P-03-32

Forsmark site investigation

Drilling of the telescopic borehole KFM01A at drilling site DS1

Lars-Åke Claesson, Mirab Mineral Resurser AB
Göran Nilsson, GNC AB

May 2004

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

ISSN 1651-4416
SKB P-03-32

Forsmark site investigation

Drilling of the telescopic borehole KFM01A at drilling site DS1

Lars-Åke Claesson, Mirab Mineral Resurser AB
Göran Nilsson, GNC AB

May 2004

Keywords: AP PF 400-02-03, Field note no. Forsmark 11, 28, 31 and 46, Percussion drilling, Core drilling, Telescopic borehole, Drilling site DS1.

Summary

The major part of the deep boreholes drilled within the scope of the Forsmark site investigations are performed as telescopic boreholes, entailing that the upper 100 m are percussion drilled with a diameter of c 200–250 mm, whereas section 100–1000 m is core drilled with a diameter of approximately 76–77 mm. Performance of and results from drilling and measurements during drilling of the first deep borehole drilled by applying this technique are presented in this report. The borehole, which is denominated KFM01A, 1001.49 m long and subvertical (inclined 84.73° from the horizon). KFM01A is of so called SKB chemical type, intended for detailed hydrogeochemical and microbiological investigations.

During percussion drilling of section 0–100 m with the diameter Ø 165 mm, an un-stable, fractured section was encountered at about 48–52 m, interpreted as a sub-horizontal fracture zone. This zone was heavily water-yielding, and an inflow of 800 L/min was measured. Another, although much less water-bearing subhorizontal zone, was penetrated a bit higher up in the borehole. Due to the high water capacity and un-stable borehole wall, the borehole was reamed to Ø 251 mm, whereupon a stainless steel casing was installed, and the gap between the borehole wall and the casing was grouted. These measures resulted in that all inflow of groundwater to the percussion drilled part of the borehole ceased.

A relatively complicated flushing water/return water system was applied for the core drilling, 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 estimation 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 surrounding the borehole.

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

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

One experience from drilling KFM01A is that the quartz-rich bedrock in Forsmark is hard to drill, entailing rapid wearing of drill bits. Other lasting impressions from the drilling are the water-yielding sub-horizontal fracture zones encountered in the shallow part of the bedrock and the, on the other hand, very low fracture frequency and low water-yielding capacity of the major part of the core drilled section of KFM01A.

Sammanfattning

De flesta djupa borrhål inom Forsmarks platsundersökning utförs som teleskopborrhål. Det innebär att de övre 100 metrarna hammarborras med ca 200–250 mm diameter, medan avsnittet 100–1000 m kärnborras med 76–77 mm diameter. Resultaten från det första djupborrhålet i Forsmark som har borrats med denna teknik redovisas i denna rapport. Borrhålet, som benämns KFM01A är 1001,49 m långt och nästan vertikalt (lutar 84,73° från horisontalplanet). KFM01A är ett så kallat kemiprioriterat borrhål, vilket innebär att det planeras att utnyttjas 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.

Vid hammarborrning av avsnittet 0–100 m med diametern Ø 165 mm påträffades ett instabilt, sprucket avsnitt vid ca 48–52 m, vilket tolkades som en subhorisontell sprickzon. Zonen hade en betydande vattenkapacitet, och ett inflöde på 800 L/min uppmättes. Även högre upp i borrhålet fanns en subhorisontell sprickzon, dock med relativt liten vattenföring. Eftersom borrhålet var instabilt och kraftigt vattenförande rymdes det upp till Ø 251 mm och kläddes in med rostfritt foderrör, varefter spalten mellan borrhålsvägg och foderrör cementinjekterades, så att allt vatteninflöde i denna del av hålet upphörde.

För kärnborrningen av avsnittet 100–1001,49 m användes ett relativt komplicerat spol- och returvattensystem, där spolvattnet preparerades i olika steg före användning. Returvattnet ledes till ett system av containrar, så att borrkaxet kunde sedimentera i tre steg innan returvattnet leddes vidare till recipient.

Under borrningen registrerades ett antal borr- och spolvattenparametrar, så att god kontroll uppnåddes dels avseende borrningens tekniska genomförande, dels beträffande den påverkan av spolvatten och borrkax som borrhålet utsattes för. Slutsatsen efter borrning var att endast relativt små mängder spolvatten och borrkax har trängt ut i formationen utanför borrhålet.

Ett mät- och provtagningsprogram för hammarborrningen och ett annat program för kärnborrningen gav preliminär information om borrhålets geologiska och hydrauliska karaktär direkt under pågående borrning samt underlag för fördjupade analyser efter borrning. Bland de insamlade proverna utgör borrkärnorna från den kärnborrade delen av borrhålet och borrkaxproverna från den hammarborrade delen, tillsammans med videofilm av borrhålsväggen (s k BIPS-bilder), arbetsmaterialet för den borrhålskartering (s k Boremap-kartering) som utförs efter borrning. Även resultaten från Boremap-karteringen av KFM01A finns redovisad i föreliggande rapport.

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

En erfarenhet från borrningen av KFM01A är att den kvartsrika berggrunden i Forsmark är svårborrad och att borrkroneslitaget är högt. Andra bestående intryck är dels de subhorisontella, delvis kraftigt vattenförande zoner som påträffades i den hammarborrade delen av borrhålet, dels att, omvänt, sprickfrekvensen och vattenföringen i större delen av det kärnborrade partiet av borrhålet visade sig vara mycket låga.

Contents

1 Introduction

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

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

The deepest boreholes drilled at the site investigation are core drilled boreholes in hard rock. So far, three sub-vertical and one inclined, approximately 1000 m long, cored boreholes have been drilled within the investigation area. The locations of the four drilling sites in question, DS1, DS2, DS3 and DS4, are illustrated in Figure 1-1.

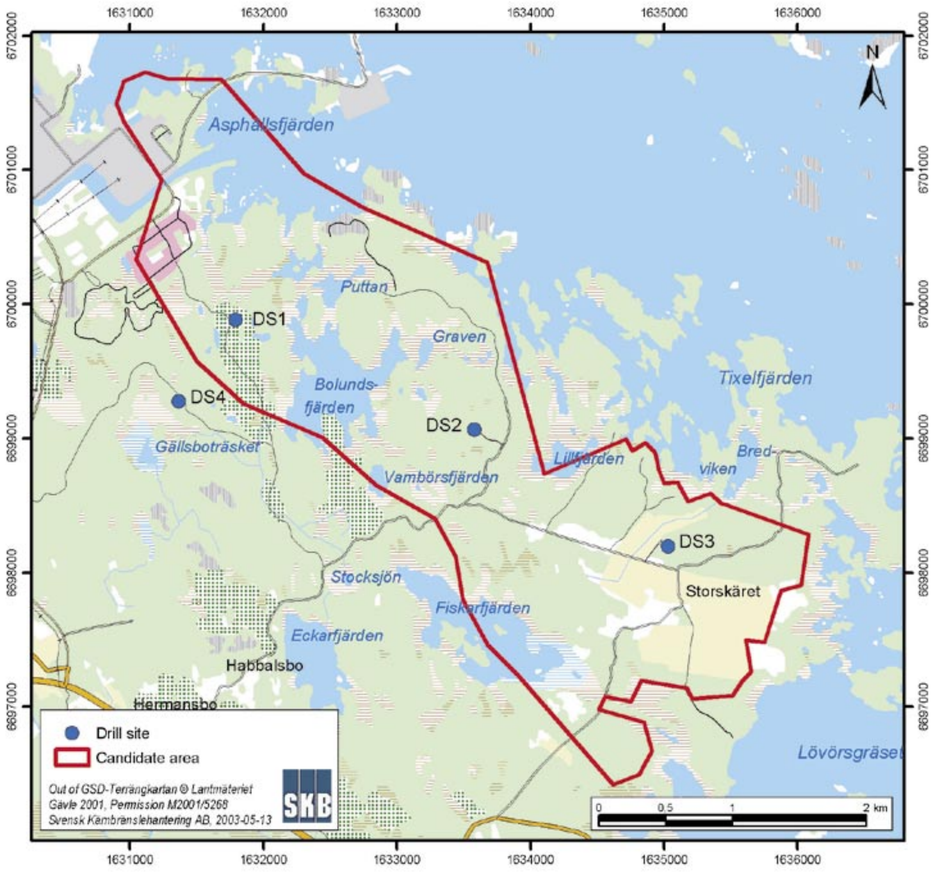


Figure 1-1. *The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drilling sites DS1-4 are marked with blue dots.*

By drilling the deep boreholes, so called telescopic drilling technique is applied, entailing that the upper 100 m of the borehole is percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section 100–1000 m is core drilled with a diameter of approximately 76–77 mm. This technical approach was adopted also when drilling the borehole presented in this report, KFM01A, which has a total drilling length of 1001.49 m (approximately equal to the vertical depth, as the borehole is near-vertical). Besides, borehole KFM01A is of the so called SKB chemical type, implying that the borehole is prioritized for hydrogeochemical and microbiological investigations. A practical consequence of this is that all DTH (Down The Hole) equipment used during and/or after drilling must undergo severe cleaning procedures, see Chapter 4.

In order to compensate for the missing core in the borehole section 0–100 m, a shorter borehole, KFM01B, located c 10 m NW of KFM01A, see Figure 1-2, was core drilled all the way from the rock surface. A second aim of drilling this borehole was to perform rock stress measurements in the rock interval down to c 500 m using overcoring technique. Borehole KFM01B is inclined 85° from the horizontal plane and is 500.52 m long.

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

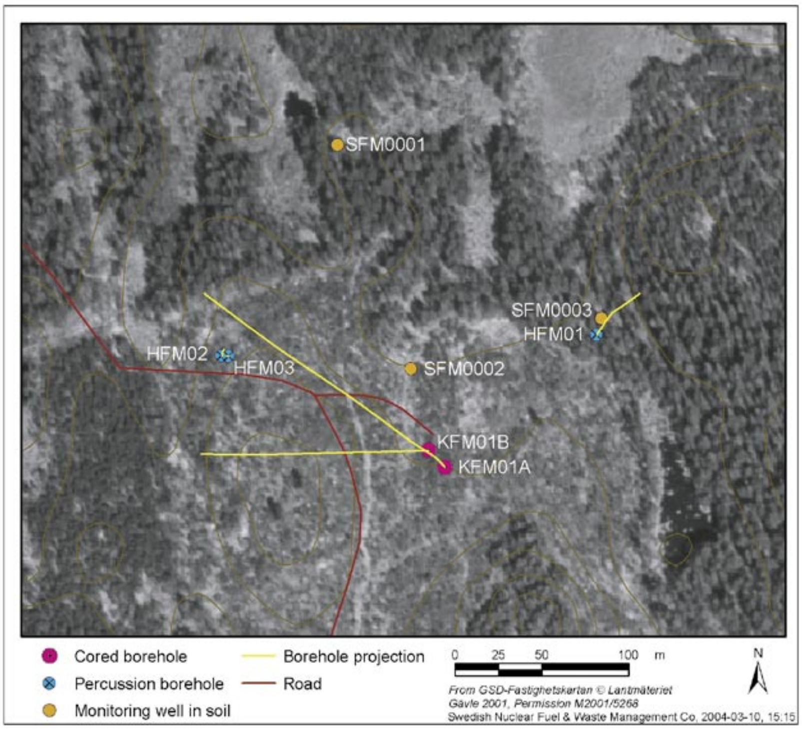


Figure 1-2. *Borehole locations at drilling site DS1. Besides the core drilled boreholes KFM01A and KFM01B, the drilling site incorporates a flushing water well (HFM01), two monitoring wells in solid rock (HFM02 and HFM03), and three monitoring wells in the unconsolidated overburden (SFM0001–03). The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

Drilling site DS1 is located in the north-western part of the candidate area, c 1 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 700 m north-east of the drilling site (Figure 1-1 and Figure 1-3).

In the present report, performance of and results from drilling and investigations made during and immediately after drilling of the telescopic borehole KFM01A at drilling site DS1 are presented.

Results from drilling of the flushing water well HFM01 and the two monitoring wells in hard rock, HFM02–03, have been reported separately /3/. So have the results from drilling of the three monitoring wells in regolith, SFM0001–03, /4/. Results from geological mapping of borehole KFM01A (so called Boremap mapping) are treated in /5/. Finally, drilling of KFM01B is presented in /6/, the overcoring measurements in this borehole in /7/ and the Boremap mapping of KFM01B in /8/.

Drilling of borehole KFM01A was performed according to Activity Plan AP PF 400-02-03, Version 1.0, which refers to SKB MD 610.003, Version 1.0 (Method Description for percussion drilling), and SKB MD 620.003, Version 1.0 (Method Description for core drilling). The Activity Plan and Method Descriptions are SKB internal controlling documents.

Drillcon Core AB, Nora, Sweden, was engaged for the drilling commission. Two different drilling equipments were employed, a percussion drilling machine for drilling the upper c 100 m, whereas core drilling of the remaining part (section 100.48–1001.49 m) was carried out with a wireline core drilling system.

Figure 1-3. *Drilling site DS1 at Forsmark. View towards north-east.*

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 7 x 5 m in size and having an approximately 5 cm high bund around its periphery, was cast around the actual borehole position, see Figure 1-4. The slab serves as a firm platform for anchorage of the drilling machine while drilling, and provides a protection against any leaks of environmentally hazardous liquids, such as oil. The working area was also fenced in (Figure 1-4).

When the drilling site was prepared, the drilling equipment was mobilized, first the percussion drilling equipment for drilling of section 0–100 m, and later the core drilling equipment. Figure 1-5 illustrates when all core drilling equipment systems with accessories, including the supply and discharge water systems, a standby electrical generator, barracks for monitoring system, equipment repair, accommodation etc, are in place, and core drilling can start.

Figure 1-4. *The ground surface was levelled off and covered with coarse gravel, and a 7 x 5 m cement slab was cast around the planned borehole position.*

Figure 1-5. *Drilling site DS1 with the complete core drilling outfit mobilized.*

2 Objective and scope

The main objectives of drilling deep cored boreholes at the site investigation (applicable also to KFM01A) are the following:

- To provide rock samples from the ground surface to the borehole bottom. Percussion drilling through the overburden produces soil samples recovered to the surface by compressed air. These samples are collected with a frequency of one sample per metre. The same sampling frequency is applied for the drill cuttings produced when percussion drilling the upper c 100 m of the solid rock. Below 100 m, the core drilling provides (in principle) continuous drill cores down to the borehole bottom. In order to compensate for the missing drill core in borehole section 0–100 m in KFM01A, borehole KFM01B was drilled close to KFM01A. The rock samples collected during drilling are used for a lithological, structural and rock mechanical characterization as well as determination of the retention properties of the bedrock from the rock surface to the full drilling depth.
- To render geophysical borehole investigations possible, e.g. TV logging, borehole radar logging and conventional geophysical logging as an aid for the geological/rock mechanical characterization.
- To allow hydraulic borehole tests (single hole tests as well as interference tests, in some cases performed as tracer tests) for characterization of the hydrogeological conditions of the bedrock.
- To make water sampling possible down to and below repository depth. High-class hydrogeochemical sampling/analysis demands special measures during and after drilling in order to keep the borehole clean. When these measures have been taken, the borehole is categorized as a borehole of chemical type. Only boreholes of this category are approved for advanced hydrogeochemical and microbiological characterization.
- To enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

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

Furthermore, a number of hydraulic tests and water samplings are normally performed during the drilling process, whereby a specifically designed test system, a so called wireline probe, is utilized. However, during drilling of borehole KFM01A, the wireline probe suffered from technical problems, entailing that such tests had to be cancelled.

3 Equipment and basic technical functions

Two types of drilling machines were used. The upper c 100 m were drilled with a percussion drilling machine of type Puntel MX 1000 (Figure 3-1). For core drilling of section 100.48–1001.49 m, a wireline-76 core drilling system, type Onram 2000 CCD, see Figure 3-5, was engaged.

3.1 Percussion drilling equipment

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

Figure 3-1. *The Puntel drilling machine in operation.*

At drilling site DS1, the bedrock is covered by approximately 12 m of sandy-silty till with some boulder content. This part had to be cased off with a solid pipe. To achieve a borehole as straight as possible in this type of soil, the choice of technique is important. In this case the NO-X technique was applied, following the principles and dimensions presented in Figure 3-2. The NO-X technique is described more in detail in SKB MD 610.003 (Method Description for percussion drilling). Figure 3-2 is a schematic diagram where the drilling depths presented are approximate. The true depths in the respective drilling sequences performed in KFM01A are presented in Section 5.2.

Figure 3-3 is a photo showing the two drill bits used for drilling through the unconsolidated overburden and fractured rock and some metres further into fresh, low-fractured rock.

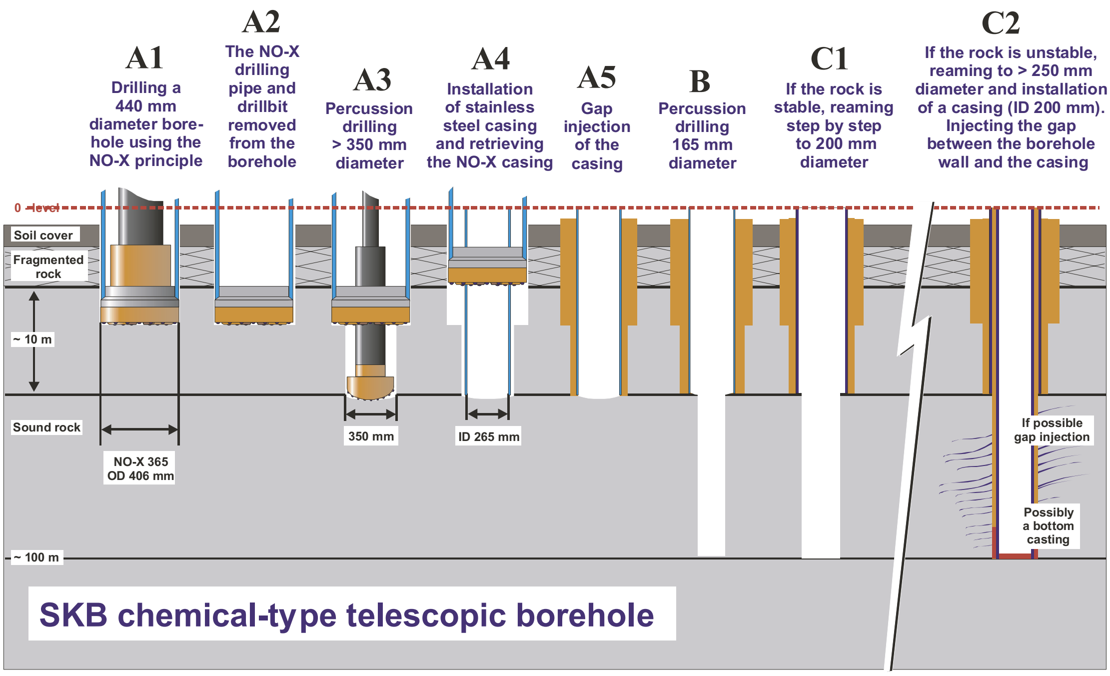


Figure 3-2. Schematic diagram showing the various stages of drilling the 0–100 m section of an SKB chemical-type telescopic borehole. The letters and numerals over each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB MD 620.003, Version 1.0.

Figure 3-3. The Puntel machine with 420 and 350 mm drill bits.

3.2 Gap injection technique

For investigation of the groundwater conditions, especially the hydrogeochemical characteristics, of the cored part of a telescopic borehole, it is essential that the deeper groundwater is not mixed with surface water or groundwater from the shallow parts of the bedrock. Therefore, if groundwater is encountered in the borehole during percussion drilling of the telescopic borehole, it is essential to prevent this water to reach the deeper parts of the bedrock. This is achieved by cement grouting the gap between the borehole wall and the casing. Also those parts of open, water yielding fractures, which are situated near and penetrated by the borehole, will in most cases be sealed by the injected agent during gap injection. Application of cement in the gap between the borehole wall and the casing pipe can be performed according to different techniques. Two variants are illustrated in Figure 3-4.

