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Drilling of the cored boreholes KFM09A and KFM09B, and overburden drilling of KFM09C at drill site DS9

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March 2007

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Keywords: AP PF 400-05-077, AP PF 400-05-102, AP PF 400-05-103 core drilling, Drill site DS9.

Abstract

The major part of the deep boreholes drilled within the scope of the Forsmark site investigations are performed as telescopic boreholes, entailing that no drill core is received from the bedrock surface to c 60–100 metres. At drill site DS9 within the Forsmark investigation area, only traditional cored boreholes were drilled in order to retrieve drill cores also from the shallow part of the bedrock.

The first borehole, which is denominated KFM09A, is 799.67 m long, inclined 59.46° from the horizon, has a bearing of 200.08° from N, and reaches about 625 m in vertical distance from the ground surface. Overburden drilling with the core drilling machine was difficult, but could in the end be completed with installation of a stainless steel casing to 7.79 m before core drilling commenced.

During core drilling in the upper part, permeable and fractured rock was encountered. The return water disappeared at 108 m. After a drilling break, the borehole was refilled with groundwater and injected flushing water mixed with drill cuttings to such an extent that drilling was impossible to continue. The entire borehole section to 108 m was therefore grouted before core drilling could continue.

The second borehole, KFM09B, is 616.45 m long, inclined 55.08° and with bearing 140.83°. This borehole reaches about 476 m in vertical distance from the ground surface. In order to improve the efficiency of overburden drilling, a percussion drilling machine was employed. A steel casing was installed to 9.12 m before core drilling commenced.

Also during core drilling in the upper part of KFM09B, unstable, fractured and high-transmissive rock was penetrated. In section 10–55 m a major pressure loss was observed and a hydraulic transmissivity of 1E–5 m^2/s was measured in four 5 m sections within this interval. No return water was recovered which indicated that all flushing water and drill cuttings were injected into the formation. During drill stops also in this borehole, return water and cuttings refilled the borehole, making drilling impossible to perform. Therefore the entire section to 106 m was injected before drilling could re-commence.

A third cored borehole, KFM09C, was planned to be drilled at DS9. However, after overburden drilling and casing driving to 9.09 m, a decision was made to cancel core drilling. This short and cased borehole, which is drilled c 2.5 m into the bedrock surface, is at the collaring inclined 54.39° and directed 9.71° from N.

A sampling- and measurement programme for core drilling of KFM09A and KFM09B 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 KFM09A and KFM09B are included in this report.

After completed drilling of KFM09A and B, 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

De flesta djupa borrhål inom Forsmarks platsundersökning utförs som s k teleskopborrhål, varför borrkärna saknas i avsnittet från bergytan ner till ca 60–100 m. På borrplats BP9 i Forsmarks undersökningsområde borrades emellertid endast traditionella kärnborrhål för att borrkärnor skulle erhållas även från det ytnära berget.

Det första borrhålet, som benämns KFM09A, är 799,67 m långt, är ansatt med 59,46° lutning från horisontalplanet i riktning 200,08° samt når ca 625 m i vertikal riktning. Även jordborrningen utfördes med kärnborrutrustningen, vilket dock visade sig besvärligt. Detta moment kunde dock så småningom avslutas med foderrörsdrivning ner till 7,79 m.

Vid kärnborrningen i den övre delen påträffades permeabelt och sprucket berg. Vid 108 m inträffade total spolvattenförlust. Vid borruppehåll återfylldes borrhålet med grundvatten och spolvatten blandat med borrkax i sådan mängd att det omöjliggjorde fortsatt borrning. Därför måste hela sektionen ner till 108 m cementinjekteras innan borrningen kunde fortsätta.

Det andra borrhålet, KFM09B, är 616,45 m långt, är ansatt med 55,08° lutning och har bäringen 140,83°. Hålet når ca 476 m vertikaldjup. För att effektivisera jordborrningen utnyttjades en hammarborrmaskin som drev ner ett foderrör till 9,12 m borrlängd. I detta hål inträffade vid den efterföljande kärnborrningen total spolvattenförlust vid 107 m och även i detta fall återfylldes borrhålet med vatten och borrkax vid borruppehåll, så att fortsatt borrning omöjliggjordes. Den hydrauliska transmissiviteten uppmättes mellan 10–55 m borrlängd i 5 m sektioner med SKB's PSS3-utrustning, varvid en transmissivitet om ca 1E–5 m^2/s noterades i fyra av de mätta sektionerna. Därefter måste hela sektionen till 106 m injekteras innan borrningen kunde fortsätta.

Även ett tredje kärnborrhål, KFM09C, planerades utföras på borrplats BP9. Efter avslutad jordborrning och foderrörsdrivning till 9,09 m beslutades det dock att borrningen skulle avbrytas. KFM09C, som är borrat ca 2,5 m ner i ytberget, är ansatt med 54,39° lutning och riktat 9,71° från N.

Ett mät- och provtagningsprogram för kärnborrningen av KFM09A och KFM09B 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 KFM09A och KFM09B finns redovisad i föreliggande rapport.

Efter avslutad borrning av KFM09A och B 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

This document reports the results gained by core drilling of boreholes KFM09A and KFM09B, as well as of overburden drilling of KFM09C, which are three of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plans AP PF 400-05-077, AP PF 400-05-102 and AP PF 400-05-103. In Table 1-1 controlling documents for performing this activity are listed. Both activity plans and method descriptions are SKB's internal controlling documents.

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

The deepest boreholes drilled at the site investigation are drilled with core drilling technique. So far (March 2007), three sub-vertical and eight inclined, approximately 900–1,000 m long, cored boreholes have been drilled within the investigation area. Besides the deep holes, fourteen short or semi-deep (c 100–900 m) boreholes have been core drilled. The locations of the drill sites in question, DS1 to DS12, are illustrated in Figure 1-1.

By drilling many (although not all) of the deep boreholes, so called telescopic drilling technique is applied, meaning that the upper c 60–100 metres of the borehole are percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section below is core drilled with a diameter of approximately 76–77 mm.

In order to compensate for the missing core in the shallow part of the bedrock, a shorter core drilled borehole might be drilled all the way from the rock surface to 60–100 m. Such compensating boreholes were drilled at drill site DS1 (KFM01B), DS3 (KFM03B), DS6 (KFM06B), DS7 (KFM07B) and DS8 (KFM08B). Boreholes KFM01B and KFM07B were, however, prolonged from the planned length of 100 m to 500 m respectively 300 m, because of decisions to perform rock stress measurement by overcoring.

At DS9, the two core drilled boreholes, KFM09A and KFM09B, were drilled with the purpose of investigating the rock volume which in the future may serve as going under of the entrance tunnel and as the central area for the nuclear waste repository (Decision 1039868) /1/. A third, semi-deep borehole, KFM09C, was planned to be drilled at DS9, directed towards northwest,

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

Activity plan	Number	Version
Kärnborrning av KFM09A	AP PF 400-05-077	1.0
Kärnborrning av KFM09B	AP PF 400-05-102	1.0
Kärnborrning av KFM09C	AP PF 400-05-103	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för kärnborrning.	SKB MD 620.003	1.0
Metodbeskrivning för hammarborrning.	SKB MD 610.003	2.0
Metodbeskrivning för genomförande av hydrauliska enhålspumptester.	SKB MD 321.003	1.0
Metodbeskrivning för registrering och provtagning av spolvattenparametrar samt borrkax under kärnborrning.	SKB MD 640.001	1.0
Metodbeskrivning för pumptest, tryckmätning och vattenprovtagning i samband med wireline-borrning.	SKB MD 321.002	1.0

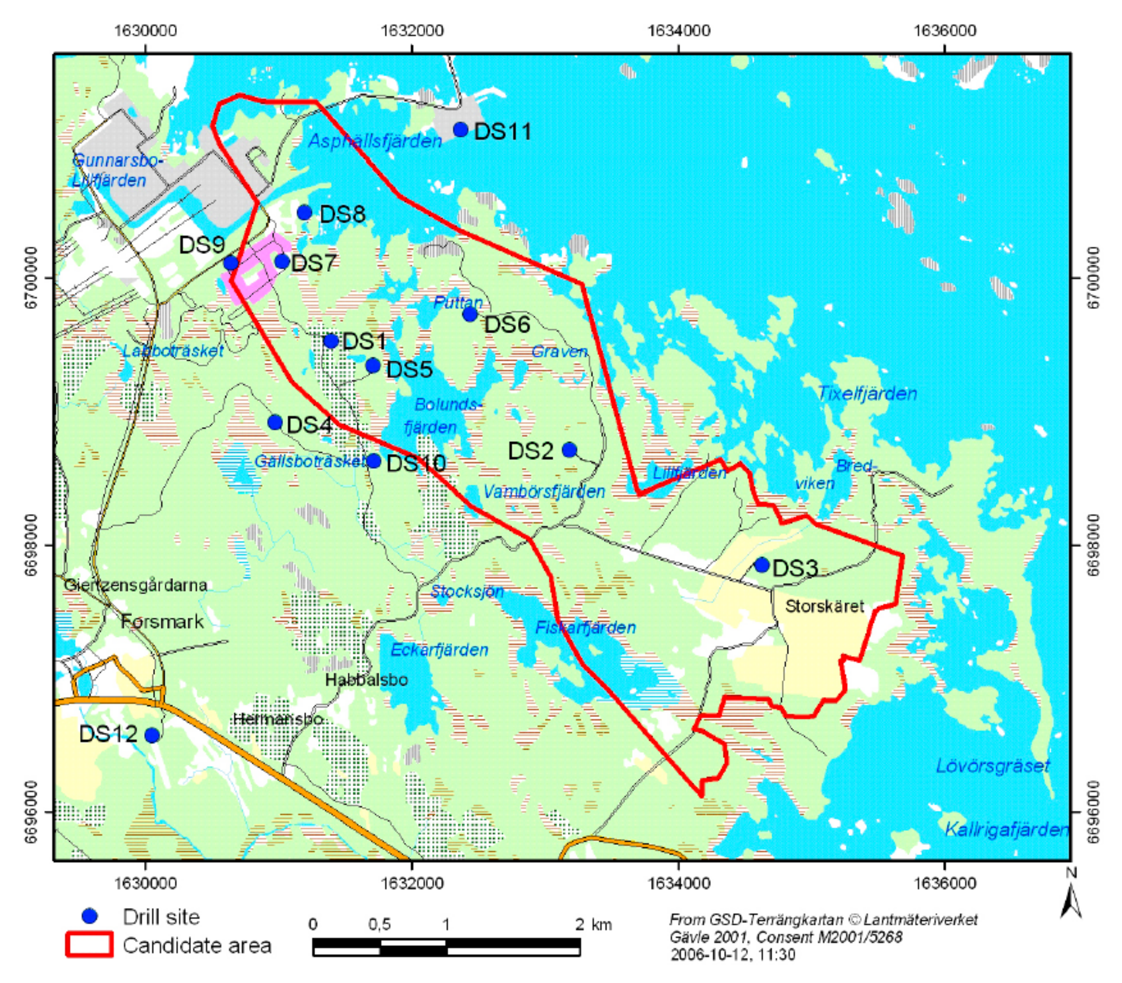


***Figure 1-1.** Part of the site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drill sites DS1–12 are marked with blue dots.*

but after soil drilling the planned subsequent core drilling was cancelled, mainly because the earlier drilled borehole KFM07A penetrated approximately the same rock volume as was to be investigated by KFM09C.

Close to the two core drilled boreholes at drill site DS9, also percussion drilled boreholes in soil and solid rock have been drilled for different purposes. The lengths of these boreholes vary between a few metres to 211 m. The locations of all boreholes at drill site DS9 as well as at the adjacent drill site DS7 are displayed in Figure 1-2.

Results from drilling of two monitoring wells, boreholes HFM23 and HFM28, at DS9 as well as drilling of borehole HFM24 (flushing water well) and borehole SFM0080 (monitoring well in soil) at DS10 have been reported separately in /2/. Results from geological mapping of boreholes HFM23 and HFM28 (so called Boremap mapping) are treated in /3/. Finally, Boremap mapping of KFM09A and KFM09B is presented in /4/ respectively /5/.

Original data from the reported activities are stored in the primary database SICADA. Data are traceable in SICADA by the Activity Plan numbers (AP PF 400-05-077, AP PF 400-05-102 respectively AP PF 400-05-103). 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*.

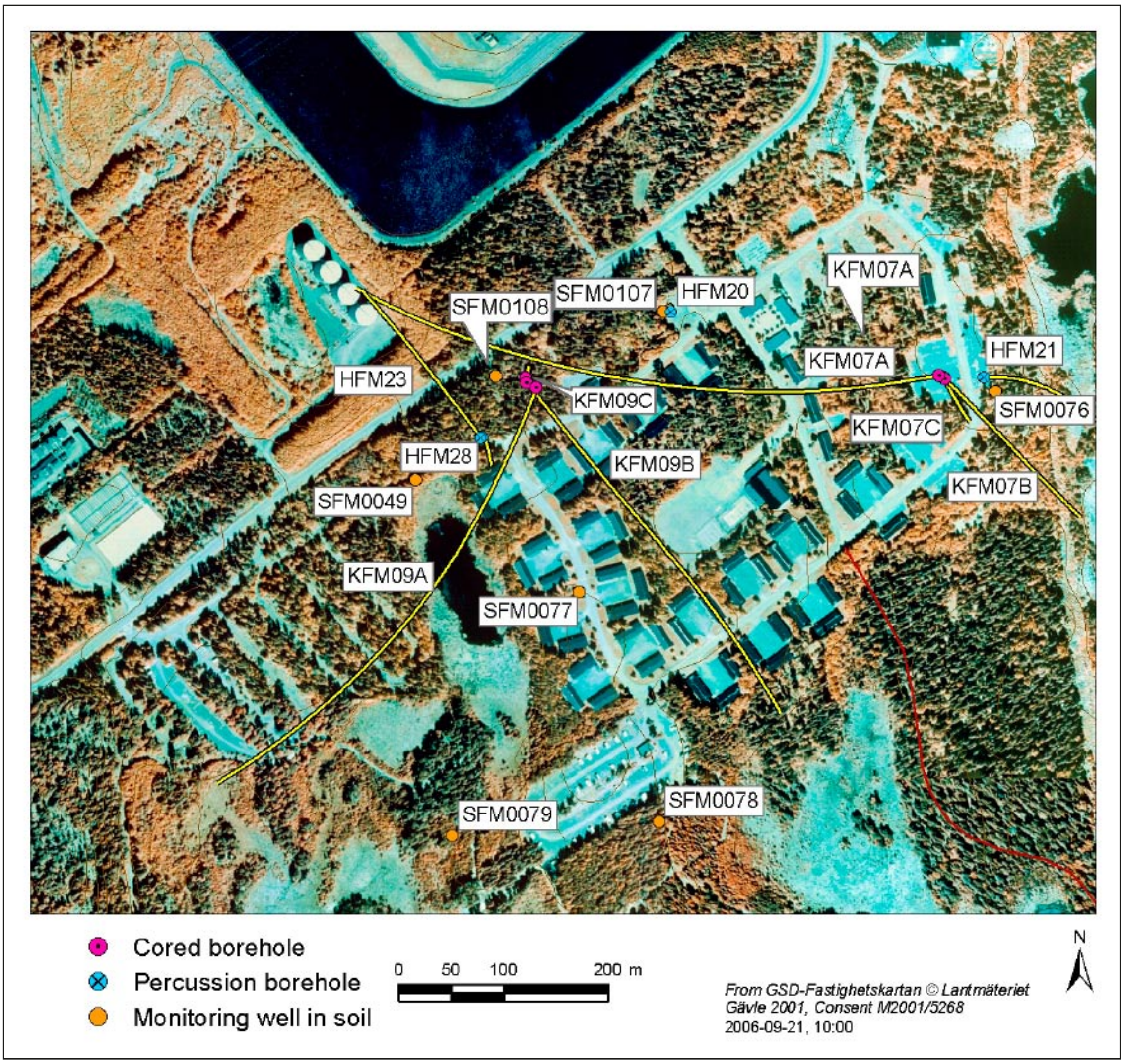


Figure 1-2. *Borehole locations at and near drill sites DS9 and DS7. Besides the core drilled boreholes KFM09A and KFM09B, and the incomplete borehole KFM09C, drill site DS9 comprises two monitoring wells in bedrock (HFM23 and HFM28), and two monitoring wells in soil (SFM0049 and SFM0108). The map also shows some other boreholes in the surrounding area. The projection of inclined boreholes on the horizontal plane at the ground surface (top of casing) is displayed in the map.*

2 Objective and scope

The main objective of drilling boreholes KFM09A, KFM09B and KFM09C at the site investigation was to investigate the rock volume potentially intended for serving as the going under of the entrance tunnel and as the central area for a future nuclear waste repository. The boreholes were drilled specifically to:

- To provide soil samples through the soil layer and drill cores all to way from the rock surface to the borehole bottom. The rock samples collected during drilling are used for a lithological, structural and rock mechanical characterization as well as for determination of the transport properties of the bedrock from the rock surface to the full drilling depth.
- To enable rock stress measurements to and beyond repository depth. After completion of drilling, a stress measurement campaign by hydraulic fracturing (HF) and hydraulic testing of pre-existing fractures (HTPF) was be carried out.
- To render geophysical borehole investigations possible, e.g. TV logging, borehole radar logging and conventional geophysical logging as an aid for the geological/rock mechanical characterization.
- To allow hydraulic borehole tests (single hole tests as well as interference tests,) for characterization of the hydrogeological conditions of the bedrock.
- To enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

3 Equipment

3.1 Drilling equipment for the overburden

For overburden drilling of KFM09A an Onram 2000 CCD with HQ wireline from Hagby Bruk was used (Figure 3-1), whereas a Nemek 711 percussion drilling ring was employed for KFM09B and KFM09C (Figure 3-2). The Nemek machine used the NO-X 115 system with the casing dimensions $Ø_o/Ø_i$ 139.8/123.8 mm.

