P-09-13

Drilling of the cored boreholes KFR101, KFR102B, KFR103 and KFR104

Göran Nilsson, Anders Ullberg, GNC AB

March 2009

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1651-4416
SKB P-09-13

Drilling of the cored boreholes KFR101, KFR102B, KFR103 and KFR104

Göran Nilsson, Anders Ullberg, GNC AB

March 2009

Keywords: P-report SKBDoc id 1203680, Review statement SKBDoc id 1203725, AP SFR-08-001, AP SFR-08-002, Percussion drilling, Core drilling, Project SFR extension

Abstract

Four boreholes in solid rock, KFR101, KFR102B, KFR103 and KFR104, were drilled in the environment around the Forsmark harbour, using traditional core drilling technique in order to retrieve drill cores from the shallow and semi-deep parts of the bedrock. To simplify for the core drilling and shorten the general time schedule, the overburden of the four boreholes was drilled with a percussion drilling method prior to commencement of core drilling.

The first borehole, which is denominated KFR101, is 341.76 m long, inclined 54.44º from the horizon, has a bearing of 28.77º from N, and reaches about 264 m in vertical distance from the ground surface. In order to improve the efficiency of overburden drilling of this and the other three boreholes presented in this report, a percussion drilling machine was employed. A steel casing was installed to 13.72 m borehole length before core drilling. During core drilling total flushing water loss occurred at 18 m drilling length. This entailed that all flushing water and drilling debris remains in the borehole during continued core drilling. A water sample collected in borehole section 281.92–341.76 m was hence contaminated with 50% of flushing water, in spite a water volume turnover in the section of more than 50 times before sampling.

The second borehole, KFR102B, is 180.08 m long, inclined 54.14º and with bearing 344.87º. This borehole reaches about 145 m in vertical distance from the ground surface. During percussion drilling a steel casing of 13.95 m length was installed before core drilling started.

The third borehole, KFR103, is 200.50 m long, inclined 53.91º and has a bearing of 179.87º. This borehole reaches about 161 m in vertical distance from the ground surface. During percussion drilling a steel casing was installed to 13.33 m borehole length prior to start of core drilling.

Finally, the fourth borehole, KFR104, is 454.57 m long, inclined 53.81º and with bearing 133.78º. This borehole reaches about 354 m in vertical distance from the ground surface. During percussion drilling the borehole was supplied with a 8.73 m long steel casing before core drilling commenced.

A sampling- and measurement programme for core drilling of the four boreholes in question provided preliminary but current information about the geological and hydraulic character of the boreholes directly on-site. It also served as a basis for extended post-drilling analyses. E.g. the drill cores together with later produced video images of the borehole wall (so called BIPS-images), were used as working material for the borehole mapping (so called Boremap mapping) performed after drilling. Results of the Boremap mapping of KFR101, KFR102B, KFR103 and KFR104 are included in this report.

After completed drilling of each of the boreholes, 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

Fyra traditionella kärnborrhål, KFR101, KFR102B, KFR103 och KFR104, har borrats på piren intill hamnområdet vid Forsmarks hamn. För att effektivisera jordborrningen och förkorta huvudtidsplanen utnyttjades en hammarborrmaskin som drev ner foderrören genom pirens sprängstensfyllning ner till fast berg.

Det första borrhålet, som benämns KFR101, är 341,76 m långt, är ansatt med 54,44º lutning från horisontalplanet i riktning 28,77º samt når ca 264 m från markytan i vertikal riktning. Ett 13,72 m långt foderrör drevs ner med hammarborrmaskinen. Under den efterföljande kärnborrningen inträffade redan vid 18 m borrlängd total spolvattenförlust, vilket innebar att allt borrkax och spolvatten blev kvar i borrhålet vid den fortsatta borrningen. Detta medförde att ett vattenprov som uttogs i borrhålssektionen 281,92–341,76 m innehöll ca 50 % spolvatten, trots att provtagningssektionen omsattes mer än 50 gånger.

Det andra borrhålet, KFR102B, är 180,08 m långt, är ansatt med 54,14º lutning och har bäringen 344.87º. Hålet når 145 m i vertikal riktning från markytan. Foderröret drevs till 13.95 m borrlängd.

Det tredje borrhålet, KFR103, är 200,50 m långt, är ansatt med 53,91º lutning och har bäringen 179,87º. Hålet når 161 m från markytan i vertikal riktning. Foderrörslängden är 13.33 m.

Slutligen det fjärde borrhålet, KFR104, är 454,57 m långt, är ansatt med 53,81º lutning och 133,78º bäring. Hålet når 354 m i vertikal riktning. Foderrörslängden är 8,73 m.

Ett mät- och provtagningsprogram under kärnborrningen av de fyra aktuella kärnborrhålen gav preliminär information om borrhålens geologiska och hydrauliska karaktär direkt under pågående borrning samt underlag för fördjupade analyser efter borrning. Bland de insamlade proverna utgör borrkärnorna tillsammans med videofilm av borrhålsväggen (s.k. BIPS-bilder), underlagsmaterialet för den borrhålskartering (s.k. Boremapkartering) som utförs efter borrning. Även resultaten från Boremapkarteringen av KFR101, KFR102B, KFR103 och KFR104 finns redovisade i föreliggande rapport.

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

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 bed-rock 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 over-lapping, 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-drilled and five core-drilled boreholes from the ground surface and one core-drilled 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 cored boreholes of traditional type KFR101, KFR102B, KFR103 and KFR104 which constitutes the initial investigation phase of project SFR Extension (SFR Utbyggnad) programme. The core drilling work was carried out in accordance with activity plans AP SFR-08-001 and AP SFR-08-002. 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 1985, KFR27, was rediscovered, although the borehole casing was covered with gravel of one metre thickness below ground surface. As the borehole will be restored, prolonged and used for measurements within the scope of project SFR Extension, a minor drill site was prepared also around this borehole.

Züblin (Sven Andersson in Uppsala AB) was contracted for the pre-drilling through the overburden, whereas Drillcon Core AB was employed for the core drilling commission. Support was provided from SKB-personnel regarding measurements and tests during drilling.

Pre drilling operations through overburden were carried out on May 5–6th (KFR101), May 7th (KFR102B), May 8th (KFR103) and on May 13th (KFR104). Setting of inner casing and grouting of all boreholes were carried out on June 10th, 2008, in compliance with Activity Plan AP SFR-08-001, Version 1.0.

Core drilling and measurements were carried out during the period June 12th to July 2nd (KFR101), August 6th to August 14th (KFR102B), August 15th to August 26th (KFR103) and September2nd to September 29th, 2008, (KFR104)), respectively, in accordance with Activity Plan AP SFR-08-002, Version 1.0.

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

Activity plan	Number	Version
Hammarborrning av borrhål HFR101, HFR102 och HFR105	AP SFR -08-001	1.0
Kärnborrning av borrhål KFR101, KFR102B, KFR103 och KFR104	AP SFR -08-002	1.0
Method descriptions	Number	Version
Metodbeskrivning för hammarborrning	SKB MD 610.003	4.0
Metodbeskrivning för kärnborrning	SKB MD 620.003	
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 undersökningar	SKB MD 600.006	1.0
Metodbeskrivning för genomförande av hydrauliska enhålspumptester	SKB MD 321.003	1.0
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål	SKB MD 224.001	2.0

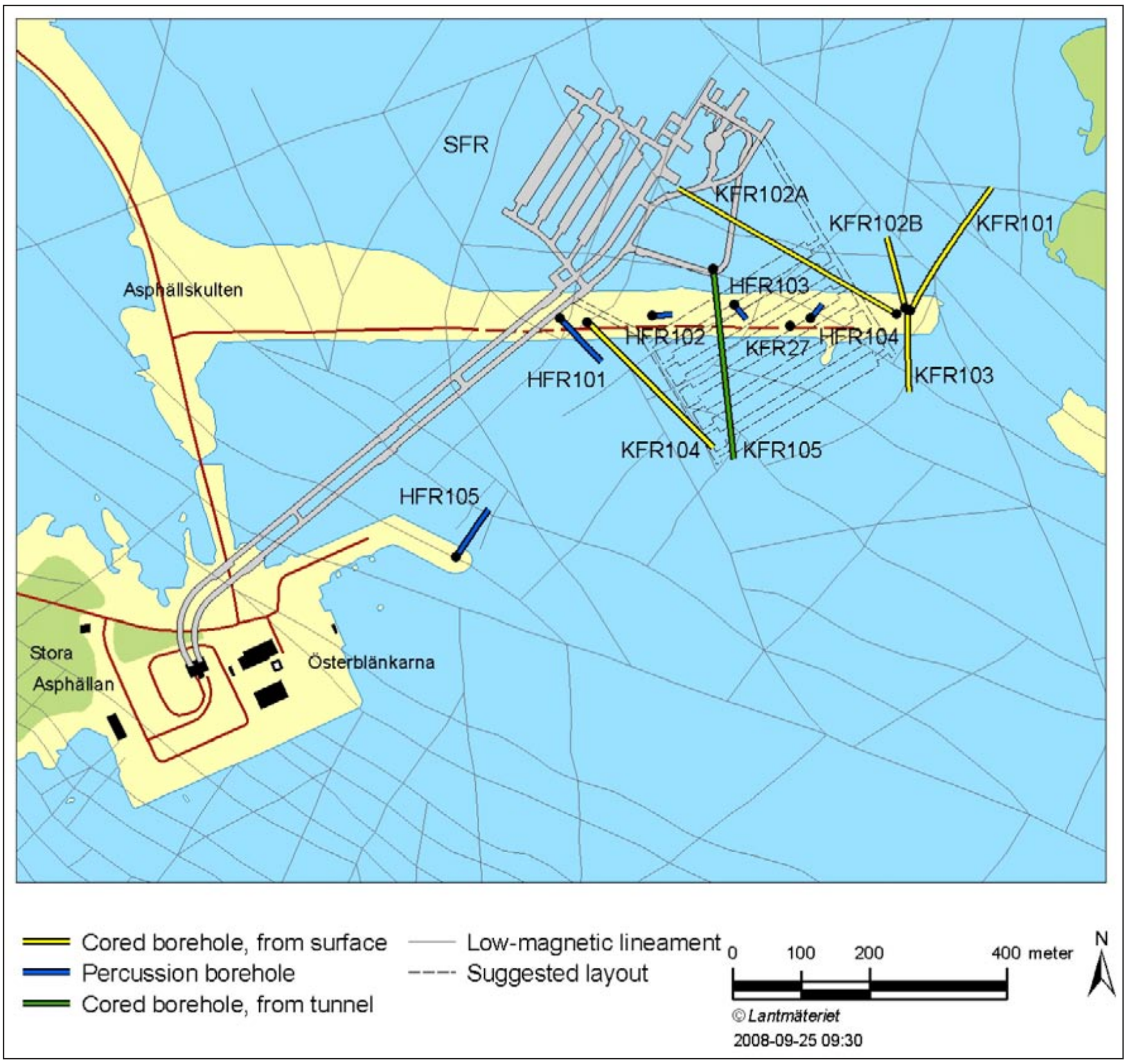


Figure 1-2. *Overview over the SFR site investigation area with planned investigation boreholes. Also the suggested layout of the extended SFR facilities as well as low-magnetic lineaments in the area are displayed.*

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan numbers (AP SFR-08-001 and AP SFR-08-001). 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.

2 Objective and scope

The overall objective of drilling boreholes KFR101, KFR102B, KFR103 and KFR104 was to investigate the rock volume selected for a future extension of SKB's final repository for radioactive operational waste (SFR). The boreholes were specifically drilled to:

- Provide drill cores all the way from the rock surface 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) for characterization of the hydrogeological conditions of the bedrock.
- Enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

The four traditionally drilled cored boreholes were aimed to confirm the current structural model of the site as well as to intersect several, previously not modelled potential deformation zones related to magnetic lineaments with a surface exposure, see Table 2-1.

KFR101 was mainly intended to traverse ZFM0805B (Zone 8 according to previous modelling terminology) and its splay, ZFM0805A, at the end of the borehole, but the borehole geometry also enabled the hole to reach the extension of the near horizontal fracture zone ZFM871 (H2 according to previous terminology) as well as lineament ZFMNW3111.

KFR102B was drilled in order to compensate for the missing drill core in section 0–70 m in KFR102A, but was extended to make an intersection with the magnetic lineament ZFMWNW3145 possible.

KFR103 was directed to the south in order to penetrate several minor magnetic lineaments as ZFMNW8028, ZFMNNE3110 and ZFMWNW3262.

Finally, the longest borehole, KFR104, was aimed to overlap the magnetic lineaments ZFMNE3115 and ZFMNE3112, but also to intersect ZFMNNW3140 and the possible extension to the south-east of ZFM871 (H2). Also lineament ZFMNE3141 was a possible target.

Table 2-1. Borehole ID and zone/lineament identity with predicted borehole length at intersection.

Borehole ID	Zone/Lineament	Predicted intersect [mbhl]
KFR101	ZFM0805B	101–118
	ZFM871 (H2)	
	ZFM0805A (Zone 8)	224–254
	ZFMNW3111	259–283
KFR102B	ZFMWNW3145	150–152
KFR103	ZFMNW8028	44–46
	ZFMNNE3110	77–80
	ZFMWNW3262	168–170
KFR104	ZFMNE3115	159–161
	ZFMNE3112	249–250
	ZFMNNW3140	344–349
	ZFM871 (H2)	353–391
	ZFMNE3141	452–454

3 Equipment

In this chapter a short presentation is given of the drilling systems and the technique applied, as well as of the equipment used for measurements and sampling during drilling. Besides, the instrumentation used for deviation measurements performed after completion of drilling is briefly described.

3.1 Equipment used for the overburden drilling

For overburden drilling of the cored boreholes of traditional type KFR101, KFR102B, KFR103 and KFR104 a Nemek 407 RE percussion drilling rig was employed applying the NO-X 115 system $Ø_o/Ø_i$ 139.7/129.7 mm.

The Nemek 407 RE drilling machine is equipped with separate engines for transportation and power supplies, see Figure 3-1. Water and drill cuttings were discharged from the borehole by means of an Atlas-Copco XRVS 455 Md 27 bars diesel compressor. The air-operated DTH drilling hammer was of type Secoroc 5", descended in the borehole by a Driconeq 76 mm pipe string.

All DTH-components were cleaned before use in the borehole with a Kärcher HDS 1195 high-capacity steam cleaner.

Figure 3-1. *The Nemek 407 RE percussion drilling machine employed for pre-drilling and casing driving through the overburden with the NO-X 115 technique for the cored boreholes KFR101, KFR102B, KFR103 and KFR104.*

3.2 Core drilling system

For drilling of the cored boreholes KFR101, KFR102B and KFR103 a drilling machine from Sandvik, type DE130, was employed. As the succeeding cored boreholes in the programme were planned to be drilled longer, the core drilling machine had to be exchanged to a more powerful system, Sandvik DE150, that was used for drilling of KFR104, see Figure 3-2. This machinery will later be in work also for drilling of a long telescopic borehole.

The manufacturer Sandvik has just recently developed the model Sandvik DE150, that was in use for core drilling of KFR104. Using a brand new drilling rig is seldom entirely favourable, due to the obvious risk of teething problems. In this case repeated disturbances of both the hydraulic rotation unit and the water pump were troublesome, furthermore causing two minor oil discharges. However, after exchanging these units, the drilling of KFR104 was over and done with on the time schedule.

Both core drilling machines were supplied with an electrically-driven hydraulic system. The drilling capacity of a Sandvik DE130 with WL76 is maximum c. 700 metres, whereas the capacity of DE150 is maximum 2,000 m. Both capacity estimates are presupposing the use of AC Corac N3/50 NT drill pipes.

The drill pipes and stainless steel core barrel used constitute a wireline system applied to fit SKB's need for a "triple tube wireline system" with a core dimension slightly exceeding 50 mm. Technical specifications of the drilling machine with fittings are given in Table 3-1.

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 boreholes KFR101, KFR102B, KFR103 and KFR104, 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.

Figure 3-2. *The Sandvik DE130 (to the left) drilled boreholes KFR101, KFR102B and KFR103, while the more powerful rig Sandvik DE150 (to the right) was used for drilling of KFR104.*

Table 3-1. Technical specifications of the Sandvik DE130 and DE150 with appurtenances.

Unit	Manufacturer/Type	Specifications
DE130	Sandvik	Capacity for 76–77 mm holes maximum approx. 700 m
DE150	Sandvik	Capacity for 76–77 mm holes maximum approx. 2,000 m
Flush water pump	Bean	Max flow rate: 170 L/min Max pressure: 103 bars
Submersible pump	Grundfoss SQ	Max flow rate: 200 L/min

3.2.1 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.

A schematic illustration of the flushing/return water system when drilling KFR101, KFR102B, KFR103 and KFR104 is displayed in Figure 3-3. Below, the following equipment systems and their functions are briefly described:

- equipment for preparing the flushing water,
- equipment for measuring flushing water parameters (flow rate and electrical conductivity),
- equipment for storage and discharge of return water.

Preparing the flushing water

The water used for the supply of flushing water for core drilling of KFR101, KFR102B and KFR103 was tap water from Forsmarks Kraftgrupp AB, whereas KFR104 was supplied with flushing water from percussion borehole HFR101 (see Figure 1-2). 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, nitrogene 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 5.2.4.

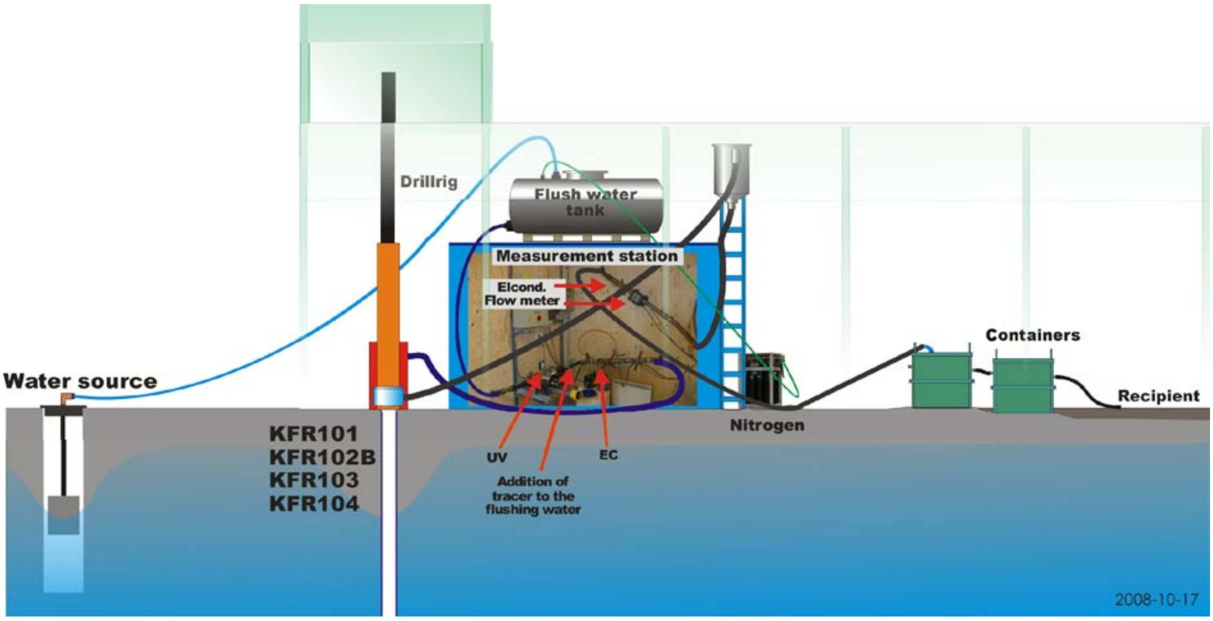


Figure 3-3. *Schematic illustration of the flushing/return water system when drilling KFR101, KFR102B, KFR103 and KFR104. The measurement station included logger units and an UV-radiation unit. The water used for the supply of flushing water for core drilling of KFR101, KFR102B and KFR103 was tap water from Forsmarks Kraftgrupp AB, whereas KFR104 was supplied with flushing water from percussion borehole HFR101.*

Measurement of flushing water parameters

The following two 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. 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 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.

Storage and discharge of return water

The return water was discharged from the borehole via the expansion vessel, a discharge hose, a flow meter and a discharge pipe to two containers (see Figure 3-3), 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 Baltic sea.

3.2.2 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 3-4. After milling, the reference grooves were detected with the SKB level indicator (a calliper instrument). A BIPS-survey provided the final confirmation that the grooves exist.

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

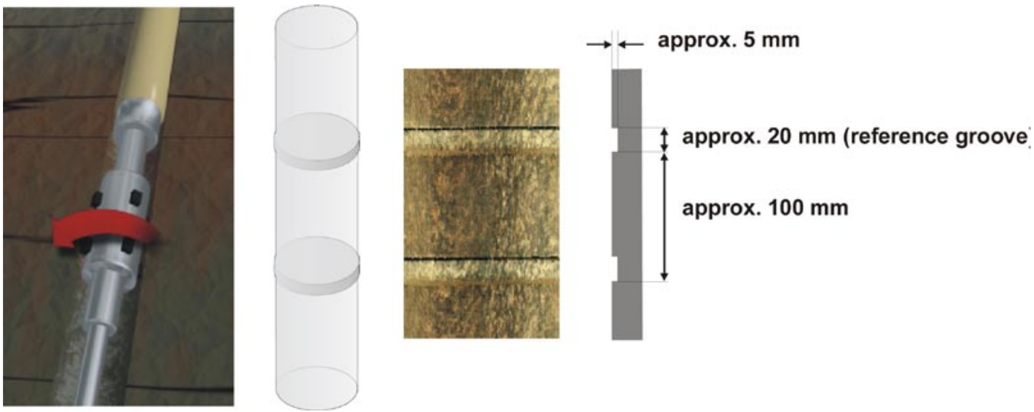


Figure 3-4. Layout and design of reference grooves.

3.3 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 5.2.8, 5.3.7, 5.4.7, and 5.5.7.

3.4 Equipment for borehole stabilization

A new technique for stabilization of borehole walls, designated the Plex technique, has just recently been developed and tested by SKB, see Figure 3-5. The Plex system can be applied for mechanical stabilization of unstable sections of the borehole wall after part of or the entire borehole has been drilled. The system components, comprising a reamer, a packer with a steel plate (perforated or non-perforated) and a top valve, are assembled on top of each other in one single unit. The tool is designed for the N-dimension. By using the same pilot drill bit and ring gauge as used for drilling the borehole in question, the tool is well adjusted to the true borehole diameter. Only one rod trip is required for reaming, expanding the steel tube and verifying the inner diameter of the borehole. Using a perforated or non-perforated steel plate is optional. A perforated plate is applied if hydraulic characterization of the unstable section remains to be done.

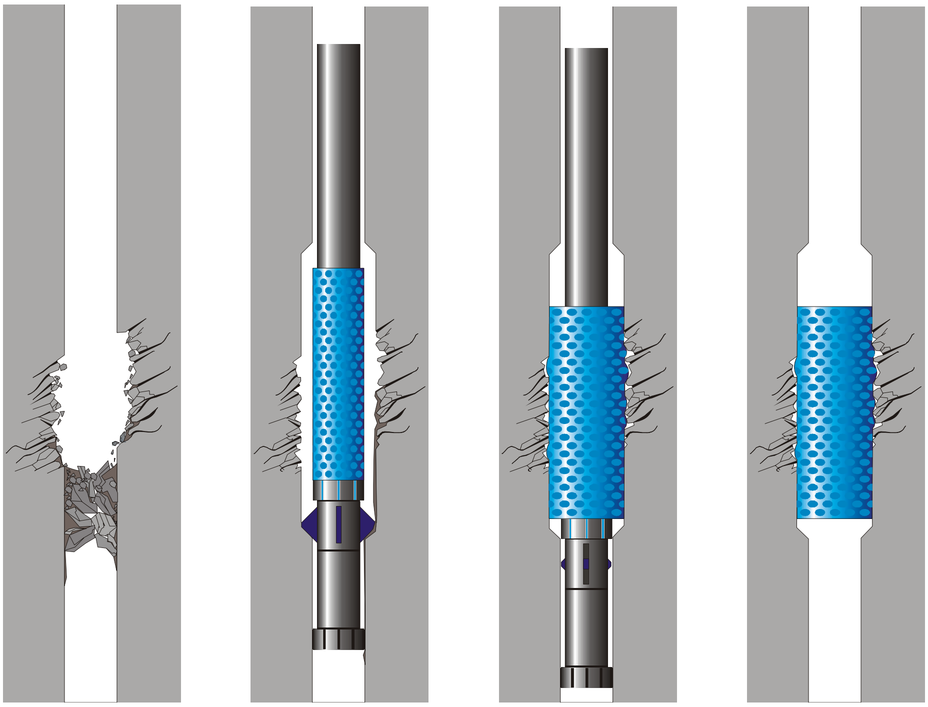


Figure 3-5. *Schematic figure illustrating the sequence of measures when stabilizing a fractured and unstable section in a core drilled borehole of N-dimension with a perforated steel plate by applying the Plex system. 1) The tool is descended, 2) the 200 cm long unstable section is reamed, 3) the packer is inflated as to expand the steel plate against the reamed part of the borehole wall, 4) the packer is deflated and 5) the tool is retrieved. As the steel tube is perforated, the stabilization does not prevent hydraulic testing of the stabilized section.*

4 Execution

4.1 General

The activities were conducted in compliance with Activity Plans AP SFR-08-001 and AP SFR-08-002, which refer to SKB MD 610.003 (Method description for percussion drilling) and SKB MD 620.003 (Method description for core drilling), respectively. The drilling operations for percussion drilling as well as for core drilling included the following parts:

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

Furthermore, the drilling activities were subject to an environmental control programme with the purpose of minimizing the risk of environmental disturbance, for example pollution of the ground layers or groundwater by oil or other contaminants.

These six items are presented more in detail in Sections 4.2–4.7.

4.2 Preparations

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 at level one in accordance with SKB MD 600.004.

4.3 Mobilization

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

4.4 Drilling, measurements and sampling during drilling

4.4.1 Overburden drilling (percussion drilling)

All four drill sites were, prior to commencement of drilling and in a separate activity, prepared according to SKB MD 600.005 (Method instruction for constructing drill sites), aiming at facilitating the drilling operations as much as possible. For example, a reinforced concrete slab was cast around the planned borehole collar to serve as a convenient working space and to enable firm anchorage of the percussion and core drilling machines during drilling. All drill sites were also connected to the local electrical- and data communication nets.

The N-OX 115 percussion drilling with the Nemek 407 RE drilling machine was performed in an opening left in the concrete slab of the respective boreholes (see e.g. Figure 5-4). The overburden prevailing at boreholes KFR101, KFR102B and KFR103 shows similar depths because the boreholes are located close to each other (permitting use of the same concrete slab), whereas the overburden layer at KFR104 is thinner. Technical data of the installed casings are presented in Chapter 5, Section 5.

Due to the limited extent of percussion drilling in each of the four boreholes, the programme for measurements and sampling during drilling was omitted.

4.4.2 Core drilling

Core drilling started from the bottom of the pre-drilled boreholes inside the stainless steel casing that was driven through overburden by the percussion drilling machine prior to core drilling.

Also core drilling is associated with a programme for sampling, measurements and other activities during and immediately after drilling, cf. SKB MD 620.003. Results from the measurements and registrations during core drilling are presented in Chapter 5.

4.5 Finishing off work

The concluding work included the following items:

1) The boreholes were flushed for a few minutes ensuing percussion drilling and for about two hours after completion of core drilling in order to rinse the boreholes from drilling debris adhered to the borehole walls, settled at the bottom of the hole or suspended in the water.
2) The drill string was pulled.
3) The boreholes were, after completed core drilling, secured with a lockable stainless steel flange.
4) The drilling equipment was removed, and after core drilling the site was cleaned and a joint inspection made by SKB and the Contractor to ensure that all agreed work had been executed and that the drill site was left in the same good condition as before drilling.

4.6 Data handling/post processing

Minutes with the following headlines: Activities, Cleaning of equipment, Drilling, Borehole, Percussion drilling penetration rate, Deliverance of field material and Discrepancy report were collected by the Activity Leader, who made a control of the information, and had it stored in the SKB database Sicada. The minutes are traceable by the respective Activity Plan numbers.

4.7 Environmental programme

A programme 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 archives.

4.8 Nonconformities

The core drilling operation in KFR101, KFR102B, KFR103 and KFR104 resulted in a number of nonconformities with the Method Descriptions and Activity Plans. Table 4-1 below presents a comparison of the suggested performance of KFR101, 102B, 103 and 104 according to SKB MD 620.003 and the Activity Plan AP SFR-08-002 with the real performance.

Table 4-1. Programme for performance and frequency of sampling, measurements, registrations and other activities during and immediately after core drilling of KFR101, KFR102B, KFR103 and KFR104 according to SKB MD 620.003, AP SFR-08-002.

Activity	Performance and frequency according to SKB MD 620.003	Performance and frequency during drilling of KFR101	Performance and frequency during drilling of KFR102B	Performance and frequency during drilling of KFR103	Performance and frequency during drilling of KFR104
Registration of drilling- and flushing water parameters.	Registration during the entire drilling.	According to programme. (Methods described in Section 3.2.1.)	According to programme (Methods described in Section 3.2.1.)	According to programme. (Methods described in Section 3.2.1.)	According to programme. (Methods described in Section 3.2.1.)
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.	According to programme.	According to programme	According to programme
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	One Maxibor measurement after completion of drilling and four measurements with Flexit.	One Maxibor measurement after completion of drilling and four measurements with Flexit.	Two Maxibor measurements after completion of drilling and two measurements with Flexit.	Two Maxibor measurements after completion of drilling and two measurements with Flexit.
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.	No measurements performed.	No measurements performed.	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.	One measurement performed.	No measurements performed.	No measurements performed.	No measurements performed.
Absolute pressure measurements.	Normally during natural pauses in drilling.	No measurements performed.	No measurements performed.	No measurements performed.	No measurements performed.
Groove milling in the borehole wall, normally at each 50 m drilling length.	Normally performed after completion of drilling.	Five grooves milled.	Three grooves grooved.	Four grooves grooved.	Nine grooves milled.

5 Results

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity plan numbers (AP SFR-08-001 and AP SFR-08-002).

This chapter is structured as follows:

- Section 5.1 – General,
- Section 5.2 – Results KFR101,
- Section 5.3 – Results KFR102B,
- Section 5.4– Results KFR103,
- Section 5.5 – Results KFR104.

Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling. Well Cad presentations of boreholes KFR101, KFR102A, KFR103 and KFR104 are shown in Appendix A, Appendix B, Appendix C and Appendix D, respectively.

Results from analyses of a water sample from KFR101 are displayed in Appendix E.

5.1 General

5.1.1 Borehole geometrical data and overburden stratigraphy

All cored boreholes presented in this report are located on the pier at Asphällskulten, see Figure 1-2. The pier functions as a breakwater for the SFR harbour and 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 used rock material delivered from the excavation during 1973–1974 of the FKA cooling water tunnel, whereas the ballast used during the second phase originated from the excavation of the SFR facility during 1982–1988.

Prior experiences have demonstrated that core drilling through an overburden of this composition could be technically difficult and time consuming. Therefore, to speed up the core drilling performance, a percussion drilling machine was employed for drilling through the overburden of all four planned cored boreholes. In addition, also an inner stainless steel casing (Ø88/77 mm) for these boreholes was installed and cement grouted in a campaign after mounting the outer casing and just prior to start of core drilling.

Figure 5-1 provides an overview of the drilling performance of the four cored boreholes KFR101, KFR102B, KFR103 and KFR104.

In order to achieve geological/geotechnical information from the upper part of the bedrock, just below the overburden, by retrieval of drill cores , pre-drilling/casing driving was limited to only c. 1 m into firm bedrock, see presentation in Table 5-1 of borehole and casing geometrical data after pre-drilling. The stratigraphy encountered during percussion drilling through the overburden is presented in Table 5-2.

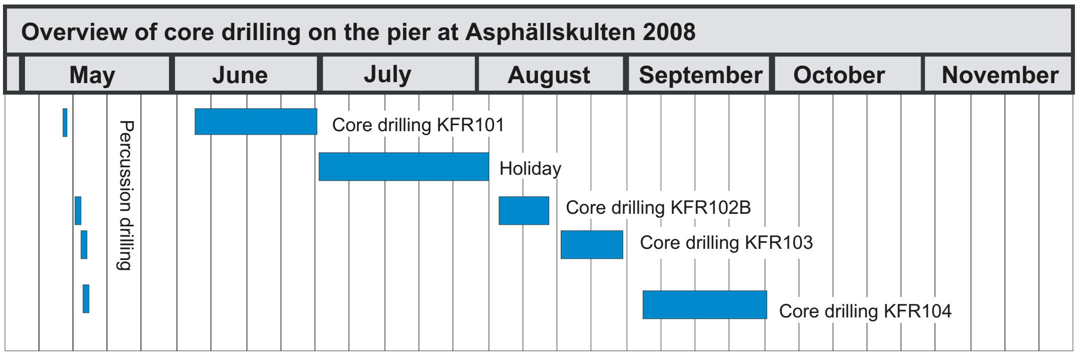


Figure 5-1. *Overview of the drilling performance of the four cored boreholes of traditional type, KFR101, KFR102B, KFR103 and KFR104, located on the pier at Asphällskulten.*

Table 5-1. Borehole and casing dimensions by percussion drilling through the overburden.

Borehole ID	NO-X 115 Outer casing diameter $Ø_o$/ $Ø_i$ = (139.7/129.7 mm) [mbl* from TOC]	Inner casing diameter $Ø_o$/ $Ø_i$ =(88/77 mm) [mbl from TOC]	Borehole diameter [mm]	Vertical depth from ground surface to rock surface [m]
KFR101	0.42–13.72	0–13.72	152	10
KFR102B	0.40–13.95	0–13.95	152	9.8
KFR103	0.20–13.33	0–13.33	152	9.5
KFR104	0.40–8.73	0–8.73	152	6.1

* mbl=metres borehole length

Table 5-2. Stratigraphy encountered during percussion drilling through the overburden at boreholes KFR101, KFR102B, KFR103 and KFR104.

KFR101		KFR102B		KFR103		KFR104	
Vertical depth from ground surface [m]	Stratigraphy	Vertical depth from ground surface [m]	Stratigraphy	Vertical depth from ground surface [m]	Stratigraphy	Vertical depth from ground surface [m]	Stratigraphy
0–6.1	Blasted rock	0–6.1	Blasted rock	0–5.7	Blasted rock	0–4.1	Blasted rock
6.1–10.0	Clay, gravel and moraine	6.1–9.8	Clay, gravel and moraine	5.7–9.5	Clay, gravel and moraine	4.1–6.1	Clay, gravel and moraine
10.0–10.9	Firm rock	9.8–11.00	Firm rock	9.5–10.6	Firm rock	6.1–6.8	Firm rock

Usually, the shallow parts of the bedrock in this area is highly fractured and can often cause complete water loss during core drilling, entailing that flushing water and drill cuttings are forced into the permeable parts of the rock. This happened in KFR101, and at c. 18 m drilling length, all flushing water was lost. On the other hand, during drilling of the second borehole, KFR102B, all flushing water was completely recovered. Finally, when drilling of borehole KFR103 started, nitrogen flushing in KFR102B was in progress. When flushing water loss occurred at c. 18 m length in KFR103, it affected the nitrogen flushing in KFR102B, so that the gas- and groundwater outflow almost ceased. This indicates some kind of hydraulic connection between the two boreholes, in spite of the initial impression that the rock penetrated by KFM102B is hydraulically non-transmissive.

The intense drilling and flushing activities have probably caused an opening up of sub-horizontal fractures just below the casings, resulting in a gently dipping hydraulic connection at shallow depth between the three boreholes KFR101, KFR102B and KFR103.

Finally, after exchanging the Sandvik DE130 drilling machine to the more powerful Sandvik DE150 system, borehole KFR104 was drilled to 454.57 m during September 2008. Ensuing drilling, geophysical logging was conducted. When the radar logging tool was lowered into the borehole, it got caught in a fracture zone at c. 276 m borehole length. To fulfil the measuring programme, it was necessary to stabilize the section in order to enable future borehole investigations, for example with the Posiva Flow Log for characterizing of hydraulic conditions. The drilling machine was re-established to the drill site, and a so called Plex-plate /6/, was installed in borehole section 275.90–277.90 m.

The core drilled borehole sections, the borehole diameter and type of drilling system used are displayed in Table 5-3.

5.1.2 Consumables

The amounts of grout used for gap injection of the casings for KFR101, KFR102B, KFR103 and KFR104, respectively, are reported in Table 5-4. For mixing of the grout, the following receipt was used; 50 kg Standard Portland cement, 1 kg Calcium Chloride and 21 L water.

The consumption of cement is proportional to the length of the casing of the respective boreholes, meaning that the gap between casings are completely filled and no grout was injected into the bedrock.

The SKB Method Instructions for the use of chemical products and material during drilling and surveys are displayed in Table 1-1. The amount of oil products (thread grease, hydraulic oil and gear oil) consumed during drilling of the respective boreholes is presented in Table 5-5. The special type of thread grease (silicon based) used in these particular boreholes was certified according to SKB MD 600.0006, version 1.

Table 5-3. Core drilled borehole sections, borehole diameter and type of drilling system applied.

Borehole ID	Section [from TOC m]	Borehole diameter [mm]	Drilling system
KFR101	13.72–341.76	75.8	Sandvik DE130
KFR102B	13.95–180.08	75.8	Sandvik DE130
KFR103	13.33–200.50	75.8	Sandvik DE130
KFR104	8.73–454.57	75.8	Sandvik DE150

Table 5-4. Cement consumption for grouting the percussion drilled part of boreholes KFR101, KFR102B, KFR103 and KFR104, respectively.

Borehole ID	Cement [kg]	CaCl [kg]	Grouting method
KFR101	125.0	2.5	Hose
KFR102B	105.0	2.1	Hose
KFR103	110.0	2.2	Hose
KFR104	55.0	1.1	Hose

Table 5-5. Oil and grease consumption during percussion drilling and core drilling of boreholes KFR101, KFR102B, KFR103 and KFR104, respectively.

Borehole ID	Preem Hydra 46* [L]	Thread grease Unisilicon L50/2** [kg]	Hydraulic Oil ECO 46** [L]	Universal Grease Statoil** [kg]	Gear Oil Sae 80/90** [L]
KFR101	1	1.5	15	0.5	1
KFR102B	1	0.5	ND***	0.5	ND***
KFR103	1	0.5	ND***	0.5	1
KFR104	1	1.5	35	1.0	4

* Percussion drilling
** Core drilling
*** Not detectable

5.1.3 Borehole geometrical definitions

After drilling is finished, usually an intensive measurement programme is carried out in the borehole. In order to perform these measurement in a rationale 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 definition of borehole geometrical data must be available shortly after completed drilling. In Figure 5-2 some important borehole geometrical definitions for the upper part of a borehole are given. 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.

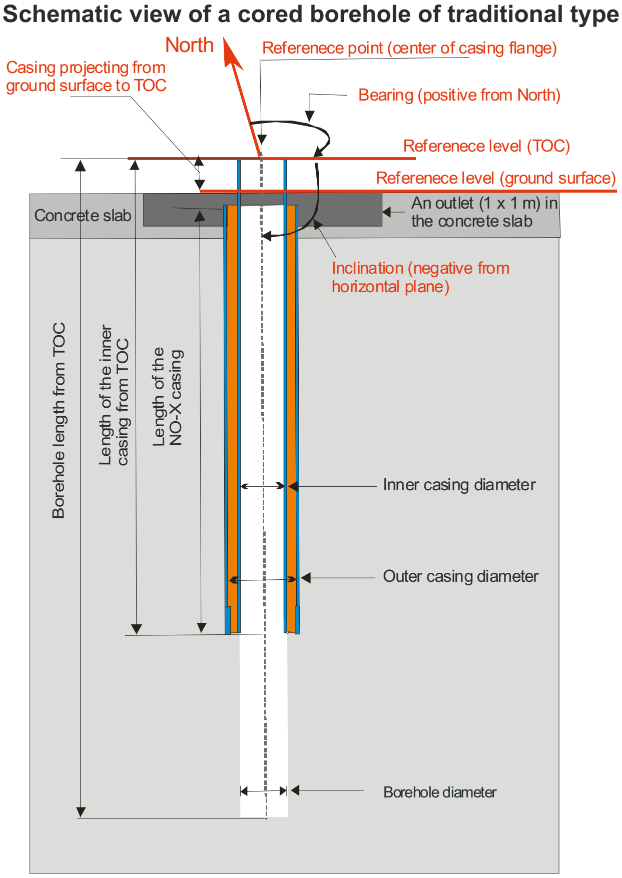


Figure 5-2. *Schematic drawing of a cored borehole of traditional type. The figure presents definitions of some crucial borehole geometrical data. Cf. Figures 5-6, 5-18, 5-30 and 5-42.*

5.2 Results KFR101

Usually, for drilling of cored boreholes of traditional type, the same drilling machine is used for overburden drilling and core drilling. As mentioned in Section 5.1, in the present case the overburden was percussion drilled. This was performed between May 5th and May 6th, while setting and gap injection of the inner casing was carried out on June 10th, 2008. Finally, core drilling was conducted between June 12th and July 2nd, 2008, see Figure 5-3.

5.2.1 Overburden drilling

Percussion drilling through the overburden is a rapid drilling method compared to core drilling, and was therefore chosen in order to shorten the drilling period for each borehole. Pre-drilling of KFR101 was accomplished during two working periods (cf. Figure 5-3) 2008-05-05 to 2008-05-06 (percussion drilling NO-X 115) and 2008-06-10 (setting of inner casing and gap injection), see Figure 5-4.

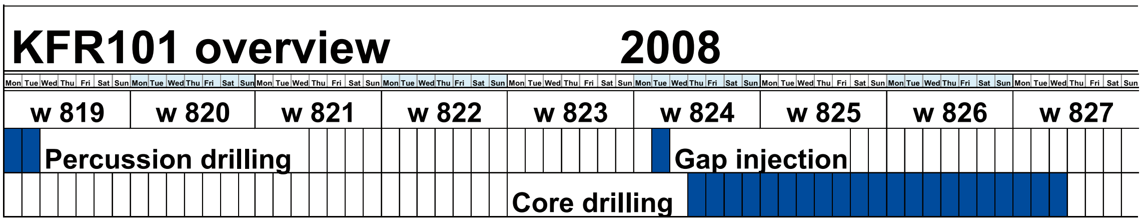


Figure 5-3. Overview of the drilling performance of borehole KFR101.

***Figure 5-4.** Installation of the inner casing was performed almost a month after completion of the percussion drilling. In KFR101 the section 0–13.72 m was supplied with an 88/77 mm stainless steel casing and the gap between the NO-X casing and the inner casing was cement grouted with use of the hose shown in the figure, from the bottom and upwards.*

The composition of the overburden at KFR101 as displayed in Table 5-2 may be commented on. The overburden at the pier is mostly consisting of blasted rock, at KFR101 reaching a vertical depth of 6.1 m from ground surface. Below that depth, the former sea bottom is encountered consisting of clay and gravel on top of a layer of morain, which is resting on the solid rock. The total thickness of these soil layers is 3.9 m. Consequently the vertical depth of the overburden from ground surface to rock surface is 10 m.

Similar geological results were achieved from KFR101, KFR102B and KFR103, depending on that the three boreholes have equal inclination (~ 55º from horizontal plane) and are located on the same concrete slab, only a few metres from each other, at the eastern end of the pier. KFR104 is also located on the pier, but 300 m to the west, and here the overburden turned out to be thinner, cf. Section 5.5.1.

5.2.2 Core drilling

Almost immediately after completion of the pre-drilling activities, core drilling commenced. The progress of the core drilling from 2008-06-12 to 2008-07-02, is illustrated in Figure 5-5.

5.2.3 Geometrical and technical design of borehole KFR101

Administrative, geometric and technical data from borehole KFR101 are presented in Table 5-6. The technical design of the borehole is illustrated in Figure 5-6.

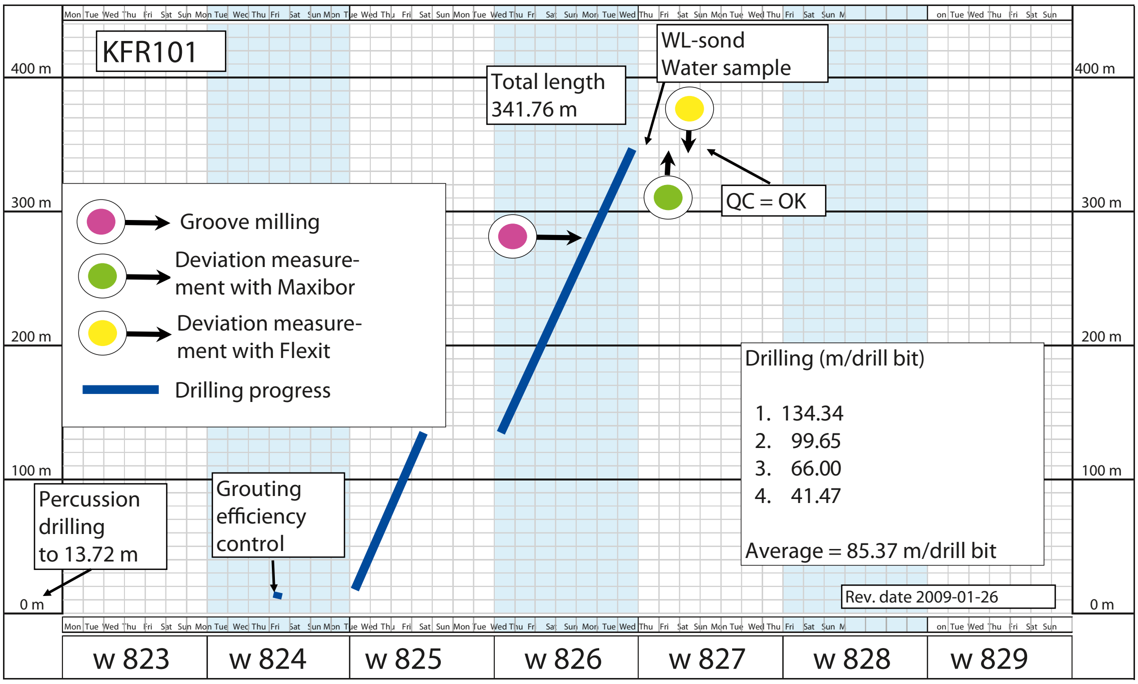
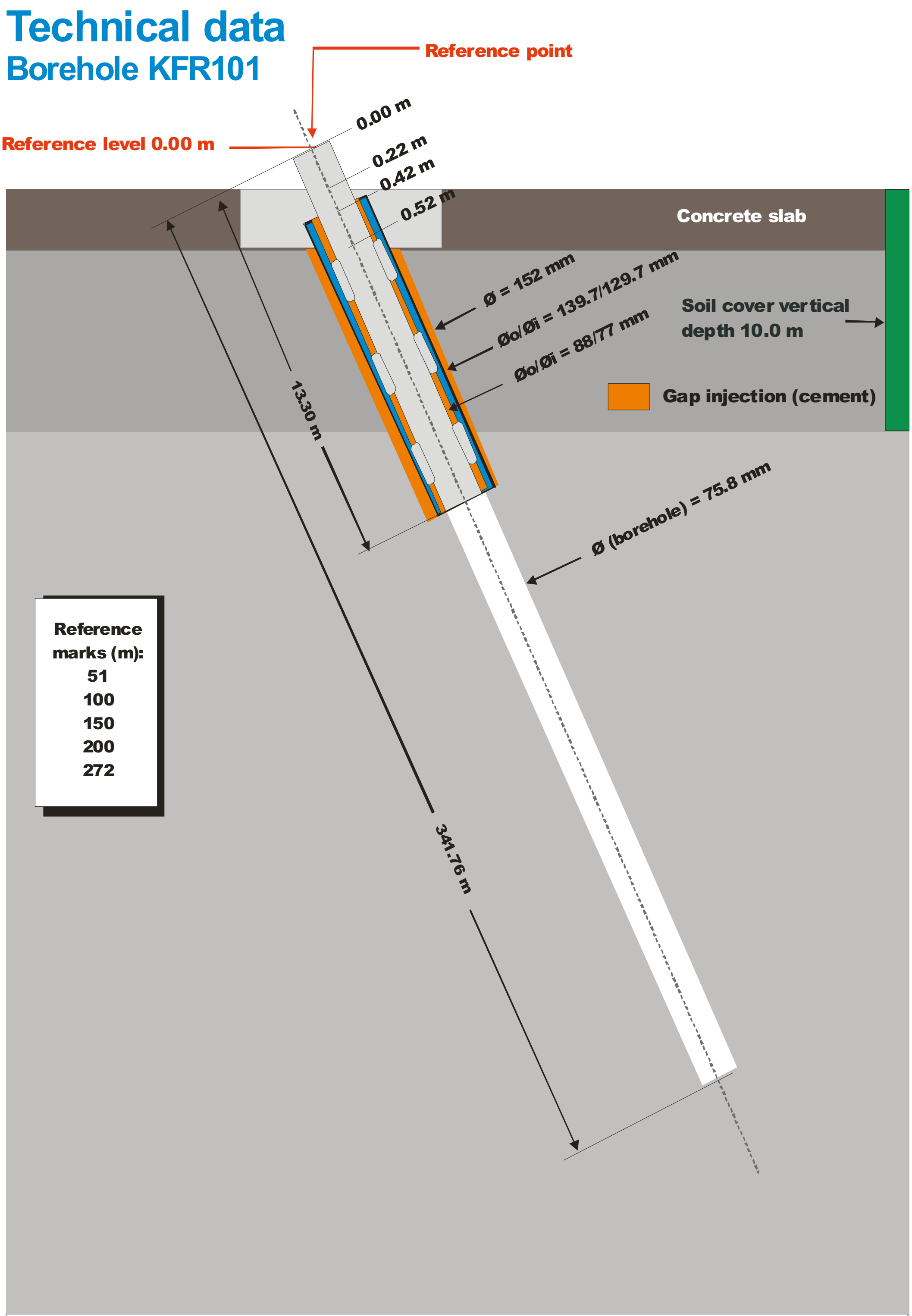


Figure 5-5. Core drilling progress KFR101 (length versus calendar time).

Table 5-6. Administrative, geometric and technical data for borehole KFR101.

Parameter	Data
Borehole name	KFR101
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	May 05, 2008
Completion date	July 02, 2008
Percussion drilling period	2008-05-05 to 2008-05-06
Core drilling period	2008-06-12 to 2008-07-02
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Züblin Svenska AB; Sven Andersson i Uppsala AB
Percussion drill rig	Nemek 407 RE
Core drill rig	Sandvik DE130 (Onram 1000/3)
Position at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6701736.32 (m) E 1633351.40 (m) Z 2.44 (m RHB 70) Azimuth (0–360°): 28.77° Dip (0–90°): –54.44°
Position at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6701916.07 E 1633469.62 Z –262.03 (m RHB 70) Azimuth (0–360°): 37.22° Dip (0–90°): –44.12°
Borehole length	341.76 m
Borehole length and diameter	From 0.52 m to 13.72 m: 0.152 m From 13.72 m to 341.76 m: 0.0758 m
Outer casing, diameter and drilling length	Casing $Ø_o/Ø_i$ = 139.7 mm/129.7 mm 0.42 to 13.60 m Casing shoe $Ø_i$ = 122 mm between 13.60 and 13.64 m Casing shoe bit $Ø_o/Ø_i$ = 152 mm/116 mm between 13.64 and 13.72 m
Inner casing, diameter and drilling length	$Ø_o/Ø_i$ = 80/77 mm 0 to 13.72 m
Drill core dimension	13.72–341.76 m / Ø 50 mm
Core interval	13.72–341.76 m
Average length of core recovery	2.85 m
Number of runs	120
Diamond bits used	4
Average bit life	85.37 m



Drilling reference point

Northing:	6701736.32 (m), RT90 2,5 gon V 0:-15
Easting:	1633351.40 (m), RT90 2,5 gon V 0:-15
Elevation:	2.44 (m), RHB 70

Orientation

Bearing (degrees):	28.77°
Inclination (degrees):	-54.44°

Borehole

Length:	341.76 m

Percussion drilling period

Drilling start date:	2008-05-05
Drilling stop date:	2008-05-06

Core drilling period

Drilling start date:	2008-06-12
Drilling stop date:	2008-07-02

Rev. 2009-03-24

Figure 5-6. *Technical data of borehole KFR101.*

5.2.4 Measurement while drilling

During, and immediately after drilling, a programme for sampling and measurements was applied, cf. Section 4.4.2. Some of the results are displayed in the Well Cad presentation in Appendix A, whereas other results (flow data and electrical conductivity) are primarily used as supporting data for on-site decisions.

Flushing water and Return water flow rate – water balance

Figure 5-7 displays the accumulated volumes of flushing water respectively return water from the entire drilling period. The accumulated volumes of flushing water and return water are also illustrated in the histogram in Figure 5-8, from which the return water/ flushing water quotient at the end of the drilling period may be calculated, in this case resulting in the very low quotient 0.01, due to complete flushing water loss in the highly fractured section just below the casing for KFR101.

Uranine content 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 5-9. 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.

In drilling situations with a continuous yield of return water, which consists of a mixture of (unlabelled) groundwater and labelled flushing water, a mass balance calculation of the tracer contents in the water samples from the flushing water and return water is a method for demonstrating the amount of flushing water lost in the aquifer during drilling. When return water yield ceases, like when drilling KFR101, all flushing water is lost to the formation. According to notations in the driller's log-book, the amount of Uranine added to the borehole was 50 g, and due to the complete flushing water loss already at c. 18 m, most of that remains in the borehole. This means that between 262 and 265 m^3 flushing water (cf. Figure 5-8) were lost in the borehole.

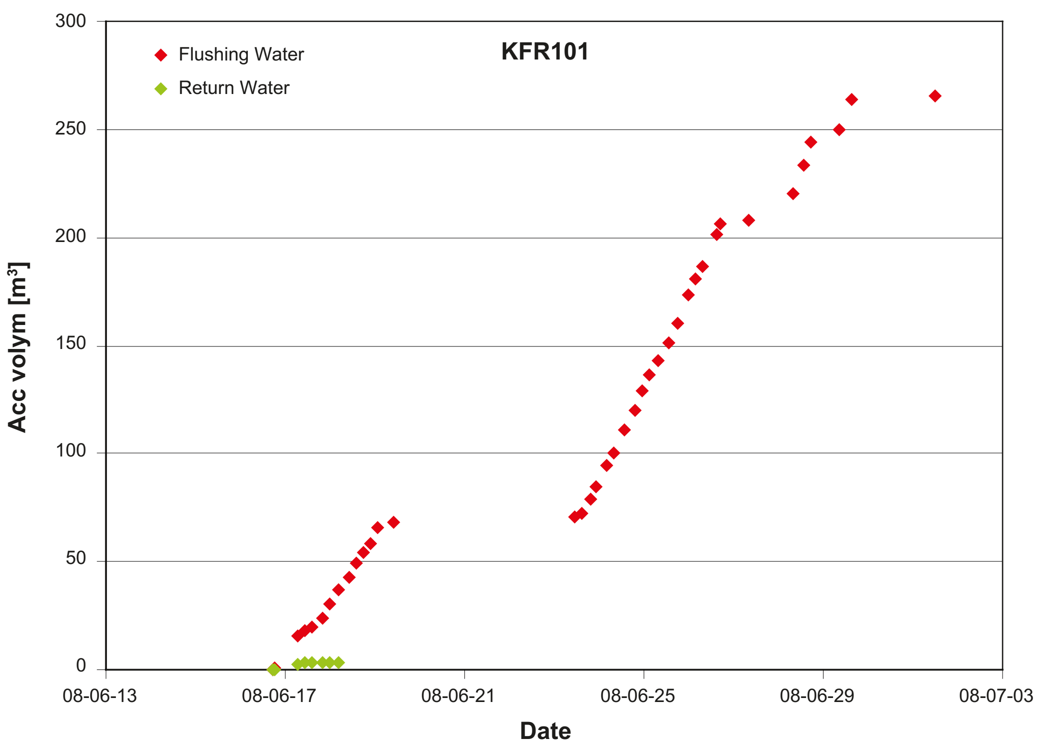


Figure 5-7. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFR101. The return water disappeared after just a short time of drilling.*

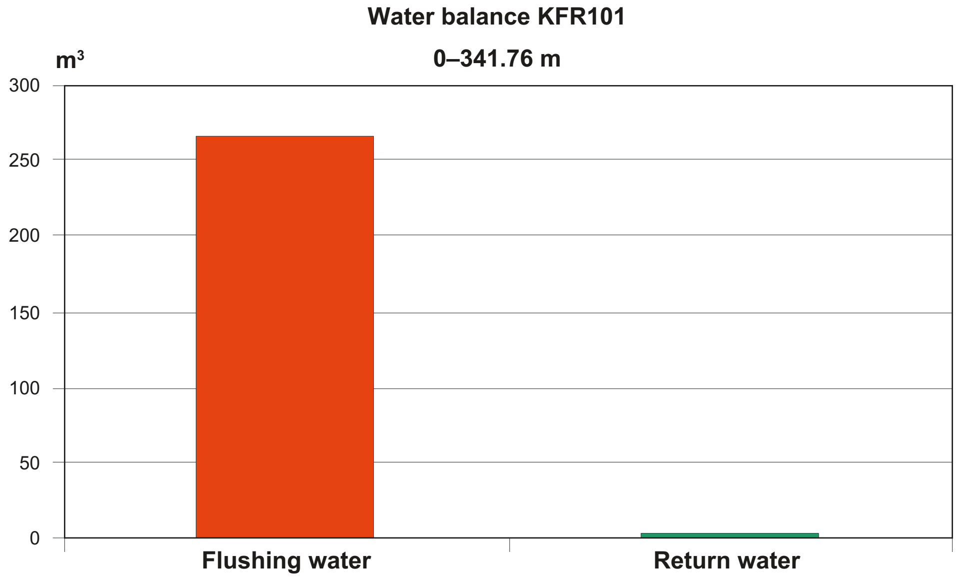


Figure 5-8. Total amounts of flushing water and return water during drilling of borehole KFR101. The total volume of flushing water used during core drilling amounted to 265 m^3. During the same period, the total volume of return water was only 3 m^3. The return water/flushing water balance is then as low as 0.01, due to loss of flushing water in the upper part of the cored borehole.

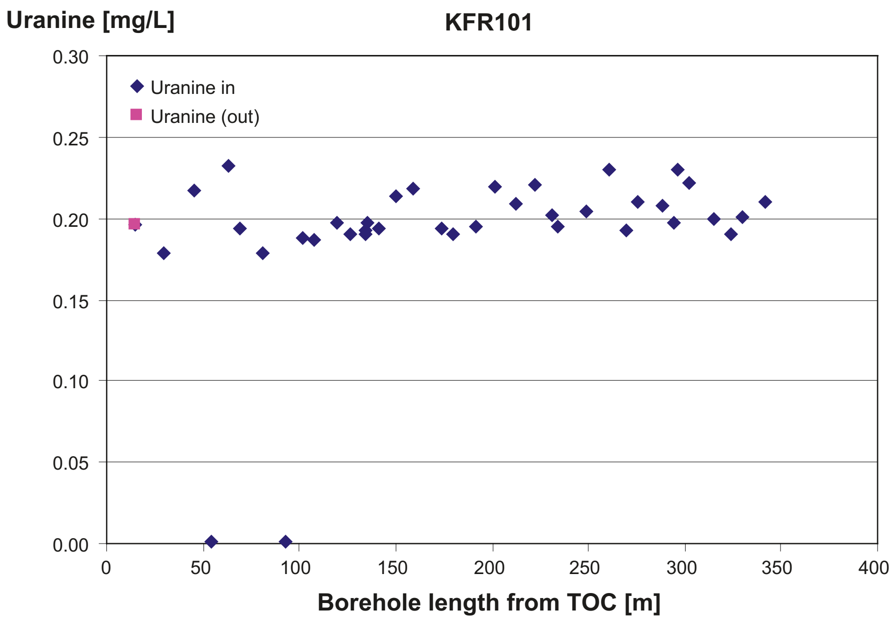


Figure 5-9. Uranine contents in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFR101. Automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine. It is notable that the return water yield ceased almost immediately and therefore analysis of the return water Uranine contents could not be performed from 18 m drilling length.

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 60 mS/m throughout the drilling period. The very few registrations of the return water, before it ceased, cannot be used for further interpretation.

Contents 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 3.2.1), it was decided to observe and document the pressure in the nitrogen bottles once a day. The nitrogen pressure reduction versus time is presented in Figure 5-11.

