P-05-172

Forsmark site investigation

Drilling of the telescopic borehole KFM08A and the core drilled borehole KFM08B at drill site DS8

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

October 2005

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

ISSN 1651-4416
SKB P-05-172

Forsmark site investigation

Drilling of the telescopic borehole KFM08A and the core drilled borehole KFM08B at drill site DS8

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

October 2005

Keywords: AP PF 400-04-86, AP PF 400-04-104, Percussion drilling, Core drilling, Telescopic borehole, Drill site DS8.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

A pdf version of this document can be downloaded from www.skb.se

Abstract

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

Performance of and results from drilling and measurements during drilling of the eighth borehole, KFM08A, drilled at Forsmark by applying telescopic technique are presented in this report. KFM08A is 1,001.19 m long, at its starting point inclined 60.89° from the horizon, and reaches about 500 m in horizontal distance. The borehole is of so called SKB chemical type, intended for detailed hydrogeochemical and microbiological investigations.

During pilot drilling of section 0–100 m with the diameter 164 mm, an unstable, fractured section, interpreted as a gently dipping fracture zone, was encountered at about 25 m. This zone displayed a water-yielding capacity of about 50 L/min at a drawdown of c 50 m. Due to the water yield and unstable borehole wall, the borehole was reamed to 250 mm, whereupon a stainless steel casing was installed, and the gap between the borehole wall and the casing was grouted. These measures entailed that all inflow of groundwater to the percussion drilled part of the borehole ceased.

A relatively complicated flushing water/return water system is applied for core drilling of the telescopic boreholes. The flushing water is prepared in several steps before use, and the return water is taken care of, as to permit drill cuttings to settle before the water is conducted to an approved recipient. During drilling, a number of technical and flushing water/return water parameters are registered in order to obtain a good control of the drilling process and to permit an estimation of the impact on the rock aquifer penetrated by the borehole of flushing water and drilling debris. The conclusion after drilling of KFM08A was that only relatively small amounts of flushing water and drill cuttings penetrated the fracture system.

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

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

One experience from drilling of KFM08A is that the quartz-rich bedrock in Forsmark is hard to drill, entailing rapid wearing of drillbits, even if the drillbits used had the longest lifetime of all the core drilled boreholes produced so far at Forsmark. Other lasting impressions from the drilling are that the gently dipping fracture zones encountered in the shallow part of the bedrock have a lower water-yielding capacity than in boreholes further to the south-east within the candidate area. Although the fracture frequency in the borehole is somewhat increased compared to many other of the core drilled boreholes at Forsmark, also the water-yielding capacity of the major part of the core drilled section of KFM08A is low.

In order to compensate for the missing drill core in the percussion drilled part of KFM08A (0–100 m), also a short borehole, KFM08B, was core drilled all the way from the ground surface to 200.54 m drilling length at drill site no 8 (DS 8). A second purpose for drilling KFM08B was to study a lineament, and therefore it was drilled deeper than 100 m. KFM08B is inclined 58.85° from the horizon.

Sammanfattning

De flesta djupa borrhål inom Forsmarks platsundersökning utförs som s k teleskopborrhål. Det innebär att de övre 100 m hammarborras i två steg, pilotborrning med dimensionen ca 160 mm följd av upprymning till ca 200–250 mm diameter. Avsnittet därunder, dvs sektionen ca 100–1 000 m, kärnborras med 76–77 mm diameter. Resultaten från det åttonde djupborrhålet i Forsmark som har borrats med denna teknik redovisas i denna rapport. Borrhålet, som benämns KFM08A är ansatt med en lutning av 60,89° från horisontal-planet, är 1 001,19 m långt och når cirka 500 m i horisontell riktning. KFM08A är ett så kallat kemiprioriterat borrhål, vilket innebär att det planeras att utnyttjas för detaljerade hydrogeokemiska och bakteriologiska undersökningar, varför all utrustning som används i borrhålet, både vid borrning och mätning, måste rengöras och desinficeras enligt speciella instruktioner.

Vid hammarborrning av avsnittet 0–100 m med diametern 164 mm påträffades ett instabilt, sprucket avsnitt vid ca 25 m, vilket tolkades som en flackt stupande sprickzon. Zonen uppvisade en vattenkapacitet på ca 50 L/min vid ca 50 m avsänkning. Eftersom borrhålet bedömdes som instabilt rymdes det upp till Ø 250 mm och kläddes in med rostfritt foderrör. Slutligen cementinjekterades spalten mellan borrhålsvägg och foderrör, så att allt vatteninflöde i den hammarborrade delen av teleskopborrhålet upphörde.

Under kärnborrningsfasen vid utförandet av teleskopborrhål används ett relativt komplicerat spol- och returvattensystem, där spolvattnet prepareras i olika steg före användning. Returvattnet leds till ett system av containrar, där borrkaxet sedimenterar i tre steg innan returvattnet leds vidare till godkänd recipient. Under borrningen registreras ett antal borr- och spolvattenparametrar, så att god kontroll uppnås dels avseende borrningens tekniska genomförande, dels beträffande den påverkan av spolvatten och borrkax som grundvatten-akviferen i anslutning till borrhålet utsätts för. Slutsatsen efter borrningen av KFM08A var att endast relativt små mängder spolvatten och borrkax har trängt ut i spricksystemet.

Ett mät- och provtagningsprogram för hammarborrningen och ett annat program för kärnborrningen gav direkt under pågående borrning preliminär information om borrhålets geologiska och hydrauliska karaktär samt underlag för fördjupade analyser efter borrning. Bland de insamlade proverna utgör borrkärnorna från den kärnborrade delen av borrhålet och borrkaxproverna från den hammarborrade delen, tillsammans med videofilm av borrhålsväggen (s k BIPS-bilder), underlaget för den borrhålskartering (s k Boremap-kartering) som utförs efter borrning. Ett resultatdiagram från Boremapkarteringen av KFM08A finns redovisad i denna rapport.

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

En erfarenhet från borrningen av KFM08A är att den kvartsrika berggrunden i Forsmark är svårborrad och att borrkroneslitaget är fortsatt högt, även om livslängden för borrkronorna är den längsta hitintills. Andra bestående intryck är att de flacka zoner som påträffades i den övre delen av KFM08A, har lägre vattenföring än i många av de teleskopborrhålen belägna längre mot sydost i kandidatområdet. Dessutom har större delen av den kärnborrade delen av KFM08A låg vattenkapacitet, trots att sprickfrekvensen är något högre än i många av de övriga kärnborrade hålen i Forsmark.

För att kompensera för den uteblivna borrkärnan från den ytliga berggrunden samt övertvära ett lineament borrades även ett kort kärnborrhål, KFM08B vid borrplats 8 (BP 8). Borrhålet lutar 58.85° från horisontalplanet och har en längd av 200,54 m.

Contents

1 Introduction

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

Drilling is one important activity within the scope of the site investigations. Three main types of boreholes are produced, 1) core drilled respectively 2) percussion drilled boreholes in solid rock and 3) boreholes drilled through regolith. The last type may be accomplished by different drilling techniques, e.g. percussion drilling or auger drilling.

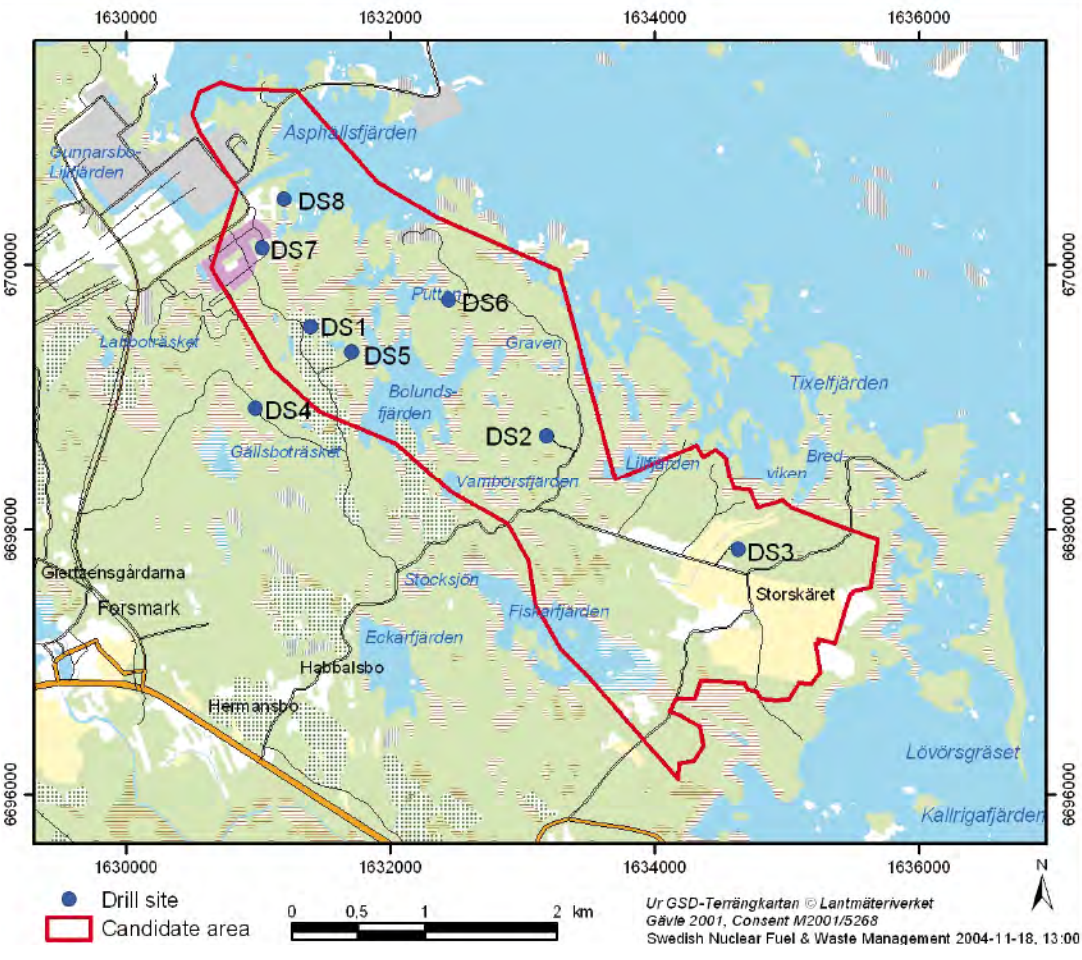


***Figure 1-1.** The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drill sites DS1–8 are marked with blue dots.*

The deepest boreholes drilled at the site investigation are core drilled boreholes in hard rock. So far (October 2005), three sub-vertical and six inclined, approximately 1,000 m long, cored boreholes have been drilled within the investigation area. The locations of the eight drill sites in question, DS1–DS8, are illustrated in Figure 1-1. Also four shorter (c 100–500 m) cored boreholes have been drilled, at drill sites DS1, DS3, DS6 and DS8.

This document reports the data and results gained by drilling the telescopic borehole KFM08A and the core drilled borehole KFM08B at drill site DS8, which is one of the activities included in the site investigations at Forsmark. The work was carried out in compliance with activity plans AP PF 400-04-86 and AP PF 400-04-104.

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

By drilling the deep boreholes, so called telescopic drilling technique is applied, involving that the upper 100 m of the borehole is percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section 100–1,000 m is core drilled with a diameter of approximately 76–77 mm. This technical approach was applied also when drilling KFM08A, which has a total drilling length of 1,001.19 m. The borehole is inclined c 60° from the horizontal plane, entailing that the horizontal extension of the borehole is approximately 500 m. Borehole KFM08A is of the so called SKB chemical-type. This implies that the borehole is prioritized for hydrogeochemical and microbiological investigations, prompting that all DTH (Down The Hole) equipment used during and/or after drilling must undergo special cleaning procedures, see Chapter 4.

In order to compensate for the missing core in borehole section 0–100 m, a shorter, inclined core drilled borehole, KFM08B, was drilled from the surface to 200.54 m borehole length.

Close to the deep borehole at drill site DS8, also a percussion drilled borehole (HFM22) in solid rock has been drilled for two different purposes, firstly to serve as a flushing water well for drilling the core drilled boreholes, and secondly to study two N-S trending lineaments. The length of borehole HFM22 is 222 m. The locations of all boreholes at drill site DS8 are shown in Figure 1-2.

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

Activity plan	Number	Version
Borrning av teleskopborrhål KFM08A	AP PF 400-04-86	1.0
Kärnborrning av KFM08B	AP PF 400-04-104	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för hammarborrning	SKB MD 610.003	2.0
Metodbeskrivning för kärnborrning	SKB MD 620.003	1.0
Metodbeskrivning för registrering och provtagning av spolvattenparametrar samt borrkax under kärnborrning	SKB MD 640.001	1.0
Metodbeskrivning för pumptest, tryckmätning och vattenprovtagning i samband med wireline-borrning.	SKB MD 321.002	1.0
Method instructions	**Number**	**Version**
Rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Användning av kemiska produkter och material vid borrning och undersökning	SKB MD 600.006	1.0
Analys av injektions- och enhålspumptester	SKB MD 320.004	1.0

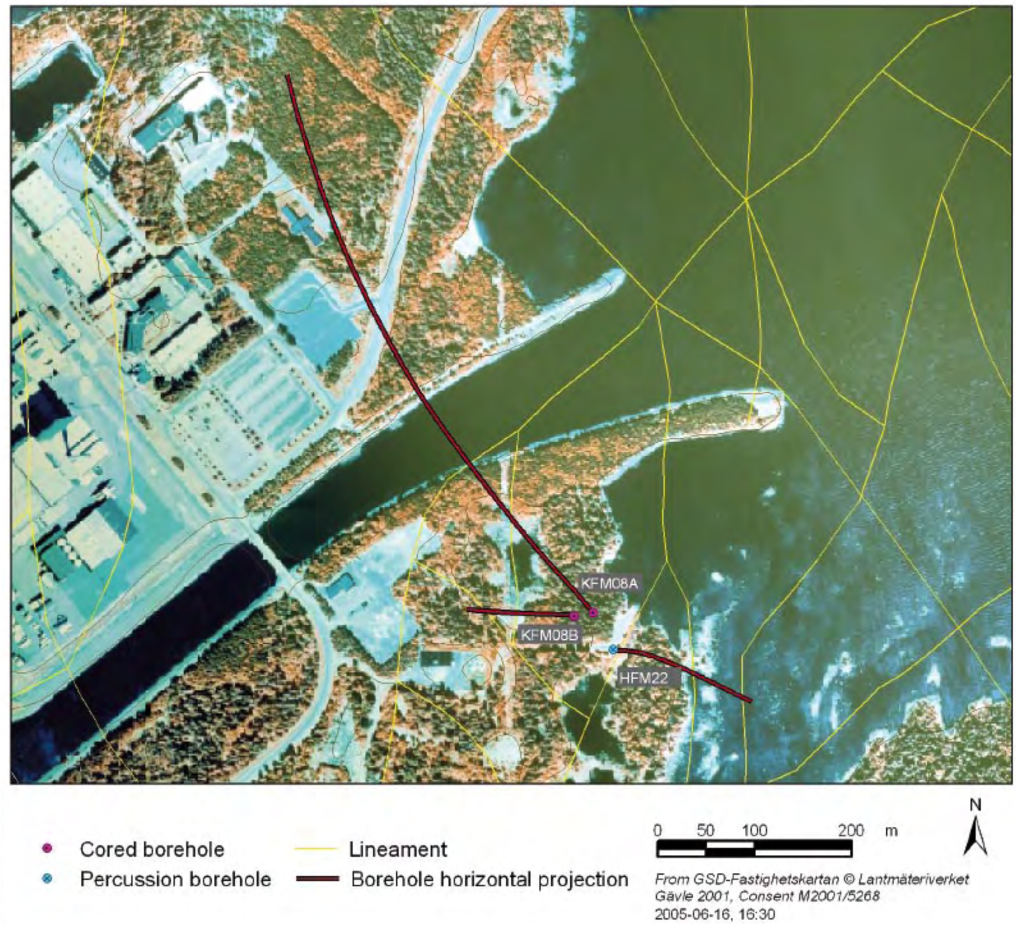


***Figure 1-2.** Borehole locations at drill site DS8. Besides the core drilled boreholes KFM08A and KFM08B, the area incorporates a monitoring well in bedrock (HFM22), also used as flushing water well for the core drilling. The projection of inclined boreholes on the horizontal plane at the ground surface (top of casing) and interpreted lineaments are shown in the figure.*

Drill site DS8 is located in the north-western part of the candidate area, c 500 m from the Forsmark power facilities.

The drilling operations in KFM08A were performed during September 13th 2004 to March 31st 2005, however with a break between September 28th 2004 to January 31st 2005, and between January3rd 2005 to January 26st 2005 in KFM08B. Drillcon Core AB, Nora, Sweden, was engaged for the drilling commission. Two different drilling equipments were employed for drilling KFM08A, a percussion drilling machine for drilling the upper c 100 m, whereas core drilling of the remaining part (section 100.55–1,001.19 m) was carried out with a wireline core drilling system. Borehole KFM08B was performed with a smaller core drilling equipment, however also this supplied with a wireline core drilling system.

In the present report, performance of and results from drilling of KFM08A and KFM08B, are presented. The report also treats investigations made during and immediately after drilling. All data from this activity are stored in the SICADA database and are traceable by the activity plan number.

2 Objective and scope

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

- To provide rock samples from the ground surface to the borehole bottom. Percussion drilling through the overburden produces soil samples recovered to the surface by compressed air. These samples are collected with a frequency of one sample per metre. The same sampling frequency is applied for the drill cuttings produced when percussion drilling the upper c 100 m of the solid rock. Below 100 m, the core drilling provides (in principle) continuous drill cores down to the borehole bottom. In order to compensate for the missing drill core in borehole section 0–100 m in KFM08A, a short cored borehole, KFM08B, was drilled from the same drill site. The rock samples collected during drilling are used for lithological, structural and rock mechanical characterization as well as for determination of transport properties of the bedrock from the rock surface to the full drilling depth.
- To render geophysical borehole investigations possible, e.g. TV logging, borehole radar logging and conventional geophysical logging as an aid for the geological/rock mechanical characterization.
- To allow hydraulic borehole tests (single hole tests as well as interference tests, in some cases performed as tracer tests) for characterization of the hydrogeological conditions.
- To make water sampling possible down to and below repository depth. High-class hydrogeochemical sampling/analysis demands special measures during and after drilling in order to keep the borehole clean. When these measures have been taken, the borehole is categorized as a borehole of chemical type. Only boreholes of this category are approved for advanced hydrogeochemical and microbiological characterization.
- To enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

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

Furthermore, a number of hydraulic tests and water samplings are normally performed during the drilling process, whereby a specifically designed test system, a so called wireline probe, is utilized.

3 Equipment

Two types of drilling machines were employed for drilling borehole KFM08A. The upper c 100 m were drilled with a percussion drilling machine of type Comacchio 1500 S. For core drilling of section 100.55–1,001.19 m, a Wireline-76 core drilling system, type Onram 2000 CCD, was engaged. For drilling borehole KFM08B (0–200.54 m) a third core drilling machine, type Onram 1000, also representing a Wireline-76 core drilling system, was employed

3.1 Percussion drilling equipment

The Comacchio 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 diesel compressor, type Atlas-Copco XRVS 466 Md.

At drill site DS8, the bedrock is covered by approximately three metres of soil. This part had to be cased off with a solid pipe (NO-X 280). During pilot drilling of the section in solid rock, water inflow and unstable rock was observed. Therefore, the borehole was reamed and a stainless casing installed. To obtain a borehole as straight as possible in this type of soil, the choice of technique is important. In this case the NO-X technique was applied, following the principles and dimensions presented in Figure 3-1. The NO-X technique is described more in detail in SKB MD 610.003 (Method Description for percussion drilling). Figure 3-1 is a schematic diagram where the drilling depths presented are approximate. The true depths in the respective drilling sequences performed in KFM08A are presented in Section 5.2.

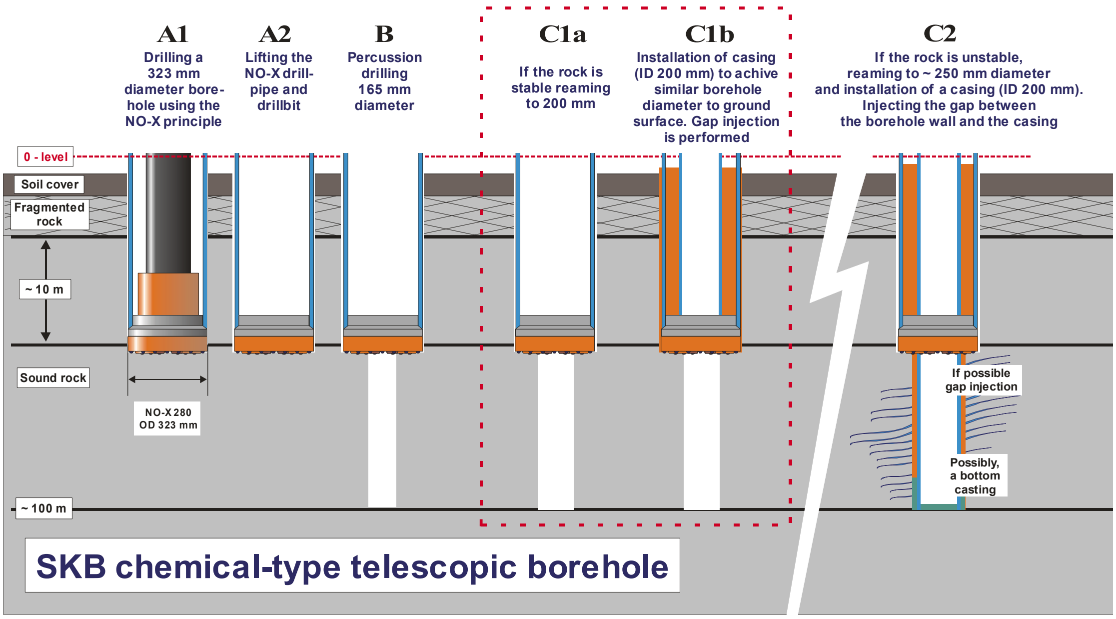


Figure 3-1. Schematic diagram showing the various stages of drilling the 0-100 m section of an SKB chemical-type telescopic borehole. The letters and numerals above each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB MD 620.003, Version 1.0.

3.2 Injection technique

For investigation of the groundwater conditions, especially the hydrogeochemical characteristics, of the cored part of a telescopic borehole, it is essential that the deeper groundwater is not mixed with surface water or groundwater from shallow parts of the bedrock. Therefore, if large inflows of groundwater are met with during percussion drilling of a telescopic borehole, it is essential to prevent it from permeating into deeper parts of the bedrock. This is achieved by cement grouting of water-yielding fractures or fracture zones, as they come across. The simplest method is to fill part of the borehole with cement and to continue drilling after setting of the cement. This is also an effective method to stabilize the borehole wall as well, e.g. if a highly fractured and unstable section is penetrated.

If the percussion drilled part of a telescopic borehole is fractured and water-yielding, it is normally cased to the full drilling length. The gap between the borehole wall and the casing is then cement grouted, which further decreases or, often, completely prevents, inflow of shallow groundwater to the borehole. Application of cement in the gap between the borehole wall and the casing pipe can be performed according to different techniques. Two variants are illustrated in Figure 3-2.

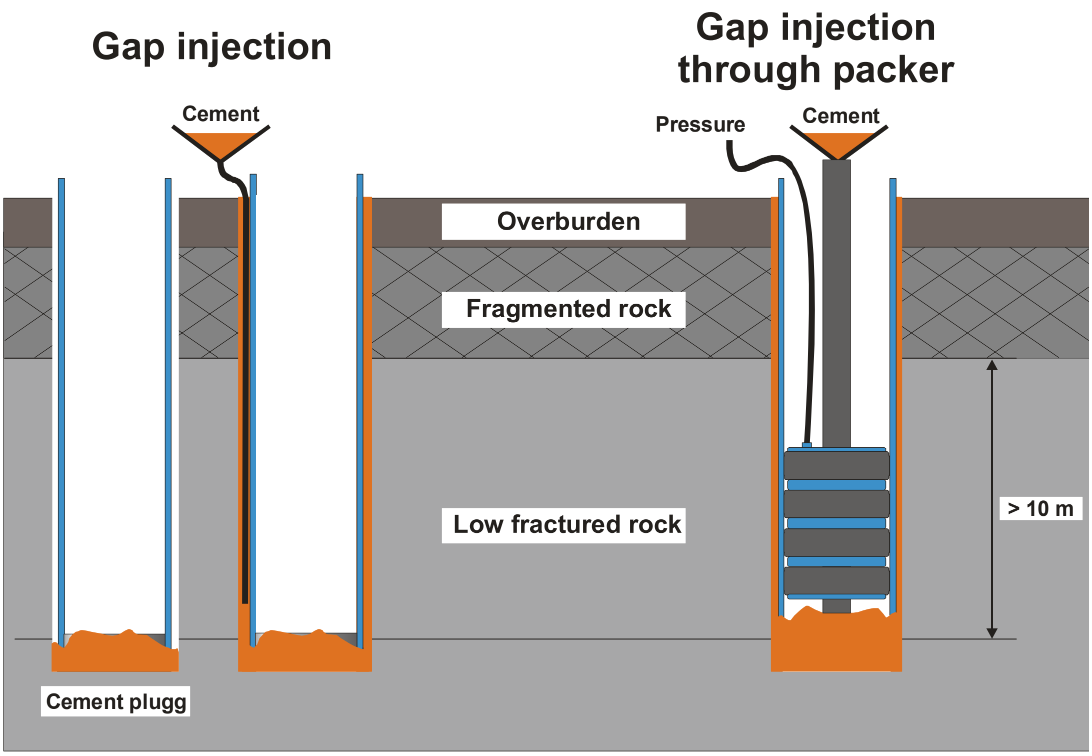


Figure 3-2. *Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer.*

Borehole KFM08A was grouted at two occasions: 1) after installation of the $Ø_i$ 200 mm, 100 m long casing (C2 in Figure 3-1). 2) After installation of the casing, injection through a packer was applied by filling the entire cased part of the borehole in section 97.14–100.55 m, in order to create a new borehole bottom.

