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Drilling of the telescopic borehole KFR102A

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Abstract

One of the six cored boreholes included in the investigation programme for the SFR Extension project, KFR102A, is designed and drilled in order to assure high-class hydrogeochemical samples below repository depth. Performance of and results from drilling and measurements during drilling of borehole KFR102A are presented in this report.

KFR102A, which is designed as a so called telescopic borehole of SKB chemistry type, is 600.83 m long and is at its starting point inclined 65.43° from the horizon. The borehole reaches about 263 m in horizontal distance from the collar and approximately 537 m in vertical depth.

During pilot drilling of the percussion drilled section 0–70.42 m with the diameter 165.0 mm, an accumulated groundwater inflow of 40 L/min was recorded for the total borehole length. After reaming this section to Ø 246.5 mm, the percussion drilled, "telescopic" 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 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 discharged to an approved recipient. During drilling, a number of technical and flushing water/return water parameters are registered in order to obtain a good control of the drilling process and to permit an estimation of the impact on the rock aquifer penetrated by the borehole of flushing water and drilling debris.

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 and the samples of drill cuttings, together with later produced video images of the borehole wall (so called BIPS-images), were used for so called Boremap mapping of the borehole performed after drilling. A diagram of the Boremap mapping results is included in this report.

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

Sammanfattning

Ett av de sex borrhål, KFR102A, som ingår i undersökningsprogrammet för borrning från markytan inom Projekt SFR-utbyggnad har utförts speciellt i syfte att säkerställa så ostörda grundvattenkemiska förhållanden som möjligt vid grundvattenprovtagning under förvarsdjup. Utförandet och resultaten från borrningen och mätningar under borrning av borrhål KFR102A presenteras i denna rapport. Borrhålet, som är utfört med teleskopborrningsteknik och är av s k SKB kemityp, är ansatt med en lutning av 65,41° från horisontalplanet, är 600,83 m långt, når cirka 263 m i horisontell riktning från påslagspunkten, och har ett vertikaldjup på ca 537 m.

Vid hammarborrning av avsnittet 0–70,42 m med diametern 165,0 mm uppmättes ett totalt inflöde av ca 40 L/min för hela hålets längd. För att stabilisera borrhålet upprymdes det till Ø 246,5 mm. Därefter kläddes det in med rostfritt foderrör och slutligen cementinjekterades spalten mellan borrhålsvägg och foderrör, så att allt vatteninflöde i den hammarborrade delen av teleskopborrhålet upphörde.

Under kärnborrningsfasen vid utförandet av teleskopborrhål används ett relativt komplicerat spol- och returvattensystem, där spolvattnet prepareras i olika moment före användning. Returvattnet leds till ett system av containrar, där borrkaxet sedimenterar i två 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 grund–vattenakvifären i anslutning till borrhålet utsätts för.

Ett mät- och provtagningsprogram för hammarborrningen och ett annat program för kärn–borrningen gav preliminär information om borrhålets geologiska och hydrauliska karaktär direkt under pågående borrning samt underlag för fördjupade analyser efter borrning. Bland de in–samlade proverna utgör borrkärnorna från den kärnborrade delen av borrhålet och borrkax–proverna från den hammarborrade delen, tillsammans med videofilm av borrhålsväggen (s.k. BIPS-bilder), underlaget för den borrhålskartering (s k Boremap-kartering) som utförs efter borrning. Ett resultatdiagram från Boremapkarteringen av KFR102A finns redovisad i denna rapport.

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

Contents

1 Introduction

The Swedish Nuclear Fuel and Waste Management Co (SKB) is since the mid 80-ies running the underground final repository for low- and medium level radioactive operational waste (SFR) at Forsmark within the Östhammar municipality, see Figure 1-1. Since April 2008, SKB conducts bedrock investigations for a future extension of the repository. The extension project, in Swedish termed ”Projekt SFR-utbyggnad” (Project SFR Extension), is organized into a number of sub-projects, of which geoscientific investigations are included in one sub-project, ”Projekt SFR-utbyggnad – Undersökningar” (Project SFR Extension – Investigations).

The geoscientific investigations for the planned extension of SFR are performed in compliance with an investigation programme /1/. Experience and data from the construction of the existing SFR facility in the 1980-ies served as important input for the programme. Further, the recently completed comprehensive site investigations for a final repository for spent nuclear high-level waste at Forsmark (controlled by a general investigation programme, /2/), provided a vast amount of data about the sub-surface realm down to about 1,000 m in the immediate vicinity of, and even overlapping, the SFR-area. Data and experiences also from these investigations have strongly influenced the elaboration of investigation strategies for the current SFR-investigation programme.

Figure 1-1. *General overview over Forsmark and the SFR site investigation area.*

For direct sub-surface investigations, drilling is an inevitable activity. Providing investigation boreholes is especially vital in the SFR-project, because the major part of the rock volume to be investigated is covered by the Baltic Sea, thereby rendering ground geophysical measurements and other surface-based investigations more difficult than at land. Two main types of boreholes will be produced within the scope of the site investigations, core drilled- and percussion drilled boreholes, respectively. For the initial phase of the investigations five percussion boreholes and five cored boreholes drilled from the ground surface and one cored borehole drilled underground from the SFR facility have been suggested /1/. However, recent assessments of the investigation results obtained so far indicate that two of the percussion boreholes, HFR103 and HFR104, may not need to be drilled in order to obtain the objectives of the site investigation.

This document reports the data and results gained by drilling the telescopic borehole KFR102A which constitutes the initial investigation phase of Project SFR Extension (SFR Utbyggnad) programme. The percussion- and core drilling operations were carried out in accordance with activity plan AP SFR-08-011. Controlling documents for performing this activity are listed in Table 1-1. Both activity plans and method descriptions are SKB's internal controlling documents.

New drill sites for five cored boreholes were built on the pier at Asphällskulten during the spring 2008, see Figure 1-2. In addition, an old borehole drilled 1981, KFR27, was rediscovered, although the borehole casing was covered with gravel of one metre thickness below ground surface. A minor drill site was prepared also around this borehole, and the borehole was restored, prolonged and used for measurements within the scope of Project SFR Extension.

Drillcon Core AB, Nora, Sweden was engaged for the drilling commission. Two different drilling equipments were used, a percussion rig for drilling the telescopic part, whereas a large core drilling rig was employed for drilling the cored borehole. Support was provided from SKB-personnel regarding measurements and tests during drilling.

The telescopic part of KFR102A was percussion drilled during the period November10th to November 17th, 2008 and core drilling and measurements were carried out during the period November 25th to December 12^{th,} 2008.

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan number (AP SFR-08-011). 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 also entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

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

Activity plan	Number	Version
Kärnborrning av borrhål KFR102A	AP SFR -08-011	1.0
Method documents	**Number**	**Version**
Metodbeskrivning för kärnborrning	SKB MD 620.003	3.0
Metodbeskrivning för hammarborrning	SKB MD 610.003	4.0
Metodinstruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning.	SKB MD 600.004	1.0
Metodinstruktion för användning av kemiska produkter och material vid borrning och undersök-ningar.	SKB MD 600.006	1.0
Metodbeskrivning för genomförande av hydrauliska enhålspumptester.	SKB MD 321.003	1.0
Metodbeskrivning för registrering och provtagning	SKB MD 640.001	2.0
av spolvattenparametrar samt vägning av borrkax under kärnborrning.		
Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wirelineborrning.	SKB MD 321 002	1.0
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål.	SKB MD 224.001	2.0

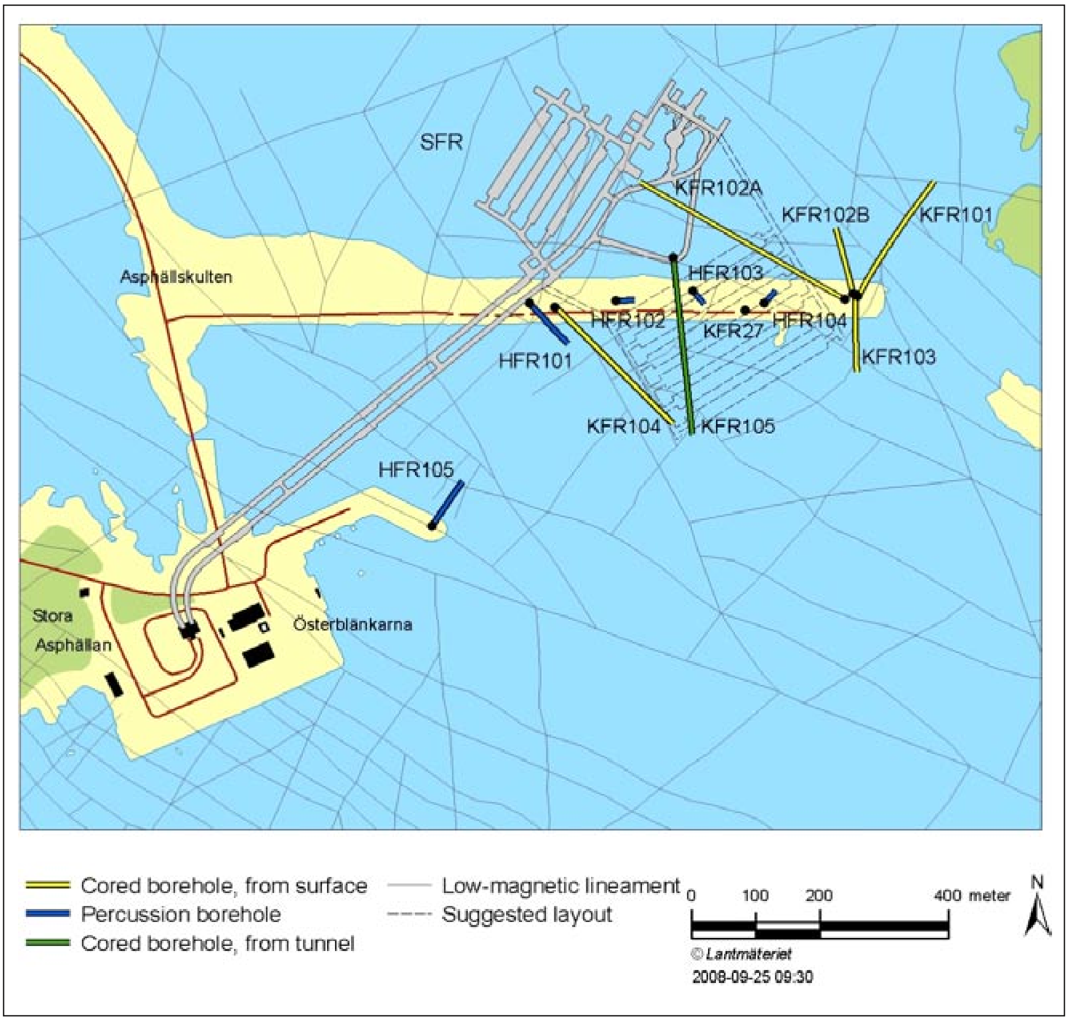


Figure 1-2. *Overview over the SFR site investigation area with planned investigation boreholes. Also the suggested layout of the extended SFR facilities as well as low-magnetic lineaments in the area are displayed.*

2 Objective and scope

The overall objective of drilling borehole KFR102A was to investigate the rock volume selected for a future extension of SKB´s final repository for radioactive operational waste (SFR). The borehole was specifically drilled to:

- Provide drill cuttings from the percussion drilled part, 0–70,42 m.
- Provide drill cores all the way below the percussion drilled part to the borehole bottom. The rock samples collected during drilling are used for lithological, structural and rock mechanical characterization.
- 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.
- Allow hydraulic borehole tests (single hole tests as well as interference tests by employing also nearby boreholes,) for characterization of the hydrogeological conditions of the bedrock.
- To make water sampling possible down to and below repository depth. High-class hydrogeochemical sampling/analysis demands special measures during and after drilling in order to keep the borehole clean. When these measures have been taken, the borehole is categorized as a borehole of chemical type. Only boreholes of this category are approved for advanced hydrogeochemical and microbiological characterization.
- Enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

A specific objective for borehole KFR102A was to investigate the extension of the permeable major subhorizontal fracture zone ZFM871 (H2) as well as the minor fracture zone ZFMNE3115. Another objective was to provide perspicuous geological information of the bedrock conditions at depth beneath the SFR facility.

During drilling, a number of drilling related parameters were monitored by a drilling monitoring system. Part of this data set, 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. The DMS-data from KFR102A are described in this report.

Furthermore, a number of hydraulic tests and water samplings are normally performed during the drilling process, whereby a specifically designed test system, a so called wireline probe, is utilized. However, during drilling of KFR102A these kinds of tests were restricted to collection of two groundwater samples.

3 Equipment

Two types of drilling machines were employed for drilling borehole KFR102A. The upper c. 70 metres were drilled with a percussion drilling machine of type Puntell MX 1000. For core drilling of section 70.42–600.83 m, a Sandvik DE 150 wireline core drilling system, was engaged.

3.1 Percussion drilling equipment

The Puntell percussion machine was equipped with separate engines for transportation and power supplies. Water and drill cuttings were retrieved from the borehole by a 28 bars air-compressor, type XRVS 466.

At drill site DS102, the bedrock is covered by approximately nine metres of blasted rock, mostly of the size of boulders and gravel. This part had to be cased off (NO-X 281). 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 KFR102A are presented in Section 5.2.

3.2 Grouting technique

For investigation of the groundwater conditions, especially the hydrogeochemical characteristics, in 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.

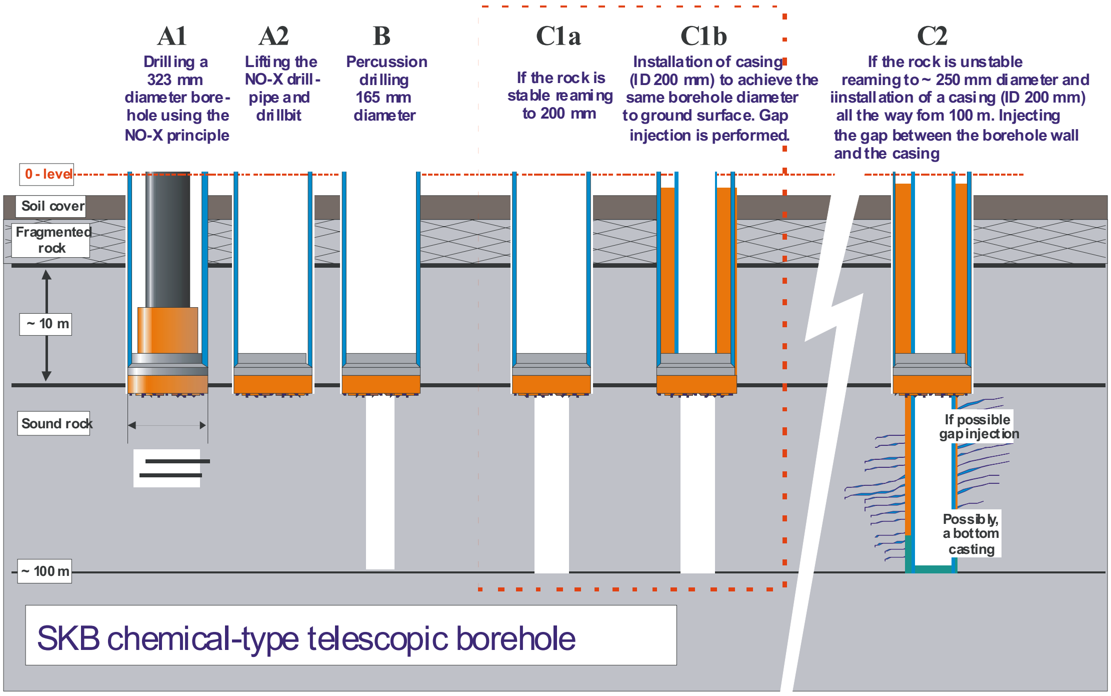


Figure 3-1. Schematic diagram showing the various stages of drilling the telescopic part (in this case assumed to embrace section 0-100 m) of an SKB chemical-type telescopic borehole. The letters and numerals above each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB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

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, 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 the 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 KFR102A was grouted after installation of the Ø$_i$ 200 mm, 70.18 m long casing. Gap injection through a packer was applied and a few days later the grouting was completed by filling the gap between the casing and the borehole wall up to surface with the use of a hose.

