P-03-52

Forsmark site investigation

Drilling of the telescopic borehole KFM02A at drilling site DS2

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June 2004

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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 metres 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 second deep borehole drilled by applying this technique are presented in this report. The borehole, which was drilled during the period November 2002 to March 2003 and is denominated KFM02A, is 1002.44 m long and subvertical (inclined 85.39° from the horizon). KFM02A 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 80 m, interpreted as a sub-horizontal fracture zone. This zone was heavily water-yielding, and an inflow of 600 L/min was measured. 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 in section 100.42-1002.44 m, 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 and adjacent formation of flushing water and drilling debris during drilling. Because high-conductive fractures were encountered at depth, probably both drill cuttings and flushing water have been forced into the formation, mainly in the upper half of 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. 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), constituted the most important part of the working material used for borehole mapping (so called Boremap mapping) performed after drilling. Also results of the Boremap mapping are included in this report.

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

One experience from drilling of KFM02A is that work is made much easier during winter conditions when using a tent as a weather protection for the drilling equipment and water supply system. The fact is, that the working conditions were even better than during summer drilling without the tent. Like during drilling of borehole KFM01A, the quartz-rich bedrock proved to be hard to drill, leading to rapid wearing of drill bits, except in section 250-300 m, where drilling progressed more rapidly due to the porous character of the

bedrock in that specific interval. Other lasting impressions from the drilling are the water-yielding sub-horizontal fracture zones encountered in the shallow part of the bedrock, a major, probably flat-dipping fracture zone between c. 410-530 m and the, on the other hand, very low fracture frequency and low water-yielding capacity of the deeper part of the core drilled section of KFM02A.

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 andra djupborrhålet i Forsmark som har utförts med denna teknik redovisas i denna rapport. Borrhålet, som benämns KFM02A och borrades under perioden november 2002 till mars 2003, är 1002.44 m långt och nästan vertikalt (lutar 85.39° från horisontalplanet). KFM02A 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 80 m, vilket tolkades som en flack sprickzon. Zonen hade en betydande vattenkapacitet och ett inflöde på 600 L/min uppmättes. 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 100.42-1002.44 m användes ett relativt komplicerat spol- och returvattensystem, där spolvattnet preparerades i olika steg före användning. Returvattnet leddes till ett system av containrar, så att borrkaxet kunde sedimentera i tre steg innan vattnet 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 och den närmast omgivande formationen utsattes för. Eftersom högkonduktiva sprickzoner påträffades på större djup, har troligen både borrkax och spolvatten trängt ut i formationen i huvudsak i den övre halvan av 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 borrkax från den hammarborrade delen, tillsammans med videofilm av borrhålsväggen (s.k. BIPS-bilder), den viktigaste delen av underlagsmaterialet för den borrhålskartering (s.k. Boremap-kartering) som utförs efter borrning. Även resultat från Boremap-karteringen av KFM02A finns redovisade 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 KFM02A är att inbyggnad av borrplatsen och borrutrustningen i ett tält samt användande av isolerade vattenledningar medför att borrning kan utföras vintertid utan problem. Det är till och med så att arbetena har fungerat bättre än under sommarborrning. Liksom vid borrningen av KFM01A medförde den kvartsrika

berggrunden generellt högt borrkroneslitage, förutom i en sektion med porös granit mellan 250-300 m, där borrningen gick lättare. Andra bestående intryck är dels de flacka, delvis sprickiga och kraftigt vattenförande zoner som påträffades i de grundare delarna av borrhålet, en betydande, sannolikt flackt stupande sprickzon, mellan ca 410 och 530 m samt den mycket låga sprickfrekvensen och vattenföringen i borrhålets djupare delar.

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, drilling of three sub-vertical and two inclined, approximately 1000 m long, cored boreholes has been terminated, whereas one inclined borehole is underway. The locations of the six drilling sites in question, DS1, DS2, DS3, DS4, DS5 and DS6, are illustrated in Figure 1-1.

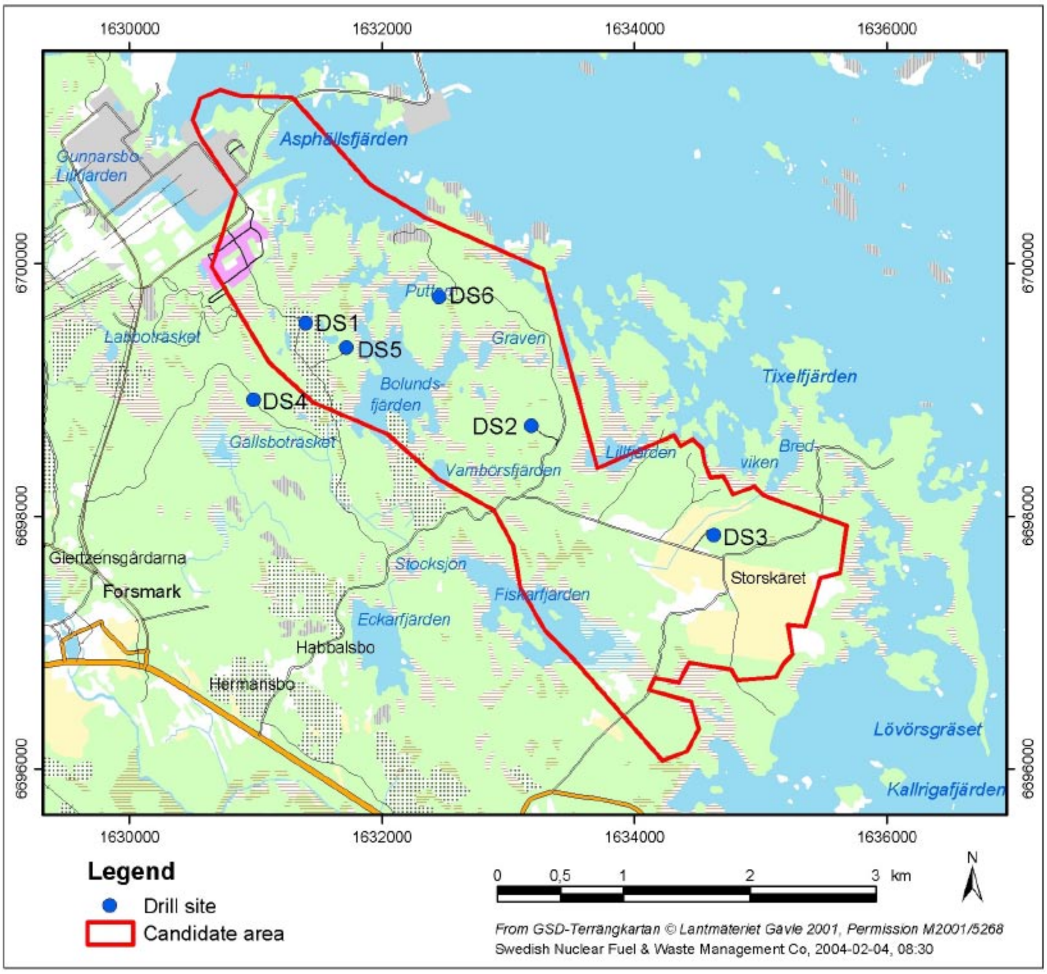


Figure 1-1. *The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drilling sites DS1-6 are marked with blue dots.*

By drilling the deep boreholes, so called telescopic drilling technique is applied, entailing that the upper 100 metres of the borehole are 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, KFM02A (located at drilling site DS2), with a total drilling length of 1002.44 m (approximately equal to the vertical depth, as the borehole is near-vertical). Besides, borehole KFM02A is of so called SKB chemical type, implying that the borehole is prioritized for hydrochemical 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, KFM02B, may later be core drilled all the way from the rock surface.

Close to the deep borehole at drilling site DS2, 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 DS2 are shown in Figure 1-2.

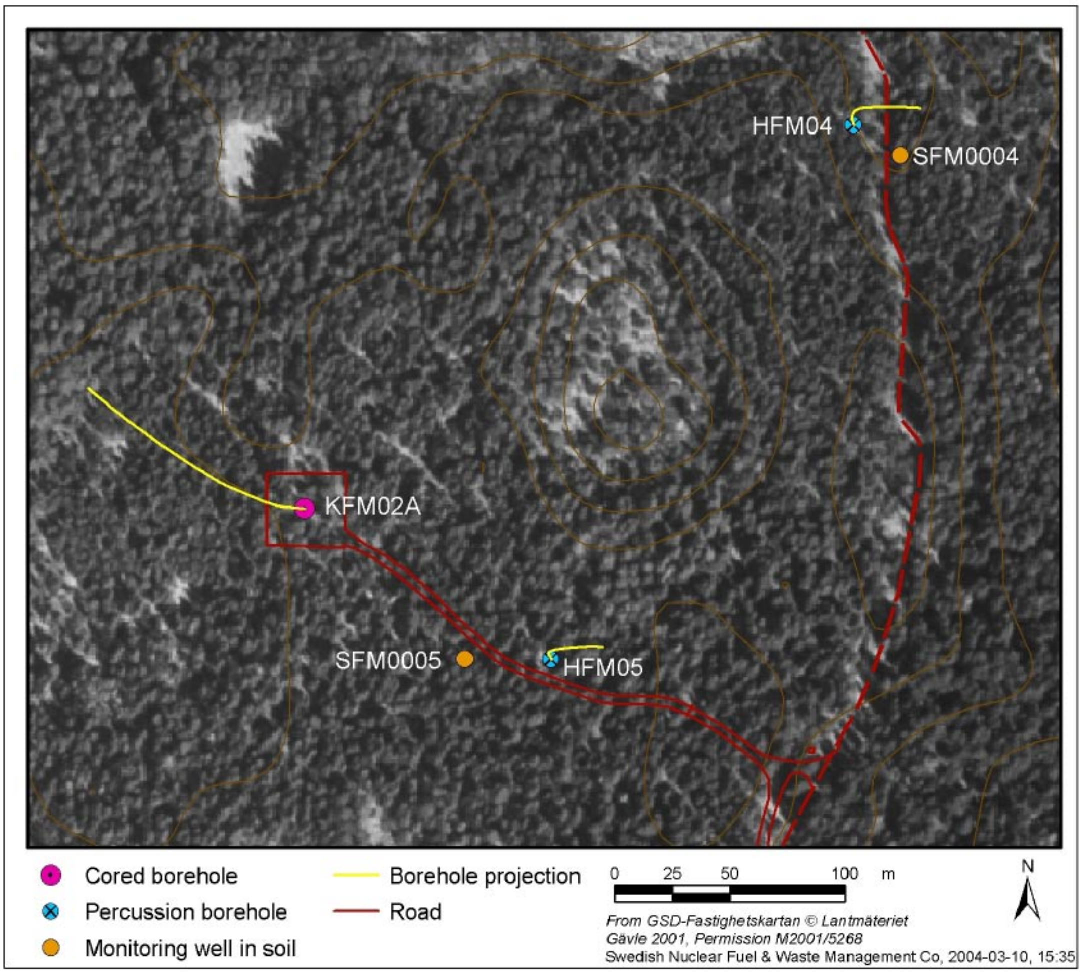


Figure 1-2. *Borehole locations at drilling site DS2. Besides the telescopic borehole KFM02A, the drilling site incorporates a flushing water well (HFM05), one monitoring well in solid rock (HFM04), and two monitoring wells in the unconsolidated overburden (SFM0004-05). The projection of inclined boreholes on the horizontal plane at top of casing is shown in the figure.*

Drilling site DS2 is located in the central part of the candidate area, c. 3 km from the Forsmark power facilities. The area is covered by forest and the surroundings are 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).

In the present report, performance of and results from drilling and investigations made during and immediately after drilling of the telescopic borehole KFM02A at drilling site DS2 are presented.

Results from drilling of the flushing water well HFM05 and the monitoring well in hard rock, HFM04, have been reported separately /3/. So have the results from drilling of the two monitoring wells in regolith, SFM0004-05, /4/. Results from geological mapping of borehole KFM02A (so called Boremap mapping) are treated in /5/.

Drilling of borehole KFM02A was performed between November 2002 to March 2003 in compliance with Activity Plan AP PF 400-02-42, 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 metres, whereas core drilling of the remaining part (section 100.42-1002.44 m) was carried out with a wireline core drilling system.

Prior to drilling, a large number of preparative measures were taken at the drilling site. For example, the ground surface was excavated and the bedrock cleaned for detailed fracture mapping (Figure 1-3). The exposed rock surface was then covered with a layer of coarse, draining gravel, which was levelled off so that a convenient working space was created.

Figure 1-3. *Overburden was removed and the bedrock cleaned at drilling site DS2.*

A cement slab, about 7 x 5 m in size and having an approximately 5 cm high bund along its perimeter, was cast around the planned borehole collaring point (Figure 1-4). The slab serves as a firm platform for anchorage of the drilling machine while drilling, and also provides a protection against any leaks of environmentally hazardous liquids, such as oil.

Plenty of accessory equipment was installed at the drilling site. A cable trench for electrical power and data communication was excavated along the forestry road leading up to the drilling site. After cable installations, the trenches were re-filled.

After completed preparations of the drilling site, the percussion drilling equipment was mobilized for drilling of section 0-100 m.

Because drilling was carried out during the winter season, a tent was put up after demobilization of the percussion drilling equipment but prior to core drilling. The tent was large enough to cover all core drilling and accessory equipment, see Figure 1-5. Electrical heaters were used to keep the temperature above zero, thereby protecting the water system and other sensitive equipment from freezing. In addition, the working environment was improved.

Figure 1-4. *The mapped outcrop was filled with gravel and a 7 x 5 m cement slab was cast around the planned collaring point of the borehole.*

Figure 1-5. *Drilling site DS2 at Forsmark. To protect the water system and other sensitive equipment from freezing, a tent with electrical heaters was used to keep the temperature above zero. Another advantage with the tent was improvement of the working environment.*

2 Objective and scope

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

- To provide rock and soil (if any) 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 KFM02A, a shorter, supplementary borehole, KFM02B, may later be drilled close to KFM02A. The rock samples collected during drilling are used for a lithological, structural and rock mechanical characterization as well as for determination of the retention and other transport properties of the bedrock from the rock surface to the full drilling depth.
- To render geophysical borehole investigations possible, e.g. TV logging, borehole radar logging and conventional geophysical logging as an aid for the geological/rock mechanical characterization.
- To allow hydraulic borehole tests (single hole tests as well as interference tests, in some cases performed as tracer tests) for characterization of the hydrogeological conditions 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 during and after drilling are transferred to SICADA (Figure 2-1), may be used as supplementary data for geological and hydraulic characterization.

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, (WL-probe) is utilized.

Figure 2-1. During drilling, a number of drilling related parameters are collected by a drilling monitoring system. Part of these data sets, in this report called DMS-data (Drilling Monitoring System), are transferred to the SKB database SICADA.

3 Equipment and basic technical functions

Two types of drilling machines were used. The upper c. 100 metres were drilled with a percussion drilling machine of type Puntel MX 1000 (Figure 3-1). For core drilling of section 100.42-1002.44 m, a Wireline-76 core drilling system, type Onram 2000 CCD 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 MX 1000 drilling machine in operation at KFM02A.*

At drilling site DS2, the bedrock was covered by approximately one metre of sandy-silty till with some boulder content. However, this till layer was removed and replaced by a layer of gravel (see Chapter 1). 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 KFM02A are presented in Section 5.2.

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 from reaching the deeper parts of the bedrock. This is achieved by cement grouting of 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. Gap injection can be performed according to different techniques. Two variants are illustrated in Figure 3-3.

Borehole KFM02A 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.

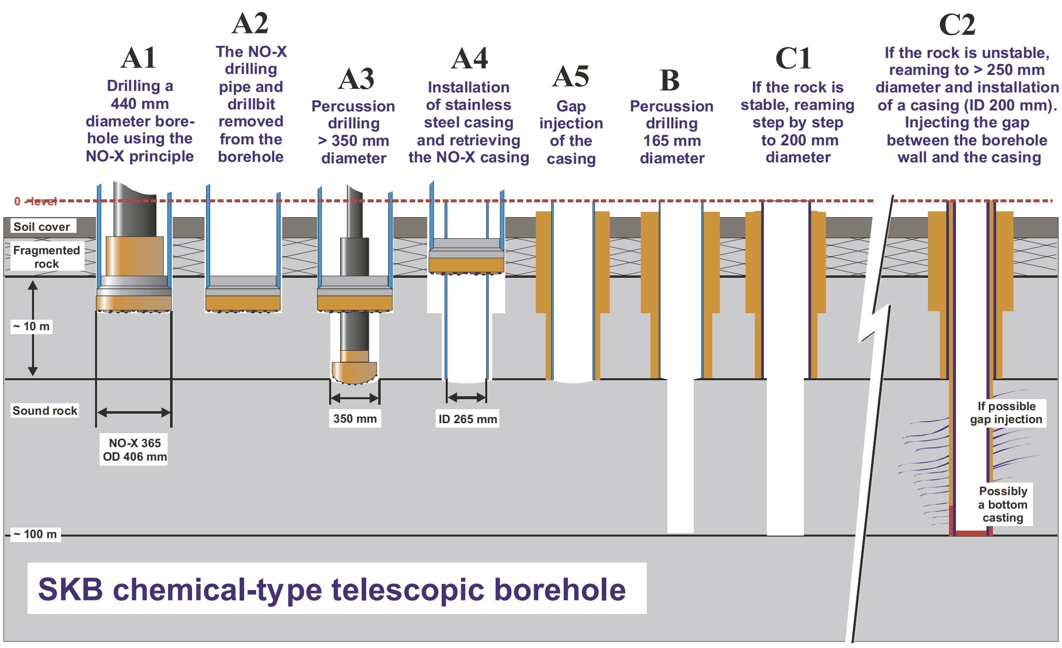


Figure 3-2. Schematic diagram showing the various stages of drilling the 0-100 m section of an SKB chemical-type telescopic borehole. The letters and numerals above each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB MD 620.003.

