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Site investigation SFR

Drilling of the traditional borehole KFR27

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Abstract

During preparation of the infrastructure for drilling of new boreholes on the pier at Asphällkulten an old cored borehole, KB7, drilled during 1981 in connection with the pre-investigations preceding construction of the SFR repository, was rediscovered, and due to its location, incorporated into the SFR-extension project. The borehole was renamed to KFR27, restored, prolonged and used for measurements within the scope of the project.

KFR27 is 501.64 m long, inclined 87.42º from the horizon, has a bearing of 248.20º from N, and reaches about 497 m in vertical distance from the ground surface. Guided drilling in section 154 m to 212 m borehole length was applied, and that changed the borehole inclination from 89.7º to 84.7º, entailing better prerequisites for accurate borehole deviation measurements.

During core drilling, total flushing water loss occurred at 192 m drilling length. Consequently, all flushing water and drilling debris remained in the borehole and in the penetrated fractures during continued core drilling. The fractured section at 192 m borehole length is interpreted as the extension of the gently dipping and water bearing fracture zone ZFM871 (H2).

A sampling- and measurement programme for core drilling of KFR27 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 KFR27 are included in this report.

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

Sammanfattning

I samband med infrastrukturella förberedelser för borrning inför projektet *SFR utbyggnad – undersökningar* återupptäcktes ett gammalt borrhål beläget på piren intill hamnområdet vid Forsmarks hamn. Borrhålet borrades 1981 i samband med förundersökningar inför konstruktionen av SFR1, benämndes då KB7 men döptes om till KFR27 och införlivades i projekt SFR-utbyggnad Först rensades borrhålsväggen genom att borrhålet rymdes upp, men senare bestämdes även att borrhålet skulle förlängas.

Borrhål KFR27 är 501,64 m långt, är ansatt med 87,42º lutning från horisontalplanet i riktning 248,20º och når ca 497 m från markytan i vertikal riktning. För att förbättra möjligheten att positionsbestämma borrhålet och dess riktning och därmed öka precisionen vid utvärdering av borrhålsinformationen utfördes styrd borrning i sektionen 154–212 m, så att lutningen ändrades från 89,7º till 84,7º.

Under kärnborrningen inträffade total spolvattenförlust vid 192 m borrlängd, vilket innebär att allt borrkax och spolvatten blev kvar i borrhålet och i de genomkorsade sprickorna vid den fortsatta borrningen. Den uppspruckna sektionen vid 192 m sammanfaller med utbredningen av den flacka vattenförande sprickzonen ZFM871 (H2).

Ett mät- och provtagningsprogram under kärnborrningen av borrhålet gav preliminär information om borrhålets geologiska och hydrauliska karaktär direkt under pågående borrning samt underlag för fördjupade analyser efter borrning. Bland de insamlade proverna utgör borrkärnorna tillsammans med videofilm av borrhålsväggen (s.k. BIPS-bilder) underlaget för borrhålskartering (s.k. Boremapkartering) som utförs efter borrning. Även resultaten från Boremapkarteringen av KFR27 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 bedrock investigations for a future extension of the repository. The extension project, in Swedish termed ”Projekt SFR-utbyggnad” (Project SFR Extension), is organized into a number of sub-projects, of which geoscientific investigations are included in one sub-project, ”Projekt SFR-utbyggnad – Undersökningar” (Project SFR Extension – Investigations).

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

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

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

Activity plan	Number	Version
Kärnborrning av borrhål KFR101, KFR102B, KFR103 och KFR104	AP SFR -08-002	1.0
Styrning och kärnborrning (förlängning) av KFR27	AP SFR -08-020	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för kärnborrning	SKB MD 620.003	3.0
Metodinstruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Metodinstruktion för användning av kemiska produkter och material vid borrning och 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

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 cleaning and reaming of the wall of the cored borehole of traditional type KFR27, ensued by prolongation of the borehole. These operations are part of the initial investigation phase of project SFR Extension (SFR Utbyggnad) programme. The drilling work was carried out in accordance with activity plans AP SFR-08-002 and AP SFR-08-020. 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, close to the Forsmark harbour, during spring 2008, see Figure 1-2. In addition, a borehole that was drilled already in 1981, KB7, in connection with pre-investigations prior to construction of the SFR site, was relocated, although the borehole casing was covered with gravel of one metre thickness. A decision was made to restore the borehole, prolong it and use it for borehole investigations within the scope of project SFR Extension, and therefore a minor drill site was prepared also around this existing borehole. The borehole was also renamed to KFR27 in order to adapt the designation to the current borehole terminology in Project SFR Extension.

Drillcon Core AB, Nora, Sweden, was engaged for the drilling commission. Two drilling equipments of different capacities were used, a smaller system for cleaning and reaming of the original borehole wall, whereas a large drilling machinery was employed for drilling during extension of the borehole. Guided drilling was applied during drilling of six sections between 154.44 m and 212.49 m drilling length. A Norwegian company, Devico AS, supplied the down-hole equipment for this purpose as well as on-site personal support. Support was also provided from SKB-personnel regarding measurements and tests during drilling.

Core drilling, cleaning and reaming the borehole wall were carried out during the period June 2nd to June 10th, 2008, in compliance with Activity Plan AP SFR-08-002 Version 1.0, while core drilling (extension) and measurements were carried out during the period October 2nd to October 22st, 2008, in accordance with Activity Plan AP SFR-08-020, Version 1.0.

Results from drilling of the flushing water well HFR101, used for the supply of flushing water when drilling KFR27and KFR104, and of the monitoring wells in hard rock, HFR102 and HFR105, have been reported separately /3/.

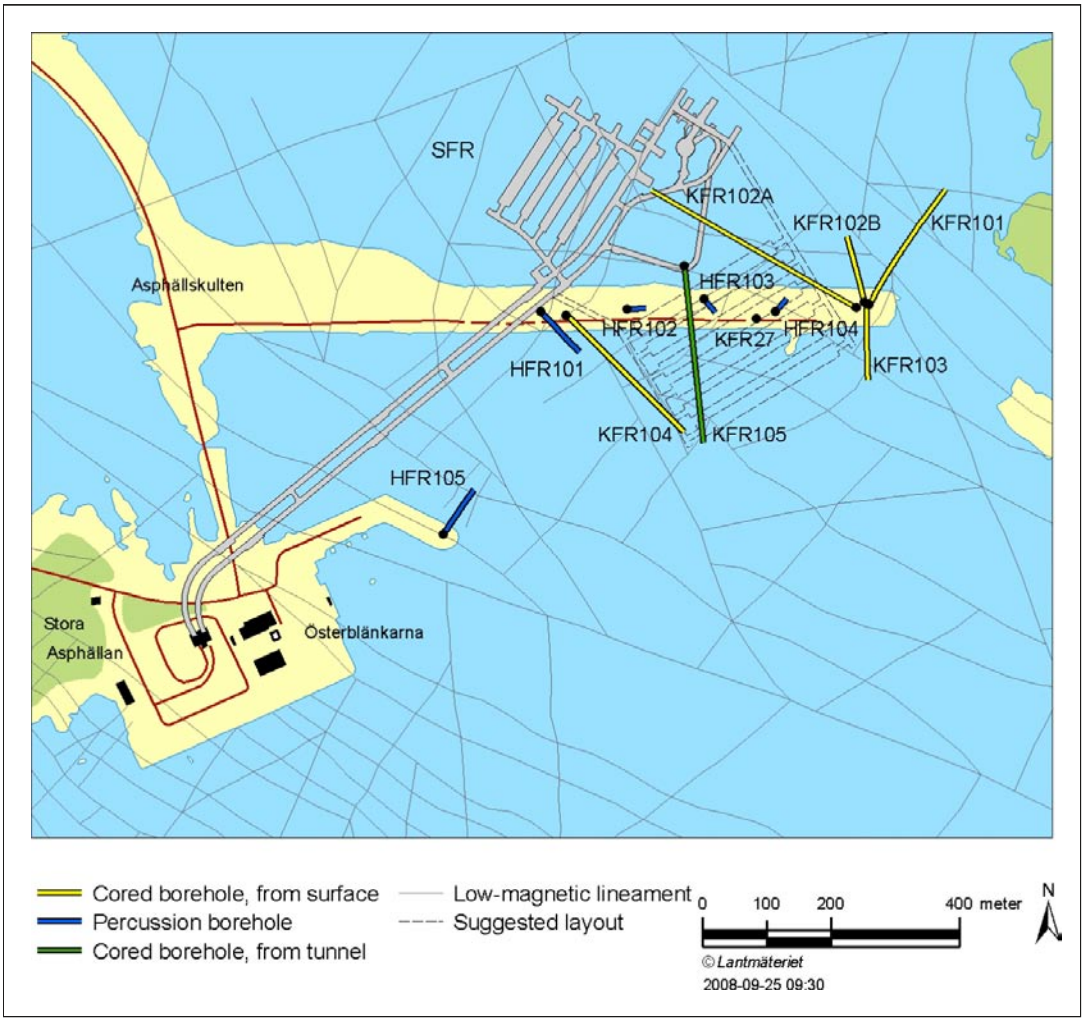


***Figure 1-2.** Overview of the SFR site investigation area with planned investigation boreholes. Also the suggested layout of the extended SFR facilities and the pattern of low-magnetic lineaments in the area are displayed.*

2 Objectives and scope

The overall objective of drilling boreholes KFR27 was to investigate the rock volume selected for a future extension of SKB´s final repository for radioactive operational waste (SFR). The borehole was specifically drilled to:

- Provide a clean borehole wall from ground surface to the borehole bottom at 146.92 m borehole length in the original borehole.
- Provide drill cores all the way from 146.92 m to the borehole bottom during drilling of the prolonged borehole. The rock samples collected during drilling are used for lithological, structural and rock mechanical characterization of the penetrated rock volume.
- 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.

A specific objective of drilling borehole KFR27 was to investigate the extension of the permeable major near horizontal fracture zone ZFM871 (H2) as well as lineament (or fracture zone) ZFMWNW0835. Another objective was to provide geological information of the bedrock conditions at depth beneath the SFR facility.

During core drilling, a number of drilling related parameters were monitored by a drilling monitoring system. Part of these data sets, in this report called DMS (Drilling Monitoring System) data, which during and after drilling were transferred to Sicada, may be used as supplementary data for geological and hydraulic characterization.

3 Equipment

In this chapter a short presentation is given of the drilling systems and 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 Core drilling system

3.1.1 General

For reaming of the cored borehole KFR27 a drilling machine from Sandvik, type DE130, was employed, see Figure 3-1. For prolongation of the borehole, a drilling system of higher capacity, Sandvik DE150, was used, see Figure 3-2. The DE150 system was also employed for drilling the succeeding cored boreholes in the drilling programme.

The Sandvik DE150 system is just recently developed and commercialized, and the copy employed at Forsmark demonstrated some teething problems. Repeated disturbances of the hydraulic rotation unit were troublesome, furthermore causing a minor oil discharge. However, after exchanging the rotation unit, the drilling of KFR27 was over and done with on the time schedule.

Both the DE130 and the DE150 systems 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 drilling length. 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.

Figure 3-1. *The rig Sandvik DE130 cleaned and reamed the borehole KFR27.*

Figure 3-2. The more powerful rig Sandvik DE150 was used for drilling of the extended borehole KFR27.

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 (both systems)	Bean	Max flow rate: 170 L/min Max pressure: 103 bars
Submersible pump (both systems)	Grundfoss SQ	Max flow rate: 200 L/min

Core drilling with a wireline system involves recovery of the core barrel via the drill pipe string, inside which it is hoisted up with the wireline winch. During drilling of borehole KFR27, 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.

However, the equipment used during guided drilling in six sections between 154.44–212.49 m, provides a minor core diameter of 31.5 mm diameter for a total core length of 29.51 m.

3.1.2 Flushing/return water treatment – equipment and methods

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 KFR27 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 rinsing an reaming of KFR27 was tap water from Forsmarks Kraftgrupp AB, whereas drilling during extension of KFR27 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.

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.

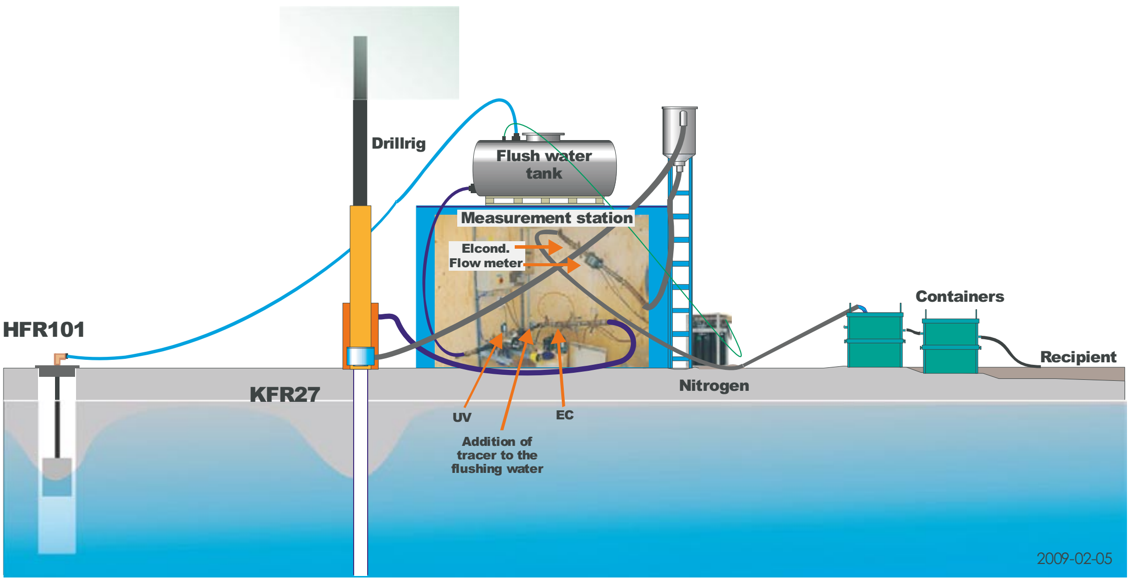


Figure 3-3. *Schematic illustration of the flushing/return water system when drilling KFR27. The measurement station included logger units and an UV-radiation unit. The percussion borehole HFR101 was used for the supply of flushing water for core drilling of KFR27.*

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

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 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.