Borehole KFM08B was grouted at one occasion: after installation of the $Ø_i$ 78 mm, 5.58 m long casing. After installation of the casing, gap injection through a hose was applied.

3.3 Core drilling equipment

3.3.1 The Wireline-76 system used for drilling KFM08A

For drilling the cored part of borehole KFM08A, a Wireline-76 system, type Hagby Bruk Onram 2000 CCD, was employed. The drilling process is operated by an electrically-driven hydraulic system supplied with a computer control. The drilling capacity for 76–77 mm holes is maximum c 1,500 m. The drill pipes and core barrel used belong to the Hagby WL76 triple-tube system. Technical specifications of the drilling machine with fittings are given in Table 3-1.

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

Unit	Manufacturer/type	Specifications	Remarks
Onram 2000	Hagby-Asahi	Capacity for 76–77 mm holes maximum approx. 1,500 m	
Flush water pump	Bean	Max flow rate: 170 L/min Max pressure: 103 bars	
Submersible pump	Grundfos SQ	Max flow rate: 200 L/min	
Mobile electrical plant	P250HE with diesel engine Perkins GCD 325	250 KVA, 200 kW, 360 A.	
Compressor	Atlas Copco GA75P-13	Max pressure: 12 bars Flow: > 5 L/sec	Electrically supplied
CCD-system	Dunfoss		Standard system modified by the manufacturer for core drilling

3.3.2 The Onram 1000 used for drilling KFM08B

A wireline-76 core drilling system, type Onram 1000, was engaged for the core drilling. The drilling process is operated by an electrically-driven hydraulic system. The drilling capacity for 76 mm holes is maximum c 700 m. Technical specifications of the drilling machine with fittings are given in Table 3-2.

Table 3-2. Technical specifications of the Onram 1000-system from Hagby-Asahi with appurtenances.

Unit	Manufacturer/type	Specifications	Remarks
Onram 1000	Hagby-Asahi	Capacity for 76 mm holes maximum approx. 700 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.	

3.3.3 Flushing/return water system – function and equipment

Core drilling involves pumping of flushing water down the drill string, through the drill bit and out into the borehole in order 1) to conduct frictional heat away from the drill bit, and 2) to enhance the recovery of drill cuttings to the ground surface. The cuttings, suspended in the flushing water (in general mixed with groundwater), are forced from the borehole bottom to the ground surface via the gap between the borehole wall and the drill pipes. However, if the borehole has penetrated water conductive rock fractures, part of, and sometimes all of the return water from the borehole, including drill cuttings, may be forced into these fractures. This renders a correct characterization of the in situ hydraulic and hydrogeochemical conditions more difficult, due to partial or complete clogging by drill cuttings and due to the contribution of 'foreign' flushing water in the fracture system.

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

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

Preparing the flushing water

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

The water well used for the supply of flushing water for core drilling of KFM08A and KFM08B was a percussion drilled well in hard rock, HFM22, situated ca 35 m southeast of DS8. Besides the basic demands on the flushing water quality, which were fulfilled when drilling KFM08A and KFM08B, the flushing water was also prepared in three steps before use, in accordance with SKB MD 620.003 (Method description for core drilling).

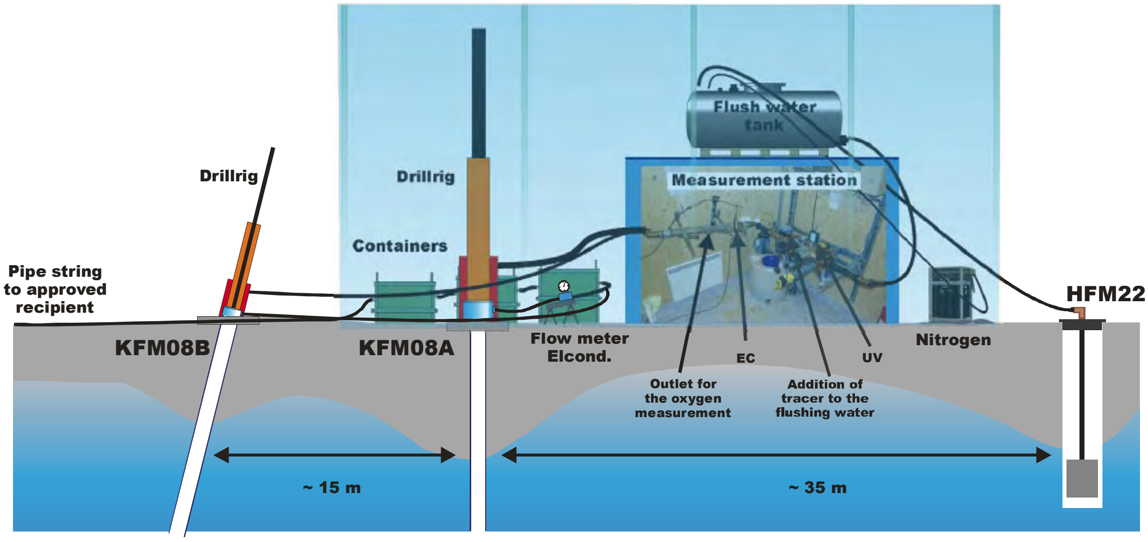


Figure 3-3. *Schematic illustration of the flushing/return water system when drilling KFM08A and KFM08B at DS8. The measurement station included logger units and an UV-radiation unit. For flushing water flow rate and pressure measurements, the drilling machine gauges were applied.*

1) Incoming water from the water well was pumped into the flush water tank (see Figure 3-3).
2) Nitrogen was bubbled through the water in the tank in order to expel oxygen which might be dissolved in the water (see Figure 3-3). Expelled oxygen was discharged through a pressure reducing valve. Oxygen must be avoided in the flushing water because it is a critical parameter in the programme for hydrogeochemical characterization of the groundwater. The water was then kept continuously under a positive nitrogen pressure (about 1 bar) until pumped down into the borehole.
3) After leaving the water tank, the flushing water was exposed to UV-radiation (inside the measurement station) before entering the tracer doser equipment, illustrated in Figure 3-3. The microbe content in the water was thereby radically reduced.
4) An organic tracer dye, Uranine, was added by the tracer doser at a concentration of 0.2 mg/L, before the water was pumped into the borehole, see Figure 3-3. Labelling the flushing water with the tracer aims at enabling detection of the flushing water content in groundwater samples collected in the borehole during or after drilling.

Measurement of flushing water parameters

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

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

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

The total quantity of water supplied to the borehole is double-checked by comparing the readings from the SKB flow meter and the flow meter on the drill rig.

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

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

Air-lift pumping while drilling

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

The air-lift pumping equipment in KFM08A consisted of the following main components, see Figure 3-4:

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

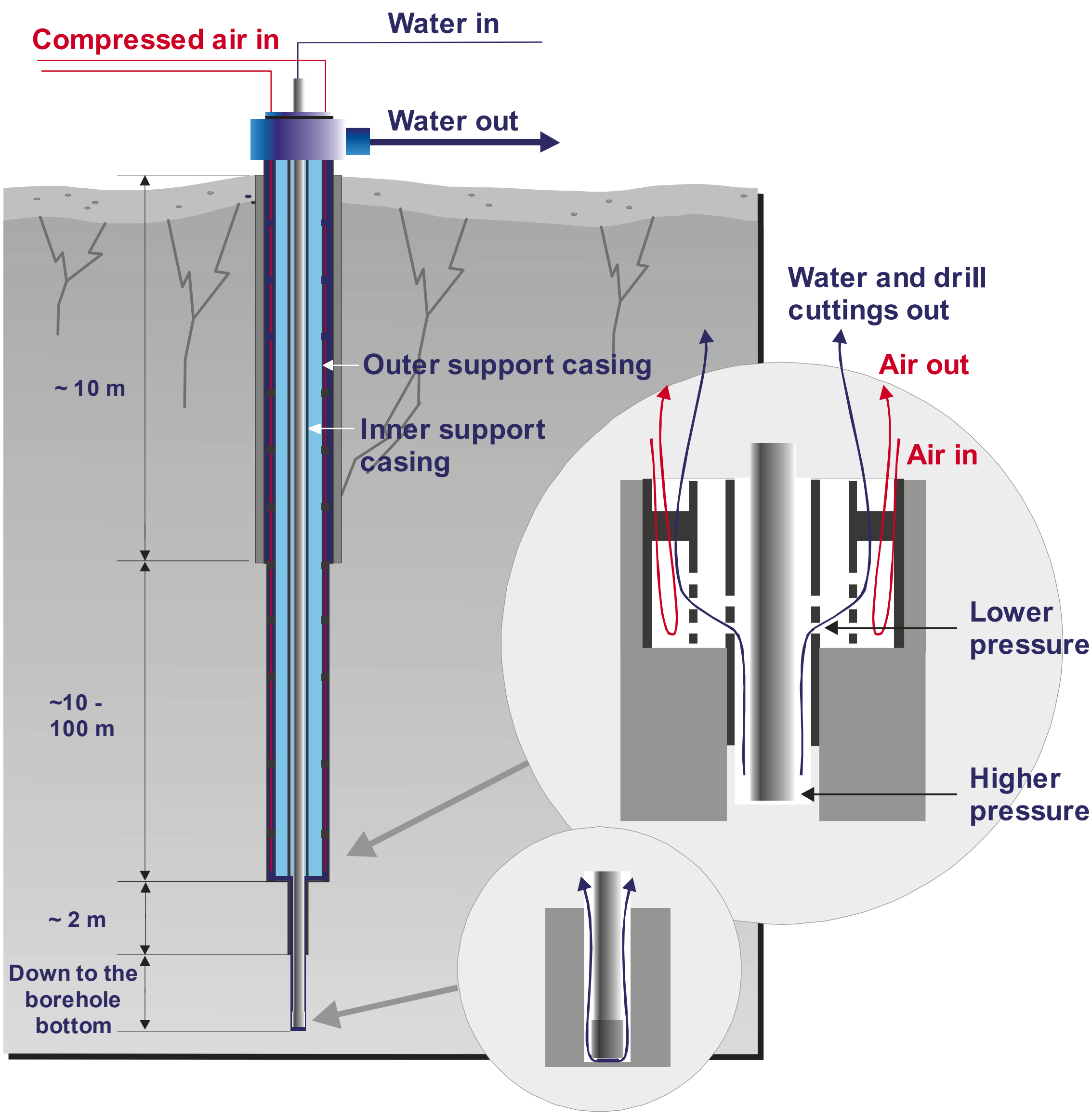


Figure 3-4. *Air-lift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole.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

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

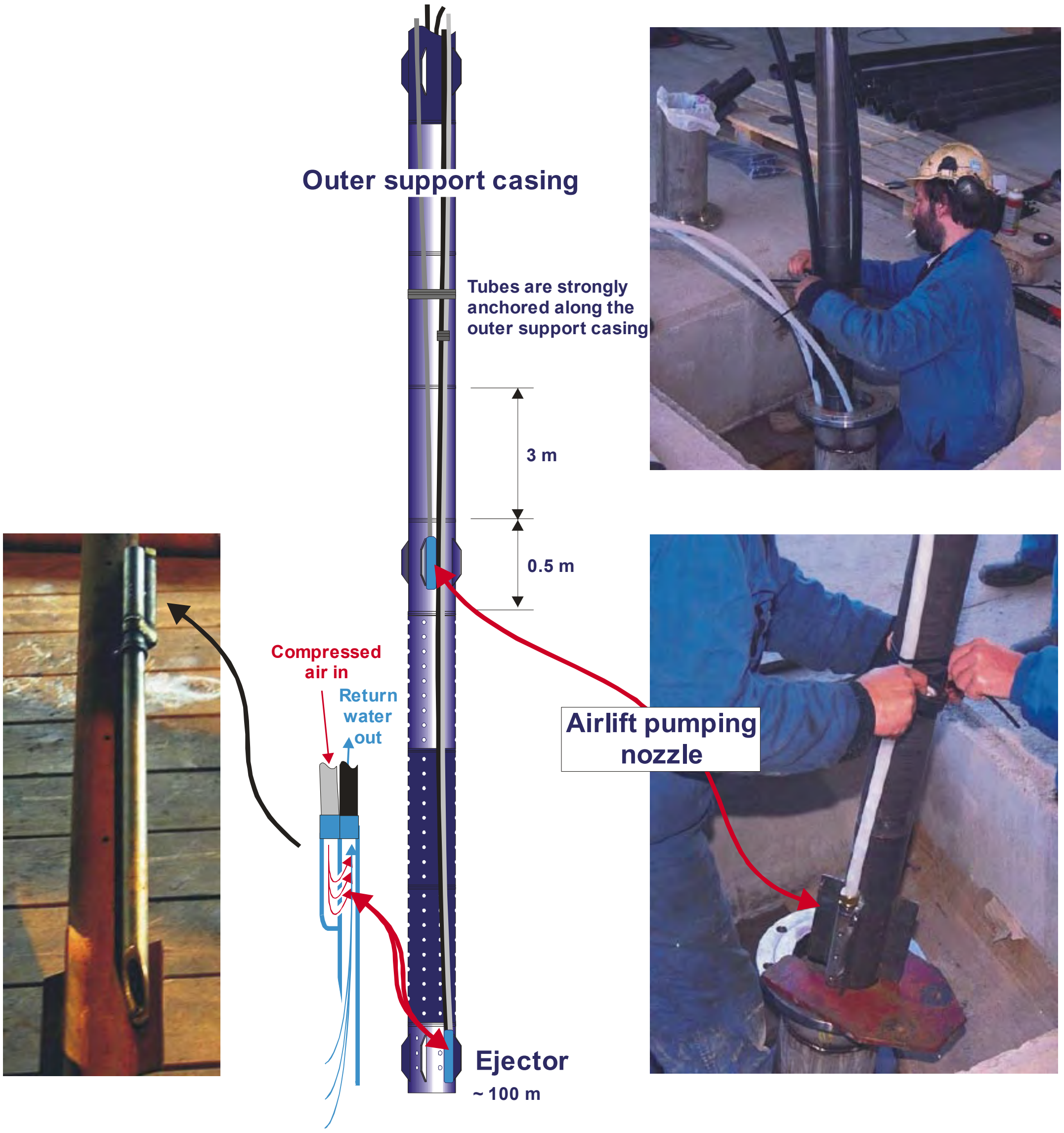


Figure 3-5. *Schematic representation of connection and installation of air-lift pumping nozzle and ejector on the outer protective casing.*

Storage and discharge of return water for KFM08A

At the surface level, the return hose was connected to a return pipe between the discharge head and the first return water container, see Figures 3-3 and 3-6. The return water was discharged from the borehole via the expansion vessel and a flow meter to three containers, in which the drill cuttings separated out in three sedimentation steps. The cuttings were preserved in the containers for later weighing. Due to environmental restrictions, the return water was pumped through an exit pipe string directly to the Baltic Sea.

The flow rate and electrical conductivity of the return water was measured and data stored in the data-logging system. Technical specifications of the measurement instruments are given in Table 3-4.

Flow rate- and other flushing water data were continuously stored in an automatic data-logging system, see Section 3.3.4. As a back-up and double-check, the total quantity of water supplied to the borehole was acquired by counting the number of filled water tanks used, multiplied by the tank volume.

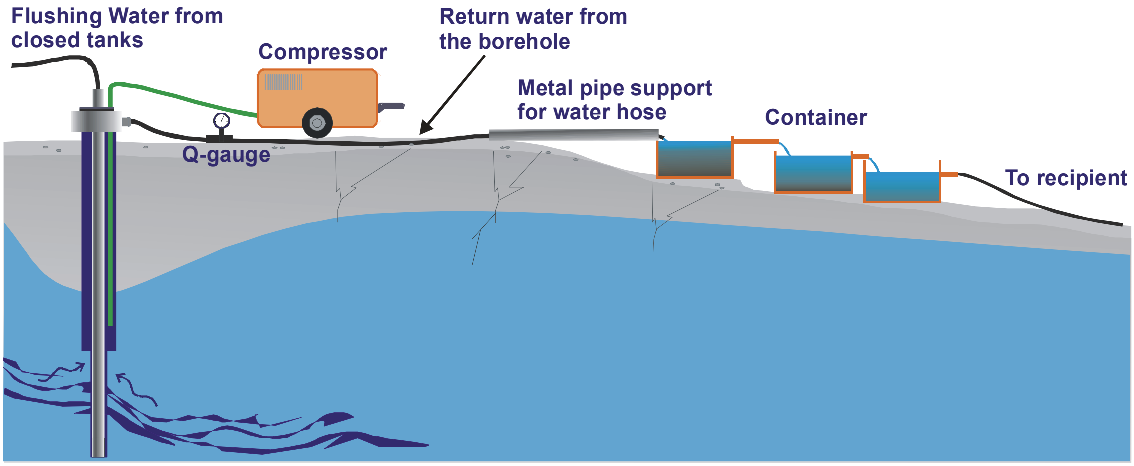


Figure 3-6. *Return water system. Air-lift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in three stages in the containers (where it is preserved for later weighing), after which the water is pumped to an approved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

Table 3-4. Technical specifications for instruments used for measurement of return water parameters.

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

3.3.4 Drilling monitoring system

The ONRAM 2000-CCD drilling machine is supplied with a computer based logging kit integrated in the steering system (cf Section 3.3.1). The parameters logged are those used for automatic operation of the drilling machine. During drilling of the earlier telescopic boreholes, KFM01A to KFM04A, quality problems with the core and the borehole wall were observed from time to time. Therefore an upgraded software was installed and some parts of the steering system were exchanged already prior to drilling of borehole KFM05A. The new software and equipment have been in use since then.

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

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

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

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

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

- electric conductivity,
- dissolved oxygen,

as well as the return water parameters:

- flow rate,
- electric conductivity.

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

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

3.3.5 Equipment for deviation measurements

During drilling of borehole KFM08A, deviation measurement were made at one occasion, in order to check the straightness of the borehole. The measurement, which was made after completion of drilling as a final deviation measurement, was performed with a Reflex MAXIBOR™, which is an optical, i.e. non-magnetic, measurement system. Azimuth and dip are determined 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. Also in KFM08B one deviation measurement with the Reflex MAXIBOR™ system was carried out after completed drilling.

3.3.6 Equipment for hydraulic tests, absolute pressure measurements and water sampling during drilling in KFM08A

It is stated in SKB MD 620.003 that hydraulic tests, absolute pressure measurements and water sampling should be performed at certain intervals using a down-hole tool specially designed for the Wireline-76 system. The tool, which is denominated “the wireline probe” or “WL-probe”, is described in SKB MD 321.002, see Table 1-1.

4 Execution

4.1 Percussion drilling of borehole section 0–100 m in KFM08A

The percussion drilling operations included:

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

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

4.1.1 Preparations

The preparation stage included the Contractor's service and function control of his equipment. The machinery was obliged to be supplied with fuel, oil and grease exclusively of the types stated in SKB MD 600.006, see Table 1-1. Finally, the equipment was cleaned in accordance with the cleaning instruction in SKB MD 600.004, see Table 1-1, for boreholes of SKB chemical type.

4.1.2 Mobilization

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

4.1.3 Drilling, measurements and sampling during drilling

The percussion drilling started with drilling through the overburden during simultaneous casing driving and subsequent gap injection. These activities followed the principles described in Sections 3.1 and 3.2. The borehole was drilled and cased with NO-X 280 to 9.14 m. During pilot drilling with Ø 164 mm to 100.55 m, a water inflow and unstable rock was observed. Therefore the borehole section 9.14 m to 100.45 m was reamed to 250 mm.

In order to seal water-yielding fractures in the percussion drilled section, the gap between the casing and borehole wall was grouted using the packer technique illustrated in Figure 3-2. After grouting, the recharge of water into the borehole ceased completely.

Measurements and sampling while percussion drilling (and immediately after drilling) were performed according to a specific measurement/sampling programme, which was applied in association with the Ø 164 mm drilling sequence. The measurement/sampling programme performed was in accordance with SKB MD 610.003, see Table 1-1, and included:

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

After completion of drilling with the Ø 250 mm drill bit, deviation measurements were made.

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

4.1.4 Finishing off work

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

4.1.5 Nonconformities

When checking that the borehole was cleaned from the cement grouting, a 195 mm drill bit was almost jammed at c 97 m borehole length due to deformation of the casing.

As a deformation of the stainless steel casing would make it difficult mounting the air-lift pumping equipment as well as the transition cone, it was decided to create a new borehole bottom by filling the borehole with cement grout just above the damaged part of the casing. Cement, reinforced with ballast, was applied and after hardening a new borehole bottom was created at 97.14 m.

4.2 Core drilling of KFM08A

The core drilling operations included:

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

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

4.2.1 Preparations

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

4.2.2 Mobilization

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

4.2.3 Drilling, measurements and sampling during drilling

Core drilling of borehole KFM08A was performed with two borehole dimensions. Section 97.14–102.40 m was drilled with a borehole diameter of 86.0 mm, whereas the main part of the borehole, section 102.40–1,001.19 m, was drilled with Ø 77.3 mm. The inner Ø 84/77 mm support casing was fitted into the short Ø 86 mm borehole. In this way the casing was centralized in the borehole and fixed laterally. The outer Ø 98/89 mm support casing is resting on the bottom of the percussion drilled borehole, see Figure 3-4.

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

Core drilling with a wireline system involves recovery of the core barrel via the drilling pipe string, inside which it is hoisted up with the wireline winch. During drilling of borehole KFM08A, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 77.3 mm part of the borehole is 50.8 mm. Minor deviations from this diameter may, however, occur.

Like the percussion drilling, the core drilling is associated with a programme for sampling, measurements and other activities during and immediately after drilling, cf SKB MD 620.003 (Table 1-1). However, for different reasons, during drilling of KFM08A some deviations from this programme could not be avoided. In order to elucidate the nonconformities, the programme according to the Method Description is presented in Section 4.2.4, Table 4-1, together with the actual performance when drilling KFM08A.

Results from mapping of the drill core samples are presented in /3/, whereas the remaining measurements and registrations during core drilling are presented in Chapter 5.

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

The concluding work included the following items:

1) The borehole was flushed for about 10 hours during simultaneous air-lift pumping in order to clean it from drilling debris adhered to the borehole walls, sedimented at the bottom of the hole or suspended in the water. After finished flushing/air-lift pumping, the recovery of the groundwater table was registered as an estimate of the hydraulic conditions of the entire borehole. The results are presented in Chapter 5.
2) The drill string was pulled.
3) The inner support casing was removed with aid of a crane lorry.
4) The outer support casing was removed with the same crane lorry.
5) The discharge head was removed.
6) Using the drill rig, a stainless steel transition cone was installed between the reamed and cased percussion drilled respectively the cored part of the borehole, as shown in Figure 5-4. The cone is located at 94.08–102.26 m.
7) The borehole was again secured with the lockable stainless steel flange.
8) The core drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the Contractor.

4.2.4 Nonconformities

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

Table 4-1. Programme for sampling, measurements, registrations and other activities during and immediately after core drilling according to SKB MD 620.003 compared to the actual performance during drilling of borehole KFM08A.

Activity	Performance and frequency according to SKB MD 620.004	Performance and frequency during drilling of KFM08A
Registration of drilling- and flushing water parameters.	Described in Section 3.3.4. Registration during the entire drilling.	According to programme.
Registration of the groundwater level in the borehole during drilling.	Every 10th second.	According to programme.
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	One measurement with the Maxibor system 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.	Values presented in Figure 5-21 are from material properties of the drill pipe string.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drilling pipe string should be controlled before each test.	No pumping test was made.
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drilling pipe string should be controlled before each test.	One sample was collected at about 200 m. Below this length the inflow of water was low. The samples was taken at open hole conditions, from water pumped to the ground surface. The WL-probe was not used.

Absolute pressure measurements.	Normally during natural pauses in drilling.	Four measurements were performed.
Groove milling in the borehole wall, normally at each 100 m.	Normally performed after completion of drilling.	Eigthteen millings performed.
Collecting and weighing of drilling debris.	Drilling debris settled in containers weighed after finished drilling.	Not carried out for the percussion drilled part of the borehole. According to programme for the core drilled part.
Flushing of the entire borehole.	After finishing the borehole.	Ordinary flushing combined with nitrogen flushing.