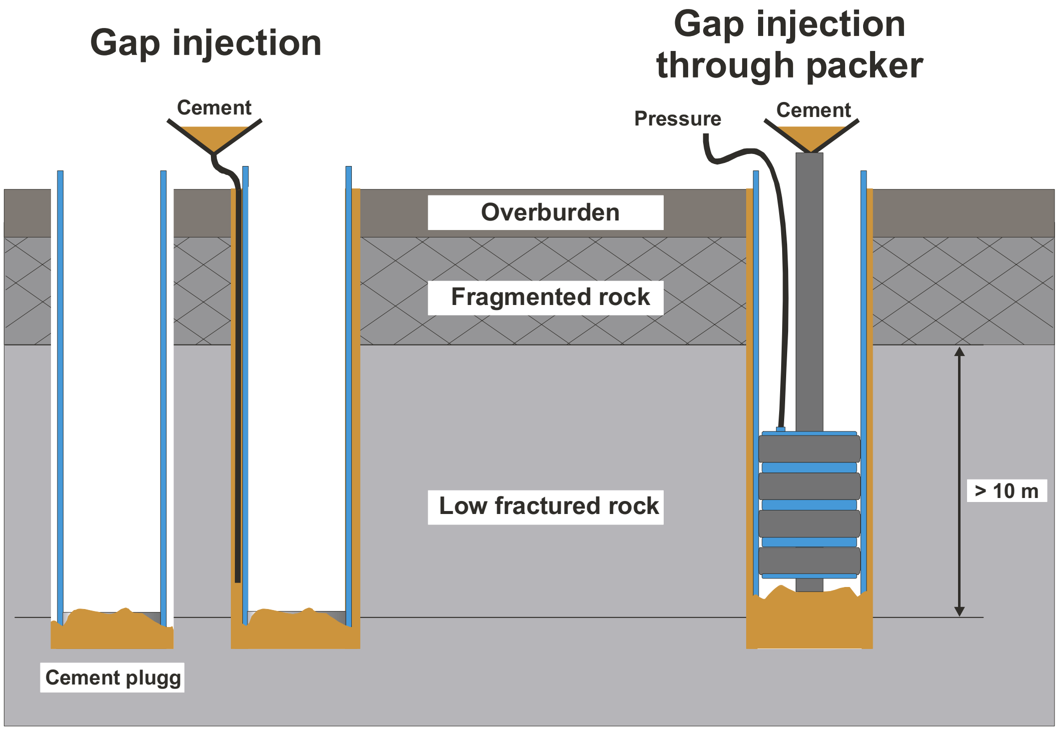


Figure 3-4. *Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer.*

Borehole KFM01A was 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). In both cases gap injection through a packer was applied.

3.3 Core drilling equipment

3.3.1 The wireline-76 system

For drilling the cored part of borehole KFM01A, a wireline-76 system, type Hagby Bruk Onram 2000 CCD, was employed. The drilling process is operated by an electrically-driven hydraulic system supplied with a computer control. The drilling capacity for 76 mm holes is maximum c 1500 m. The drill pipes and core barrel used belong to the Hagby WL76 triple-tube system. A photograph of the Onram WL76-system is displayed in Figure 3-5. Technical specifications of the drilling machine with fittings are given in Table 3-1.

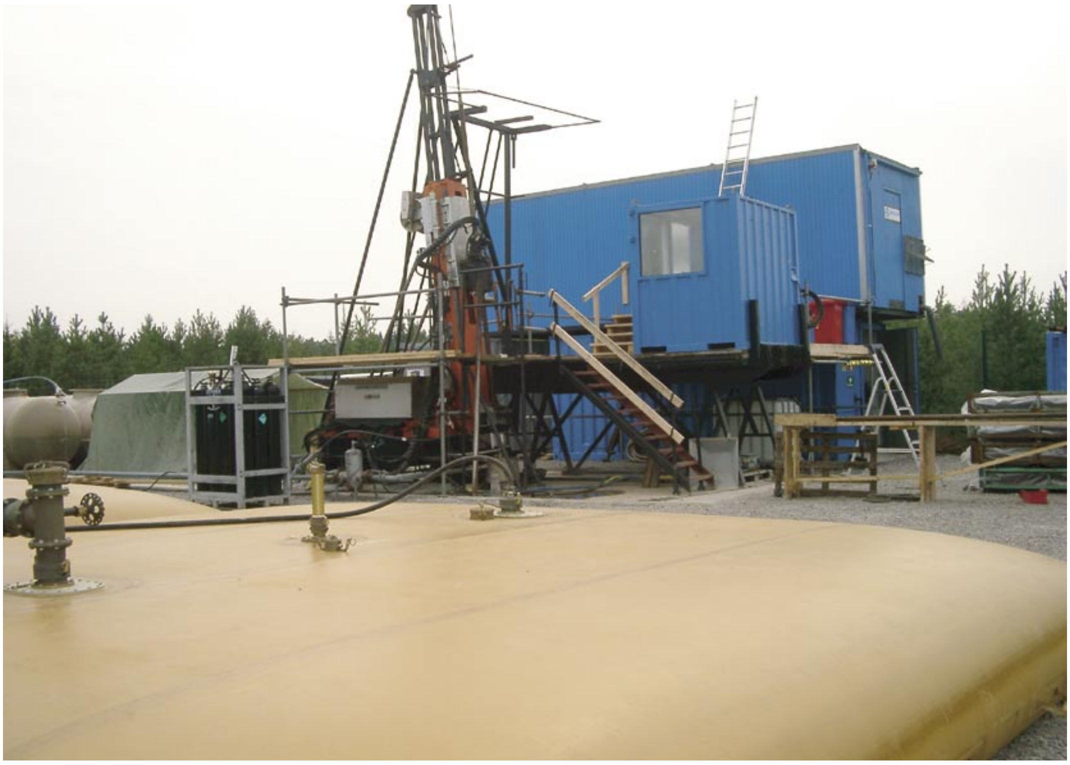


Figure 3-5. *The Hagby Bruk Onram 2000 CCD WL76-system with electrically-driven fluid mechanics. An elastic, closed water tank with a large expansive capacity used for collecting return water during drilling is seen in the foreground.*

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 1500 m	
Flush water pump	Bean	Max flow rate: 170 L/min Max pressure: 103 bars	
Submersible pump	Grundfos SQ	Max flow rate: 200 L/min	
Mobile electrical plant	P250HE with diesel engine Perkins GCD 325	250 KVA, 200 kW, 360 A	
Compressor	Atlas Copco GA75P-13	Max pressure: 12 bars Flow: > 5 L/sec	Electrically supplied
CCD-system	Dunfoss		Standard system modified for core drilling by the manufacturer

3.3.2 Flushing/return water system – function and equipment

Core drilling involves pumping of flushing water down the drill string, through the drill bit and out into the borehole in order 1) to conduct frictional heat away from the drill bit, and 2) to enhance the recovery of drill cuttings to the ground surface. The cuttings, suspended in the flushing water (in general mixed with groundwater), are forced from the borehole bottom to the ground surface via the gap between the borehole wall and the 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. The equipment consists of the components shown in Figure 3-6. 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),
- equipment for airlift pumping while drilling,
- equipment for storage and discharge of return water.

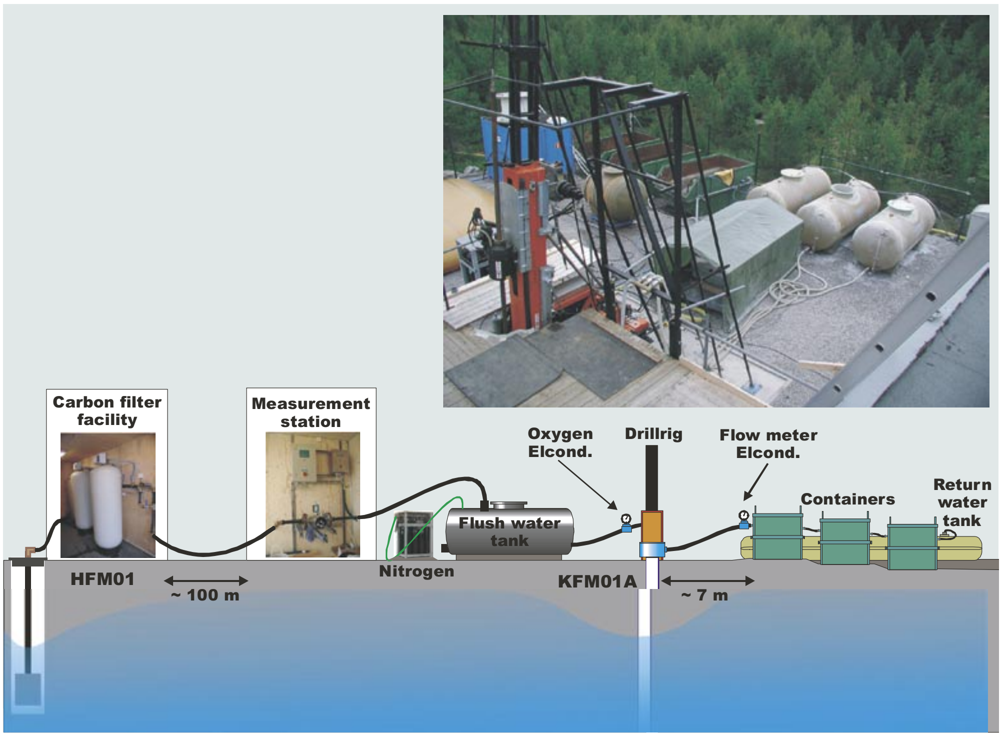


Figure 3-6. *Schematic illustration (foreground) and photograph (background) of the flushing/return water system when drilling KFM01A at DS1. The measurement station included the logger units and the UV-radiation unit. For flushing water flow rate and pressure measurements, the drilling machine gauges were used.*

Preparing the flushing water

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

1) The water well used for the supply of flushing water for core drilling of KFM01A was a percussion drilled well in hard rock, HFM01A (see Figure 1-2), situated approximately 110 m from KFM01A. 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 good enough to serve as flushing water, however with one exception. The organic content (Total Organic Content, TOC), which amounted to 10–12 mg/L, was considered as too high. Therefore, a mobile filtering plant was installed quite close to the water well. By pumping all water from the flushing water well through two large active coal filter set-ups, the TOC-content was reduced to an acceptable level. A photograph of the filter plant is shown in Figure 3-7.

Figure 3-7. *The active carbon filter plant used for reduction of total organic content (TOC) in the flushing water.*

Besides these basic demands on the flushing water quality, which were fulfilled when drilling KFM01A, the flushing water was also prepared in three steps before use, in accordance with SKB MD 620.003 (Method description for core drilling).

1) The incoming water from the water well was exposed to UV-radiation before entering the 5 m^3 water tank illustrated in Figure 3-8 (this tank is identical with the 'Flush water tank' in Figure 3-6). The microbe content in the water was thereby radically reduced.

2) An organic tracer dye, uranine, was added to the flushing water at a concentration of 0.2 mg/L before the water was pumped into the borehole, see Figure 3-8. The tracer was thoroughly mixed with the flushing water in the tank. Labelling the flushing water with the tracer aims at enabling detection of the flushing water content in groundwater samples collected in the borehole during or after drilling.

3) Nitrogen was bubbled through the water in the tank in order to expel oxygen which might be dissolved in the water (see Figure 3-8). Expelled oxygen was discharged through a pressure reducing valve. Oxygen must be avoided in the flushing water because it is a critical parameter in the programme for hydrogeochemical characterization of the groundwater. The water was then stored under a positive nitrogen pressure (about 1 bar) until pumped down into the borehole. The nitrogen bubbling also contributed to an effective mixing of water and uranine.

Measurement of flushing water parameters

The following flushing water parameters were measured on-line when pumping the flushing water into the borehole:

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

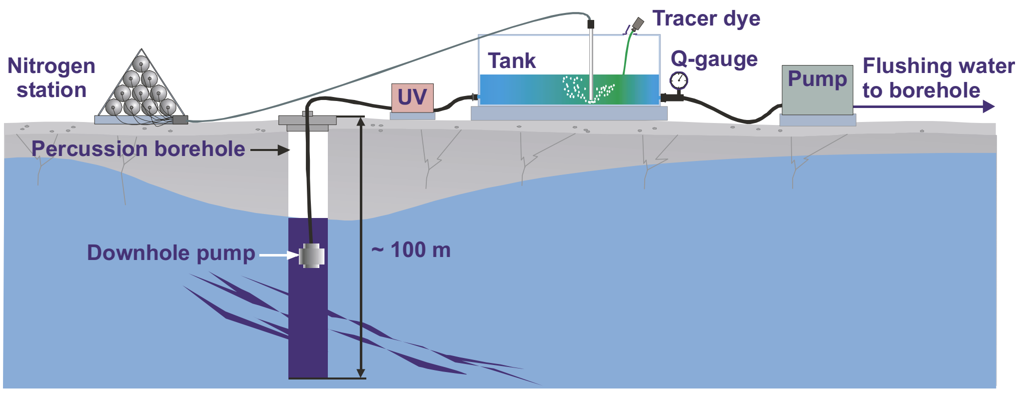


Figure 3-8. *The flushing water set-up used for borehole KFM01A and preparation of flushing water. The incoming water from the water well was UV-radiated before entering the water tank, in which it was labelled with a tracer dye. Nitrogen was bubbled through the water during and after filling, thus mixing the tracer and water as well as expelling dissolved oxygen.*

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		

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

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

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 80–90 m. As it 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 3-9. The resulting return water is a mixture of flushing water, groundwater from fracture zones in the rock and drill cuttings. Some of the flushing water and drill cuttings will, however, be forced into the local fracture systems and a minor part will be left in the borehole. The airlift pumping is continued throughout the drilling period.

The airlift pumping equipment in KFM01A consisted of the following main components, see Figure 3-9:

- Compressor, 12 bars/10 m³/min.
- 100 m outer support casing, 98/89 mm diameter.
- 100.5 m inner support casing, 84/77 mm diameter.
- PEM hose: 20 bars, 22 mm diameter, 400 m.
- PEM hose: 20 bars, 28 mm diameter, 200 m.
- Expansion vessel (= discharge head).
- Pressure sensor, 10 bars, instrumentation and data-logging unit.
- Electrical supply cubicle, at least 16 A.
- Ejector tube.
- Two – 22 mm diameter hoses at about 90 m.
- One – 22 mm diameter hose at about 100 m.
- Two – 28 mm diameter hoses at about 100 m.

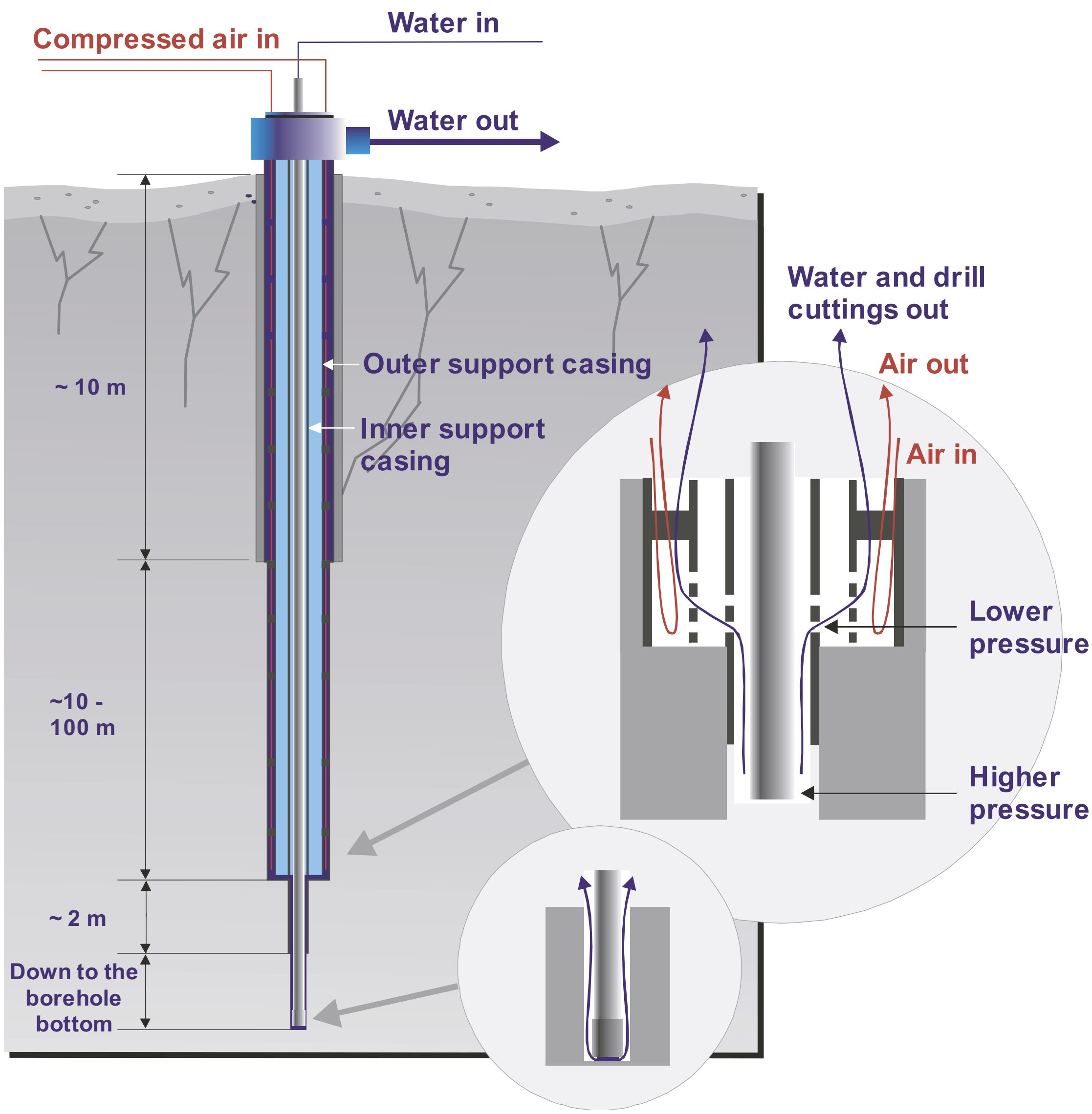


Figure 3-9. Airlift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole. 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.

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 3-10. 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.