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.

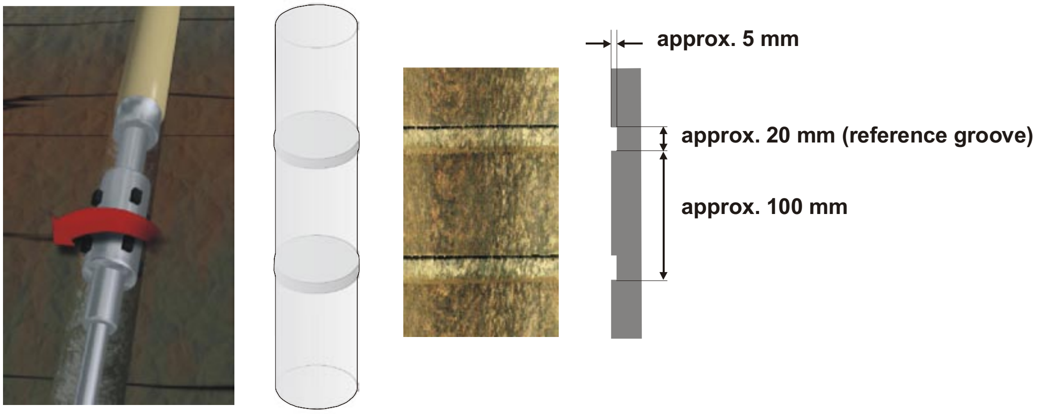


Figure 3-4. *Layout and design of reference grooves.*

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.

3.4 Equipment for borehole stabilization

A new technique for stabilization of borehole walls, designated the Plex technique, has 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.

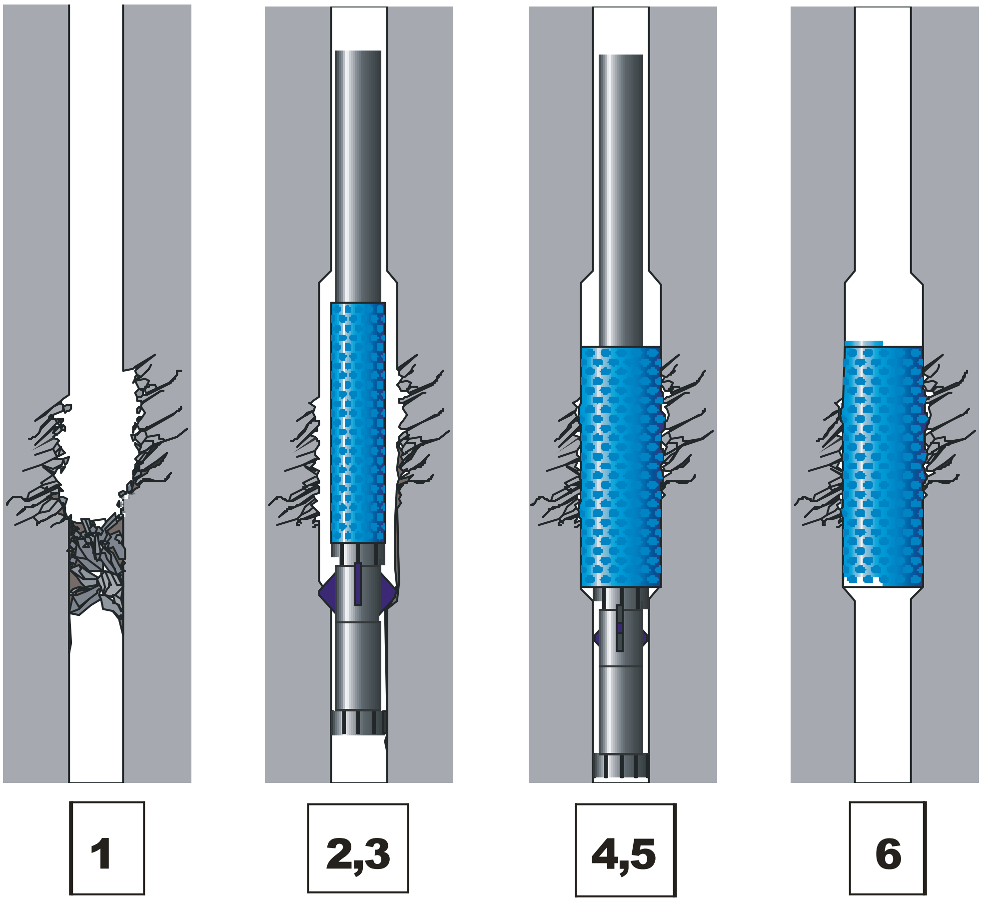


Figure 3-5. *Schematic figure illustrating the sequence of measures when stabilizing a fractured and unstable section in a core drilled borehole of N-dimension with a perforated steel plate by applying the Plex system. 1) The instability prior to stabilization, 2) the tool is descended, 3) the 200 cm long unstable section is reamed, 4) the packer is inflated as to expand the steel plate against the reamed part of the borehole wall, 5) the packer is deflated and 6) 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-08-002, AP SFR08-020, which refer to SKB MD 620.003 (Method description for core drilling). The drilling operations were conducted in two phases, firstly a phase of reaming and rinsing KFR27 to 148.51 m and, secondly, prolongation of the borehole to 501.64 m. The drilling operations included the following items:

- preparations of drilling equipment,
- mobilisation,
- drill site preparations, reaming, rinsing, core drilling, measurements and sampling during drilling,
- finishing off work,
- data handling.

These items are presented more in detail in Sections 4.2–4.6.

The commission was performed in compliance with an environmental control programme, see Section 4.7.

Nonconformities with the Method Documents and Activity Plans are presented in Section 4.8.

4.2 Preparations of drilling equipment

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

4.3 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 Drill site preparations, reaming, rinsing, core drilling, measurements and sampling during drilling

4.4.1 Drill site preparations

The drill site was, prior to commencement of drilling operations and performed as 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 platform and to enable firm anchorage of the core drilling machinery during drilling. However, as the TOC of the existing borehole was damaged and located below ground surface, the casing was uncovered, extended above the ground level, and the ground was carefully restored, before the concrete slab was established. The site was also connected to the local electrical- and data communication nets.

4.4.2 Reaming, rinsing, core drilling, measurements and sampling during drilling

The previously existing borehole was rinsed and reamed and after three months break, core drilling started from bottom of the existing borehole. Core drilling of SKB investigation boreholes is normally associated with a programme for sampling, measurements and other activities during and immediately after drilling, cf SKB MD 620.003. However, for different reasons, during drilling of KFM27, deviations from this programme could not be avoided. These deviations are presented in Section 4.8 below. 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 borehole was flushed for about 3 hours in order to clean it from drilling debris adhered to the borehole walls, settled at the bottom of the hole or suspended in the water.
2) The drill string was pulled.
3) The borehole was, after completed core drilling, secured with a lockable stainless steel flange.
4) The core drilling equipment was removed, the site 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, 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 program

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 KFR27 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 KFR27 according to SKB MD 620.003 and the Activity Plans AP SFR-08-002 and AP SFR-08-020 with the real performance.

Table 4-1. Suggested programme for performance and frequency of sampling, measurements, registrations and other activities during and immediately after core drilling of KFR27 according to SKB MD 620.003, AP SFR-08-002 and AP SFR-08-020 compared to the real performance.

Activity	Performance and frequency according to SKB MD 620.003	Performance and frequency during drilling of KFR27
Registration of drilling- and flushing water parameters.	Registration during the entire drilling.	According to programme. (Methods described in Section 3.1.2.).
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	One Maxibor measurement and five measurements with Flexit after completion of drilling.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drill pipe string should be controlled before each test.	No measurements performed.
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/ zones. The tightness of the drill pipe string should be controlled before each test.	One measurement performed.
Absolute pressure measurements.	Normally during natural pauses in drilling.	No measurements performed.
Groove milling in the borehole wall, normally at each 50 m drilling length .	Normally performed after completion of drilling.	Ten 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-08-002 and AP SFR-08-020). Only data in databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major revisions entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

This chapter is structured as follows:

- Section 5.1 – General.
- Section 5.2 – Results KFR27.

Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling. Well Cad presentations of borehole KFR27 are shown in Appendix A.

An analysis from a water sample from KFR27 is displayed in Appendix B.

5.1 General

Experiences and data from the construction of the existing SFR facility in the 1980s, served as important input for the investigation programme governing the current investigation programme. During drill site preparations, an old borehole, KB7, drilled from the ground surface on the pier at Asphällskulten as part of the pre-investigations of that time, was discovered within the investigation area for Project SFR Extension. The discovery was important for two reasons. Firstly, this borehole may be re-used as an investigation borehole within the current pre-investigations. Secondly, an open borehole between the ground surface and a repository tunnel is not acceptable, and is therefore this borehole, as well as all other boreholes potentially extending into the repository, has to be localized and later, after completed investigations sealed.

All coordinates defining the horizontal and vertical position of geographical objects during investigation and construction of the existing SFR facility related to a local network, denominated SFR T-U. All investigations executed later by SKB, including the recently comprehensive site investigation for a final repository for spent nuclear fuel at Forsmark, applied the national Swedish reference frame. The coordinates of these points are presented in the horizontal network RT90 2.5 gon V 0:-15 and in the vertical network RHB 70.

Consequently, for the SFR-extension pre-investigations it was decided that all data used for analyzing and modelling, old data included, should be transformed to the RT90-RHB 70 system. However, quality control indicated some divergences when old data were transformed to the new system. Therefore a measurement programme was initiated, including upgrading of the existing fixed points and establishing new points in the SFR-tunnels. Furthermore, new coordinates were established for a few underground boreholes. As a result from this project, a new algorithm for coordinate transformation was established.

These measures also resulted in new coordinates for borehole KB7 located on the pier at Asphällskulten, and at the indicated location, a metal detector gave a significant signal. The borehole could be laid bare although the borehole casing was covered with ballast of one metre thickness, see Figure 5-1. As mentioned, the borehole was renamed to KFR27, restored, prolonged and used for measurements within the scope of Project SFR Extension, see Figure 5-2.

Figure 5-1. *Left: The original and deformed casing of KFR27 was localised although it was covered with rock fill. Right: The casing has been extended above ground surface. An outer casing serves as a protective cover when the pit is re-filled with gravel.*

Figure 5-2. *Left: A mould with reinforcing bars surrounding the borehole casing has been prepared for the concrete casting. Right: the drill site concrete platform is finished, filled up with gravel, and the casing is levelled for the drilling and measuring programme. Borehole KFR27 has been surveyed and the coordinates (according to the RT90-RHB 70 system) as well as and the borehole inclination and azimuth are stored in Sicada, and the borehole is ready for investigations.*

Initially, KB7 (KFR27) was drilled during 1981 (see Figure 5-4). The pier at Äsphällskulten functions as a breakwater for the SFR harbour. It was constructed in two phases, during two different time periods. The ballast used for the construction was blasted rock, mostly of the size of boulders and gravel. The first construction phase 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. It is obvious that KFR27 was drilled after the first phase and finally was covered with ballast during the second phase.

5.1.1 Borehole geometrical definitions

After the drilling activity is executed, an intensive measurement programme is normally carried out in the borehole. In order to perform these measurement in a rational way and to enable quality assurance of measurement data, crucial borehole geometrical data, like borehole collar coordinates, borehole orientation and inclination, borehole and casing lengths and diameters etc are needed as input data.

To facilitate collection and further treatment of logging data, and in order to minimise the risk of misunderstandings of e.g. which level in the borehole the measured data are associated to, clear and indisputable definition of borehole geometrical data must be available shortly after the drilling is completed. In Figure 5-3 some important borehole geometrical definitions are given.

As previously mentioned, the coordinate system used for all geographical objects in this report is:

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 logging crews, are fully aware of these definitions to ensure correct data filing.

