P-06-171

Forsmark site investigation

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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 c. 60–100 metres 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. 500–1,000 m.

Performance of and results from drilling and measurements during drilling of KFM08C and KFM08D at Forsmark by applying telescopic technique are presented in this report. KFM08C is 951.08 m long, at its starting point inclined 60.46° from the horizon, and reaches about 783 m vertical depth, whereas KFM08D is 942.30 m long and at its starting point inclined 55.00° from the horizon. KFM08D reaches about 751 m vertical depth. Both boreholes are of so called SKB chemical type, intended for detailed hydrogeochemical and microbiological investigations.

During pilot drilling of section 0–100 m in KFM08C with the diameter 161 mm, the borehole was experienced as stable, low fractured and as insignificantly water yielding. Therefore the percussion drilled part was reamed to its final diameter, 191 mm, and the borehole was left uncased, except for the part through the soil layer and a few metres into firm bedrock.

One of the main objectives of drilling KFM08D was to investigate a sequence of NE-SW-trending lineaments earlier identified by ground geophysical measurement. During pilot drilling of KFM08D, section 0–59 m, with the diameter 157 mm, a relatively low water-yield, c. 30 L/min was measured. As the borehole was inclined 55°, a higher risk of instability and outfall from the borehole wall prevails, and after reaming to Ø c. 243 mm, the percussion drilled part was cased with a stainless steel casing, and the gap between the borehole wall and the casing was grouted. These measures entailed that all inflow of groundwater to the percussion drilled part of the borehole ceased.

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

The conclusion after drilling was that only relatively small amounts of flushing water and drill cuttings penetrated the fracture system of KFM08C, whereas the higher frequency of open fractures in the upper part of borehole KFM08D caused higher amounts of flushing water and drill cuttings to discharge into the fracture system in of this borehole. The NE-SW-trending lineaments investigated by KFM08D appeared to correspond to minor, steeply dipping fracture zones, of which some showed moderately increased hydraulic transmissivity values, whereas others were non-transmissive.

A sampling- and measurement programme for percussion drilling and another programme for core drilling provided preliminary but current information about the geological and hydraulic character of the borehole directly on-site. It also served as a basis for extended post-drilling analyses. For example, the drill cores from the core drilled part and the samples of drill cuttings from the percussion drilled section, together with later produced video images of the borehole wall (so called BIPS-images), were used for mapping of the borehole (so called Boremap mapping) performed after drilling. Diagrams of the Boremap mapping results are 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. Unfortunately, in KFM08C, the milled grooves below 450 m length were not detectable, due to instrument failure.

Earlier experience from drilling is that the quartz-rich bedrock in Forsmark is hard to drill, entailing rapid wearing of drill bits. During drilling of KFM08C a new type of drill bits was tested. Initially, when drilling KFM08C the results were not satisfactory, but during drilling of KFM08D the average lifetime of drill bits increased with almost 100% compared to when drilling at the Forsmark site investigation started in 2002.

Other lasting impressions from the drilling of KFM08C and KFM08D are that some gently dipping fracture zones encountered in the shallow part of the bedrock at DS8 were water-yielding in KFM08D but almost dry in KFM08C. The major parts of the core drilled sections in KFM08C and D displayed a very low fracture frequency and low water-yielding capacity. Regarding KFM08D, this was true also for the minor, steeply dipping, NE-SW-trending fracture zones encountered.

Sammanfattning

De flesta djupa borrhål inom Forsmarks platsundersökning utförs som s.k. teleskopborrhål. Det innebär att de övre ca 60–100 metrarna hammarborras i två steg, pilotborrning med dimensionen ca 160 mm följd av upprymning till ca 200–250 mm diameter. Avsnittet därunder kärnborras med 76–77 mm diameter. Resultaten från KFM08C och KFM08D, som båda har borrats med teleskopborrningsteknik redovisas i denna rapport. KFM08C är ansatt med en lutning av 60,46° från horisontalplanet, är 951,08 m långt och når ca 783 m vertikaldjup, medan KFM08D är ansatt med en lutning av 55.00° från horisontalplanet, är 942,30 m långt och når ca 751 m vertikaldjup. Båda borrhålen är så kallat kemiprioriterat borrhål, vilket innebär att de planeras att användas för detaljerade hydrogeokemiska och bakteriologiska undersökningar, varför all utrustning som används i borrhålen, både vid borrning och mätning, måste rengöras och desinficeras enligt speciella instruktioner.

Vid hammarborrning av avsnittet 0–100 m i KFM08C med diametern 161 mm befanns att borrhålet är stabilt och har låg sprickfrekvens och obetydlig vattenföring, varför det rymdes upp till slutdimensionen 191 mm utan att foderrörsbeklädas mer än genom jordlagren och ytterligare ca 10 meter ner i fast berg.

Ett huvudsyfte med KFM08D var att undersöka en serie lineament med NO-SV-lig strykning som tidigare hade identifierats med markgeofysiska mätningar. Vid hammarborrningen av avsnittet 0–59 m i KFM08D med diametern 157 mm uppmätte ett grundvatteninflöde av 30 L/min. Då borrhålet är relativt flackt ansatt, ca 55° från horisontalplanet, ökar risken för utfall från bergväggen, varför hålet upprymdes till 243 mm och försågs med ett rostfritt foderrör, varefter spalten mellan borrhålsvägg och foderrör cementinjekterades, så att allt vattenflöde i denna del av borrhålet upphörde.

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

Slutsatsen efter borrningen av KFM08C var att endast relativt små mängder spolvatten och borrkax har trängt ut i spricksystemet, medan förekomsten av fler öppna sprickor i den övre delen av KFM08D medförde att en högre andel spolvatten och borrkax kan ha trängt ut i spricksystemet i detta borrhål. De NO-SV-liga lineamenten som genomborrades visade sig motsvara mindre sprickzoner, av vilka några uppvisade en något förhöjd hydraulisk transmissivitet i jämförelse med omgivande berg, medan andra tycktes var helt täta.

Ett mät- och provtagningsprogram för hammarborrningen och ett annat program för kärnborrningen gav preliminär information om borrhålets geologiska och hydrauliska karaktär direkt under pågående borrning samt underlag för fördjupade analyser efter borrning. Bland de insamlade proverna utgör borrkärnorna från den kärnborrade delen av borrhålet och borrkaxproverna från den hammarborrade delen, tillsammans med videofilm av borrhålsväggen (s.k. BIPS-bilder), underlaget för den borrhålskartering (s.k. Boremap-kartering) som utförs efter borrning. Resultatdiagram från Boremapkarteringen av KFM08C respektive KFM08D finns redovisade 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.

Den kvartsrika berggrunden i Forsmark är svårborrad och borrkroneslitaget är högt men under borrningen av KFM08C utprovades nya borrkronor, som till en början, under borrningen av

KFM08C, gav mindre tillfredsställande resultat. Senare, mot slutet av borrningen av KFM08D, kunde dock konstateras att borrkronornas livslängd ökat med nästan 100 % sedan borrningarna i Forsmark startade 2002.

Andra bestående intryck av borrkampanjen är att några av de flacka zoner som påträffades i den övre delen av borrplats BP8 är vattenförande i KFM08D, men har en knappt märkbar vattenföring i KFM08C. Sprickfrekvensen och vattenföringen i större delen av de kärnborrade partierna av borrhålen KFM08C och KFM08D visade sig vara låga. Även de små, brantstående, NO-SV-liga sprickzonerna som påträffades i KFM08D visade sig ha låg hydraulisk transmissivitet.

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 and 2) percussion drilled boreholes in solid rock and 3) boreholes drilled through regolith. The last type may be accomplished by different drilling techniques, e.g. percussion drilling and auger drilling.

This document reports the data and results gained by drilling of the telescopic boreholes KFM08C and KFM08D at drill site DS8, which is two of the activities included in the site investigations at Forsmark. The work was carried out in compliance with activity plans AP PF 400-05-016 and AP PF 400-06-093.

Figure 1-1. *The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drill sites DS1-12 are marked with blue dots.*

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.

The deepest boreholes drilled at the site investigation are drilled with core drilling techniques. In total, three sub-vertical and eleven inclined, approximately 800–1,000 m long, cored boreholes are drilled within the investigation area. Besides the deep holes, six semi-deep (500–800 m) boreholes and five short (100–500 m) boreholes have been core drilled. The boreholes are located at twelve drill sites, see Figure 1-1, where each site may include between one and four cored boreholes as well as percussion drilled holes and soil boreholes.

By drilling many of the deep boreholes so called telescopic drilling technique is applied, meaning that the upper 60–100 m of the borehole are percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section below is core drilled with a diameter of approximately 76–77 mm. This technical approach was applied also when drilling KFM08C and KFM08D, which have a total drilling length of 951.08 m and 942.30 m, respectively. Borehole KFM08C is inclined c. 60 degrees from the horizontal plane, entailing that the vertical depth of the borehole is about 783 m and the horizontal extension reaches approximately 537 m. Borehole KFM08D, which is inclined c. 55 degrees from the horizontal plane, has a vertical depth of c. 751 m and a horizontal extension of about 568 m. Both boreholes are of the so called SKB chemical type. This implies that the boreholes is prioritized for hydrogeochemical and microbiological investigations, necessitating that all DTH (Down The Hole) equipment used during and/or after drilling shall undergo special cleaning procedures, see Chapter 4.

A short (c. 200 m) core drilled borehole, KFM08B, has previously been drilled in order to compensate for the missing core in section 0–100 m in the telescopic borehole KFM08A, which was the first cored borehole to be drilled at drill site DS8.

Close to the deep boreholes at drill site DS8, also a percussion drilled borehole in solid rock has been drilled for different purposes. The length of this borehole is 222 m. The locations of all boreholes at DS8 are shown in Figure 1-2. As shown in the figure, the onsets of the four boreholes KFM08A, KFM08B, KFM08C and KFM08D at DS8 are very close to each other.

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

Activity Plans	Number	Version
Borrning av teleskopborrhål KFM08C	AP PF 400-05-016	1.0
Borrning av teleskopborrhål KFM08D	AP PF 400-06-093	1.0
Method Descriptions	**Number**	**Version**
Metodbeskrivning för hammarborrning	SKB MD 610.003	2.0*
Metodbeskrivning för hammarborrning	SKB MD 610.003	3.0**
Metodbeskrivning för kärnborrning	SKB MD 620.003	1.0*
Metodbeskrivning för kärnborrning	SKB MD 620.003	2.0**
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

* Used for KFM08C.
** Used for KFM08D.

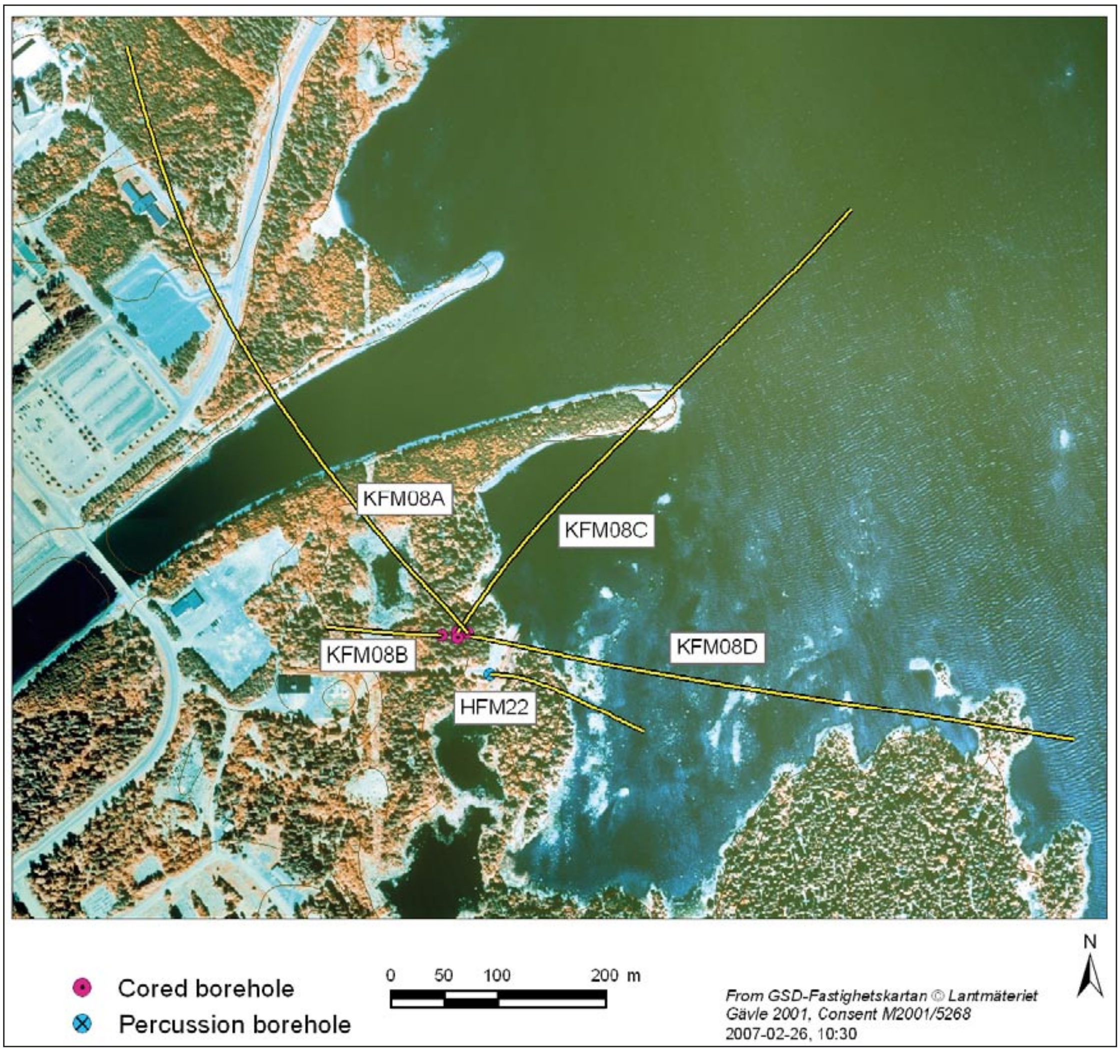


Figure 1-2. *Borehole locations at drill site DS8. Besides the core drilled boreholes KFM08A, KFM08B, KFM08C and KFM08D, the area incorporates a monitoring well in bedrock (HFM22), also used as flushing water well for the core drilling. The projection of inclined boreholes on the horizontal plane at the ground surface (top of casing) is shown in the figure.*

Drill site DS8 is located in the north-western part of the candidate area, c. 400 m east of the Forsmark power facilities, and close to the cooling water inlet of the power facilities, see Figure 1-1.

The drilling operations for KFM08C were performed during two periods, between April 14th 2005 to April 26th 2005 (percussion drilling) and Jan 30th 2006 to May 9th 2006 (core drilling), respectively. KFM08D was drilled between Nov 23rd and Dec 4th 2006 (percussion drilling) and Dec13th 2006 and Feb 10th 2007 (core drilling). Drillcon Core AB, Nora, Sweden, was engaged for the drilling commission.

In the present report, performance of and results from drilling of KFM08C and KFM08D, are presented. The report also treats investigations made during and immediately after drilling.

Original data from the reported activities are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan number (AP PF 400-05-016 and AP PF 400-06-093, respectively). Only data in databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major revisions entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

2 Objectives 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. 60–100 m of the solid rock. Below 60–100 m, the core drilling provides (in principle) continuous drill cores down to the borehole bottom. A short core borehole, KFM08B, was drilled earlier at drill site DS8 to compensate for the missing core of the upper part of the bedrock. 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 fracture system 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.

An extensive ground geophysical measurement campaign was previously performed in the land and sea areas north-east of the Forsmark candidate area /3/. With the method applied (magnetometry), a sequence of NE-SW-trending lineaments intersecting the candidate area were identified. In order to investigate the lithological-structural and hydraulic significance of these lineaments, a core drilled borehole, KFM08D, was directed in such a way as to penetrate these lineament more or less perpendicular. This was the primary objective of drilling KFM08D.

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.

3 Equipment

Two types of drilling machines were employed for drilling borehole KFM08C. The upper c. 100 metres were drilled with a percussion drilling machine of type Commacchio 1500 S. Core drilling c. 100–950 m, was performed with a Wireline-76 core drilling system, type Onram 2000 CCD.

Borehole KFM08D was performed with a percussion drilling machine of type Puntell MX 1000 for the upper c. 60 metres, whereas core drilling was accomplished with the same machine as for KFM08C.

3.1 Percussion drilling equipment

Both the Commacchio and the Puntell percussion machines are equipped with separate engines for transportation and power supplies. Water and drill cuttings were retrieved from the borehole by a 27 bars air-compressor, type Atlas-Copco XRVS 466 Md.

At drill site DS8, the bedrock is covered by approximately one metre of gravel fill. This part had to be cased off with a solid pipe (NO-X 280). 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 KFM08C are presented in Section 5.2 and for KFM08D in Section 5.6.

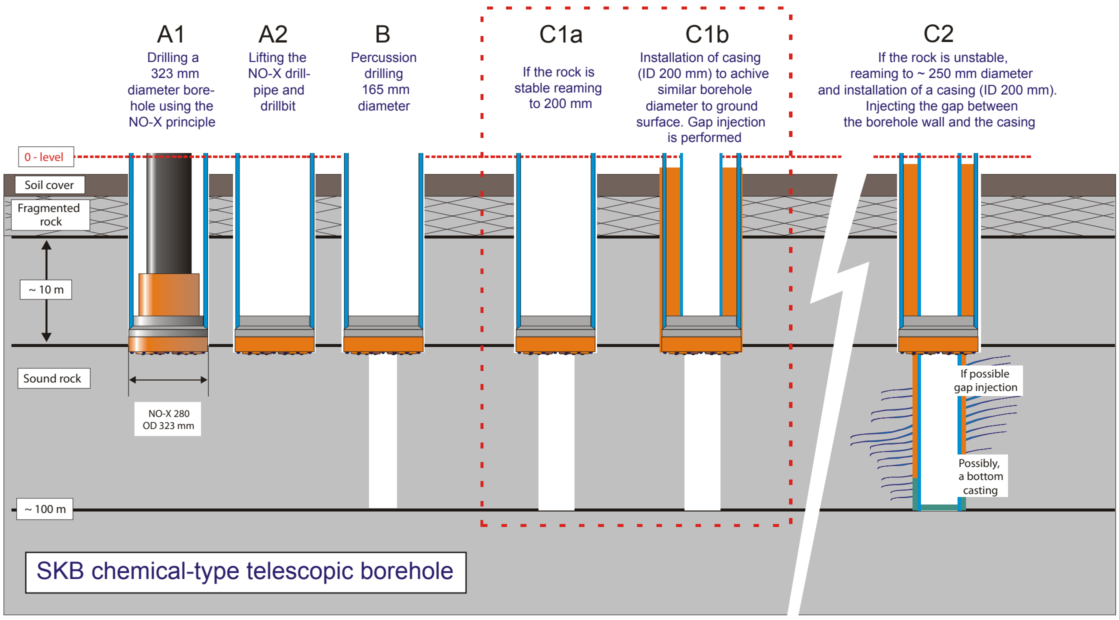


Figure 3-1. *Schematic diagram showing the various stages of drilling the 0–100 m section of an SKB chemical-type telescopic borehole. The letters and numerals above each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB MD 620.003.*

3.2 Grouting 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 in SKB site investigation boreholes normally cased to the full drilling length. The gap between the borehole wall and the casing is then cement grouted, which further decreases or, often, completely prevents, inflow of shallow groundwater to the borehole. Application of cement in the gap between the borehole wall and the casing pipe can be performed according to different techniques. Two variants are illustrated in Figure 3-2.

Borehole KFM08C was grouted at three occasions: 1) after installation of the $Ø_o/Ø_i$ 208/200 mm, 12.06 m long casing (C2 in Figure 3-1) a bottom plug was grouted just below the casing, 2) gap injection through a packer without achieving an observable cement level in the gap, and 3) using a flexible hose lowered between the casing and the borehole wall whereby satisfactory grouting results were obtained.

Borehole KFM08D was grouted after installation of the $Ø_o/Ø_i$ 208/200 mm, 58.80 m long casing (C2 in Figure 3-1) by gap injection through a packer, see Figure 3-2.

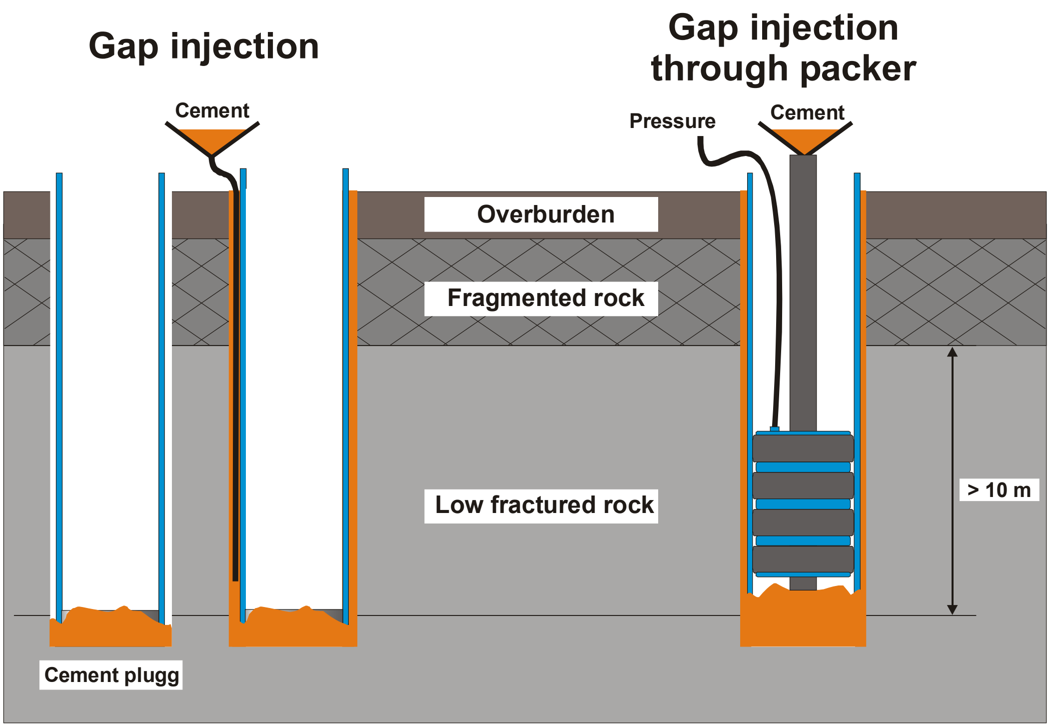


Figure 3-2. *Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer.*

3.3 Core drilling equipment

3.3.1 The wireline-76 system

For drilling the cored parts of boreholes KFM08C and KFM08D, 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 metres. The drill pipes and core barrel used belong to the Hagby WL76 triple-tube system. Technical specifications of the drilling machine with fittings are given in Table 3-1.

3.3.2 Flushing/return water system – function and equipment

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

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

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

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

Unit	Manufacturer/type	Specifications	Remarks
Onram 2000	Hagby-Asahi	Capacity for 76–77 mm holes maximum approx. 900–1,500 m depending on choise of drill string	
Flush water pump	Bean	Max flow rate: 170 L/min Max pressure: 103 bars	
Submersible pump	Grundfos SQ	Max flow rate: 200 L/min	
Mobile electrical plant	P250HE with diesel engine Perkins GCD 325	250 KVA, 200 kW, 360 A.	
Compressor	Atlas Copco GA75P-13	Max pressure: 12 bars Flow: > 5 L/sec	Electrically supplied
CCD-system	Dunfoss		Standard system modified for core drilling by the manufacturer

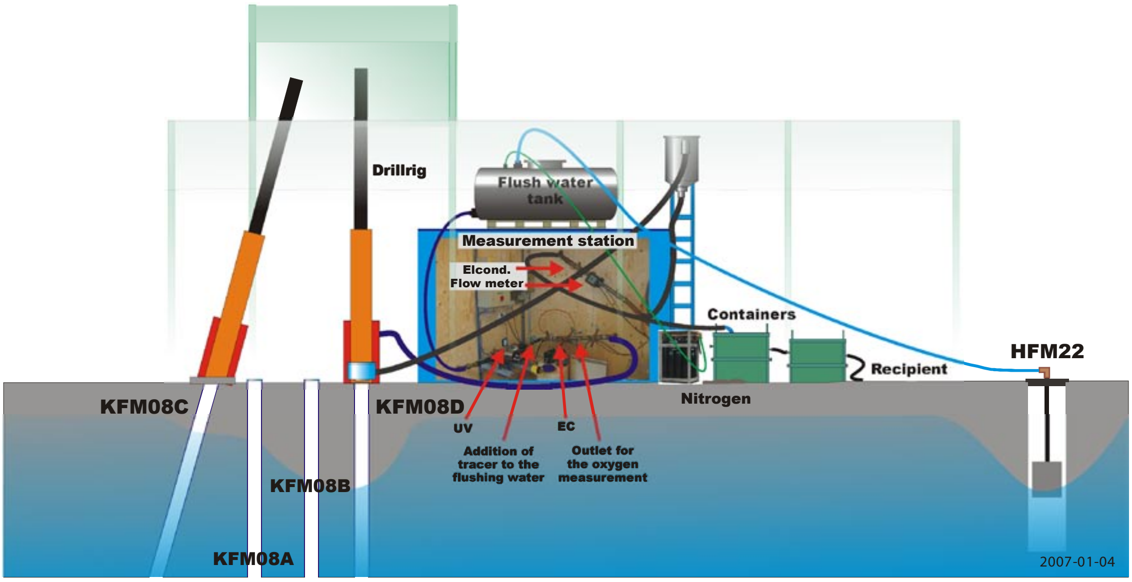


Figure 3-3. *Schematic illustration of the flushing/return water system when drilling KFM08C and KFM08D at DS8. The measurement station included logger units and an UV-radiation unit. For flushing water flow rate and pressure measurements, the drilling machine gauges were applied.*

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 contents 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 KFM08C and KFM08D was a percussion drilled well in hard rock, HFM22, situated at DS8 approximately 50 m away of the core drilled boreholes, see Figure 1-2.

Besides the above mentioned basic demands on the flushing water quality, which were fulfilled when drilling KFM08C and KFM08D, the flushing water was also prepared in three steps before use, in accordance with SKB MD 620.003.

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

Measurement of flushing water parameters

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

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

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

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

Air-lift pumping while drilling

Air-lift pumping during core drilling telescopic boreholes involves pumping of compressed air into the percussion drilled portion of the borehole, forcing it to emerge at a depth of about 40–100 m depending on the depth of the percussion drilled borehole section, the groundwater yield and the capacity of the air-lift pump. 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 KFM08C and KFM08D consisted of several main components, see Table 3-3 and Figure 3-4.

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 in KFM08C and D, 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 40 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.

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

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

Table 3-3. Air-lift pumping equipment used in KFM08C and KFM08D.

Item	KFM08C	KFM08D
Air compressor, 12 bars/10 m³/min	X	X
Electrical supply cubicle, at least 16 A	X	X
Outer support casing, Ø 98/89 mm diameter	100 m	59 m
Inner support casing, Ø 84/77 mm diameter	100.5 m	59.5 m
2 Ejector pumps, each contains;*		
PEX hose, 1 x Ø 22 mm	2 x 100+30** m	2 x 60+30** m
PEM hose, 1 x Ø 40 mm	2 x 100+20** m	2 x 60+20** m
Air nozzle		
PEX hose, 1 x Ø 22 mm	90+30** m	50+30** m
Expansion vessel (= discharge head)	X	X
PEM hose: 20 bars, Ø 32 mm (pressure transducer)	90 m	60 m
Pressure transducer, 10 bars, instrumentation and data-logging unit	X	X

* Two separate mammoth pumps system are always installed in a telescopic borehole.
** Extended hose; PEX connected to air compressor and PEM connected to Cyclone.

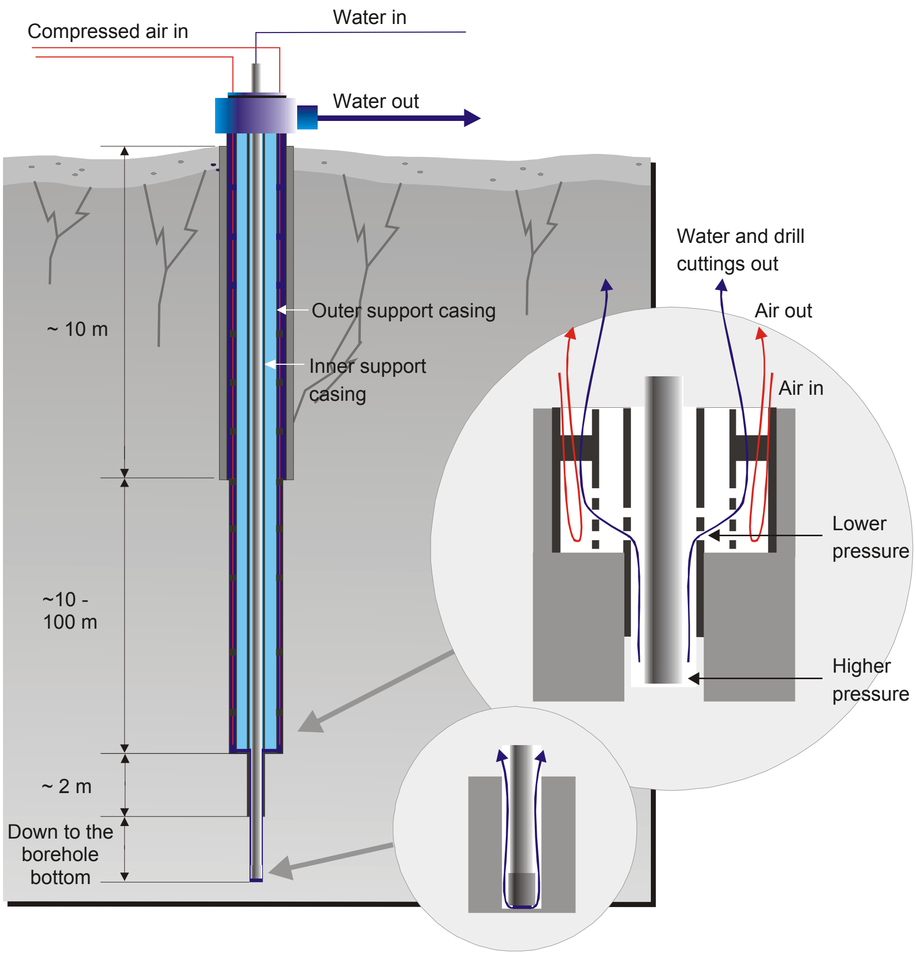


Figure 3-4. *Air-lift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole. 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.*

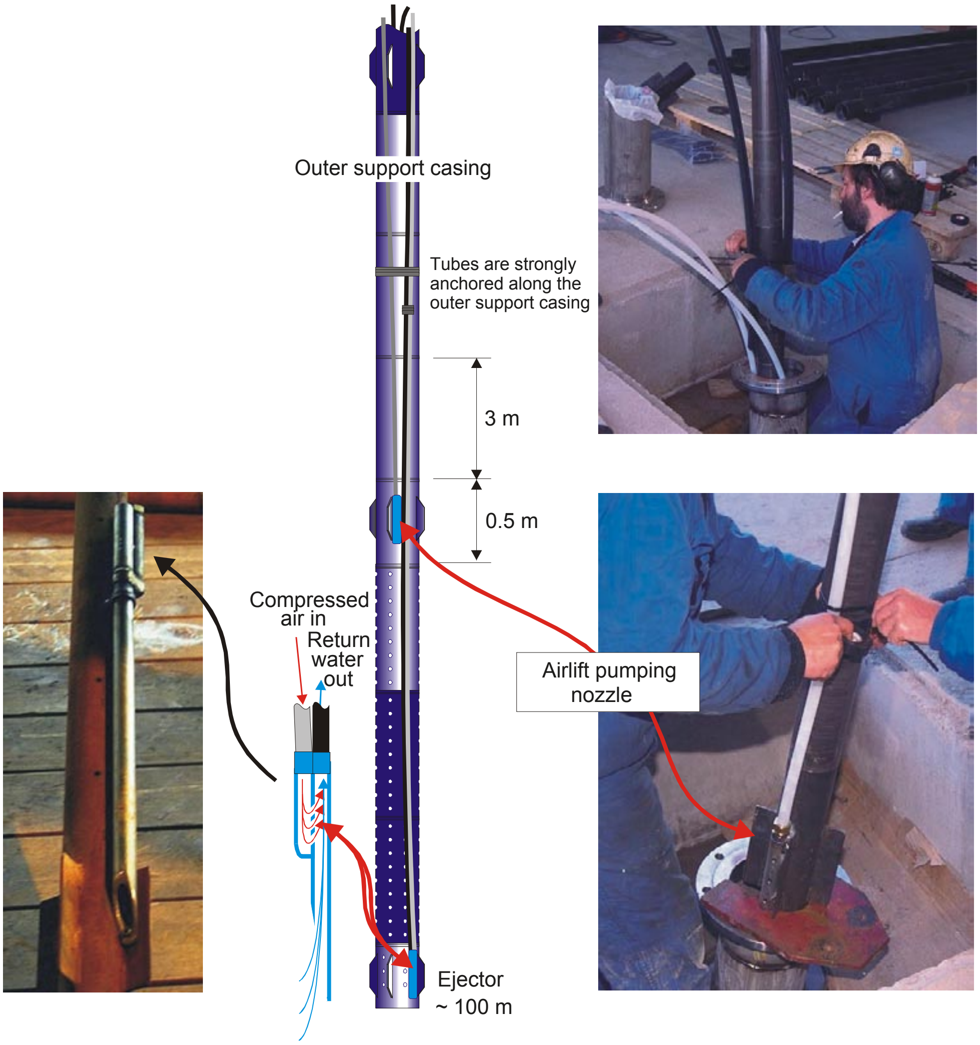


Figure 3-5. *Schematic representation of connection and installation of air-lift pumping nozzle and ejector on the outer protective casing.*

Storage and discharge of return water

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 were 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 3.3.3. As a back-up and double-check, the total quantity of water supplied to the borehole was acquired by counting the number of filled water tanks used, multiplied by the tank volume.

