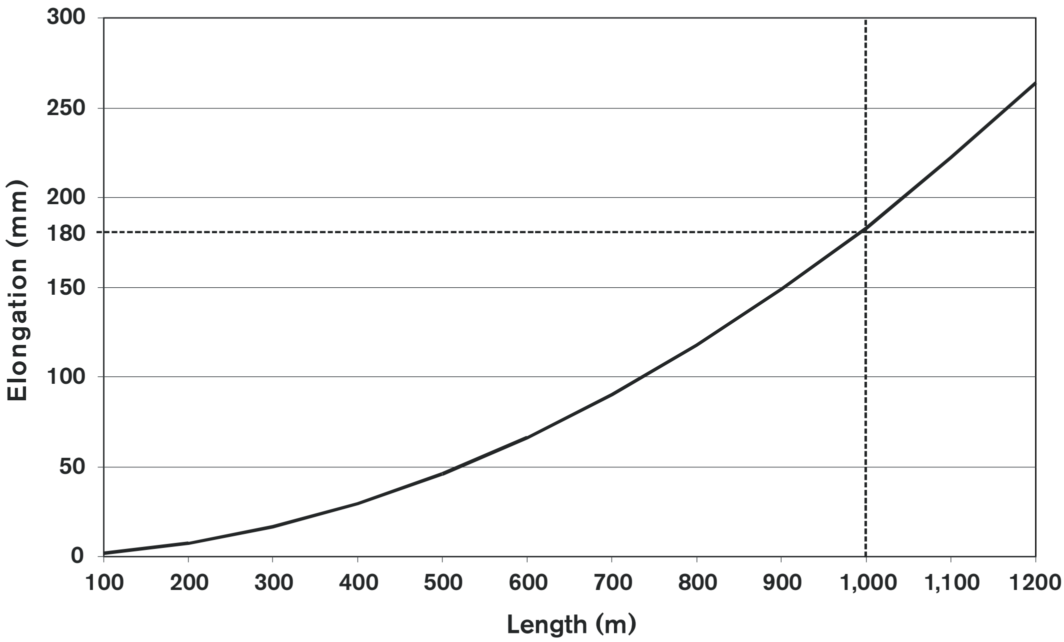


Figure 5-19. *The diagram illustrates the elongation of the WL-76 drilling pipe string when hanging in a vertical water filled borehole. Values from a laboratory load tests of the drilling pipe string.*

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)

Results from pumping tests and pressure measurements from borehole KFM06A are presented in Tables 5-2 and 5-3.

One successful pumping test was performed in section 737.70–821.56 m. Absolute pressure measurements were conducted in a total of two sections, see Table 4-1. Test diagrams are attached in Appendix D and E.

For the pumping test the specific capacity (Q/s) and the hydraulic transmissivity (T_M) were calculated according to SKB MD 320.004 (Table 1-1).

Table 5-2. Pumping tests with wireline probe in KFM06A.

Tested section (m)	Q/s (m^2/s)	T_{Moye} (m^2/s)	Comments
737.70–821.56	1.8E–6	2.3E–6	A draw-down of c 394 kPa was generated in the section. Stable pressure and flowrate.

Table 5-3. Absolute pressure measurement in KFM06A.

Test section (m)	Last pressure reading during test (kPa)	Test duration (h)	Borehole length to pressure sensor (m from ToC)
470.20– 583.93	4,061.5	> 48	471.18
898.90– 975.70	7,510.5	> 48	899.88

5.4.11 Groove milling

After completion of drilling, borehole KFM06A will be used for 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 at certain levels with a specially designed tool. This was carried out after termination of 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 5-20. Table 5-4 presents the reference levels selected for milling. The table also reveals that milling failed at certain levels (cf Section 5.4.3, "Flushing water pressure"). After milling, the reference grooves were detected with the SKB level indicator (a caliper). A BIPS-survey provided the final conformation of where the groove milling was successful and where it failed.

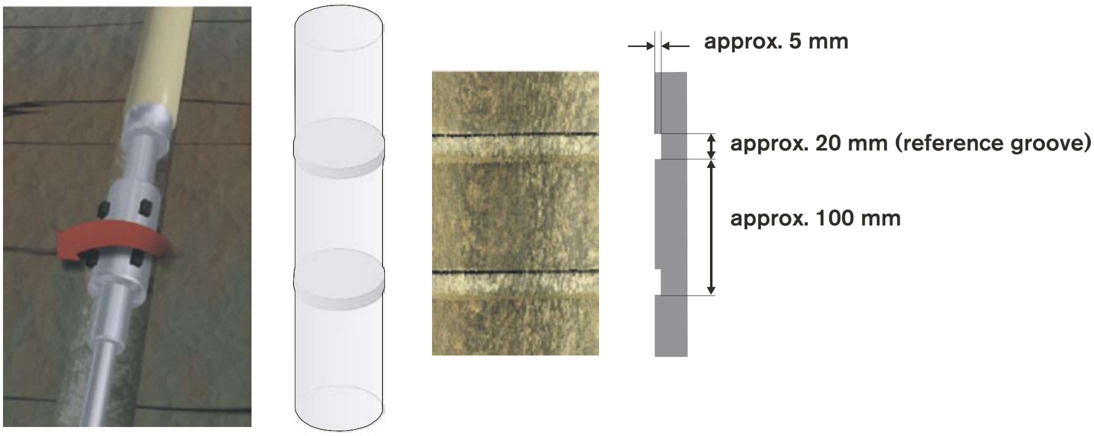


Figure 5-20. *Layout and design of reference grooves. The milling tool shown to the left.*

Table 5-4. Compilation of length to the reference grooves. The positions of the grooves are determined from the length of the 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
150	Yes	Yes	600	Yes	Yes
200	Yes	Yes	650	No	Yes[1]
250	Yes	Yes	700	No	Yes[1]
301	Yes	Yes	750	No	Yes[1]
350	Yes	Yes	800	No	Yes[1]
402	Yes	Yes	850	No	Yes[1]
450	Yes	Yes	900	No	Yes[1]
500	Yes	Yes	980	No	Yes[1]
550	Yes	Yes			

[1] weak

5.4.12 Consumables

The amount of oil products consumed during drilling of the percussion drilled part of KFM06A (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, se Figure 5-21. Due to the 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, see Figure 5-21, whereupon the iron filings are dried weighed. The amount of retrieved magnetic iron filings from KFM06A is presented in Table 5-7 and compared with the amount from the previously drilled telescopic borehole KFM05A.

5.4.13 Recovery measurements after cleaning by air-lift pumping

The final cleaning of KFM06A by air-lift pumping caused a draw-down of 25 m. After completed pumping, the recovery of the groundwater table was monitored. The results are displayed in the diagram of Figure 5-22. Pressure registration was conducted during six hours, and the water-yielding capacity could be determined from the diagram. From the diagram an inflow of > 160 L/min at a drawdown of 25 m can be estimated.

Prior to drilling of KFM06A, borehole HFM16 was percussion drilled c 40 m south of drill site DS6. The pumping activities in KFM06A revealed a clear hydraulic connection between HFM16 at shallow levels (< 100 m).

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
KFM06A	Approx 20 L (not documented)	No consumption measured	7.2 kg

Figure 5-21. The outlet of return water pipe from the borehole is placed right above a magnetic steel plate mounted in the first container. Magnetic iron filings in the return water are caught on the plate during flooding of the return water over the plate. The filings are collected on a regular basis.

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

Borehole ID	Length (m)	Cement volume (Aalborg Portland Cement/microsilica)	Grouting method	Remarks
KFM06A	12.00	1,071 kg/1,200 L	Hose	Entire borehole
KFM06A	100.30	2,642 kg/2,960 L	Hose	Entire borehole
KFM06A	100.30	1,856 kg/2,080 L	Gap injection	

Table 5-7. Total magnetic iron retrieved during drilling of KFM05A and KFM06A.

Borehole ID	Weight magnetic (kg)	Comment
KFM05A	45.3	
KFM06A	36	

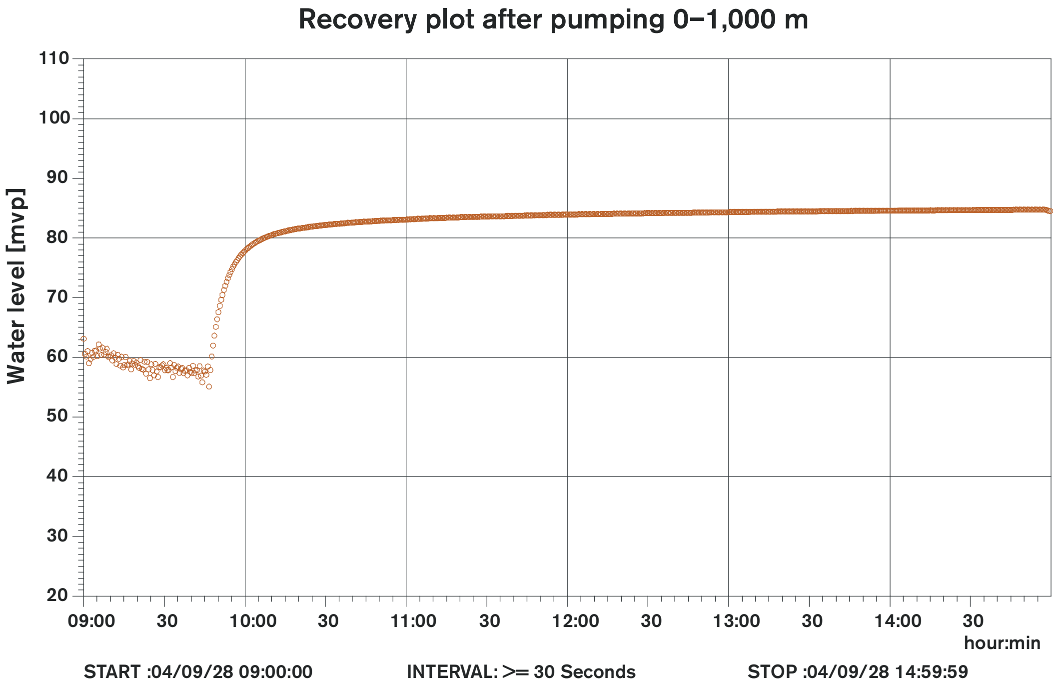


Figure 5-22. *Recovery of groundwater table in section 0–1,000.64 m of KFM06A after stop of air-lift pumping.*

5.5 Geometrical and technical design of borehole KFM06B

Administrative, geometric and technical data for the telescopic borehole KFM06B are presented in Table 5-8. The technical design of the borehole is illustrated in Figure 5-23. A Well Cad-presentation of borehole KFM06B is given in Appendix F.