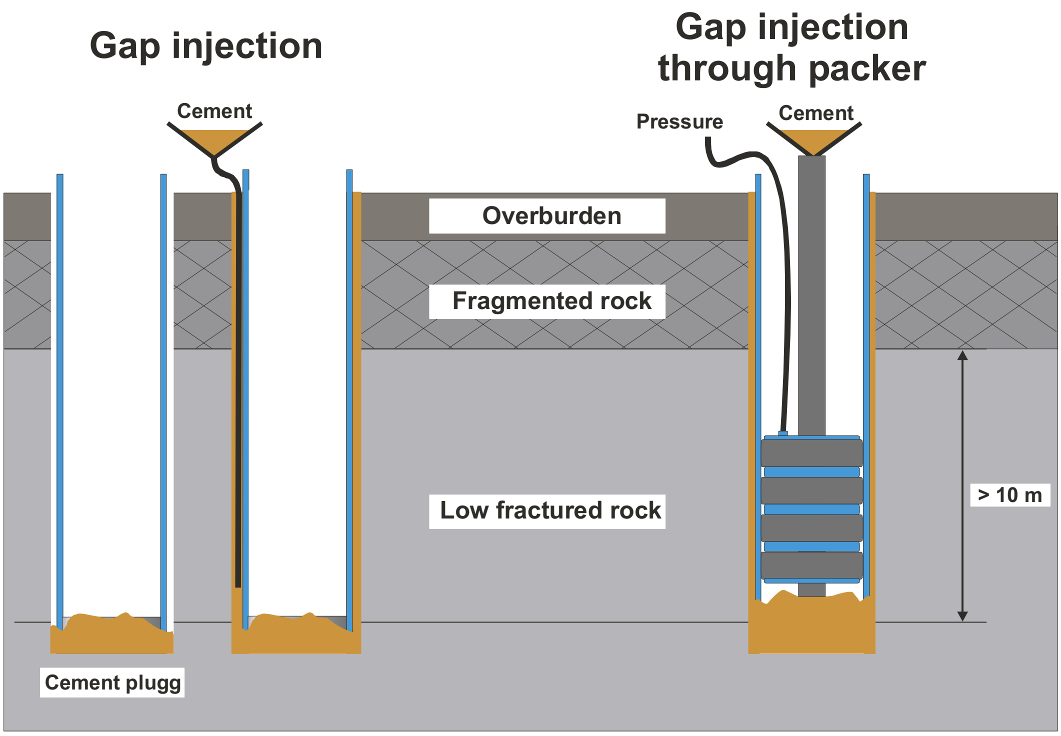


Figure 3-3. *Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer.*

3.3 Core drilling equipment

3.3.1 The wireline-76 system

For drilling the cored part of borehole KFM02A, 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 metres. The drilling pipes and core barrel used belong to the Hagby WL76 triple-tube system. Technical specifications of the drilling machine with accessories are given in Table 3-1.

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

Unit	Manufacturer/Type	Specifications	Remarks
Onram 2000	Hagby-Asahi	Capacity for 76 mm holes maximum approx. 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, which is conducted through the borehole tubing and the drill bit and further 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 3-4. The system includes equipment for pumping, transport and storage of water. The flushing/return water system may be divided into:

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

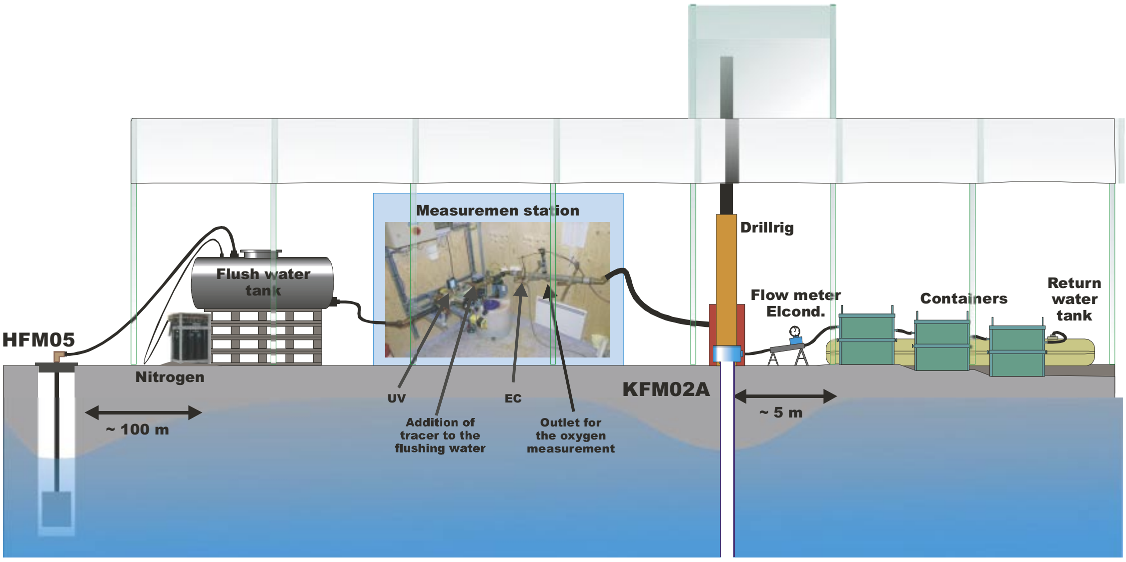


Figure 3-4. Schematic illustration of the flushing/return water system when drilling KFM02A at DS2. The measurement station included the gauges and logger units for measurements of EC (electrical conductivity) and dissolved oxygen in the flushing water, the dosing feeder for labelling the flushing with a tracer, and the UV-radiation unit. For flushing water flow rate and pressure measurements, the drilling machine gauges were used.

Preparation of the flushing water

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

The water well used for supply of flushing water was a percussion drilled well in hard rock, HFM05 (see Figure 1-2), situated approximately 100 m from KFM02A. 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 sufficiently good to serve as flushing water.

Besides these basic demands on the flushing water quality, 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 entered the 5 m^3 water tank illustrated in Figure 3-4. Nitrogen was bubbled through the water in the tank in order to expel oxygen which might be dissolved in the water. 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 further to the measurement station.
2) In the measurement station, the water from the tank was exposed to UV-radiation, whereby the microbe content in the water was radically reduced.
3) An organic tracer dye, Uranine, was added to the flushing water with a dosing feeder at a concentration of 0.2 mg/L before the water was pumped into the borehole, see Figure 3-4. Labelling the flushing water with the tracer aims at enabling detection of the flushing water content in groundwater samples collected in the borehole during or after drilling.

Measurement of flushing water parameters

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

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

The measurement gauges for the two latter parameters were placed in the measurement station, whereas gauges integrated with the drilling equipment were used for the measurements of flushing water flow rate and pressure.

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

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

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

Instrument	Manufacturer/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		

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, thereby producing the airlift pumping effect. The resulting pressure drop entails transport of much of the mixture of water and drill cuttings from the bottom of the hole up to the surface, see Figure 3-5. The resulting return water is a mixture of flushing water, groundwater from 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 KFM02A consisted of the following main components, see Figure 3-5:

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

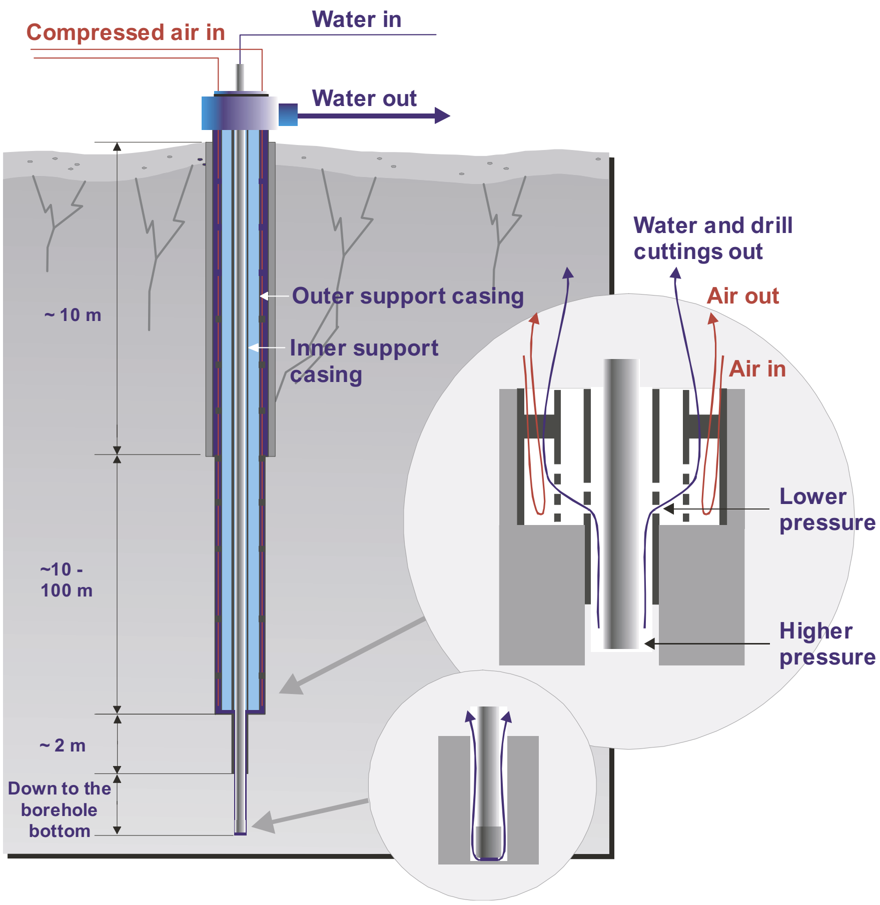


Figure 3-5. *Airlift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air- and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole.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

When installing the outer support casing and hoses, they were lowered into the borehole with a mobile crane. The ejector tube was fit to the outer support casing, about 200 mm above the bottom of the telescopic borehole. A 22 mm supply hose and a 28 mm return hose were connected to the ejector tube as shown in Figure 3-6. With this construction, the air leaving the ejector rises, reducing the pressure in the lower part of the ejector tube, helping to lift drill cuttings from the bottom of the hole.

Storage and discharge of return water

At the surface level, the return hose was connected to a return pipe between the discharge head and the first return water container, see Figures 3-4 and 3-7. 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 an elastic water tank with an expansive capacity of up to 40 m^3.

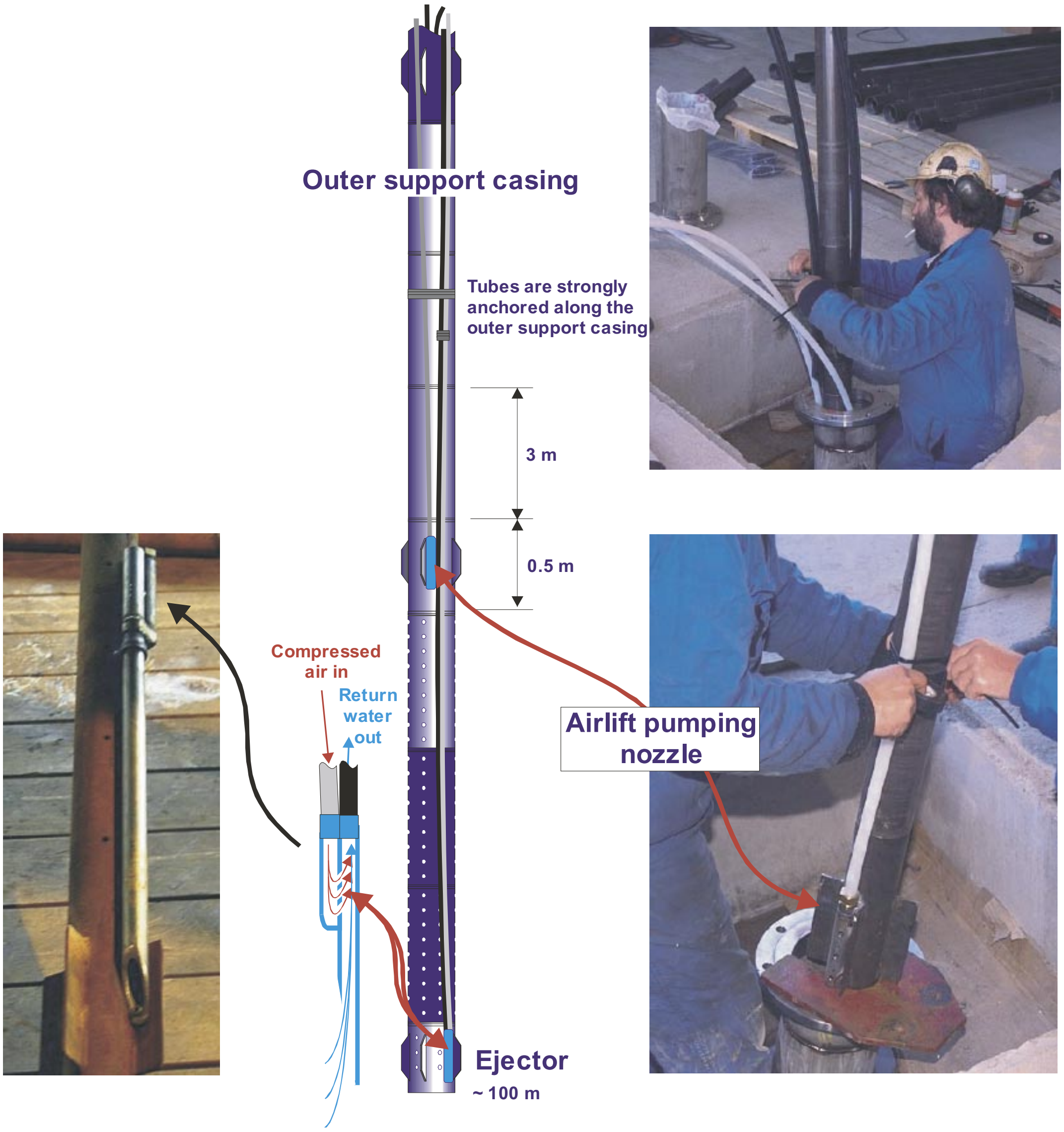


__Figure 3-6.__ Schematic representation of connection and installation of airlift pumping nozzle and ejector on the outer protective casing.

The flow rate and electrical conductivity of the return water were measured (see Figure 3-4) and data stored in the data-logging system. Technical specifications of the measurements 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.

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

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

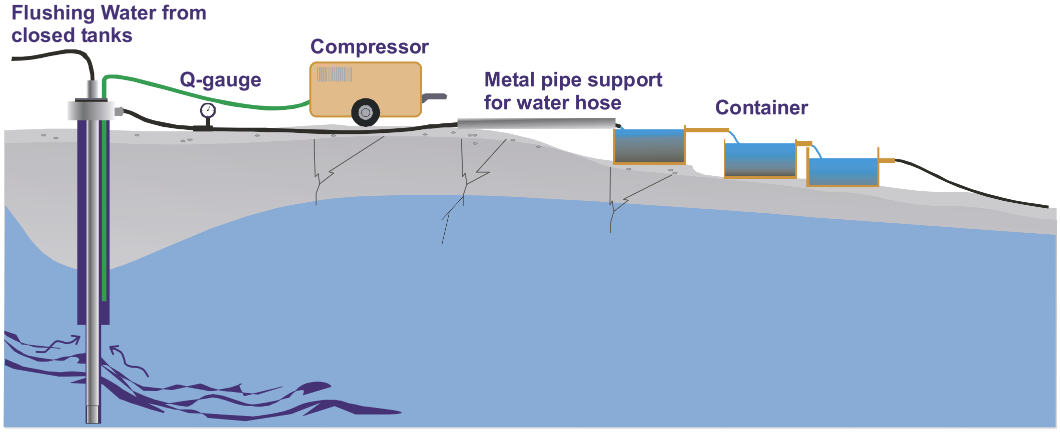


Figure 3-7. Return water system. Airlift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in three stages in the containers (where it is preserved for later weighing), after which the water can be pumped to the recipient.

3.3.3 Drilling monitoring system

The ONRAM 2000-CCD drilling machine is supplied with a computer based logging system integrated in the steering system (cf. Section 3.3.1). 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
- water pressure
- water flow.

However, during drilling of borehole KFM02A, the registration was extended to include also the following flushing water parameters:

- electric conductivity
- dissolved oxygen
- flow rate

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 KFM02A, deviation measurements were made at two 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 400-02-42, 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, and transport of drilling equipment, sampling pots for soil and drill cuttings, hand tools and other necessary outfit to the site. 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 (Figure 4-1) and final function control.

4.1.3 Drilling, measurements and sampling during drilling

The percussion drilling started with drilling through the overburden while 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 11.80 m and the casing material used was SS2333 stainless steel.

Figure 4-1. *Lining up the drilling machine was made with the help of a theodolite.*

The continued percussion drilling through solid rock was performed with a 164 mm drill bit to 100.42 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 around 80 m, which also showed a high water yielding capacity, about 600 L/min.

For stabilization of the entire percussion drilled part, the borehole was reamed to Ø 251 mm with a special reamer bit to 100.35 m drilling length (i.e. 0.07 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 rough hydraulic capacity test of the percussion drilled part of the borehole, since the recovery of the groundwater table was registered after the compressor had been turned off. The results were used on-site, i.a. for preparation of the gap injection of the casing.

In order to prevent leakage of water from the heavily water-yielding fractures penetrated by the borehole, via the gap between the borehole wall and the casing, the gap was grouted using the packer technique illustrated in Figure 3-3. After grouting, the recharge of water into the borehole ceased completely.

Measurements and sampling while percussion drilling (and immediately after drilling) were performed according to a specific measurement/sampling programme. Concerning the section below the casing through the overburden down to 100.42 m, the measurements and sampling during and immediately after drilling were carried out in association with the Ø 164 mm drilling sequence and in accordance with SKB MD 610.003 (Method Description for percussion drilling). The programme included:

1) Sampling of drill cuttings at every third metre. Each sample consisted of three individual samples collected one per metre. The samples were stored in a plastic bottle marked with a sample number. Ocular inspection and a preliminary description of the mineral content was made on-site as a basis for classification of the rock type.

2) Manual measurement of the penetration rate at every 20 cm.

3) Observation of the flow rate (if any) at every 20 cm. When a significant increase of the flow rate was noticed, it was measured using a graduated vessel and a stop-watch.

4) Observation of the water colour at every 20 cm.

5) Measurement of the electric conductivity of the groundwater at every three metres.

Analyses of drill cuttings from the soil layer respectively from the section of solid rock were performed as separate activities. The results of the analyses of the cuttings from the soil layer are integrated with the results from the mapping of Quaternary deposits /6/, whereas the analyses of cuttings from solid rock are 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 251 mm. The borehole was secured with a lockable stainless steel flange. The drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

4.1.5 Nonconformities

The percussion drilling of borehole section 0-100.42 m in KFM02A was performed according to programme, i.e. without deviations.

4.2 Core drilling

The performance of the core drilling followed Activity Plan AP PF 400-02-42, 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
- mobilisation, including lining up the machine and measuring the position
- drilling, measurements, and sampling during drilling
- finishing off work
- data handling
- environmental control.

The four first items are presented in Section 4.2, while the last two 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, and transport of drilling equipment, flushing water equipment, sampling boxes for drill cores, hand tools etc to the site. Furthermore, the mobilization consisted of cleaning 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 KFM02A was performed with two borehole dimensions. Section 100.42-101.00 m was drilled with a borehole diameter of 86.0 mm, whereas the main part of the borehole, section 101.00-1002.44 m, was drilled with Ø 77.3 mm. Reaming to a diameter of 86.0 mm between 101.00-102.00 m was made, whereafter the inner Ø 84/77 mm support casing was fitted into the 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.)