Schematic view of a cored borehole of traditional type

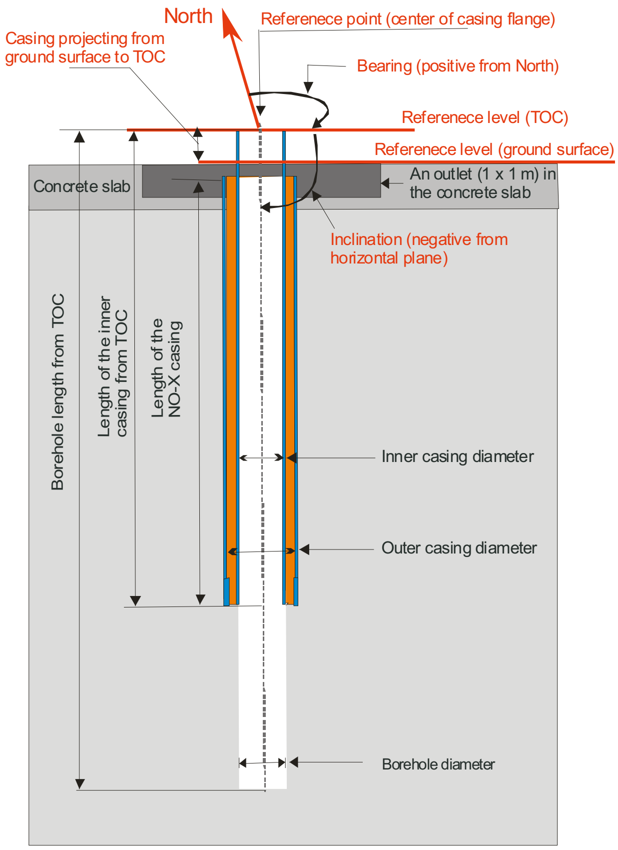


Figure 5-3. *Schematic drawing of the upper part of a cored borehole of traditional type. The figure shows definitions of the most important data, as reference points, lengths and dimensions used for the technical description of the borehole in this report.*

5.2 Results KFR27

5.2.1 Rinsing and reaming

Borehole KF7 (KFR27) was initially drilled during August 6th to September 10th, 1981 (see Figure 5-4), and was primarily aimed for over coring rock stress measurements. The original borehole dimension was not correctly documented, but several factors indicate that the drilling dimension applied was T76 mm, which provides a borehole with the approximate diameter 76,3 mm. When the new drillsite for KFR27 had been set in order, see Section 5.1, a Sandvik DE130 drill rig, was employed for rinsing and reaming the borehole.

Borehole KFR27 was supplied with an extended casing, and consequently a new reference point (see Figures 5-2 and 5-3) was established. This also changed the borehole length (see definition in Figure 5-3). Ensuing rinsing the borehole from obstacles, it was extended by using a Corac N3/50 core barrel (Ø 75.8 mm). After recovering of a 1.59 m drill core, the borehole length from the new reference point was accurately determined and revealed to be 148.51 m.

Previous experiences have shown that BIPS-measurements performed in old boreholes often produce a poor image quality, especially in boreholes lacking a straddle-packer installation. This is due to internal groundwater circulation between different fracture systems in the borehole, entailing mixing of groundwater of different hydrochemical character, which often results in precipitation of chemical substances on the borehole wall and sometimes chemical reactions between the precipitates and the borehole wall minerals. In these cases the BIPS images often display a mainly dark coated borehole wall, resulting in difficulties to document the lithological and structural characteristics of the borehole wall.

Therefore, as KF7 had been existing for 27 years without a straddle-packer installation, and furthermore because all drill cores from the original drilling operations in 1981 are missing, it was decided to ream the borehole, in order to obtain an uncoated borehole wall and thereby, hopefully, an acceptable quality of the images from the BIPS logging that was planned to be conducted after completed extension of the borehole. The borehole was reamed with a Ø 76.80 mm reamer from borehole length 11.91 m to 146.92 m whereby the reamer tool, and hence the borehole diameter, successively decreased to Ø 76.45 mm.

The rinsing and reaming activity consumed 13 m^3 of tap water from FKA used as flushing water. The return water volume could not be measured, as the reaming generated a thick mud with low water content. After completion of drilling, the borehole was repeatedly nitrogen flushed, see also Section 5.2.10.

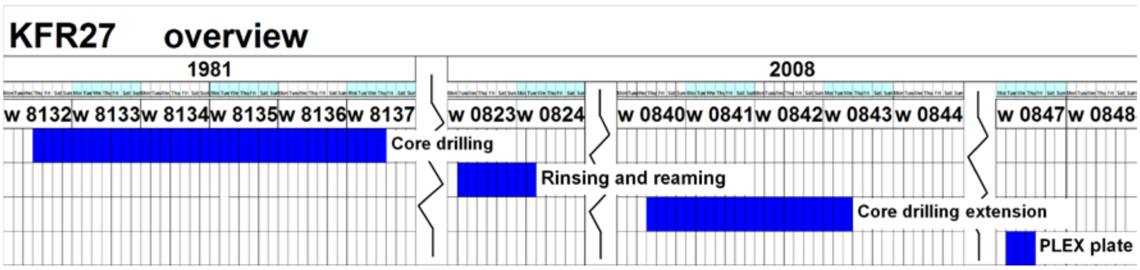


Figure 5-4. Overview of the drilling performance of the cored borehole of traditional type, KF7, later re-named to KFR27, located on the pier at Asphällskulten.

5.2.2 Core drilling – extension of KFR27

Shortly after the rediscovery of borehole KF7 (KFR27), a programme for extending the borehole was formed. The original borehole KF7 (c 148 m long), showed to be vertical, and previous experiences have demonstrated significant difficulties to obtain reliable results from deviation measurements in boreholes with an inclination close to vertical /4/. This entails uncertainties regarding orientation of geological features. Therefore, guided drilling had to be applied for the initial phase of the drilling in order to change the borehole inclination to approximately 85° before the continued extension of the borehole.

The logistics of the core drilling extension from 2008-10-02 to 2008-10-22 is illustrated in Figure 5-5.

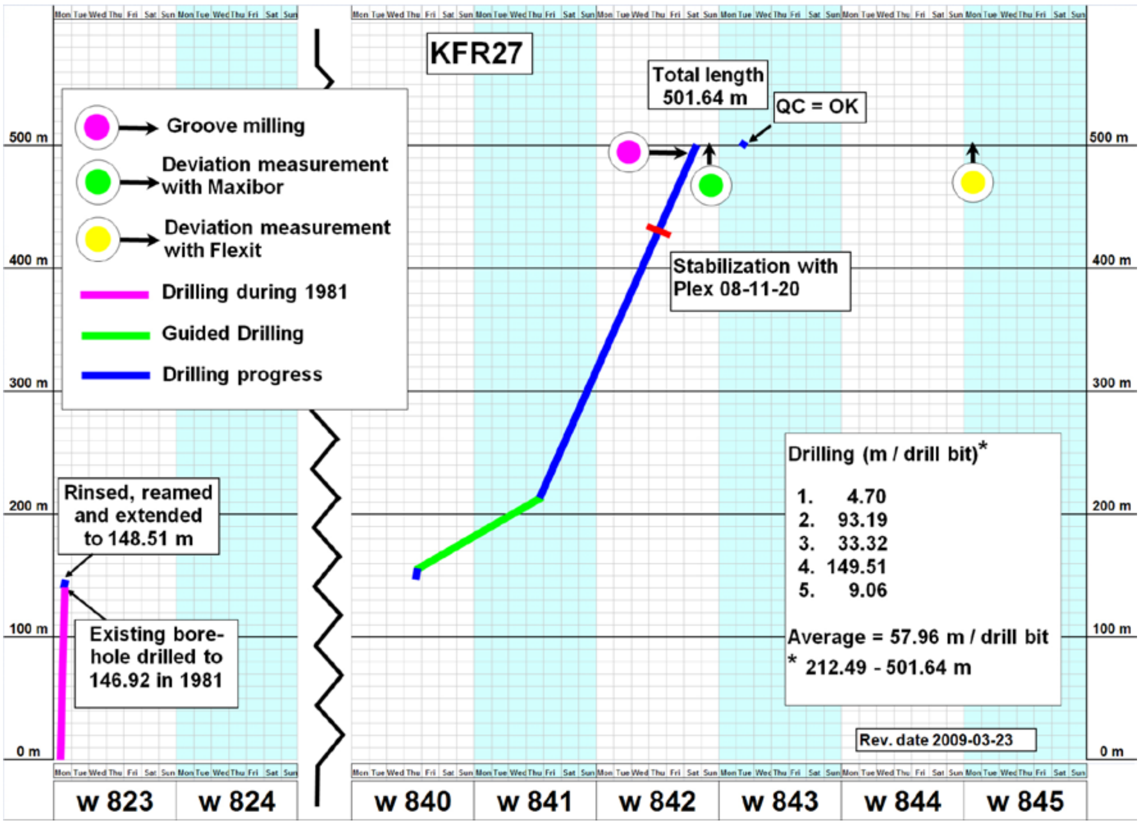


***Figure 5-5.** Extension KFR27– core drilling progress KFR27 (length versus calendar time).*

5.2.3 Geometrical and technical design of borehole KFR27

Table 5-1. Administrative, geometric and technical data for borehole KFR27.

Parameter	
Borehole name	KFR27
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	Aug 06, 1981
Completion date	Nov 20, 2008
Core drilling period KF7 during 1981	1981-08-06 to 1981-09-10
Core drilling period, rinsing, reaming and short extension	2008-06-02 to 2008-06-10
Core drilling period, full extension	2008-10-02 to 2008-10-22
Core drilling period, Plex	2008-11-18 to 2008-11-20
Contractor core drilling during 2008	Drillcon Core AB
Subcontractor, guided drilling	Devico AS, Norway
Core drill systems	Sandvik DE130 for rinsing, reaming and short extension Sandvik DE150 for full extension
Position at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6,701,714.42 (m) E 1,633,175.52 (m) Z 2.87 (m RHB 70) Azimuth (0–360°): 248.20° Dip (0–90°): –87.42°
Position at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6,701,701.94 [m] E 1,633,144.10 [m] Z –496.92 (m RHB70) Azimuth (0–360°): 258.31° Dip (0–90°): –82.72°
Borehole length	501.64 m
Borehole length and diameter	From 11.91 m to 146.92 m: from 0.07680 to 0.07645 m From 146.92 m to 430.80 m: 0.0758 m From 430.80 m to 433.00 m: 0.0840 m From 433.00 m to 501.64 m: 0.0758 m
Casing diameter and drilling length	Øo/Øi = 84.00 mm/77.00 mm 0.00 to 11.91 m Øo/Øi = 84.00 mm/80.00 mm to 430.80 to 433.00 m Plex
Drill core dimension	0.00 – 146.92 (core is missing) 146.92 –148.51 m / Ø = 0.0502 mm (first extension) 148.51 – 154.44 m / Ø = 0.0502 mm 154.44 – 163.40 m / Ø = 0.0315 mm 163.40 – 164.94 m / Ø = 0.0502 mm 164.94 – 176.97 m / Ø = 0.0315 mm 176.97 – 177.56 m / Ø = 0.0502 mm 177.56 – 188.03 m / Ø = 0.0315 mm 188.03 – 188.94 m / Ø = 0.0502 mm 188.94 – 190.94 m / Ø = 0.0315 mm 190.94 – 197.94 m / Ø = 0.0502 mm 197.94 – 212.49 m / Ø = 0.0315 mm 212.49 – 501.64 m / Ø = 0.0502 mm
Core interval	146.92 – 501.64 m = 354.72 m
Average length of core recovery	2.98 m (section 212.49 – 501.64)
Number of runs	119 (section 212.49 – 501.64)
Diamond bits used	5 (section 212.49 – 501.64)
Average bit life	57.96 m (section 212.49 – 501.64)

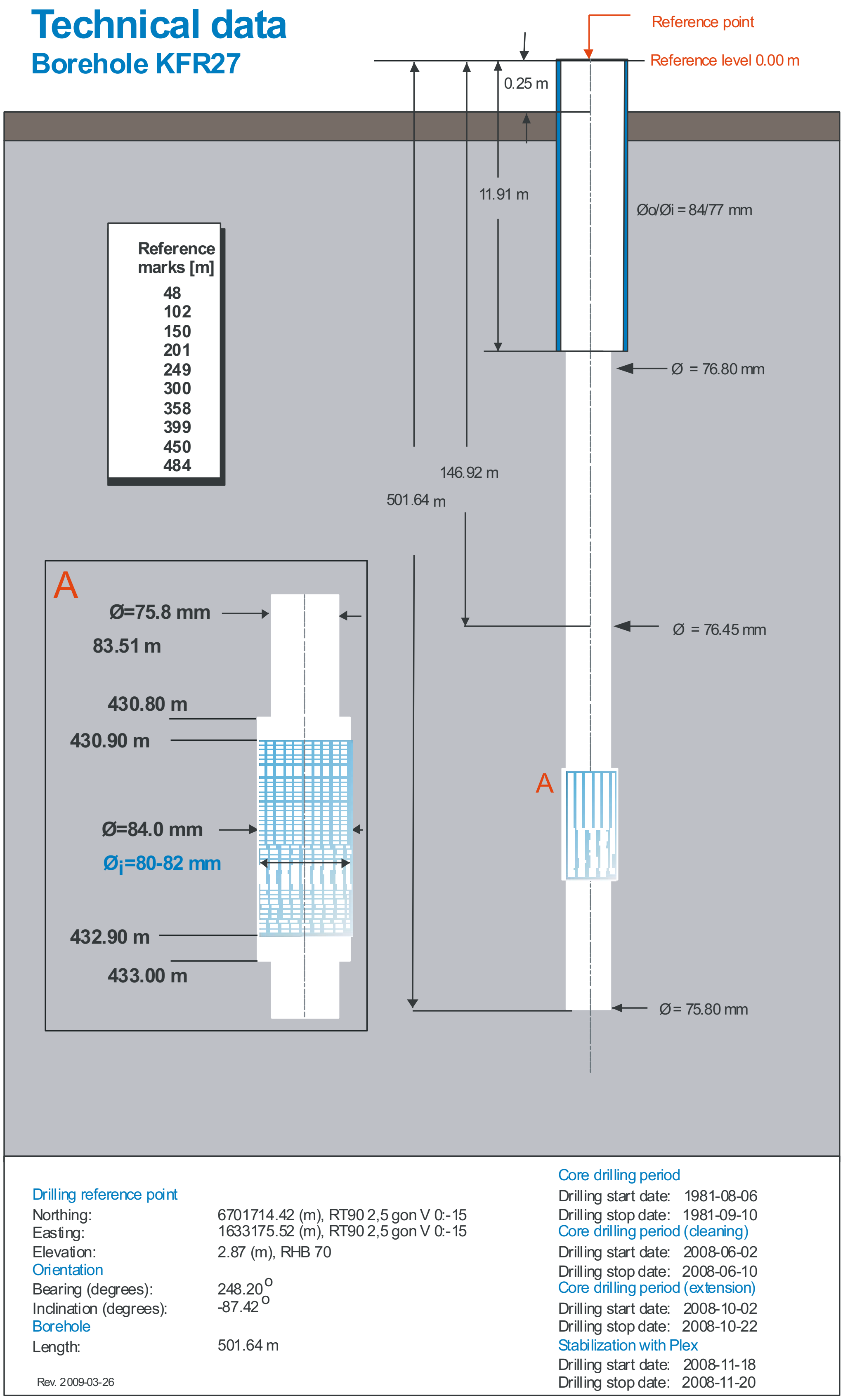


Figure 5-6. *Technical data of borehole KFR27.*

5.2.4 Guided drilling

Originally, borehole KFR27 was aimed for over coring rock stress measurements, which explains the borehole diameter applied (Ø 76 mm) and also why the borehole was vertically directed. As mentioned in Section 5.2.2, previous experiences indicate major difficulties to obtain reliable results from deviation measurements in vertical or near-vertical boreholes /4/. Therefore, it was decided to apply guided drilling at the beginning of the drilling period aimed for extension of KFR27 in order to make the extended part of the borehole non vertical.