3.3 Core drilling equipment

3.3.1 The wireline-76 system

For drilling the cored part of borehole KR102A, a Wireline-76 core drilling system, type Sandvik DE150, was employed. The drilling process is operated by an electrically-driven hydraulic system supplied with a pilot steering. The drilling capacity with AC Corac N3/50 NT drill pipes is maximum c. 2,000 metres. The drill pipes and core barrel used fulfil SKB´s demands for a triple-tube system. Technical specifications of the drilling machine with fittings are given in Table 3-1.

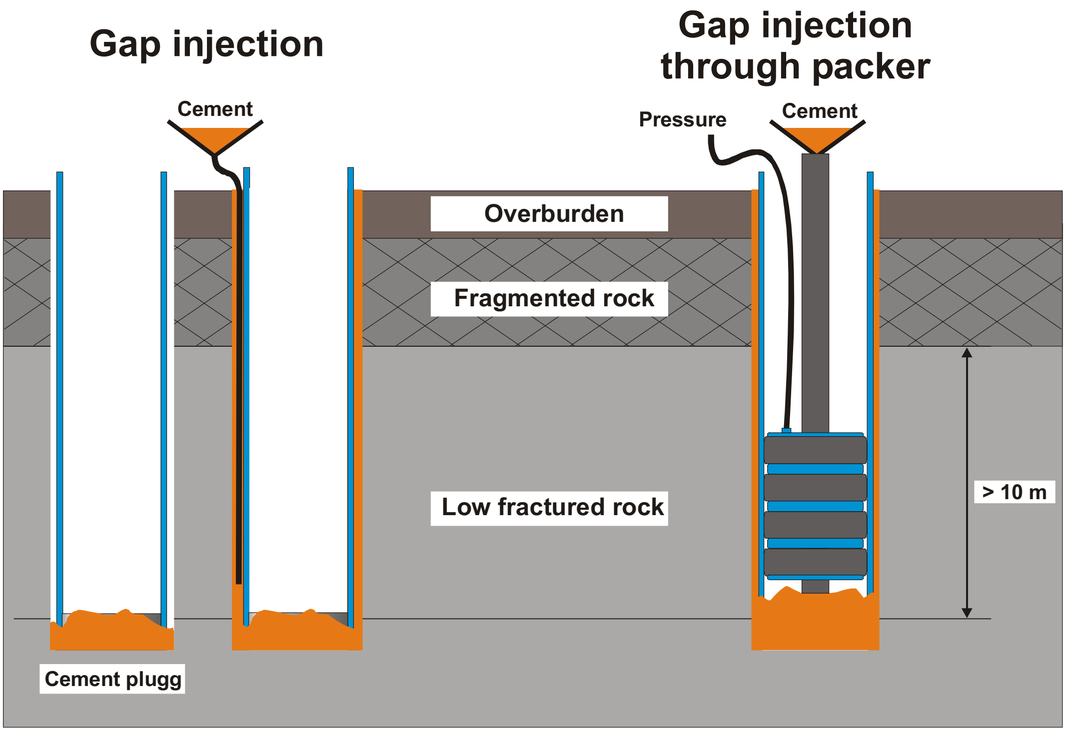


Figure 3-2. *Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer.*

Table 3-1. Technical specifications of the Sandvik DE150 with appurtenances.

Unit	Manufacturer/Type	Specifications	Remarks
Sandvik DE150	Sandviken	Capacity for 76–77 mm holes maximum approx. 2,000 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

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 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.

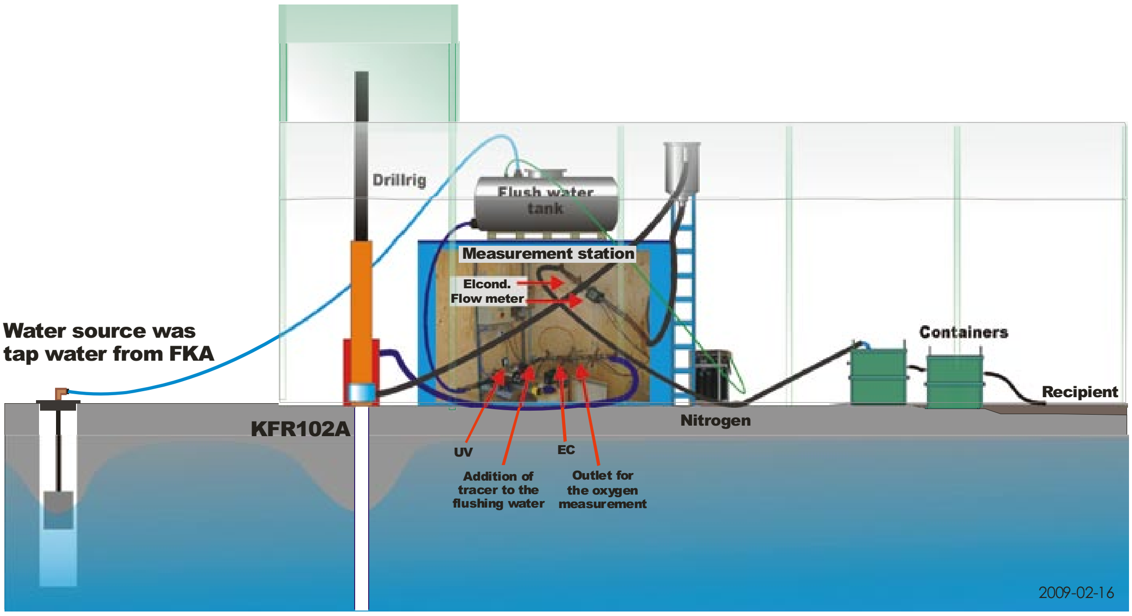


Figure 3-3. Schematic illustration of the flushing/return water system when drilling KFR102A. The measurement station included logger units and an UV-radiation unit. Flushing water was supplied from a water tap at Forsmark's Kraftgrupp AB.

The system includes equipment for pumping, transport and storage of water. The flushing/return water system may be divided into:

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

Preparing the flushing water

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

The water well used for the supply of flushing water for core drilling of KFR102A was tap water from Forsmarks Kraftgrupp AB.

The flushing water was prepared before use in accordance with SKB MD 620.003 (Method description for core drilling), with an organic dye tracer, Uranine, which was added to the flushing water at a concentration of 0.2 mg/L before the water was pumped into the borehole, see Figure 3-3. The tracer was thoroughly mixed with the flushing water in the tank. Labelling the flushing water with the tracer aims at enabling detection of flushing water contents in groundwater samples collected in the borehole during or after drilling.

In order to reduce the contents of dissolved oxygen in the flushing water, nitrogen gas was continuously flushed through the flushing water tank, see Figure 3-3. The oxygen contents of the flushing water was measured before use in the borehole, see Section 5.5.3.

Measurement of flushing water parameters

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

- flow rate,
- electrical conductivity.

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.

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	
Electrical conductivity	YOKOGAWA SC72	0.1 μ/cm–20 S/m	Hand held instrument

The total quantity of water supplied to the borehole, used as a double-check of the flow measurements, was acquired by manual reading of flow meters and a conductivity meter. The readings were stored and then afterwards compared to the automatic readings, which served as a data quality check.

Air-lift pumping while drilling

Air-lift pumping during drilling of 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 KFR102A 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 stabilization system, in order to reduce 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 KFR102A, 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 part of the 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, thereby helping to lift drill cuttings from the bottom of the hole.

Table 3-3. Air-lift pumping equipment used in KFR102A.

Item	KFR102A
Air Compressor, 12 bars/10 m³/min	X
Electrical supply cubicle, at least 16 A	X
Outer support casing, 98/89 mm diameter	70.18 m
Inner support casing, 84/77 mm diameter	70.68 m
2 Ejector pumps, each contained;*	
PEX hose, 1 x 22 mm	2 x 68.5** m
PEM hose, 1 x 40 mm	2 x 68.5** m
Expansion vessel (= discharge head)	X
PEM hose: 20 bars, 32 mm diameter (pressure transducer)	68.60 m
Pressure sensor, 10 bars, instrumentation and data-logging unit	X

* Two mammoth pumps are always installed in each telescopic borehole.

** Extended hose; PEX connected to Air Compressor and PEM connected to Cyclone.

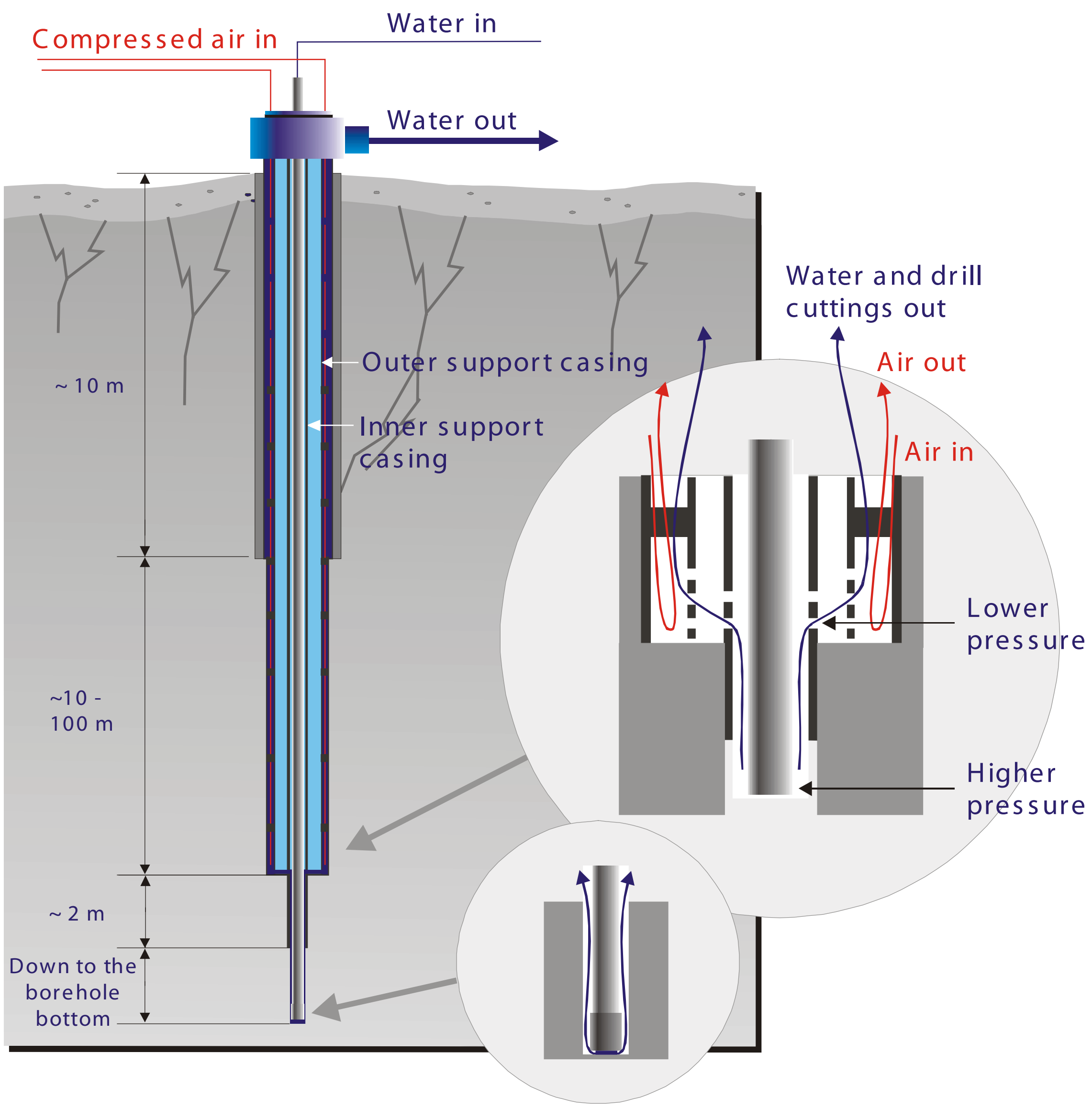


Figure 3-4. *Air-lift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole.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

Storage and discharge of return water for KFR102A

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 two containers, in which the drill cuttings separated out in two 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 recipient, which in this case was 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.

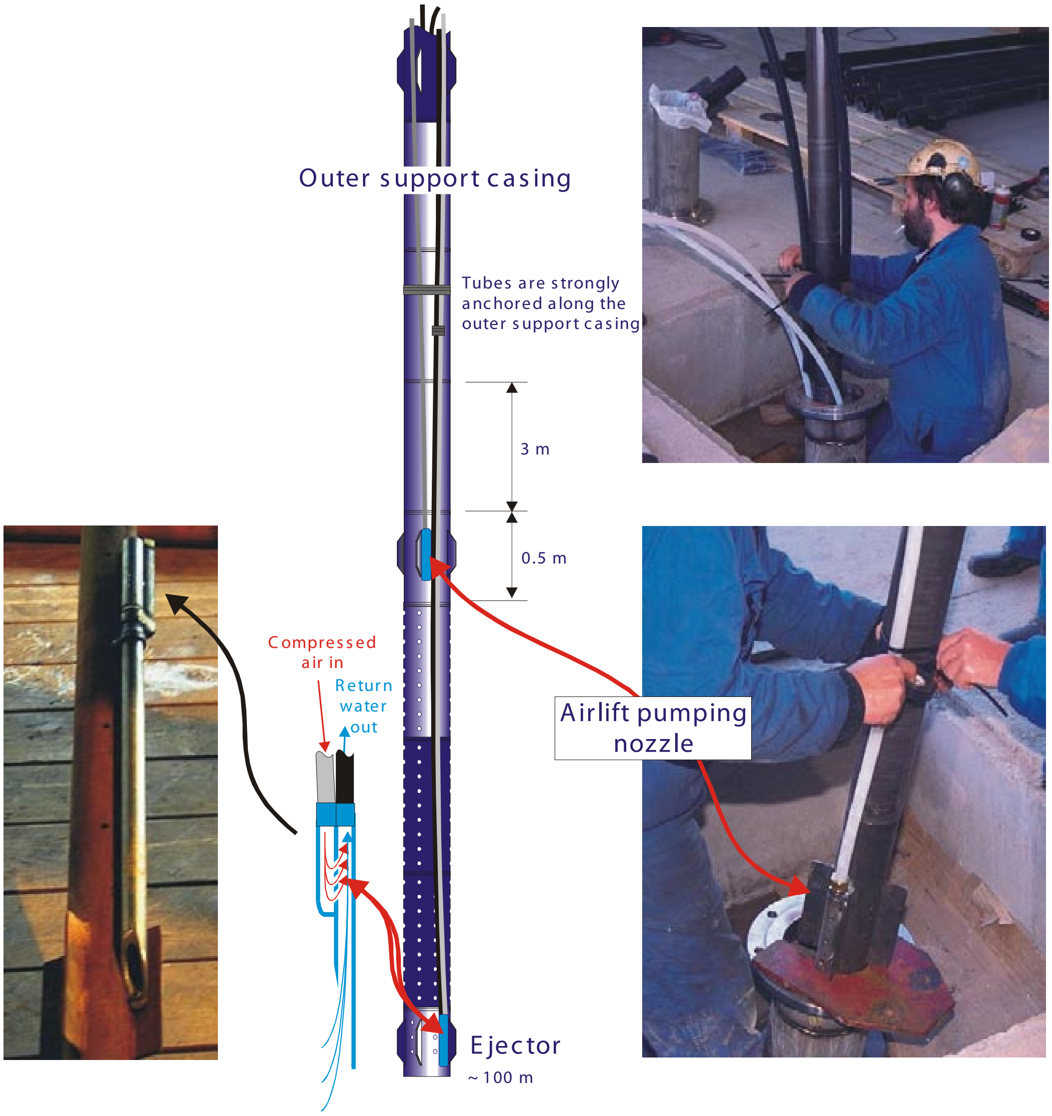


Figure 3-5. Schematic representation of connection and installation of air-lift pumping nozzle and ejector on the outer protective casing.