5.2.5 Groundwater sampling and analysis during drilling

One so called first strike water sample was collected from the section 281.92–341.76 m in KFR101. Despite the fact that the section was pumped and water extracted from it during 13 hours and 50 minutes, thereby replacing the water volume in the test section more than 50 times, the flushing water content was as high as 50%. Cored boreholes of traditional type are not optimized for water sampling, and when complete flushing water loss occurs early during drilling, which happened in KFR101 at 18 m drilling length, drilling debris and flushing water is lost to the borehole, making sampling of virgin groundwater difficult. The results from the analysis of the water sample are presented in Appendix E.

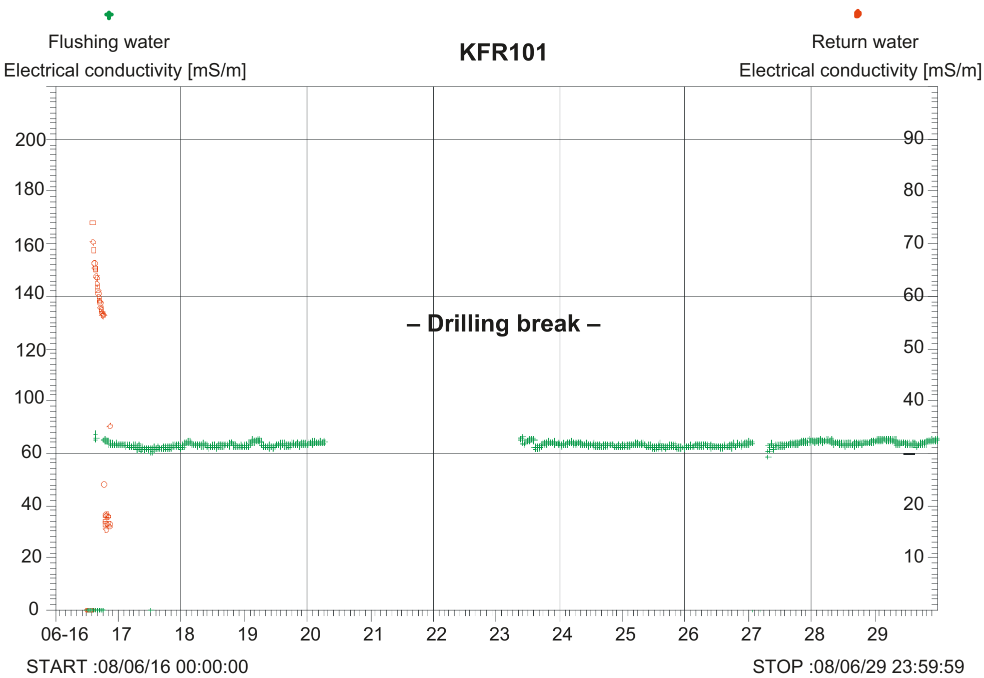


Figure 5-10. *Electrical conductivity of flushing water (tap water from FKA). As total return water loss occurred at c. 18 m in KFR101, only a few return water data points were registered.*

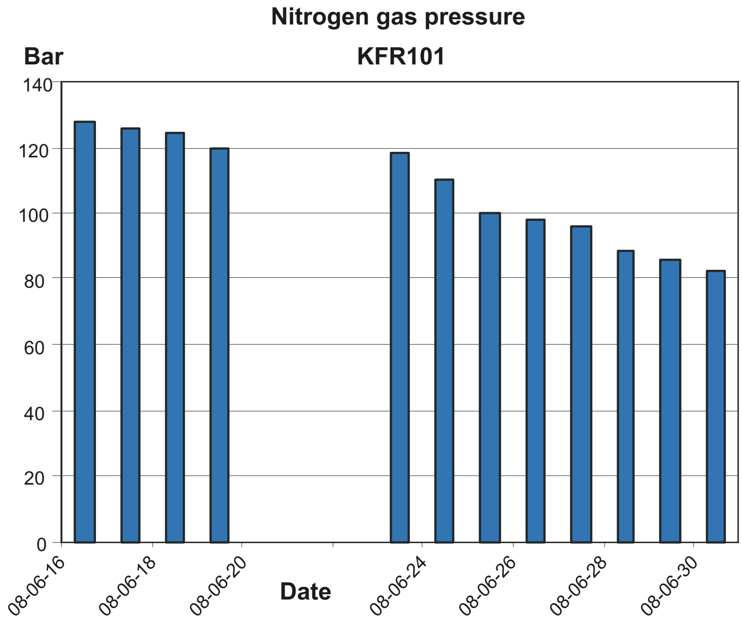


Figure 5-11. *Nitrogen contents (measured as pressure) in the bottles used for nitrogen bubbling of flushing water in KFR101.*

5.2.6 Core sampling

The average drill core length per run obtained from the drilling was 2.85 m. No unbroken core was recovered. Fracture minerals were relatively well preserved. A preliminary core logging was performed continuously in connection with the drilling, see Figure 5-12.

5.2.7 Recovery of drill cuttings

The theoretical volume of drill cuttings from the cored section between 13.72–341.76 m is calculated to 0.834 m^3, and most of that is left in the formation as a complete water loss occurred at c.18 m drilling length.

5.2.8 Devitaion measurements in KFR101

The types and measurement principles of the equipment systems used for deviation measurements were explained in Section 3.3. Following the recently revised edition of SKB MD 224.001, Version 4, measurements with two different techniques have to be applied. An optic method (Maxibor II^{TM} instrument) and a method based on magnetometer-/accelerometer technique (Flexit Tool System), was chosen for the deviation measurements performed in KFR101.

To ensure high quality measurements with the Flexit tool, the disturbances of the magnetic field must be small. A measuring 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 July 2nd 2008 is seen in Figure 5-13 and displays only minor disturbances when the Flexit-surveys in KFR101 were performed.

A description of the construction of deviation data for the core drilled borehole KFR101 is given below.

The deviation data used for construction of the final deviation file is one Maxibor II^{TM} –logging to 339 m and four loggings with the Flexit Smart Tool System to 339 m borehole length, respectively, see Table 5-5. With the Flexit system, the deviation measurements were carried out every 3 m both downwards and upwards and with the Maxibor II^{TM} every 3 m downwards. The activities marked "CF" in Table 5-7 include comments besides measurement data.

All deviation measurement surveys in the borehole have followed the recommended quality routines according to SKB MD 224.001, Version 4.0. This final deviation file is termed EG154 (Borehole deviation multiple measurements). See illustration of the construction principles in Figure 5-14.

__Figure 5-12.__ The core boxes were transported every morning during the drilling period to the core store-room, the so called Llentab facility. A simplified geological core mapping was performed, and afterwards all core boxes were photographed. Detailed core mapping, so called Boremap mapping, will be carried out after completion of drilling.

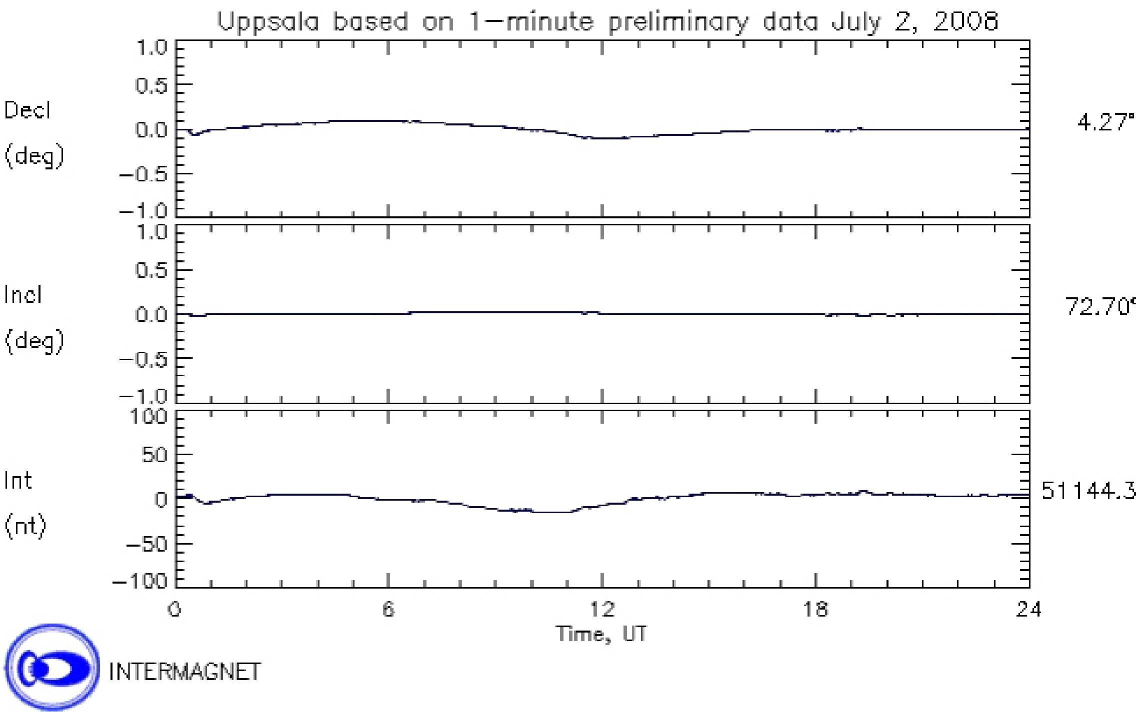


__Figure 5-13.__ Magnetic field variation during Flexit surveys performed on July 2nd 2008 in KFR101.

Table 5-7. Activity data for deviation measurements approved for KFR101 (from Sicada).

ID code	Deviation activity ID	Activity type code	Activity	Start date	Secup (mbl*)	Seclow (mbl*)	Flags
KFR101	13191974	EG161	Maxibor II measurement	2008-07-01 13:30	3.00	339.00	CF
KFR101	13191976	EG157	Magnetic accelerometer measurement	2008-07-02 16:41	3.00	339.00	CF
KFR101	13191979	EG157	Magnetic accelerometer measurement	2008-07-02 18:12	3.00	339.00	CF
KFR101	13191977	EG157	Magnetic accelerometer measurement	2008-07-02 19:11	3.00	339.00	CF
KFR101	13191980	EG157	Magnetic accelerometer measurement	2008-07-02 20:19	3.00	339.00	CF
KFR101	13192035	EG154	Borehole deviation multiple measurements	2008-07-04 08:20			IC

*mbl=metres borehole length

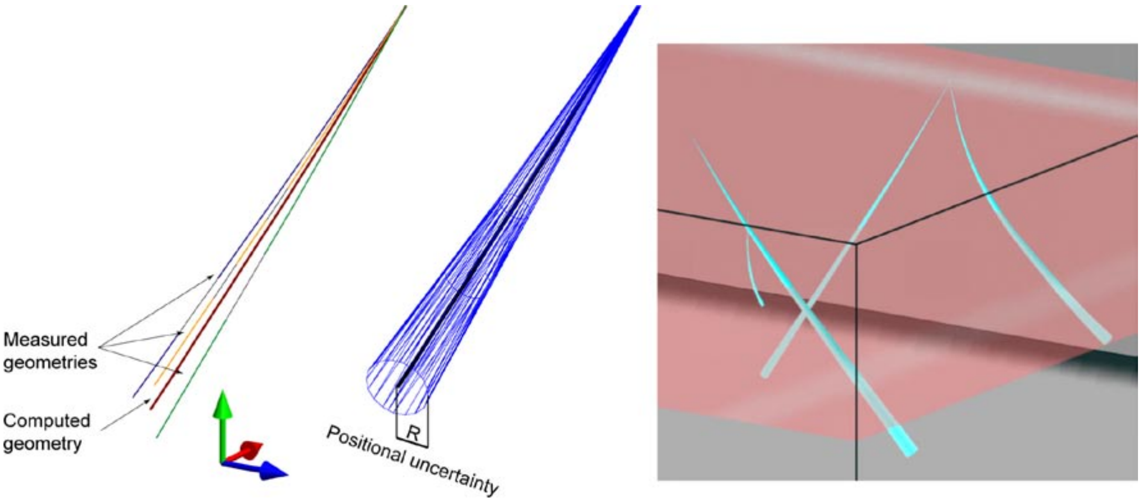


Figure 5-14. The figure to the left is an illustration of the principles for calculating the borehole geometry from several deviation measurements. The two other figures illustrate one of the uncertainty measures used for deviation measurements. In the middle figure, "R" denotes "radial uncertainty", 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 5-9. 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 /Munier and Stigsson 2007/).

The EG154-activity (see Table 5-8) specifies the sections of the deviation measurements used in the resulting calculation presented in Table 5-9. 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 15 m steel casing which is not the case for the inclinometer measurements (inclination).

A subset of the resulting deviation files and the estimated radial uncertainty is presented in Table 5-9. 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 KFR101shows that the borehole deviates upwards and to the left with an absolute deviation of 27 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 collar.

5.2.9 Groove milling KFR101

A compilation of the positions of the reference grooves and a comment on the success of detecting the grooves are given in Table 5-10. 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.

Table 5-8. Contents of the EG154 file for KFR101 (multiple borehole deviation intervals).

Deviation activity ID	Deviation angle type	Approved Secup (mbl*)	Approved Seclow (mbl*)
13191974	BEARING	3.00	333.00
13191974	INCLINATION	3.00	333.00
13191976	BEARING	21.00	339.00
13191976	INCLINATION	3.00	339.00
13191977	BEARING	21.00	339.00
13191977	INCLINATION	3.00	339.00
13191979	BEARING	21.00	339.00
13191979	INCLINATION	3.00	339.00
13191980	BEARING	21.00	339.00
13191980	INCLINATION	3.00	339.00

*mbl=metres borehole length

Table 5-9. Deviation and uncertainty data for the deviation measurements in KFR101 for approximately every 40 m vertical length calculated from EG154.

Idcode	Northing (m)	Easting (m)	Elevation (m RHB70)	Length (mbl**)	Vertical depth (m)	Inclina-tion* (degrees)	Bearing* (degrees)	Inclination-uncertainty (degrees)	Bearing uncertainty (degrees)	Radial uncertainty (m)
KFR101	6,701,736.32	1,633,351.40	2.44	0.00	0.00	–55.50	28.79	0.060	0.569	0.00
KFR101	6,701,760.63	1,633,364.30	–36.89	48.00	39.33	–54.87	29.20	0.060	0.569	0.27
KFR101	6,701,785.99	1,633,379.35	–78.49	99.00	80.93	–54.18	31.90	0.060	0.569	0.57
KFR101	6,701,810.18	1,633,394.83	–116.95	147.00	119.39	–52.32	33.24	0.060	0.569	0.85
KFR101	6,701,836.75	1,633,412.50	–156.73	198.00	159.17	–50.23	34.21	0.060	0.569	1.17
KFR101	6,701,865.81	1,633,432.60	–197.56	252.00	200.00	–47.93	35.67	0.060	0.569	1.52
KFR101	6,701,895.77	1,633,454.39	–236.85	306.00	239.28	–45.58	36.44	0.060	0.569	1.89
KFR101	6,701,916.07	1,633,469.62	–262.03	341.76	264.47	–44.12	37.22	0.060	0.569	2.14

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a discrepancy against the values seen in Borehole direction surveying (EG151).
** mbl=metres borehole length

Table 5-10. Reference grooves in KFR101.

Reference groove at (mbl*)	Detection with the SKB level indicator	Confirmed from BIPS
51	Yes	Yes
100	Yes	Yes
150	Yes	Yes
200	Yes	Yes
272	Yes	Yes

* mbl=metres borehole length

5.2.10 Nitrogen flushing (KFR101)

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 applied. If the shallow part of the bedrock penetrated by a cored borehole of traditional type is highly fractured, total loss of flushing water may occur during drilling, entailing that all flushing water and drill cuttings are forced into the permeable part of the rock. This happened in KFR101, at c. 18 m drilling length, and all flushing water was lost, resulting in that 0.834 m^3 (2,210 kg) drilling debris remains in the formation.

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. KFR101 had to be nitrogen flushed nine times during July 1st and July 4th 2008 before this happened, see Figure 5-15 and Table 5-11. The estimated recovered water volumes are 9 m^3, compared to 265 m^3 flushing water that was lost in the borehole during drilling, see Section 5.2.4.

Figure 5-15. Nitrogen is forced through a hose to the bottom of the borehole. When the gas expands, the mixture of flushing water and drilling debris is lifted up from the borehole bottom. When the supply of nitrogen is closed, the gas- and groundwater outflow ceases. The groundwater level has to recover before further nitrogen flushing can begin.

Table 5-11. Nitrogen flushing periods and estimated uplift of groundwater from KFR101 (from EG036).

ID	Start Date_time	Stop Date_time	Recovered water volume (L)	Comments
KFR101	2008-07-01 18:32:00	2008-07-01 19:01:00	1,000	Water up through TOC, 18:49. Blow out 18:51.
KFR101	2008-07-01 21:24:00	2008-07-01 21:45:00	1,000	Water up through TOC, 21:29. Blow out 21:33.
KFR101	2008-07-01 23:34:00	2008-07-02 00:02:00	1,000	Water up through TOC, 3:40. Blow out 23:43.
KFR101	2008-07-02 07:20:00	2008-07-02 07:37:00	1,000	Water up through TOC, 07:25. Blow out 07:28.
KFR101	2008-07-04 08:38:00	2008-07-04 08:55:00	1,000	Water up through TOC, 08:44. Blow out 08:49.
KFR101	2008-07-04 10:19:00	2008-07-04 10:38:00	1,000	Water up through TOC, 10:23. Blow out 10:26.
KFR101	2008-07-04 11:34:00	2008-07-04 11:52:00	1,000	Water up through TOC, 11:39. Blow out 11:41.
KFR101	2008-07-04 12:47:00	2008-07-04 13:05:00	1,000	Water up through TOC, 12:52. Blow out 12:54.
KFR101	2008-07-04 13:45:00	2008-07-04 14:01:00	1,000	Water up through TOC, 13:49. Blow out 13:51.

5.2.11 Risk assessment KFR101

Ensuing completion of drilling activities, an intensive 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 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 KFR101, are summarized in Table 5-12. Twenty sections in borehole KFR101 have been classified as involving a potential risk (1), meaning that the core section is highly fractured except for section 107.50–109.00 m, where also rock fallouts were observed, which however faded and ceased at continued drilling.

Table 5-12. Documented sections of potential risk from observations during drilling and preliminary geological core mapping of KFR101.

From (mbl*)	To (mbl*)	Risk Level (code)	Description
18.60	18.70	1	Highly fractured section
31.80	32.80	1	”
33.50	33.70	1	”
37.20	39.00	1	”
56.15	56.30	1	”
107.50	109.00	1	Crush zone with some rock fallout found at the following core recovery. The rock fallout faded and stopped during the core drilling action.
109.80	110.80	1	Highly fractured section
127.60	128.05	1	”
180.90	181.10	1	”
182.60	182.80	1	”
257.90	258.15	1	”
261.60	262.30	1	”
265.80	266.00	1	”
293.50	305.00	1	”
307.40	307.60	1	”
314.70	316.00	1	”
320.50	320.90	1	”
323.60	324.00	1	”
336.80	337.10	1	”
339.30	339.50	1	”

*mbl=metres borehole length

5.3 Results KFR102B

As mentioned in Section 5.1 the overburden for all four boreholes presented in this report was percussion drilled. Regarding KFR102B this was performed on May 5th, while setting and gap injection of the inner casing was carried out on June 10th, 2008. Finally, core drilling was conducted between August 6th and August 14th, 2008, see Figure 5-16.

5.3.1 Overburden drilling

Percussion drilling through the overburden is a rapid drilling method compared to core drilling, and was therefore chosen in order to shorten the drilling period for each borehole. Pre drilling of KFR102B was accomplished during two working periods (cf. Figure 5-16), 2008-05-05 (percussion drilling NO-X 115) and 2008-06-10 (setting of inner casing and gap injection). Figure 5-4 illustrates installation of an inner casing.

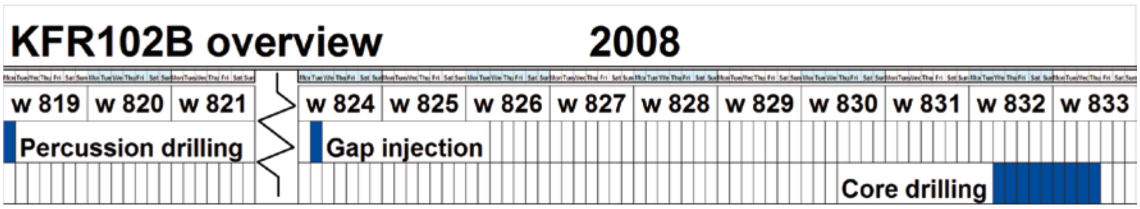


Figure 5-16. Overview of the drilling performance of borehole KFR102B.

The composition of the overburden at KFR102B as displayed in Table 5-2 may be commented on. As stated eralier, the overburden at the pier is mostly consisting of blasted rock, at KFR102B reaching a vertical depth of 6.1 m from ground surface. Below that depth, the former sea bottom is encountered consisting of clay and gravel on top of a layer of moraine, which is resting on the solid rock. The total thickness of these soil layers is 3.7 m. Consequently the vertical depth of the overburden from ground surface to rock surface is 9.8 m. As was mentioned in Section 5.2.1, similar geological results were achieved at KFR101 and KFR103.

5.3.2 Core drilling

Almost immediately after completion of the pre-drilling activities, core drilling commenced. The progress of the core drilling from 2008-06-08 to 2008-14-08, is illustrated in Figure 5-17.

5.3.3 Geometrical and technical design of borehole KFR102B

Administrative, geometric and technical data from borehole KFR102B are presented in Table 5-13. The technical design of the borehole is illustrated in Figure 5-18.

5.3.4 Measurement while drilling KFR102B

During, and immediately after drilling, a programme for sampling and measurements was applied, cf. Section 4.4.2. Some of the results are displayed in the Well Cad presentation in Appendix B whereas other results (flow data and electrical conductivity) are primarily used as supporting data for on-site decisions.

Flushing water and Return water flow rate – water balance

Figure 5-19 displays the accumulated volumes of flushing water respectively return water from the entire drilling period. The accumulated volumes of flushing water and return water are also illustrated in the histogram in Figure 5-20, from which the return water/flushing water quotient at the end of the drilling period may be calculated, in this case resulting in the quotient 1.

Uranine content 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 5-21. 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.

The kind of mass balance calculation from Uranine concentrations in flushing water and return water samples as described in Section 5.2.4 was made for KFR102B. According to the notations in the logbook, the amount of Uranine added to the borehole was 14 g. If the averages of the Uranine concentration values in the flushing water and in return water are used to calculate the amount of Uranine added and recovered from the borehole, the calculation gives 13.7 g and 11.4 g respectively. After finished drilling, the nitrogen flushing in KFR102B confirmed 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 5-22. The electrical conductivity of the flushing water (tap water) is constant at 30 mS/m throughout the drilling period. The average electrical conductivity of the return water from KFR102B is generally lower than the return water values, but this could be an effect of lower temperature of the return water than that of the flushing water. On the other hand, after the weekly drilling breaks, the return water shows a higher frequency of spikes with increased EC-values, that could indicate minor inflows of more saline water to the borehole.

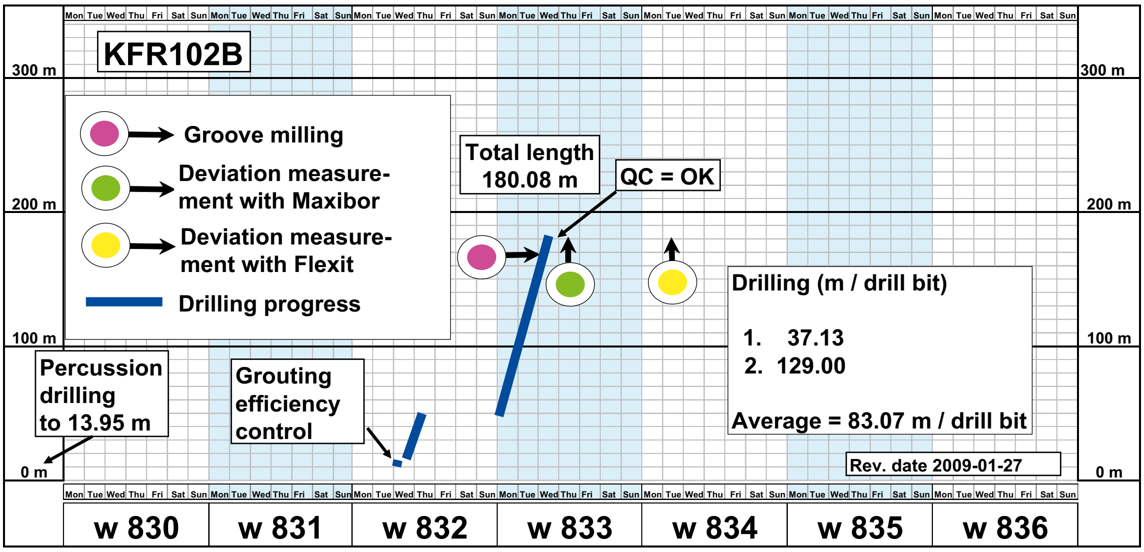
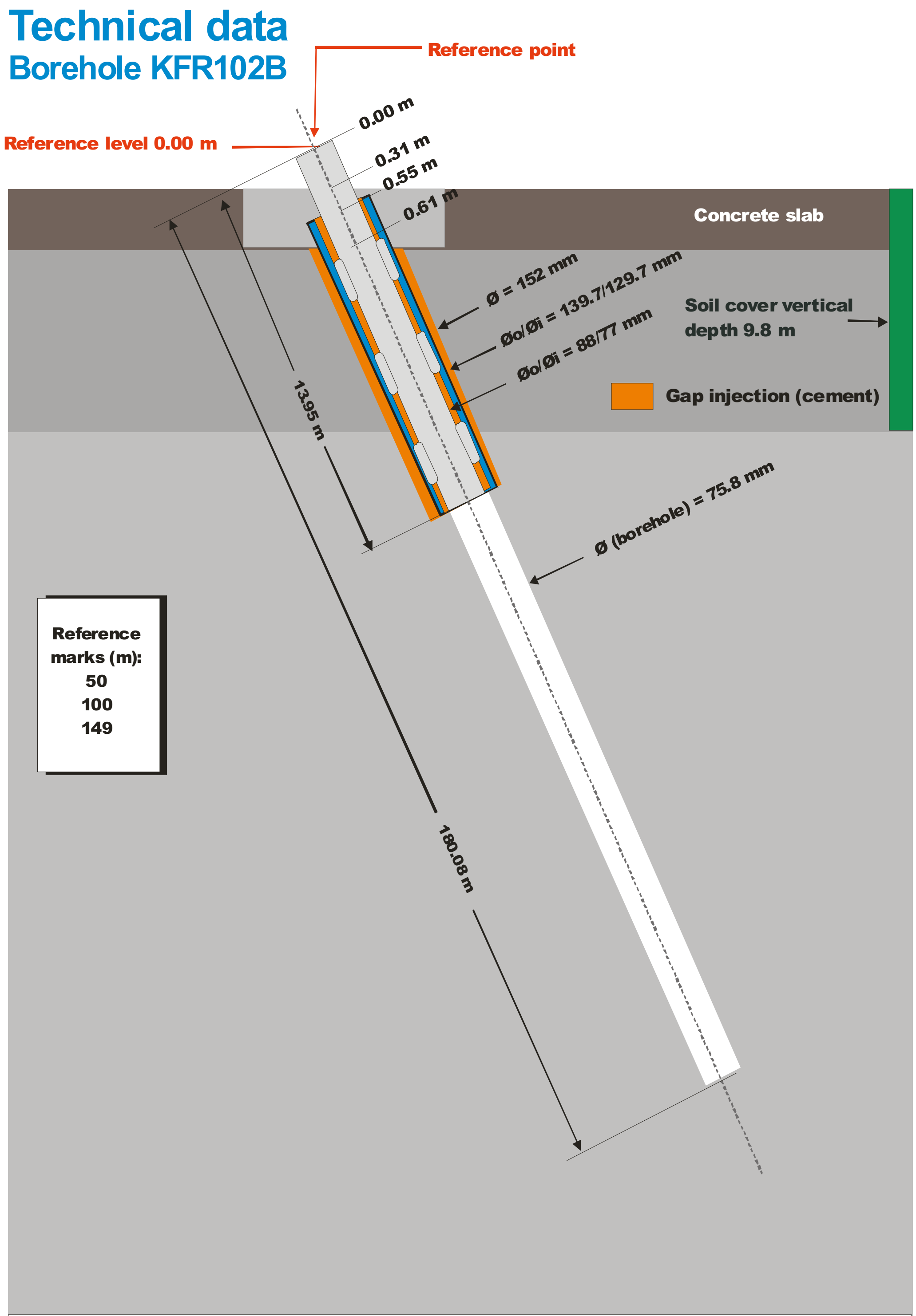


Figure 5-17. Core drilling progress KFR102B (length versus calendar time).

Table 5-13 Administrative, geometric and technical data for borehole KFR102B.