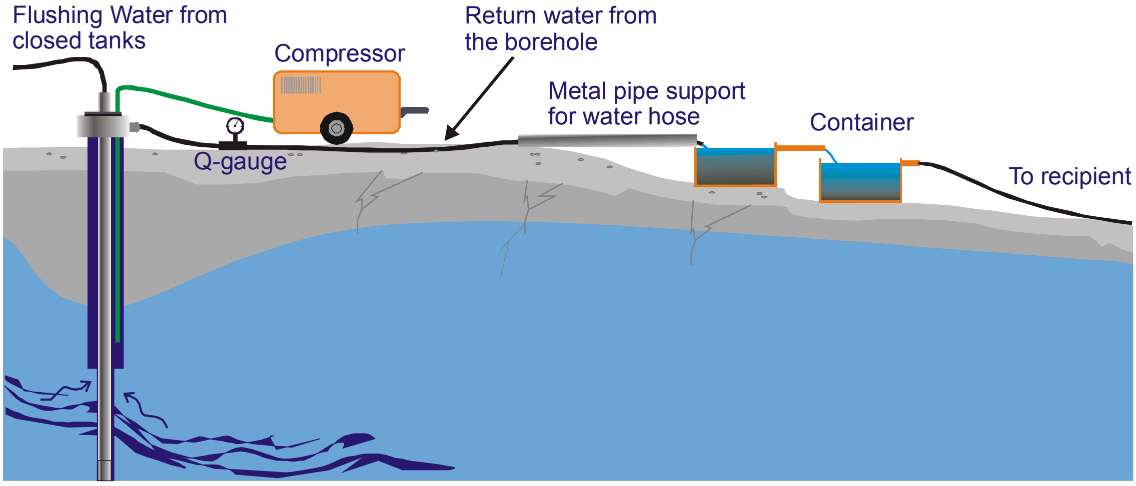


Figure 3-6. *Return water system. Air-lift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in three stages in the containers (where they are preserved for later weighing), after which the water is pumped to an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

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

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

3.3.3 Drilling monitoring system

The Onram 2000-CCD drilling machine is supplied with a computer based logging kit integrated in the steering system (cf. Section 3.3.1). The parameters logged are those used for automatic operation of the drilling machine. During drilling of some 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, which was drilled during the period February 10th 2004 to April 20th 2004 /4/. 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 contents.

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

3.3.4 Groove milling equipment

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

At each level, two 20 mm wide grooves were milled with a distance of 10 cm between them, see Figure 3-7. After milling, the reference grooves were detected with the SKB level indicator (a calliper). A BIPS-survey provided the final confirmation that the grooves exist.

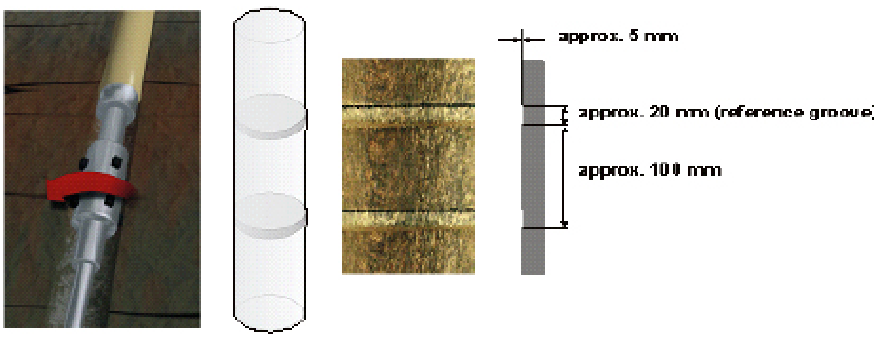


Figure 3-7. *Layout and design of reference grooves.*

3.3.5 Equipment for deviation measurements

During drilling of boreholes KFM08C and KFM08D, deviation measurements were made after completed drilling in order to check the straightness of the borehole. The measurements were initially performed with a Reflex Maxibor™ system, which is an optical, i.e. non-magnetic, measurement system. Azimuth and dip are measured at every third metre. The collaring point coordinates and the measured values are used for calculating the coordinates of the position of the borehole at every measurement point.

Also another method, based on magnetic accelerometer technique, was applied for deviation measurements in KFM08C and KFM08D in order to check the validity of the Maxibor™-measurements. The surveying instrument used was the Flexit Smart Tool System.

At the time of drilling KFM08C and KFM08D, the Maxibor™-method was assessed as the most reliable of different deviation methods tested by SKB, and Maxibor-data stored in the database Sicada were normally assigned as the only deviation data set permitted to be used (so called "in use displayed data") even if another or several deviation methods had been applied in the borehole as well. However, in connection with a major quality revision regarding orientation of all identified geological objects (fractures, fracture zones rock contacts etc) conducted by SKB during late autumn 2006 to winter/early spring 2007, a reassessment of the reliability of deviation measurement methods was made, whereby the Flexit-method was judged as providing the most reliable results. Therefore a revision was made also for boreholes KFM08C and KFM08D, and to-day Flexit-data are the in use displayed deviation data set. However, all available deviation measurements, i.e. for boreholes KFM08C and KFM08D Flexit- as well as Maxibor-data have been used for estimation of the uncertainty of deviation data.

Results from the deviation measurements and data handling are presented in Sections 5.4.10 and 5.8.9.

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

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

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

KFM08C

The percussion drilling started with drilling through the overburden during simultaneous casing driving (NO-X 280) and subsequent gap injection. These activities followed the principles described in Sections 3.1 and 3.2. The borehole was drilled and cased with $Ø_i$ 310 mm casing to 11.86 m, ensuing continued drilling. The borehole was extended to 100.48 m with the pilot bit.

In order to prevent leakage from the shallow water-yielding fractures penetrated by the borehole, a stainless steel casing, $Ø_i$ 200, mm was then installed to 12.06 m and after a cement bottom plug had been injected, the gap between the casing and borehole wall was grouted using the packer technique illustrated in Figure 3-2.

Finally, the borehole was reamed to Ø 193.1 mm to 100.44 m length, whereupon the borehole was cleaned from drill cuttings by a "blow out" with the compressor working at maximum capacity during 30 minutes. This also served as a hydraulic capacity test of the percussion drilled part of the borehole, as the recovery of the groundwater table was registered after the compressor had been turned off.

KFM08D

The percussion drilling started by penetrating the overburden during simultaneous casing driving (NO-X 280) and subsequent gap injection. These activities followed the principles described in Sections 3.1 and 3.2. The borehole was drilled and cased with $Ø_i$ 310 mm casing to 5.6 m, after which drilling continued and the borehole was extended to 59.12 m with the pilot bit.

For stabilization of the entire percussion drilled part, the borehole was reamed to 253.3 mm diameter to 58.99 m length, and a stainless steel casing with $Ø_i$ 200 mm was installed to 58.80 m length.

Before installing the casing, the borehole was cleaned from drill cuttings by a "blow out" with the compressor working at maximum capacity during 30 minutes. This also served as a hydraulic capacity test of the borehole, as the recovery of the groundwater table was registered after the compressor had been turned off. The results were used on-site for rating the gap injection of the casing, see below.

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

KFM08C and KFM08D

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 161 mm (KFM08C) respectively 157 mm (KFM08D) 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 contents was made on-site as a basis for classification of the rock type.
2) Manual measurements of the penetration rate at every 20 cm.
3) Observation of the flow rate (if any) at every 20 cm. When a significant increase of the flow rate was noticed, it was measured using a graduated vessel and a stop-watch.
4) Observation of the water colour at every 20 cm.
5) Measurement of the electric conductivity of the groundwater at every three metres.

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 between approximately 191 mm (lower reamed part) and 197 mm (upper reamed part) in KFM08C and c. 253 mm in KFM08D. The boreholes were then secured with lockable stainless steel flanges. The drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the Contractor.

4.1.5 Nonconformities

None.

4.2 Core drilling

The core drilling operations included:

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

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

4.2.1 Preparations

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

4.2.2 Mobilization

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

4.2.3 Drilling, measurements and sampling during drilling

KFM08C

Core drilling of borehole KFM08C was performed with two borehole dimensions. Section 100.48–102.23 m was drilled with a borehole diameter of 86.0 mm, whereas the main part of the borehole, section 102.23–951.08 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 during drilling resting on the bottom of the percussion drilled borehole, see Figure 3-4.

KFM08D

Also core drilling of borehole KFM08D was performed with two borehole dimensions. Section 59.04–60.80 m was drilled with a borehole diameter of 86.0 mm, whereas the main part of the borehole, section 60.80–942.30 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.

KFM08C and KFM08D

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 space water in the rock matrix.

Core drilling with a wireline system involves recovery of the core barrel via the drill pipe string, inside which it is hoisted up with the wireline winch. During drilling of the boreholes KFM08C and KFM08D, 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 KFM08C and KFM08D 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 KFM08C and KFM08D.

Results of mapping of the drill core samples from KFM08C are presented in /5/ and from KFM08D in /6/, 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 boreholes was flushed for about 10 hours during simultaneous air-lift pumping in order to clean it from drilling debris adhered to the borehole walls, settled at the bottom of the hole, injected into the fracture system 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 percussion drilled and the cored part of the borehole, as shown in Figure 5-4. The cone in KFM08C is located at 97.43–102.23 m, whereas in KFM08D it is located at 55.71–60.75 m.
7) The boreholes were again secured with the lockable stainless steel flangs.
8) The core drilling equipment was removed, the sites cleaned and a joint inspection made by SKB and the Contractor.

4.2.4 Nonconformities in KFM08C and KFM08D

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

One important nonconformity in conjunction with drilling of KFM08C was that the drill bit was completely worn out during reaming to c. 74 m borehole length. The diameter of the drill bit was initially 196.7 mm and approximately 190 mm at 74 m length. Since the Method Description stipulates 194 mm as the smallest diameter for telescopic boreholes and since reaming can not restart with a new drill bit due to a high risk of wedging, a decision was made to continue the reaming with a smaller drill bit. The new drill bit was at the beginning 193.0 mm, and reaming was performed from 74 m to 100.44 m. The borehole diameter is 191.3 mm at 100.44 m.

The last item but one 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 obtain a measure of the drill cuttings recovery.

Table 4-1. Nonconformities regarding performance and frequency for sampling, measurements, registrations and other activities during and immediately after core drilling according to SKB MD 620.003, AP PF 400-05-016 and AP PF 400-06-093 during drilling of boreholes KFM08C and KFM08D respectively.

Activity	Performance and frequency according to SKB MD 620.004	Performance and frequency during drilling of KFM08C	Performance and frequency during drilling of KFM08D
Registration of drilling- and flushing water parameters.	Described in Section 3.3.2. Registration during the entire drilling.	According to programme.	According to programme.
Registration of the groundwater level in the borehole during drilling.	Every 10th second.	According to programme.	According to programme.
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	One measurement after completion of drilling with the Maxibor system and three measurement with the Flexit system.	One measurement after completion of drilling with the Maxibor system and one measurement with the Flexit system.
Measurements of the difference in length between the compressed drilling pipe string and as extended by its own weight.	Normally performed every 100 m.	Values presented in Figure 5-23 are from material properties of the drill pipe string.	Values presented in Figure 5-44 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 test made.	No test made.
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drilling pipe string should be controlled before each test.	No test made.	No test made.
Absolute pressure measurements.	Normally during natural pauses in drilling.	No test made.	No test made.
Groove milling in the borehole wall, normally at each 100 m.	Normally performed after completion of drilling.	Sixteen grooves performed. Only six grooves were detectable.	Seventeen grooves performed. All were detected.
Collecting and weighing of drilling debris.	Drilling debris settled in containers weighed after completed drilling.	Not carried out for the percussion drilled part of the borehole. According to programme for the core drilled part.	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.	Ordinary flushing combined with nitrogen flushing.

4.3 Data handling

4.3.1 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 caused it to be stored in the SKB database Sicada.

4.3.2 Nonconformities

None.

4.4 Environmental programme

4.4.1 Performance

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

4.4.2 Nonconformities

None.

5 Results

This chapter is structured as follows:

- Section 5.1 – drilling progress of KFM08C.
- Section 5.2 – geometrical data and technical design of KFM08C.
- Section 5.3 – results from percussion drilling of KFM08C.
- Section 5.4 – results from core drilling of KFM08C.
- Section 5.5 – drilling progress of KFM08D.
- Section 5.6 – geometrical data and technical design of KFM08D.
- Section 5.7 – results from percussion drilling of KFM08D.
- Section 5.8 – results from core drilling of KFM08D.

Well Cad-plots are composite diagrams presenting the most important technical and geo-scientific results from drilling and investigations made during and immediately after drilling. Well Cad presentations and hydrochemical data of boreholes KFM08C and KFM08D are shown in:

- Appendix A (percussion drilled part of KFM08C).
- Appendix B (the complete KFM08C).
- Appendix C (chemical analyses of flushing water for KFM08C).
- Appendix D (percussion drilled part of KFM08D).
- Appendix E (the complete KFM08D).
- Appendix F (chemical analyses of flushing water for KFM08D).

5.1 Drilling progress KFM08C

Drilling of borehole KFM08C was carried out during two periods, between April 14th 2005 and April 26th 2005 (percussion drilling) and Jan 30th 2006 to May 9th 2006 (core drilling), see Figure 5-1.

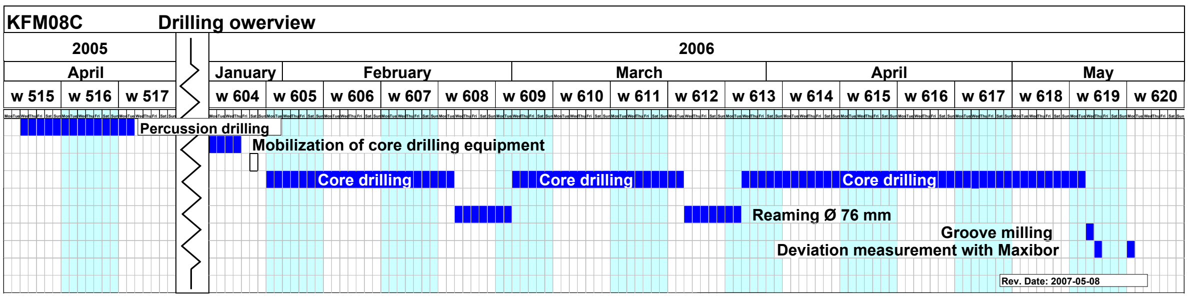


Figure 5-1. Overview of the drilling performance of borehole KFM08C.

5.1.1 Percussion drilling period

Percussion drilling is normally a rapid drilling method compared to core drilling. However, the relatively complex approach applied for the drilling, and especially the grouting sequences when drilling KFM08C, resulted in a rather long total working period, see Figure 5-2.

5.1.2 Core drilling period

Ensuing percussion drilling of section 0–100.48 m, a break of nine months followed, whereupon core drilling commenced. The progress of the core drilling from 2006-01-30 to 2006-05-09, is presented in Figure 5-3. The pace of drilling decreases versus time, due to that with increasing borehole length, retrieval of the core barrel, e.g. for change of drill bit, becomes more and more time consuming.

5.2 Geometrical data and technical design of borehole KFM08C

Administrative, geometric and technical data for the telescopic borehole KFM08C are presented in Table 5-1. The technical design is illustrated in Figure 5-4.

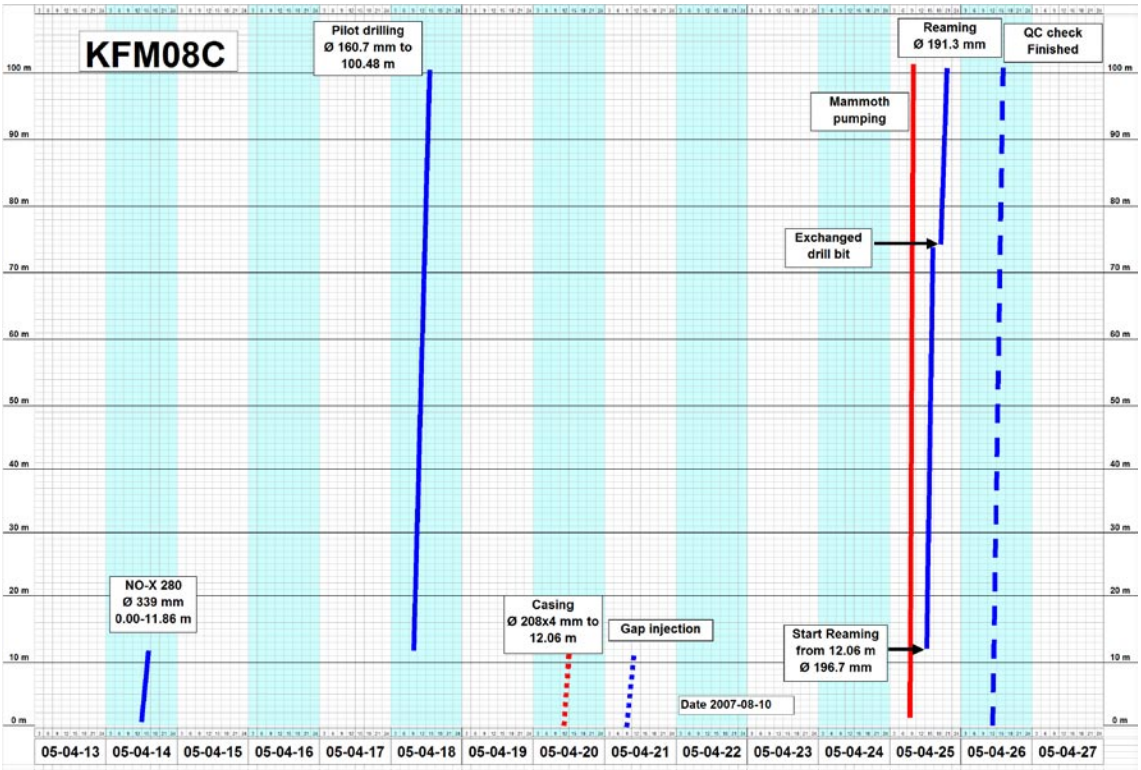


Figure 5-2. *Percussion drilling progress (length and activity versus calendar time).*

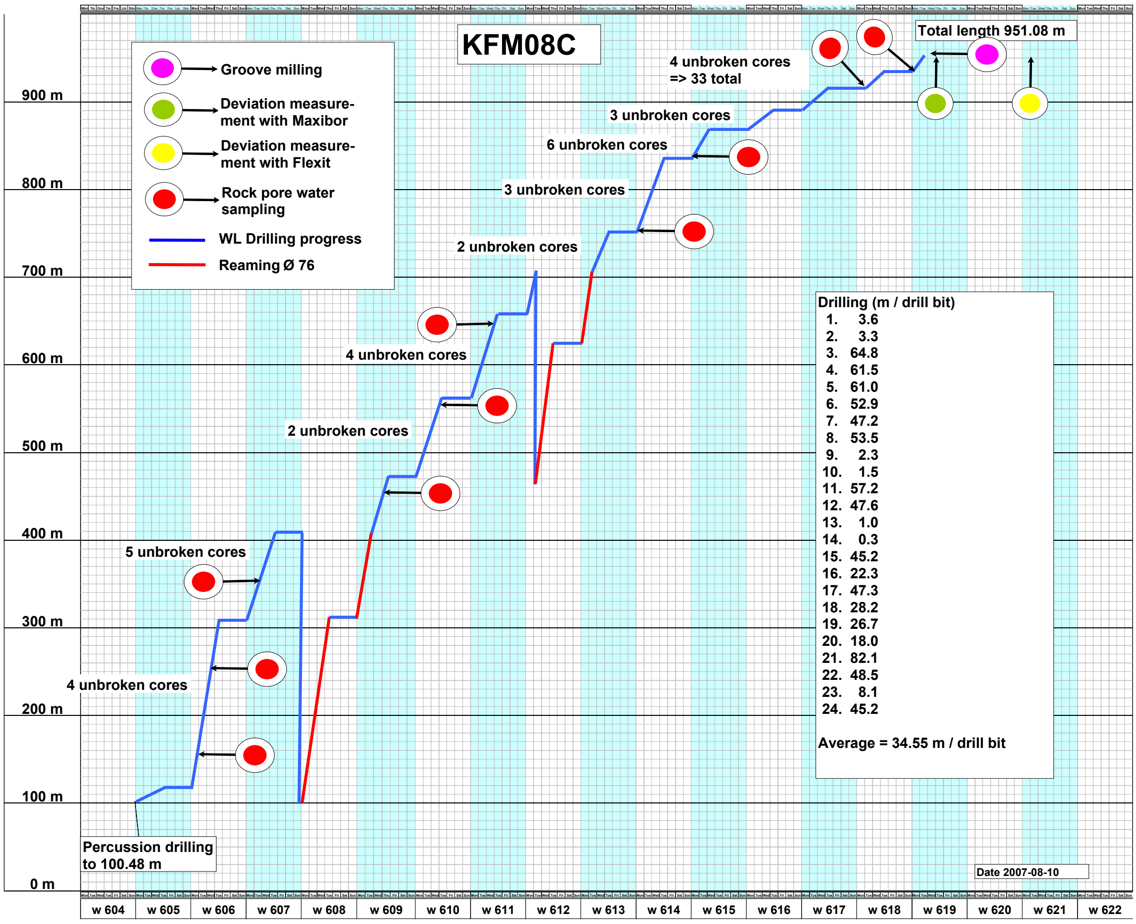


Figure 5-3. *Core drilling progress (length versus calendar time). The figure includes logistics for WL-drilling, groove milling, Maxibor- and Flexit deviation measurements and rock pore sampling, as well as number of unbroken cores and drill bits used.*

5.3 Percussion drilling KFM08C 0–100.48 m

5.3.1 Drilling

As mentioned in Section 4.1.3, the upper part to 11.86 m of borehole KFM08C was drilled and cased according to NO-X 280. During the pilot drilling to 100.48 m with 160.7 mm diameter, no water inflow was observed, and the borehole gave the impression of being stable, low fractured and with a low water yielding capacity. Hence, it did not seem necessary to case the complete borehole. In order to smooth out the edge below the NO-X 280, a Ø 208/200 mm stainless steel casing was installed to 12.06 m, whereupon the gap between the NO-X 280 and the Ø 208/200 mm casing was cement grouted. When the cement had settled, the borehole was reamed, first to c.74 m. During reaming the drill bit was worn out, and the diameter decreased from 196.7 mm to 191.3 mm, see Section 4.2.4. After having exchanged the drill bit, reaming was completed at 100.44 m. Also the second drill bit lost diameter size during reaming, from 193.0 mm at 74 m to 191.3 mm at 100.44 m.

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 used only as supporting data for on-site decisions.

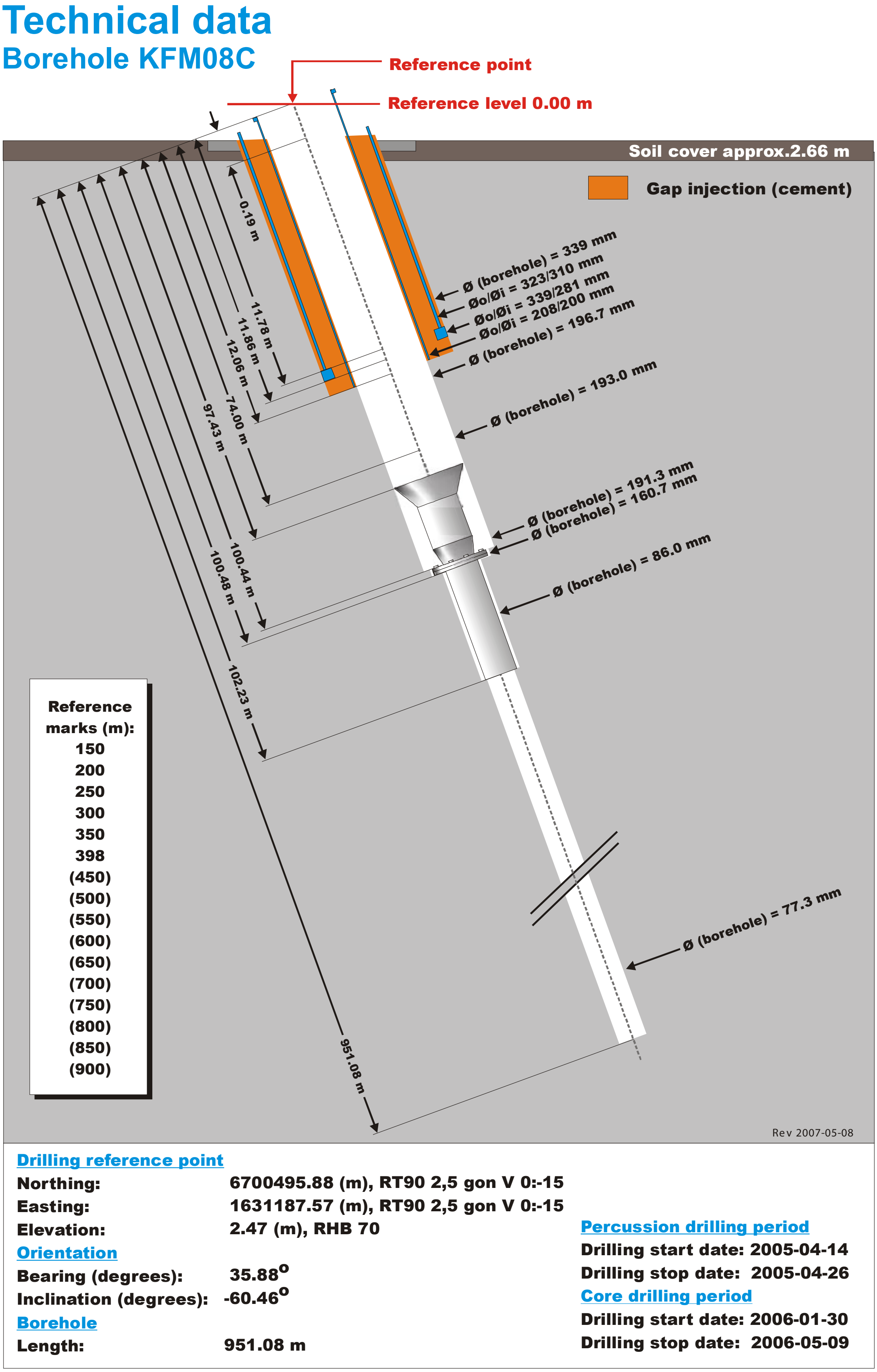


Figure 5-4. *Technical data of borehole KFM08C.*

Table 5-1. Administrative, geometric and technical data for borehole KFM08C.

Parameter	
Borehole name	KFM08C
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	April 14th, 2005
Completion date	May 9th, 2006
Percussion drilling period	2005-04-14 to 2005-04-26
Core drilling period	2006-01-30 to 2006-05-09
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Sven Andersson i Uppsala AB
Percussion drill rig	Commacchio 1500 S
Core drill rig	Onram 2000 CCD
Position KFM08C at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6700495.88 E 1631187.57 Z 2.47 (m.a.s.l.) Azimuth (0–360°): 35.88° Dip (0–90°): –60.46°
Position KFM08C at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6700888.98 E 1631553.07 Z –780.81 (m.a.s.l.) Azimuth (0–360°): 42.18° Dip (0–90°): –51.17°
Borehole length	951.08 m
Borehole diameter and length	From 0.00 m to 12.06 m: 0.3390 m From 12.06 m to 74.00 m: 0.1930 m From 74.00 m to 100.44 m: 0.1913 m From 100.44 m to 100.48 m: 0.1607 m From 100.48 m to 102.23 m: 0.0860 m From 102.23 m to 951.08 m: 0.0773 m
Casing diameter and drilling length	$Ø_o/Ø_i$ = 323 mm/310 mm to 11.78 m $Ø_o/Ø_i$ = 339 mm/281 mm to 11.86 m $Ø_o/Ø_i$ = 208 mm/200 mm to 12.06 m
Transition cone inner diameter	At 97.43 m: 0.189 m At 102.23 m: 0.080 m
Drill core dimension	100.48–951.08 m/Ø 51 mm
Core interval	100.48–951.08 m
Average length of core recovery	2.73 m
Number of runs	311
Diamond bits used	24
Average bit life	34.55 m

5.4 Core drilling KFM08C 100.48–951.08 m

5.4.1 Drilling

The bedrock within the so called Forsmark tectonic lens has appeared to be relatively hard to drill, probably to a large extent depending on the high quartz contents. As drill site DS8 is located in the north-western part of the tectonic lens, the bedrock composition was prior to drilling assumed to be of similar character. The low life time of drill bits in Forsmark has been a challenge for the manufacturer of expendable supplies, e.g. drill bits, calibre rings and drill rods. When drilling KFM08C, new types of drill bits were tested with varying results. Probably a batch of drill bits with lower material quality, see Figure 5-5, caused considerable disturbances in the drilling activity, e.g. necessitated cleaning the borehole from diamond segments that had come loose or reaming of the borehole due to quickly worn out drill bits.

However, in average, the life-time was 34.55 m drilled metres per drill bit in KFM08C, which is 10 m less than in KFM08A.

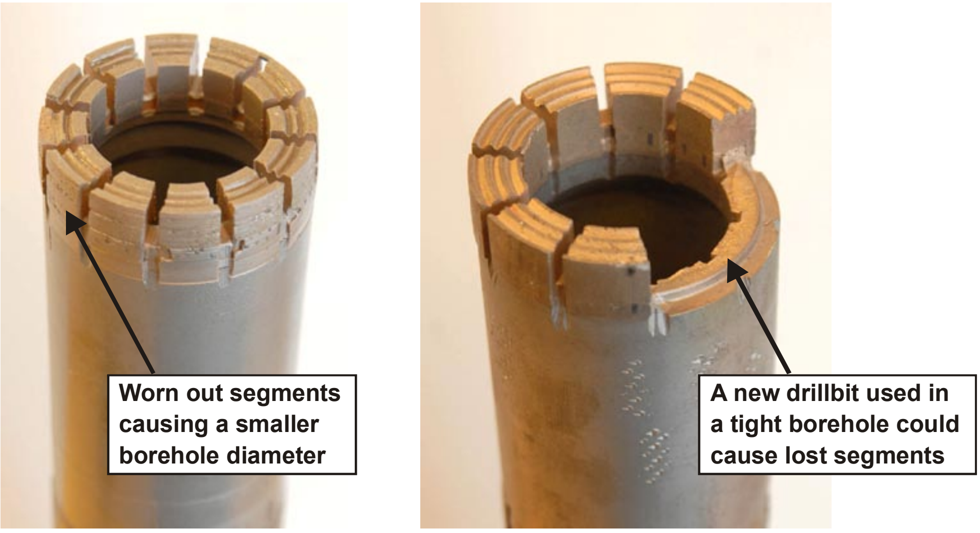


Figure 5-5. *The photos show examples of different damages of the drill bits that were tested during drilling of KFM08C. On the drill bit to the left, the outer diameter of the diamond impregnated segments has been worn out, causing a smaller borehole diameter. When changing to a new drill bit, the borehole is too narrow and has to be reamed to the actual borehole length. In the worst case, segments can come loose from the new drill bit (to the right) and fall to the borehole bottom. During continued drilling, often another new drill bit is consumed to clear the borehole.*

5.4.2 Measurements while drilling

During, and immediately after drilling, a program for sampling, measurements, registration of technical and geo-scientific parameters and some other activities was applied, as described in Section 4.2.3. The results are presented in Sections 5.4.3–5.4.16 below.

Mapping of the drill core samples from KFM08C is presented in /5/.

5.4.3 Registration of drilling parameters

A selection of results from drilling parameter registration is presented in diagrams below. As regards the complete dataset of drilling parameters, it is referred to Sicada, were data are traceable by the activity plan number.

Drill bit position versus time

Figure 5-6 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 5-6 serves as a basis for Figure 5-3, to which it should be compared.

During drilling of KFM08C, new developed and improved in-hole drilling equipments were tested. A new core barrel, equipped with a shock absorber, in order to improve the core quality, was used for the first time in field. Furthermore, testing of newly produced drill bits was carried out, aiming at improving the core quality and to increase the drilling length per drill bit used.

However, the tests were not entirely successful. The tested drill bits performed in such a way that the borehole at several occasions had to be reamed, as the outer diameter of the bit was worn too quickly and lost too much diameter size, cf. Figure 5-5. When lowering the drill string with a new drill bit mounted, the borehole appeared often to be too narrow, and the core barrel was jammed, in some cases more than 100 m above the borehole bottom. These activities caused at least a two weeks delay of the time schedule.

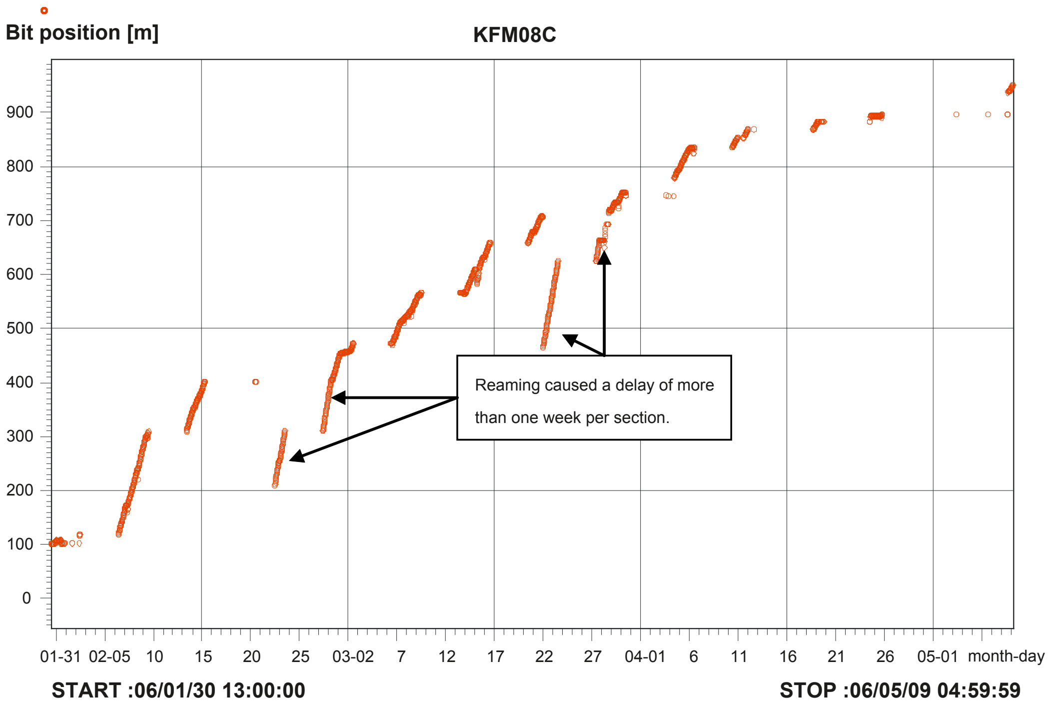


Figure 5-6. *Drill bit positioning in KFM08C versus time.*

Penetration rate

The penetration rate, see Figure 5-7, was in average almost the same as during drilling of KFM01A /7/. Initially, the penetration rate was 11–13 cm/min, but was lowered to 9–10 cm/min in section 330–420 m. From 500 m the penetration rate was c. 10 cm/min, but for the last 100 m drilling it successively fell back to c. 9 cm/min, corresponding to the increasing frictional resistance of the return water flow, which is discharged in the narrow gap between the borehole wall and the pipe string.