5.6 Core drilling 2.51–100.33 m (KFM06B)

Core drilling of KFM06B was accomplished during three weeks (Figure 5-24). The soil depth at DS6 proved to be 2.51 m and was drilled with a B-dimension (Ø 116 mm) core barrel. After core drilling and reaming to Ø 101 mm, a stainless steel casing of c 4.61 m length was installed and grouted, see Figure 5-23. Core drilling with Ø 77.3 mm diameter was terminated after three shifts. When the first post-drilling measurement (BIPS-logging) was performed, an outfall in the borehole at c 55 m was discovered. The instability prevented further measurements until the borehole was stabilized seven months later.

5.6.1 Flushing water and return water flow rate – water balance

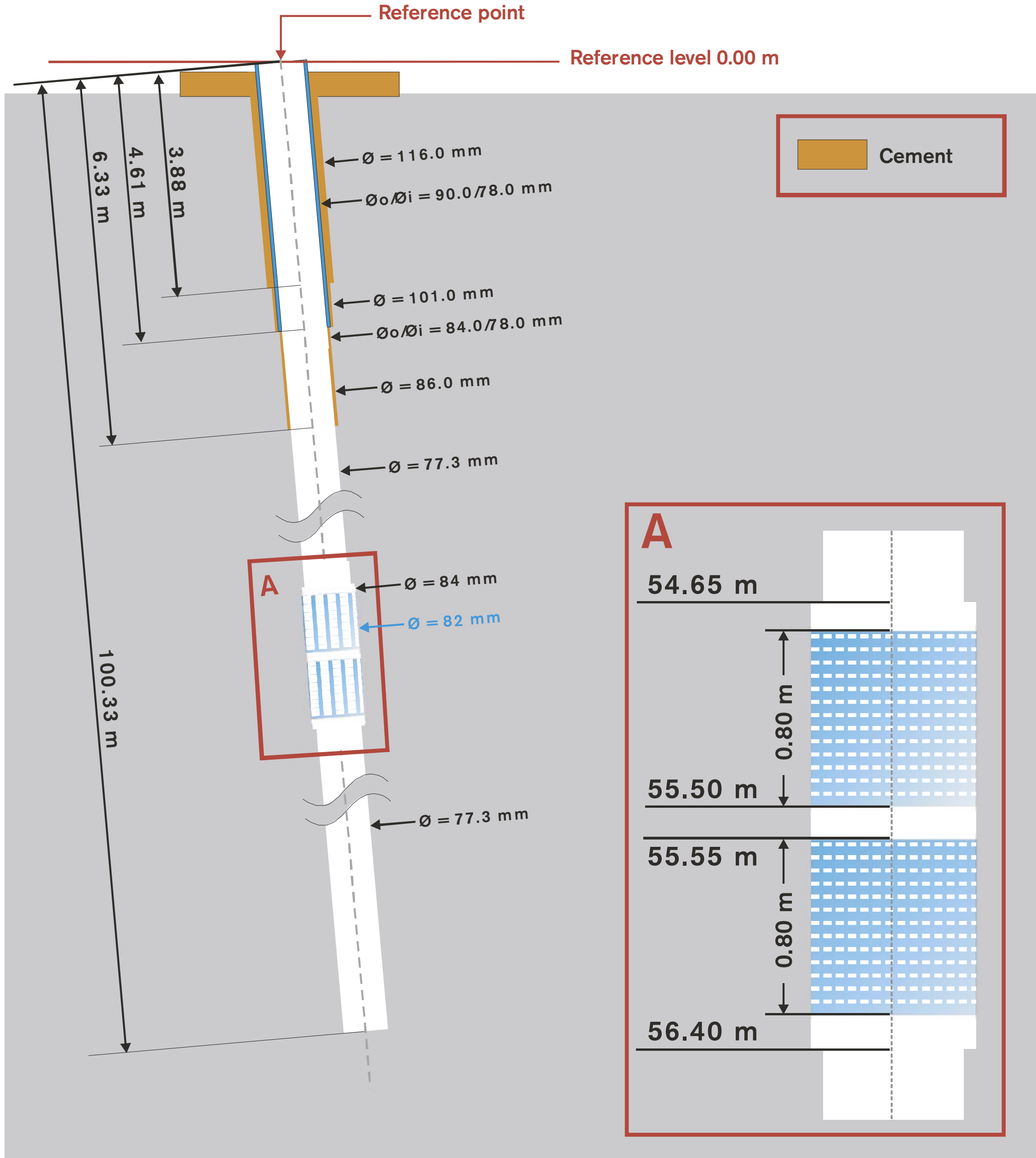
Figure 5-25 displays the accumulated volumes of flushing water and return water from the entire drilling period. Figure 5-25 illustrates the accumulated volumes of flushing water and return water at the end of the drilling period, from which a return water/ flushing water quotient of 0.27 can be estimated.

Table 5-8. Administrative, geometric and technical data for borehole KFM06B.

Parameter	KFM06B
Borehole name	KFM06B
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	May 26, 2004
Completion date	June 08, 2004
Core drilling period	2004-05-26 to 2004-06-08
Contractor core drilling	Drillcon Core AB
Core drill rig	ONRAM 2000 CCD
Position KFM06B at top of casing (RT90 2,5 gon V 0:-15 / RHB 70)	N 6699732.24 E 1632446.41 Z 4.13 (m.a.s.l.)
	Azimuth (0–360°): 296.96°
	Dip (0–90°): –83.52°
Position KFM06B at bottom of hole (RT90 2,5 gon V 0:-15 / RHB 70)	N 6699737.54 E 1632436.39 Z –95.55 (m.a.s.l.)
	Azimuth (0–360°): 298.44°
	Dip (0–90°): –83.60°
Borehole length	100.33 m
Borehole diameter and length	From 0.00 m to 3.88 m: 0.116 m
	From 3.88 m to 4.61 m: 0.101 m
	From 4.61 m to 6.33 m: 0.086 m
	From 6.33 m to 100.33 m: 0.077 m
Casing diameter and length	$Ø_o/Ø_i$ = 90 mm/78 mm from 0.00 to 4.61 m
	Casing length from reference level 4.61 m
Drill core dimension	2.51–6.33 m / Ø72 mm
	6.33–100.33 m/ Ø51 mm
Core interval	2.51–100.33 m
Average core length retrieved in one run	2.76 m
Number of runs	34 from 6.33 m (77 mm)
Diamond bits used	2
Average bit life	47 m

Technical data

Borehole KFM06B



Drilling reference point

Northing: 6699732.24 (m), RT90 2,5 gon V 0:-15
Easting: 1632446.41 (m), RT90 2,5 gon V 0:-15
Elevation: 4.13 (m), RHB 70

Orientation

Bearing: 296.96°
Inclination: -83.52°

Length: 100.33 m

Drilling period

Drilling start date: 2004-05-26
Drilling stop date: 2004-06-08

PLEX installation

Start date: 2005-02-03
Stop date: 2005-02-08

Figure 5-23. *Technical data of borehole KFM06B including the perforated steel plates.*