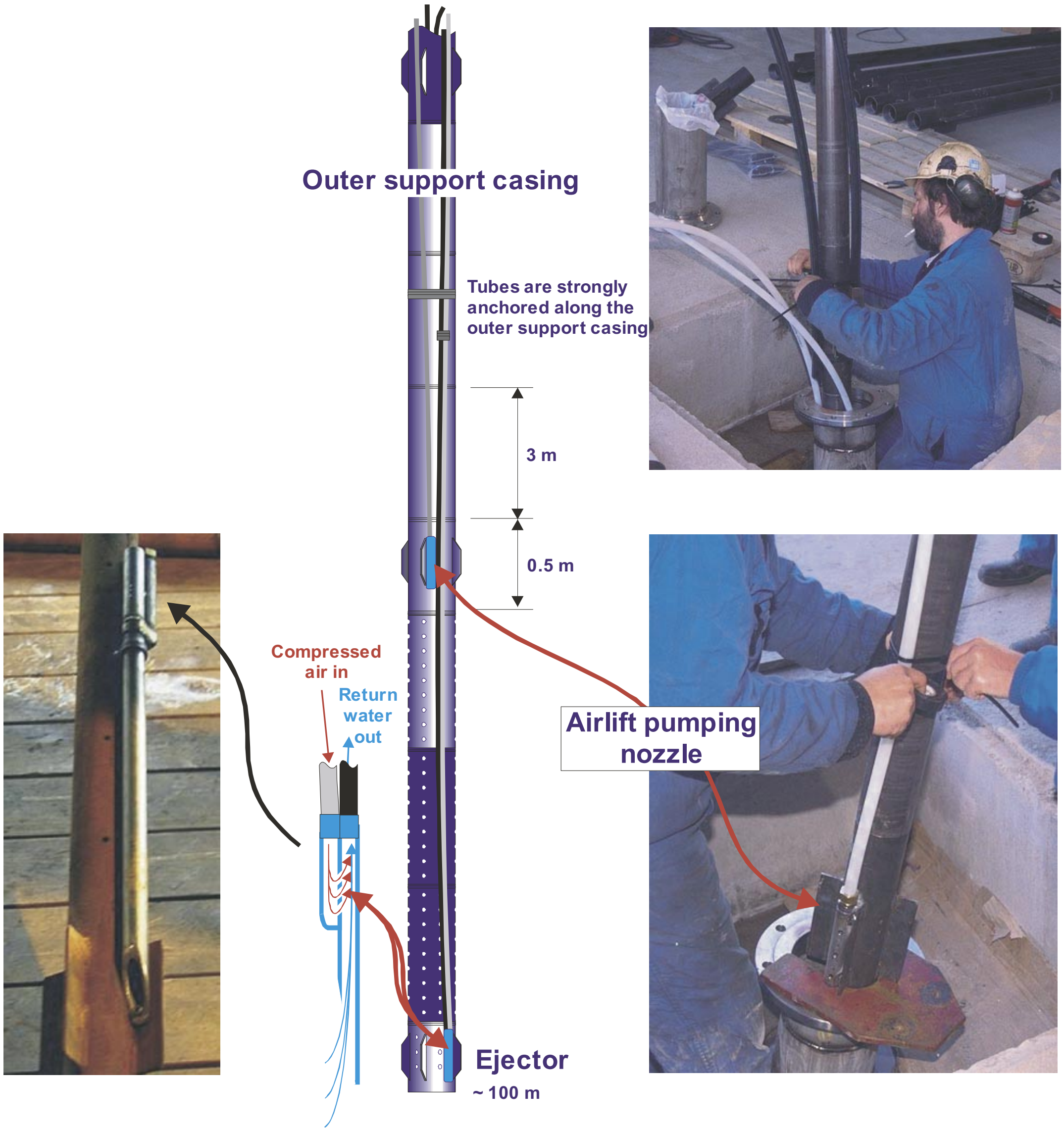


Figure 3-10. *Schematic representation of connection and installation of airlift pumping nozzle and ejector on the outer protective casing.*

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 3-6 and 3-11. 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 via a 1 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 3-5.

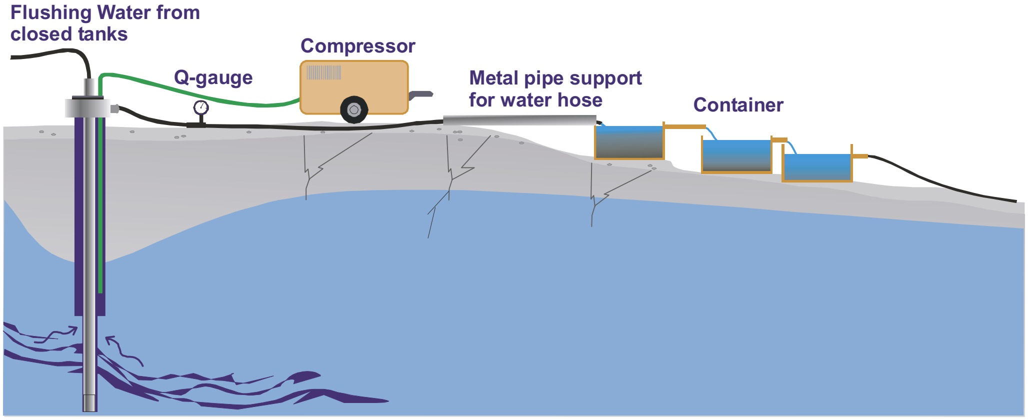


Figure 3-11. *Return water system. Airlift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in three stages in the containers (where it is preserved for later weighing), after which the water can be pumped to the recipient.*

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

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

The flow rate and electrical conductivity of the return water was measured and data stored in the data-logging system. Technical specifications of the measurement instrument 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.

3.3.3 Drilling monitoring system

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

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 KFM01A, 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.

3.3.4 Equipment for deviation measurements

During drilling of borehole KFM01A, deviation measurements were made at six occasions 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.

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, Version 1.0 (Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wireline-borrning), which is an SKB internal controlling document.

4 Execution

4.1 Percussion drilling of borehole section 0–100 m

The performance of the percussion drilling followed Activity Plan AP PF 400-02-03, which refers to SKB MD 610.003 (Method Description for percussion drilling). The Activity Plan and Method Description are both SKB internal controlling documents. The percussion drilling operations included the following parts:

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

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

4.1.1 Preparations

The preparation stage included the contractor's service and function control of his equipment. The machinery was obliged to be supplied with fuel, oil and grease exclusively of the types stated in SKB MD 600.006, Version 1.0 (Instructions for the use of chemical products and construction materials in equipment for drilling and investigations). Finally, the equipment was cleaned in accordance with the cleaning instruction in SKB MD 600.004, Version 1.0 (Instruction for cleaning borehole equipment and certain surface equipment), for boreholes of SKB chemical type. Both instructions are SKB internal controlling documents.

4.1.2 Mobilization

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

4.1.3 Drilling, measurements and sampling during drilling

The percussion drilling started with drilling through the overburden during simultaneous casing driving and subsequent gap injection. These activities followed the principles described in Sections 3.1 and 3.2 (corresponding to A1–A5 in Figure 3-2). The length of the $Ø_i$ 265 mm casing was 29.4 m and the casing material used was SS2333 stainless steel.

The continued percussion drilling through solid rock was performed with a 165 mm drill bit to 100.52 m drilling length (corresponding to B in Figure 3-2). The borehole section below the casing turned out to be unstable, especially in the section 48–52 m, which also showed a high water yielding capacity, about 800 L/min at a drawdown of 50–60 m.

For stabilization of the entire percussion drilled part, the borehole was reamed to Ø 251 mm with a special reamer bit to 100.48 m drilling length (i.e. 0.04 m of the pilot hole was left unreamed), and a SS2333 stainless steel $Ø_i$ 200 mm casing was installed (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 3-4. After grouting, the recharge of water into the borehole ceased completely.

Measurements and sampling while percussion drilling (and immediately after drilling) were performed according to a specific measurement/sampling programme. Concerning the section below the casing through the overburden down to 100.52 m, the measurements and sampling during and immediately after drilling were carried out in association with the Ø 165 mm drilling sequence. The measurement/sampling programme performed was in accordance 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.

After completion of drilling with the Ø 165 mm drill bit, deviation measurements were made.

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 /9/, whereas the analysis of cuttings from solid rock is presented in /5/. Results from the remaining measurements and observations are presented in Chapter 5.

4.1.4 Finishing off work

Finishing off work included measurements of the final diameter of the drill bit after reaming to Ø 250 mm. The borehole was secured with a lockable stainless steel flange. The drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

4.1.5 Nonconformities

The percussion drilling of borehole section 0–100 m in KFM01A was performed according to programme, i.e. without deviations.

4.2 Core drilling

The performance of the core drilling followed Activity Plan P PF 400-02-03, which refers to SKB MD 620.003 (Method description for core drilling). The Activity Plan and Method Description are both SKB internal controlling documents. The core drilling operations included the following parts:

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

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

4.2.1 Preparations

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

4.2.2 Mobilization

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

4.2.3 Drilling, measurements and sampling during drilling

The core drilling of borehole KFM01A was performed with two borehole dimensions. Section 100.52–101.08 m was drilled with a borehole diameter of 86.0 mm, whereas the main part of the borehole, section 101.08–1001.49 m, was drilled with Ø 76.3 mm. The inner Ø 84/77 mm support casing was fitted into the short Ø 86 mm borehole. In this way the casing was centralized in the borehole and fixed laterally. (The outer Ø 98/89 mm support casing is resting on the bottom of the percussion drilled borehole.) Finally, after completion of drilling, the section 101.08–102.13 m was reamed from 76.3 mm to 86.0 mm to enable installation of a transition cone between the percussion drilled respectively core drilled parts of the borehole, see Section 4.2.4.

Core drilling with Ø 76.3 mm of the main part of the borehole serves many purposes, cf Chapter 2. One of the most essential objectives is to provide (in principle) continuous rock samples, i.e. drill cores, down to the borehole bottom, which allows a lithological, structural and rock mechanical characterization of the bedrock. The drill cores may also be used for determination of retention 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 KFM01A, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 76.3 mm part of the borehole is 50.8 mm. Minor deviations from this diameter may, however, occur.

Like the percussion drilling, the core drilling is associated with a programme for sampling, measurements and other activities during and immediately after drilling, cf SKB MD 620.003. However, for different reasons, during drilling of KFM01A 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 KFM01A.

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

Besides the activities mentioned in Table 4-1, water samples were collected from different positions in the flushing water system, see Figure 3-6, 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 /10/.

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, sedimented at the bottom of the hole or suspended in the water. After finished flushing/air-lift pumping, the recovery of the groundwater table was registered as an estimate of the hydraulic conditions of the entire borehole. The results are presented in Chapter 5.

2) The drill string was pulled.

3) The inner support casing was removed with aid of a crane lorry.

4) The outer support casing was removed with the same crane lorry.

5) The discharge head was removed.

6) Using the drill rig, a stainless steel transition cone was installed between the reamed and cased percussion drilled respectively the cored part of the borehole, as shown in Figure 4-1. The lower, pipe-shaped part of the cone is located at 100.39–101.99 m. The upper part of the cone fits tightly against the wall at 97.33 m in the percussion-drilled section of the borehole.

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.

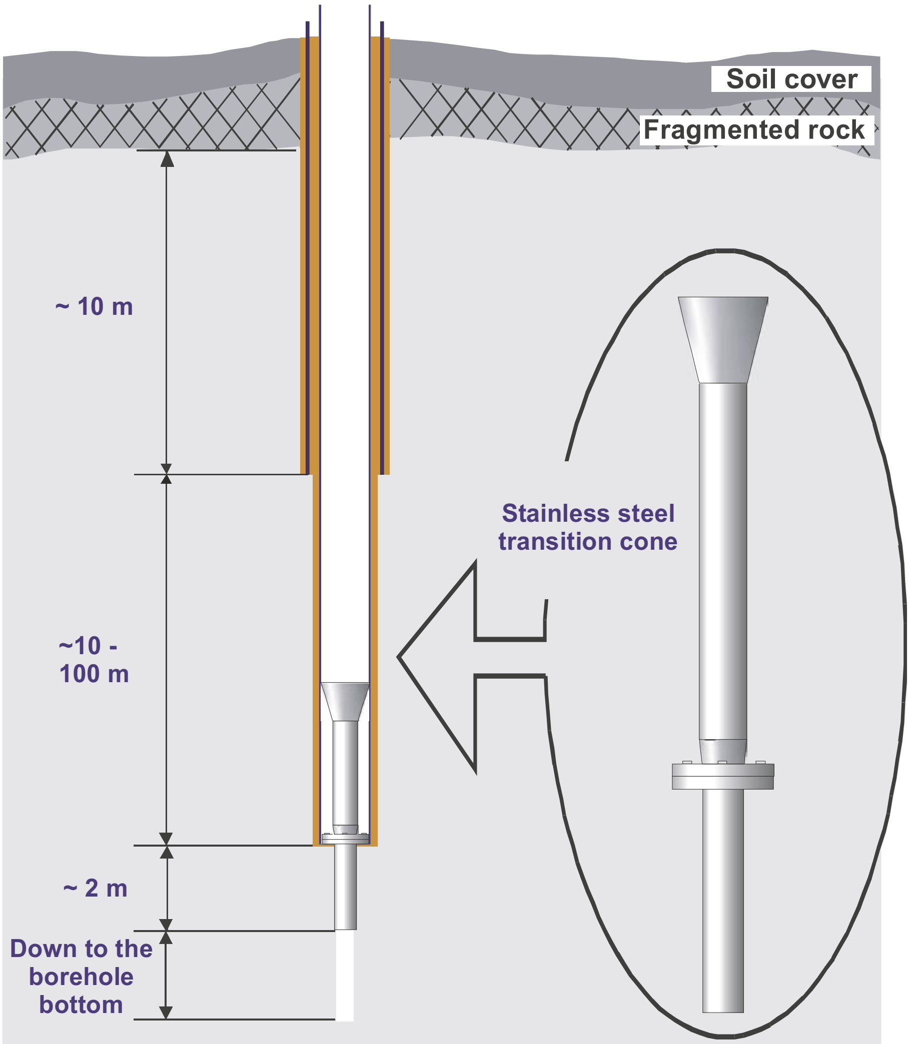


***Figure 4-1.** Schematic illustration of the transition cone between the upper, wide section and the lower, slim part of a telescopic borehole. In KFM01A, the entire upper, percussion drilled part was cased.*

4.2.5 Nonconformities

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

Table 4-1. Programme for sampling, measurements, registrations and other activities during and immediately after core drilling according to SKB MD 620.003 and the actual performance during drilling of borehole KFM01A.

Activity	Performance and frequency according to SKB MD 620.004	Performance and frequency during drilling of KFM01A
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.
Weighing of drill cuttings from drilling of the entire borehole.	After completion of drilling.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	Six measurements 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 5-17 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.	No successful measurements performed due to: 1) extremely low inflow of groundwater and 2) technical problems with the test equipment.
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: 1) extremely low inflow of groundwater and 2) technical problems with the test equipment.
Absolute pressure measurements.	Normally during natural pauses in drilling.	No successful measurements performed due to technical problems with test equipment.
Groove milling in the borehole wall, normally at each 100 m.	Normally performed after completion of drilling.	Fourteen grooves performed. Missing groove at 450 m due to packer damage. No grooves at 850, 900, and 950 m due to technical problems.
Collecting and weighing of drilling debris.	Drilling debris settled in containers weighed after finished drilling.	Not carried out for the percussion drilled part of the borehole. According to programme for the core drilled part.

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 3-6 and 3-11 (except the finest fractions which stayed suspended in the discharge water from the third container). The collected drill cuttings were weighed after concluded drilling in order to give a measure of the drill cuttings recovery.

4.3 Data handling

4.3.1 Performance

Minutes for several items with the following headlines: Activities, Cleaning of the equipment, Drilling, 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 /11/. Field Note numbers are presented in Chapter 5.

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. Field Note numbers are Forsmark 11, 28, 31 and 46 /11/. An overview of the drilling progress of borehole KFM01A is given in Section 5.1, whereas geometrical data and technical design are presented in Section 5.2. Results from drilling and measurements during drilling are accounted for in Section 5.3 (percussion drilling) and Section 5.4 (core drilling). Finally, so called Well Cad-presentations of borehole KFM01A are shown in Appendix A (percussion drilled part) and Appendix B (core drilled part). 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 KFM01A was drilled during a period of approximately 6 months, including the summer holiday, see Figure 5-1. Since this was the first deep drilled borehole within the Forsmark site investigation programme, many technical constructions and working routines used were un-tested. Both the drill crew and the support organization had to be trimmed for the situation, resulting in a prolonged drilling performance than with solely proven technology and fully trained staff.

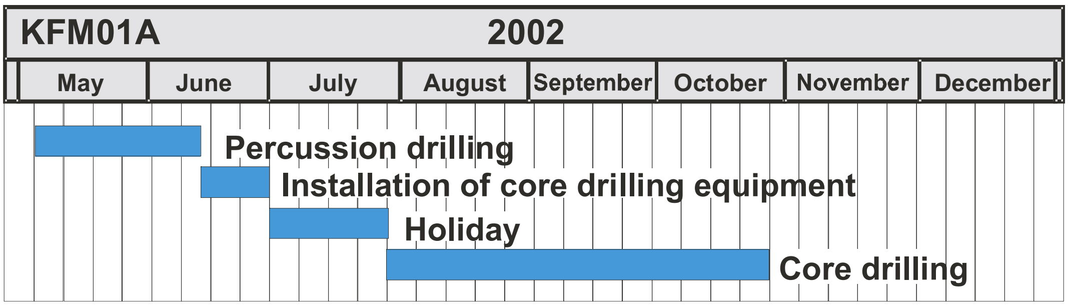


***Figure 5-1.** Overview of the drilling performance of borehole KFM01A.*

5.1.1 Percussion drilling period

The duration of the different operations included in the percussion drilling period from May 7th, 2002 to June 10th, 2002 are presented in Figure 5-2.

Percussion drilling is normally a swift drilling method. However, the relatively complex approach applied for the drilling and grouting sequences when drilling KFM01A resulted in a relatively long total work period for accomplishing the percussion drilled part of the borehole.

5.1.2 Core drilling period

The progress of the core drilling period from June 25th, 2002 to Oct 28th, 2002 is presented in Figure 5-3.

After percussion drilling of section 0–100.52 m and following the summer holiday, core drilling commenced (only minor initial work was done before the holiday). Normally, 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. However, when core drilling KFM01A, section 100–550 m needed almost as much time as the deep section 550–1000 m.

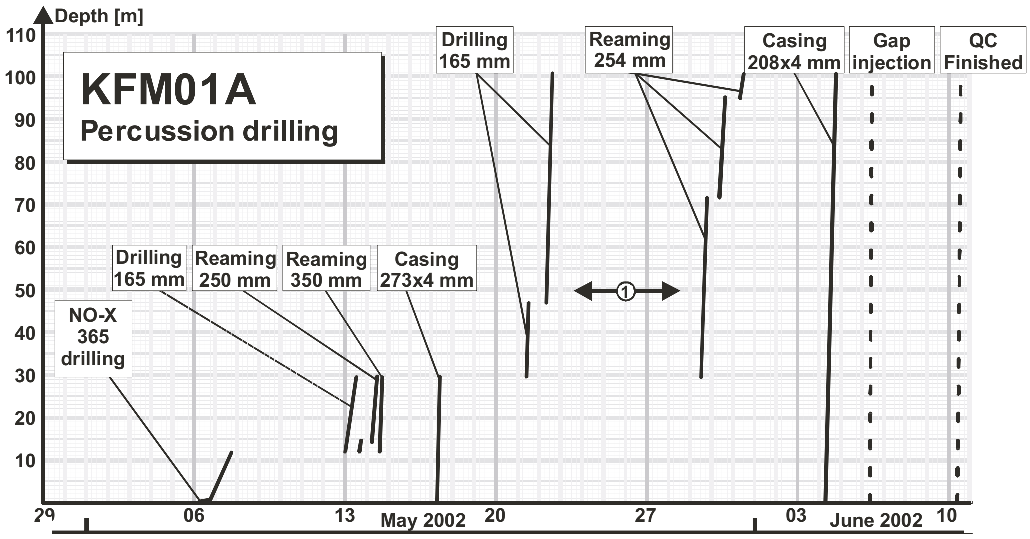


Figure 5-2. Percussion drilling period (depth and activity versus calendar time). Number 1 within circle represents a BIPS measurement.

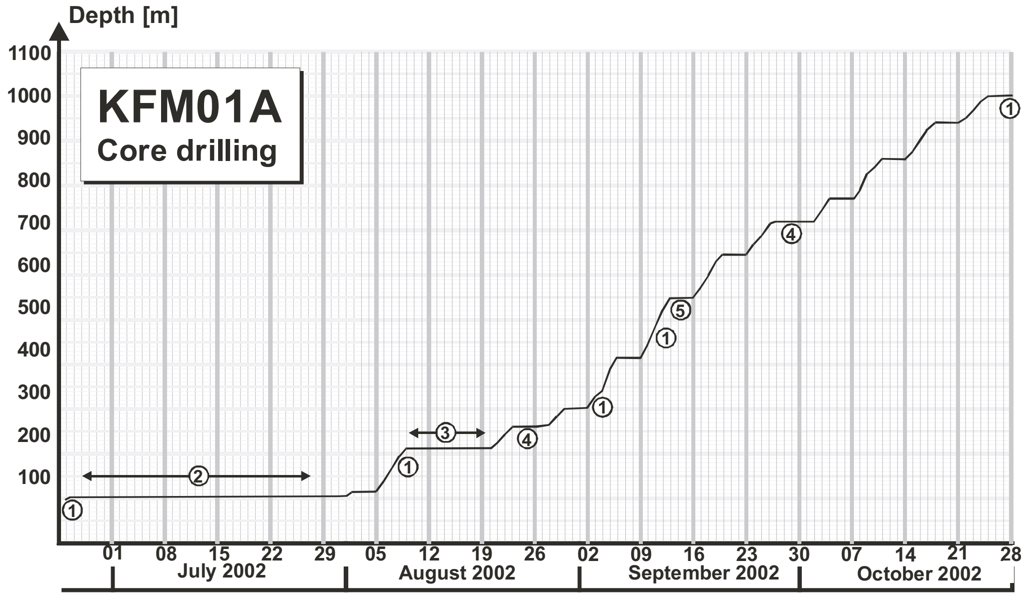


Figure 5-3. *Core drilling period (depth versus calendar time). Number 1) Deviation measurement (Maxibor), Number 2) Holiday period, Number 3) Completion of measurement devices, Number 4) Repairing drilling equipment, Number 5) Testing WL-probe. The plateaus in the diagram represent weekends when usually no drilling was performed.*

The most time demanding 100 m section of all was the one between 200 m and 300 m, which was due to the fact that some measurement device had to be installed. This and similar types of running-in problems caused the prolongation of the initial core drilling phase illustrated in Figure 5-3. On the hole, these problems had been overcome after 400–500 m of drilling, and the late drilling phases run smoothly. The above mentioned problems with the WL-probe both delayed and saved time. Much delay was caused initially during repeated tests of the non-functioning probe. Later, when it became obvious that the tool did not work, no more test attempts were made, which instead speeded up the drilling process.