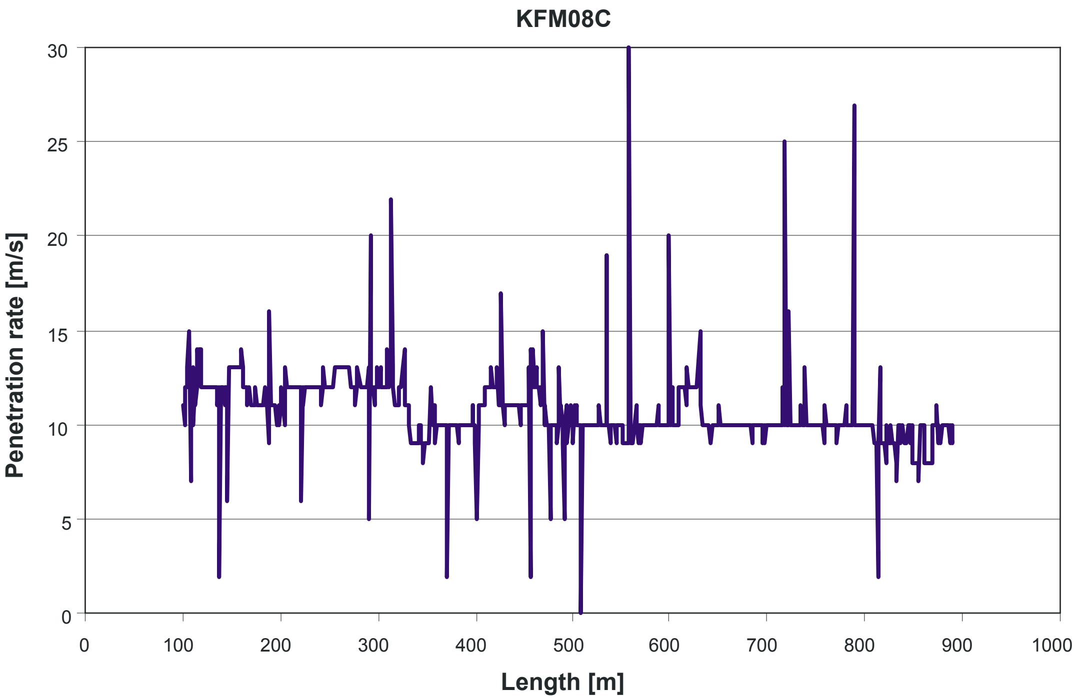


Figure 5-7. *Penetration rate during core drilling of KFM08C.*

Feed force

In Figure 5-8 the feed force is plotted versus borehole length. As the software for the steering system had been upgraded, resulting in a better control of the drilling parameters, the level of feed force when drilling KFM08C was lower compared with the feed force registered when drilling the previous boreholes KFM01A to KFM04A, but equal to that in KFM08A, situated nearby at drill site DS8.

From the start at 100 m the feed force was significantly lower than later, which probably reflects the more fractured and permeable rock in the upper part of the borehole. Thereafter the feed force was smoothly undulating, and displayed significantly lower values in section 550–900 m.

Rotation speed

The rotation speed diagram, Figure 5-9, shows only minor variations between 850–900 rpm during the entire drilling period. This is probably to a large extent depending on the aforementioned testing of drill bits. The testing programme benefits from as constant rotation speed as possible in order to obtain similar drilling conditions during the entire testing programme, and the drilling crew made special efforts to reach that goal.

5.4.4 Flushing water and return water flow parameters

Flushing water and return water flow rate measurements – water balance

As borehole KFM08C is of SKB chemical type, it is important to estimate the amount of flushing water pumped into the borehole during drilling as well as the amount of return water recovered to permit a water balance calculation. A flow gauge in the measurement station, registered the flushing water flow rate, see Figure 3-3. The return water was measured by another flow meter, mounted on-line with the discharge pipeline, see Figures 3-3 and 3-6.

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

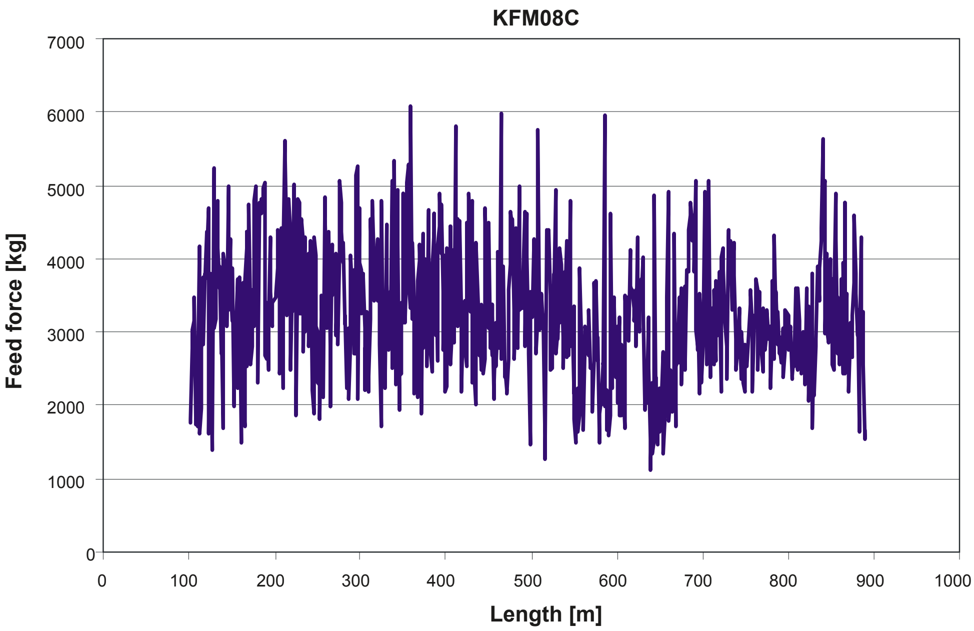


Figure 5-8. *Feed force versus borehole length during drilling of borehole KFM08C.*

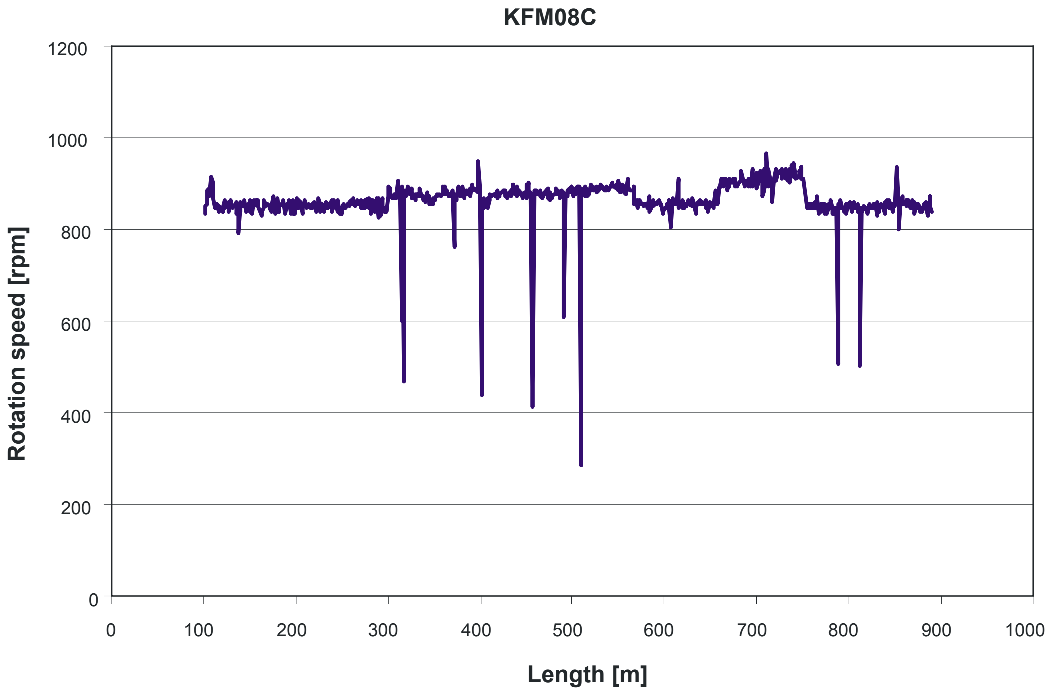


Figure 5-9. *Rotation speed versus borehole length during drilling of borehole KFM08C.*

Figure 5-10 illustrates the accumulated volume of flushing water and return water versus time during core drilling, whereas Figure 5-11 displays the accumulated volumes of flushing water and return water from the entire drilling period, giving a return water/flushing water quotient of 1.81 [2,394 L/1,324 L]. Results from Uranine measurements are presented in the next section.

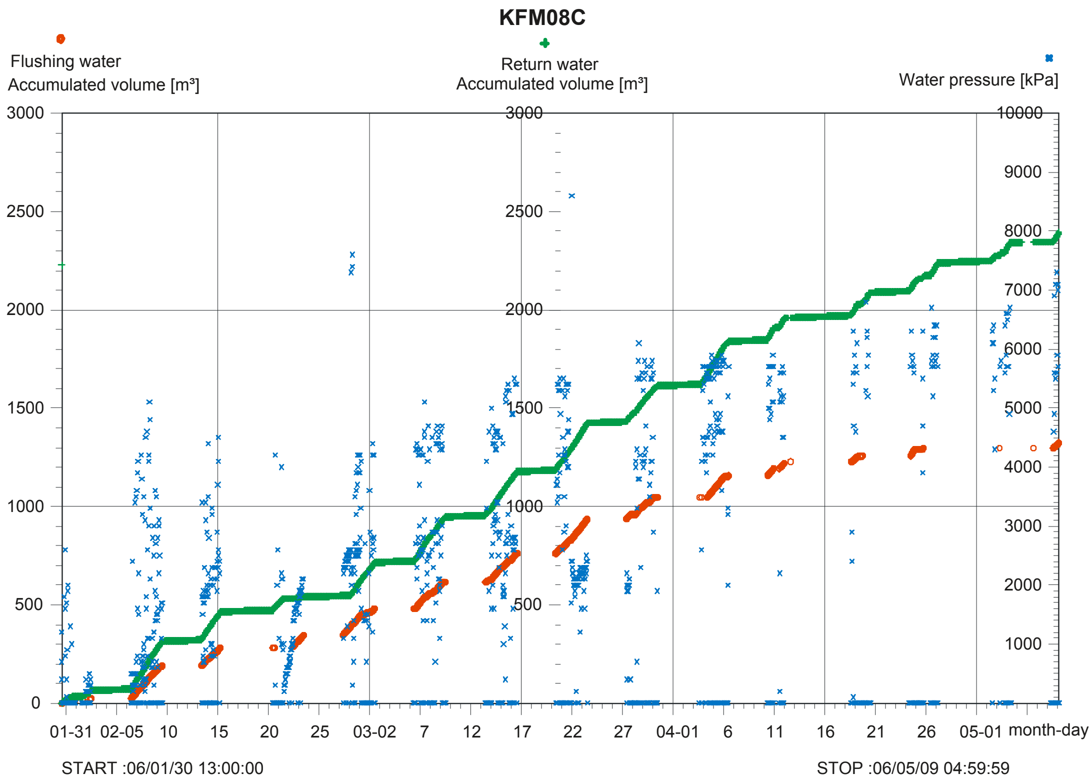


Figure 5-10. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM08C. Also the return water pressure(blue) is displayed in the figure.*

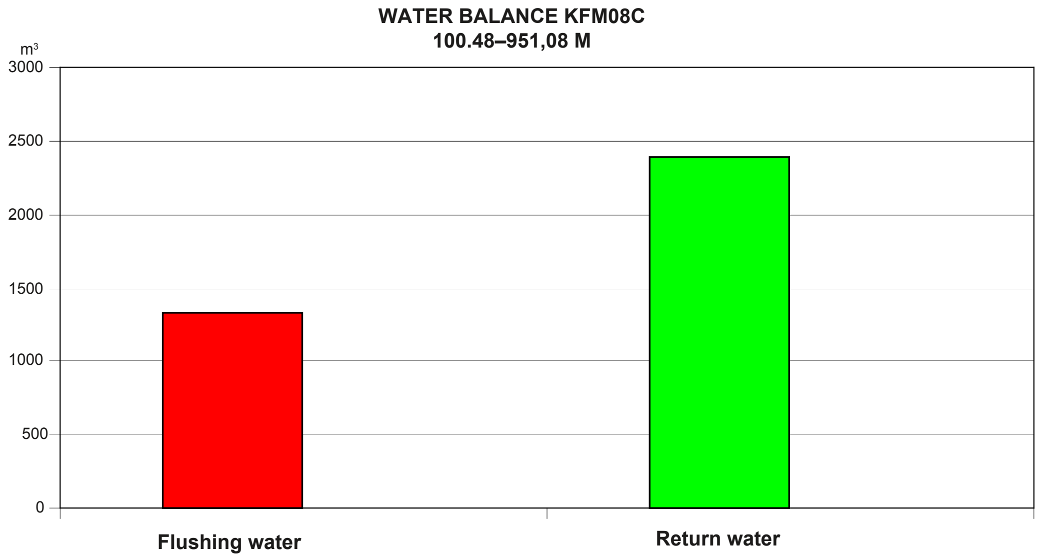


Figure 5-11. *Total amounts of flushing water and return water during drilling of borehole KFM08C. The total volume of flushing water used during core drilling amounted to 1,324 m³. During the same period, the total volume of return water was 2,394 m³, which results in a return water/flushing water balance of 1.81.*

However, in Figure 5-10 a loss of flushing water at shallow depths in the borehole is observed, as well as a significant excess of return water at depths exceeding c. 100 m, Feb 2nd 2006. This reflects the fact that when the drill bit position is close to water conductive fractures in the borehole, flushing water is forced into these fractures, because the flushing water pressure much exceeds that of the formation. When the drill bit has passed this section, the pressure gradient will eventually be reversed due to the air-lift pumping in the upper part of the borehole. If no other highly water conductive fractures are penetrated, where flushing water losses may occur, larger amounts of return water (groundwater and flushing water) are then extracted from the borehole when flushing water is supplied to it.

Figure 5-12 illustrates the variations of flushing water and return water flow rate together with variations of the groundwater table during core drilling of borehole KFM08C. The return water flow rate depends on the hydraulic transmissivity of the borehole, as well as on the magnitude of draw-down (accomplished by the air-lift pumping). To cool the drill bit and keep the borehole bottom clean, drilling usually requires a flushing water flow rate of c. 35 L/min. However, immediately after a core recovery, a temporarily higher flushing water flow rate is often applied.

Although the upper 100 m of the borehole are not cased or cement grouted, there was no observable return water inflow above the core drilled part of the borehole. Shortly after core drilling started, the return water flow rate was c. 40 L/min, i.e. exceeding that of the flushing water flow rate, indicating water yielding fractures just below 100 m. When core drilling commenced, the water inflow was enhanced simultaneously as the groundwater table draw-down increased. However, it seems that the difference between return- and flushing water flow rate was kept around 20 L/min throughout the drilling period, which indicates absence of major water yielding structures at larger depths.

Uranine contents of flushing water and return water – mass balance

During the drilling period, sampling and analysis of flushing water and return water for analysis of the contents of Uranine was performed systematically with a frequency of approximately one sample per every fourth hour during the drilling period, see Figure 5-13. Like in all boreholes drilled during the site investigation except KFM01A and KFM01B, a dosing feeder controlled by a flow meter was used for labelling the flushing water with Uranine to a concentration of 0.2 mg/L.

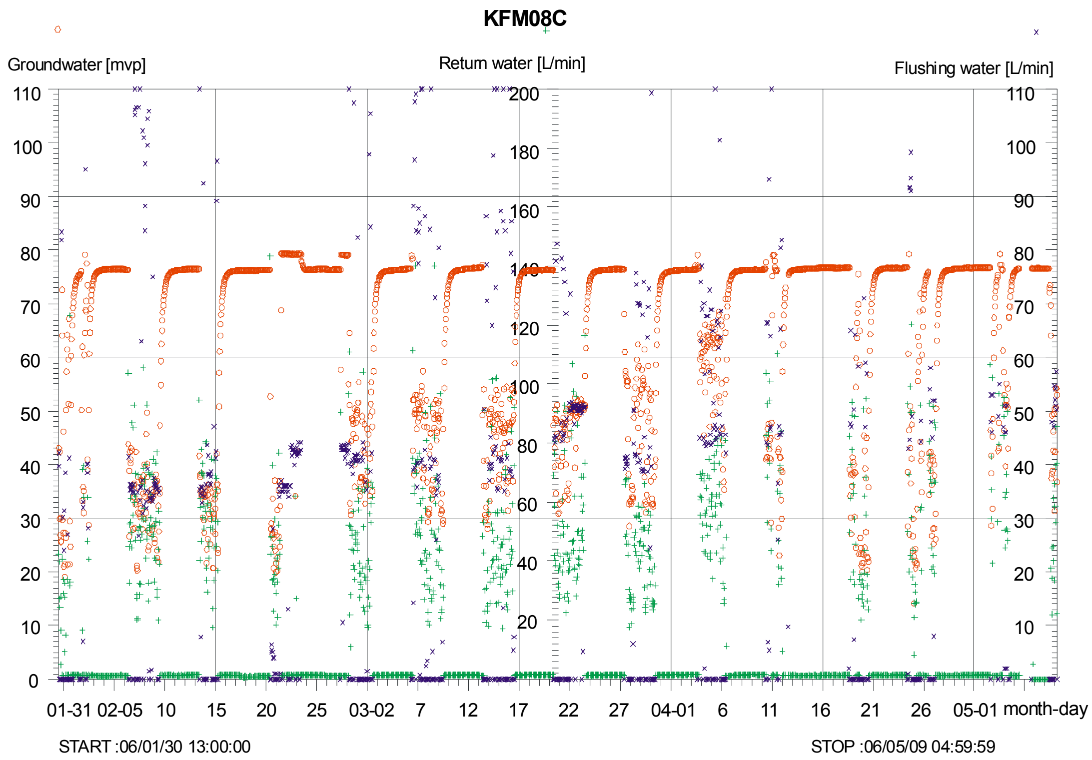


Figure 5-12. *Ground water table (red), flushing water flow rate (purple) and return water flow rate (green) versus time during core drilling of borehole KFM08C.*

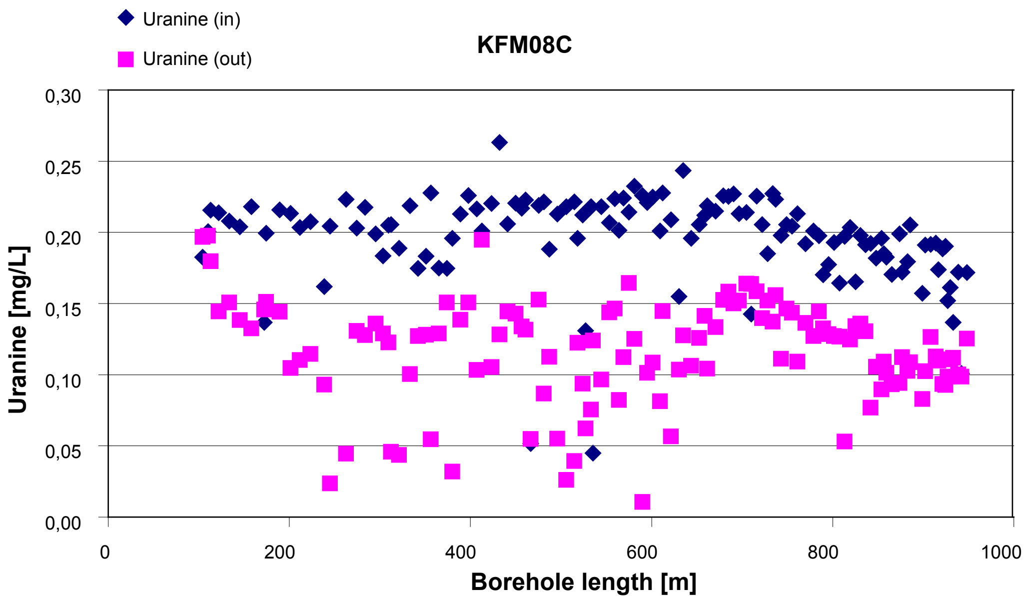


Figure 5-13. *Uranine contents in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFM08C. An automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.*

A mass balance calculation of the accumulated volumes of flushing water and recovered flushing water in the return water suggests that minimum 225 m^3 of flushing water was lost in the borehole. According to notations in the log book, the amount of Uranine added to the borehole was 320 g. If the averages of the Uranine concentration values in the flushing water and in the return water are used to calculate the amount of Uranine added to and recovered from the borehole, the calculations give 258 g and 276 g respectively. The excess amount of recovered Uranine is probably due to Uranine remaining in the groundwater formation after the previous drilling of KFM08A and B.

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM08C is exposed in Figure 5-14. Like in the telescopic boreholes KFM02A, KFM03A, KFM04A, KFM05A, KFM06A, KFM06C, KFM07A and KFM08A the borehole diameter was 77.3 mm, i.e. increased by c. 1 mm compared to in borehole KFM01A. This resulted in lower flushing water pressure than in KFM01A.

After an almost continuous increase of flushing water pressure versus borehole length in KFM08A, this trend was interrupted in section 480–650 m, probably as an effect of the reaming activities than of more fractured and permeable bedrock.

When the drilling passed these reamed sections, the flushing water pressure raised by c. 12 bars and was almost continuously increasing during the remaining drilling period. The final water pressure was 10–20 bars higher than in the deeper parts of boreholes KFM02A and KFM03A, which was the case also in e.g. KFM04A, KFM05A, KFM06A, KFM06C, KFM07A and KFM08A. A possible explanation to this may be that these boreholes are more inclined than the previous boreholes (c. 60° compared to 85° from the horizon), which makes recovery of drill cuttings more difficult, demanding higher water pressures and increased flow rates.

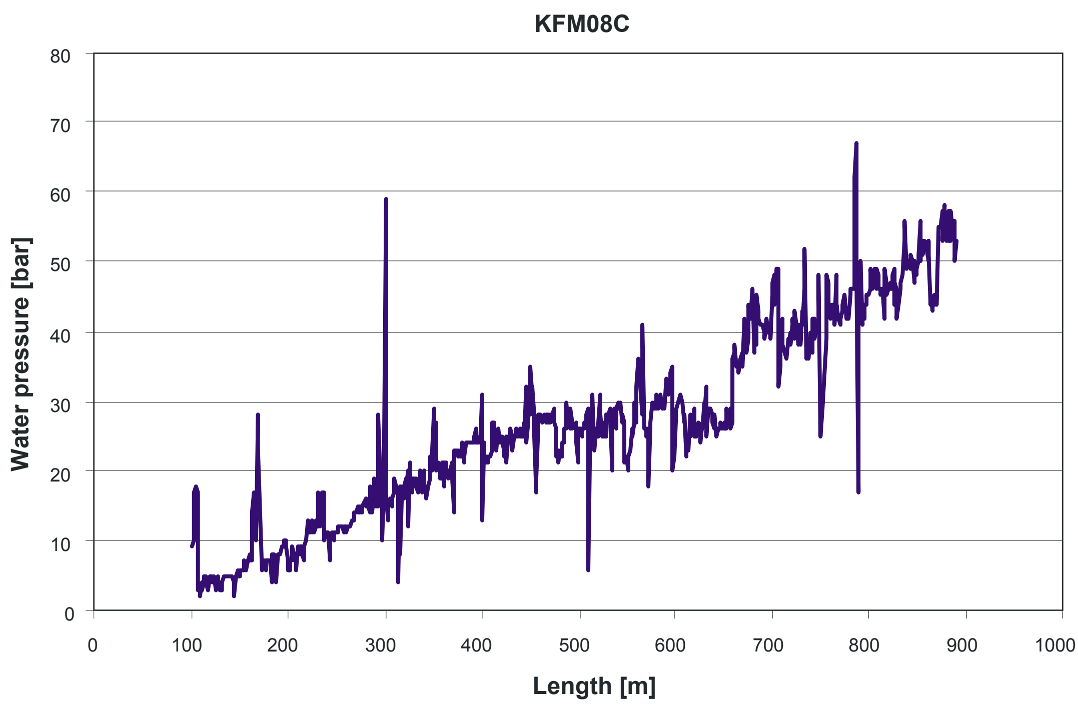


Figure 5-14. *Flushing water pressure versus drilling length when drilling KFM08C.*

5.4.5 Electric conductivity of flushing water

Flushing water was supplied from percussion borehole HFM22 (cf. Section 3.3.2). A sensor in the measurement station registered the electric conductivity (EC) of the flushing water on-line before the water entered the borehole, see Figure 3-3.

Another sensor for registration of the electric conductivity of the return water (Figure 5-15) was positioned between the surge diverter (discharge head) and the sedimentation containers (Figure 3-3).

The electrical conductivity (salinity) of the flushing water from the 222 m long supply well HFM22 with its major inflow at c. 62 m has from start a significantly decreasing trend during the entire drilling period. At commencement of drilling, the EC-value is c. 900 mS/m but decreases to c. 700 mS/m at completion of drilling.

The average electrical conductivity of the return water, which exhibits an initial EC-value of about 1,200 mS/m, follows the same decreasing trend as that of the flushing water, and ends with a value around 850 mS/m. The most possible explanation is that the shallow groundwater inflow dominates in KFM08C, and that very minor amounts of more saline water from depths are added to the return water.

5.4.6 Contents of dissolved oxygen in flushing water

The level of dissolved oxygen is plotted versus time in Figure 5-16. The contents of dissolved oxygen was from the beginning kept between 5–7 mg/L but during the reaming of the borehole it raised to 7–9 mg/L. Finally, during the remaining drilling period the level of dissolved oxygen generally has been kept between 3–4.5 mg/L.

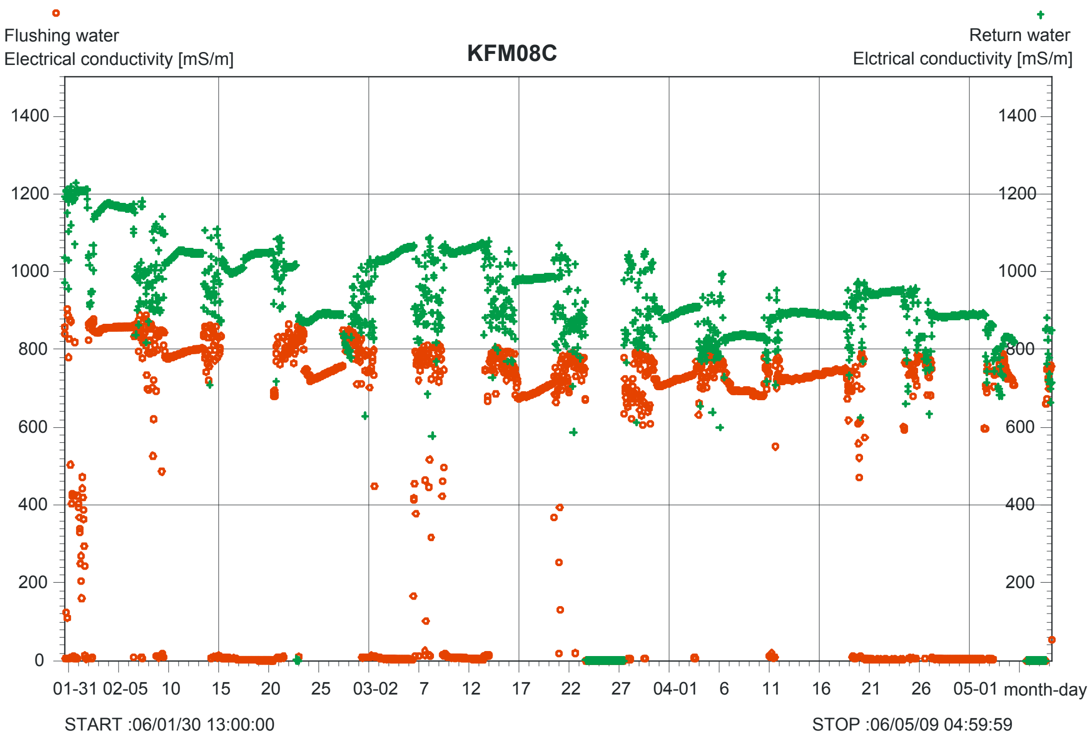


Figure 5-15. Electrical conductivity of flushing water from HFM22 and return water from KFM08C. The dataset has been reduced as well as cleaned from outliers.

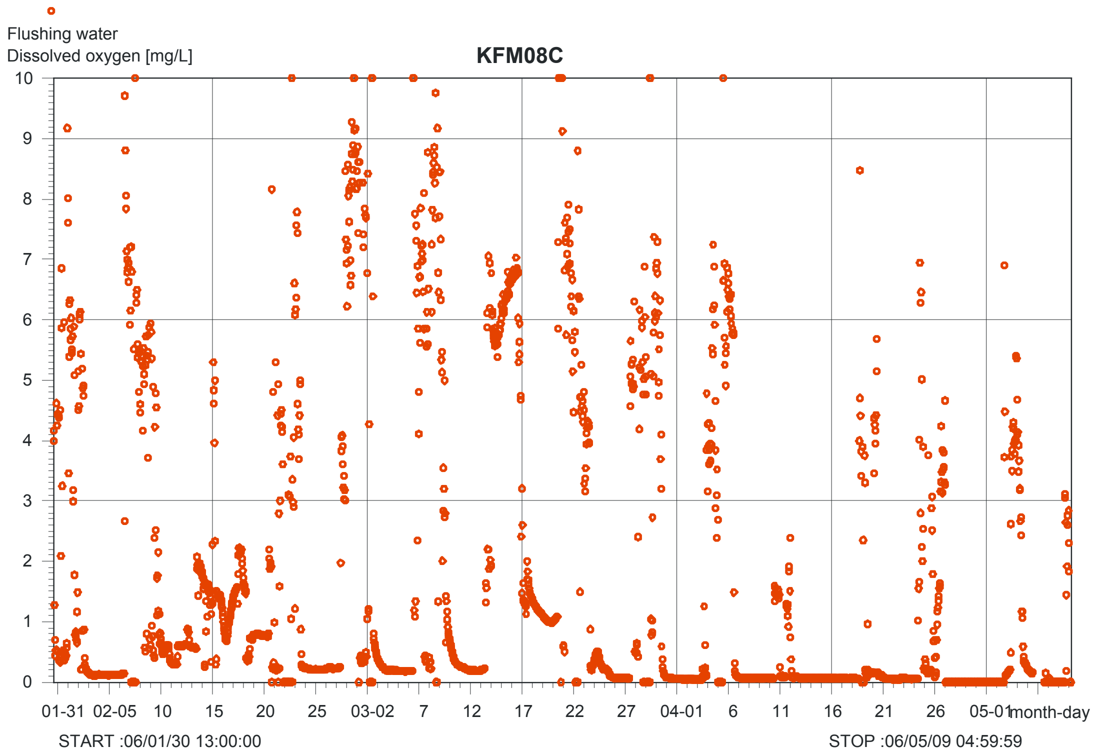


Figure 5-16. *Dissolved oxygen contents in the flushing water versus time when drilling KFM08C.*

5.4.7 Chemical composition of flushing water

The flushing water was sampled at three occasions during drilling for the following reasons:

- Initially, to check if the quality was satisfactory. One main concern is the contents of organic constituents, which should be low, preferably below 5 mg/L. The reason is that introduction of hydrocarbons may affect the microbiological flora in the borehole, which would obstruct a reliable characterization of the in situ microbiological conditions.
- To monitor the groundwater chemical composition during drilling. The chemical composition of the flushing water is important when estimating the effect, or correcting for the effect, of remaining flushing water in water samples collected from telescopic boreholes for chemical analyses.

The results from chemical analyses of flushing water from the supply well HFM22 are compiled in Appendix C. Results from previous sampling and analyses in HFM22 are compiled in /8/. As shown in Appendix C, the chemical composition of the groundwater from HFM22 revealed a slight change during the drilling period. For example, the chloride concentration decreased from 2,800 to 2,500 mg/L from the first to the second and last sample.

Borehole HFM22 has been used before as flushing water supply well (for drilling of KFM08A and B) and the concentration of Total Organic Carbon (TOC) was known to be sufficiently low. The samples collected during the drilling period showed that the TOC concentration was in the range 4.7–5.1 mg/L (should preferably fall below 5.0 mg/L). The flushing water well was used without further measures (e.g. using an active carbon filter system for reduction of organic substances as was applied when drilling KFM01A /7/).

The microbe contents in the flushing water was not determined during drilling of KFM08C. The microbe results from drilling of the preceding boreholes KFM05A /9/ and KFM06A /10/ showed convincingly that the cleaning procedure works well. It was therefore concluded that check of microbes at all drilling occasions was no longer necessary.

5.4.8 Registration of the groundwater level in KFM08C

To enhance the recovery of drill cuttings from the borehole, air-flush (mammoth) pumping was applied during the entire drilling period. The pumping capacity was checked by registration of the groundwater level in the borehole, below plotted versus time of the drilling period (Figure 5-17).

From the beginning, the mammoth pumping was set at the maximum draw-down of 45–50 m, but during reaming and flushing, the draw-down was adjusted to approximately 35–40 m below top of casing. Shortly before end of drilling, the draw-down was again adjusted and increased to approximately 45 m. Drilling was performed continuously during Monday-Thursday. During the weekend stop of drilling and pumping, the groundwater table recovered slowly due to recharge of groundwater into the borehole, resulting in the (positive) peaks in the diagram. The slow recovery confirms that the total inflow of formation water to the borehole (below the upper cased and grouted parts) was low. When pumping was restarted, draw-down again increased rapidly.

5.4.9 Core sampling

The average drill core length per run obtained from the drilling was 2.73 m. Due to the low fracture frequency at depth, thirty-three 3 m long unbroken drill cores were recovered. Fracture minerals were relatively well preserved. Rotation marks on the drill core occurred, see Table 5-2, especially in those sections where new core barrels and drill bits were tested. A preliminary on-site core logging was performed continuously.

Table 5-2. Borehole KFM08C – Compilation of drill core defects.

Drill hole No.	Core length [m]	Weakly rotated [m]	[%]*	Clearly rotated [m]	[%]*	Other defects [m]	[%]*
KFM08C	850.60	81.00	9.52	231.00	21.16	10.02	1.18

* Percentage of total core length.