3.2 Core drilling equipment

The Onram 2000 CCD with WL 76 was used for the core drilling of both KFM09A and KFM09B. A short presentation of the core drilling equipment is provided below.

This machine has an electrically-driven hydraulic system. The drilling capacity of an Onram 2000 with WL 76 is maximum c 1,500 metres. The drill pipes and core barrel used (stainless steel) 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 entails recovery of the core barrel via the drill pipe string, inside which it is hoisted up with the wireline winch. During drilling of boreholes KFM09A and KFM09B, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 77.3 mm part of the borehole is 51.0 mm. Minor deviations from this diameter may however occur.

Figure 3-1. *The Onram 2000 CCD core drilling machine in operation on borehole KFM09A.*

Figure 3-2. Soil drilling with a Nemek 711 percussion drilling machine at borehole KFM09B.

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

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

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 out into the borehole in order 1) to conduct frictional heat away from the drill bit, and 2) to enhance the recovery of drill cuttings to the ground surface. The cuttings, suspended in the flushing water (in general mixed with groundwater), are forced from the borehole bottom to the ground surface via the gap between the borehole wall and the drill pipes. A schematic illustration of the flushing/return water system when drilling KFM09A and KFM09B at DS9 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 storage and discharge of return water.

Preparing the flushing water

The water used for the supply of flushing water for core drilling of KFM09A and KFM09B was tap water from Forsmarks Kraftgrupp AB. Because the boreholes were not prioritized for hydrogeochemical investigations, the water from Forsmarks Kraftgrupp AB was used without nitrogen bubbling, which is a measure undertaken to expel oxygen in the flushing water used when drilling so called telescopic boreholes of SKB chemical type, see SKB MD 620.003.

The flushing water was, however, prepared before use, in accordance with SKB MD 620.003 (Method description for core drilling), with an organic tracer dye, 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 the flushing water content in groundwater samples collected in the borehole during or after drilling.

Measurement of flushing water parameters

The total quantity of water supplied to the borehole was acquired by counting the number of filled water tanks used, multiplied by the tank volume.

Storage and discharge of return water

At the surface level, the return hose was connected to a return pipe between the discharge head and the first return water container, see Figure 3-3. The return water was discharged from the borehole via an expansion vessel and a flow meter to two containers, in which the drill cuttings separated out in the sedimentation container. Since the return water had an increased salt content, it could not, for environmental reasons, be discharged into any fresh water recipient, but had to be transported from the container with tractor and tank to the Baltic Sea. Intermittently, the return water was, after separation of drill cuttings, stored in one elastic water tank with an expansive capacity of up to 40 m^3, see Figure 3-3.

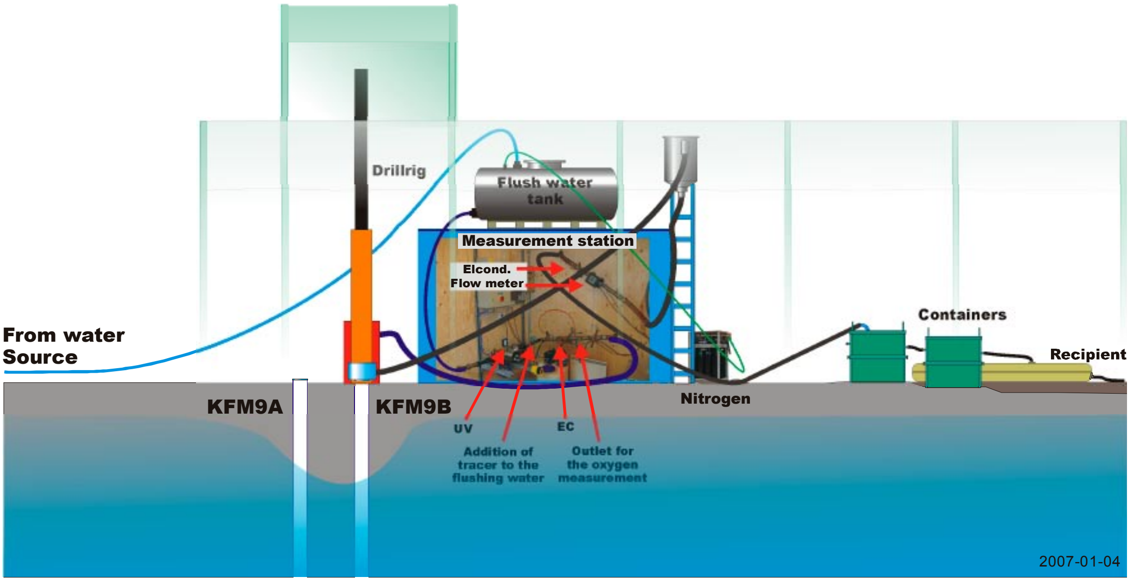


Figure 3-3. Schematic illustration of the flushing/return water system when drilling KFM09A and KFM09B at DS9. For measurements of the accumulated return water volume, a mechanical water gauge were used.

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

In SKB MD 620.003 it is stated that hydraulic tests, absolute pressure measurements and water sampling should be performed at certain intervals using a down-hole tool. The tool, which is denominated "the wireline probe" or "WL-probe", is described in SKB MD 321.002, Version 1.0 (Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wireline-borrning), which is an SKB internal controlling document. In borehole KFM09A two pressure tests were conducted with the wireline probe, whereas in borehole KFM09B, no tests were made with the probe.

3.4 Equipment for deviation measurements

After completion of drilling, a deviation measurement was carried out with a Reflex MAXIBOR™-system, which is an optical, i.e. non-magnetic measurement system. Azimuth and dip are measured at every third metre. The collaring point coordinates and the measured values are used for calculating the coordinates of the position of the borehole at every measurement point.

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

At the time of drilling KFM09A and KFM09B, the MAXIBOR™-method was assessed as the most reliable of different deviation methods tested by SKB, and MAXIBOR-data stored in the database SICADA were normally assigned as the only deviation data set permitted to be used (so called "in use displayed data"), even if another or several deviation methods had been applied in a borehole as well. However, in connection with a major quality revision regarding orientation of all identified geological objects (fractures, fracture zones, rock contacts etc) conducted by SKB during late autumn 2006 to winter/early spring 2007, a reassessment of the reliability of deviation measurement methods was made, whereby the FLEXIT-method was judged as providing the most reliable results. Therefore a revision was made also for boreholes KFM09A and KFM09B, and today FLEXIT-data are in use displayed. However, all available deviation measurements (i.e. for boreholes KFM09A and KFM09B FLEXIT- as well as MAXIBOR-data) have been used for estimation of the uncertainty of deviation data.

Results from the deviation measurements stored in SICADA are presented in Sections 5.5.3 and 5.9.3.

3.5 Groove milling

After completion of drilling, boreholes KFM09A and KFM09B have been used and will further 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 have been 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 drill pipe string.

At each level where milling was performed, 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). A BIPS-survey provided the final confirmation that the grooves exist.

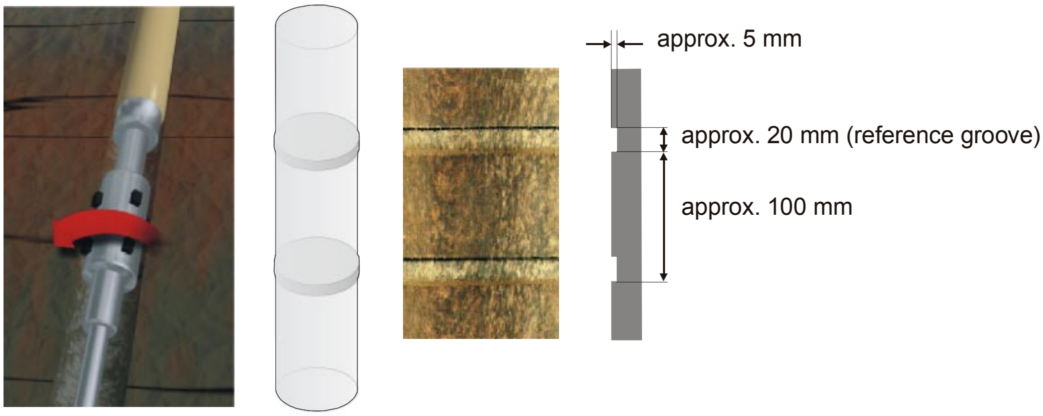


Figure 3-4. *Layout and design of reference grooves.*

4 Execution

4.1 General

The activities were conducted in compliance with Activity Plans AP PF 400-05-077, AP PF 400-05-102 and AP PF 400-05-103, which refer to SKB MD 620.003 (Method description for core drilling). The drilling operations 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.

The items are presented more in detail in Sections 4.2–4.5.

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 in accordance with SKB MD 600.004.

4.3 Execution of field work

4.3.1 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 (Figure 4-1) and final function control of all equipment.

4.3.2 Overburden drilling

KFM09A

Drilling of borehole KFM09A started with the Onram 2000 machine, drill dimension HQ (96 mm) down to 7.00 m, followed by reaming with dimension B (116 mm) to 7.23 m and then HQ drilling to 7.79 m, installation of a steel casing to 7.79 m and cement grouting. The soil cover was 6.10 m.

KFM09B

Prior to drilling of KFM09B, the concrete slab had to be forced by special drilling equipment to prevent any reinforcement bars to damage the drill bit (Figure 4-2). Thereafter the percussion machine (Nemek 711) performed the soil drilling to 9.12 m with NO-X 115. A 113 mm support casing was installed in the borehole and an attempt with the Onram 2000 and HQ to drill approximately 3 m into solid rocks was made, but failed. The flow meter for the water pump broke down and made further drilling impossible. Therefore a decision was made to grout the casing without further drilling. Cleaning after the percussion drilling and removal of the HQ and the 113 mm support casing was followed by driving a 77/90 mm stainless steel casing with Ø 124 mm steering.

Figure 4-1. Gerry Johansson from Geocon preparing the lining up of the drilling machine.

KFM09C

The drilling of KFM09C was made almost exactly as for KFM09B with NO-X 115 to 9.12 m and a casing with dimension $Ø_o/Ø_i$ 139.8/123.8 mm.

4.3.3 Core drilling, measurements and sampling during drilling

KFM09A

Core drilling of borehole KFM09A was made in section 7.79–799.67 m with the Onram 2000 machine resulting in a borehole diameter of 77.3 mm.

KFM09B

The same machine, resulting in the same borehole diameter as in KFM09A, was used in borehole KFM09B when drilling section 9.12–616.45 m.

KFM09C

Continued drilling was cancelled after soil drilling.

Figure 4-2. Special drilling equipment was used for making a hole through the concrete slab to prevent reinforcement bars to damage the drill bit when drilling KFM09B.

Sampling and measurements

Core drilling is 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 KFM09A and KFM09B some deviations from this programme could not be avoided. These deviations are presented in Section 4.6 below.

Results from the measurements and registrations during core drilling are presented in Chapter 5.

4.4 Finishing off work

The concluding work included the following items:

1) The boreholes were flushed for about 3 hours in order to clean them 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 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.

4.5 Data handling

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

4.6 Nonconformities

The core drilling operation in KFM09A and KFM09B 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 KFM09A and B according to SKB MD 620.003 and the respective Activity Plans with the real performance. Besides the nonconformities displayed in the table, the employment of a percussion drill machine for overburden drilling in boreholes KFM09B and C was not originally planned and may therefore be regarded as a nonconformity.

4.7 Environmental programme

4.7.1 Performance

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

4.7.2 Nonconformities

None.

Table 4-1. Program for performance and frequency for sampling, measurements, registrations and other activities during and immediately after core drilling of KFM09A and KFM09B according to SKB MD 620.003, AP PF 400-05-077 and AP PF 400-05-102.

Activity	Performance and frequency according to SKB MD 620.004	Performance and frequency during drilling of KFM09A	Performance and frequency during drilling of KFM09B
Registration of drilling- and flushing water parameters.	Registration during the entire drilling.	Described in Section 3.2.2.	Described in Section 3.2.2.
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	One MAXIBOR-measurement after completion of drilling and one measurement with FLEXIT.	One MAXIBOR-measurement after completion of drilling and one 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.
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.	No measurements performed.	No measurements performed.
Absolute pressure measurements.	Normally during natural pauses in drilling.	Two pressure measurements performed.	No measurements performed.
Groove milling in the borehole wall, normally at each 50 m.	Normally performed after completion of drilling.	Fourteen grooves performed.	Twelve grooves performed.

5 Results

All data were stored in the SICADA database. An overview of the drilling progress of boreholes KFM09A, KFM09B and KFM09C is given in Section 5.1, whereas geometrical data and technical design are presented in Sections 5.2, 5.6 and 5.11.

Results from drilling and measurements during drilling are accounted for in:

- Sections 5.3 and 5.7 (drilling).
- Section 5.4 and 5.8 (core sampling).
- Section 5.5 and 5.9 (measurements while drilling).
- Section 5.10 (consumables).
- Section 5.11 (KFM09C).

Well Cad-presentations for KFM09A and KFM09B are shown in Appendix A respectively Appendix B. The Well Cad plots are composite diagrams presenting the most important technical and geoscientific results from drilling and investigations made during and immediately after drilling.

5.1 Drilling progress

As drill site DS9 is located close to the Forsmark power plant residential area, special consideration had to be taken to minimize the disturbance caused by noise from the drilling equipment. The solution was to drill inside a tent during the autumn and winter 2005, when the at this time of the year relatively few residents could be placed further away from the drill site.

Borehole KFM09A was completed during a period of two months. To speed up the drill performance a percussion drilling machine was employed for drilling through the overburden for KFM09B and KFM09C. As the boreholes are located on the same drill site, demobilization from KFM09A and mobilization to KFM09B went quite simply and drilling of borehole KFM09B was finished before Christmas 2005, see Figure 5-1. The plans for drilling KFM09C were changed just after the overburden drilling had been completed, and continued drilling was cancelled.

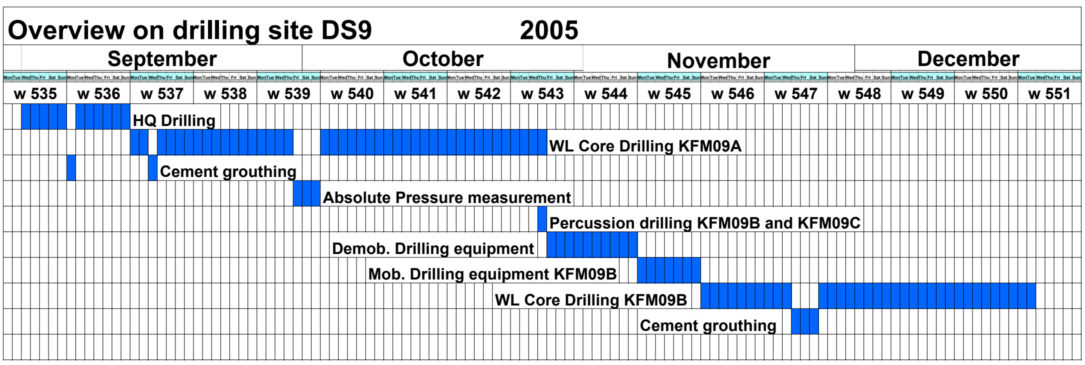


Figure 5-1. Overview of the drilling performance of boreholes KFM09A, KFM09B and KFM09C at DS9.

5.2 Geometrical and technical design of borehole KFM09A

Administrative, geometric and technical data for borehole KFM09A, are presented in Table 5-1. The technical design of the borehole is illustrated in Figure 5-2.

5.3 Drilling KFM09A

5.3.1 Overburden drilling KFM09A

Drilling of the section 0–7.79 m (borehole length) was progressing from Aug 31st to Sept 5th, 2005 (Figure 5-3). As mentioned in Section 4.3.2, the upper part down to 7.23 m of the borehole was drilled in soil, while section 7.23–7.79 was drilled in the upper part of the bedrock. The soil cover was 6.10 m vertical depth. Section 0–7.79 m is also supplied with a 90/77 mm steel casing which was cement grouted.