5.2 Geometrical and technical design of borehole KFM01A

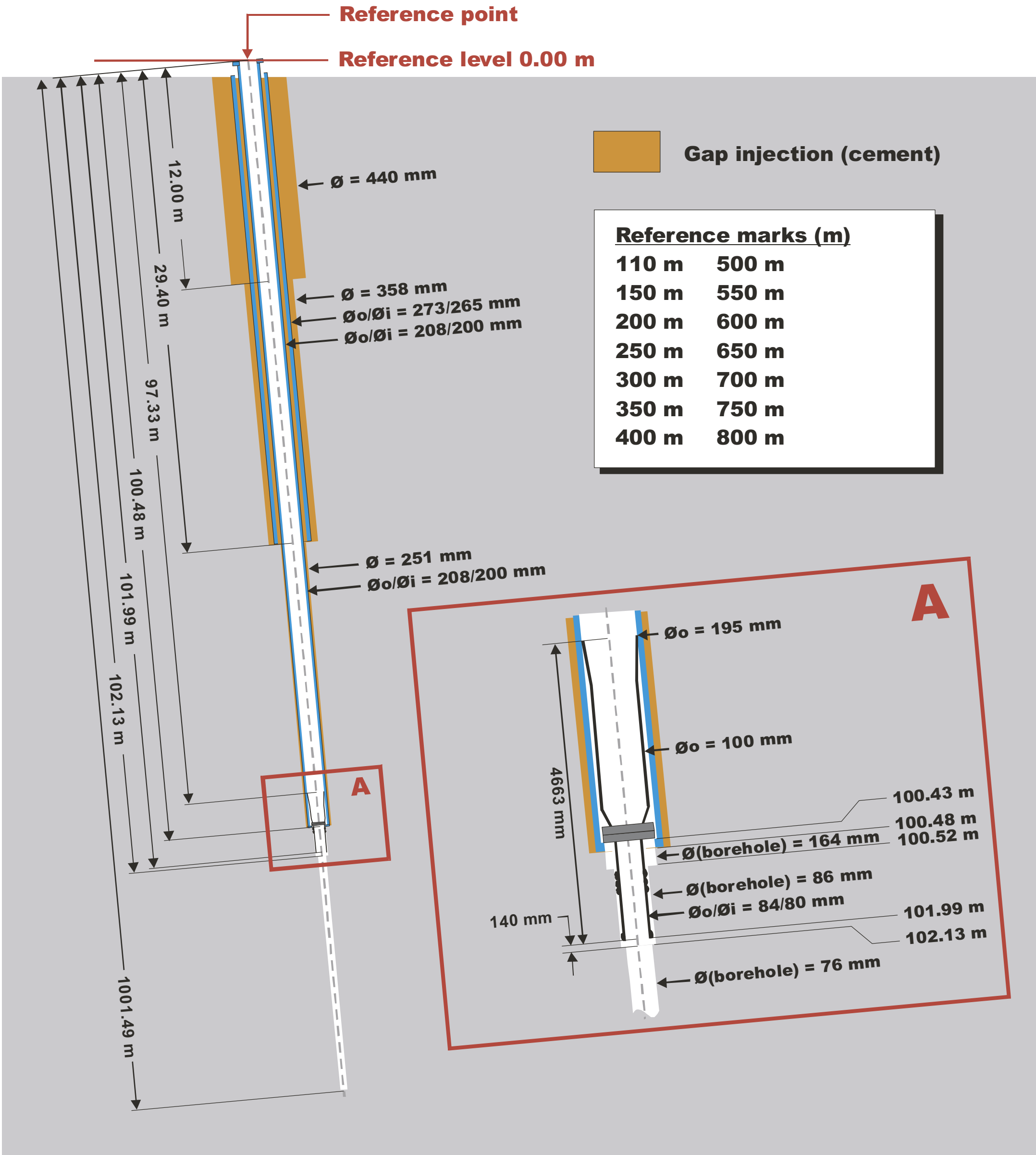
Administrative, geometric and technical data for the telescopic borehole KFM01A are presented in Table 5-1. The technical design of the borehole is illustrated in Figure 5-4.

Table 5-1. Administrative, geometric and technical data for borehole KFM01A.

Parameter	KFM01A
Borehole name	KFM01A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	May 7, 2002
Completion date	October 28, 2002
Percussion drilling period	May 7th, 2002 to June 10th, 2002
Core drilling period	June 25th, 2002 to October 28th, 2002
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 KFM01A at top of casing (RT90 2,5 gon V 0:–15; RHB 70)	Northing: 6699529.81 Easting: 1631397.16 Elevation: 3.13 (m a s l) Azimuth (0–360°): 318.35° Dip (0–90°): –84.73°
Position KFM01A at bottom of hole (RT90 2,5 gon V 0:–15; RHB 70)	Northing: 6699628.79 Easting: 1631258.40 Elevation: –982.31 (m a s l) Azimuth (0–360°): 307.13° Dip (0–90°): –75.01°
Borehole length	1001.49 m
Borehole diameter and length	From 0.00 m to 12.00 m: 0.440 m From 12.00 m to 29.40 m: 0.358 m From 29.40 m to 100.48 m: 0.251 m From 100.48 m to 100.52 m: 0.164 m From 100.52 m to 102.13 m: 0.086 m From 102.13 m to 1001.49 m: 0.076 m
Casing diameter and length	$Ø_o/Ø_i$ = 273 mm/265 mm to 29.40 m $Ø_o/Ø_i$ = 208 mm/200 mm between 0.00 and 100.43 m Casing shoe $Ø_i$ = 165 mm between 100.43 and 100.48 m
Transition Cone inner diameter	At 97.33 m: 0.195 m At 101.99 m: 0.080 m
Drill core dimension	50.8 mm
Core interval	100.52–1001.49 m
Average core length retrieved in one run	2.53 m
Number of runs	356
Diamonds bits used	33
Average bit life	27 m

Technical data

Borehole KFM01A



Drilling reference point

Northing: 6699529.81 (m), RT90 2,5 gon V 0:-15

Easting: 1631397.16 (m), RT90 2,5 gon V 0:-15

Elevation: 3.13 (m), RHB 70

Borehole

Bearing: 318.35°

Inclination: -84.73°

Length: 1001.49 m

Percussion drilling period

Drilling start date: 2002-05-07

Drilling stop date: 2002-06-10

Core drilling period

Drilling start date: 2002-06-25

Drilling stop date: 2002-10-28

Figure 5-4. *Technical data of borehole KFM01A.*

5.3 Percussion drilling 0–100.52 m

5.3.1 Drilling

As mentioned in Section 4.1.3, the upper 29.40 m of the borehole was cased and cement grouted. During pilot drilling to 100.52 m, unstable bedrock was observed. The penetration rate increased below 40 m, and especially at 52 m, see Appendix A. When this section had been penetrated, a water inflow of 800 L/min was measured. Therefore the borehole section 0–100.48 m was reamed to 251 mm, and a 200 mm stainless steel casing was installed. The gap between the casing and borehole wall was cement grouted, thereby sealing the gap completely so that the water inflow ceased.

5.3.2 Measurements while drilling

During, and immediately after drilling, a 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 KFM01A (also displayed in the Well Cad-presentation in Appendix A) are commented on. The analyses of drill cuttings from the percussion drilled part of KFM01A are presented in /5/ (rock) and /9/ (soil).

Borehole deviation

The end (bottom) point of the percussion borehole deviates approximately 6 m upwards and 7 m to the left compared to an imagined straight line following the dip and strike of the borehole collaring point (inclination –84.73° and bearing 318.35°).

5.4 Core drilling 100.52–1001.49 m

5.4.1 Drilling

The bedrock in the Forsmark candidate area has proved to be surprisingly hard and difficult to drill, probably mostly depending on the high quartz content. This has been noticed due to the short life-time of the drill bits. In average, the life-time in KFM01A was 27 drilled metres per drill bit. As a consequence, core drilling was more time consuming and costly than in average granitic rocks.

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. The results are presented in Sections 5.4.2–5.4.12 below.

Mapping of the drill core samples from KFM01A is presented in /5/.

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 numbers 11, 28, 31 and 46 /11/.

Drill bit position versus time

Figure 5-5 shows how the drilling proceeded versus time. Generally, drilling ran 24 hours a day from Monday to Thursday with a weekend stop from Thursday night to Monday morning. Initially, after the first week, there was a stop lasting one week. This is seen in the figure around the 15th of August.

Penetration rate

As borehole KFM01A was the first core drilled borehole within the scope of the Forsmark site investigation, the contractor was testing different drill bits to find the type most suitable for drilling in the Forsmark bedrock. This is observed in Figure 5-6, section 102–250 m, where the penetration rate is quite irregular. A general, decreasing trend of the penetration rate versus length is observed, probably caused by the narrow gap between the borehole wall and the drill string, entailing a large frictional resistance of the return water flow, which reduces the retrieval of drill cuttings and slows down the penetration rate.

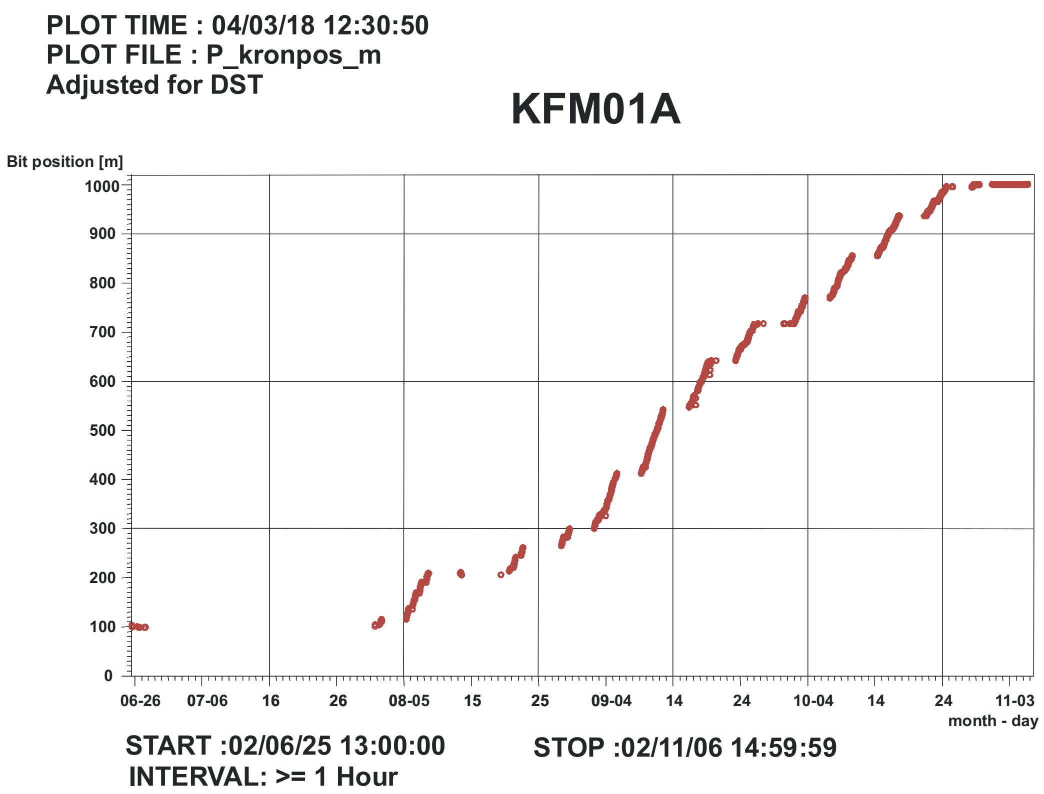


Figure 5-5. Drill bit position versus time.

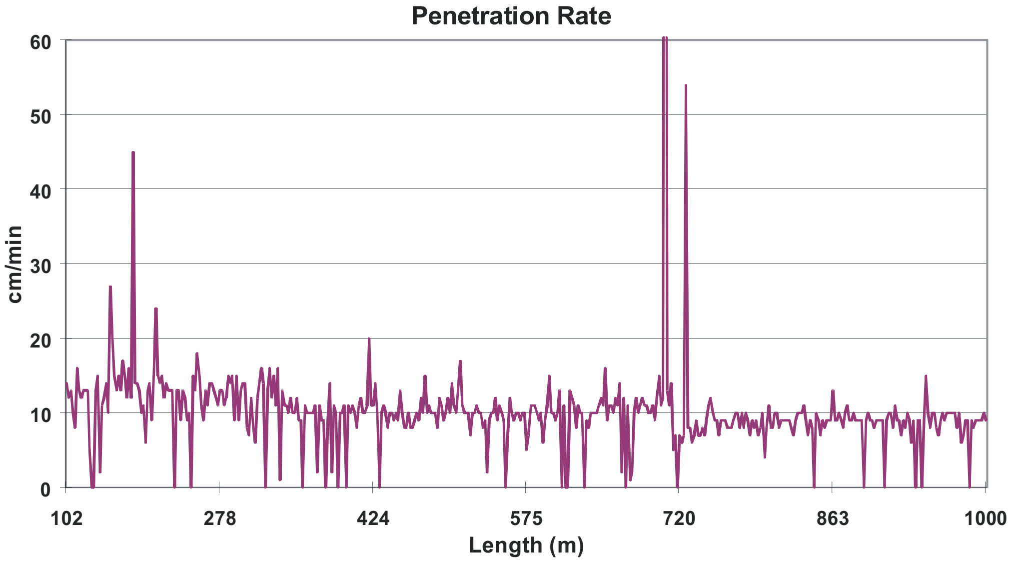


Figure 5-6. *Penetration rate during core drilling of KFM01A.*

Feed force

In Figure 5-7 the feed force is plotted versus borehole length. At the beginning, the feed force varies much, due to the efforts of the drilling crew to optimize different parameters in order to achieve as efficient drilling as possible. Later on, the force is more stable, although sudden changes sometimes occur. Decreases down to zero are the result of the feed force being shut off. The smooth trend of feed force increase versus borehole length is probably an effect of the narrow gap between the borehole wall and the drill string, which demands successively augmented force to overcome the increasing frictional resistance of the return water with suspended drilling debris in order to maintain a reasonably high penetration rate.

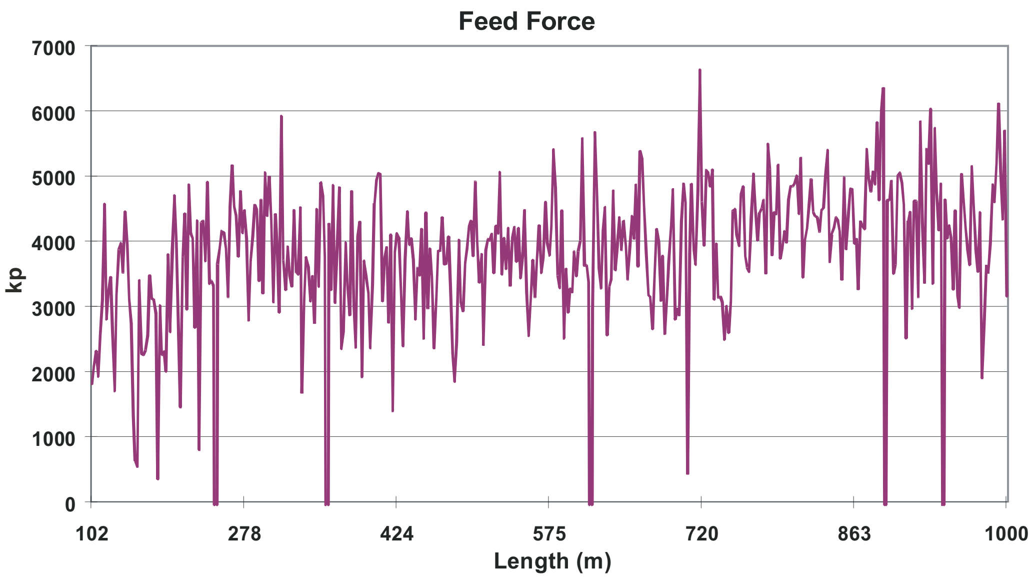


Figure 5-7. *Feed force versus borehole length during drilling of borehole KFM01A.*

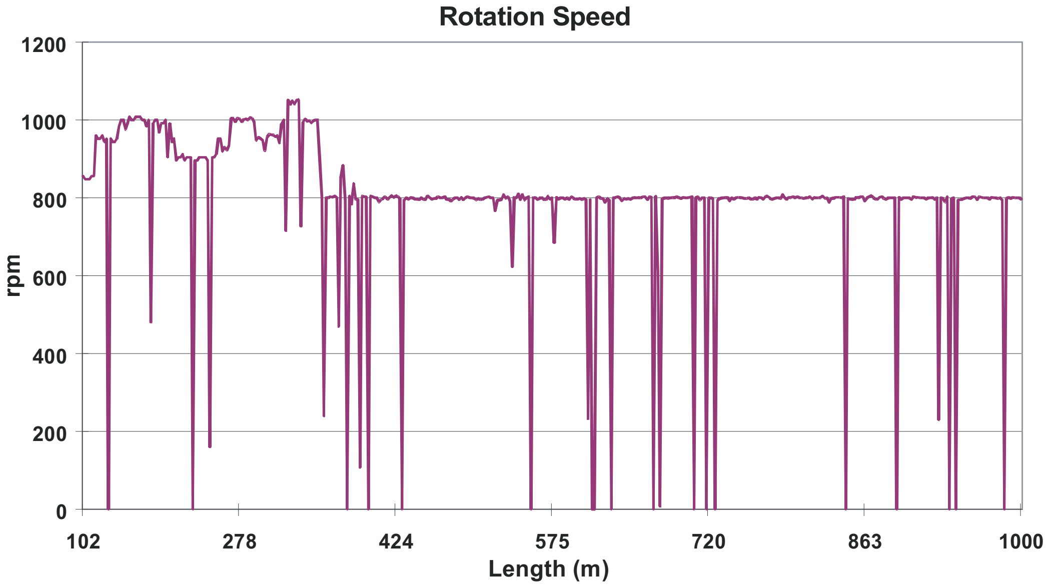


***Figure 5-8.** Rotation speed versus borehole length during drilling of borehole KFM01A.*

Rotation speed

As KFM01A was the first core drilled borehole, the contractor was testing different drill bits and also a variety of the drilling parameters, to optimize the drilling. From start, see Figure 5-8, the rotation speed was between 850–1000 rpm/min, but from 300 m the drilling was performed with an almost constant rotation speed of 800 rpm/minutes. 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 KFM01A 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 placed at the storage tank outlet, see Figure 3-9 and the return water by another flow rate gauge mounted on-line with the discharge pipeline, see Figures 3-6 and 3-11. A back-up calculation of the accumulated volume of flushing water consumed was also made by multiplying the number of filled water tanks by their volume.

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

Figure 5-9 illustrates the accumulated volume of flushing water and return water versus time during core drilling of borehole KFM01A, while Figure 5-10 displays the total volumes of flushing water and return water from the entire drilling period (results from uranine measurements are presented in the next section).