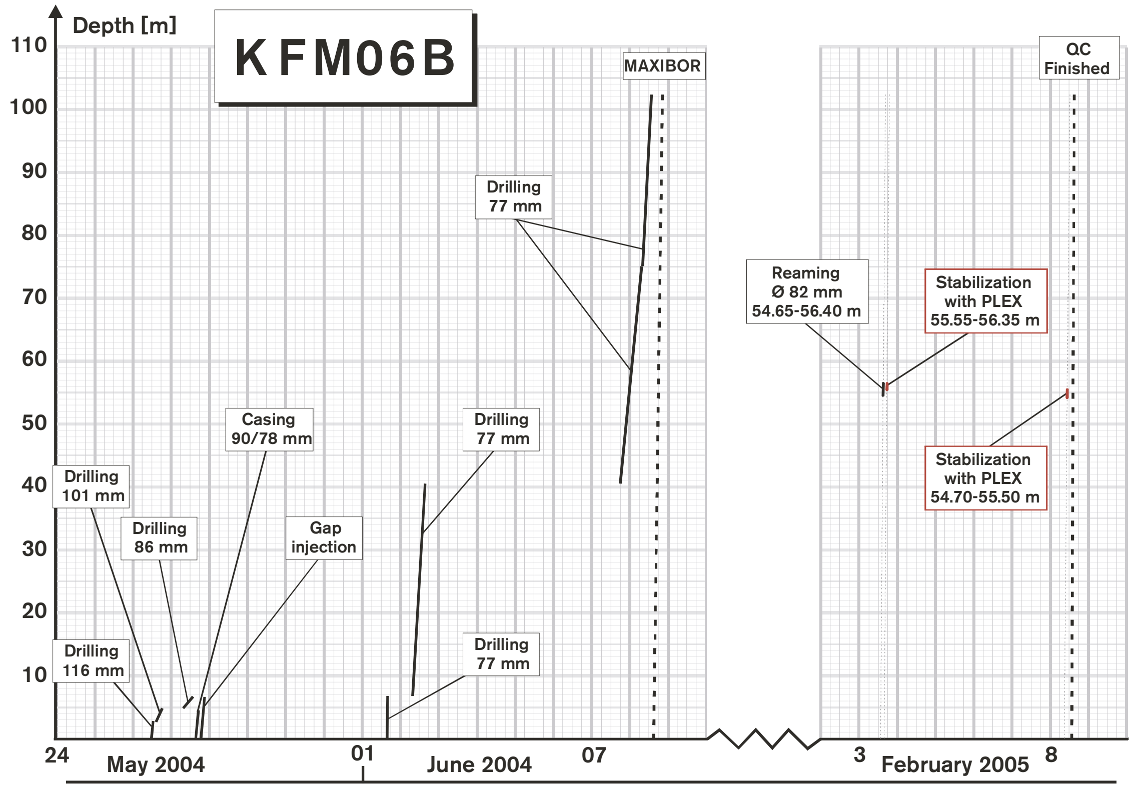


Figure 5-24. *Soil and core drilling of KFM06B (depth versus calendar time), as well as stabilization with the PLEX-system.*

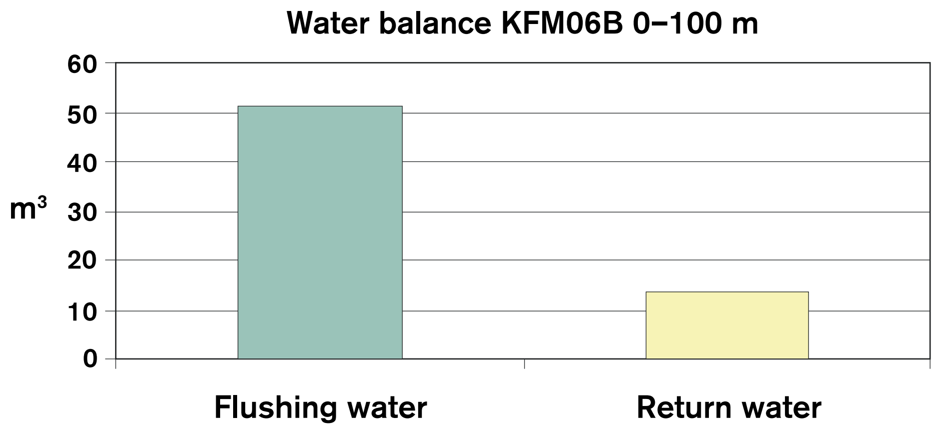


Figure 5-25. *The total volume of flushing water used during core drilling of KFM06B was 51 m^3. During the same period, the total volume of return water was 13.8 m^3. The return water/flushing water balance is then 0.27, i.e. far below 1.0 due to a major flushing water loss in a highly fractured section at approximately 35 m in the borehole.*

Labelling of the flushing water with a tracer

As during drilling of KFM06A, the flushing water was labelled with the organic tracer Uranine and with the same concentration of 0.20 mg/L. The same dosage feeder as in KFM06A was used in KFM06B for adding the tracer. The main loss of flushing water occurred in the highly fractured rock at c 35 m drilling length.

5.6.2 Consumables

The amount of oil products consumed during drilling of the cored drilled borehole KFM06B, thread grease used, and grout used for injections of the casing are reported in Tables 5-9 and 5-10.

The same type of thread grease (silicon based) as used when drilling KFM06A was applied also for drilling of KFM06B.

5.6.3 Deviation measurements

The deviation measurements made in borehole KFM06B with the Reflex Maxibor system show that the borehole is almost straight, following dip and strike of the borehole collaring point.

Table 5-9. Oil and grease consumption.

Borehole ID	Thread grease Unisilikon L50/2	Grease for other purposes
KFM06B	0.8 kg	0.4 kg

Table 5-10. Cement consumption for sealing the gap between the casing and the borehole wall.

Borehole ID	Length (m)	Cement volume (Portland Standard Cement)	Grouting method	Remarks
KFM06B	4.61	1,150 kg/1,000 L	Hose	

5.7 Stabilization

Ensuing completion of drilling of a borehole at the site investigation, an extensive borehole measurement programme is conducted. When the first logging tool applied in KFM06B, the BIPS video-camera, was descended into the borehole, a rock fragment probably falling out from c 55 m caused the instrument to get wedged between the fragment and the borehole wall. However, before that, the camera transferred video-images of the unstable borehole section, see Figure 5-26. The images were used to plan what method was suitable to apply in order to stabilize the borehole wall, as to permit continued borehole investigations. The BIPS-camera could be rescued without damage before the unstable section was attended to.

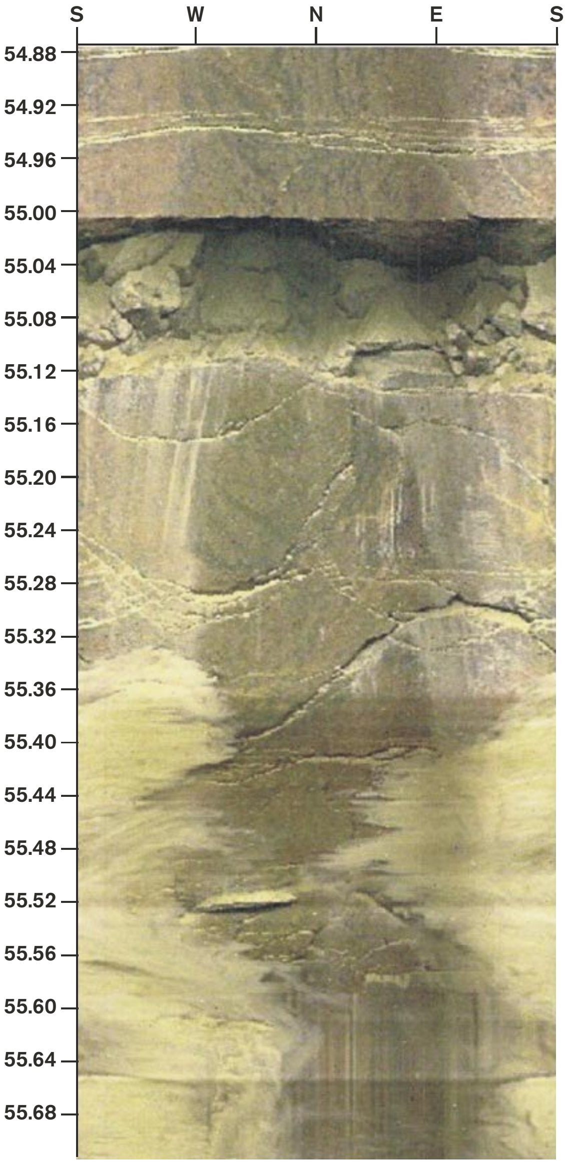


***Figure 5-26.** BIPS-image of instable section in borehole KFM06B.*

It was decided to test the newly developed PLEX-system described in Section 3.3.6 for stabilization of the borehole wall in KFM06B. The following sequence of actions was taken (cf Figures 3-7 and 5-27):

1) The instable section between 54.70–56.40 was reamed to 84 mm.
2) The PLEX tool supplied with two perforated stainless steel plates was attached to the drill pipe string lowered into the borehole.
3) The packer was inflated with an excess pressure of between 60–150 bars whereby the two perforated stainless steel plates were forced into the reamed part of the borehole wall.
4) The packer was deflated.
5) The tool was retrieved from the borehole.
6) After the PLEX operation, the entire borehole was logged with the BIPS-camera, see Figure 5-27. The video images show that the lower plate has been was expanded as much as to be deformed and split open, which also probably caused packer damage when mounting the lower plate. Also the upper plate is much deformed and has been forced out into the cavity of the fracture zone at c 55 m even if the packer was expanded with caution.

After the PLEX stabilization, the borehole has been possible to investigate without problems with instrument jamming. Because the steel plates are perforated, it is also possible to perform hydraulic tests in the entire borehole. However, a decreasing transmissivity of the section in one order of magnitude is achieved /7/ and /8/.

