P-03-82

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Drilling of the telescopic borehole KFM04A and the percussion drilled borehole KFM04B at drilling site DS4

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June 2004

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Summary

The majority of the deep boreholes drilled within the scope of the Forsmark site investigations are performed as so called telescopic boreholes, entailing that the upper 100 m are percussion drilled with a diameter of c 200–250 mm, whereas section 100–1,000 m is core drilled with a diameter of approximately 77 mm. Performance of and results from drilling and measurements during drilling of the fourth deep borehole drilled in Forsmark by applying this technique are presented in this report. The borehole, which is drilled at drilling site DS4 and denominated KFM04A, is 1,001.42 m long and drilled with a strike of 45.24° clockwise from north and with an inclination of 60.08° from the horizon. KFM04A is of so called SKB chemical type, intended for detailed hydrogeochemical and microbiological investigations.

At drilling site DS4 also the percussion drilled part of a planned telescopic borehole, KFM04B, was drilled. During percussion drilling of section 0–100 m in KFM04A with the diameter Ø 165 mm, an unstable, fractured section was encountered at about 100 m. Also in borehole KFM04B a corresponding instability occurred, at about 80 m. The fractured intervals are interpreted to represent a sub-horizontal fracture zone. This zone was heavily water-yielding, and an inflow of 100–200 L/min was observed in both boreholes. Due to the high water capacity and unstable borehole wall, the percussion drilled part of KFM04A was prolonged to c 107.42 m and reamed to Ø 247 mm. Also KFM04B was reamed, to Ø 248 mm. Stainless steel casings were installed in each borehole to the full percussion drilled length, and the gap between the borehole wall and the casing was grouted. After these measures, all inflow of groundwater to the percussion drilled part of the two boreholes ceased.

A relatively complicated flushing water/return water system was applied for the core drilling in section c 107–1,001.42 m of KFM04A, where the flushing water was prepared in several steps before use, and the return water was taken care of, as to permit drill cuttings to settle before the water was conducted to the recipient. During drilling, a number of technical and flushing water/return water parameters were registered in order to obtain a good control of the drilling process and to permit an estimate of the impact on the borehole of flushing water and drilling debris during drilling. The conclusion after drilling was that only relatively small amounts of flushing water and drill cuttings penetrated the formation adjacent to the borehole, principally in section 107–480 m.

A sampling- and measurement programme applied during percussion drilling and another programme during core drilling provided preliminary but current on-site information about the geological and hydraulic character of the borehole. The results also served as a basis for extended post-drilling analyses. E.g. the drill cores from the core drilled part and the samples of drill cuttings from the percussion drilled section of KFM04A, together with later produced video images of the borehole wall (so called BIPS-images), were used for the borehole mapping (so called Boremap mapping) performed after drilling. Results of the Boremap mapping of KFM04A are presented in this report, whereas BIPS-logging and Boremap mapping of the so far existing section 0–100 m of borehole KFM04B has not been performed.

After completed drilling of KFM04A, 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.

The collarings of KFM04A and KFM04B are sited quite close to each other, outside the Forsmark tectonic lens. Borehole KFM04A is inclined towards the lens and KFM04B in the opposite direction, i.e. away from the lens. By drilling KFM04A, it was established that the transition towards depth between the quartz-rich, low-deformed bedrock of the Forsmark lens and the tectonized bedrock delimiting the lens towards south-west is steeply dipping or dipping slightly south-westwards away from the lens.

Sammanfattning

De flesta djupa borrhål inom Forsmarks platsundersökning utförs som s.k. teleskopborrhål. Förfarandet innebär att de övre 100 metrarna hammarborras med ca 200–250 mm diameter, medan avsnittet 100–1 000 m kärnborras med ca 77 mm diameter. Resultaten från det fjärde djupborrhålet i Forsmark som har borrats med denna teknik redovisas i denna rapport. Borrhålet, som är beläget på borrplats BP4 och benämns KFM04A, är 1 001,42 m långt och är borrat i riktning 45,24° medsols från norr samt är ansatt med lutningen 60,08° från horisontalplanet. KFM04A är ett så kallat kemiprioriterat borrhål, vilket innebär att det planeras att användas för detaljerade kemiska och bakteriologiska undersökningar, varför all utrustning som används i borrhålet, både vid borrning och mätning, måste rengöras och desinficeras enligt speciella instruktioner.

På BP4 borrades även den övre, grova delen av ett planerat nytt teleskopborrhål, KFM04B. Vid hammarborrning av KFM04A i avsnittet 0–100 m med diametern Ø 165 mm påträffades ett uppsprucket avsnitt vid ca 100 m, varför den hammarborrade delen förlängdes till 107,42 m. Vid hammarborrningen av KFM04B påvisades ett motsvarande sprucket och instabilt parti, vid ca 80 m. Dessa sektioner tolkades representera en flack sprickzon med betydande vattenkapacitet. Inflöden på 100–200 L/min uppmättes i båda borrhålen. Eftersom borrhålen var instabila och vattenförande rymdes de upp till Ø 247 mm (KFM04A) respektive Ø 248 mm (KFM04B) och kläddes in med rostfritt foderrör i hela den hammarborrade delen, varefter spalten mellan borrhålsvägg och foderrör cementinjekterades, så att allt vatteninflöde i denna del av hålet upphörde.

För kärnborrningen av avsnittet ca 107–1 001,42 m i KFM04A användes ett relativt komplicerat spol- och returvattensystem, där spolvattnet preparerades i olika steg före användning. Returvattnet leddes till ett system av containrar, så att borrkaxet kunde sedimentera i tre steg innan returvattnet pumpades vidare till recipient.

Under borrningen registrerades ett antal borr- och spolvattenparametrar för kontroll av dels borrningens tekniska genomförande, dels av den påverkan av spolvatten och borrkax som borrhålet utsattes för. Det kan dock inte uteslutas att spolvatten och borrkax har trängt ut i formationen, speciellt i de övre, mer vattenförande och uppspruckna partierna mellan ca 107–480 m.

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), arbetsmaterialet för den borrhålskartering (s k Boremap-kartering) som utförs efter borrning. Även resultaten från Boremap-karteringen av KFM04A finns redovisad i föreliggande rapport. I KFM04B har däremot BIPS-filmning och Boremap-kartering inte utförts.

Efter avslutad borrning av KFM04A 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.

KFM04A ansattes utanför den tektoniska lins som utgör kandidatområdet i Forsmark, i den omvandlade berggrund som utgör linsens sydvästra begränsning, med riktning in mot linsen. KFM04B däremot, med påslagspunkt strax intill KFM04A, stryker i rakt motsatt riktning, dvs bort från linsen. Genom att borra KFM04A kunde det påvisas att gränsen mellan den kvartsrika, lågdeformerade berggrunden inom linsen och de tektoniserade bergarter, som utgör linsens begränsning mot sydväst, stupar brant eller svagt mot sydväst.

Contents

1 Introduction

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

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

The deepest boreholes drilled at the site investigation are core drilled. So far, three sub-vertical and two inclined, approximately 1,000 m long, cored boreholes have been drilled within the investigation area. The locations of the five drilling sites in question, DS1, DS2, DS3, DS4 and DS5, as well as of drilling site DS6 where an inclined deep borehole is currently being drilled, are illustrated in Figure 1-1.

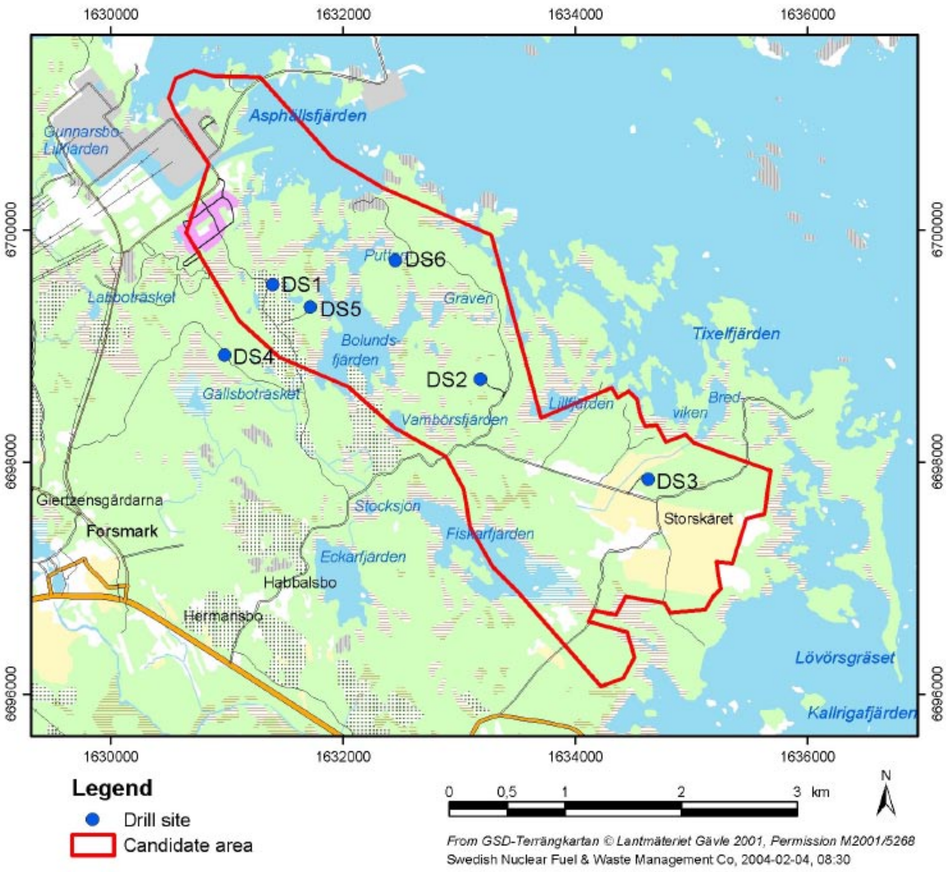


Figure 1-1. *The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drilling sites DS1-6 are marked with blue dots.*

By drilling the deep boreholes, a so called telescopic drilling technique is applied, entailing that the upper c 100 m of the borehole is percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section c 100–1,000 m is core drilled with a diameter of approximately 77 mm. This technical approach was adopted also when drilling the borehole presented in this report, KFM04A, which has a total drilling length of 1,001.42 m (corresponding to approximately 803 m vertical depth, as the borehole is inclined). KFM04A is of the so called SKB chemical type, implying that the borehole is prioritized for hydrogeochemical and microbiological investigations. This infers, that all DTH (Down The Hole) equipment used during drilling must undergo severe cleaning procedures, see Chapter 4.

Another telescopic borehole, KFM04B, see Figure 1-2, has also been planned with the purpose of investigating the area south-west of the drilling site and further into the tectonized parts outside the candidate area. However, only the percussion drilled part has so far been accomplished. Borehole KFM04B, striking 180° from KFM04A, is inclined 60° from the horizontal plane and is 100.53 m long.

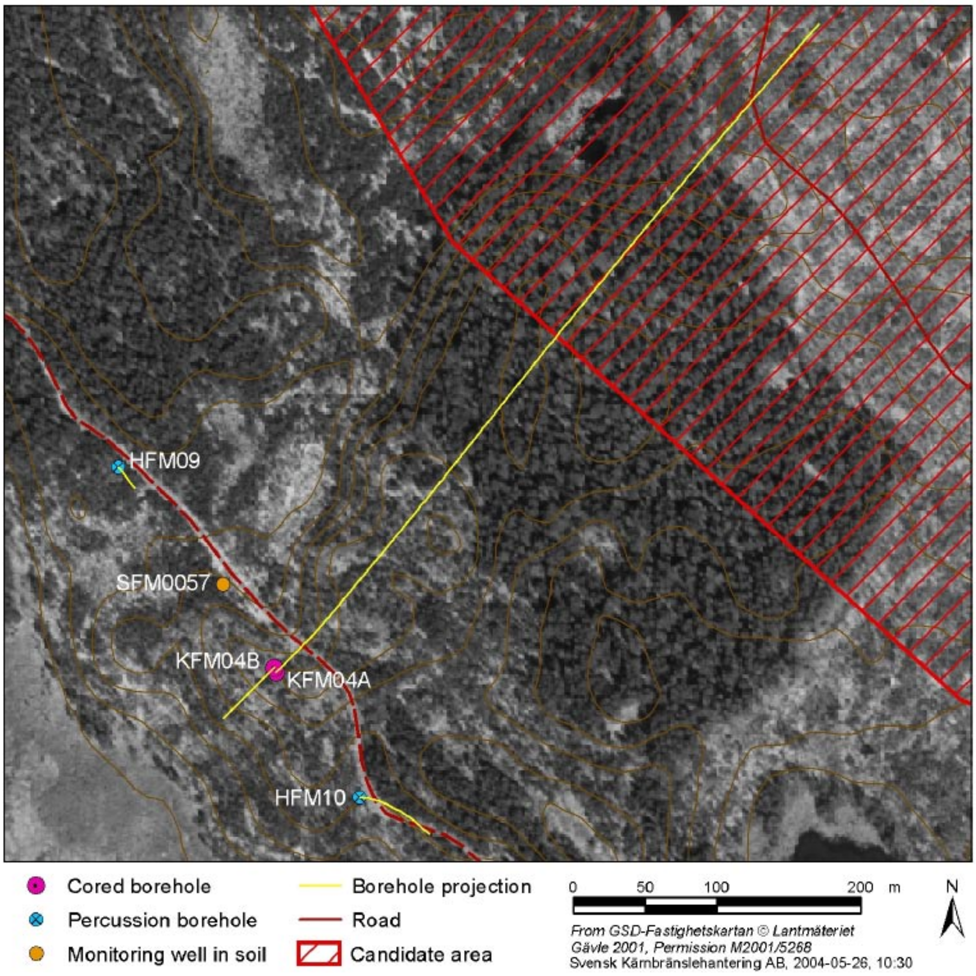


Figure 1-2. *Borehole locations at drilling site DS4. Besides the core drilled borehole KFM04A and the percussion drilled part of borehole KFM04B, the drilling site incorporates a flushing water well (HFM10), a monitoring well in solid rock (HFM09), and a monitoring well in the unconsolidated overburden (SFM0057). The projection of inclined boreholes in the horizontal plane at the ground surface (top of casing) is shown in the figure.*

Drilling site DS4 also involves percussion drilled boreholes in soil and solid rock, drilled for different purposes. The lengths of these boreholes vary between a few metres to c 150 m. The locations of all boreholes at drilling site DS4 are shown in Figure 1-2.

Drilling site DS4 is located in the north-western 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 1.5 km northeast of the drilling site (Figure 1-1).

In the present report, performance of and results from drilling and investigations made during and immediately after drilling of the telescopic borehole KFM04A and the percussion drilled part of KFM04B at drilling site DS4 are presented.

Drilling of boreholes KFM04A and KFM04B was performed in compliance with a number of SKB controlling documents, which are presented in Table 1-1 below. Some of these documents are in Swedish, others are available also in English.

The two first method descriptions in Table 1-1 refer to a number of method instructions and measurement system descriptions, some only in Swedish, others also in English, see Table 1-2.

Table 1-1. SKB internal controlling documents for performance of the activity.

Activity Plans	Number	Version
Undersökningar i Forsmarksområdet. Borrning av teleskopborrhål KFM04A.	AP PF 400-03-40	1.0
Undersökningar i Forsmarksområdet. Hammarborrning av teleskopborrhål KFM04B, 0–100 m (f d KFM06A).	AP PF 400-03-42	1.0
Method descriptions and instructions.		
Metodbeskrivning för hammarborrning.	SKB MD 610.003	1.0
Method Description for drilling cored boreholes.	SKB MD 620.004	1.0
Metodbeskrivning för registrering och provtagning av spolvattenparametrar samt vägning av borrkax under kärnborrning.	SKB MD 640.001	1.0
Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wireline-borrning.	SKB MD 321.002	1.0

Table 1-2. Method instructions and Measurement System Descriptions (SKB internal controlling documents) referred to in Method descriptions SKB 610.003 and 620.003.

Method instructions and Measurement System Descriptions		
Instruktion för utsättning och ansättning av hammar- och kärnborrhål.	SKB MD 600.002	1.0
Instructions for cleaning borehole equipment and certain surface equipment.	SKB MD 600.004e	1.0
Instructions for setting up at drilling sites.	SKB MD 600.005e	1.0
Instructions for the use of chemical products and construction materials in equipment for drilling and investigations.	SKB MD 600.006e	1.0
Instruction for flushing water management for core drilling.	SKB MD 620.008	1.0
Instruktion för längdmarkering i kärnborrhål.	SKB MD 620.009	1.0
Instruction for length calibration in investigation of core boreholes.	SKB MD 620.010	1.0
Mätsystembeskrivning för övervakning av spolvattenparametrar.	SKB MD 640.002-006	1.0

Results from drilling of the flushing water well HFM10 and the monitoring well HFM09, have been reported separately /3/. The geological mapping of borehole KFM04A (so called Boremap mapping) is presented in /4/. Finally, drilling of the monitoring well in soil, SFM0057, is reported in /3/.

Drillcon Core AB, Nora, Sweden, was engaged for the drilling commission. Two different drilling equipments were employed, a percussion drilling machine for drilling the upper c100 m of KFM04A and KFM04B, whereas core drilling of the remaining part of KFM04A (section 106.95–1,001.42 m) was carried out with a wireline core drilling system.

Prior to drilling, a large number of preparative measures were taken at the drilling site. For example, the ground surface was levelled off and covered with a layer of coarse, draining gravel, so that a convenient working space was created. A cement slab, about 11×7 m in size and with an approximately 5 cm high bund around its periphery, was cast around the borehole collarings. The slab serves as a firm platform for anchorage of the drilling machine while drilling, and also provides a protection against any leaks of environmentally hazardous liquids, such as oil. The working area was also fenced in. When the drilling site had been prepared, the drilling equipment was mobilized, first the percussion drilling equipment for drilling section 0–100 m of the two boreholes, and later the core drilling equipment.

KFM04A was drilled during the period May 20th – November 19th 2003 and KFM04B during May 20th – June 30th 2003.

2 Objective and scope

Siting of borehole KFM04A was primarily governed by a decision (SKB Decision 1019287) to investigate dip and geological character of the border between the low-deformed bedrock of the Forsmark tectonic lens and the tectonized bedrock delimiting the lens towards south-west. Another deep borehole at the same site, but directed 180° from the strike of KFM04A, had also been recommended in connection with the discussions preceding the decision of drilling KFM04A. Due to this recommendation, the telescopic part of that borehole was drilled in connection with percussion drilling of KFM04A, in order to prepare core drilling of a presumed, although not yet decided, new deep borehole at drilling site DS4. Since the percussion drill rig was mobilized on site, this seemed to be a both cost effective and time saving step. This second borehole at drilling site DS4 was at first assigned the name KFM06A. However, later the name was changed to KFM04B.

Drilling deep cored boreholes provides possibilities to perform rock investigations according to the following main items:

- Rock sampling 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 during percussion drilling of 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. The rock samples collected during drilling are used for a lithological, structural and rock mechanical characterization as well as for determination of the transport properties of the bedrock from the rock surface to the full drilling depth.
- Geophysical borehole investigations, e.g. TV logging, borehole radar logging and conventional geophysical logging as an aid for the geological/rock mechanical characterization.
- Hydraulic borehole tests (single-hole tests as well as interference tests, in some cases performed as tracer tests) for characterization of the hydrogeological properties of the bedrock.
- Water sampling 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.
- 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. DMS-data from KFM04A are described in this report.

Hydraulic tests and water samplings are normally performed during as well as after the drilling process. In the former case, a specifically designed test system, a so called wireline probe, is utilized.

3 Equipment and basic technical functions

Two types of drilling machines were used. The upper c100 m of KFM04A and KFM04B were drilled with a percussion drilling machine of type Puntel MX 1000. For core drilling of section 107.42–1,001.42 m in KFM04A, a wireline-76 core drilling system, type Onram 2000 CCD, was engaged.

3.1 Percussion drilling equipment

The Puntel percussion machine (Figure 3-1) 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 drilling site DS4, the bedrock was outcropping and only a minor part of the site was covered by maximum 0.5 m of clayey-silty till. So called NO-X technique was applied for drilling through the overburden, following the principles and dimensions presented in Figure 3-2. The NO-X technique is described more in detail in SKB MD 610.003 (Method Description for percussion drilling). Figure 3-2 displays a schematic diagram illustrating the entire drilling sequence through the overburden and c 100 m down into the bedrock. The drilling depths presented are approximate. The true depths in the respective drilling sequences performed in KFM04A and KFM04B are presented in Section 5.2.

***Figure 3-1.** The Puntel drilling machine during drilling of KFM04A and KFM04B at drilling site DS4.*

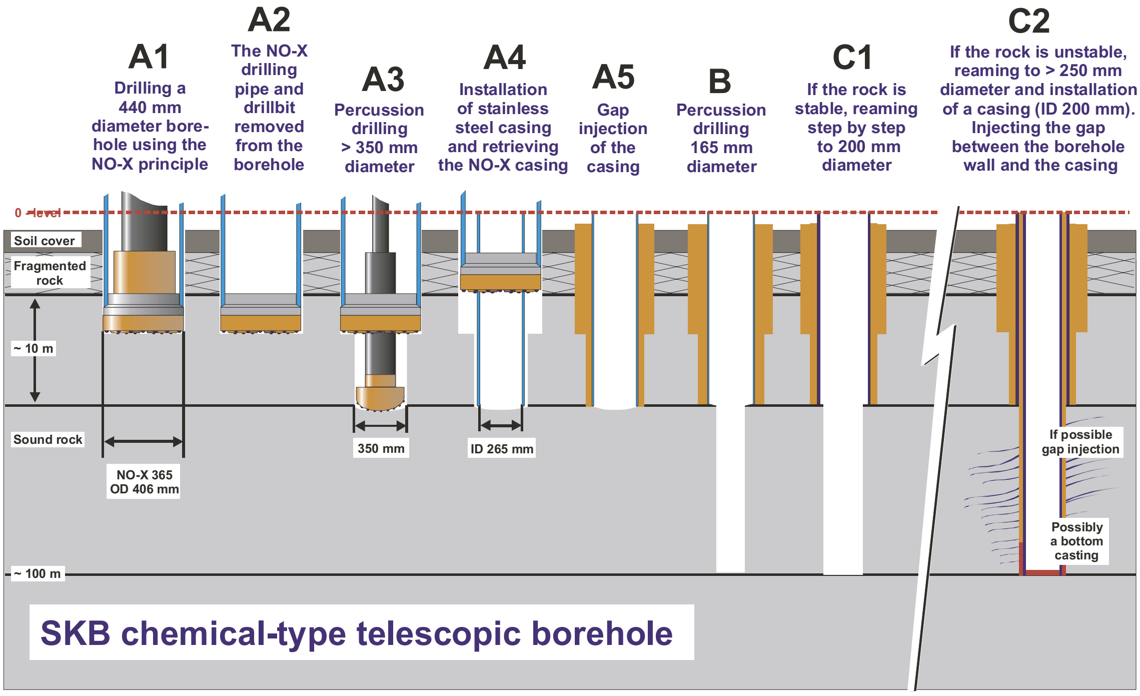


Figure 3-2. *Schematic diagram showing the various stages of drilling the 0-100 m section of an SKB chemical-type telescopic borehole. The letters and numerals above each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB MD 620.003.*

3.2 Gap injection technique

For investigation of 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 groundwater is encountered in the borehole during percussion drilling of a telescopic borehole, it is essential to prevent this water to reach the deeper parts of the bedrock. This is achieved by cement grouting of the gap between the borehole wall and the casing. Also open, water-yielding fractures penetrated by the borehole will in most cases be sealed by the injected agent during gap injection. Different techniques are available for gap grouting, of which two variants are illustrated in Figure 3-3.