5.3.2 Core drilling KFM09A

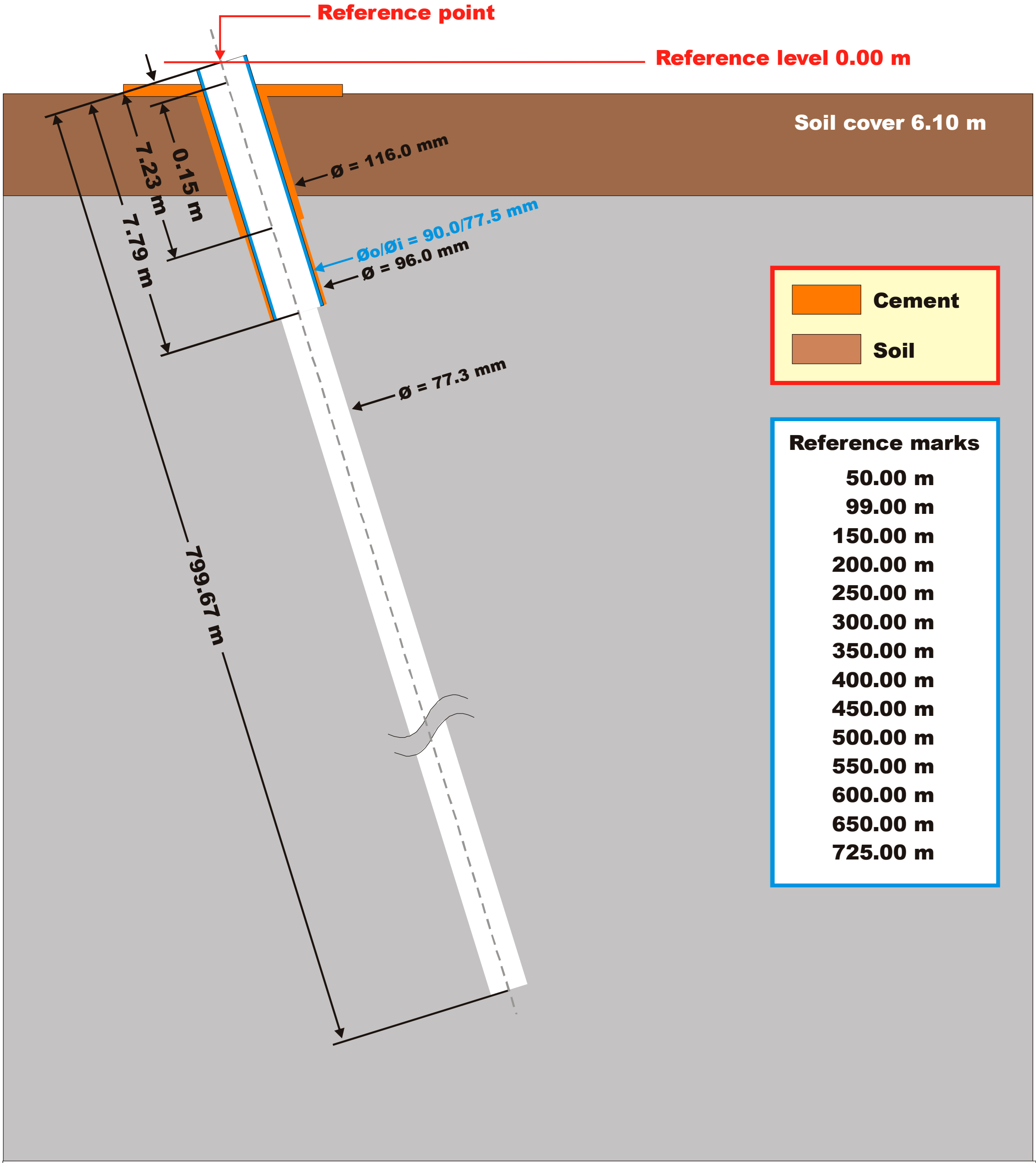
The core drilling progress during the period from September 5th to October 27th, 2005, is presented in Figures 5-3 and Figure 5-4.

Table 5-1. Administrative, geometric and technical data for borehole KFM09A.

Parameter	
Borehole name	KFM09A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	Aug 31, 2005
Completion date	Oct 27, 2005
Drilling periods	Aug 31–Sept 5, 2005 (0–7.79 m)
	Sept 5 to Oct 27, 2005 (7.79–799.67 m)
Contractor core drilling	Drillcon Core AB
Core drill rig	ONRAM 2000 CCD
Position at top of casing (RT90 2.5 gon V 0:–15/RHB 70)	N 6700115.04 E 1630647.50 Z 4.29 (m.a.s.l.)
	Azimuth (0–360°): 200.08° Dip (0–90°): –59.46
Position at bottom of hole (RT90 2.5 gon V 0:–15/RHB 70)	N 6699740.47 E 1630343.37 Z –621.21 (m.a.s.l.)
	Azimuth (0–360°): 238.70° Dip (0–90°): –40.79°
Borehole length	799.67 m
Borehole diameter and length	Ø 116.0 mm between 0.00–7.23 m Ø 96.0 mm between 7.23–7.79 m Ø 77.3 mm between 7.79–799.67 m
Casing diameter and length	$Ø_o/Ø_i$ = 90.0 mm/77.5 mm between 0.00–7.79 m
Drill core dimension and length	Ø 63.3 mm between 7.23–7.79 m Ø 51.0 mm between 7.79–799.67 m
Core interval	7.23–799.67 m

Technical data

Borehole KFM09A



Drilling reference point

Northing: 6700115.04 (m), RT90 2,5 gon V 0:-15
Easting: 1630647.50 (m), RT90 2,5 gon V 0:-15
Elevation: 4.29 (m), RHB 70

Orientation

Bearing: 200.08°
Inclination: -59.46°

Drilling period

Drilling start date: 2005-08-31
Drilling stop date: 2005-10-27

Rev 2007-02-21

Figure 5-2. *Technical data of borehole KFM09A.*

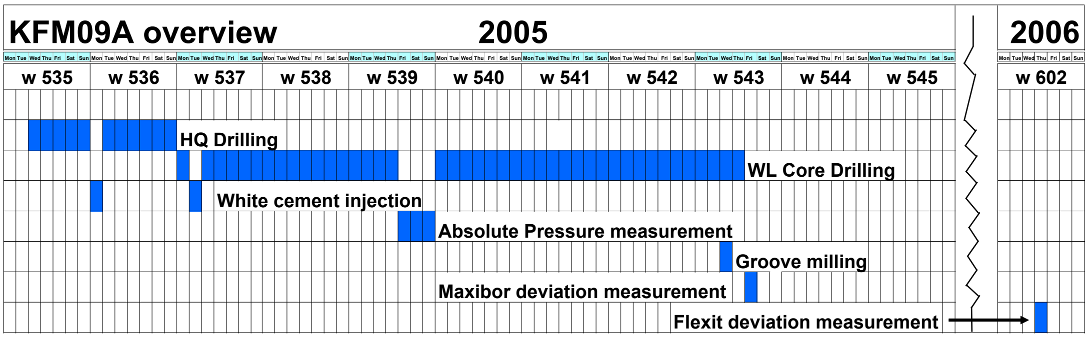


Figure 5-3. Overview of the drilling performance of boreholes KFM09A.

Drilling of traditional cored boreholes in highly fractured rock often causes water loss, meaning that flushing water and drilling debris is pressed into the permeable part of the rock. During core recovery, when the inner tube is winched up, a low water pressure is induced, causing the drilling debris and flushing water to recharge into the borehole. It is often difficult to resume drilling, as drilling debris can clog the drill bit channels and prevent efficient cooling of the bit. If total water stop occurs, the drill bit will almost immediately be worn out, or in the worst case, get caught at the borehole bottom. This is what happened in KFM09A, and therefore the borehole had to be grouted at two occasions.

The first grouting comprised injection with 1,100 kg white cement from the bottom of the borehole, 42.62 m, to prevent loss of the flushing water. Core drilling could then continue, but when the borehole had reached 107.91 m length it was again impossible to continue drilling,

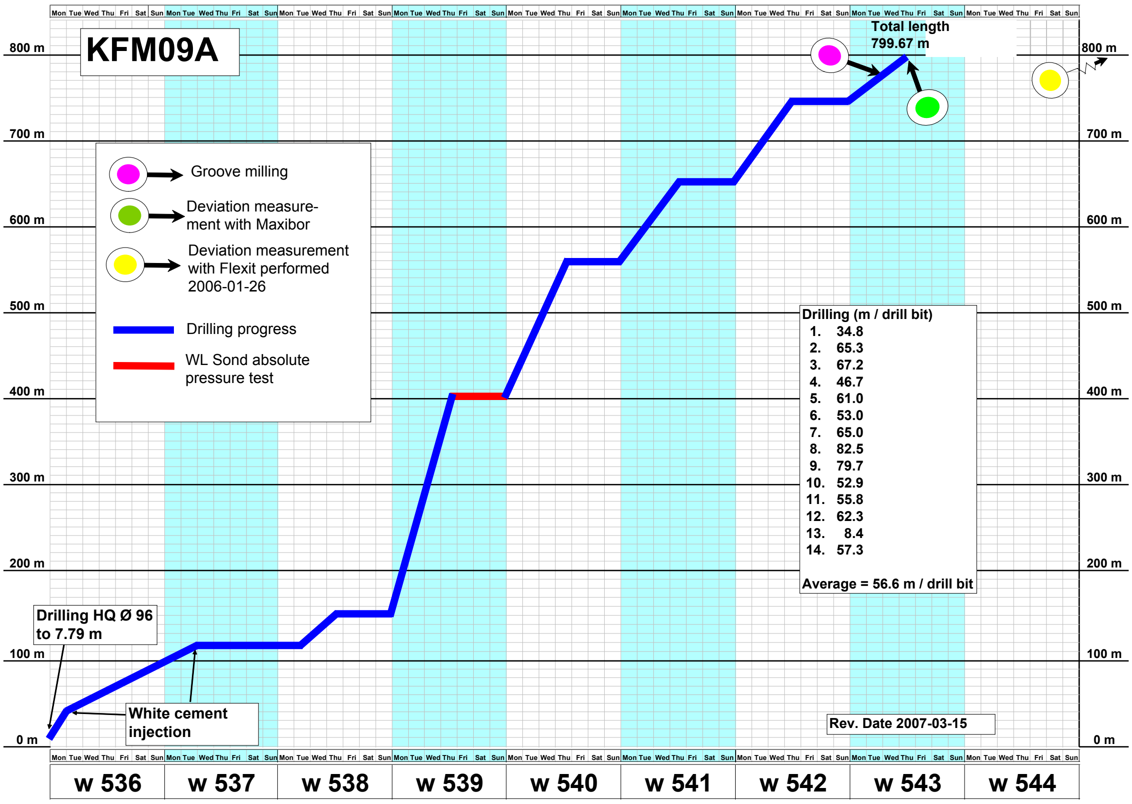


Figure 5-4. Core drilling progress KFM09A (length versus calendar time).

because large amounts of drilling debris was flowing back into the borehole. A new grouting with approximately 500 kg white cement was performed in the borehole. The injected cement partly sealed the permeable fractures, thereby decreasing recharge of water and drill cuttings into the borehole, so that drilling could restart. Later the pace of the drilling progress continuously decreased versus time due to the fact that with increasing borehole length, retrieval of the core barrel, e.g for change of drill bit, became more and more time consuming.

The bedrock within the so called Forsmark tectonic lens has appeared to be relatively difficult to drill due to its hardness, probably to a large extent depending on the high quartz content. Drill site DS9 is located in the north-western part of the tectonic lens. Borehole KFM09A is however directed towards south-west, into a rock domain delineating the tectonic lens. Drilling in this domain resulted in the longest life-time of the drill bits observed so far during the site investigation. In average, the life-time was 56.6 drilled metres per drill bit, which is almost 100% more than in e.g. borehole KFM01A, situated in the centre of the tectonic lens.

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

5.4 Core sampling

A preliminary on-site core logging was performed continuously in connection with the drilling.

5.5 Measurements while drilling

During, and immediately after drilling, a program for sampling and measurements was applied, cf Section 4.3.3. The results are presented in Sections 5.5.1–5.5.5 below.

5.5.1 Flushing water and return water flow rate – water balance

Figure 5-5 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 5-6, from which the return water/flushing water quotient for the end of the drilling period may be calculated, in this case resulting in the very low quotient 0.05 for KFM09A.

5.5.2 Uranine content of flushing water

An organic tracer, Uranine, was automatically added to the flush water tank, see Section 3.2.1. During the drilling period, sampling of flushing water and analyses of the tracer content was performed systematically with a frequency of approximately one sample per 20–30 m drilling length, see Figure 5-7.

5.5.3 Deviation measurements in KFM09A

The principles of the equipment for deviation measurements were explained in Section 3.4. Also the changed strategy for deviation measurements during the site investigations was commented on, including the fact that the FLEXIT-method is now the principal method applied for deviation measurements, also in borehole KFM09A. When MAXIBOR™-measurements or deviation measurements with some other method have been performed as well, these are (if the quality is acceptable) used for uncertainty determinations of the deviation measurements.

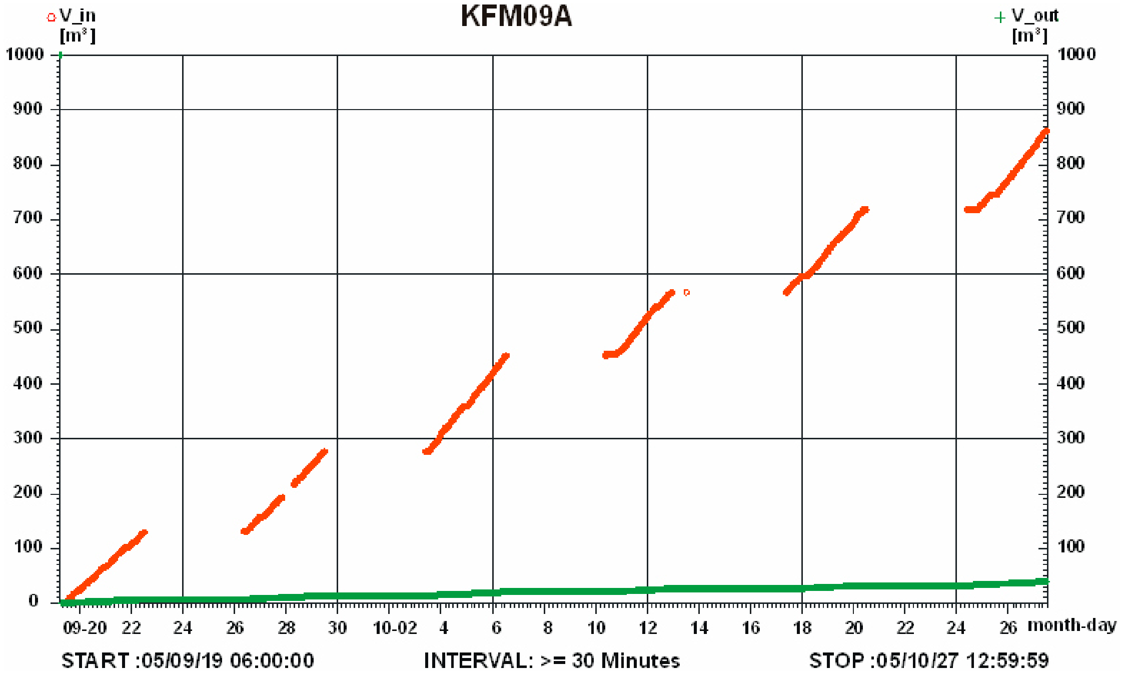


Figure 5-5. Accumulated volumes of flushing water (red) and return water (green) versus time during drilling of borehole KFM09A.

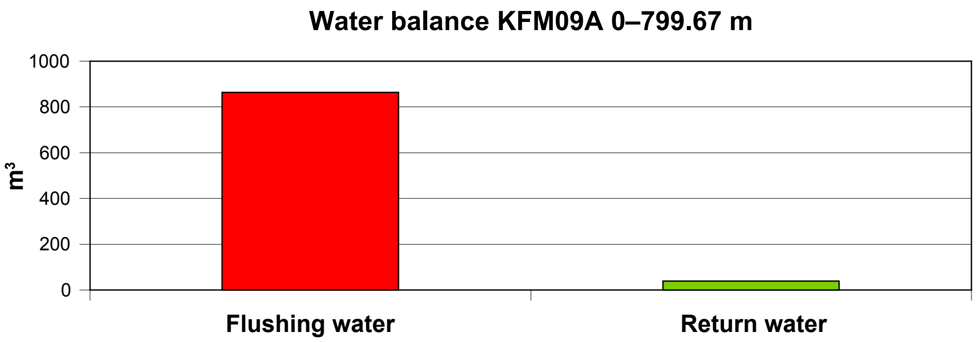


Figure 5-6. Total amounts of flushing water and return water during drilling of borehole KFM09A. The total volume of flushing water used during core drilling amounted to 864 m³. During the same period, the total volume of return water was only 39 m³. The return water/flushing water balance is then 0.05, i.e. far below 1.0 due to major flushing water loss in the highly fractured sections.

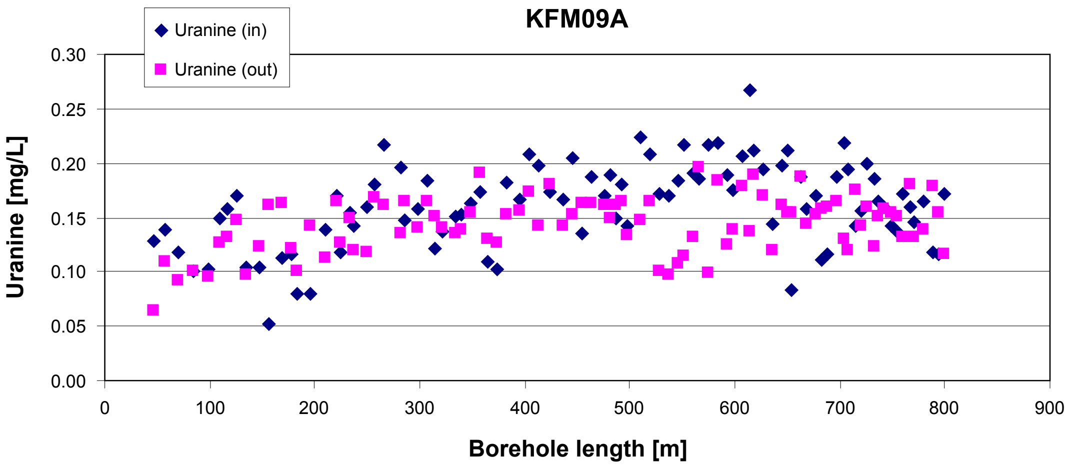


Figure 5-7. Uranine content in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFM09A. An automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.