The next last item in Table 4-1 may be commented on. All drilling debris produced during drilling (percussion drilling as well as core drilling) was collected in the sedimentation containers of the return water system, see Figures 3-3 and 3-6 (except the finest fractions which stayed suspended in the discharge water from the third container). The collected drill cuttings from the core drilled part were weighed after completed drilling in order to get a measure of the drill cuttings recovery.

4.3 Core drilling of KFM08B

Borehole KFM08B is located close to borehole KFM08A, drilled from a separate concrete slab at DS8, see Figure 1-2. The preparation and mobilization followed the same procedure as for KFM08A, see sections 4.2.1 to 4.2.2.

4.3.1 Drilling, measurements and sampling during drilling

The soil (4.92 m drill length) was drilled with a Ø 93 mm core barrel. Thereafter core drilling and reaming to 5.58 m commenced, and a casing with Ø 90 mm was installed. The gap between the casing and the borehole wall was cement grouted, after which core drilling with Ø 76.2 mm, entailing a core diameter of 51 mm to 200.54 m was performed.

During drilling of borehole KFM08B, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 76.3 mm part of the borehole is 50.8 mm. Minor deviations from this diameter may, however, occur.

Results from mapping of the drill core samples are presented in /3/, whereas the remaining measurements and registrations during core drilling are presented in Chapter 5.

The concluding work included the following items:

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

4.4 Data handling

4.4.1 Performance

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

4.4.2 Nonconformities

None.

4.5 Environmental programme

4.5.1 Performance

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

4.5.2 Nonconformities

None.

5 Results

This chapter is structured as follows:

- Section 5.1 – an overview of the drilling progress of KFM08A and KFM08B.
- Section 5.2 – geometrical data and technical design of KFM08A.
- Section 5.3 – results from percussion drilling of KFM08A.
- Section 5.4 – results from core drilling of KFM08A.
- Section 5.5 – geometrical data and technical design of KFM08B.
- Section 5.6 – results from core drilling of KFM08B.

Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling. Well Cad-presentations of boreholes KFM08A and KFM08B are shown in:

- Appendix A (percussion drilled part of KFM08A).
- Appendix B (the complete KFM08A).
- Appendix C (complete KFM08B).
- Appendix D (water composition).
- Appendix E (absolute pressure measurements).

5.1 Drilling progress

Drilling of borehole KFM08A was carried out during three periods between September 2004 and early April 2005. KFM08B was drilled during a couple of weeks in January 2005. Because preparation of both drill sites DS7 and DS8 was performed simultaneously, percussion drilling of KFM07A and KFM08A and associated water wells was conducted in immediate succession in mid 2004. During the last months of 2004, core drilling of KFM07A was accomplished, whereupon drilling of both KFM08A and KFM08B was performed during a period of approximately 4 months, see Figure 5-1.

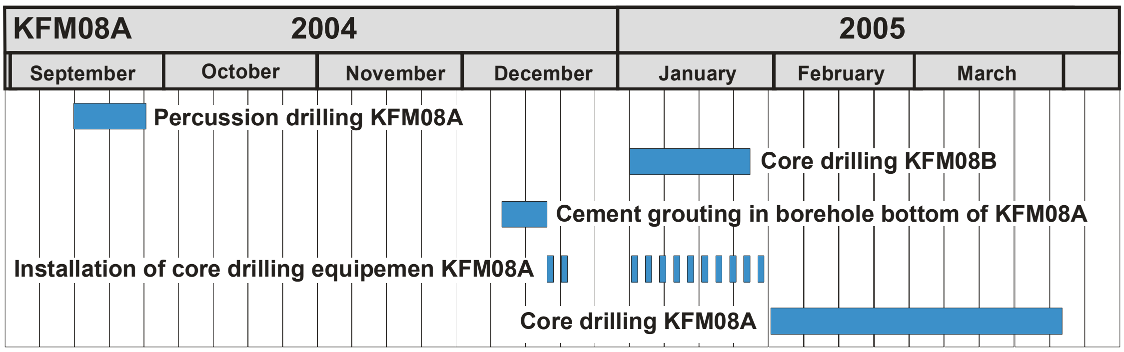


Figure 5-1. *Overview of the drilling performance of borehole KFM08A and KFM08B.*

5.1.1 Percussion drilling period

Percussion drilling is normally a rapid drilling method compared to core drilling. Initially, percussion drilling of KFM08A worked out extraordinarily well. However, the final quality control showed that the casing was deformed at c 97 m. To solve the problem, some measures were taken in mid December 2004, which did not delay the general time schedule, although it involved some increased expenditure.

The duration of the different operations included in the percussion drilling from 2004-09-13 to 2004-09-27 together with that for the above mentioned extra work in December is presented in Figure 5-2.

5.1.2 Core drilling period

After percussion drilling of section 0–100.55 m, followed by a three months break, core drilling commenced. The progress of the core drilling from 2005-01-31 to 2005-03-31 and the concluding works is illustrated in Figure 5-3. The pace of the drilling progress decreased versus time, due to that with increasing borehole length, retrieval of the core barrel, e.g. for change of drill bit, became more and more time consuming.

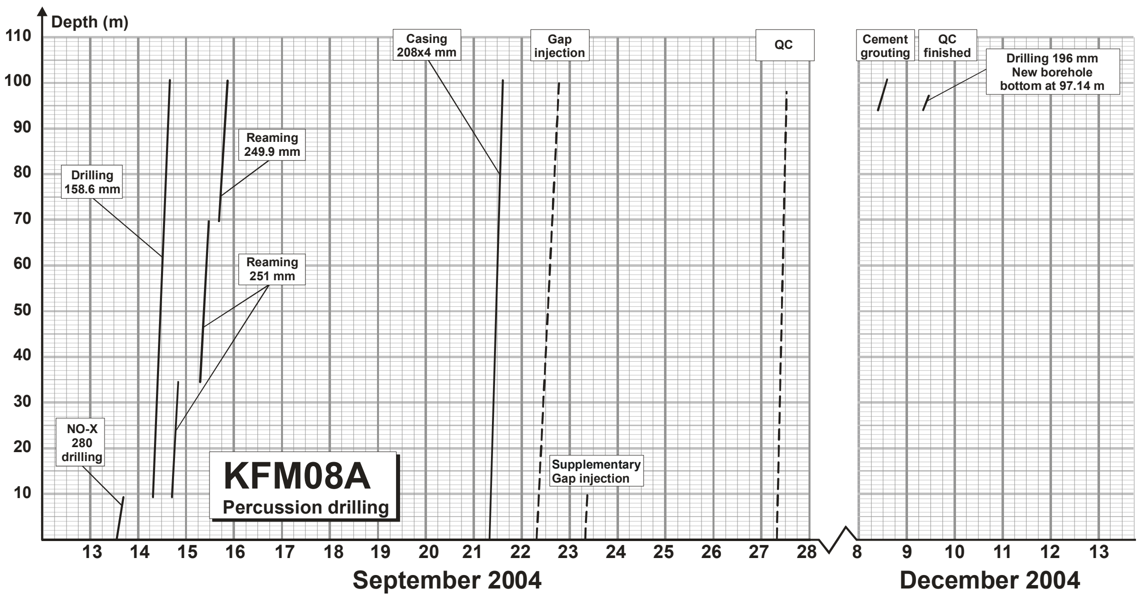


Figure 5-2. Percussion drilling progress (depth and activity versus calendar time).

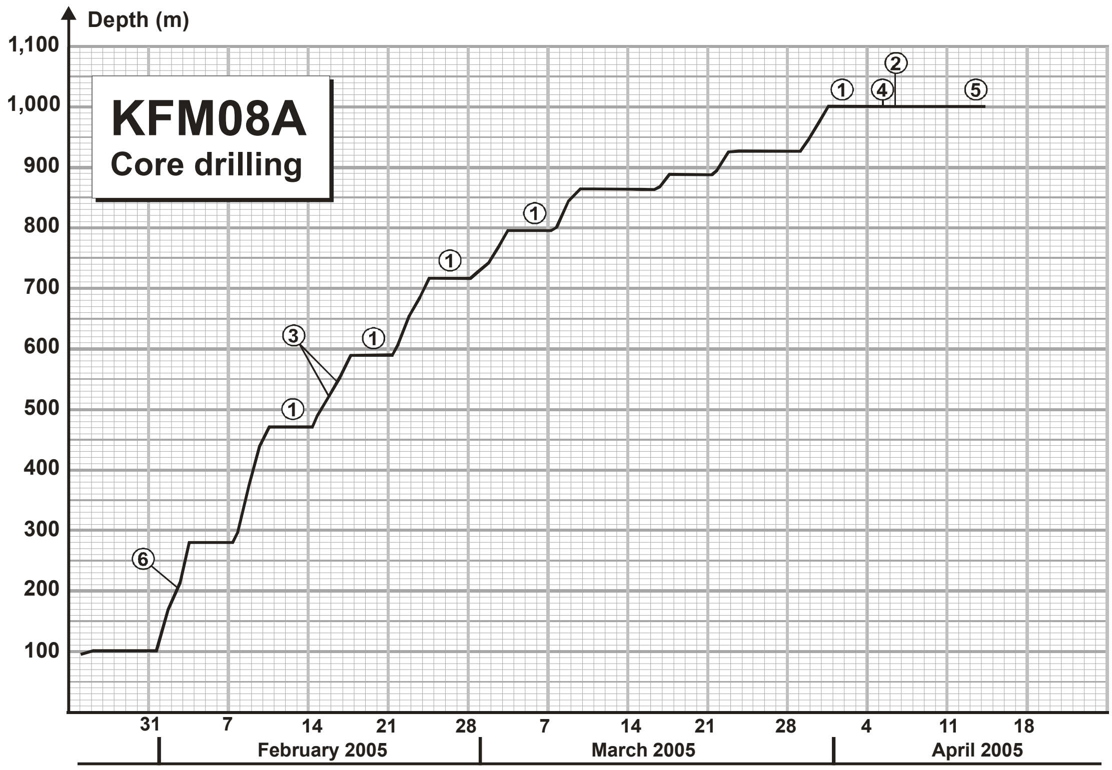


Figure 5-3. *Core drilling progress (depth versus calendar time). ① WL-test, ② deviation measurement (Maxibor), ③ over-coring tests, ④ groove milling, ⑤ mounting the transition cone, ⑥ water sample.*

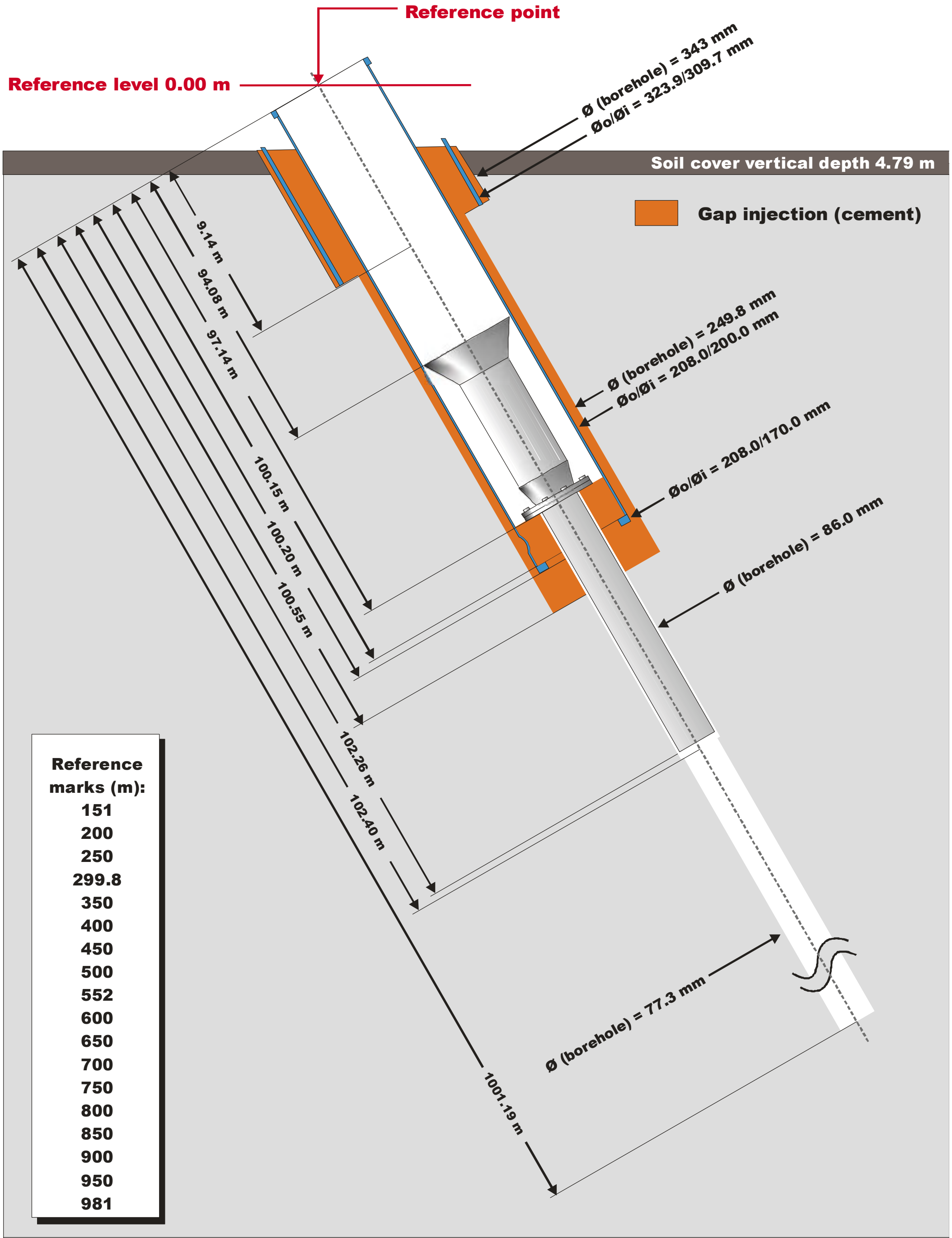
5.2 Geometrical and technical design of borehole KFM08A

Geometric and technical data together with some basic administrative information for the telescopic borehole KFM08A 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 KFM08A.

Parameter	KFM08A
Borehole name	KFM08A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	September 13, 2004
Completion date	March 31, 2005
Percussion drilling period	2004-09-13 to 2004-09-27
Core drilling period	2005-01-31 to 2005-03-31
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Sven Andersson i Uppsala AB
Percussion drill rig	Commachio 1500
Core drill rig	ONRAM 2000 CCD
Position KFM08A at top of casing (RT90 2.5 gon V 0:–15/RHB 70)	N 6700494.49 E 1631197.06 Z 2.49 (m a s l) Azimuth (0–360°): 321.00° Dip (0–90°): –60.89°
Position KFM08A at bottom of hole (RT90 2.5 gon V 0:–15/RHB 70)	N 6701049.55 E 16300881.26 Z –752.602 (m a s l) Azimuth (0–360°): 345.75° Dip (0–90°): –36.39°
Borehole length	1,001.19 m
Borehole diameter and length	From 0.00 m to 9.14 m: 0.343 m From 9.14 m to 100.45 m: 0.250 m From 100.45 m to 100.55 m: 0.159 m From 100.55 m to 102.40 m: 0.086 m From 102.40 m to 1,001.19 m: 0.077 m
Casing diameter and drilling length	$Ø_o/Ø_i$ = 324 mm/310 mm to 9.14 m $Ø_o/Ø_i$ = 208 mm/200 mm to 100.15 m Casing shoe $Ø_i$ = 170 mm between 100.15 and 100.20 m
Cement grouting in casing	97.14–100.55 m
Transition cone inner diameter	At 94.08 m: 0.195 m At 102.26 m : 0.080 m
Drill core dimension	100.55–1,001.19 m/Ø 51 mm
Core interval	100.55 –1,001.19 m
Average length of core recovery	2.78 m
Number of runs	323
Diamond bits used	20
Average bit life	45.0 m

Technical data
Borehole KFM08A



Drilling reference point

Northing: 6700494.49 (m), RT90 2,5 gon V 0:-15
Easting: 1631197.06 (m), RT90 2,5 gon V 0:-15
Elevation: 2.49 (m), RHB 70

Orientation

Bearing (degrees): 321.00°
Inclination (degrees): -60.89°

Borehole

Length: 1001.19 m

Percussion drilling period

Drilling start date: 2004-09-13
Drilling stop date: 2004-09-27

Core drilling period

Drilling start date: 2005-01-31
Drilling stop date: 2005-03-31

Ver 2005-08-17

Figure 5-4. Technical data of borehole KFM08A.

5.3 Percussion drilling 0–100.55 m of borehole KFM08A

5.3.1 Drilling

As mentioned in Section 4.1.3, the upper section to 9.14 m of the borehole was drilled and cased with NO-X 280. During pilot drilling to 100.55 m, a water inflow of 50 L/min and unstable rock was observed at c 25 m. Therefore the borehole section 9.14 m to 100.55 m was reamed to 250 mm, and a stainless steel casing was installed. The gap between the casing and borehole wall was cement grouted, so that the water inflow ceased completely.

Finally, when checking that the borehole was cleaned from cement grout, a 195 mm drill bit was almost jammed at c 97 m borehole length. A televiewer measurement confirmed that the casing was buckled, see Figure 5-5.

As the deformation of the stainless steel casing would make it difficult mounting the air-lift pumping equipment as well as the transition cone, it was decided to create a new borehole bottom by filling the borehole with cement grout just above the damaged part of the casing.

A special cement type, reinforced with ballast, was applied and after hardening a new borehole bottom was created at 97.14 m.

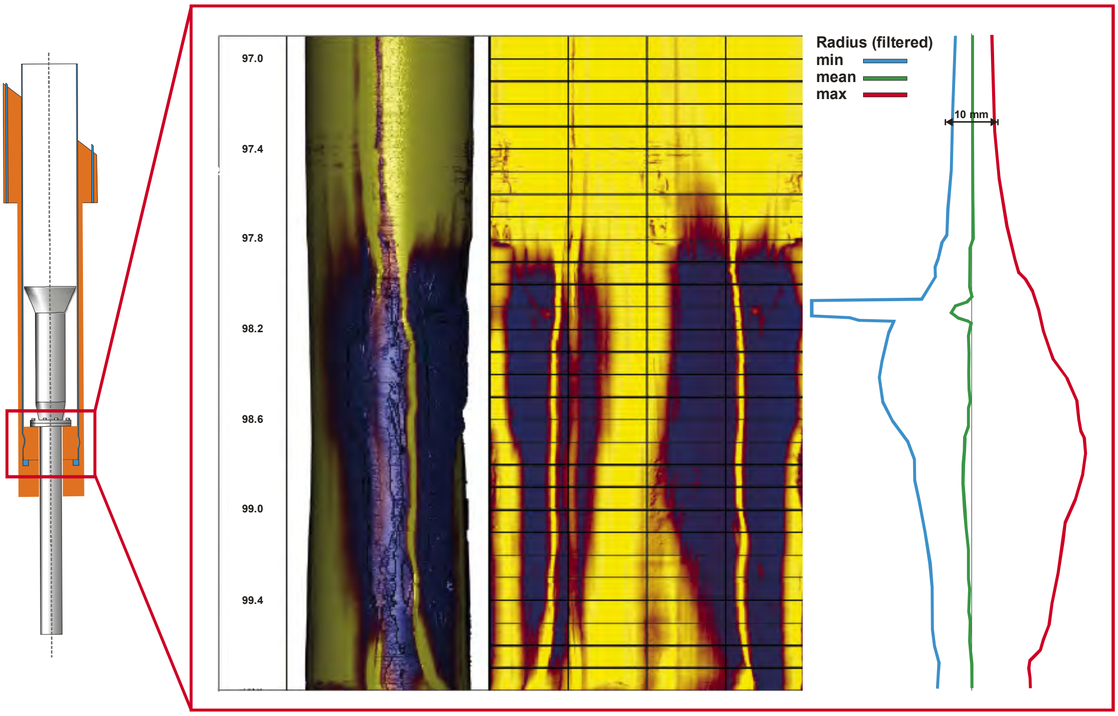


Figure 5-5. *The televiewer measurement performed in KFM08A showed that the casing is deformed in section 97.4 m to approximately 100 m. A hole in the casing wall is also indicated at 98.10 m. The minimum casing diameter is estimated at c 180 mm.*

5.3.2 Measurements while drilling

During, and immediately after drilling, a program for sampling and measurements was applied, cf Section 4.1.3. Some of the results are displayed in the Well Cad-presentation in Appendix A (deviation measurements, penetration rate and rock type distribution), whereas other results (flow data and electrical conductivity) are only used as supporting data for on-site decisions. Below, the results of the deviation measurements made after completed percussion drilling of KFM08A are commented on.

Borehole deviation

The end (bottom) point of the percussion borehole deviates approximately 1.2 m upwards and 2.8 m to the left compared to an imagined straight line following the dip and strike of the borehole collaring point (inclination –60.89º and bearing 321.00º).

5.4 Core drilling 100.55–1,001.19 m of borehole KFM08A

5.4.1 Drilling

The bedrock in the Forsmark tectonic lens has turned out to be relatively hard to drill, probably to a large extent depending on the high quartz content. As drill site DS8 is located in the very north-western part of the tectonic lens, close to the border towards another rock domain, the bedrock composition was assumed to be of somewhat different character than in the rest of the Forsmark candidate area. However, no major lithological changes were observed except towards the end of the borehole, below 850 m, where an interplay between volcanic rocks and amphibolites and pegmatites is observed. Also in KFM08A the fractures frequency in the core drilled part is low, 1.5 fracture/m in section 100.55–1,001.19 m, although not as low as in e.g. KFM07A /5/. The total groundwater inflow from the borehole was estimated at 20–25 L/min at a drawdown of c 40 m. The major part of that inflow is observed at c 198 m.

In spite of the small geological differences observed in KFM08A compared to previously drilled boreholes, drilling of this borehole resulted in the longest life-time of drill bits obtained so far during the site investigations. In average, the life-time was 45 drilled m per drill bit in KFM08A, which is 7.4 m more than in KFM07A /5/ and 18 m more than in KFM01A /7/. When comparing these figures, it should however be remembered that different types of drill bits have been tested during the site investigation at Forsmark, and that the bit life-time is also depending on the type and quality of the bits used.

The rock stresses within the Forsmark candidate area are believed to be relatively high. During drilling of KFM08A, which is striking approximately in the same direction as the major principal stress, two sections in KFM08A were pilot-drilled and then over-cored, as a test of the tendency of core discing at depth. Sections at 519.43 m and at 543.41 m were pilot drilled, and then successfully over-cored, see Figure 5-6.

During, and immediately after drilling, a program for sampling, measurements, registration of technical and geoscientific parameters and some other activities was applied, as described in Section 4.2.3. The results are presented in Sections 5.4.2–5.4.14 below. Mapping of the drill core samples from KFM08A is presented in /3/.

Figure 5-6. Two sections in KFM08A were tested regarding the tendency of core discing. To the left, a successfully overcored (without core discing) 62 mm core from c 519 m borehole length, and to the right, a likewise successfully overcored 51 mm core from c 543 m.

5.4.2 Registration of drilling parameters

A selection of results from drilling parameter registration is presented in diagrams below. The data from this activity are stored in the SICADA database and are traceable by the Activity Plan number.

Drill bit position versus time

Figure 5-7 illustrates how drilling proceeded versus time. Generally, drilling ran 24 hours a day from Monday to Thursday with a weekend stop from Thursday night to Monday morning. Figure 5-7 serves as a basis for Figure 5-3, which it should be compared with.

Penetration rate

The penetration rate, see Figure 5-8, was in average very similar to that when drilling KFM06A /4/ and KFM07A /5/. Initially, the penetration rate was c 12 cm/min, but in section 200–450 m it is increased to c 14–16 cm/min, with peaks sometimes exceeding 20 cm/min. In section 450–600 m, the penetration rate falls back and is almost constant at c 12 cm/min, followed by a section of high peaks in section 600–700 m. Further down the penetration rate is slightly decreasing, corresponding to the increasing frictional resistance of the return water flow, which is observed during drilling of all deep cored boreholes. This reduces the retrieval of drill cuttings and slows down the penetration rate.