Parameter	Data
Borehole name	KFR102B
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	May 05, 2008
Completion date	August 14, 2008
Percussion drilling period	2008-05-05 to 2008-05-05
Core drilling period	2008-08-06 to 2008-08-14
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Züblin Svenska AB; Sven Andersson i Uppsala AB
Percussion drill rig	Nemek 407 RE
Core drill rig	Onram 1000/3
Position at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6701740.53 (m) E 1633343.91 (m) Z 2.51 (m RHB 70) Azimuth (0–360°): 344.87° Dip (0–90°): –54.14°
Position at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6701843.23 E 1633316.67 Z –142.88 (m RHB 70) Azimuth (0–360°): 345.59° Dip (0–90°): –53.10°
Borehole length	180.08 m
Borehole length and diameter	From 0.61 m to 13.95 m: 0.152 m From 13.95 m to 180.08 m: 0.0758 m
Casing diameter and drilling length	Øo/Øi = 139.7 mm/129.7 mm from 0.55 m to 13.83 m Casing shoe Øi = 122 mm between 13.83 and 13.87 m Øo/Øi = 152 mm/116 mm between 13.87 and 13.95 m
Drill core dimension	13.95–180.08 m / Ø 50 mm
Core interval	13.95–180.08 m
Average length of core recovery	2.68 m
Number of runs	62
Diamond bits used	2
Average bit life	83.07 m



Drilling reference point

Northing:	6701740.53 (m), RT90 2,5 gon V 0:-15
Easting:	1633343.91 (m), RT90 2,5 gon V 0:-15
Elevation:	2.51 (m), RHB 70

Orientation

Bearing (degrees):	344.87°
Inclination (degrees):	-54.14°

Borehole

Length:	180.08 m

Percussion drilling period

Drilling start date:	2008-05-05
Drilling stop date:	2008-05-05

Core drilling period

Drilling start date:	2008-08-06
Drilling stop date:	2008-08-14

Rev. 2009-03-24

Figure 5-18. *Technical data of borehole KFR102B.*

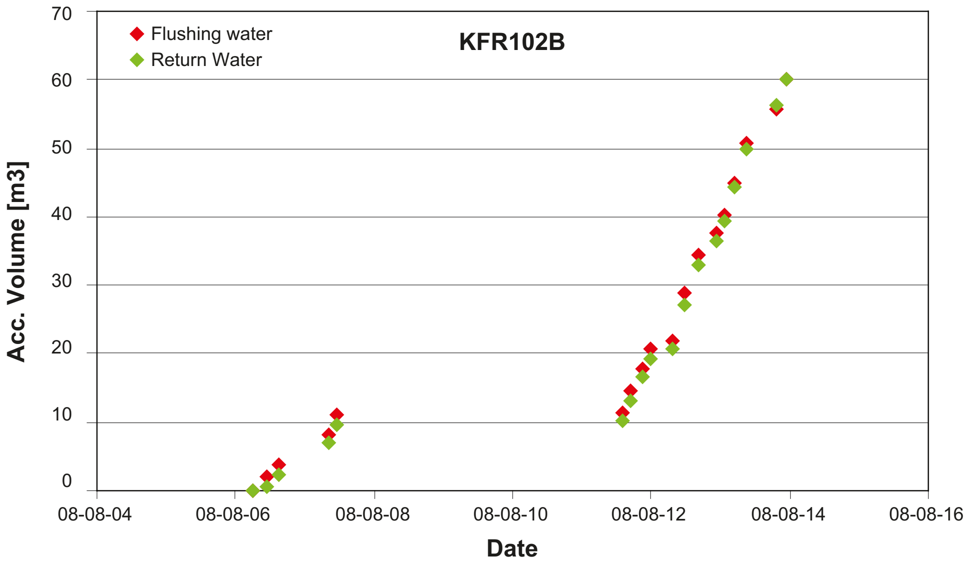


Figure 5-19. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFR102B.*

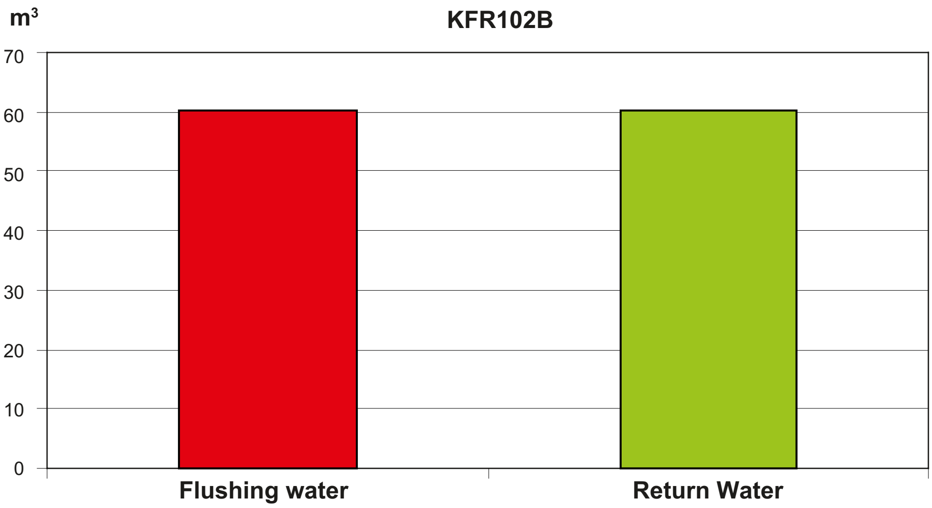


Figure 5-20. *Total amounts of flushing water and return water during drilling of borehole KFR102B. The total volume of flushing water used during core drilling amounted to 60.08 m³. During the same period, the total volume of return water was 60.18 m³. The return water/flushing water balance is then almost exactly 1.*

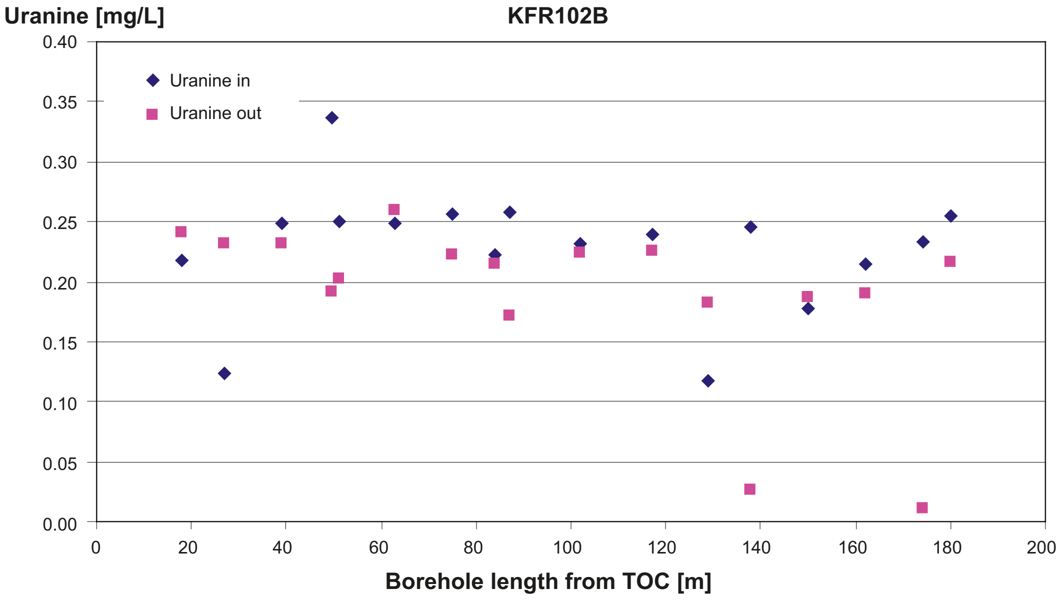


Figure 5-21. Uranine contents in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFR102B. Automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.

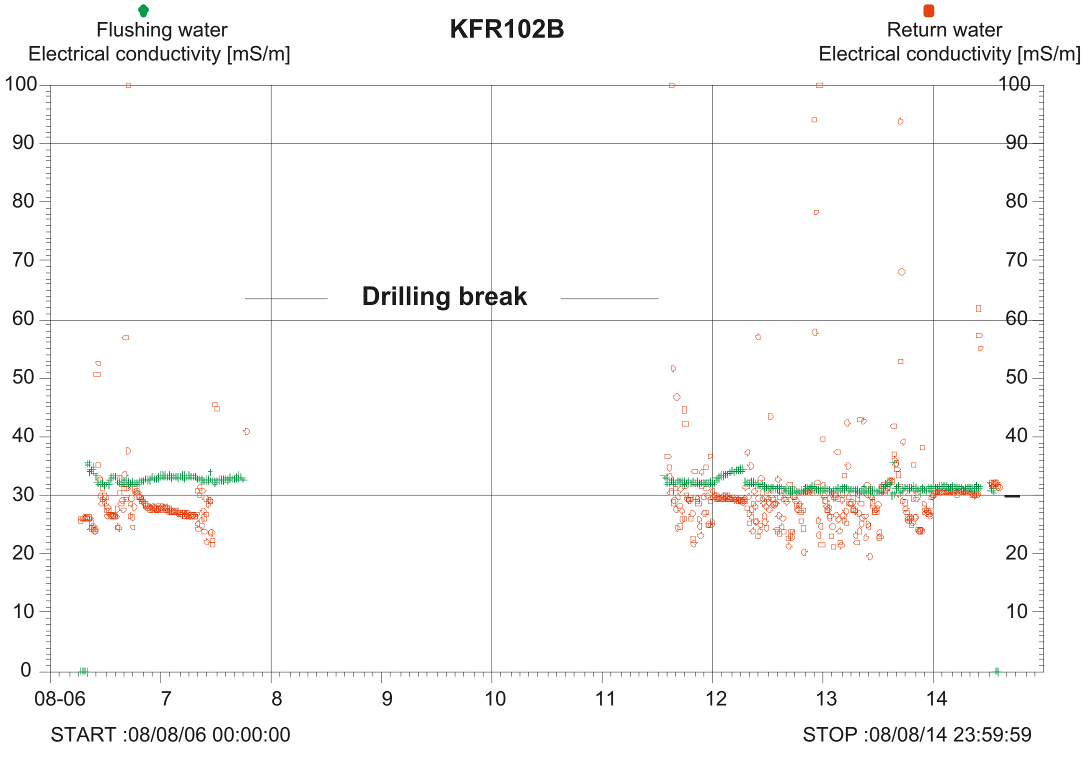


Figure 5-22. Electrical conductivity of flushing water (tap water from FKA) and return water from KFR102B.

Contents 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 3.2.1), 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 5-23.

5.3.5 Core sampling

The average drill core length per run obtained from the drilling was 2.68 m. No unbroken core was recovered. Fracture minerals were relatively well preserved. A preliminary core logging was performed continuously in connection with the drilling, see Figure 5-24.

5.3.6 Recovery of drill cuttings

The theoretical difference in volume of the core drilled part of KFR102B (13.95–180.08 m) and the drill core is calculated to be 0.417 m^3. This volume should correspond to the amount of drill cuttings produced during drilling. If a density of 2.65 kg/ m^3 is applied (approximate figure for granites in the Forsmark area), the total weight of the theoretical amount of debris is estimated at 1,109 kg. The calculated dry weight of the debris from core drilling recovered and weighed in the container is 659 kg, which gives a recovery of 68%.

The recovery figure could be commented on. The dwell time in the container system is too short for sedimentation of the suspended finest fractions. No estimation was made of the amount of suspended material, but weighing of the container including water and debris is associated with some uncertainty.

However, it seems also plausible that some drilling debris has been injected into the fracture system of the formation, although strong indications during drilling that the part of the bedrock that is penetrated by KFR102B is hydraulically very low-transmissive.

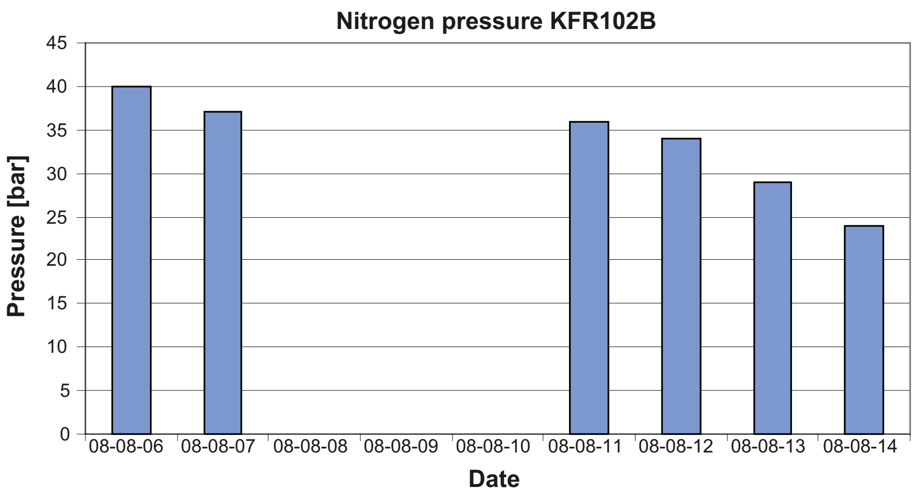


Figure 5-23. *Nitrogen contents (measured as pressure) in the bottles used for nitrogen bubbling of flushing water in KFR102B.*

Figure 5-24. The core boxes were transported every morning during the drilling period to the core store-room, the so called Llentab facility. A simplified geological core mapping was performed, and afterwards all core boxes were photographed. A detailed core mapping (Boremap mapping) will be carried out after completion of drilling.

5.3.7 Devitaion measurements in KFR102B

The types and principles of the equipment for deviation measurements were explained in Section 3.3, and the method enjoined according to SKB MD 224.001, Version 4, for constructing the final deviation file was demonstrated in Section 5.2.8. As in KFR101 Maxibor and Flexit measurements were performed in KFR102B.

The magnetic field variations during August 19th, 2008, are displayed in Figure 5-25 and show only minor disturbances when the Flexit-surveys in KFR102B were made.

The deviation data used for construction of the final deviation file is one Maxibor II™ –logging to 177 m and four Flexit-loggings to 177 m borehole length, respectively, see Table 5-14. With the Flexit Smart Tool System the deviation measurements were carried out every 3 m both downwards and upwards and with the Maxibor II™ every 3 m downwards. Activities marked "CF" include comments besides measurement data.

All deviation measurements surveys in the borehole have followed the recommended quality routines according to SKB MD 224.001, Version 4.0. This file is termed EG154 (Borehole deviation multiple measurements). See illustration of the construction principle in Figure 5-14 explained in Section 5.2.8.

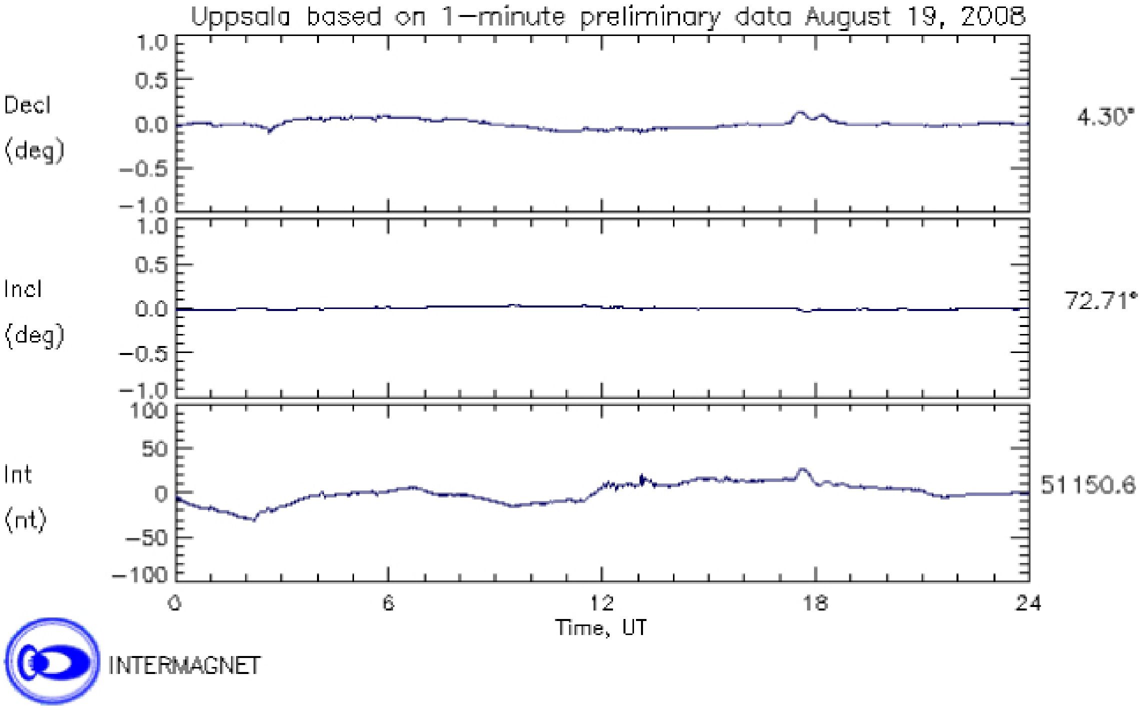


***Figure 5-25.** Magnetic field variation during Flexit surveys performed on August 19th, 2008 in KFR102B.*

Table 5-14. Activity data for deviation measurements approved for KFR102B (from Sicada).

ID code	Activity ID	Activity type code	Activity	Start date	Secup (mbl*)	Seclow (mbl)	Flags
KFR102B	13192991	EG161	Maxibor II measurement	2008-08-14 07:00	3.00	177.00	F
KFR102B	13192796	EG157	Magnetic accelerometer measurement	2008-08-19 17:00	3.00	177.00	CF
KFR102B	13192798	EG157	Magnetic accelerometer measurement	2008-08-19 17:30	3.00	177.00	CF
KFR102B	13192797	EG157	Magnetic accelerometer measurement	2008-08-19 18:00	3.00	177.00	CF
KFR102B	13192799	EG157	Magnetic accelerometer measurement	2008-08-19 18:30	3.00	177.00	CF
KFR102B	13193006	EG154	Borehole deviation multiple measurements	2008-08-28 07:35			IC

mbl=metres borehole length

The EG154-activity specifies the sections of the deviation measurements used in the resulting calculation presented in Table 5-15. The different length of the upper sections between the bearing and the inclination are chosen due to that the magnetic accelerometer measurements (bearing) is influenced by the 14 m steel casing which is not the case for the inclinometer measurements (inclination).

A subset of the resulting deviation files and the estimated radius uncertainty is presented in Tables 5-16A and 5-16B.

Table 5-15. Contents of the EG154 file for KFR102B (multiple borehole deviation intervals).

Deviation activity ID	Deviation angle type	Approved Secup (mbl*)	Approved Seclow (mbl*)
13192796	BEARING	21.00	177.00
13192796	INCLINATION	3.00	177.00
13192797	BEARING	21.00	177.00
13192797	INCLINATION	3.00	177.00
13192798	BEARING	21.00	177.00
13192798	INCLINATION	3.00	177.00
13192799	BEARING	21.00	177.00
13192799	INCLINATION	3.00	177.00
13192991	BEARING	3.00	171.00
13192991	INCLINATION	3.00	171.00

*mbl=metres borehole length

Table 5-16A. Deviation data from KFR102B for approximately every 20 m elevation calculated from EG154.

Borehole	Length (mbl**)	Northing (m)	Easting (m)	Elevation (m RHB 70)	Inclination* (degrees)	Bearing* (degrees)
KFR102B	0.00	6,701,740.53	1,633,343.91	2.51	–55.10	344.89
KFR102B	24.00	6,701,753.99	1,633,340.40	–17.05	–54.29	345.88
KFR102B	48.00	6,701,767.57	1,633,336.91	–36.52	–54.20	345.98
KFR102B	75.00	6,701,782.93	1,633,333.00	–58.38	–53.90	346.05
KFR102B	99.00	6,701,796.63	1,633,329.34	–77.75	–53.70	345.24
KFR102B	123.00	6,701,810.37	1,633,325.67	–97.08	–53.59	344.30
KFR102B	174.00	6,701,839.70	1,633,317.60	–138.01	–53.13	344.45
KFR102B	180.08	6,701,843.23	1,633,316.67	–142.88	–53.10	345.59

*The starting values of inclination and bearing in EG154 are calculated and could therefore show a discrepancy against the values seen in Borehole direction surveying (EG151).
**mbl=metres borehole length.

Table 5-16B. Uncertainty data for the deviation measurements in KFR102B for approximately every 20 m elevation calculated from EG154.

Borehole	Length (mbl*)	Northing (m)	Easting (m)	Elevation (m RHB 70)	Inclination uncertainty (degrees)	Bearing uncertainty (degrees)	Radial uncertainty (m)
KFR102B	0.00	6,701,740.53	1,633,343.91	2.51	0.100	0.590	0.00
KFR102B	24.00	6,701,753.99	1,633,340.40	–17.05	0.100	0.590	0.14
KFR102B	48.00	6,701,767.57	1,633,336.91	–36.52	0.100	0.590	0.29
KFR102B	75.00	6,701,782.93	1,633,333.00	–58.38	0.100	0.590	0.45
KFR102B	99.00	6,701,796.63	1,633,329.34	–77.75	0.100	0.590	0.60
KFR102B	123.00	6,701,810.37	1,633,325.67	–97.08	0.100	0.590	0.74
KFR102B	174.00	6,701,839.70	1,633,317.60	–138.01	0.100	0.590	1.06
KFR102B	180.08	6,701,843.23	1,633,316.67	–142.88	0.100	0.590	1.09

*mbl=metres borehole length

The calculated deviation (EG154-file) in borehole KFR102B shows that the borehole is almost straight with an absolute deviation of 1 m compared to an imagined straight line following the dip and strike of the borehole start.

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 collar.

5.3.8 Groove milling KFR102B

A compilation of the positions of the reference grooves and a comment on the success of detecting the grooves are given in Table 5-17. 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.

5.3.9 Nitrogen flushing (KFR102B)

As mentioned in Section 5.2.10, 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 applied. Usually, the shallow parts of the bedrock in this area are highly fractured and may cause complete water loss during core drilling, entailing that flushing water and drill cuttings are forced into the hydraulically transmissive parts of the rock. In KFR102B, the total volume of flushing water used was almost exactly the same as the volume of return water, but still 32% (450 kg) of drilling debris was left in the formation.

Usually, a borehole is nitrogen flushed, until the recovered return water is judged to be clean or with a minimimum content of drilling debris. KFR102B had to be nitrogen flushed eight times during two periods, August 15th and August 18th and September 1st to September 2nd, 2008, before this happened, see Table 5-18. When drilling of borehole KFR103 started, a third nitrogen flushing in KFR102B was in progress. When flushing water loss occurred at c. 18 m length in KFR103, it affected the nitrogen flushing in KFR102B, so that the gas- and groundwater outflow almost ceased. For the following flushing an increased nitrogen pressure was used, entailing a renewed discharge of water from the borehole. The estimated recovered water volumes amounted to 4.5 m^3.

The intense drilling and flushing activities have probably caused an opening up of sub-horizontal fractures just below the casings of boreholes KFR101, KFR102B and KFR103, resulting in a gently dipping hydraulic connection at shallow depth between these three boreholes.

Table 5-17. Reference grooves in KFR102B.

Reference groove at (mbl*)	Detection with the SKB level indicator	Confirmed from BIPS
50	Yes	Yes **
100	Yes	Yes **
149	Yes	Yes **

*mbl=metres borehole length
** BIPS not adjusted

Table 5-18. Nitrogen flushing periods and estimated uplift of groundwater from KFR102B (from EG036).

Borehole	Pressure (bar)	Start Date_time	Stop Date_time	Recovered water volume (L)	Comment
KFR102B	50	2008-08-15 13:05:00	2008-08-15 13:09:00	500	Water up through TOC 13:07 Blow out 13:09
KFR102B	50	2008-08-15 17:22:00	2008-08-15 17:25:00	500	Water up through TOC 17:23 Blow out 17:26
KFR102B	0	2008-08-16 11:35:00	2008-08-16 11:41:00	0	Gas- and groundwater outflow ceased due to hydraulic connection with KFR103
KFR102B	70	2008-08-18 07:43:00	2008-08-18 07:43:00	500	Water up through TOC 17:47 Blow out 07:50
KFR102B	70	2008-09-01 15:42:00	2008-09-01 15:49:00	500	Water up through TOC 15:45 Blow out 15:47
KFR102B	60	2008-09-01 16:42:00	2008-09-01 16:52:00	500	Water up through TOC 16:48 Blow out 16:50
KFR102B	70	2008-09-02 06:20:00	2008-09-02 06:25:00	500	Water up through TOC 06:22 Blow out 06:24
KFR102B	70	2008-09-02 07:24:00	2008-09-02 07:30:00	500	Water up through TOC 07:26 Blow out 07:28

5.3.10 Risk assessment KFR102B

Following the compulsory guidelines for risk assessments for boreholes presented in Section 5.2.11, the assessments after completed drilling of borehole KFR102B are summarized in Table 5-19. Nineteen sections in borehole KFR102B have been classified as involving a potential risk (1), depending on the fact that the respective core sections are highly fractured and thus involve a risk for rock fallout.

5.4 Results KFR103

As mentioned in Section 5.1, the overburden for the four boreholes presented in this report was percussion drilled. Regarding KFR103 this was performed on May 8th, whereas setting and gap injection of the inner casing was carried out on June 10th, 2008. Finally, core drilling was conducted between August 15th and August 26th, 2008, see Figure 5-26.

5.4.1 Overburden drilling

Percussion drilling through the overburden is a rapid drilling method compared to core drilling, and was therefore chosen in order to shorten the drilling period for each borehole. Pre-drilling of KFR103 was accomplished during two working periods (cf. Figure 5-26), 2008-05-08 (percussion drilling NO-X 115) and 2008-06-10 (setting of inner casing and gap injection), see Figure 5-27.

Table 5-19. Documented sections of potential risk from observations during drilling and preliminary geological core mapping of KFR102B.

From (mbl*)	To (mbl*)	Risk level (code)	Description
18.15	18.30	1	Highly fractured section
20.45	20.75	1	”
24.75	25.00	1	”
28.70	28.85	1	”
29.05	29.15	1	”
29.90	31.00	1	“
32.55	32.75	1	”
37.15	37.50	1	”
38.10	39.10	1	”
44.00	44.20	1	”
47.45	47.85	1	”
48.55	48.75	1	”
68.90	69.30	1	”
109.55	111.20	1	”
113.55	114.20	1	”
134.00	136.50	1	”
139.70	141.20	1	”
149.70	150.20	1	”
178.60	180.08	1	”

*mbl=metres borehole length

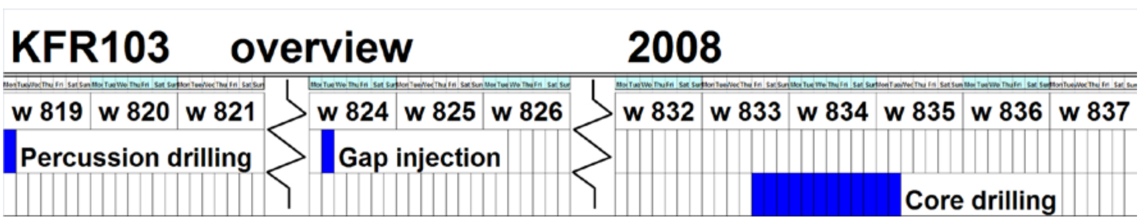


Figure 5-26. Overview of the drilling performance of borehole KFR103.

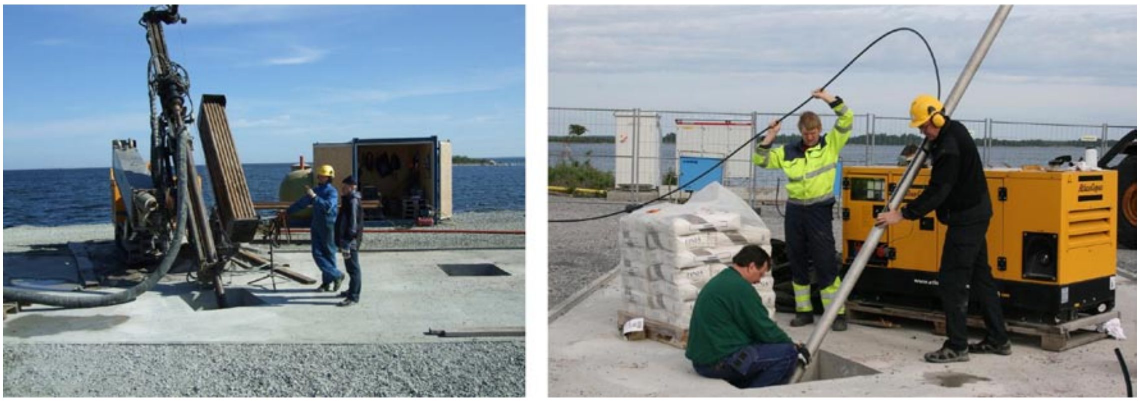


Figure 5-27. To the left the Nemek 407 RE percussion drilling machine is driving the casing through the overburden with the NO-X 115 technique, and to the right the inner casing is installed, more than a month after completion of the percussion drilling. In KFR103 the section 0–13.33 m was supplied with an 88/77 mm stainless steel casing and the gap between the NO-X casing and the inner casing was cement grouted with use of the hose shown in the figure, from the bottom and upwards.

The composition of the overburden at KFR103 as displayed in Table 5-2 may be commented on. The fill material consisting of blasted rock reaches a vertical depth of 5.7 m from ground surface at KFR103. Below that depth, the former sea bottom was encountered composed of clay and gravel on top of a layer of moraine, which is resting on the solid rock. The total thickness of these soil layers is 3.8 m. Consequently the vertical depth of the overburden from ground surface to rock surface is 9.5 m.

Similar geological results were achieved from KFR101 and KFR102B, depending on that the three boreholes have equal inclination (~ 55º from horizontal plane) and are located on the same concrete slab, only a few metres from each other, at the eastern end of the pier.

5.4.2 Core drilling

Almost immediately after completion of the pre-drilling activities, core drilling commenced. The progress of the core drilling from 2008-08-15 to 2008-08-26, is illustrated in Figure 5-28.

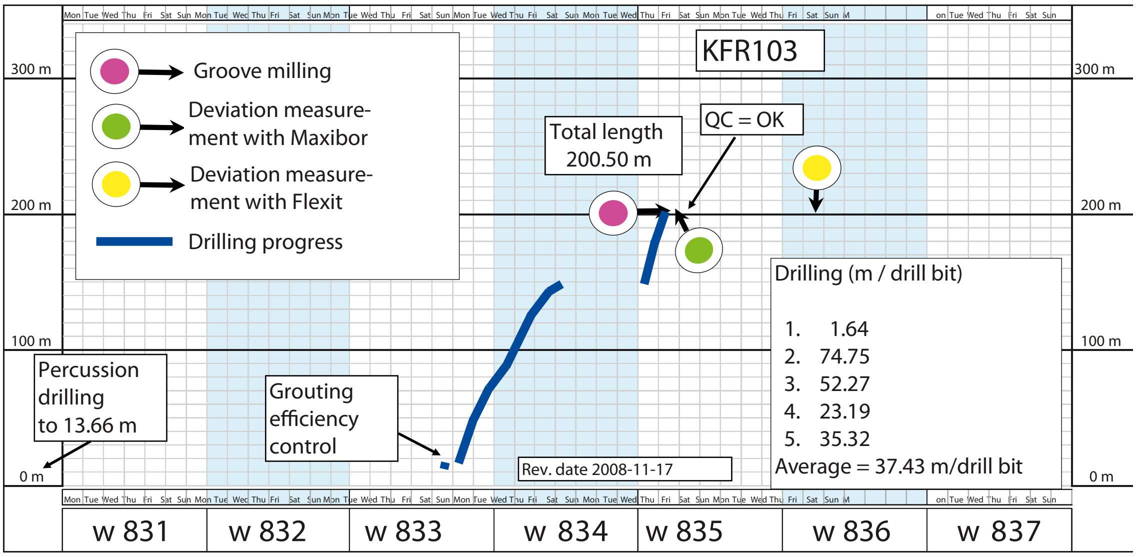


Figure 5-28. Core drilling progress KFR103 (length versus calendar time).