Both boreholes KFM04A and KFM04B were gap grouted at two occasions: 1) after installation of the $Ø_i$ 265 mm casing (A5 in Figure 3-2), and 2) after installation of the $Ø_i$ 200 mm, 100 m long casing (C2 in Figure 3-2). The first injection (of the short casing) was performed according to the hose technique, whereas for gap injection of the long casing the packer technique was applied.

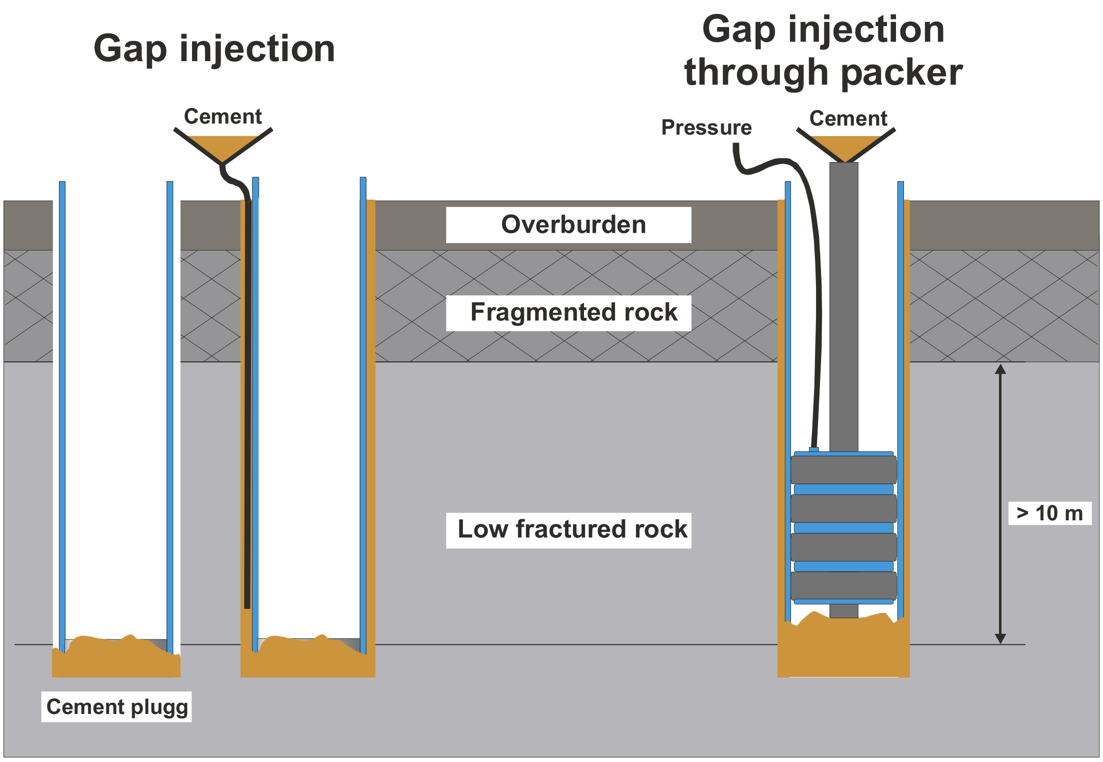


Figure 3-3. Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer.

3.3 Core drilling equipment

3.3.1 The wireline-76 system

A Hagby Bruk Onram 2000 CCD wireline-76 system was employed for drilling the cored part of borehole KFM04A. The drilling process is operated by an electrically-driven hydraulic system supplied with a computer control. The drilling capacity for 76 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.

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 mm holes maximum approx. 1,500 m.	
Flush water pump	Bean	Max flow rate: 170 L/min. Max pressure: 103 bars.	
Submersible pump	Grundfoss SQ	Max flow rate: 200 L/min.	
Mobile electrical plant	P250HE with diesel engine Perkins GCD 325	250 KVA, 200 kW, 360 A.	
Compressor	Atlas Copco GA75P-13	Max pressure: 12 bars. Flow: > 5 L/sec.	Electrically supplied.
CCD-system	Dunfoss		Standard system modified for core drilling by the manufacturer.

3.3.2 Flushing/return water system – function and equipment

Core drilling involves pumping of flushing water down the drill string, through the drill bit and out into the borehole in order 1) to conduct frictional heat away from the drill bit, and 2) to enhance the recovery of drill cuttings to the ground surface. The cuttings, suspended in the flushing water (in general mixed with groundwater), are forced from the borehole bottom to the ground surface via the gap between the borehole wall and the drilling 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 makes 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 illustrated in Figure 3-4. 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 oxygene) as well as return water parameters (flow rate and electrical conductivity),
- equipment for airlift pumping while drilling,
- equipment for storage and discharge of return water.

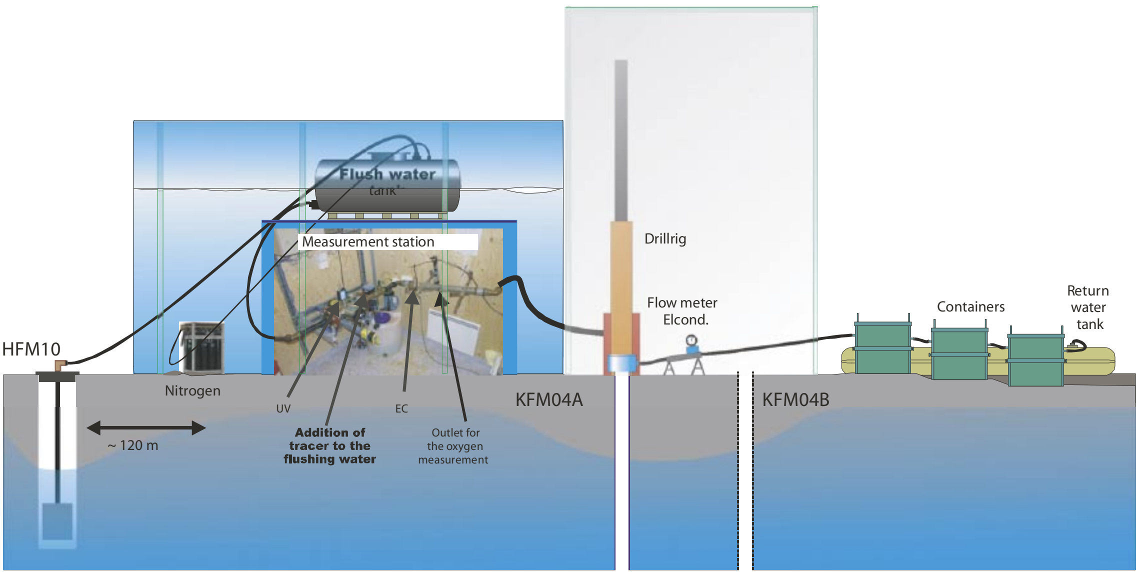


Figure 3-4. *Schematic illustration of the flushing/return water system when core drilling KFM04A at DS4. The measurement station included logger units, a UV-radiation unit and a dosing equipment for labelling the flushing water with Uranine. For flushing water flow rate and pressure measurements, the drilling machine gauges were used.*

Preparing the flushing water

The quality of the flushing water must satisfy 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 must 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 KFM04A was a percussion drilled well in hard rock, HFM10 (see Figure 1-2), situated approximately 100 m from KFM04A. The water quality was analysed before use. The results of the analysis are presented in Section 5.4.3. The water quality was considered as satisfactory for serving as flushing water.

Besides the basic demands on the flushing water quality, which were complied with when drilling KFM04A, the flushing water was also prepared in four steps before use, in accordance with SKB MD 620.004 (Method Description for drilling cored boreholes).

1) Incoming water from the water well (HFM10) was pumped into the flush water tank (see Figure 3-4).
2) Nitrogen was bubbled through the water in the tank in order to expel oxygen which might be dissolved in the water (see Figure 3-4). Oxygen must be avoided in the flushing water because it is a critical parameter in the programme for hydrochemical characterization of the groundwater. The expelled oxygen was discharged through a pressure reducing valve, and the water was kept continuously under a positive nitrogen pressure (about 1 bar) until pumped down into the borehole.
3) In order to reduce the microbe content in the water from the flush water tank, it was exposed to UV-radiation by a UV-system placed inside the measurement station, see Figure 3-4.
4) After UV-radiation, an organic tracer dye, Uranine, was added with aid of a dosage equipment at a concentration of 0.2 mg/L, before the water was pumped into the borehole, see Figure 3-4. Labelling 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 during pumping the flushing water into the borehole:

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

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

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		

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

Airlift pumping while drilling

Airlift pumping during core drilling involves pumping of compressed air into the percussion drilled portion of the telescopic borehole, so that it emerges at a depth of about 80–100 m. As the air expands in rising out of the borehole, it lifts the water up, to produce the airlift 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 3-5. The resulting return water is a mixture of flushing water, groundwater from water-yielding fractures and fracture zones and drill cuttings. Some of the flushing water and drill cuttings will, however, normally be forced into the local fracture systems and a minor part will be left in the borehole. The airlift pumping is continued throughout the drilling period.

The airlift pumping equipment in KFM04A consisted of the following main components, see also Figures 3-5, 3-6 and 3-7:

- Compressor, 12 bars/10 m³/min
- 107 m outer support casing, 98/89 mm diameter
- 108.7 m inner support casing, 84/77 mm diameter
- Expansion vessel (= discharge head)
- PEM hose: 20 bars, 28 mm diameter, 105 m
- Two PEM hoses: 20 bars, 40 mm diameter, 106 m
- Two 22 mm diameter hoses at about 106 m
- One 22 mm diameter hose at about 80 m.
- Pressure sensor, 10 bars, instrumentation and data-logging unit
- Two ejector tubes and one pumping nozzle
- Electrical supply cubicle, at least 16 A

When installing the outer support casing and hoses, they were lowered into the borehole 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 3-6. With this construction, the air leaving the ejector rises, reducing the pressure in the lower part of the ejector tube, helping to lift drill cuttings from the bottom of the hole.

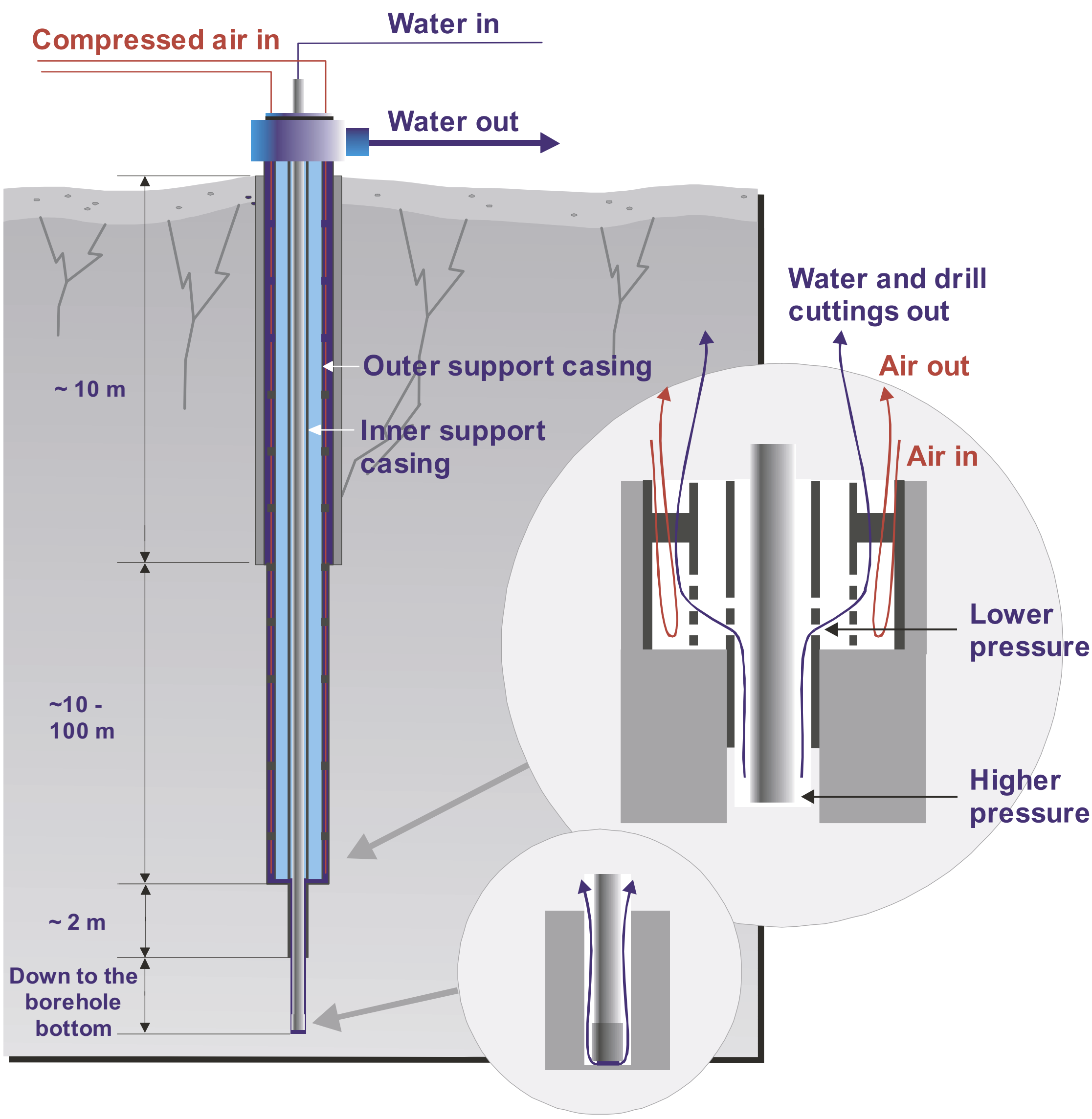


Figure 3-5. *Airlift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole. Return water flows between the borehole wall and the drilling pipe string and then through holes in the support casing before being transported up to the surface.*

Storage and discharge of return water

At the surface level, the return hose was connected to a return pipe between the discharge head and the first return water container, see Figures 3-4 and 3-8. 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. Since the return water had an increased salt content, it could not, for environmental reasons, be discharged into any fresh water recipient, but had to be pumped from the containers to a pumping station at drilling site DS1 one km away, and further via a c one km long pipe string to the Baltic Sea. Intermittently, the return water was, after separation of drill cuttings, stored in two elastic water tanks with an expansive capacity of up to 40 m^3 each, see Figure 3-4.

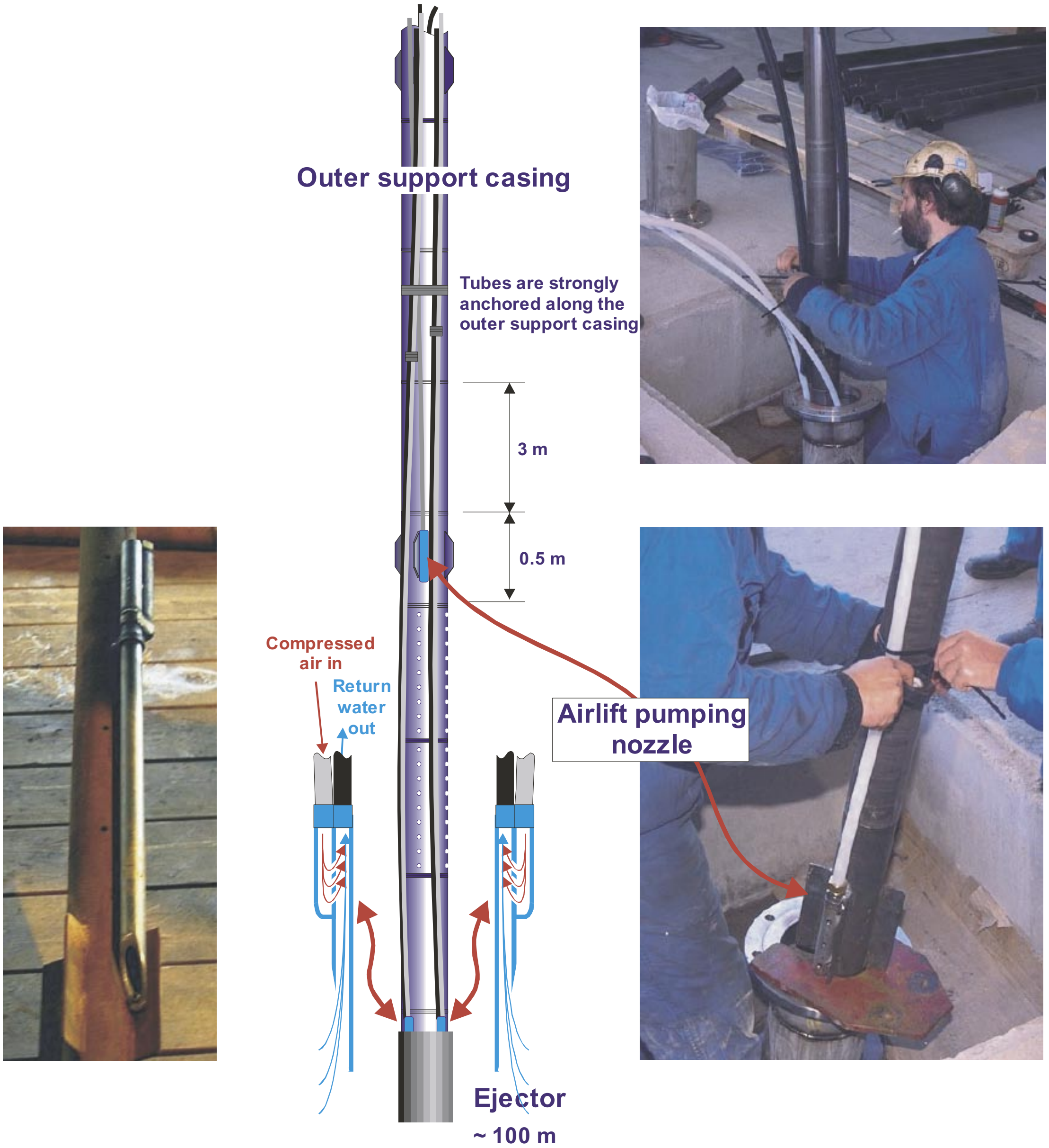


Figure 3-6. *Schematic representation of connection and installation of airlift pumping nozzle and ejector on the outer protective casing.*

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

Flow rate data and other flushing water data were continuously stored in an automatic data-logging system, see Section 3.3.3. As a back-up and double-check, the total quantity of water supplied to the borehole was acquired by counting the number of filled water tanks used, multiplied by the tank volume.

Figure 3-7. Installation of airlift pumping equipment in borehole KFM04A.

Table 3-3. Technical specifications of 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	

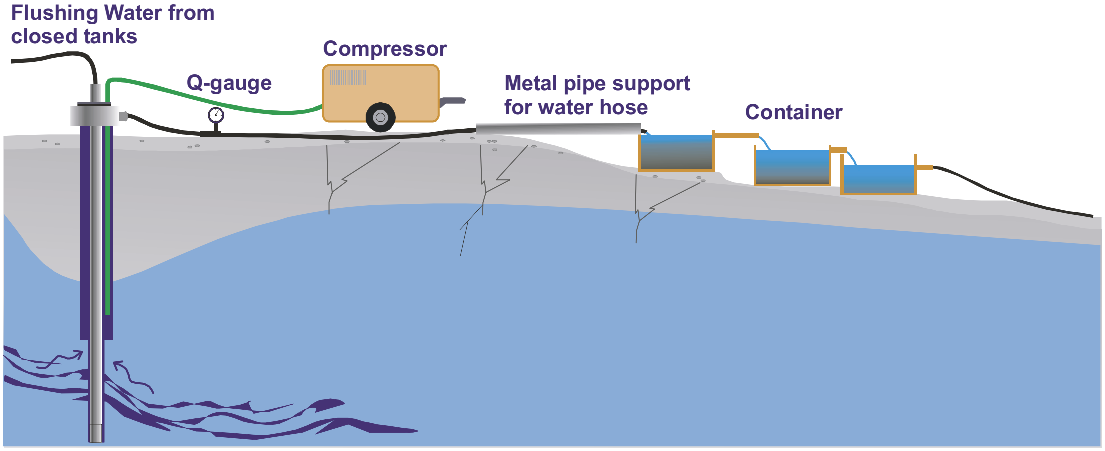


Figure 3-8. *Return water system. Airlift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in three stages in the containers (where it is preserved for later weighing), after which the water can be pumped to the recipient.*

3.3.3 Drilling monitoring system

The ONRAM 2000-CCD drilling machine is supplied with a computer based logging system integrated in the steering unit (cf Section 3.3.1). Hence, the parameters logged are those used for automatic operation of the drilling process.

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 borehole KFM04A, the registration was 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 was registered during drilling.

3.3.4 Equipment for deviation measurements

During drilling of borehole KFM04A, deviation measurements were made at one occasion in order to check the straightness of the borehole. After completion of drilling, a final deviation measurement was carried out. All 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.

No deviation measurements were performed in KFM04B.

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

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

4 Execution

4.1 Percussion drilling of boreholes KFM04A and KFM04B, section 0–100 m

The performance of the percussion drilling followed Activity Plan AP PF 400-03-40 (KFM04A) and AP PF 400-03-42 (KFM04B), respectively, which both refer to SKB MD 610.003 (Method Description for percussion drilling), cf Tables 1-1 and 1-2. The percussion drilling operations included the following items:

- 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 matters are treated in the present section (Section 4.1), whereas the last two points, 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 600.006e (Instructions for the use of chemical products and construction materials in equipment for drilling and investigations), cf Table 1-2. Finally, the equipment was cleaned in accordance with the cleaning instruction in SKB MD 600.004e (Instructions for cleaning borehole equipment and certain surface equipment) for boreholes of SKB chemical type.

4.1.2 Mobilization

Mobilization onto and at the site included preparation of the drilling site, transport of drilling equipment, 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 600.004e, lining up the machine and final function control.

4.1.3 Drilling, measurements and sampling during drilling

As the bedrock was exposed (see Figure 4-1), the percussion drilling started with drilling through the upper, fractured part of the bedrock during simultaneous casing driving and subsequent gap injection. These activities followed the principles described in Sections 3.1 and 3.2 (corresponding to A1–A5 in Figure 3-2). Soil drilling in both KFM04A and 4B was performed with NO-X 365 followed by pilot drilling Ø 162 mm to solid rock.

The pilot hole is then reamed in two steps, 250 mm respectively 350 mm. The length of the $Ø_i$ 265 mm casing was 12.03 m (KFM04A) and 12.02 m (KFM04B), and the casing material used was SS2333 stainless steel.

The continued percussion drilling through solid rock was performed with a Ø 165–161 mm drill bit to 107.42 m (KFM04A) respectively 100.60 m (KFM04B) drilling length (corresponding to B in Figure 3-2).

For stabilization of the entire percussion drilled part, the borehole was reamed to Ø 247 mm with a special reamer bit to 107.33 m drilling length in KFM04A and to Ø 248 mm 100.33 m in KFM04B (i.e. 0.05 m in KFM04A respectively 0.27 m in KFM04B of the pilot holes were left unreamed), and a SS2333 stainless steel $Øo/Ø_i$ 208/200 mm casing was installed to 106.95 m (KFM04A) and 100.32 m (KFM04B) (corresponding to C2 in Figure 3-2).