The quality control program of deviation measurements is mostly concentrated to the handling of the instrument as well as routines applied for the performance. It is not possible to execute an absolute control measurement, as no long borehole is available with access both to the borehole collar and the borehole end, so that the position of the borehole end may be determined with an independent method. To ensure high quality measurements with the FLEXIT-tool, the disturbances of the magnetic field must be small. In Uppsala, a measuring station provides one-minute magnetic field values that are available on the Internet at www.intermagnet.org, which gives sufficient information. The magnetic field variation during November 8th, 2005, is seen in Figure 5-8 and shows only minor disturbances when the FLEXIT-surveys in KFM09A was performed between 13:00 to 17:20.

In the following a systematic description of the construction of the revised deviation data for borehole KFM09A is given.

The deviation data used are two FLEXIT-loggings between 12 m and 798 m borehole length, respectively, and one complete MAXIBOR™-logging between 0 m and 798 m, see Table 5-2. With the FLEXIT Smart Tool System, deviation measurements in borehole KFM09A were carried out every 3 m downwards and at every 30 m upwards. These two surveys, with activity numbers 13131803 and 13131779, provided almost repeatable results, (the absolute deviation is only 1.3 m and were therefore chosen for the construction of the deviation file to be "in use displayed" in SICADA, see explanation in Section 3.4). This file is designated as EG154. The "absolute deviation" is here defined as the shortest distance in space between a point in the borehole at a certain borehole length and the imaginary position of that point, if the borehole had followed a straight line with the same inclination and bearing as of the borehole collaring.

Table 5-2 provides the SICADA Activity log for the deviation logging activities in borehole KFM09A and Table 5-3 shows the content of the EG154-file. The upper sections start at 12 m so that bearing should not be influenced by the 7.79 m steel casing.

A subset of the resulting deviation file together with the estimated uncertainty radius is presented in Table 5-4.

The calculated deviation (EG154-file) for borehole KFM09A shows that the borehole deviates upwards and to the right with an absolute deviation of 178 m compared to an imagined straight line following the dip and strike of the borehole collaring (Figures 5-9 and 5-10).

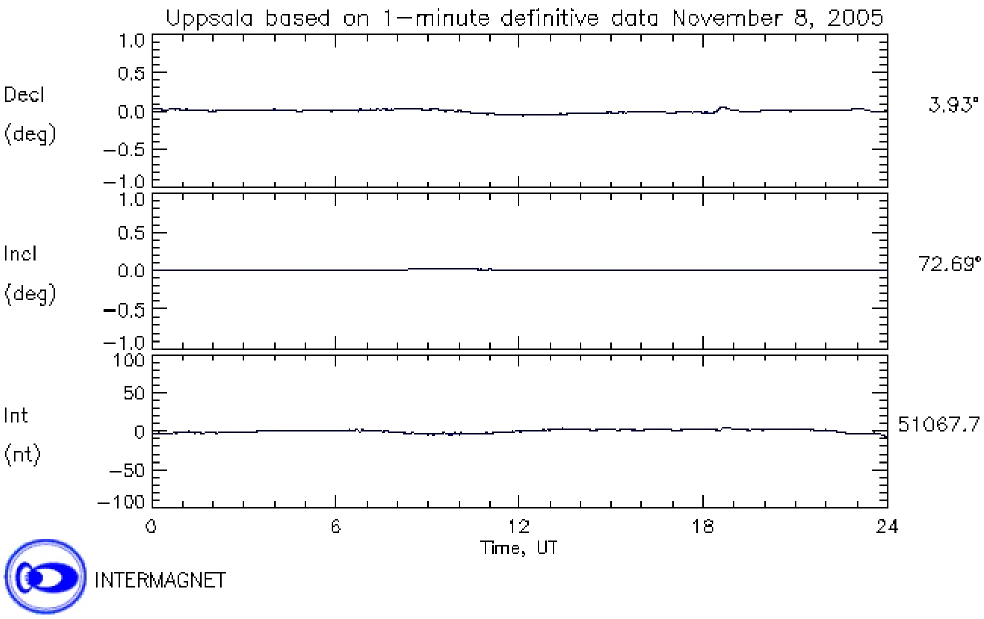


Figure 5-8. *Magnetic field variation during the FLEXIT-surveys performed November 8th, 2005, between 13:00 to 17:20.*

Table 5-2. Activity data for the three deviation measurements and the EG154-file showing the activities and the sections used for the multiple deviation calculation approved for KFM09A (from SICADA). The two magnetic measurements were used for the final calculations of the borehole deviation, whereas also the MAXIBOR-survey was included for calculation of the uncertainty.

Activity ID	Activity type code	Activity	Start date	Id code	Secup (m)	Seclow (m)	Flags
13092480	EG156	MAXIBOR-measurement	2005-10-31 15:00	KFM09A	0.00	798.00	
13131803	EG157	Magnetic – accelerometer measurement	2005-11-08 13:00	KFM09A	12.00	798.00	CF
13131779	EG157	Magnetic – accelerometer measurement	2005-11-08 16:30	KFM09A	12.00	798.00	CF
13141379	EG154	Borehole deviation multiple measurements	2006-12-05 14:00	KFM09A			IC

C = Comments, F = Files, I = In use.

Table 5-3. Content of the EG154-file (multiple borehole deviation intervals).

Deviation activity ID	Deviation angle type	Approved secup (m)	Approved seclow (m)
13131779	Bearing	12.00	798.00
13131779	Inclination	12.00	798.00
13131803	Bearing	12.00	798.00
13131803	Inclination	12.00	798.00

Table 5-4. Deviation data from KFM09A from approx. every 100 m vertical depth calculated from EG154. Inclination-, bearing- and uncertainty radius are included.

Borehole	Length (m)	Northing (m)	Easting (m)	Elevation (m)	Inclination (degrees)	Bearing (degrees)	Inclination uncertainty	Bearing uncertainty	Radius uncertainty
KFM09A	0	6700115.04	1630647.50	4.29	–59.46	200.08	0.20	1.77	0.00
KFM09A	123	6700055.45	1630622.70	–100.40	–57.46	204.75	0.20	1.77	1.99
KFM09A	243	6699996.28	1630593.44	–200.60	–55.81	208.56	0.20	1.77	4.03
KFM09A	366	6699935.36	1630556.38	–300.78	–53.30	214.07	0.20	1.77	6.23
KFM09A	492	6699875.25	1630508.19	–400.43	–50.99	222.63	0.20	1.77	8.61
KFM09A	624	6699814.70	1630446.10	–499.85	–47.00	229.83	0.20	1.77	11.29
KFM09A	768	6699753.00	1630363.62	–600.32	–41.87	237.56	0.20	1.77	14.47
KFM09A	799.67	6699740.47	1630343.37	–621.21	–40.79	238.70	0.20	1.77	15.20

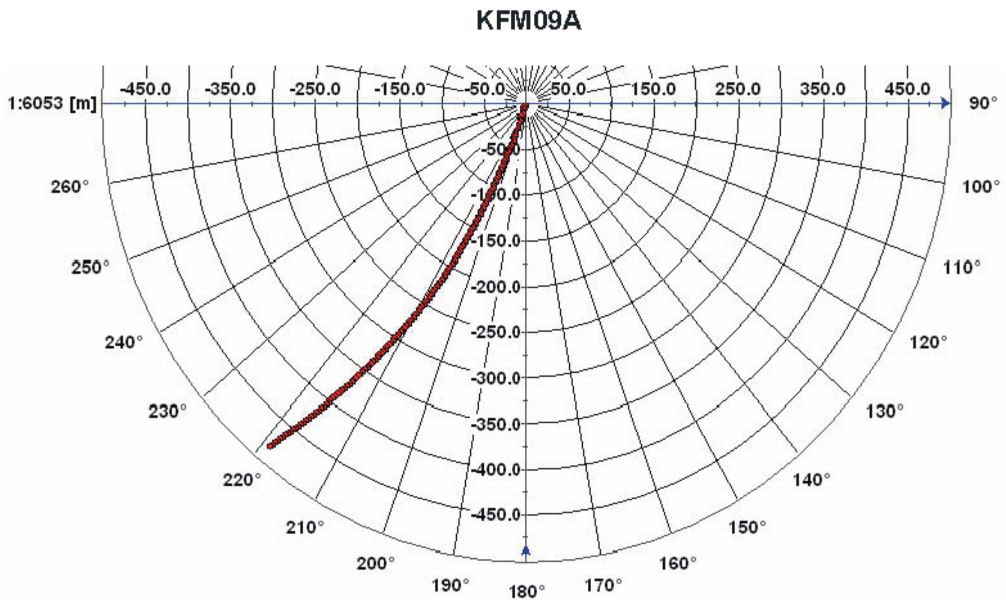


Figure 5-9. *Horizontal projection of measured deviation of KFM09A.*

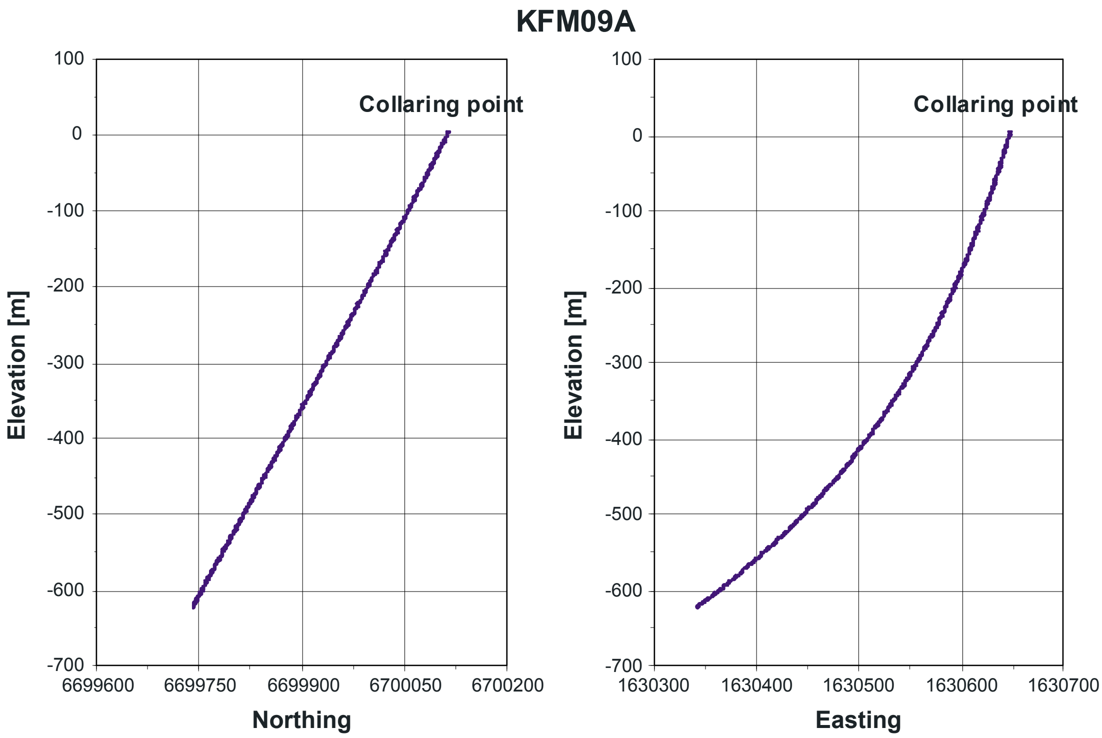


Figure 5-10. *Two vertical projections of measured deviation in KFM09A.*

5.5.4 Hydraulic tests during drilling (tests with the wireline probe)

Results from the pressure measurements performed in borehole KFM09A are presented in Table 5-5. Two absolute pressure measurement but no pumping tests were conducted in the borehole.

After packer inflation the pressure stabilization phase by using the wireline probe often displays different types of transient effects, both of increasing and decreasing pressure. These transients may be due to different reasons, e.g. previous disturbances in the borehole caused by the drilling operations.

During the first test in KFM09A (section 111.00–251.89 m) pressure transients of an oscillating nature were observed. This is believed to be caused by an intermittent pumping activity in a nearby percussion borehole. The second test in this borehole showed a strongly decreasing trend during the entire test period, falling by 900 kPa during c 92 h. The reason for this strong pressure decrease is not clear. No representative pressure value could be determined for either of the tests. Pressure trends are however displayed in Appendix B.

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

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

By measuring the length difference between these two conditions, it was hoped that the length error could be determined for different lengths of the pipe string and for different inclinations of the borehole. The practical difficulties and uncertainties in the results however turned out to be considerable. Therefore it is recommended that the length error is determined from the diagram in Figure 5-11, which is based on load tests performed in the laboratory by the manufacturer of the drill pipes.

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

Table 5-5. Absolute pressure measurement in KFM09A.

Test section (m)	Last pressure reading during test (kPa)	Test duration (h)	Borehole length to pressure sensor (m fr. Ref)	Elevation of pressure sensor (m.a.s.l.)
111.00–251.89	–	c 92	111.98	–91.1
250.20–400.81	–	c 92	251.18	–207.4

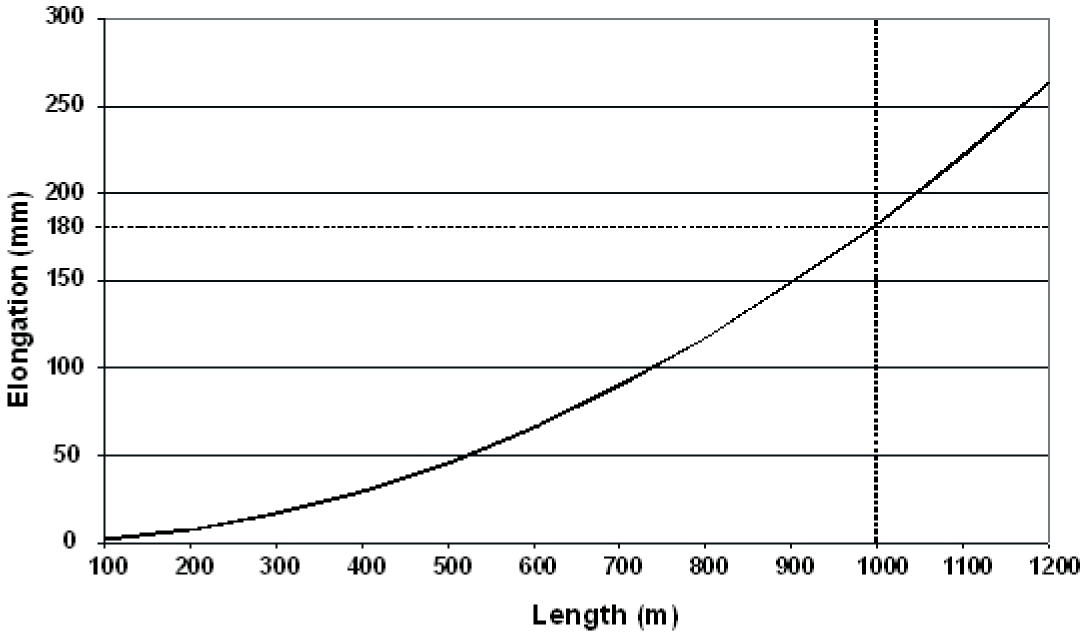


Figure 5-11. *The diagram illustrates the elongation of the WL-76 drill pipe string when hanging in a vertical water filled borehole. Values from laboratory load tests of the drill pipes.*

5.5.6 Groove milling

A compilation of the length from top of casing to the reference grooves and a comment on the success of detecting the grooves are given in Table 5-6. The positions of the grooves are determined from the length of the drill pipes used at the milling process. The length is measured from the upper part of the upper two grooves.

Table 5-6. Compilation of length to the reference grooves.

Reference groove at (m) KFM09A	Detection with the SKB level indicator	Confirmed from BIPS
50	Yes	Yes
99	Yes	Yes
150	Yes	Yes
200	Yes	Yes
250	Yes	Yes
300	Yes	Yes
350	Yes	Yes
400	Yes	Yes
450	Yes	Yes
500	Yes	Yes
550	Yes	Yes
600	Yes	Yes
650	Yes	Yes
725	Yes	Yes

5.6 Geometrical and technical design of borehole KFM09B

Administrative, geometric and technical data for borehole KFM09B are presented in Table 5-7. The technical design of the borehole is illustrated in Figure 5-12.