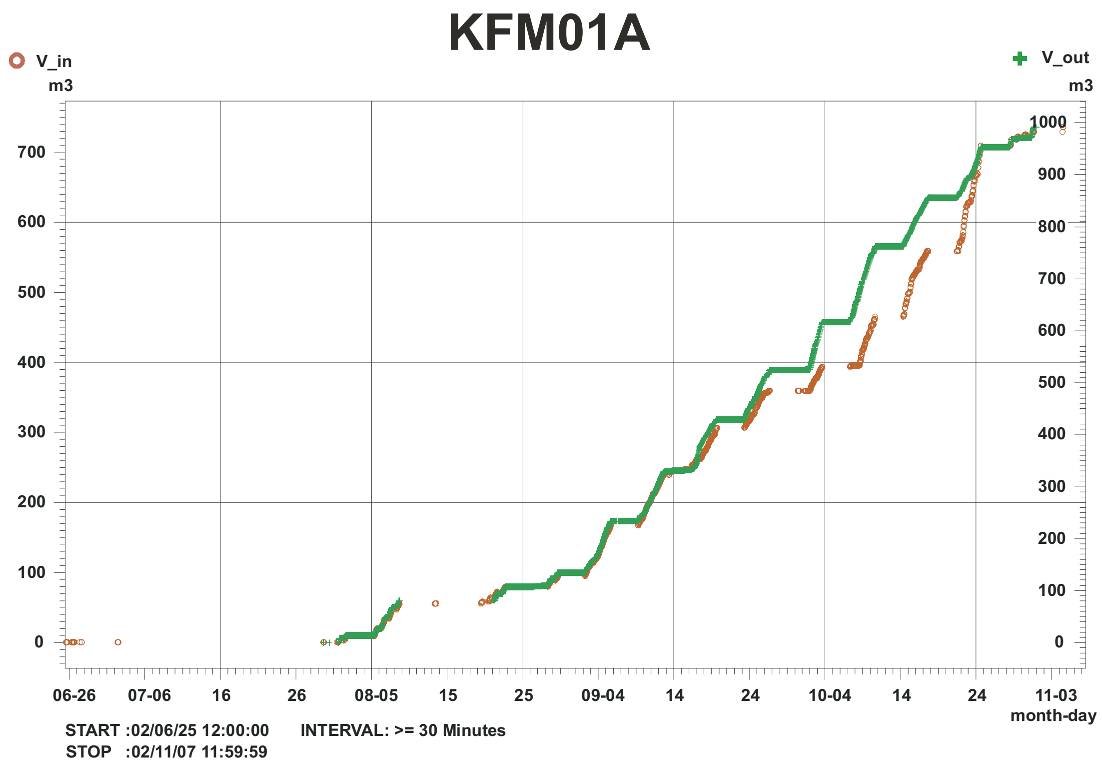


***Figure 5-9.** Accumulated volumes of flushing water and return water versus time during core drilling of borehole KFM01A.*

As is obvious from both Figure 5-9 and Figure 5-10, the accumulated and total volumes of flushing water respectively return water are almost equal at the end of the drilling period, giving a return water/flushing water quotient of 1.03. This low value may be interpreted as a result of low groundwater inflow to the borehole below the cased part, which is also supported by the minor differences in electrical conductivity values between flushing water and return water, see Figure 5-14.

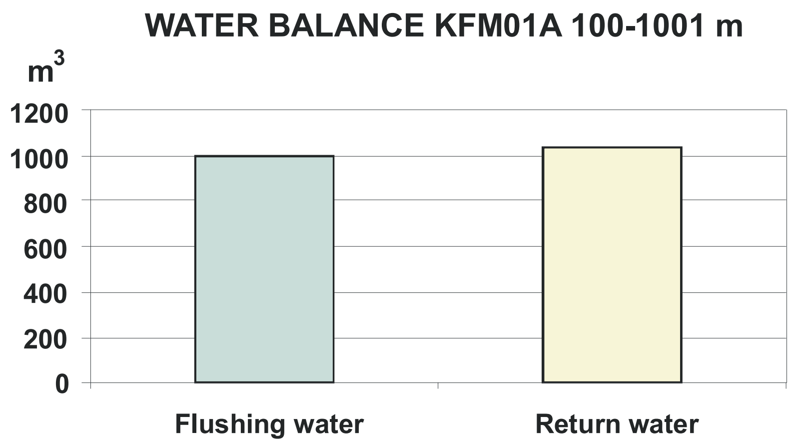


***Figure 5-10.** The total volume of flushing water used during core drilling was 999 m³. During the same period, the total volume of return water was 1030 m³. The return water/flushing water balance is then only 1.03, probably due to the low inflow of groundwater into the borehole.*

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 and Figure 5-12. From the two graphs it can immediately be concluded that the decrease of uranine content in the return water is small compared to the content in the flushing water. This indicates a low addition of groundwater to the return water.

A mass balance calculation of the accumulated volumes of flushing water consumed during drilling and recovered flushing water in the return water indicates that about 220 m^3 flushing water was lost in the borehole. However, in this particular borehole, this cannot be the case, since the yield of water from the borehole itself is extremely small and the volume of return water pumped out is somewhat larger than the volume introduced. A conclusion that can be drawn from the Uranine budget is that the calculations are not fully reliable, and that a more frequent sampling is needed in order to obtain more correct information.

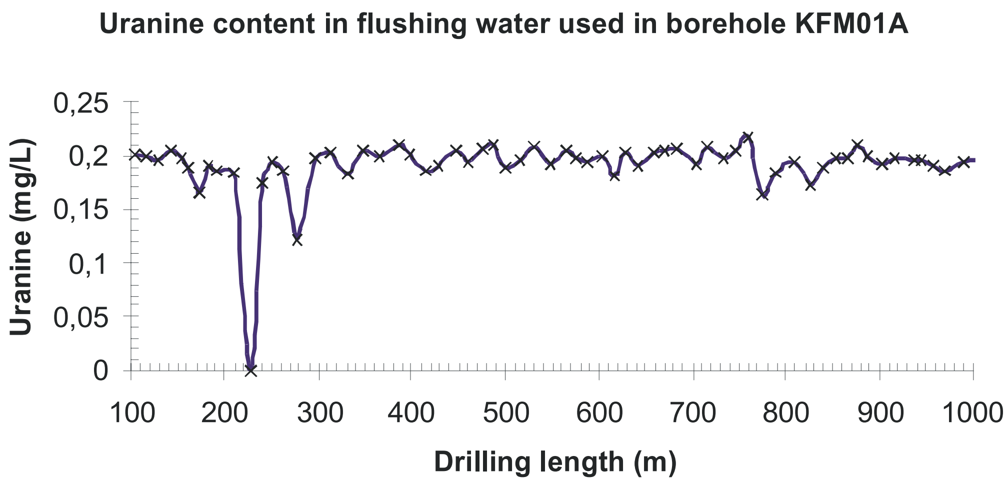


Figure 5-11. *Uranine content versus drilling length in flushing water consumed during drilling of borehole KFM01A.*

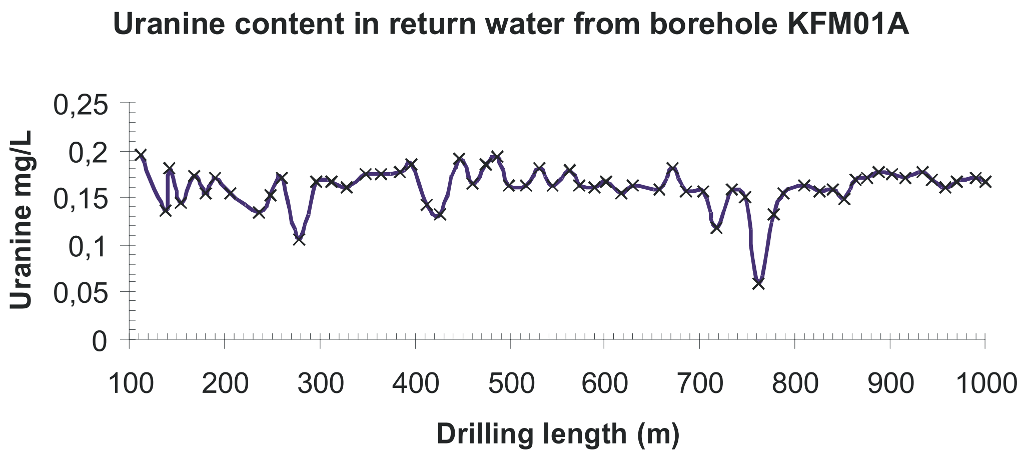


Figure 5-12. *Uranine content versus drilling length in return water from borehole KFM01A.*

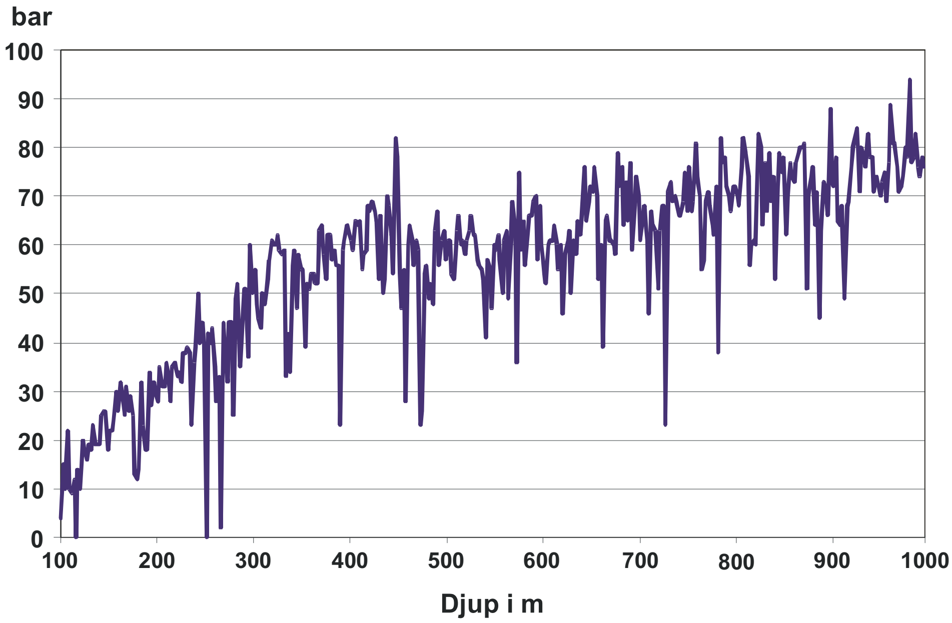


***Figure 5-13.** Flushing water pressure versus drilling length when drilling KFM01A.*

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM01A is exposed in Figure 5-13. The drilling system WL-76, used for drilling of KFM01A, is constructed to give a large core dimension. This, however, entails that the gap dimension between the drilling string and the borehole wall becomes small, resulting in relatively high flushing water pressures to allow the flushing water flow rates needed. The increasing trend of the pressure versus drilling length reflects the augmented frictional resistance with increasing length of the drilling string.

Electric conductivity of flushing water

Flushing water was supplied from percussion borehole HFM01. A sensor for on-line registration of the electric conductivity of the flushing water was placed immediately before the flushing water entered the flush water tank, see Figure 3-6.

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 3-6.

There is only a small difference between the electrical conductivity (salinity) of the flushing water from the 200.20 m deep borehole HFM01 and that of the return water from KFM01A (Figure 5-14). The result indicates that the inflow of formation water into KFM01A at depth is very low. The average conductivity of the return water seems a bit lower than that of the flushing water. This may be a combined effect of suspended drill cuttings and a high content of water bubbles in the turbulent flow of the return water, as well as a generally lower temperature of the return water than of the flushing water, all factors resulting in decreased EC-values.

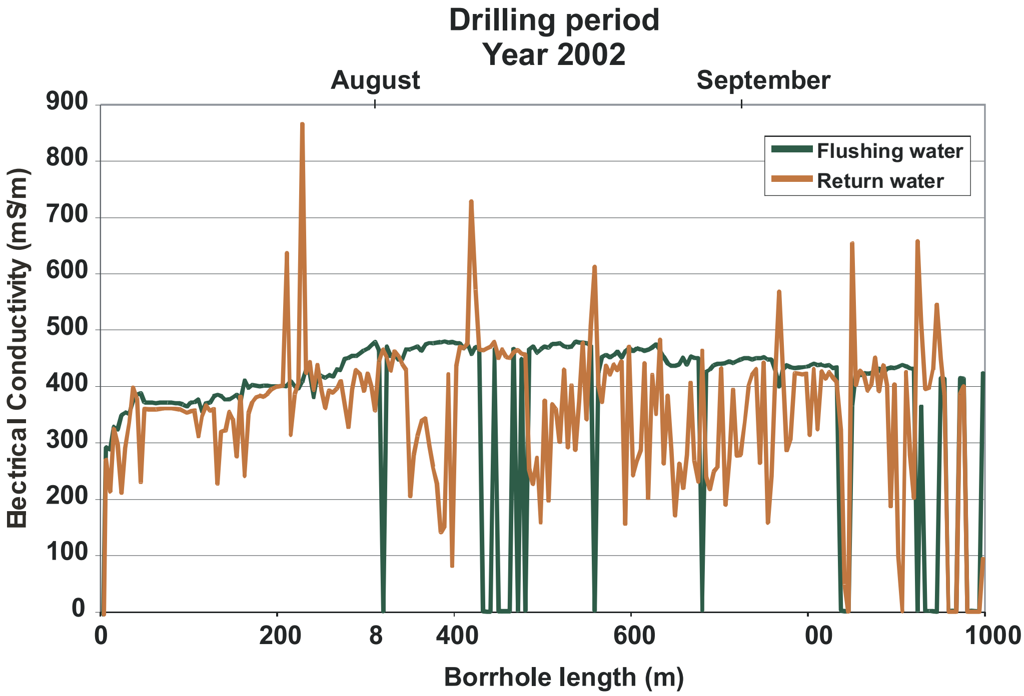


Figure 5-14. *Electrical conductivity of flushing water from HFM01 and return water from KFM01A.*

The 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 settle 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 moment, because of an increased content of formation water and a lower content of drill cuttings and air bubbles than before the weekend.

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 chemical analyses of water from the supply well for flushing water, HFM01, 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 of the un-treated groundwater.
- To check the function of the active carbon filter plant and the organic content in the water after treatment.
- To check if the hydro-chemical composition changes versus time during pumed conditions.

The chemical composition of the flushing water is important when estimating the effect, or correcting for the effect, of remaining flushing water in water samples from borehole KFM01A.

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 HFM01 prior to the core drilling was in the range 10–12 mg/L. These values were considered as too high for the groundwater to be used as flushing water without further measures. Other alternative flushing water sources were considered, like drinking water from a fire hydrant not very far from the drilling site, and also water pumped from the sea. However, also the alternatives had disadvantages, and it was decided to use HFM01 as the flushing water well together with an active carbon filter system for reduction of organic substances from the pumped groundwater.

During drilling, samples were collected before and after the carbon filter system and at different occasions in order to check its efficiency, see Figure 5-15 and Appendix C. It could be concluded, that the TOC content was generally reduced to between 1 and 5 mg/L, but a few values were as high as close to 8 mg/L. In the future, a more frequent sampling is needed in order to keep full control of the system. It was also found that the active carbon filter mass should be changed more often in order to reach the desired reduction of the TOC concentration.

Microbes

The results from the control of the microorganism content in the flushing water used in KFM01A are reported in /10/. The control, which was performed at one occasion in October 2002, shows that the ultraviolet (UV) radiation unit was not installed optimally in the system. The best position is after the storage tanks, just before the drilling machine.

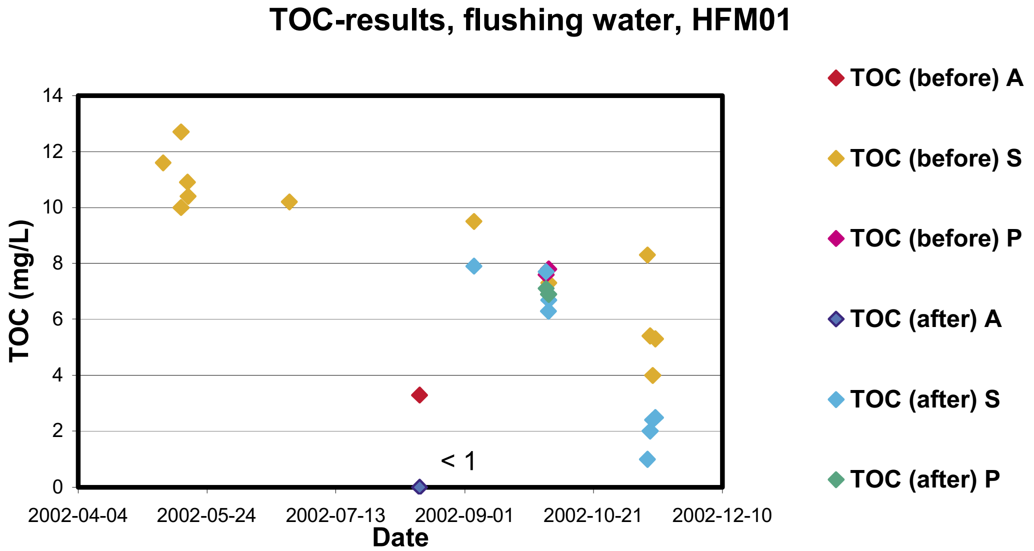


Figure 5-15. *TOC concentrations in water samples from HFM01 and collected before and after the carbon filter plant. The samples from April and May were collected before the filter system was installed. The last sampling in November was conducted after a change of active carbon filter mass in the system. The analyses are performed by several consulted laboratories, as follows: A = AnalyCen AB, S = Dept. of System Ecology, Stockholm University, P = Paavo Ristola OY.*

The number of cultivable microorganisms increased considerably in the water tanks used for preparation and storage of flushing water (Figure 3-8). Storage of flushing water in tanks over weekend triggered a significant growth of microbes.

Water composition

The flushing water was sampled at two occasions (three samples) during drilling and also prior to drilling, in connection with hydraulic testing of borehole HFM01 /12/ and /13/. As shown in Appendix C, the composition of the water from HFM01 changes due to the pumping. Therefore, a conclusion from this firstly drilled telescopic borehole is, that sampling should be performed more frequently, say twice a month during the drilling period.

5.4.4 Registration of the groundwater level in KFM01A

To enhance the recovery of drill cuttings from the borehole, air-flush (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 5-16). The mammoth pumping caused a draw-down of in average approximately 60 m. From about 500 m borehole length, 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 below the upper cased and grouted parts of the borehole was very low.

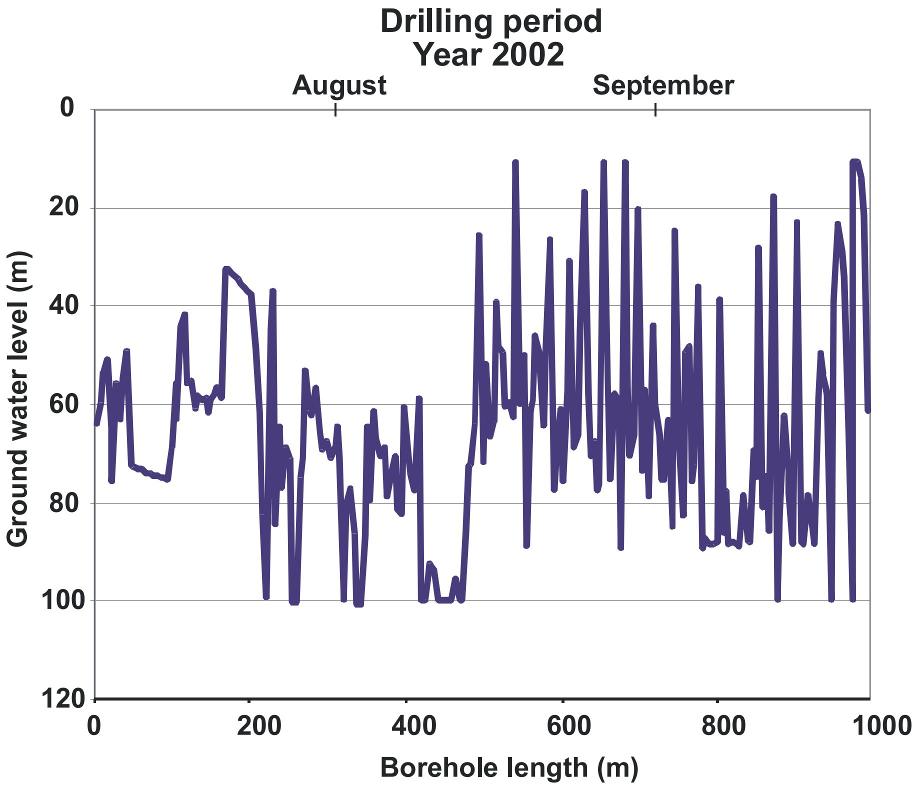


Figure 5-16. *Variation of the level of the groundwater table in KFM01A during drilling.*

5.4.5 Core sampling

The average drill core length obtained from the drilling was 2.53 m. Due to the very low fracture frequency, 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. This caused a relatively large and uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations. However, 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 casing to full borehole length worked well without obstruction from settled drill cuttings.