However, 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, since the recovery of the groundwater table was registered after the compressor had been turned off. The results were used as a rough capacity test of the percussion drilled part of the borehole, used on-site i.e. for preparation of the gap injection of the casing, see below.

In order to prevent leakage of water from the heavily water-yielding fractures penetrated by the borehole via the gap between the borehole wall and the casing, the gap was grouted using the packer technique illustrated in Figure 3-3. 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 carried out in association with the Ø 165 mm drilling sequence. The programme was performed in compliance with SKB MD 610.003 (Method Description for percussion drilling) 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 measurement 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.

Analyses of drill cuttings from the soil layer respectively from the section of solid rock were performed as separate activities. The results of the analyses of the cuttings from the soil layer are integrated with the results from the mapping of Quaternary deposits /5/, whereas the analysis of cuttings from solid rock is presented in /4/. Results from the remaining measurements and observations are presented during drilling in Chapter 5.

Figure 4-1. *Boreholes KFM04A and KFM04B secured with lockable stainless steel flanges.*

4.1.4 Finishing off work

Finishing off work included measurements of the final diameter of the drill bit after reaming to c Ø 250 mm. The boreholes were secured with lockable stainless steel flanges (Figure 4-1). The drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

4.1.5 Nonconformities

The percussion drilling of borehole section 0–100 m in KFM04A and KFM04B was performed according to plan, i.e. without deviations.

4.2 Core drilling

The performance of the core drilling of KFM04A followed Activity Plan AP PF 400-03-40. This Activity Plan refers to SKB MD 620.004 (Method Description for drilling cored boreholes). The core drilling operations included the following parts:

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

The four first items are presented in the present Section (Section 4.2), while the last two points 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 600.006e. Finally, the equipment was cleaned in accordance with SKB MD 600.004e.

4.2.2 Mobilization

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

4.2.3 Drilling, measurements and sampling during drilling

The core drilling of borehole KFM04A was performed with two borehole dimensions. Section 106.95–108.69 m was drilled with a diameter of 86.0 mm (section 106.95–107.42 core drilling in cement from grouting), whereas the main part of the borehole, section 108.69–1,001.42 m, was drilled with the diameter 77.3 mm. The inner Ø 84/77 mm support casing in KFM04A was fitted into the short Ø 86 mm part of the borehole. In this way, the casing was centralized in the borehole and fixed laterally. The outer Ø 98/89 mm support casing in KFM04A is resting on the bottom of the percussion drilled part, cf Figure 3-5.

Core drilling of the main part of the borehole serves many purposes, see 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 may also be used for determination of transport properties of the rock and for the study of chemical characteristics of the pore water in the rock matrix.

Core drilling with a wireline system entails recovery of the core barrel via the drilling pipe string, inside which it is hoisted up with the wireline winch. During drilling of borehole KFM04A, 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. Finally, for specific reasons (see Section 5.4.1), borehole section 1,000.89–1,001.42 m was performed with the core dimension Ø 62.0 mm.

Like the percussion drilling, the core drilling was associated with a programme for sampling, measurements and other activities during and immediately after drilling, cf SKB MD 620.004. However, for different reasons, during drilling of KFM04A some deviations from this programme could not be avoided. In order to elucidate the nonconformities, the programme according to the Method Description is presented in Section 4.2.5, Table 4-1, together with the actual performance when drilling KFM04A.

The measurements and registrations during core drilling are presented in Chapter 5 of the present report.

Besides the activities mentioned in Table 4-1, water samples were collected from different positions in the flushing water system, see Figure 3-4, in order to reveal if the content of microbes changed during transport through the vessels, pipes and hoses included in the system. The results of the study are presented in /6/.

4.2.4 Finishing off work

The concluding work included the following items:

1) The borehole was flushed for about 10 hours during simultaneous airlift pumping in order to clean it from drilling debris adhered to the borehole walls, settled at the bottom of the hole or suspended in the water. After finished flushing/airlift pumping, the recovery of the groundwater table was registered as an estimate of the water-yielding capacity 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 the drill rig.
4) The outer support casing was removed with aid of a 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, cf Figures 4-2 and 5-4. The transition cone is located at 103.8–108.61 m in borehole KFM04A.
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.

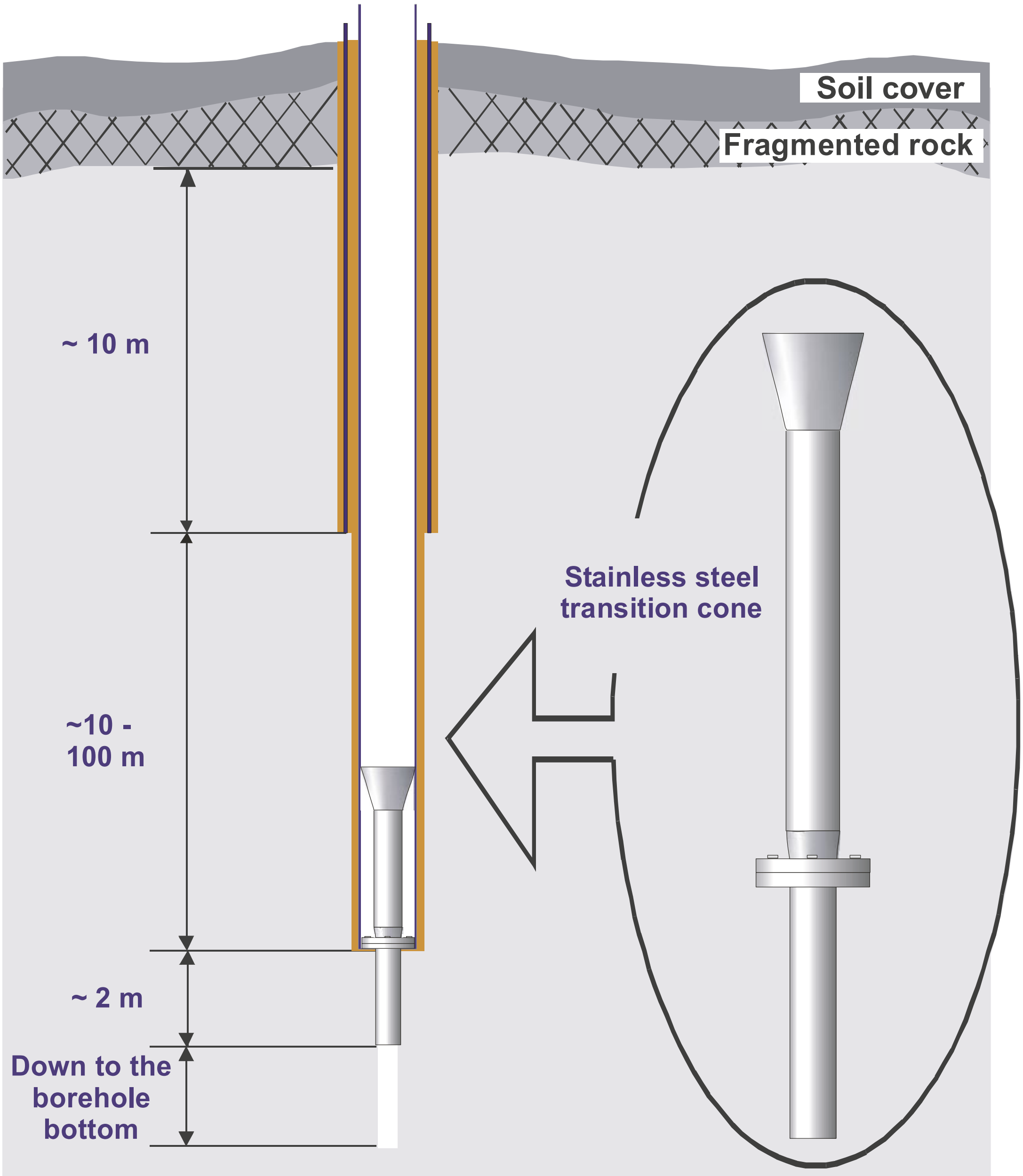


***Figure 4-2.** Schematic illustration of the transition cone between the upper, wide section and the lower, slim part of a telescopic borehole. In KFM04A, the entire upper, percussion drilled part was cased.*

4.2.5 Nonconformities

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

Table 4-1. Programme for sampling, measurements, registrations and other activities during and immediately after core drilling according to SKB MD 620.004 and the actual performance during drilling of borehole KFM04A.

Activity	Performance and frequency according to SKB MD 620.004	Performance and frequency during drilling of KFM04A
Registration of drilling- and flushing water parameters.	Described in Section 3.3.2. Registration during the entire drilling.	Technical problems with oxygen transducer. No measurements performed.
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.
Measurements of the difference in length between the compressed drilling pipe string and as extended by its own weight.	Normally performed every 100 m.	Uncertain measurements made and rejected. Values presented in Figure 5-15 are from material properties of the drilling 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 successful pumping test.
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 successful measurements performed due to technical problems with the test equipment depending on that the borehole was inclined.
Absolute pressure measurements.	Normally performed during natural pauses in drilling.	Four successful measurements performed.
Groove milling in the borehole wall, normally performed after completion of drilling.	Normally performed at each 100 m.	Eighteen grooves performed.
Cleaning of the borehole	Normally performed after finished drilling.	Ordinary water flushing performed.
		Nitrogen air flushing 0–1,000 m performed.
Collecting and weighing of drilling debris.	Drilling debris settled in containers and weighed after finished drilling.	Not carried out for the percussion drilled part of the borehole. According to programme for the core drilled part.

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 3-4 and 3-8 (except the finest fractions which stayed suspended in the discharge water from the third container). The collected drill cuttings from the core drilling were weighed after concluded drilling in order to give a measure of the drill cuttings recovery. However, weighing of the drill cuttings produced during percussion drilling and comparison with the weight of the theoretical volume was not carried out due to the extreme high water flow. This caused a relatively large and uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations.

4.3 Data handling

4.3.1 Performance

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

4.3.2 Nonconformities

None.

4.4 Environmental programme

4.4.1 Performance

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

4.4.2 Nonconformities

None.

5 Results

All data were stored in the SICADA database under field note nos Forsmark 171, 202, 239 and 283. An overview of the drilling progress of boreholes KFM04A and KFM04B are given in Section 5.1, whereas geometrical data and technical design are presented in Section 5.2 (KFM04A) and Section 5.5 (KFM04B).

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

- Section 5.3 (percussion drilling of KFM04A).
- Section 5.4 (core drilling of KFM04A).
- Section 5.6 (percussion drilling of KFM04B).

Well Cad-presentations of borehole KFM04A and KFM04B are shown in:

- Appendix A (percussion drilled part of borehole KFM04A).
- Appendix B (core drilled part of borehole KFM04A.
- Appendix C (percussion drilled part of borehole KFM04B).

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

5.1 Drilling progress

Borehole KFM04A was drilled during a period of approximately 5 months, including the summer holiday, see Figure 5-1. Since this was the fourth deep borehole drilled within the Forsmark site investigation programme, the technical constructions and working routines were well established. Both the drill crew and the support organization were trimmed after having performed the three previous deep boreholes KFM01A – KFM03A. The time schedule in Figure 5-1 below includes percussion drilling of both KFM04A and KFM04B, which were sited quite close to each other, see Figure 4-1, and drilled in opposite directions.

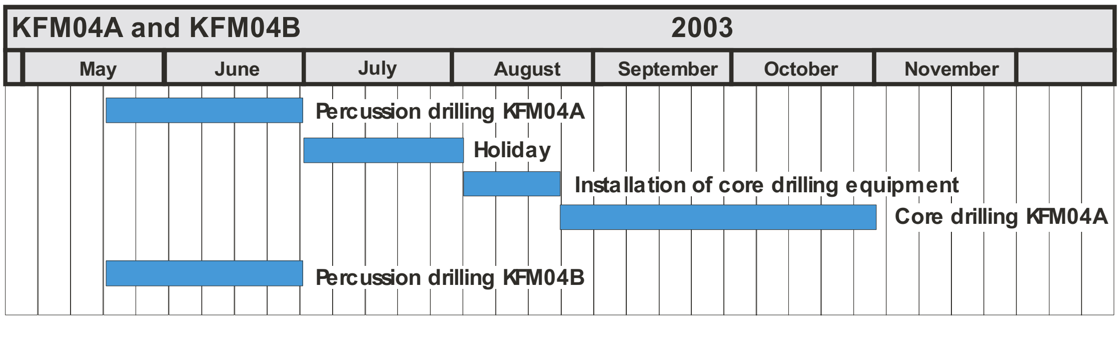


Figure 5-1. *Overview of the drilling performance of boreholes KFM04A and KFM04B. As the two boreholes are sited close to each other, different stages of the percussion drilling and grouting could be performed concurrently, entailing that waiting time could be much reduced.*

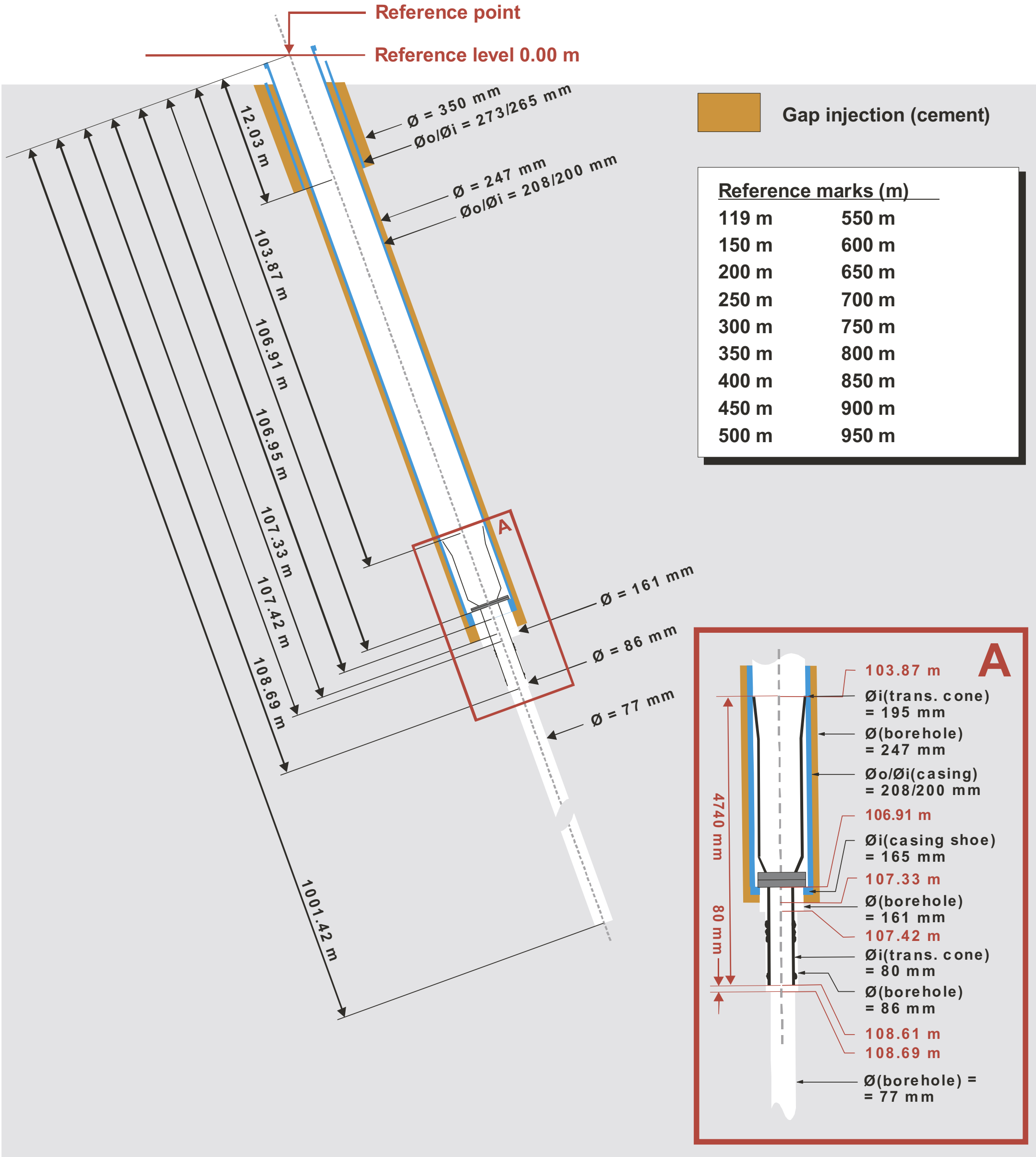
5.2 Geometrical and technical design of borehole KFM04A

Administrative, geometric and technical data for the telescopic borehole KFM04A are presented in Table 5-1, and the technical design of the borehole is illustrated in Figure 5-2.

Table 5-1. Administrative, geometric and technical data for borehole KFM04A.

Parameter	KFM04A
Borehole name	KFM04A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	May 20, 2003
Completion date	November 19, 2003
Percussion drilling period	2003-05-20 to 2003-06-30
Core drilling period	2003-08-25 to 2003-10-30
	2003-11-19 overcoring of lost equipment at 1,000.89–1,001.42 m
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 KFM04A at top of casing (RT90 2.5 gon V 0:–15; RHB 70)	N 6698921.74
	E 1630978.96
	Z 8.77 (m a s l)
	Azimuth (0–360°): 45.24°
	Dip (0–90°): –60.08°
Position KFM04A at bottom of hole (RT90 2.5 gon V 0:–15; RHB 70)	N 6699373.14
	E 1631357.03
	Z –794.24 (m a s l)
	Azimuth (0–360°): 41.53°
	Dip (0–90°): –43.92°
Borehole length	1,001.42 m
Borehole diameter and length	From 0.00 m to 12.03 m: 0.350 m
	From 12.03 m to 107.33 m: 0.247 m
	From 107.33 m to 107.42 m: 0.161 m
	From 107.42 m to 108.69 m: 0.086 m
	From 108.69 m to 1,001.42 m: 0.077 m
Casing diameter and length	Øo/Øi = 273/265 mm to 12.03 m
	Øo/Øi = 208/200 mm between 0.00 and 106.91 m
	Øo/Øi = 208/165 mm (casing shoe) between 106.91 and 106.95 m
Transition Cone inner diameter	At 103.87 m: 0.195 m
Drill core dimension	107.42–108.69 m/Ø 72 mm
	108.69 –1,000.89 m/Ø 51 mm
	1,000.89 –1,001.42 m/Ø 62 mm
Core interval	107.42–1,001.42 m
Average core length retrieved in one run	2.65 m
Number of runs	337
Diamonds bits used	21
Average bit life	42.5 m

Technical data
Borehole KFM04A



Drilling reference point		
Northing:	6698921.74	(m), RT90 2,5 gon V 0:-15
Easting:	1630978.96	(m), RT90 2,5 gon V 0:-15
Elevation:	8.77 (m), RHB 70	

Borehole	
Bearing:	45.24 °
Inclination:	-60.08 °
Length:	1001.42 m

Percussion drilling period	
Drilling start date:	2003-05-20
Drilling stop date:	2003-06-30

Core drilling period	
Drilling start date:	2003-08-25
Drilling stop date:	2003-10-30
	(2003-11-19)

Figure 5-2. *Technical data of borehole KFM04A.*

5.3 Percussion drilling 0–107.42 (KFM04A)

Drilling site DS4 was planned for two deep boreholes, KFM04A and KFM04B. The percussion drilled parts of the two boreholes were drilled with the same drilling equipment in direct succession. So far, only KFM04A has been completed to full borehole length by core drilling.

Percussion drilling is normally a swift drilling method. However, a relatively complex approach is applied for the drilling and grouting sequences. The duration of the different operations included in the percussion drilling from 2003-05-20 to 2003-06-30 are presented in Figure 5-3.

5.3.1 Drilling

As mentioned in Section 4.1.3, the upper 12.03 m of the borehole were cased and cement grouted. During pilot drilling with Ø 165 mm, unstable bedrock was observed around 100 m. When this section had been penetrated, a water inflow of 400 L/min was measured. 100 m was the planned end length of the percussion drilled part, but due to the instability and high water-yielding capacity, the borehole was extended to 107.42 m and the entire borehole section 0–107.33 m was reamed to 247 mm, whereupon a 200 mm stainless steel casing was installed. The gap between the casing and borehole wall was cement grouted, thereby sealing the gap completely so that the water inflow ceased.

5.3.2 Measurements while drilling

During, and immediately after drilling, a programme for sampling and measurements was applied, cf Section 4.1.3. Below, the results of the deviation measurements made after completed percussion drilling of KFM04A (also displayed in the Well Cad-presentation in Appendix A) are commented on. The analyses of drill cuttings from the percussion drilled part of KFM04A are presented in /4/ (rock) and /5/ (soil).

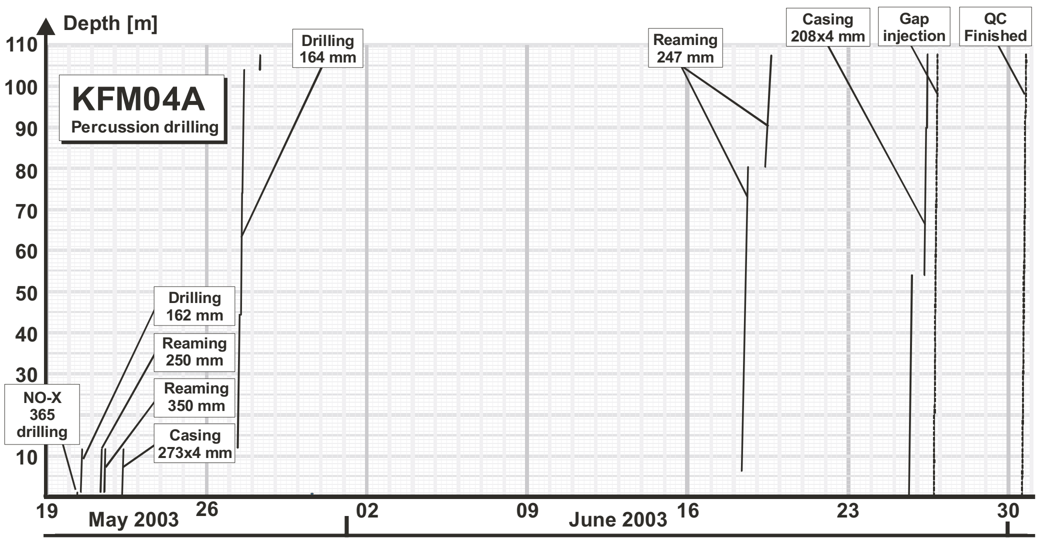


Figure 5-3. Percussion drilling period (depth and activity versus calendar time).

Borehole deviation

The end (bottom) point of the percussion borehole deviates approximately 1.4 m downwards and 2 m to the left compared to an imagined straight line following the dip and strike of the borehole collaring point (inclination –60.08° and bearing 45.24°).

5.4 Core drilling 107.42–1,001.42 m (KFM04A)

The progress of the core drilling period from 2003-08-25 to 2003-10-30 is presented in Figure 5-4.

After percussion drilling of section 0–107.42 m and following the summer holidays, core drilling commenced as seen in Figure 5-4.