5.7 Drilling KFM09B

5.7.1 Drilling progress KFM09B

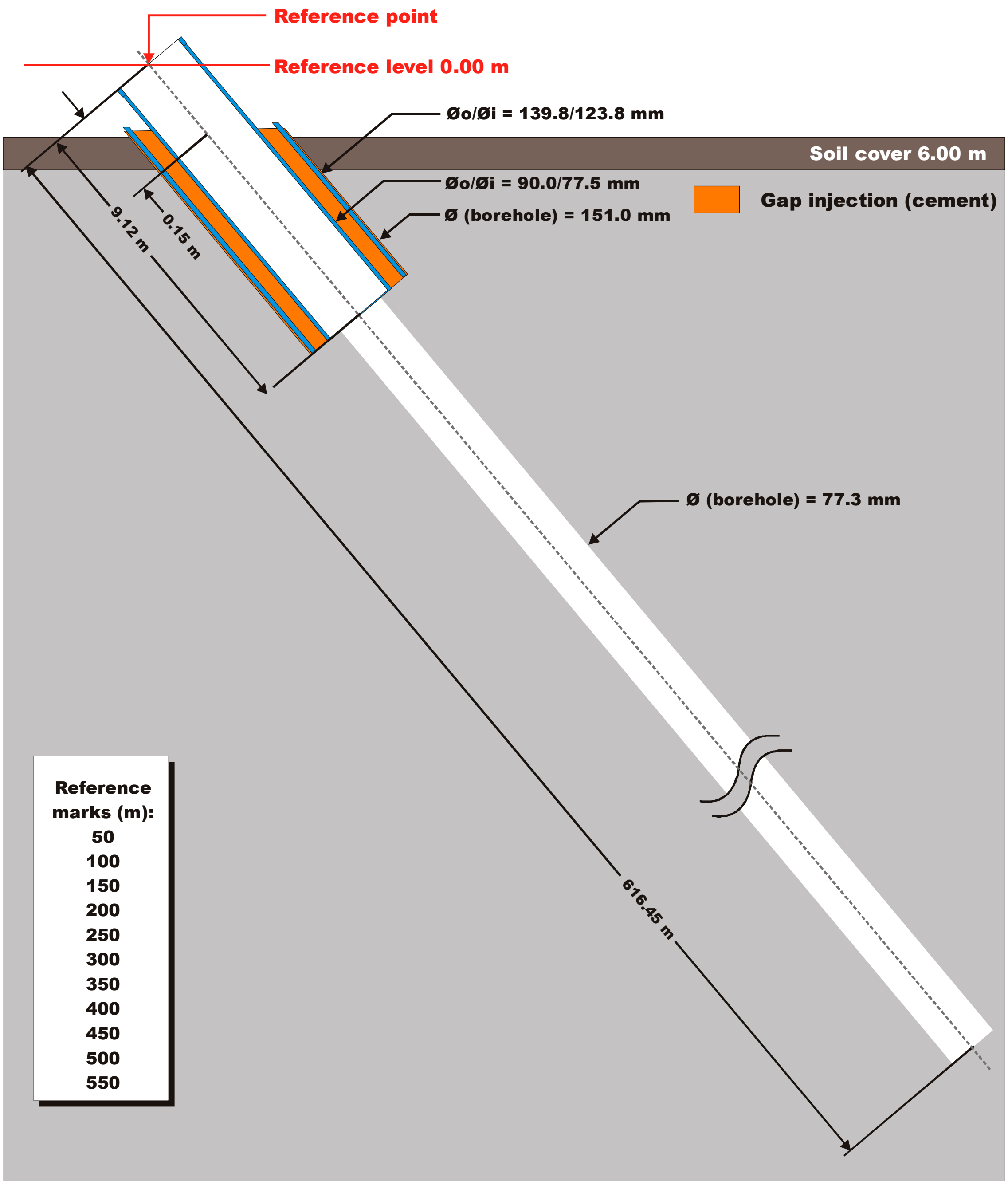
Drilling with the percussion drilling machine was performed to 9.09 m borehole length on Oct 27th, 2005 (Figure 5-13). A casing with diameter 139.8/123.8 mm and a casing shoe was mounted to 9.09 m. (Later on a new reference level was established so the length became 9.12 m). Since the HQ core drilling with the Onram 2000 a few metres into the rock surface failed, grouting of the 90/77 mm casing was made directly against the bedrock. The vertical soil depth at KFM09B was 6.00 m.

Table 5-7. Administrative, geometric and technical data for borehole KFM09B.

Parameter	
Borehole name	KFM09B
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	Oct 27, 2005
Completion date	Dec 19, 2005
Drilling periods	Oct 27, 2005 (0–9.12 m) Nov 10 to Dec 19, 2005 (9.12–616.45 m)
Contractor core drilling	Drillcon Core AB
Core drill rig	ONRAM 2000 CCD
Position at top of casing (RT90 2.5 gon V 0:–15/RHB 70)	N 6700119.89 E 1630638.78 Z 4.30 (m.a.s.l.)
	Azimuth (0–360°): 140.83° Dip (0–90°): –55.08
Position at bottom of hole (RT90 2.5 gon V 0:–15/RHB 70)	N 6699813.15 E 1630877.44 Z –472.00 (m.a.s.l.)
	Azimuth (0–360°): 150.96° Dip (0–90°): –42.85°
Borehole length	616.45 m
Borehole diameter and length	Ø 151 mm between 0.00–9.12 m Ø 77.3 mm between 9.12–616.45 m
Casing diameter and length	$Ø_o/Ø_i$ = 139.8 mm/123.8 mm between 0.00– 9.12 m $Ø_o/Ø_i$ = 90.0 mm/77.3 mm between 0.00–9.12 m
Drill core dimension and length	Ø 51 mm between 9.12–616.45 m
Core interval	9.12–616.45 m

Technical data

Borehole KFM09B



Drilling reference point

Northing:	6700119.89 (m), RT90 2,5 gon V 0:-15
Easting:	1630638.78 (m), RT90 2,5 gon V 0:-15
Elevation:	4.30 (m), RHB 70

Orientation

Bearing (degrees):	140.83°
Inclination (degrees):	-55.08°

Borehole

Length:	616.45 m

Percussion drilling period

Drilling start date: 2005-10-27
Drilling stop date: 2005-10-27

Core drilling period

Drilling start date: 2005-11-10
Drilling stop date: 2005-12-19

Rev. 2007-02-21

Figure 5-12. Technical data of borehole KFM09B.

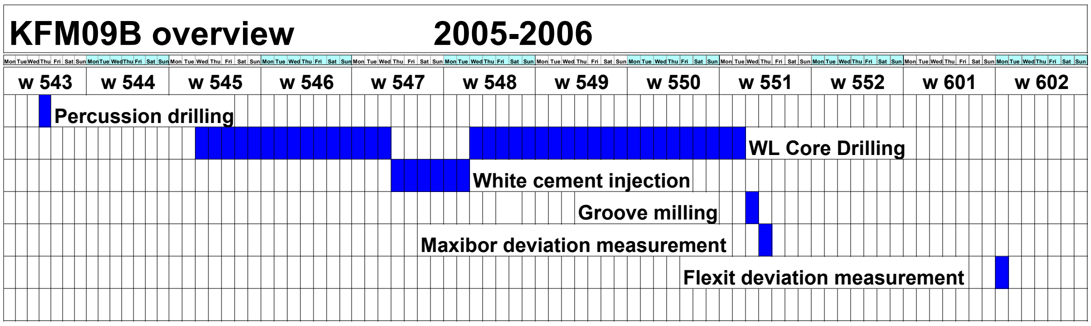


Figure 5-13. *Core drilling progress KFM09B (length versus calendar time).*

5.7.2 Core drilling KFM09B

Usually, the shallow bedrock within the tectonic lens at Forsmark is highly fractured and water yielding. Therefore the majority of the telescopic boreholes that have been drilled are cased and the gap between the casing and the borehole wall cement grouted (to between c 60–100 m borehole length). Consequently, detailed hydraulic characterization after drilling of this part of the bedrock is in these cases impossible. As mentioned previously, the boreholes at DS9 were designed as traditional cored boreholes, meaning that they are cased only through the overburden and a short section into solid rock, and that drill cores are retrieved also from the shallow bedrock. Despite that, KFM09A had to be cement grouted in the upper section, 0–107.91 m, see Section 5.3.2, whereby the possibility to afterwards perform hydraulic tests in that part was brought to nothing. To ensure achievement of hydraulic data from the upper part of the bedrock in KFM09B, hydraulic test equipment was prepared and made immediately accessible when core drilling in KFM09B started.

The core drilling progress during the period from November 10th to December 19th, 2005, is presented in Figure 5-14. During the first week of core drilling a borehole length of 106.41 m was reached. As expected, similar rock conditions in KFM09B were encountered as in KFM09A, entailing that recharge of groundwater/flushing water and drilling debris into the borehole prevented continued drilling progress.

During the weekly break, water injection tests in 5 m sections were performed in the highly fractured rock between 10.50–57.75 m, see Figure 5-15.

To avoid disturbances with remaining drilling debris in the borehole, a packer was expanded at 55 m and the borehole section 0–55 m was cement grouted. After setting of the cement, the water/drilling debris recharge ceased, and core drilling could proceed to the final length of 616.45 m.

5.8 Core sampling

A preliminary on-site core logging was performed continuously in connection with the drilling.

5.9 Measurements while drilling

5.9.1 Flushing water and return water flow rate – water balance

Figure 5-16 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 5-17, from which the return water/flushing water quotient for the end of the drilling period may be calculated, in this case resulting in the very low quotient 0.06 for KFM09B.

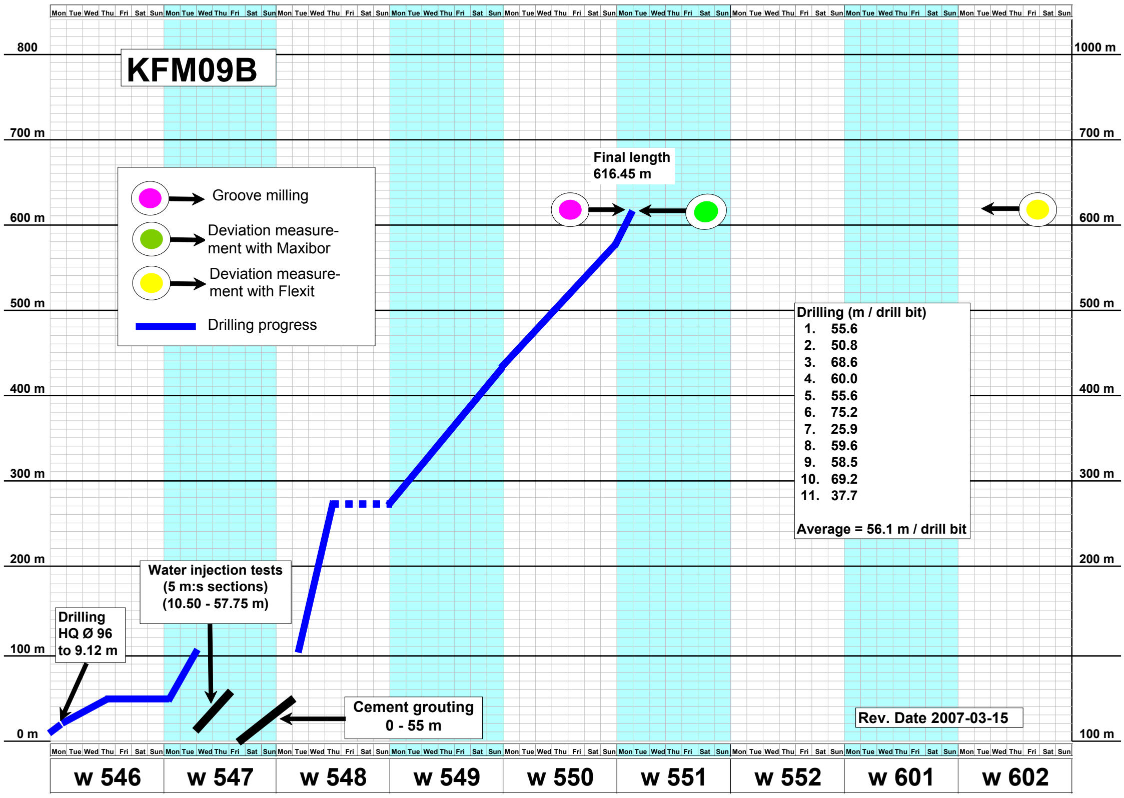


Figure 5-14. *Core drilling progress KFM09B (length versus calendar time).*

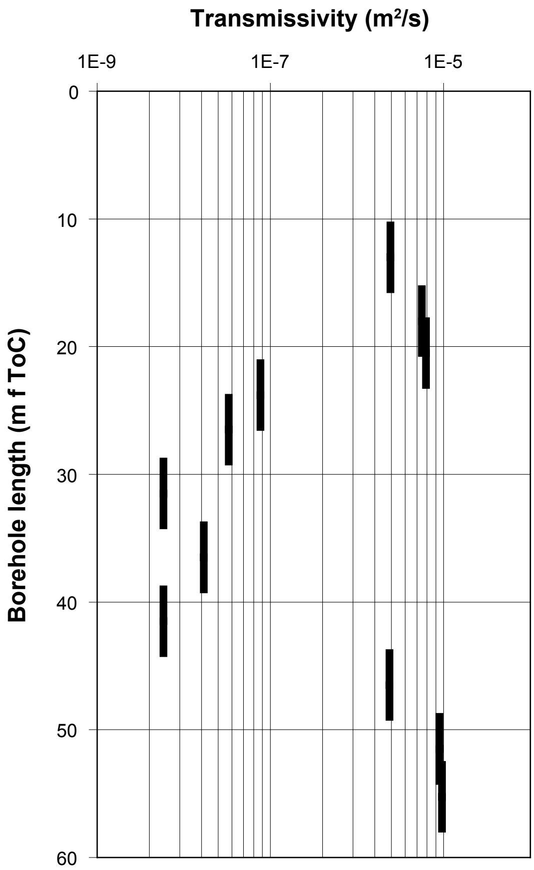


Figure 5-15. *Transmissivity from hydraulic injection tests performed in 5 m sections with PSS3 in KFM09B.*

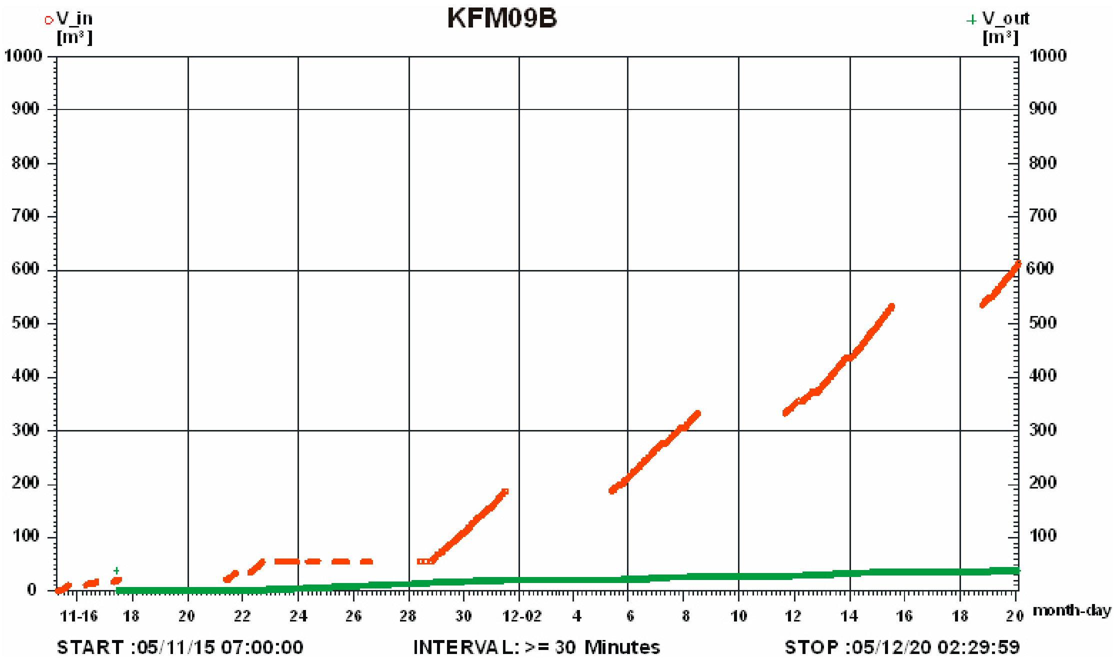


Figure 5-16. *Accumulated volumes of flushing water (red) and return water (green) versus time during drilling of borehole KFM09B.*

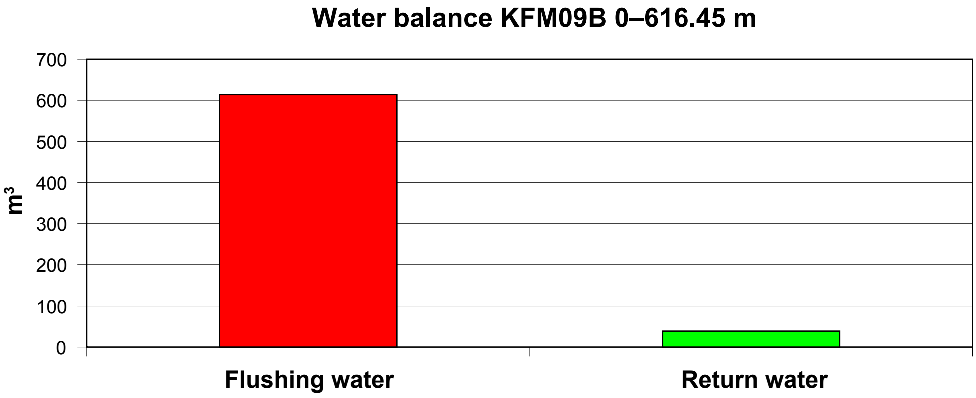


Figure 5-17. *Total amounts of flushing water and return water during drilling of borehole KFM09B. The total volume of flushing water used during core drilling amounted to 614 m³. During the same period, the total volume of return water was only 39 m³. The return water/flushing water balance is then 0.06, i.e. far below 1.0 due to major flushing water loss in the highly fractured sections.*

5.9.2 Uranine content of flushing water

An organic tracer, Uranine, was automatically added to the flush water tank, see Section 3.2.1. During the drilling period, sampling of flushing water and analyses of the tracer content was performed systematically with a frequency of approximately one sample per 20–30 m drilling length, see Figure 5-18.