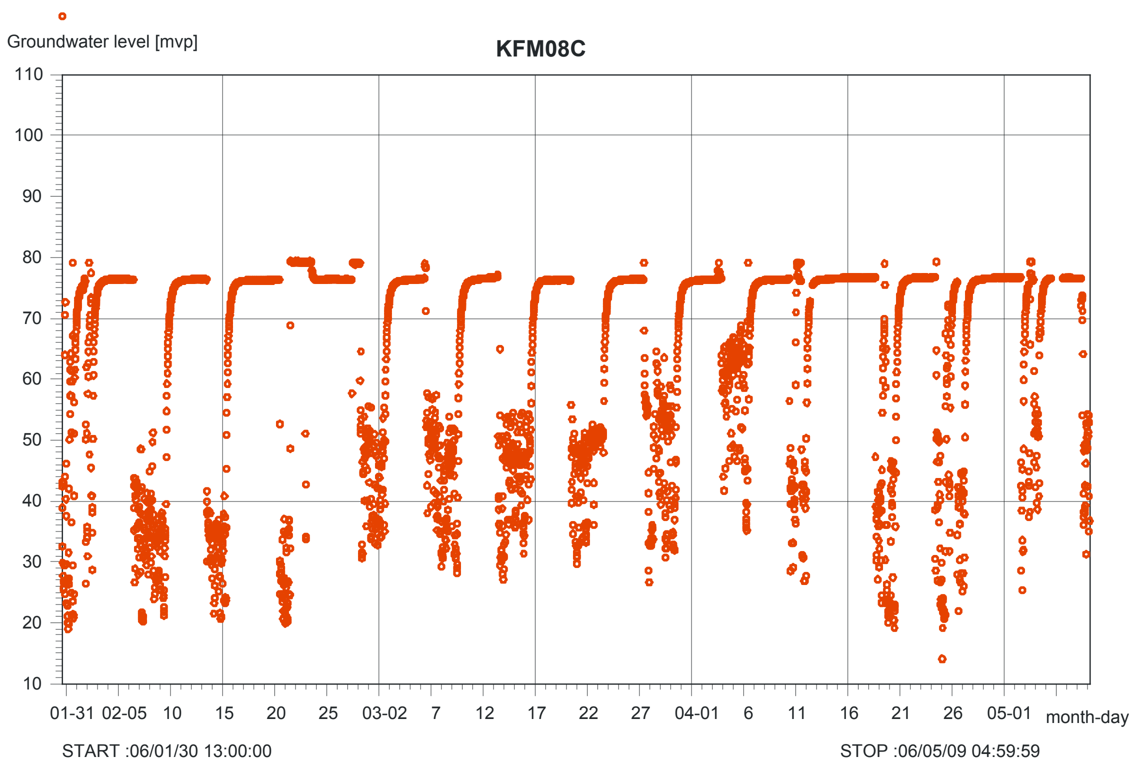


Figure 5-17. Variation of the level of the groundwater table in KFM08C during the drilling period.

5.4.10 Pore space groundwater sampling

An additional sampling of drill cores was carried out when drilling KFM08C, sampling for hydrochemical analysis of pore space groundwater. The methodology for sampling and chemical analysis of pore space groundwater was initially developed at the Äspö HRL and was successfully applied to the previously drilled borehole KFM06A /11/, although including a major logistic effort. This resulted in a continued sampling programme from the remaining boreholes to be drilled in the target area, besides in KFM08C also in KFM01D and KFM02B.

The sampling is basically quite simple but speed and care are crucial to prevent any potential evaporation of the groundwater when the drill core is first exposed to the atmosphere. The different measures during the sampling are described in the text below and in Figure 5-18. The sampling dates and levels are given in Table 5-3.

Immediately after the core was recovered from the borehole, a representative and homogeneous c. 40 cm long core specimen was selected. After photo-documentation, the sample was placed in a heavy duty plastic bag and flushed with nitrogen to remove the air. Thereafter the nitrogen was completely evacuated, and the plastic bag was carefully sealed. The packed sample was placed in an additional plastic bag and the evacuation and sealing procedure was repeated. Finally, the double packed sample was placed in a plastic bag lined with aluminium foil, flushed with nitrogen, evacuated and sealed and in similar fashion as carried out for the previous plastic bags. The well preserved sample was packed in a shock proofed portable aluminium box that within 24 hours was delivered to the laboratory, in this case at the University of Bern.

In KFM08C sampling was carried out at every 100 m length and the above described procedure was successfully repeated for all ten occasions, see Table 5-3.

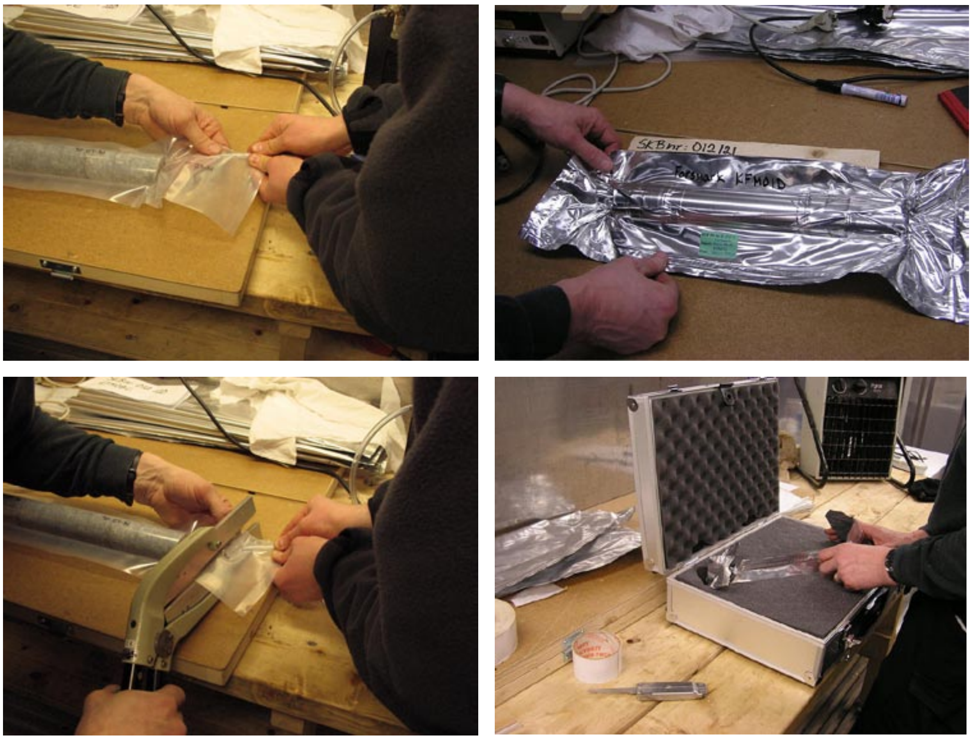


Figure 5-18. *The photos show the careful handling of the samples for pore space groundwater in low permeable rocks performed in KFM08C. To the upper left the core has been recovered from the borehole and is placed in a nitrogen filled plastic bag from which the nitrogen is evacuated. To the upper right the plastic bag is permanently heat sealed. To the lower left the sample is well preserved in two plastic bags and a third plastic bag lined with aluminium foil is also permanently heat sealed. Finally, to the lower right, the sample is placed in a shock proofed aluminium box thats within 24 hours is delivered to the University of Bern.*

Table 5-3. Pore space groundwater sampling from KFM08C.

Activity	Start date	Idcode	Secup (m)	Seclow (m)
Rock pore water – sampling	2006-02-06 22:41	KFM08C	154.55	154.83
Rock pore water – sampling	2006-02-08 15:34	KFM08C	254.71	255.12
Rock pore water – sampling	2006-02-14 06:58	KFM08C	353.70	354.14
Rock pore water – sampling	2006-03-01 13:39	KFM08C	455.51	455.93
Rock pore water – sampling	2006-03-08 23:56	KFM08C	553.01	553.38
Rock pore water – sampling	2006-03-16 08:07	KFM08C	648.41	648.75
Rock pore water – sampling	2006-03-30 05:43	KFM08C	751.31	751.59
Rock pore water – sampling	2006-04-10 14:15	KFM08C	839.57	839.91
Rock pore water – sampling	2006-05-02 18:03	KFM08C	917.04	917.38
Rock pore water – sampling	2006-05-08 17:43	KFM08C	938.10	938.50

5.4.11 Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0–100 m) is c. 3.6 m^3. Weighing of drill cuttings and comparison with the weight of the theoretical volume was not carried out due to the relatively high water flow. This caused an uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations. However, it seems probable that the percussion drilled part was well cleaned from debris, since casing driving and gap grouting to full borehole length worked well, without obstruction from settled drill cuttings.

The theoretical difference in volume of the core drilled part of KFM08C and the drill core is calculated to be 2.254 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 granitites in the Forsmark area) is applied, the total weight of the theoretical amount of debris is estimated at 5,973 kg. The calculated dry weight of the debris from the core drilling recovered and weighed in the containers is 4,899 kg. The difference between the theoretically produced and recovered dry weight of debris is 1,074 kg, which gives a recovery of 82%.

The recovery figure could be commented on. The dwell time in the return water system is too short for sedimentation of the suspended finest fractions. No estimation was made of the amount of suspended material, but the true recovery is probably much higher than 82%. 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, even if there are not many permeable sections with increased fracture frequency in the borehole.

5.4.12 Deviation measurements

The principles of the equipment for deviation measurements were explained in Section 3.3.5. Also the changed strategy for deviation measurements during the site investigations was commented on, including the fact that the Flexit-method is now the principal method applied for deviation measurements, also in borehole KFM08C. When Maxibor™-measurements or deviation measurements with some other method have been performed as well, these may be used for uncertainty determinations of the deviation measurements.

The quality control program of deviation measurements is mostly concentrated to the handling of the instrument as well as routines applied for the performance. It is not possible to execute an absolute control measurement, as no long borehole is available permitting exact determination of the position of both to the borehole collar and the borehole end (e.g. in a tunnel) with an independent method. To ensure high quality measurements with the Flexit tool, the disturbances of the magnetic field must be low. A measuring station in Uppsala provides one-minute magnetic field values that are available on the Internet at www.intermagnet.org and give sufficient information. The magnetic field variation during May 12th 2005, June 1st 2006 and Nov 8th 2006, is seen in Figures 5-19 and 5-20 and displays only minor disturbances when the Flexit-surveys in KFM08C were performed.

In the following a systematic description of the construction of the revised deviation data for borehole KFM08C is given.

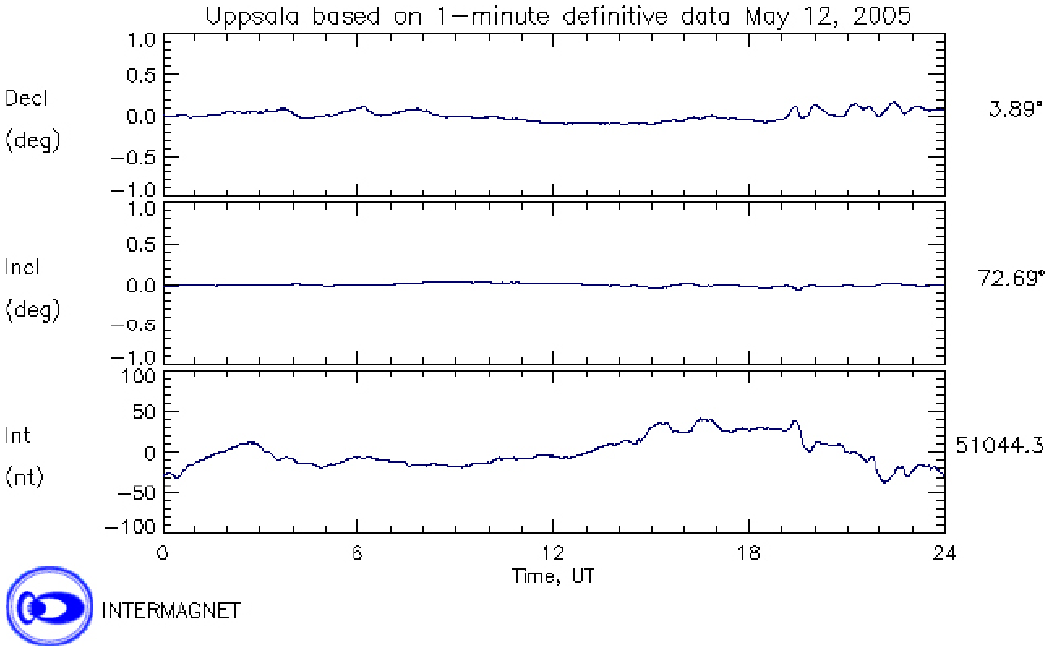


Figure 5-19. *Magnetic field variation during the Flexit-survey performed on May 12th 2006.*

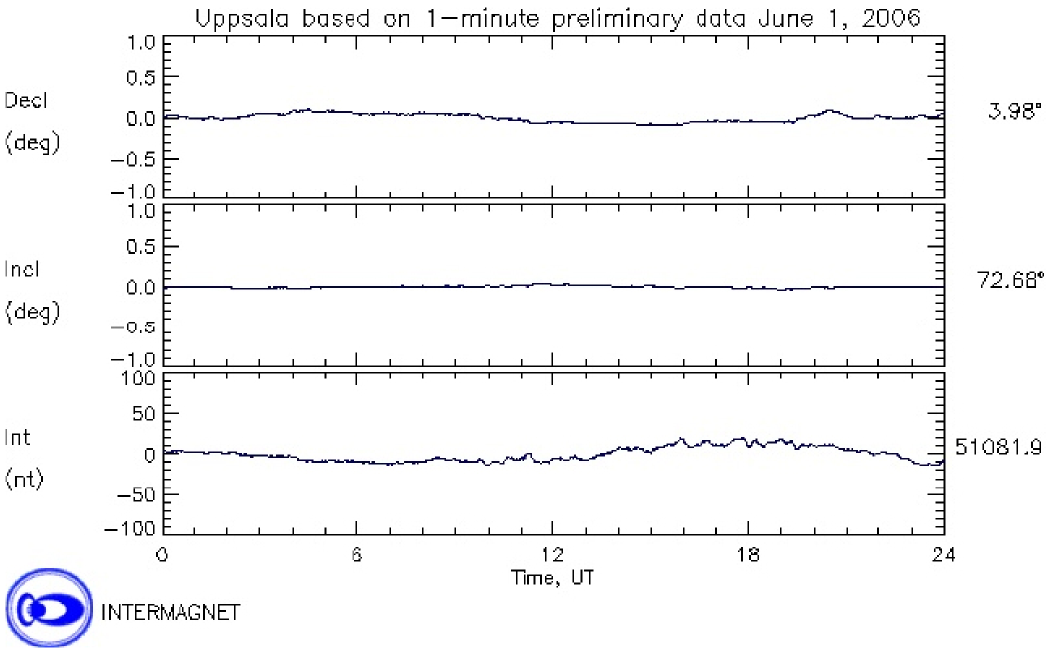


Figure 5-20a. *Magnetic field variation during the Flexit-survey performed June 1st 2006 between 07:30 and 11:30.*

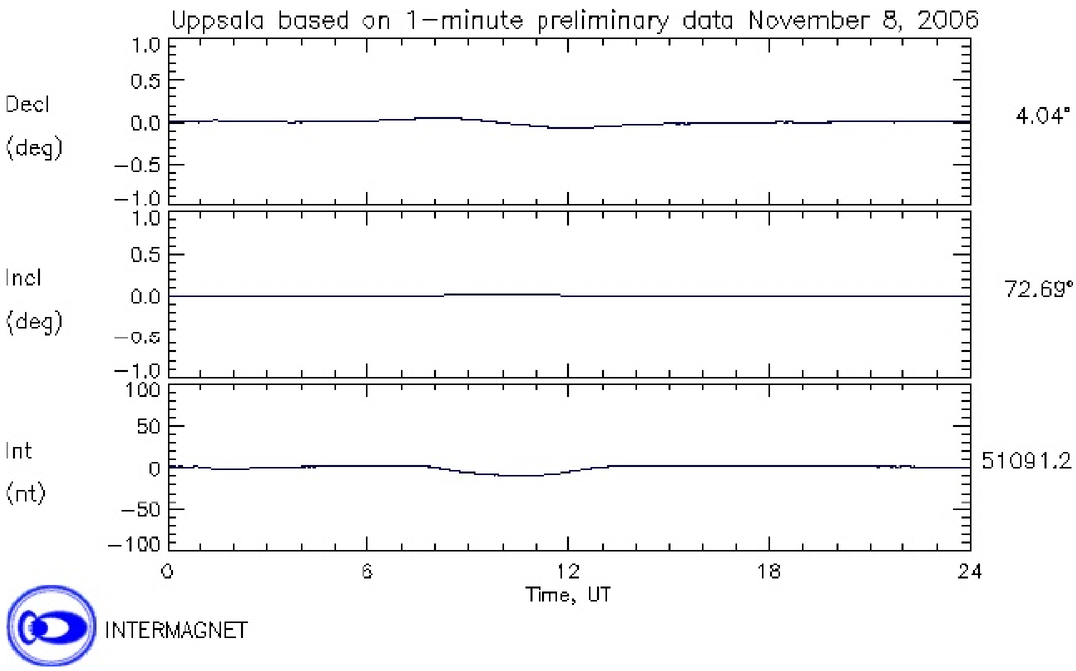


Figure 5-20b. *Magnetic field variation during the Flexit-survey performed November 8th 2006 between10:30 and 14:30.*

The deviation data emerge from three Flexit-loggings, one survey from the telescopic part to 99 m and two surveys to 948 m borehole length, respectively, see Table 5-4. With the Flexit Smart Tool System, the deviation measurements in borehole KFM08C were carried out every 3 m downwards. The two surveys to 948 m, with activity numbers 13116460 and 13135313, provided almost repeatable results, and were therefore chosen for the construction of the deviation file to be "in use displayed" in Sicada (see explanation in Section 3.3.5). This file is designated as EG154.

The EG154-activity specifies the deviation measurements used in the resulting calculation presented in Table 5-5. The upper values for bearing start at 36 and 18 m so that they should not be influenced by the 12 m steel casing (measurements by magnetic method). Since the inclination measurements are performed with accelerometer technique, the inclination values are not disturbed by the casing.

Table 5-4. Activity data for the four deviation measurements approved for KFM08C (from Sicada). The two complete magnetic measurements were used for calculation of the final borehole deviation file, whereas also the magnetic measurement in the percussion drilled borehole was used for calculation of the uncertainty.

Activity Id	Activity type code	Activity	Start date	Idcode	Secup (m)	Seclow (m)	F*
13133032	EG157	Magnetic-accel. m.	2005-05-12 10:15	KFM08C	15.00	99.00	F
13113696	EG156	Maxibor-measurement	2006-05-08 08:00	KFM08C	0.00	945.00	EC
13116460	EG157	Magnetic-accel. m.	2006-06-01 07:30	KFM08C	15.00	948.00	C
13135313	EG157	Magnetic-accel. m.	2006-11-08 10:30	KFM08C	3.00	948.00	CF
13141378	EG154	Bh deviation multiple m.	2006-12-05 12:00	KFM08C			I C

* C = Comment, F = File, I = In-use flag, E = Error.

Table 5-5. Contents of the EG154 file (multiple borehole deviation intervals).

Deviation activity Id	Deviation angle type	Approved secup (m)	Approved seclow (m)
13116460	Bearing	36.00	948.00
13116460	Inclination	15.00	948.00
13135313	Bearing	18.00	948.00
13135313	Inclination	3.00	948.00

A subset of data from the resulting deviation file is presented in Table 5-6 and the estimated inclination-, bearing- and radius uncertainties are displayed in Table 5-7. The radius uncertainty may at every point in the borehole be represented by a circle surrounding the hole. The radius of this circle = radius uncertainty in that point.

Table 5-6. Deviation data from KFM08C for approximately every 100 m vertical length calculated from EG154.

Borehole	Length (m)	Northing (m)	Easting (m)	Elevation (m)	Inclination (degrees)	Bearing (degrees)
KFM08C	0	6700495.88	1631187.57	2.47	–60.48*	35.88
KFM08C	117	6700543.71	1631221.28	–98.84	–59.68	36.45
KFM08C	237	6700592.73	1631261.21	–200.81	–57.34	41.56
KFM08C	357	6700640.83	1631306.14	–301.14	–56.24	44.59
KFM08C	477	6700687.76	1631354.15	–400.61	–55.58	45.53
KFM08C	597	6700736.06	1631403.19	–498.90	–54.38	45.21
KFM08C	723	6700788.44	1631456.13	–600.53	–53.26	44.92
KFM08C	849	6700842.62	1631510.02	–700.71	–52.25	43.87
KFM08C	951.08	6700888.98	1631553.07	–780.81	–51.17	42.18

* The starting values of inclination and bearing in EG154 are calculated, and may therefore show a discrepancy against the values seen in Borehole direction surveying (EG151), which are measured values.

Table 5-7. Uncertainty data for the deviation measurements in KFM08C for approximately every 100 m vertical length calculated from EG154.

Borehole	Length (m)	Northing (m)	Easting (m)	Elevation (m)	Inclination uncertainty	Bearing uncertainty	Radius uncertainty
KFM08C	0	6700495.88	1631187.57	2.47	0.045	0.79	0
KFM08C	117	6700543.71	1631221.28	–98.84	0.045	0.79	0.807
KFM08C	237	6700592.73	1631261.21	–200.81	0.045	0.79	1.68
KFM08C	357	6700640.83	1631306.14	–301.14	0.045	0.79	2.588
KFM08C	477	6700687.76	1631354.15	–400.61	0.045	0.79	3.514
KFM08C	597	6700736.06	1631403.19	–498.90	0.045	0.79	4.463
KFM08C	723	6700788.44	1631456.13	–600.53	0.045	0.79	5.49
KFM08C	849	6700842.62	1631510.02	–700.71	0.045	0.79	6.544
KFM08C	951.08	6700888.98	1631553.07	–780.81	0.045	0.79	7.417

The calculated deviation (EG154-file) in borehole KFM08C shows that the borehole deviates upwards and to the right with an absolute deviation of 102 m compared to an imagined straight line following the dip and strike of the borehole start point (Figures 5-21 and 5-22). The ”absolute deviation” is here defined as the shortest distance in space between a point in the borehole at a certain borehole length and the imaginary position of that point if the borehole had followed a straight line with the same inclination and bearing as of the borehole collaring.

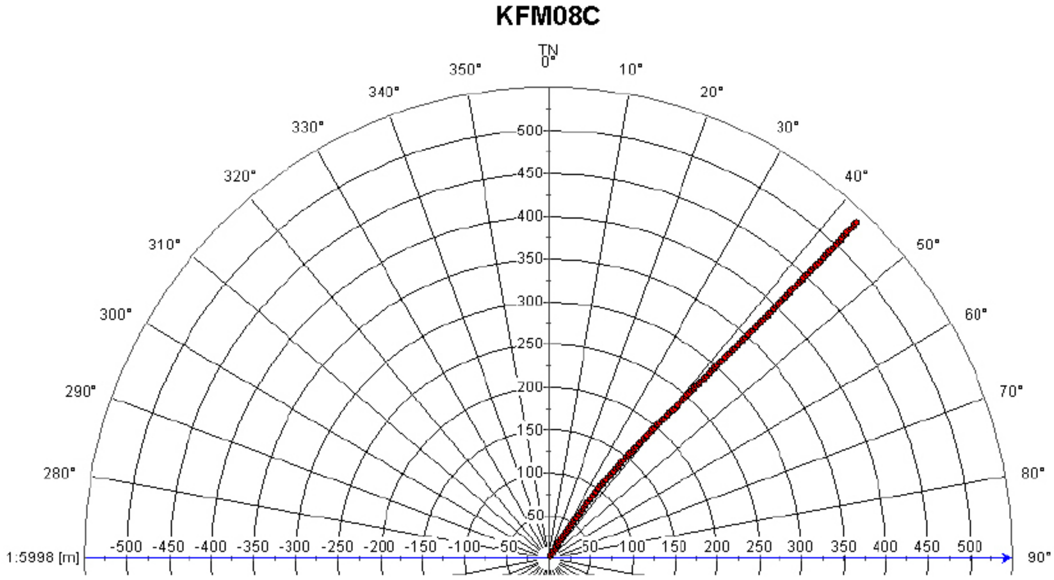


Figure 5-21. Horizontal projection of the in use-flagged deviation data from KFM08C.

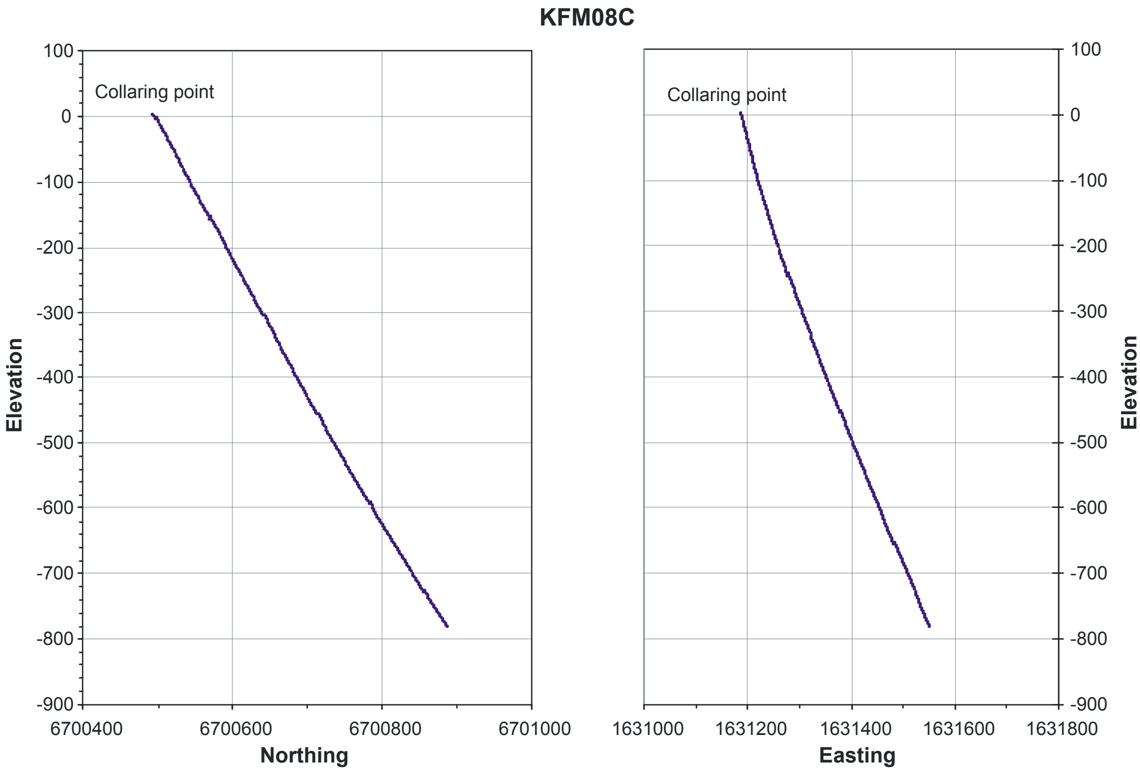


Figure 5-22. Two vertical projections of the in use-flagged deviation data from KFM08C.

5.4.13 Groove milling

A compilation of length to the reference grooves and a comment on the success of detecting the grooves are given in Table 5-8. The positions of the grooves are determined from the length of the drilling pipes used at the milling process. The length is measured from the upper part of the upper two grooves.

In most of the earlier drilled boreholes the milling equipment has functioned in a satisfactory way, but in KFM08C groove millings could be detected with the SKB level indicator only to 398 m drilling length. At larger depths some weak marks on the borehole wall have been revealed by the BIPS-camera, see Table 5-8, but the segments have obviously not milled the grooves deep enough. The force on the segments is controlled by the flushing water pressure, and a leaking drill string would decrease the pressure. That this would have been the problem is however not confirmed from the registered water pressure, se Section 5.4.4. On the contrary, the water pressure in KFM08C increased unusually regularly versus depth, see Figure 5-14. A more plausible explanation is that some parts in the well used equipment were worn out, causing an increasing internal friction. Later, after the instrument had been carefully examined and the movable parts been lined with Teflon, grove milling has functioned perfectly in the later drilled boreholes.

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

All length values used for measurements in the borehole and of the drill core originate from registrations of the length of the drill pipe string. However, such registrations involve a small error depending on the gravitational stretching of the pipe string when hanging freely and thus exposed to its own weight. When the pipe string is lowered to the borehole bottom, and the lifting force from the drill rig is set to zero, the pipe string will be resting on the borehole bottom and thus relieved from the previous load, and the stretching will cease. Instead, the load from the pipe string will now cause compression, and to some extent bending of it.

By measuring the length difference between these two conditions, it was hoped that the length error could be determined for different lengths of the pipe string and for different inclinations of the borehole. The practical difficulties and uncertainties in the results however turned out to be considerable. Therefore it is recommended that the length error is determined from the diagram in Figure 5-23, which is based on load tests performed in the laboratory by the manufacturer of the drill 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.

Table 5-8. Reference grooves in KFM08C.

Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS	Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS
150	Yes	Yes	600	No	No
200	Yes	Yes	652	No	No
250	Yes	Yes	700	No	No
300	Yes	Yes	750	No	Yes *
350	Yes	Yes	800	No	Yes*
398	Yes	Yes	850	No	No
450	No	Yes	900	No	No
500	No	Yes			
550	No	Yes *			

* Weak marks on the borehole wall.

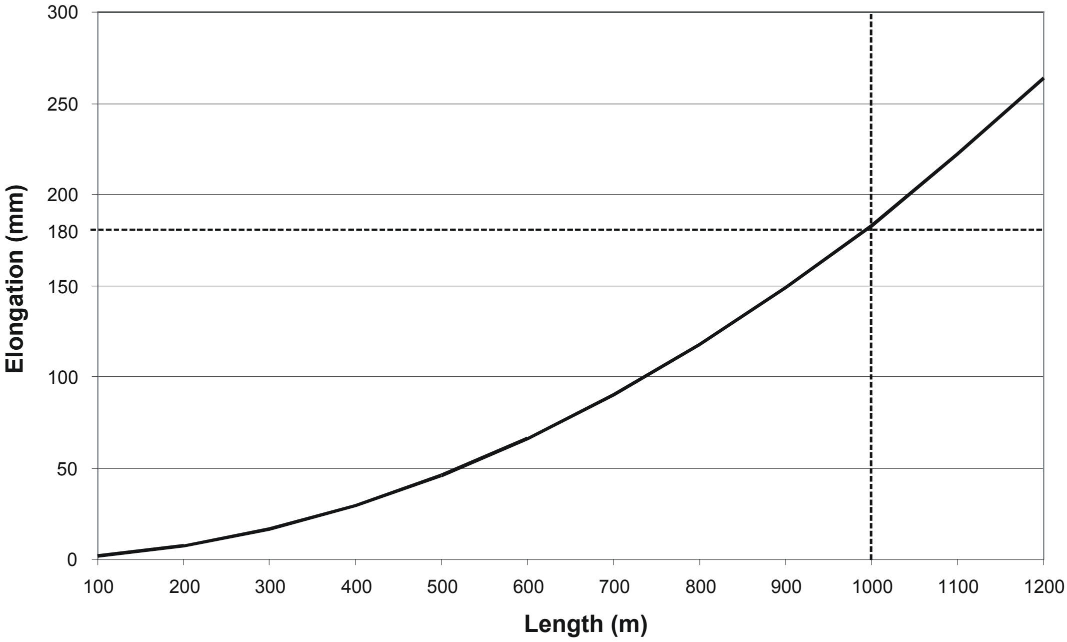


Figure 5-23. *The diagram illustrates the elongation of the WL-76 drill pipe string when hanging in a vertical water filled borehole. Values from laboratory load tests of the drill pipes.*

5.4.15 Consumables

The amount of oil products consumed during drilling of the percussion drilled part of KFM08C (0–100 m) is reported in Table 5-9, whereas amounts of grease, oil and diesel used during core drilling are presented in Table 5-10. Amount of grout used for gap injections of the respective casings are shown in Table 5-11. Regarding hammer oil and compressor oil, these products are indeed entering the borehole but are, on the other hand, continuously retrieved from the borehole due to the permanent air flushing during drilling. After completion of drilling, only minor remainders of the products are left in the borehole.

The special type of thread grease (silicon based) used during core drilling in this particular borehole was certified according to SKB MD 600.006 (Table 1-1). The experience from a technical point of view of the grease is not fully satisfactory. Although expensive, the grease has a low adhesion capacity to the threads, and the lubrication characteristics are not as favorable as for conventional lubricants.

Table 5-9. Oil consumption during percussion drilling of KFM08C.

Borehole ID	Hammer oil (percussion drilling) Preem Hydra 46	Compressor oil (percussion drilling) Schuman 46
KFM08C	15 L	No consumption measured

Table 5-10. Oil and grease consumption during core drilling of KFM08C.

Borehole ID	Thread grease (core drilling) Unisilikon L50/2	Grease for the drilling machine Statoil AB	Engine oil Castrol Tection 15W-40	Hydraulic oil Premium ECO HT-E 46	Diesel engines OKQ8 Diesel miljöklass 1
KFM08C	6 kg	3.5 kg	9 L	45L	15,300 L

Table 5-11. Cement consumption for grouting the percussion drilled part of KFM08C 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
KFM08C	11.00–12.14	72 kg/80 L	Gap injection	Bottom plug
KFM08C	12.14	178.5 kg/200 L	Gap injection using a packer	
KFM08C	0.0–12.14	500 kg/560 L	Gap injection with a hose	

5.4.16 Recovery measurements after cleaning by air-lift pumping

The final cleaning of KFM08C by air-lift pumping caused a draw-down of 47 m. After completed pumping, the recovery of the groundwater table was monitored. The results are displayed in the diagram of Figure 5-24. Pressure registration was proceeding during six hours, and the water-yielding capacity could be determined from the diagram. An inflow of < 10 L/min at a drawdown of 47 m was estimated.

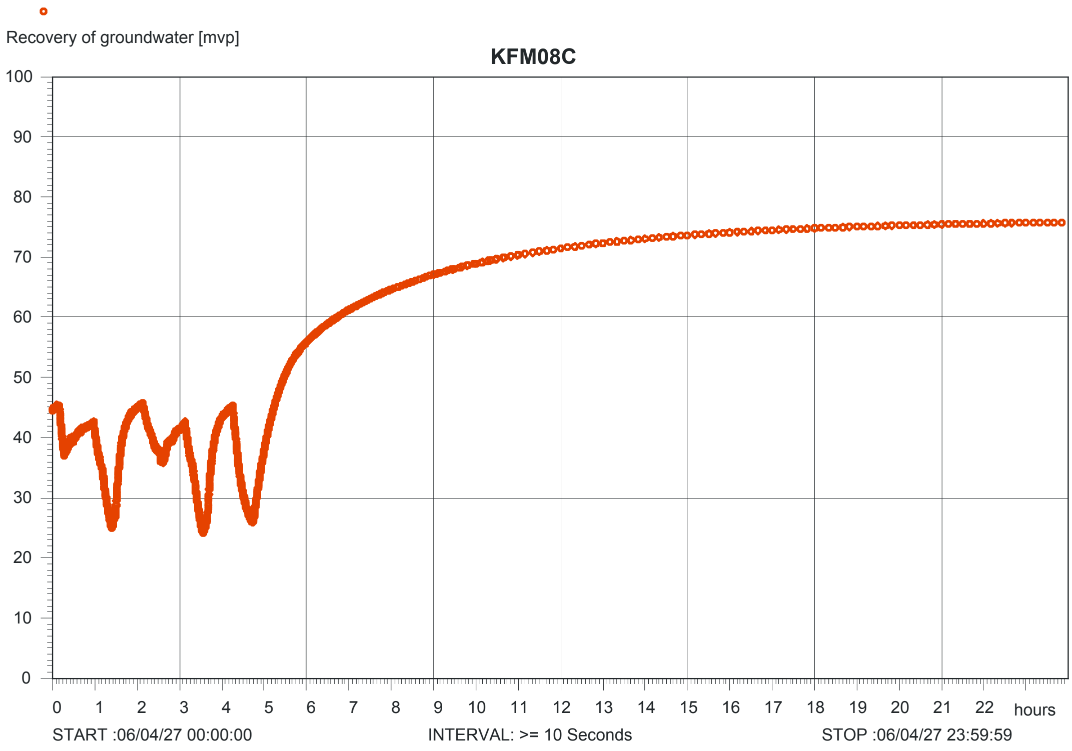


Figure 5-24. *Recovery of groundwater table in section 0–951.08 m of KFM08C after stop of air-lift pumping.*

5.5 Drilling progress KFM08D

The primary aim of drilling KFM08D was to investigate a rock volume south-east of drill site DS8,which is intersected by a sequence of NE-SW-trending lineaments, cf. Chapter 2. Drilling of borehole KFM08D, which is one of the last boreholes to be drilled inside the Forsmark candidate area, was a challenge for the site organization to manage to perform drilling, borehole measurements and borehole monitoring within the existing time schedule. Drilling of borehole KFM08D was carried out during two periods, between Nov 23rd 2006 and Dec 4th 2006 (percussion drilling) and between Dec 13th 2006 to Feb10th 2007 (core drilling), including three weeks Christmas break, see Figure 5-25.