The theoretical difference in volume of the core drilled part of KFM01A and the drill core is calculated to be 2.278 m^3. This volume corresponds to the amount of drill cuttings produced during drilling. If a density of 2650 kg/m^3 (approximate figure for granitoids in the Forsmark area) is applied, the total weight of debris is estimated at 6037 kg. The measured wet weight of the debris recovered from the borehole was 8890 kg. The calculated dry weight of the debris would then be 4764 kg. The difference between estimated and calculated dry weight of debris is 1273 kg, which gives a recovery of 79 %.

The recovery figures could be commented on. The dwell time in the system is too short for settling of the suspended finest fractions. No estimation was made of the amount of suspended material, but the true recovery is probably somewhat higher than 79 %. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

The low fracture frequency and the absence of major fracture zones below the cased part, indicates that only minor amounts of drilling debris might have been injected into the fracture system of the bedrock.

5.4.7 Deviation measurements

The deviation measurements made in borehole KFM01A show that the deviation of the borehole is limited (see Appendix B). The bottom of the borehole deviates 11 m upwards and 77 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 5-17, 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 1000 m length in a vertically drilled borehole is 180 mm. In inclined boreholes the elongation of the pipe string should theoretically be less.

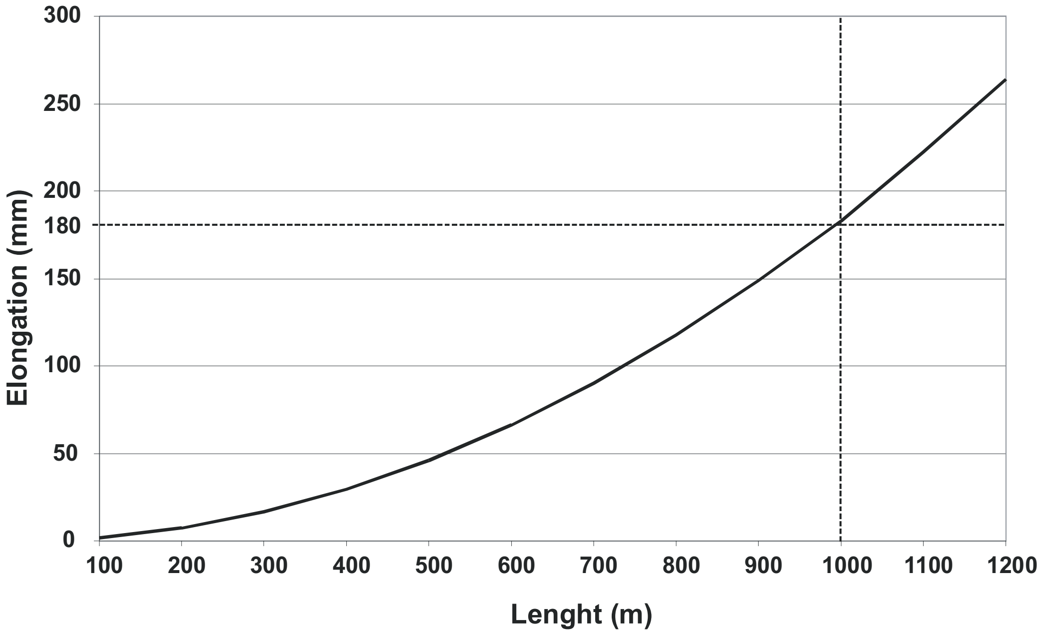


Figure 5-17. *The diagram illustrates the elongation of the WL-76 drilling pipe string when hanging in a vertical water filled borehole. Values from a laboratory load tests of the drilling pipe string.*

5.4.9 Hydraulic tests

No measurements were performed due to technical problems with the WL-probe, cf Section 3.3.5. Besides, the inflow of water into the borehole was very limited.

5.4.10 Groundwater sampling – groundwater quality

Cf Section 5.4.9.

5.4.11 Absolute pressure measurments

Cf Section 5.4.9.

5.4.12 Groove milling

After completion of drilling, borehole KFM01A will be used for borehole measurements, employing many types of borehole instruments with different stretching characteristics (pipe strings, wires, cables etc). In order to provide a system for length calibration in the borehole, reference grooves were milled into the borehole wall 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 5-18. Table 5-2 presents the reference levels selected for milling. The table also reveals that milling failed at certain levels. After milling, the reference grooves were detected with the SKB level indicator (a calliper). A BIPS-survey gives the final conformation that the grooves exist.

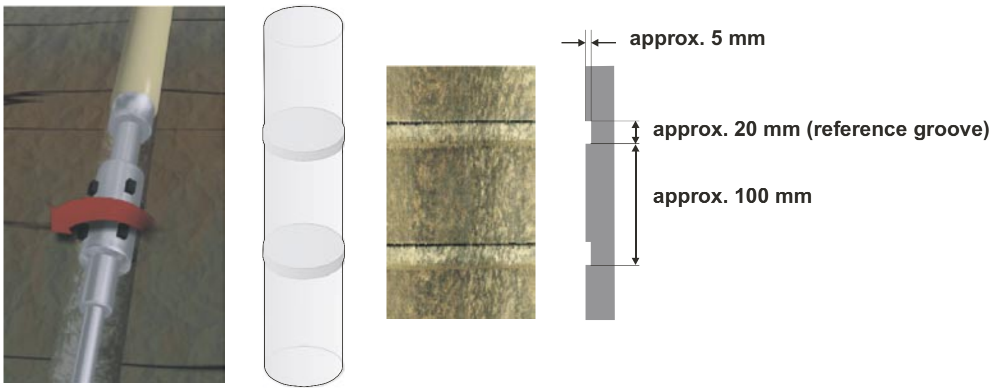


Figure 5-18. *Layout and design of reference grooves.*

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

Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS	Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS
110	Yes	Yes	550	Yes	Yes
150	Yes	Yes	600	Yes	Yes
200	Yes [1]	Yes	650	Yes	Yes
250	Yes	Yes	700	Yes [3]	Yes
300	Yes	Yes	750	Yes	Yes
350	Yes	Yes	800	No	Yes
400	Yes	Yes	850	No [4]	No
450	No [2]	No	900	No [4]	No
500	Yes	Yes	950	No [4]	No

[1] veinlets indicated before the slots,

[2] sinker cup broken during milling process,

[3] weak signal,

[4] due to the tight borehole.

5.4.13 Consumables

The amount of oil products consumed during drilling in the percussion drilled borehole (0–100 m) and grout used for gap injections of the respective casings are reported in Table 5-3 and Table 5-4. 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.

Table 5-3. Oil and grease consumption.

Borehole ID	Hammer oil (percussion drilling) Preem Hydra 46	Compressor oil (percussion drilling) Schuman 46	Thread grease (core drilling) Cargo Fluor
KFM01A	15 L	Not detected	7.3 kg

Table 5-4. 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
KFM01A	29.4	1400 kg/1120 L	Hose	Stop pressure 5 bars
KFM01A	100.48	2500 kg/2000 L	Packer/Hose	Stop pressure 20 bars

The special type of thread grease (silicon based) used in this particular borehole was certified according to SKB MD 600.006, Version 1.0, Instruction for the use of chemical products and material during drilling and surveys (SKB internal controlling document). The experience from a technical point of view of the grease, is not satisfactory. Although expensive, the grease had low adhesion capacity to the threads and would therefore increase the risk of contamination in the borehole. Furthermore, the lubrication characteristics were not as good as for conventional lubricants.

5.5 Hydrogeology

After finishing the drilling to the final length (1001.49 m), the borehole was cleaned by airlift pumping in the section 0–100 m causing a drawdown of 63 m. The recovery of the groundwater table was registered during the weekend and confirmed the extremely low water inflow into the borehole (Figure 5-19). From the diagram an inflow of < 1 L/min can be estimated.

Prior to drilling start of KFM01A, the flushing water well HFM01 was drilled at drilling site DS1. During the period when drilling of KFM01A was ongoing, also percussion drilling of HFM02–03 at the drilling site was carried out, see Figure 1-2. The pumping activities in KFM01A respectively in the three percussion drilled boreholes at drilling site DS1, revealed hydraulic connections between all four boreholes at shallow levels (< 100 m).

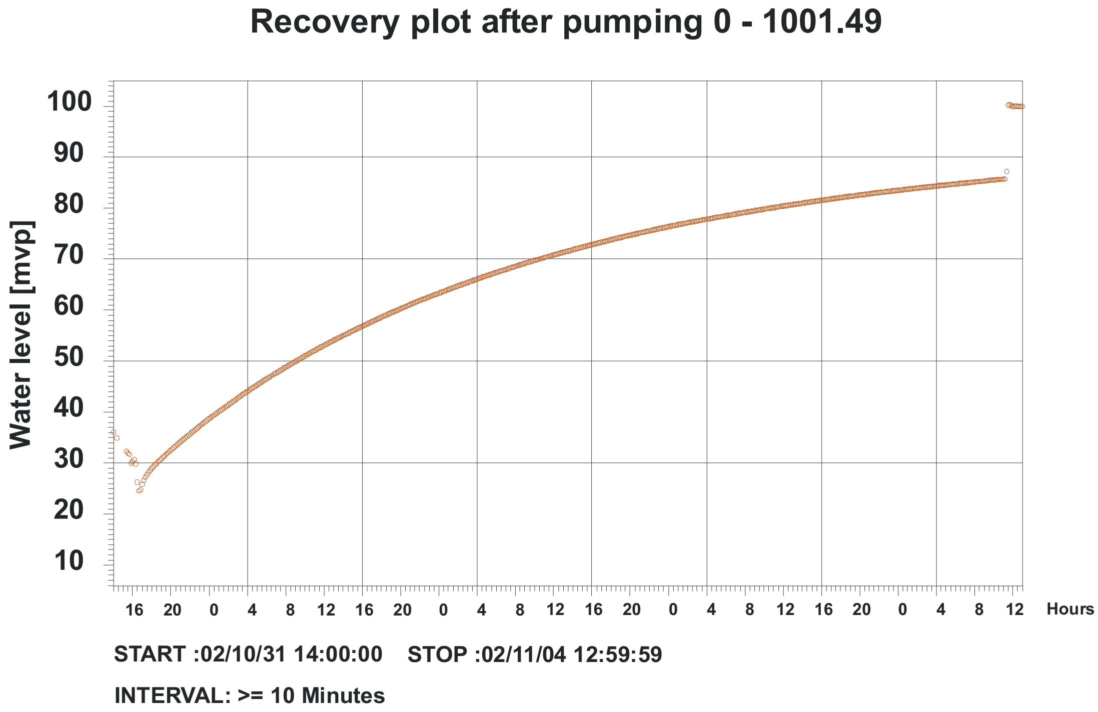


Figure 5-19. *Recovery of groundwater table in section 0–1001.49 m of KFM01A.*

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, HFM01, and two groundwater monitoring wells, HFM02 and HFM03, at drilling site DS1. SKB P-03-30, Svensk Kärnbränslehantering AB

/4/ **SKB, 2003.** Claesson L-Å, Nilsson G. Forsmark site investigation. Drilling of monitoring wells SFM0001–SFM0003 in soil at drilling site DS1. SKB P-03-13, Svensk Kärnbränslehantering AB.

/5/ **SKB, 2003.** Petersson J, Wängnerud A. Site investigations at Forsmark. Boremap mapping of telescopic drilled borehole KFM01A. SKB P-03-23, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2004.** Claesson L-Å, Nilsson G. Forsmark site investigation. Drilling of core borehole KFM01B at drilling site DS1. SKB P-report in progress. Svensk Kärnbränslehantering AB.

/7/ **SKB, 2004.** Sjöberg J. Forsmark site investigation. Overcoring rock stress measurements in borehole KFM01B. SKB P-report in progress. Svensk Kärnbränslehantering AB.

/8/ **SKB, 2004.** Petersson J, Wängnerud A. Site investigations at Forsmark. Boremap mapping of core borehole KFM01B. SKB P-report in progress. Svensk Kärnbränslehantering AB.

/9/ **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.

/10/ **SKB, 2003**. Pedersen K. Site investigations in the Forsmark area. Control of microorganism content in flushing water used for drilling in KFM01A. SKB P-03-03, Svensk Kärnbränslehantering AB.

/11/ **SICADA.** Field note numbers 11, 28, 31 and 46**.**

/12/ **SKB, 2003.** Ludvigson J-E, Jönsson S, Levén J. Forsmark site investigation. Pumping tests and flow logging. Boreholes KFM01A (0–100 m), HFM01, HFM02 and HFM03. SKB P-03-33, Svensk Kärnbränslehantering AB.

/13/ **SKB, 2003.** Nilsson A-C. Forsmark site investigation. Sampling and analyses of groundwater in percussion drilled boreholes and shallow monitoring wells at drilling site DS1. Results from the percussion boreholes HFM01, HFM02, HFM03, KFM01A (borehole section 0–100 m) and the monitoring wells SFM0001, SFM0002 and SFM0003. SKB P-03-47, Svensk Kärnbränslehantering AB.

Appendix A

Well Cad presentation of the percussion drilled part of borehole KFM01A

Title **PERCUSSION DRILLED BOREHOLE KFM01A**

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM01A	**Northing [m]**	6699529.81
Diameter [mm]	251	**Easting [m]**	1631397.16
Length [m]	100.48	**Elevation [m.a.s.l.]**	3.13
Bearing [°]	318.35	**Drilling Start Date**	2002-05-07 09:30:00
Inclination [°]	-84.73	**Drilling Stop Date**	2002-06-10 14:39:00
Remark		**Plot Date**	2004-02-16 21:03:38

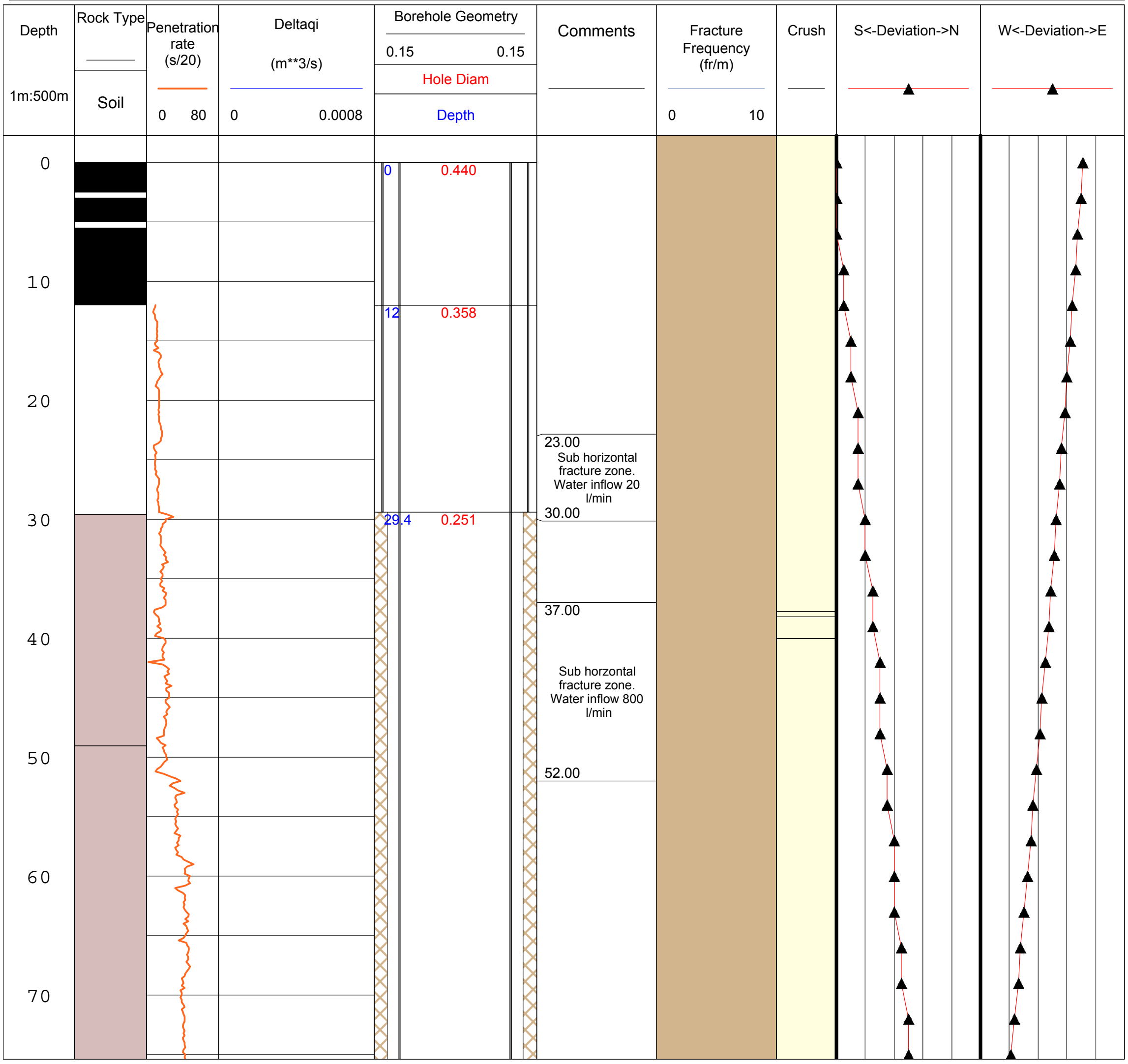
ROCKTYPE

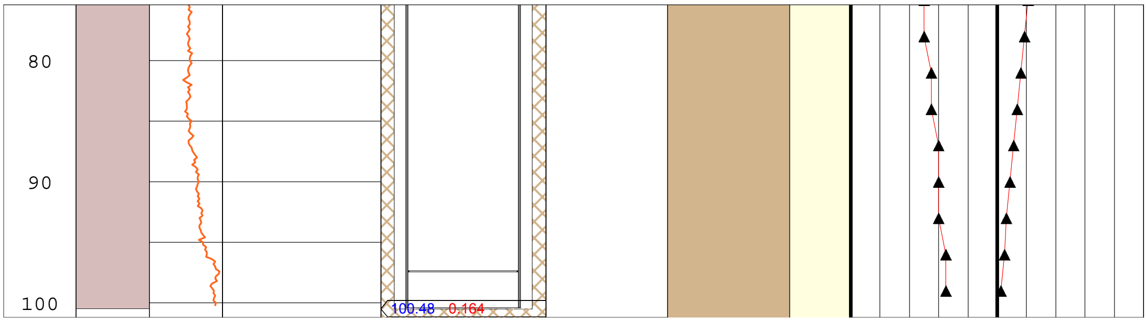
Granite to granodiorite, metamorphic, medium-grained