Core drilling 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 investigations of the retention and other transport properties of the rock and for the study of chemical characteristics of the pore water in the rock matrix.

Core drilling with a wireline system entails recovery of the core barrel via the drilling pipe string, inside which it is hoisted up with the wireline winch. During drilling of borehole KFM02A, a 3 m triple tube core barrel was used (Figure 4-2). The nominal core diameter for the Ø 77.3 mm part of the borehole is 50.8 mm. Minor deviations from this diameter may, however, occur.

Like the percussion drilling, 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 KFM02A 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 KFM02A.

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 3-4, in order to reveal if the content of microbes changed during transport through the vessels, pipes and hoses included in the system. The results of the study are presented in /7/.

Figure 4-2. *For core drilling of KFM02A a 3 m triple tube WL-76 system was used. With the technique applied, a high core quality was obtained. The system provides a borehole diameter of Ø 77.3, and the core diameter is 50.8 mm. To the right, a complete core barrel with drill bit and reamer. To the left, the inner tube with one half of the split tube.*

4.2.4 Finishing off work

The concluding work included the following items:

1) The borehole was flushed for about 10 hours during simultaneous airlift pumping, in order to clean it from drilling debris adhered to the borehole walls, settled at the bottom of the hole or suspended in the water. After finished flushing/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 drilling 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 4-3. The cone is located between 97.08-101.74 m. From May 10th, 2004, the transition cone was exchanged and is now located between 97.08-101.86 m.
7) The borehole was again secured with the lockable stainless steel flange.
8) The core drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

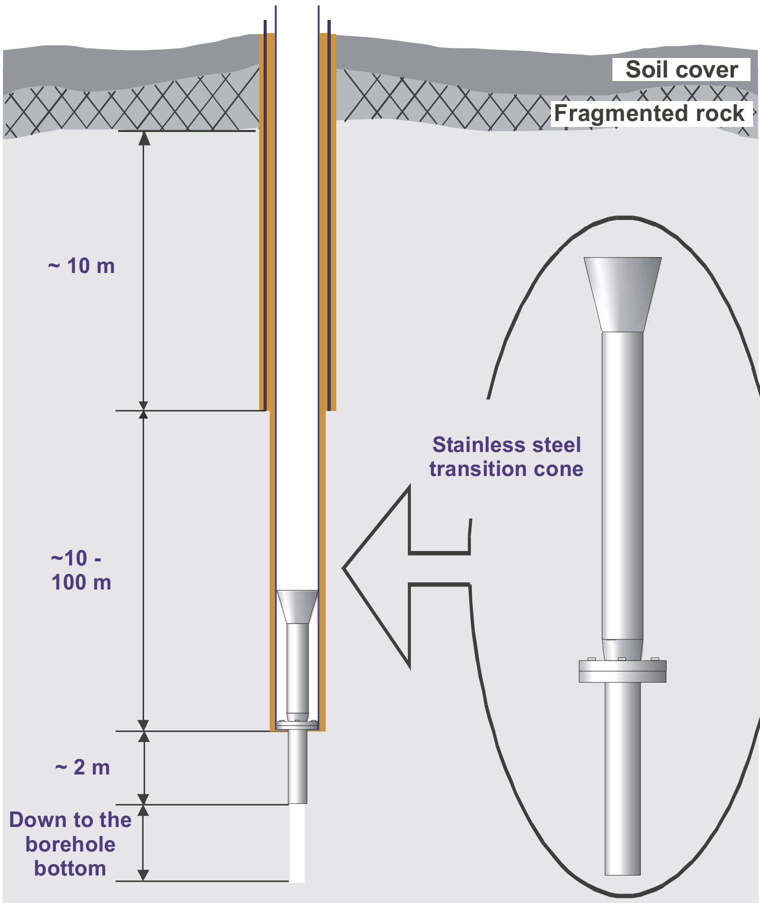


Figure 4-3. *Schematic illustration of the transition cone between the upper, wide section and the lower, slim part of a telescopic borehole. In KFM02A, the entire upper, percussion drilled part was cased.*

4.2.5 Nonconformities

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

Table 4-1. Programme for sampling, measurements, registrations and other activities during and immediately after core drilling according to SKB MD 620.003 and the actual performance during drilling of borehole KFM02A.

Activity	Performance and frequency according to SKB MD 620.003	Performance and frequency during drilling of KFM02A
Registration of drilling- and flushing water parameters.	Described in Section 3.3.2. Registration during the entire drilling.	Technical problems with oxygen transducer. No measurements performed.
Registration of the groundwater level in the borehole during drilling.	Every 10th second.	According to programme.
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	Two 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 5-15 are from material properties of the drilling pipe string.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drilling pipe string should be controlled before each test.	Two successful measurements performed, and one failed.
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drilling pipe string should be controlled before each test.	One successful measurement performed. Three failed 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.	Two estimations of absolute pressure made from the hydraulic test plots.
Groove milling in the borehole wall, normally at each 100 m.	Normally performed after completion of drilling.	All eighteen grooves performed.
Collecting and weighing of drilling debris.	Drilling debris settled in containers and weighed after finished drilling.	Not carried out for the percussion drilled part of the borehole. According to programme for the core drilled part.

The last item in Table 4-1 may be commented on. All drilling debris produced during drilling (percussion drilling as well as core drilling) was collected in the sedimentation containers of the return water system, see Figures 3-4 and 3-7, except the finest fractions which stayed suspended in the discharge water from the third container. The collected drill cuttings from the core drilled part of the borehole were weighed after concluded drilling in order to give a measure of the drill cuttings recovery, whereas this was not undertaken for the percussion drilled part of the borehole. This was due to the extreme high water flow, which caused a relatively large and uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations.

4.3 Data handling

4.3.1 Performance

Minutes for several items with the following headlines were filled in by the field crew: Activities, Cleaning of the equipment, Drilling, Drillhole, Core drilling penetration rate, Deliverance of field material and Discrepancy report. The minutes were collected by the Activity Leader, who made a control of the information and had it stored in the SKB database SICADA /8/. 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 under Field Note No. Forsmark 55 /8/. An overview of the drilling progress of borehole KFM02A 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 KFM02A are shown in Appendix A (percussion drilled part) and Appendix B (the complete drilled borehole). The Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling.

5.1 Drilling progress

Borehole KFM02A was drilled during a period of approximately 4 months, including the Christmas holiday, see Figure 5-1. Since this was the second deep borehole drilled within the Forsmark site investigation programme, the technical constructions and working routines used had now been tested. Both the drill crew and the support organization were trimmed after termination of borehole KFM01A /9/. In addition, the working environment was favourable because the drill rig with water supply system was weather protected by a tent, resulting in more effective drilling and, hence, shorter drilling performance.

5.1.1 Percussion drilling period

Percussion drilling is normally a swift drilling method. However, the relatively complex approach applied for the drilling and grouting sequences when drilling KFM02A, including a relatively long break for a BIPS measurement, resulted in a rather long total working period.

The durations of the different operations included in the percussion drilling from 2002-11-20 to 2002-12-12 are presented in Figure 5-2.

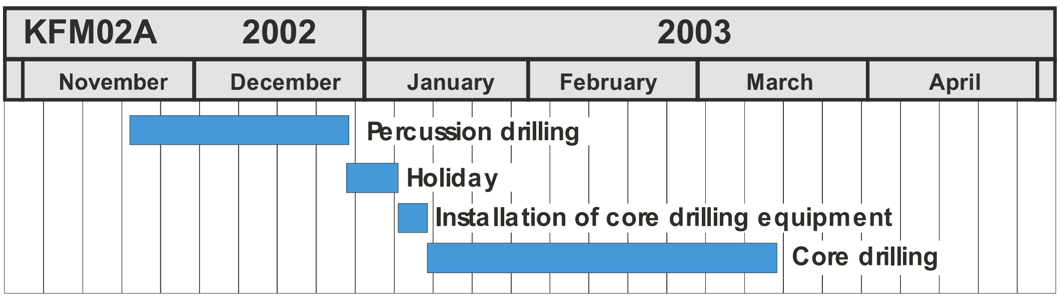


Figure 5-1. *Overview of the drilling performance of borehole KFM02A.*

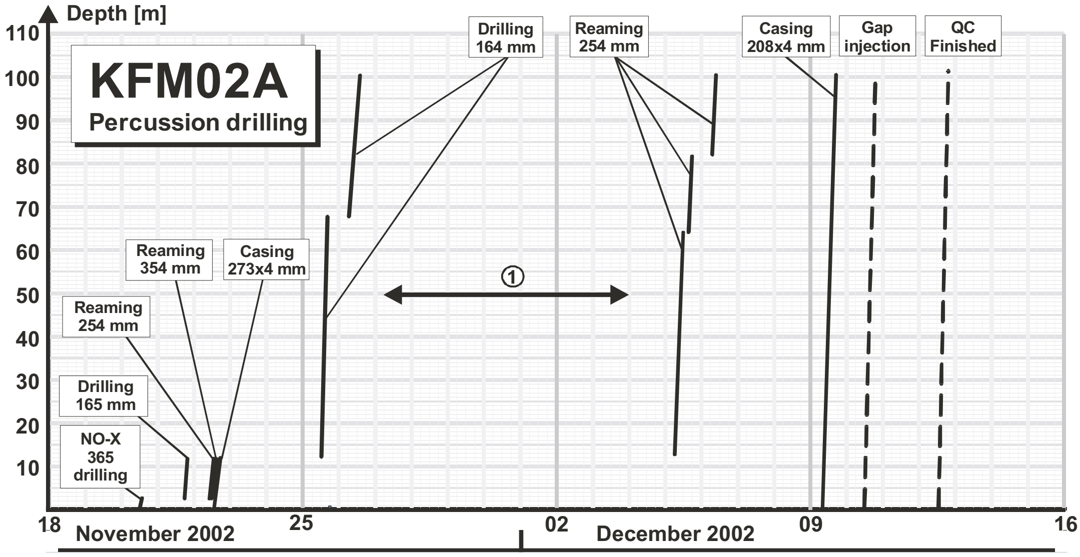


Figure 5-2. Percussion drilling progress (depth and activity versus calendar time). *① represents BIPS measurement.*

5.1.2 Core drilling period

After percussion drilling of section 0-100.42 m and following the Christmas holiday, core drilling commenced. The progress of the core drilling from 2003-01-08 to 2003-03-12 is presented in Figure 5-3. 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.

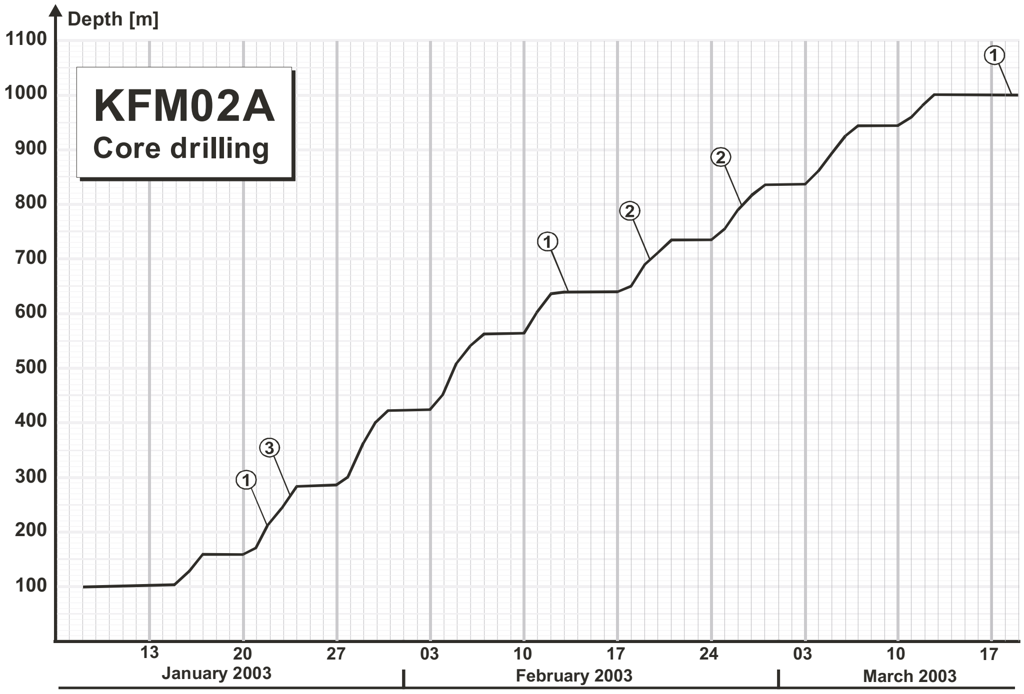


Figure 5-3. *Core drilling progress (depth versus calendar time). ① Deviation measurement (Maxibor), ② WL-test, ③ drilling through porous granite.*

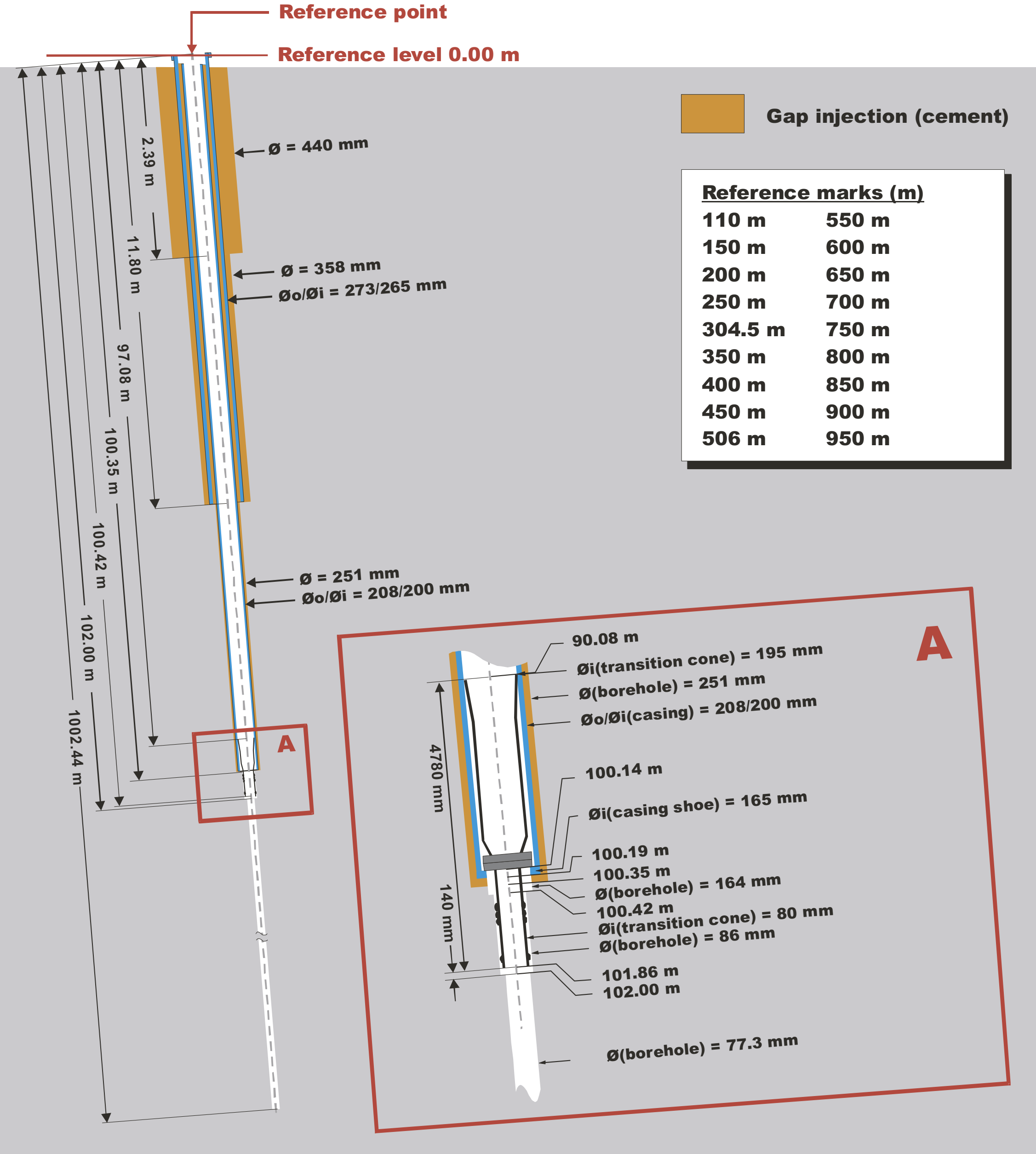
5.2 Geometrical and technical design of borehole KFM02A

Administrative, geometric and technical data for the telescopic borehole KFM02A are presented in Table 5-1. The technical design is illustrated in Figure 5-4.

Table 5-1. Administrative, geometric and technical data for borehole KFM02A.

Parameter	KFM02A
Borehole name	KFM02A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	November 20, 2002
Completion date	March 12, 2003
Percussion drilling period	2002-11-20 to 2002-12-12
Core drilling period	2003-01-08 to 2003-03-12
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 KFM02A at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6698712.50 E 1633182.86 Z 7.35 (m.a.s.l.) Azimuth (0-360°): 275.76° Dip (0-90°): -85.38°
Position KFM02A at bottom of hole (RT90 2.5 gon V 0:-15 / RHB 70)	N 6698764.56 E 1633089.36 Z –985.30 (m.a.s.l.) Azimuth (0-360°): 310.99° Dip (0-90°): -80.47°
Borehole length	1002.44 m
Borehole diameter and length	From 0.00 m to 2.39 m: 0.440 m From 2.39 m to 11.80 m: 0.358 m From 11.80 m to 100.35 m: 0.251 m From 100.35 m to 100.42 m: 0.164 m From 100.42 m to 102.00 m: 0.086 m From 102.00 m to 1002.44 m: 0.0773 m
Casing diameter and length	$Ø_o/Ø_i$ = 273 mm/265 mm to 11.80 m $Ø_o/Ø_i$ = 208 mm/200 mm between 0.00 and 100.14 m Casing shoe $Ø_i$ = 165 mm between 100.14 and 100.19 m
Transition cone inner diameter	At 97.08 m: 0.195 m Transition Cone exchanged 2004-05-10 New level at 101.86 m: 0.080 m
Drill core dimension	100.42-101.00 m / Ø 72 mm 101.00 –1002.44 m/ Ø 50.8 mm
Core interval	100.42-1002.44 m
Average length of core recovery	2.70 m
Number of runs	333
Diamond bits used	27
Average bit life	33.4 m

Technical data
Borehole KFM02A



Drilling reference point

Northing: 6698712.50 (m), RT90 2,5 gon V 0:-15

Easting: 1633182.86 (m), RT90 2,5 gon V 0:-15

Elevation: 7.35 (m), RHB 70

Borehole

Bearing: 275.76°

Inclination: -85.38°

Length: 1002.44 m

Percussion drilling period

Drilling start date: 2002-11-20

Drilling stop date: 2002-12-12

Core drilling period

Drilling start date: 2003-01-08

Drilling stop date: 2003-03-12

Figure 5-4. *Technical data of borehole KFM02A.*

5.3 Percussion drilling 0-100.42 m

5.3.1 Drilling

As mentioned in Section 4.1.3, the upper 11.80 m of the borehole was cased and cement grouted. During pilot drilling to 100.42 m, unstable bedrock was observed. The penetration rate suddenly decreased below 80 m, and was almost constant to 100.42 m, see Appendix A. When section 80-82 m had been penetrated, a water inflow of 600 L/min was measured. Therefore, the borehole section 0-100.35 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 KFM02A (also displayed in the Well Cad-presentation in Appendix A) are commented on. The analyses of drill cuttings from the percussion drilled part of KFM02A are presented in /5/ (rock) and /6/ (soil).