5.5.1 Percussion drilling period

Percussion drilling is normally a rapid drilling method compared to core drilling. The relatively complex approach applied for the drilling, and especially the grouting sequences could be time consuming, but as the telescopic section of KFM08D is shorter than usual, c. 59 m, this resulted, however, in a rather short working period, see Figure 5-26.

5.5.2 Core drilling period

After percussion drilling of section 0–59.04 m, after which followed a break of one week, core drilling commenced. The progress of the core drilling is presented in Figure 5-27. Due to the tight time schedule, from start the core drilling ran 24 hours per day for started The pace of drilling decreases versus time, due to that with increasing borehole length, retrieval of the core barrel, e.g. for change of drill bit, becomes more and more time consuming.

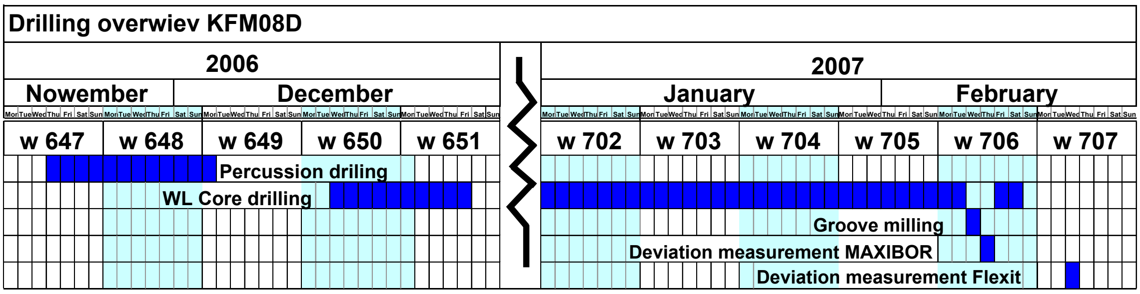


Figure 5-25. Overview of the drilling performance of borehole KFM08D.

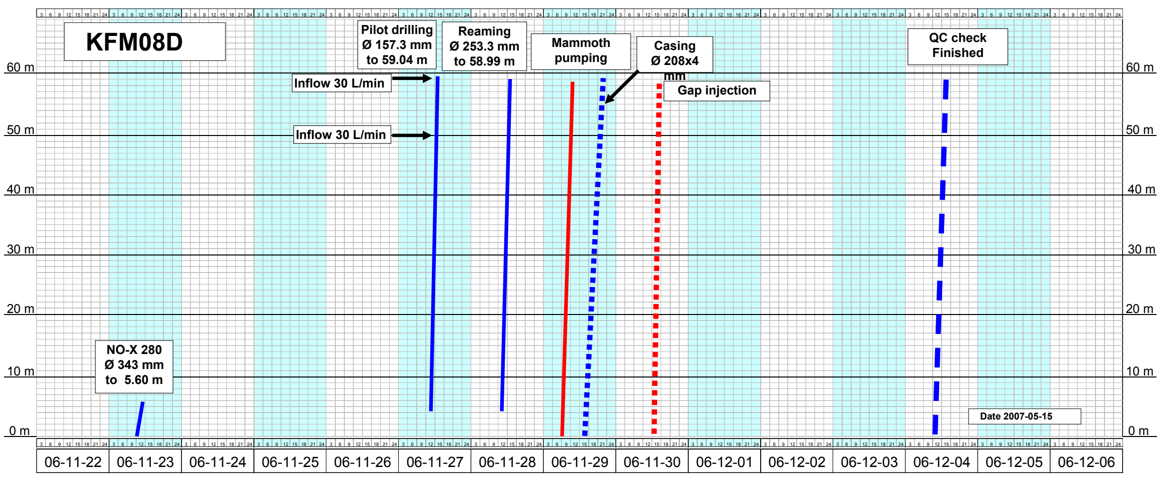


Figure 5-26. Percussion drilling progress (depth and activity versus calendar time).

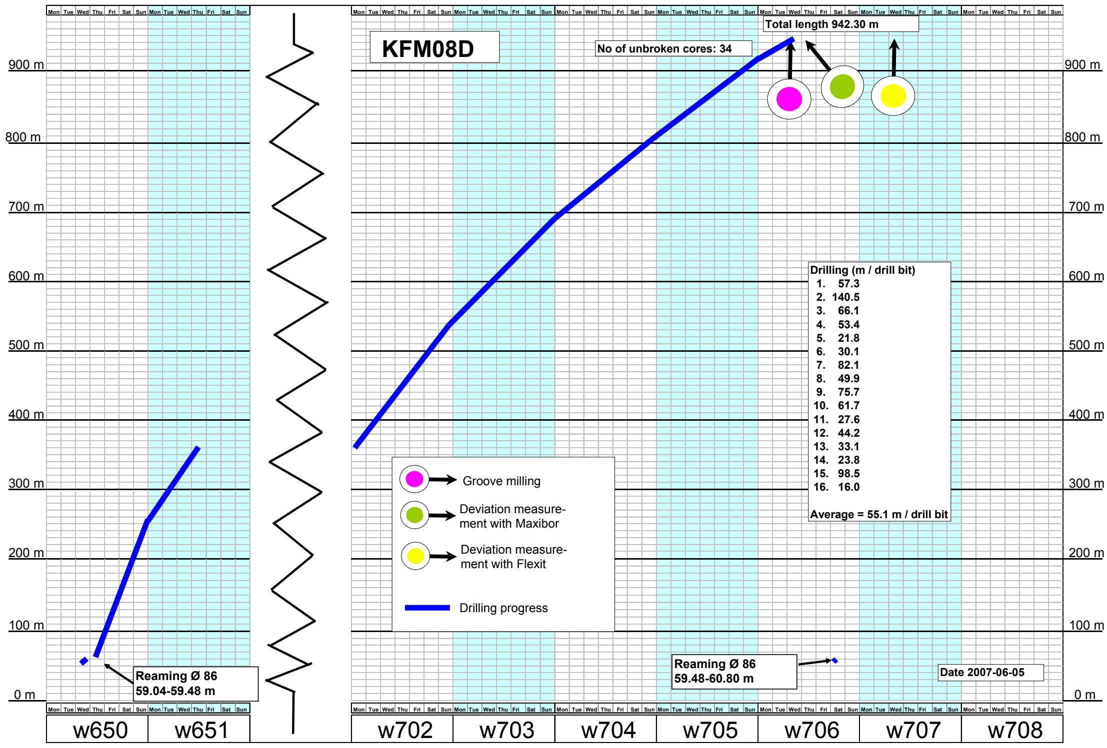


Figure 5-27. Core drilling progress (length versus calendar time). The figure includes logistics for WL-drilling, groove milling and Maxibor- and Flexit deviation measurenest, as well as number of unbroken cores and drill bits used.

5.6 Geometrical data and technical design of borehole KFM08D

Administrative, geometric and technical data for the telescopic borehole KFM08D are presented in Table 5-12. The technical design is illustrated in Figure 5-28.

5.7 Percussion drilling KFM08D 0–59.04 m

5.7.1 Drilling

As mentioned in Section 4.1.3, the upper part to 5.60 m of the borehole was drilled and cased according to NO-X 280. During pilot drilling to 59.04 m with 157.3 mm diameter a inflow of 30 L/min was encountered. As a borehole inclination as large as 55° from the horizontal plane involves an elevated risk of instability and outfall from the borehole wall, the borehole section to 58.99 m was reamed to 253.3 mm and a stainless steel casing of diameter $Ø_o/Ø_i$=208/200 mm was installed to 58.80 m. Finally, the gap between the casing and the borehole wall was cement grouted, so that the water inflow ceased completely.

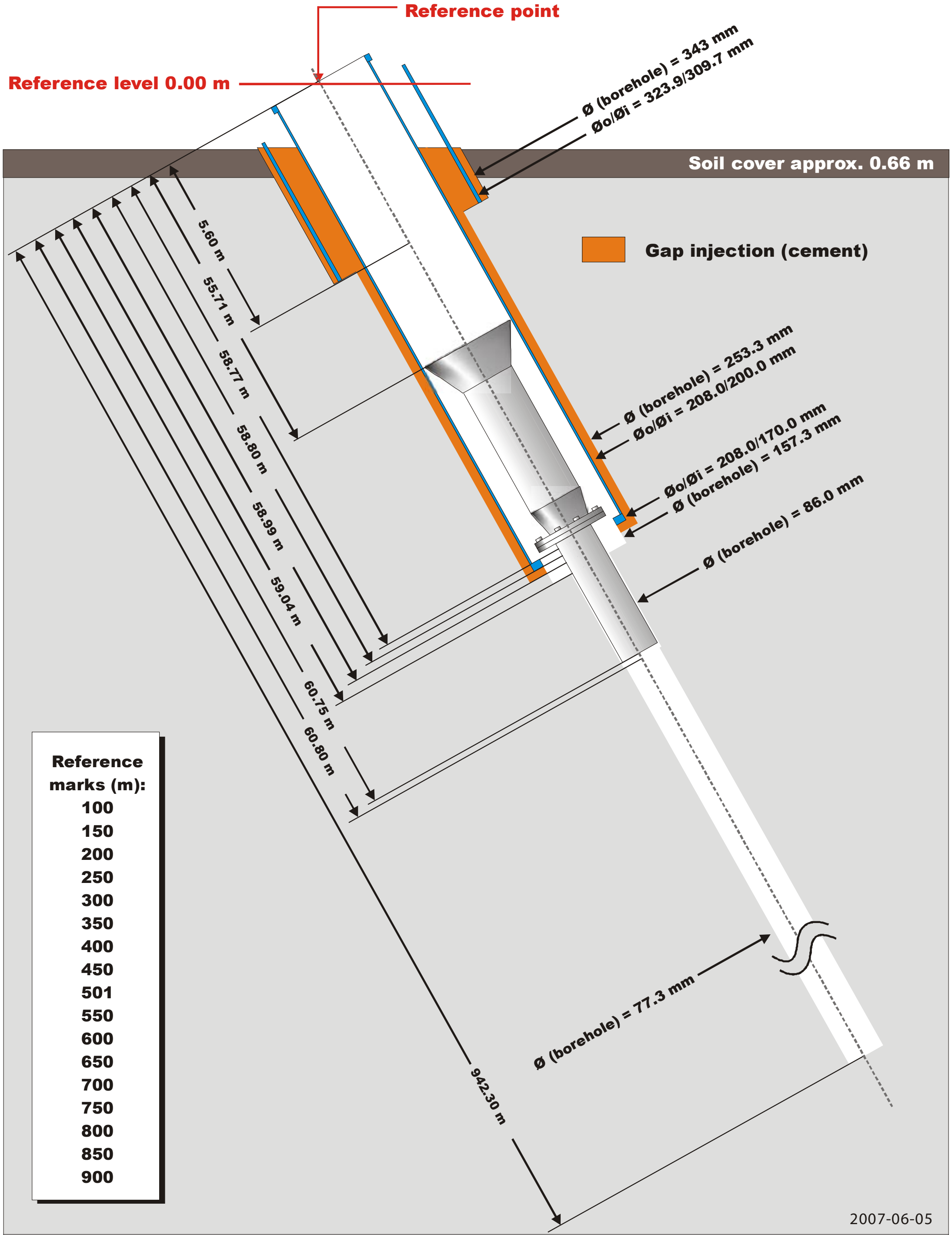
Table 5-12. Administrative, geometric and technical data for borehole KFM08D.

Parameter	
Borehole name	KFM08D
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	Nov 23rd, 2006
Completion date	Feb 10th, 2007
Percussion drilling period	2006-11-23 to 2006-12-04
Core drilling period	2006-12-13 to 2007-02-10
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Sven Andersson i Uppsala AB
Percussion drill rig	Puntell MX 1000
Core drill rig	Onram 2000 CCD
Position KFM08D at top of casing (RT90 2.5 gon V 0:–15 / RHB 70)	N 6700491.68 E 1631199.16 Z 2.61 (m.a.s.l.)
	Azimuth (0–360°): 99.98° Dip (0–90°): –55.00°
Position KFM08D at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6700395.77 E 1631759.45 Z –748.28 (m.a.s.l.)
	Azimuth (0–360°): 98.89° Dip (0–90°): –49.27°
Borehole length	942.30 m
Borehole diameter and length	From 0.00 m to 5.60 m: 0.3430 m From 5.60 m to 58.99 m: 0.2533 m From 58.99 m to 59.04 m: 0.1573 m From 59.04 m to 60.80 m: 0.0860 m From 60.80 m to 942.30 m: 0.0773 m
Casing diameter and drilling length	$Ø_o/Ø_i$ = 323 mm/310 mm to 5.60 m $Ø_o/Ø_i$ = 208 mm/200 mm to 58.80 m
Transition cone inner diameter	At 55.71 m: 0.197 m At 60.75 m: 0.080 m
Drill core dimension	59.04–59.48 m/Ø 62 mm 59.48–942.30 m/Ø 51 mm
Core interval	59.04–942.30 m
Average length of core recovery	2.57 m
Number of runs	343
Diamond bits used	16
Average bit life	55.1 m

5.7.2 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 D (deviation measurements, penetration rate and rock type distribution), whereas other results (flow data and electrical conductivity) are used only as supporting data for on-site decisions.

Technical data
Borehole KFM08D



Drilling reference point

Northing:	6700491.68 (m), RT90 2,5 gon V 0:-15
Easting:	1631199.16 (m), RT90 2,5 gon V 0:-15
Elevation:	2.61 (m), RHB 70

Orientation

Bearing (degrees):	99.98°
Inclination (degrees):	-55.00°

Borehole

Length:	942.30 m

Percussion drilling period

Drilling start date: 2006-11-23

Drilling stop date: 2006-12-04

Core drilling period

Drilling start date: 2006-12-13

Drilling stop date: 2007-02-10

2007-04-08

Figure 5-28. *Technical data of borehole KFM08D.*

5.8 Core drilling KFM08D 59.04–942.30 m

5.8.1 Drilling

The bedrock within the so called Forsmark tectonic lens has appeared to be relatively hard to drill, probably to a large extent depending on the high quartz contents. As drill site DS8 is located in the north-western part of the candidate area, the bedrock composition was prior to drilling assumed to be of similar character. However, in average, the life-time was 55.1 drilled metres per drill bit in KFM08D, which actually is 10 m more than in KFM08A and about 20 m more than in KFM08C (cf. Section 5.4.1).

On the whole, even if there is a positive trend for developing drill bits with longer life-time, core drilling in granites at Forsmark is still more time consuming and costly than in average granites.

5.8.2 Measurements while drilling

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 5.8.3–5.8.15.

Mapping of the drill core samples from KFM08D is presented in /6/.

5.8.3 Registration of drilling parameters

A selection of results from drilling parameter registration is presented in diagrams below. As regards the complete dataset of drilling parameters, it is referred to Sicada, where data are traceable by the activity plan number.

Drill bit position versus time

Figure 5-29 illustrates how drilling proceeded versus time. Drilling work schedule was 24 hours a day from Monday to Thursday, but due to the strained time table, extra 12 hours shifts per day from Friday to Sunday were introduced, resulting that drilling reached 360 m borehole length already before the Christmas break. Figure 5-29 serves as a basis for Figure 5-25, to which it should be compared.

Penetration rate

The penetration rate, see Figure 5-30, was in average a little bit higher than in KFM08C. Initially, the penetration rate was 11–12 cm/min, but fell successively back to c. 10–11 cm/min between 420 m and 550 m, corresponding to the increasing frictional resistance of the return water flow, which is discharged in the narrow gap between the borehole wall and the pipe string, but probably also due to a harder rock type (albitized granite with increased contents of quartz) in the middle of the borehole. A slight increase is observed when drilling is conducted in rock around 600 m with tonalitic composition as well as close to the bottom, when the borehole penetrates more fractured and mafic rock. Just before completion of drilling, when the rock type changes to granite, the penetration rate again decreases. Due to the flatness of KFM08D, retrieval of drill cuttings is more difficult, which may have slowed down the penetration rate.

Feed force

In Figure 5-31 the feed force is plotted versus borehole length. The feed force during drilling of KFM08D was in general between 500–1,000 kp lower than during drilling of KFM08C, cf. Section 5.4.3. Generally, the feed force is smoothly undulating but displays significantly lower values in section 580–620 when the drilling is performed in tonalitic bedrock, Finally, from 880 m to 920 m the feed force is low, which approximately coincides with drilling in amphibolitic rock. Towards bottom, when the rock type changes to granite, feed force is again increased.

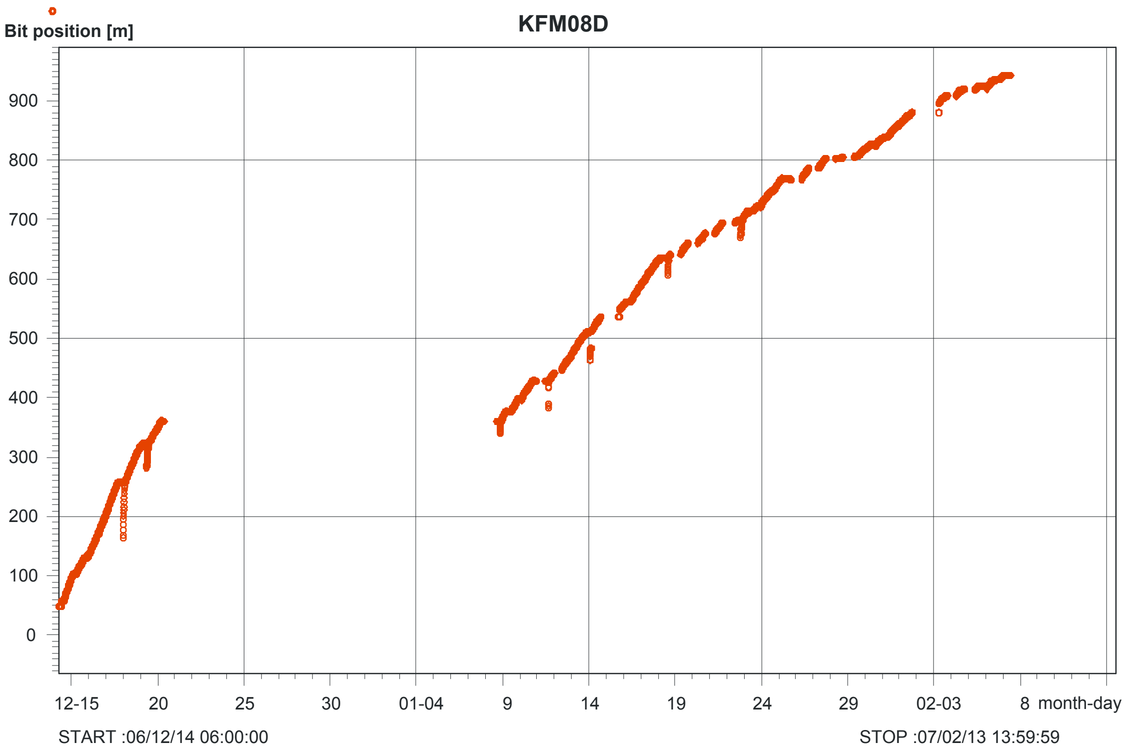


Figure 5-29. *Drill bit position in KFM08D versus time.*

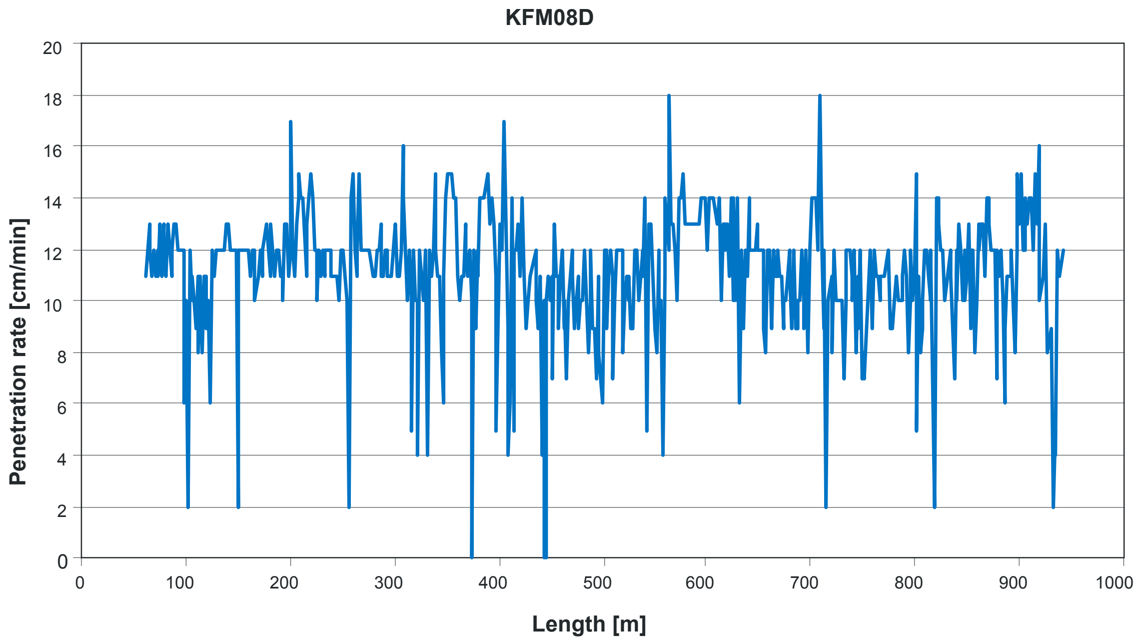


Figure 5-30. *Penetration rate during core drilling of KFM08D.*

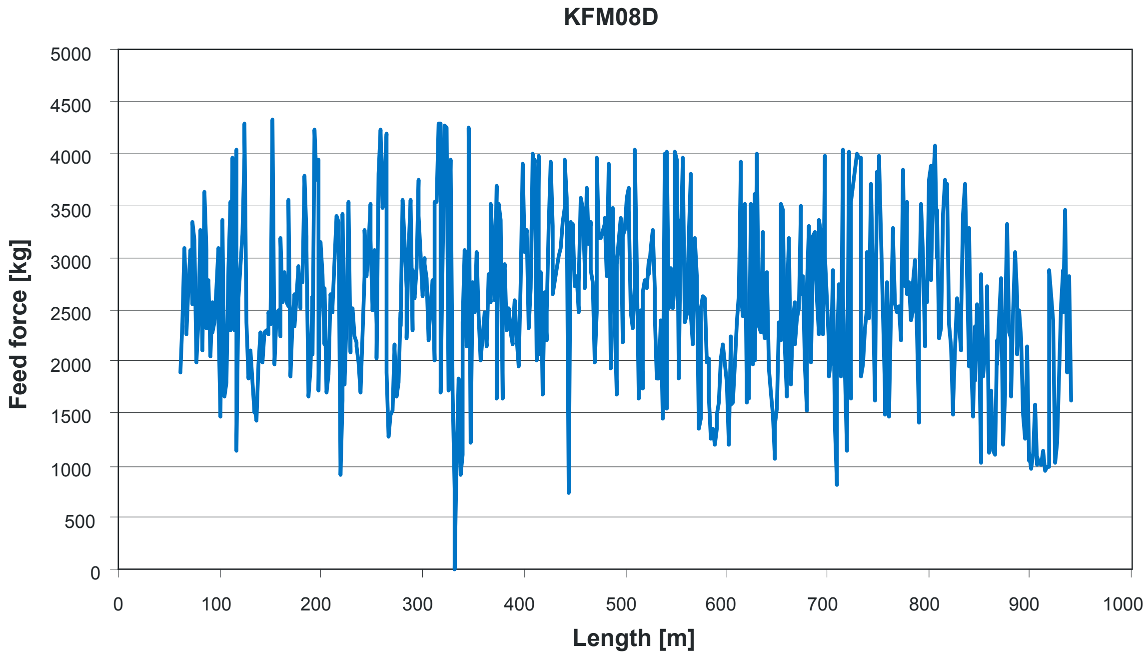


Figure 5-31. *Feed force versus borehole length during drilling of borehole KFM08D.*

Rotation speed

The rotation speed diagram, Figure 5-32, shows from start an almost constant rotation speed of 800 rpm, which however is raised to c. 850 rpm at c. 400 m. Sudden drops in the curve represent drilling shut off. The rotation speed diagram from KFM08C shows approximately the same pattern, although the speed was a little bit lower in that borehole, see Figure 5-9.

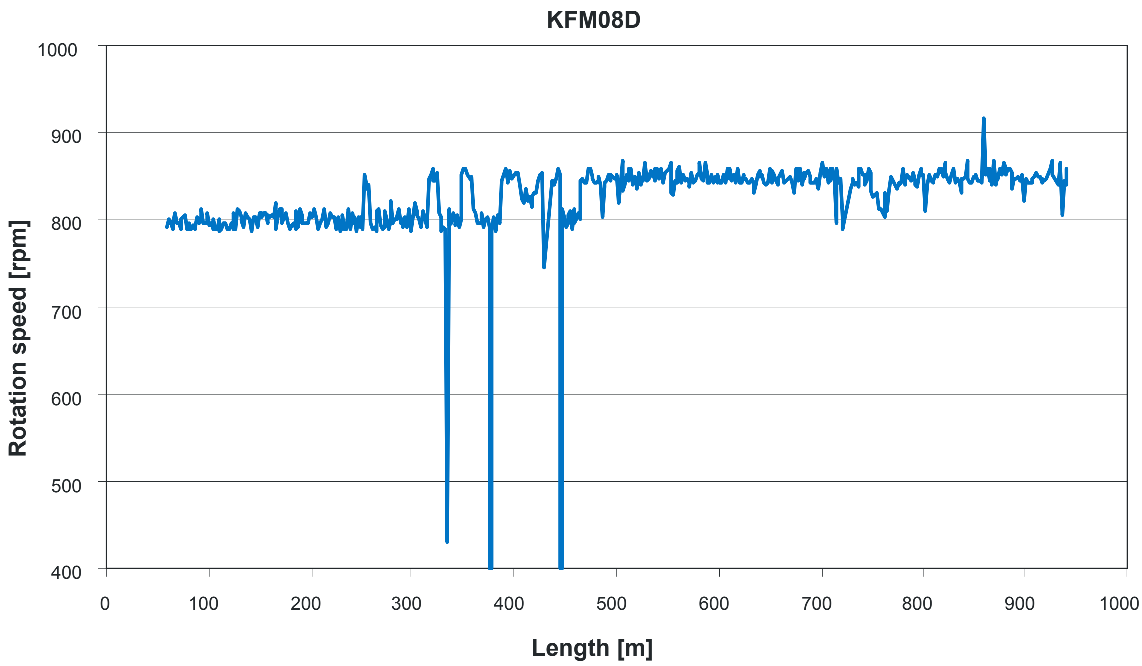


Figure 5-32. *Rotation speed versus borehole length during drilling of KFM08D.*

5.8.4 Flushing water and return water flow parameters

Flushing water and return water flow rate measurements – water balance

As borehole KFM08D is of SKB chemical type, it is important to estimate the amount of flushing water pumped into the hole during drilling as well as the amount of return water recovered to permit a water balance calculation. A flow gauge in the measurement station registered the flushing water flow rate, see Figure 3-3. The return water was measured by another flow meter, mounted on-line with the discharge pipeline, see Figures 3-3 and 3-6.

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

Figure 5-33 illustrates the accumulated volume of flushing water and return water versus time during core drilling, whereas Figure 5-34 displays the accumulated volumes of flushing water and return water from the entire drilling period, giving a return water/flushing water quotient of 2.24 [1,975 L/883 L] (results from Uranine measurements are presented in the next section).

However, in Figure 5-33 a loss of flushing water at shallow depths in the borehole is observed, as well as a significant excess of return water at depths exceeding c. 100 m (Dec 12th 2006). This reflects the fact that when the drill bit position is close to water conductive fractures in the borehole, flushing water is forced into these fractures, because the flushing water pressure much exceeds that of the formation. When the drill bit has passed this section, the pressure gradient will eventually be reversed due to the air-lift pumping in the upper part of the borehole. If no other highly water conductive fractures are penetrated, where flushing water losses may occur, larger amounts of return water (groundwater and flushing water) are then extracted from the borehole than flushing water is supplied to it.

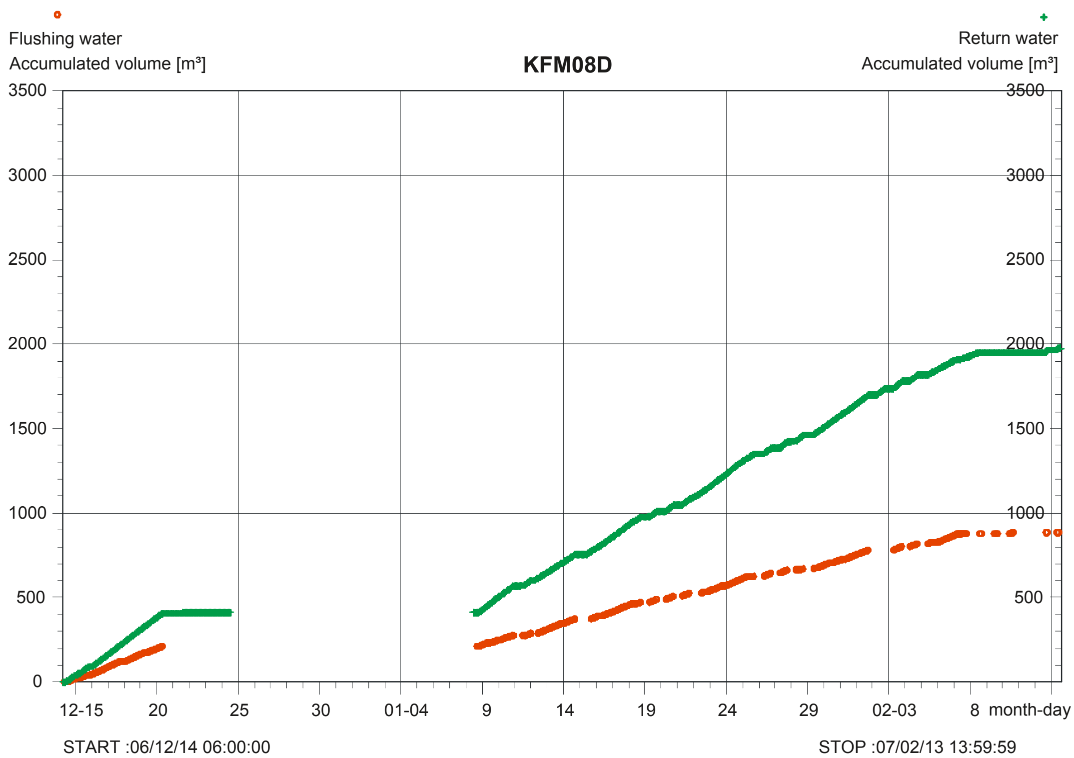


Figure 5-33. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM08D.*

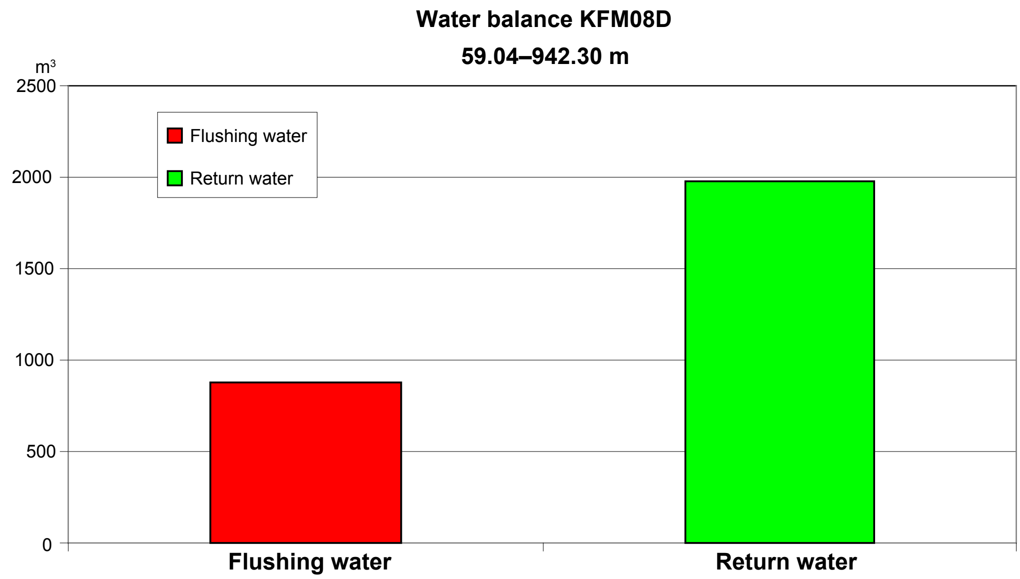


Figure 5-34. *Total amounts of flushing water and return water during drilling of borehole KFM08D. The total volume of flushing water used during core drilling amounted to 883 m³. During the same period, the total volume of return water was 1,975 m³ resulting in a return water/flushing water balance as high as 2.24 mainly due to the large inflow of groundwater into the upper part of the borehole.*

Figure 5-35 illustrates the variations of flushing water and return water flow rate together with variations of the groundwater table during core drilling of borehole KFM08D. The return water flow rate depends on the hydraulic transmissivity of the borehole, as well as on the draw-down (accomplished by the air-lift pumping). To cool the drill bit and keep the borehole bottom clean, drilling usually requires a flushing water flow rate of c. 35 L/min. However, immediately after a core recovery, a temporarily higher flushing water flow rate is often applied.