5.9.3 Deviation measurements in KFM09B

The strategy changes for deviation measurements and data handling are described in Sections 3.4 and 5.5.3. The magnetic field variation measured at Uppsala during January 26th, 2006 (from www.intermagnet.org), is presented in Figure 5-19 and shows only minor disturbances when the FLEXIT-surveys in KFM09B was performed between 12:40 to 15:30.

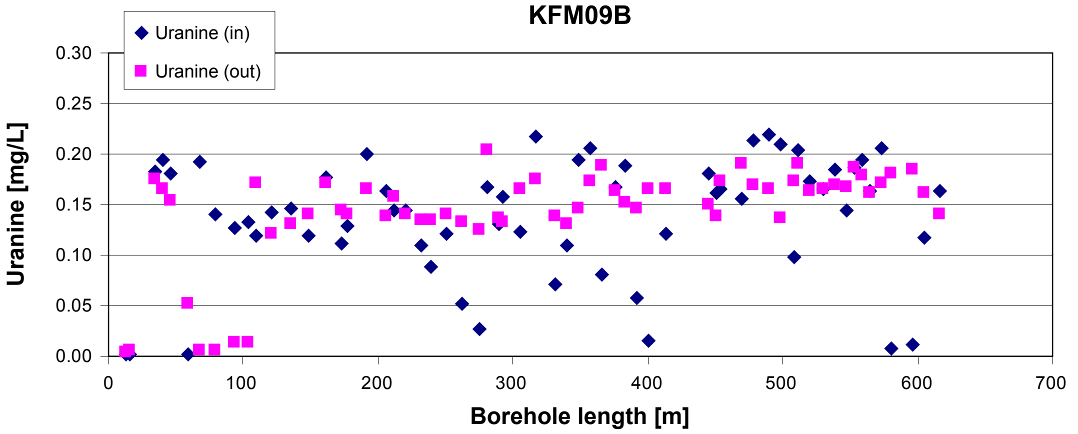


Figure 5-18. *Uranine content in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFM09B. An automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine.*

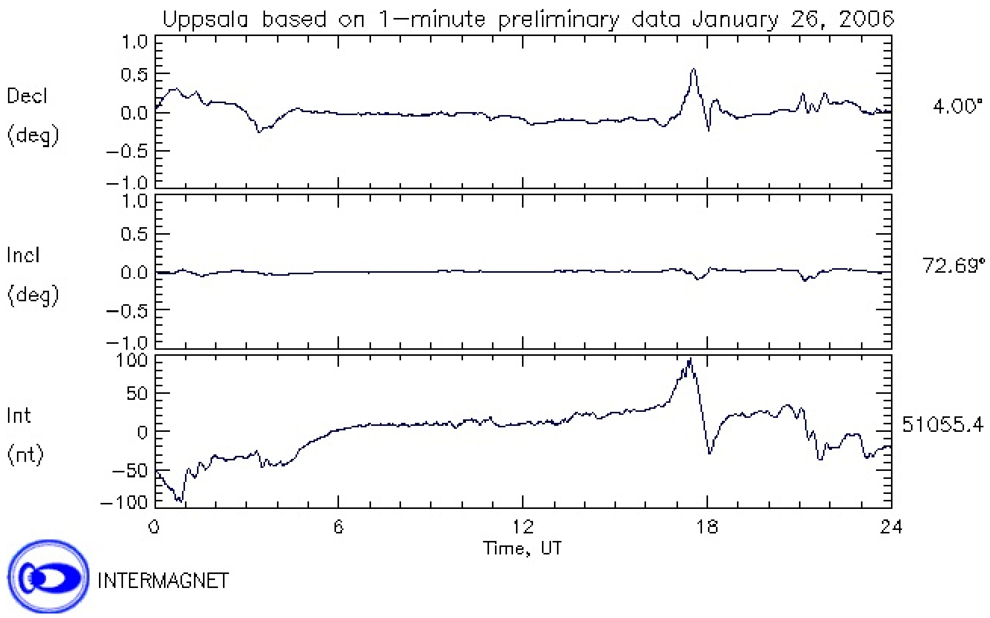


Figure 5-19. *Magnetic field variation during the FLEXIT-surveys performed on January 26th, 2006, between 12:40–15:30.*

The deviation data used are two FLEXIT-loggings between 12 m and 615 m borehole length, respectively, and two complete MAXIBOR™-loggings between 3 m and 612 m, see Table 5-8. With the FLEXIT Smart Tool System, deviation measurements in borehole KFM09B were carried out every 3 m downwards and at every 30 m upwards. These two surveys, with activity numbers 13131958 and 13131959, provided almost repeatable results, (the absolute deviation is only 1.96 m) and were therefore chosen for the construction of the EG154-deviation file.

The EG154-activity, which specifies sections of the deviation measurements used in the resulting calculations, is presented in Table 5-9. The upper sections start at 12 m so that bearing should not be influenced by the 9.12 m steel casing.

Table 5-8. Activity data for the four deviation measurements and the EG154-file that showing the activities and the sections used for the multiple deviation calculation approved for KFM09B (from SICADA). The two magnetic measurements were used for the final calculations of the borehole deviation, whereas also the MAXIBOR-surveys were included for calculation of the uncertainty.

Activity ID	Activity type code	Activity	Start date	Id code	Secup m)	Seclow (m)	Flags
13101644	EG156	MAXIBOR-measurement	2005-12-21 01:00	KFM09B	3.00	612.00	
13101645	EG156	MAXIBOR-measurement	2005-12-21 03:30	KFM09B	3.00	612.00	
13131958	EG157	Magnetic – accelerometer measurement	2006-01-26 12:40	KFM09B	12.00	615.00	CF
13131959	EG157	Magnetic – accelerometer measurement	2006-01-26 14:50	KFM09B	12.00	615.00	CF
13140512	EG154	Borehole deviation multiple measurements	2006-12-13 08:00	KFM09B			IC

C = Comments, F = Files, I = In use.

Table 5-9. Content of the EG154-file (multiple borehole deviation intervals).

Deviation activity ID	Deviation angle type	Approved secup (m)	Approved seclow (m)
13131958	Bearing	12.00	612.00
13131958	Inclination	12.00	612.00
13131959	Bearing	12.00	612.00
13131959	Inclination	12.00	612.00

A subset of the resulting deviation file together with the estimated uncertainty radius is presented in Table 5-10. The calculated deviation (EG154-file) for borehole KFM09B shows that the borehole deviates upwards and to the right with an absolute deviation of 47 m compared to an imagined straight line following the dip and strike of the borehole collaring (Figures 5-20 and 5-21).

Table 5-10. Deviation data from KFM09B from approx. every 100 m vertical depth calculated from EG154. Inclination-, bearing- and uncertainty radius are included.

Borehole	Length (m)	Northing (m)	Easting (m)	Elevation (m)	Inclination (degrees)	Bearing (degrees)	Inclination Uncertainty	Bearing Uncertainty	Radius Uncertainty
KFM09B	0	6700119.89	1630638.78	4.30	–55.08	140.83	1.31	0.82	0.00
KFM09B	129	6700062.93	1630686.34	–101.22	–54.17	139.67	1.31	0.82	2.95
KFM09B	252	6700006.83	1630733.94	–199.77	–52.28	138.68	1.31	0.82	5.76
KFM09B	381	6699946.09	1630786.50	–300.71	–50.21	140.35	1.31	0.82	8.71
KFM09B	516	6699874.03	1630839.83	–401.56	–46.41	146.87	1.31	0.82	11.80
KFM09B	616.45	6699813.15	1630877.44	–472.00	–42.85	150.96	1.31	0.82	14.09

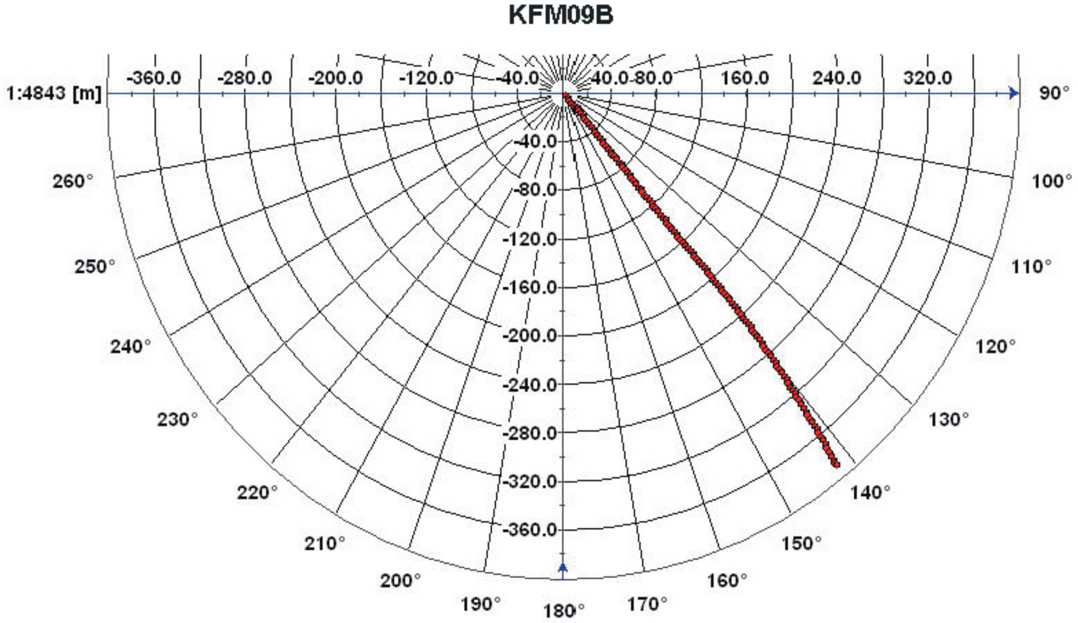


Figure 5-20. *Horizontal projection of measured deviation of KFM09B.*

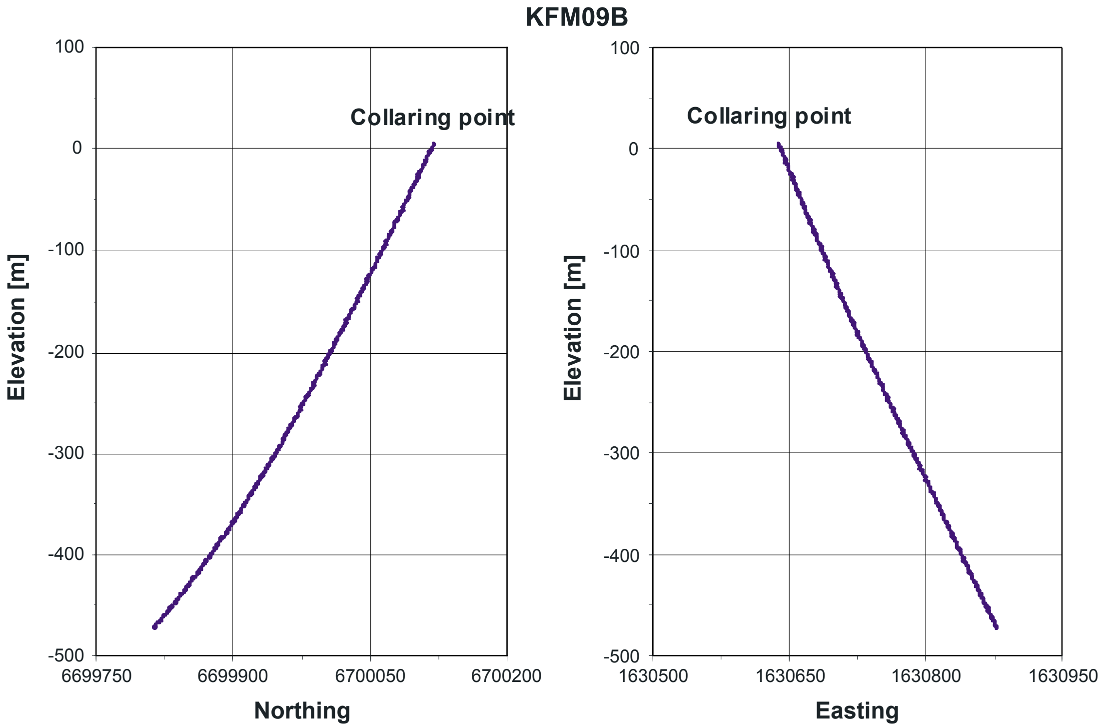


Figure 5-21. *Two vertical projections of measured deviation in KFM09B.*

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

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

By measuring the length difference between these two conditions, it was hoped that the length error could be determined for different lengths of the pipe string and for different inclinations of the borehole. The practical difficulties and uncertainties in the results however turned out to be considerable. Therefore it is recommended that the length error is determined from the diagram in Figure 5-22, which is based on load tests performed in the laboratory by the manufacturer of the drill pipes.

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

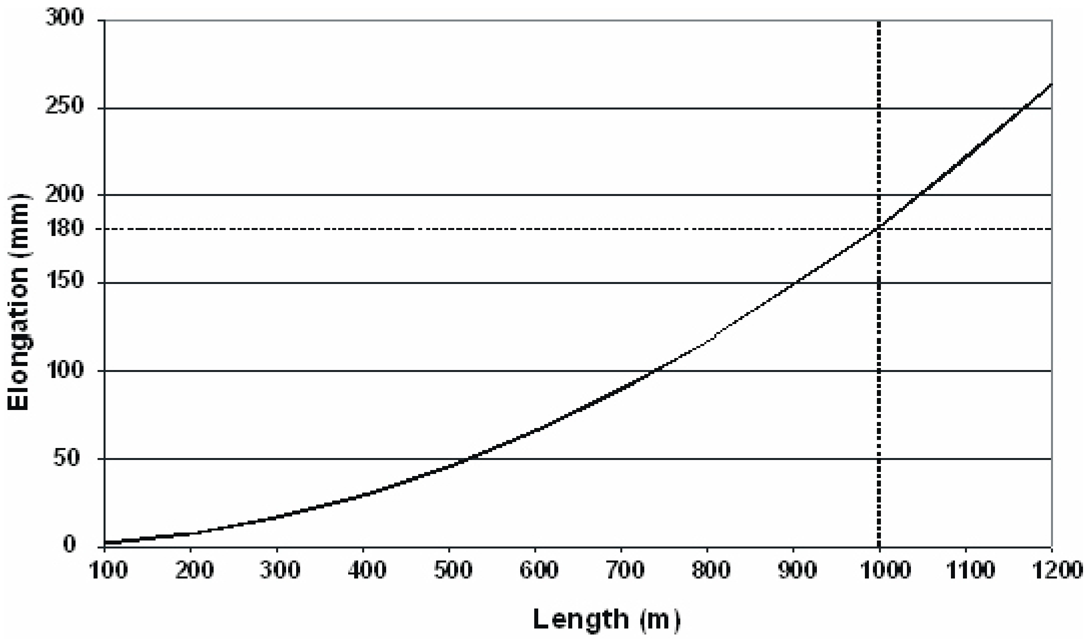


Figure 5-22. *The diagram illustrates the elongation of the WL-76 drill pipe string when hanging in a vertical water filled borehole. Values from laboratory load tests of the drill pipes.*

5.9.5 Groove milling

A compilation of the length from top of casing to the reference grooves and a comment on the success of detecting the grooves are given in Table 5-11. The positions of the grooves are determined from the length of the drill pipes used at the milling process. The length is measured from the upper part of the upper two grooves.

5.10 Consumables

The special type of thread grease (silicon based) used in these particular boreholes was certified according to SKB MD 600.006, Version 1.0, Instruction for the use of chemical products and material during drilling and surveys, see Table 1-1. Oil and grease consumptions are given in Table 5-12 below.

The amounts of grout for sealing the casing and tighten all boreholes at DS9 are reported in Table 5-13 below.

5.11 KFM09C

Drilling in soil and moraine can be time consuming with a core drilling rig, and to shorten the drilling time, a percussion machine performed the overburden drilling for KFM09B and installed a casing. And since the plan, at the time being, was to drill a third borehole on DS9, the percussion machine prepared also the third borehole, KFM09C, by drilling the overburden and setting a casing to 9.09 m.

Drilling of this borehole was made Oct 27th, 2005. The position at top of casing (RT90 2.5 gon V 0:–15/RHB 70) is N 6700124.48, E 1630637.87 and Z 4.28 metres above sea level, the azimuth (0–360°) is 9.71° and the dip (0–90°) 54.39°. An 139.8/123.8 mm casing with a casing shoe 130/108 mm and a ring bit of 151/99 mm was mounted to 9.09 m. The borehole diameter is 151 mm and the bedrock was hit at 6.55 m, which gives a vertical soil cover of 5.23 m.

Table 5-11. Compilation of length to the reference grooves. The positions of the grooves are determined from the length of the drill pipes used at the milling process. The length is measured from the upper part of the upper two grooves.