5.4.3 Geometrical and technical design of borehole KFR103

Administrative, geometric and technical data from borehole KFR103, are presented in Table 5-20. The technical design of the borehole is illustrated in Figure 5-29.

Measurement while drilling (KFR103)

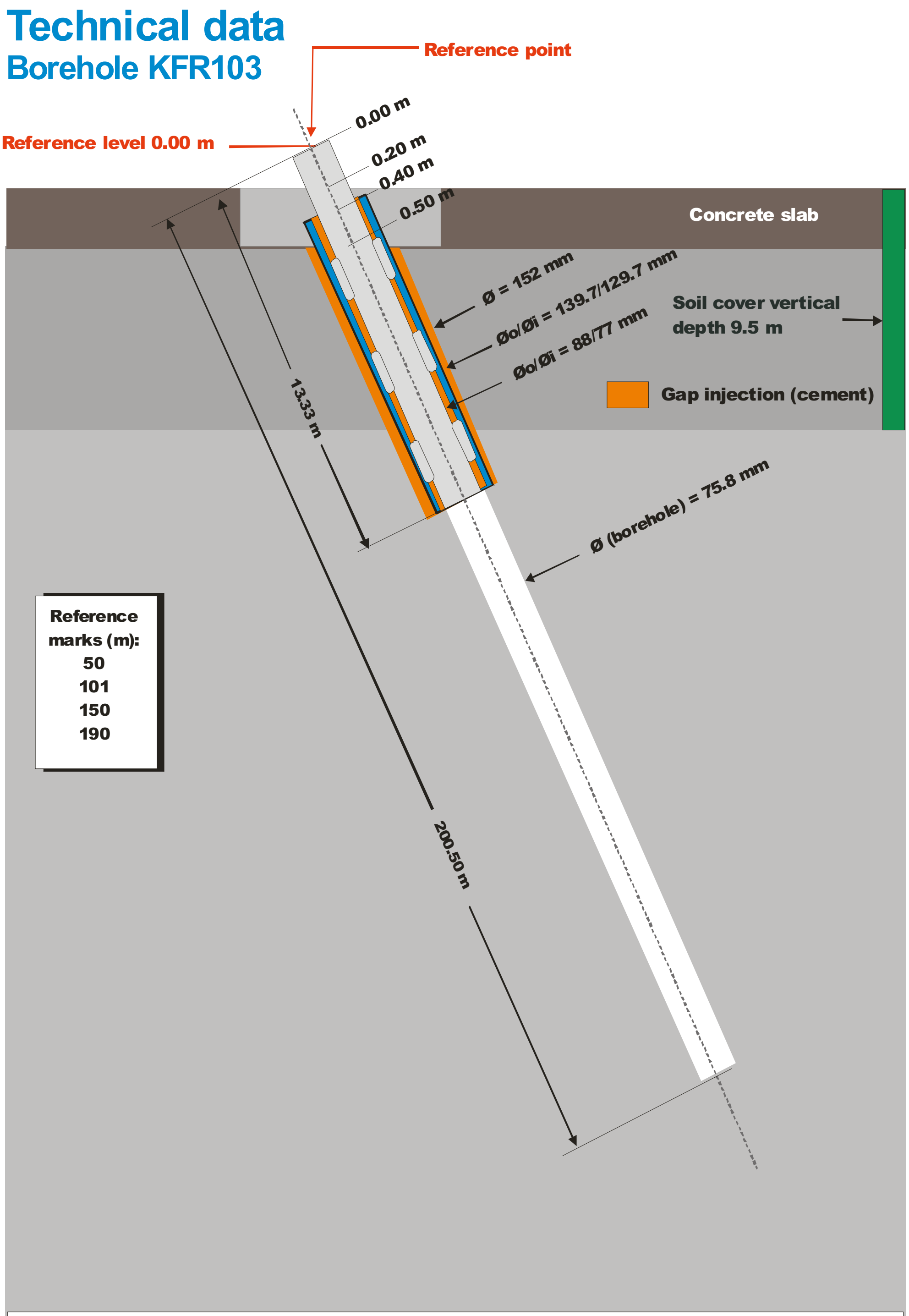
During, and immediately after drilling, a programme for sampling and measurements was applied, cf. Section 4.4.3. Some of the results are displayed in the Well Cad presentation in Appendix C, whereas other results (flow data and electrical conductivity) are primarily used as supporting data for on-site decisions.

5.4.4 Flushing water and Return water flow rate – water balance

Figure 5-30 displays the accumulated volumes of flushing water respectively return water from the entire drilling period. The accumulated volumes of flushing water and return water are also illustrated in the histogram in Figure 5-31 from which the return water/flushing water quotient at the end of the drilling period may be calculated, in this case resulting in the very low quotient 0.01, due to complete flushing water loss in the highly fractured section just below the casing of KFR103.

Table 5-20. Administrative, geometric and technical data for borehole KFR103.

Parameter	Data
Borehole name	KFR103
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	May 05, 2008
Completion date	Aug 26, 2008
Percussion drilling period	2008-05-08 to 2008-05-08
Core drilling period	2008-08-15 to 2008-08-26
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Züblin Svenska AB; Sven Andersson i Uppsala AB
Percussion drill rig	Nemek 407 RE
Core drill rig	Sandvik DE130 (Onram 1000/3)
Position at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6701737.13 (m) E 1633347.20 (m) Z 2.43 (m RHB 70) Azimuth (0–360°): 179.89° Dip (0–90°): –53.91°
Position at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6701618.11 E 1633349.36 Z –158.89 (m RHB 70) Azimuth (0–360°): 177.86° Dip (0–90°): –53.00°
Borehole length	200.50 m
Borehole length and diameter	From 0.50 m to 13.33 m: 0.152 m From 13.33 m to 200.50 m: 0.0758 m
Outer casing, diameter and drilling length	Casing Øo/Øi = 139.7 mm/129.7 mm 0.40 to 13.21 m Casing shoe Øi = 122 mm between 13.21 and 13.25 m Casing shoe bit Øo/Øi = 152 mm/116 mm between 13.25 and 13.33 m
Inner casing, diameter and drilling length	Øo/Øi = 80/77 mm 0 to 13.33 m
Drill core dimension	13.33–200.50 m / Ø 50 mm
Core interval	13.33–200.50 m
Average length of core recovery	2.67 m
Number of runs	70
Diamond bits used	5
Average bit life	37.43 m



Drilling reference point

Northing:	6701737.13 (m), RT90 2,5 gon V 0:-15
Easting:	1633347.20 (m), RT90 2,5 gon V 0:-15
Elevation:	2.43 (m), RHB 70

Orientation

Bearing (degrees):	179.89°
Inclination (degrees):	-53.91°

Borehole

Length:	200.50 m

Percussion drilling period

Drilling start date:	2008-05-08
Drilling stop date:	2008-05-08

Core drilling period

Drilling start date:	2008-08-15
Drilling stop date:	2008-08-26

Rev. 2009-03-24

Figure 5-29. *Technical data of borehole KFR103.*

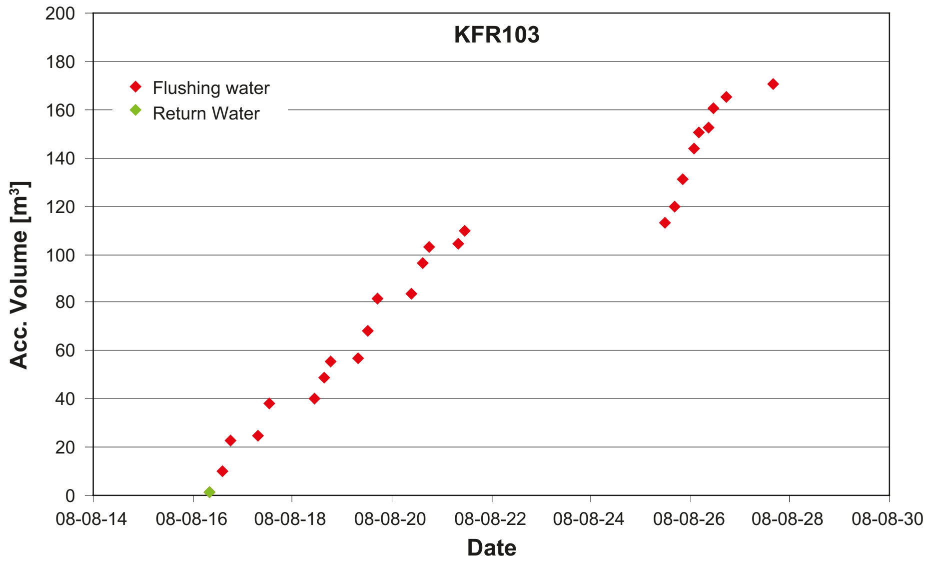


Figure 5-30. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM103. The return water disappeared after just a short time of drilling.*

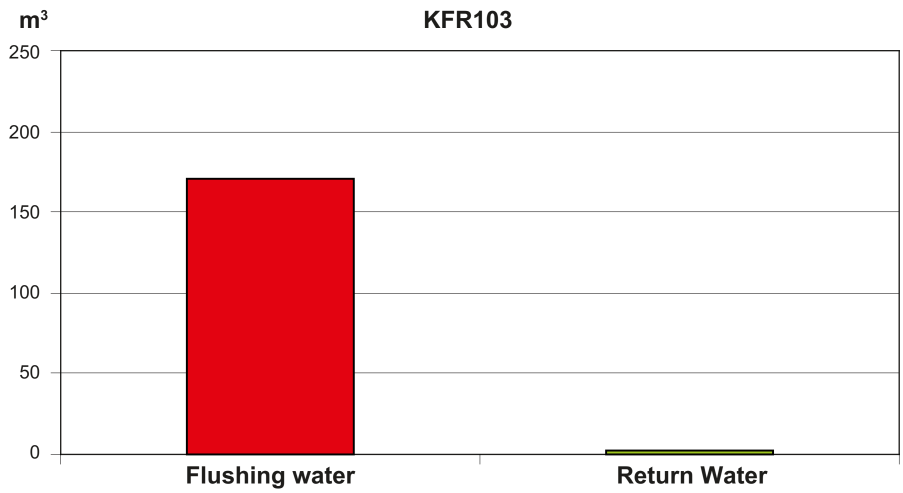


Figure 5-31. *Total amounts of flushing water and return water during drilling of borehole KFR103. The total volume of flushing water used during core drilling amounted to 170 m³. During the same period, the total volume of return water was only 1.5 m³. The return water/flushing water balance is then as low as 0.01, due to loss of flushing water in the upper part of the cored borehole.*

Uranine content 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 5-32. 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.

As described in Section 5.2.4, in drilling situations with a continuous yield of return water, which consists of a mixture of (unlabelled) groundwater and labelled flushing water, a mass balance calculation of the tracer contents in the water samples from the flushing water and return water is a method for demonstrating the amount of flushing water lost in the aquifer during drilling. When, however, the return water yield ceases, like when drilling KFR103, all flushing water is lost to the formation. According to notations in the driller's log-book, the amount of Uranine added to the borehole was 38 g, and due to the complete flushing water loss already at c. 18 m, most of that remains in the borehole. This means that between 169 m^3 flushing water (cf. Figure 5-32) were lost in the borehole.

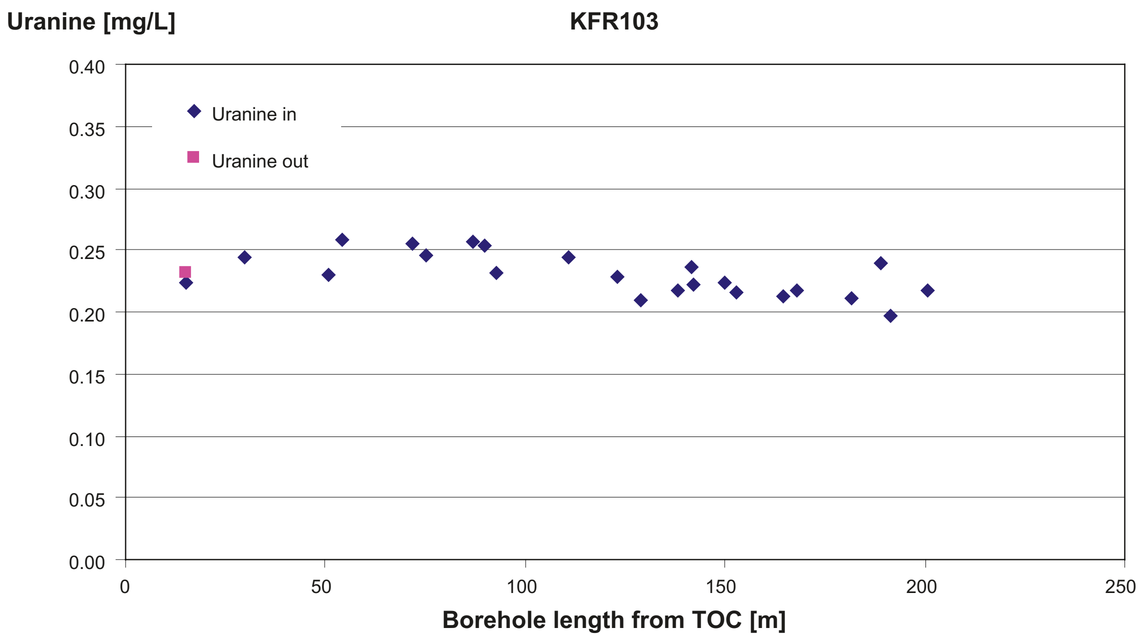


Figure 5-32. *Uranine contents in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFR103. Automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine. It is notable that the return water disappeared almost immediately and therefore analysis of the return water Uranine contents could not be performed from 18 m drilling length.*

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 5-33. The electrical conductivity of the flushing water (tap water) is constant at 90 mS/m through the drilling period. The very few registration of the return water, before it ceased, cannot be used for further interpretation.

Contents of dissolved oxygen in flushing water

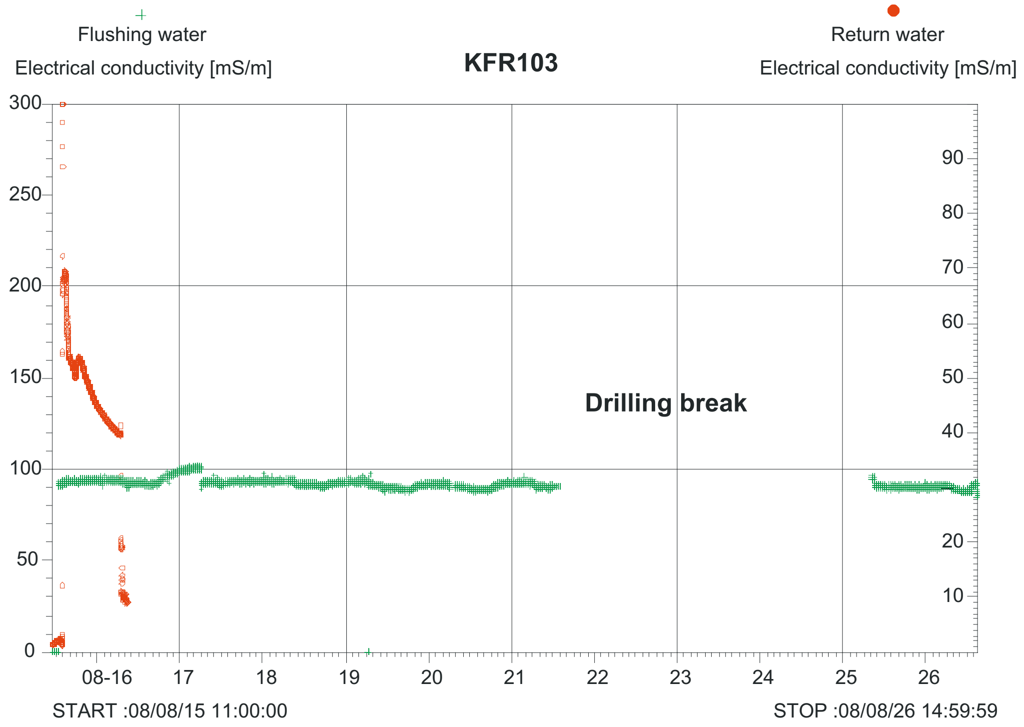
The level of dissolved oxygen in the flushing water was measured and plotted versus time. The concentration of dissolved oxygen has generally been kept between 2–4 mg/L. In order to ensure a continuous inflow of nitrogen to the flushing water tank (cf. Section 3.2.1), it was decided to observe and document the pressure in the nitrogen bottles once a day. The pressure reduction of nitrogen is presented in Figure 5-34.

5.4.5 Core sampling

The average drill core length per run obtained from the drilling was 2.67 m. No unbroken core was recovered. Fracture minerals were relatively well preserved. A preliminary core logging was performed continuously in connection with the drilling, see Figure 5-35.

5.4.6 Recovery of drill cuttings

The theoretical volume of drill cuttings from the cored section between 13.33–200.50 m is estimated at 0.470 m^3, and most of that is left in the formation as a complete water loss occurred at c.18 m drilling length.



Figur 5-33. Electrical conductivity of flushing water (tap water from FKA) and return water from KFR103. As there was a total water loss at c. 18 m in KFR103, only a few return data points were registered.

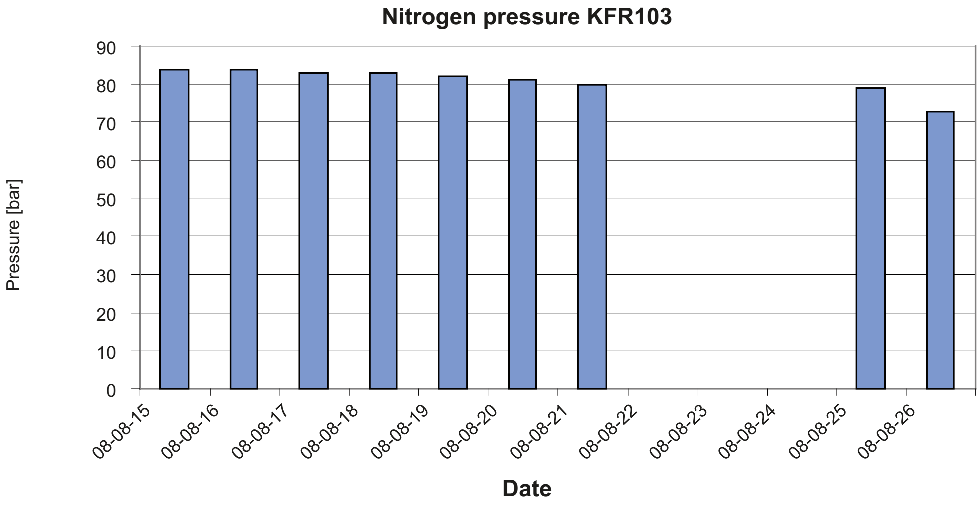


Figure 5-34. *Nitrogen contents (measured as pressure) in the bottles used for nitrogen bubbling of flushing water in KFR103.*

Figure 5-35. The core boxes were transported every morning during the drilling period to the core store-room, the so called Lentab facility. A simplified geological core mapping was performed, and afterwards all core boxes were photographed. A detailed core mapping (Boremap mapping) will be carried out after completion of drilling.

5.4.7 Devitaion measurements in KFR103

The types and principles of the equipment for deviation measurements were explained in Section 3.3, and the method enjoined according to SKB MD 224.001, Version 4, for constructing the final deviation file was demonstrated in Section 5.2.8. As in KFR101 and KFR102B, Maxibor and Flexit measurements were performed in KFR103.

The magnetic field variations during September 2nd, 2008, are displayed in Figure 5-36 and show only minor disturbances when the Flexit-surveys in KFR103 were made.

The deviation data used for construction of the final deviation file is two Maxibor II^{TM} –loggings to 198 m and two Flexit-logging to 198 m borehole length, respectively, see Table 5-21. The deviation measurements were carried out every 3 m both downwards and upwards with the Flexit Smart Tool System aas well as with the Maxibor II^{TM} System. Activities marked “CF” include comments besides measurement data.

All deviation measurements surveys in the borehole have followed the recommended quality routines according to SKB MD 224.001, Version 4.0. This file is termed EG154 (Borehole deviation multiple measurements). See illustration of the construction principle in Figure 5-14 explained in Section 5.2.8.

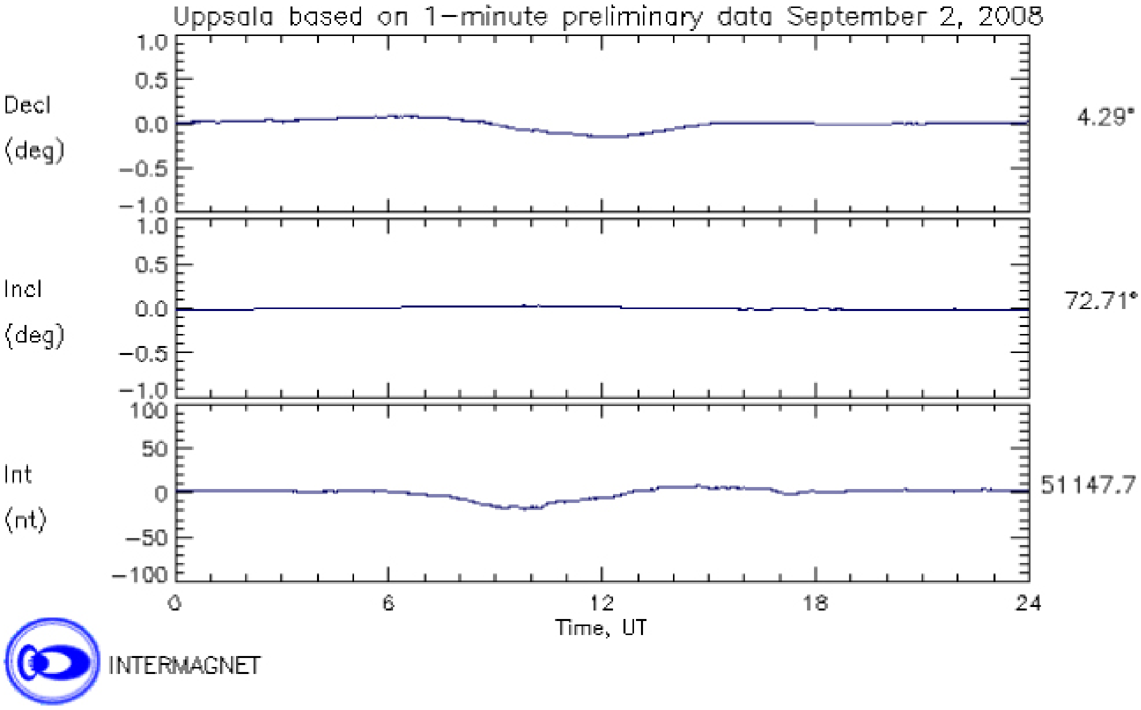


Figure 5-36. *Magnetic field variation during Flexit surveys performed September 2nd, 2008, in KFR103.*

Table 5-21. Activity data for deviation measurements approved for KFR103 (from Sicada).

ID code	Deviation activity ID	Activity type code	Activity	Start date	Secup (mbl*)	Seclow (mbl*)	Flags
KFR103	13193012	EG161	Maxibor II measurement	2008-08-26 13:30	3.00	198.00	CF
KFR103	13193013	EG161	Maxibor II measurement	2008-08-26 14:30	3.00	198.00	CF
KFR103	13193191	EG157	Magnetic accelerometer measurement	2008-09-02 13:45	3.00	198.00	CF
KFR103	13193192	EG157	Magnetic accelerometer measurement	2008-09-02 14:36	3.00	198.00	CF
KFR103	13194540	EG154	Borehole deviation multiple measurements	2008-09-10 17:05			IC

*mbl=metres borehole length

The EG154-activity specifies the sections of the deviation measurements used in the resulting calculation presented in Table 5-22. The different length of the upper sections between the bearing and the inclination are chosen due to that the magnetic accelerometer measurement (bearing) is influenced by the 14 m steel casing which is not the case for the inclinometer measurements (inclination).

A subset of the resulting deviation files and the estimated radial uncertainty is presented in Tables 5-23A and 5-23B.

The calculated deviation (EG154-file) in borehole KFR103 shows that the borehole deviates slightly upwards and to the left but with only of an absolute deviation of 2.2 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 collar.

Table 5-22. Contents of the EG154 file for KFR103 (multiple borehole deviation intervals).

Deviation activity ID	Deviation angle type	Approved Secup (mbl*)	Approved Seclow (mbl*)
13193012	BEARING	3.00	198.00
13193012	INCLINATION	3.00	198.00
13193013	BEARING	3.00	198.00
13193013	INCLINATION	3.00	198.00
13193191	BEARING	24.00	198.00
13193191	INCLINATION	3.00	198.00
13193192	BEARING	24.00	198.00
13193192	INCLINATION	3.00	198.00

*mbl=metres borehole length

Table 5-23A. Deviation data from KFR103 for approximately every 20 m elevation calculated from EG154.

Borehole	Length (mbl**)	Northing (mbl**)	Easting (m)	Elevation (m RHB 70)	Inclination* (degrees)	Bearing* (degrees)
KFR103	0.00	6,701,737.13	1,633,347.20	2.43	–55.10	179.90
KFR103	24.00	6,701,723.17	1,633,347.21	–17.09	–54.05	179.97
KFR103	48.00	6,701,709.09	1,633,347.27	–36.53	–53.96	179.70
KFR103	75.00	6,701,693.19	1,633,347.41	–58.35	–53.88	179.23
KFR103	99.00	6,701,678.97	1,633,347.61	–77.68	–53.52	179.15
KFR103	123.00	6,701,664.68	1,633,347.86	–96.96	–53.34	178.78
KFR103	150.00	6,701,648.51	1,633,348.31	–118.58	–53.10	178.31
KFR103	174.00	6,701,634.07	1,633,348.77	–137.75	–52.89	178.00
KFR103	198.00	6,701,619.62	1,633,349.31	–156.90	–53.00	177.86
KFR103	200.50	6,701,618.11	1,633,349.36	–158.89	–53.00	177.86

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a discrepancy against the values seen in Borehole direction surveying (EG151).
**mbl=metres borehole length.

Table 5-23B. Uncertainty data for the deviation measurements in KFR103 for approximately every 20 m elevation calculated from EG154.

Borehole	Length (mbl*)	Northing (mbl*)	Easting (m)	Elevation (m RHB 70)	Inclination-uncertainty (degrees)	Bearing uncertainty (degrees)	Radial uncertainty (m)
KFR103	0.00	6,701,737.13	1,633,347.20	2.43	0.100	0.500	0.00
KFR103	24.00	6,701,723.17	1,633,347.21	–17.09	0.100	0.500	0.12
KFR103	48.00	6,701,709.09	1,633,347.27	–36.53	0.100	0.500	0.24
KFR103	75.00	6,701,693.19	1,633,347.41	–58.35	0.100	0.500	0.38
KFR103	99.00	6,701,678.97	1,633,347.61	–77.68	0.100	0.500	0.51
KFR103	123.00	6,701,664.68	1,633,347.86	–96.96	0.100	0.500	0.63
KFR103	150.00	6,701,648.51	1,633,348.31	–118.58	0.100	0.500	0.77
KFR103	174.00	6,701,634.07	1,633,348.77	–137.75	0.100	0.500	0.90
KFR103	198.00	6,701,619.62	1,633,349.31	–156.90	0.100	0.500	1.03
KFR103	200.50	6,701,618.11	1,633,349.36	–158.89	0.100	0.500	1.04

*mbl=metres borehole length

5.4.8 Groove milling KFR103

A compilation of length to the reference grooves and a comment on the success of detecting the grooves are given in Table 5-24. 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.

Table 5-24. Reference grooves in KFR103.

Reference groove at (mbl*)	Detection with the SKB level indicator	Confirmed from BIPS
50	Yes	Yes
101	Yes	Yes
150	Yes	Yes
190	Yes	Yes

*mbl=metres borehole length

5.4.9 Nitrogen flushing (KFR103)

As mentioned in Section 5.2.10, 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 applied. If the shallow part of the bedrock is highly fractured, complete water loss during drilling may occur, entailing that flushing water and drill cuttings are forced into the permeable parts of the rock. This happened in KFR103 at c.18 m drilling length. All flushing water was lost, resulting in that 0.470 m^3 (1,245 kg) of drill cuttings were left in the formation.

Usually, a borehole is nitrogen flushed, until the recovered return water is judged to be clean or with a minimum content of drilling debris. KFR103 had to be nitrogen flushed sixteen times during August 26th and September 1st, 2008, before this happened, see Table 5-25. The estimated recovered water volumes amounted to 5 m^3, compared with 170 m^3 flushing water that were lost in the borehole during drilling, see Section 5.4.4.

Table 5-25. Nitrogen flushing periods and estimated uplift of groundwater from KFR103 (from EG036).

Borehole	Pressure (bar)	Start date_time	Stop date_time	Recovered water volume (L)	Comments
KFR103	50	2008-08-26 20:56	2008-08-26 21:00	750	Water up through TOC 20:58 Blow out 21:00
KFR103	55	2008-08-26 23:00	2008-08-26 23:03	750	Water up through TOC: 23:01 Blow out: 23:03
KFR103	52	2008-08-27 00:26	2008-08-27 00:29	750	Water up through TOC: 00:28 Blow out: 00:30
KFR103	50	2008-08-27 09:35	2008-08-27 09:45	750	Water up through TOC: 09:38 Blow out: 09:41
KFR103	50	2008-08-27 10:14	2008-08-27 10:20	750	Water up through TOC : 10:17 Blow out: 10:21
KFR103	55	2008-08-28 11:30	2008-08-28 11:42	750	Water up through TOC : 11:34 Blow out: 11:42
KFR103	80	2008-08-28 12:23	2008-08-28 12:27	750	Water up through TOC : 12:26 Blow out: 12:27
KFR103	50	2008-08-28 13:07	2008-08-28 13:15	750	Water up through TOC: 13:09 Blow out: 13:10
KFR103	50	2008-08-29 07:47	2008-08-29 07:51	750	Water up through TOC: 07:50 Blow out: 07:51
KFR103	70	2008-08-29 09:48	2008-08-29 09:50	750	Water up through TOC: 09:51 Blow out: 09:52
KFR103	60	2008-08-29 12:47	2008-08-29 12:50	750	Water up through TOC: 12:50 Blow out: 12:51
KFR103	55	2008-08-29 15:10	2008-08-29 15:12	750	Water up through TOC: 15:12 Blow out: 15:13
KFR103	55	2008-09-01 08:10	2008-09-01 08:14	750	Water up through TOC: 08:14 Blow out: 08:15
KFR103	55	2008-09-01 09:22	2008-09-01 10:44	750	Water up through TOC : 09:26 Blow out: 09:26
KFR103	65	2008-09-01 12:48	2008-09-01 13:01	750	Water up through TOC: 12:51 Blow out: 12:52
KFR103	70	2008-09-01 13:43	2008-09-01 13:51	750	Water up through TOC: 13:44 Blow out: 13:45

5.4.10 Risk assessment KFR103

Following the compulsory guidelines for risk assessments for boreholes presented in Section 5.2.11, the assessments after completed drilling of KFR103 are summarized in Table 5-26. Thirteen sections in borehole KFR103 have been classified as involving a potential risk (1), depending on the fact that the respective core sections are highly fractured and thus involve a risk for rock fallout.