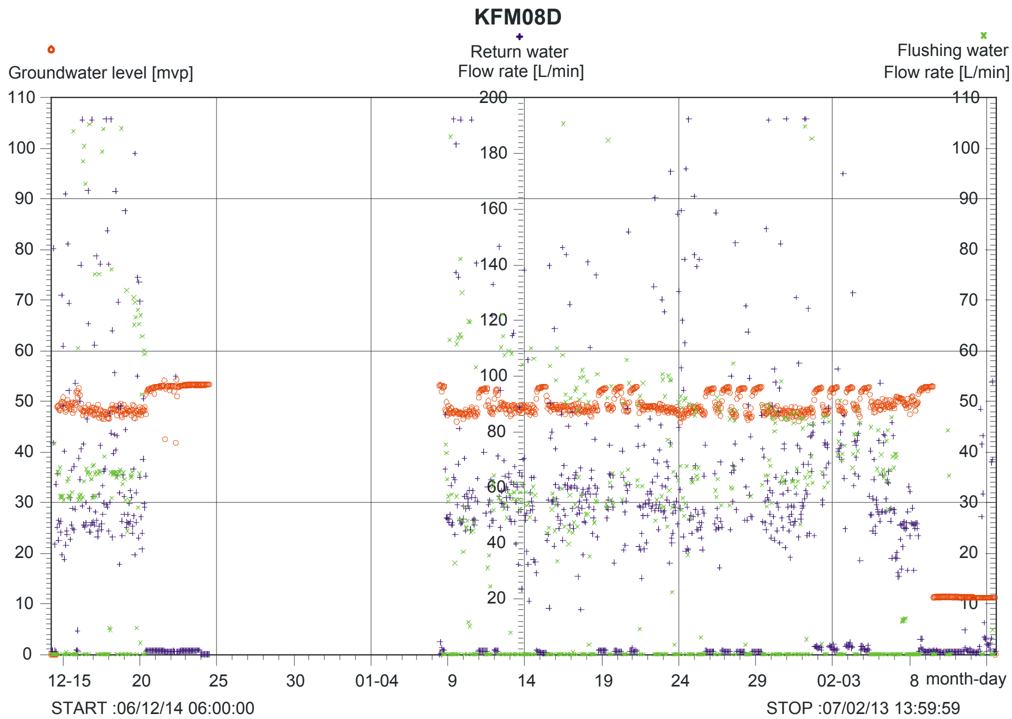


Figure 5-35. *Groundwater table (red), flushing water flow rate (green) and return water flow rate (purple) versus time during core drilling of borehole KFM08D.*

As the upper 59 m of the borehole are cased and cement grouted, there was no return water inflow above the core drilled part of the borehole. Shortly after core drilling started, the return water flow rate was c. 40 L/min, indicating water yielding fractures just below 100 m. When core drilling commenced, the water inflow increased simultaneously as the groundwater table draw-down was larger. However, after the Christmas holidays, both the return water flow rate and the draw-down stabilized. The results indicate absence of major groundwater inflows to the borehole at larger depths, which is an important result, because borehole KFM08D penetrates a sequence of steeply dipping minor fracture zones (cf. Chapter 2 and Section 5.5), which obviously are low- or non-transmissive.

Uranine contents of flushing water and return water – mass balance

During the drilling period, sampling and analysis of flushing water and return water for analysis of the contents of Uranine was performed systematically with a frequency of approximately one sample per every fourth hour during the drilling period, see Figure 5-36. Like in all boreholes drilled during the site investigation except KFM01A and KFM01B, a dosing feeder controlled by a flow meter was used for labelling the flushing water with Uranine to a concentration of 0.2 mg/L.

A mass balance calculation of the accumulated volumes of flushing water and recovered flushing water in the return water suggests that minimum 290 m^3 of flushing water was lost in the borehole. According to notations in the logbook, the amount of Uranine added to the borehole was 197 g. If the averages of the Uranine concentration values in the flushing water and in the return water are used to calculate the amount of Uranine added to and recovered from the borehole, the calculations give 179 g and 120 g respectively. After finished drilling, the water chemistry sampling in KFM08D also showed that flushing water still remain in the borehole.

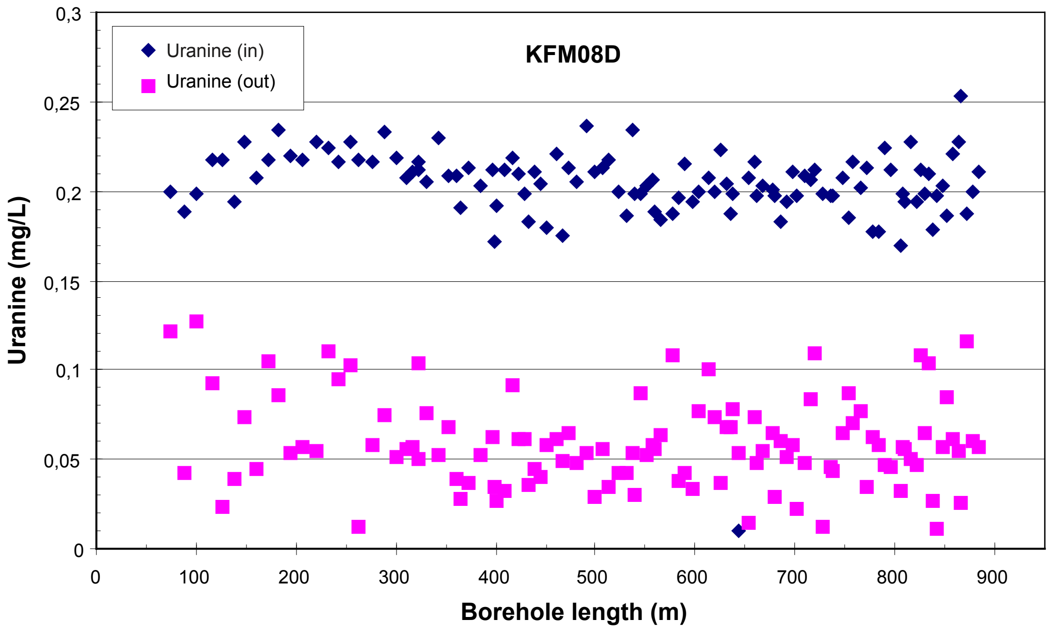


Figure 5-36. *Uranine contents in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFM08D. An automatic dosing equipment, controlled by a flow meter, accomplished the labeling with Uranine.*

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM08D is exposed in Figure 5-37. Like in boreholes KFM02A, KFM03A, KFM04A, KFM05A, KFM06A, KFM06C, KFM07A, KFM08A and KFM08C, the borehole diameter was 77.3 mm, i.e. increased c. 1 mm compared to in borehole KFM01A. This resulted in lower flushing water pressure than in KFM01A.

There is an almost continuous increase of flushing water pressure versus borehole length, although it shows some variations when drilling is restarted at c. 360 m after Christmas break. Also when drilling through the fractured rock at the end of the borehole the water pressure has a significant drop.

The final water pressure in KFM08D was 5–10 bars higher than in the deeper parts of boreholes KFM02A and KFM03A. A possible explanation to this may be that KFM08D is more inclined than the previous boreholes (c. 55° compared to 85° from the horizon), which makes recovery of drill cuttings more difficult, demanding higher water pressures and increased flow rates. However, the flushing water pressure is also significantly higher compared to in KFM08C, see Figure 5-14, although the difference in borehole inclination in this case is moderate, c. 55° compared to 60°.

5.8.5 Electric conductivity of flushing water

Flushing water was supplied from percussion borehole HFM22 (cf. Section 3.3.2). A sensor in the measurement station, registered the electric conductivity (EC) of the flushing water on-line before the water entered the borehole, see Figure 3-3.

Another sensor for registration of the electric conductivity of the return water (Figure 5-38) was positioned between the surge diverter (discharge head) and the sedimentation containers (Figure 3-3).

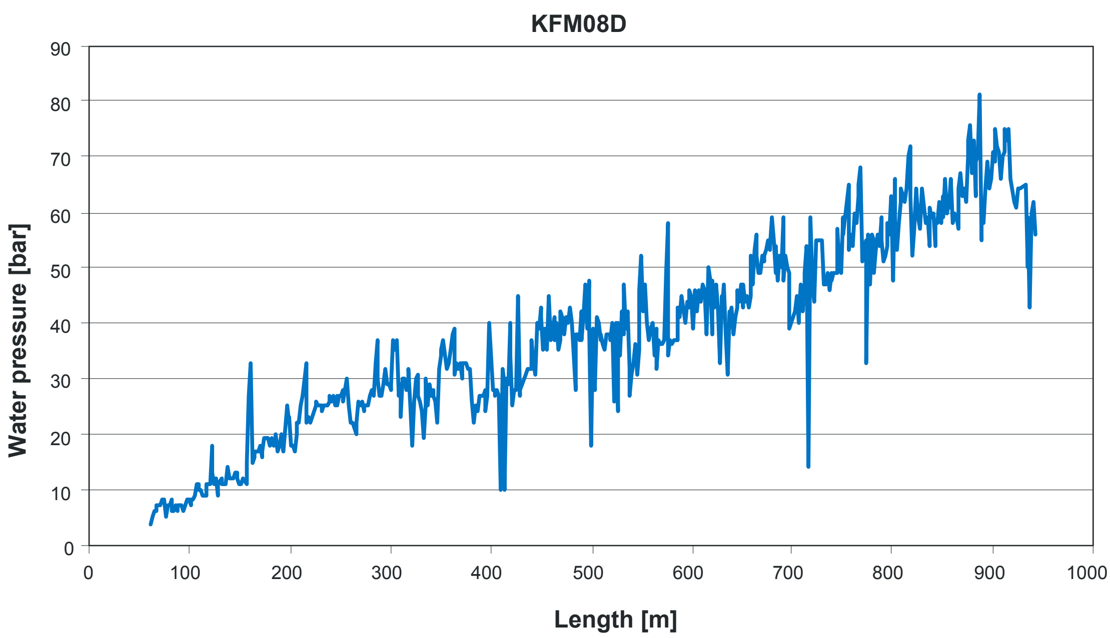


***Figure 5-37.** Flushing water pressure versus drilling length when drilling KFM08D.*

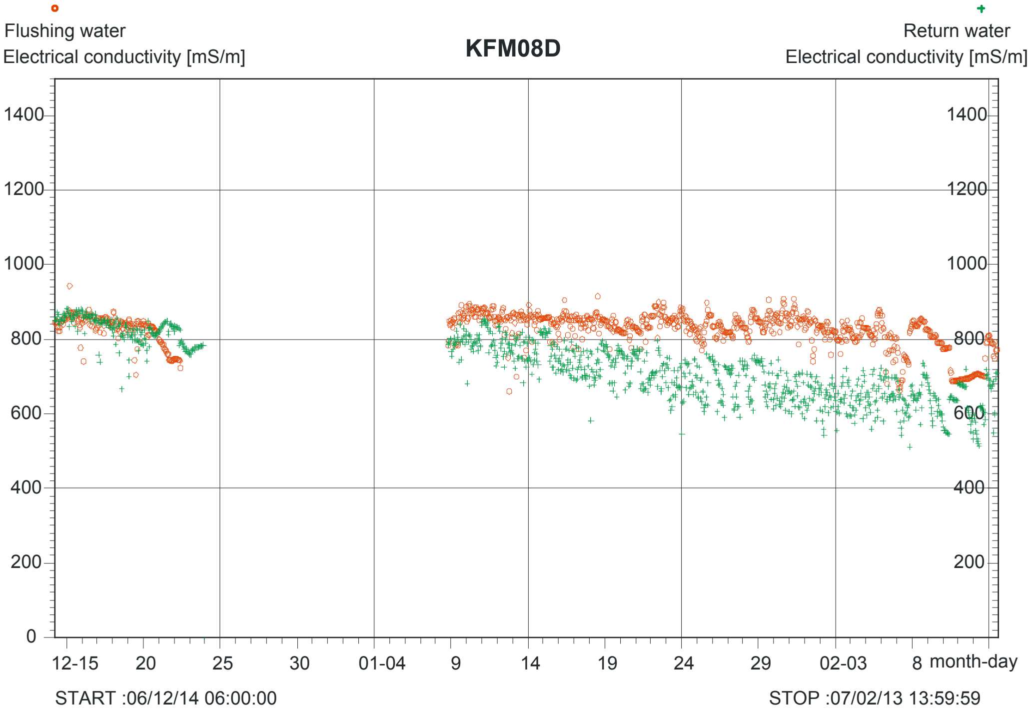


Figure 5-38. *Electrical conductivity of flushing water (red) from HFM22 and return water (green) from KFM08D. The dataset has been reduced as well as cleaned from outliers.*

The electrical conductivity (salinity) of the flushing water from the 222 m deep supply well HFM22 with its major inflow at c. 62 m has from start a significantly decreasing trend during the weekly pumping (Monday to Thursday around the clock) of flushing water. At the beginning, the EC-value is c. 850 mS/m but decreases to around 800 mS/m by the end of the drilling period. This indicates that by increasing draw-down in HFM22, the proportion of shallow, less saline water increases. During the week-end stops, the salinity recovers to the normal, undisturbed EC-level.

The average electrical conductivity of the return water is from the beginning equal with the flushing water, but generally lower during the remaining drilling period, The most probable explanation is that the shallow, low-saline groundwater inflows around c. 100 m dominate in KFM08D.

5.8.6 Contents of dissolved oxygen in flushing water

In Figure 5-39, the level of dissolved oxygen is plotted versus time. The transmitter seems to have been out of function from start. When restarting drilling after the Christmas break, contents of dissolved oxygen has generally been kept between 2–6 mg/L. When the contents of dissolved oxygen has raised, it is either because of lack of nitrogen or, at drilling stops, nitrogen is shut off. During the last three weeks of drilling the transmitter has again malfunctioned.

5.8.7 Chemical composition of flushing water

Results from previous chemical analyses of groundwater from the supply well HFM22 are compiled in /8/. The flushing water was sampled at one occasion also during drilling of KFM08D, see Appendix F, for the following reasons:

- Initially, to check if the quality was satisfactory. One main concern is the contents 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.

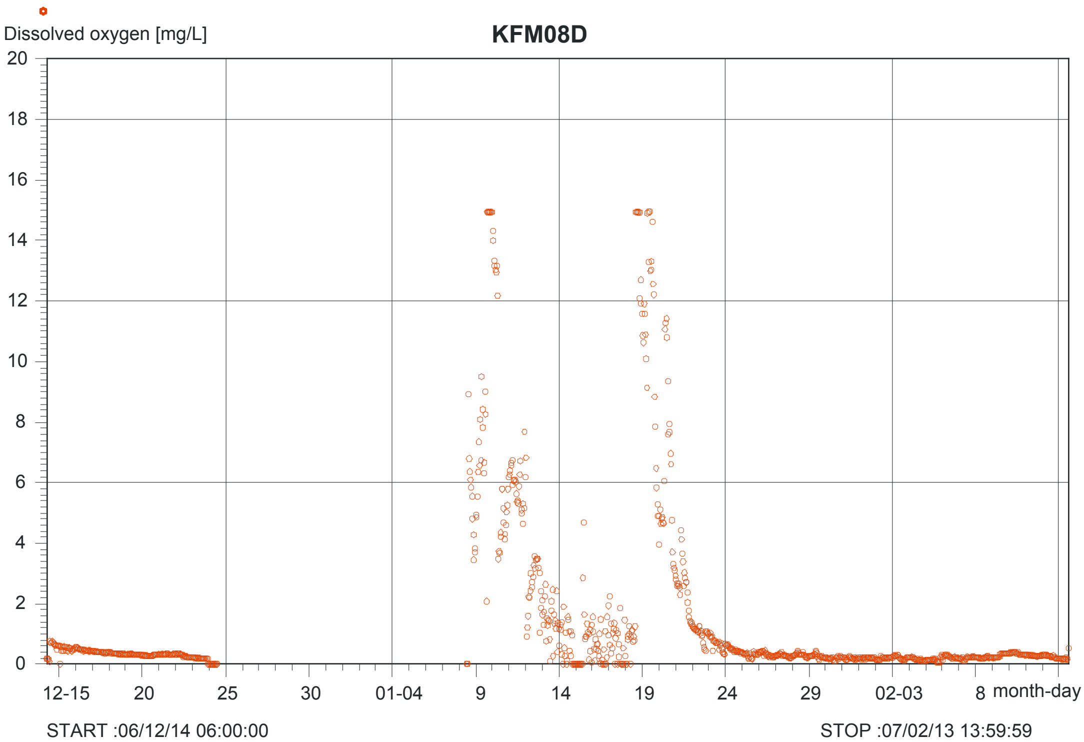


***Figure 5-39.** Dissolved oxygen contents in the flushing water versus time when drilling KFM08D.*

- To check the groundwater chemical composition during drilling. The chemical composition of the flushing water is important when estimating the effect, or correcting for the effect, of remaining flushing water in water samples collected from telescopic boreholes for chemical analyses.

The percussion borehole HFM22 has been used before as flushing water supply well (during drilling of KFM08A, B and C), and the concentration of Total Organic Carbon (TOC) was known to be sufficiently low (should preferably fall below 5.0 mg/L). The sample collected during the drilling period showed a TOC concentration of 5.1 mg/L. The flushing water well was used without further measures (e.g. using an active carbon filter system for reduction of organic substances as was applied when drilling KFM01A /7/).

The microbe contents in the flushing water was not determined during drilling of KFM08D. The microbe results from drilling of the preceding boreholes KFM05A /9/ and KFM06A /10/ showed convincingly that the cleaning procedure works well. It was therefore concluded that check of microbes at all drilling occasions was no longer necessary.

5.8.8 Registration of the groundwater level in KFM08D

To enhance the recovery of drill cuttings from the borehole, air-flush (mammoth) pumping was applied during the entire drilling period. The pumping capacity was checked by registration of the groundwater level in the borehole, below plotted versus time of the drilling period (Figure 5-40).

Already from the beginning, only one of the two mammoth pumps installed was functioning. This, in combination with the heavily water-yielding fractures at c. 100 m entailed that, although the mammoth pumping adjusted at maximum capacity, the draw-down obtained was less than 5 m. The draw-down was kept more or less constant during the entire drilling period. The diagram in Figure 5-40 shows that drilling was performed continuouslyduring the first period, before Christmas break, and thereafter 24 hours per day from Monday to Thursday and with one 12 hours shift per day from Friday to Sunday.

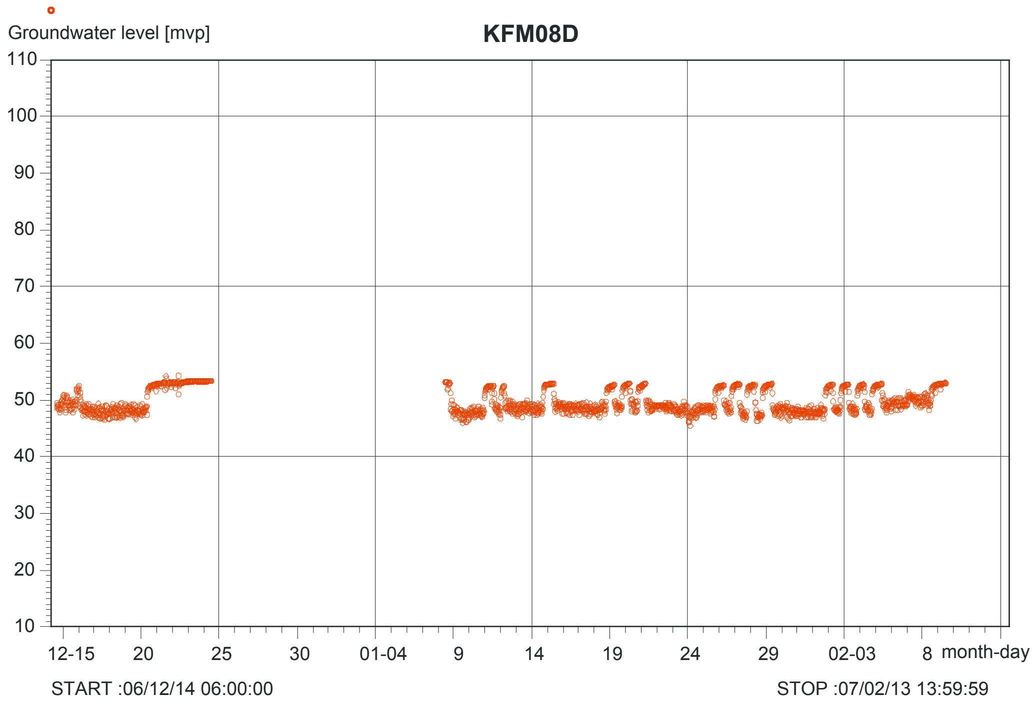


Figure 5-40. *Variation of the level of the groundwater table in KFM08D during drilling.*

During stop of drilling and pumping, the groundwater table recovered rapidly due to recharge of groundwater into the borehole, resulting in the (positive) peaks in the diagram. This confirms that the total inflow of formation water in the upper part of the borehole (but below the upper cased and grouted parts) was high. When pumping was restarted, a slow draw-down occurred.

The relatively small draw-down probably had an impact of the recovery of drill cuttings, that was lower in KFM08D compared to the recovery from KFM08C, where a more efficient mammoth pumping was achieved, se Section 5.4.9 and Section 5.8.8.

5.8.9 Core sampling

The average drill core length per run obtained from the drilling was 2.57 m. Due to the low fracture frequency at depth, thirty-four 3 m long unbroken cores were recovered. Fracture minerals were relatively well preserved. Rotation marks on the drill core occurred, but with a low frequency. A preliminary on-site core logging was performed continuously.

Table 5-13. Borehole KFM08D – Compilation of drill core defects.

Drill hole No.	Core length	Weakly rotated		Clearly rotated		Other defects	
	[m]	[m]	[%]*	[m]	[%]*	[m]	[%]*
KFM08D	883.26	23.00	2.60	8.00	0.91	9.33	1.06

* Percentage of total core length.

5.8.10 Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0–59 m) is c. 2.7 m^3. Weighing of drill cuttings and comparison with the weight of the theoretical volume was not carried out due to the relatively high water flow. This caused an uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations. However, it seems probable that the percussion drilled part was well cleaned from debris, since casing driving and gap grouting to full borehole length worked well, without obstruction from settled drill cuttings.

The theoretical difference in volume of the core drilled part of KFM08D and the drill core is calculated to be 2.340 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 granitites in the Forsmark area) is applied, the total weight of the theoretical amount of debris is estimated at 6,200 kg. The calculated dry weight of the debris from the core drilling recovered and weighed in the containers is 3,770 kg. The difference between the theoretically produced and recovered dry weight of debris is 2,430 kg, which gives a recovery of 61%, i.e. a much lower recovery than in KFM08C.

The recovery figure could be commented on. The dwell time in the return water system is too short for sedimentation of the suspended finest fractions. No estimation was made of the amount of suspended material, but the true recovery is probably much higher than 61%. 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 above c. 200 m in the borehole.

5.8.11 Deviation measurements

The principles of the equipment for deviation measurements were explained in Section 3.3.5. Also the changed strategy for deviation measurements during the site investigations was commented on, including the fact that the Flexit-method is now the principal method applied for deviation measurements, also in borehole KFM08D. When Maxibor™-measurements or deviation measurements with some other method have been performed as well, these may be used for uncertainty determinations of the deviation measurements.

As mentioned in Section 5.4.10, to ensure high quality measurements with the Flexit tool, the disturbances of the magnetic field must be low. The magnetic field variation during Feb 14th 2007, obtained from www.intermagnet.org and displayed in Figure 5-41, shows only minor disturbances when the two Flexit-survey in KFM08D was performed between 13:40 to 20:25. In the following a systematic description of the construction of the revised deviation data for borehole KFM08D is given.

The deviation data used are two Flexit-loggings to 936 m borehole length, and two complete Maxibor™-loggings, i.e. to 924 m, see Table 5-14. The two Maxibor measurements are though error marked as they are not repeatable and the deviation differs significantly from the Flexit curves.

With the Flexit Smart Tool System, the deviation measurements in borehole KFM08D were carried out every 3 m downwards at two different occasions. These two surveys, with activity numbers ID 13148134 and 13148138, provided almost repeatable results, and were therefore chosen for the construction of the deviation file to be "in use displayed" in Sicada (see explanation in Section 3.3.5). This file is designated as EG154.

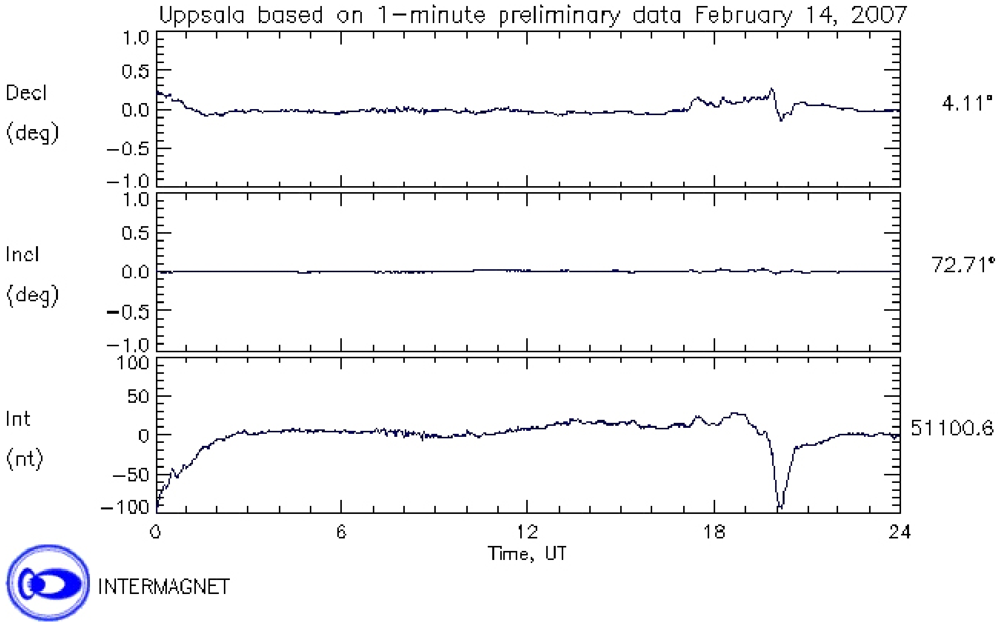


Figure 5-41. *Magnetic field variation during the Flexit-survey performed February 14th 2007 between13:40 and 17:10.*

Table 5-14. Activity data for the four deviation measurements excuted in KFM08D (from Sicada). The two magnetic measurements were used for calculation of the final borehole deviation file, whereas the two Maxibor measurements are error marked as they are not repeatable and the deviation differs significantely from the Flexit curves.

Activity Id	Activity Type code	Activity	Start date	Idcode	Secup (m)	Seclow (m)	F*
13148078	EG156	Maxibor-measurement	2007-02-08 02:00	KFM08D	0.00	924.00	ECF
13148079	EG156	Maxibor-measurement	2007-02-08 08:00	KFM08D	0.00	924.00	ECF
13148134	EG157	Magnetic – accel. m.	2007-02-14 13:40	KFM08D	3.00	936.00	CF
13148138	EG157	Magnetic – accel m.	2007-02-14 17:19	KFM08D	3.00	936.00	CF
13140514	EG154	Bh deviation multiple m.	2007-02-15 20:00	KFM08D			I C

* C = Comment, F = File, I = In-use flag, E = Error.

The EG154-activity specifies the deviation measurements used in the resulting calculation presented in Table 5-15. The upper values for bearing start at 66 m so that they should not be influenced by the 59 m steel casing (measurements by magnetic method). Since the inclination measurements are performed with accelerometer technique, the inclination values are not disturbed by the casing.

The calculated deviation (EG154-file) in borehole KFM08D shows that the borehole deviates upwards but almost straight with an absolute deviation of only 38 m compared to an imagined straight line following the dip and strike of the borehole start point (Figures 5-42 and 5-43). A subset of the resulting deviation file is presented in Table 5-16 and the estimated radius uncertainty is presented in Table 5-17. For explanation of "absolute deviation" and radius uncertainty, see Section 5.4.10.

Table 5-15. Contents of the EG154 file (multiple borehole deviation intervals).

Deviation activity Id	Deviation angle type	Approved secup (m)	Approved seclow (m)
13148134	Bearing	66.00	936.00
13148134	Inclination	3.00	936.00
13148138	Bearing	66.00	936.00
13148138	Inclination	3.00	936.00

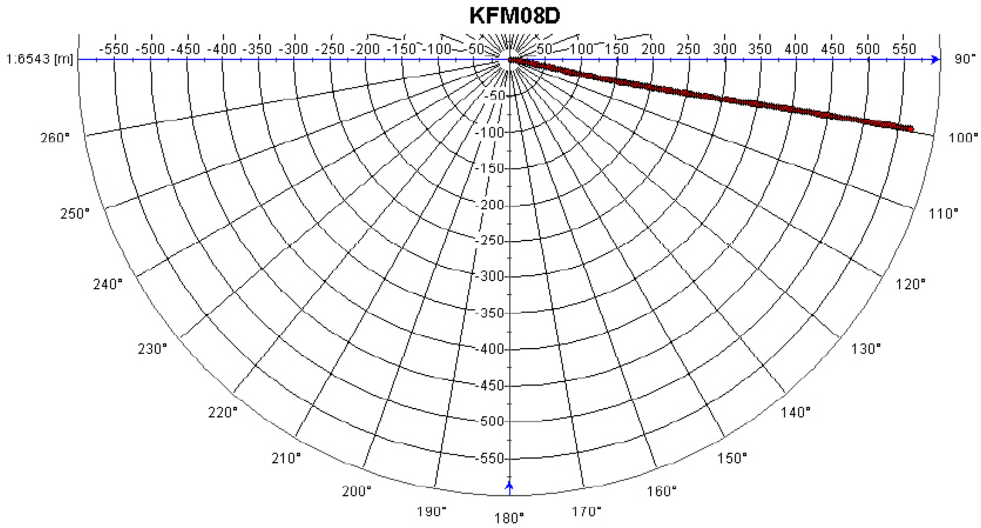


Figure 5-42. Horizontal projection of the in use-flagged deviation data from KFM08D (Flexit).

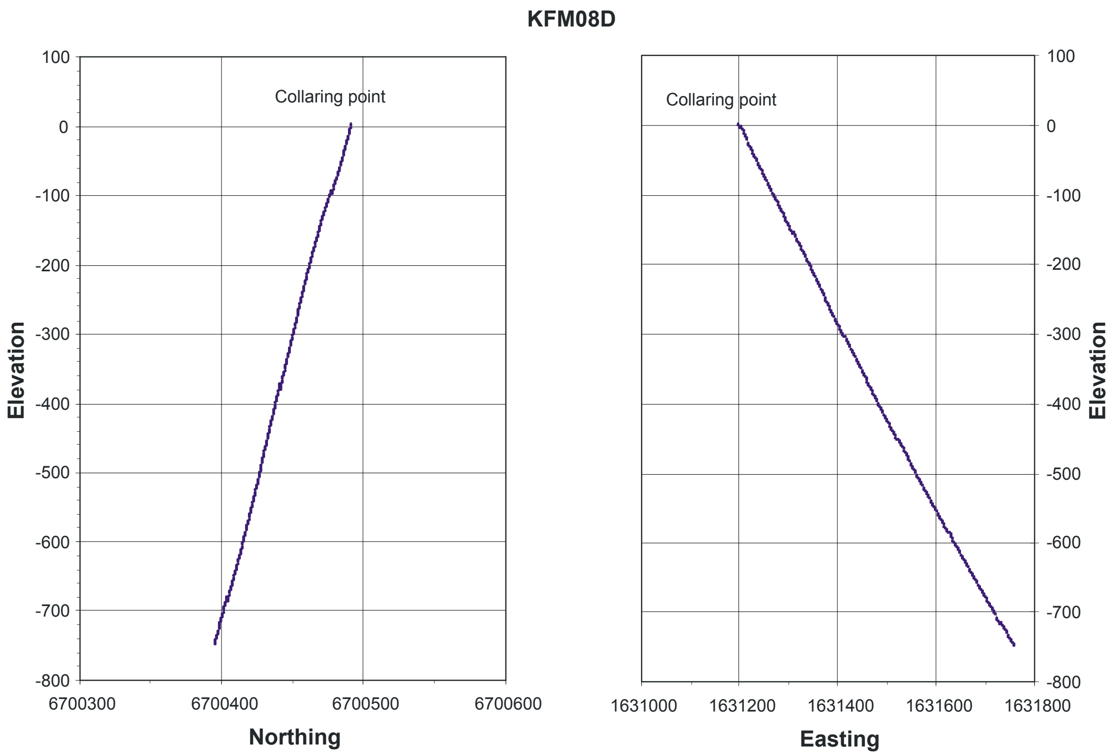


Figure 5-43. Two vertical projections of in use-flagged deviation data from KFM08D (Flexit).

Table 5-16. Deviation data from KFM08D for approximately every 100 m vertical length calculated from EG154.

Borehole	Length (m)	Northing (m)	Easting (m)	Elevation (m)	Inclination (degrees)	Bearing (degrees)
KFM08D	0	6700491.67	1631199.16	2.61	–55.19*	99.98
KFM08D	126	6700477.09	1631270.44	–100.25	–53.59	102.25
KFM08D	249	6700462.63	1631341.80	–199.37	–55.14	99.89
KFM08D	372	6700450.55	1631411.42	–300.05	–54.33	100.05
KFM08D	495	6700439.01	1631483.27	–399.21	–53.14	98.92
KFM08D	621	6700427.61	1631558.78	–499.43	–52.27	98.45
KFM08D	750	6700415.39	1631637.84	–600.63	–51.17	99.18
KFM08D	879	6700402.25	1631718.92	700.09	–49.80	99.08
KFM08D	942.30	6700395.77	1631759.45	–748.28	–49.27	98.89

* The starting values of inclination and bearing in EG154 are calculated, and may therefore show a discrepancy against the values seen in Borehole direction surveying (EG151), which are measured values.

Table 5-17. Uncertainty data for the deviation measurements in KFM08D for approximately every 100 m vertical length calculated from EG154.

Borehole	Length (m)	Northing (m)	Easting (m)	Elevation (m)	Inclination uncertainty	Bearing uncertainty	Radius uncertainty
KFM08D	0	6700491.67	1631199.16	2.61	0.03	0.6	0.00
KFM08D	126	6700477.09	1631270.44	–100.25	0.03	0.6	0.76
KFM08D	249	6700462.63	1631341.80	–199.37	0.03	0.6	1.52
KFM08D	372	6700450.55	1631411.42	–300.05	0.03	0.6	2.26
KFM08D	495	6700439.01	1631483.27	–399.21	0.03	0.6	3.03
KFM08D	621	6700427.61	1631558.78	–499.43	0.03	0.6	3.83
KFM08D	750	6700415.39	1631637.84	–600.63	0.03	0.6	4.66
KFM08D	879	6700402.25	1631718.92	700.09	0.03	0.6	5.53
KFM08D	942.30	6700395.77	1631759.45	–748.28	0.03	0.6	5.96

5.8.12 Groove milling

A compilation of length to the reference grooves and a comment on the success of detecting the grooves are given in Table 5-18. The positions of the grooves are determined from the length of the drilling pipes used at the milling process. The length is measured from the upper part of the upper two grooves. As can be seen, all milled grooves could be detected.

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

All length values used for measurements in the borehole and of the drill core originate from registrations of the length of the drill pipe string. However, such registrations involve a small error depending on the gravitational stretching of the pipe string when hanging freely and thus exposed to its own weight. When the pipe string is lowered to the borehole bottom, and the lifting force from the drill rig is set to zero, the pipe string will be resting on the borehole bottom and thus relieved from the previous load, and the stretching will cease. Instead, the load from the pipe string will now cause compression, and to some extent bending of it.