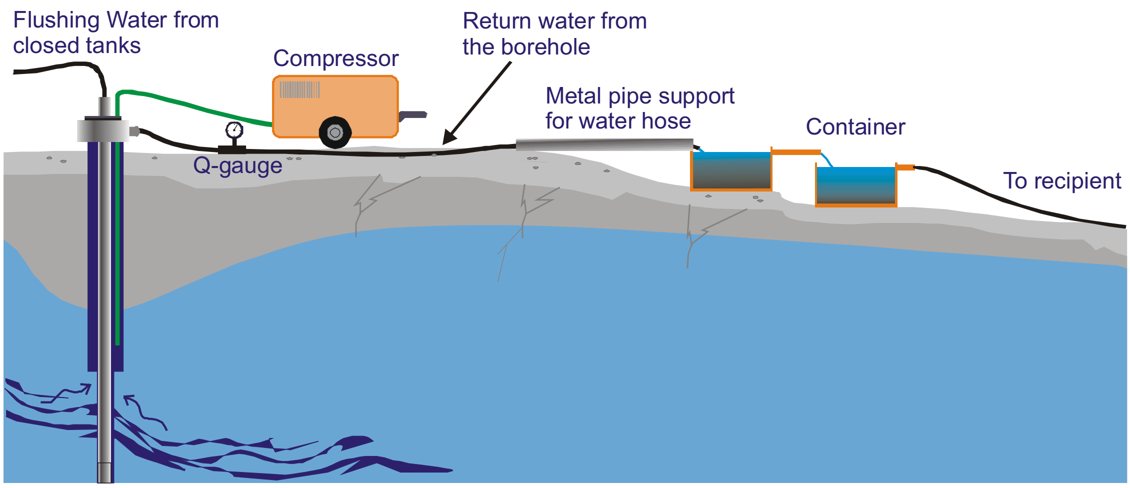


Figure 3-6. Return water system. Air-lift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in two stages in the containers (where they are preserved for later weighing), after which the water is pumped to an approved 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	
Electrical conductivity	YOKOGAWA SC72	0.1 μ/cm–20 S/m	Hand held instrument

3.3.3 Drilling monitoring system

The DE150 drilling machine employed was not supplied with a computer control system. The registration in the SKB logger system included the parameters electric conductivity of the flushing water, and electric conductivity and flow rate of the return water. The system is also provided with a device 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 borehole is 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.

3.3.5 Equipment for deviation measurements

After completed drilling, deviation measurements were made in order to check the straightness of the borehole. The measurements were performed with a Reflex Maxibor II™-system, which is an optical, i.e. non-magnetic, measurement system. Azimuth and dip are measured at every third metre. The borehole collar 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 magnetometer-/accelerometer technique, was applied for deviation measurements in the boreholes. The surveying instrument used was the Flexit Smart Tool System. All available deviation measurements, 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 5.5.8.

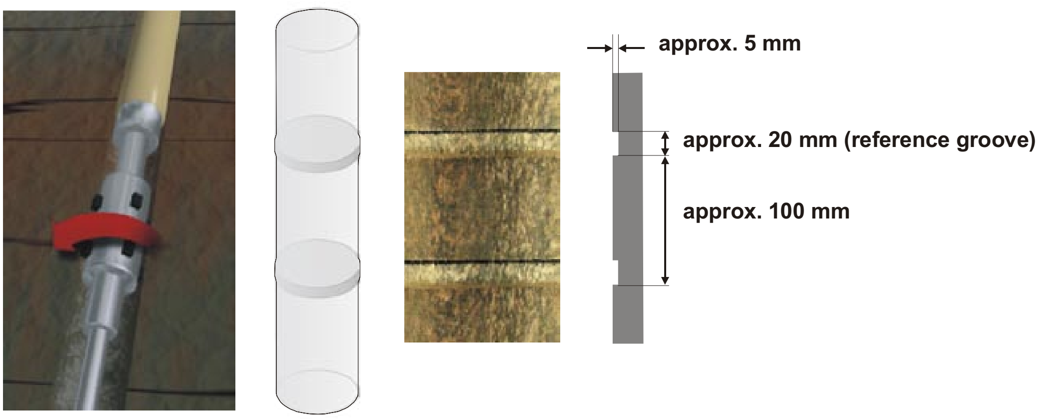


Figure 3-7. Layout and design of reference grooves.

4 Execution

4.1 Percussion drilling of borehole section 0–70.42 m in KFR102A

The percussion drilling operations included:

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

The first four 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, respectively.

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 means of assistance. Furthermore, the mobilization included cleaning of all in-the-hole equipment at level two in accordance with SKB MD 600.004, lining up the machine and final function control.

4.1.3 Drilling, measurements, and sampling during drilling

The percussion drilling started with drilling through the overburden during simultaneous casing driving (NO-X 281) 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 13.21 m. The continued percussion drilling through solid rock was performed with a 165 mm drill bit to 70.42 m drilling length. For stabilization of the entire percussion drilled part, the borehole was reamed to 246.5 mm to 70.38 m length and a stainless steel $Ø_i$ 200 mm casing was then installed to 70.18 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 test of the borehole, as the recovery of the groundwater table was registered after the compressor had been turned off. The results were used as a rough capacity test of the percussion drilled part of the borehole, used on-site i.e. for preparation of the gap injection of the casing, see below.

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

Measurements and sampling while percussion drilling (and immediately after drilling) were performed according to a specific measurement/sampling programme, which was applied in association with the Ø 165.0 mm drilling sequence. This programme was performed in accordance with SKB MD 610.003, see Table 1-1, and included:

1) Sampling of drill cuttings at every third metre. Each sample consists of three individual samples collected one per metre. The samples were stored in a plastic bottle marked with a sample number. Ocular inspection and a preliminary description of the mineral content were 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 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 Ø 246.5 mm. The borehole was secured with a lockable stainless steel flange. The drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the Contractor.

4.1.5 Nonconformities

The length of the percussion drilled part of KFR102A became 70.42 m compared to 70 m that was suggested in the Activity Plan.

4.2 Core drilling of KFR102A

The core drilling operations included:

- preparations,
- mobilisation, including lining up the machine and measuring the position,
- drilling, measurements, and sampling during drilling,
- finishing off field 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 Mobilisation

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

4.2.3 Drilling, measurements and sampling during drilling

Core drilling of borehole KFR102A was performed with two borehole dimensions. Section 70.42–72.02 m was drilled with a borehole diameter of 86.3 mm, whereas the main part of the borehole, section 72.02–600.83 m, was drilled with Ø 75.8 mm. The inner Ø 84/77 mm support casing was fitted into the short Ø 86.3 mm borehole. In this way the casing was centralized in the borehole and fixed laterally in its lower part. The outer Ø 98/89 mm support casing, which is supplied with steel wings towards the borehole wall, is during drilling resting on the bottom of the percussion drilled borehole, see Figure 3-4.

Core drilling with Ø 75.8 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.

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 borehole KFR102A, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 75.8 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 KF102A 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 KFR102A.

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

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

The concluding work included the following items:

1) The borehole was flushed for about 10 hours during simultaneous air-lift pumping in order to clean it from drilling debris adhered to the borehole walls, 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 a wheel loader, a stainless steel transition cone was installed between the reamed and cased percussion drilled respectively the cored part of the borehole, as shown in Figures 5-2 and 5-6. The cone is located at 66.99–71.94 m.
7) The borehole was again secured with the lockable stainless steel flange.
8) The core drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the Contractor.

4.2.4 Nonconformities

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

Table 4-1. Programme for performance and frequency of sampling, measurements, registrations and other activities during and immediately after core drilling of KFR102A according to SKB MD 620.003 and AP SFR-08-011.

Activity	Performance and frequency according to SKB MD 620.003	Performance and frequency during drilling of KFR27
Registration of drilling- and flushing water parameters.	Registration during the entire drilling.	According to programme. (Methods described in Section 3.2.1.)
Registration of the groundwater level in the borehole during drilling	Every 10th second.	According to programme.
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	Two Maxibor measurement and two measurements with Flexit after completion of drilling.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drill pipe string should be controlled before each test.	No measurements performed.
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drill pipe string should be controlled before each test.	Two measurements performed.
Absolute pressure measurements.	Normally during natural pauses in drilling.	No measurements performed.
Groove milling in the borehole wall, normally at each 50 m drilling length.	Normally performed after completion of drilling.	Eleven grooves milled.
Collecting and weighing of drilling debris.	Drilling debris settled in containers weighed after finished drilling.	Not carried out for the percussion drilled part of the borehole. According to programme for the core drilled part.
Flushing of the entire borehole	After finishing the borehole and including nitrogen.	According to programme.

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

4.3 Data handling

4.3.1 Performance

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

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 – General.
- Section 5.2 – Drilling progress.
- Section 5.3 – Geometrical and technical design of borehole KFR102A.
- Section 5.4 – Percussion drilling KFR102A, 0–70.42 m.
- Section 5.5 – Core drilling KFR102A, 70.42–600.83 m.

Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling. Well Cad presentations of borehole KFR102A are shown in Appendix A and B.

Analysis of two water samples from KFR102A is displayed in Appendix C.

5.1 General

The telescopic borehole KFR102A presented in this report is located on the pier at Asphällskulten, see Figure 1-2. This pier functions as a breakwater for the SFR harbour. It was constructed in two phases, during two different time periods. The ballast used for the construction was blasted rock, mostly of the size of boulders and gravel. The first construction phase made used of rock material delivered from the excavation during 1973–1974 of the FKA cooling water tunnel, whereas the ballast for the second phase originated from the excavation of the SFR facility during 1982–1988.

Because drill site DS102 with among others borehole KFR102A is located farthest east on the pier (see Figure 1-2), and hence is very exposed to the wind from the Baltic Sea, and as drilling was carried out during the winter season, a tent was set up after demobilization of the percussion drilling equipment but prior to core drilling. The tent was large enough to cover all core drilling and accessory equipment, see Figure 5-1. Electrical heaters and surplus heat from the air compressor was used to keep the temperature above zero, thereby protecting the water system and other sensitive equipment from freezing.

Figure 5-1. *Drill site DS102 with borehole KFR102A, located farthest east on the pier at Asphällskulten. To protect the water system and other sensitive equipment from freezing, a tent with electrical heathers was used to keep the temperature above zero. Another advantage with the tent was improvement of the working environment.*

5.1.1 Definitions

After completion of drilling, an extensive measurement programme was carried out in the KFR102A. In order to perform these measurement in a rational way and to enable quality assurance of measurement data, crucial borehole geometrical data, like borehole collar coordinates, borehole orientation and inclination, borehole and casing lengths and diameters etc are needed as input data. To facilitate collection and further treatment of logging data, and in order to minimise the risk of misunderstandings of e.g. which level in the borehole measurement data are associated with, clear and indisputable borehole geometrical data, for which definitions are given in Figure 5-2, must be available shortly after completed drilling. Therefore, such data were determined for KFR102A during and as soon as possible after completed drilling.

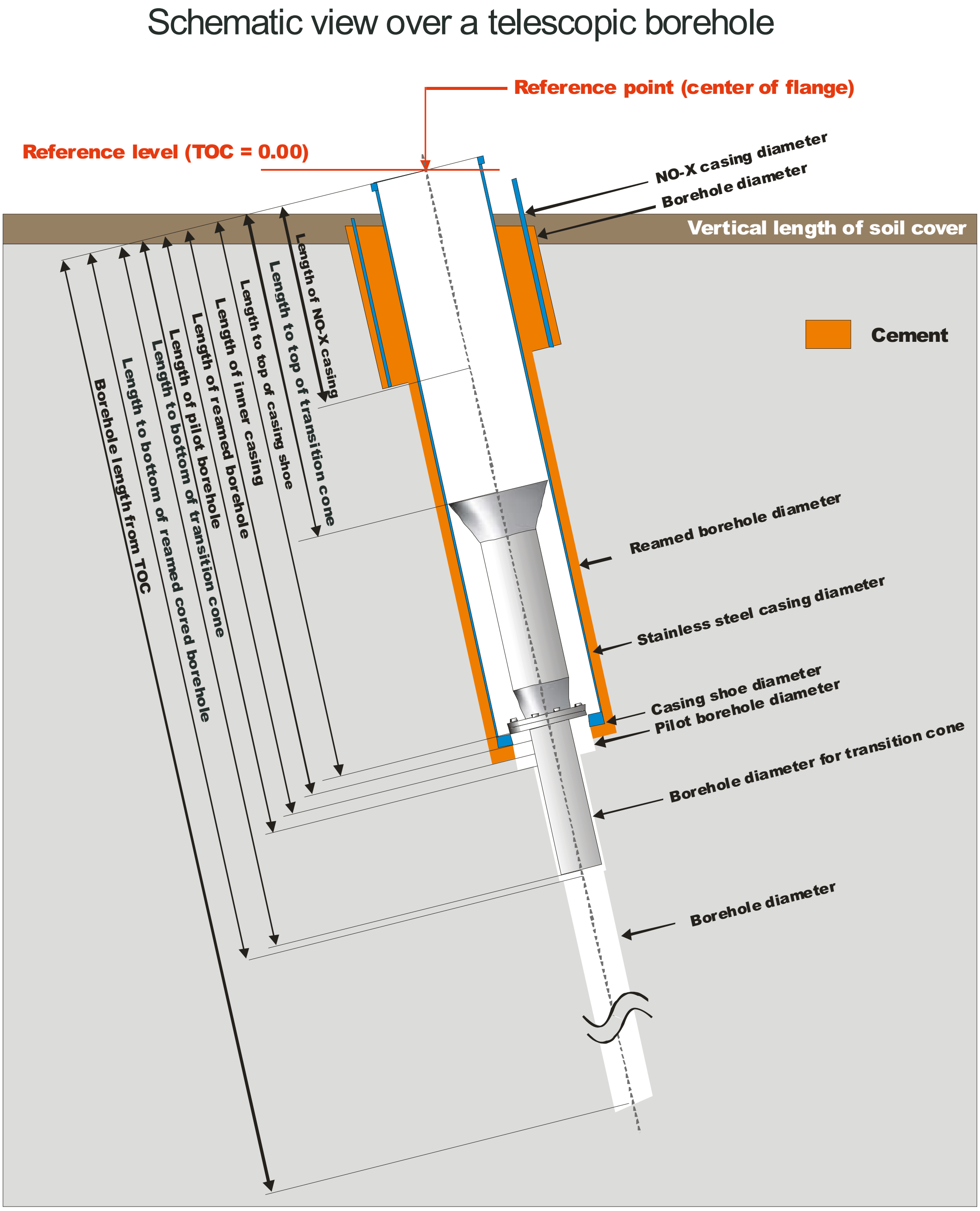


Figure 5-2. *Schematic drawing of the upper part of a cored borehole of telescopic type. The figure presents definitions of the most important geometrical data, such as reference points together with borehole- and casing lengths and diameters.*

The coordinate system used for all geographical objects in this report are:

RT90 2.5 gon V 0:-15 (x- and y-coordinates),

RHB 70 (z-coordinates).

It is important that the SKB field-crew, who is managing the drilling operations, and all following measurement crews are fully aware of these definitions so that correct adjustments of data are ensured.