As the borehole was reamed to 146.92 m it was necessary to extend the borehole to 154.44 m with Corac N3/50 dimension in order to achieve a suitable and quality secured start for the succeeding deviation equipment. The exclusive aim of the guided drilling was to change the borehole inclination from close to 90º to approximately 85° from the horizon, without consideration to the borehole bearing. The equipment used, gave a minor core diameter in the guided sections, of 31.5 mm diameter for a total core length of 29.51 m.

The guided drilling was carried out in six sections, between 154.44 and 212.49 m borehole length. During these operations the borehole inclination changed from 89.7º to 84.7º, see Table 5-2 and Figure 5-7. Simultaneously, the bearing changed from c.113º to c. 258º.

Generally, in order to leave the way free in a borehole for logging instruments, of which many have a length of several metres, guided drilling must be performed in steps with minor deviation changes per length unit. The longest instrument used in SKB investigation boreholes is a water chemistry probe, which (presupposing the instrument to be completely stiff) will be hindered from passing through a borehole bend with a deviation exceeding 0.1º/m in a Ø 76 mm borehole. Fortunately, because this probe has a certain degree of flexibility, it can probably tolerate a deviation slightly exceeding 0.1º/m, but for safety reasons this value should preferably not be much exceeded. Figure 5-8 presents the variations of the borehole curvature in degrees per metre, (calculated from the deviation measurements). The major part of the borehole displays values below 0.1º/m, but peaks of up to 0.25º/m occur. Despite such relatively sharp bends, the complete measuring programme has successfully been carried out in the borehole.

Although this was the first time guided drilling was performed in the project, the technique worked satisfactory, also regarding time schedule and budget.

5.2.5 Measurement while drilling KFR27

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 only used as supporting data for on-site decisions.

Table 5-2. Borehole sections where guided drilling was applied giving a minor core diameter of 31.5 mm. [EG055].

Secup [m]	Seclow [m]	Core diameter [mm]
154.44	163.40	31.5
164.94	176.97	31.5
177.56	188.03	31.5
188.94	190.94	31.5
197.94	212.49	31.5

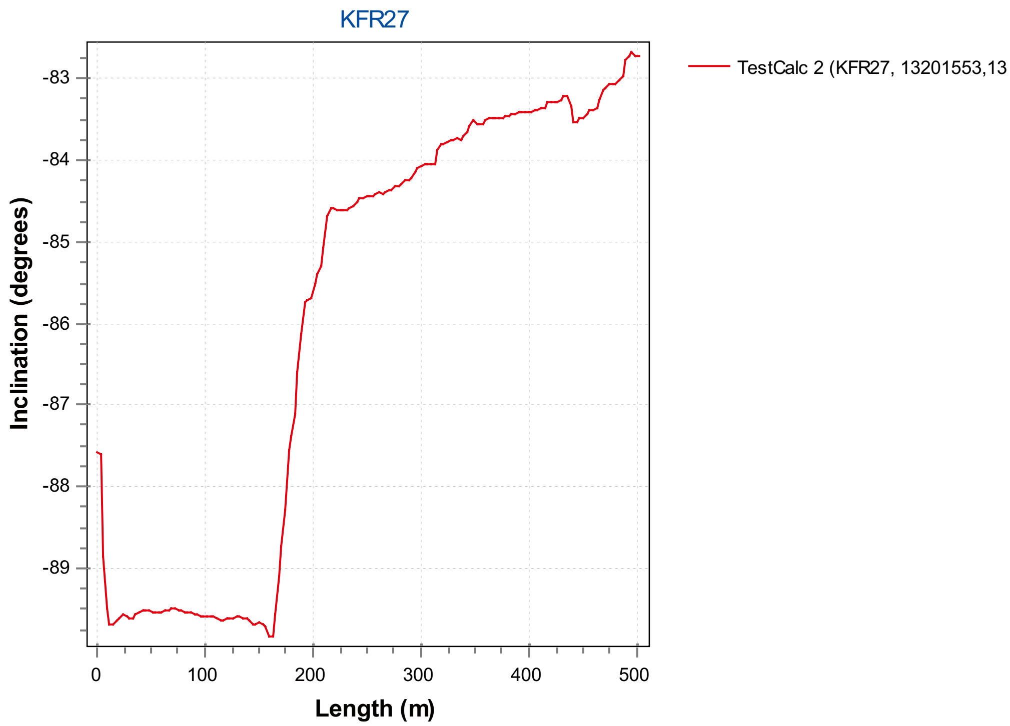


Figure 5-7. *Guided drilling was performed between 154–212 m, and the figure shows that the inclination has been steered from 89.8° to 84.6° in that section, i.e. in average 0.09°/m. The inclination has continued to change after the guided drilling, but much slower, from 84.6°to 82.8° at full borehole length.*

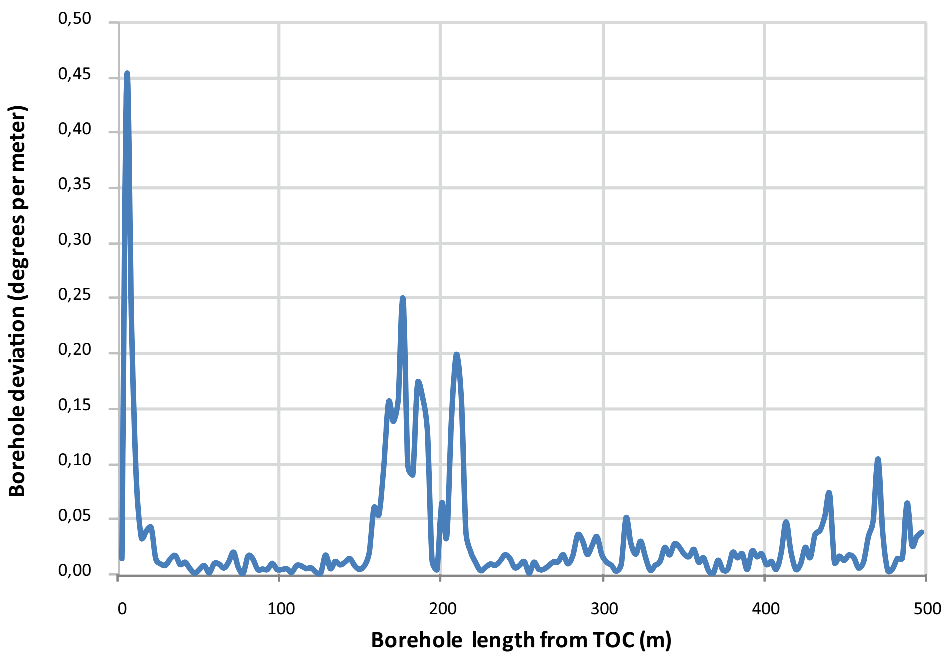


Figure 5-8. *The figure illustrates that the guided drilling in section 154–212 m was performed very cautiously, as the borehole curvature generally is kept below c. 0.1°/m, even if some peaks up to 0.24°/ m occur.*

Flushing water and return water flow rate – water balance

Figure 5-9 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 5-10, from which the return water/flushing water quotient at the end of the drilling period may be calculated, in this case resulting in a quotient of 0.18, due to complete flushing water loss at 192 m drilling length.

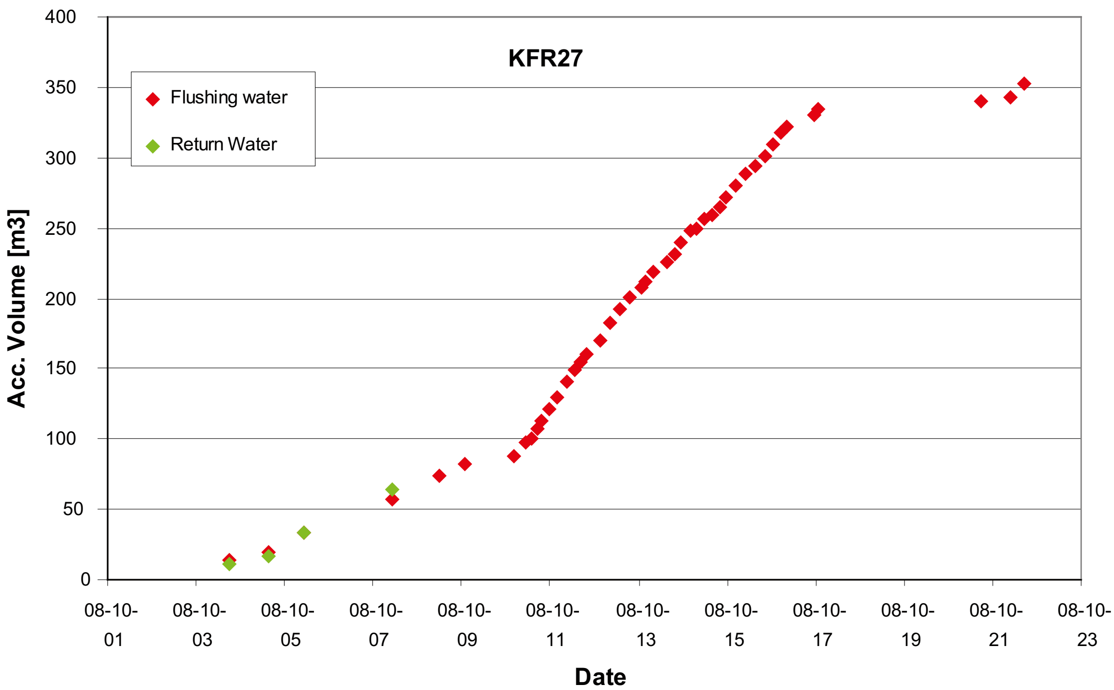


***Figure 5-9.** Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFR27. The return water disappeared after a short time of drilling.*

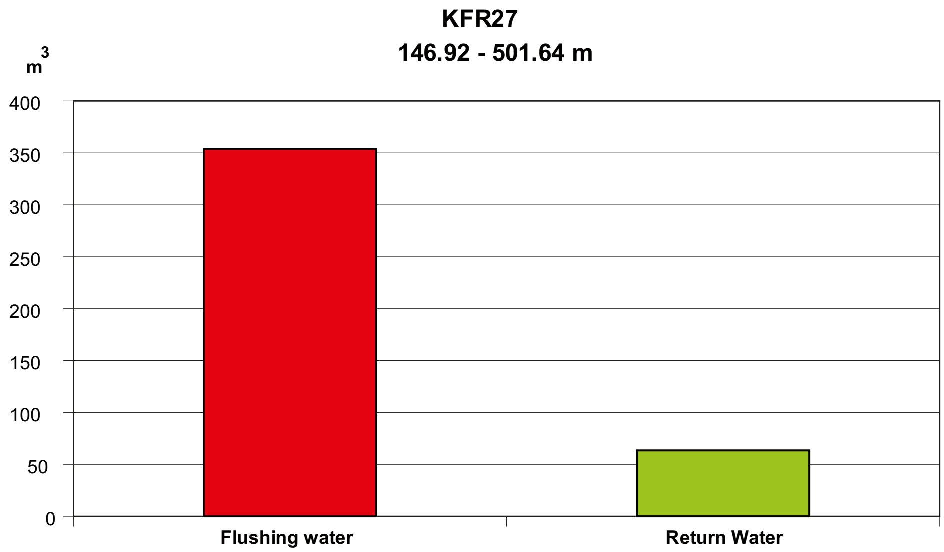


***Figure 5-10.** Total amounts of flushing water and return water during drilling of borehole KFR27. The total volume of flushing water used during core drilling amounted to 353.1 m^3. During the same period, the total volume of return water was only 63.5 m^3. The return water/flushing water balance is then as low as 0.18 due to loss of return water at 192 m length.*

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 5-11. 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 in KFR27, all flushing water is lost to the formation.

According to notations in the logbook, the amount of Uranine added to the borehole was 77 g. If the averages of the Uranine concentration values in the flushing water and return water samples (to 192 m borehole length) are used to calculate the amount of Uranine added and recovered from the borehole, the result is 72 g and 13 g, respectively. After finished drilling, water samples collected in connection with nitrogen flushing in KFR27 confirmed that flushing water still remains in the borehole.

Electric conductivity of flushing water and return water

Flushing water during extension drilling of KFR27, from 148.51 m to 501.64 m, 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 5-12.