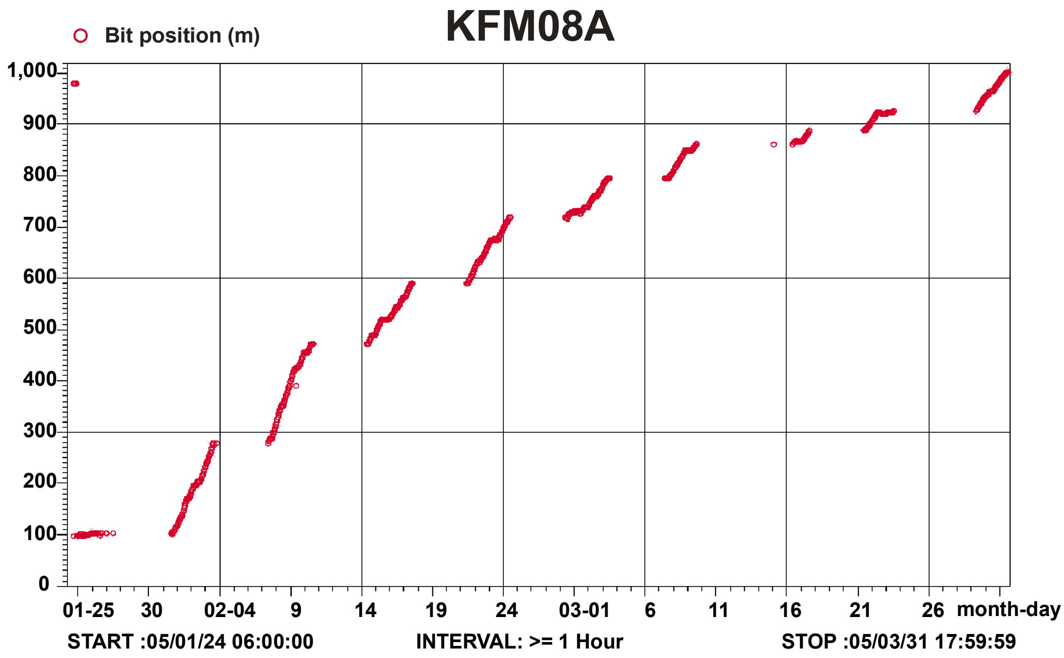


Figure 5-7. *Drill bit position versus time.*

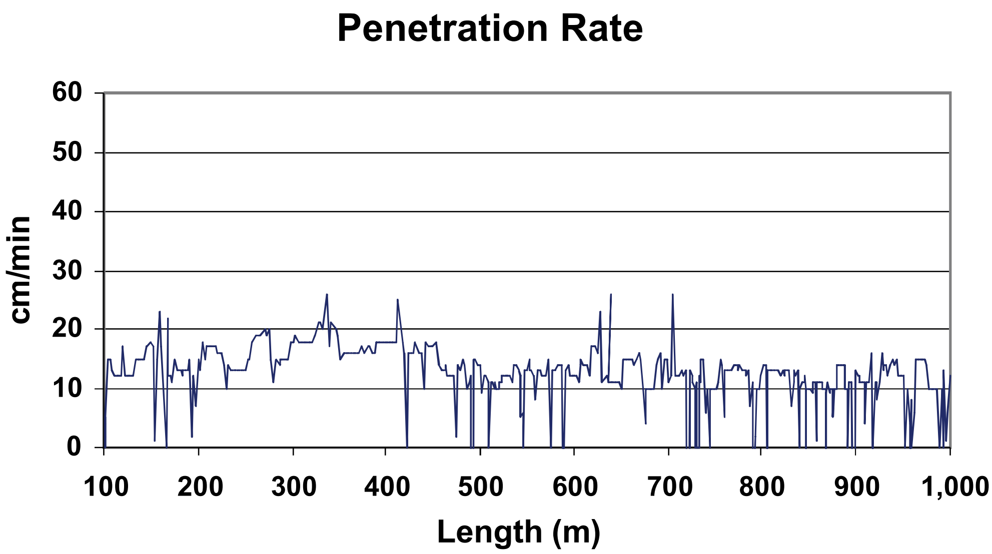


Figure 5-8. *Penetration rate during core drilling of KFM08A.*

Rotation speed and feed force

The structure of the rotation speed diagram in Figure 5-9 is very similar to that of the penetration rate diagram in Figure 5-8, where the same drilling events are reflected in both figures. Also the feed force diagram, Figure 5-10, displays congruities with the rotation speed and penetration rate diagrams. The reduction of the rotation speed corresponds to a decrease in feed force and vice versa, which is an effect of the automatic adjustment by the steering system of the drilling machine. The combined effect of changes in feed force and rotation speed most certainly results in changes in penetration rate. However, to distinguish between geological and technical factors when interpreting variations in penetration rate is complicated and demands a deeper analysis than possible in the present context.

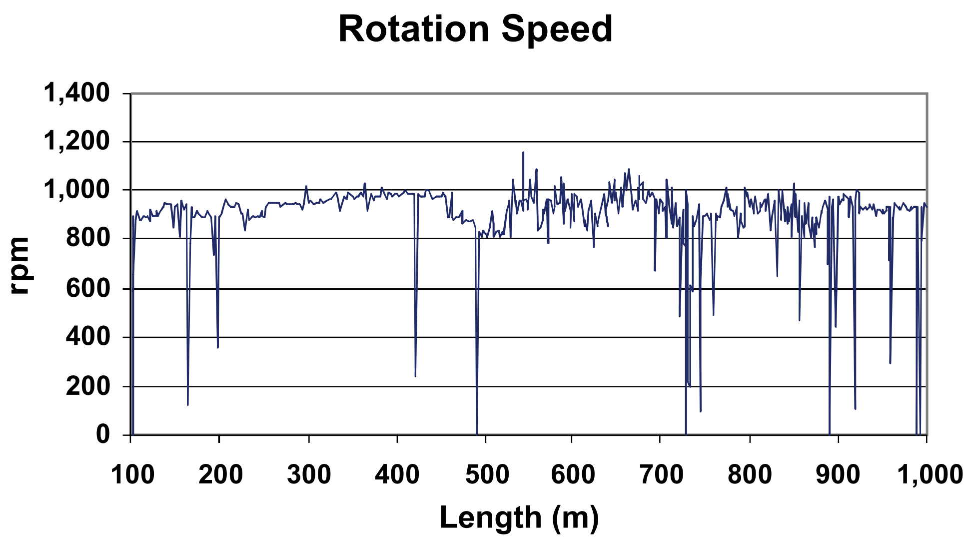


Figure 5-9. *Rotation speed versus borehole length during drilling of borehole KFM08A.*

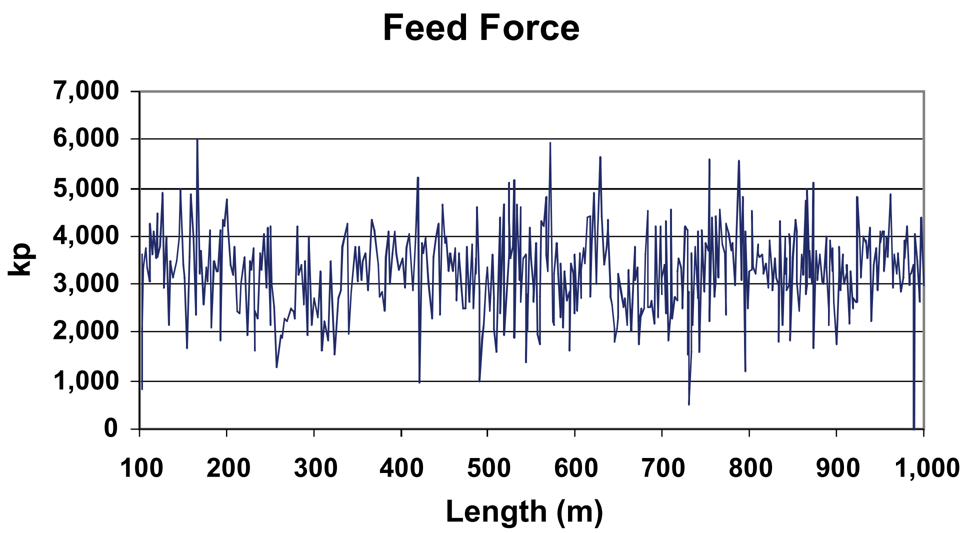


Figure 5-10. *Feed force versus borehole length during drilling of borehole KFM08A.*

5.4.3 Registration and sampling of flushing water and return water

Flushing water and return water flow rate – water balance

As borehole KFM08A is of SKB chemical type, it is important to estimate the amount of flushing water pumped into the borehole during drilling as well as the amount of return water recovered, to permit a water balance calculation. A flow gauge in the measurement station registered the flushing water flow rate, see Figure 3-3. The return water was measured by another flow meter, mounted on-line with the discharge pipeline, see Figures 3-3 and 3-6.

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

Figure 5-11 illustrates the accumulated volume of flushing water and return water versus time during core drilling, while Figure 5-12 displays the accumulated volumes of flushing water and return water from the entire drilling period giving a return water/flushing water quotient of 1.01 (results from Uranine measurements are presented in the next section).

As is obvious from both Figure 5-11 and Figure 5-12, the volumes of flushing water and return water measured by two methods are almost equal at the end of the drilling period, giving a return water/flushing water quotient of 1.01. This low value may be interpreted as a result of low groundwater inflow to the borehole. A groundwater inflow at c 198 m drilling length was, however observed.

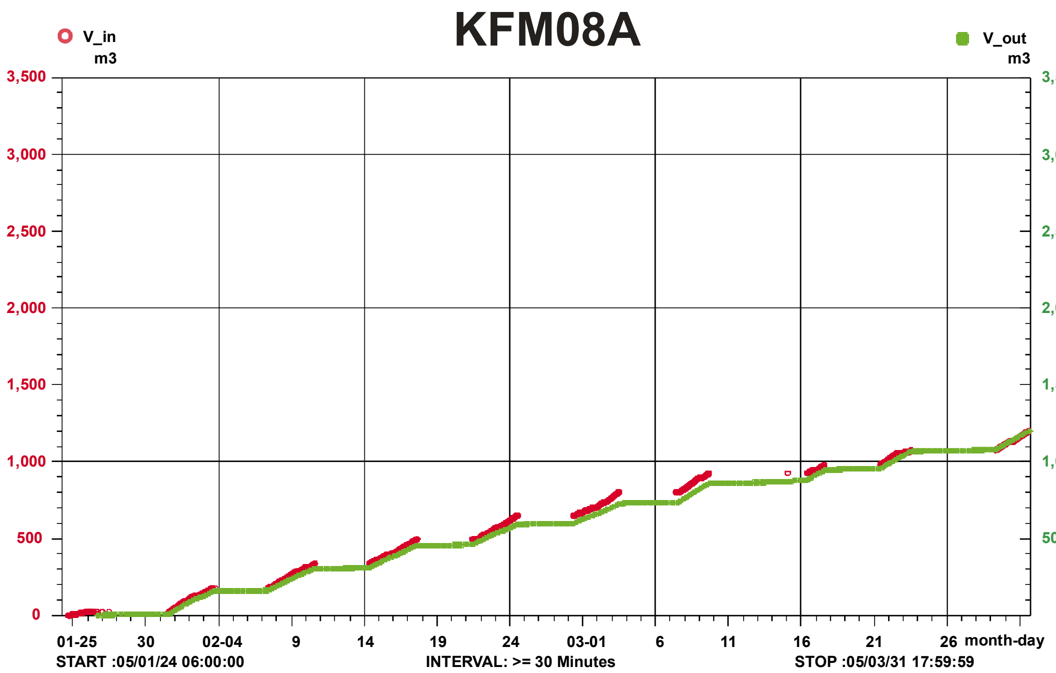


Figure 5-11. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM08A.*

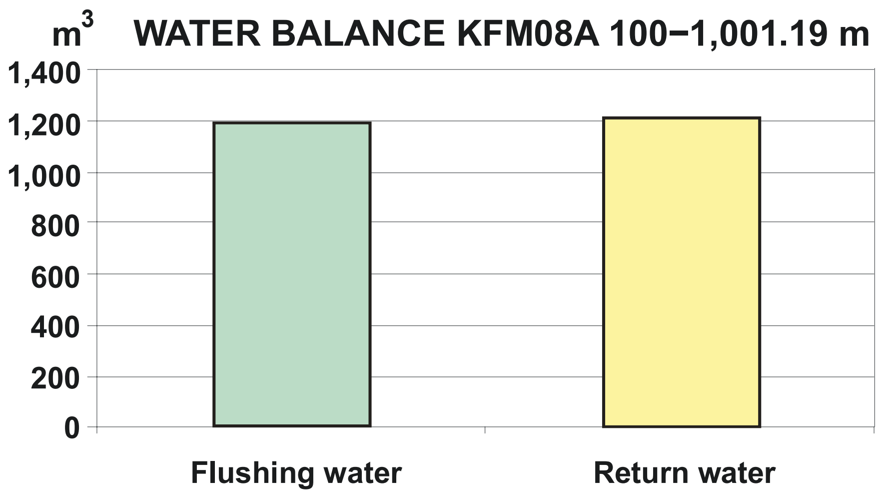


Figure 5-12. *The total volume of flushing water used during core drilling was 1,196 m^3. During the same period, the total volume of return water was 1,210 m^3. The return water/flushing water balance is then as low as 1.01, due to the low inflow of groundwater into the borehole.*

Figure 5-13 illustrates the variations of flushing water and return water flow rate together with variations of the ground water table during core drilling of borehole KFM08A. The return water flow rate depends on the flushing water flow rate and the water yielding capacity of the borehole, as well as on the drawdown in the borehole created by the air-lift pumping. In order to cool the drill bit and keep the borehole bottom clean, normally a flushing water flow rate of c 35 L/min is needed, but often immediately after a core recovery, a temporarily increased flushing water flow rate is used.

As the upper 100 m of the borehole is cased and cement grouted, there was no return water inflow above the core drilled part of the borehole. It is, however, obvious that the groundwater inflow also to the core drilled part was surprisingly low. Normally, when drilling a telescopic borehole supplied with air-lift pumping equipment, the return water flow rate is significantly higher than the flushing water flow rate, but in this case the flushing water and return water flow rates were almost identical.

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 every fourth hour during the drilling period, see Figure 5-14. Like in boreholes KFM02A, KFM03A, KFM04A, KFM05A, KFM06A and KFM07A a dosage pump controlled by a flow meter was used for labelling the flushing water with Uranine. The flow meter malfunctioned at a few occasions during the drilling period.

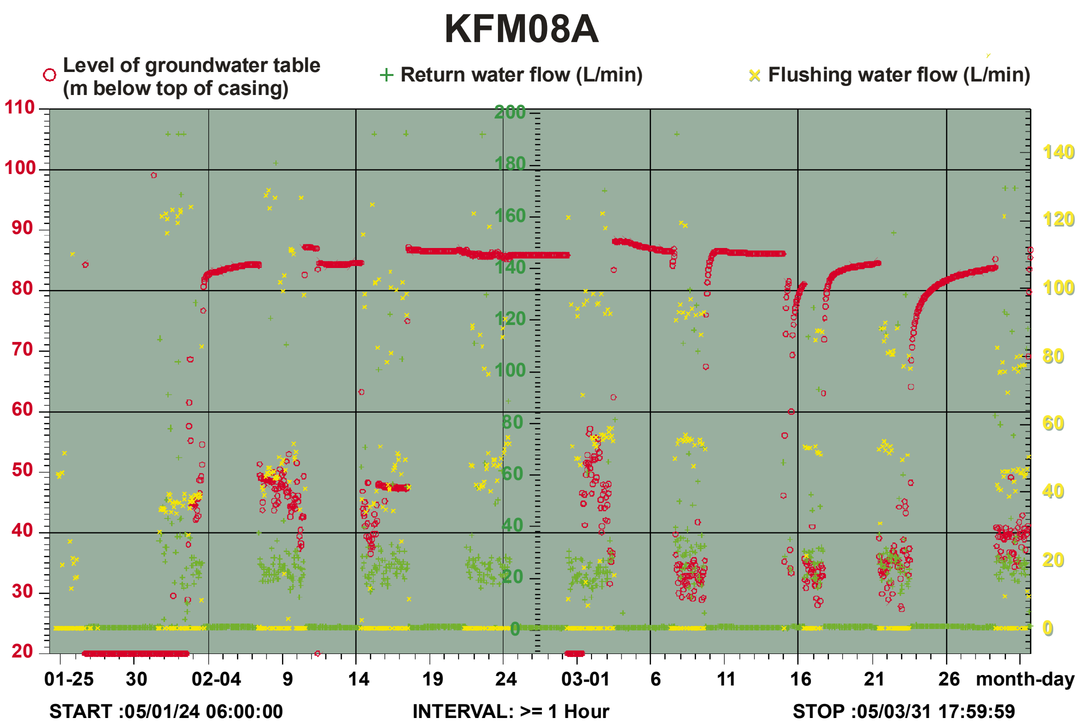


***Figure 5-13**. Ground water table (red), flushing water flow rate (yellow) and return water flow rate (green) versus time during core drilling of borehole KFM08A. Because a measuring hose was damaged, no pressure transducer was mounted, entailing that no registration of the drawdown was possible during the first week of the drilling period.*

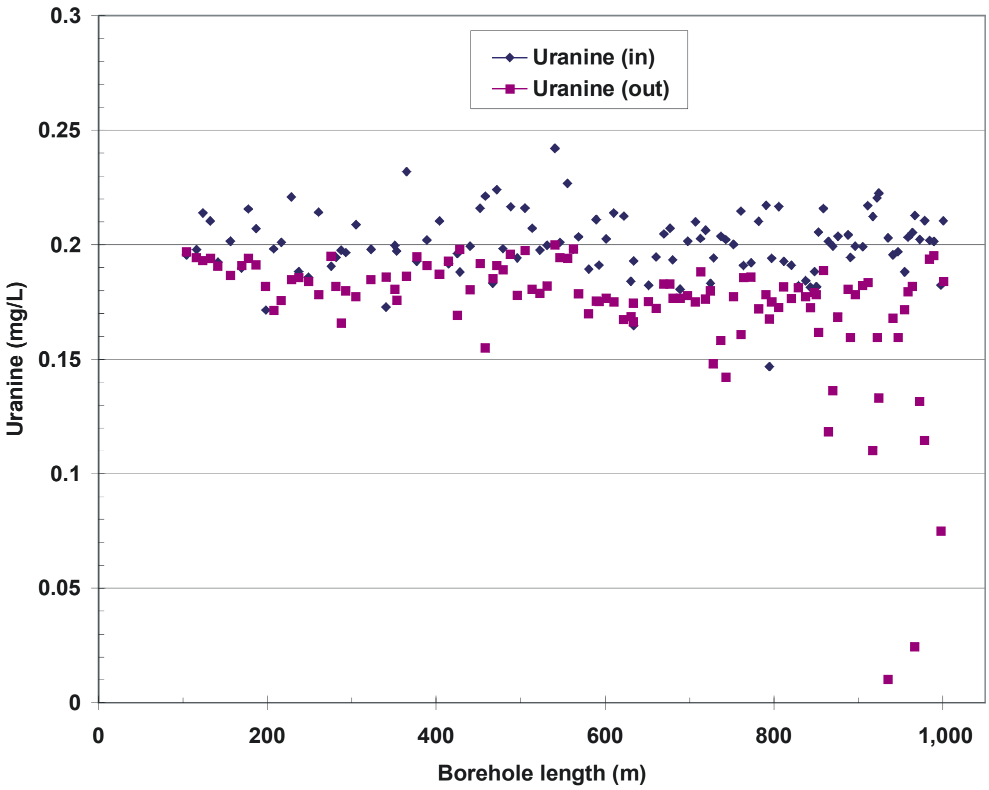


***Figure 5-14.** Uranine content in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFM08A. An automatic dosage equipment, controlled by a flow meter, accomplished the labelling with Uranine.*

The concentration of the tracer Uranine in the flushing water was stable and close to the nominal value of 0.2 mg/L during the drilling period. According to notations in the log book, the amount of Uranine added to the borehole was 245 g. If the averages of the Uranine concentration values in the flushing water (0.200 mg/L) and in the return water (0.173 mg/L) are used to calculate the amount of Uranine added to and recovered from the borehole, the calculations give 240 g and 209 g respectively.

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM08A is exposed in Figure 5-15. Like in boreholes KFM02A, KFM03A, KFM04A, KFM05A, KFM06A and KFM07A the borehole diameter was 77.3 mm, i.e. by increased c 1 mm compared to in borehole KFM01A. This resulted in generally lower flushing water pressures than in KFM01A in KFM08A as well as in the other telescopic boreholes drilled after KFM01A.

After an almost continuous increase of flushing water pressure versus borehole length to c 430 m, this trend was interrupted and followed by irregular flushing water pressures, even though a small increasing trend can bee seen in the diagram to c 630 m. In section 630–870 m the flushing water pressure levels away, although peaks both up an down occur. Finally the flushing water pressure increased and ended at c 60 bars. The final water pressure was c 10 bars higher than the final pressure in KFM02A, KFM03A and KFM06A but c 10 bars lower than in KFM04A, KFM05A and KFM07A. The differences of final flushing water pressure could, besides differences in the gap diameter between the borehole wall and the pipe string, depend on different borehole deviations as well as on differences in the hydraulic conductivity of the borehole.

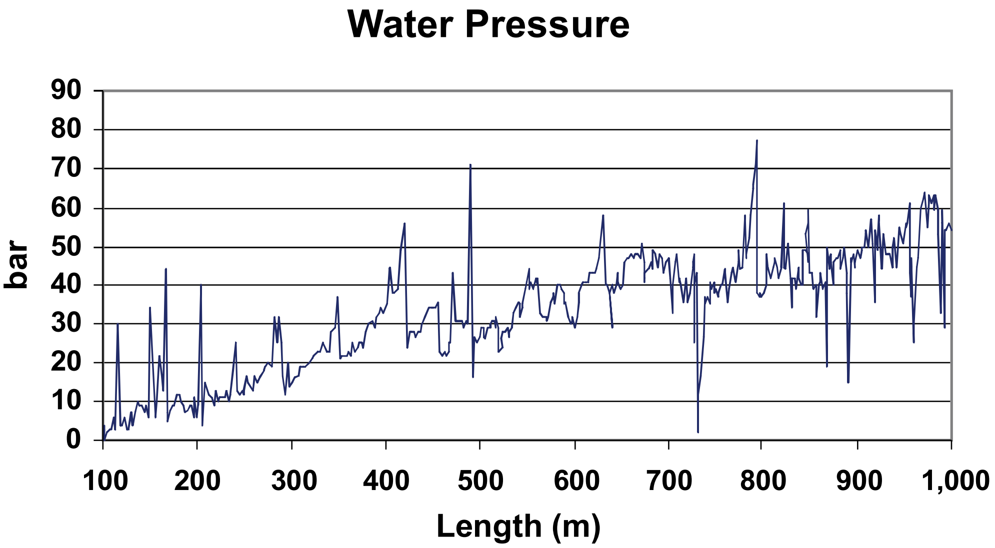


Figure 5-15. *Flushing water pressure versus drilling length when drilling KFM08A.*

Electric conductivity of flushing water

Flushing water was supplied from percussion borehole HFM22. A sensor for on-line registration of the electric conductivity (EC) of the flushing water was placed in the measurement station, before the flushing water entered the borehole, see Figure 3-3.

The sensor for registration of the electric conductivity (Figure 5-16) of the return water was positioned between the surge diverter (discharge head) and the sedimentation containers, see Figure 3-3.

The electrical conductivity (salinity) of the flushing water from the 222 m deep supply well HFM22 with its major inflow at c 62 m had from start a significantly decreasing trend, starting with an EC-value of c 1,200 mS/m. At c 650 m drilling length the value stabilized at c 900 mS/m, a value which was maintained until drilling was completed.

The average electrical conductivity of the return water followed almost exactly the same trend as the flushing water, verifying only minor groundwater inflow in KFM08A and also indicating that the major part of the groundwater inflow is restricted to the upper part of the borehole. It is, however, not excluded that minor inflows of groundwater of increased salinity exist deeper in the borehole.

Content of dissolved oxygen in flushing water

In Figure 5-17, the level of dissolved oxygen is plotted versus time. During the first half of the drilling period, the amount of dissolved oxygen was generally kept below 4.5 mg/L. Unfortunately the transmitter was out of function for a week. Thereafter a significantly higher content of dissolved oxygen is displayed in the flushing water, c 5–5.5 mg/L, which either reflects a calibration problem, or that the amount of surface water in the flushing water has increased.