5.2 Drilling progress

The drilling operations were performed during two periods, between November 10th to November 17th, 2008, (percussion drilling) and November 25th to December 12th, 2008, (core drilling), see Figure 5-3. The favourable working environment with the drill rig and water supply system weather protected by a tent, see Section 5.1, contributed much to effective drilling operations and, consequently, a rapid drilling performance.

5.2.1 Percussion drilling 0–70.42 m

Percussion drilling is usually a rapid method compared to core drilling. That is the reason for choosing this method for performance of the upper telescopic part of the borehole. Percussion drilling was conducted during the period November, 10th, 2008, to November 17th, 2008, (Figure 5-4).

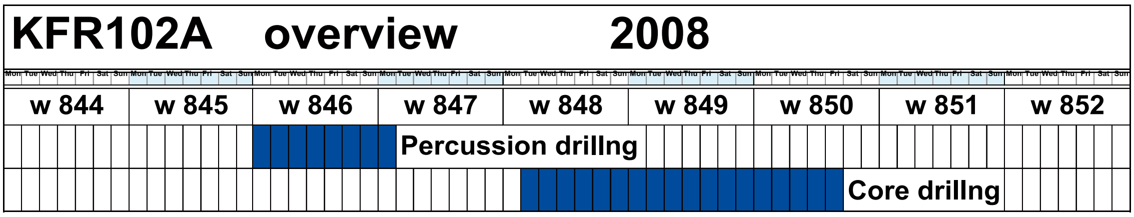


Figure 5-3. *Overview of the drilling performance of borehole KFR102A.*

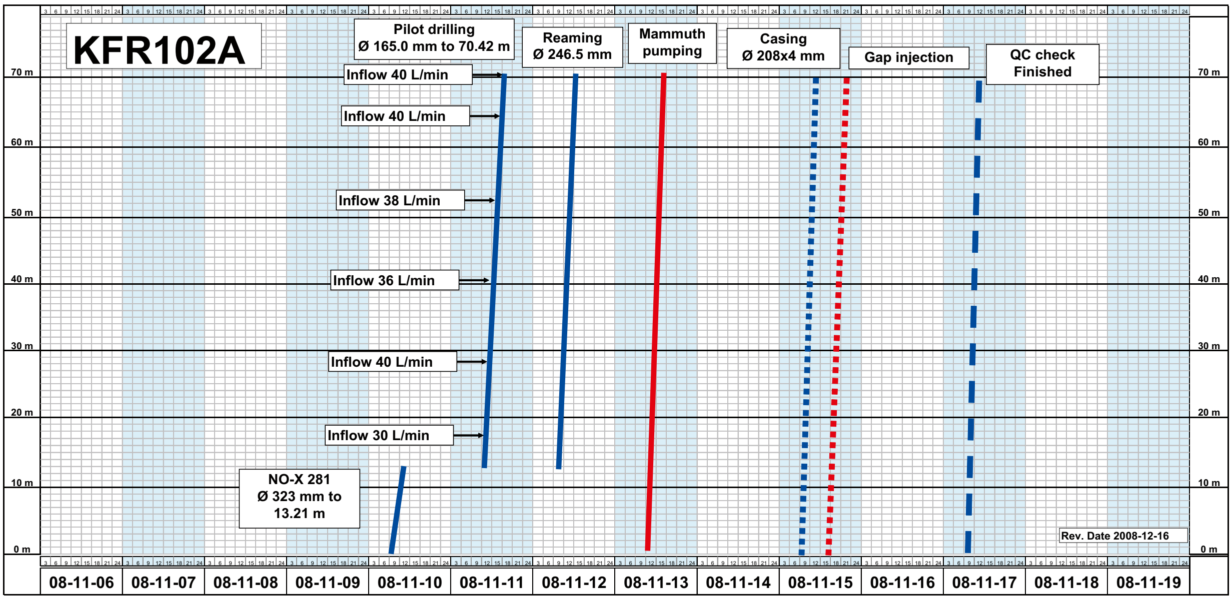


Figure 5-4. *Percussion drilling progress (length and activity versus calendar time). "Inflow" in the figure refers to measured accumulated groundwater inflow.*

5.2.2 Core drilling 70.42–600.83 m

Ensuing percussion drilling of section 0–70.42 m, a break of less than one week followed, after which core drilling commenced. The progress of the core drilling decreased versus time, due to with increasing borehole length, retrieval of the core barrel, e.g. for change of drill bit, becomes more and more time consuming.

5.3 Geometrical and technical design of borehole KFR102A

Administrative, geometric and technical data for the telescopic borehole KFR102A are presented in Table 5-1. The technical design is illustrated in Figure 5-5.

Table 5-1. Administrative, geometric and technical data for the telescopic borehole KFR102A.

Parameter	
Borehole name	KFR102A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	Nov 10th, 2008
Completion date	Dec 12th, 2008
Percussion drilling period	2008-11-10 to 2008-11-17
Core drilling period	2008-11-25 to 2008-12-12
Contractor core drilling	Drillcon Core AB
Subcontractor, percussion drilling	Züblin Svenska AB, avd Sven Andersson i Uppsala
Core drill rig	Sandvik DE 150
Percussion drill rig	Puntell MX1000
Position at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6701730.30 (m) E 1633330.21 (m) Z 2.66 (m) Azimuth (0–360°): 302.26° Dip (0–90°): –65.41°
Position at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6701884.42 [m] E 1633117.23 [m] Z –537.33 (m) Azimuth (0–360°): 307.26° Dip (0–90°): –61.48°
Borehole length	600.83 m
Borehole length and diameter	From 0.38 m to 13.21 m: 0.339 m From 13.21 m to 70.38 m: 0.2465 m From 70.38 m to 70.42 m: 0.1650 m From 70.42 m to 72.02 m: 0.0862 m From 72.02 m to 600.83 m: 0.0758 m
Casing diameter and drilling length	Øo/Øi = 323.00 mm/310.00 mm 0.38 to 13.13 m Øo/Øi = 339.00 mm/281.00 mm 13.13 to 13.21 m. (drilling shoe) Øo/Øi = 208.00 mm/200.00 mm 0.00 to 70.15 m Øo/Øi = 208.00 mm/170.00 mm 70.15 to 70.18 m (casing shoe)
Transition cone outer diameter Transition cone inner diameter	At 66.99 m 0.195 m At 71.94 m 0.080 m
Drill core dimension	70.42–72.02 m/ Ø = 0.0720 mm 72.02–600.83 m/ Ø = 0.0502 mm
Core interval	70.42 m–600.83 m = 530.41 m
Average length of core recovery	2.71 m
Number of runs	196
Diamond bits used	12
Average bit life	44.18 m

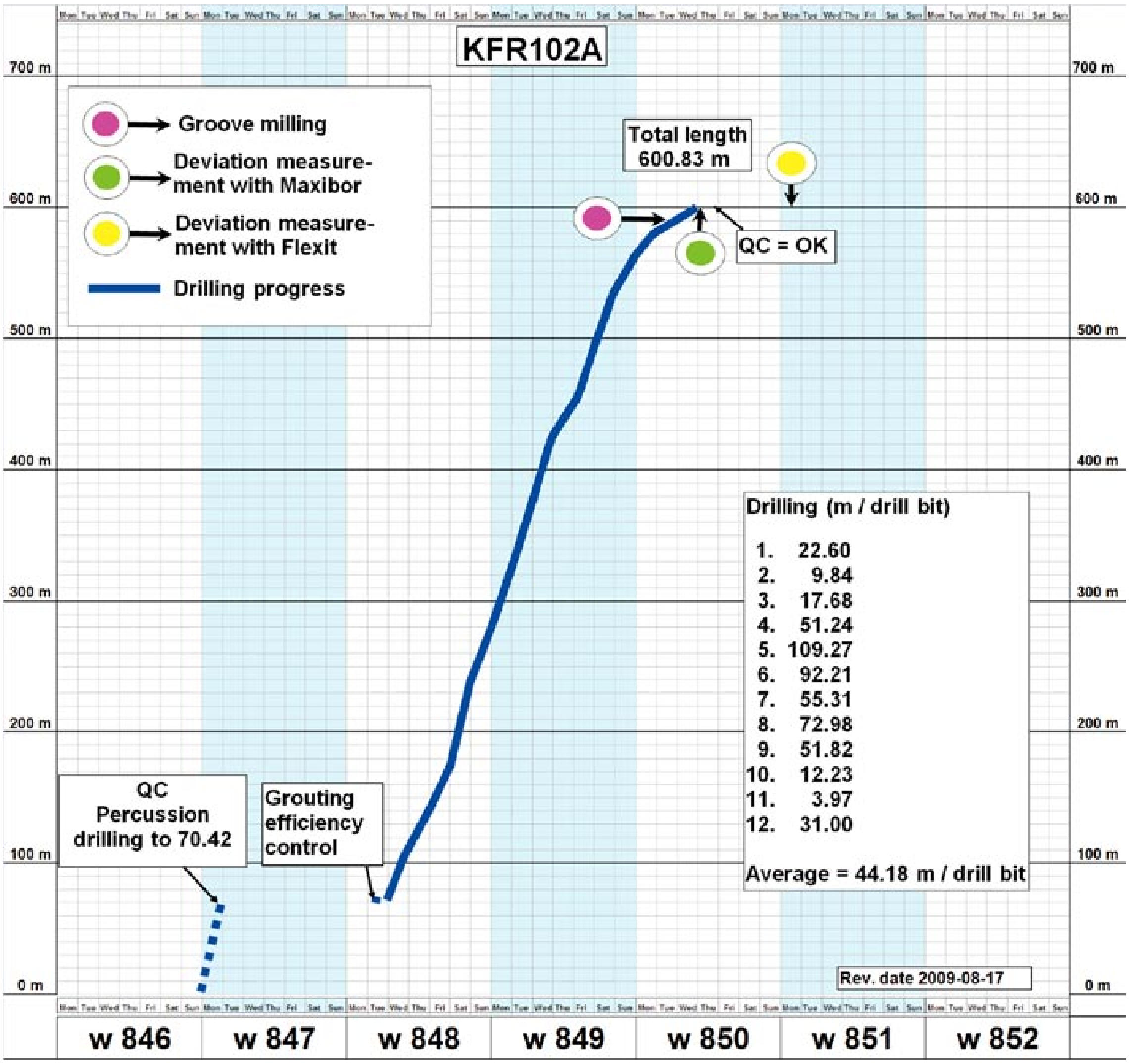


Figure 5-5. *Core drilling progress (length and activity versus calendar time).*

5.4 Percussion drilling KFR102A 0–70.42 m

5.4.1 Drilling

As mentioned in Section 4.1.3 the upper 13.21 m of the borehole was drilled and cased according to NO-X 281. During pilot drilling to 70.42 m with 165.0 mm diameter, a groundwater inflow of 40 L/min was encountered, see Figure 5-4. As a borehole inclination as large as 65º from the horizontal plane involves an increased risk of instability and outfall from the borehole wall, the borehole section to 70.38 m was reamed to 246.5 mm and a stainless steel casing of diameter $Ø_o/Ø_i$ 208/200 mm was installed to 70.18 m. Finally, the gap between the casing and the borehole wall was cement grouted, so that the water inflow ceased completely.

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

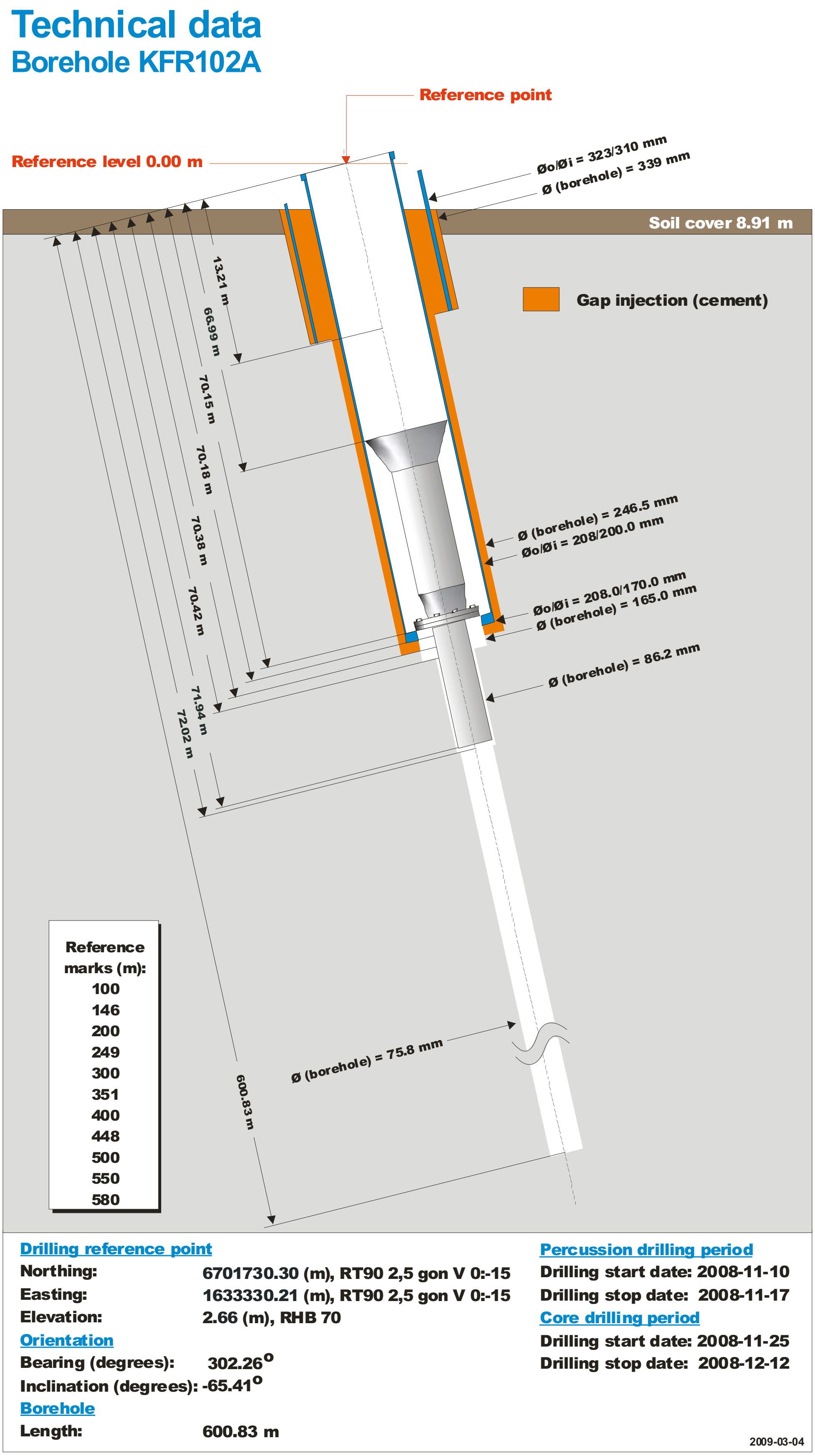


Figure 5-6. *Illustrated technical data for borehole KFR102A.*

5.5 Core drilling KFR102A, 70.42–600.83 m

Generally, the investigated rock volume around the SFR facility shows a varying rock composition, where granitoides, pegmatite and amphibolites dominate. From the preliminary on-site core logging, the average fracture frequency for all cored boreholes investigated so far within Project SFR Extension-Investigations has been calculated. During the drilling activity, also the consumption of drill bits, as well as the core recovery length has been documented. These data have been compiled in Table 5-2.

In a telescopic borehole, as in KFR102A, the constant mammoth pumping creates a draw-down of the groundwater table surrounding the borehole, in spite of the fact that flushing water simultaneously is added to the borehole in order to cool the drill bit, see also Section 5.5.4.