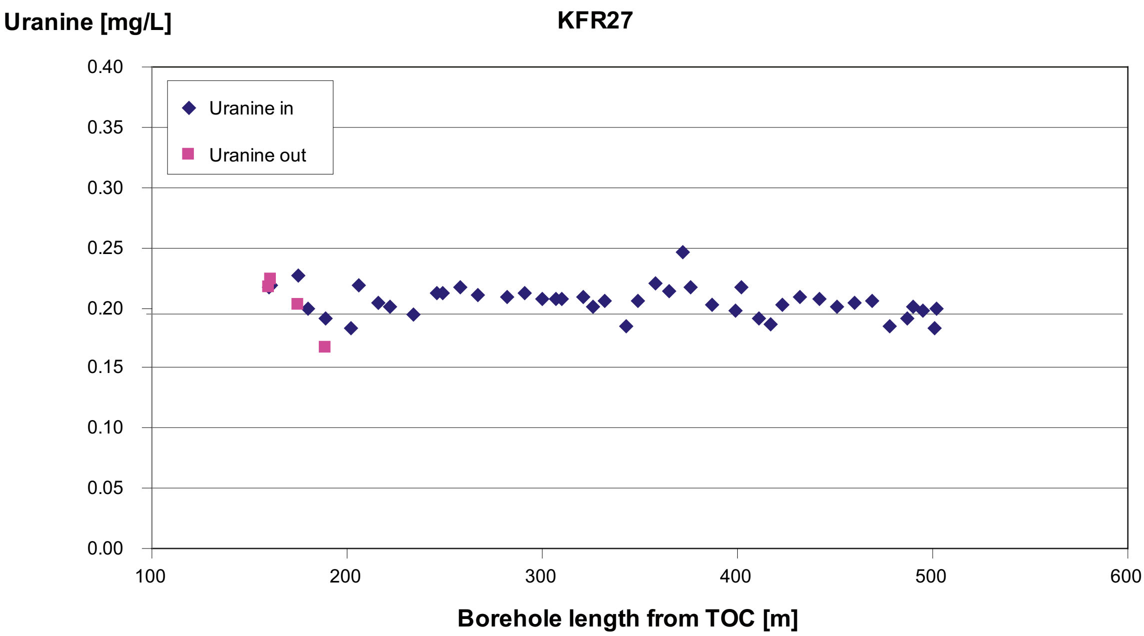
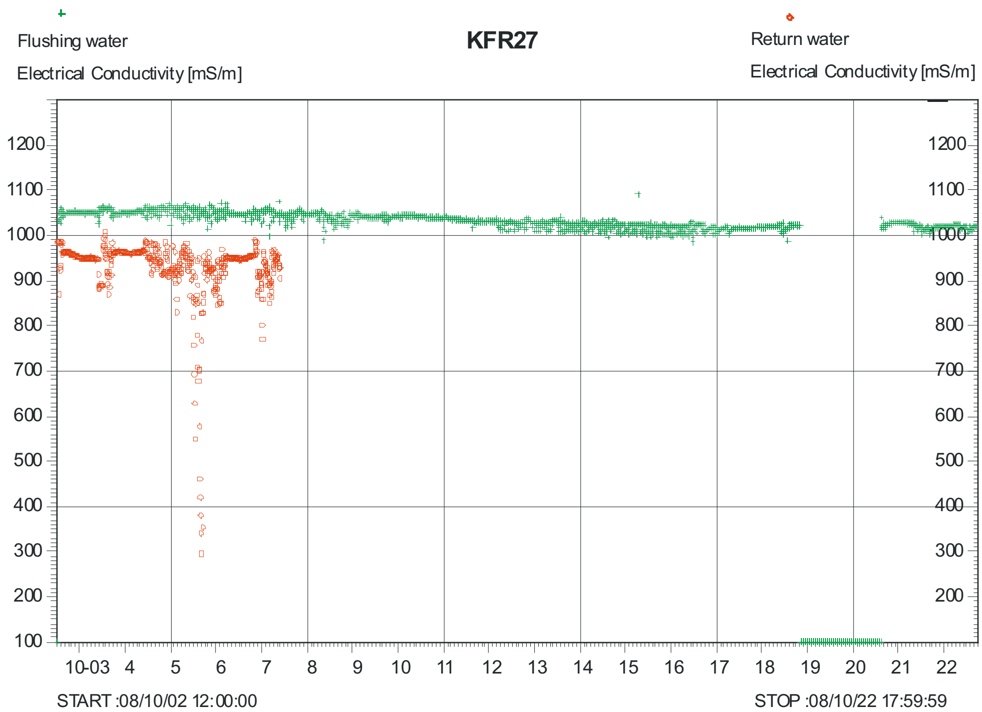


Figure 5-11. *Uranine contents in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFR27. Automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.*



Figur 5-12. *Electrical conductivity of flushing water from HFR101 and return water from KFR27.*

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 lens during 2002–2007 /5/.

In order to supply KFR27 with flushing water, the maximum well capacity of HFR101 was required, a result of the continuous drilling during October 2008. The average electrical conductivity of the flushing water was almost constant at c. 1,050 mS/m from beginning to the end of the drilling period, see Figure 5-12.

The average electrical conductivity of the return water from KFR27 (Figure 5-12) was generally lower than that of the flushing water, indicating inflows in the upper part of the borehole, whereby shallow water (less saline water) was mixed with the flushing water, giving the return water lower EC-values. As mentioned, total water loss occurred at 192 m borehole length.

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 3.1), it was decided to observe and document the pressure in the nitrogen bottles once a day, see Figure 5-13.

Water sampling during drilling (section 189.64–212.49 m)

One first strike WL-sample was collected from KFR27 in connection with a wireline probe pumping test. During the guided drilling, a total water loss occurred at 192 m drilling length. Therefore, as soon as the guided drilling was completed, the drill rods were lowered to 180 m borehole length and prepared for nitrogen flushing inside the rods which creates a pumping effect on the section below the lower end of the lowermost drill rod, between 180 and 212.49 m borehole length. After three hours of nitrogen flushing, c. 16.7 m^3 return water were recovered, which rinsed this borehole section from drilling debris and decreased the amount of flushing water remaining in the fractures penetrated by the borehole.

Thereafter, the borehole section between 189.64–212.49 m was isolated by the inflatable packer of the WL-sond. A pump lowered inside the drill rods was used for pumping during another c. 5.5

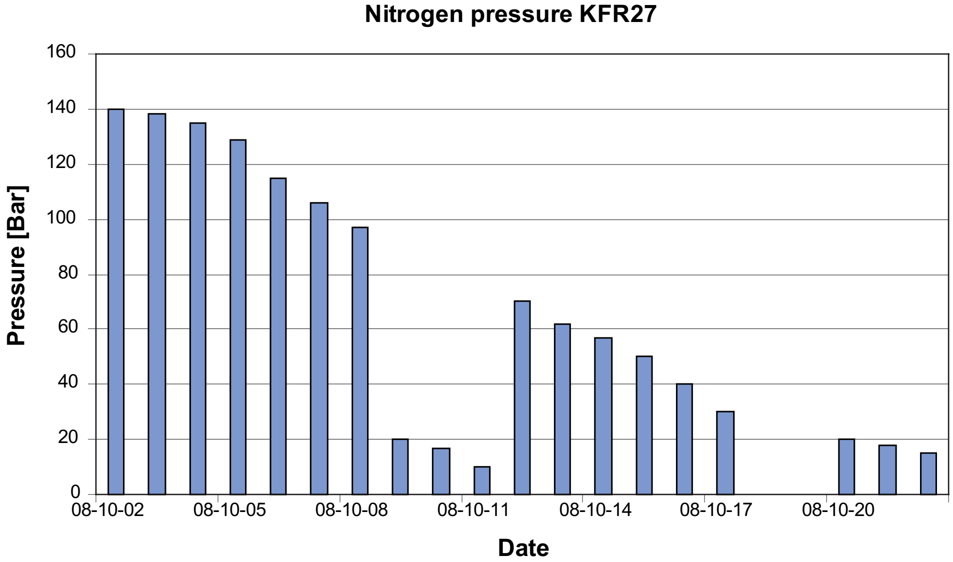


Figure 5-13. Nitrogen contents (measured as pressure) in the bottles used for nitrogen bubbling of flushing water in KFR27.

hours, and 3.2 m^3 more return water was recovered before a first strike water sample was collected. Despite the extensive pumping, still 25% of Uranine remained in the formation water. The complete results from the analyis of the water sample are presented in Appendix B.

5.2.6 Core sampling

The average drill core length per run obtained from the drilling was 2.98 m (section 212.49–501.64 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 5-14.

Figure 5-14. 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 together with analysis of BIPS-images, so called Boremap mapping, will be carried out after completion of drilling.

5.2.7 Recovery of drill cuttings

The theoretical volume of drill cuttings from section148.51 – 501.64 m is calculated to 0.894 m^3, and c. 0.784 m^3 of that is left in the formation because complete water loss occurred at c. 192 m drilling length.

5.2.8 Deviation measurements in KFR27

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 2, measurements with two different techniques have to be applied. An optic method (Maxibor II™ instrument) and a method based on magnetometer-/accelerometer technique (Flexit Tool System), was chosen for the deviation measurements performed in KFR27.

To ensure high quality measurements with the Flexit tool, the disturbances of the magnetic field must be small. Several measurement stations around the world provide magnetic field values, generally available on the Internet. For the Forsmark area the closest station is situated in Uppsala, and this station presents one-minute magnetic field values at www.intermagnet.org. The magnetic field variations during two loggings in June 17th and three loggings in November 3rd 2008 are seen in Figures 5-15 and 5-16 and display only minor disturbances when the Flexit-surveys in KFR27 were performed.

A description of the construction of deviation data for the core drilled borehole KFR27 is given below.

With the Flexit system, the deviation measurements were carried out every 3 m both downwards and upwards. The used activity marked "CF" in Table 5-3 also includes comments as well as a file describing the measures that have been applied.

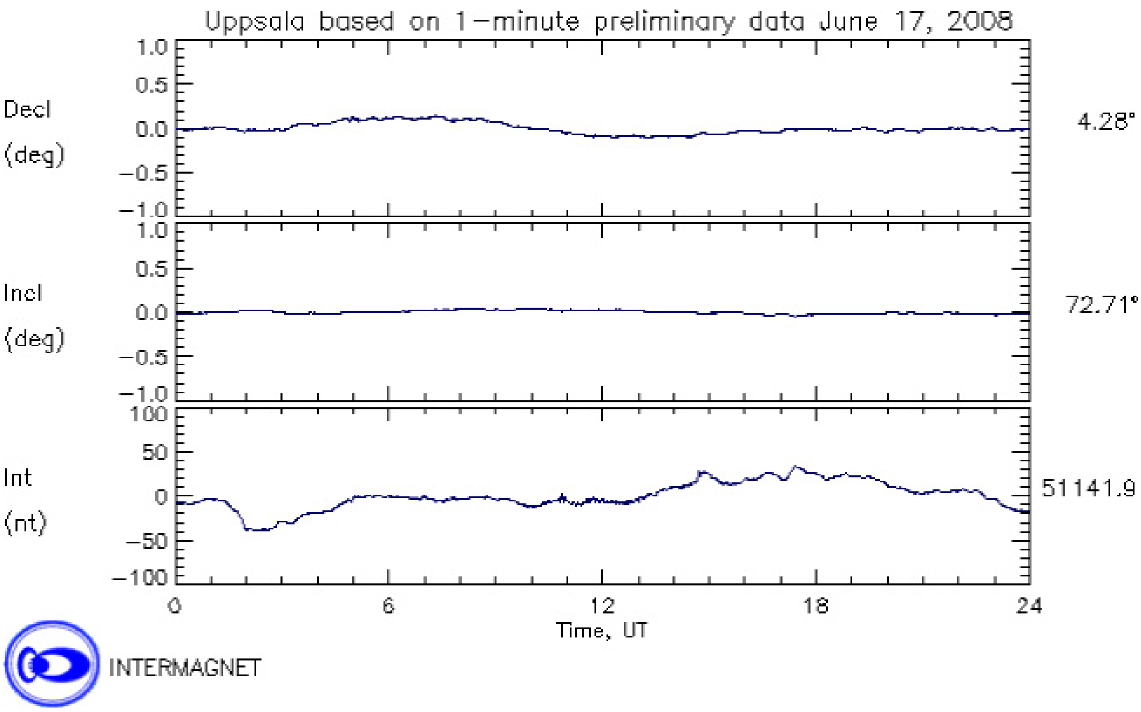


Figure 5-15. Magnetic field variations during Flexit surveys performed on June 17th 2008 in KFR27.