Borehole deviation

The end (bottom) point of the percussion borehole deviates approximately 0.1 m downwards and 1 m to the right compared to an imagined straight line following the dip and strike of the borehole collaring point (inclination –85.38º and bearing 275.76º).

5.4 Core drilling 100.42-1002.44 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. However, the upper part of the bedrock at DS2 is more fractured and also contains a section of porous granite. This was first noticed due to increased drilling speed and longer life-time of the drill bits in the upper half of the borehole compared to the conditions at greater depths. In average, the life-time was 33 drilled metres per drill bit in KFM02A compared to 27 m in KFM01A /9/. On the whole, core drilling in both KFM01A and KFM02A 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 5.4.2-5.4.11 below.

Mapping of the drill core samples from KFM02A 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 provide input to a trigger-unit, and a specific software controls the drilling operations. Additionally, the same data set is stored in a database, which constitutes 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 No. 55 /8/.

Drill bit position versus time

Figure 5-5 illustrates 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. Figure 5-5 serves as a basis for Figure 5-3, with which it should be compared.

Penetration rate

As borehole KFM02A was the second core drilled borehole within the scope of the Forsmark site investigation, the contractor was more experienced regarding selection of drill bits appropriate for drilling in the hard Forsmark bedrock, and the penetration rate was in average higher than in KFM01A /9/, see Figure 5-6. However, the penetration rate displays a decreasing trend versus drilling length, which probably is due to the increasing frictional resistance of the return water flow, which is conducted in the narrow gap between the borehole wall and the pipe string. This reduces the retrieval of drill cuttings and slows down the penetration rate, however not as much as in KFM01A, since the borehole diameter was increased from c. 76 mm in KFM01A to to 77.3 mm in KFM02A.

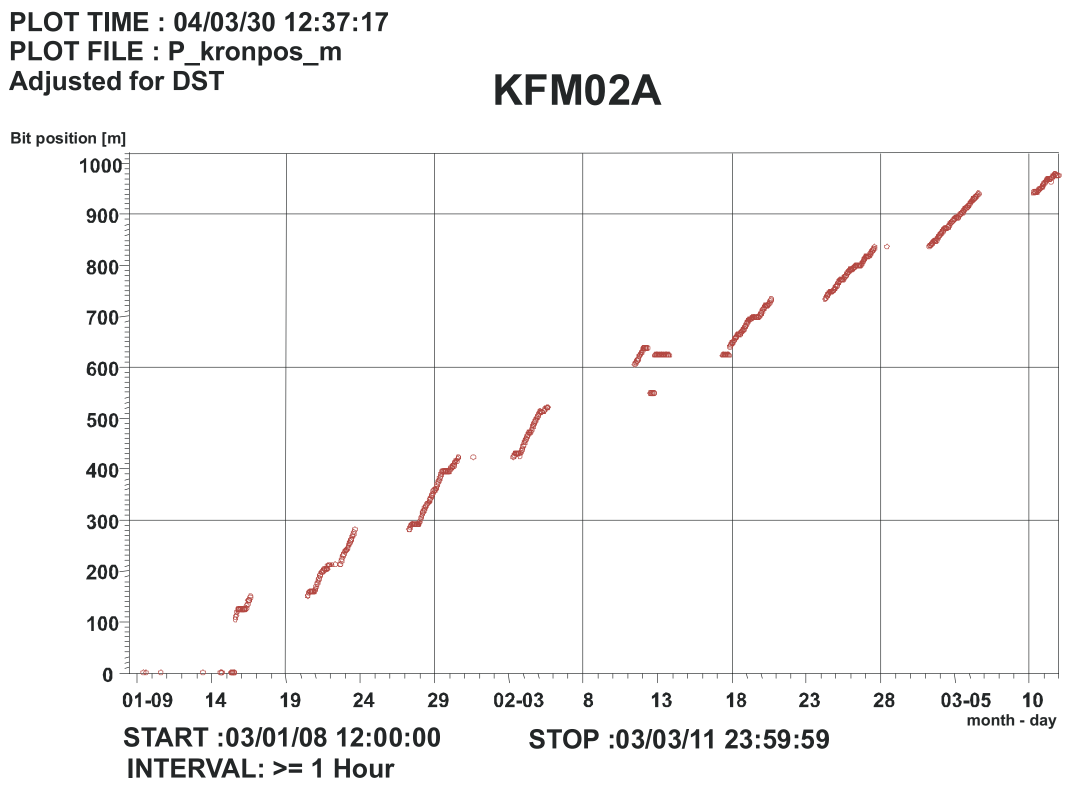


Figure 5-5. Drill bit position versus time.

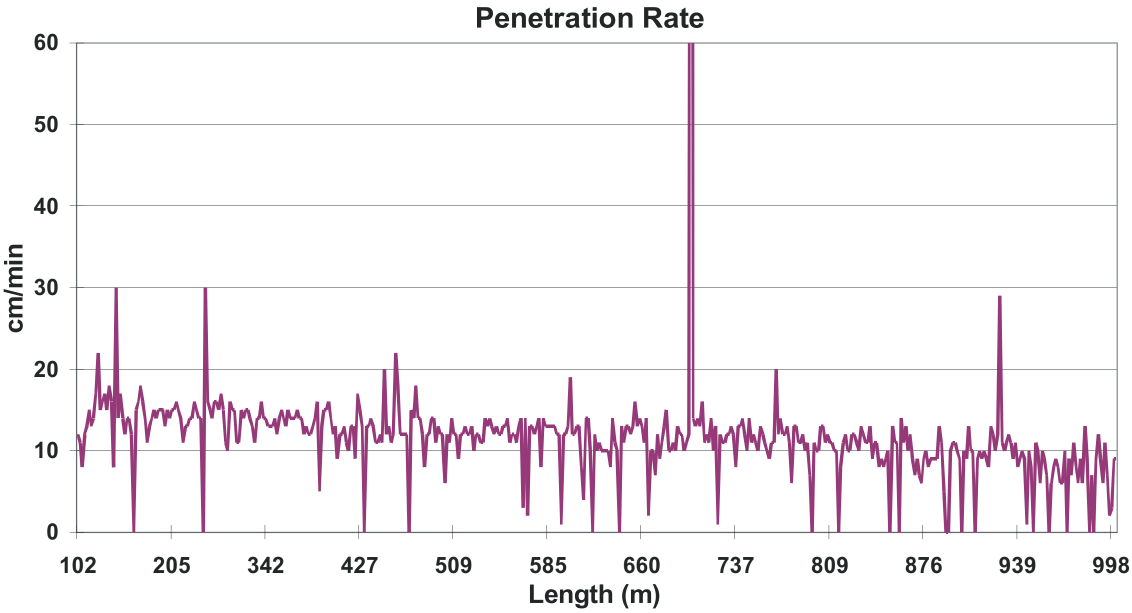


Figure 5-6. Penetration rate during core drilling of KFM02A.

Feed force

In Figure 5-7 the feed force is plotted versus borehole length. At the early stage of the drilling, the feed force varies considerably due to the efforts of the drilling crew to optimize different parameters, including feed force, in order to achieve as efficient drilling as possible. In section 250-300 m, the feed force decreases, which reflects drilling through the porous granite mentioned above. In section 300-470 m the force stabilizes, but decreases in section 470-540 m, which indicates drilling in more fractured and permeable bedrock. Later on, the force has a smooth rising trend, an effect of hard granite again being penetrated. Below c. 750 m to c. 940 m, the decreasing feed force trend coincides with a frequent occurrence of amphibolitic dikes and tonalitic bodies.

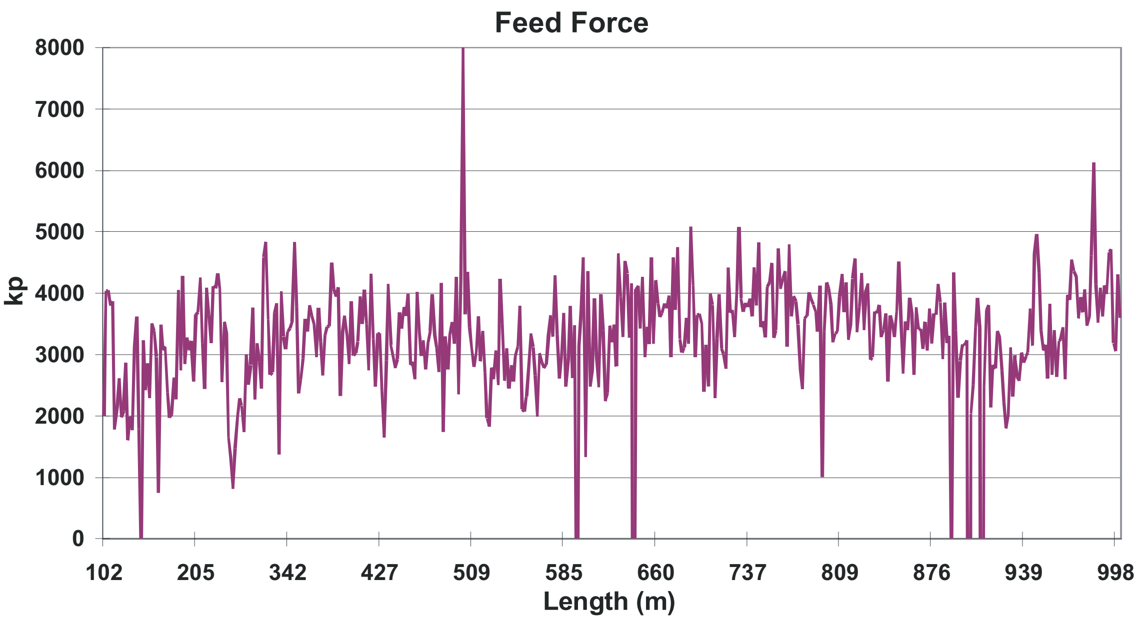


Figure 5-7. Feed force versus borehole length during drilling of borehole KFM02A.

From 940 m to end of borehole the feed force increases rapidly, which probably is a combined effect of hard rock being reached and increasing frictional resistance of the return water with suspended drilling debris. The latter demands successively augmented feed force to maintain a reasonably high penetration rate.

Rotation speed

From start, the rotation speed was about 800 rpm, see Figure 5-8, but was adjusted to c. 1000 rpm at 150 m drilling length. This rotation speed was then maintained almost constant during the remaining drilling. 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 KFM02A 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 meter placed in the measurement station, see Figure 3-4. The return water was measured by another flow meter mounted on-line with the discharge pipeline, see Figures 3-4 and 3-7.

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.

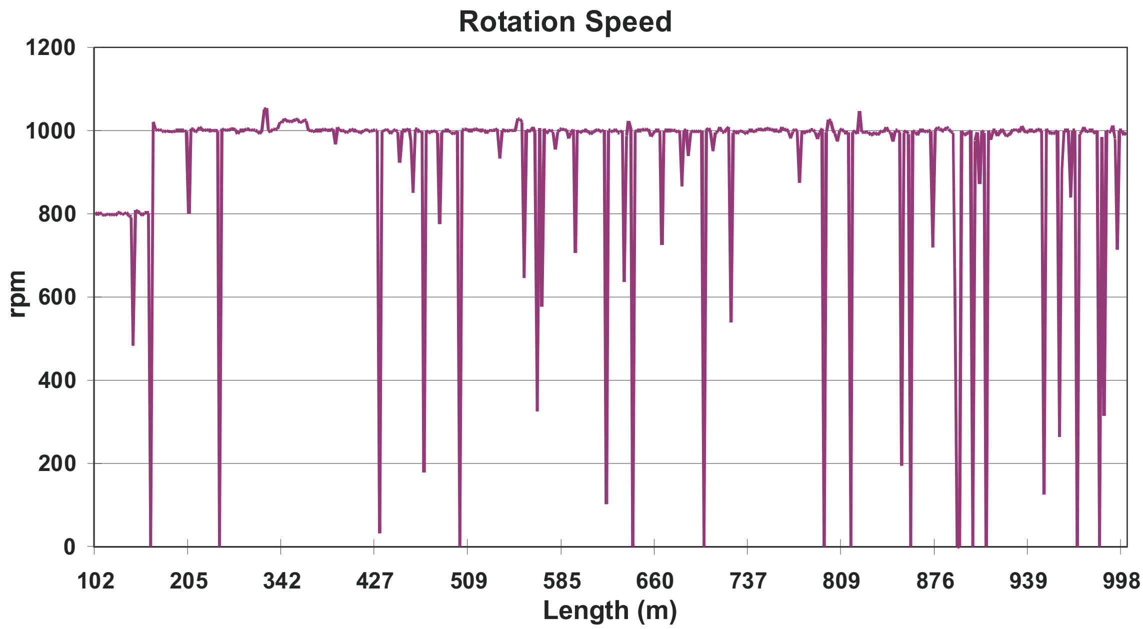


Figure 5-8. *Rotation speed versus borehole length during drilling of borehole KFM02A.*

Figure 5-9 illustrates the accumulated volume of flushing water and return water versus time during core drilling, while Figure 5-10 displays the accumulated volumes of flushing water and return water from the entire drilling period, giving a return water/flushing water quotient of 1.78. (results from Uranine measurements are presented in the next section).

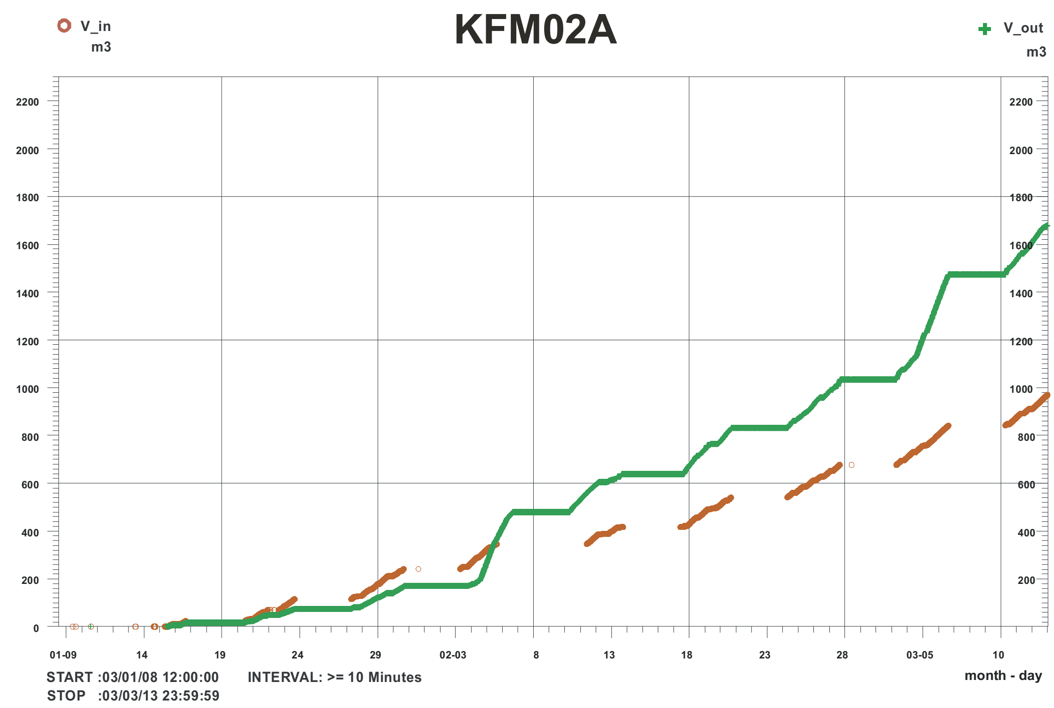


Figure 5-9. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM02A.*

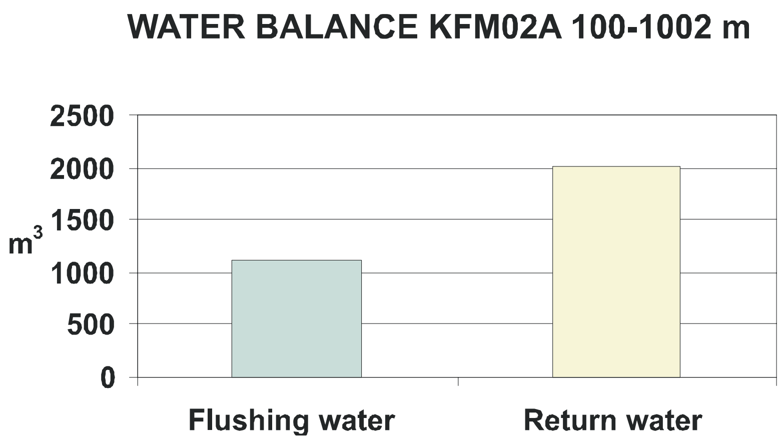


Figure 5-10. *The total volume of flushing water used during core drilling was 1128 m*^{3}*. During the same period, the total volume of return water was 2003 m*^{3}*. The return water/flushing water balance is then as high as 1.78, due to the large inflow of groundwater into the borehole.*

However, in Figure 5-9 a loss of flushing water at shallow depths in the borehole is observed, as well as a significant excess of return water at depths exceeding c. 350 m. This reflects the fact that when the drill bit position is close to water conductive fractures of the borehole, flushing water is forced into these fractures, because the flushing water pressure much exceeds that of the formation. When the drill bit has passed this section, the pressure gradient will eventually be reversed due to the air–lift pumping in the upper part of the borehole. Larger amounts of return water (groundwater and flushing water) is then extracted from the borehole than flushing water is supplied to it.