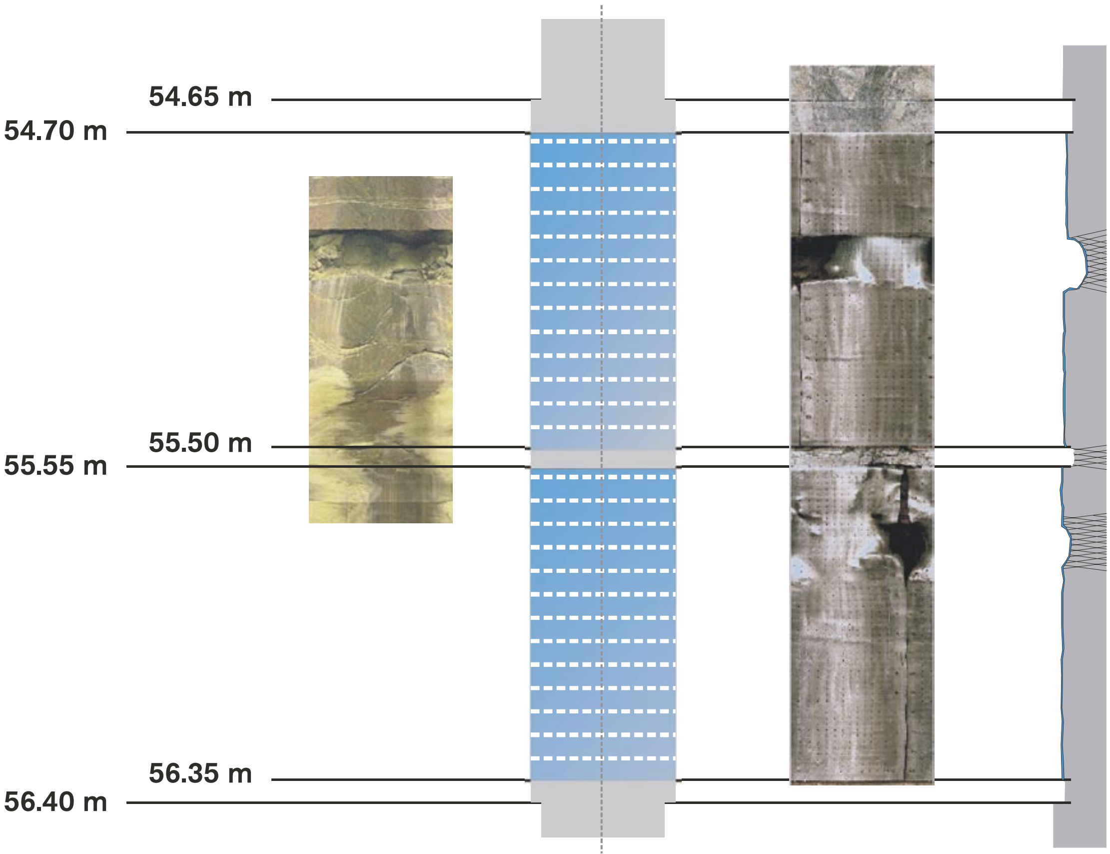


Figure 5-27. *Schematic figure of the stabilized section in borehole KFM06B with BIPS images of the borehole section in question prior to (left) respectively after (right) stabilization with the PLEX system.*

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, 2004.** Claesson, L-Å & Nilsson, G. Forsmark. Forsmark site investigation. Drilling of the telescopic borehole KFM05A at drilling site DS5. SKB P-04-222, Svensk Kärnbränslehantering AB.

/4/ **SKB, 2005.** Petersson, J, Berglund, J, Skogsmo, G, Wängnerud, A, Stråhle, A. Site investigations at Forsmark. Boremap mapping of telescopic drilled borehole KFM06A and cored drilled borehole KFM06B. SKB P-05-101, 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, 2003.** Nilsson, A-C. Forsmark site investigation. Sampling and analyses of groundwater in percussion drilled boreholes and shallow monitoring wells at drillsite DS 2. SKB P-03-48, Svensk Kärnbränslehantering AB.

/7/ **SKB, 2004.** Ludvigson, J-E, Jönsson, S. Hjerne, C. Forsmark site investigation. Pumping tests and flow logging. Boreholes KFM06A (0–100 m) and HFM16. SKB P-04-65, Svensk Kärnbränslehantering AB.

/8/ **SKB, 2005.** Hjerne, C, Ludvigson, J-E, Lindquist, A. Forsmark site investigation. Single-hole injection tests in boreholes KFM06A and KFM06B. SKB P-05-165, Svensk Kärnbränslehantering AB.

Appendix A

Well Cad presentation 0–100 m

Title	PERCUSSION DRILLED BOREHOLE KFM06A

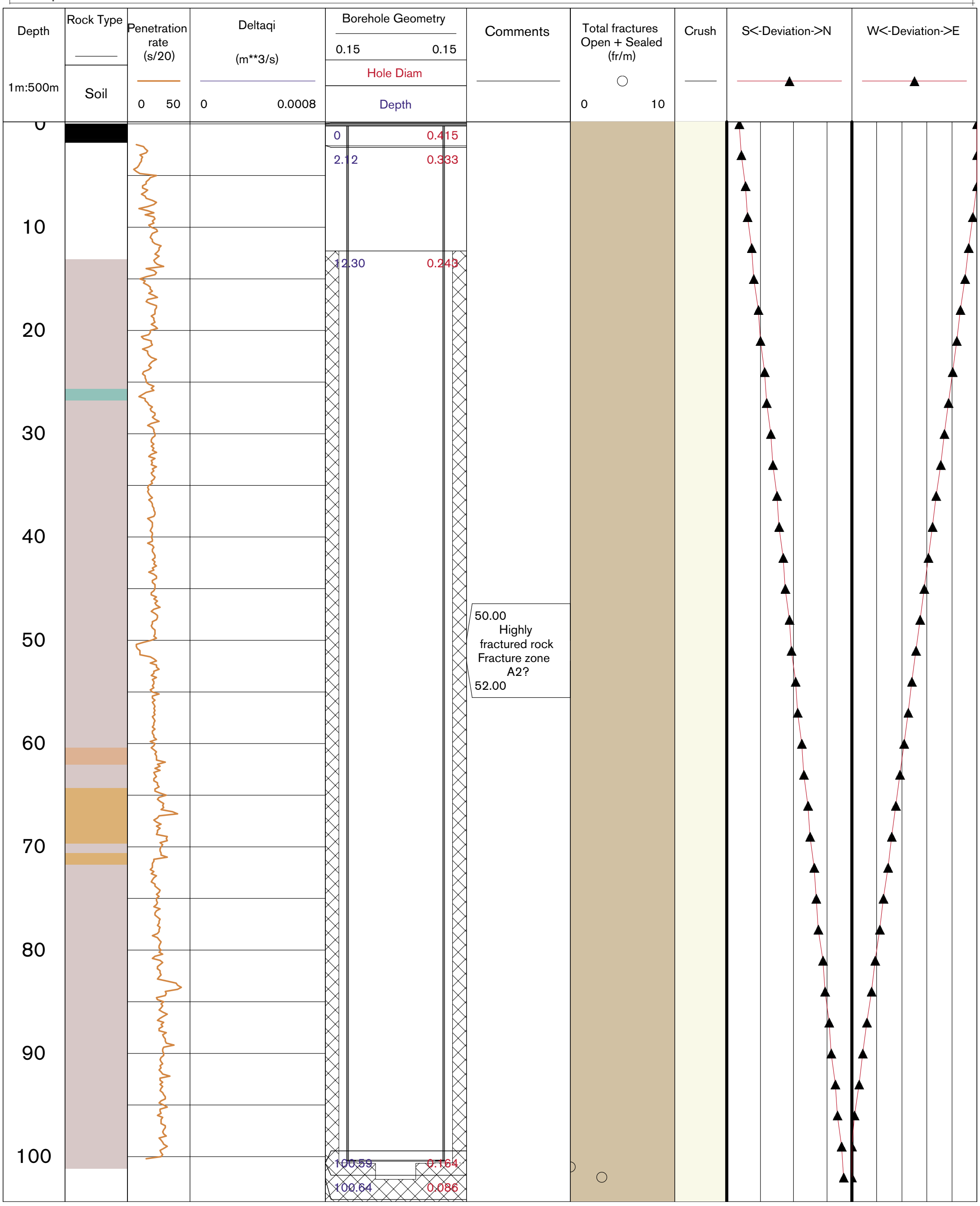
Svensk Kärnbränslehantering AB

Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	KFM06A	Northing [m]	6699732.88
Diameter [mm]	77	Easting [m]	1632442.51
Length [m]	1000.64	Elevation [m.a.s.l.]	4.10
Bearing [°]	300.92	Drilling Start Date	2003-11-11 16:25:00
Inclination [°]	-60.25	Drilling Stop Date	2004-01-20 03:37:00
Date of mapping		Plot Date	2005-04-11 22:24:39