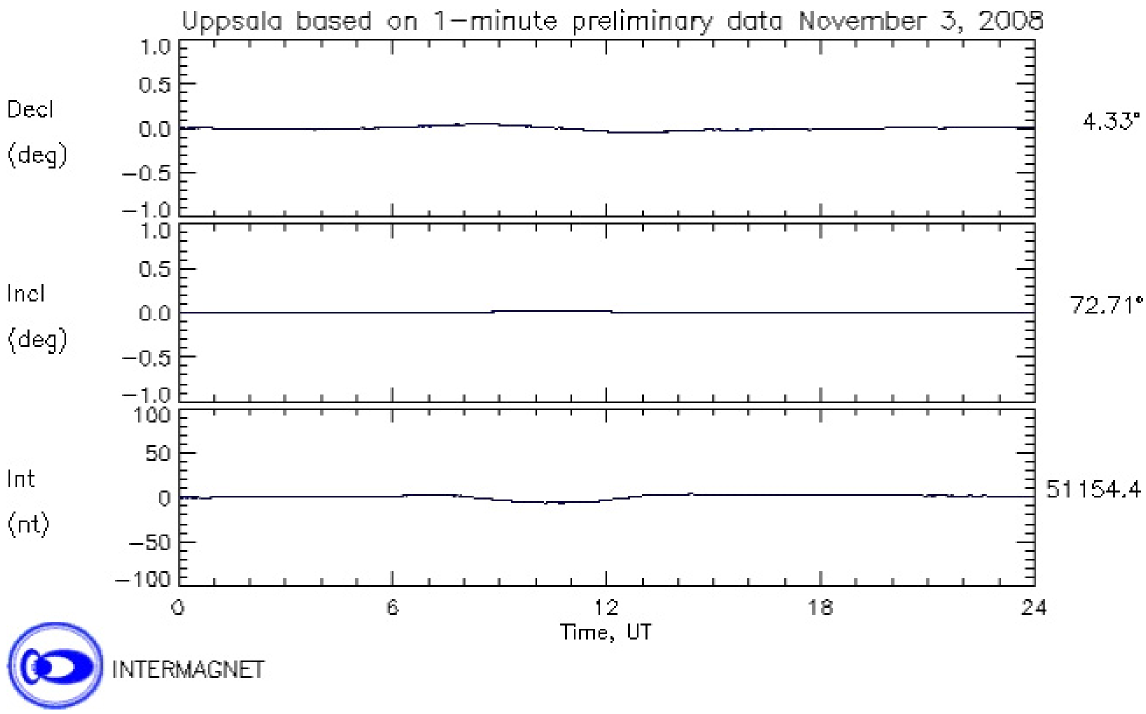


Figure 5-16. *Magnetic field variations during Flexit surveys performed on November3rd 2008 in KFR27.*

All deviation measurement surveys in the borehole have followed the recommended quality routines according to SKB MD 224.001, Version 2.0. This final deviation file is termed EG154 (Borehole deviation multiple measurements). See illustration of the construction principle in Figure 5-17.

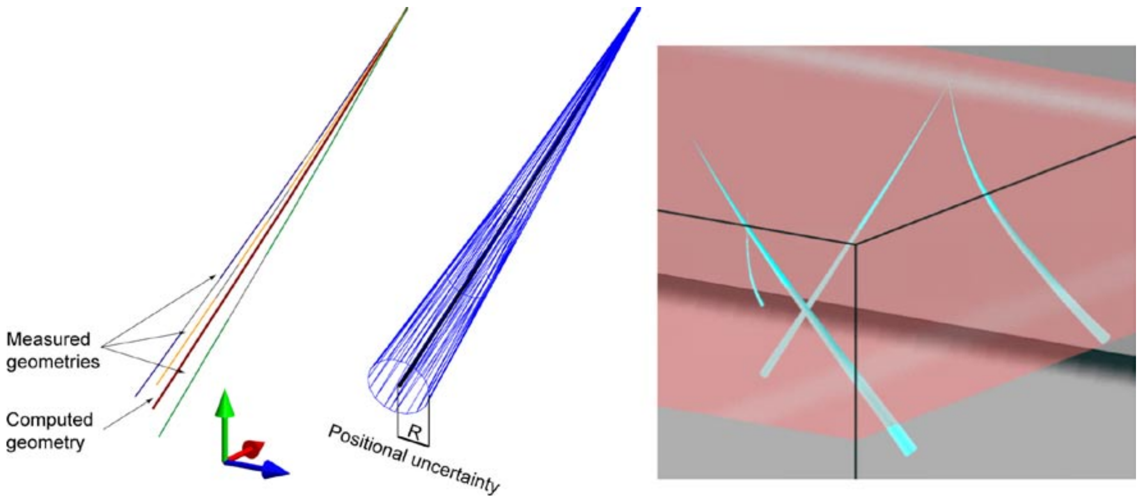


Figure 5-17. *The figure to the left is an illustration of the principles for calculating the borehole geometry from several deviation measurements. The two other figures illustrate one of the uncertainty measures used for deviation measurements. In the middle figure, "R" denotes "Radial uncertainty", representing a function, which is monotonously increasing versus borehole length in relation to the borehole axis, defining the shape of a cone surrounding the borehole axis and corresponding to the parameter in the column furthest to the right in Table 5-6. The figure to the right is a block diagram imaging four fictitious boreholes deviating in different ways and with radius uncertainty illustrated as blue cones (modified after Figures 4-1, 5-1 and 5-3 in /6/, Munier and Stigsson 2007).*

The Maxibor II™-logging to 445 m is error marked ("E") in Table 5-3 due to the inability of the measurement method to produce reliable data in a near vertical borehole (inclination >85º from the horizon). Therefore, the deviation data used for construction of the final deviation file are two loggings with the Flexit Smart Tool System to 147 m and three loggings to 495 m borehole length, respectively, see Table 5-4.

The EG154-activity (see Table 5-4) specifies the sections of the deviation measurements used in the resulting calculation presented in Table 5-6. 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 12 m steel casing which is not the case for the inclinometer measurements (inclination).

Table 5-3. Activity data for all deviation measurements approved for KFR27 (from Sicada). The five magnetic measurements in the borehole were used for calculation of the final borehole deviation file, as well as used for calculation of the deviation uncertainty.

Activity ID	Activity type code	Activity	Start Date	Idcode	Secup (m)	Seclow (m)	Flags
13189552	EG157	Magnetic accelerometer measurement	2008-06-17 13:50	KFR27	3.00	147.00	CF
13189732	EG157	Magnetic accelerometer measurement	2008-06-17 14:23	KFR27	3.00	147.00	CF
13201101	EG161	Maxibor II measurement	2008-10-19 12:30	KFR27	3.00	486.00	ECF
13201041	EG157	Magnetic accelerometer measurement	2008-11-03 14:15	KFR27	3.00	495.00	CF
13201059	EG157	Magnetic accelerometer measurement	2008-11-03 15:56	KFR27	3.00	495.00	CF
13201046	EG157	Magnetic accelerometer measurement	2008-11-03 17:18	KFR27	3.00	495.00	CF
13203003	EG154	Borehole deviation multiple measurements	2008-12-09 12:35	KFR27	3.00	495.00	ICF

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

Deviation activity Id	Deviation angle type	Approved secup (m)	Approved seclow (m)
13189552	BEARING	24.00	147.00
13189552	INCLINATION	3.00	147.00
13189732	BEARING	24.00	147.00
13189732	INCLINATION	3.00	147.00
13201041	BEARING	24.00	495.00
13201041	INCLINATION	3.00	495.00
13201046	BEARING	24.00	495.00
13201046	INCLINATION	3.00	495.00
13201059	BEARING	24.00	495.00
13201059	INCLINATION	3.00	495.00

A subset of the resulting deviation files and the estimated radius uncertainty is presented in Table 5-6. Figure 5-17 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 KFR27 shows that the borehole deviates upwards and to the left with an absolute deviation of 11.3 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.

Table 5-5. Deviation data from KFR27 for approximately every 50 m vertical length calculated from EG154. Coordinate system RT90 2.5 gon V 0:-15 / RHB 70.

Borehole	Length [m]	Northing [m]	Easting [m]	Elevation [m]	Inclination [degrees]	Bearing [degrees]
KFR27	0.00	6,701,714.42	1,633,175.52	2.87	–87.60*	248.20
KFR27	51.00	6,701,714.09	1,633,175.52	–48.12	–89.55	118.76
KFR27	102.00	6,701,713.89	1,633,175.89	–99.12	–89.60	118.63
KFR27	153.00	6,701,713.71	1,633,176.19	–150.12	–89.69	110.51
KFR27	201.00	6,701,713.25	1,633,174.46	–198.07	–85.51	259.70
KFR27	252.00	6,701,711.35	1,633,170.19	–248.85	–84.44	243.72
KFR27	303.00	6,701,709.21	1,633,165.59	–299.60	–84.04	246.36
KFR27	354.00	6,701,707.04	1,633,160.51	–350.30	–83.56	247.14
KFR27	405.00	6,701,704.79	1,633,155.16	–400.96	–83.39	249.12
KFR27	453.00	6,701,703.13	1,633,149.87	–448.64	–83.43	255.81
KFR27	498.00	6,701,702.03	1,633,144.55	–493.31	–82.72	258.31
KFR27	501.64	6,701,701.94	1,633,144.10	–496.92	–82.72	258.31

* 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).

Table 5-6. Uncertainty data for the deviation measurements in KFR27 for approximately every 50 m vertical length calculated from EG154. Cordinate system RT90 2.5 gon V 0:-15 / RHB 70.

Borehole	Northing [m]	Easting [m]	Elevation [m]	Inclination uncertainty	Bearing uncertainty	Radius uncertainty
KFR27	6,701,714.42	1,633,175.52	2.87	0.110	16.658	0.00
KFR27	6,701,714.09	1,633,175.52	–48.12	0.110	16.658	0.15
KFR27	6,701,713.89	1,633,175.89	–99.12	0.110	16.658	0.27
KFR27	6,701,713.71	1,633,176.19	–150.12	0.110	16.658	0.37
KFR27	6,701,713.25	1,633,174.46	–198.07	0.110	16.658	0.94
KFR27	6,701,711.35	1,633,170.19	–248.85	0.110	16.658	2.30
KFR27	6,701,709.21	1,633,165.59	–299.60	0.110	16.658	3.75
KFR27	6,701,707.04	1,633,160.51	–350.30	0.110	16.658	5.34
KFR27	6,701,704.79	1,633,155.16	–400.96	0.110	16.658	7.01
KFR27	6,701,703.13	1,633,149.87	–448.64	0.110	16.658	8.60
KFR27	6,701,702.03	1,633,144.55	–493.31	0.110	16.658	10.16
KFR27	6,701,701.94	1,633,144.10	–496.92	0.110	16.658	10.29

5.2.9 Groove milling KFR27

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

5.2.10 Nitrogen flushing

The final operation, before the drilling activity was concluded, was to rinse the borehole in order to minimize the contents of drilling debris or other unwanted material remaining in the borehole. For this purpose, nitrogen flushing was applied. Depending on that drilling was performed during two separate phases, nitrogen flushing was applied twice, firstly after rinsing the borehole to 148.92, see Table 5-8, and secondly after the full extension of the borehole, see Table 5-9.

At next stage, during the guided drilling a complete water loss occurred at c.192 m, entailing that flushing water and drill cuttings are forced into the permeable part of the rock resulting in that 0.784 m^3 (2,077 kg) drilling debris is left 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. After the first drilling phase, KFR27 had to be nitrogen flushed 15 times, on June 10th and 18th 2008, before this was achieved, see Figure 5-18 and Tables 5-8 and 5-9. The accumulated recovered water volume was estimated at 4.35 m^3.

After the full extension of KFR27 to 501.64 m, the borehole was flushed another 11 times on October 27th and October 29th before the return-water was judged to be clean or containing only a minimum of drilling debris. The estimated accumulated recovered water volume was 18.7 m^3, compared to 290 m^3 flushing water that was lost in the borehole during drilling, see Section 5.2.5.

Table 5-7. Reference grooves in KFR27.

Reference groove at [m]	Detection with the SKB level indicator	Confirmed from BIPS
48	Yes	Yes *
102	Yes	Yes *
150	Yes	Yes *
201	Yes	Yes *
249	Yes	Yes *
300	Yes	Yes *
358	Yes	Yes *
399	Yes	Yes *
450	Yes	Yes *
484	Yes	Yes *

* BIPS not adjusted.

Table 5-8. Nitrogen flushing periods in KFR27 after rinsing, reaming and extension to 148.51 m borehole length, nitrogen pressure applied and estimated discharged volumes of groundwater (from EG036 in Sicada).

ID	Start Date_time	Stop date_time	Pressure (bar)	Volume (m^3)	Comment
KFR27	2008-06-10 15:49:00	2008-06-10 15:55:00	13		
KFR27	2008-06-10 17:25:00	2008-06-10 17:30:00	17	100	Water up through TOC 17:28 Blow out 17:32
KFR27	2008-06-10 18:35:00	2008-06-10 18:43:00	18	150	Water up through TOC 18:38 Blow out 18:40
KFR27	2008-06-11 09:57:00	2008-06-11 10:03:00	17	150	Water up through TOC 10:02 Blow out 10:10
KFR27	2008-06-11 12:34:00	2008-06-11 12:40:00	16	100	Water up through TOC 12:42 Blow out 12:46
KFR27	2008-06-11 14:50:00	2008-06-11 14:58:00	18	150	Water up through TOC 14:55 Blow out 15:00
KFR27	2008-06-11 17:14:00	2008-06-11 17:21:00	30	400	Water up through TOC 17:17 Blow out 17:22
KFR27	2008-06-12 08:45:00	2008-06-12 08:51:00	25	300	Water up through TOC 08:47 Blow out 08:54
KFR27	2008-06-12 12:01:00	2008-06-12 12:15:00	30	400	Water up through TOC 12:15 Blow out 12:15
KFR27	2008-06-12 13:49:00	2008-06-12 13:56:00	35	400	Water up through TOC 13:51 Blow out 13:56
KFR27	2008-06-12 15:15:00	2008-06-12 15:21:00	40	450	Water up through TOC 15:17 Blow out 15:22
KFR27	2008-06-16 12:26:00	2008-06-16 12:32:00	40	450	Water up through TOC 12:28 Blow out 12:32
KFR27	2008-06-16 17:45:00	2008-06-16 17:51:00	40	450	Water up through TOC 17:47 Blow out 17:51
KFR27	2008-06-18 07:05:00	2008-06-18 07:10:00	40	400	Water up through TOC 07:07 Blow out 07:11
KFR27	2008-06-18 11:00:00	2008-06-18 11:05:00	50	450	Water up through TOC 11:03 Blow out 11:04

Table 5-9. Nitrogen flushing periods in KFR27 after full extension to 501.64 m borehole length, nitrogen pressure applied and estimated discharged volumes of groundwater (from EG036 in Sicada).