When core drilling KFM04A, the pace of the drilling progress decreases versus time, due to that with increasing borehole length, retrieval of the core barrel, e.g. for change of drill bit, becomes more and more time consuming.

5.4.1 Drilling

The bedrock in the Forsmark tectonic lens (approximately the candidate area) has proved to be relatively hard to drill, probably to a large extent depending on the high quartz content. However, drilling site DS4 is located outside the tectonic lens, in bedrock that has been exposed to extensive plastic deformation. Also the brittle deformation is enhanced, i.e. the fracture frequency is increased, compared to within the lens. The collaring of KFM04A is situated within the deformed rock, but the borehole is directed towards the tectonic lens. The transition between the two rock domains, which is relatively distinct, was encountered at c 480 m borehole length, see Appendix B and /4/.

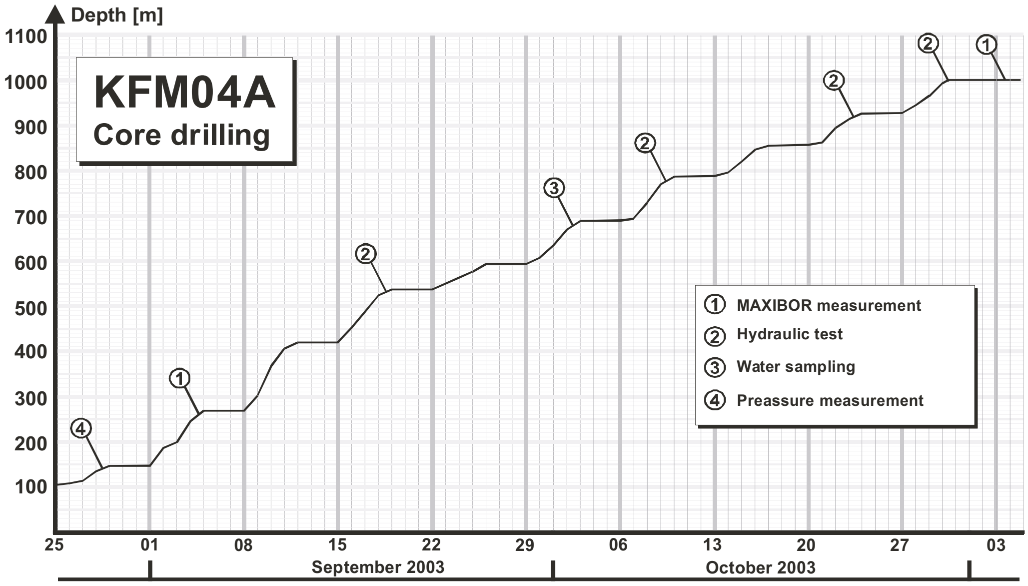


Figure 5-4. Core drilling period (depth versus calendar time).

From a drill-technical point of view, this was noticed as a difference in drill bit life-time between the respective rock domains. Life-time was significantly longer in the upper, deformed half of the borehole than in the deeper part situated within the tectonic lens. In average, the life-time was 42.5 drilled metres per drill bit in KFM04A compared to 27 m in KFM01A.

During, and immediately after drilling, a programme for sampling, measurements, registration of technical and geoscientific parameters and some other activities was applied, as described in Section 4.2.3. To achieve a more efficient rinsing of the borehole from drilling debris and flushing water, nitrogen gas flushing was performed in section 0–1,000 m, as described in Section 4.2.5. However, lifting of the air flushing equipment failed, as the upper 40 m drillrods were dropped, including the nozzle. To ensure the recovery of the lost equipment, it was necessary to perform an overcore drilling with T-76, providing a borehole dimension of 77.3 mm and a core dimension of 62 mm between 1,000.89–1,001.42 m.

The results from drilling of KFM04A are presented in Sections 5.4.2 to 5.4.11 below.

Mapping of the drill core samples from KFM04A is presented in /4/.

5.4.2 Registration of drilling parameters

The letters CCD in the designation "Onram 2000 CCD" is an abbreviation for Computer Controlled Drilling. The Onram hydraulic driving device is supplied with built-in transmitters. The signals give input to a trigger-unit, and a specific software controls the drilling operations. Additionally, the same dataset is stored in a database, which forms one part of the drilling parameters collected for technical control and for geoscientific analyses. Additional drilling parameters are acquired by gauges for flushing and return water flow rate, flushing water pressure, electrical conductivity of flushing and return water and, finally, dissolved oxygen in the flushing water.

A selection of drilling parameters is presented in diagrams below. As regards the complete dataset of drilling parameters, it is referred to SICADA, field note nos 171, 202, 239 and 283.

Drill bit position versus time

Figure 5-5 shows how the drilling length proceeded versus time. Generally, drilling ran 24 hours per day from Monday to Thursday with a weekend stop from Thursday night to Monday morning.

Penetration rate

Figure 5-6 illustrates the penetration rate versus drilling depth. Generally, the penetration rate is relatively high, at about the same level as during drilling of KFM03A, although a slight decrease versus depth is observed, approximately corresponding to the transition between the highly deformed respectively low-deformed rock domains at the middle of the borehole. Two periods of especially decreased penetration rate are observed in Figure 5-6: initially, before drilling has stabilized, and between 535–559 m, where different drilling parameters were varied in an attempt to improve the core quality.

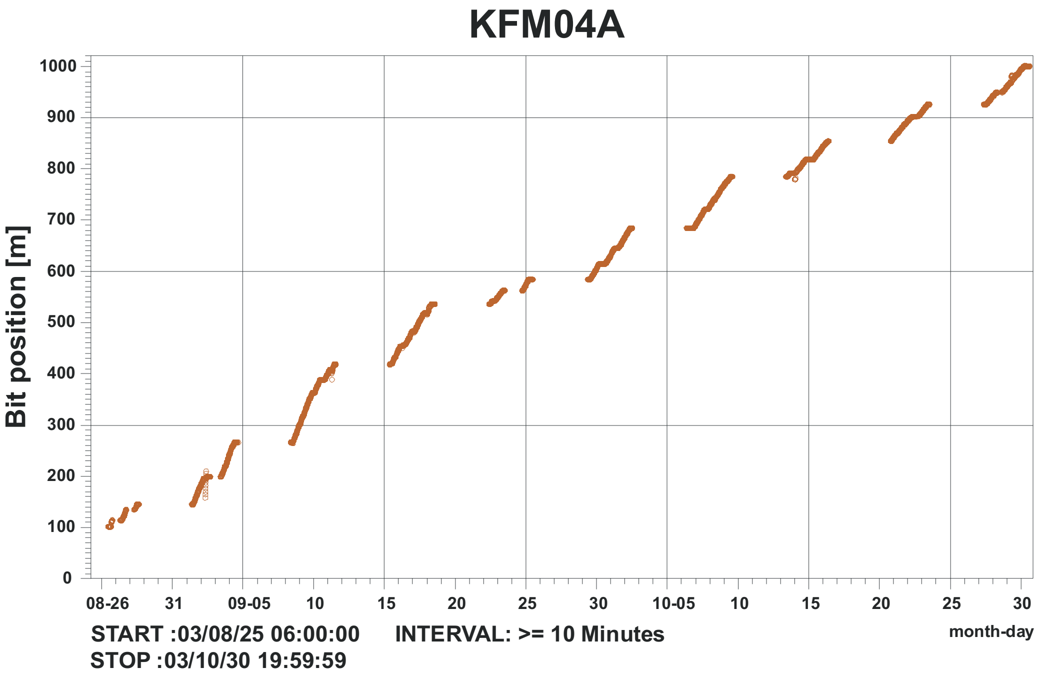


Figure 5-5. Drill bit position versus time.

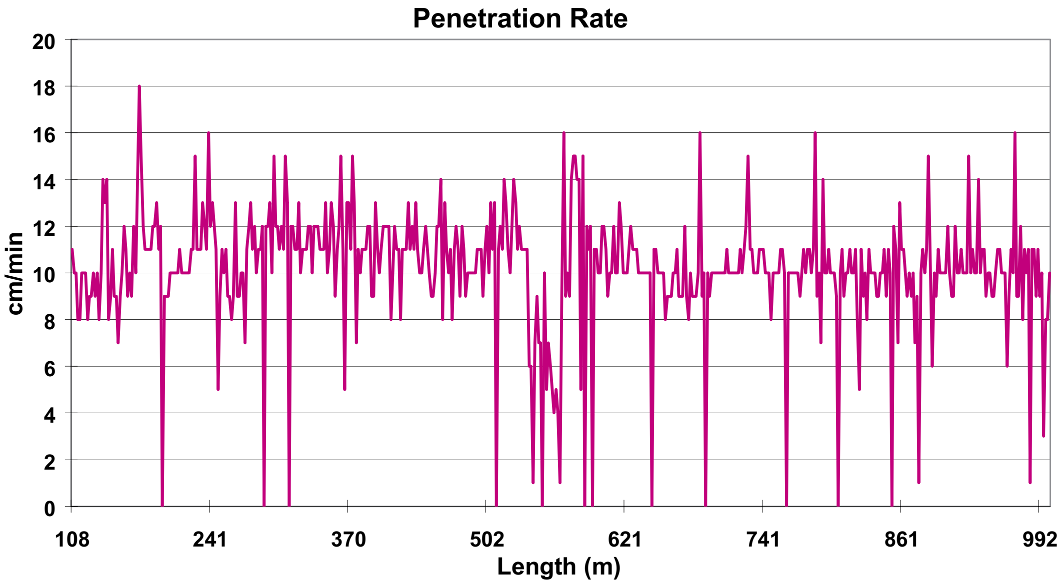


Figure 5-6. *Penetration rate during core drilling of KFM04A. The attempts to improve core quality by adjusting different drilling parameters can be observed in section 535–559 m.*

Feed force

In Figure 5-7 the feed force is plotted versus borehole length. After an initial period of feed force adjustments, this parameter is relatively stable with an increasing trend versus drilling length. The increase is an effect of successively higher return water friction with depth. Feed force decreases down to zero are the result of the feed force being shut off.

Rotation speed

The rotation speed diagram (Figure 5-8) is characterized by two distinct parts. Until c 500 m the rotation speed varies between c 850 and 1,000 rpm, and below that drilling length the speed is almost constant at c 900 rpm until c 910 m, when it is decreased to about 850 rpm. The transition between the two parts corresponds to the two rock domains mentioned above, if at random or not is difficult to tell. The sudden drops in the curve represent drilling shut off.

5.4.3 Registration and sampling of flushing water and return water

Flushing water and return water flow rate – water balance

As borehole KFM04A 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. The flushing water flow rate was registered by a flow gauge in the measurement station, see Figure 3-4, and the return water by another flow rate gauge mounted on-line with the discharge pipeline, see Figures 3-4 and 3-8.

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

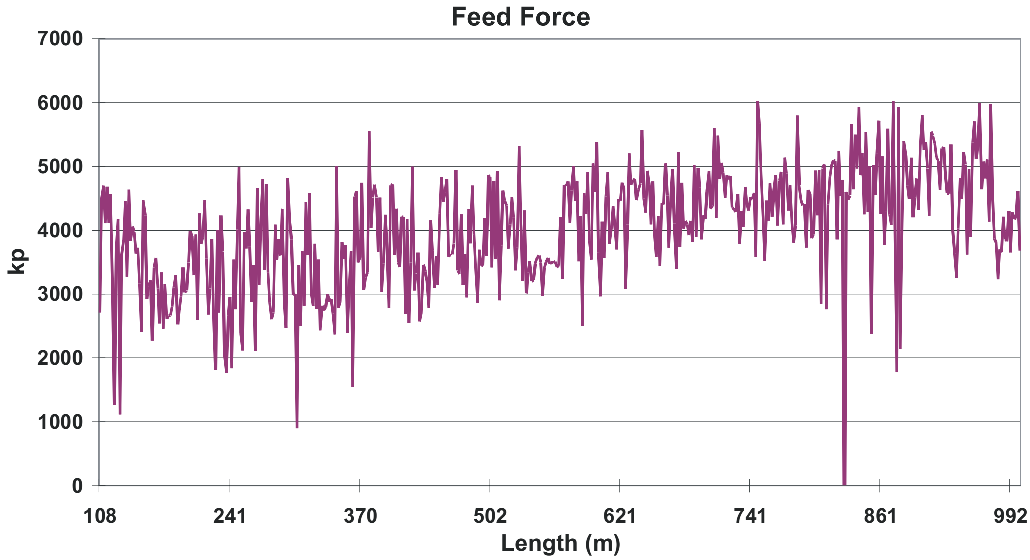


Figure 5-7. *Feed force versus borehole length during drilling of borehole KFM04A. The attempts to improve core quality by adjusting different drilling parameters can be observed in section 535–559 m.*

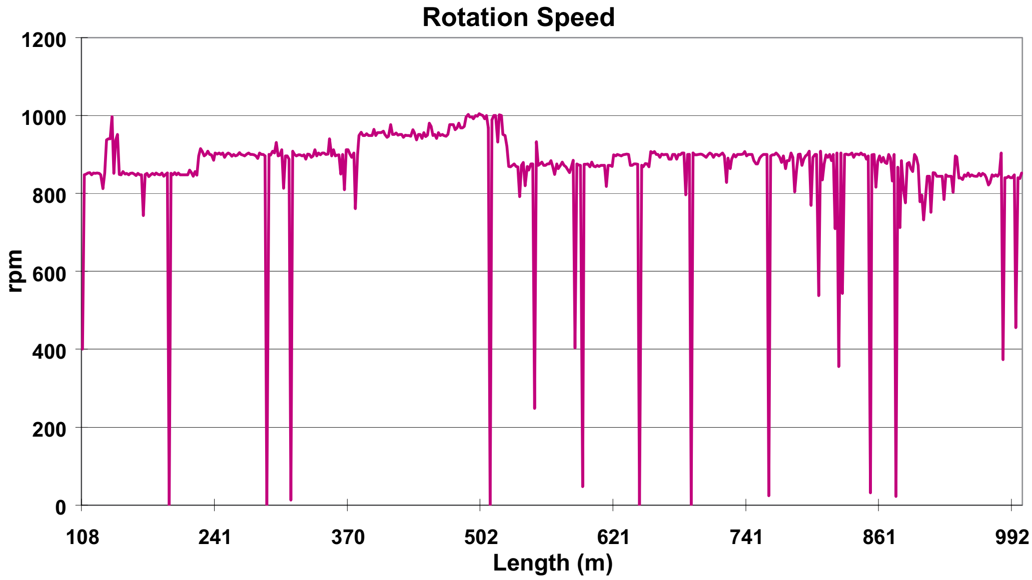


Figure 5-8. *Rotation speed versus borehole length during drilling of borehole KFM04A.*

Figure 5-9 illustrates the accumulated volume of flushing water and return water versus time during core drilling of borehole KFM04A, while Figure 5-10 displays the accumulated volumes of flushing water and return water from the entire drilling period (results from Uranine measurements are presented in the next section).

From the accumulated volumes of flushing water and return water at the end of the drilling period illustrated in Figure 5-10, a return water/flushing water quotient of 3.31 for the entire borehole was calculated. Figure 5-9 shows that the supply of flushing water to the borehole was reduced from October 30th, i.e. from the date core drilling stopped, whereafter only rinsing of the borehole was performed. The reduced rate of flushing water flow to the borehole is also reflected in the return water diagram as a decreased flow rate.

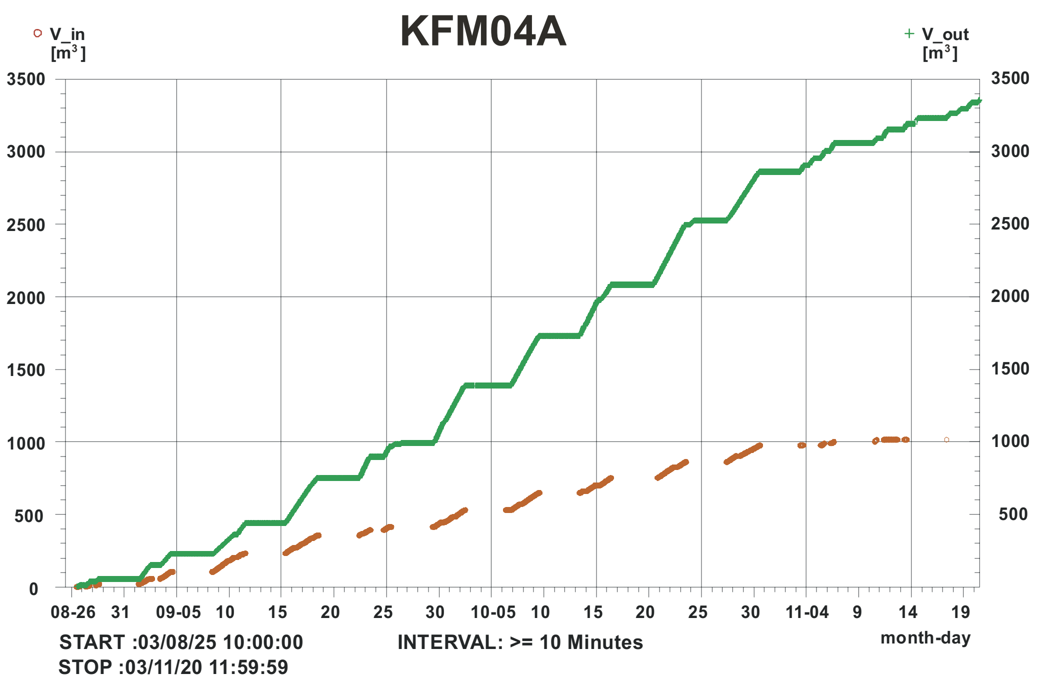


Figure 5-9. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM04A.*

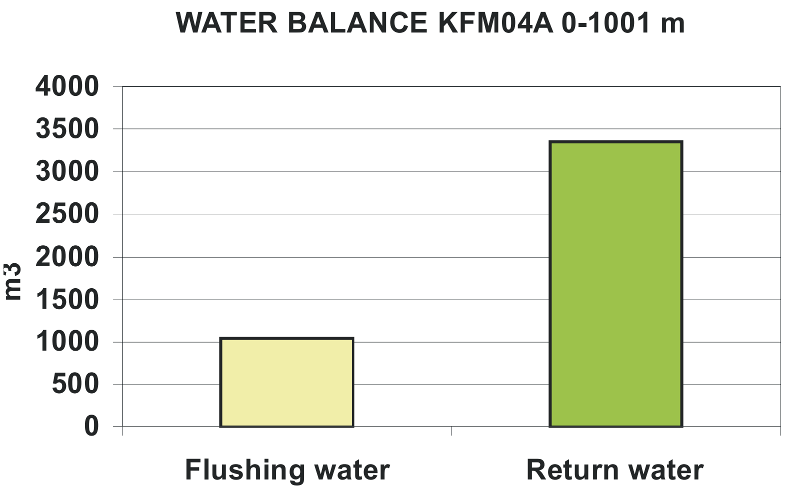


Figure 5-10. The total measured volume of flushing water used during core drilling was 1,015 m^3. During the same period, the total volume of return water was 3,358 m^3. The return water/flushing water balance is then 3.31. This high value indicates a relatively large groundwater-yield.

Uranine content of flushing water and return water–mass balance

During the drilling period, sampling and analysis of flushing water and return water was performed systematically with a frequency of approximately one sample per 10–20 m drilling length, see Figure 5-11. Like in boreholes KFM02A and KFM03A, a dosing feeder controlled by a flow meter was used for labelling the flushing water with Uranine. However, the flow meter malfunctioned during part of the drilling period, resulting in unstable dosage.

A mass balance calculation based on the Uranine content in both the flushing water and return water samples was made. The platform for such a calculation was improved in KFM04A compared to for the previous deep boreholes in the sense that the sampling frequency of the return water and the flushing water was doubled. However, in spite of that, due to the unstable dosage of Uranine in the flushing water, the calculation cannot be regarded as fully reliable, but merely as a rough estimate. The calculation indicates that approximately 100 m^3 of flushing water was lost to the borehole and the adjacent host bedrock, which is the same magnitude as for boreholes KFM01A, KFM02A respectively KFM03A.

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM04A is exposed in Figure 5-12. Like in KFM02A and KFM03A, the borehole diameter was 77.3 mm, i.e. increased c 1 mm compared to in borehole KFM01A. This resulted in lower flushing water pressures than in KFM01A, more like in KFM02A and KFM03A, although the water pressures below c 700 m were 10–20 bars higher than in the two latter boreholes. The reason for this is not clear. One possible explanation may be that KFM04A is more inclined than the previous boreholes, which makes recovery of drill cuttings more difficult, demanding higher flushing water pressures and increased flow rates.

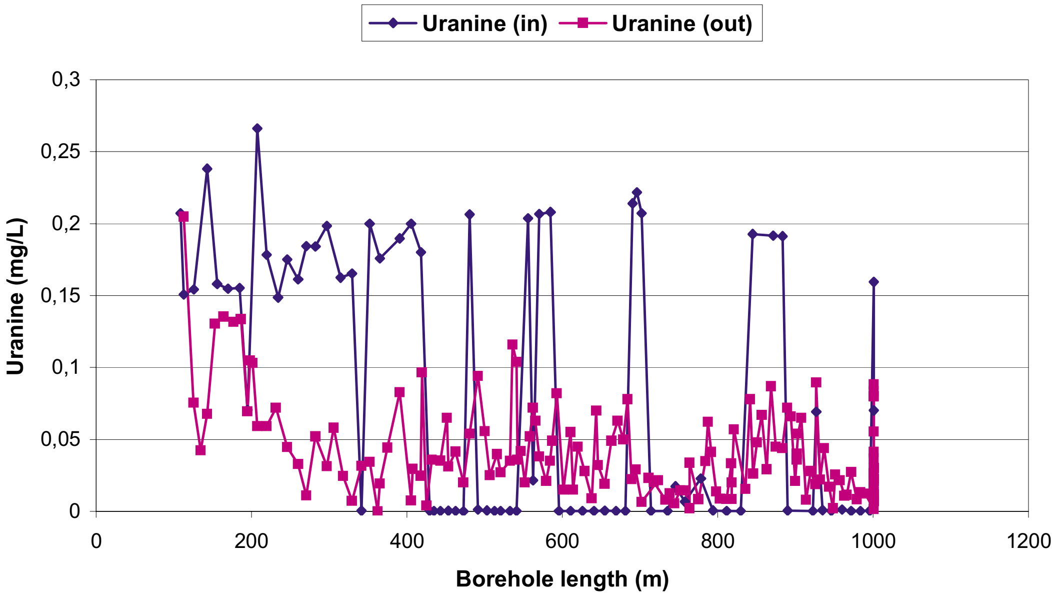


Figure 5-11. *Uranine concentrations versus drilling length in the flushing water consumed and in the return water recovered during drilling of KFM04A. The labelling with Uranine was accomplished by an automatic dosing equipment which is controlled by a flow meter. Malfunction of the flow meter caused irregular and erroneous dosage of Uranine, why the calculations of the amount of flushing water remaining in the formation is not fully reliable.*

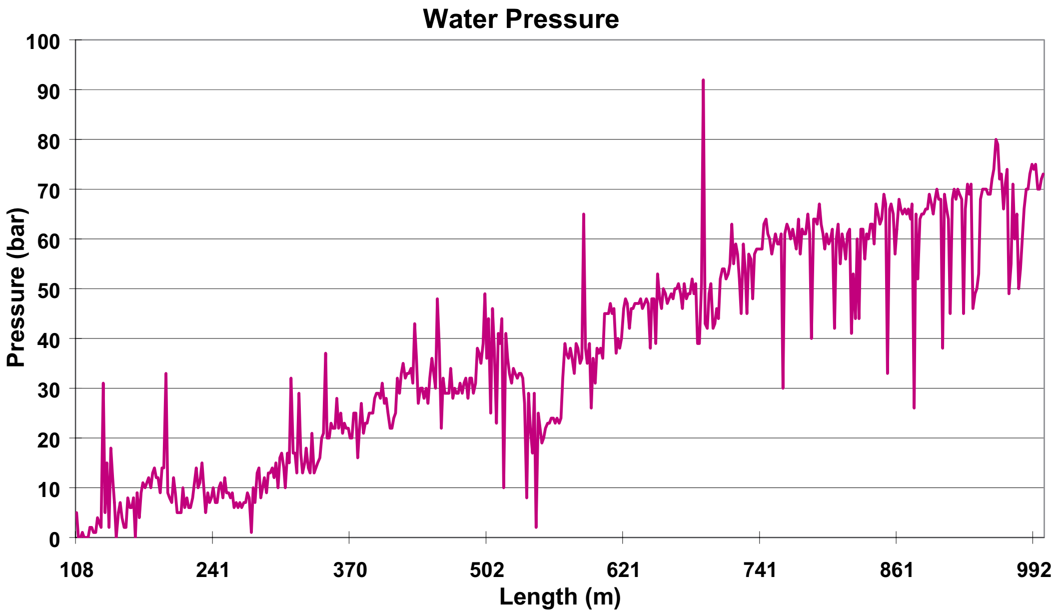


Figure 5-12. *Flushing water pressure versus drilling length when drilling KFM04A. For improving core quality the contractor tested different drilling parameters in section 535–559 m.*

Electric conductivity of flushing water

Flushing water was supplied from percussion borehole HFM10, see Figure 1-2. A sensor for on-line registration of the electric conductivity of the flushing water was placed in the measurement station, before the flushing water entered the borehole, see Figure 3-4.