ROCKTYPE
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite

SOIL
- Soil

Script Name



Appendix B

Well Cad presentation 0–1,000 m

Title KFM06A

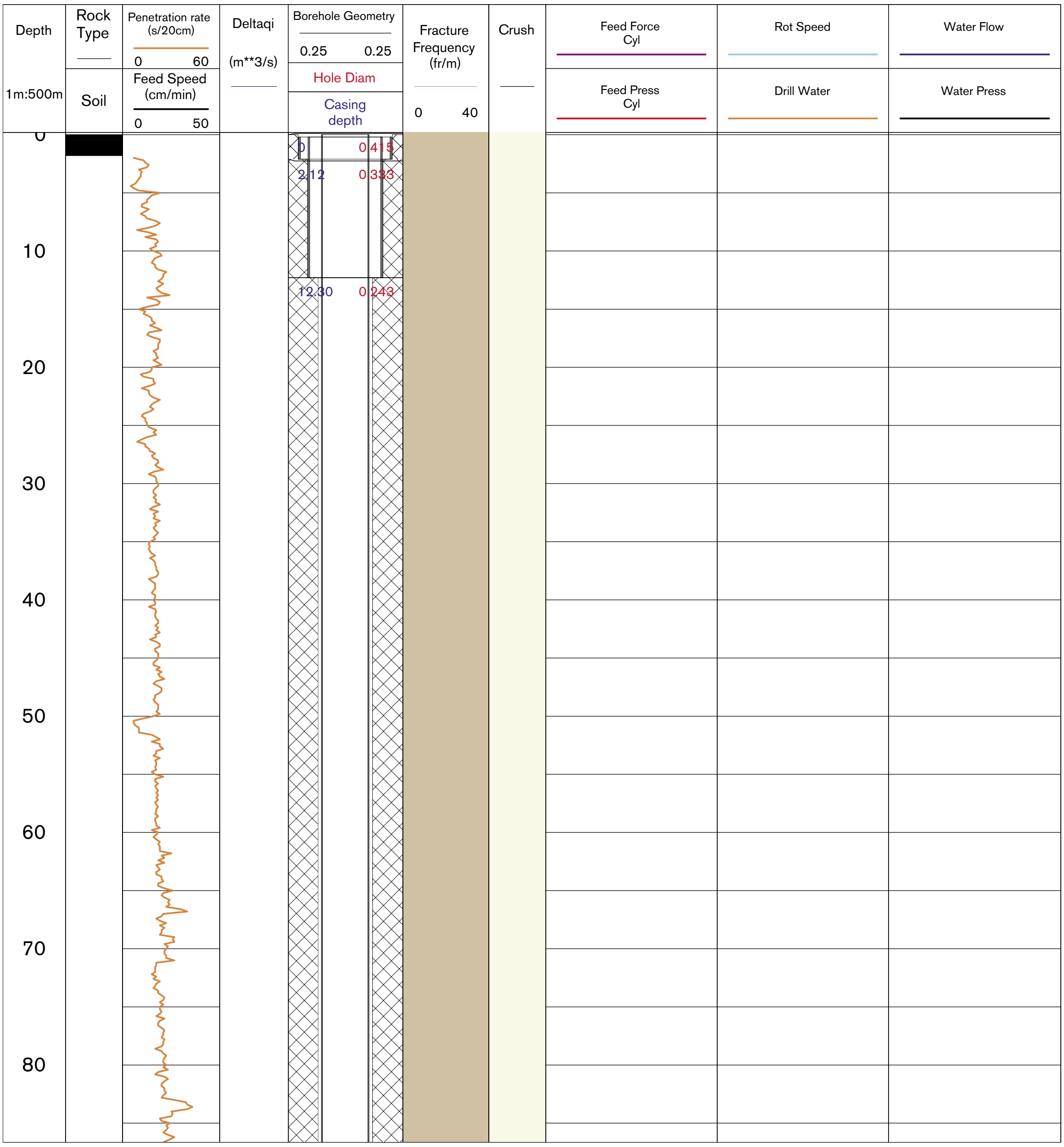
Svensk Kärnbränslehantering AB

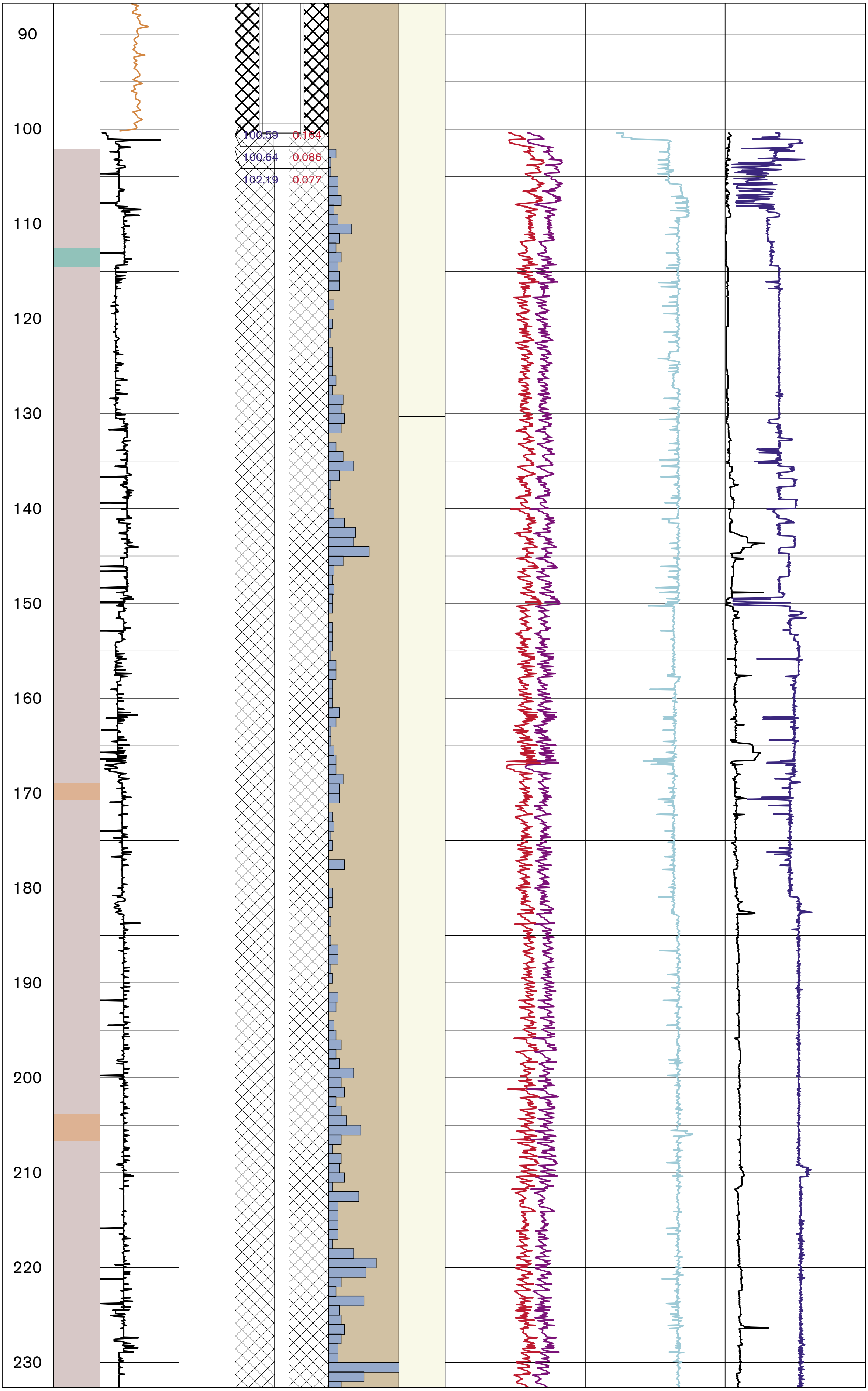
Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	KFM06A	Northing [m]	6699732.88
Diameter [mm]	77	Easting [m]	1632442.51
Length [m]	1000.64	Elevation [m.a.s.l.]	4.10
Bearing [°]	300.92	Drilling Start Date	2003-11-11 16:25:00
Inclination [°]	-60.25	Drilling Stop Date	2004-10-05 03:37:00
Date of mapping		Plot Date	2005-04-13 10:49:42

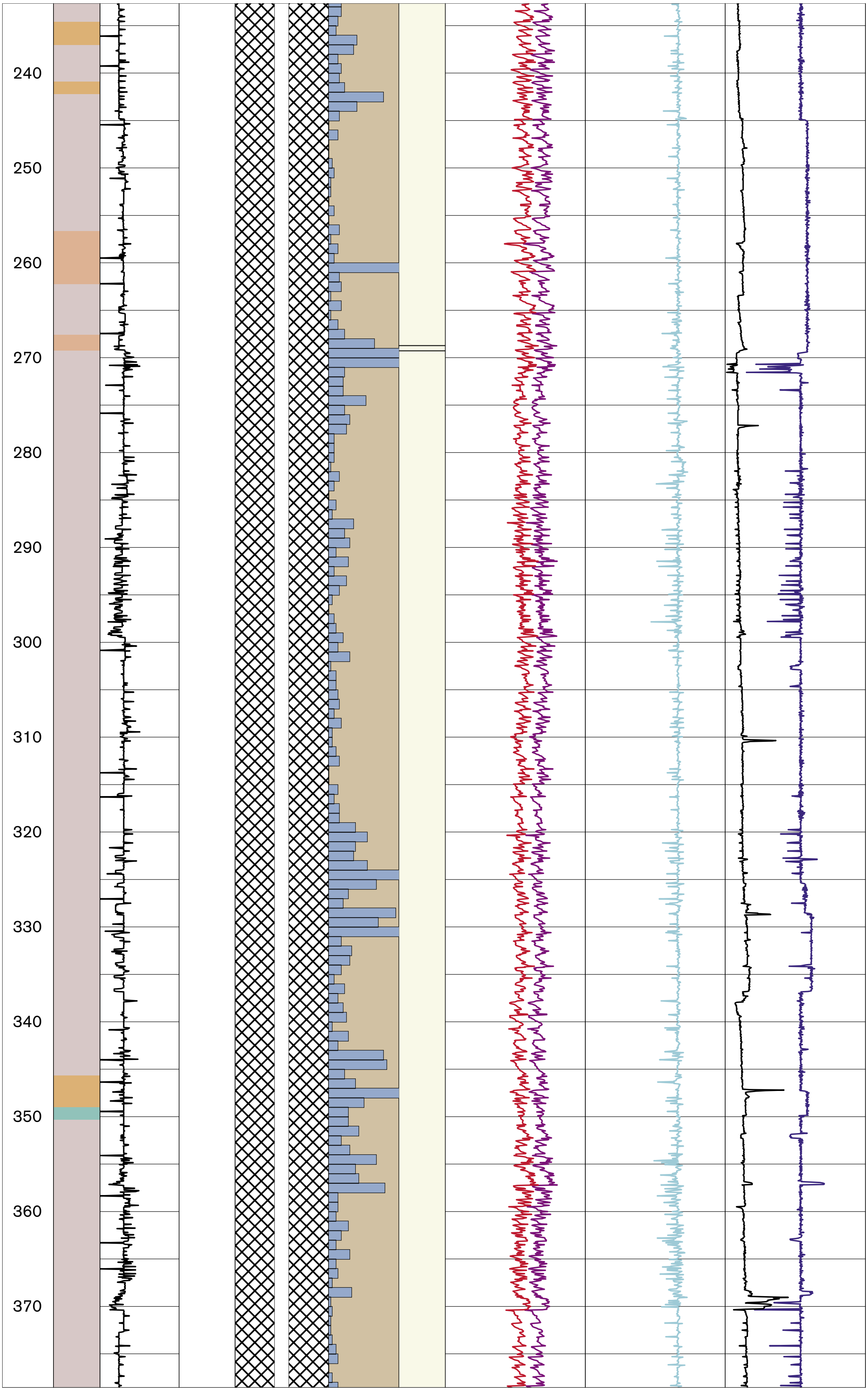
ROCKTYPE FORSMARK
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Granodiorite, metamorphic
- Amphibolite