These contradictory activities, supplying and withdrawal of water to and from the borehole, respectively, cause a conflict with implications for drilling efficiency, because cooling of the drill bit may be disturbed, especially in the upper part of the borehole. For the entire borehole drilling of KFR102A the average lifetime of drill bits was only 44.20 metres/bit, probably caused by this disturbance of the cooling water supply. The common procedure when sharpening a diamond drill bit is to shut off the flushing water supply for a very short period while drilling. Hereby, a part of, or the entire front of the drill bit, will become very hot, entailing loss of the front level of blunt diamonds. As soon this has happened, the water flushing must immediately be turned on, so that the sharpened drill bit will cooled off as rapidly as possible. If not, more layers of diamonds will disappear, and the entire drill bit may be worn out.

Probably, a major draw-down causes a depletion of flushing water available for cooling the drill bit, due to the upward directed gradient in the borehole. Combined with increased vibrations of the drill string (as there is no water between the inner casing and the drill string in a large part of the telescopic part of the borehole due to the draw-down), this is a plausible explanation for the fact that the drill bits had a shorter lifte-time at the beginning of the core drilling starting at 70 m borehole length. The first three used drill bits were worn out already after 22.60, 9.84 m, and 17.68 m, respectively, whereas the average life-time for the remaining drill bits used is 53.3 m with a maximum of 109.3 m for drill bit no 5, see Figure 5-5.

5.5.1 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 5.5.2–5.5.10 below. Mapping of the drill core samples from KFR102A is reported separately.

Table 5-2. Summary of the average fracture frequency, average lifetime of drill bits and average core recovery length from all six cored boreholes drilled from ground surface within Project SFR Extension-Investigations.

Borehole	Section [m]	Average fracture frequency [fractures/m]	Average drill bit lifetime [m/drill bit]	Average core recovery length [m]
KFR101	13.72–341.76	3.91	85.44	2.85
KFR102B	13.95–180.08	3.30	83.65	2.68
KFR103	13.33–200.50	2.95	37.43	2.67
KFR104	08.73–454.57	2.91	85.44	2.58
KFR27	146.92–501.64	4.05	57.83	2.98
KFR102A	70.42–600.83	2.91	44.18	2.71

5.5.2 Registration and sampling of flushing water and return water

As borehole KFR102A 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 content of the Uranine tracer dye in the flushing water and return water. This enables a mass balance calculation from which the flushing water content in the borehole can be determined.

Figure 5-7 illustrates the accumulated volume of flushing water and return water versus time during core drilling, whereas Figure 5-8 displays the accumulated volumes of flushing water and return water from the entire drilling period, giving a return water/flushing water quotient of 2.93 (results from Uranine measurements are presented in the next section).

Uranine content of flushing water and return water – mass balance

During the drilling period, sampling of flushing water and return water for analysis of the content of Uranine was performed systematically with a frequency of approximately one sample per every fourth hour during the drilling period, see Figure 5-9. Like in all boreholes drilled during the site investigation, 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.

Usually, a mass balance calculation of the accumulated volumes of flushing water and recovered flushing water in the return water suggests that flushing water is lost in the borehole. According to notations in the logbook, the amount of Uranine added to the borehole was 106 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 96 g and 179 g, respectively. Because a higher amount of Uranine cannot be recovered from the borehole than added to it, the calculation using average values has in this borehole resulted in an unacceptably high unreliability.

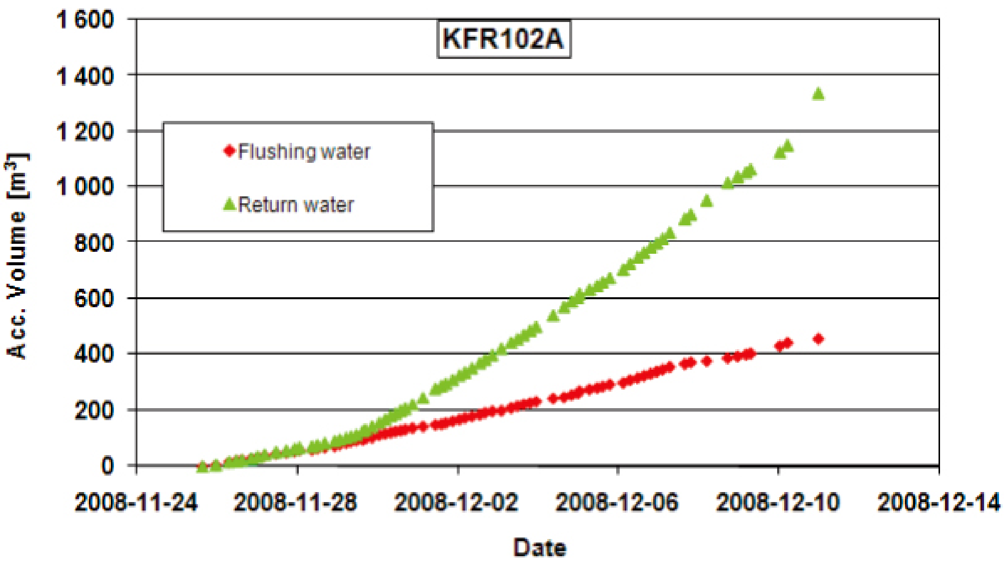


Figure 5-7. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFR102A.*

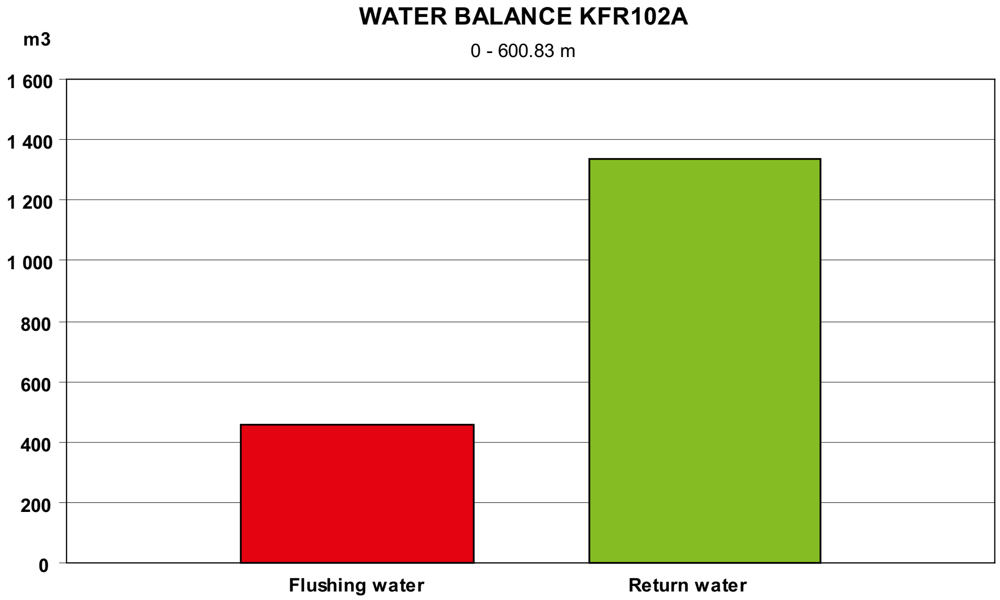


Figure 5-8. Total amounts of flushing water and return water during drilling of borehole KFR102A. The total volume of flushing water used during core drilling was amounted to 457 m³. During the same period, the total volume of return water was 1,337 m³. The return water/flushing water balance is then as high as 2.93, due to the large inflow of groundwater into the upper part of the cored borehole.

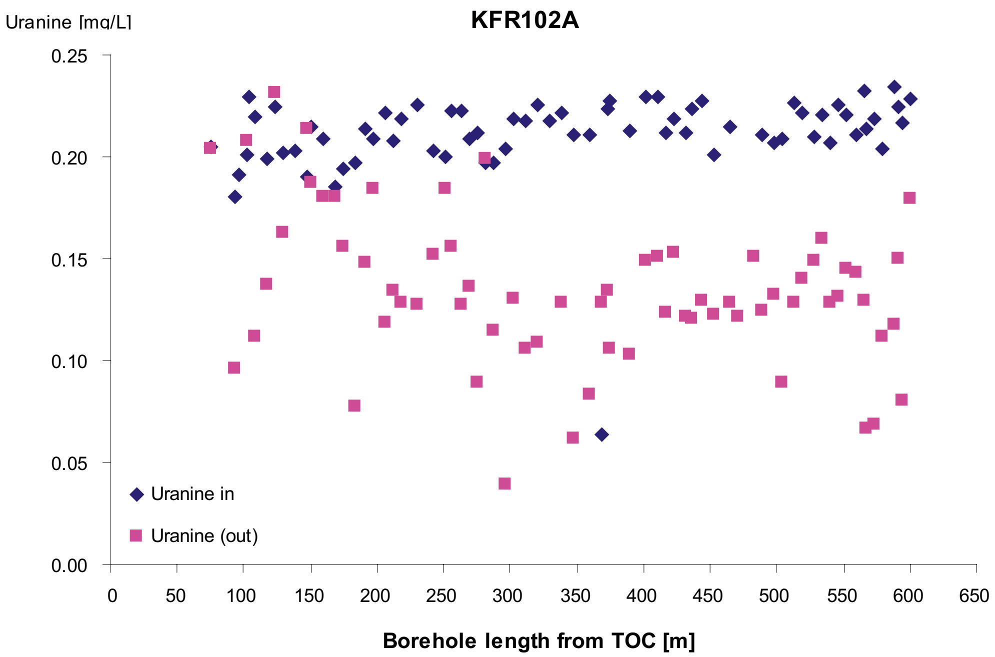


Figure 5-9. Uranine content in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFR102A. Automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine. Six analyses have been judged as unreliable and the diagram has been cleaned from these outliers.

After finished drilling, the water chemistry sampling in KFR102A also showed that flushing water still remains in the borehole.

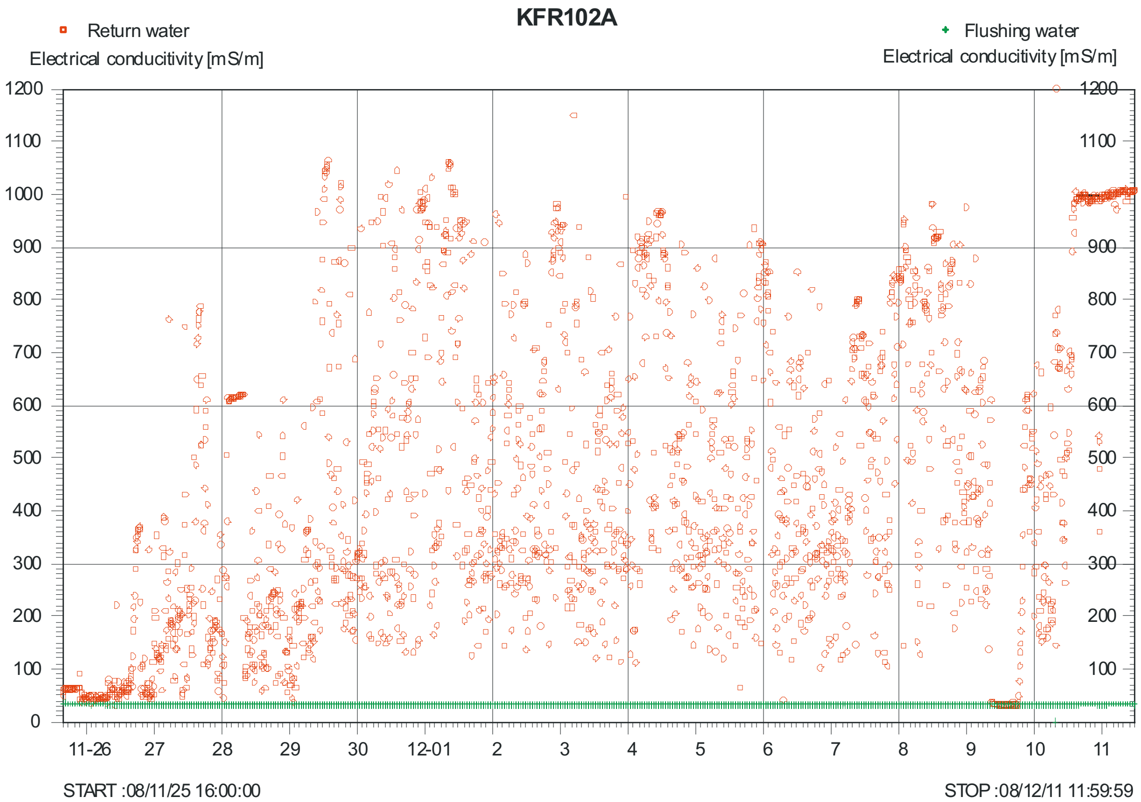
Electric conductivity of flushing water and return water

Flushing water was supplied from a water tap at Forsmark's Kraftgrupp AB. 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 was positioned between the surge diverter (discharge head) and the sedimentation containers (Figure 3-3). The results of the EC-measurements are displayed in Figure 5-10. The electrical conductivity of the flushing water (tap water) is constant at 40 mS/m through the complete drilling period.

The average electrical conductivity of the return water from KFR102A (Figure 5-10) is from start at the same level as the tap water but is soon rising to c. 400 mS/m. After further drilling for another day, the EC-value has a peak up to 800 mS/m, before it is stabilized at 600 mS/m. Finally, the EC-value increases to c 1,000 mS/m (at c 200–250 m drilling length) and is then kept almost constant during the drilling period. The return water is a mixture of flushing water (tap water) and inflow of groundwater into the borehole, and as tap water only has an EC-value of 40 mS/m, the results indicate saline groundwater inflow at depth.

Content of dissolved oxygen in flushing water

The level of dissolved oxygen in the flushing water was measured and plotted versus time. The concentration of dissolved oxygen has generally been kept between 2–4 mg/L. In order to ensure a continuous inflow of nitrogen to the flushing water tank (cf. Section 3.3.2), it was decided to observe and document the pressure in the nitrogen bottles once a day. The pressure reduction of nitrogen is presented in Figure 5-11.



Figur 5-10. *Electrical conductivity of flushing water (tap water from FKA) and return water from KFR102A.*

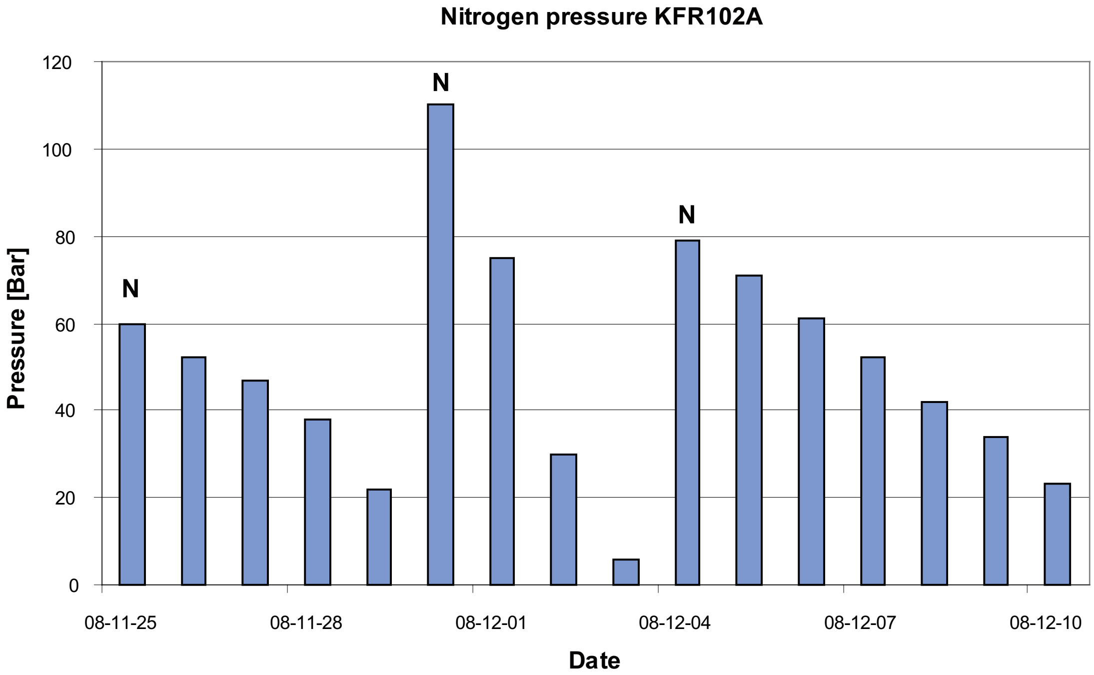


Figure 5-11. *Nitrogen contents (measured as pressure) in the bottles for nitrogen bubbling of flushing water in KFR102A. "**N**" above bars equals to change of nitrogen bottle batteries.*

5.5.3 Groundwater sampling and analyses during drilling

Two so called first strike water samples were collected from sections 70.42–125.83 m and 70.42–293.83 m, respectively, in KFR102A. The results from the analysis of the water sample are presented in Appendix C.