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. In the previously drilled borehole KFM01A, Uranine was added manually to the flushing water /9/. Prior to drilling of KFM02A, an automatic dosing feeder system was installed to fulfil this task. Figure 5-11 demonstrates that after some initial regulation problems, approximately correct concentration values (0.2 mg/L) are obtained. However, technical problems remaining until about 500 m drilling length cause sudden intermittent concentration drops, sometimes down to zero. During drilling of the last half of the borehole, the feeder system was fully adjusted and functioned well, giving an almost stable concentration, although slightly exceeding the recommended one.

A mass balance calculation of the accumulated volumes of flushing water and recovered flushing water in the return water indicates that about 100 m^3 flushing water was lost in the borehole. 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 to be desired, in order to increase the accuracy of the mass calculations.

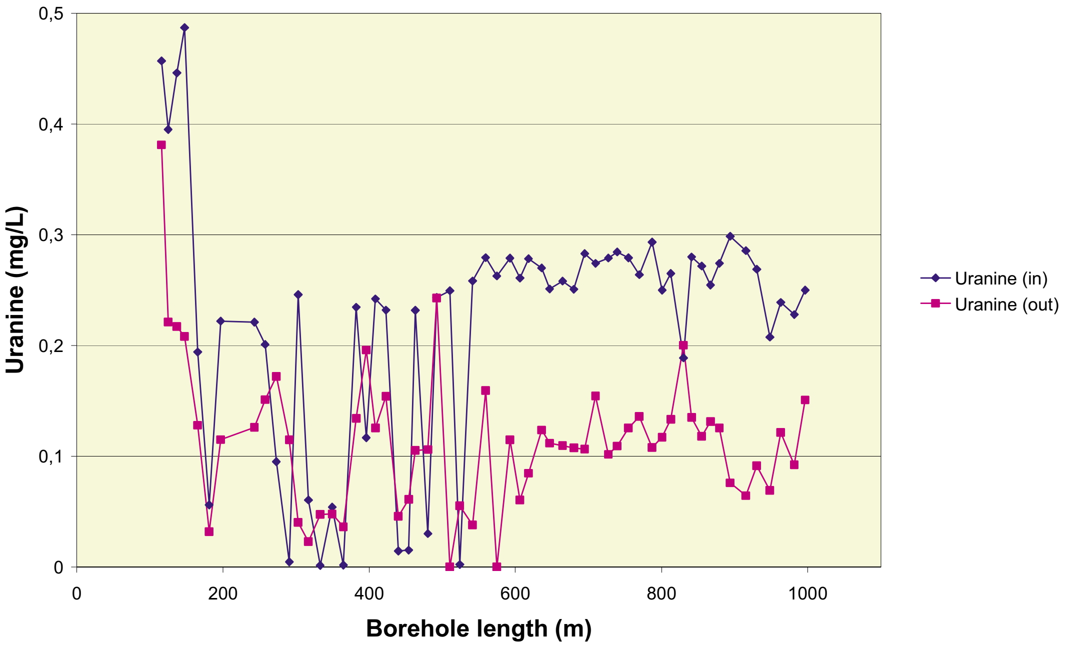


Figure 5-11. *Uranine content versus drilling length in flushing water and return water during drilling of borehole KFM02A.*

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM02A is exposed in Figure 5-12. The drilling system WL-76, used for drilling of KFM02A, 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. In order to diminish this problem, on the eve of drilling KFM02A the dimension of the drillbit and centralizers was increased by one mm compared to when drilling KFM01A /9/. This resulted in a borehole diameter of 77.3 mm.

The increasing trend of the pressure versus drilling length observed in Figure 5-12 reflects the augmented frictional resistance with increasing length of the borehole tubing. However, the increased borehole diameter resulted in a significantly lower flushing water pressure than during drilling of KFM01A /9/. The final pressure, i.e. that prevailing during drilling of the last 100 m, was in fact 20-30 bars lower than the final pressure during drilling of KFM01A.

Drilling through the porous granite in section 250-300 m results in a distinct dip in the pressure diagram, and a similar effect is observed in the major fracture zone at c. 410-530 m.

Electric conductivity of flushing water

Flushing water was supplied from percussion borehole HFM05. A sensor for on-line registration of the electric conductivity (EC) of the flushing water, was placed in the measurement station shown in Figure 3-4. The sensor for registration of the electric conductivity of the return water was positioned between the surge diverter (discharge head) and the sedimentation containers, see Figure 3-4.

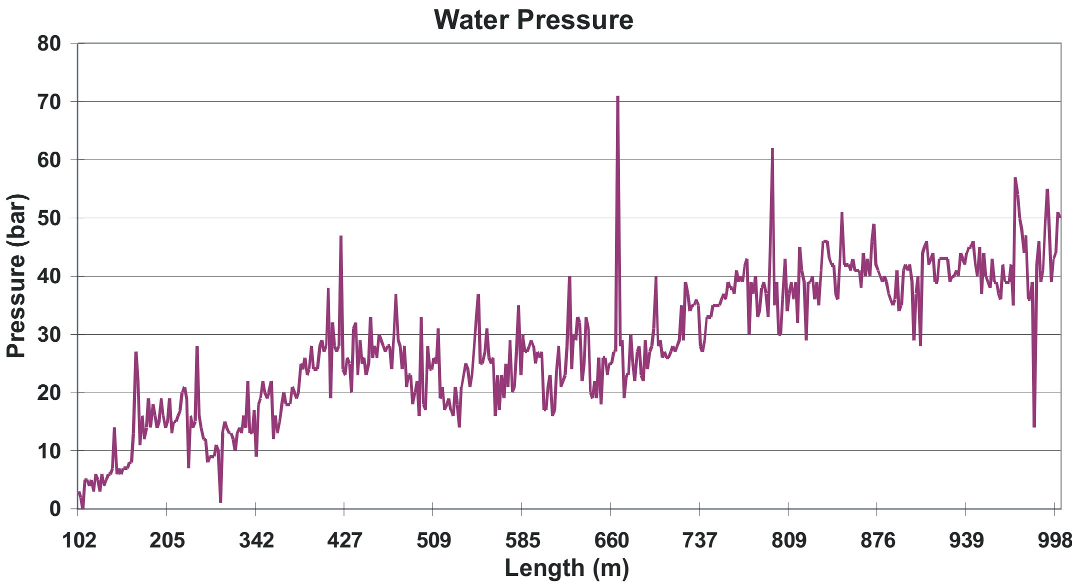


Figure 5-12. *Flushing water pressure versus drilling length when drilling KFM02A.*

The electrical conductivity (salinity) of the flushing water from the 200.10 m deep supply well HFM05 with its major inflow at c. 156 m is almost constant during the drilling period, although a slight decreasing trend is observed in Figure 5-13. The average electrical conductivity of the return water is obviously lower than that of the flushing water. It is, however difficult to draw definite conclusions about the reasons for that. One possible explanation is that the electrical conductivity of the groundwater share of the return water is much lower than that of the flushing water, indicating that shallow groundwater inflows dominate in KFM02A. Other explanations are related to technics of measurement and the prerequisites for the EC-measurements. The relatively low average electrical conductivity of the return water may be a combined effect of the high amount of suspended drill cuttings and air bubbles in the turbulent flow of the return water after being exposed to the airlift (mammoth) pumping. Furthermore, the EC-measurements were not temperature compensated, and the generally lower temperature of the return water than of the flushing water is another factor resulting in decreased EC-values.

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

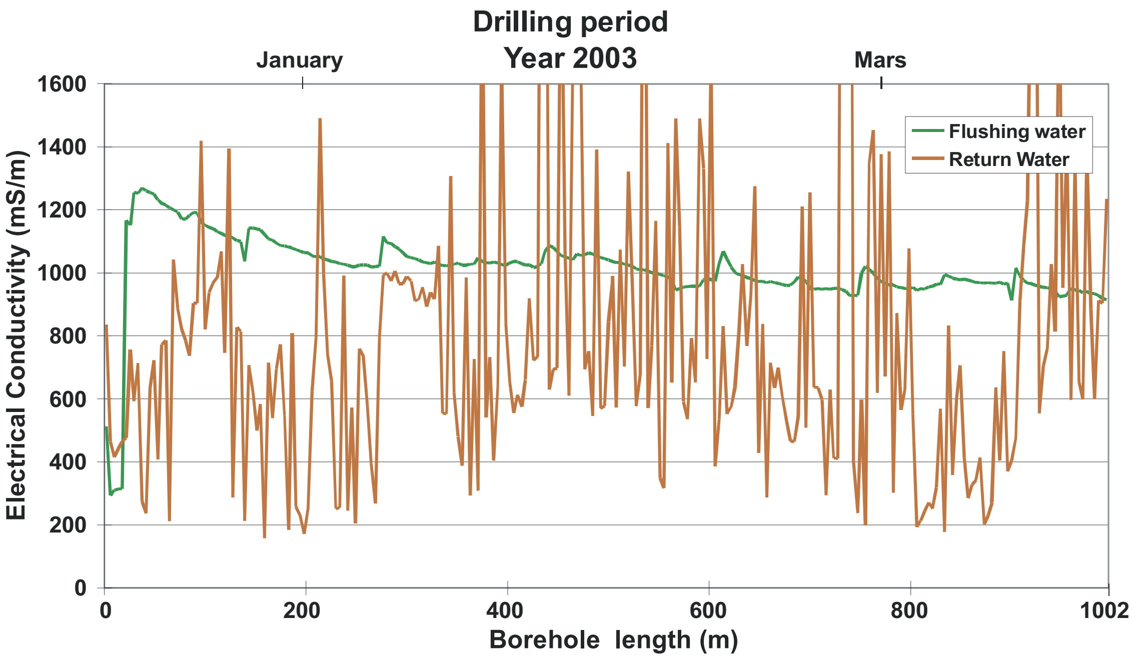


Figure 5-13. *Electrical conductivity of flushing water from HFM05 and return water from KFM02A.*

The high EC-values of the peaks indicate that the low average EC-values of the return water is an imaginary effect, to a large extent related to the measurement problems mentioned above, and that with equal measurement conditions, EC of the return water would turn out to equal or even exceed that of the flushing water for the major part of the borehole. This was confirmed by the fact that EC-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.

The drop in electrical conductivity observed in Figure 5-13 between 800 and 900 m may be due to an increased extraction of return water, see Section 5.4.4 and Figure 5-14.

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 chemical analyses of flushing water from the supply well HFM05 are compiled in Appendix C. The flushing water was sampled prior to commencement of core drilling and at a few occasions during drilling, for the following reasons:

- Initially, to check if the quality was satisfactory.

  The main concern is the content of organic constituents, which should be low, preferably below 5 mg/L. The reason is that introduction of hydrocarbons may affect the microbiological flora in the borehole, which would obstruct a reliable characterization of the in situ microbiological conditions.

- To check the microbe content.
- To monitor the water composition.

The chemical composition of the flushing water is important when estimating the effect, or correcting for the effect of remaining flushing water in the water samples from borehole KFM02A.

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

Organic constituents

The concentration of Total Organic Carbon (TOC) in the samples collected in HFM05 prior to core drilling was in the range 2.3-5.4 mg/L. These values were considered low enough, and it was decided to use HFM05 as the flushing water well without further measures (e.g. using an active carbon filter system for reduction of organic substances as was applied when drilling KFM01A /9/).

Microbes

The results from the control of the microorganism content in the flushing water used in KFM02A are reported in /7/. The control, which was performed at one occasion in March 2003, showed that the amounts of algae and bacteria in the flushing water entering the borehole was reduced compared to the situation in KFM01A /9/. This was probably the positive result of that no storage tank was used after the ultraviolet (UV) radiation unit. However, the microbe content still exceeded the desired maximum level, and further measures need to be taken in order to avoid microbial growth in the flushing water in future drilling activities.

Water composition

The flushing water was sampled at four occasions during drilling and also prior to drilling, in connection with hydraulic testing of borehole HFM05 /10/ and /11/. Furthermore one sample was collected in August after completion of drilling. As shown in Appendix C, the composition of the water from HFM05 changes from time to time, possibly due to the pumping situation (pumping flow rate, pumping intervals etc). Therefore, a conclusion that can be drawn, is that sampling should be made more frequently, say twice a month during the drilling period.

5.4.4 Registration of the groundwater level in KFM02A

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 the groundwater level in the borehole, below plotted versus borehole length (Figure 5-14).

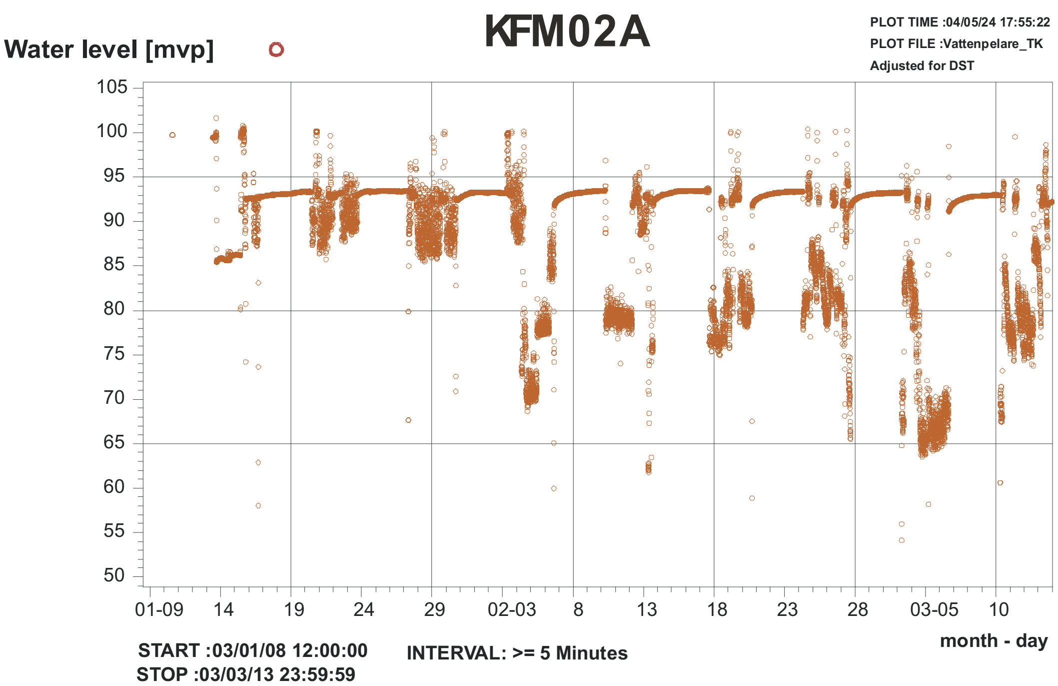


Figure 5-14. Variation of the level of the groundwater table in KFM02A during drilling.

The mammoth pumping was set to a drawdown of, in average, approximately 10 metres at the beginning of the drilling period, as the drill crew noted vibrations in the drill string with increased drawdown. From about 400 m borehole length, the drawdown was set to approximately 20 metres and from 800 m the drawdown was further increased to approximately 30 metres. Drilling was performed continuously during Monday-Thursday. During the weekend stop of drilling and pumping, the groundwater table recovered rapidly due to recharge of groundwater into the borehole, resulting in the (positive) peaks in the diagram. This confirms that the total inflow of formation water in the upper part of the borehole (but below the upper cased and grouted parts) was high. When pumping was restarted, a simultaneous drawdown occurred.

5.4.5 Core sampling

The average drill core length per run obtained from the drilling was 2.70 m. Due to the very low fracture frequency at depth, several 3 m long, unbroken cores were recovered. Minerals in natural fractures were relatively well preserved. Rotation marks on the drill core occurred, but with a rather low frequency. A preliminary on-site core logging was performed continuously.

5.4.6 Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0-100 m) is 5 m^3. Weighing of drill cuttings and comparison with the weight of the theoretical volume was not carried out due to the extreme high water flow. 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 gap grouting to full borehole length worked well, without obstruction from settled drill cuttings.

The theoretical difference in volume of the core drilled part of KFM02A and the drill core is calculated to be 2.278 m^3. This volume should correspond 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 calculated dry weight of the debris is 3082 kg. The difference between estimated and calculated dry weight of debris is 2955 kg, which gives a recovery of 51 %.

The recovery figure could be commented on. The dwell time in the system is too short for sedimentation of the suspended finest fractions. No estimation was made of the amount of suspended material, but the true recovery is probably somewhat higher than 51 %. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

However, it is probable that relatively large amounts of drilling debris have been injected into the fracture system in the bedrock, in the main into the permeable section with increased fracture frequency in the upper half of the borehole.

5.4.7 Deviation measurements

The deviation measurements made in borehole KFM02A show that the deviation of the borehole is relatively small (see Appendix B). The bottom of the borehole deviates 4 m upwards and 94 m to the right 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 inclinations of the borehole. The practical difficulties and uncertainties in the results however turned out to be considerable. Therefore it is recommended that the length error is determined from the diagram in Figure 5-15, which is based on load tests performed in the laboratory by the manufacturer of the drilling pipes.

As seen in the diagram, the maximum elongation at 1000 m length in a vertically drilled borehole is 180 mm. In inclined boreholes the elongation of the pipe string should theoretically be less.

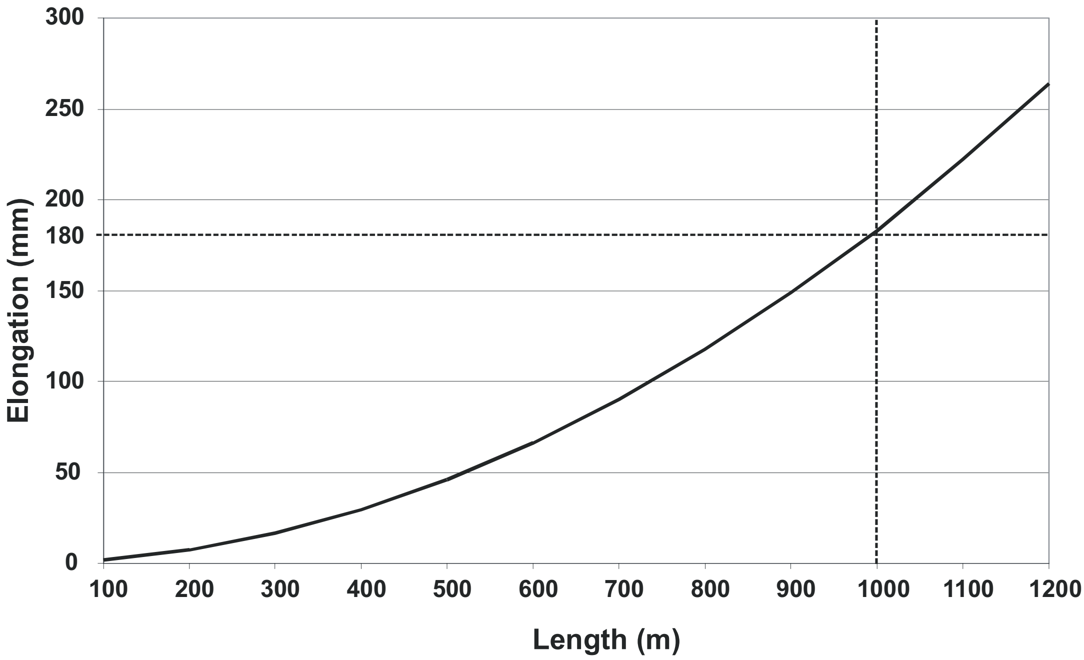


Figure 5-15. *The diagram illustrates the elongation of the WL-76 drilling pipe string when hanging in a vertical water filled borehole. Values from a laboratory load tests of the drilling pipe string.*

5.4.9 Hydraulic tests and water sampling during drilling

After the technical problems with the wireline (WL)-probe observed during measurements in borehole KFM01A /9/, the equipment was modified. In KFM02A three hydraulic tests, of which two were successful, and three water sampling attempts, of which one was successful, were performed. From the hydraulic test diagrams, estimations of absolute pressure in the two tested sections were made.