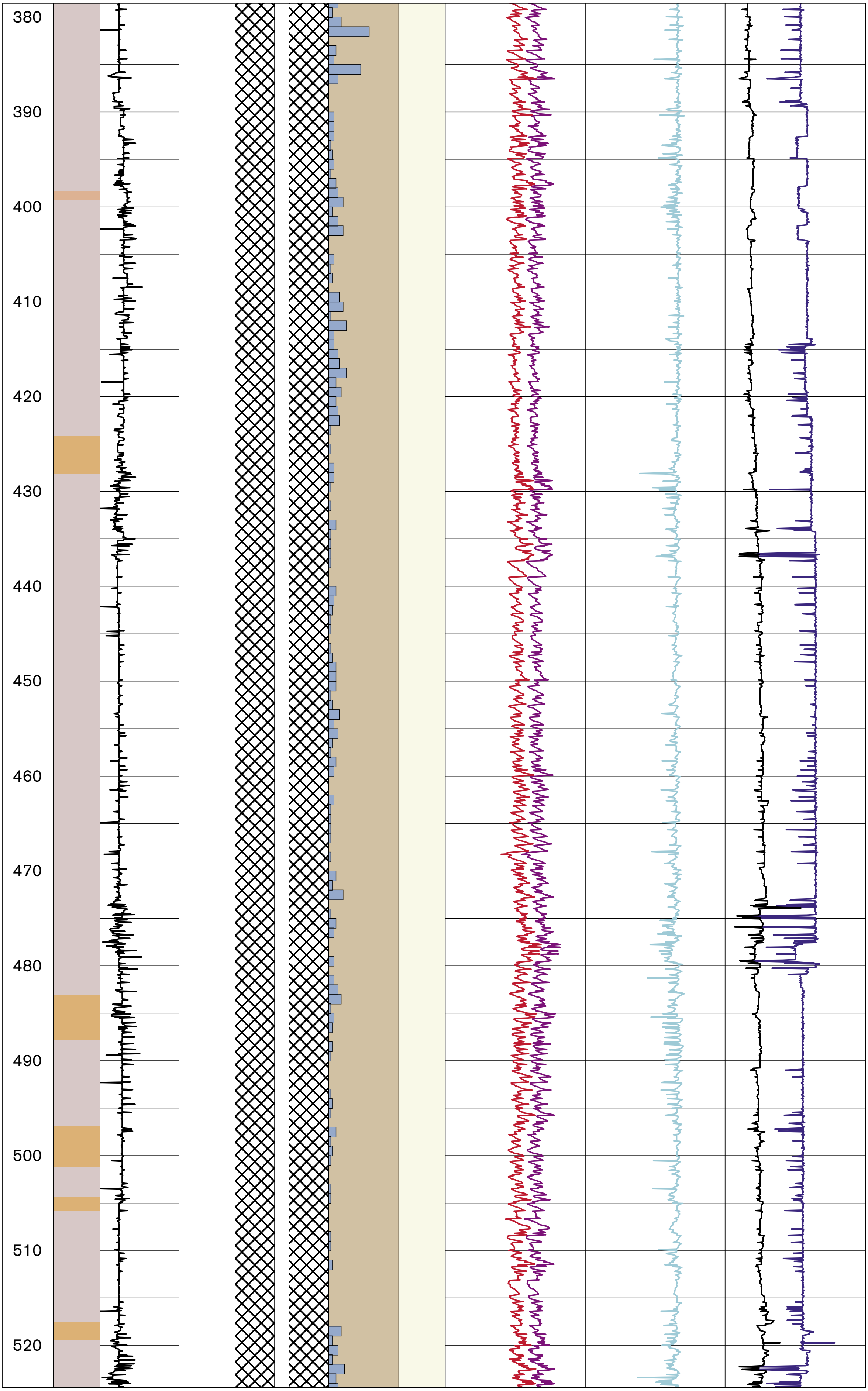
SOIL
- Soil

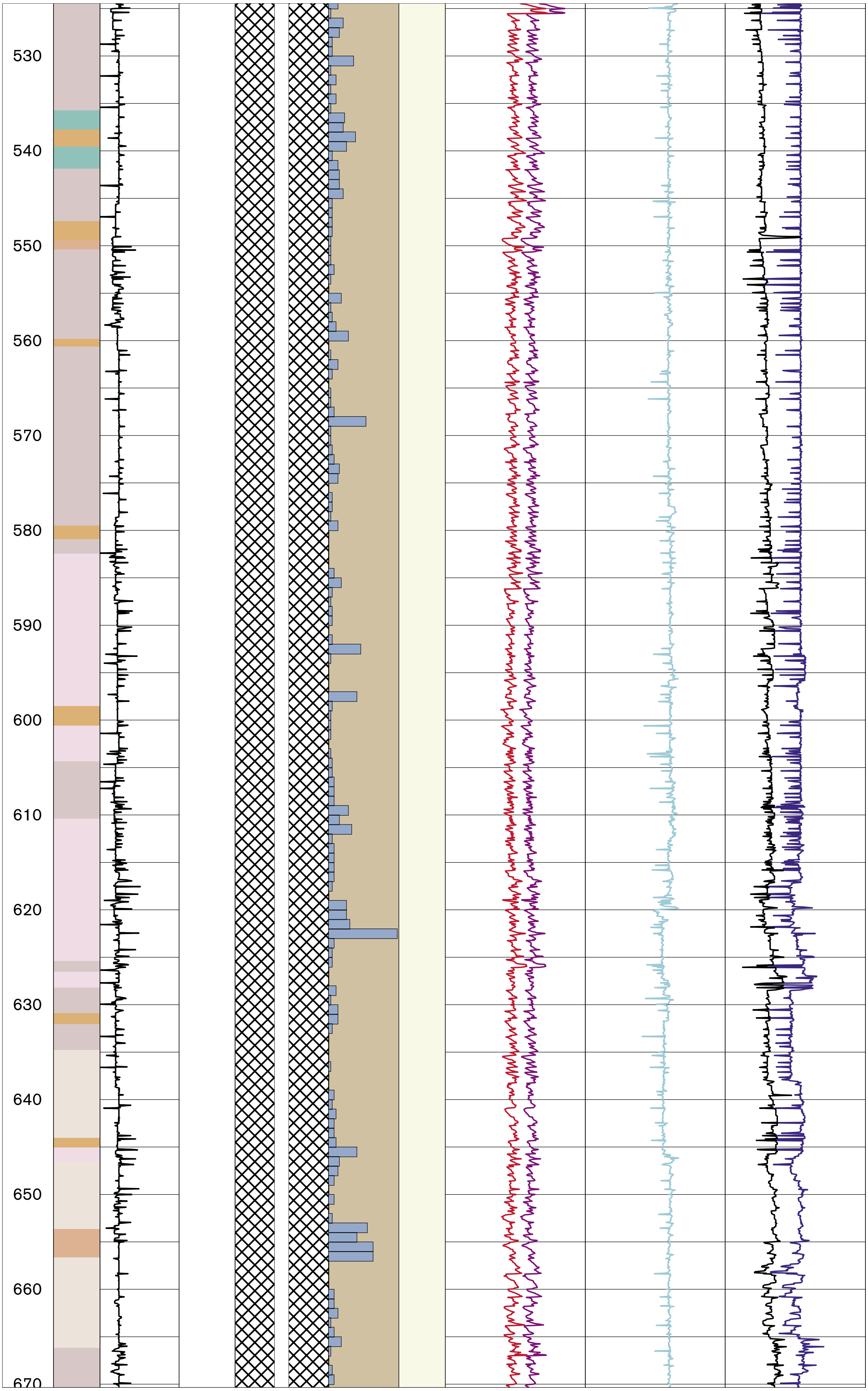
Script Name

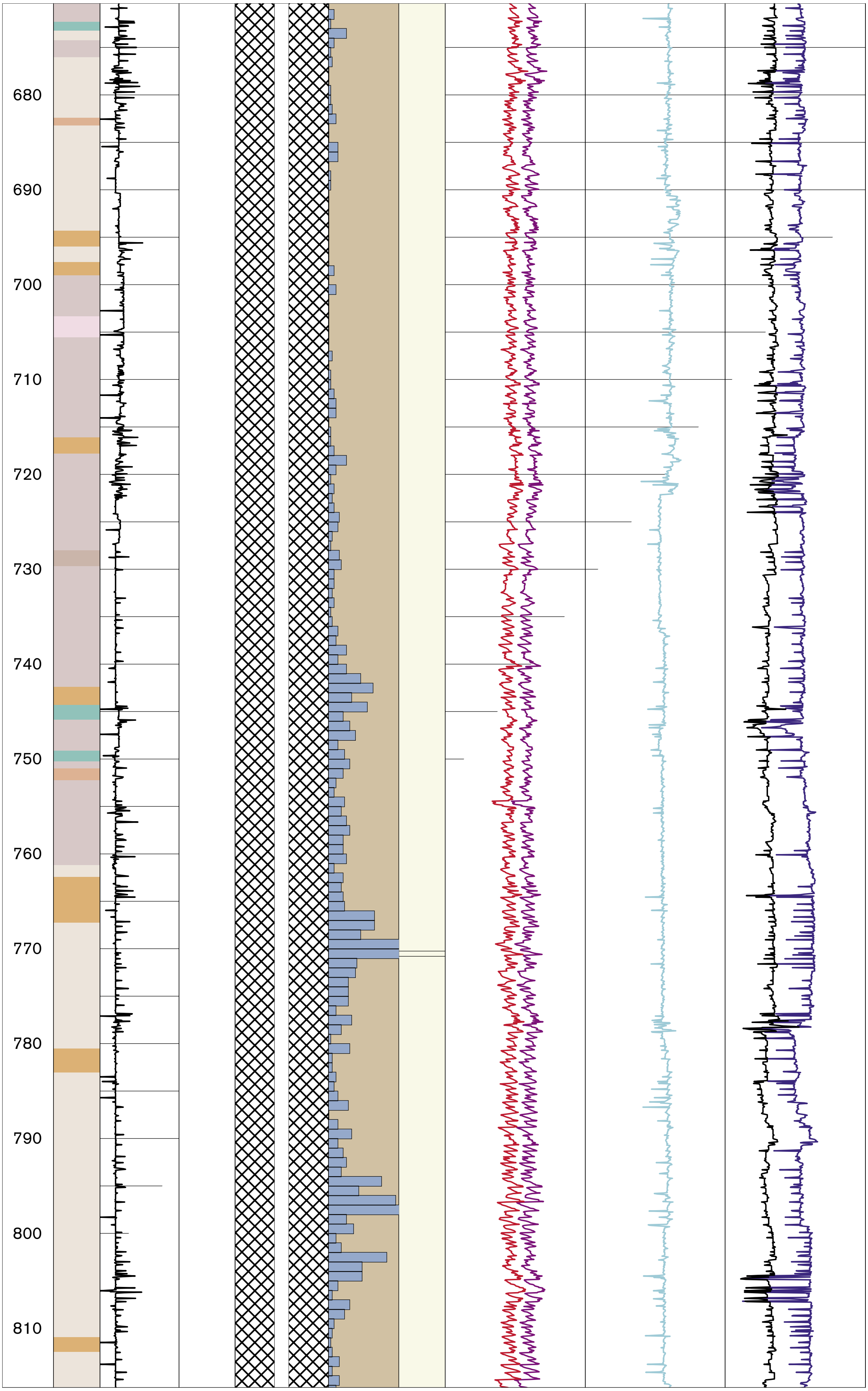