The sensor for registration of the electric conductivity (EC) of the return water was positioned between the surge diverter and the sedimentation containers see Figure 3-5.

There is a surprising difference between the electrical conductivity (salinity) of the flushing water from the 150 m deep borehole HFM10 and that of the return water from the deep borehole KFM04A, see Figure 5-13. Normally the salinity increases versus depth, but in this case the salinity of HFM10 seems to be higher than that of KFM04A, and not until the drilling length of KFM04A has reached c 900 m (c 780 m vertical depth), the salinity of the return water from KFM04A seems to be on the same level as that of the flushing water. This may seem astonishing, since according to Figures 5-9 and 5-10, the portion of groundwater is high in the return water. However, the phenomenon is probably a combined effect of several factors. Firstly, the major part of the groundwater from KFM04A emerges probably from shallow, relatively low-saline parts of KFM04A, about 100–400 m. Secondly, suspended drill cuttings and a high content of water bubbles in the turbulent flow of the return water reduces the electrical conductivity.

Finally, a generally lower temperature of the return water than that of the flushing water also results in decreased EC-values.

The positive peaks observed in the return water diagram are due to the weekend drilling stops. At the end of every weekly drill shift, pumping is stopped, whereupon formation water is recharging into the borehole during the weekend. At the same time, drill cuttings sediment towards the bottom of the borehole and the air bubbles disappear because the mammoth pumping is shut off. When air flushing is restarted, the EC-value of the mixed return water is higher for a short period due to an increased content of formation water and a lower content of drill cuttings and air bubbles than before the weekend.

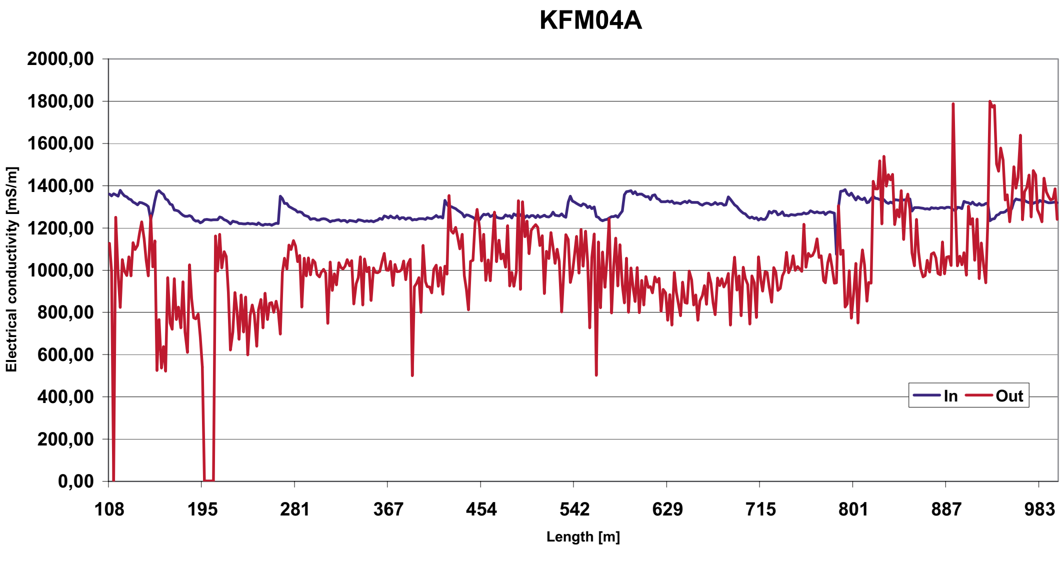


Figure 5-13. *Electrical conductivity of flushing water from HFM05 and return water from KFM04A.*

That the lower EC-values from the on-line measurements of the return water during drilling probably is an imaginary effect, was confirmed by the fact that measurements of return water samples (i.e. when drill cuttings had settled and air bubbles disappeared and when the groundwater had reached a higher temperature) resulted in EC-values in the same range as for the flushing water.

Content of dissolved oxygen in flushing water

The transmitter for measuring dissolved oxygen was out of function from start and could not be exchanged during the drilling period. Hence, no satisfactory readings were made.

Flushing water quality

The results from flushing water analyses of water from the supply well HFM10 are compiled in Appendix C. The flushing water was sampled prior to the core drilling and at a few occasions during the period of core 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.
- To monitor the water composition.

The chemical composition of the flushing water is important when estimating the effect, or correcting for the effect, of remaining flushing water in the water samples from borehole KFM04A.

The results concerning organic constituents, microbes and water composition are presented below.

Organic constituents

The concentration of Total Organic Carbon (TOC) in the samples collected in HFM10 prior to core drilling was in the range 2.3–2.9 mg/L. These values were considered as sufficiently low, and it was decided to use HFM10 as the flushing water well without further measures (like an active carbon filter system for reduction of organic substances as in KFM01A).

Microbes

Analyses of the microbe content in the flushing water, before and after the UV-system, was performed during drilling /6/. The results showed that the amount of algae and bacteria in the flushing water entering the borehole was reduced compared to the situation in KFM01A, probably due to the absence of the in-line storage tank after the UV-system. However, the microbe content was still too high to be satisfactory and further measures need to be taken in order to avoid microbial growth in the flushing water in future drilling activities.

Water composition

The flushing water was sampled at four occasions during drilling and also prior to drilling, in connection with hydraulic testing of borehole HFM10 /7/ and /8/. Furthermore one sample was collected in August after completion of drilling. As shown in Appendix C, the composition of the water from HFM10 changes from time to time possibly due to the pumping situation. Therefore, sampling should be performed more frequently, say twice a month during the drilling period.

5.4.4 Registration of the groundwater level in KFM04A

To enhance the recovery of drill cuttings from the borehole, airlift (mammoth) pumping was applied during the entire drilling period. The effect of the pumping was checked by registration of he groundwater level in the borehole, below plotted versus borehole length (Figure 5-14).

The mammoth pumping was set to a draw-down of in average approximately 20 m at the beginning of the drilling period. When increasing the draw-down, the return water outflow rate overcome the capacity of the 2.5 km long water pipe line between drilling site DS4 and the recipient. By using the 40 m^3 bladder tank as a buffer for the return water, it was possible to temporary increase the draw-down, seen as variations of the drawn-down in Figure 5-14. During the weekly drilling stops, the water from the bladder tank was empted to the recipient.

The drilling was performed continuously during Monday–Thursday. During the weekend stop of drilling and pumping, the groundwater table recovered due to recharge of groundwater into the borehole, resulting in the (positive) peaks in the diagram. When pumping was re-started, a simultaneous draw-down occurred. These results confirm that the total inflow of formation water at shallow levels below the upper cased and grouted parts of the borehole was high.

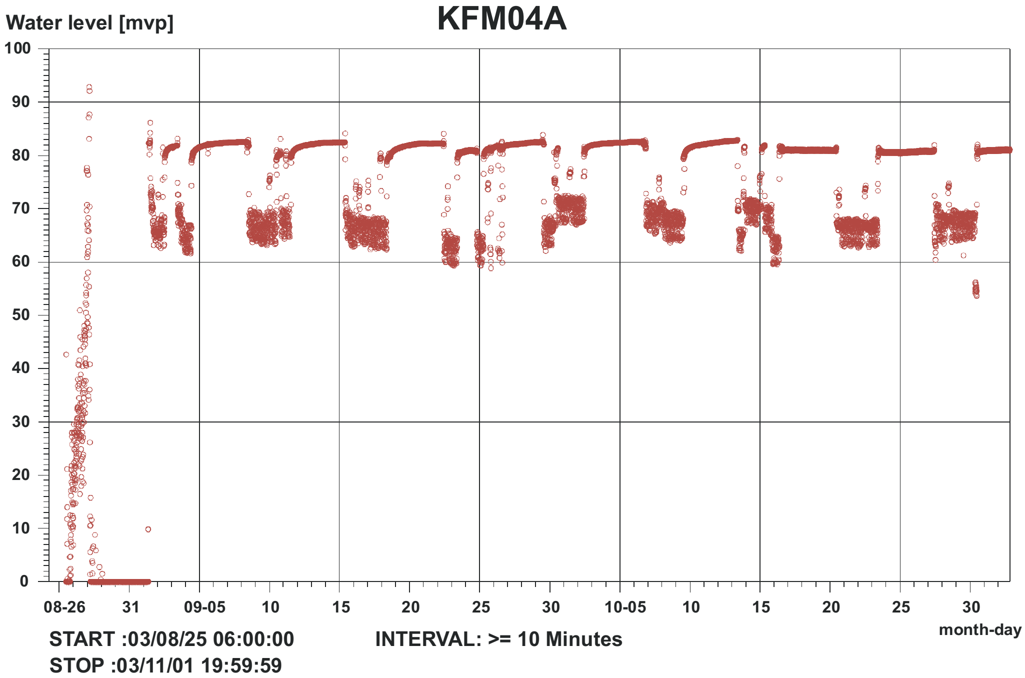


Figure 5-14. *Variation of the level of the groundwater table in KFM04A during core drilling.*

5.4.5 Core sampling

The average drill core length obtained from the drilling was 2.65 m. Due to the very low fracture frequency at depth, several 3 m long, unbroken cores were recovered. Minerals in natural fractures were relatively well preserved. Rotation marks on the drill core occurred, but with a rather low frequency. A preliminary on-site core logging was performed continuously.

5.4.6 Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0–100 m) is 5 m^3. Weighing of drill cuttings and comparison with the weight of the theoretical volume was not carried out due to the extreme high water flow, which caused a relatively large and uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations. However, it seems probable that the percussion drilled part was well cleaned from debris, since casing driving and grouting of the gap between the borehole wall and the casing to full borehole length worked well without obstruction from sedimented drill cuttings.

The theoretical difference in volume of the core drilled part of KFM04A and the drill core is calculated to be 2.350 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 theoretical dry weight of debris is estimated at 6,228 kg. The recovered drill cuttings from the core drilled part of KFM04A was weighed in a water-saturated state and the dry weight was calculated. It amounted to 3,508 kg. The difference between theoretical respectively weighed and calculated dry weight of debris is 2,721 kg, which gives a recovery of 56%.

The recovery figures 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 56%. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

It cannot be excluded that drilling debris could have been injected into the fracture system in the bedrock, especially in the permeable sections with higher fracture frequency in the upper half of the borehole.

5.4.7 Deviation measurements

The deviation measurements made in borehole KFM04A show that the deviation of the borehole is planning out at c 110 m drilling length (see Appendix B). The bottom of the borehole deviates approximately 65 m upwards and 20 m to the left compared to an imagined straight line following the dip and strike of the borehole start point.

5.4.8 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 emerge 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).

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 inclination 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 5-15, which is based on load tests performed in the laboratory by the manufacturer of the drilling pipes. As seen in the diagram, the maximum elongation at 1,000 m length in a vertically drilled borehole is 180 mm. In inclined boreholes the elongation of the pipe string should theoretically be less.

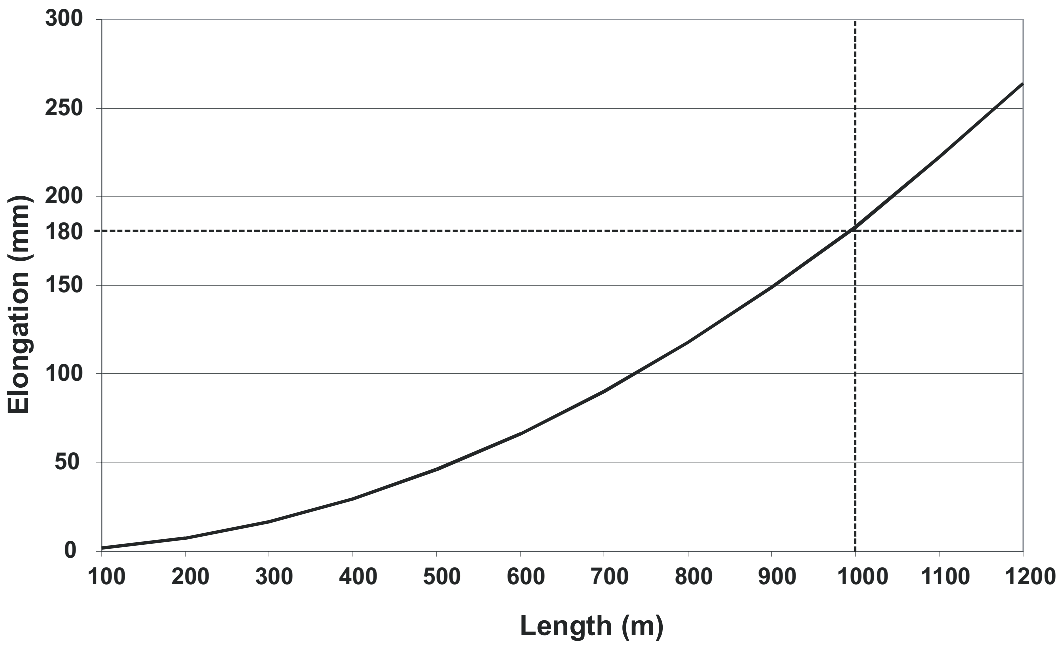


Figure 5-15. *The diagram illustrates the elongation of the WL-76 drilling pipe string when hanging in a vertical water filled borehole. Values from a laboratory load tests of the drilling pipe string.*

5.4.9 Hydraulic tests and water sampling during drilling

In KFM04A one hydraulic measurement was successful, but the water sampling attempts failed. Four successful absolute pressure measurements were conducted.

After completion of drilling, the borehole was cleaned by airlift pumping causing a drawdown of c 25 m. The recovery of the groundwater table was registered during a weekend.

Results of the hydraulic tests and absolute measurements in KFM04A are presented below.

Pumping tests and absolute measurements with the wireline probe

One successful pumping test was performed, in section 649.20–684.17 m. Results from the test are presented in Table 5-2. The specific capacity (Q/s) was calculated according to SKB MD 320.004. However, no hydraulic transmissivity value (T_M) was calculated due to a low and unstable pumping flow rate.

No first strike WL-sample was collected from KFM04A in connection with the wireline probe pumping test. The reason was that drilling debris from the borehole clogged the WL-sond equipment and made it impossible to operate.

Absolute pressure measurements were performed in a total of four sections, see Table 5-3. Test diagrams are attached in Appendix D.

Table 5-2. Pumping test with the wireline probe in KFM04A.

Tested Section (m)	Q/s (m^2/s)	T_{Moye} (m^2/s)	Comments
649.20–684.17	3.1E-7	–	A drawdown of c 315 kPa was generated in the section. Unstable pressure and flow rate. The flow rate at the end of the test was very low (c 0.6 L/min) which resulted in an uncertain value of Q/s.

Table 5-3. Absolute pressure measurements in KFM04A.

Test section (m)	Last pressure reading during test (kPa)	Test duration (h)	Borehole length to pressure sensor (m fr. Ref)
496.25–535.71	4,285	88	497.23
683.8–784.30	5,750	90	684.78
851.20–925.66	6,960	96	852.18
923.86–1,000.89	7,740	96	924.84

Recovery measurement after airlift rinsing

After drilling to 1,000.89 m, the borehole was cleaned by airlift pumping in the section 0–100 m causing a drawdown of c 25 m. The recovery of the groundwater table was registered during the weekend and confirmed the high water-yielding capacity of the borehole, see Figure 5-16. From the diagram an inflow of > 100 L/min can be estimated.

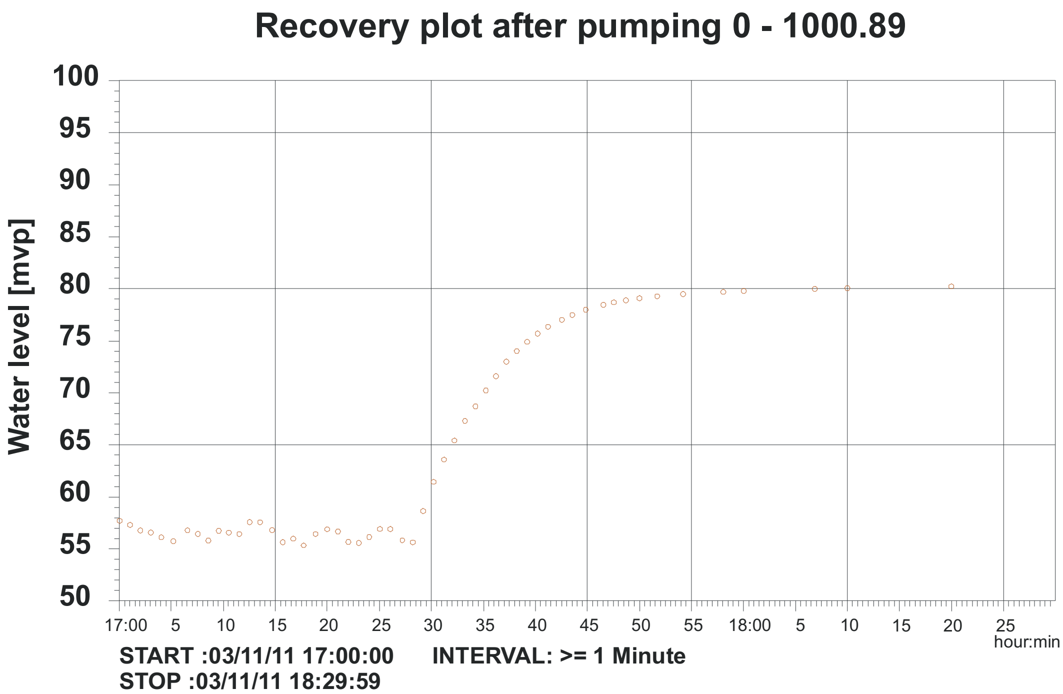


***Figure 5-16.** Recovery of groundwater table in section 0–1,000.89 m of KFM04A.*

5.4.10 Groove milling

After completion of drilling, borehole KFM04A will be used for a variety of borehole measurements, employing many types of in-the-hole equipment (pipe strings, wires, cables etc) with different stretching characteristics. In order to provide a system for length calibration in the borehole, reference grooves were milled into the borehole wall with a specially designed tool at certain levels. This was carried out after drilling, but with use of the drilling machine and pipe string.

At each level, two 20 mm wide grooves were milled with a distance of 10 cm between them, see Figure 5-17. Table 5-4 presents the reference levels selected for milling. After milling, the reference grooves were detected with the SKB level indicator (a calliper). A BIPS-survey gives the final confirmation that the grooves exist.

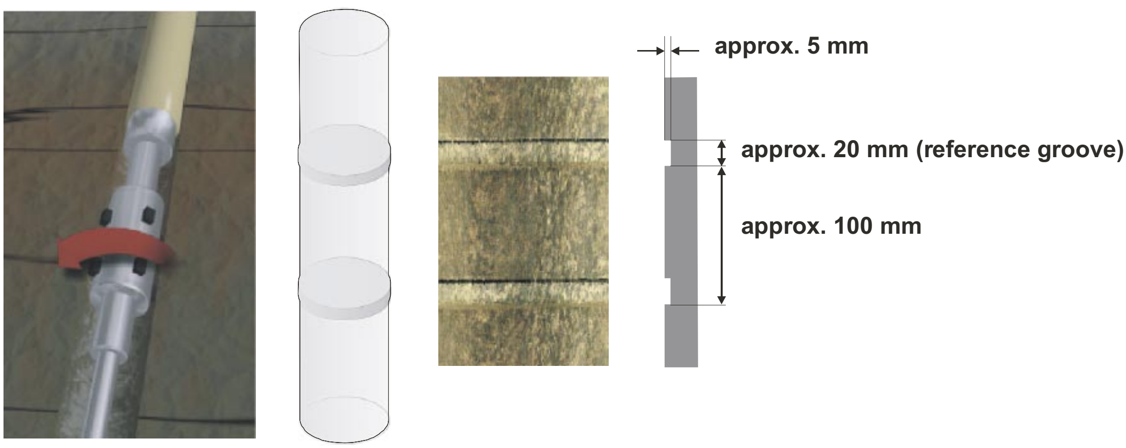


***Figure 5-17.** Layout and design of reference grooves.*

Table 5-4. Compilation of length to the reference grooves in KFM04A. 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
119	Yes	Yes	550	Yes	Yes
150	Yes	Yes	600	Yes	Yes
200	Yes	Yes	650	Yes	Yes
250	Yes	Yes	700	Yes	Yes
300	Yes	Yes	750	Yes	Yes
350	Yes	Yes	800	Yes	Yes
400	Yes	Yes	850	Yes	Yes
450	Yes	Yes	900	Yes	Yes
500	Yes	Yes	950	Yes	Yes

5.4.11 Consumables

The amount of oil products consumed during drilling the percussion drilled borehole (0–100 m) and grout used for gap injections of the respective casings are reported in Table 5-5 and Table 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 in this particular borehole was certified according to SKB MD 600.006e, Instruction for the use of chemical products and construction materials during drilling and investigations. This type of grease was selected in order to avoid contamination of the borehole with organic substances. The experience from a technical point of view is that the lubricating properties are not as satisfactory as for conventional products, mainly due to a relatively low adhesive capacity.