ID	Start Date_time	Stop date_time	Pressure (bar)	Volume (m^3)	Comment
KFR27	2008-10-27 13:50:00	2008-10-27 14:40:00	70	1,700	Water up through TOC 14:10 Blow out 14:14
KFR27	2008-10-27 15:39:00	2008-10-27 16:22:00	70	1,700	Water up through TOC 15:57 Blow out 15:58
KFR27	2008-10-27 17:32:00	2008-10-27 18:14:00	70	1,700	Water up through TOC 17:49 Blow out 17:50
KFR27	2008-10-28 07:12:00	2008-10-28 07:53:00	70	1,700	Water up through TOC 07:31 Blow out 07:34
KFR27	2008-10-28 09:30:00	2008-10-28 10:11:00	70	1,700	Water up through TOC 09:45 Blow out 09:48
KFR27	2008-10-28 11:23:00	2008-10-28 12:01:00	70	1,700	Water up through TOC 11:39 Blow out 11:41
KFR27	2008-10-28 13:11:00	2008-10-28 13:51:00	70	1,700	Water up through TOC 13:28 Blow out 13:29
KFR27	2008-10-28 15:20:00	2008-10-28 15:57:00	80	1,700	Water up through TOC 15:35 Blow out 15:36
KFR27	2008-10-29 07:06:00	2008-10-29 08:05:00	65	1,700	Water up through TOC 07:27 Blow out 07:30
KFR27	2008-10-29 09:03:00	2008-10-29 09:41:00	105	1,700	Water up through TOC 09:13 Blow out 09:15
KFR27	2008-10-29 10:42:00	2008-10-29 11:24:00	105	1,700	Water up through TOC 10:54 Blow out 10:55

Figure 5-18. Illustration of nitrogen flushing. Nitrogen under a high pressure is forced through a hose to the bottom of the borehole. When the gas expands in the borehole, 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 additional nitrogen flushing can begin.

5.2.11 Risk assessment KFR27

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 observed risk.

1 = a **potential** risk observed, but no incident has occurred (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 KFR27 are summarized in Table 5-10. Thirty-one sections of borehole KFR27 have been classified as involving a potential risk (1), in this case implying that the core section is highly fractured and associated with a risk of rock fallout.

5.2.12 Stabilization KFR27

During extension of KFR27, highly fractured rock associated with a rock contact was penetrated at c. 430 m borehole length, see Figure 5-19. When drilling progressed, rock fragments came off the borehole wall within this section, and therefore a flushing tool (nozzle) was adapted to the core barrel and descended in the borehole by the drill rig under simultaneous rotation and flushing of the borehole wall with high-pressurized water, see Figure 5-20. After rinsing (by applying this method) of several fractured sections in the borehole, the work was completed with drilling in order to grind the rock fragments that had come loose during the flushing and recover the drilling debris.

After completed drilling, a borehole investigation programme started. Measurements along the complete borehole length with geophysical logging tools and the BIPS camera were successful. However, the BIPS images confirmed the occurrence of unstable sections associated with an increased risk of rock outfall. Specifically, the BIPS images revealed a high-risk section at 430 m borehole length, and therefore it was decided not to carry out borehole radar measurements below that level. The succeeding investigation method in the planned investigation programme was flow logging with the Posiva Flow Log. After several trips down- and upwards with Posiva´s dummy, still some rock pieces were collected on top of the dummy.

Table 5-10. Documented sections of potential risk from observations during drilling and preliminary geological core mapping of KFR27.

From (mbl)*	To (mbl)	Risk level (code)	Description	From (mbl)	To (mbl)	Risk level (code)	Description
148.51	162.50	0		361.20	364.70	0	
162.50	163.40	1		364.70	365.20	1	
163.40	179.20	0		365.20	371.20	0	
179.20	180.50	1		371.20	373.00	1	
180.50	192.20	0		373.00	375.50	0	
192.20	193.20	1		375.50	379.00	1	
193.20	197.50	0		379.00	381.00	0	
197.50	197.90	1		381.00	381.40	1	
197.90	206.30	0		381.40	394.60	0	
206.30	206.70	1		394.60	395.10	1	
206.70	239.30	0		395.10	397.20	0	
239.30	239.80	1		397.20	397.80	1	
239.80	245.40	0		397.80	424.60	0	
245.40	246.00	1		424.60	425.60	1	
246.00	249.20	0		425.60	427.00	0	
249.20	249.60	1		427.00	427.80	1	
249.60	263.00	0		427.80	428.40	0	
263.00	263.90	1		428.40	428.90	1	
263.90	309.45	0		428.90	431.00	0	
309.45	310.00	1		431.00	432.70	1	Stabilized with Plex
310.00	311.70	0		432.70	435.40	0	
311.70	313.20	1		435.40	436.00	1	
313.20	323.80	0		436.00	445.40	0	
323.80	325.10	1		445.40	446.00	1	
325.10	328.70	0		446.00	451.40	0	
328.70	329.50	1		451.40	451.80	1	
329.50	331.50	0		451.80	455.10	0	
331.50	331.80	1		455.10	456.00	1	
331.80	343.40	0		456.00	463.80	0	
343.40	344.00	1		463.80	464.20	1	
344.00	349.40	0		464.20	477.00	0	
349.40	349.80	1		477.00	477.90	1	
349.80	353.85	0		477.90	495.50	0	
353.85	354.60	1		495.50	497.80	1	
354.60	359.90	0		497.80	501.64	0	
359.90	361.20	1					

* = metres borehole length

In order to pursue the investigation programme, it was regarded as necessary to stabilize the high-risk section, and therefore a decision was made to use a drill rig to:

- rinse the borehole,
- stabilize the high-risk section identified from the BIPS-logging by applying the Plex technique and,
- clean the borehole bottom.

The Plex -system for stabilization of the borehole wall is described in Section 3.4 and in /7/. The section 430.90–432.90 m where the Plex -plate was installed (after eliminating obstracting rock fragments) is commented on below.

Figure 5-19. *Image of the drill core at the instable section just below 430 m borehole length in borehole KFR27.*

Figure 5-20. *Flushing tool consisting of a nozzle mounted in the drill bit and designed to flush the borehole wall with high-pressurized water during simultaneous tripping and rotated in the borehole.*

Section 430.90–432.90

The following sequence of actions was carried out when stabilizing borehole section 430.90–432.90 (cf. Figures 3-5 and 5-21):

- The Plex tool, supplied with a perforated stainless steel plate and the reamer was attached to the drill pipe string and descended in the borehole.
- The instable section between 430.80 – 433.00 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 430.90–432.90 m.
- The packer was deflated after which the tool was retrieved from the borehole.

After the Plex-stabilization, the borehole has been possible to investigate without problems. Because the steel plate is perforated, it is also possible to perform hydraulic tests in the entire borehole.

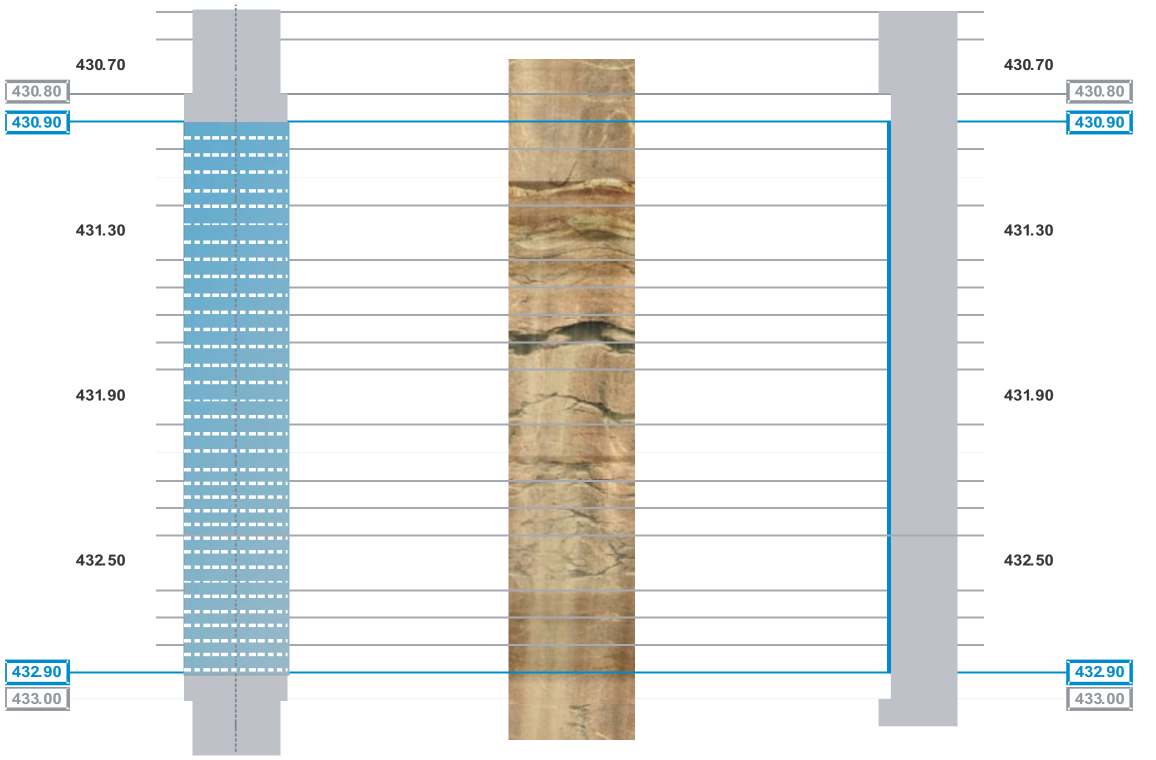


Figure 5-21. Schematic figure of the stabilized section in borehole KFR27 (left) with BIPS-images of the borehole section before stabilization with the Plex system (right).

5.2.13 Consumables

The special type of thread grease (silicon based) used in these particular boreholes was certified according to SKB MD 600.006, version 1. Instructions for the use of chemical products and material during drilling and surveys see Table 1-1. Oil and grease consumptions are given in Table 5-11.

Table 5-11. Oil and grease consumption during reaming and core drilling of borehole KFR27.

Borehole length from TOC [m]	Diesel [L]	Thread grease Unisilicon L50/2 [kg]	HydraulicOil ECO 46 [L]	UniversalGrease Statoil [kg])	Gear Oil SAE 80/90 [L]
0–148.51	350*	–	15	–	–
148.51–501.64	–	1.3	10	0.8	4

* Diesel-powered operation only during reaming because the electricity installation was delayed.

6 References

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

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

/3/ **Nilsson G, Ullberg A, 2008.** SFR utbyggnad, delprojekt undersökningar. Drilling of water well HFR101 and monitoring wells HFR102 and HFR105. SKB P-08-95 in progress.

/4/ **Nilsson G, Nissen J, 2007.** Forsmark site investigation. Revision of borehole deviation in Forsmark. SKB P-07-28, Svensk Kärnbränslehantering AB.

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/7/ **Håkanson N, Nilsson G, 2007.** Plex – Utrustning för mekanisk stabilisering. Metodbeskrivning & handhavande – Version 1.0. Docq nr 1077121.