Reference groove at (m) KFM09B	Detection with the SKB level indicator	Confirmed from BIPS
50	Yes	Yes
100	Yes	Yes
150	Yes	Yes
200	Yes	Yes
250	Yes	Yes
300	Yes	Yes
350	Yes	Yes
400	Yes	Yes
450	Yes	Yes
500	Yes	Yes
550	Yes	Yes

Table 5-12. Grease, oil and diesel consumption.

Borehole ID	Thread grease Üni Silikon L50/2	Grease for the drilling machine Castrol AB	Engine oil Castrol Tection 15W-40	Hydraulic oil Premium ECO HT-E 46	Diesel engines OKQ8 Diesel miljöklass 1
KFM09A	2.4 kg	2.0 kg	16 L	4 L	8,359 L
KFM09B	1.8 kg	1.6 kg	12 L	2.4 L	4,900 L

Table 5-13. Cement consumption.

Borehole ID	Casing or borehole length at grouting (m)	Cement volume (vitcem/silica)	Grouting method	Remarks on date
KFM09A	0.00–42.62	1,100 kg/484 kg	Hose	2005-09-06
KFM09A	0.00–107.91	500/220 kg	Hose	2005-09-14
KFM09B	0.00–9.12	175 kg/77 kg	Hose	2005-11-10
KFM09B	0.00–55.00	350/132 kg	Hose	2005-11-26
KFM09C				No cement used

6 References

/1/ **Decision 1039868.** Beslut om placering av borrplats 9 samt kärnborrhålen KFM09A, KFM09B och KFM09C.

/2/ **Claesson L-Å, Nilsson G, 2004.** Forsmark site investigation. Drilling of monitoring wells HFM23 and HFM28 at drilling site DS9 as well as HFM24 and SFM0080 at drilling site DS10. SKB P-05-278, Svensk Kärnbränslehantering AB.

/3/ **Döse C, Samuelsson E, 2006.** Forsmark Site Investigation. Boremap mapping of percussion boreholes HFM23–HFM32. SKB P-06-206, Svensk Kärnbränslehantering AB.

/4/ **Petersson J, Skogsmo G, von Dalwigk I, Wängnerud A, Berglund J, 2006.** Forsmark Site Investigation. Boremap mapping of core drilled borehole KFM09A. SKB P-06-130, Svensk Kärnbränslehantering AB.

/5/ **Petersson J, Skogsmo G, von Dalwigk I, Wängnerud A, Berglund J, 2006.** Forsmark Site Investigation. Boremap mapping of core drilled borehole KFM09B. SKB P-06-131, Svensk Kärnbränslehantering AB.

Appendix A

Well Cad presentation of the core drilled borehole KFM09A

Title KFM09A

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Signed data**	
Borehole	KFM09A	**Coordinate System**	RT90-RHB70
Diameter [mm]	77	**Northing [m]**	6700115.04
Length [m]	799.670	**Easting [m]**	1630647.50
Bearing [°]	200.08	**Elevation [m.a.s.l.]**	4.29
Inclination [°]	-59.46	**Drilling Start Date**	2005-08-31 00:00:00
Date of mapping		**Drilling Stop Date**	2005-10-27 13:00:00
		Plot Date	2006-08-22 21:12:57

ROCKTYPE FORSMARK

- **Pegmatite, pegmatitic granite**
- **Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained**
- **Granite, metamorphic, aplitic**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Granodiorite, metamorphic**
- **Tonalite to granodiorite, metamorphic**
- **Diorite, quarts diorite and gabbro, metamorphic**
- **Amphibolite**

SOIL

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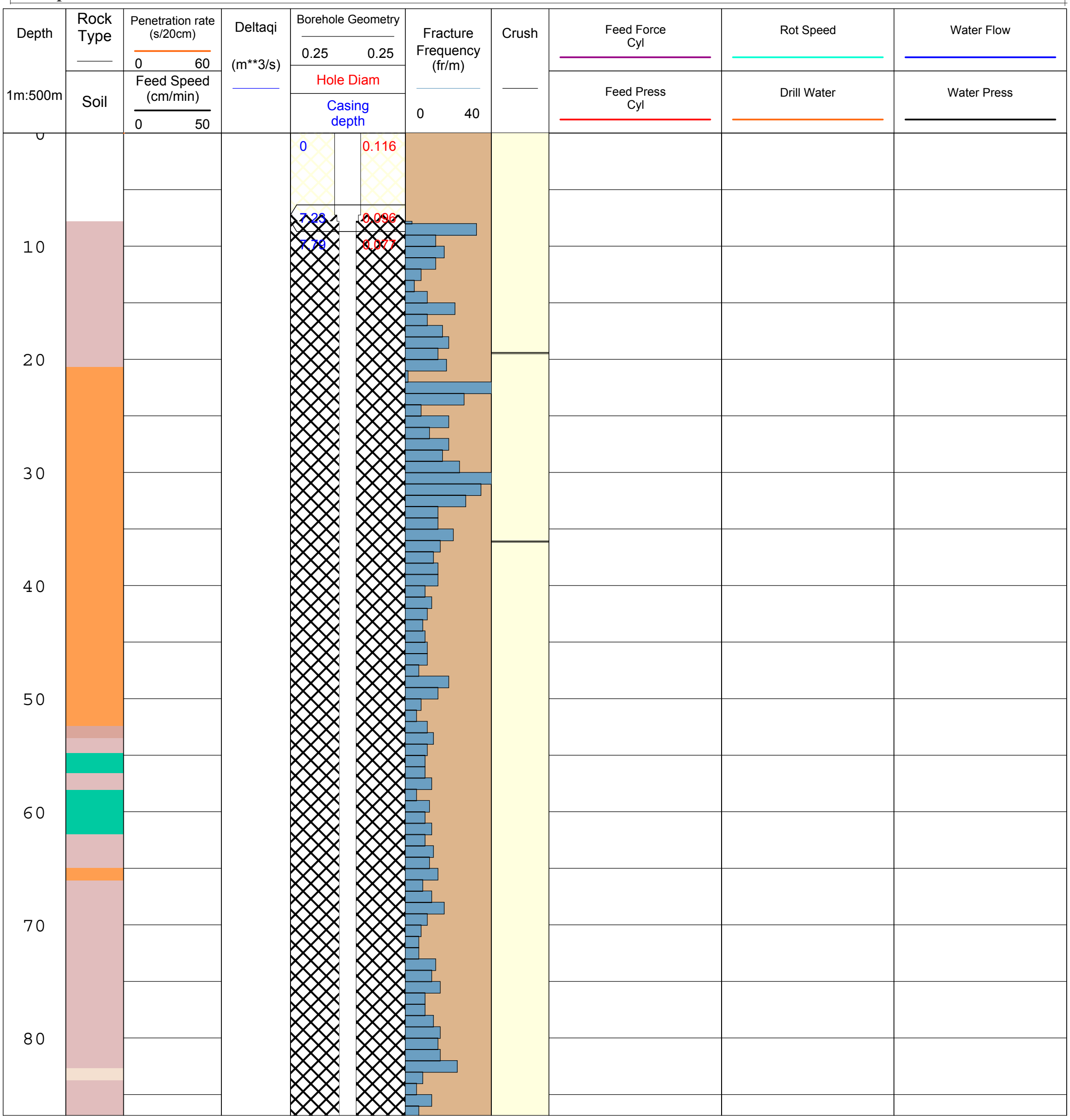

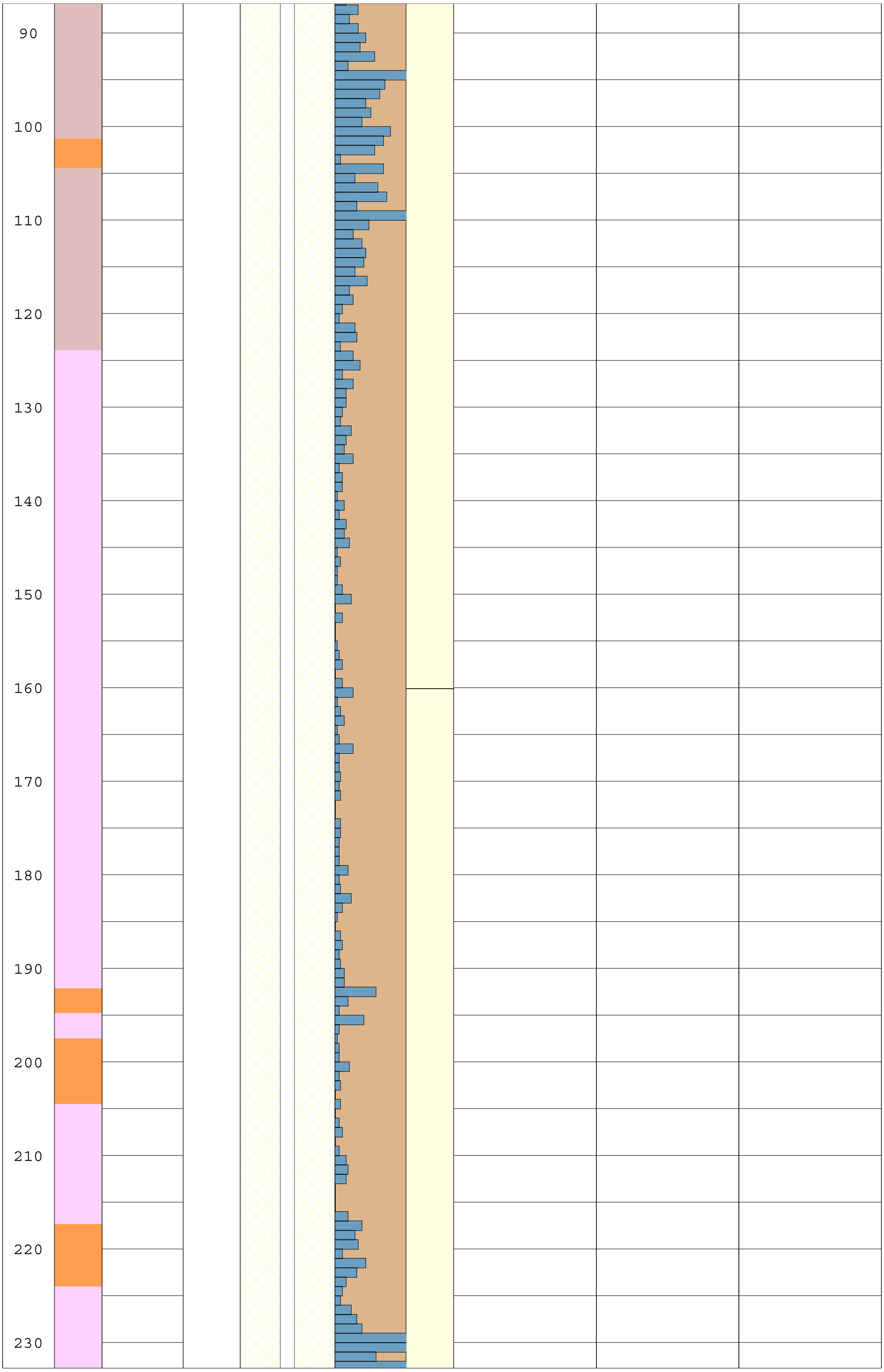
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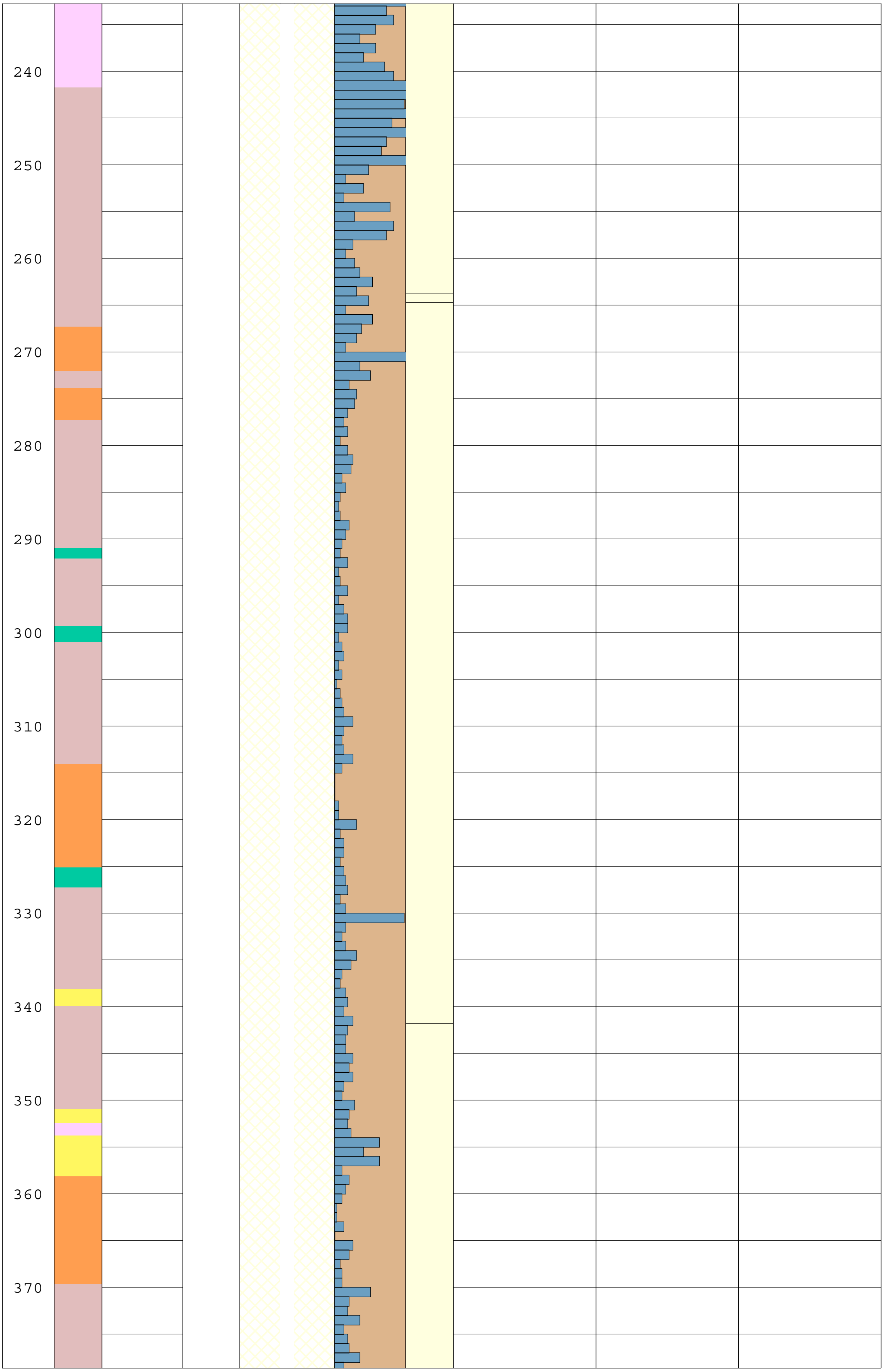
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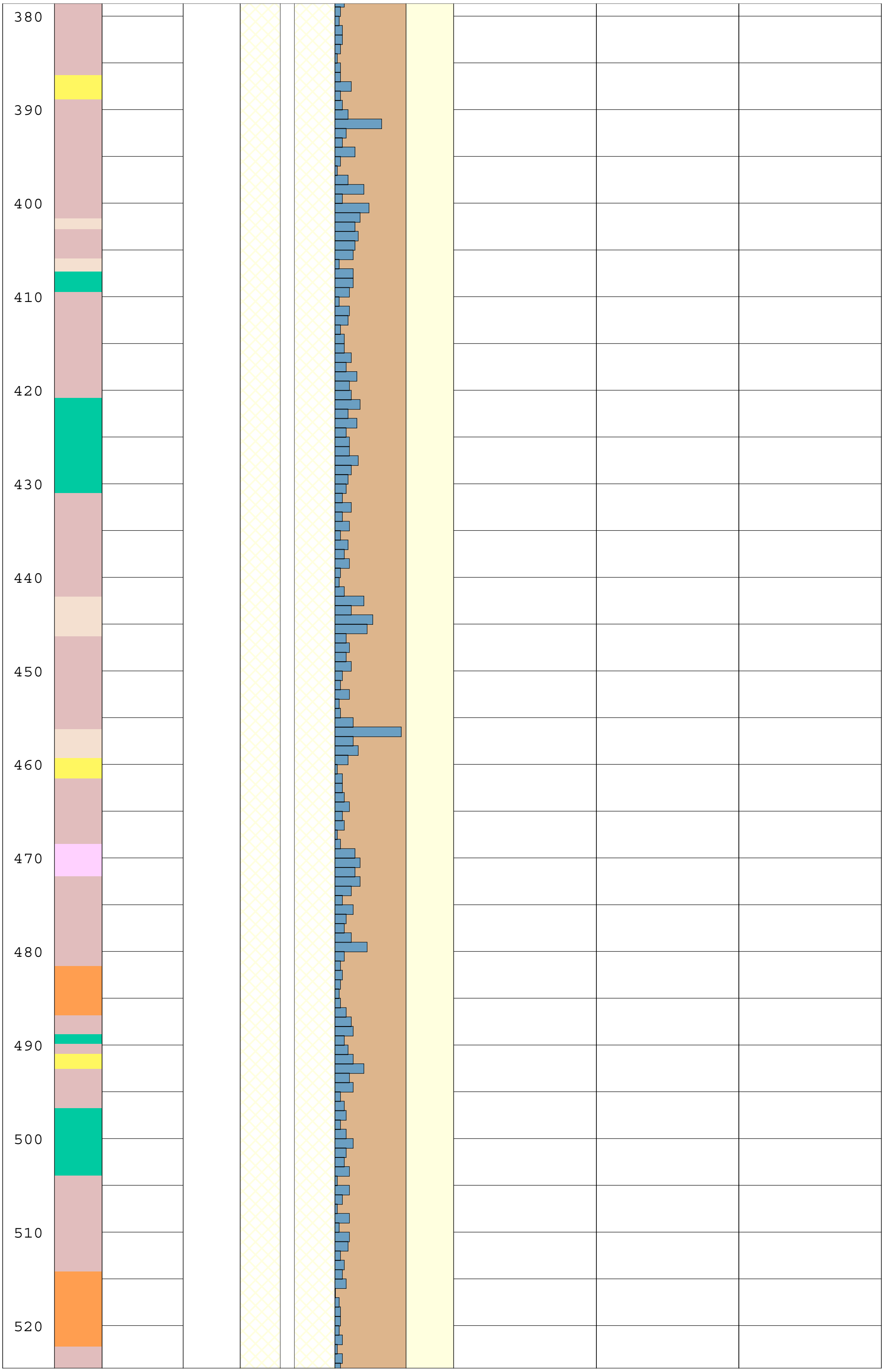
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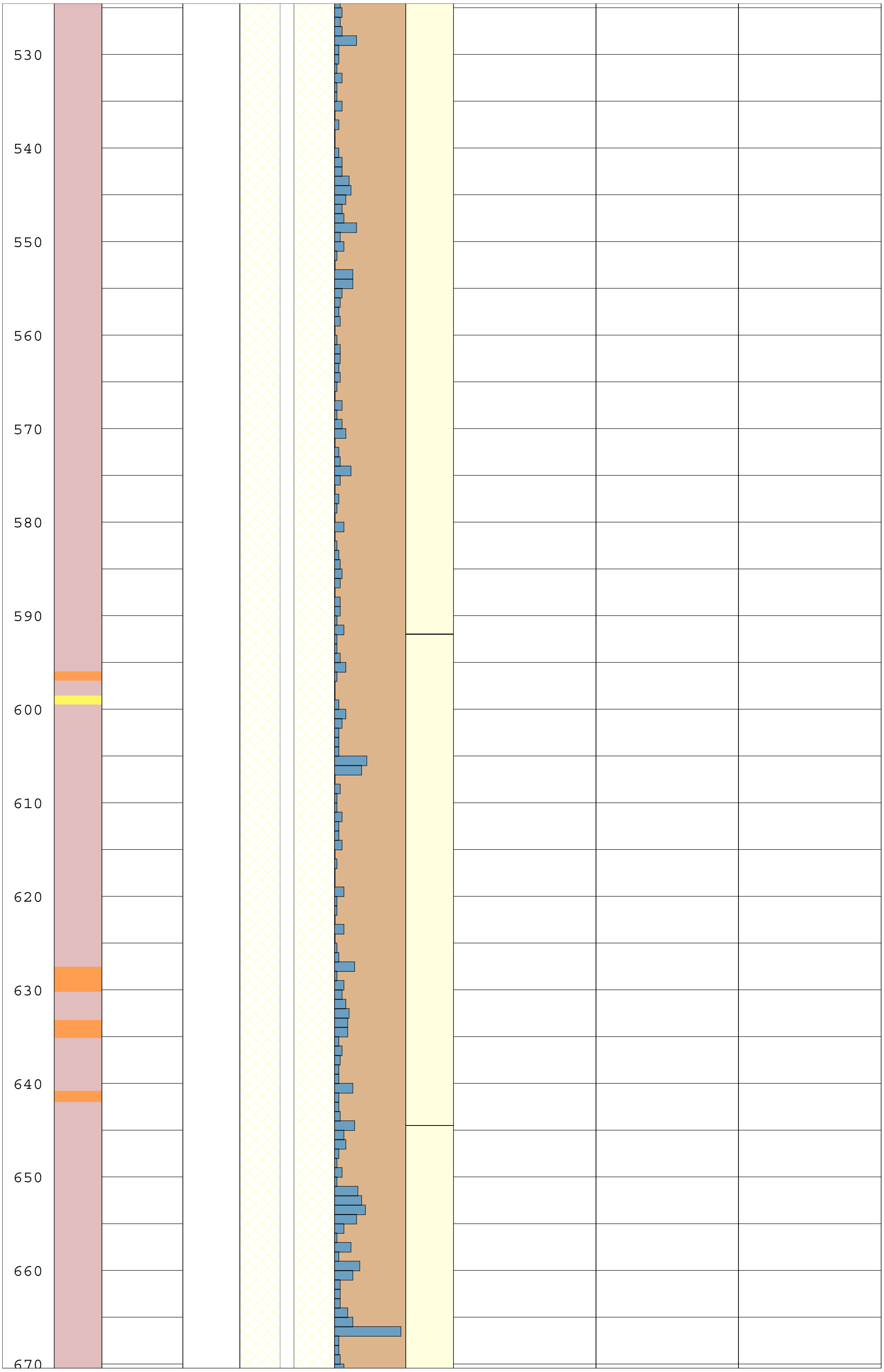
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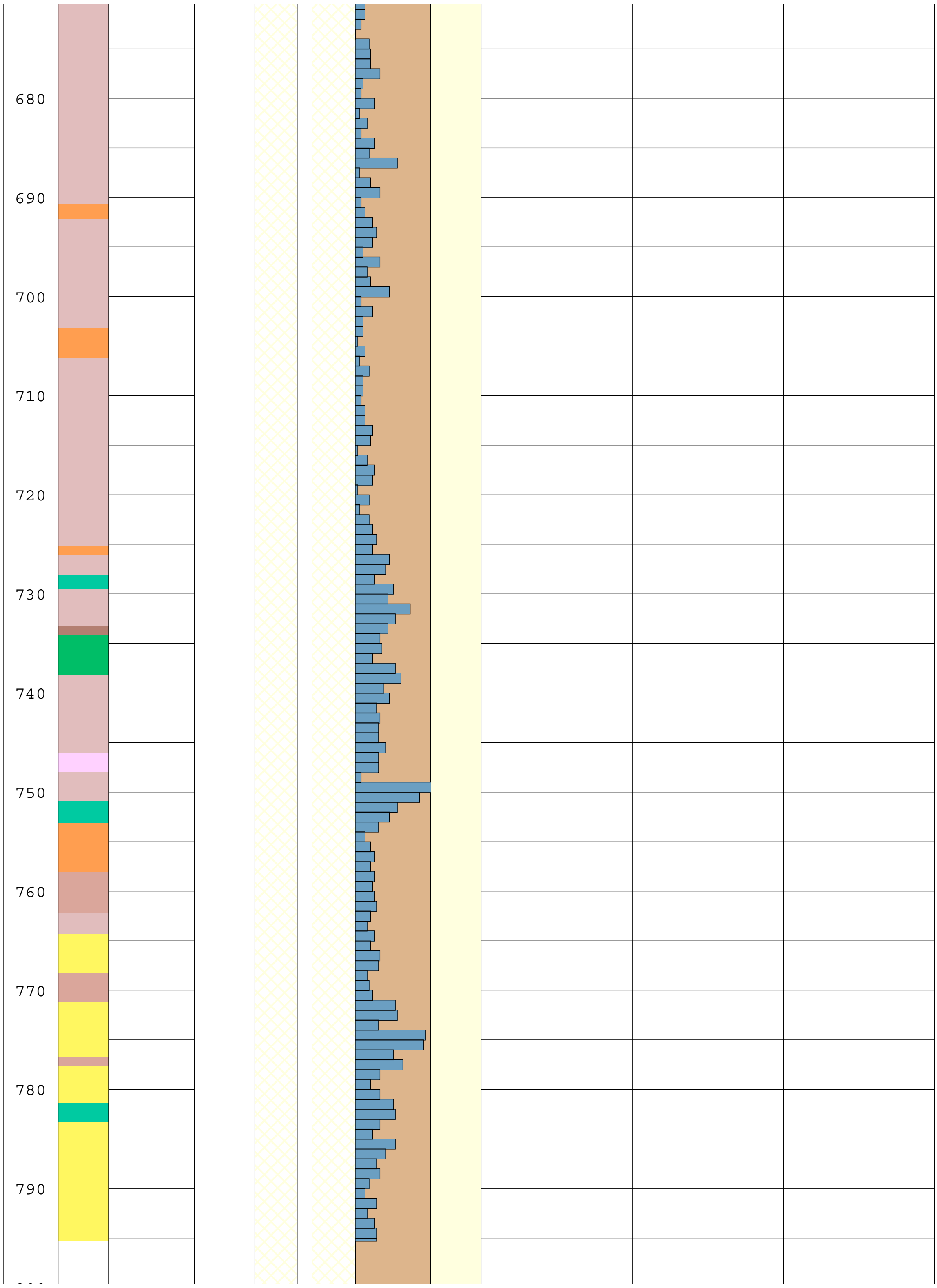
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Appendix B