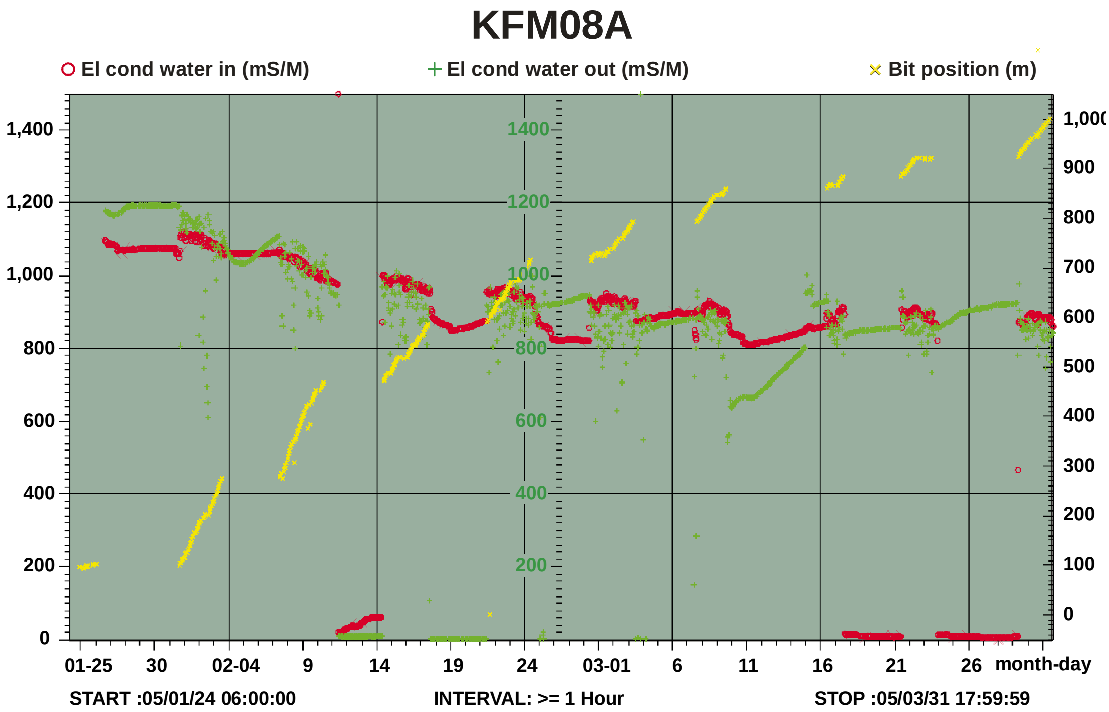


Figure 5-16. *Electrical conductivity of flushing water from HFM22 and return water from KFM08A.*

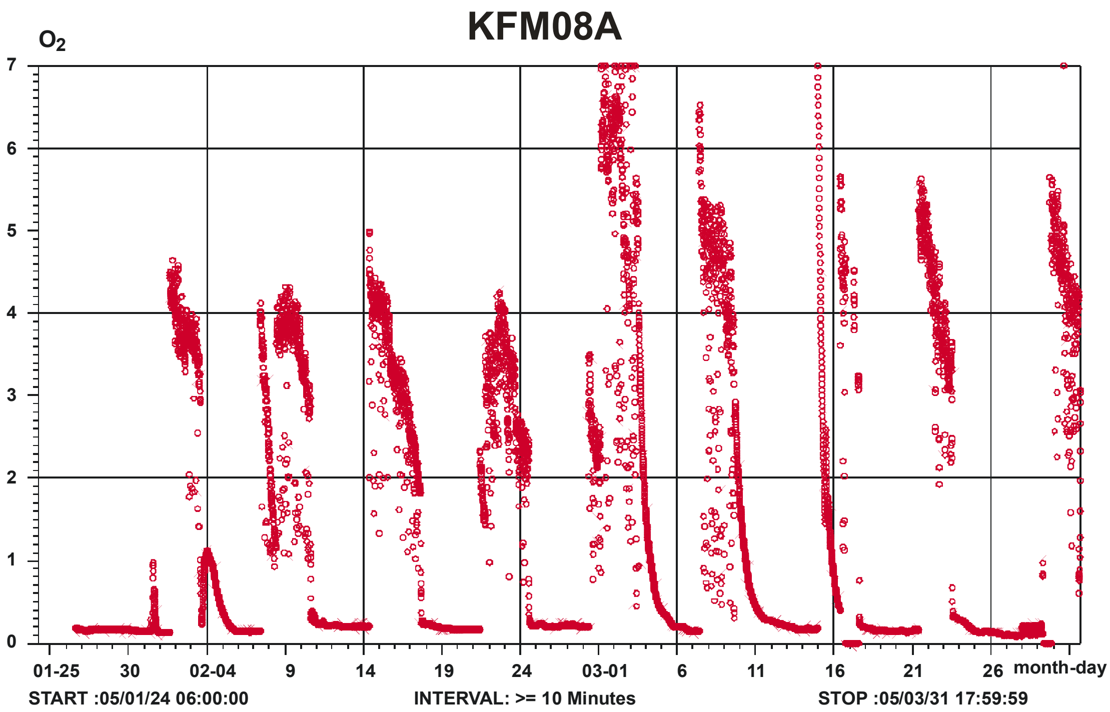


Figure 5-17. *Dissolved oxygen content in the flushing water versus time when drilling KFM08A.*

Flushing water quality

The results from chemical analyses of flushing water from the supply well HFM22 are compiled in Appendix D and /6/. The flushing water was sampled during drilling, for the following reasons:

- Initially, to check if the quality was satisfactory. The main concern is the content of organic constituents, which should be low, preferably below 5 mg/L. The reason is that introduction of hydrocarbons may affect the microbiological flora in the borehole, which would obstruct a reliable characterization of the in situ microbiological conditions.
- Generally it is useful to check also the microbe content. This was however not performed in KFM08A.
- To monitor possible changes with time of the water composition.

The chemical composition of the flushing water is important when estimating the effect, or correcting for the effect, of remaining flushing water in water samples collected from borehole KFM08A during or after drilling.

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

Organic constituents

The concentration of Total Organic Carbon (TOC) in two samples collected in HFM22 prior to core drilling amounted to 4.2 and 4.8 mg/L. These values were considered as sufficiently low, and it was decided to use HFM22 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 /7/).

Chemical composition of flushing water

The flushing water from HFM22 was sampled at two occasions during drilling. A small salinity decrease was observed between the two sampling occasions, see Appendix D.

5.4.4 Sampling of return water during drilling

The return water, i.e. water pumped up from the borehole during drilling, is a mixture of flushing water and formation water from the borehole. In the KFM08A case, the return water was drained off to the Baltic sea. The return water may be quite saline or possibly show enhanced concentrations of other components that could have a local effect on the lake environment. Therefore, in order to prevent potential environmental changes, not only the flushing water but also the return water was sampled at the same two occasions. The water analysis data from one sample of return water is compiled in Appendix D.

5.4.5 Groundwater sampling and analyses during drilling

A first strike sample was collected from the return water in section 100–203.5 m in KFM08A during the drilling period. The water analysis data are compiled in Appendix D.

5.4.6 Registration of the groundwater level in KFM08A

To enhance the recovery of drill cuttings from the borehole, air-lift pumping was applied during the entire drilling period. The pumping capacity was checked by registration of the groundwater level in the borehole, below plotted versus borehole length (Figure 5-18).

However, from the beginning there was no registration of the groundwater level, as the pressure transducer could not be lowered into the pressure transducer hose, which had been damaged. Instead, one of the two mammoth pumps was taken out of order, and the transducer was temporarily mounted in that hose.

From the beginning, the air-lift pumping was set at the maximum draw-down possible, c 40–45 m, with only one mammoth pump working. Later on the drawdown was increased to c 50 m, when the air-lift pumping equipment was restored to original status with two mammoth pumps and a separate measuring hose. Drilling was performed continuously during Monday–Thursday. During the weekend stop of drilling and pumping, the groundwater table recovered quite slowly 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 into the borehole was low. When pumping was restarted, a simultaneous drawdown occurred.

5.4.7 Core sampling

The average drill core length per run obtained from the drilling was 2.78 m. Due to the relatively low fracture frequency, sixteen 3 m long unbroken cores were recovered. Fracture minerals were relatively well preserved. Rotation marks on the drill core occurred, with a quite high frequency, especially at depth. A preliminary on-site core logging was performed continuously.

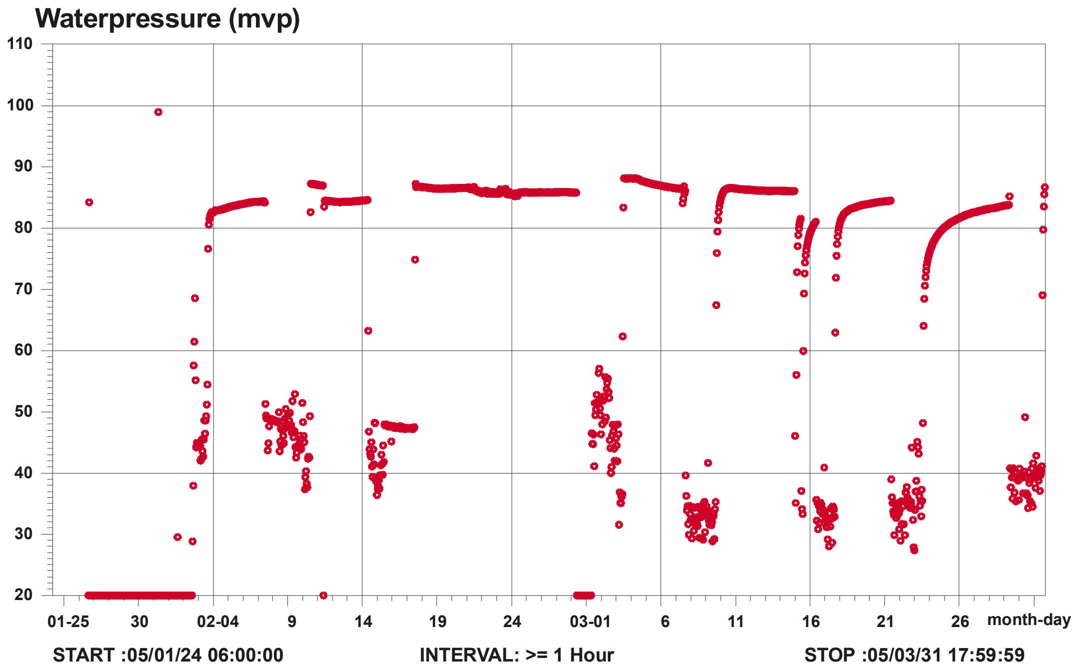


Figure 5-18. *Variation of the level of the groundwater table in KFM08A during drilling.*

5.4.8 Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0–100 m) is c 5 m^3. Weighing of drill cuttings from that part of the borehole and comparison with the weight of the theoretical volume was not carried out. A relatively large and uncontrolled overflow of return water with suspended drill cuttings occurs during the heavy air flushing during percussion drilling, making it difficult to obtain reliable results of a drill cuttings estimation. 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 KFM08A and the drill core is calculated to be 2.406 m^3. This volume should correspond to the amount of drill cuttings produced during drilling. If a density of 2,650 kg/m^3 (approximate figure for granitoids in the Forsmark area) is applied, the total weight of the theoretical amount of debris is estimated at 6,376 kg. The dry weight of the debris recovered from the core drilling, which was weighed in the containers, was 4,392 kg. The difference between the theoretically produced and recovered dry weight of debris is 1,984 kg, which gives a recovery of 69%.

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 must be somewhat higher than 69%. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

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

5.4.9 Deviation measurements

The deviation measurements made in borehole KFM08A with the Reflex Maxibor system show that the borehole deviates 120 m upwards and 173 m to the right compared to an imagined straight line following the dip and strike of the borehole start point (Figures 5-19 and 5-20).

5.4.10 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 hence relieved from the previous load, and the stretching will cease. Instead, the load from the pipe string will now cause compression of the pipe string, and to some extent bending of it.

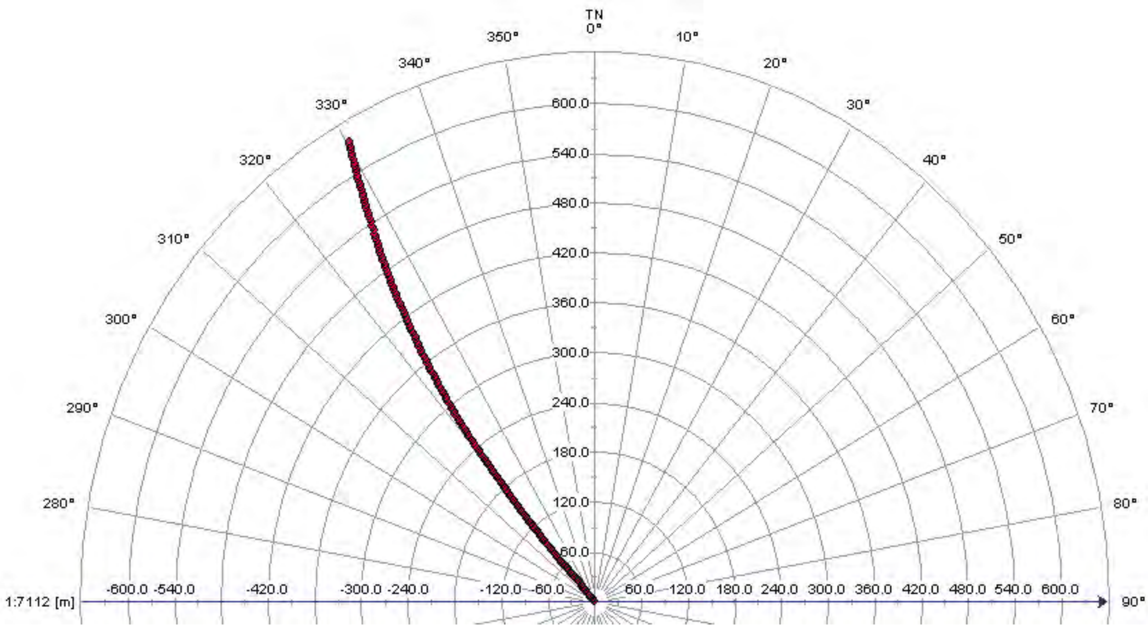


Figure 5-19. *Horizontal projection of measured deviation in KFM08A.*

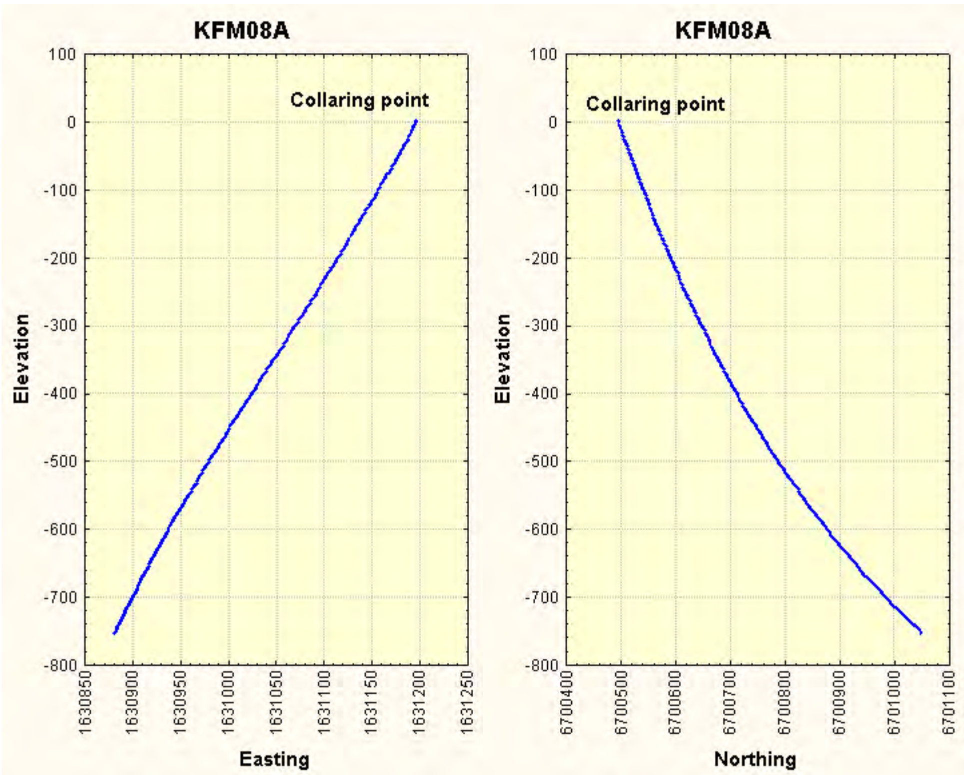


Figure 5-20. *Two vertical projections of measured deviation in KFM08A.*

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 5-21, which is based on load tests performed in the laboratory by the manufacturer of the drilling pipes.

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

5.4.11 Hydraulic tests during drilling (wireline tests)

Results from the pressure measurements performed in borehole KFM08A are presented in Table 5-2. No pumping tests were conducted due to the very low transmissivity of the borehole.

Measurements of the absolute pressure were carried out in four sections, see Table 5-2. Graphical results from the tests are shown in Figure 5-22 and in Appendix F.

After packer inflation the pressure stabilization phase often displays different types of transient effects, both of increasing and decreasing pressure. The reasons for these transients are not fully known, although they might be attributable to previous disturbances in the borehole caused by the drilling operations.

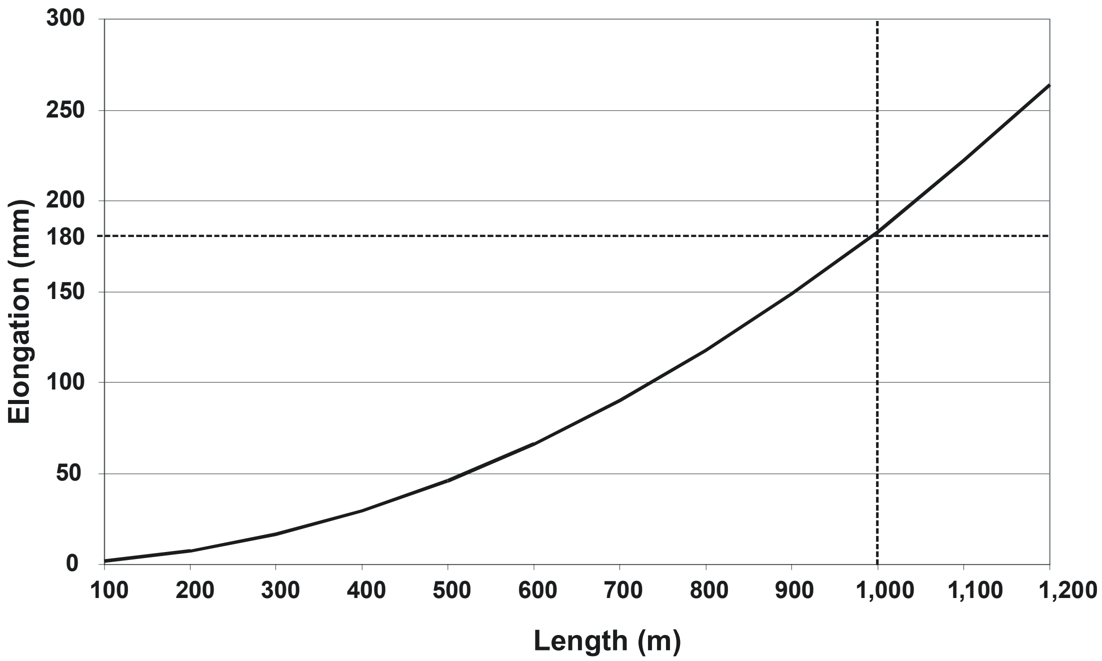


Figure 5-21. *The diagram illustrates the elongation of the WL-76 drilling pipe string when hanging in a vertical water filled borehole. Values from a laboratory load tests of the drilling pipe string.*

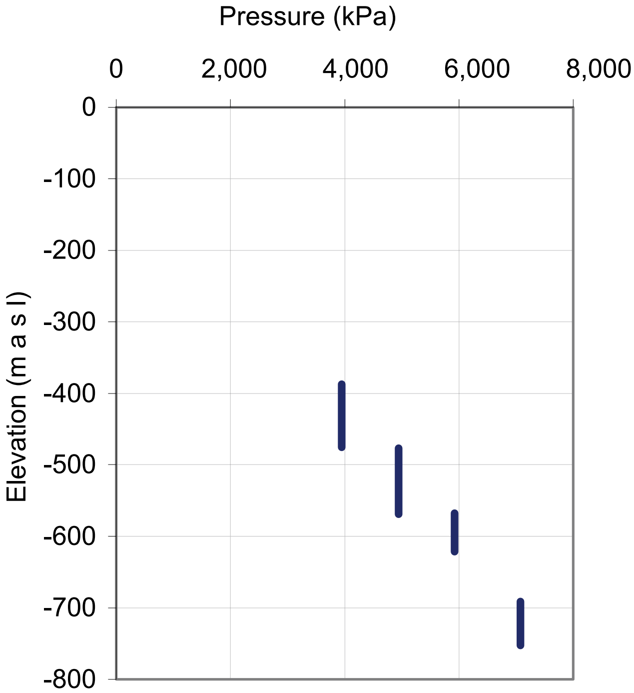


Figure 5-22. *Absolute pressure measurements from wireline tests in KFM08A.*

Table 5-2. Absolute pressure measurement in KFM08A.

Test section (m)	Last pressure reading during test (kPa)	Test duration (h)	Borehole length to pressure sensor (m fr Ref)	Elevation of pressure sensor (m a s l)
472.72–589.34	3,,945.90	c 92	473.70	–387.92
590.70–718.80	4,,942.01	c 92	591.68	–477.17
717.20–794.44	5,,924.08	c 95	718.18	–568.51
900.70–1,001.19	7,,074.03	c 92	901.68	–691.54

5.4.12 Groove milling

After completion of drilling, borehole KFM08A 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 5-23. 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 caliper). A BIPS-survey gave the final conformation of where the groove milling was successful and where it failed.

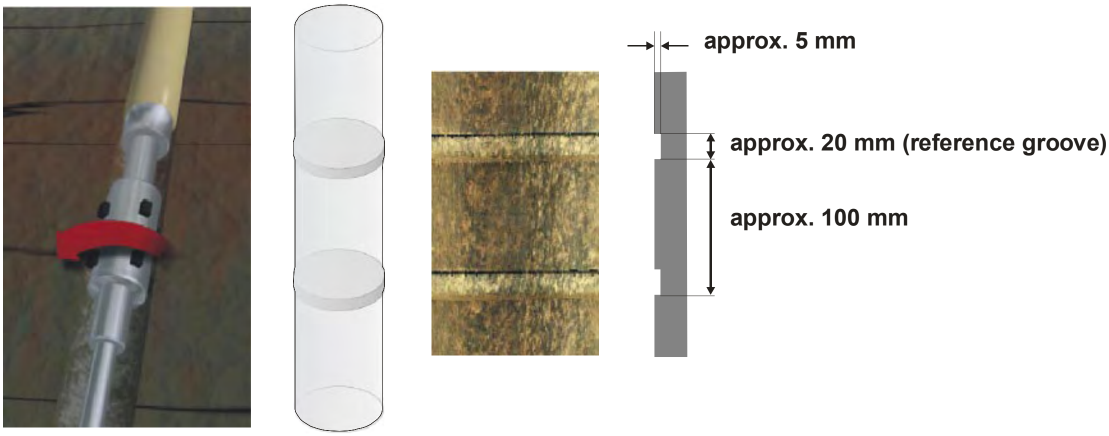


Figure 5-23. *Layout and design of reference grooves. The milling tool shown to the left.*

Table 5-3. Compilation of length to the reference grooves. The positions of the grooves are determined by the length of the drilling pipe string used at the milling process. The length is measured from the upper part of the upper groove.

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
151	Yes	Yes	600	Yes	Yes
200	Yes	Yes	650	Yes	Yes
250	Yes	Yes	700	Yes	Yes
299,8	Yes	Yes	750	Yes	Yes
350	Yes	Yes	800	Yes	Yes
400	Yes	Yes	850	Yes	Yes
450	Yes	Yes	900	Yes	Yes
500	Yes	Yes	950	Yes	Yes
552	Yes	Yes	981	Yes	Yes

5.4.13 Consumables

The amount of oil products consumed during drilling of the percussion drilled part of KFM08A (0–100 m), thread grease used during core drilling, and grout used for gap injections of the respective casings are reported in Tables 5-4 and 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 a low adhesion capacity to the threads, and the lubrication characteristics are 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) Unisilikon L50/2
KFM08A	Approx 12 L	No consumption measured	9.2 kg

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

Borehole ID	Length (m)	Cement volume (Aalborg Portland Cement/microsilica	Grouting method	Remarks
KFM08A	100.20	2,534 kg/2,840 L	Gap injection	
KFM08A	100.20	214 kg/240 L	Hose	Supplementary gap grouting

5.4.14 Recovery monitoring after cleaning by air-lift pumping

The recovery registration after the final cleaning of the borehole by air-lift pumping, which caused a drawdown of 50 m, is displayed in the diagram of Figure 5-24. The recovery of the groundwater table was registered during a day and confirmed the low yielding capacity of the borehole. From the diagram an inflow of c 30 L/min can be estimated, which can be compared with the corresponding values from KFM06A, 160 L/min at a drawdown of c 25 m /4/, and KFM07A, > 60 L/min, likewise at a drawdown of c 25 m /5/.