After completion of drilling, the borehole was cleaned by airlift pumping, causing a drawdown of 33 m. The recovery of the groundwater table was registered during a weekend.

Results of hydraulic tests and water sampling in KFM02A are presented below.

Pumping tests and absolute pressure measurements with the wireline probe

Results of pumping tests with the WL-probe are presented in Table 5-2 and in Figures D-1 and D-2 of Appendix D.

The flow rate value by the end of the drawdown phase was used for calculating the specific capacity (Q/s) and transmissivity (T_M), where "Q" is the flow rate in L/min, "s" is the drawdown in kPa and "T_M" is the transmissivity according to SKB MD 320.004, Version 1.0, "Analys av injections- och enhålspumptester", (SKB internal controlling document). Absolute pressure measurements were performed during the pumping tests and are shown in Appendix D.

Table 5-2. Pumping tests with WL-probe in KFM02A.

Tested Section (m)	Q/s (m^2/s)	T_{Moye} (m^2/s)	Comments
159.10 – 291.45	$7·10^{-05}$	$9·10^{-05}$	A drawdown of c. 40 kPa was generated in the test section. The flow decreased from 22-17 L/min during the test. Pressure recovery was only about c. 10 kPa. A decreasing pressure trend occurred before start of pumping, indicating that the pressure in the section was not stable, mainly due to packer compliance. A rough steady-state evaluation of specific capacity and transmissivity was made on data from the drawdown phase. The absolute pressure in the test section was estimated at 1622 kPa from the test diagram.
602.94 – 697.81	10^{-07}	10^{-07}	A drawdown of c. 550 kPa was generated in the test section. The flow from the section was due to leakage in the pipe string which was hard to estimate, but assumed to be very small (less than 1 L/min, manual observations). Pressure recovery amounted to c. 450 kPa. A decreasing pressure trend occurred before start of pumping, indicating that the pressure in the section was not stable, mainly due to packer compliance. A rough steady-state evaluation of specific capacity and transmissivity was performed on data from the drawdown phase. The flow rate of 1 L/min used in the calculation is very uncertain and was probably even smaller. The absolute pressure in the test section was estimated at 5952 kPa from the test diagram.
698.96-800.66	-	-	No test performed, due to packer failure.

The pressure phase, after packer inflation, lasted c. 10 minutes and showed a decreasing pressure trend (due to packer compliance). Stable pressure before start of pumping was not achieved in any of the tests.

Recovery monitoring after cleaning by airlift pumping

The recovery registration after the final cleaning of the borehole by airlift pumping, which caused a drawdown of 33 m, is displayed in the diagram of Figure 5-16. The recovery of the groundwater table was registered during a weekend and confirmed the high yielding capacity of the borehole. From the diagram an inflow of >200 L/min can be estimated.

Prior to drilling start of KFM02A, the flushing water well HFM05 was drilled at drilling site DS2. During the period when drilling of KFM02A was ongoing, also percussion drilling of HFM04 at the drilling site was carried out, see Figure 1-2. The pumping activities in KFM02A respectively in the two percussion drilled boreholes at drilling site DS2, revealed hydraulic connections between all three boreholes at shallow levels (<100 m).

Groundwater sampling-groundwater quality

Three so called first strike WL-samples were collected from the sections 105-159 m, 250-290 m respectively 249-396 m. However, the flushing water contents were quite high, 43, 20 and 89 %, respectively. Isotopes were analysed only for the sample from section 250-290 m. The results are presented in Appendix C.

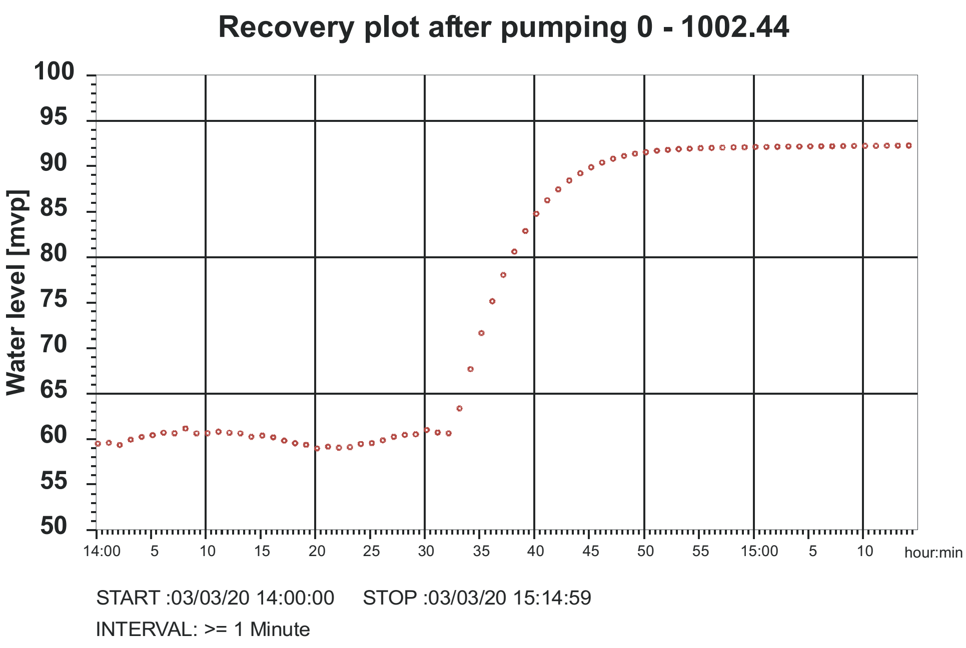


***Figure 5-16.** Recovery of groundwater table in section 0-1002.44 m of KFM02A.*

5.4.10 Groove milling

After completion of drilling, borehole KFM02A will be used for borehole measurements, employing many types of borehole instruments with different stretching characteristics (pipe strings, wires, cables etc.). In order to provide a system for length calibration in the borehole, reference grooves were milled into the borehole wall at certain levels with a specially designed tool. This was carried out after termination of drilling, but with use of the drilling machine and pipe string.

At each level, two 20 mm wide grooves were milled with a distance of 10 cm between them, see Figure 5-17. Table 5-3 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 gave the final conformation of where the groove milling was successful and where it failed.

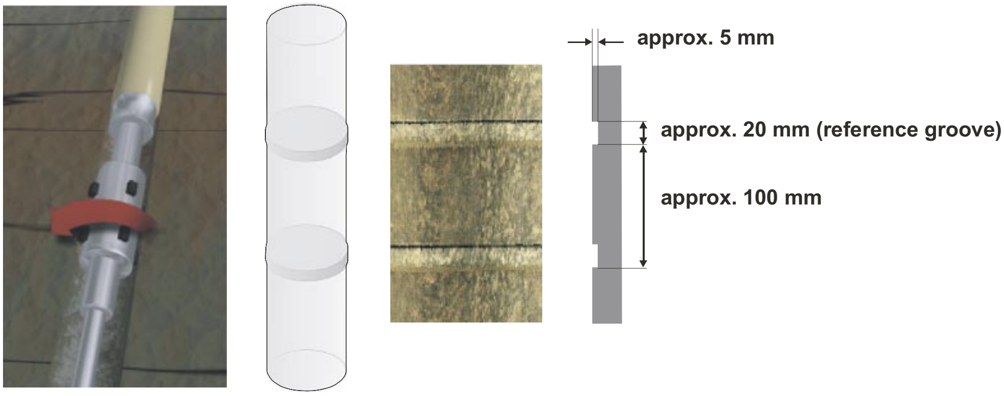


Figure 5-17. *Layout and design of reference grooves.*

Table 5-3. 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	Yes	650	Yes	Yes
250	Yes	Yes	700	Yes	Yes
304.5	Yes	Yes	750	Yes	Yes
350	Yes	Yes	800	Yes	Yes
400	Yes	Yes	850	Yes	Yes
450	Yes	Yes	900	No	Yes[1]
506	Yes	Yes	950	Yes	Yes

[1] weak

5.4.11 Consumables

The amount of oil products consumed during drilling the percussion drilled part of KFM02A (0-100 m), thread grease used during core drilling, and grout used for gap injections of the respective casings are reported in Table 5-4 and Table 5-5. Regarding hammer oil and compressor oil, these products are indeed entering the borehole but are, on the other hand, continuously retrieved from the borehole due to the permanent air flushing during drilling. After completion of drilling, only minor remainders of the products are left in the borehole.

The special type of thread grease (silicon based) used during core drilling in this particular borehole was certified according to SKB MD 600.006, Instruction for the use of chemical products and material during drilling and surveys. 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 contaminating the borehole. Furthermore, the lubrication characteristics were not as good as for conventional lubricants.

Table 5-4. 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
KFM02A	15 L	Not detected	5.7 kg

Table 5-5. 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
KFM02A	11.40-11.80	13 kg/15 L		Bottom plug
KFM02A	11.80	500 kg/400 L	Hose	
KFM02A	100.19	3800 kg/2800 L	Packer	Stop pressure 30 bars

6 References

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

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

/3/ **SKB, 2003.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of a flushing water well, HFM05, and a groundwater monitoring well, HFM04, at drilling site DS2. SKB P-03-51, Svensk Kärnbränslehantering AB

/4/ **SKB, 2003.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of monitoring wells SFM0004-SFM0005 in soil at drilling site DS2. SKB P-03-50, Svensk Kärnbränslehantering AB.

/5/ **SKB, 2003.** Petersson, J & Wängnerud, A. Site investigations at Forsmark. Boremap mapping of telescopic drilled borehole KFM02A. SKB P-03-98, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2003.** Sohlenius, G, Rudmark, L and Hedenström, A. Forsmark site investigation. Mapping of unconsolidated Quaternary deposits. Field data 2002. SKB P-03-11, Svensk Kärnbränslehantering AB.

/7/ **SKB, 2003.** Pedersen, K & Kalmus, A. Forsmark site investigation. Control of microorganism content in flushing water used for drilling in KFM02A and KFM04A. SKB P-03-92, Svensk Kärnbränslehantering AB.

/8/ **SICADA.** Field Note No. 55.

/9/ **SKB, 2003.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of the telescopic borehole KFM01A at drilling site DS1. SKB P-03-32, Svensk Kärnbränslehantering AB.

/10/ **SKB, 2003.** Nilsson, A-C. Forsmark site investigation. Sampling and analyses of groundwater in percussion drilled boreholes and shallow monitoring wells at drillsite DS 2. SKB P-03-48, Svensk Kärnbränslehantering AB.

/11/ **SKB, 2003.** Ludvigson, J-E, Jönsson, S. & Svensson, T. Pumping tests and flow logging Boreholes KFM02A (0-100 m), HFM04, HFM05. SKB P-03-34, Svensk Kärnbränslehantering AB.

Appendix A

Well Cad presentation of the percussion drilled part of borehole KFM02A

Title PERCUSSION DRILLED BOREHOLE KFM02A

Svensk Kärnbränslehantering AB

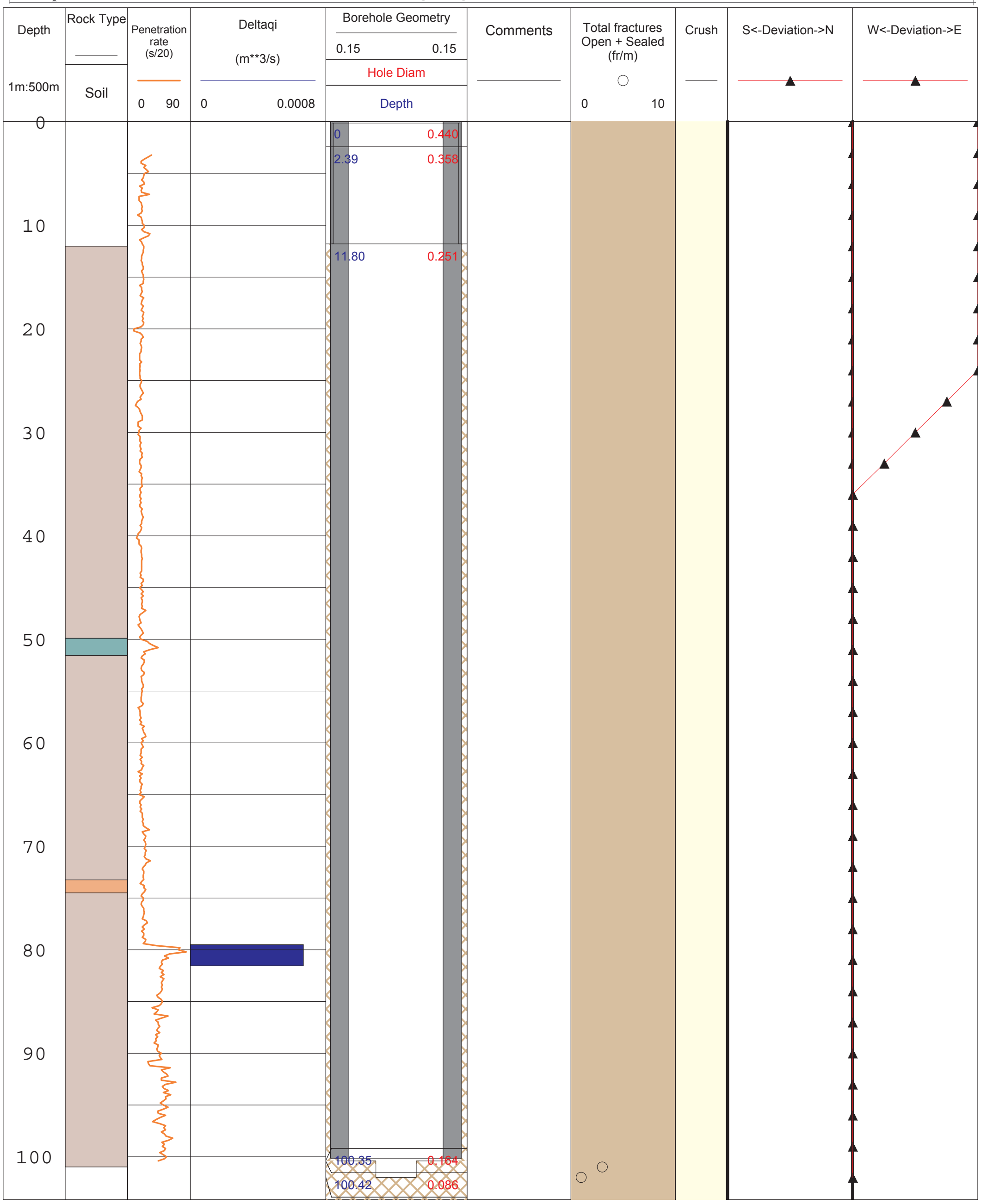
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM02A	**Northing [m]**	6698712.50
Diameter [mm]	251	**Easting [m]**	1633182.86
Length [m]	100.42	**Elevation [m.a.s.l.]**	7.35
Bearing [°]	275.76	**Drilling Start Date**	2002-11-20 14:03:00
Inclination [°]	-85.38	**Drilling Stop Date**	2002-11-26 11:35:00
Date of mapping		**Plot Date**	2004-06-15 21:05:36

ROCKTYPE

- **Granite, fine- to medium-grained**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Amphibolite**

SOIL

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



Appendix B

Well Cad presentation of the complete borehole KFM02A

Title KFM02A

Svensk Kärnbränslehantering AB

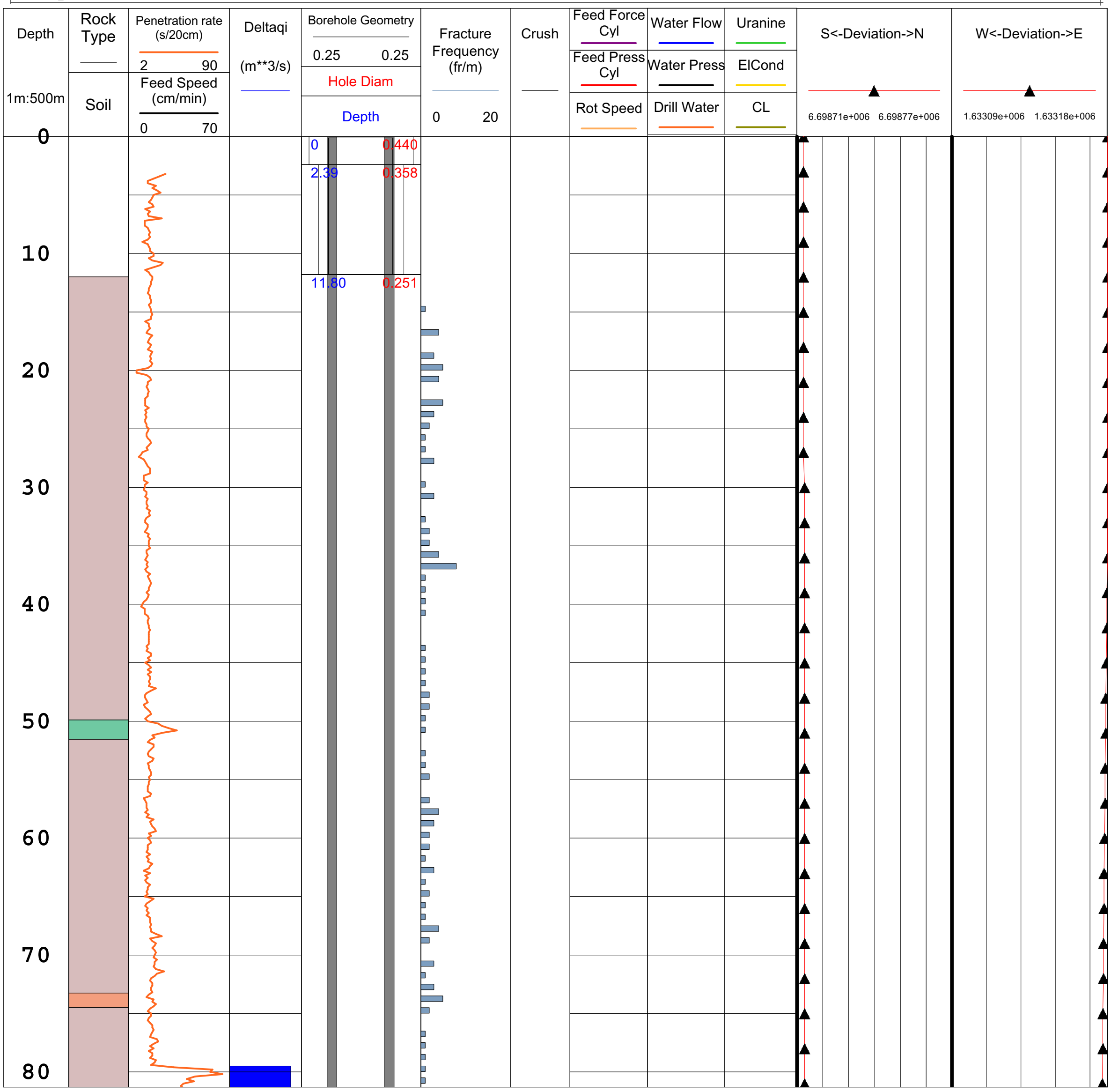
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM02A	**Northing [m]**	6698712.50
Diameter [mm]	77	**Easting [m]**	1633182.86
Length [m]	1002.44	**Elevation [m.a.s.l.]**	7.35
Bearing [°]	275.76	**Drilling Start Date**	2002-11-20 14:03:00
Inclination [°]	-85.38	**Drilling Stop Date**	2003-03-12 21:30:00
Date of mapping		**Plot Date**	2004-06-15 21:05:36