5.5 Results KFR104

As mentioned in Section 5.1, overburden for the four boreholes presented in this report was percussion drilled. Overburden drilling in KFR104 was performed on May 13th, while setting and gap injection of the inner casing was carried out on June 10th, 2008. Finally, core drilling was conducted between September 2nd and September 29th, 2008, see Figure 5-37.

When the radar logging tool was lowered into the borehole during the subsequent borehole investigations, it got stuck in a fracture zone at c. 276 m borehole length. It was necessary to stabilize this fractured section in order to enable future borehole investigations, for example with the Posiva Flow Log for characterization of hydraulic conditions. The drilling machine was re-established to the drill site, and a so called Plex-plate /6/, was installed in borehole section 275.90–277.90 m between October 27th and October 29th, see Figure 5-37.

5.5.1 Overburden drilling 0–8.73 m

Percussion drilling through the overburden is a rapid drilling method compared to core drilling, and was therefore chosen in order to shorten drilling period for each borehole. Pre drilling of KFR104 was accomplished during two working periods (cf. Figure 5-37), 2008-05-13 (percussion drilling NO-X 115) and 2008-06-10 (setting of inner casing and gap injection), see Figure 5-38.

The composition of the overburden at KFR104 as displayed in Table 5-2 may be commented on. The thickness of the embankment fill (mostly consisting of blasted rock) reaches at KFR104 a vertical depth of 4.1 m from ground surface. Below that depth, the former sea bottom was encountered consisting of clay and gravel on top of a layer of morain, which is resting on the solid rock. The total thickness of these soil layers is 2.0 m. Consequently the vertical depth of the overburden from ground surface to rock surface is 6.1 m. As displayed in Table 5-2, the thickness of the soil layers at KFR104 are thinner than those prevailing at KFR101, KFR102B and KFR103, which primarily is a consequence of that KFR104 is located 300 m closer to the coastline.

5.5.2 Core drilling

Almost immediately after completion of the pre-drilling activities, core drilling commenced. The progress of the core drilling from 2008-09-02 to 2008-09-29, is illustrated in Figure 5-39.

Table 5-26. Documented sections of potential risk from observations during drilling and preliminary geological core mapping of KFR103.

From (mbl*)	To (mbl*)	Risk level (code)	Description
24.30	26.20	1	Highly fractured section
32.70	33.20	1	“
39.30	40.40	1	“
42.40	43.20	1	“
45.40	46.10	1	“
74.70	75.00	1	“
84.50	85.00	1	“
85.50	87.00	1	“
134.50	134.80	1	“
163.90	164.30	1	“
166.40	167.00	1	“
181.00	182.20	1	“
195.80	196.30	1	“

*mbl=metres borehole length

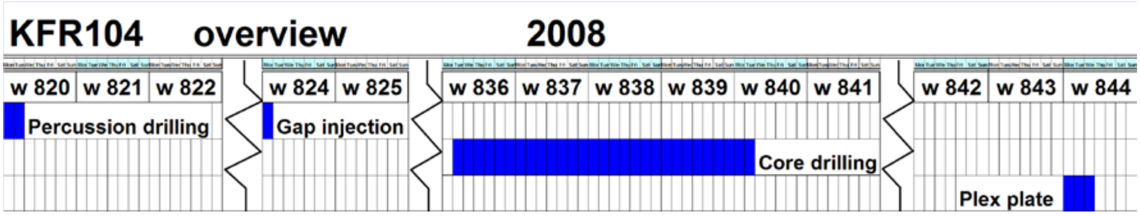


Figure 5-37. Overview of the drilling performance of borehole KFR104.

Figure 5-38. To the left the Nemek 407 RE percussion drilling machine is driving the casing through the overburden with the NO-X 115 technique. The photo to the right illustrates installation of an inner casing. Regarding KFR104 this was performed almost a month after completion of the percussion drilling. The section 0–8.73 m was supplied with an 88/77 mm stainless steel casing and the gap between the NO-X casing and the inner casing was cement grouted with use of the hose shown in the photo, from the bottom and upwards.

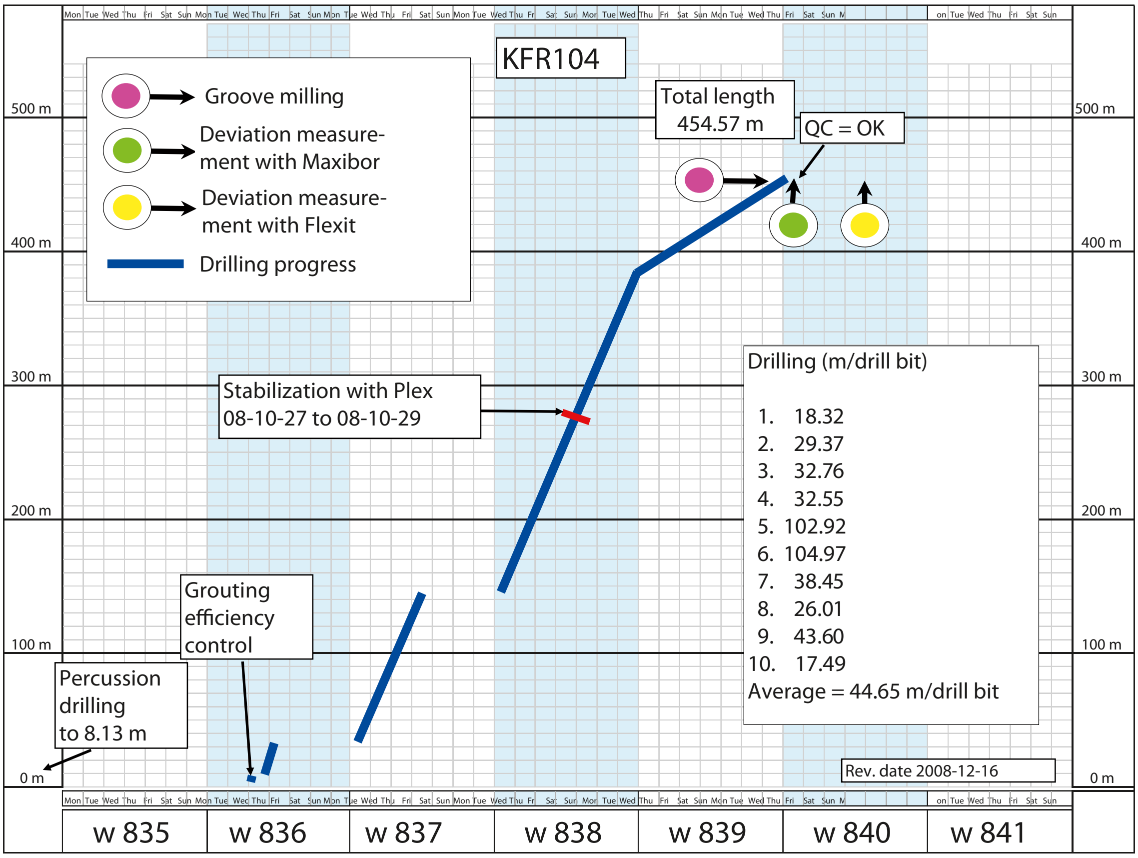


Figure 5-39. Core drilling progress KFR104 (length versus calendar time).

5.5.3 Geometrical and technical design of borehole KFR104

Administrative, geometric and technical data from borehole KFR104, are presented in Table 5-27. The technical design of the borehole is illustrated in Figure 5-40.

5.5.4 Measurement while drilling KFR104

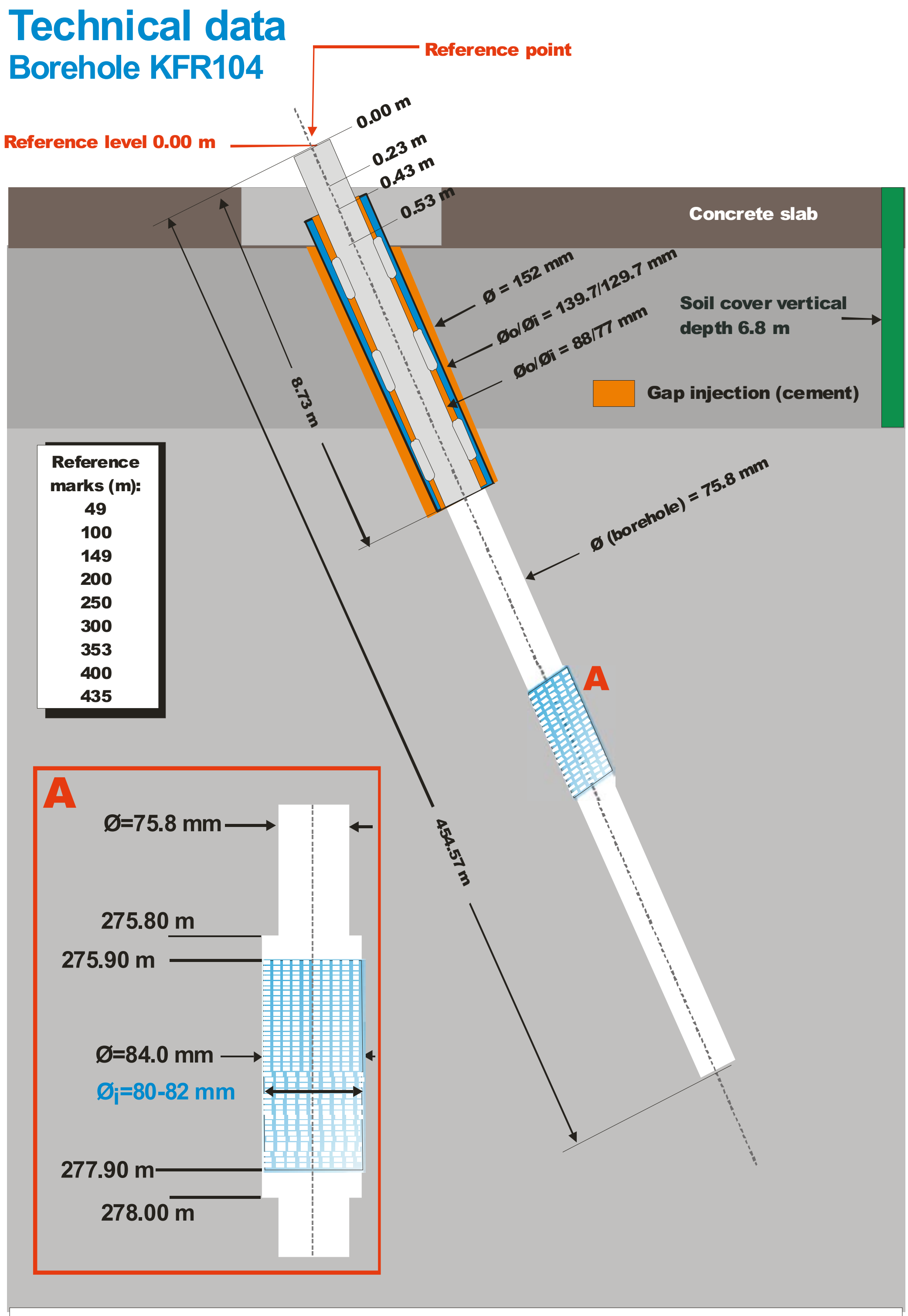
During, and immediately after drilling, a programme for sampling and measurements was applied, cf. Section 4.4.3. Some of the results are displayed in the Well Cad presentation in Appendix D whereas other results (flow data and electrical conductivity) are primarily used as supporting data for on-site decisions.

Flushing water and Return water flow rate – water balance

Figure 5-41 displays the accumulated volumes of flushing water respectively return water from the entire drilling period. The accumulated volumes of flushing water and return water are also illustrated in the histogram in Figure 5-42, from which the return water/flushing water quotient at the end of the drilling period was calculated, resulting in a quotient of 1.09.

Table 5-27. Administrative, geometric and technical data for borehole KFR104.

Parameter	Data
Borehole name	KFR104
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	May 13, 2008
Completion date (including stabilization)	Oct 29, 2008
Percussion drilling period	2008-05-13 to 2008-05-13
Core drilling period	2008-09-02 to 2008-09-29
Stabilization with Plex plate	2008-10-27 to 2008-10-29
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Züblin Svenska AB; Sven Andersson i Uppsala AB
Percussion drill rig	Nemek 407 RE
Core drill rig	Sandvik DE150
Position at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6701719.45 (m) E 1632879.34 (m) Z 2.83 (m RHB 70.) Azimuth (0–360°): 133.78° Dip (0–90°): –53.81°
Position at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6701528.85 E 1633089.71 Z –351.72 (m RHB 70) Azimuth (0–360°): 129.71° Dip (0–90°): –47.80°
Borehole length	454.57 m
Borehole length and diameter	From 0.53 m to 8.73 m: 0.152 m From 8.73 m to 454.57 m: 0.0758 m
Outer casing, diameter and drilling length	Casing Øo/Øi = 139.7 mm/129.7 mm 0.43 to 8.61 m Casing shoe Øi = 122 mm between 8.61 and 8.65 m Casing shoe bit Øo/Øi = 152 mm/116 mm between 8.65 and 8.73 m
Inner casing, diameter and drilling length	Øo/Øi = 80/77 mm 0 to 8.73 m
Drill core dimension	8.73–454.57 m / Ø 50 mm
Core interval	8.73–454.57 m
Average length of core recovery	2.58 m
Number of runs	173
Diamond bits used	10
Average bit life	44.65 m



Drilling reference point
Northing: 6701719.45 (m), RT90 2,5 gon V 0:-15
Easting: 1632879.34 (m), RT90 2,5 gon V 0:-15
Elevation: 2.83 (m), RHB 70

Orientation
Bearing (degrees): 133.78°
Inclination (degrees): -53.81°

Borehole
Length: 454.57 m

Percussion drilling period
Drilling start date: 2008-05-13
Drilling stop date: 2008-05-13

Core drilling period
Drilling start date: 2008-09-02
Drilling stop date: 2008-09-29

Stabilization Plex plate
Drilling start date: 2008-10-27
Drilling stop date: 2008-10-29

Rev. 2009-03-24

Figure 5-40. Technical data of borehole KFR104.

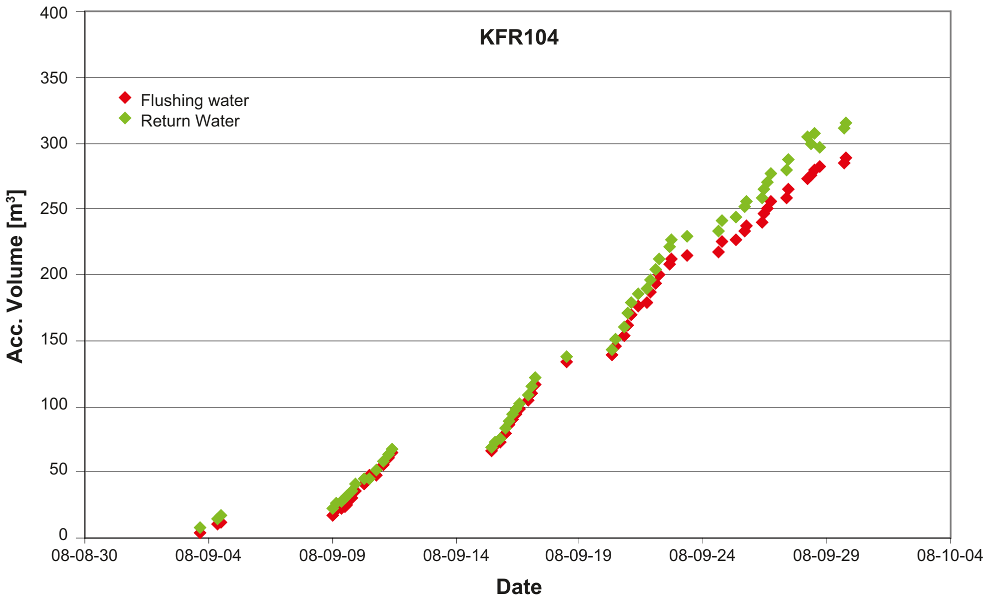


Figure 5-41. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFR104.*

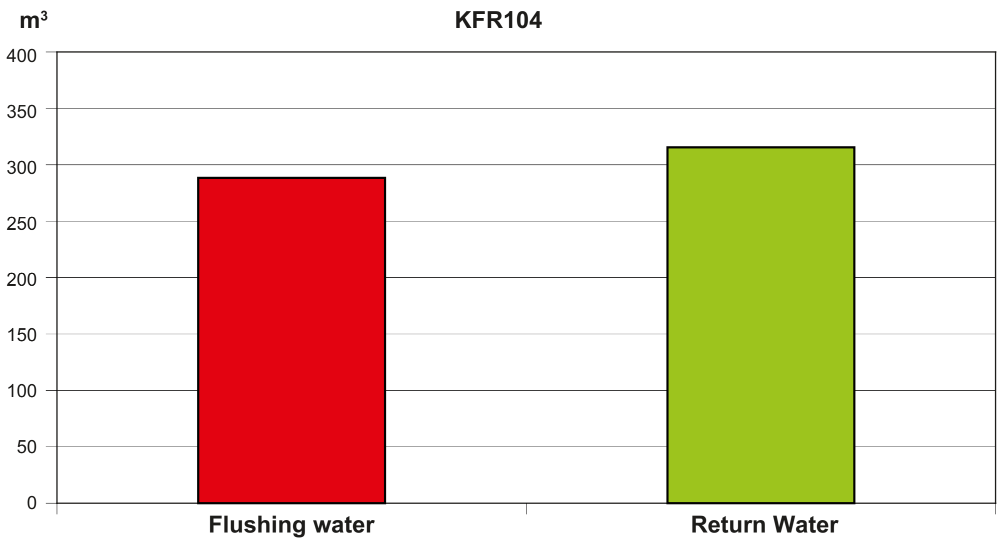


Figure 5-42. *Total amounts of flushing water and return water during drilling of borehole KFR104. The total volume of flushing water used during core drilling amounted to 288.65 m^3. During the same period, the total volume of return water was 314.95 m^3 resulting in a return water/flushing water balance of 1.09.*

Uranine content 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 5-43. 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.

The same kind of mass balance calculation from Uranine concentrations in flushing water and return water samples as for KFR101 and KFR102B was made for KFR104.

According to the notations in the logbook, the amount of Uranine added to the borehole was 68 g. If the averages of the Uranine concentration values in the flushing water and in return water are used to calculate the amount of Uranine added and recovered from the borehole, the calculation gives 62 g and 59 g, respectively. After finished drilling, the nitrogen flushing in KFR104, also showed that flushing water still remained in the borehole.

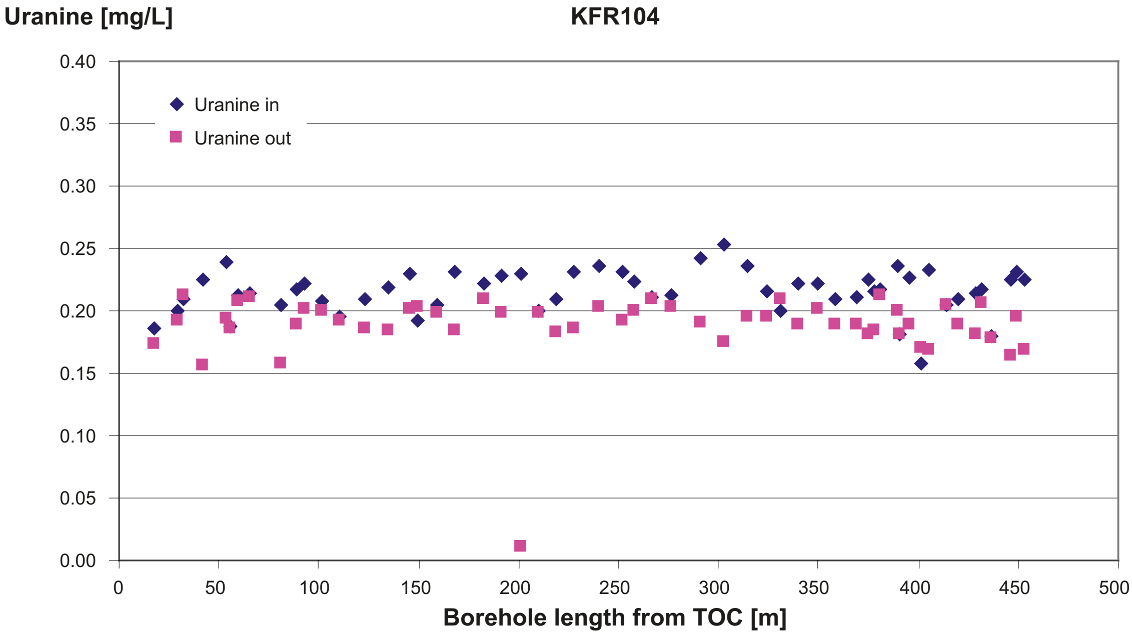


Figure 5-43. *Uranine contents in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFR104. Automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.*

Electric conductivity of flushing water and return water

Flushing water was supplied from percussion borehole HFR101. 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 5-44.

The electrical conductivity of flushing water from the 209 m deep supply well HFR101, with major inflow at c. 150–170 m displays similar values as the majority of other supply wells drilled during the site investigation of the Forsmark tectonic lence during 2002–2007.

In order to supply KFR104 with flushing water, the maximum well capacity of HFR101 was required, a result of the continuous drilling during September 2008. The average electrical conductivity of the flushing water is almost constant at c. 1,050 mS/m from the beginning to the end of the drilling period.

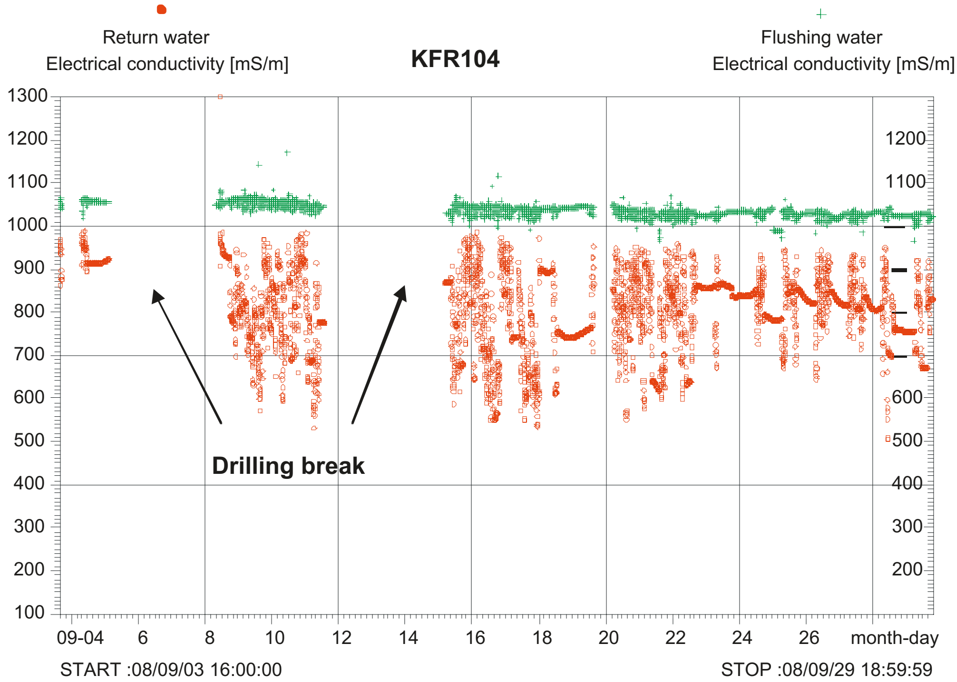
The average electrical conductivity of the return water from KFR104 (Figure 5-44) is generally lower than the flushing water, indicating inflows in the upper section, whereby shallow water (less saline water) is mixed with the flushing water, giving the return water lower EC-values.

Contents 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 3.2.1), 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 5-45.

5.5.5 Core sampling

The average drill core length per run obtained from the drilling was 2.58 m. No unbroken core was recovered. Fracture minerals were relatively well preserved. A preliminary core logging was performed continuously in connection with the drilling, see Figure 5-46.



Figur 5-44. *Electrical conductivity of flushing water from HFR101 and return water from KFR104.*

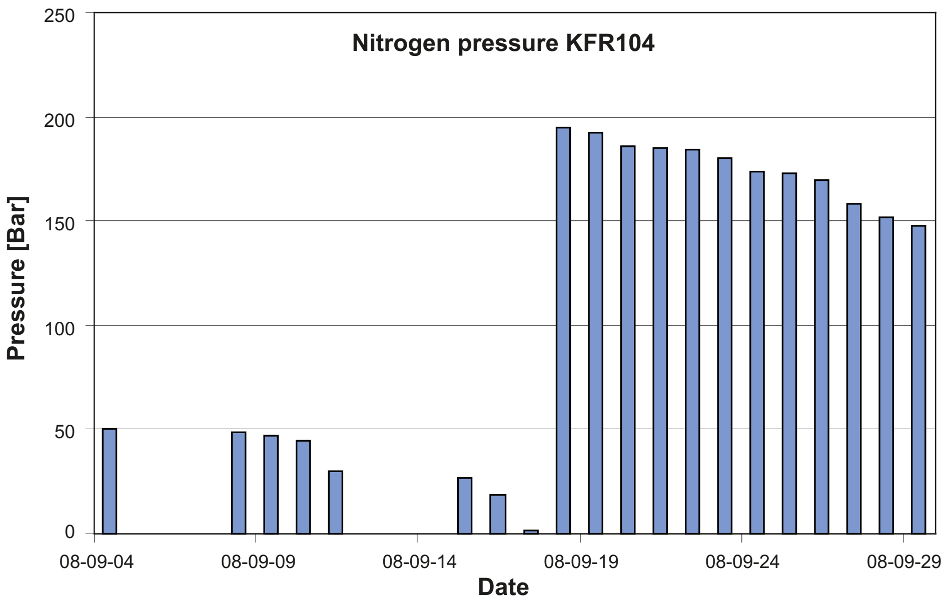


Figure 5-45. *Nitrogen contents (measured as pressure) in the bottles used for nitrogen bubbling of flushing water in KFR104.*

Figure 5-46. The core boxes were transported every morning during the drilling period to the core store-room, the so called Llentab facility. A simplified geological core mapping was performed, and afterwards all core boxes were photographed. A detailed core mapping (Boremap mapping) will be carried out after completion of drilling.

5.5.6 Recovery of drill cuttings

The theoretical difference in volume of the core drilled part of KFR104 (8.73–454.57 m) and the drill core is calculated to be 1,119 m^3. This volume should correspond to the amount of drill cuttings produced during drilling. If a density of 2.65 kg/ m^3 is applied (approximate figure for granites in the Forsmark area), the total weight of the theoretical amount of debris is estimated at 2,976 kg. The calculated dry weight of the debris from core drilling recovered and weighed in the container is 2,309 kg, which gives a recovery of 78%.

The recovery figure could be commented on. The dwell time in the container system is too short for sedimentation of the suspended finest fractions. No estimation was made of the amount of suspended material, but weighing of the container including water and debris is associated with some uncertainty.

However, it seems also plausible that some drilling debris has been injected into the fracture system of the formation, especially as KFR104 is a traditionally drilled borehole. Such boreholes are not supplied with a system for continuous discharge of water and drill cuttings from the borehole during drilling unlike so called telescopic boreholes, cf. SKB MD 620.003.

5.5.7 Devitaion measurements in KFR104

The types and principles of the equipment for deviation measurements were explained in Section 3.3, and the method enjoined according to SKB MD 224.001, Version 4, for constructing the final deviation file was demonstrated in Section 5.2.8. As in KFR101, KFR102B and KFR103, Maxibor and Flexit measurements were performed in KFR104.

The magnetic field variations during October 13th, 2008, are displayed in Figure 5-47 and show only minor disturbances when the Flexit-surveys in KFR104 were made.

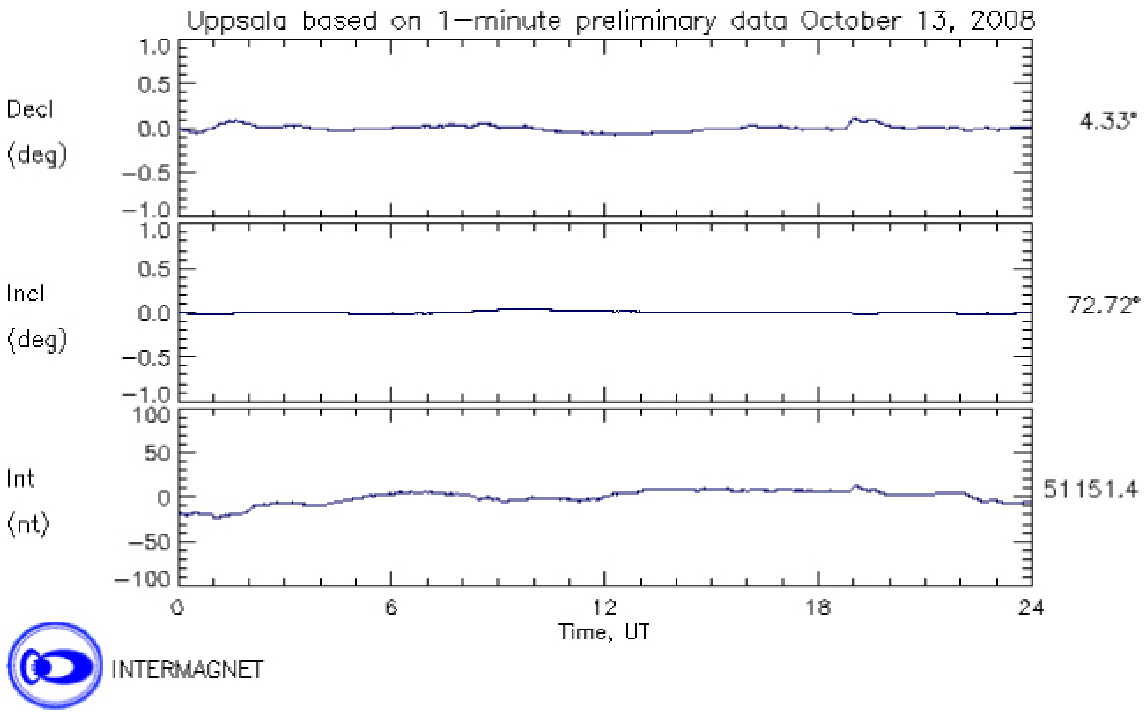


Figure 5-47. Magnetic field variation during Flexit surveys performed October 13th, 2008, in KFR104.