5.5.4 Registration of the groundwater level in KFR102A

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 5-12).

From the beginning, the mammoth pumping was set at the maximum draw-down, but after a major inflow in the upper part had been encountered, the draw-down was adjusted to approximately 40 m below top of casing. Shortly before the end of drilling, the draw-down was again decreased, to approximately 35 m.

The return water flow rate depends on the hydraulic transmissivity of the borehole as well as of the magnitude of the draw-down (accomplished by the mammoth pumping). To cool the drill bit and keep the borehole bottom clean usually requires a water flow rate of c 35 L/min. However, immediately after a core recovery, a temporarily higher flushing water rate is often applied. As the upper 70 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 the core drilling started, the return water flow rate was c. 20 L/min, i.e below the added flushing water flow rate, but that explains marked variations of the draw-down during the first two days. When core drilling commenced, the draw-down was stabilized to approximately 35 m.

5.5.5 Core sampling

The average drill core length per run obtained from the drilling was 2.71 m. No unbroken cores were recovered. Fracture minerals were relatively well preserved. Rotation marks on the drill core occurred with a pretty low frequency. A preliminary on-site core logging was performed continuously.

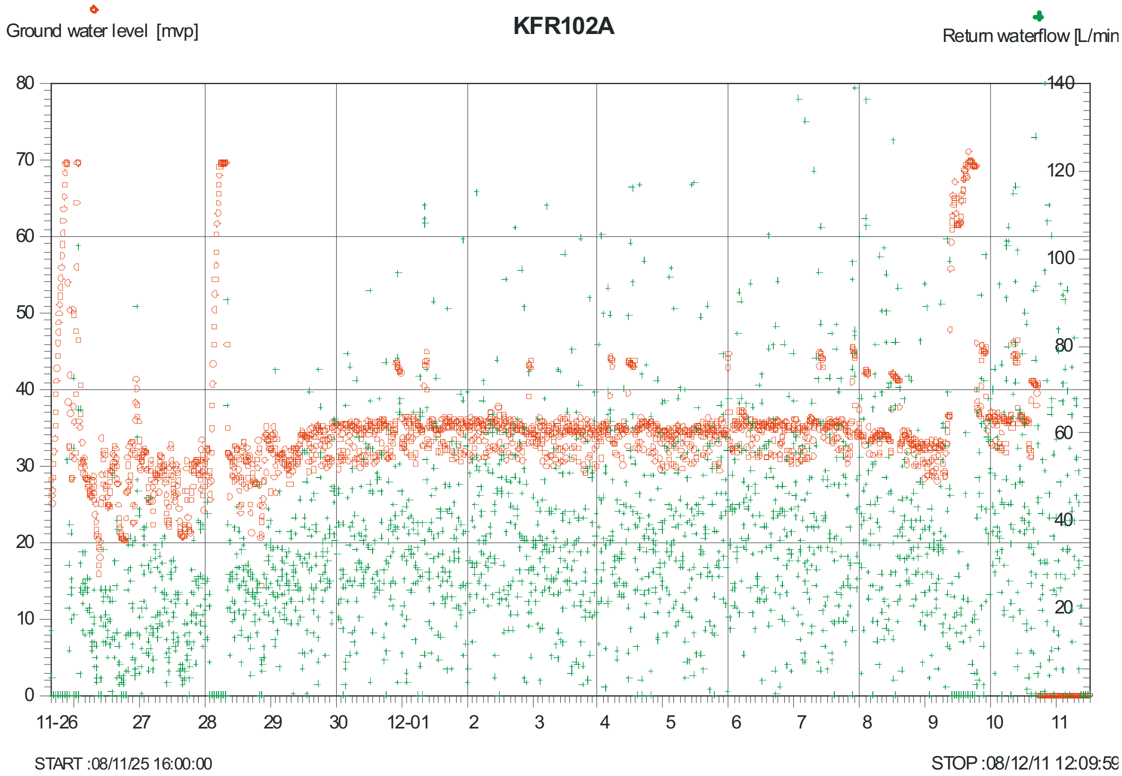


Figure 5-12. *Variation of the level of the groundwater table (red) and return water flow rate (green) versus time during core drilling of borehole KFR102A.*

5.5.6 Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0–13.2 m to 339 mm and 13.2–70.4 to 246.5 mm) is c 3.9 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 the full borehole length worked well, without obstruction from settled drill cuttings.

The theoretical difference in volume of the core drilled part of KFR102A and the drill core is calculated to be 1.331 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 3,541 kg. The calculated dry weight of the debris from the core drilling recovered and weighed in the containers is 2,811 kg. The difference between the theoretically produced and recovered dry weight of debris is 730 kg, which gives a recovery of 79.4%.

The recovery figure could be commented on. The dwell time in the system is too short for sedimentation of the suspended finest fractions. No estimation was made of the amount of suspended material, but the true recovery must be somewhat higher than 79.4%. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

However, it seems plausible that drilling debris has been injected into the fracture system of the formation, especially in the permeable sections with increased fracture frequency above c 150 m in the borehole.

5.5.7 Deviation measurements

The types and measurement principles of the equipment systems used for deviation measurements were explained in Section 3.3.5. Following the recently revised edition of SKB MD 224.001, Version 2, measurements with two different techniques have to be applied. An optic method (Maxibor II™ instrument) and a method based on magnetometer-/accelerometer technique (Flexit Tool System), was chosen for the deviation measurements performed in KFR102A.

To ensure high quality measurements with the Flexit tool, the disturbances (variations) of the global magnetic field must be small during the period of measurements. Regular registrations of the global magnetic field are made at a number of measurement stations all over the world. For magnetic field values that apply for Forsmark with surroundings, a measurement station in Uppsala provides one-minute magnetic field values that are available on the Internet at www.intermagnet.org and gives sufficient information. The magnetic field variations during the two Flexit surveys in KFR102A on December 19th, 2008, are shown in Figure 5-13 and display only minor disturbances.

A description of the construction of deviation data for the core drilled borehole KFR102A is given below.

The deviation data used for construction of the final deviation file were two Maxibor II™- loggings to 597 m and two loggings with the Flexit Smart Tool System, likewise to 597 borehole length, respectively, see Table 5-3. The deviation measurements were carried out every 3 m with both instruments, downwards as well as upwards. The activities marked "CF" in Table 5-3 includes comments besides measurement data.

All deviation surveys in the borehole have followed the recommended quality routines according to SKB MD 224.001, Version 2.0. This final deviation file is termed EG154 (Borehole deviation multiple measurements). See illustration of the construction principle in Figure 5-14.

The EG154-activity (see Table 5-4) specifies the sections of the deviation measurements used in the resulting calculation presented in Table 5-5. The different lengths of the upper sections between the bearing and the inclination are due to that the magnetic accelerometer measurement (bearing) is influenced by the 70 m steel casing which is not the case for the inclinometer measurements (inclination).

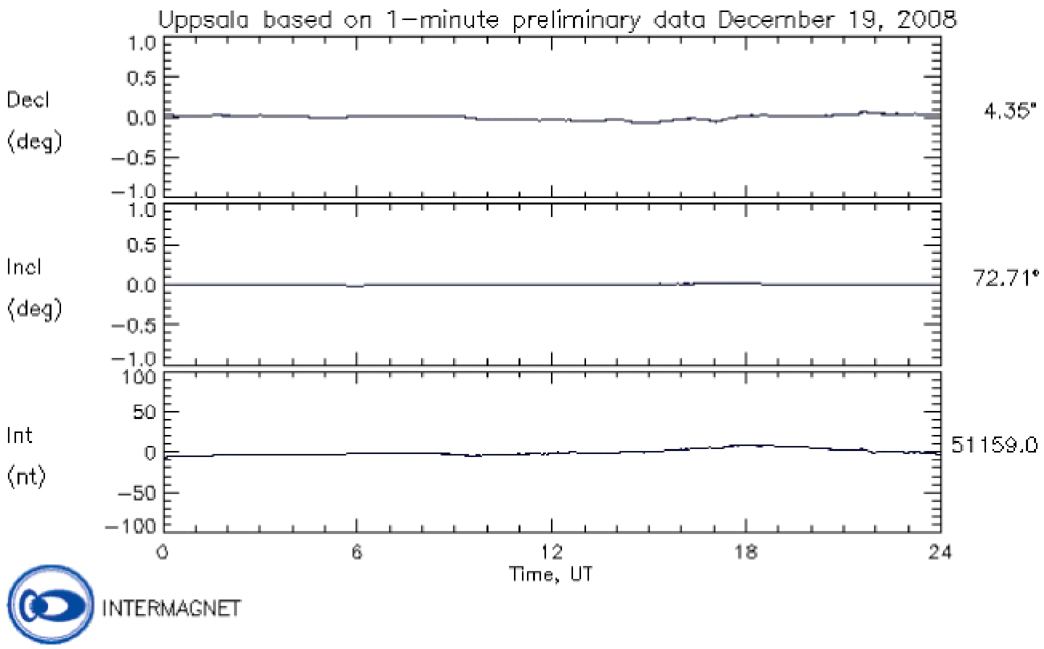


Figure 5-13. Magnetic field variations during Flexit surveys performed on December 19th, 2008, in KFR102A.

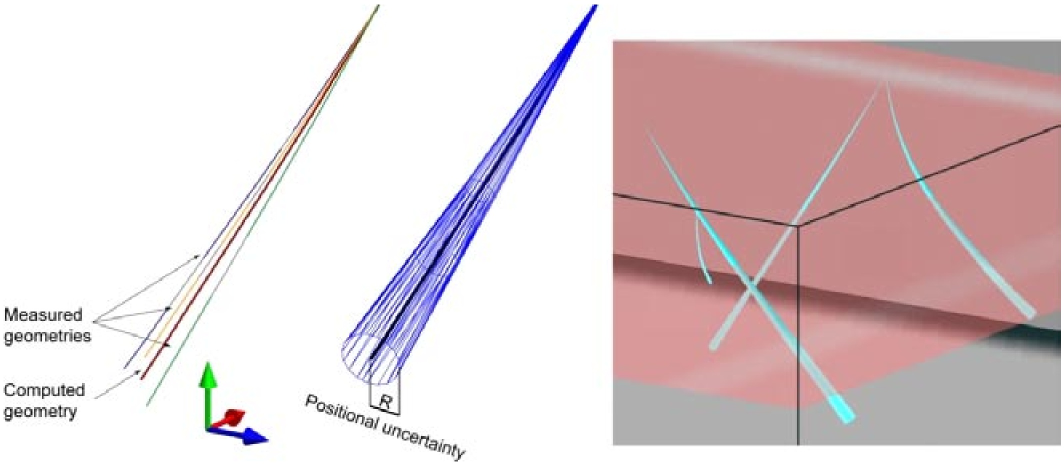


__Figure 5-14.__ The figure to the left is an illustration of the principles for calculating the borehole geometry from several deviation measurements. The two other figures illustrate one of the uncertainty measures used for deviation measurements. In the middle figure, "R" denotes "Radial uncertainty", representing a function, which is monotonously increasing versus borehole length in relation to the borehole axis, defining the shape of a cone surrounding the borehole axis and corresponding to the parameter in the column furthest to the right in Table 5-6. The figure to the right is a block diagram imaging four fictitious boreholes deviating in different ways and with radius uncertainty illustrated as blue cones. (Modified after Figures 4-1, 5-1 and 5-3 in /3/).

Table 5-3. Activity data for all deviation measurements approved for KFR102A (from Sicada). Two magnetic measurements and two Maxibor II^{TM} measurements in the borehole were used for calculation of the final borehole deviation file, as well as for calculation of the deviation uncertainty.

Activity ID	Activity Type Code	Activity	Start Date	Idcode	Secup (m)	Seclow (m)	Flags
13203557	EG161	Maxibor II measurement	2008-12-10 08:15	KFR102A	3.00	597.00	CF
13203559	EG161	Maxibor II measurement	2008-12-10 12:00	KFR102A	3.00	597.00	CF
13203754	EG157	Magnetic – accelerometer measurement	2008-12-19 08:30	KFR102A	3.00	597.00	CF
13203755	EG157	Magnetic – accelerometer measurement	2008-12-19 10:55	KFR102A	3.00	597.00	CF
13204344	EG154	Borehole deviation multiple measurements	2009-01-12 15:00	KFR102A	3.00	597.00	ICF

Table 5-4. Contents of the EG154 file (multiple borehole deviation intervals).

Deviation Activity Id	Deviation Angle Type	Approved Secup [m]	Approved Seclow [m]
13203557	BEARING	3.00	597.00
13203557	INCLINATION	3.00	597.00
13203559	BEARING	3.00	597.00
13203559	INCLINATION	3.00	597.00
13203754	BEARING	87.00	597.00
13203754	INCLINATION	3.00	597.00
13203755	BEARING	87.00	597.00
13203755	INCLINATION	3.00	597.00

Table 5-5. Deviation data from KFR102A for approximately every 50 m vertical length calculated from EG154.

Borehole	Length [m]	Northing [m]	Easting [m]	Elevation [m]	Inclination* [degrees	Bearing* [degrees]
KFR102A	0.00	6701730.30	1633330.21	2.66	–65.64	302.26
KFR102A	51.00	6701741.70	1633312.64	–43.84	–66.21	304.09
KFR102A	99.00	6701752.70	1633296.63	–87.73	–65.87	304.44
KFR102A	150.00	6701764.62	1633279.33	–134.20	–65.53	304.79
KFR102A	201.00	6701776.77	1633261.92	–180.57	–65.19	305.37
KFR102A	249.00	6701788.63	1633245.50	–224.09	–64.78	305.80
KFR102A	300.00	6701801.50	1633227.63	–270.09	–64.12	305.88
KFR102A	351.00	6701814.69	1633209.46	–315.88	–63.55	305.98
KFR102A	399.00	6701827.48	1633192.02	–358.73	–63.02	306.62
KFR102A	450.00	6701841.53	1633173.33	–404.06	–62.45	307.38
KFR102A	501.00	6701855.96	1633154.53	–449.22	–62.24	307.52
KFR102A	552.00	6701870.42	1633135.63	–494.32	–62.06	307.11
KFR102A	600.00	6701884.18	1633117.54	–536.60	–61.48	307.26
KFR102A	600.83	6701884.42	1633117.23	–537.33	–61.48	307.26

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a discrepancy compared to the values seen in Borehole direction surveying (EG151).

A subset of the resulting deviation files and the estimated radius uncertainty is presented in Table 5-6. Figure 5-14 illustrates the principles behind computing the borehole deviation, i.e. the borehole geometry, from several measurements, and also displays the concept of radial uncertainty.

The calculated deviation (EG154-file) in borehole KFR102A shows that the borehole deviates upwards and slightly to the left with an absolute deviation of 30.3 m compared to an imagined straight line following the dip and strike of the borehole start point. 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.

Table 5-6. Uncertainty data for the deviation measurements in KFR102A for approximately every 50 m vertical length calculated from EG154.