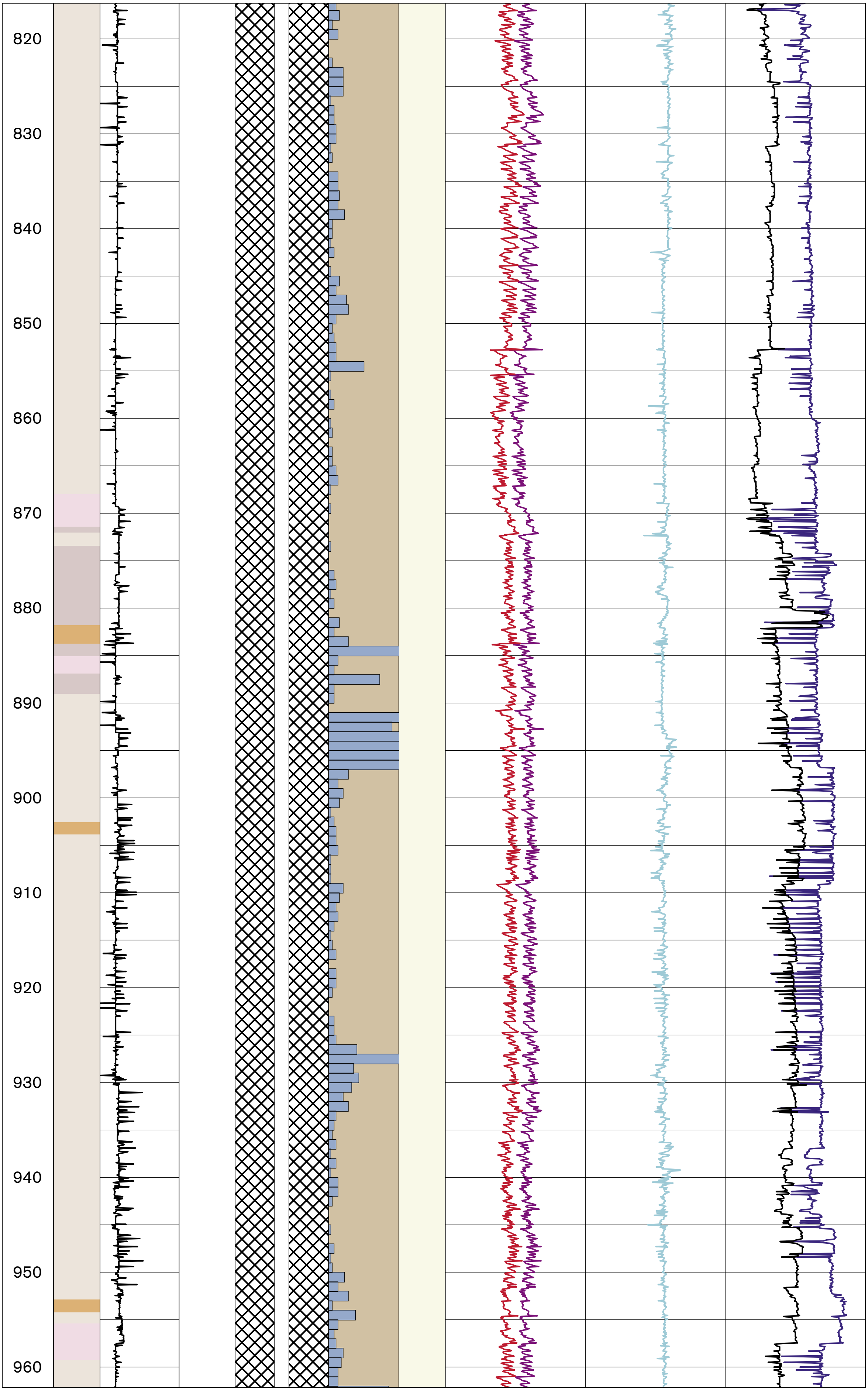

90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
100.59
0.164
100.64
0.086
102.19
0.077