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
KFM04A	15 L	Not detected	4.0 kg

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

Borehole ID	Casing length (m)	Cement volume (White Cement)	Grouting method	Remarks
KFM04A	12.03	786 kg/880 L	Hose	
KFM04A	106.95	2,142 kg/2,400 L	Packer	Stop pressure 12.5 bars

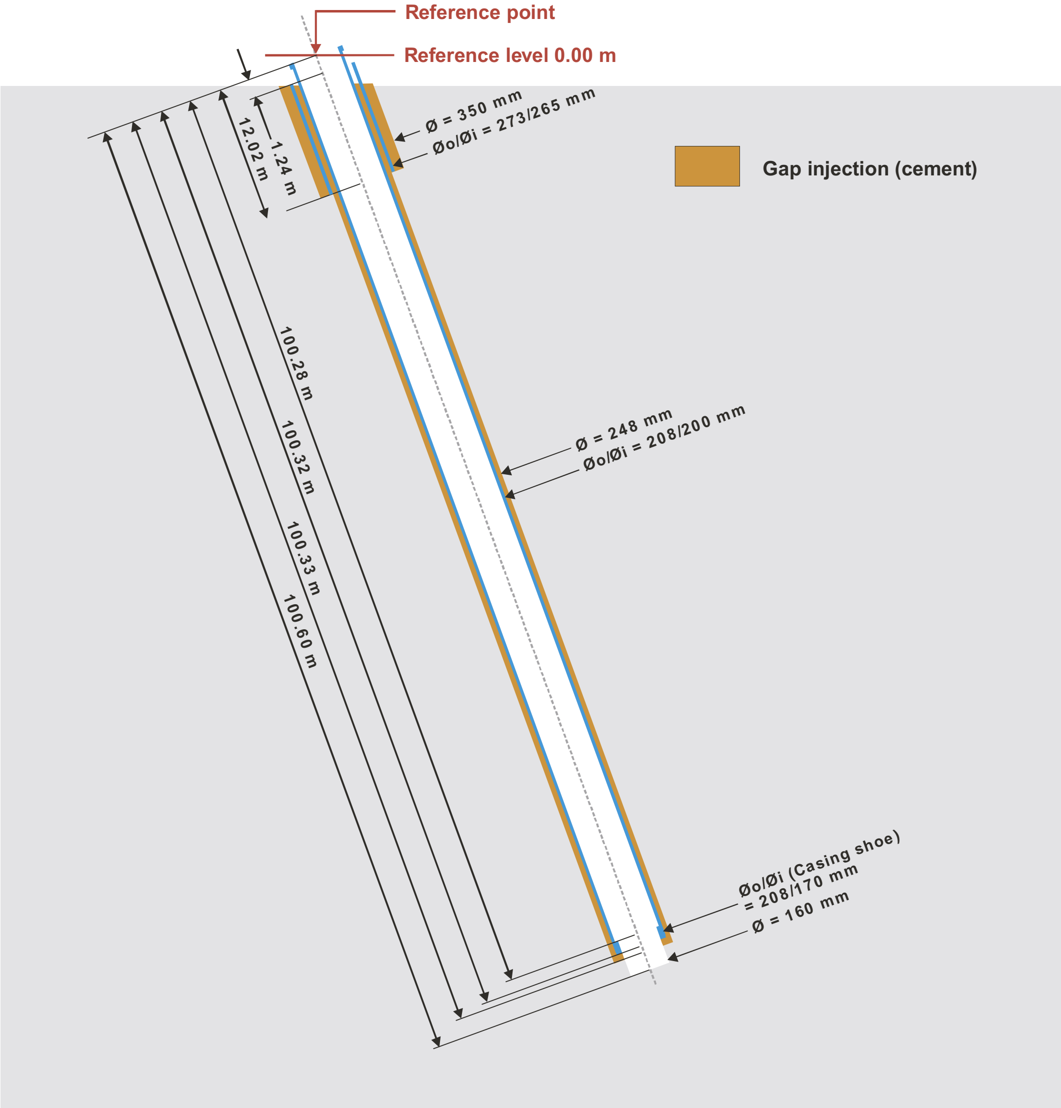
5.5 Geometrical and technical design of borehole KFM04B

Administrative, geometric and technical data for the telescopic borehole KFM04B are presented in Table 5-7. The technical design of the borehole is illustrated in Figure 5-18.

Table 5-7. Administrative, geometric and technical data for borehole KFM04B.

Parameter	KFM04B
Borehole name	KFM04B
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	May 20, 2003
Completion date	June 30, 2003
Percussion drilling period	2003-05-20 to 2003-06-30
Contractor drilling	Drillcon Core AB
Subcontractor percussion drilling	Sven Andersson i Uppsala AB
Percussion drill rig	Puntel MX 1000
Position KFM04B at top of casing (RT90 2.5 gon V 0:–15 ; RHB 70)	N 6698925.15 E 1630978.07 Z 8.76 (m a s l)
	Azimuth (0–360°): 225.59° Dip (0–90°): –59.94°
Borehole length	100.60 m
Borehole diameter and length	From 0.00 m to 12.02 m: 0.350 m From 12.02 m to 100.33 m: 0.248 m From 100.33 m to 100.60 m: 0.160 m
Casing diameter and length	$Ø_o/Ø_i$ = 273/265 mm to 12.02 m $Ø_o/Ø_i$ = 208/200 mm between 0.00 and 100.28 m $Ø_o/Ø_i$ = 208/170 mm (casing shoe)between 100.28 and 100.32 m

Technical data
Borehole KFM04B



Drilling reference point

Northing:	6698925.15	(m), RT90 2,5 gon V 0:-15
Easting:	1630978.07	(m), RT90 2,5 gon V 0:-15
Elevation:	8.76 (m), RHB 70	

Borehole

Bearing:	225.59 °
Inclination:	-59.94 °
Length:	100.60 m

Percussion drilling period

Drilling start date:	2003-05-20
Drilling stop date:	2003-06-30

Figure 5-18. *Technical data of borehole KFM04B.*

5.6 Percussion drilling 0–100.60 (KFM04B)

The duration of the different operations included in the percussion drilling of KFM04B from 2003-05-20 to 2003-06-30 are presented in Figure 5-19.

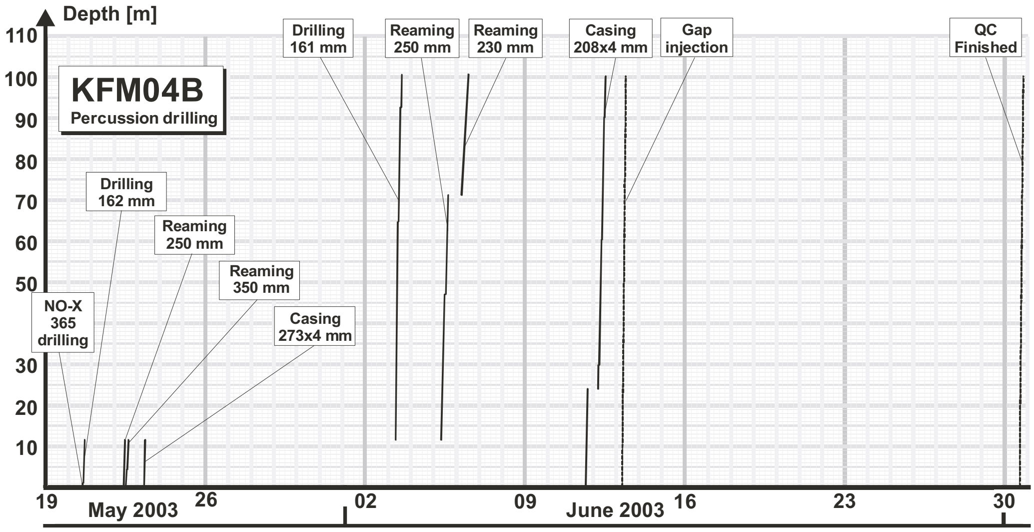


Figure 5-19. Percussion drilling period (depth and activity versus calendar time).

5.6.1 Consumables

Table 5-8. Cement consumption when sealing the gap between the casing and the reamed borehole wall.

Borehole ID	Casing length (m)	Cement volume (Portland Standard Cement)	Grouting method	Remarks
KFM04B	12.02	36 kg/40 L		Bottom plug
KFM04B	11.07	322 kg/360 L	Hose	
KFM04B	100.33	2,821 kg/3,160 L	Packer	Stop pressure 12.5 bars

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, 2003.** Claesson L-Å, Nilsson G. Forsmark site investigation. Drilling of a flushing water well, HFM10, a groundwater monitoring well in solid bedrock, HFM09, and a groundwater monitoring well in soil, SFM0057, at drilling site DS4. SKB P-04-76, Svensk Kärnbränslehantering AB.

/4/ **SKB, 2003.** Petersson J, Wängnerud A. Site investigations at Forsmark. Boremap mapping of telescopic drilled borehole KFM04A. SKB P-03-98, Svensk Kärnbränslehantering AB.

/5/ **SKB, 2003.** Sohlenius G, Rudmark L, Hedenström, A. Forsmark site investigation. Mapping of unconsolidated Quaternary deposits. Field data 2002. SKB P-03-11, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2003.** Pedersen K, Kalmus A. Forsmark site investigation. Control of microorganism content in flushing water used for drilling in KFM02A and KFM04A. SKB P-03-92, Svensk Kärnbränslehantering AB.

/7/ **SKB, 2004.** Nilsson D. Forsmark site investigation. Sampling and analyses of groundwater from percussion drilled boreholes. Results from the percussion boreholes HFM09 to HFM19 and the percussion drilled part of KFM06A. SKB P-04-92, Svensk Kärnbränslehantering AB.

/8/ **SKB, 2003.** Ludvigson J-E, Jönsson S, Svensson T. Pumping tests and flow logging Boreholes KFM04A (0–100m), HFM04, HFM05. SKB P-03-34, Svensk Kärnbränslehantering AB.

Well Cad presentation of the percussion drilled part of borehole KFM04A

Title PERCUSSION DRILLED BOREHOLE KFM04A

Svensk Kärnbränslehantering AB

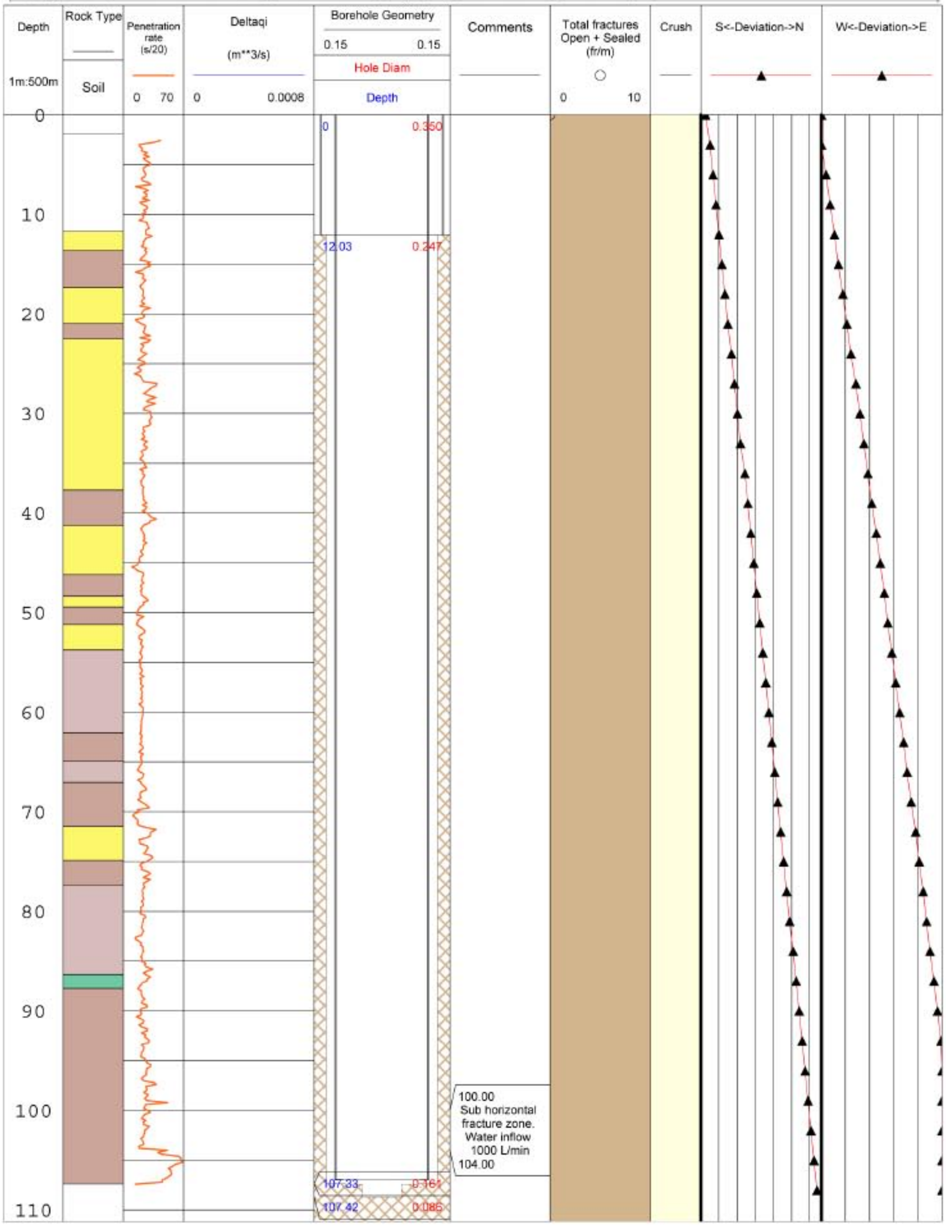
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM04A	**Northing [m]**	6698921.74
Diameter [mm]	247	**Easting [m]**	1630978.96
Length [m]	107.42	**Elevation [m.a.s.l.]**	8.77
Bearing [°]	45.24	**Drilling Start Date**	2003-05-20 07:00:00
Inclination [°]	-60.08	**Drilling Stop Date**	2003-06-30 17:40:00
Date of mapping		**Plot Date**	2004-06-15 21:05:36

ROCKTYPE

- Granite to granodiorite, metamorphic, medium-grained
- Granodiorite, metamorphic
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

SOIL

Script Name HammarBorrHål_FORSMARK_Eng_Log_2003-03-28_[SICADA].sql



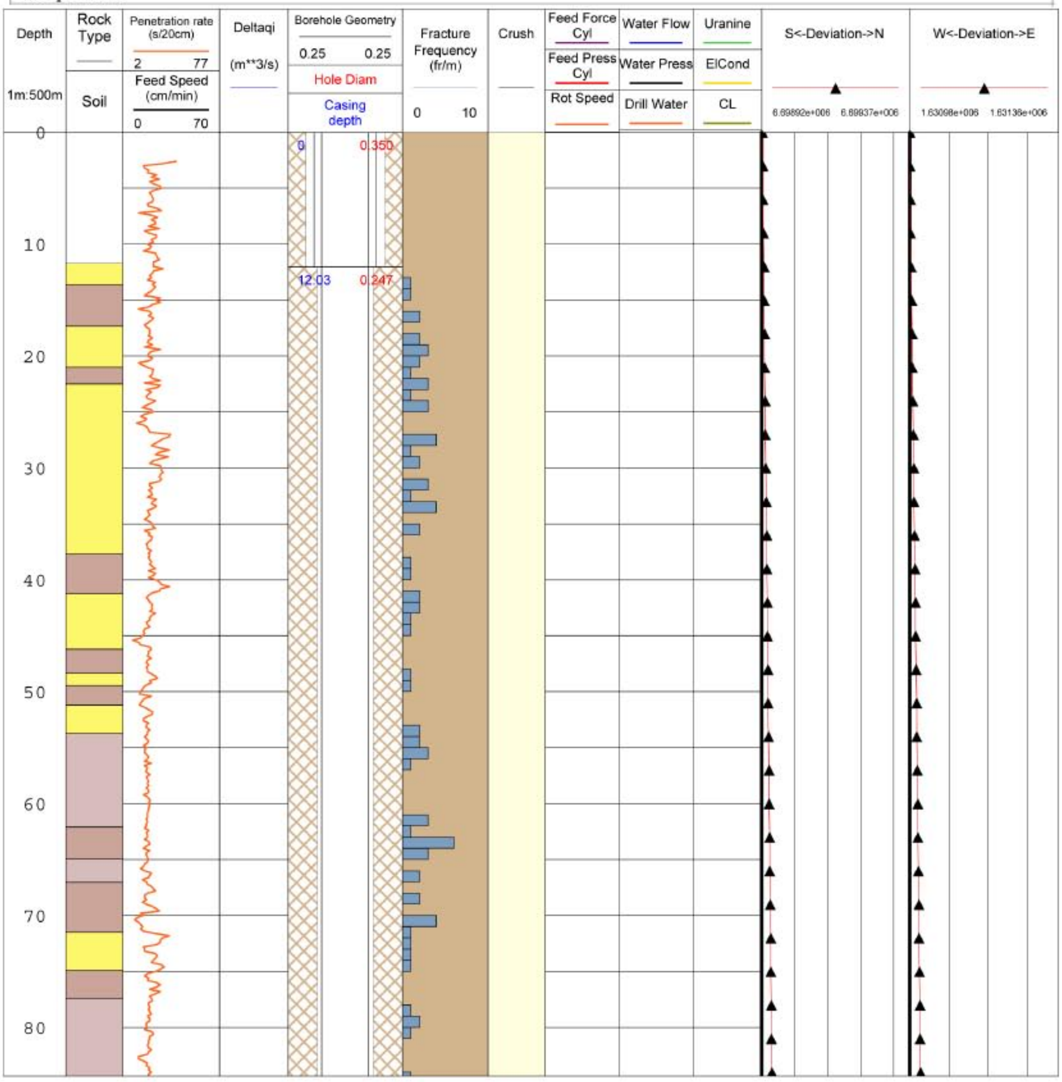
Well Cad presentation of borehole KFM04A

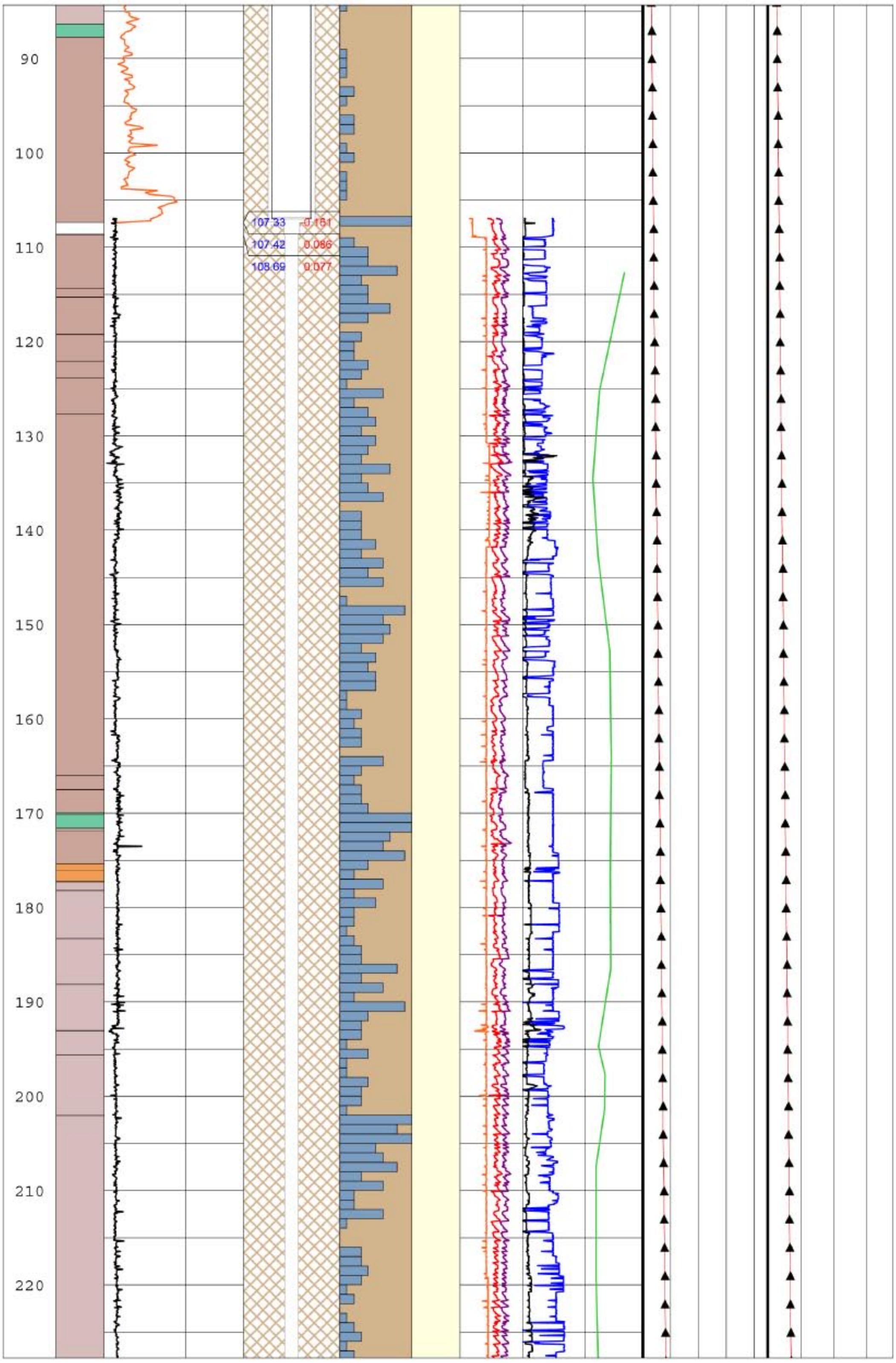
Title	KFM04A		
Svensk Kärnbränslehantering AB			
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM04A	**Northing [m]**	6698921.74
Diameter [mm]	77	**Easting [m]**	1630978.96
Length [m]	1001.42	**Elevation [m.a.s.l.]**	8.77
Bearing [°]	45.24	**Drilling Start Date**	2003-05-20 07:00:00
Inclination [°]	-60.08	**Drilling Stop Date**	2003-11-19 15:15:00
Date of mapping		**Plot Date**	2004-06-28 21:02:25