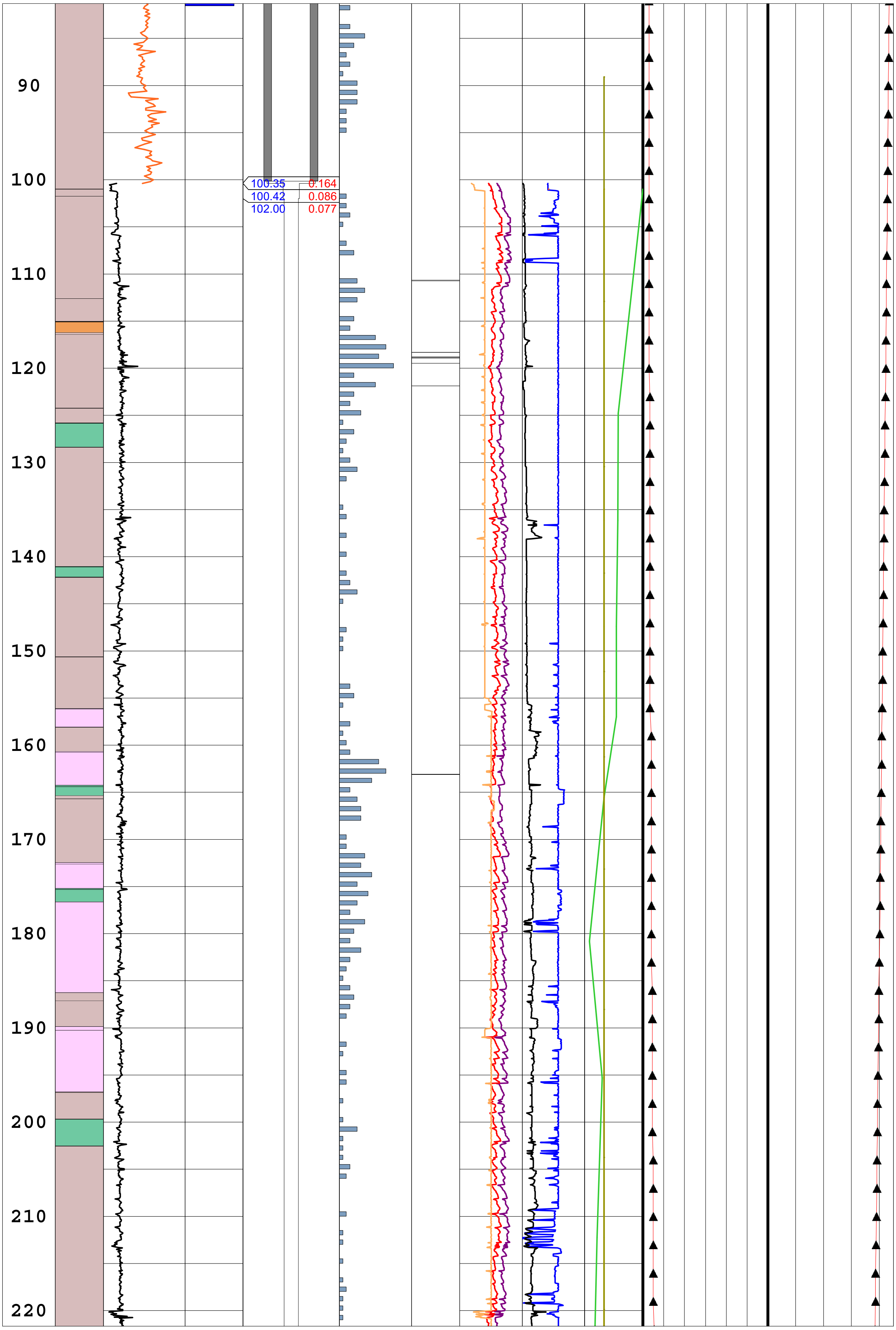
ROCKTYPE FORSMARK

SOIL

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

Script Name





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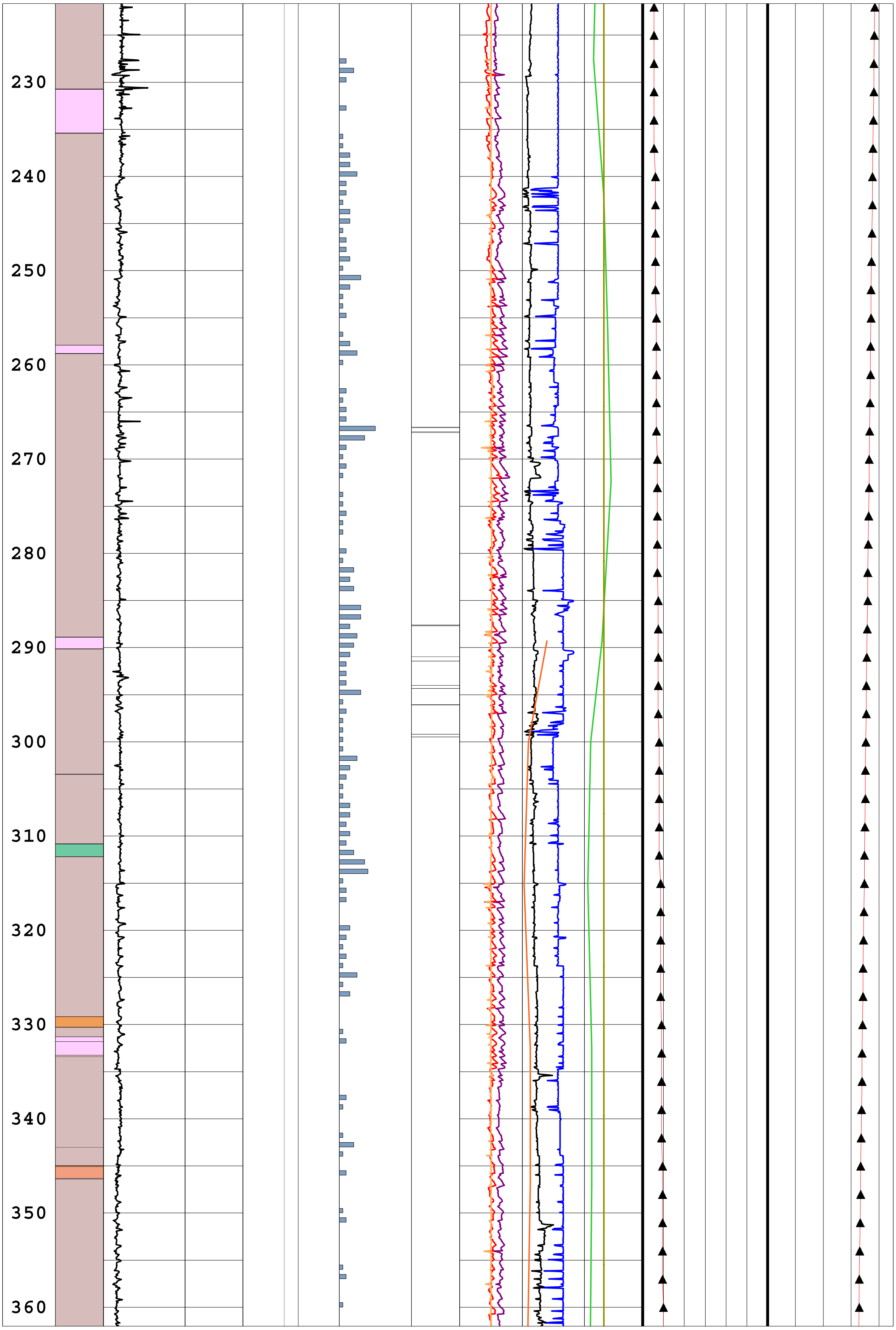
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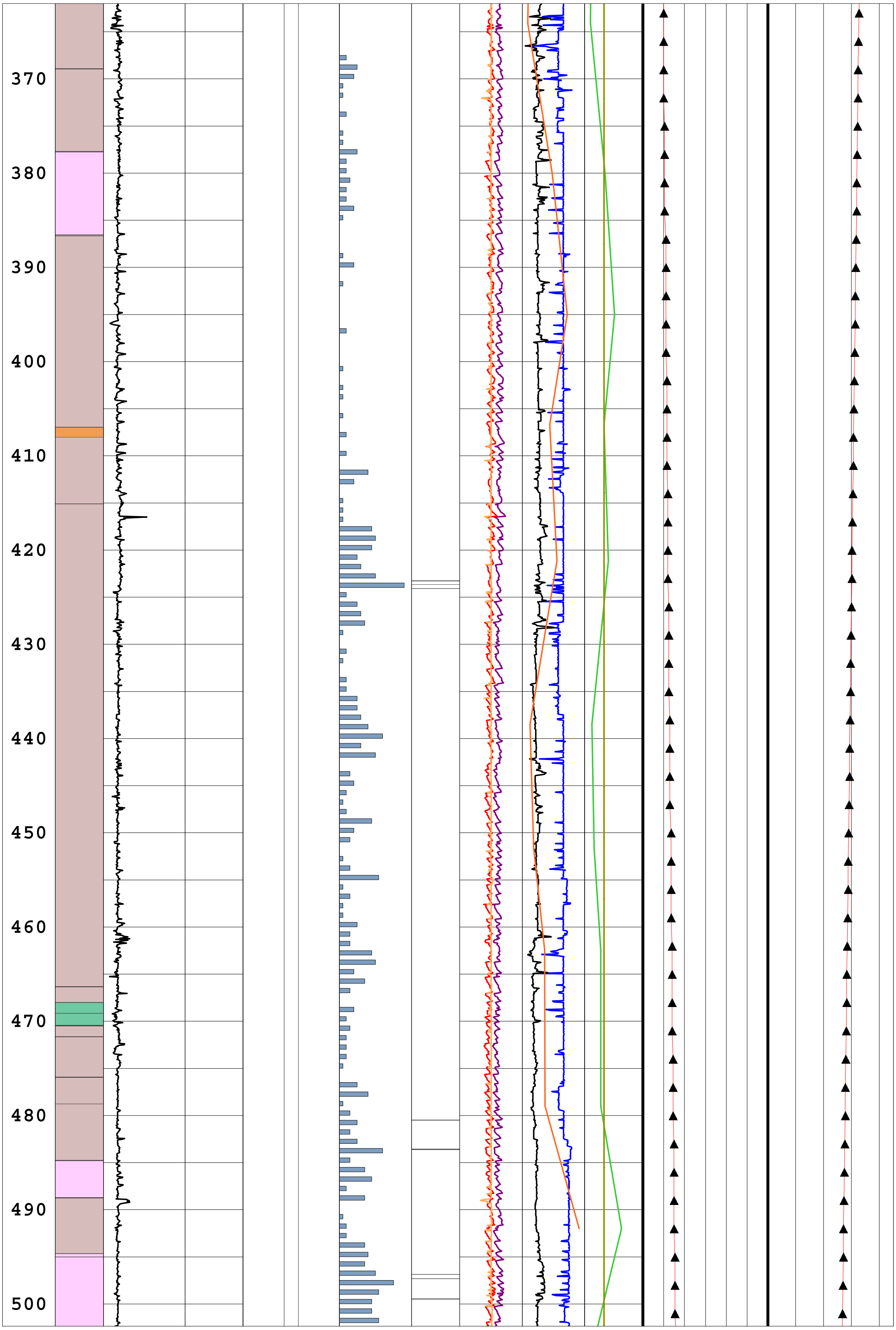
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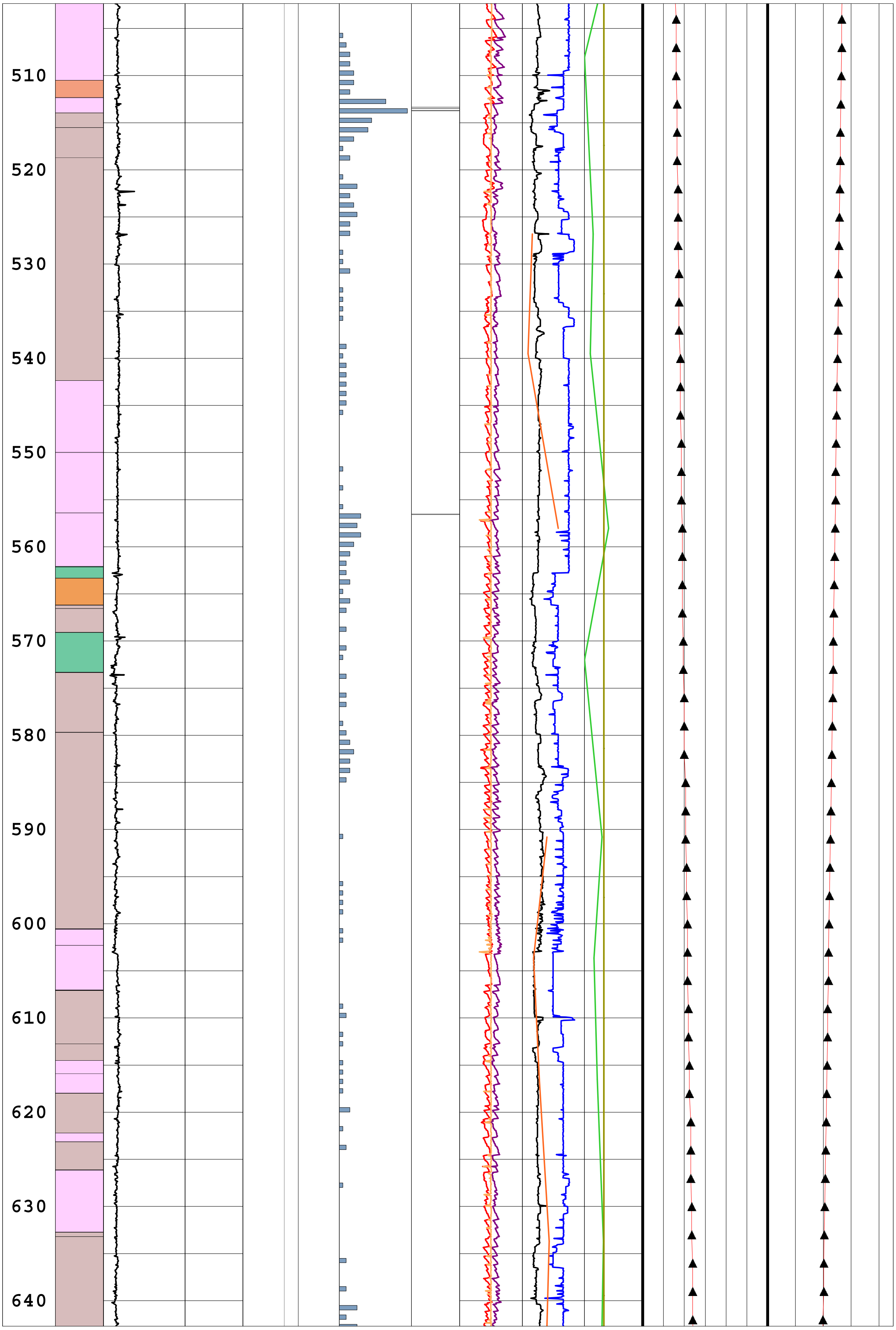
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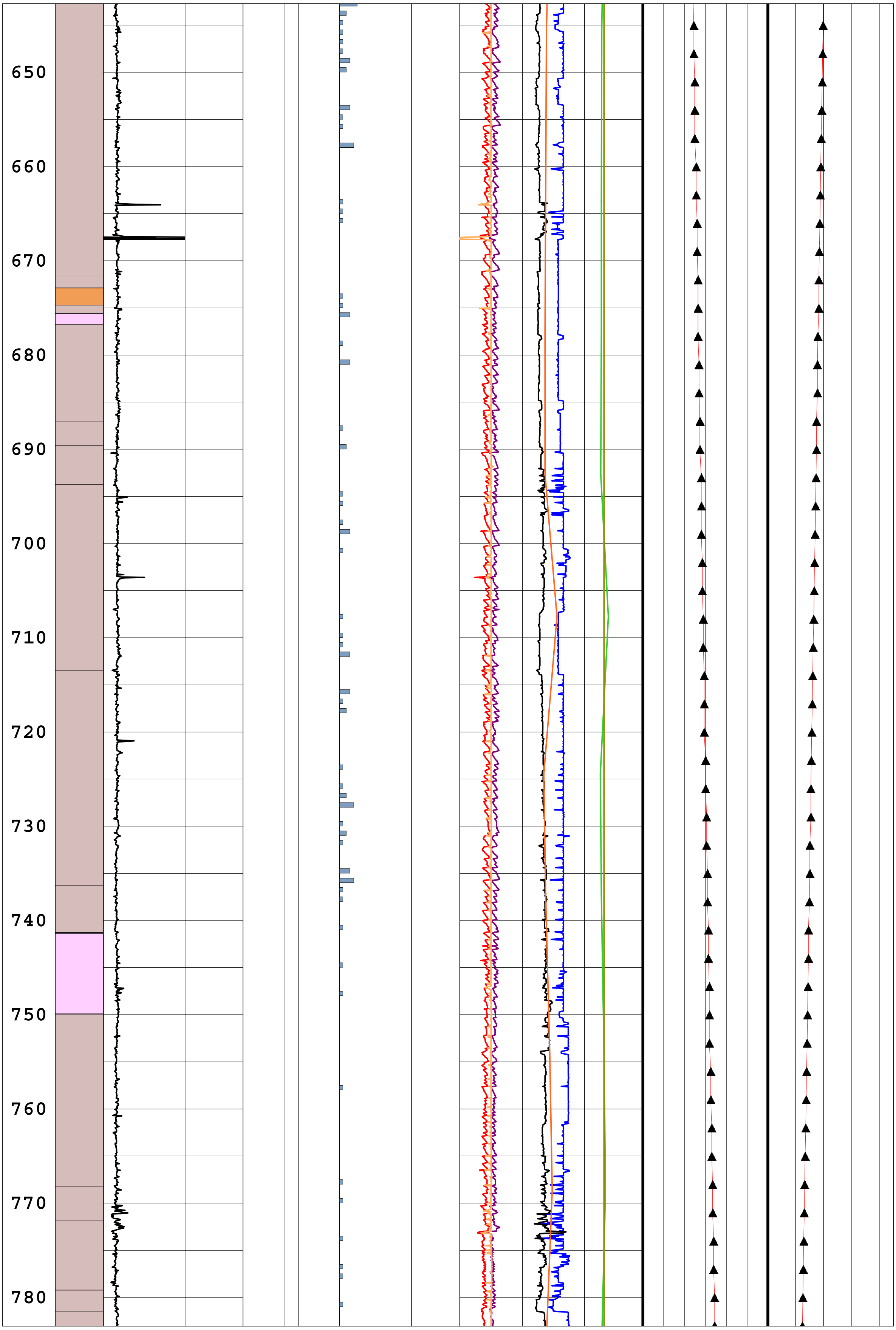
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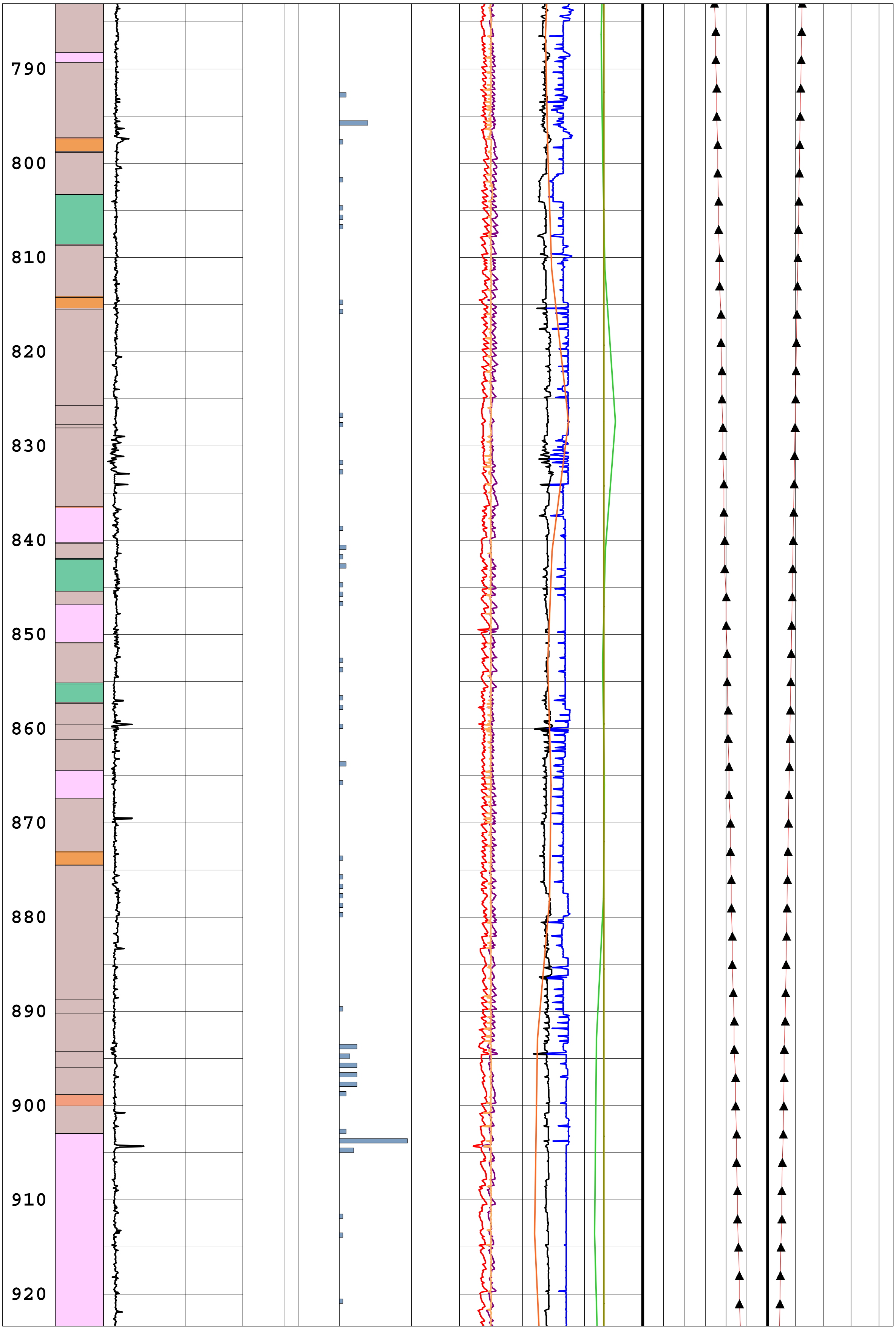
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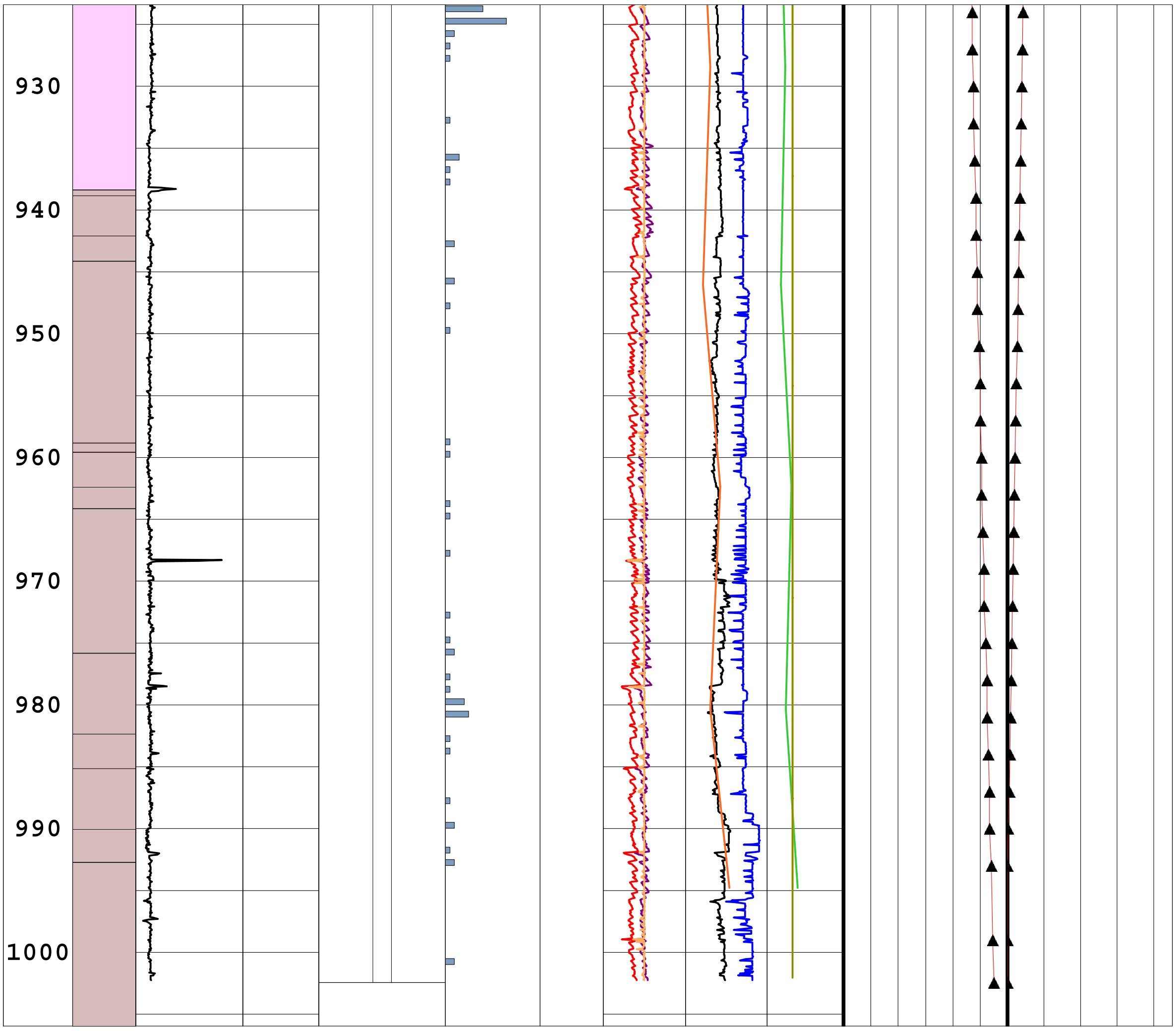
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Water Composition