The deviation data used for construction of the final deviation file is two Maxibor II™ –logging, to 438 m and two Flexit-logging to 450 m borehole length, respectively, see Table 5-28. The deviation measurements were carried out every 3 m both downwards and upwards with the Flexit Smart Tool System as well as with the Maxibor II™ System. Activities marked "CF" include comments besides measurement data.

All deviation measurements surveys in the borehole have followed the recommended quality routines according to SKB MD 224.001, Version 4.0. This file is termed EG154 (Borehole deviation multiple measurements). See illustration of the construction principle in Figure 5-14 explained in Section 5.2.8.

The EG154-activity specifies the sections of the deviation measurements used in the resulting calculation presented in Table 5-29. The different length of the upper sections between the bearing and the inclination are chosen due to that the magnetic accelerometer measurement (bearing) is influenced by the 9 m steel casing which is not the case for the inclinometer measurements (inclination).

Table 5-28. Activity data for deviation measurements approved for KFR104 (from Sicada).

ID code	Deviation activity ID	Activity type code	Activity	Start date	Secup (mbl*)	Seclow (mbl*)	Flags
KFR104	13198224	EG161	Maxibor II measurement	2008-09-28 14:00	3.00	438.00	C
KFR104	13198225	EG161	Maxibor II measurement	2008-09-28 16:00	3.00	438.00	C
KFR104	13198556	EG157	Magnetic accelerometer measurement	2008-10-13 14:00	3.00	450.00	CF
KFR104	13198557	EG157	Magnetic accelerometer measurement	2008-10-13 16:00	3.00	450.00	CF
KFR104	13198666	EG154	Borehole deviation multiple measurements	2008-10-20 16:30	3.00	450.00	ICF

*mbl=metres borehole length

Table 5-29. Contents of the EG154 file for KFR104 (multiple borehole deviation intervals).

Deviation activity ID	Deviation angle type	Approved Secup (mbl*)	Approved Seclow (mbl*)
13198224	BEARING	3.00	438.00
13198224	INCLINATION	3.00	438.00
13198225	BEARING	3.00	438.00
13198225	INCLINATION	3.00	438.00
13198556	BEARING	21.00	450.00
13198556	INCLINATION	3.00	450.00
13198557	BEARING	21.00	450.00
13198557	INCLINATION	3.00	450.00

*mbl=metres borehole length

A subset of the resulting deviation files and the estimated radius uncertainty is presented in Tables 5-30A and 5-30B.

The calculated deviation (EG154-file) in borehole KFR104 shows that the borehole deviates upwards and to the left with an absolute deviation of 21.3 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 collar.

5.5.8 Groove milling KFR104

A compilation of positions to the reference grooves and a comment on the success of detecting the grooves are given in Table 5-31. 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.

Table 5-30A. Deviation data from KFR104 for approximately every 50 m elevation calculated from EG154.

Borehole	Length (mbl**)	Northing (mbl**)	Easting (m)	Elevation (m)	Inclination* (degrees)	Bearing* (degrees)
KFR104	0.00	6,701,719.45	1,632,879.34	2.83	–54.87	133.78
KFR104	63.00	6,701,694.28	1,632,905.66	–48.58	–54.28	133.56
KFR104	123.00	6,701,669.94	1,632,931.50	–96.95	–52.97	133.17
KFR104	186.00	6,701,643.76	1,632,959.54	–146.92	–51.88	132.76
KFR104	249.00	6,701,617.16	1,632,988.54	–196.12	–50.69	132.40
KFR104	315.00	6,701,588.96	1,633,019.90	–246.88	–49.87	131.40
KFR104	381.00	6,701,560.62	1,633,052.35	–296.89	–48.61	130.97
KFR104	450.00	6,701,530.81	1,633,087.35	–348.33	–47.80	129.72
KFR104	454.57	6,701,528.85	1,633,089.71	–351.72	–47.80	129.71

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a discrepancy against the values seen in Borehole direction surveying (EG151).
** mbl=metres borehole length.

Table 5-30B. Uncertainty data for the deviation measurements in KFR104 for approximately every 50 m elevation calculated from EG154.

Borehole	Length (mbl*)	Northing (mbl*)	Easting (m)	Elevation (m)	Inclination uncertainty (degrees)	Bearing uncertainty (degrees)	Radial uncertainty (m)
KFR104	0.00	6,701,719.45	1,632,879.34	2.83	0.085	0.330	0.00
KFR104	63.00	6,701,694.28	1,632,905.66	–48.58	0.085	0.330	0.21
KFR104	123.00	6,701,669.94	1,632,931.50	–96.95	0.085	0.330	0.41
KFR104	186.00	6,701,643.76	1,632,959.54	–146.92	0.085	0.330	0.64
KFR104	249.00	6,701,617.16	1,632,988.54	–196.12	0.085	0.330	0.86
KFR104	315.00	6,701,588.96	1,633,019.90	–246.88	0.085	0.330	1.11
KFR104	381.00	6,701,560.62	1,633,052.35	–296.89	0.085	0.330	1.35
KFR104	450.00	6,701,530.81	1,633,087.35	–348.33	0.085	0.330	1.62
KFR104	454.57	6,701,528.85	1,633,089.71	–351.72	0.085	0.330	1.64

*mbl=metres borehole length

Table 5-31. Reference grooves in KFR104.

Reference groove at (mbl*)	Detection with the SKB level indicator	Confirmed from BIPS
49	Yes	Yes
100	Yes	Yes
149	Yes	Yes
200	Yes	Yes
250	Yes	Yes
300	Yes	Yes
353	Yes	Yes
400	Yes	Yes
435	Yes	Yes **

*mbl=metres borehole length
** BIPS image not adjusted

5.5.9 Nitrogen flushing (KFR104)

As mentioned in Section 5.2.10, 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 applied. If the shallow part of the bedrock is highly fractured, complete water loss during drilling may occur, entailing that flushing water and drill cuttings are forced into the permeable parts of the rock. However, in KFR104 all flushing water was completely recovered. In fact, the total volume of flushing water used was somewhat less than the recovered volume of the return water, but still 22% (667 kg) of drilling debris was injected into the formation.

This happened in KFR103 at c.18 m drilling length. All flushing water was lost, resulting in that 0.470 m^3 (1,245 kg) of drill cuttings were left in the formation.

Usually, the boreholes are nitrogen flushed, until the recovered return water is judged to be clean or with a minimum content of drilling debris. KFR104 had to be nitrogen flushed fourteen times during October 3rd and October 6th and November 3rd and November 4th, 2008, before this happened, see Table 5-32. The estimated recovered water volume was 14 m^3.

Table 5-32. Nitrogen flushing periods and estimated uplift of groundwater from KFR104 (from EG036).

Borehole	Pressure (bar)	Start date_time	Stop date_time	Recovered water volume (L)	Comments
KFR104	80	2008-10-03 11:34	2008-10-03 12:00	500	Water up through TOC : 11:41 Blow out 11:48
KFR104	80	2008-10-03 13:59	2008-10-03 14:20	1000	Water up through TOC : 14:06 Blow out: 14:11
KFR104	90	2008-10-03 18:02	2008-10-03 18:30	1000	Water up through TOC : 18:09 Blow out: 18:14
KFR104	85	2008-10-04 08:26	2008-10-04 08:50	1500	Water up through TOC: 08:33 Blow out: 08:39
KFR104	80	2008-10-04 12:15	2008-10-04 12:40	1000	Water up through TOC : 12:23 Blow out: 12:28
KFR104	80	2008-10-04 17:25	2008-10-04 17:50	1000	Water up through TOC : 17:33 Blow out: 17:38
KFR104	110	2008-10-06 09:59	2008-10-06 10:20	1000	Water up through TOC : 10:04 Blow out: 10:10
KFR104	90	2008-11-03 16:30	2008-11-03 16:46	1000	Water up through TOC : 16:34 Blow out 16:42
KFR104	100	2008-11-04 07:53	2008-11-04 08:06	1000	Water up through TOC : 07:57 Blow out: 08:03
KFR104	110	2008-11-04 09:20	2008-11-04 09:33	1000	Water up through TOC : 09:24 Blow out: 09:28
KFR104	80	2008-11-04 10:46	2008-11-04 11:01	1000	Water up through TOC: 10:51 Blow out: 10:55
KFR104	80	2008-11-04 12:39	2008-11-04 12:55	1000	Water up through TOC : 12:43 Blow out: 12:48
KFR104	80	2008-11-04 13:58	2008-11-04 14:18	1000	Water up through TOC : 14:03 Blow out: 14:07
KFR104	80	2008-11-04 15:03	2008-11-04 15:32	1000	Water up through TOC : 15:09 Blow out: 15:12

5.5.10 Risk assessment KFR104

Following the compulsory guidelines for risk assessments for boreholes presented in Section 5.2.11, the assessments after completed drilling of KFR104 are summarized in Table 5-33. Forty-five sections in borehole KFR104 have been classified as involving a potential risk (1), depending on the fact that the respective core sections are highly fractured and thus involve a risk for rock fallout. One of these sections, between borehole lengths 276.30 m and 276.80 m, was originally classified as a potential risk (2) because of a rock fallout that almost got a radar measuring tool stuck in the borehole. Borehole section 275.90–277.90 m was later mechanically stabilized by applying the Plex-system, and the risk of rock fallouts is thereby minimized, see Section 5.5.11. However, this procedure creates slightly different borehole diameters which could cause problem for some measurement tools to pass through, see Figure 5-48.

Table 5-33. Documented sections of potential risk from observations during drilling and preliminary geological core mapping of KFR104.

From (mbl*)	To (mbl*)	Risk level (code)	Description
18.70	18.90	1	Highly fractured section
24.60	24.90	1	“
27.40	27.60	1	“
32.40	32.80	1	“
33.15	33.40	1	“
45.90	46.20	1	“
49.90	50.10	1	“
54.10	54.50	1	“
61.60	62.00	1	“
63.10	63.50	1	“
64.90	65.10	1	“
67.10	67.50	1	“
72.40	72.90	1	“
73.70	74.40	1	“
80.00	82.00	1	“
97.60	97.90	1	“
105.70	106.10	1	“
108.30	109.40	1	“
111.90	112.20	1	“
115.60	116.00	1	“
116.70	118.60	1	“
134.50	135.40	1	“
137.50	137.80	1	“
144.00	145.10	1	“
149.90	151.00	1	“
161.30	162.00	1	“
174.60	175.80	1	“
187.90	188.50	1	“
237.80	238.10	1	“
252.80	254.00	1	“
259.30	260.50	1	“
263.00	263.30	1	“
265.60	266.60	1	“
269.10	269.35	1	“
269.80	270.90	1	“
275.00	276.30	1	“
276.30	276.80	2	Borehole section 275.90–277.90 m has been mechanically stabilized and is now associated with a low risk (1).
276.80	278.30	1	“
297.80	298.40	1	“
318.50	318.70	1	“
367.10	367.50	1	“
395.80	401.00	1	“
403.80	404.30	1	“
411.00	412.10	1	“
416.50	417.50	1	“
423.70	424.40	1	#

* mbl=metres borehole length

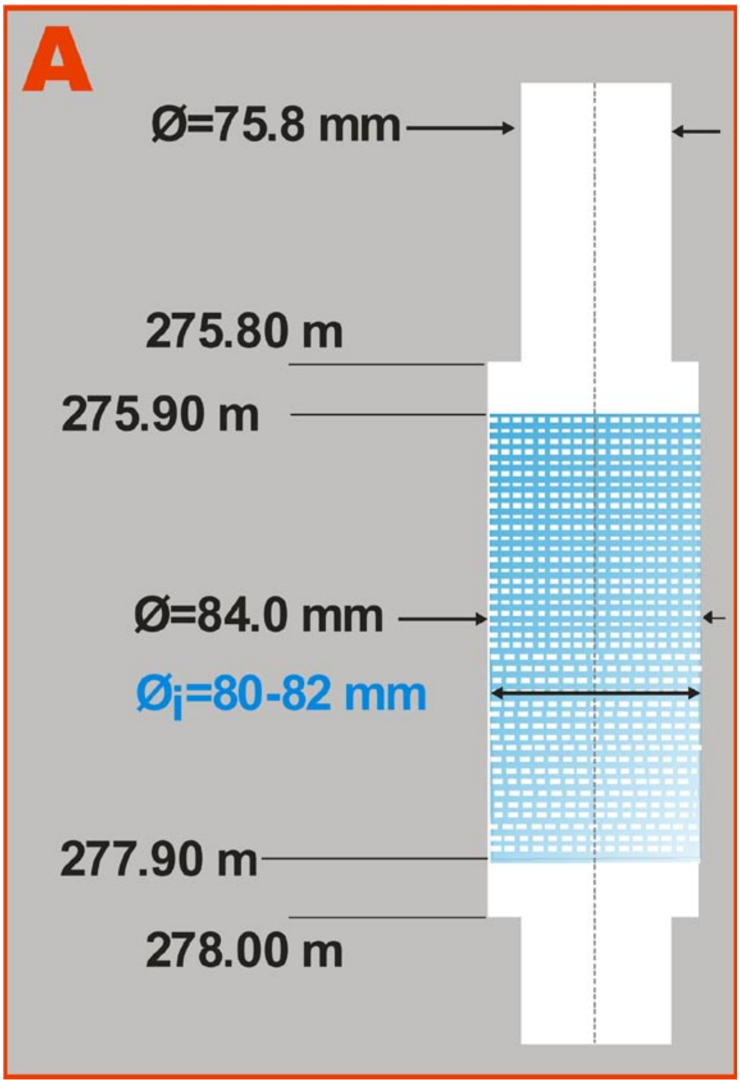


Figure 5-48. *Detailed technical data of borehole dimension and dimension of the Plex-plate installed in borehole KFR104.*

5.5.11 Stabilization KFR104

Drilling of inclined boreholes in highly fractured rock involves an increased risk of instable sections of the borehole wall, implying a higher risk for borehole instruments to get stuck. Initially, measurements along the complete borehole length with geophysical logging and BIPS were successful, even though the BIPS measurement confirmed the occurrence of unstable sections with a higher risk of rock outfall. However, when the radar logging tool was lowered into the borehole, it got caught in a fracture zone at c. 276 m borehole length, see Figure 5-49. To fulfil the measurement programme, for example with the Posiva Flow Log for characterizing of hydraulic conditions, it was necessary to stabilize the section.

The SFR modelling group gave high priority to achieve hydrogeological and hydrogeochemical data from the lower part of the borehole, and therefore a decision was made to use a drill rig in order to:

- rinse the borehole
- stabilize the high risk borehole section (identified from the BIPS-logging) with the Plex technique and
- clean the borehole bottom.

The Plex system for stabilization of the borehole wall is described in Section 3.4. The section 275.90–277.90 m, where the Plex-plate was installed (after eliminating the obstacles of rock pieces) is commented on below.

Figure 5-49. *Image of the instable section in borehole KFR104.*

Section 275.90–277.90

The following sequence of actions was taken (cf. Figures 3-5 and 5-50):

- The Plex tool, supplied with a perforated stainless steel plate and the reamer, was attached to the drill pipe string and lowered into the borehole.
- The instable section between 275.80–278.00 m was reamed to Ø 84 mm.
- The packer was inflated with an excess pressure of 60–70 bars, whereby the perforated stainless steel plate was forced into the reamed part of the borehole wall between 275.90–277.90 m.
- The packer was deflated, after which the tool was retrieved from the borehole.

After the Plex operation, part of the borehole was logged with the BIPS-camera, see Figure 5-50. The video images show that the perforated plate was expanded in the reamed section without any damages. After the Plex stabilization, it has been possible to investigate the borehole without problems. Because the steel plate is perforated, it is also possible to perform hydraulic tests in the entire borehole.

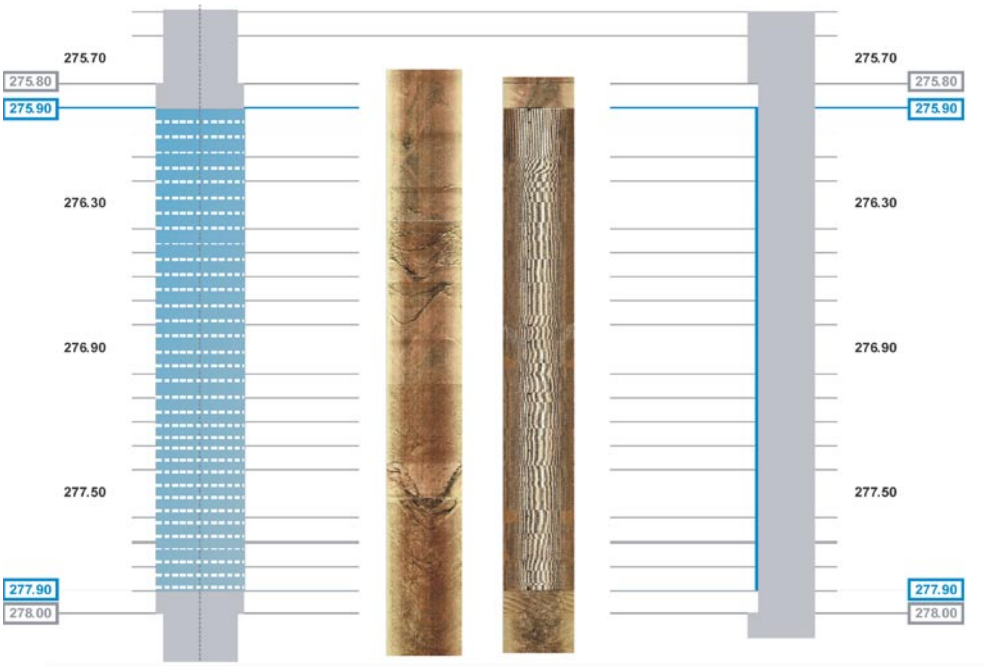


Figure 5-50. *Schematic figure of the stabilized section in borehole KFR104 with BIPS –images of the borehole section, both before and after stabilization with the Plex system.*

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, 2008. Site investigations.** Investigation methods and general execution programme, SKB TR-01-29, 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.

/4/ **Follin S, Levén J, Hartley L, Jackson P, Joyce S, Roberts D, Swift B, 2007.** Hydrogeological characterisation and modelling of deformation zones and fracture domains, Forsmark modelling stage 2.2. SKB R-07-48, Svensk Kärnbränslehantering AB.

/5/ **Nilsson G, Ullberg A, 2008.** SFR utbyggnad, delprojekt undersökningar. Drilling of water well HFR101 and monitoring wells HFR102 and HFR105. SKB P-08-95, report in progress, Svensk Kärnbränslehantering AB.

/6/ **Håkanson N, Nilsson G, 2007.** Plex – Utrustning för mekanisk stabilisering. Metodbeskrivning & handhavande – Version 1.0 . Docq nr 1077121.

Appendix A

Well Cad presentation of borhole KFR101

Title CORE DRILLED BOREHOLE KFR101

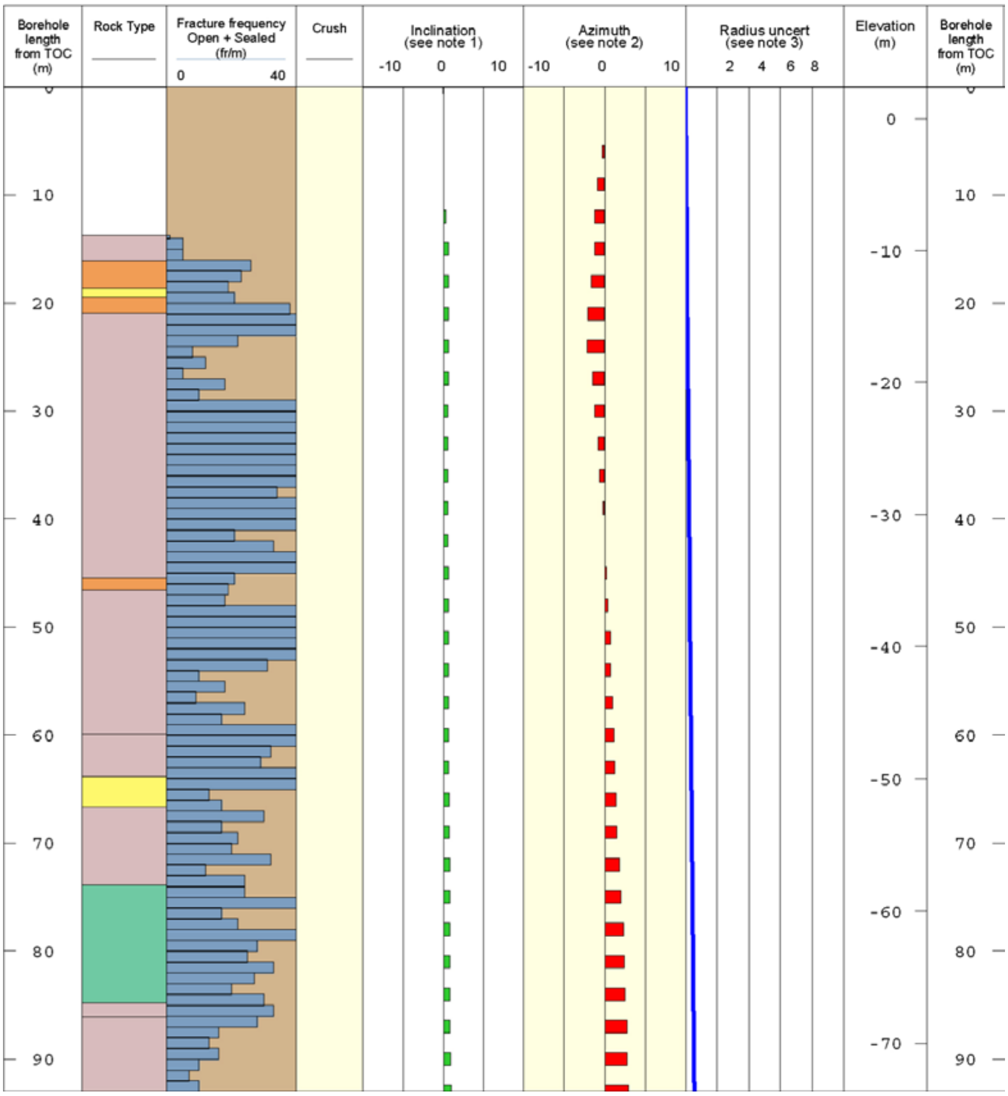
Svensk Kärnbränslehantering AB

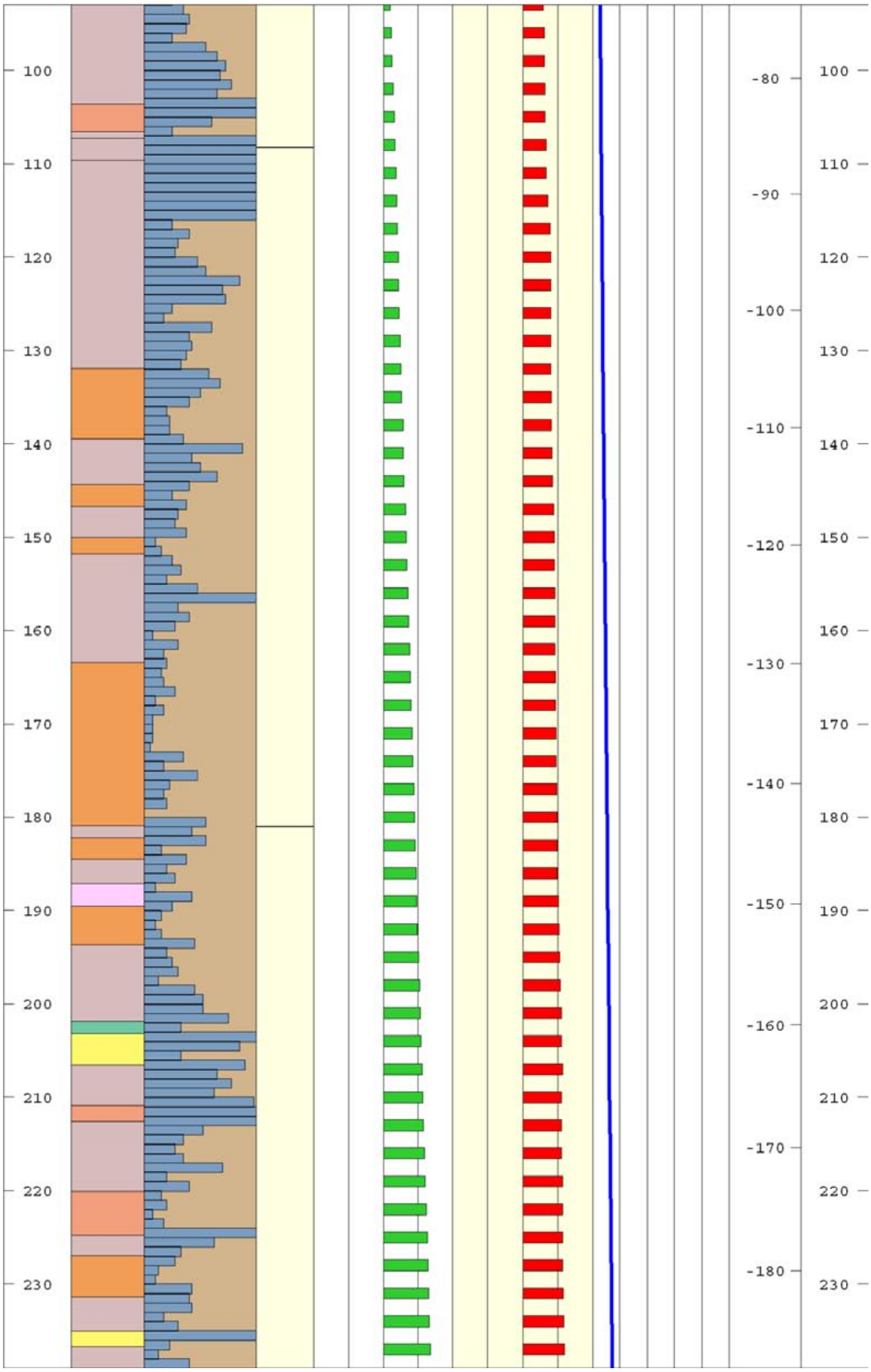
Site	FORSMARK - SFR	Coordinate System	RT90-RHB70
Borehole	KFR101	Northing [m]	6701736.32
Diameter [mm]	76	Easting [m]	1633351.40
Length [m]	341.76	Elevation [m]	2.44
Azimuth [°]	28.77	Drilling Start Date	2008-06-12
Inclination [°]	-54.44	Drilling Stop Date	2008-07-02
		Plot Date	2009-04-01

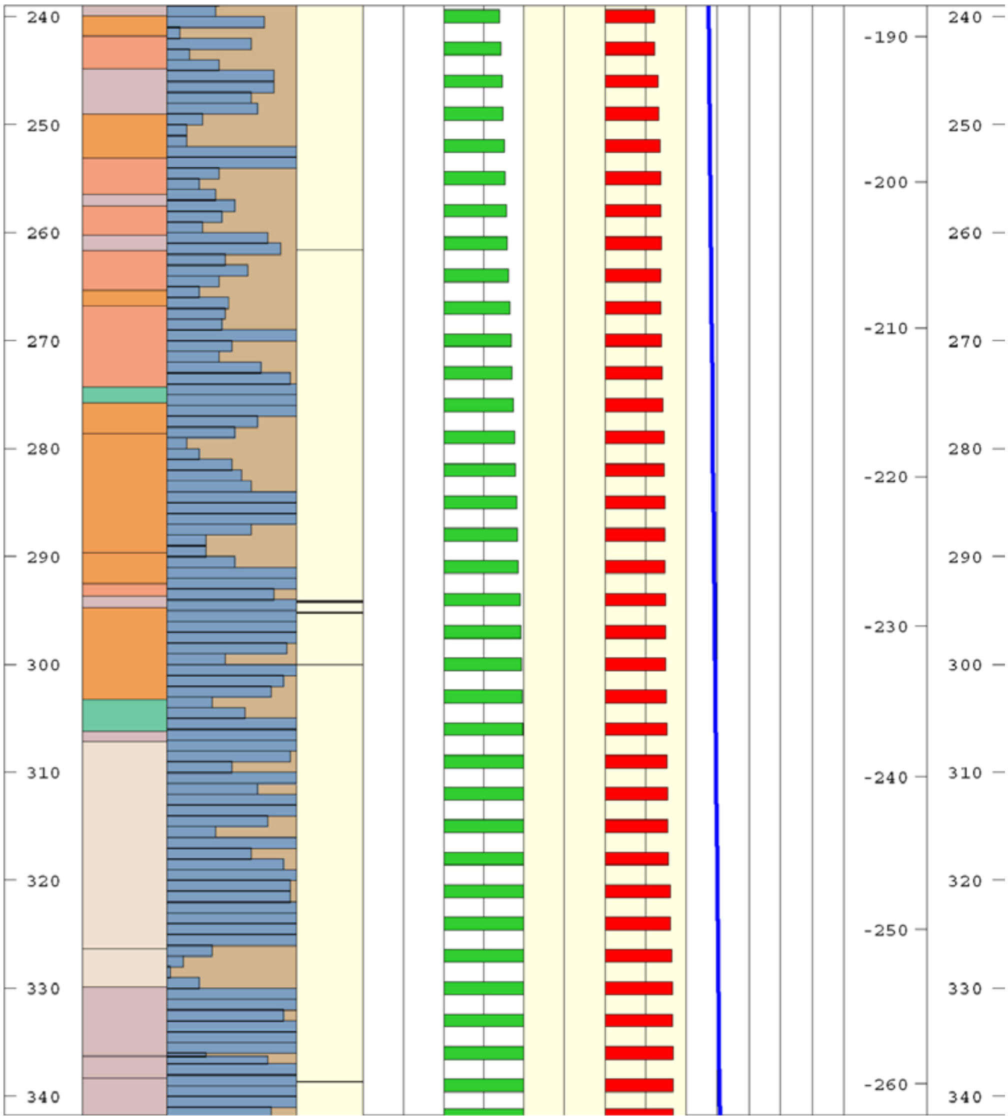
ROCK TYPE

- 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
- 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.