ROCKTYPE FORSMARK — SOIL

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

Script Name

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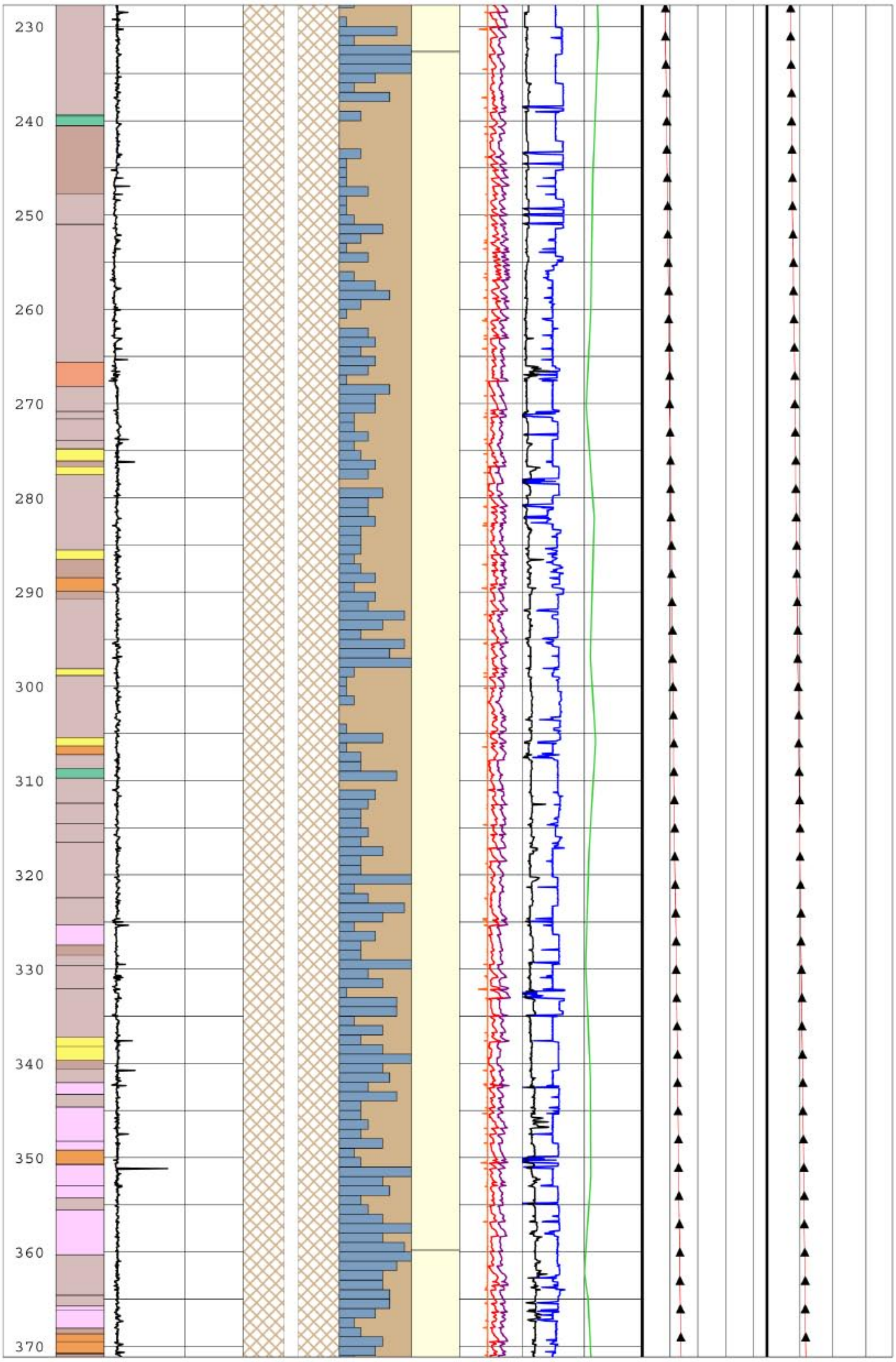
200
210
220
107.33
-0.161
107.42
0.086
108.69
0.077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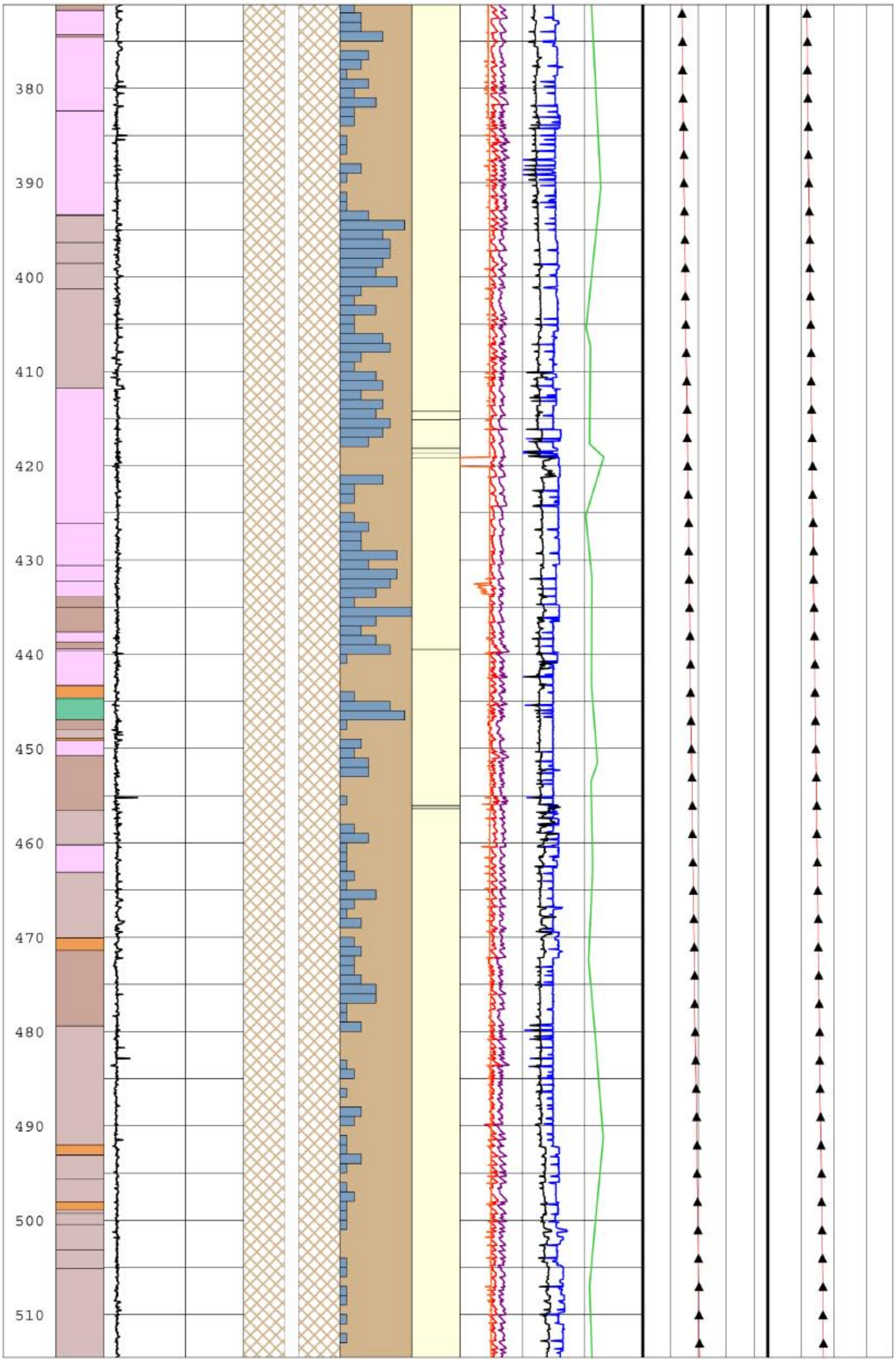
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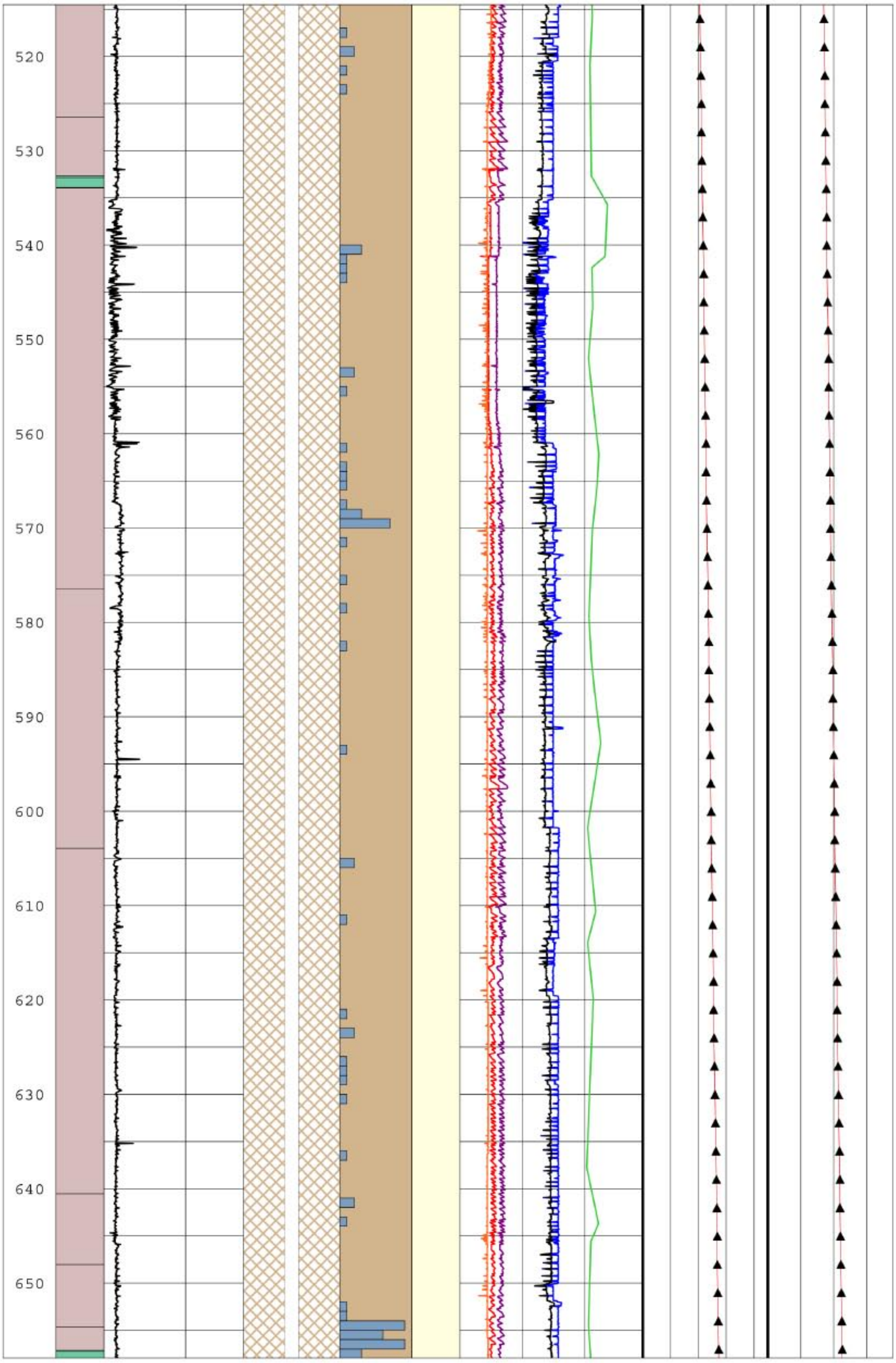
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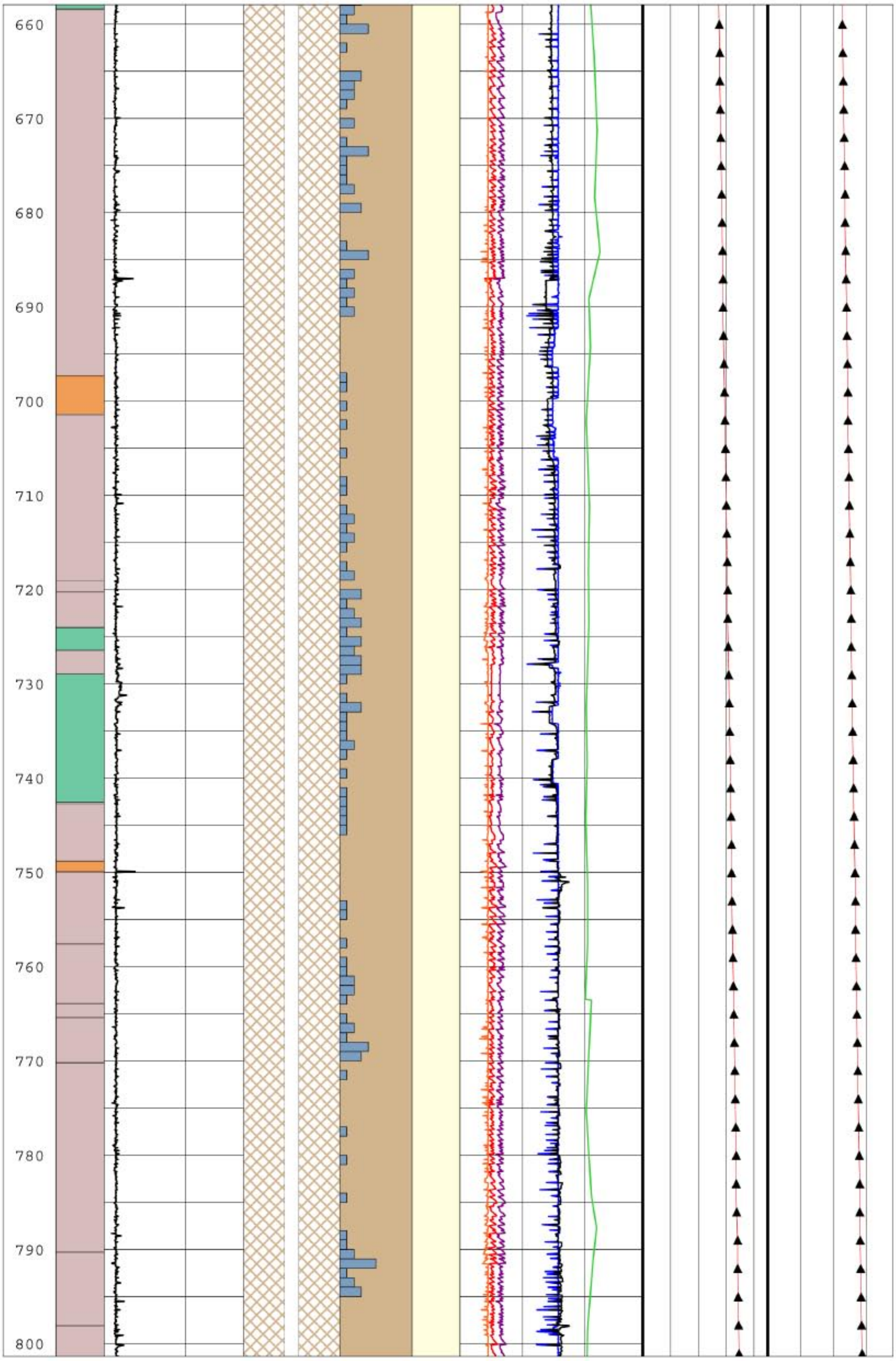
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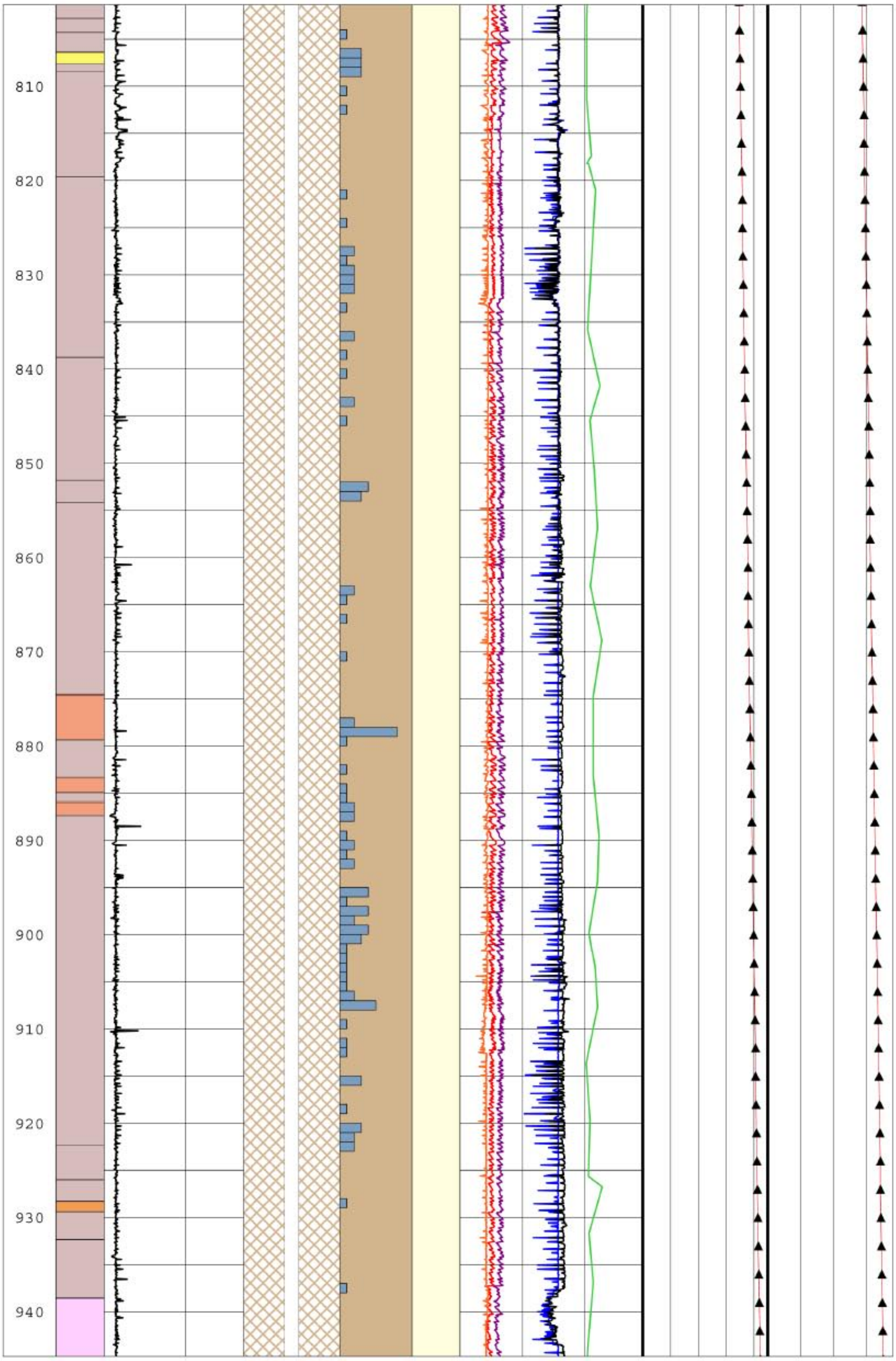
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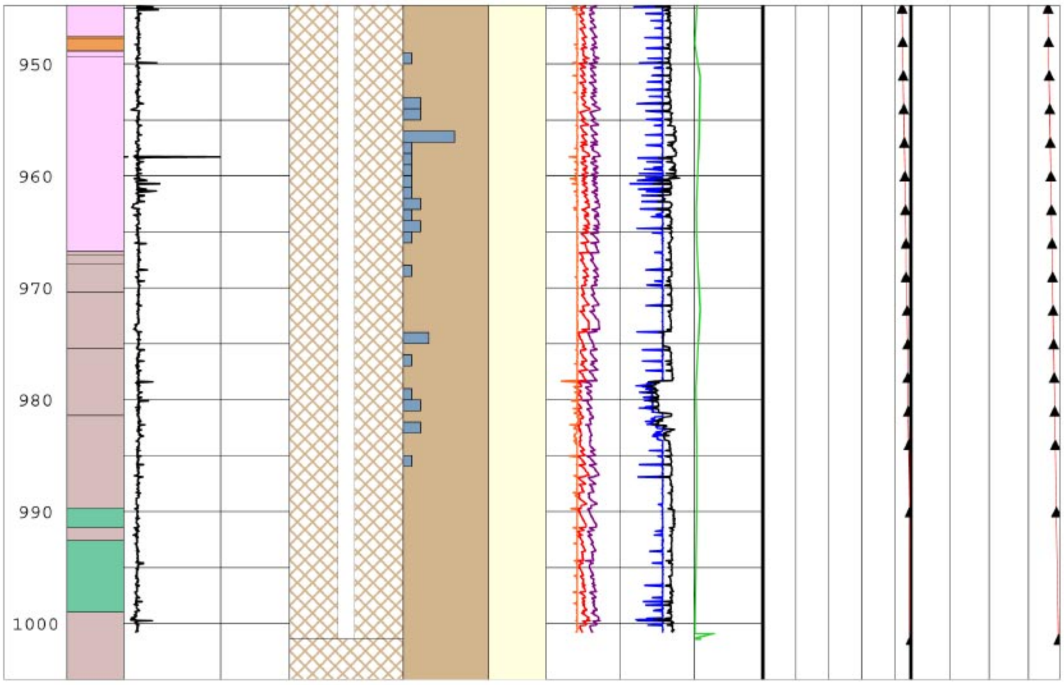
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990
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Appendix C

Well Cad presentation of borehole KFM04B

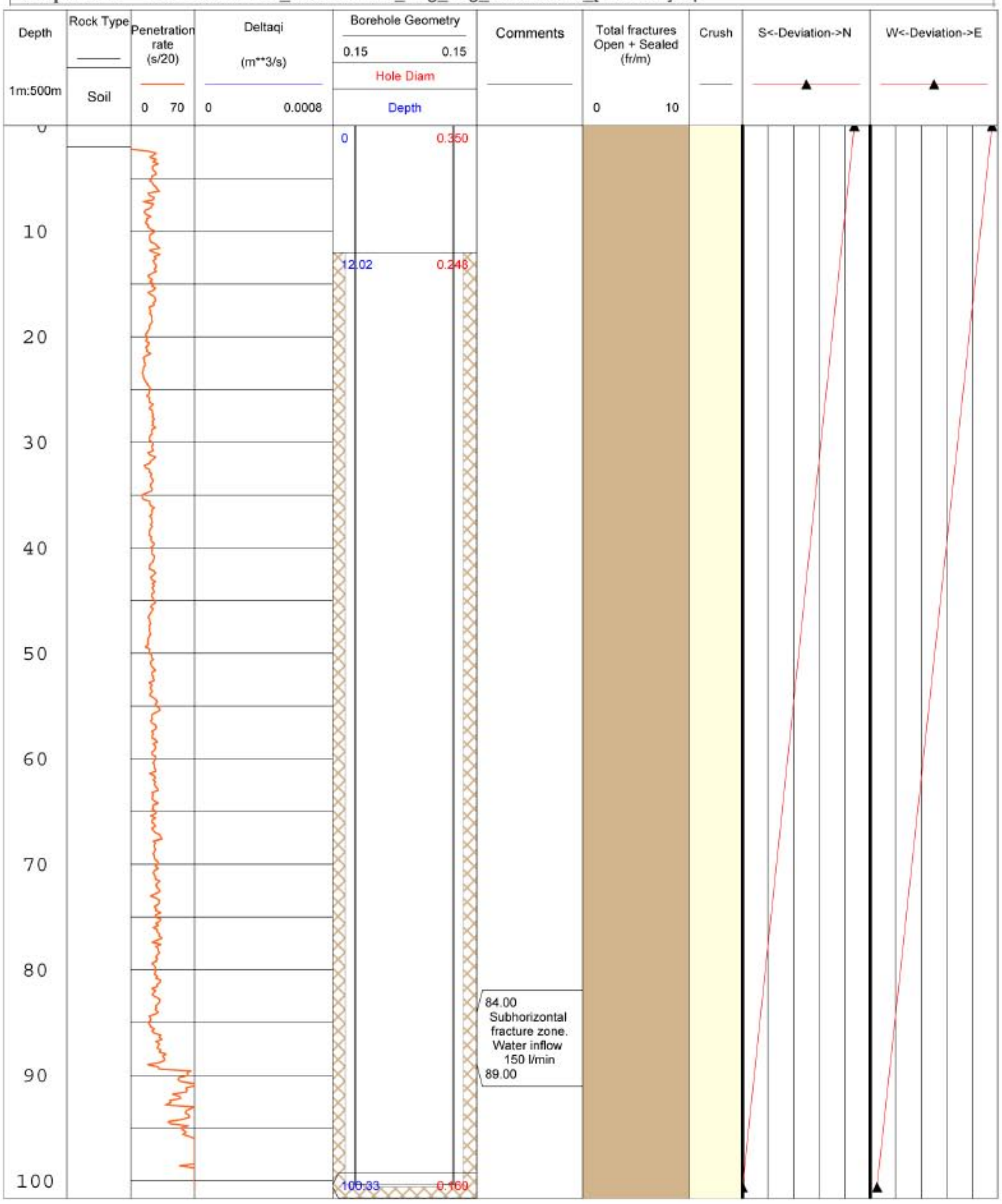
Title PERCUSSION DRILLED BOREHOLE KFM04B