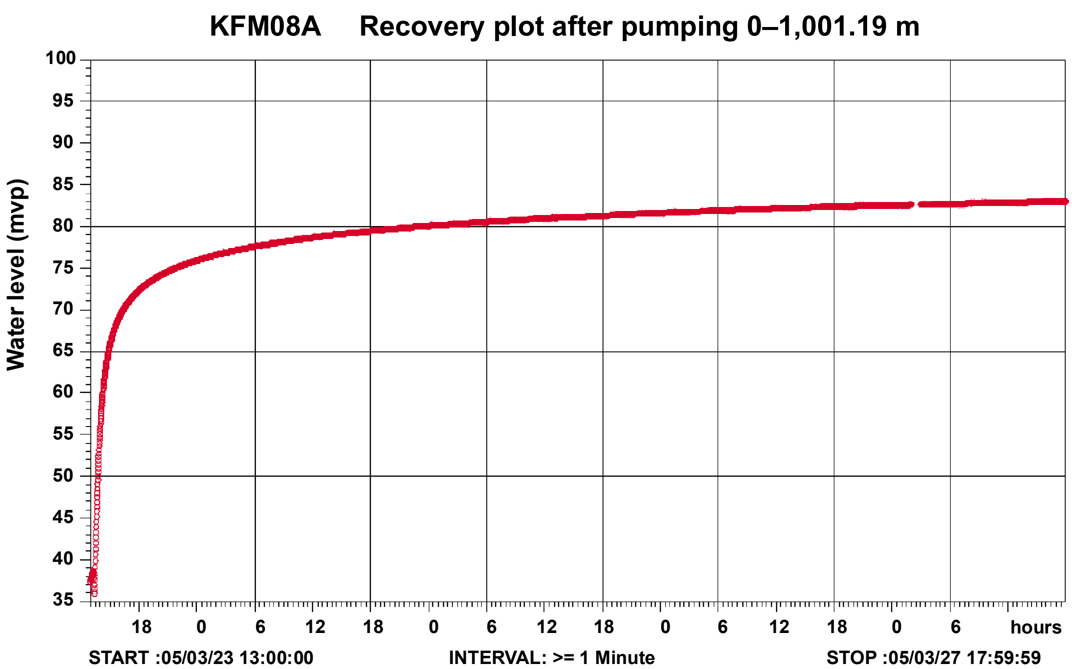


Figure 5-24. *Recovery of groundwater table in section 100.55–1,001.19 m of KFM08A (section 0–100.55 m cased and gap grouted).*

5.5 Geometrical and technical design of borehole KFM08B

Administrative, geometric and technical data for the telescopic borehole KFM08B are presented in Table 5-6. The technical design of the borehole is illustrated in Figure 5-25. A Well Cad-presentation of borehole KFM08B is given in Appendix C.

Table 5-6. Administrative, geometric and technical data for borehole KFM08B.

Parameter	KFM08B
Borehole name	KFM08B
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	January 03, 2005
Completion date	January 26, 2005
Core drilling period	2005-01-03 to 2005-01-26
Contractor core drilling	Drillcon Core AB
Core drill rig	ONRAM 1000
Position KFM08B at top of casing (RT90 2,5 gon V 0:–15/RHB 70)	N 6700492.75 E 1631173.27 Z 2.25 (m a s l)
	Azimuth (0–360°): 270.45°
	Dip (0–90°): –58.85°
Position KFM08B at bottom of hole (RT90 2,5 gon V 0:–15/RHB 70)	N 6700498.156 E 1631066.075 Z –167.099 (m a s l)
	Azimuth (0–360°): 275.23°
	Dip (0–90°): –56.08°
Borehole length	200.54 m
Borehole diameter and length	From 0.00 m to 5.58 m: 0.093 m
	From 5.58 m to 200.54 m: 0.076 m
Casing diameter and length	$Ø_o/Ø_i$ = 90 mm/78 mm from 0.00 to 5.58m
Drill core dimension	4.92–200.54 m/Ø 51 mm
Core interval	4.92–200.54 m
Average core length retrieved in one run	2.76 m
Number of runs	71 from 4.92 m (76.2 mm)
Diamond bits used	5
Average bit life	39.1 m

Technical data

Borehole KFM08B

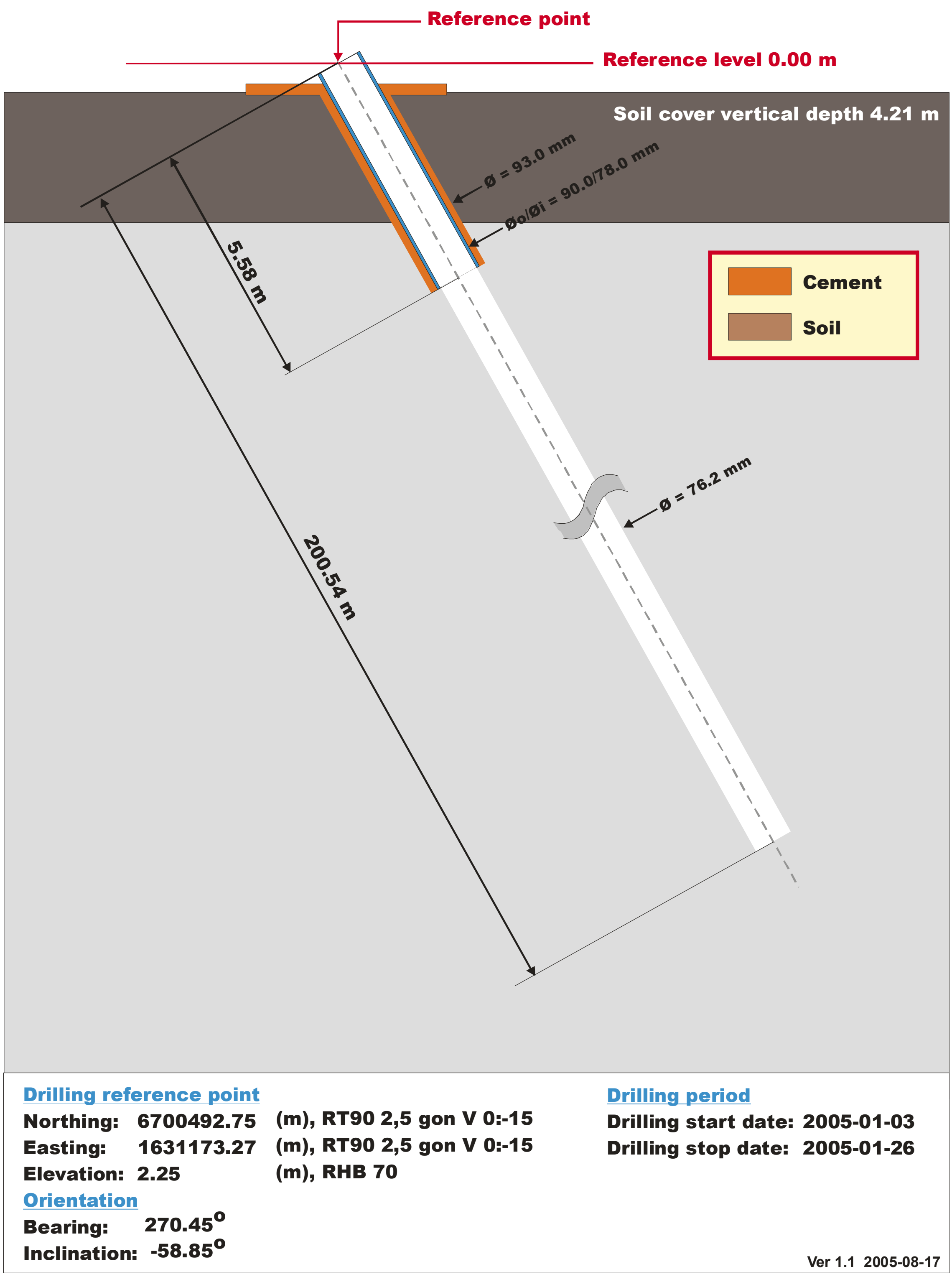


***Figure 5-25**. Technical data of borehole KFM08B.*

5.6 Core drilling 4.92–200.54 m of borehole KFM08B

Core drilling of KFM08B was accomplished in four weeks (Figure 5-26). After drilling and reaming, a stainless steel casing of c 5.58 m length was installed and grouted, see Figure 5-25. Core drilling with 76 mm diameter was terminated after three shifts. When the first measurement was performed, a rock outfall in the borehole at c 55 m was discovered. The instability prevented further measurements until the borehole was stabilized seven months after completion of drilling.

5.6.1 Flushing water and return water flow rate – water balance

A complete serie of measurements of the flushing and return water parameters was monitored. Below some selected parameters are presented.

Figure 5-27 displays the accumulated volumes of flushing water and return water from the entire drilling period (results from Uranine measurements are presented in the next section). From Figure 5-27 showing the accumulated volumes of flushing water and return water at the end of the drilling period, a return water/flushing water quotient of 0.02 is calculated. This low value is typical when drilling cored boreholes through shallow, fractured rock without applying air-lift pumping and/or sealing of conductive fractures by grouting.

Uranine content of flushing water and return water–mass balance

During the drilling period, sampling of flushing water and return water was performed systematically with a frequency of approximately one sample per 10–20 m drilling length. The same dosage pump as in KFM08A was used in KFM08B for adding the tracer. The main loss of return water occurred in fractured rock at c 30 m drilling length, entailing that almost all return water was lost during continued drilling.

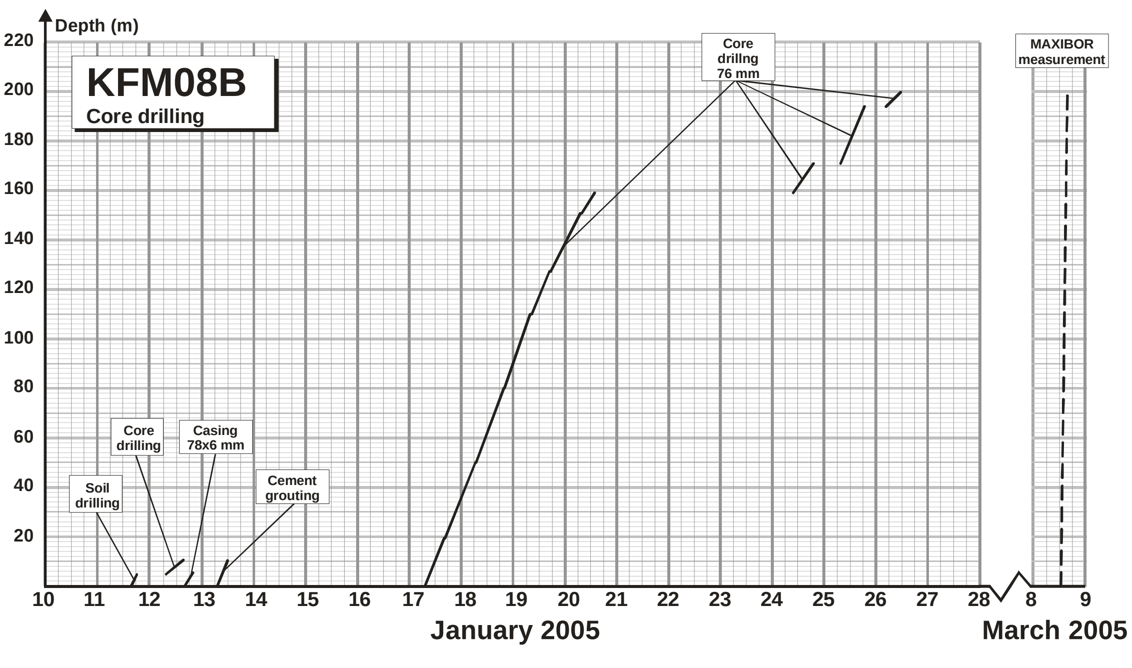


***Figure 5-26**. Core drilling period KFM08B (depth versus calendar time).*

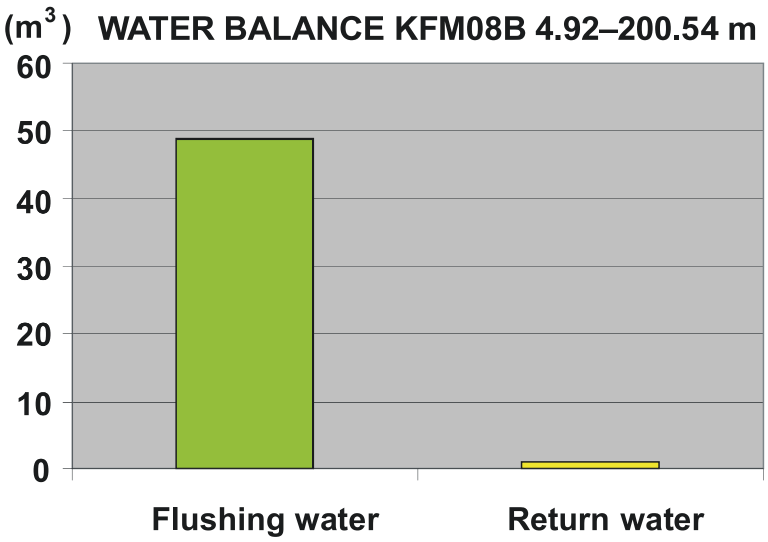


Figure 5-27. The total volume of flushing water used during core drilling of KFM08B was 48.8 m³. During the same period, the total volume of return water was 1.0 m³. The return water/flushing water balance is then 0.02, i.e. much below 1.0, mainly due to a major flushing water loss in a highly conductive fracture at approximately 31 m borehole length in the borehole.

5.6.2 Consumables

The amount of oil products consumed during drilling of the core-drilled borehole KFM08B, thread grease and grout used for injections of the casing are reported in Tables 5-7 and 5-8.

Table 5-7. Oil and grease consumption.

Borehole ID	Grease for other purposes	Thread grease Unisilikon L50/2
KFM08B	0.4 kg	0.8 kg

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

Borehole ID	Length (m)	Cement volume (Aalborg Portland Cement/microsilica)	Grouting method	Remarks
KFM08B	10.42	180 kg/150 L	Packer	8 bar

5.6.3 Deviation measurements

The deviation measurements made in borehole KFM08B with the Reflex Maxibor system show that the borehole deviates approximately 2.3 m upwards and 6 m to the right compared to an imagined straight line following the dip and strike of the borehole collaring point.

6 References

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

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

/3/ **SKB, 2005.** Petersson, J, Berglund, J, Skogsmo, G, Wängnerud, A. Site investigations at Forsmark. Boremap mapping of telescopic drilled borehole KFM08A and cored drilled borehole KFM08B. SKB P-report in progress, Svensk Kärnbränslehantering AB.

/4/ **SKB, 2005.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of the telescopic borehole KFM06A and the core drilled borehole KFM06B at drill site DS6. SKB P-05-50, Svensk Kärnbränslehantering AB.

/5/ **SKB, 2005.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of the telescopic borehole KFM07A at drill site DS7. SKB P-05-50, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2005.** Nilsson, D. Forsmark site investigation. Sampling and analyses of groundwater from percussion drilled boreholes. Results from the percussion drilled boreholes HFM20-22. SKB P-03-48, Svensk Kärnbränslehantering AB.

/7/ **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.

Appendix A

Well Cad presentation of the percussion drilled part of borehole KFM08A

Title PERCUSSION DRILLED BOREHOLE KFM08A

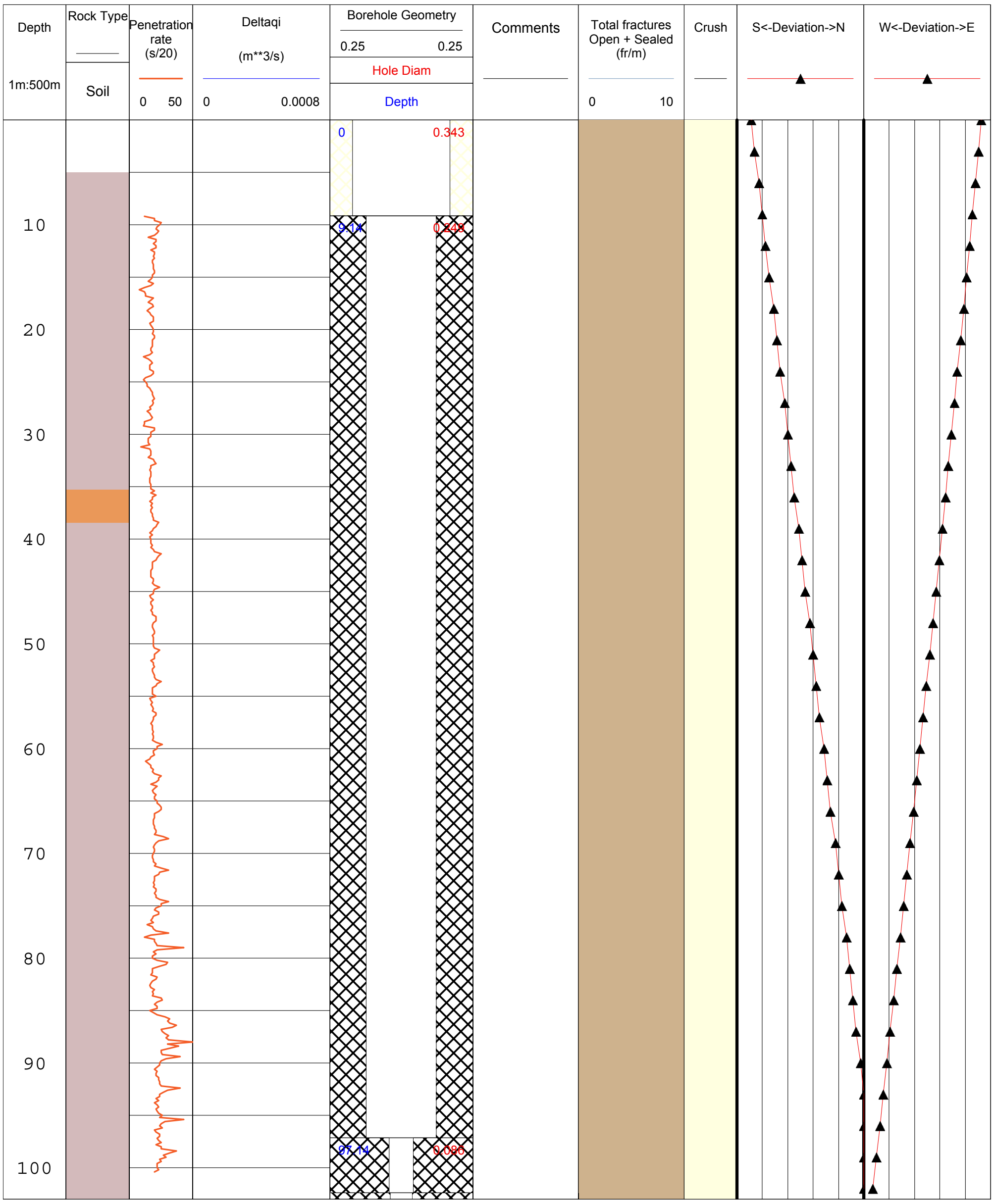
Svensk Kärnbränslehantering AB

Site	FORSMARK	**Signed data**	
Borehole	KFM08A	**Coordinate System**	RT90-RHB70
Diameter [mm]	77	**Northing [m]**	6700494.49
Length [m]	1001.190	**Easting [m]**	1631197.06
Bearing [°]	321.00	**Elevation [m.a.s.l.]**	2.49
Inclination [°]	-60.88	**Drilling Start Date**	2004-09-13 11:03:00
Date of mapping		**Drilling Stop Date**	2005-03-31 10:40:00
		Plot Date	2005-10-20 01:11:02

ROCKTYPE FROM ON-SITE DESCRIPTION FORSMARK

SOIL

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



Well Cad presentation of the complete borehole KFM08A

Title **KFM08A**

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Signed data**	
Borehole	KFM08A	**Coordinate System**	RT90-RHB70
Diameter [mm]	77.3	**Northing [m]**	6700494.49
Length [m]	1001.19	**Easting [m]**	1631197.06
Bearing [°]	321.00	**Elevation [m.a.s.l.]**	2.49
Inclination [°]	-60.89	**Drilling Start Date**	2004-09-13 11:03:00
Date of mapping		**Drilling Stop Date**	2005-03-31 10:40:00
		Plot Date	2005-10-20 01:11:02