Borehole	Northing [m]	Easting [m]	Elevation [m]	Inclination Uncertainty	Bearing Uncertainty	Radius Uncertainty
KFR102A	6701730.30	1633330.21	2.66	0.084	1.042	0.00
KFR102A	6701741.70	1633312.64	–43.84	0.084	1.042	0.38
KFR102A	6701752.70	1633296.63	–87.73	0.084	1.042	0.73
KFR102A	6701764.62	1633279.33	–134.20	0.084	1.042	1.12
KFR102A	6701776.77	1633261.92	–180.57	0.084	1.042	1.50
KFR102A	6701788.63	1633245.50	–224.09	0.084	1.042	1.87
KFR102A	6701801.50	1633227.63	–270.09	0.084	1.042	2.27
KFR102A	6701814.69	1633209.46	–315.88	0.084	1.042	2.68
KFR102A	6701827.48	1633192.02	–358.73	0.084	1.042	3.07
KFR102A	6701841.53	1633173.33	–404.06	0.084	1.042	3.50
KFR102A	6701855.96	1633154.53	–449.22	0.084	1.042	3.93
KFR102A	6701870.42	1633135.63	–494.32	0.084	1.042	4.36
KFR102A	6701884.18	1633117.54	–536.60	0.084	1.042	4.78
KFR102A	6701884.42	1633117.23	–537.33	0.084	1.042	4.78

5.5.8 Groove milling KFR102A

A compilation of length to the reference grooves and a comment on the success of detecting the grooves are given in Table 5-7. The positions of the grooves are determined from the length of the drill pipes used at the milling process. The length is measured from TOC to the upper part of the upper two grooves.

5.5.9 Nitrogen flushing and pumping in KFR102A

The final effort, before the drilling activity is concluded, is to rinse the borehole in order to minimize the contents of drilling debris or other unwanted material left in the borehole. For this purpose, nitrogen flushing is used.

In cored boreholes of traditional type a hydraulic hose is lowered to the borehole bottom and connected to high pressurized nitrogen gas bottles. When the gas reaches the lower end of the hose, gas bubbles are created in the water which will strive upwards through the borehole water column. The volume of the bubbles increases as the static water pressure decreases, towards the borehole outlet. This creates a lifting capacity on the borehole water column that ends with a blow-out, when the compressed nitrogen bubbles reache TOC (top of casing), see Figure 5-15 (to the left).

In SKB´s telescopic boreholes, where the upper section is percussion drilled with a wider diameter, the volume per length unit in that part is seven times larger compared to the lower core drilled part. This has a negative effect on the lifting capacity when the nitrogen flushing is used, as described above. When the lifted water reaches the wider part of the borehole, the flow velocity is decreases and part of the suspended material will settle in the borehole.

Therefore, a modified nitrogen flushing program was applied in KFR102A. The nitrogen hose was lowered to the borehole bottom, whereupon a water-well pump was lowered to the bottom of the wider part, see Figure 5-15 (to the right). This pump had a capacity of 80 L/min which was sufficient to continue the transport of the nitrogen flushed borehole water, through a PEM 40 hose, to the ground surface.

Usually, a borehole is nitrogen flushed, until the recovered return-water is judged (by optical observation) to be clean or with a minimum content of drilling debris. KFR102A was flushed and pumped between December 17th, 16:33, and December18th, 11:32, 2008, before this was achieved. The estimated recovered water volumes of these activities were 135 m^3.

5.5.10 Risk assessment KFR102A

Ensuing completion of drilling activities, an extensive measurement programme will be carried out in the borehole. Some of the measuring tools used are developed especially for this application, and damage or loss of an instrument in a borehole will have considerable impact on costs and time-schedule. Therefore a strategy has been elaborated for risk assessment of the current status of

Table 5-7. Reference grooves in KFR102A.

Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS
100	Yes	Yes *
146	Yes	Yes *
200	Yes	Yes *
249	Yes	Yes *
300	Yes	Yes *
351	Yes	Yes *
400	Yes	Yes *
448	Yes	Yes *
500	Yes	Yes *
550	Yes	Yes *
580	Yes	Yes *

* BIPS not adjusted

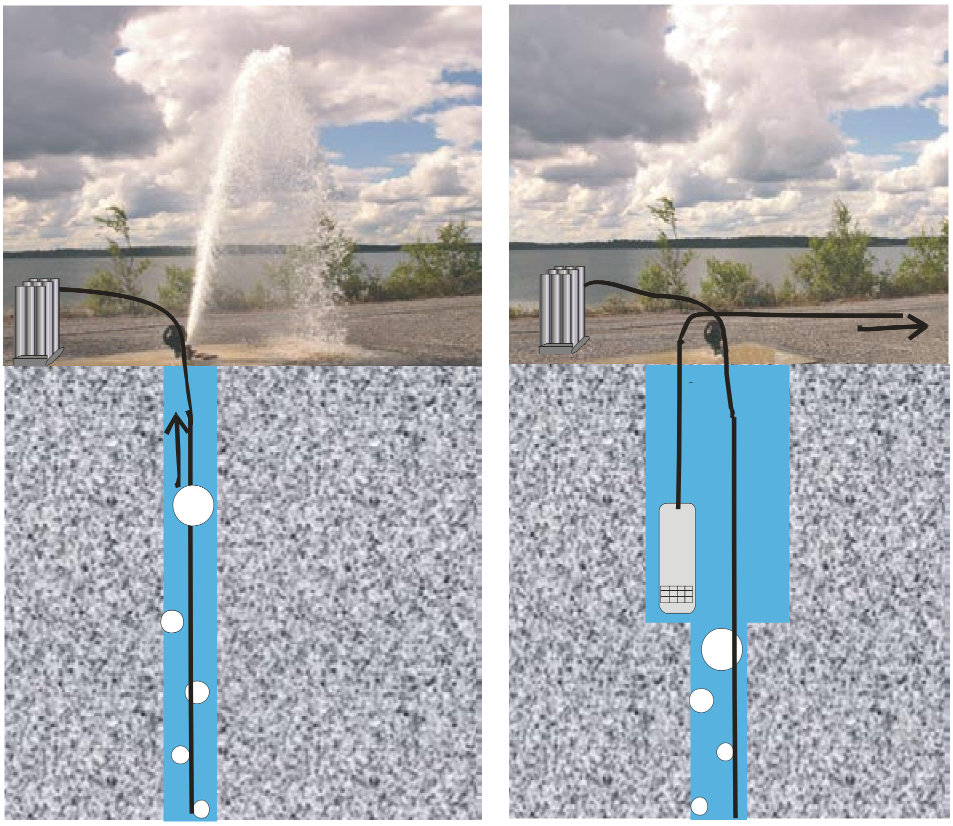


Figure 5-15. Illustration of rinsing boreholes from remaining drilling debris and flushing water after drilling. High pressure nitrogen is forced through a hose to the bottom of the borehole. When the gas expands in the borehole, the mixture of groundwater, flushing water and drilling debris is lifted up from the borehole bottom. When the supply of nitrogen is shut off, the gas- and water outflow ceases. The groundwater level has to recover before additional nitrogen flushing can begin. The figure to the left illustrates this process in a cored borehole of traditional type, whereas the figure to the right displays a telescopic borehole in which an ordinary submersible water-well pump enhances the discharge of water and drill cuttings in the telescopic part of the borehole.

boreholes with bearing on the activities planned in the borehole. This risk assessment will be kept topical throughout the activity period for the borehole and, furthermore, be documented in Sicada.

The risk assessment is based on a classification system consisting of four risk levels, denominated risk classes. These classes are:

0 = no risk observations at all.

1 = an observation of a **potential** risk, but no incident (e.g. very fractured rock observed during drilling).

2 = very serious incident (e.g. probe stuck in the borehole).

3 = borehole collapse.

Following these compulsory guidelines, the risk assessments after finishing the drilling activities of borehole KFR102A are summarized in Table 5-8. Thirty sections of borehole KFR102A have been classified as involving a potential risk (1), meaning that the core section is highly fractured and thus is associated with a risk for rock fallout.

5.6 Consumables

The special type of thread grease (silicon based) used in KFR102A was certified according to SKB MD 600.006, version 1, see Table 1-1. The amounts of oil and grease consumed during drilling of KFR102A are given in Table 5-9.

Table 5-8. Documented sections of potential risk from observations during drilling and preliminary geological core mapping of KFR102A.

From length (m)	To length (m)	Risk level (code)	Description	From length (m)	To length (m)	Risk level (code)	Description
70.42	71.94	1	Lower end of borehole cone, different diameter.	321.70	322.30	1	Fractured zone
71.94	72.02	1	Borehole diameter Ø86,2 mm	322.30	323.30	0	
72.02	93.70	0		323.30	324.00	1	Fractured zone
93.70	94.10	1	Fractured zone	324.00	426.70	0	
94.10	98.70	0		426.70	427.10	1	Fractured zone
98.70	99.10	1	Fractured zone	427.10	427.30	0	
99.10	107.40	0		427.30	430.10	1	Fractured zone
107.40	108.00	1	Fractured zone	430.10	433.50	0	
108.00	146.00	0		433.50	434.10	1	Fractured zone
146.00	146.80	1	Fractured zone	434.10	434.50	0	
146.80	148.30	0		434.50	436.80	1	Fractured zone
148.30	150.20	1	Fractured zone	436.80	438.80	0	
150.20	179.70	0		438.80	439.00	1	Fractured zone
179.70	180.00	1	Fractured zone	439.00	443.40	0	
180.00	193.70	0		443.40	443.90	1	Fractured zone
193.70	194.20	1	Fractured zone	443.90	451.30	0	
194.20	197.20	0		451.30	451.90	1	Fractured zone
197.20	198.50	1	Fractured zone	451.90	456.40	0	
198.50	199.00	0		456.40	456.70	1	Fractured zone
199.00	199.60	1	Fractured zone	456.70	457.30	0	
199.60	210.00	0		457.30	457.70	1	Fractured zone
210.00	211.10	1	Fractured zone	457.70	472.10	0	
211.10	249.30	0		472.10	472.30	1	Fractured zone
249.30	249.80	1	Fractured zone	472.30	473.30	0	
249.80	273.60	0		473.30	474.40	1	Fractured zone
273.60	275.00	1	Fractured zone	474.40	489.40	0	
275.00	283.00	0		489.40	490.00	1	Fractured zone
283.00	283.50	1	Fractured zone	490.00	524.50	0	
283.50	308.00	0		524.50	524.80	1	Fractured zone
308.00	309.50	1	Fractured zone	524.80	600.83	0	
309.50	321.70	0					

Table 5-9. Oil and grease consumption during percussion- and core drilling of borehole KFR102A.

Borehole length from TOC[m]	Hammer Oil Hydra 46 [L]	Thread Grease Unisilicon L50/2 [kg]	Hydraulic Oil ECO 46 [L]	Universal Grease (Statoil) [kg])	Gear Oil Sae 80/90 [L]
0–70.42 m	15	ND*	ND*	ND*	ND*
70.42–600.83 m	ND*	1.5	200**	0.8	1

* ND=Not Detected **Change of Hydraulic Oil

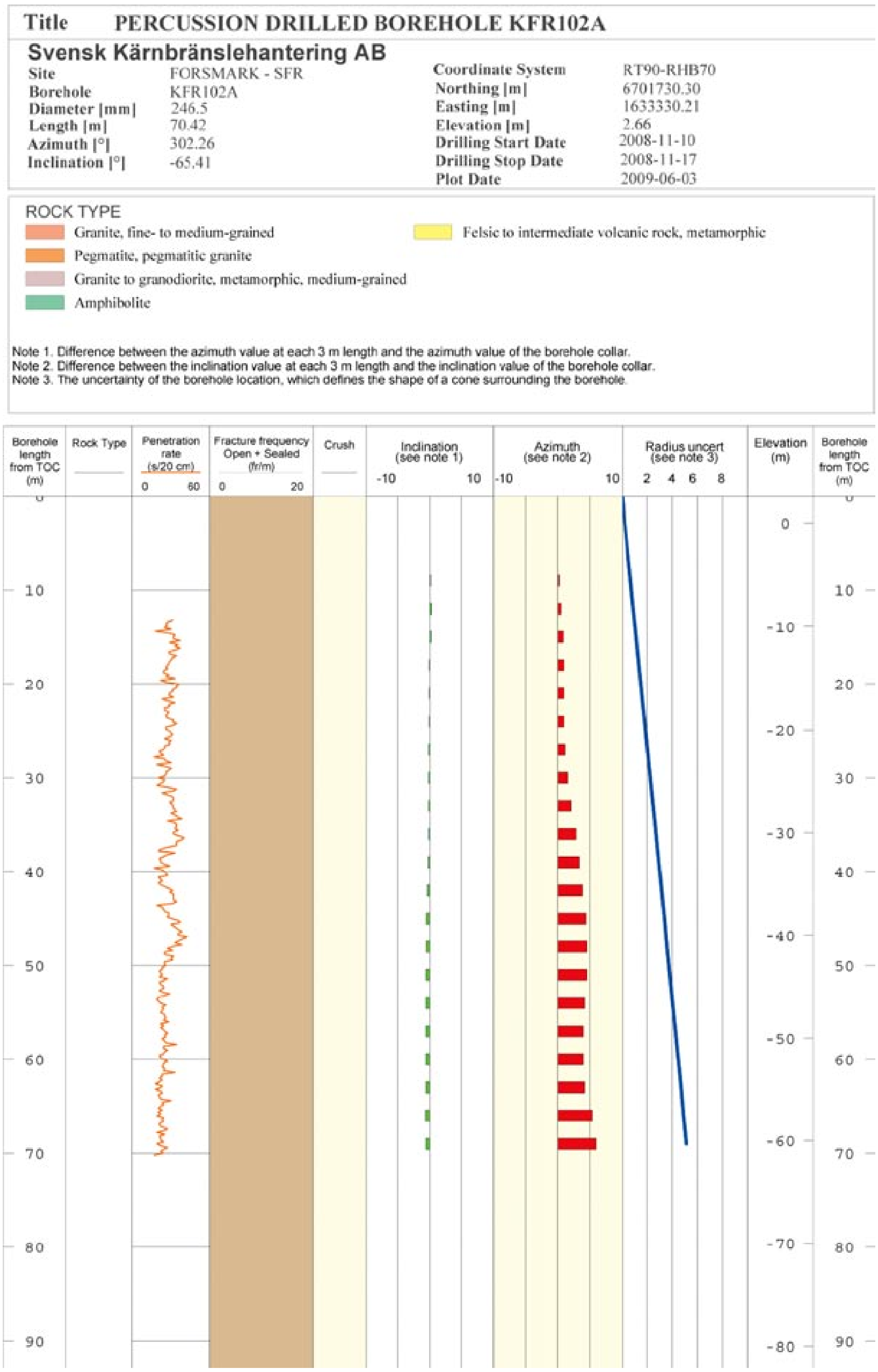
6 References

/1/ **SKB, 2008.** Undersökningsprogram för Projekt SFR-utbyggnad [Investigation programme for the extension of SFR]. SKB R-08-67, Svensk Kärnbränslehantering AB.

/2/ **SKB, 2001.** Program för platsundersökning vid Forsmark. SKB R-01-42, Svensk Kärnbränslehantering AB.

/3/ **Munier R, Stigsson M, 2007.** Implementation of uncertainties in borehole geometries and geological orientation data in Sicada. SKB R-07-19, Svensk Kärnbränslehantering AB.