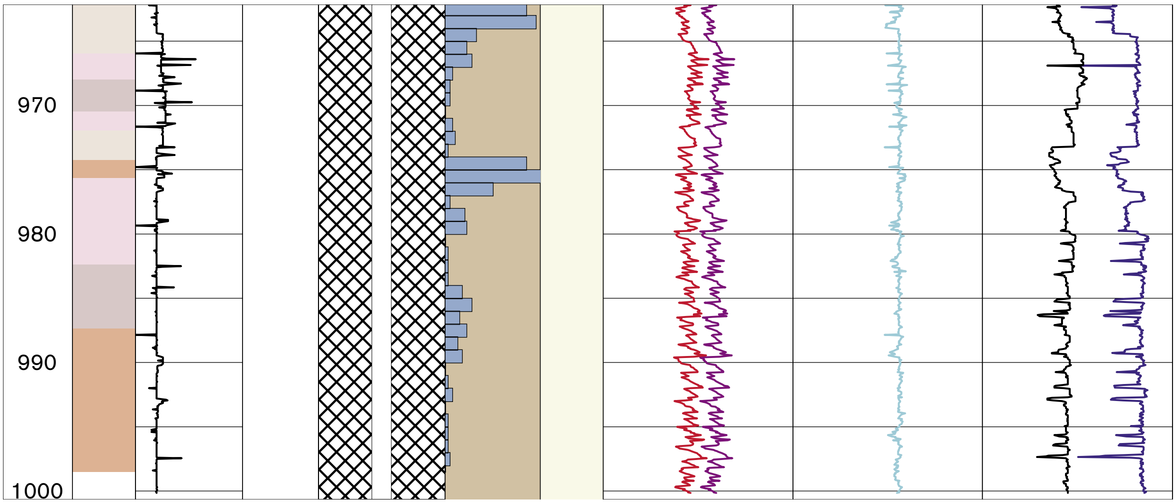

240
250
260
270
280
290
300
310
320
330
340
350
360
370


380
390
400
410
420
430
440
450
460
470
480
490
500
510
520


530
540
550
560
570
580
590
600
610
620
630
640
650
660
670


680
690
700
710
720
730
740
750
760
770
780
790
800
810


820
830
840
850
860
870
880
890
900
910
920
930
940
950
960


970
980
990
1000

Appendix C

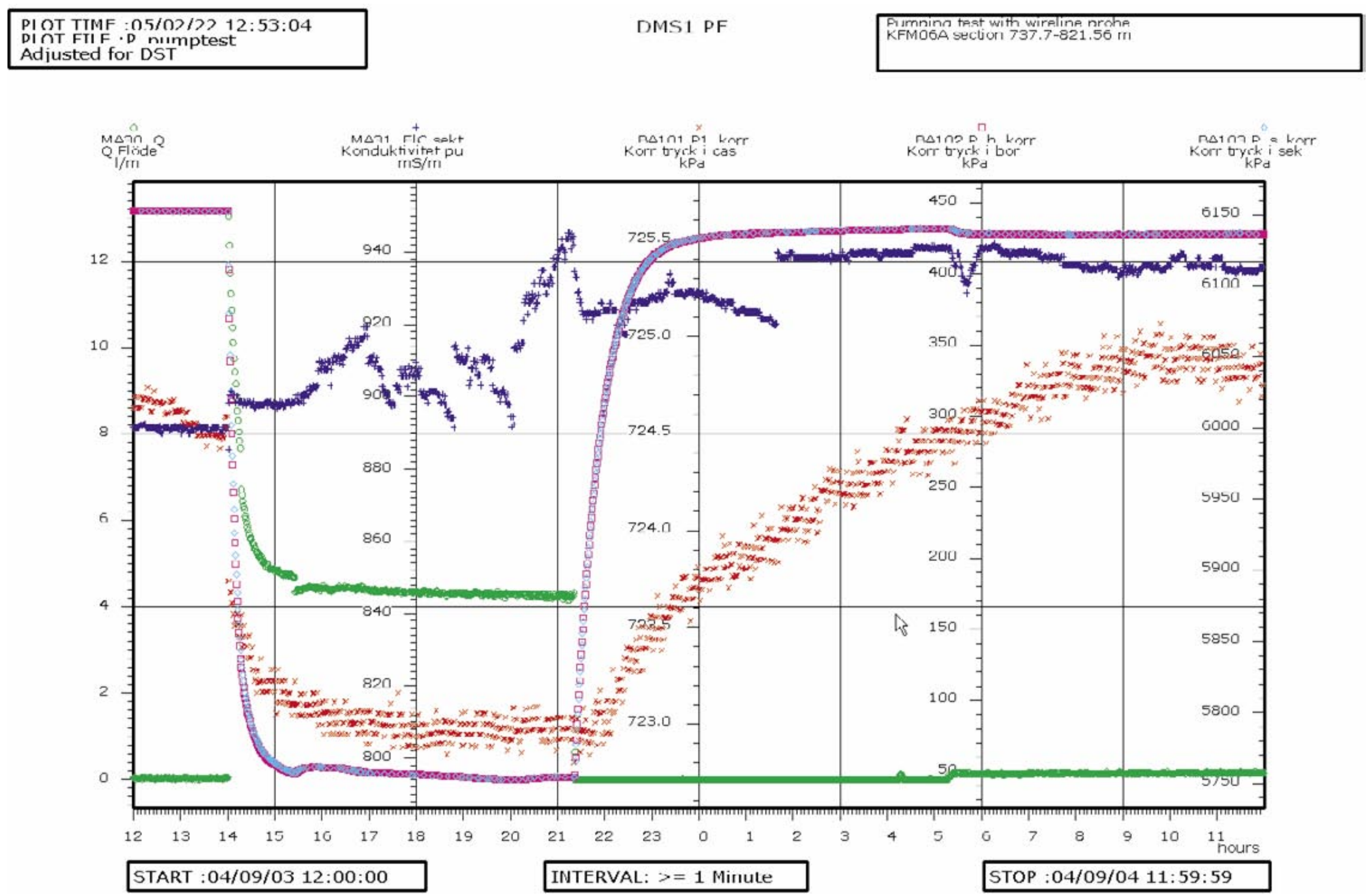
Chemical analysis

ID code	Sample no	Date	Water type	Charge balance (%)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	SO_4-S (mg/L)	Br (mg/L)	F (mg/L)	Si (mg/L)	Li (mg/L)	Sr (mg/L)	pH
KFM06A	8621	2004-08-23 10:45	Return water	–1.18	1,270	29.4	519	139	210	3,080	258	81.7	12.0	1.40	6.25	0.045	3.77	7.74
KFM06A	8624	2004-09-07 09:55	Return water	–2.21	1,500	29.6	656	167	158	3,860	309	96.7	13.9	1.10	5.82	0.042	5.01	7.62
KFM06A	8636	2004-09-21 07:40	Return water	–1.64	1,490	30.2	628	161	170	3,730	300	92.5	13.8	1.10	6.37	0.043	4.71	7.45

ID code	Secup (m)	Seclow (m)	Sample no	Date	Water type	Charge balance (%)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	SO_4-S (mg/L)	Br (mg/L)	F (mg/L)	Si (mg/L)	Li (mg/L)	Sr (mg/L)	pH
HFM05	25.0	200.1	8622	2004-08-23 10:45	Flushing water	–0.78	1,360	31.8	550	151	205	3,280	270	87.1	12.2	1.35	6.68	0.039	3.97	7.37
HFM05	25.0	200.1	8623	2004-09-07 10:05	Flushing water	–2.38	1,220	29.2	508	137	210	3,060	254	80.2	11.2	1.30	6.73	0.034	3.63	7.36
HFM05	25.0	200.1	8639	2004-09-21 07:30	Flushing water	–2.22	1,210	32.1	531	138	209	3,080		82.1	11.9		6.53	0.041	3.65	7.36

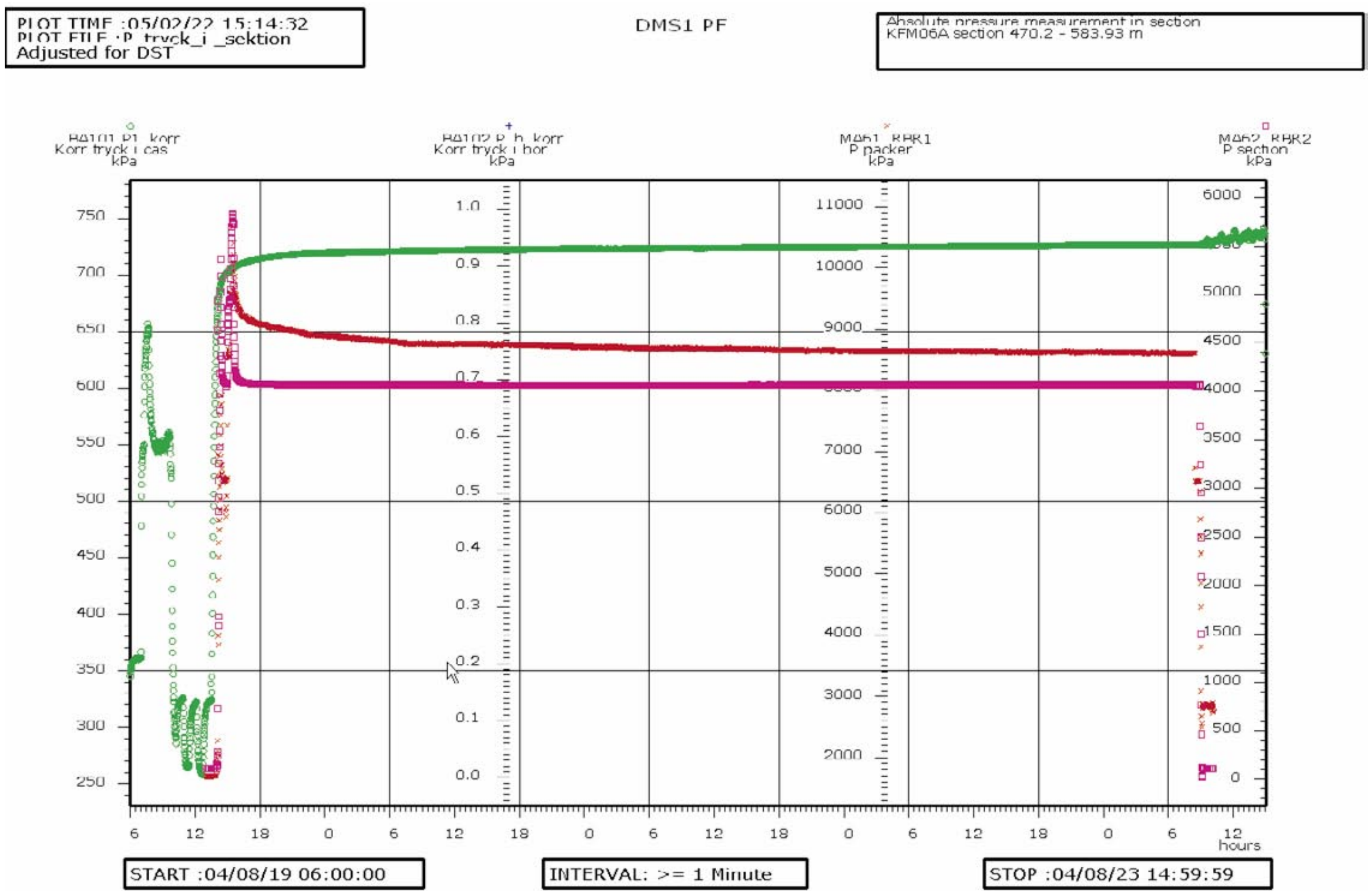
Appendix D

Hydraulic pumping test



Appendix E

Absolut pressure



Appendix F

Well Cad presentation of KFM06B

Title	KFM06B

Svensk Kärnbränslehantering AB

Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	KFM06B	Northing [m]	6699732.24
Diameter [mm]	77	Easting [m]	1632446.41
Length [m]	100.33	Elevation [m.a.s.l.]	4.13
Bearing [°]	296.96	Drilling Start Date	2004-05-26 07:00:00
Inclination [°]	-83.52	Drilling Stop Date	2004-06-08 12:16:00
Date of mapping		Plot Date	2005-04-13 10:49:42

ROCKTYPE FORSMARK

SOIL

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

Script Name