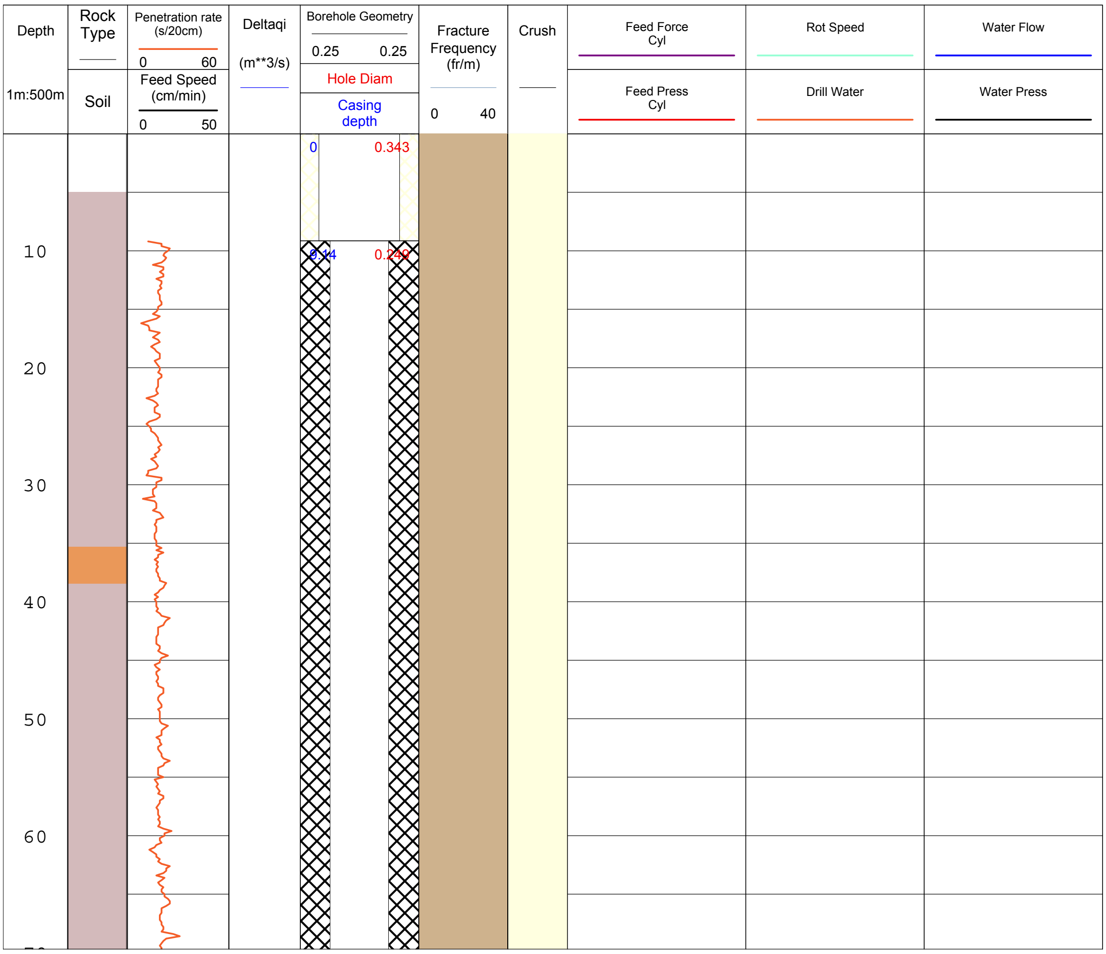
ROCKTYPE FORSMARK

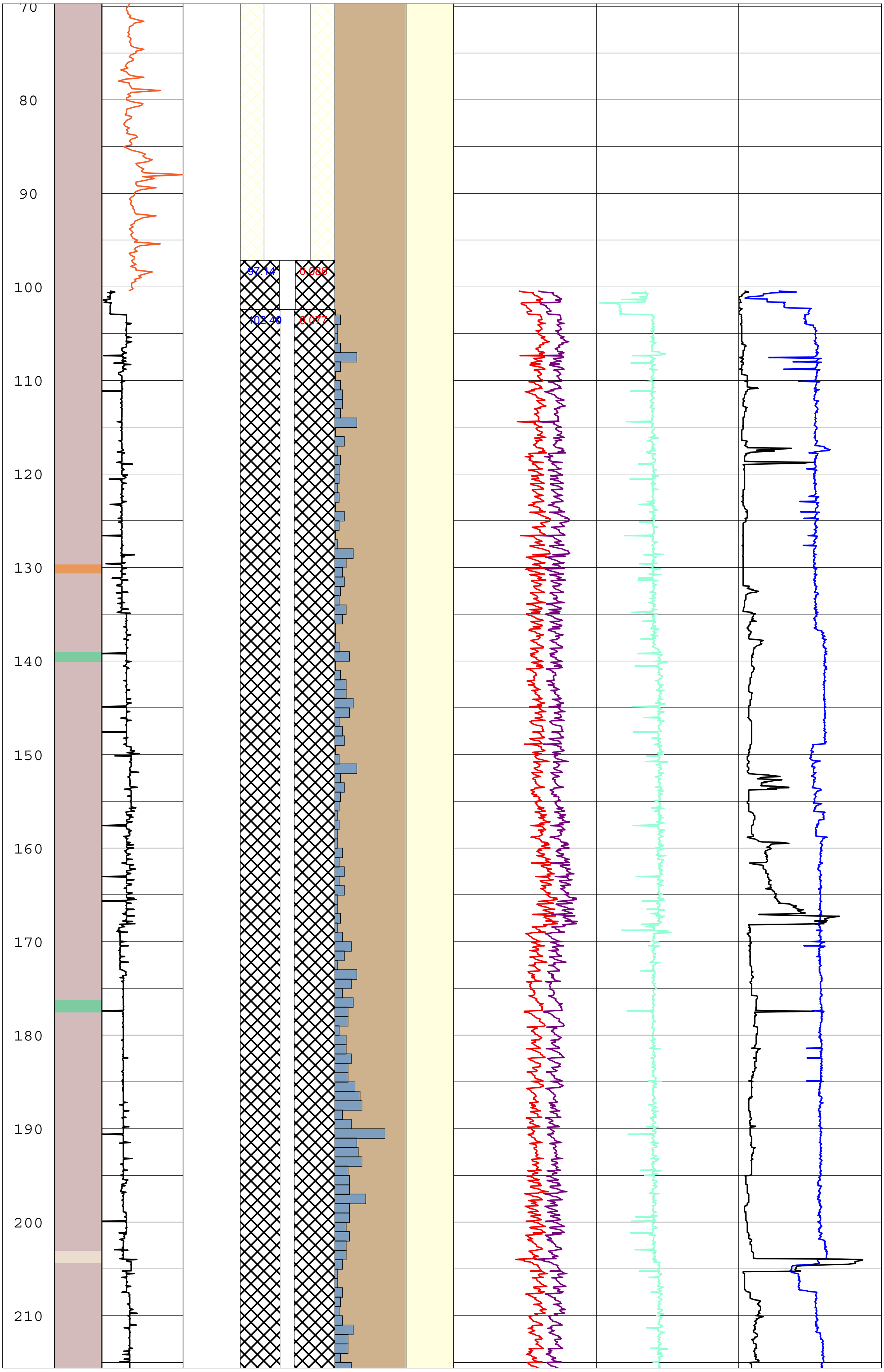
SOIL

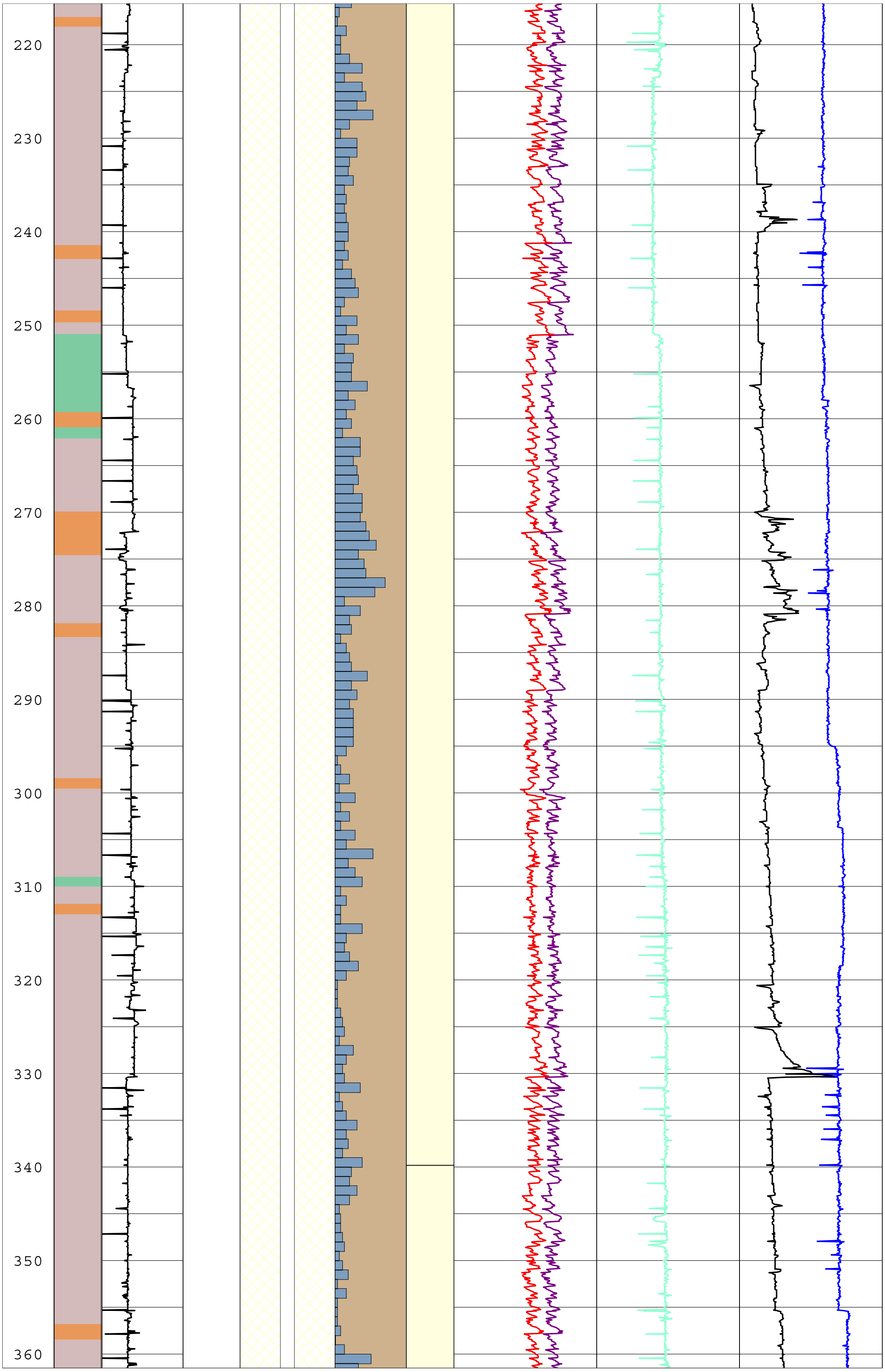
- **Pegmatite, pegmatitic granite**
- **Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained**
- **Granite, metamorphic, aplitic**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Amphibolite**
- **Felsic to intermediate volcanic rock, metamorphic**

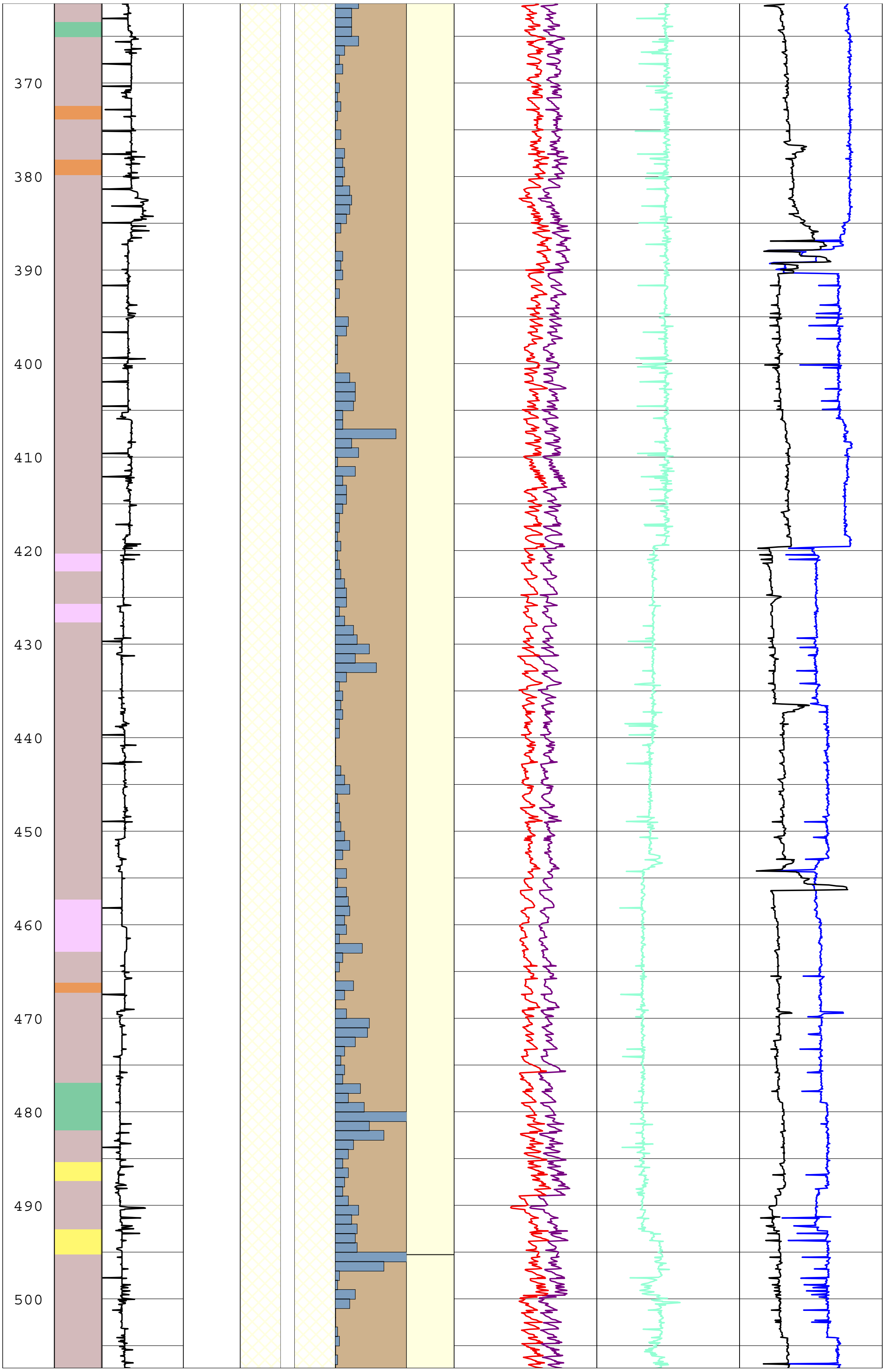
ROCKTYPE FROM ON-SITE DESCRIPTION FORSMARK

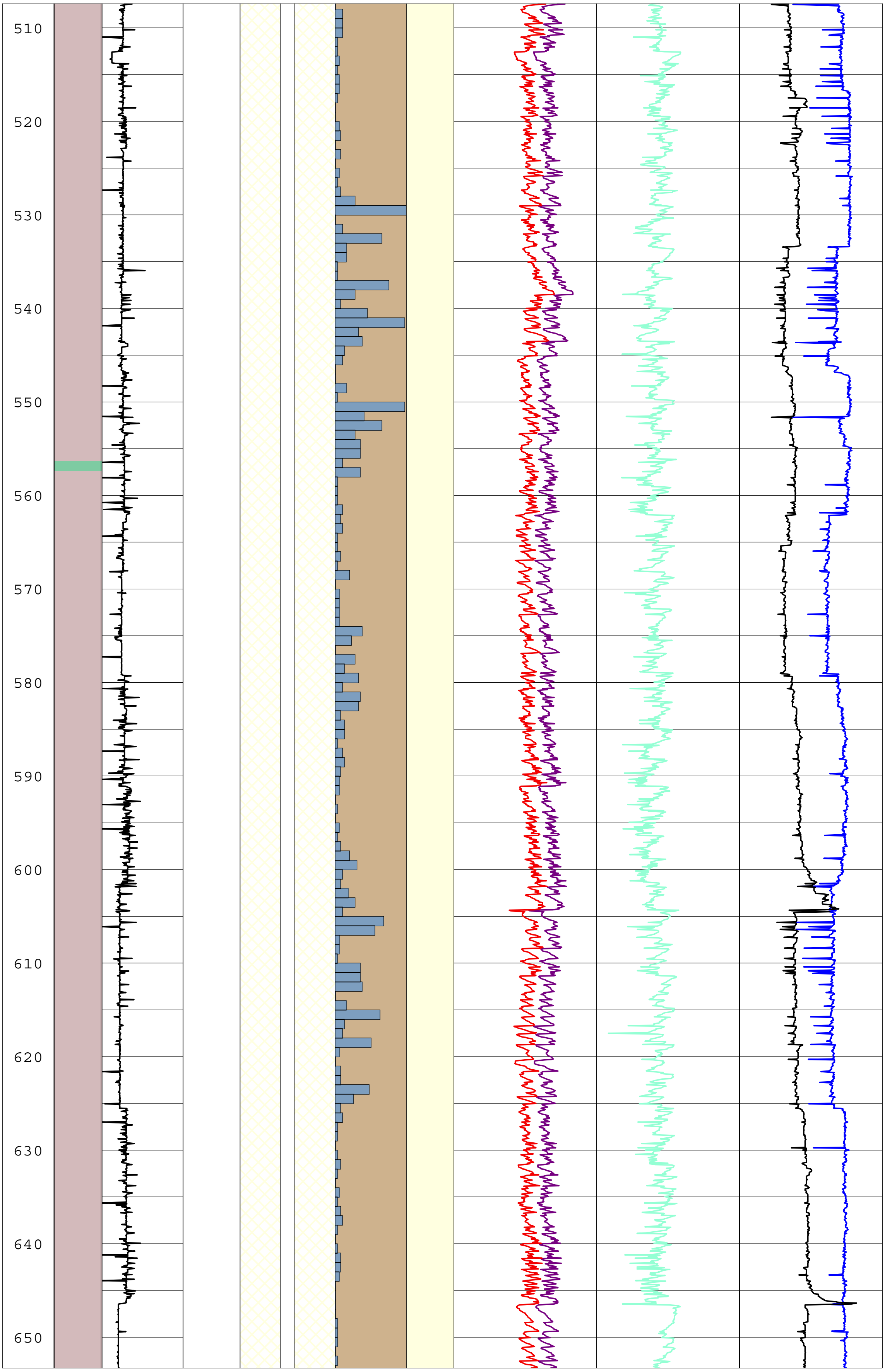
- **Pegmatite, pegmatitic granite**
- **Granite to granodiorite, metamorphic, medium-grained**



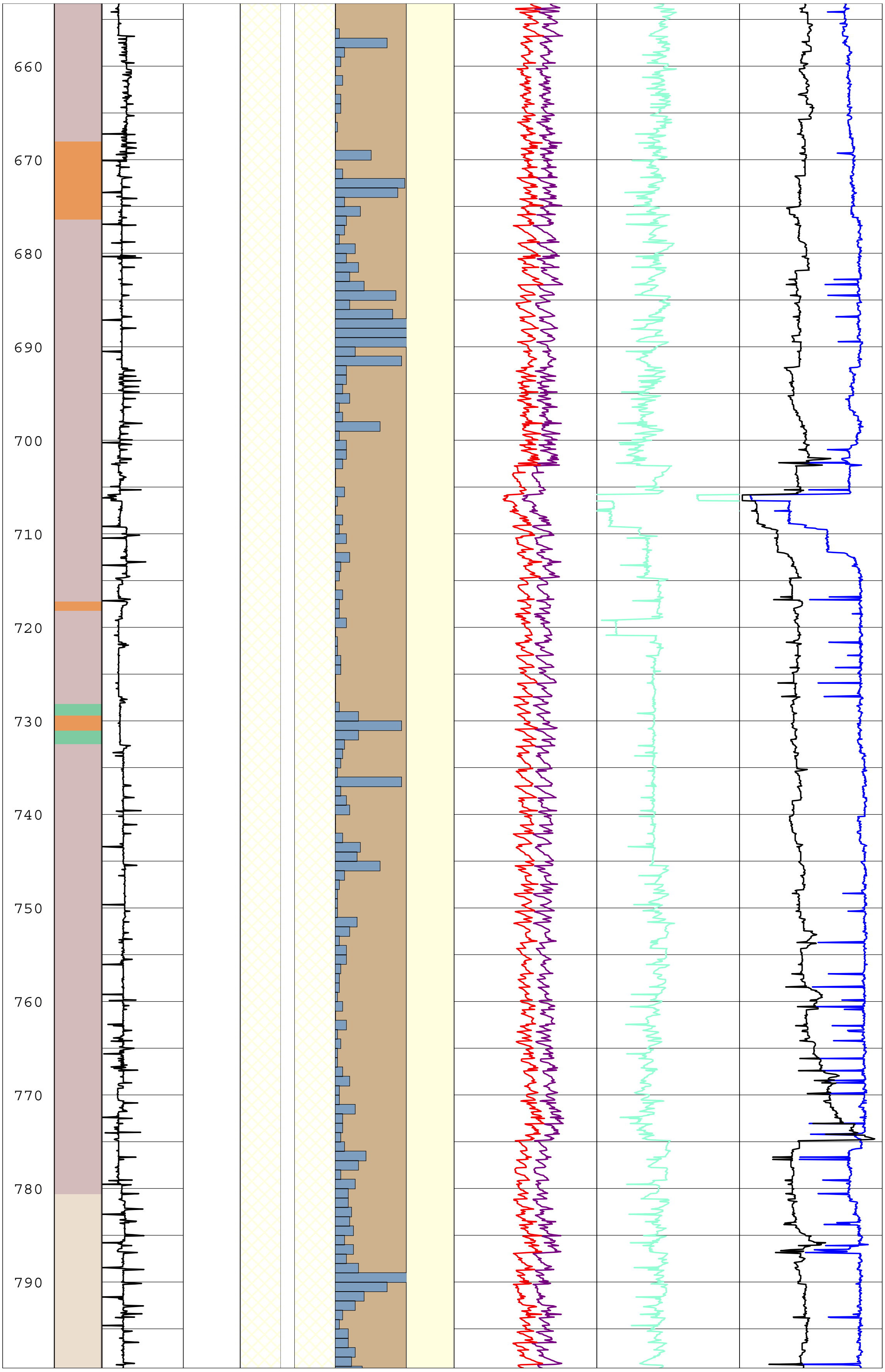

70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
97.14
0.086
102.40
0.077

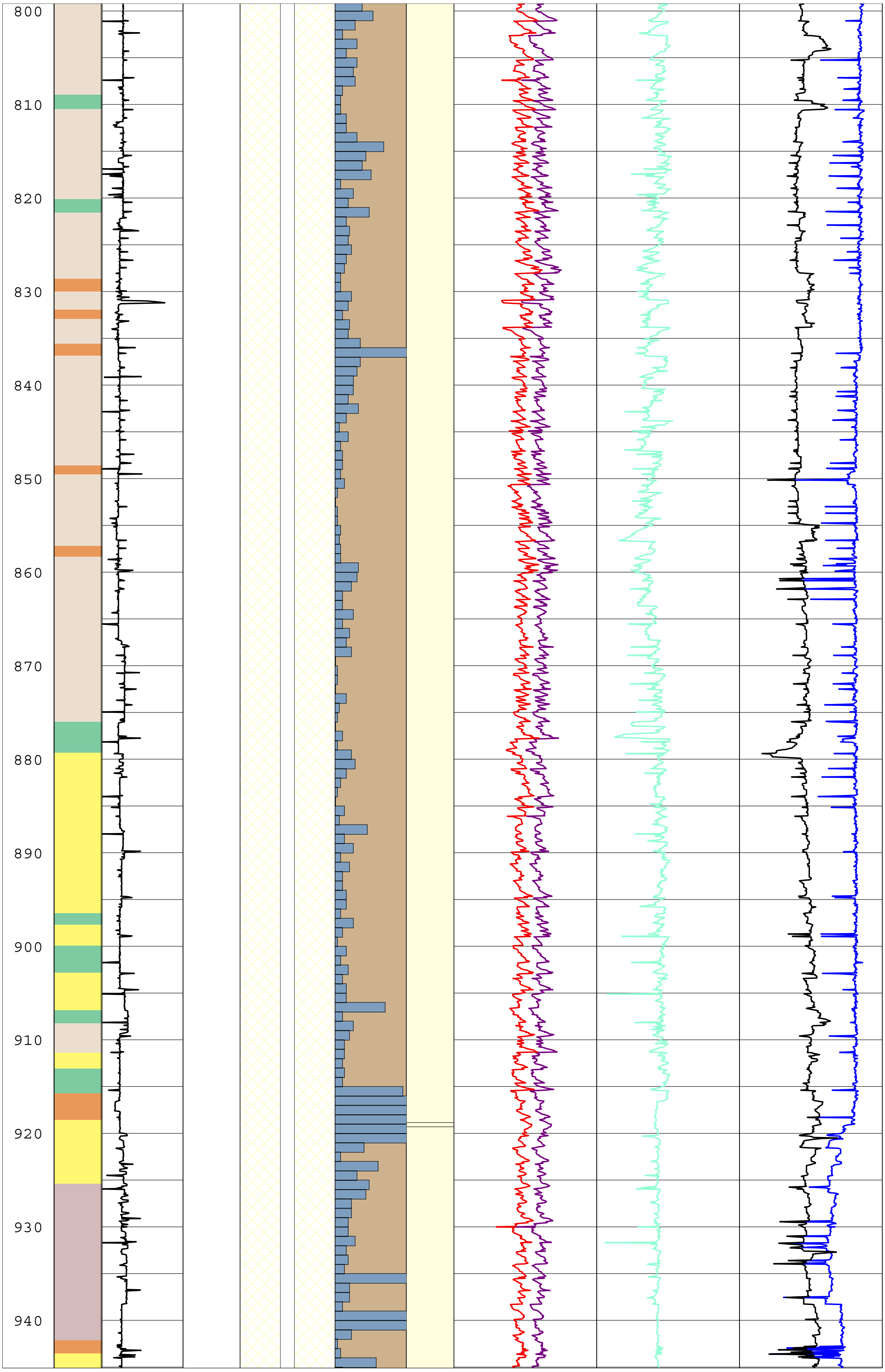

220
230
240
250
260
270
280
290
300
310
320
330
340
350
360

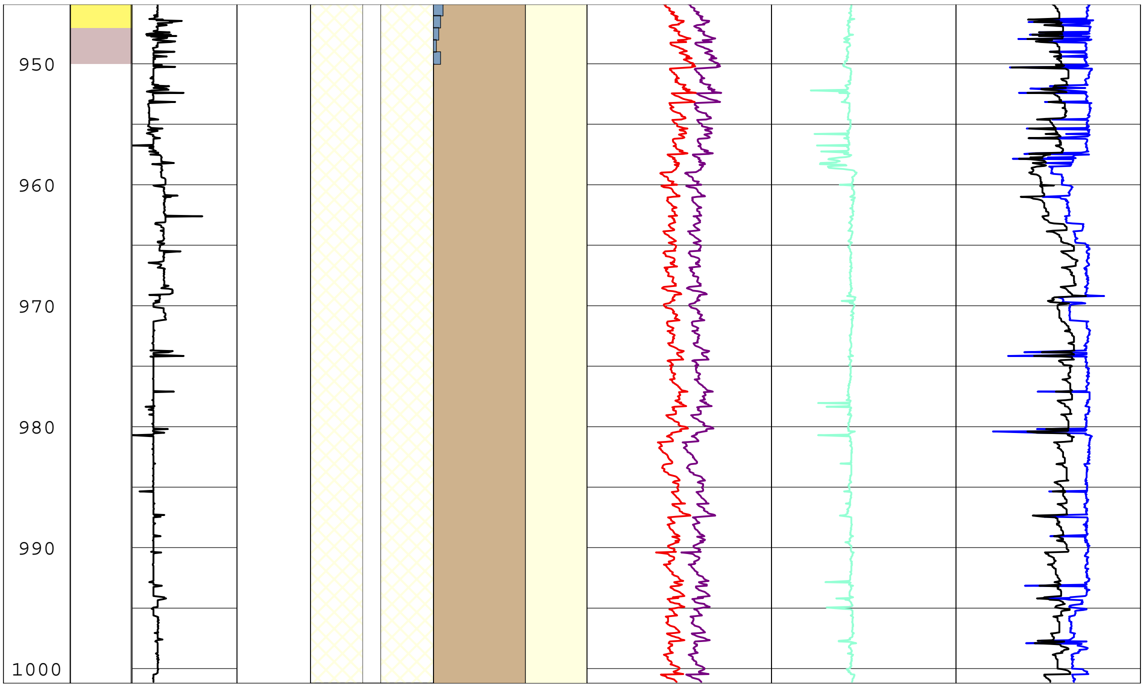

370
380
390
400
410
420
430
440
450
460
470
480
490
500



510
520
530
540
550
560
570
580
590
600
610
620
630
640
650


660
670
680
690
700
710
720
730
740
750
760
770
780
790


800
810
820
830
840
850
860
870
880
890
900
910
920
930
940


950
960
970
980
990
1000

Well Cad presentation of the complete borehole KFM08B

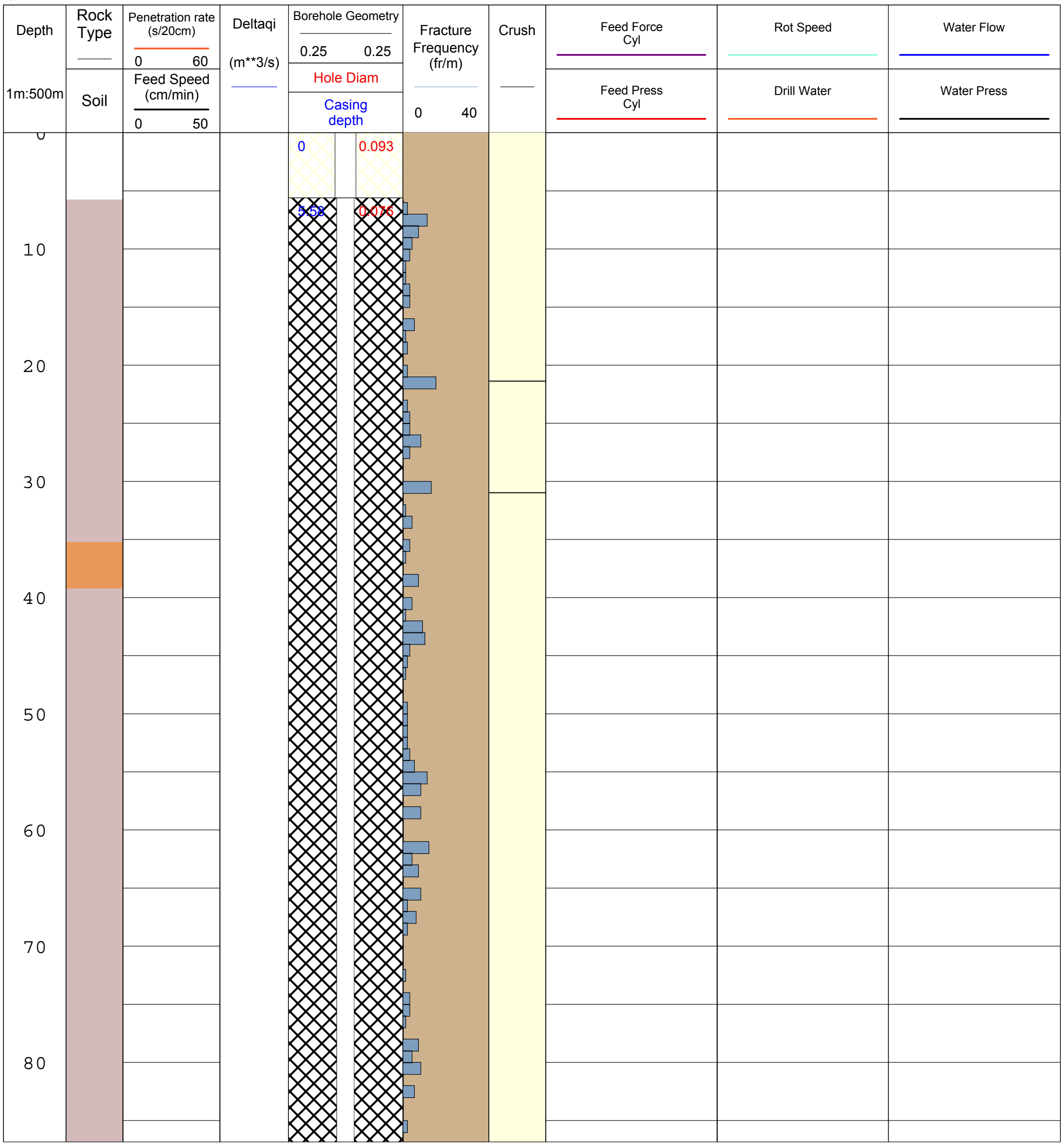
Title	**KFM08B**		
Svensk Kärnbränslehantering AB		**Signed data**	
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM08B	**Northing [m]**	6700492.75
Diameter [mm]	76.2	**Easting [m]**	1631173.27
Length [m]	200.54	**Elevation [m.a.s.l.]**	2.25
Bearing [°]	270.45	**Drilling Start Date**	2005-01-03 16:04:00
Inclination [°]	-58.85	**Drilling Stop Date**	2005-01-26 14:51:00
Date of mapping		**Plot Date**	2005-10-20 01:11:02