Well Cad presentation of KFR102A (percussion drilled section)



Well Cad presentation of KFR102A (complete borehole)

Title CORED DRILLED BOREHOLE KFR102A

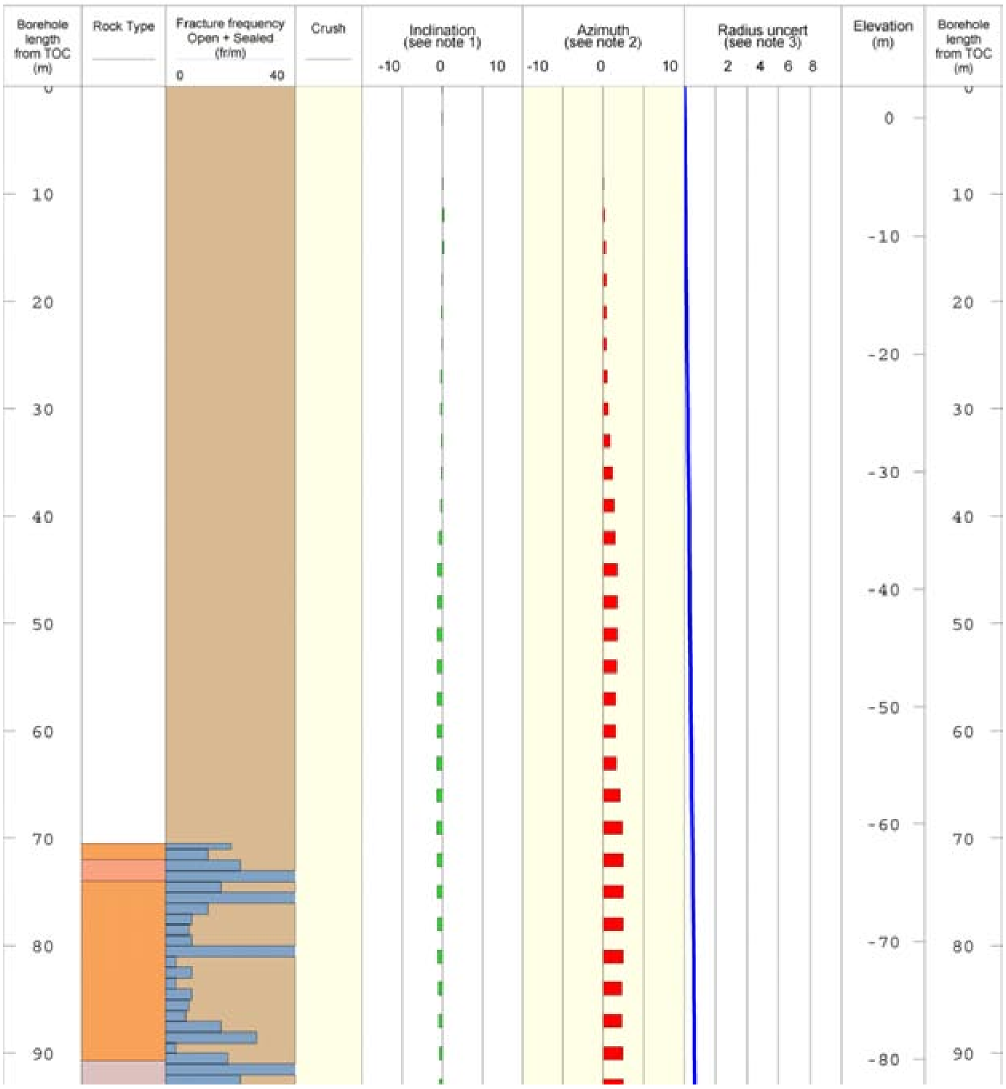
Svensk Kärnbränslehantering AB

Site	FORSMARK - SFR	**Coordinate System**	RT90-RHB70
Borehole	KFR102A	**Northing [m]**	6701730.30
Diameter [mm]	76	**Easting [m]**	1633330.21
Length [m]	600.83	**Elevation [m]**	2.66
Azimuth [°]	302.26	**Drilling Start Date**	2008-11-25
Inclination [°]	-65.41	**Drilling Stop Date**	2008-12-12
		Plot Date	2009-05-25

ROCK TYPE

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

Note 1. Difference between the azimuth value at each 3 m length and the azimuth value of the borehole collar.
Note 2. Difference between the inclination value at each 3 m length and the inclination value of the borehole collar.
Note 3. The uncertainty of the borehole location, which defines the shape of a cone surrounding the borehole.

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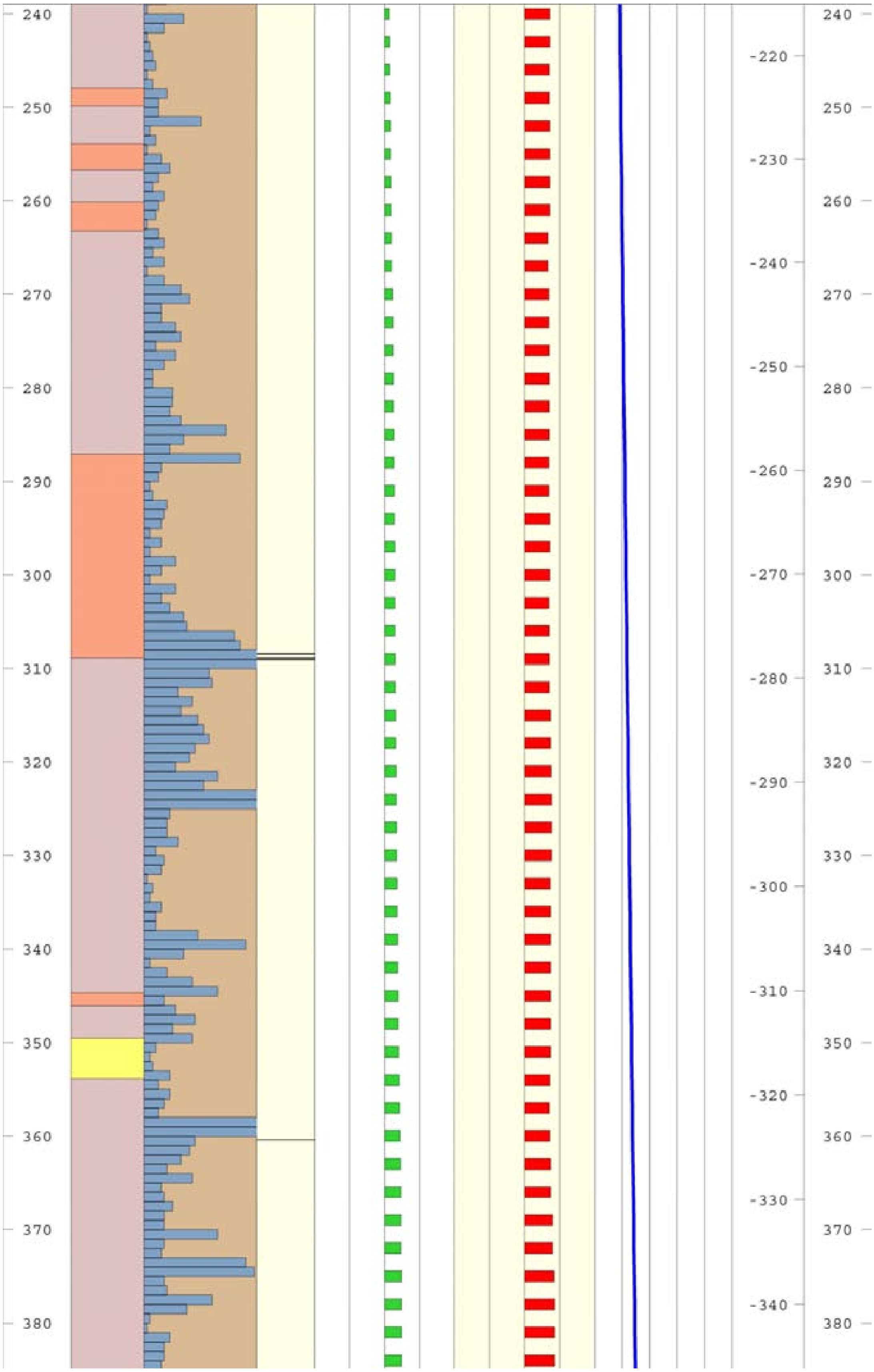
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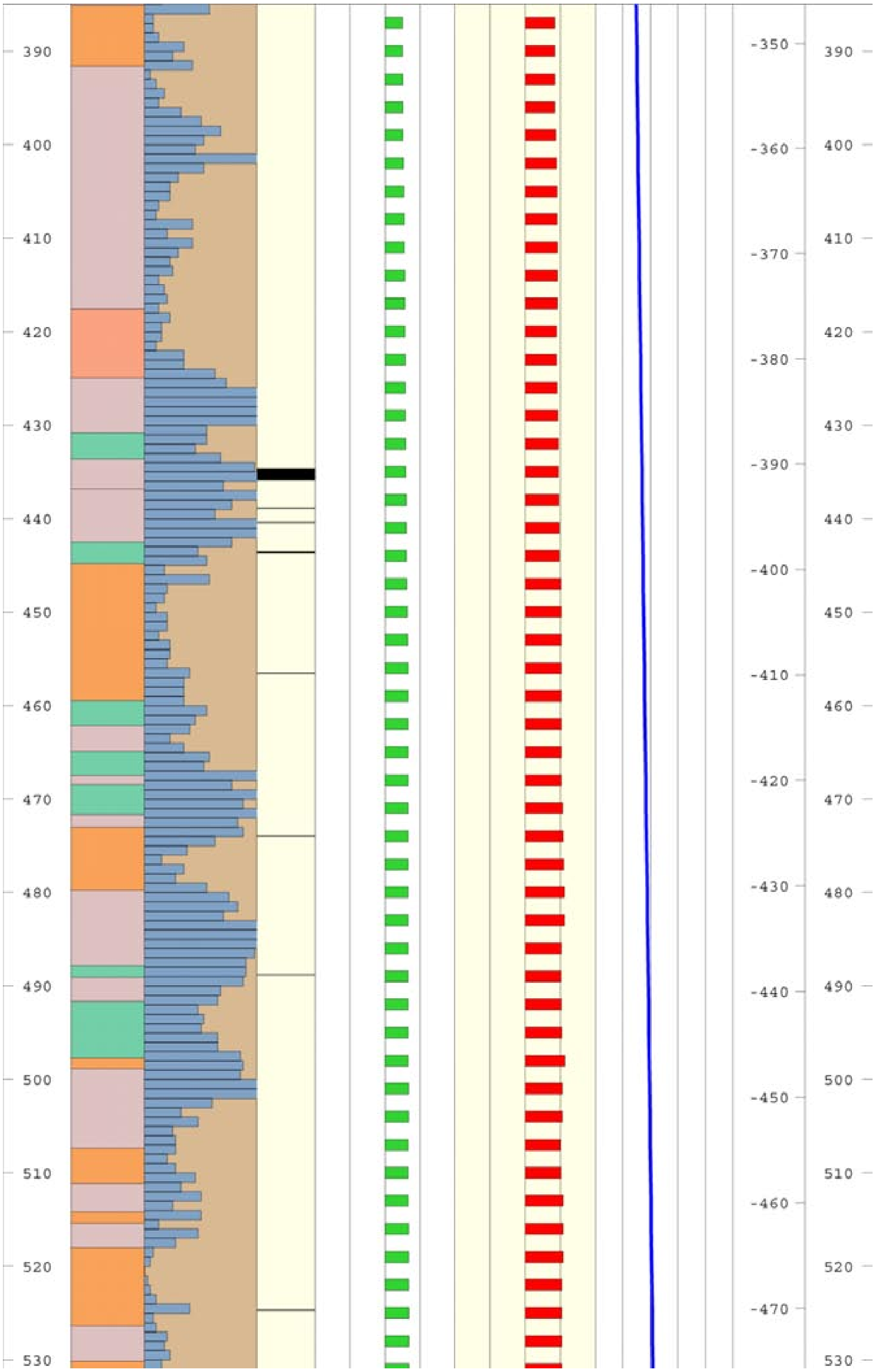
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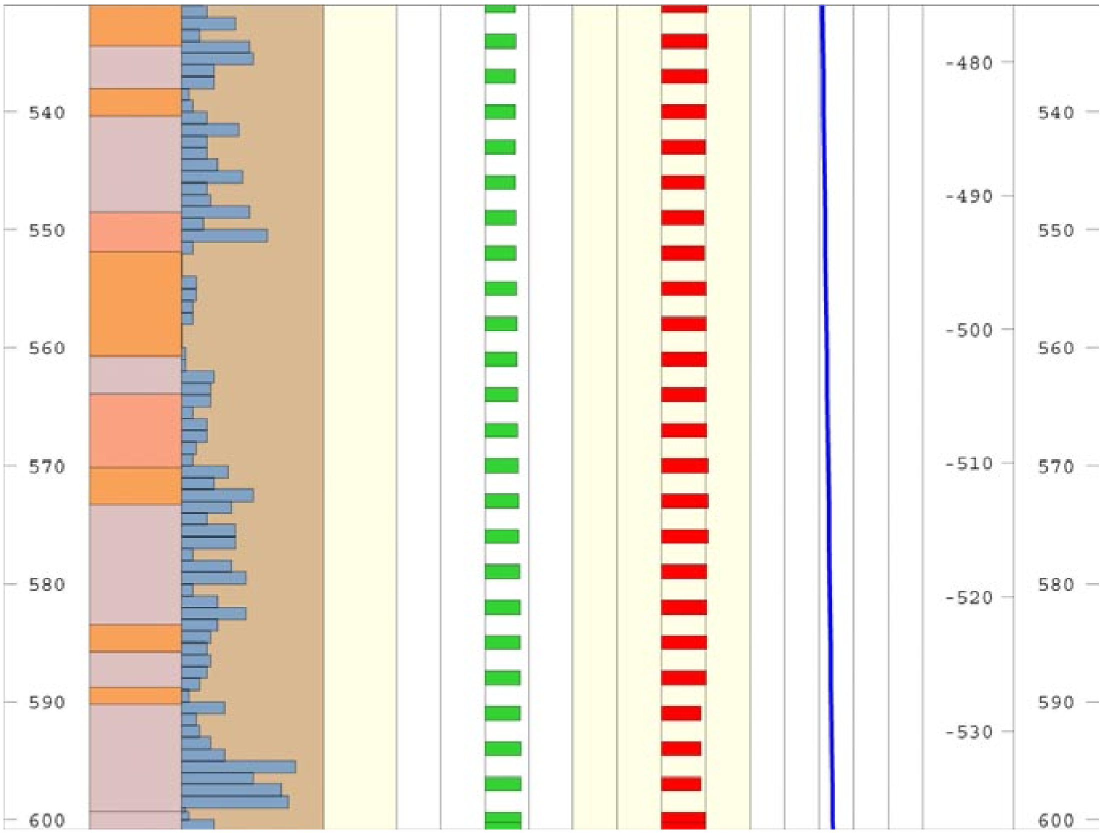
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Appendix C

Water composition KFR102A

Section 70.42 to 125.83 m

Water sampling, class 3

Start Date	Stop Date	Idcode	Secup (m)	Seclow (m)	Sample No	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Hco3 (mg/l)	Cl (mg/l)	So4 S (mg/l)	F (mg/l)	Si (mg/l)	No3 N (mg/l)	No2no3 N (mg/l)	N (mg/l)	Nh4 N (mg/l)	Po4 P Hlysis (mg/l)	P (mg/l)
2008-11-27 15:25	2008-11-27 15:25	KFR102A	70.42	125.83	16172	892.0	5.46	479.0	73.20	68.70	2,250.0	64.10	0.91	5.20	0.0346	6.420	7.54	694.0	52.90	25.20

Section 70.42 to 293.83 m

Water sampling, class 3

Start Date	Stop Date	Idcode	Secup (m)	Seclow (m)	Sample No	Cl (mg/l)	So4 (mg/l)	Br (mg/l)	F (mg/l)	Cond (mS/m)	Uranine Sample (ug/l)	Drill Water (%)
2008-12-01 09:00	2008-12-01 09:00	KFR102A	70.42	293.83	16169	3,730.0	332.00	13.100	1.44	1,090.0	34.10	16.20