Water Composition, compilation April 2003

Idcode	Secup m	Seclow m	Sample no.	Date	Type of sample	Charge Bal %	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO3 mg/L	Cl mg/L	SO4 mg/L	SO4-S mg/L	Br mg/l	F- mg/L	Si mg/L	Li mg/L	Sr mg/L	pH	ElCond mS/m	TOC mg/L	Flush water %
HFM05	25	200.1	4433	2002-12-19 11:35	Hydro. Test	-0.42	1830	42.4	805	212	110	4650	308.66	101	18.96	0.43	6,0	0.045	5.9	7.45	-	2.3	
HFM05	25	200.1	4434	2002-12-19 15:45	Hydro. Test	0.04	1800	42.2	781	207	115	4500	306.74	99.5	18.94	0.44	6.1	0.044	5.68	7.41	-	2.5	
HFM05	25	200.1	4435	2002-12-19 20:25	Hydro. Test	-0.08	1740	41.2	749	199	122	4340.3	299.24	97.3	21.98	0.57	6.1	0.043	5.42	7.41	-	2.6	
HFM05	0	200.1	4467	2003-01-23 16:40	Flush water test	-1.23	1530	34.3	608	160	172	3740	269.44	82.1	14.32	1.31	6.5	0.041	4.48	7.19	-	2.8	
HFM05	0	200.1	4482	2003-02-10 10:00	Flush water test	-0.43	1520	35,0	596	165	173	3640	269.81	89.6	13.81	1.37	6.4	0.043	4.3	7.21	-	2.6	
HFM05	0	200.1	4611	2003-03-04 14:00	Flush water test	-0.2	1290	35.6	501	141	213	3090	239.11	80.4	12.41	0.78	6.1	0.037	3.52	7.31	-	5.4	
HFM05	0	200.1	4964	2003-08-20 10:20	After drilling	-0.73	1560	35.6	640	168	161	3900	286.47	92.7	16.7	0.95	6.5	0.043	4.61	7.09	1190	-	
KFM02A	105.10	159.30	4462	2003-01-20 20:00	WL-sample	1.18	1010	27.0	382	98.3	72.0	2320	178	55.1	9.60	1.23	4.10	0.031	2.87	7.45	-	-	43,5
KFM02A	250.00	291.45	4468	2003-01-27 21:00	WL-sample	-0.09	1520	33.3	656	162	142	3740	249	83.3	19.0	1.10	4.40	0.044	5.35	7.40	-	-	20,3
KFM02A	248.75	395.88	4469	2003-01-29 21:00	WL-sample	-1.51	1420	34.4	551	150	190	3440	247	83.1	15.7	2.24	6.16	0.041	3.99	7.31	-	-	89

-= Not analysed

x= No result due to sampling problems

xx = No result due to analytical problems

-"value" = result less than detection limit

ChargeBal % = Relative charge balance error %

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

Idcode	Secup	Seclow	Sample	Date	D dev	Tr	O-18 dev	$^{10}B/^{11}B$	S-34 dev	Cl-37 dev	C-13 dev	$^{87}Sr/^{86}Sr$	C-14	Age BP
	m	m	no		SMOW	TU	SMOW	no unit	CDT	SMOC	PDB	no unit	pmC	years
HFM05	25	200.1	4433	2002-12-19 11:35	-78.2	-0.8	-10.2	0.2388	24.6	-0.03	-	0.718978	-	-
HFM05	25	200.1	4434	2002-12-19 15:45	-78.1	-0.8	-10.2	0.2393	24.5	-0.03	-6.93	0.719056	21.97	12123
HFM05	25	200.1	4435	2002-12-19 20:25	-75.0	-0.8	-10.3	0.2391	24.6	0.07	-7.07	0.719068	24.89	11121
HFM05	0	200.1	4467	2003-01-23 16:40	-79.2	2.3	-10.3	0.2381	23.6	0.49	-8.27	0.719111	33.72	8681
HFM05	0	200.1	4482	2003-02-10 16:40	-78.1	2.8	-10.2	0.2392	24.2	-0.16	-8.81	0.719250	38.30	7568
HFM05	0	200.1	4611	2003-03-04 14:00	-79.6	4.9	-10.3	0.2408	24.1	-	-9.35	0.719398	45.76	6229
HFM05	0	200.1	4638	2003-03-11 11:30	-79.7	4.3	-10.3	-	24.6	0.04	-9.80	0.719326	46.46	6106
HFM05	0	200.1	4964	2003-08-20 10:20	-77.3	2.2	-10.1	0.2389	-	-	-7.75	0.719263	29.81	9669

-= Not analysed

x= No results due to sampling problems

xx = No results due to analytical proble

Appendix D

Absolute pressure measurements

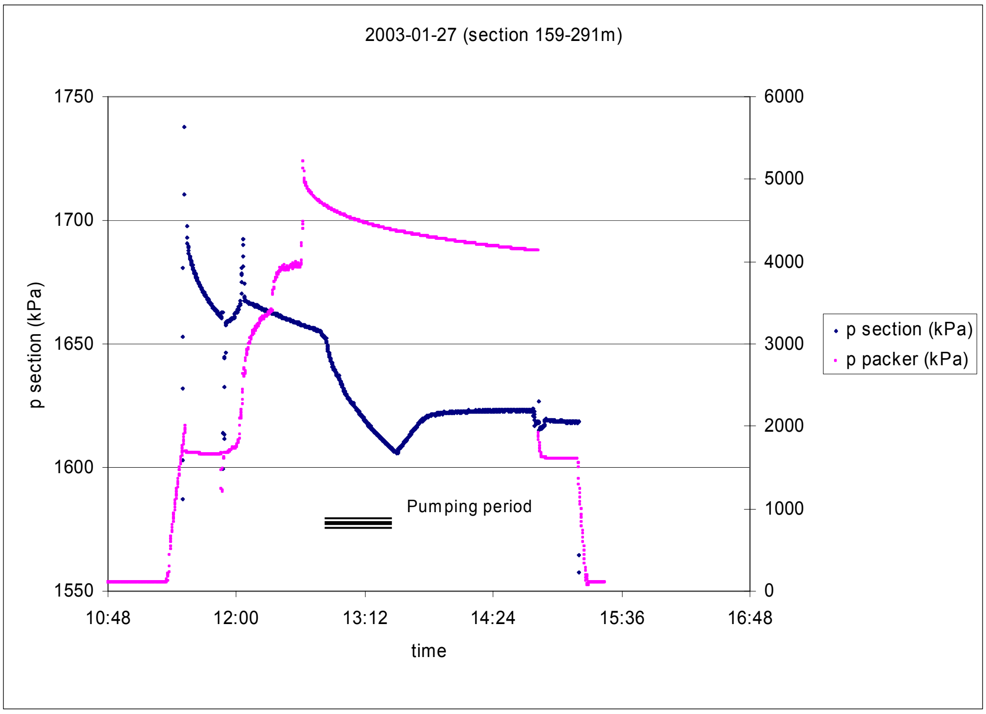

Figure D-1*. Pumping tests and absolute pressure measurements in KFM02A, section 159-291 m.*

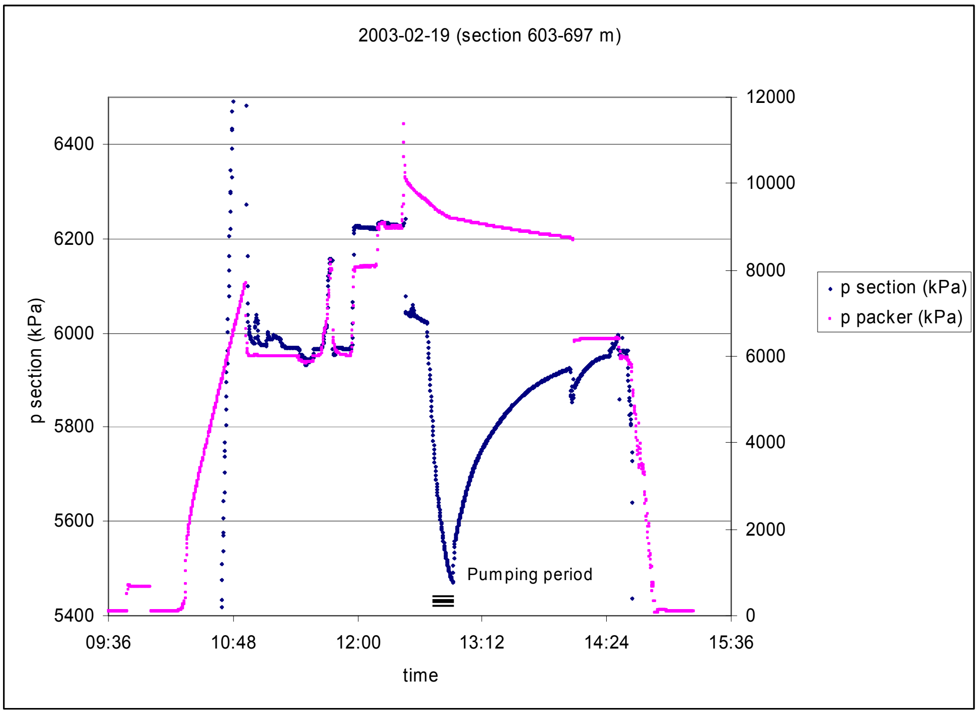

Figure D-2. *Pumping tests and absolute pressure measurements in KFM02A, section 603-697 m.*