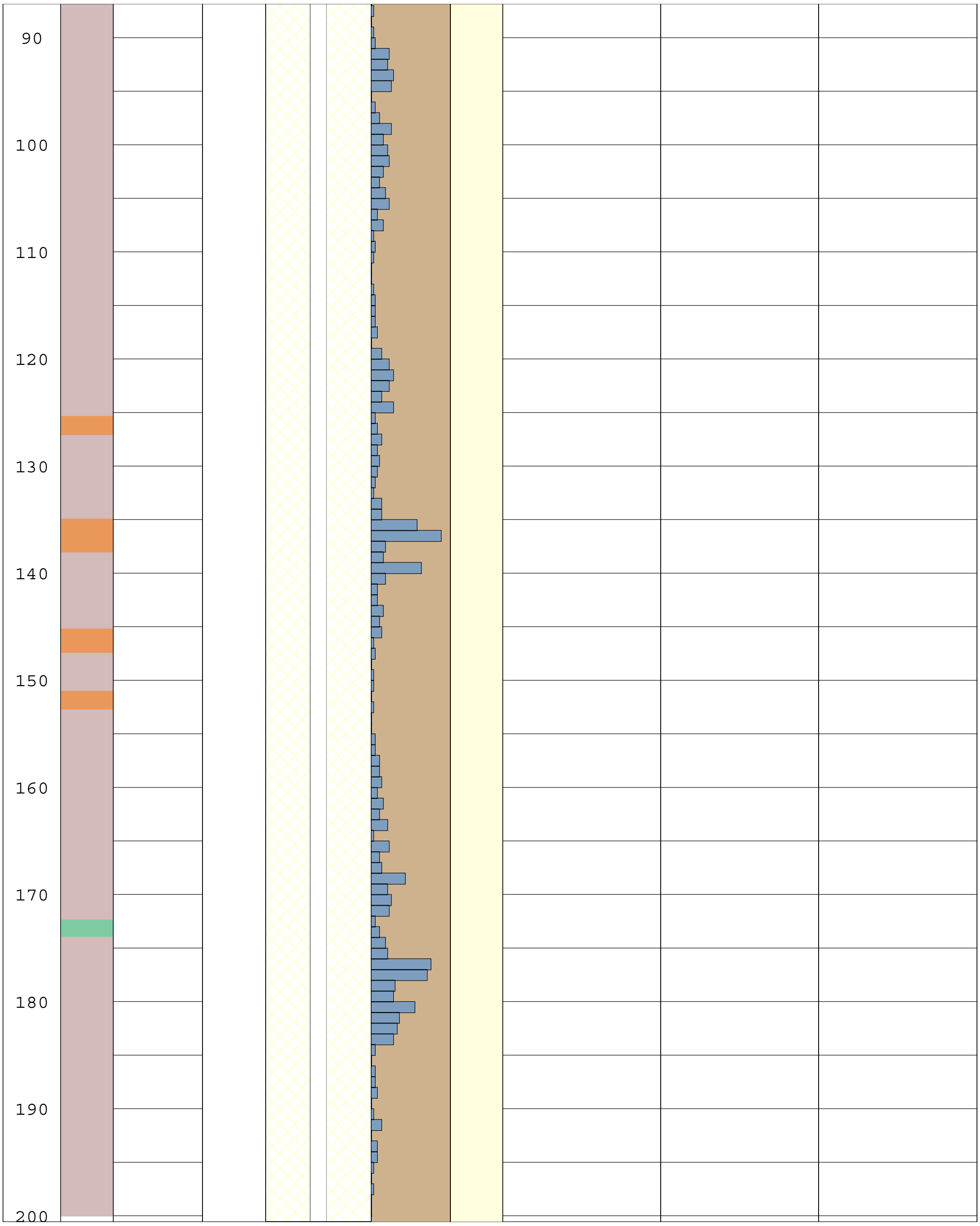
ROCKTYPE FORSMARK

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

SOIL

Script Name




90
100
110
120
130
140
150
160
170
180
190
200

Appendix D

Water Composition

Date	ID code	Sample no	Na mg/L	K	Ca	Mg	HCO_3	Cl	SO4	SO_4_S	Br	F	Si	Li	Sr	TOC	Uranine %	pH	Cond mS/m
2005-02-02	KFM08A	8786***	796	9.36	342	25.8	23.8	1,950	69.5	24.6	17.8	1.25	3.61	0.019	3.56	*	17.1	7.07	592
2005-02-22	HFM22	8805	1,340	36.8	460	127	221	3,010	340	121	22.5	0.9	5.98	0.041	2.67	4.2	*	7.44	970
2005-03-17	HFM22	8840	1,290	35.5	413	107	239	2,770	345	117	20.1	1.41	6.76	0.035	2.72	4.8	*	7.45	933

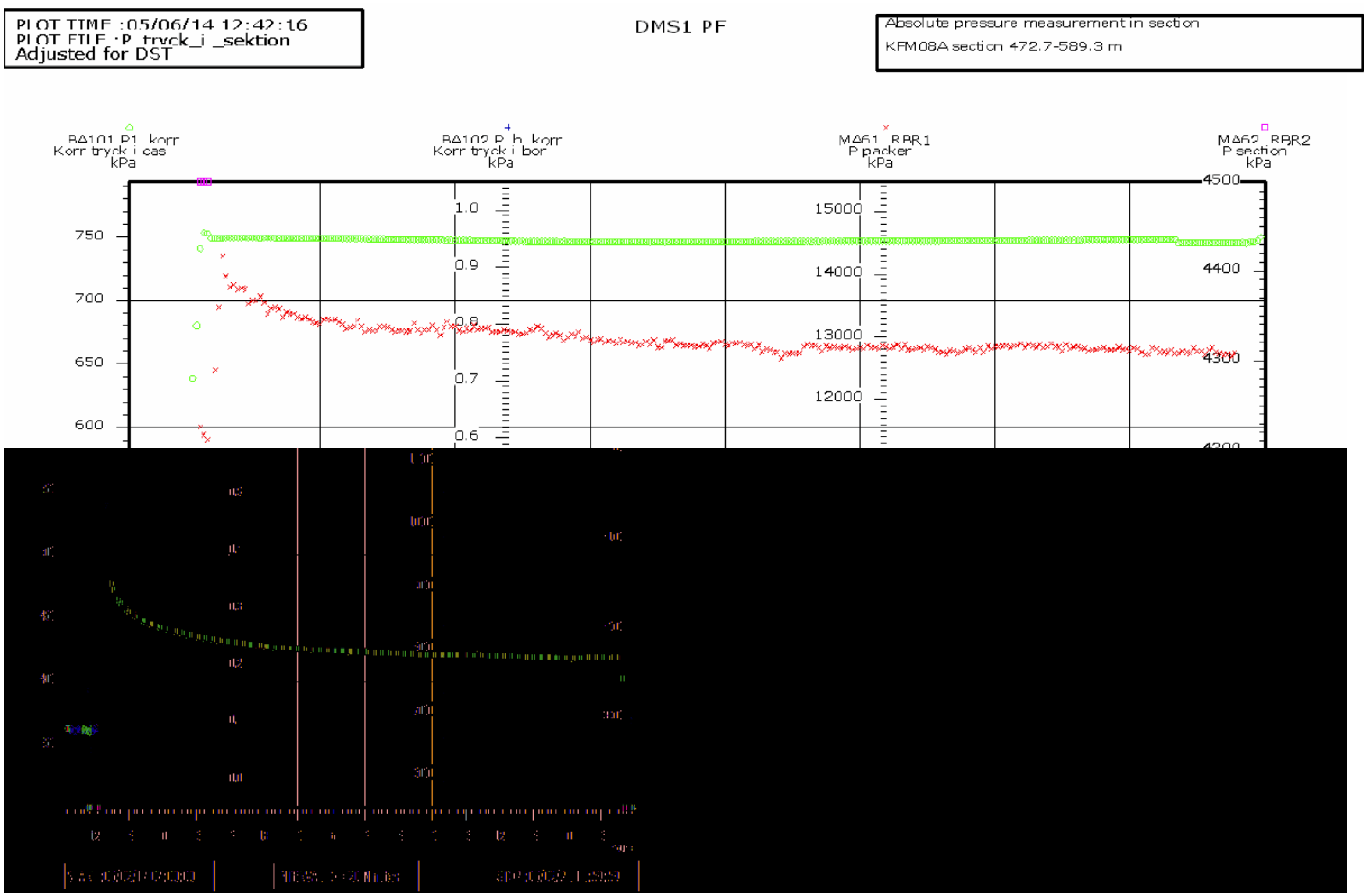
* not analysed
*** section 0–210.52 m

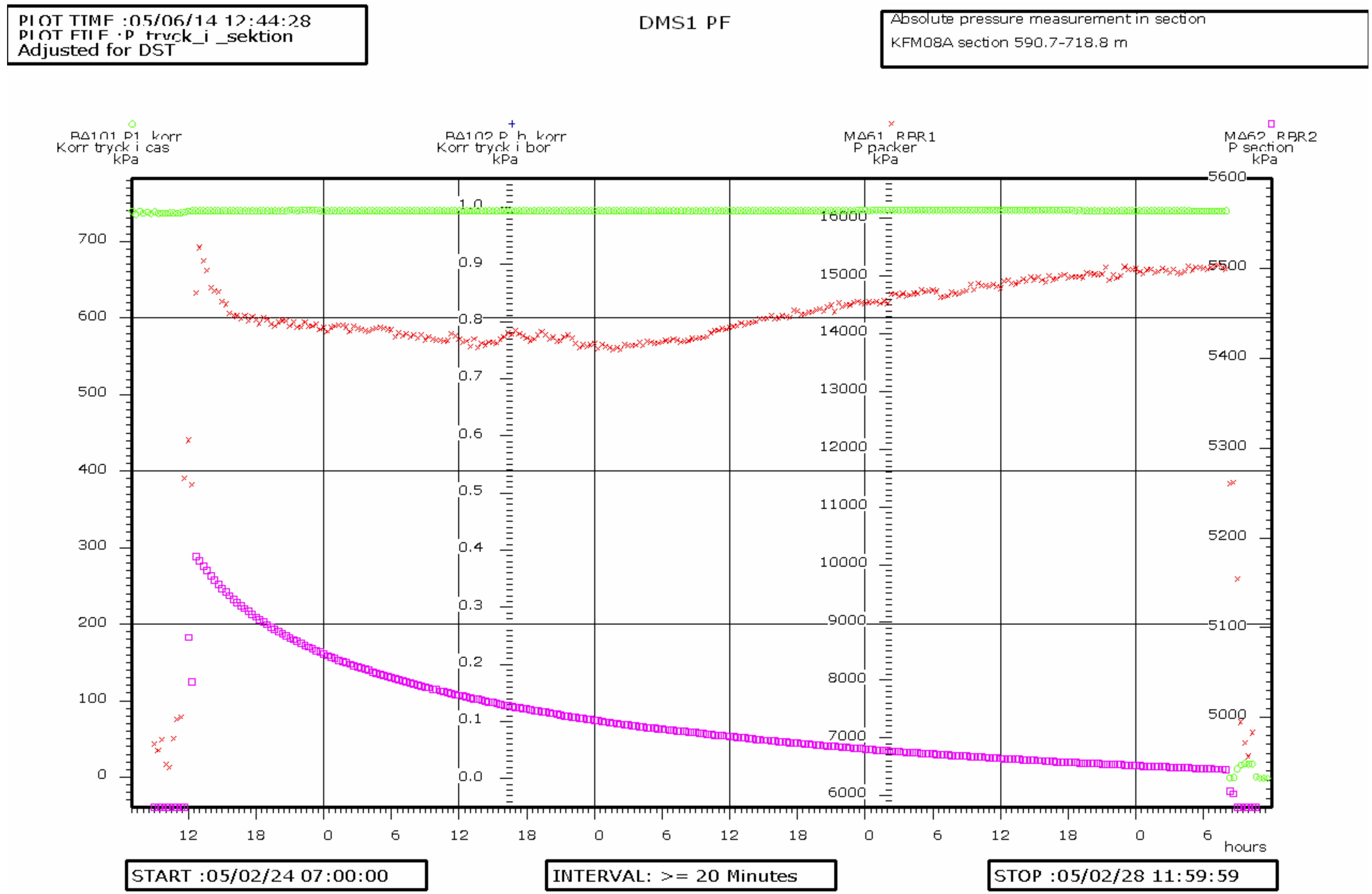
Date	IDCODE	Sample no	^{2}H dev SMOW	^{3}H(TU) Tu	^{18}O(dev) dev SMOW	^{14}C pmc	^{13}C dev PDB	Age BP year	$^{10}B/^{11}B$ no unit	34S(dev) dev CDT	$^{87}SR/^{86}Sr$ no unit	^{37}Cl dev SMOC
2005-02-02	KFM08A	8786	–109.9	0.9	–14.5	**	**	**	0.2332	27.8	0.719092	0.23
2005-02-22	HFM22	8805	–67.4	2.0	–8.7	**	–6.44	**	0.2337	23.4	0.722768	0.16
2005-03-17	HFM22	8840	–75.6	**	–9.1	**	**	**	0.2391	21.6	0.722676	–0.05

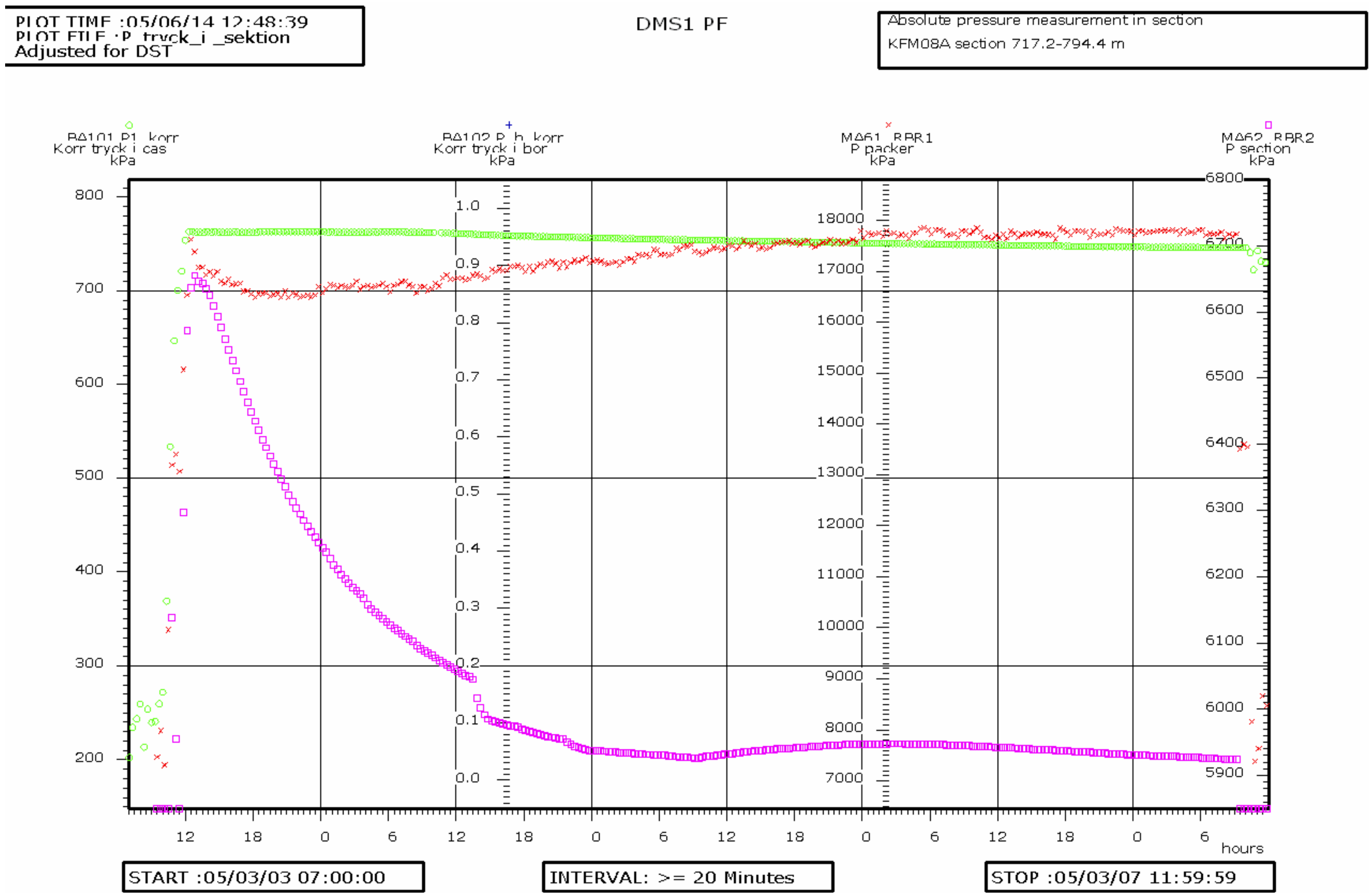
** will be reported later

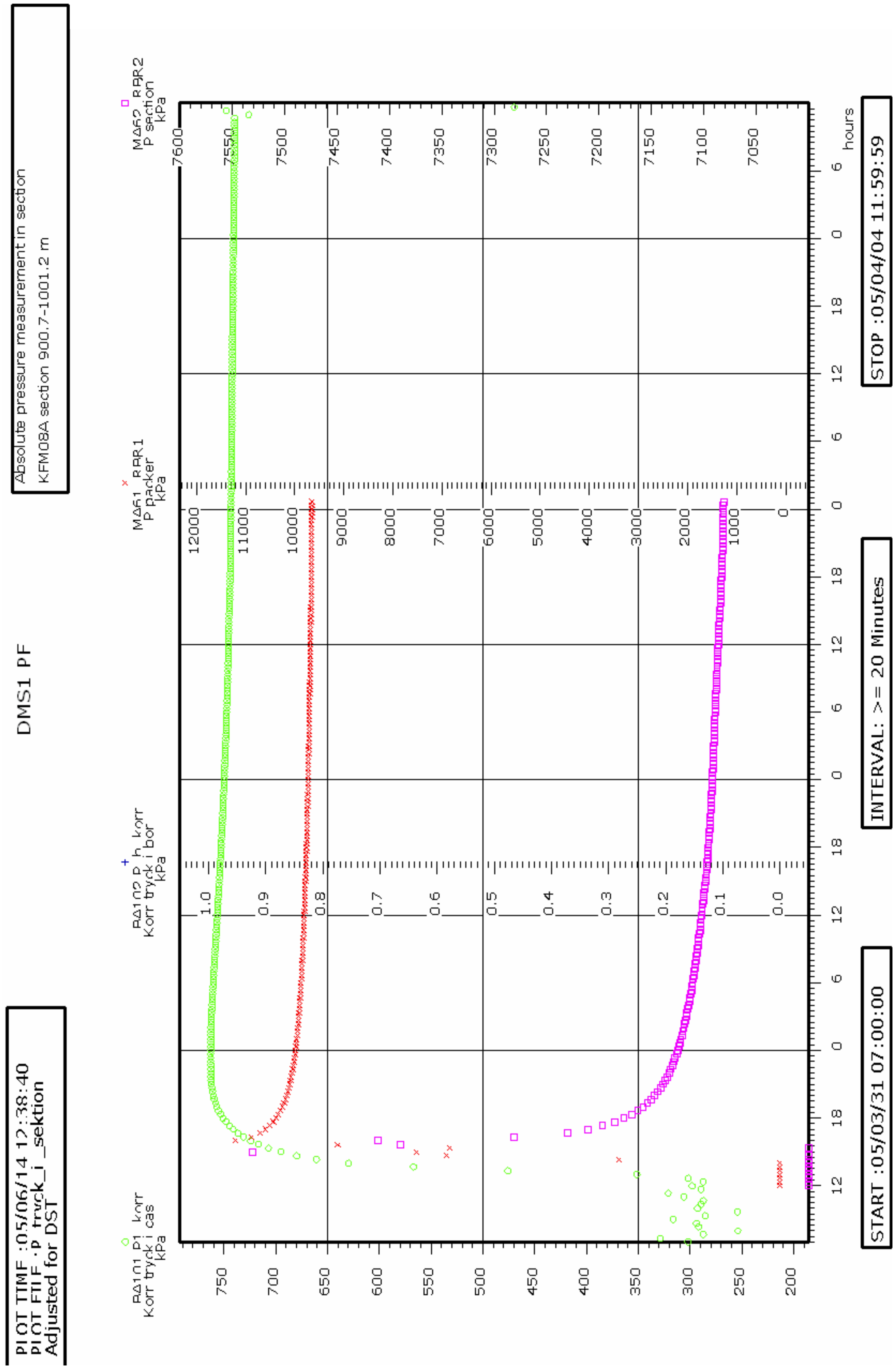
Appendix E

Absolute pressure measurement




PLOT TIME :05/06/14 12:44:28
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM08A section 590.7-718.8 m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P_h_korr
Korr tryck i bor
kPa
MA61 RBR1
P packer
kPa
MA62 RBR2
P section
kPa
hours
START :05/02/24 07:00:00
INTERVAL: >= 20 Minutes
STOP :05/02/28 11:59:59


PLOT TIME :05/06/14 12:48:39
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM08A section 717.2-794.4 m
BA101_P1_korr
Korr tryck i cas
kPa
BA102 P_h_korr
Korr tryck i bor
kPa
MA61_RBR1
P packer
kPa
MA62_RBR2
P section
kPa
hours
START :05/03/03 07:00:00
INTERVAL: >= 20 Minutes
STOP :05/03/07 11:59:59


PLOT TIME :05/06/14 12:38:40
PLOT FILE :P_tryck_i_sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM08A section 900.7-1001.2 m
RA101 P1_korr
Korr tryck i cas
kPa
RA102 P_h_korr
Korr tryck i bor
kPa
MA61 BBR1
P packer
kPa
MA62 BBR2
P section
kPa
hours
START :05/03/31 07:00:00
INTERVAL: >= 20 Minutes
STOP :05/04/04 11:59:59