100
110
120
130
140
150
160
170
180
190
200
210
220
230
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
100
110
120
130
140
150
160
170
180
190
200
210
220
230


240
250
260
270
280
290
300
310
320
330
340
-190
-200
-210
-220
-230
-240
-250
-260
240
250
260
270
280
290
300
310
320
330
340

Well Cad presentation of borhole KFR102B

Title CORE DRILLED BOREHOLE KFR102B

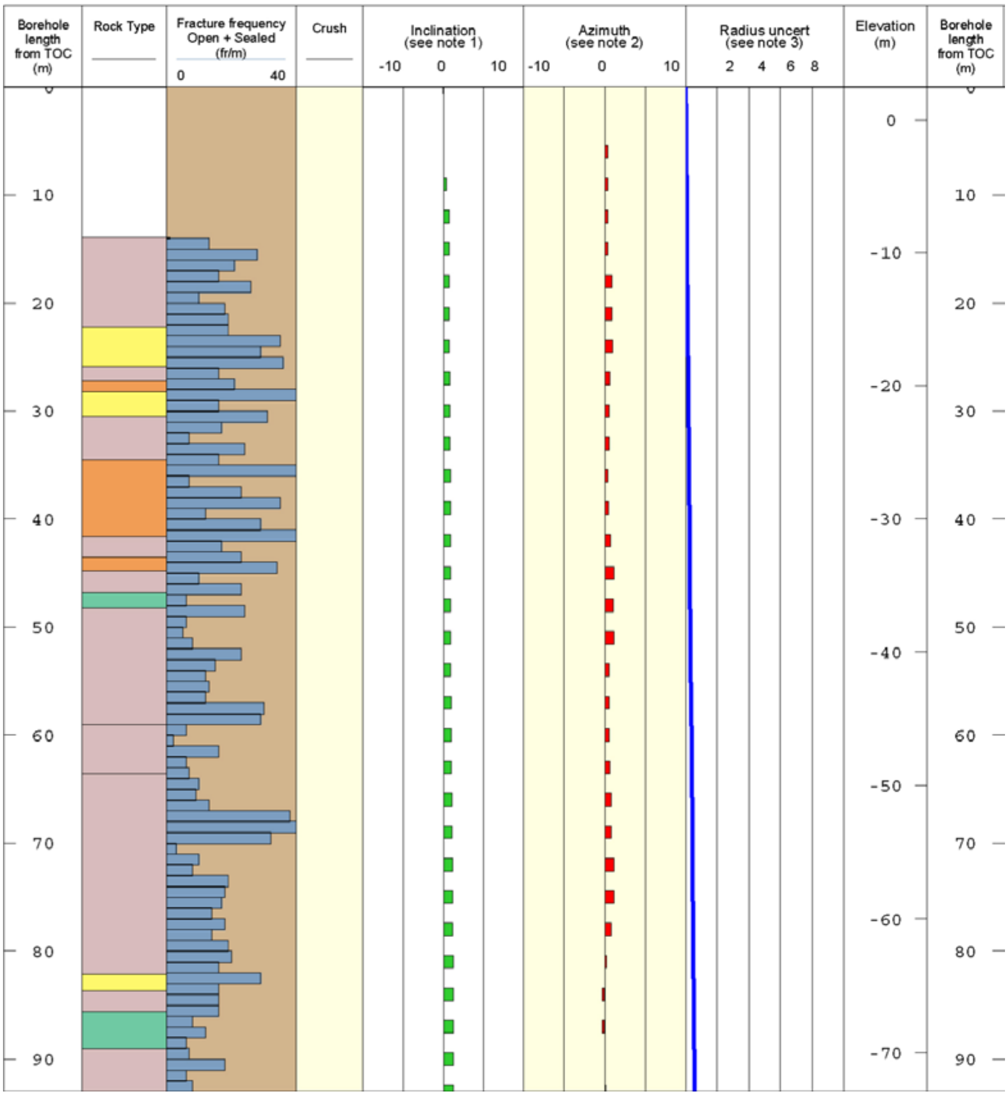
Svensk Kärnbränslehantering AB

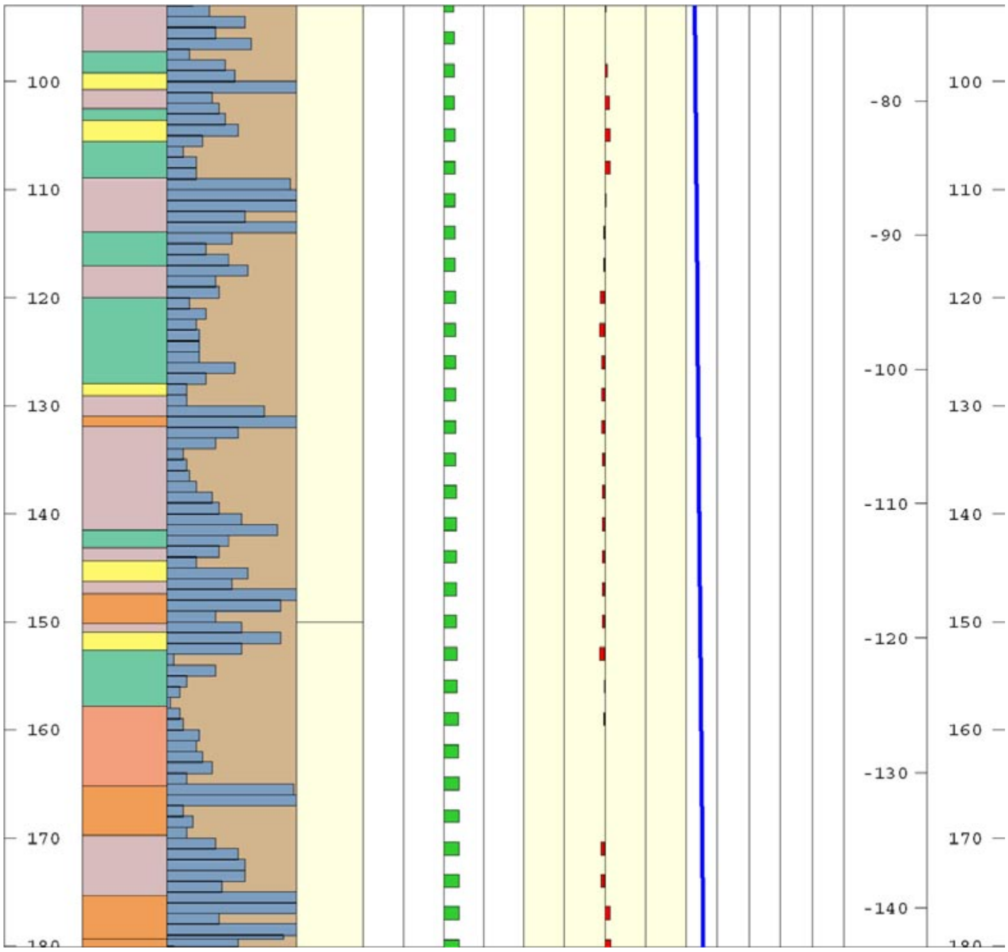
Site	FORSMARK - SFR	Coordinate System	RT90-RHB70
Borehole	KFR102B	Northing [m]	6701740.53
Diameter [mm]	76	Easting [m]	1633343.91
Length [m]	180.08	Elevation [m]	2.51
Azimuth [°]	344.87	Drilling Start Date	2008-08-06
Inclination [°]	-54.14	Drilling Stop Date	2008-08-14
		Plot Date	2009-04-01

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.




100
110
120
130
140
150
160
170
-80
-90
-100
-110
-120
-130
-140

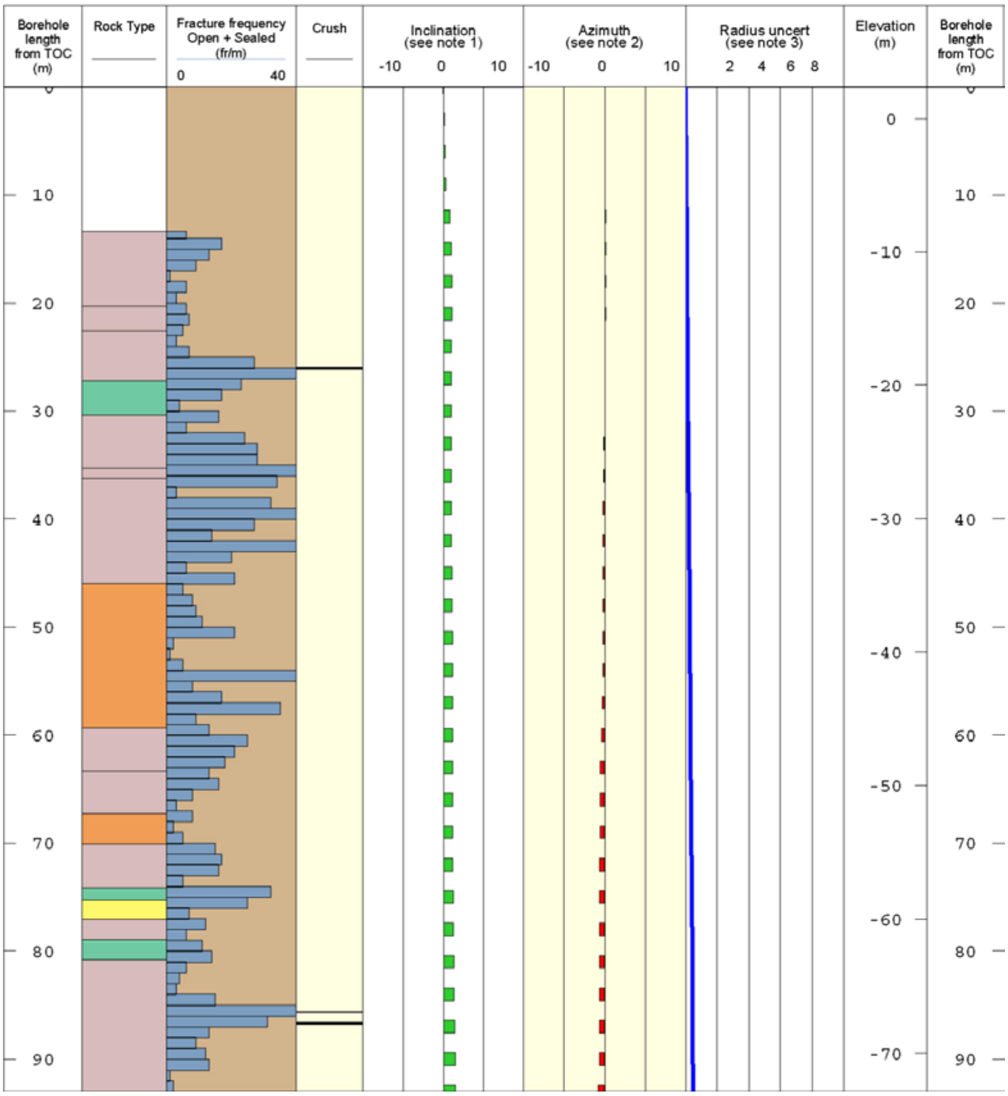
Well Cad presentation of borhole KFR103

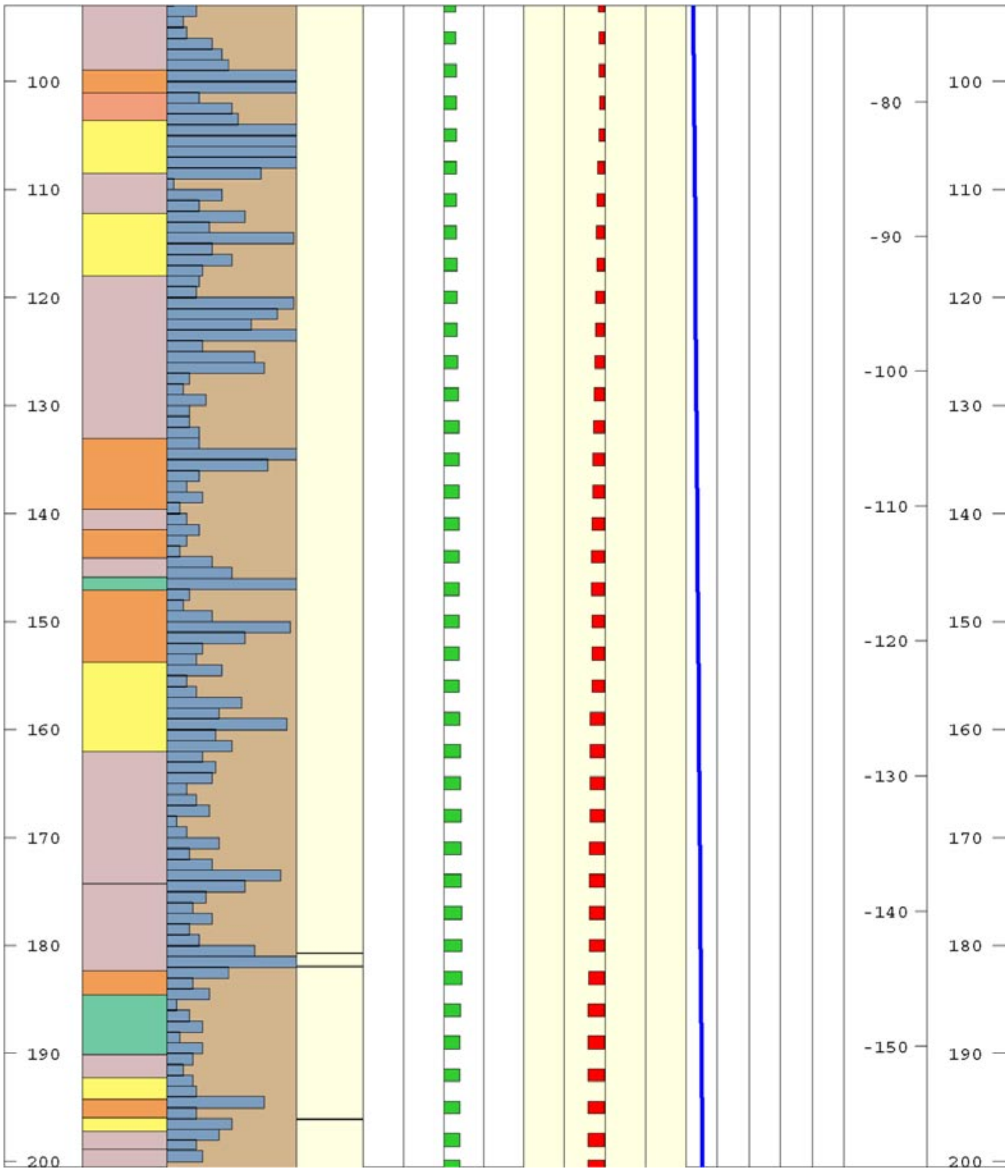
Title	CORE DRILLED BOREHOLE KFR103		
Svensk Kärnbränslehantering AB			
Site	FORSMARK - SFR	**Coordinate System**	RT90-RHB70
Borehole	KFR103	**Northing [m]**	6701737.13
Diameter [mm]	76	**Easting [m]**	1633347.20
Length [m]	200.50	**Elevation [m]**	2.43
Azimuth [°]	179.89	**Drilling Start Date**	2008-08-15
Inclination [°]	-55.09	**Drilling Stop Date**	2008-08-26
		Plot Date	2009-04-01

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.





100
110
120
130
140
150
160
170
180
190
200
-80
-90
-100
-110
-120
-130
-140
-150
100
110
120
130
140
150
160
170
180
190
200

Well Cad presentation of borhole KFR104

Title CORE DRILLED BOREHOLE KFR104

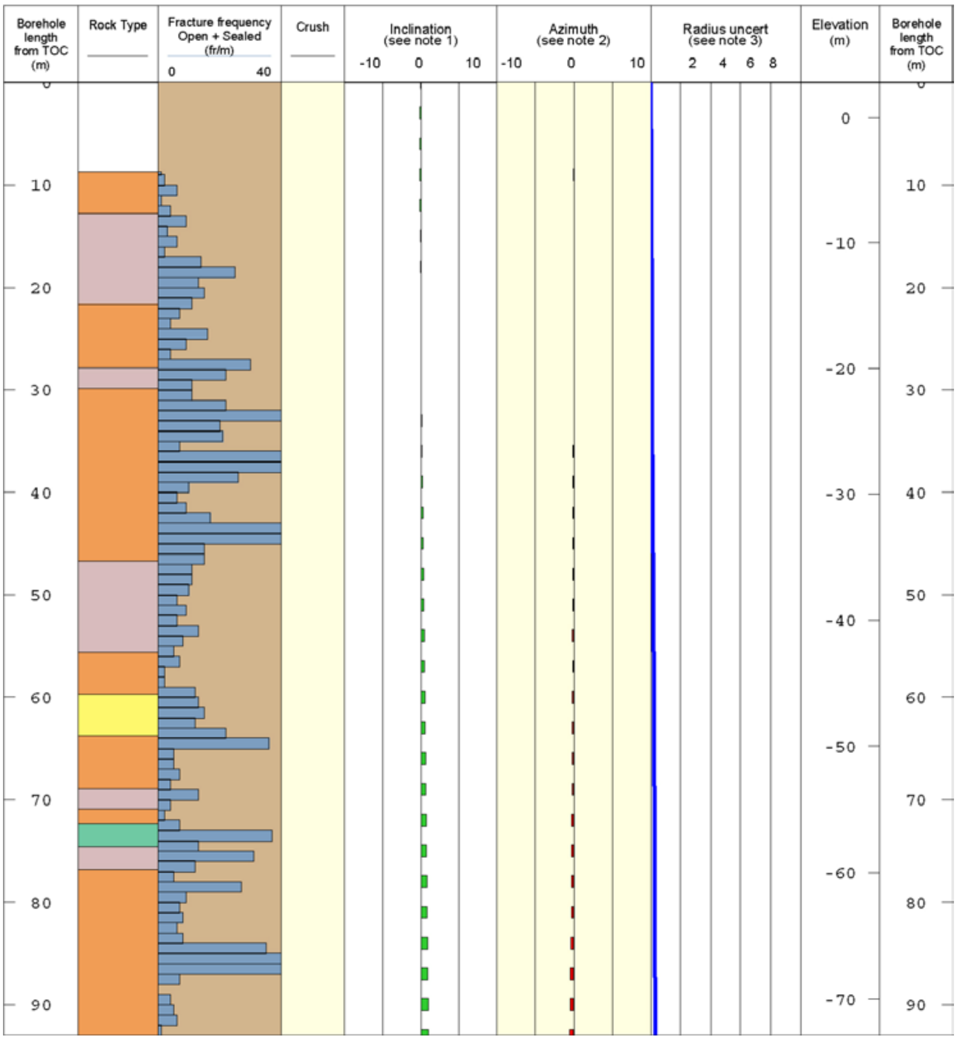
Svensk Kärnbränslehantering AB

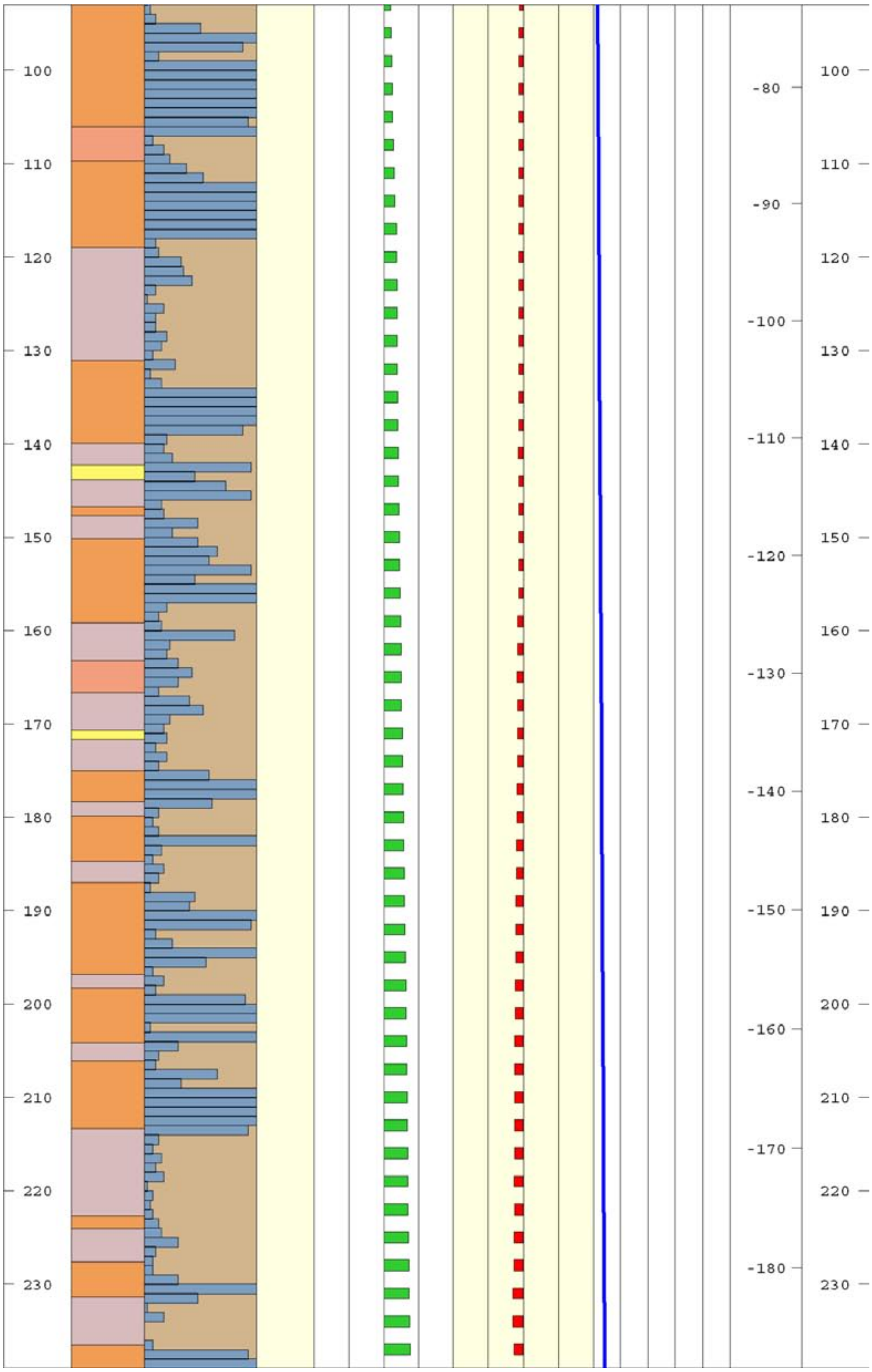
Site	FORSMARK - SFR	**Coordinate System**	RT90-RHB70
Borehole	KFR104	**Northing [m]**	6701719.45
Diameter [mm]	76	**Easting [m]**	1632879.34
Length [m]	454.57	**Elevation [m]**	2.83
Azimuth [°]	133.78	**Drilling Start Date**	2008-09-02
Inclination [°]	-53.81	**Drilling Stop Date**	2008-09-29
		Plot Date	2009-04-01

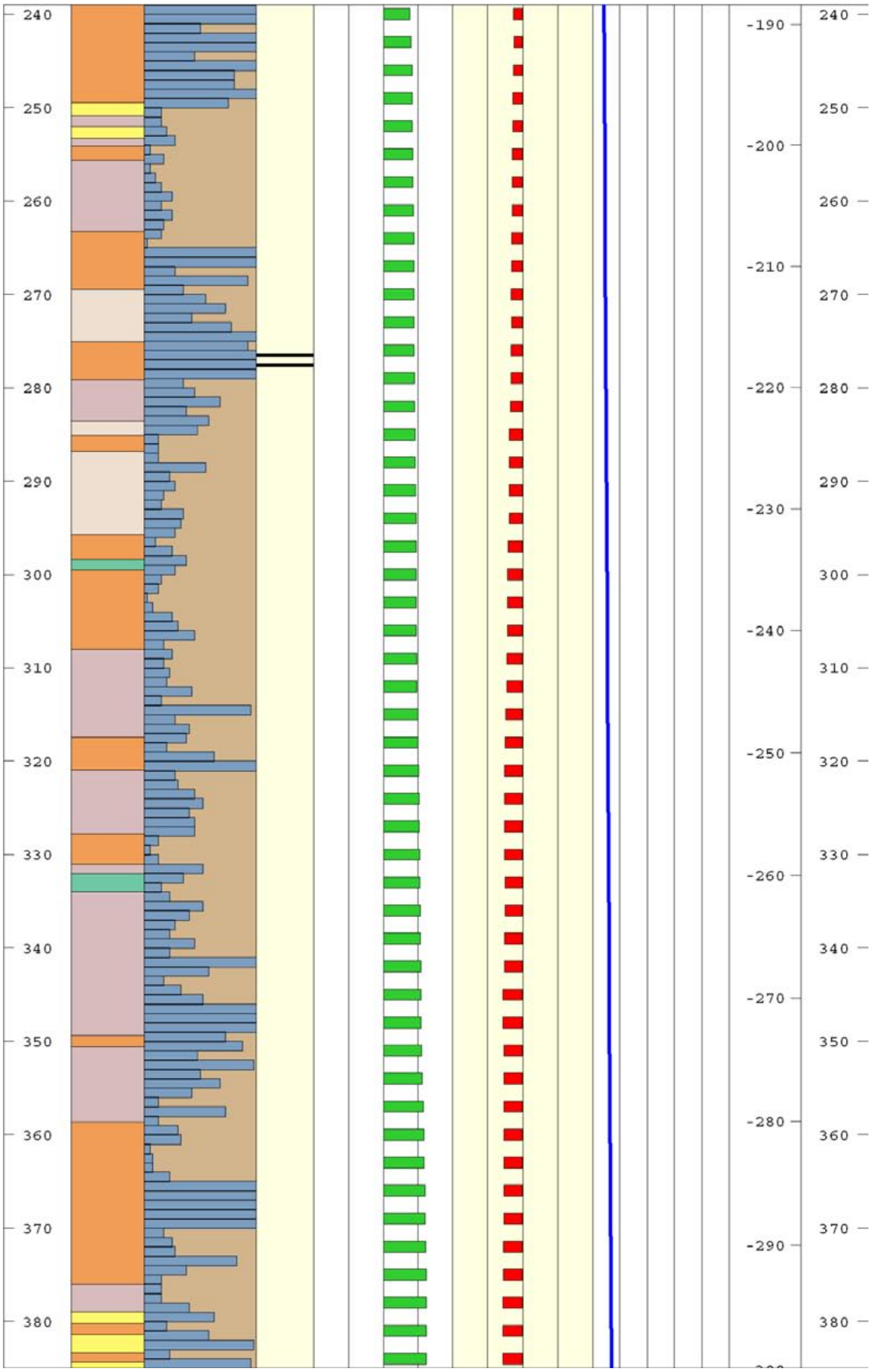
ROCK TYPE

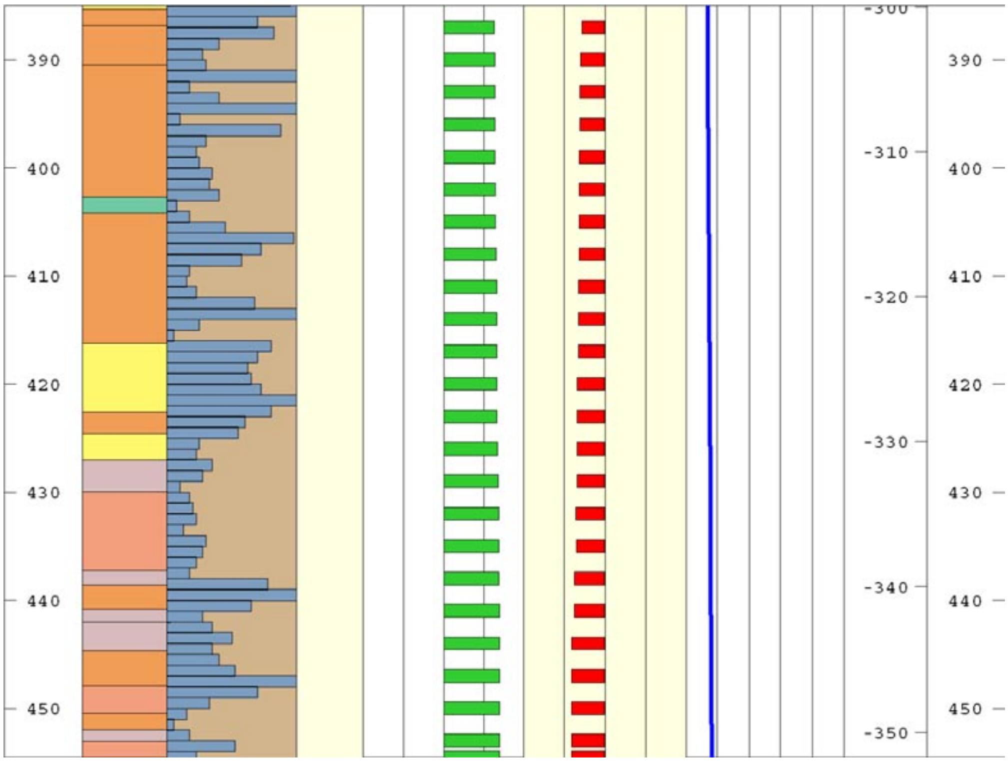
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

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.




100
110
120
130
140
150
160
170
180
190
200
210
220
230
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180


240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
-190
-200
-210
-220
-230
-240
-250
-260
-270
-280
-290


390
400
410
420
430
440
450
-300
-310
-320
-330
-340
-350

Appendix E

Water Composition

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 (mg/l)	So4 S (mg/l)	Br (mg/l)	F (mg/l)	Si (mg/l)	Li (mg/l)	Sr (mg/l)	Ph (pH unit)	Cond (mS/m)	Uranine Sample (ug/l)	Charge Balance (%)
2008-07-01 08:40	2008-07-01 08:40	KFR101	280.00	341.76	16068	664.0	23.30	119.0	59.90	122.00	1,120.0	150.00	61.10	4.750	0.73	3.29	0.0153	1.430	8.01	442.0	93.70	3.69