Table 5-18. Reference grooves in KFM08D.

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
100	Yes	Yes	550	Yes	Yes
150	Yes	Yes	600	Yes	Yes
200	Yes	Yes	650	Yes	Yes
250	Yes	Yes	700	Yes	Yes
300	Yes	Yes	750	Yes	Yes
350	Yes	Yes	800	Yes	Yes
400	Yes	Yes	850	Yes	Yes
450	Yes	Yes	900	Yes	Yes
501	Yes	Yes			

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 5-44, which is based on load tests performed in the laboratory by the manufacturer of the drill pipes.

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

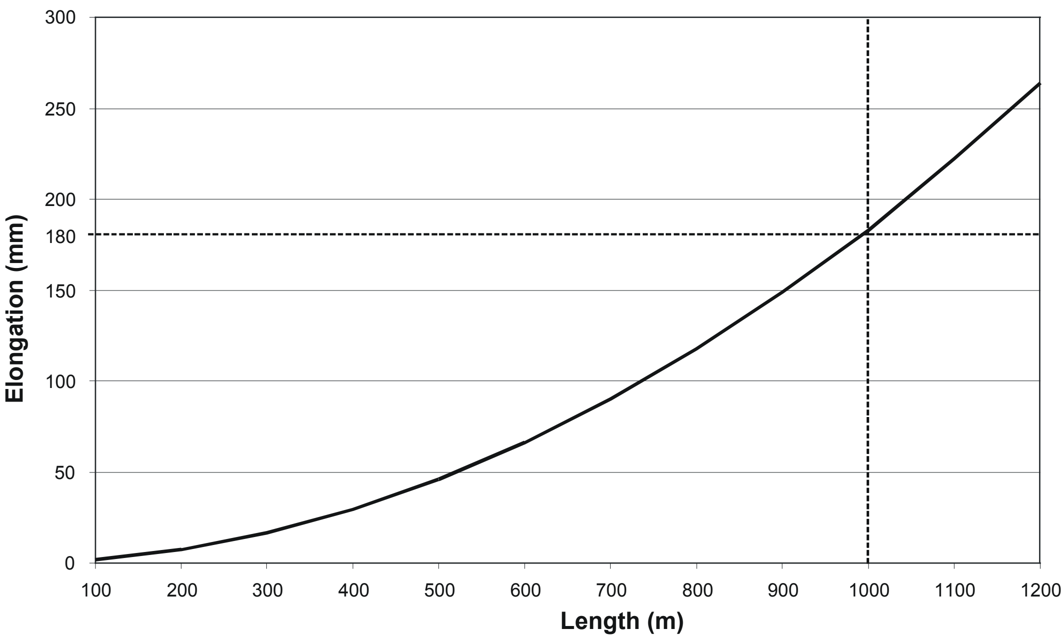


Figure 5-44. *The diagram illustrates the elongation of the WL-76 drill pipe string when hanging in a vertical water filled borehole. Values from laboratory load tests of the drill pipes.*

5.8.14 Consumables

The amount of oil products consumed during drilling of the percussion drilled part of KFM08D (0–60 m), grease, oil and diesel used during core drilling, and grout used for gap injections of the respective casings are reported in Tables 5-19, 5-20 and 5-21, respectively. Regarding hammer oil and compressor oil, these products are indeed entering the borehole but are, on the other hand, continuously retrieved from the borehole due to the permanent air flushing during drilling. After completion of drilling, only minor remainders of the products are left in the borehole.

The special type of thread grease (silicon based) used during core drilling in this particular borehole was certified according to SKB MD 600.006 (Table 1-1). The experience from a technical point of view of the grease is not fully satisfactory. Although expensive, the grease has a low adhesion capacity to the threads, and the lubrication characteristics are not as favorable as for conventional lubricants.

5.8.15 Recovery measurements after cleaning by air-lift pumping

The final cleaning of KFM08D by air-lift pumping caused a draw-down of 5 m. After completed pumping, the recovery of the groundwater table was monitored. The results are displayed in the diagram of Figure 5-45. Pressure registration was proceeding during 2 hours, and the water-yielding capacity could be determined from the diagram. An inflow of > 60 L/min at a drawdown of 5 m was estimated.

Table 5-19. Oil consumption during percussion drilling of KFM08D.

Borehole ID	Hammer oil Preem Hydra 46	Compressor oil Schuman 46
KFM08D	Estimated to 10 L	No consumption measured

Table 5-20. Grease, oil and diesel consumption during core drilling of KFM08D.

Borehole ID	Thread grease Üni Silikon L50/2	Grease for the drilling machine Statoil AB	Engine oil Castrol Tection 15W–40	Gear box oil	Hydraulic oil Premium ECO HT-E 46	Diesel engines OKQ8 Diesel miljöklass 1
KFM08D	5.6 kg	2.5 kg	12 L	7 L	70 L	13,800 L

Table 5-21. Cement consumption for grouting the percussion drilled part of KFM08D and for sealing the gap between the casing and the reamed borehole wall.

Borehole ID	Length (m)	Cement weight/volume Aalborg Portland Cement/microsilica	Grouting method
KFM08D	12–59.04	1,404 kg/1,560 L	Gap injection using a packer
KFM08D	0.3–2.8	108 kg/120 L	Hose

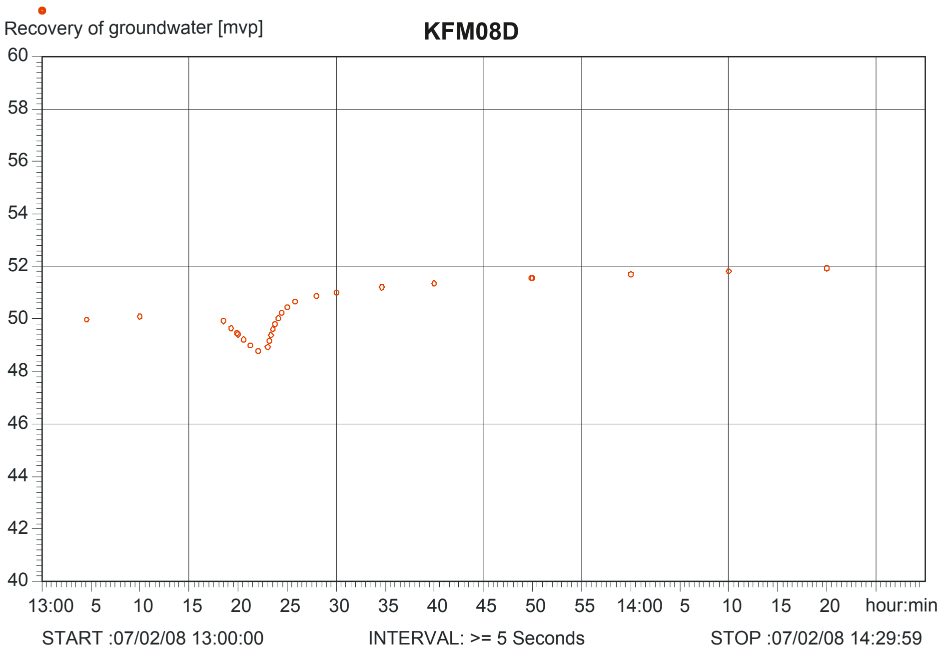


Figure 5-45. *Recovery of groundwater table in section 0–942.30 m of KFM08D after stop of air-lift pumping.*

6 References

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Well Cad-plot of the percussion drilled part of borehole KFM08C

Title PERCUSSION DRILLED BOREHOLE KFM08C

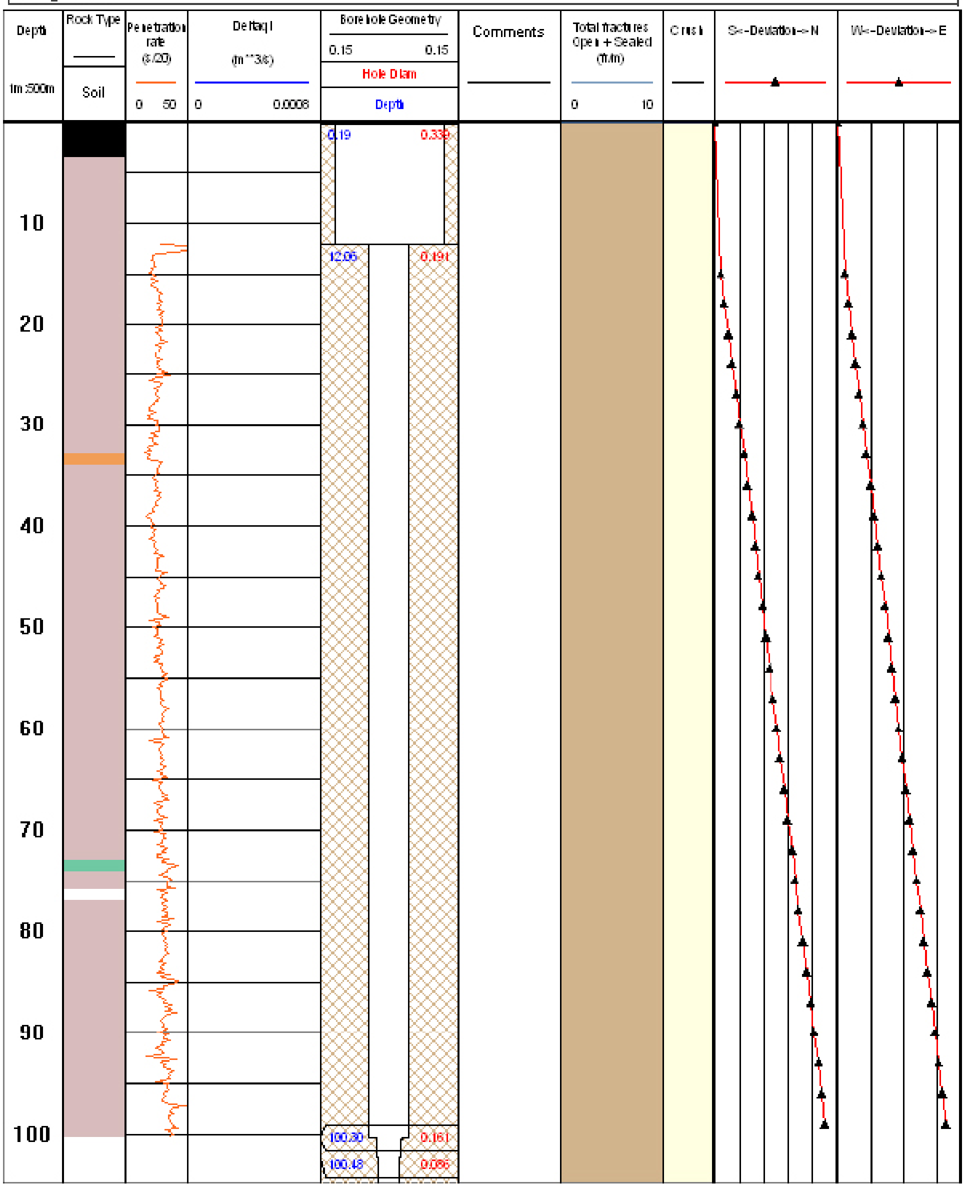
Svensk Kärnbränslehantering AB

Site	FORSMARK	**Signed data**	
Borehole	KFM08C	**Coordinate System**	RT90-RHB70
Diameter [mm]	191.3	**Northing [m]**	6700495.88
Length [m]	100.44	**Easting [m]**	1631187.57
Bearing [°]	35.88	**Elevation [m.a.s.l.]**	2.47
Inclination [°]	-60.46	**Drilling Start Date**	2005-04-14 09:00:00
Date of mapping		**Drilling Stop Date**	2005-04-26 15:00:00
		Plot Date	2006-09-10 21:10:33

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

SOIL
- Soil

Script Name



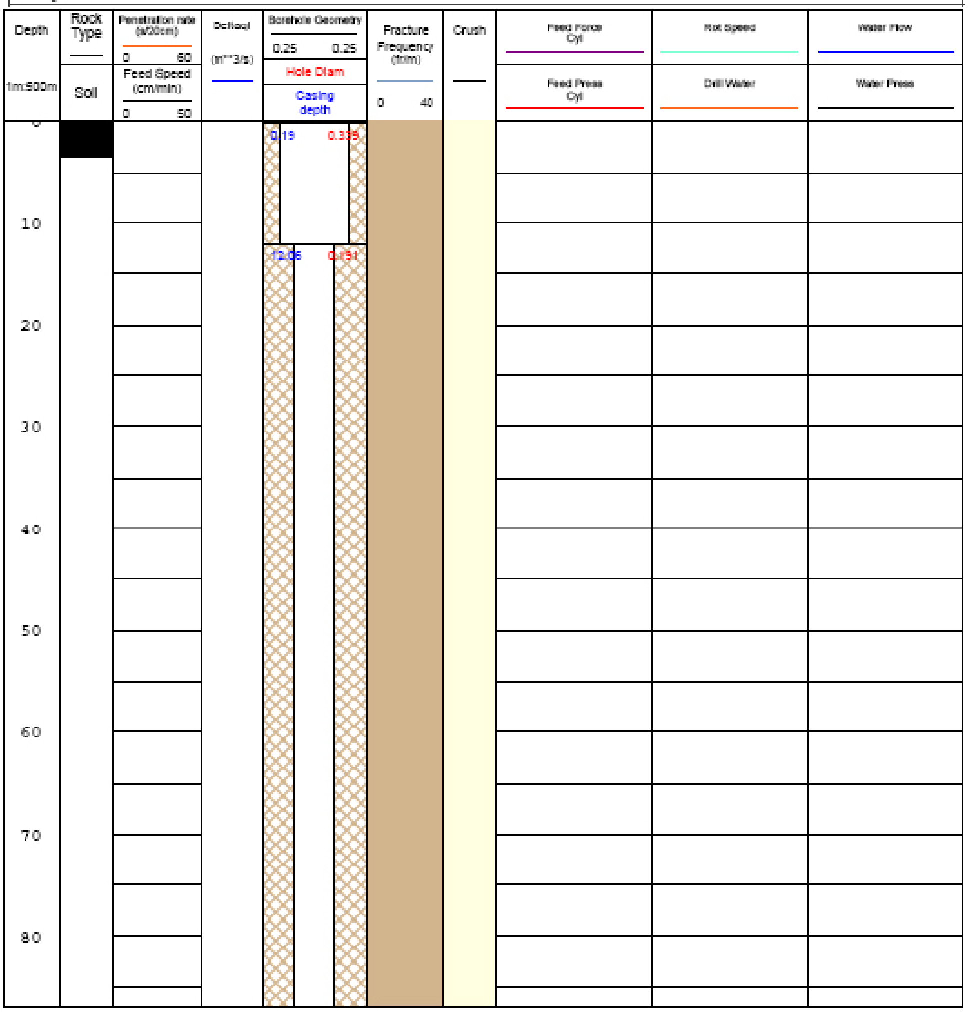
Well Cad-plot of the complete (percussion drilled and core drilled) borehole KFM08C

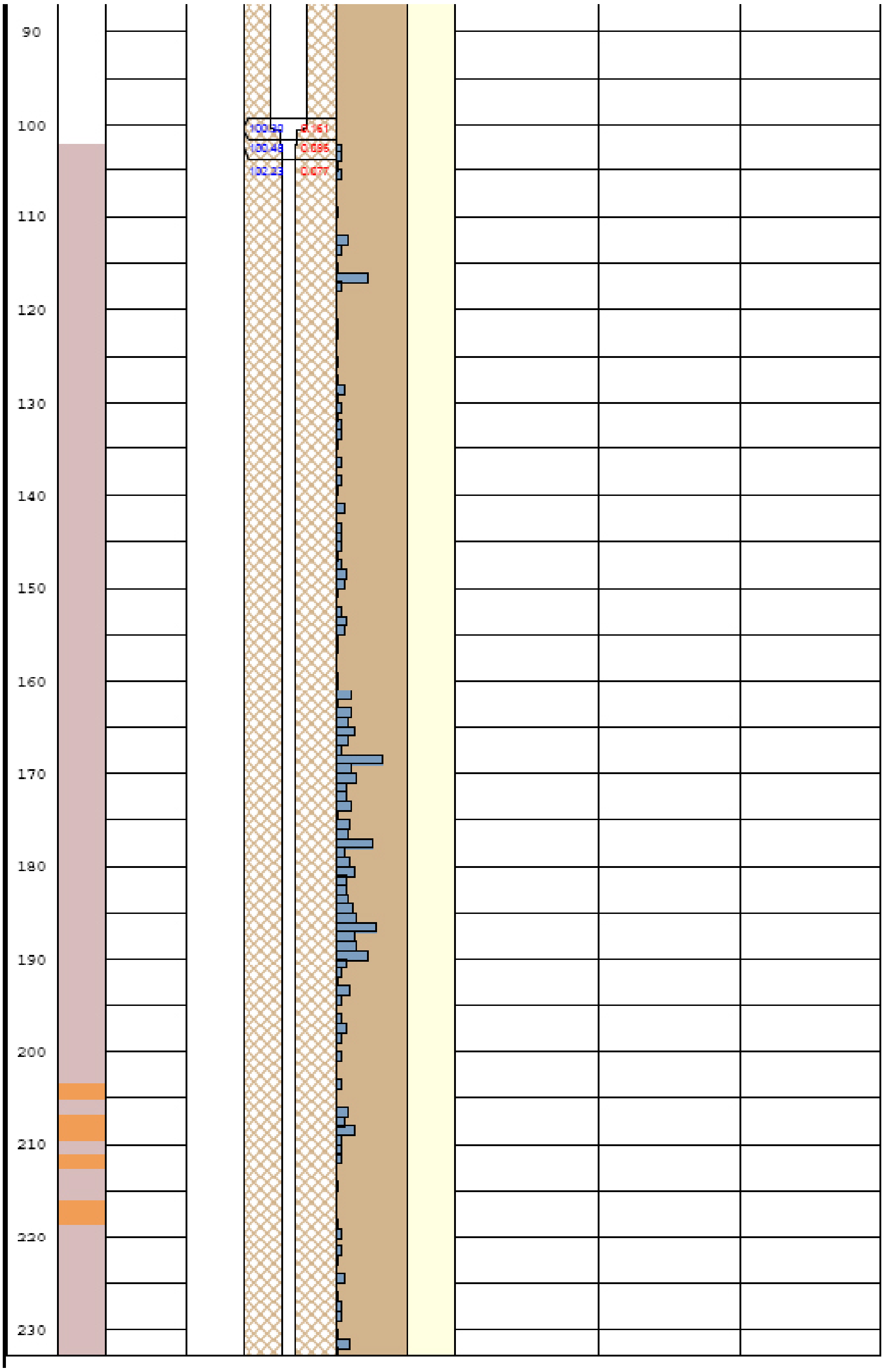
Title	KFM08C		
Svensk Kärnbränslehantering AB		Signed data	
Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	KFM08C	Northing [m]	6700495.88
Diameter [mm]	77	Easting [m]	1631187.57
Length [m]	951.08	Elevation [m.a.s.l.]	2.47
Bearing [°]	35.88	Drilling Start Date	2005-04-14 09:00:00
Inclination [°]	-60.46	Drilling Stop Date	2006-05-09 15:00:00
Date of mapping		Plot Date	2006-09-10 21:10:33

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

SOIL
- Soil

Script Name

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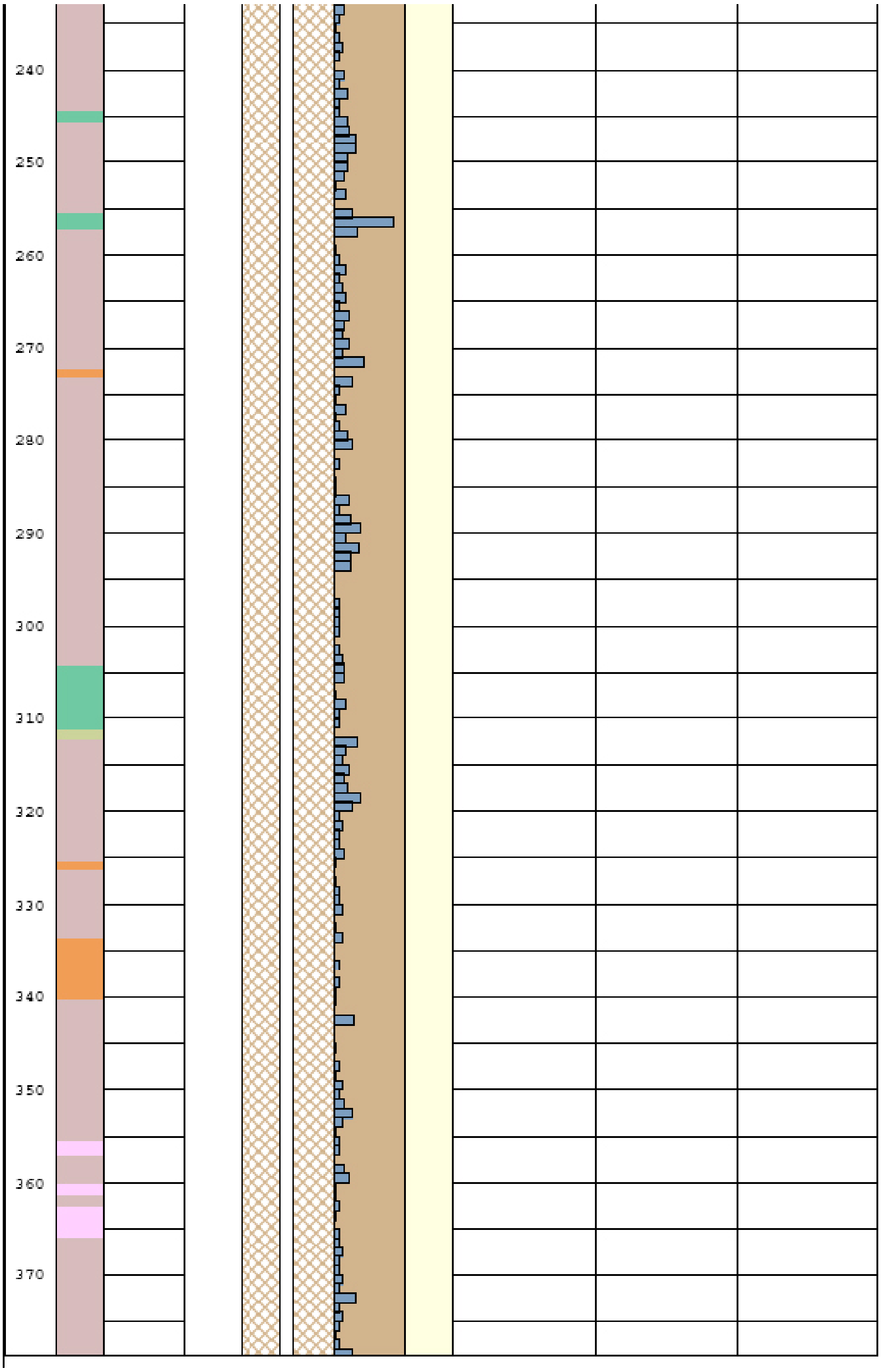
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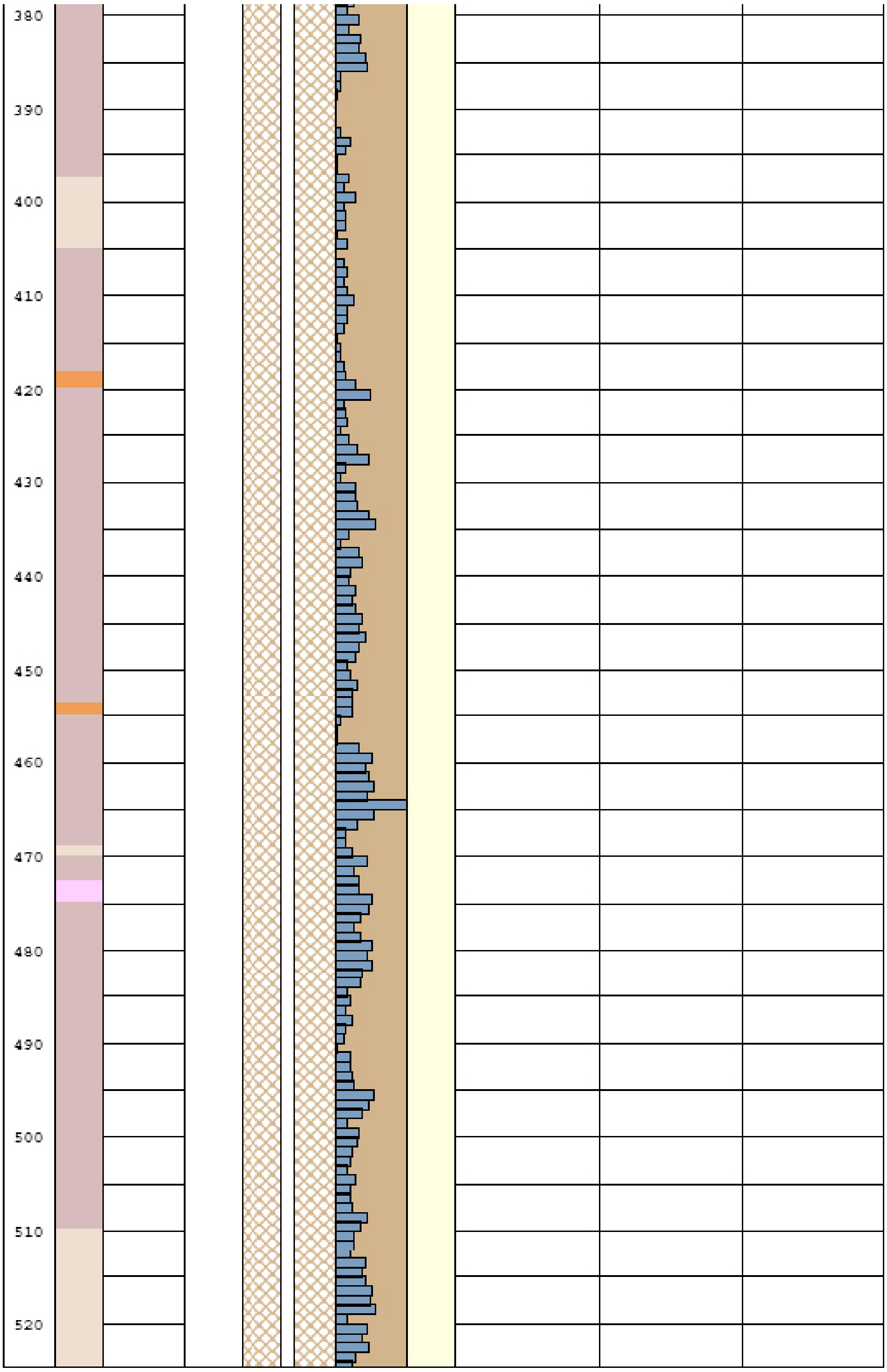
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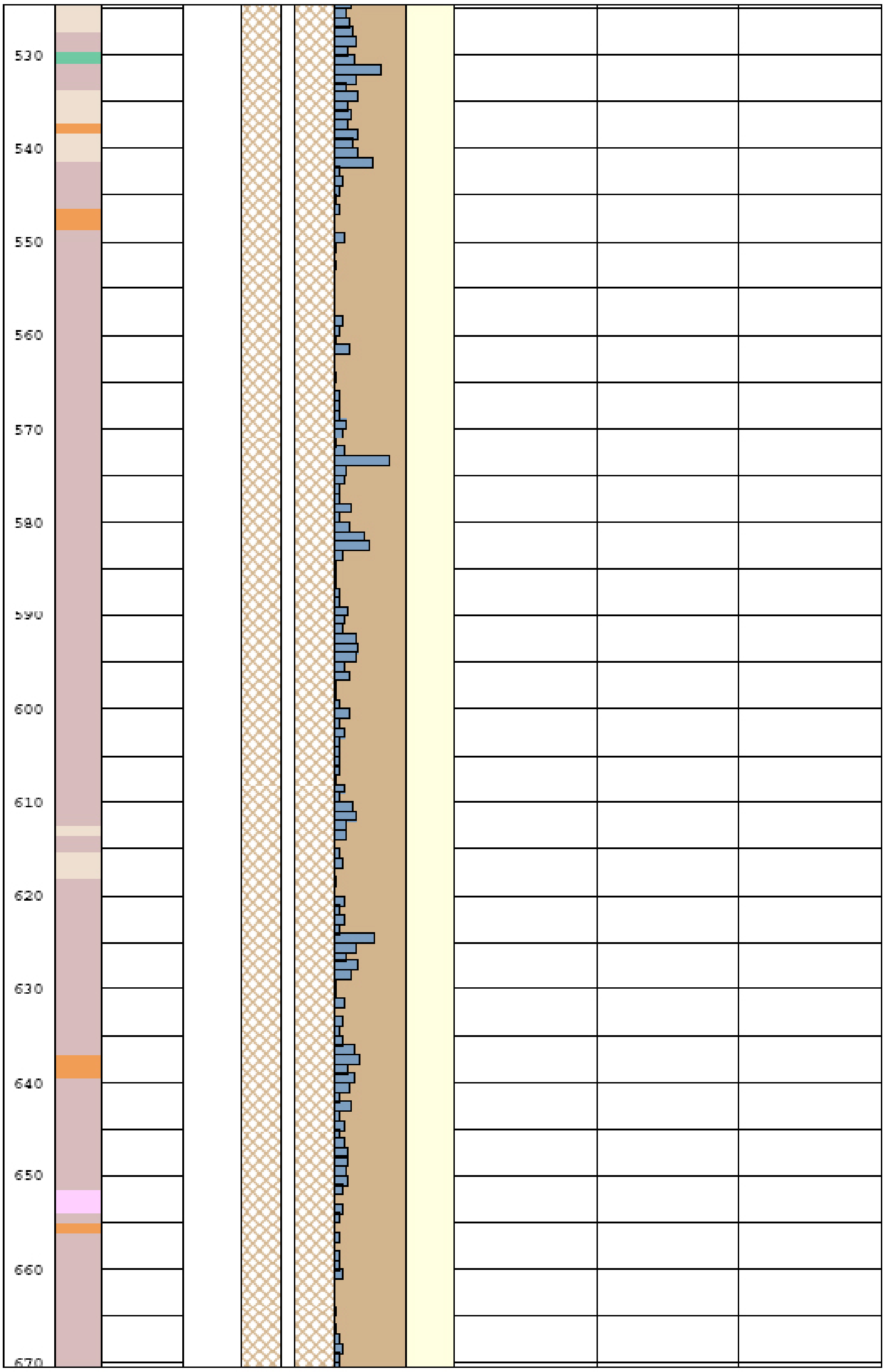
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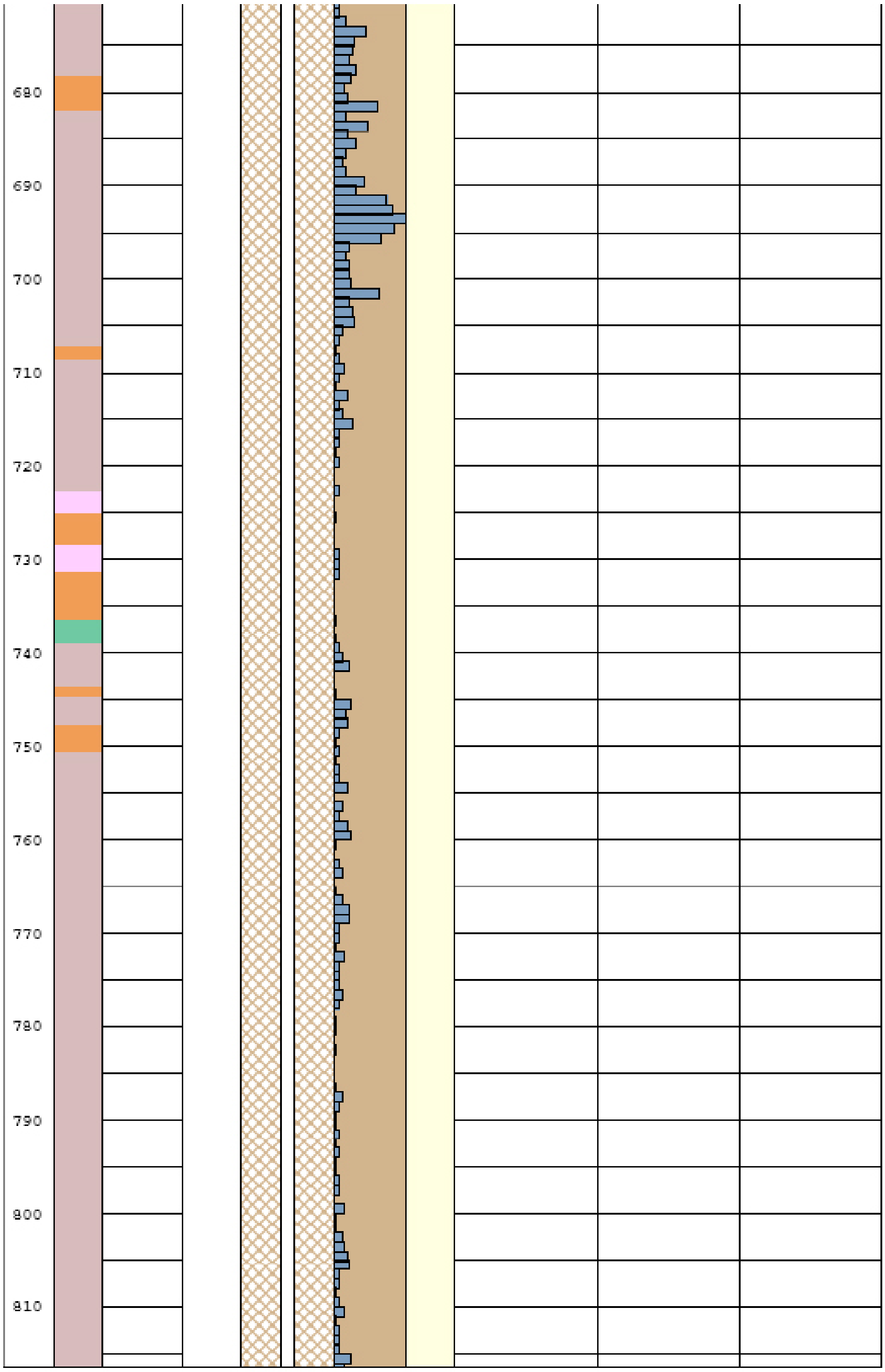