SOIL

Soil

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




80
90
100
100.48
0.164

Appendix B

Well Cad presentation of the core drilled part of borehole KFM01A

Title TELESCOPIC BOREHOLE KFM01A

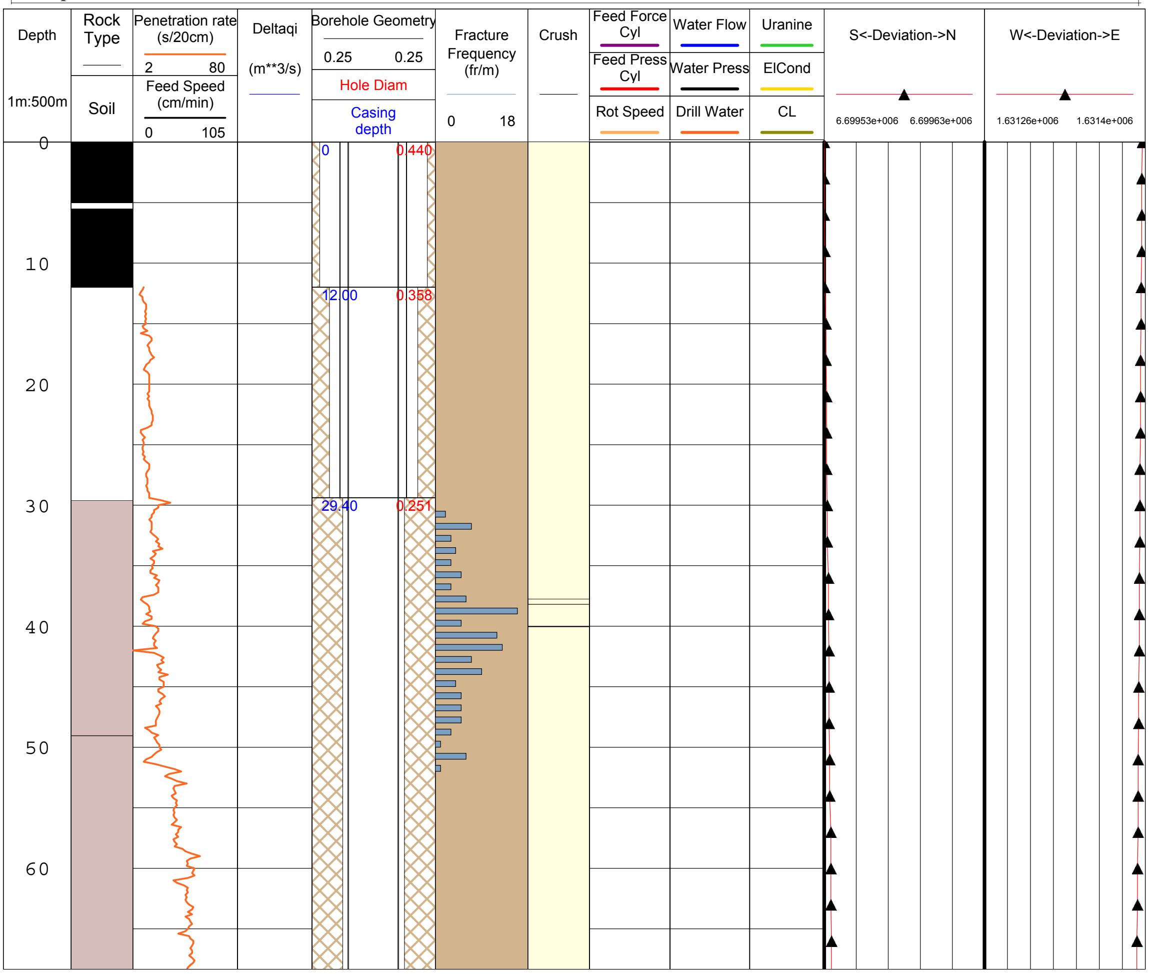
Svensk Kärnbränslehantering AB

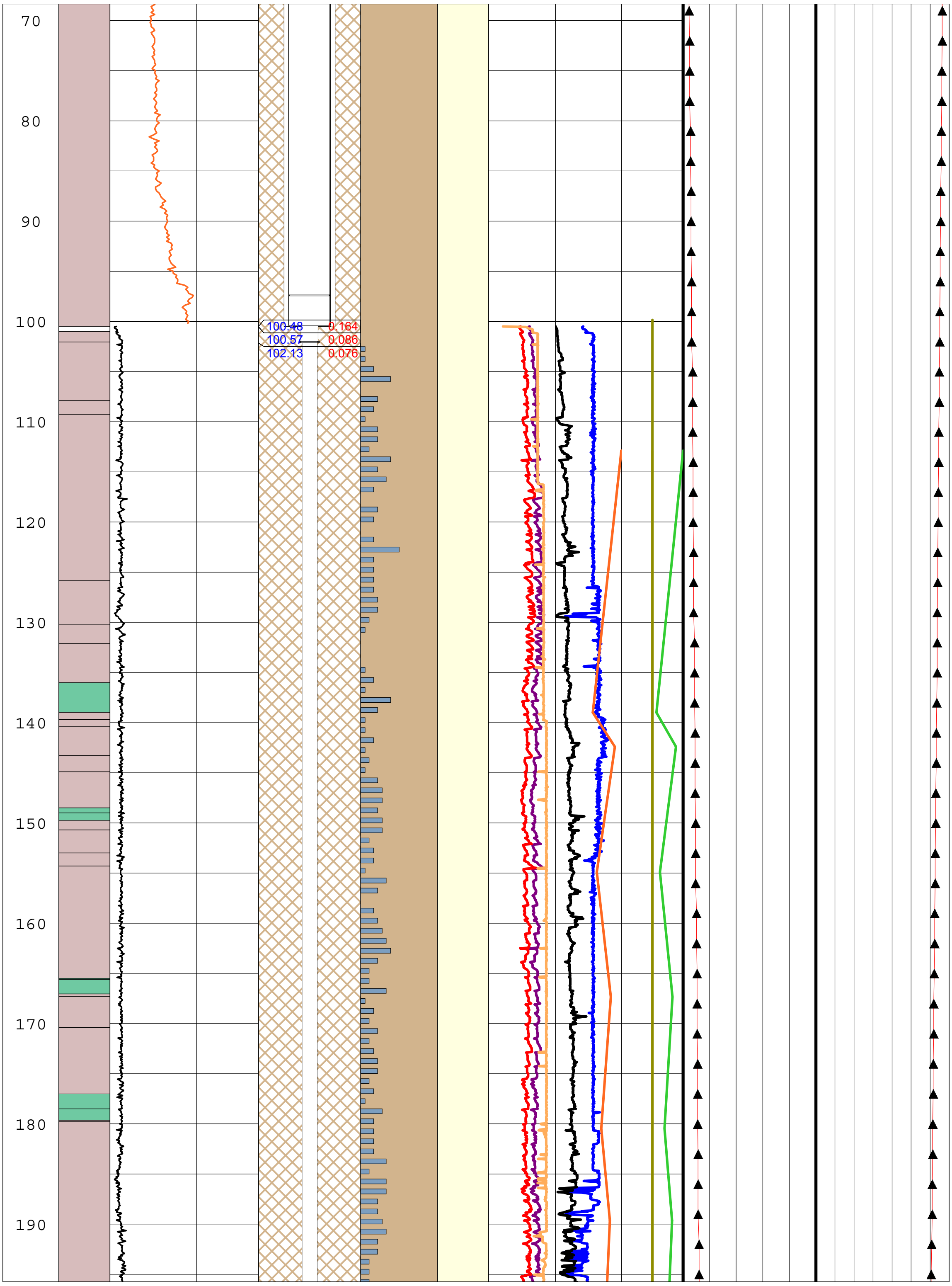
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM01A	**Northing [m]**	6699529.81
Diameter [mm]	76.3	**Easting [m]**	1631397.16
Length [m]	1001.49	**Elevation [m.a.s.l.]**	3.13
Bearing [°]	318.35	**Drilling Start Date**	2002-05-07 09:30:00
Inclination [°]	-84.73	**Drilling Stop Date**	2002-10-28 14:39:00
Remark		**Plot Date**	2004-02-17 21:03:23

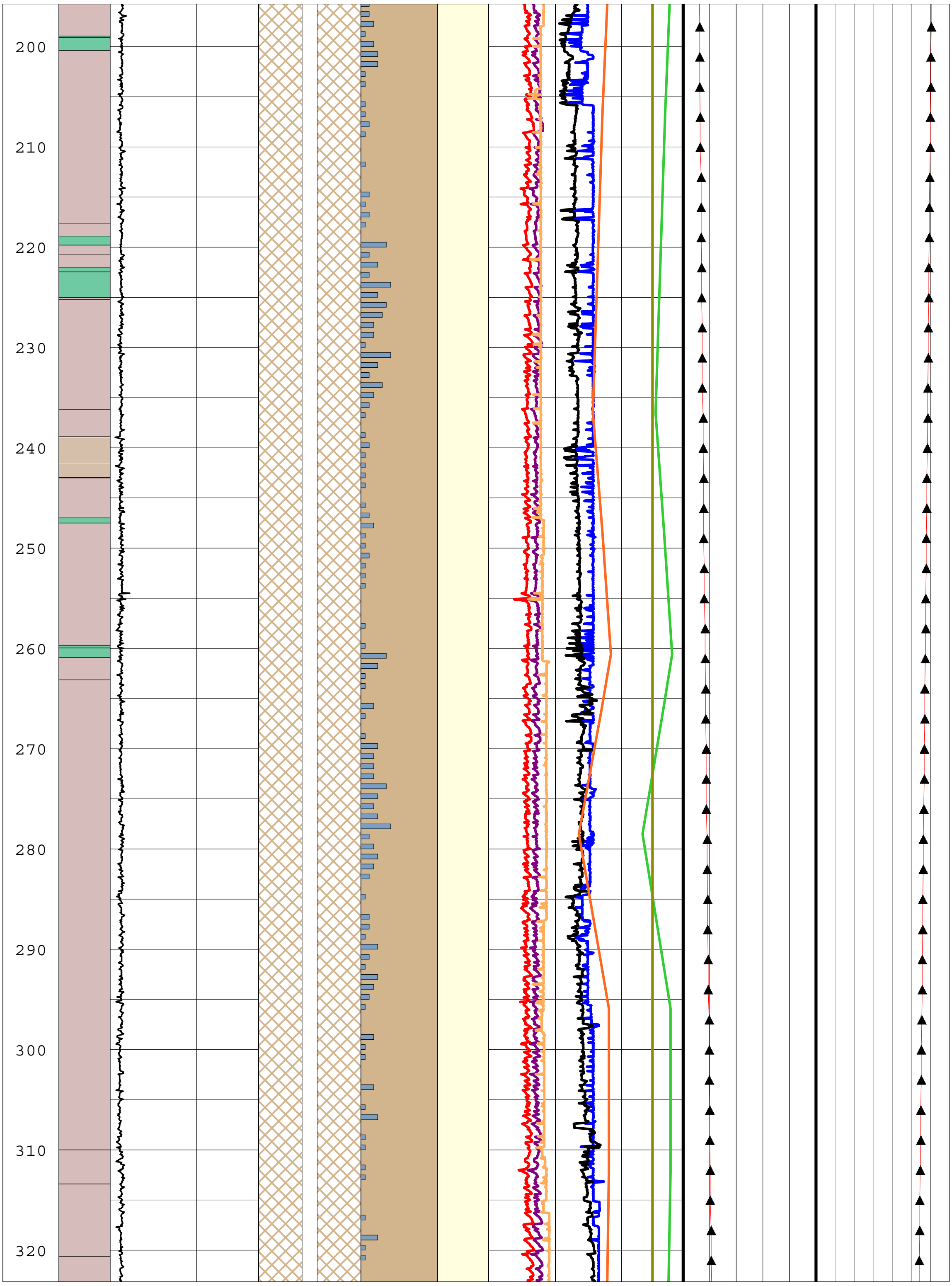
ROCKTYPE FORSMARK
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granitoid, metamorphic
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Calc-silicate rock (skarn)