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM04B	**Northing [m]**	6698925.15
Diameter [mm]	248	**Easting [m]**	1630978.07
Length [m]	100.60	**Elevation [m.a.s.l.]**	8.76
Bearing [°]	225.59	**Drilling Start Date**	2003-05-20 13:00:00
Inclination [°]	-59.94	**Drilling Stop Date**	2003-06-30 17:40:00
Date of mapping		**Plot Date**	2004-08-29 21:01:58

ROCKTYPE SOIL

Script Name HammarBorrHål_FORSMARK_Eng_Log_2003-03-28_[SICADA].sql



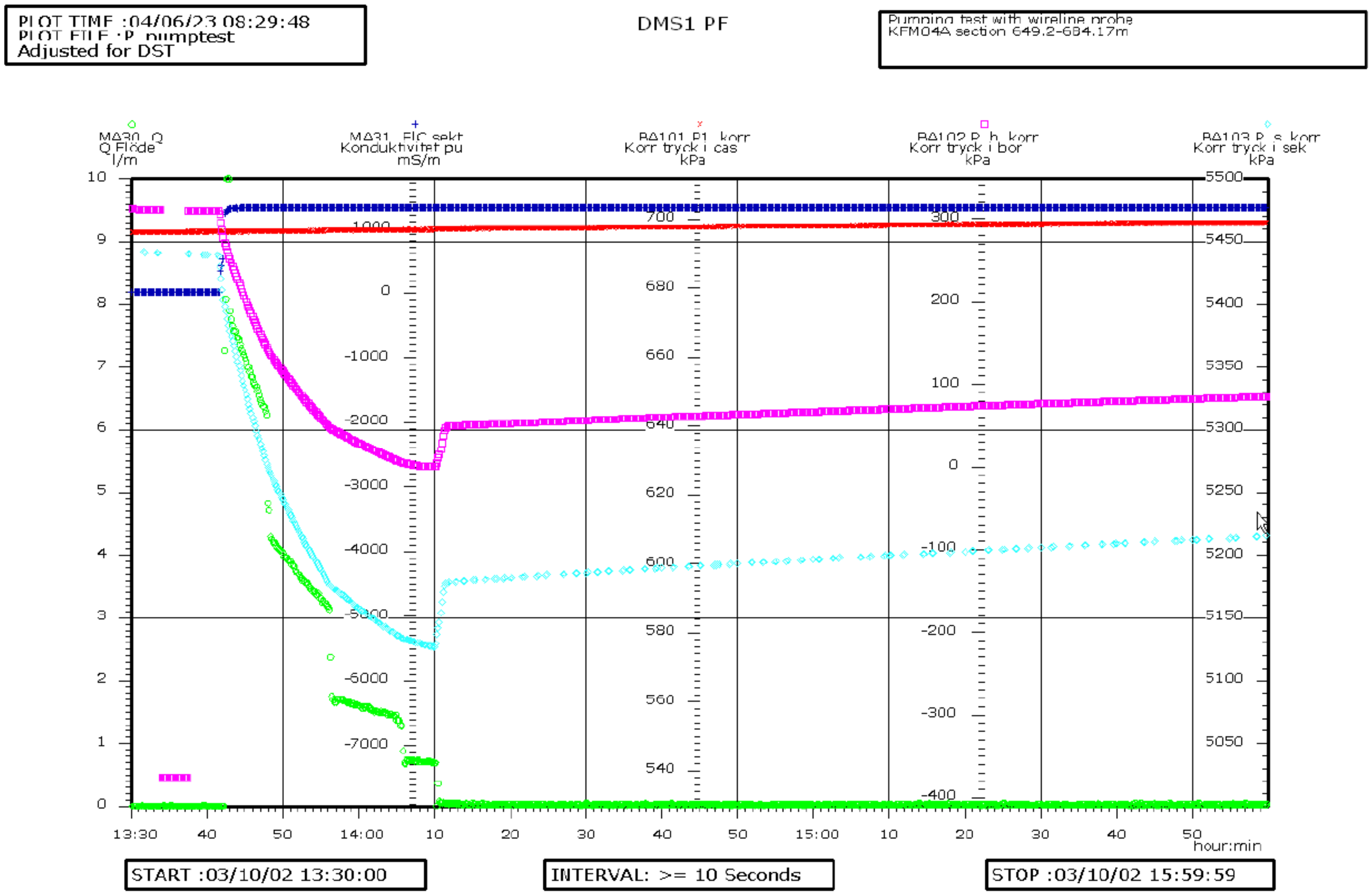
Appendix D

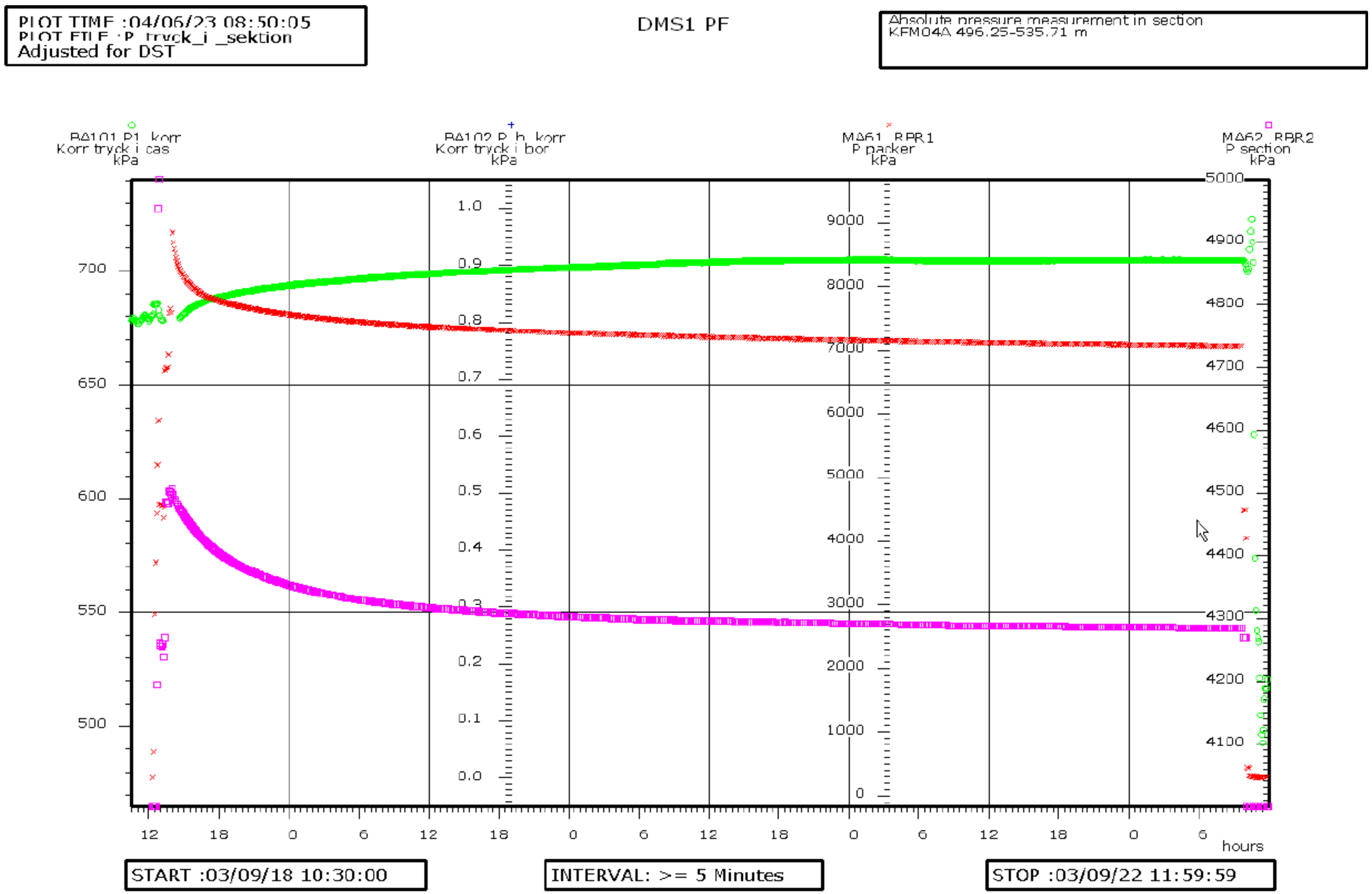
Water composition

Date	ID code	Sample no	Na mg/L	K	Ca	Mg	HCO_3	Cl	SO4	SO_4_S	Br	F	Si	Li	Sr	I	TOC	pH no unit	Cond mS/m
2003-08-21	HFM10	4965	1,610	21.6	945	173	161	4,466.4	410.22	128	16.7	0.95	8.54	0.043	9.99	0.039	2.7	7.23	1,340
2003-09-18	HFM10	8007	1,600	20.9	1040	190	165	4,498.6	414	128	18.4	0.69	7.09	0.047	10.8	0.044	2.9	7.4	1,355
2003-10-07	HFM10	8039	1,490	20.3	957	177	163	4,400	398	120	18.1	0.6	7.37	0.044	10.6	0.042	2.8	8.01	1,310
2003-10-21	HFM10	8064	1,580	20.4	1050	191	167	4,520	402	126	19.6	–0.2	6.76	0.045	10.9	0.048	2.6	7.28	1,368

Date	IDCODE	Sample no	^{2}H dev SMOW	^{3}H(TU) Tu	^{18}O(dev) dev SMOW	^{14}C pmc	^{13}C dev PDB	Age BP year	^{10}B no unit	34S(dev) dev CDT	$^{87}SR/^{86}Sr$ no unit
2003-08-21 09:30	HFM10	4965	73.2	1.9	–9.5	32.99	–8.42	8,856		24.7	0.717309
2003-10-07 13:20	HFM10	8039	–72.6	1.1	–9.7	38.47	–9.44	7,621	0.2404	25.4	0.717319
2003-09-18 13:20	HFM10	8007	–74.7	1.3	–9.8	37.43	–8.54	7,842	0.2382	25.4	0.717291
2003-10-21 16:05	HFM10	8064	–72.3	1.8	–10	38.42	–19.17	7,633	0.2282	23.7	0.717309

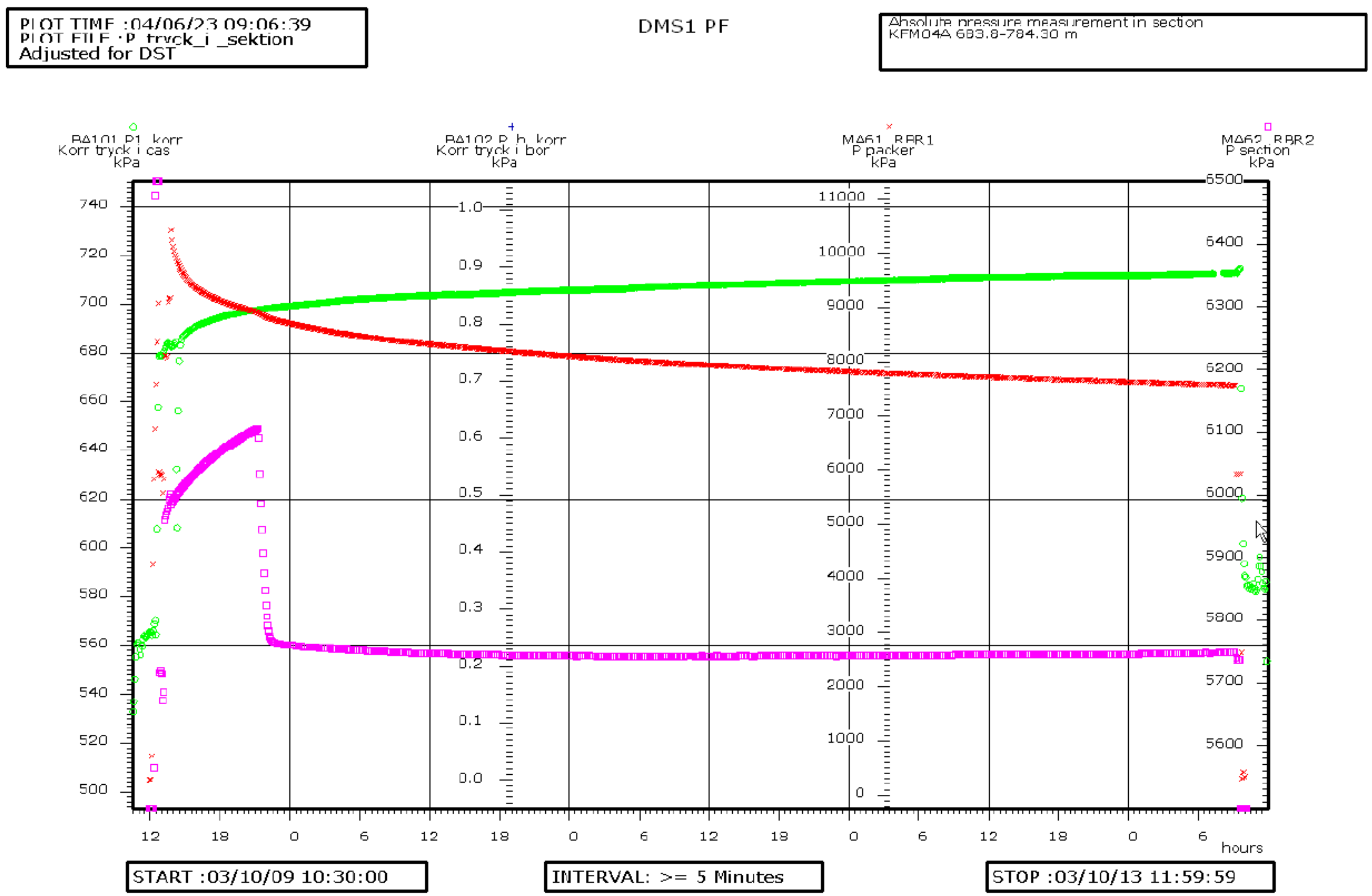
Hydraulic test and absolute pressure measurements

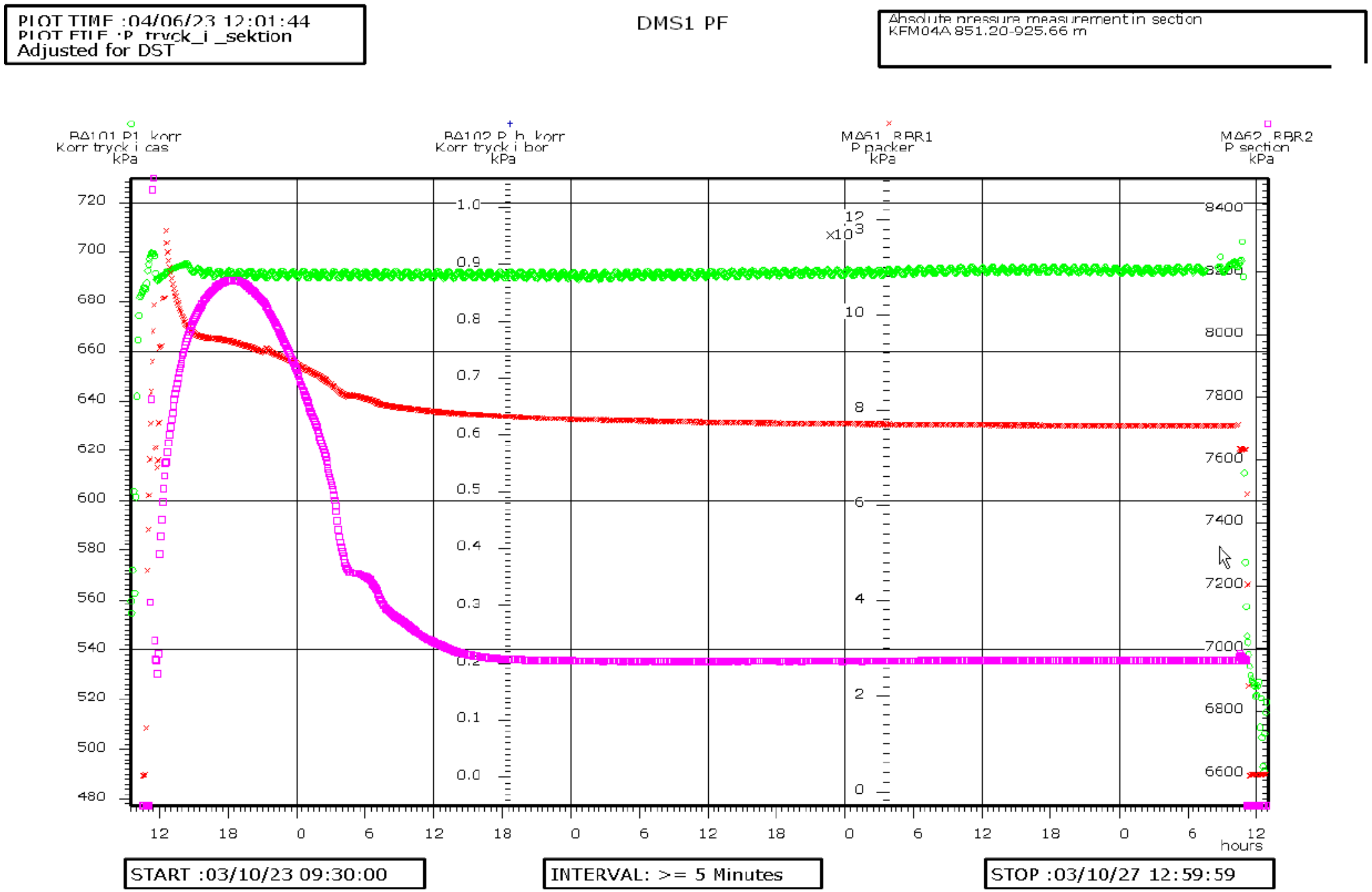




PLOT TIME :04/06/23 08:50:05
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM04A 496.25-535.71 m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P h korr
Korr tryck i bor
kPa
MA61 RBR1
P packer
kPa
MA62 RBR2
P section
kPa
hours
START :03/09/18 10:30:00
INTERVAL: >= 5 Minutes
STOP :03/09/22 11:59:59

69


PLOT TIME :04/06/23 09:06:39
PLOT FILE : P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM04A 683.8-784.30 m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P h korr
Korr tryck i bor
kPa
MA61 RBR1
P packer
kPa
MA62 RBR2
P section
kPa
hours
START :03/10/09 10:30:00
INTERVAL: >= 5 Minutes
STOP :03/10/13 11:59:59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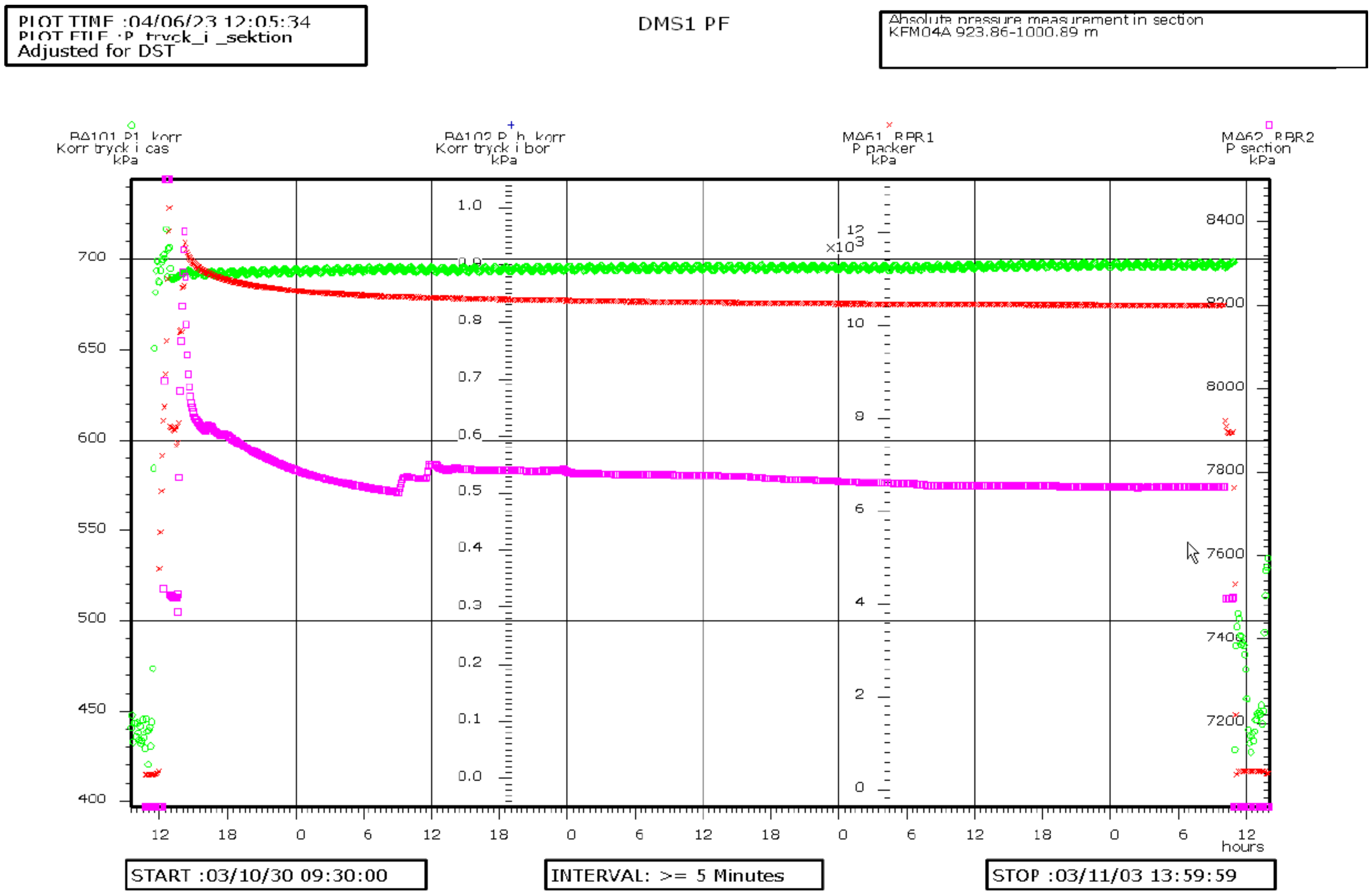
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM04A 851.20-925.66 m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P h korr
Korr tryck i bor
kPa
MA61 RBR1
P packer
kPa
MA62 RBR2
P section
kPa
hours
START :03/10/23 09:30:00
INTERVAL: >= 5 Minutes
STOP :03/10/27 12:59:59

71



PLOT TIME :04/06/23 12:05:34
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM04A 923.86-1000.89 m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P h korr
Korr tryck i bor
kPa
MA61 RPR1
P packer
kPa
MA62 RPR2
P section
kPa
×10³
hours
START :03/10/30 09:30:00
INTERVAL: >= 5 Minutes
STOP :03/11/03 13:59:59