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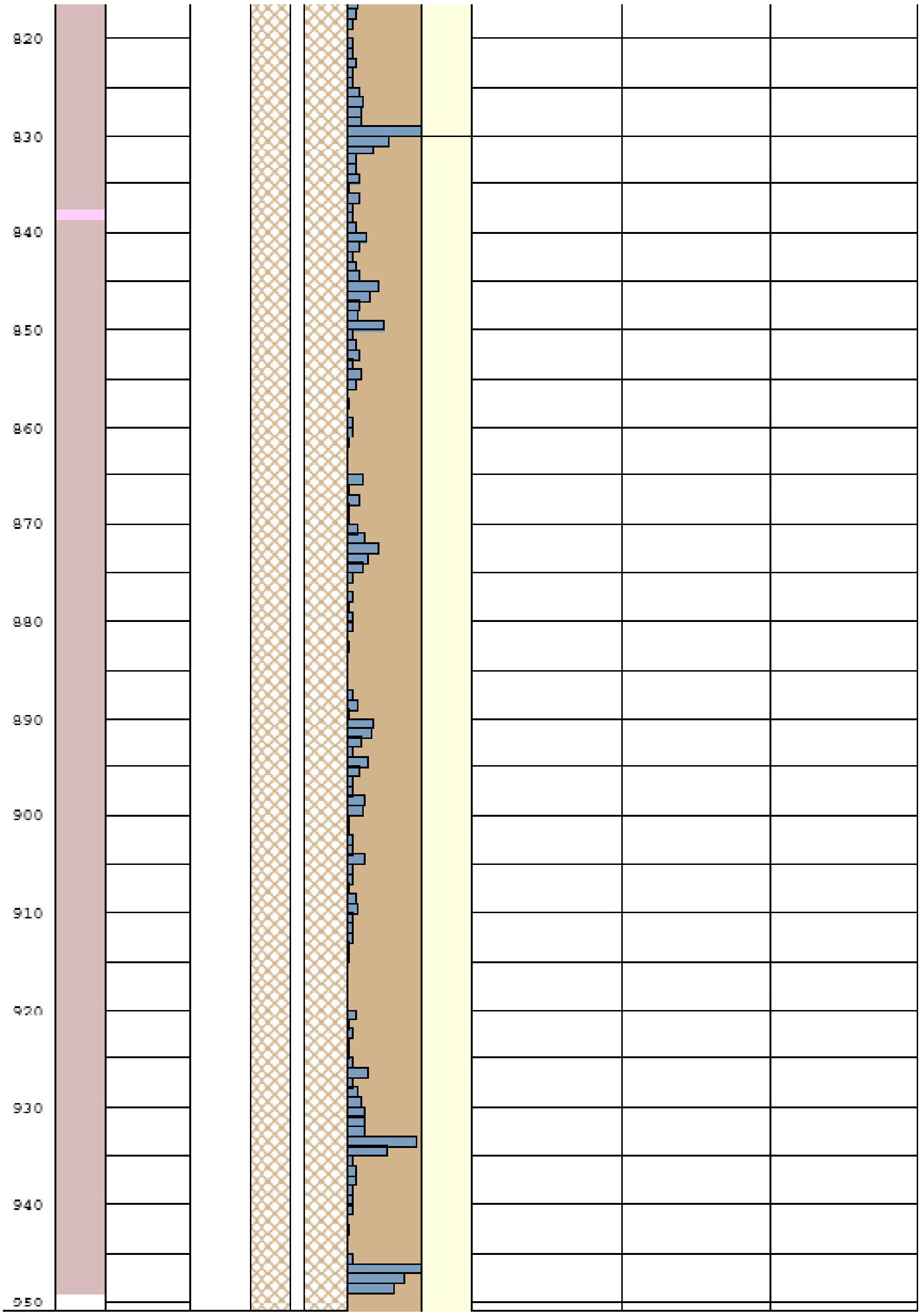
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Chemical analyses from flushing water from HFM22 during drilling of KFM08C

Date	IDCODE	Sample No.	Charge Bal%	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO_3^- mg/L	Cl^- mg/L	SO_4^{2-} mg/L	SO4_S mg/L	Br mg/l	F^- mg/L	Si mg/L	Li mg/L	Sr mg/L	I mg/L	TOC mg/L	pH	ElCond mS/m
2006-02-13	HFM22	12076	-3.8	1240	33.5	407	108	236	2800	339	123	10.1	1.55	7.13	0.04	2.47	0.031	4.7	7.50	893
2006-03-14	HFM22	12217	-2.6	1170	32.5	365	98.4	261	2500	311	116	9.5	1.61	6.93	0.039	2.21	<0.01	5.1	6.96	809

Date	IDCODE	Sample No.	δ^2H ‰ SMOW	^3H TU	$\delta^{18}O$ ‰ SMOW	^{14}C pmC	$\delta^{13}C$ ‰ PDB	$^{10}B/^{11}B$ no unit	$\delta^{34}S$ ‰ CDT	$^{87}Sr/^{86}Sr$ no unit	$\delta^{37}Cl$ ‰ SMOC
2006-02-13	HFM22	12076	-70.9	1.9	-9.4	22.91	-6.87	0.2367	24.5	0.722691	-0.06
2006-03-14	HFM22	12217	-71	3.2	-9.5	28.08	-6.99	0.2405	23.0	0.722712	0.08

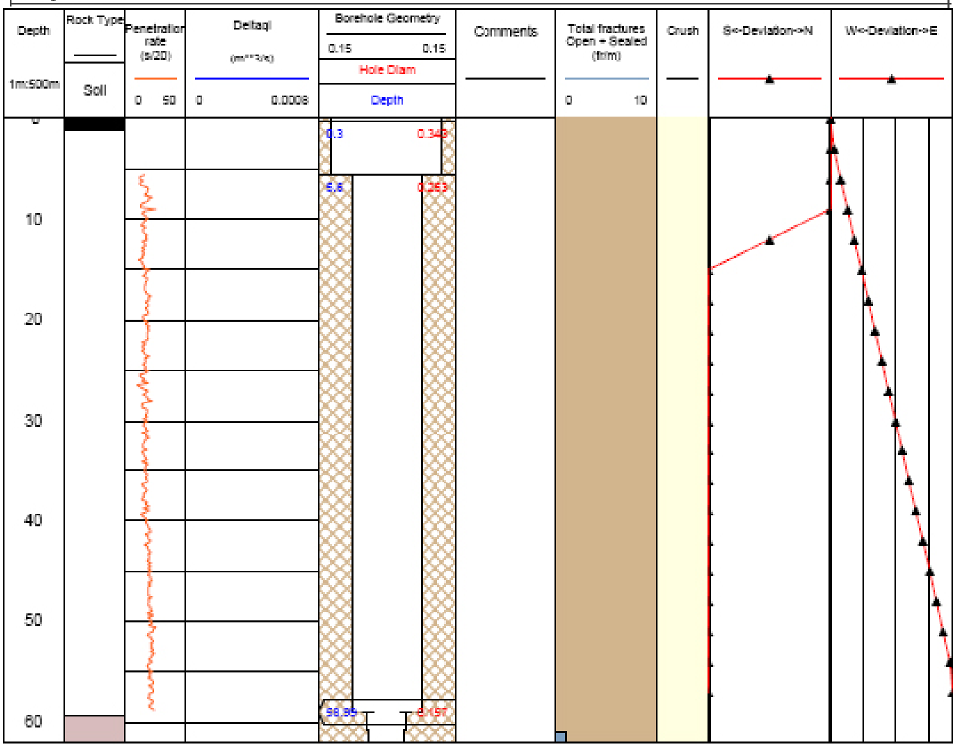
Well Cad-plot of the percussion drilled part of borehole KFM08D

Title	PERCUSSION DRILLED BOREHOLE KFM08D		
Svensk Kärnbränslehantering AB		Signed data	
Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	KFM08D	Northing [m]	6700491.68
Diameter [mm]	253	Easting [m]	1631199.16
Length [m]	59.04	Elevation [m.a.s.l.]	2.61
Bearing [°]	99.98	Drilling Start Date	2006-11-23 09:00:00
Inclination [°]	-55.00	Drilling Stop Date	2006-12-04 12:00:00
Date of mapping		Plot Date	2007-06-04 23:15:37

ROCKTYPE
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Diorite, quarts diorite and gabbro, metamorphic
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

SOIL
- Soil

Script Name



Well Cad-plot of the complete (percussion drilled and core drilled) borehole KFM08D

Title KFM08D

Svensk Kärnbränslehantering AB

Site	FORSMARK	Signed data	
Borehole	KFM08D	Coordinate System	RT90-RHB70
Diameter [mm]	77	Northing [m]	6700491.68
Length [m]	942.30	Easting [m]	1631199.16
Bearing [°]	99.98	Elevation [m.a.s.l.]	2.61
Inclination [°]	-55.00	Drilling Start Date	2006-11-22 09:00:00
Date of mapping		Drilling Stop Date	2007-02-10 12:00:00
		Plot Date	2007-06-04 23:15:37

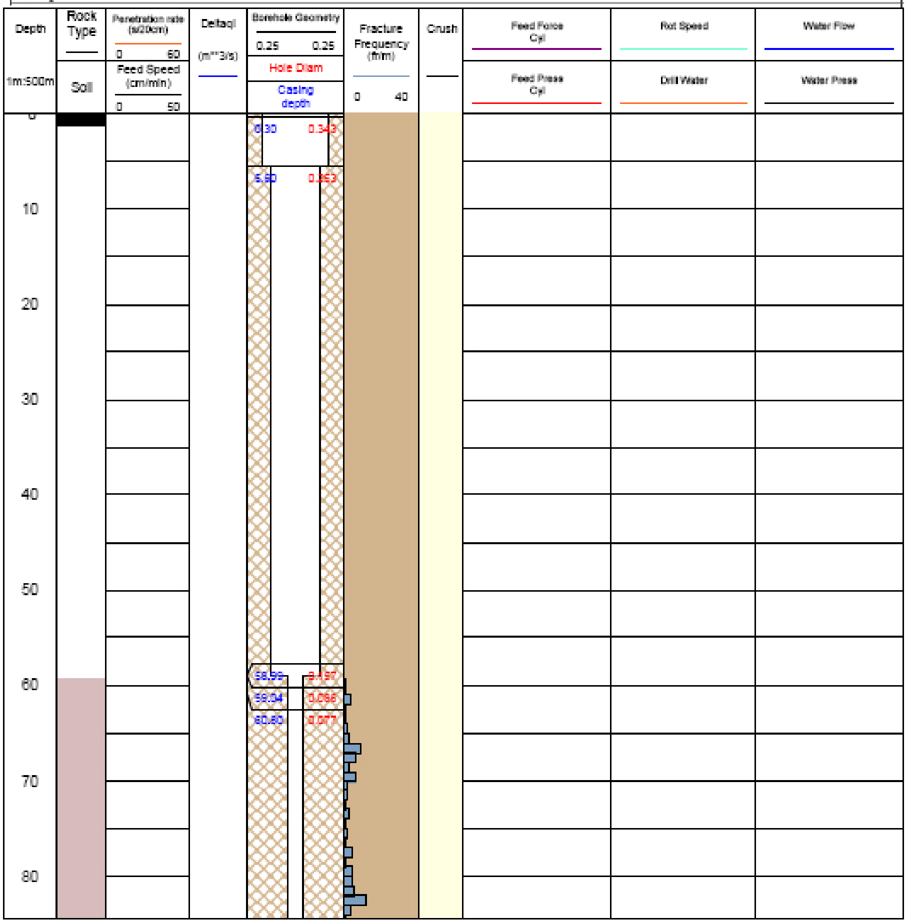
ROCKTYPE FORSMARK

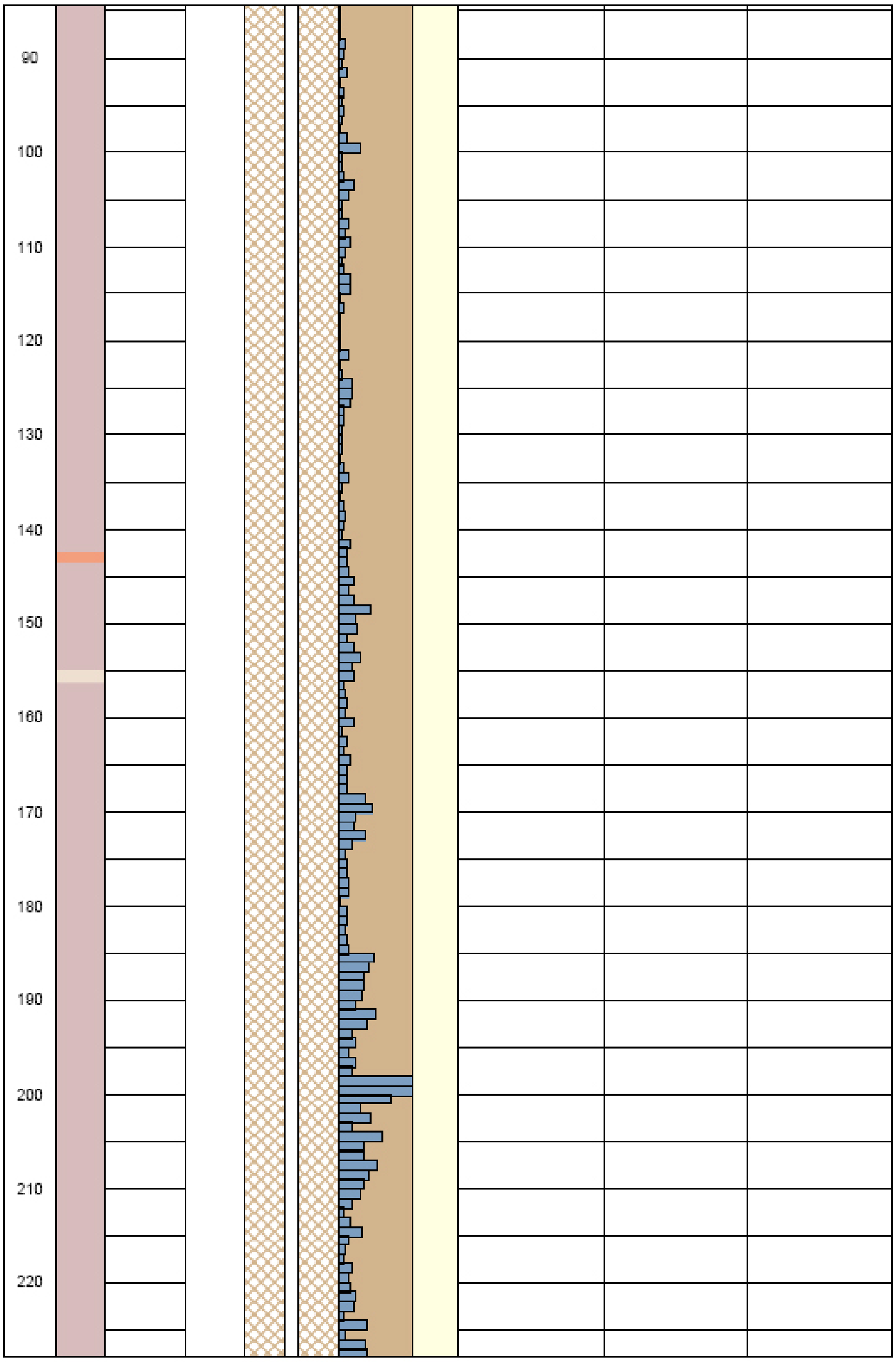
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Diorite, quartz diorite and gabbro, metamorphic
- Amphibolite
- Felsic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

SOIL

- Soil

Script Name

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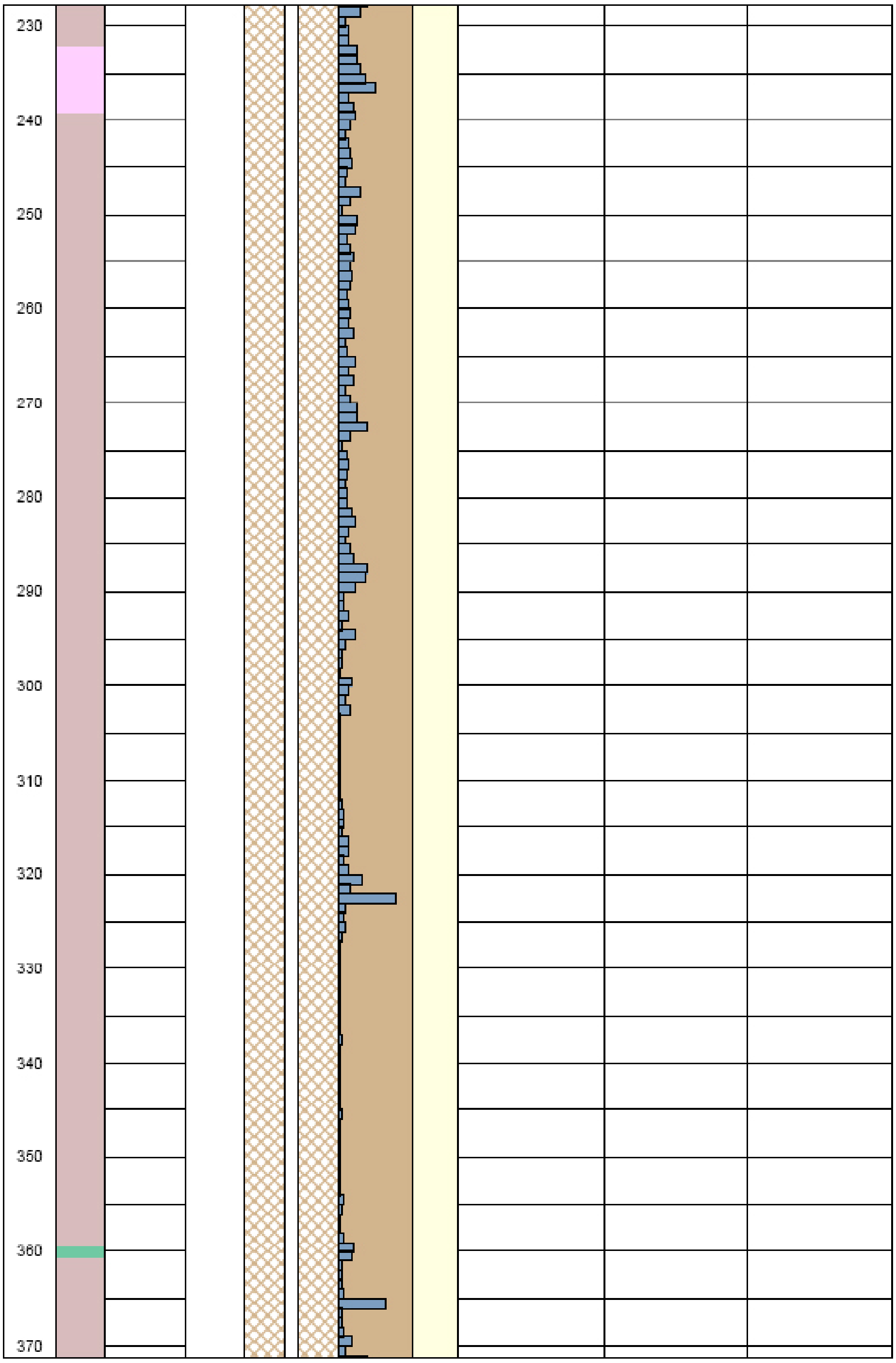
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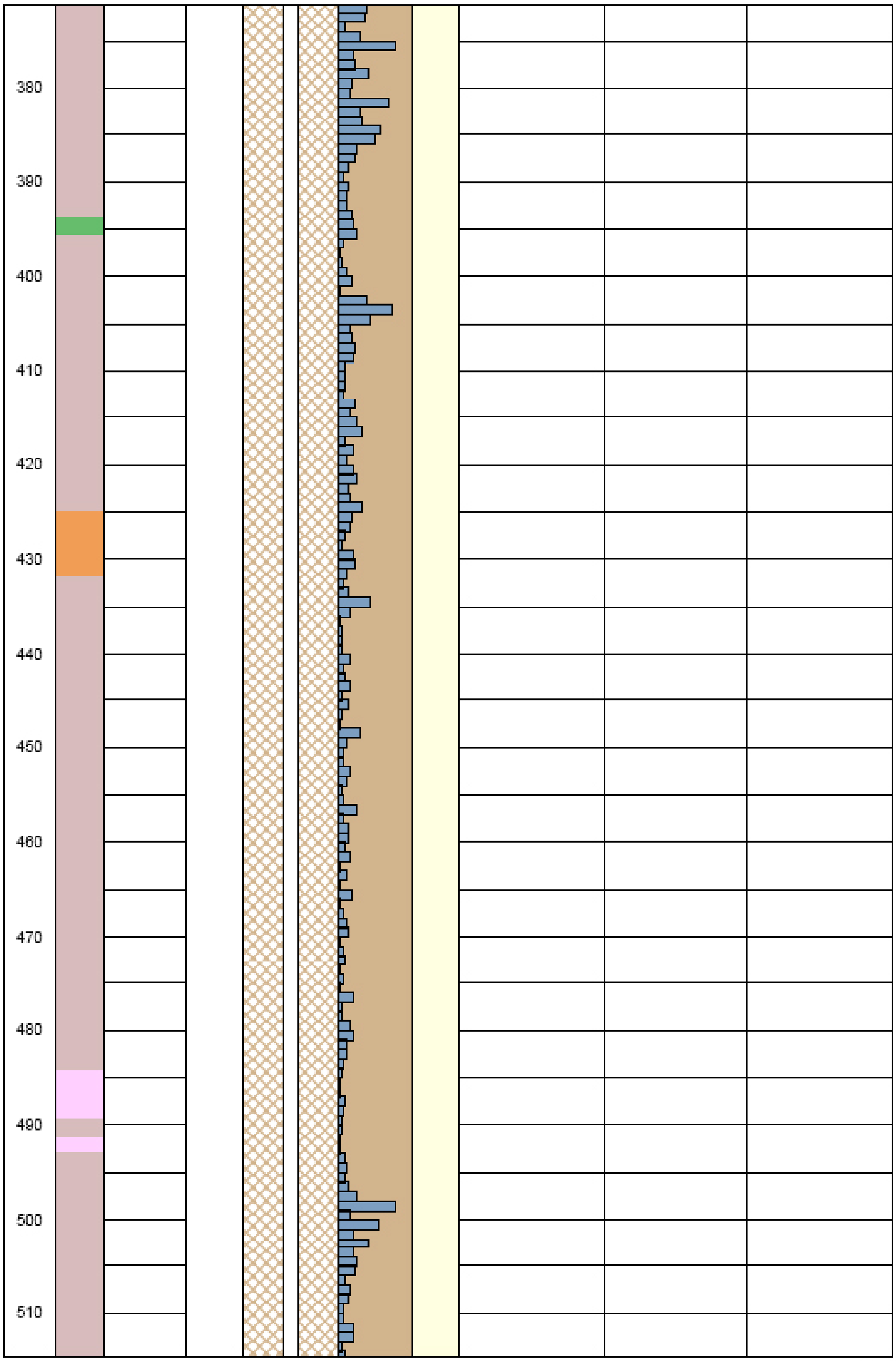
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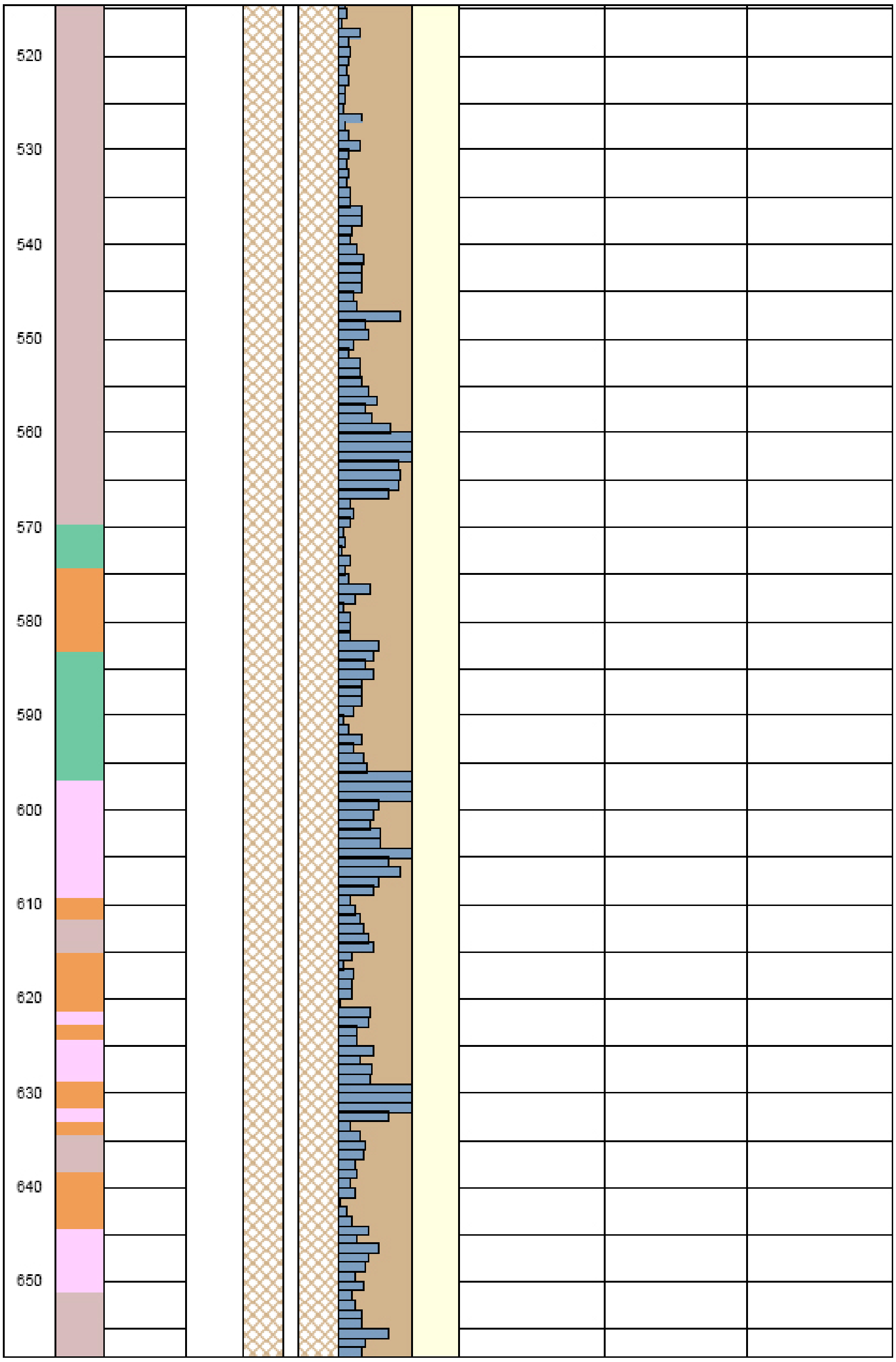
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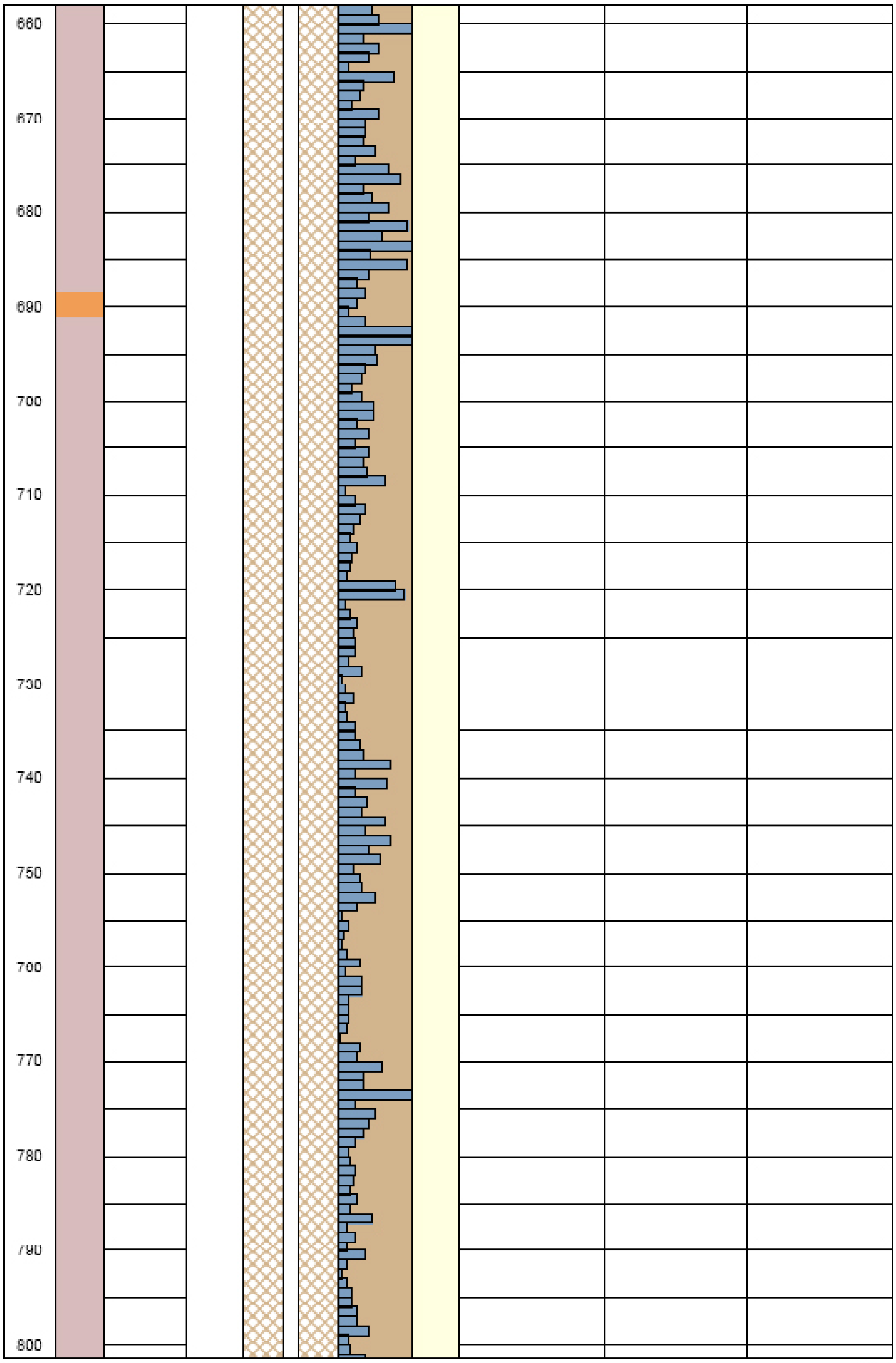
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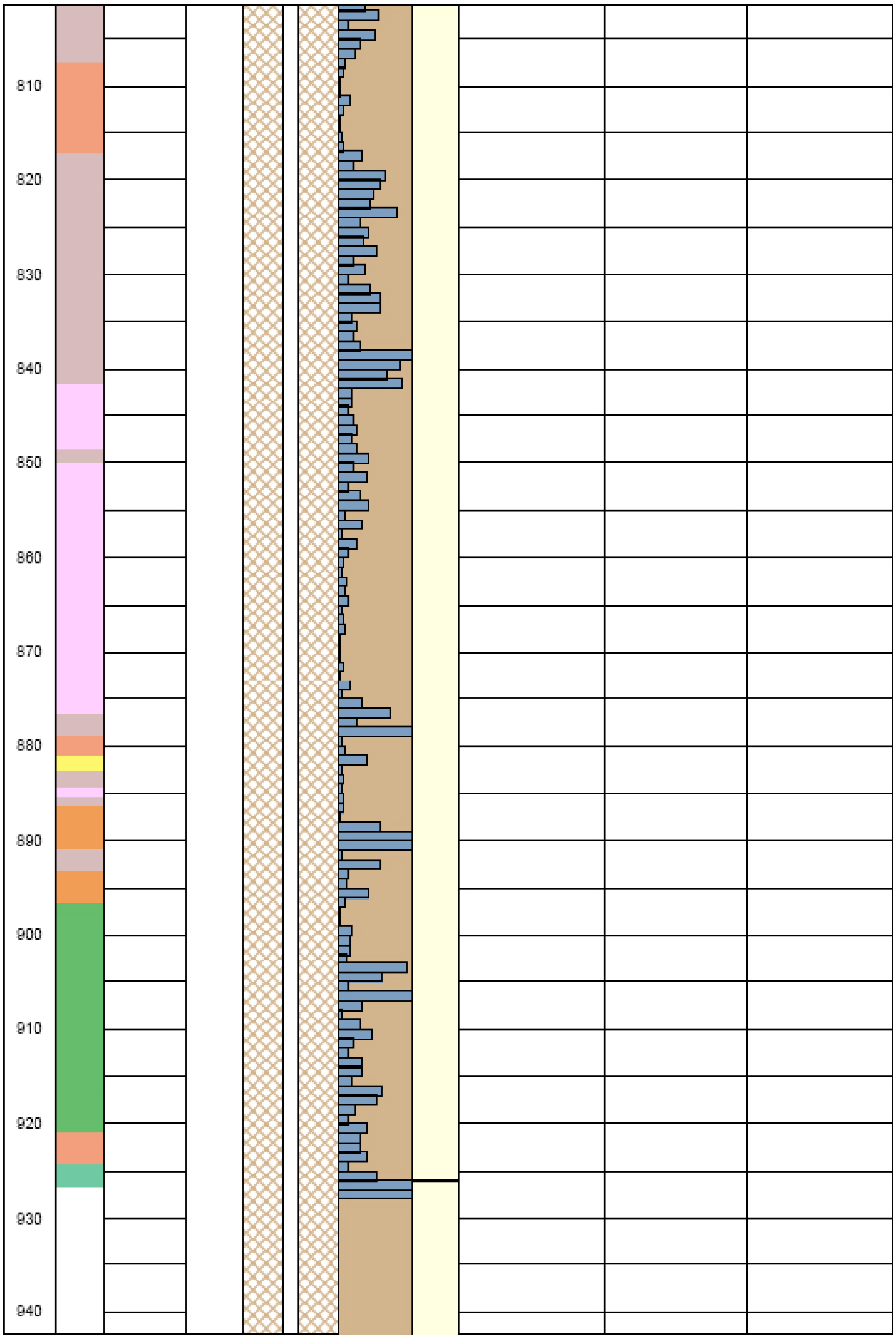
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Appendix F

Chemical analyses from flushing water from HFM22 during drilling of KFM08D

Date	IDCODE	Sample No.	Charge Bal%	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO_3^- mg/L	Cl^- mg/L	SO_4^{2-} mg/L	SO4_S mg/L	Br mg/l	F^- mg/L	Si mg/L	Li mg/L	Sr mg/L	TOC mg/L	pH	ElCond mS/m
2007-01-24	HFM22	12562	-5.4	1090	36.7	401	114	250	2660	324	118	9.88	1.65	7.01	0.043	2.43	5.1	7.57	859

Date	IDCODE	Sample No.	δ^2H ‰ SMOW	^3H TU	$\delta^{18}O$ ‰ SMOW	^{14}C pmC	$\delta^{13}C$ ‰ PDB	$^{10}B/^{11}B$ no unit	$\delta^{34}S$ ‰ CDT	$^{87}Sr/^{86}Sr$ no unit	$\delta^{37}Cl$ ‰ SMOC
2007-01-24	HFM22	12562	-70.8	A	-9.3	A	-6.19	0.2432	23.8	0.723229	A

A = results will be reported later.