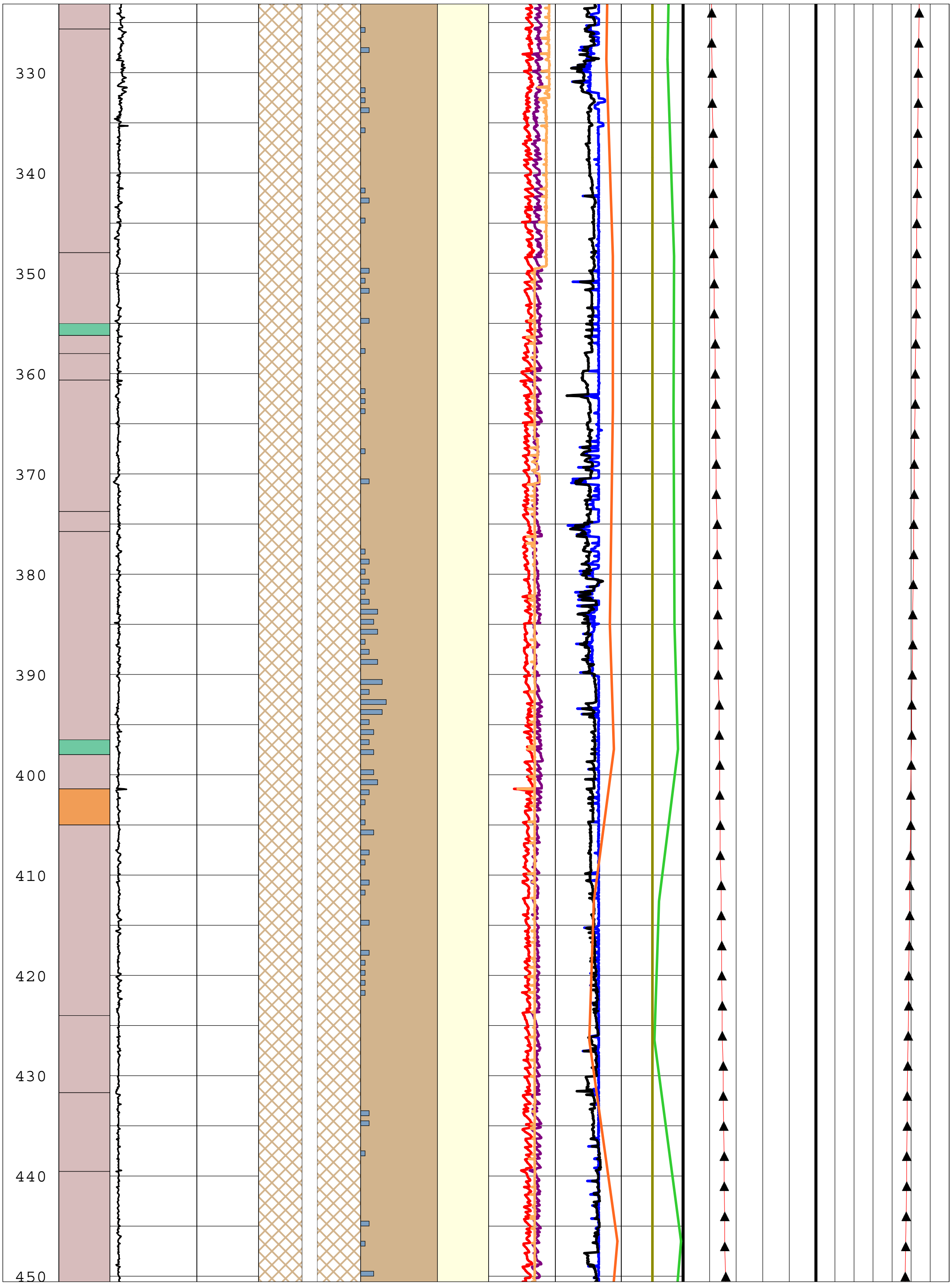
SOIL
- Soil

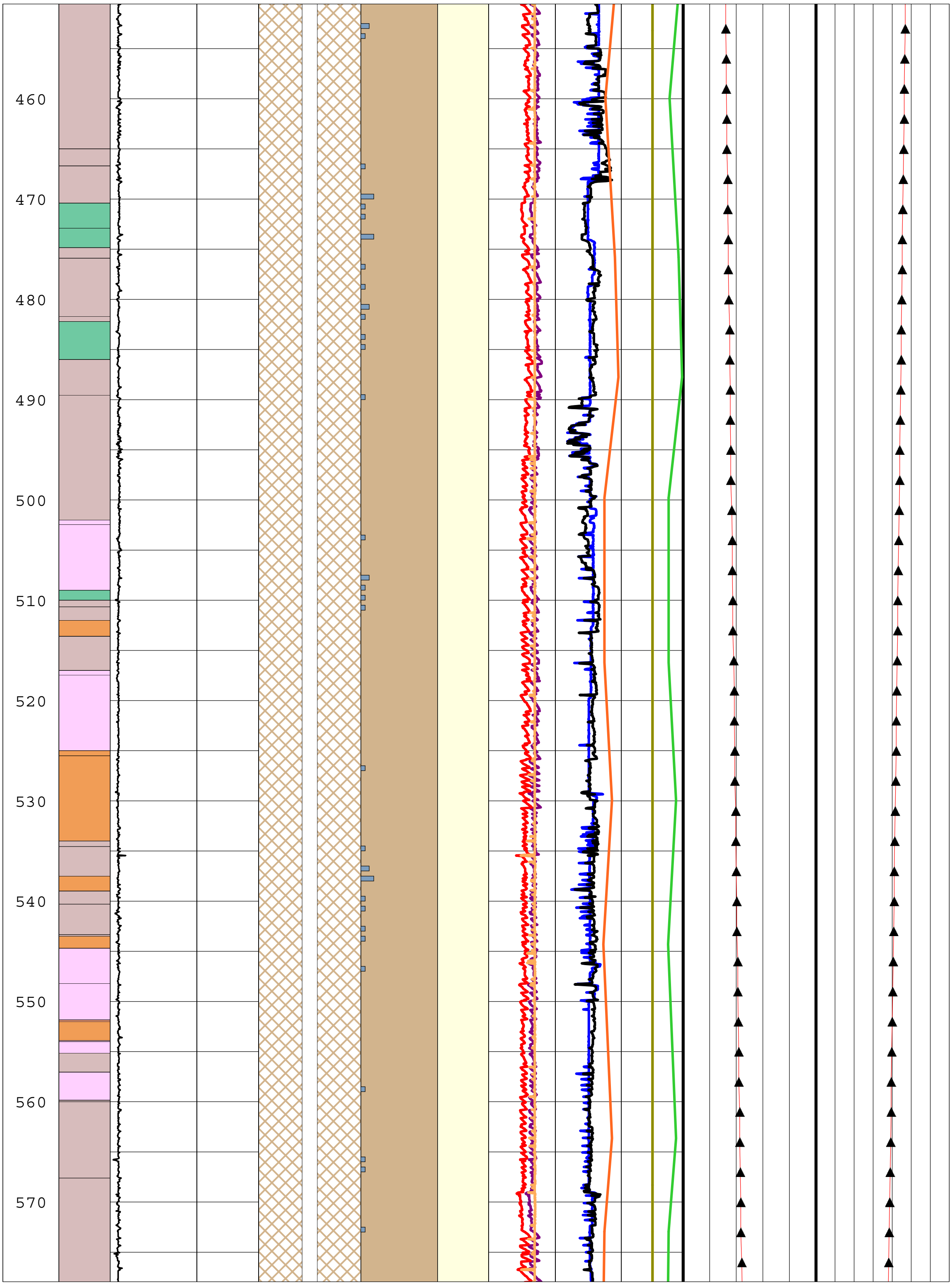
Script Name

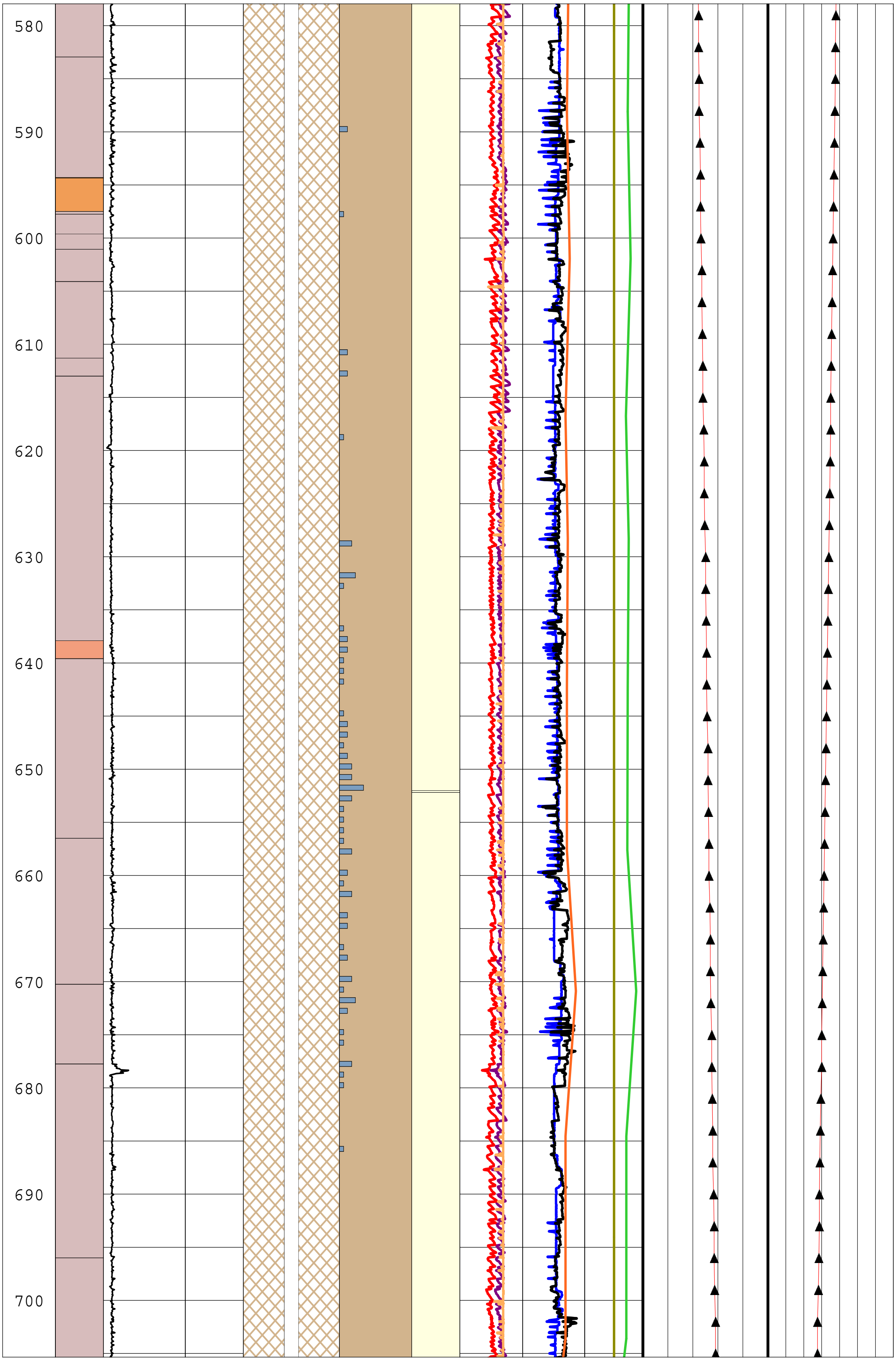


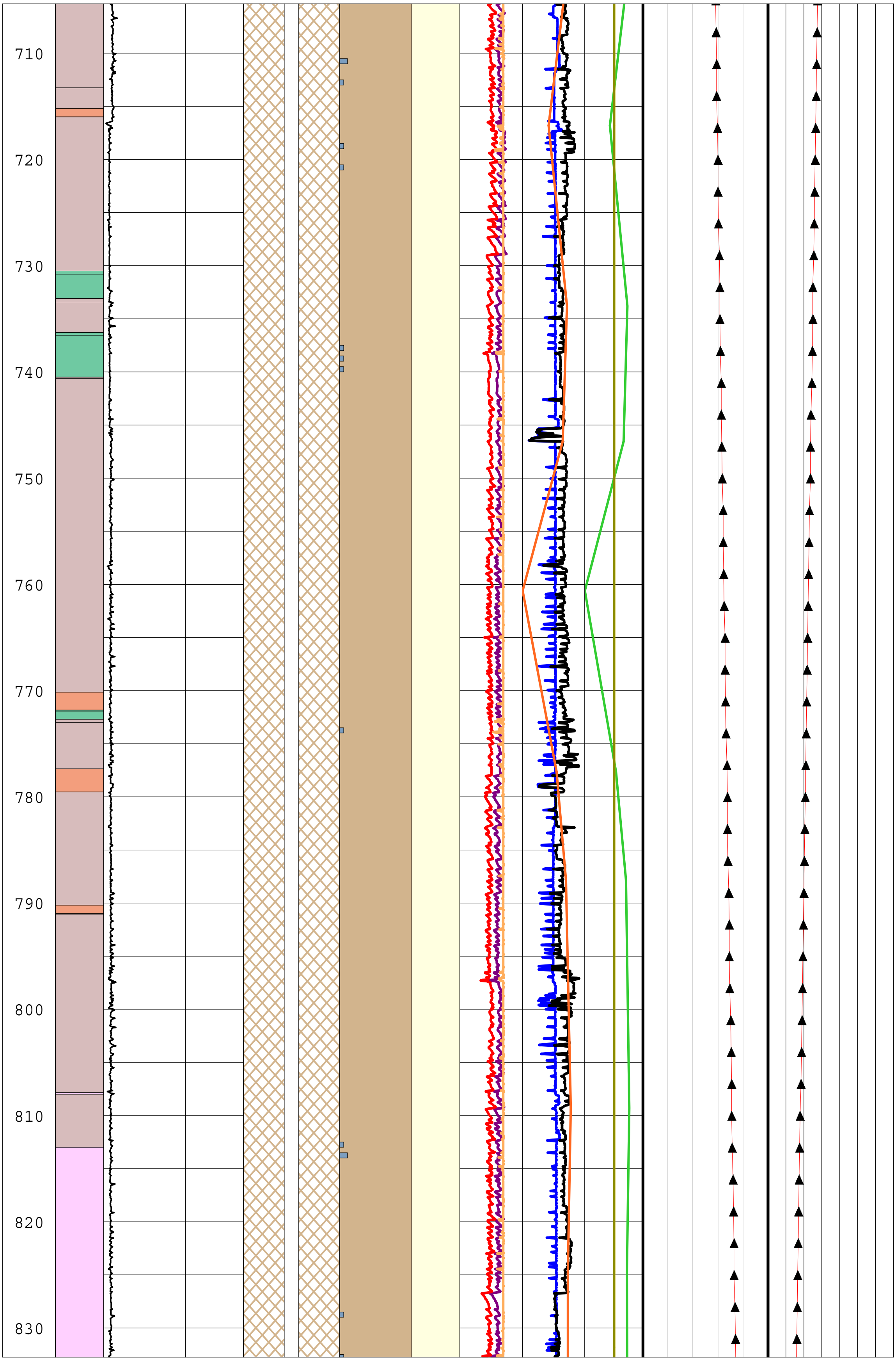

70
80
90
100
110
120
130
140
150
160
170
180
190
100.48
0.164
100.57
0.086
102.13
0.076

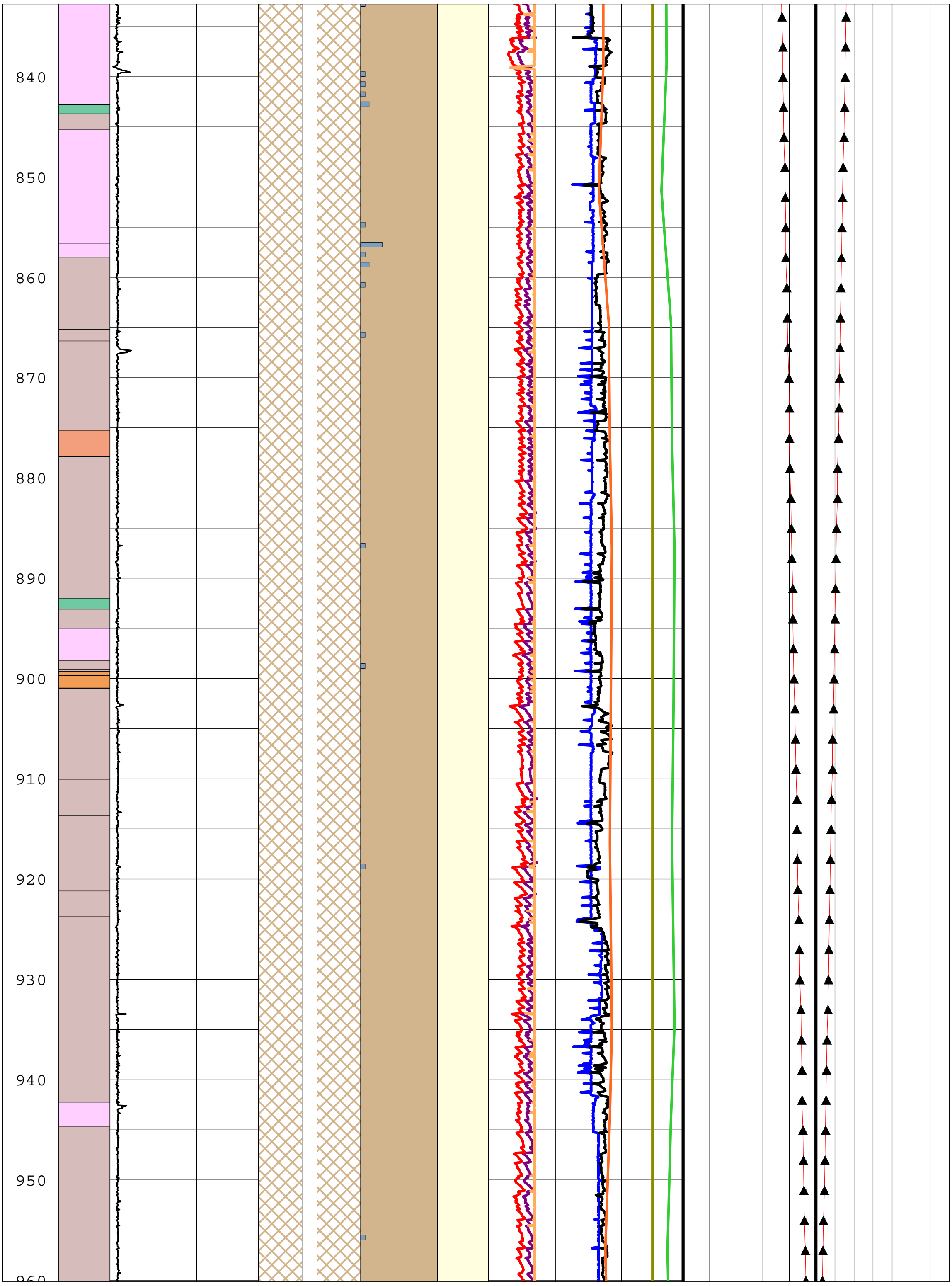

200
210
220
230
240
250
260
270
280
290
300
310
320


330
340
350
360
370
380
390
400
410
420
430
440
450

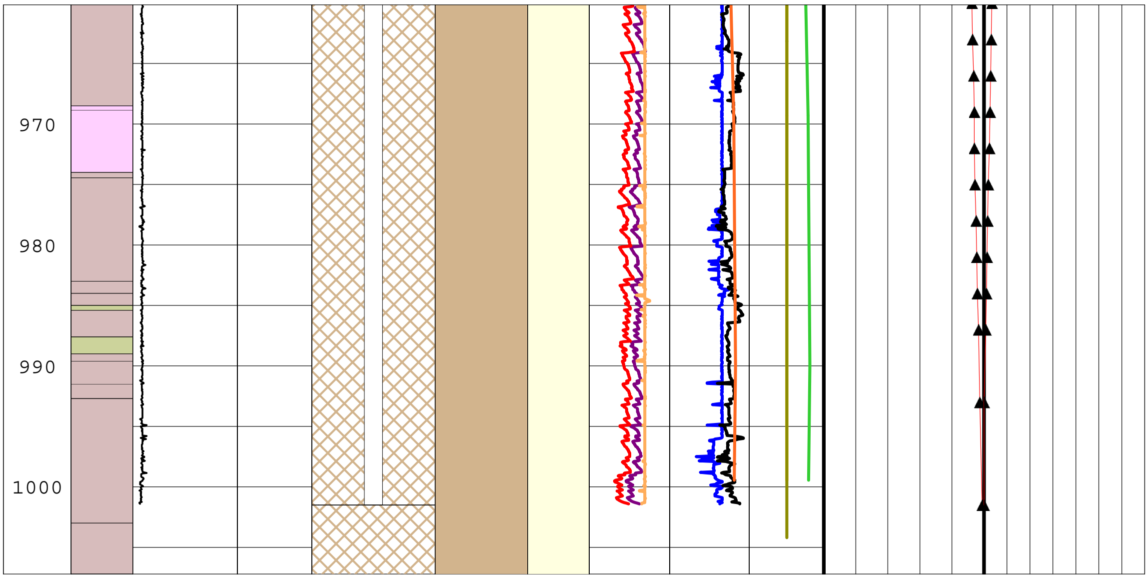

460
470
480
490
500
510
520
530
540
550
560
570


580
590
600
610
620
630
640
650
660
670
680
690
700


710
720
730
740
750
760
770
780
790
800
810
820
830



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


970
980
990
1000

Appendix C

Water Composition

Compilation April 2003

Idcode	Secup	Seclow	Sample	Date	Type of sample	Na	K	Ca	Mg	HCO3	Cl
	[m]	[m]	[no.]			[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]
HFM01	0.00	200.20	4112	2002-05-07	Hydro. Test	366	10,6	24,0	7,7	-	216
HFM01	0.00	200.20	4113	2002-05-14	Hydro. Test	42,6	5,7	39,3	7,9	-	9,00
HFM01	0.00	200.20	4114	2002-05-14	Hydro. Test	470	12,8	56,1	15,5	480	473
HFM01	71.00	200.20	4115	2002-05-16	Hydro. Test	162	12,4	46,3	8	520	30,8
HFM01	0.00	71.00	4116	2002-05-16	Hydro. Test	498	13,8	60,4	16,9	440	530
HFM01	0.00	200.20	4172	2002-06-25	Flush water test	556	15,2	79,1	22,8	480	651
HFM01	0.00	200.20	4293	2002-09-04	after C-filter	816	21,4	150	43,3	-	1170
HFM01	0.00	200.20	4294	2002-09-04	before C-filter	848	21,8	155	44,3	-	1170
HFM01	0.00	200.20	4312	2002-10-02	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4314	2002-10-02	after C-filter	-	-	-	-	-	1120
HFM01	0.00	200.20	4346	2002-10-03	before C-filter	-	-	-	-	77,0	-
HFM01	0.00	200.20	4347	2002-10-03	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4348	2002-10-03	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4349	2002-10-03	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4363	2002-11-11	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4364	2002-11-11	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4366	2002-11-12	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4367	2002-11-12	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4368	2002-11-13	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4369	2002-11-13	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4370	2002-11-14	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4371	2002-11-14	after C-filter	-	-	-	-	-	-

Idcode	Secup	Seclow	Sample	Date	Type of sample	SO4	SO4-S	Br	F^-	Si	Li
	[m]	[m]	[no.]			[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]
HFM01	0.00	200.20	4112	2002-05-07	Hydro. Test	175,7	63,3	0,73	-	5,5	0,011
HFM01	0.00	200.20	4113	2002-05-14	Hydro. Test	24,72	5,62		-	3,8	0,006
HFM01	0.00	200.20	4114	2002-05-14	Hydro. Test	195,93	72,2	2,0	-	5,8	0,014
HFM01	71.00	200.20	4115	2002-05-16	Hydro. Test	43,69	15,2	-0,2	-	6,9	0,009
HFM01	0.00	71.00	4116	2002-05-16	Hydro. Test	201,81	75,5	1,62	-	5,8	0,015
HFM01	0.00	200.20	4172	2002-06-25	Flush water test	220,09	76,9	2,49	2,15	6,2	0,016
HFM01	0.00	200.20	4293	2002-09-04	after C-filter	230,11	80,9	3,63	2,05	5,8	0,024
HFM01	0.00	200.20	4294	2002-09-04	before C-filter	227,74	83,0	3,69	2,13	6	0,019
HFM01	0.00	200.20	4312	2002-10-02	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4314	2002-10-02	after C-filter	211	-	3,89	-	-	-
HFM01	0.00	200.20	4346	2002-10-03	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4347	2002-10-03	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4348	2002-10-03	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4349	2002-10-03	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4363	2002-11-11	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4364	2002-11-11	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4366	2002-11-12	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4367	2002-11-12	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4368	2002-11-13	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4369	2002-11-13	after C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4370	2002-11-14	before C-filter	-	-	-	-	-	-
HFM01	0.00	200.20	4371	2002-11-14	after C-filter	-	-	-	-	-	-

Idcode	Secup	Seclow	Sample	Date	Type of sample	Sr	pH	ElCond	TOC	DOC
	[m]	[m]	[no.]			[mg/L]		[mS/m]	[mg/L]	[mg/L]
HFM01	0.00	200.20	4112	2002-05-07	Hydro. Test	0,130	-	208	11,6	-
HFM01	0.00	200.20	4113	2002-05-14	Hydro. Test	0,140	-	-	12,7	-
HFM01	0.00	200.20	4114	2002-05-14	Hydro. Test	0,300	8,2	268	10,0	-
HFM01	71.00	200.20	4115	2002-05-16	Hydro. Test	0,140	8,5	86,1	10,9	-
HFM01	0.00	71.00	4116	2002-05-16	Hydro. Test	0,330	8,4	289	10,4	-
HFM01	0.00	200.20	4172	2002-06-25	Flush water test	0,430	8,1	320	-	-
HFM01	0.00	200.20	4293	2002-09-04	after C-filter	0,870	-	-	7,9	6,2
HFM01	0.00	200.20	4294	2002-09-04	before C-filter	0,910	-	-	9,5	8,3
HFM01	0.00	200.20	4312	2002-10-02	before C-filter	-	-	-	7,6	7,4
HFM01	0.00	200.20	4314	2002-10-02	after C-filter	-	-	-	7,1	7,0
HFM01	0.00	200.20	4346	2002-10-03	before C-filter	-	-	-	7,8	7,9
HFM01	0.00	200.20	4347	2002-10-03	after C-filter	-	-	-	6,9	8,0
HFM01	0.00	200.20	4348	2002-10-03	before C-filter	-	-	-	7,8	7,6
HFM01	0.00	200.20	4349	2002-10-03	after C-filter	-	-	-	6,9	6,9
HFM01	0.00	200.20	4363	2002-11-11	before C-filter	-	-	-	8,3	-
HFM01	0.00	200.20	4364	2002-11-11	after C-filter	-	-	-	1,0	-
HFM01	0.00	200.20	4366	2002-11-12	before C-filter	-	-	-	5,4	-
HFM01	0.00	200.20	4367	2002-11-12	after C-filter	-	-	-	2,0	-
HFM01	0.00	200.20	4368	2002-11-13	before C-filter	-	-	-	4,0	-
HFM01	0.00	200.20	4369	2002-11-13	after C-filter	-	-	-	2,4	-

-= Not analysed
x= No result due to sampling problems
xx = No result due to analytical problems
-“value” = result less than detection limit

Isotopes I (H-, O-, B-, S-, Cl- and C-isotopes) Compilation April 2003

Idcode	Secup	Seclow	Sample	Date	D	Tr	O-18	$^{10}B/^{11}B$	S-34
	m	m	no		dev SMOW	TU	Dev SMOW	no unit	dev CDT
HFM01	0.00	71.00	4116	2002-05-16	-64,2	3,7	-9,5	_	_
HFM01	0.00	200.20	4172	2002-06-25	-64,6	3,3	-9,4	_	_

Idcode	Secup	Seclow	Sample	Date	Cl-37	C-13	$^{87}Sr/^{86}Sr$	C-14	AGE_BP
	m	m	no		dev SMOC	dev PDB	no unit	pmc	years
HFM01	0.00	71.00	4116	2002-05-16	0,19	-10,2	_	46,3	6135
HFM01	0.00	200.20	4172	2002-06-25	0,14	-10,2	_	45,2	6325

-= Not analysed
A= results will be reported later
x= No results due to sampling problems
xx = No results due to analytical problems SICADA: h_o_isotopes, b_s_cl_sr_isotopes, c_s_isotopes 020501-030301