Appendix A

Well Cad presentation of the core drilled borehole KFR27

Title KFR27

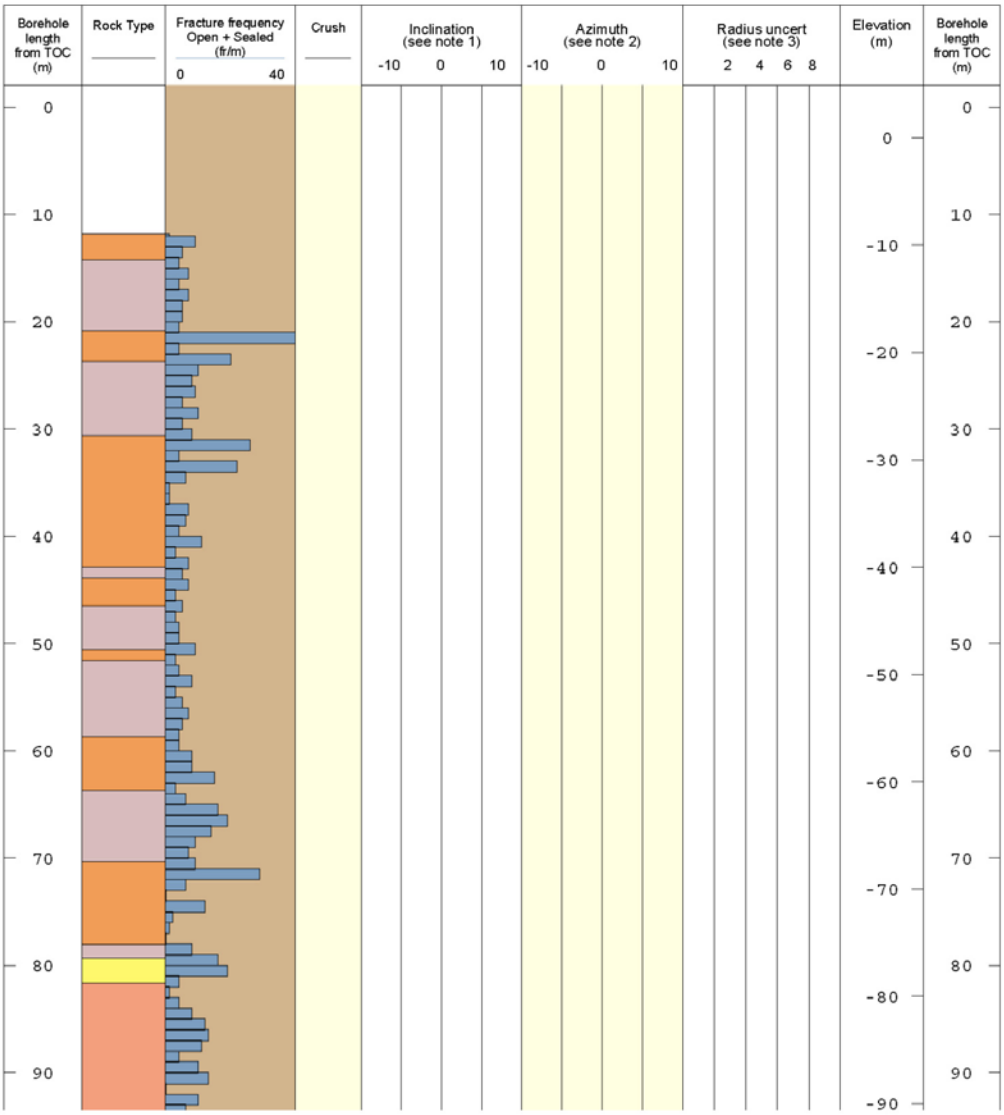
Svensk Kärnbränslehantering AB

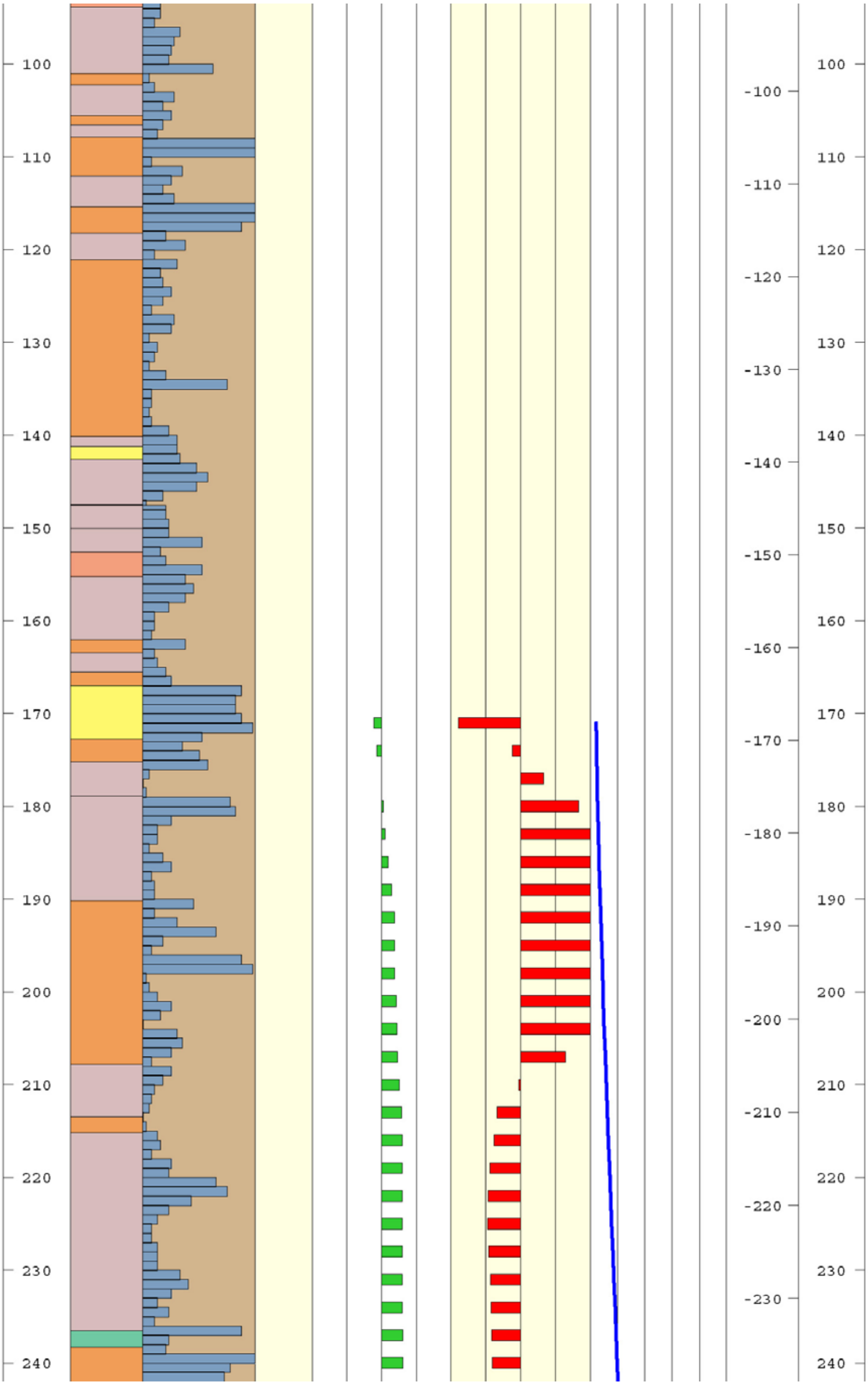
Site	FORSMARK - SFR	Coordinate System	RT90-RHB70
Borehole	KFR27	Northing [m]	6701714.42
Diameter [mm]	76	Easting [m]	1633175.52
Length [m]	501.64	Elevation [m]	2.87
Azimuth [°]	248.20	Drilling Start Date	2008-06-02
Inclination [°]	-87.42	Drilling Stop Date	2008-10-22
		Plot Date	2009-03-09

ROCK TYPE

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

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





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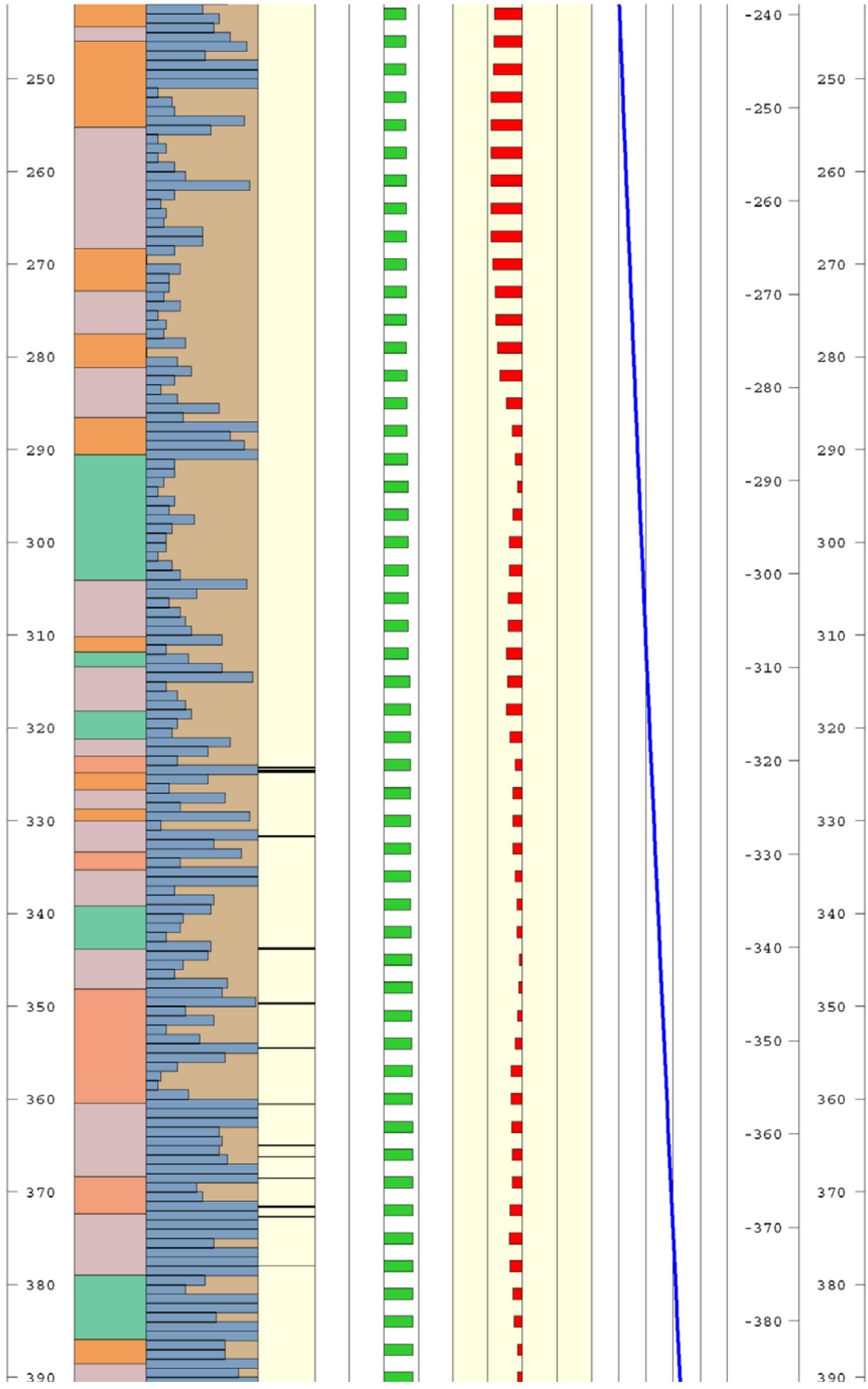
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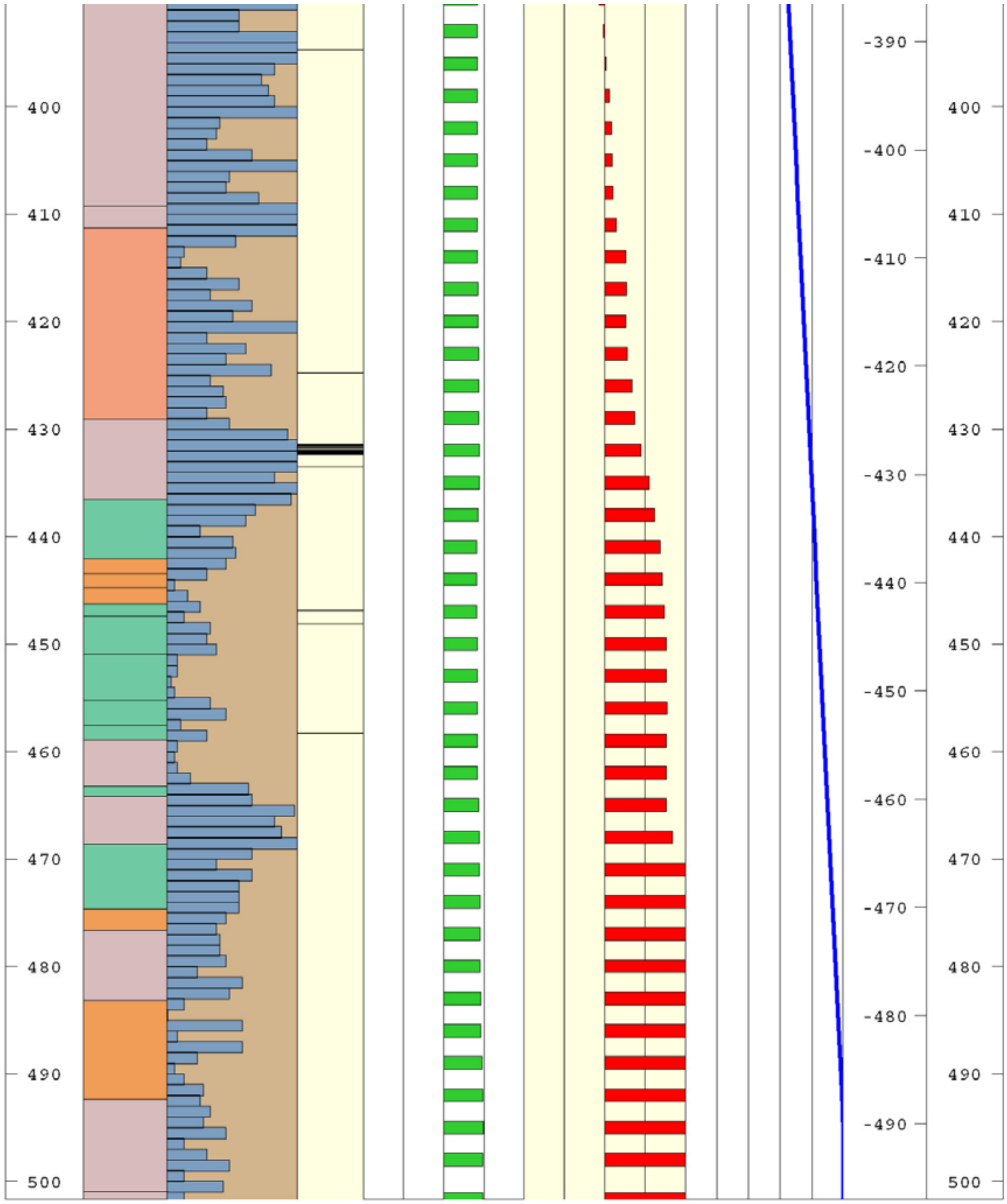
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Appendix B

Water composition

Water sampling class 3.

Start Date	Stop Date	Idcode	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)	Drill Water (%)	Charge Balance (%)
2008-10-09 20:50	2008-10-09 22:48	KFR27	16131	1,400.0	15.80	516.0	119.00	100.00	3,170.0	359.00	135.00	5.110	1.56	4.74	0.0454	6.620	7.30	982.0	48.30	23.60	–1.34