Well Cad presentation of the core drilled borehole KFM09B

Title KFM09B

Svensk Kärnbränslehantering AB

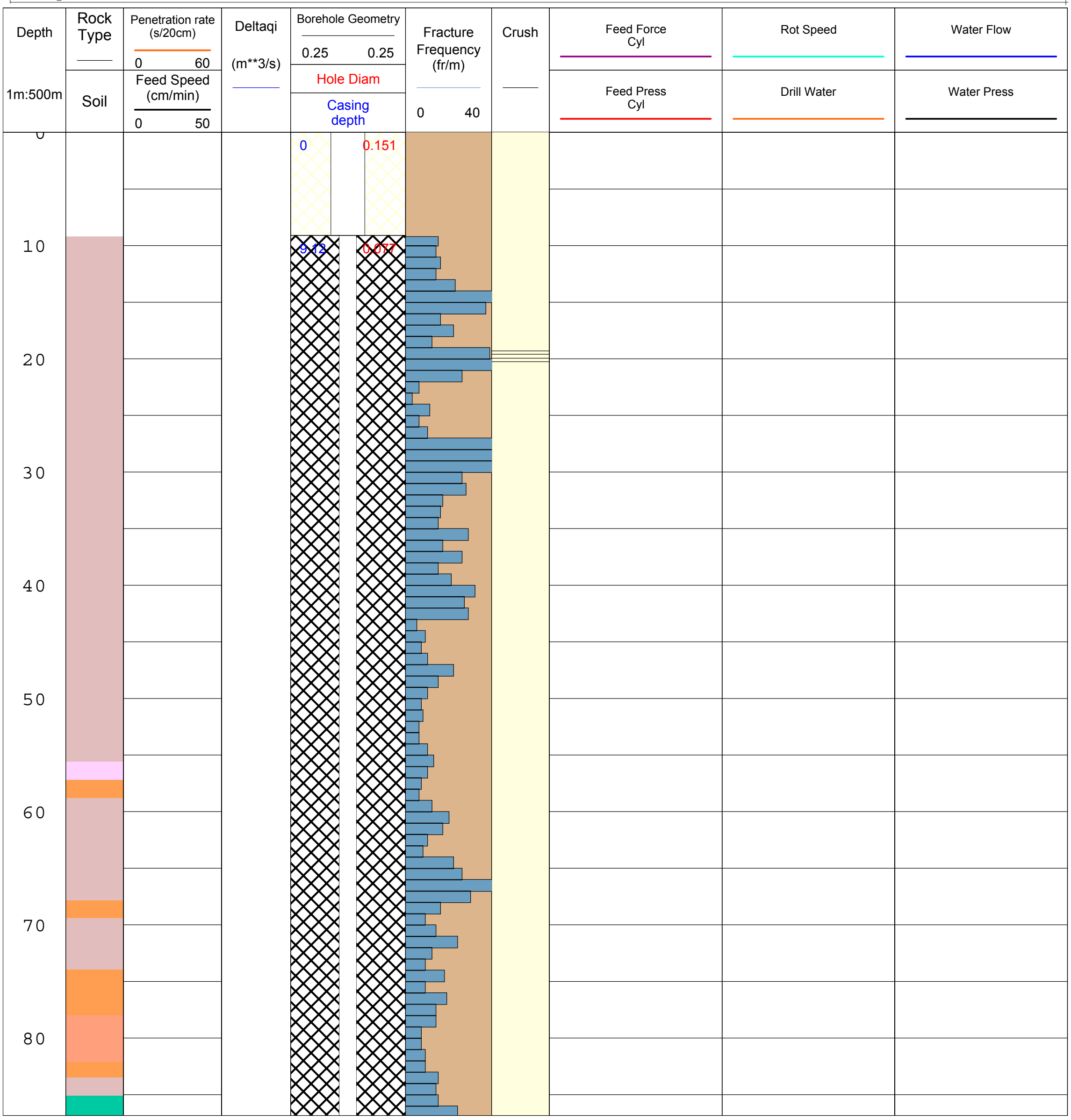
Site	FORSMARK	**Signed data**	
Borehole	KFM09B	**Coordinate System**	RT90-RHB70
Diameter [mm]	77	**Northing [m]**	6700119.89
Length [m]	616.450	**Easting [m]**	1630638.78
Bearing [°]	140.83	**Elevation [m.a.s.l.]**	4.30
Inclination [°]	-55.08	**Drilling Start Date**	2005-11-14 00:00:00
Date of mapping		**Drilling Stop Date**	2005-12-19 00:00:00
		Plot Date	2006-08-22 21:12:57

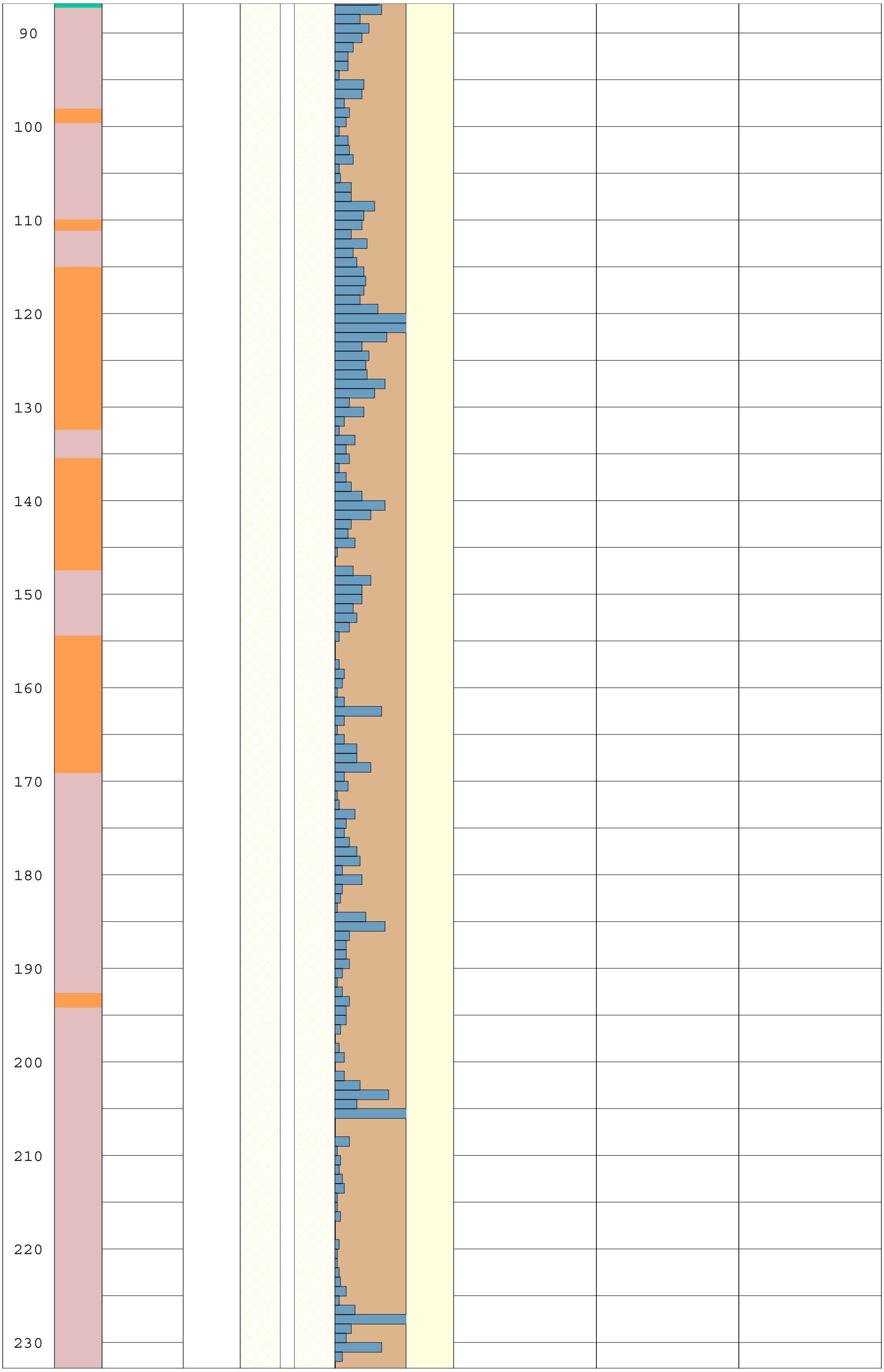
ROCKTYPE FORSMARK

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

SOIL

Script Name

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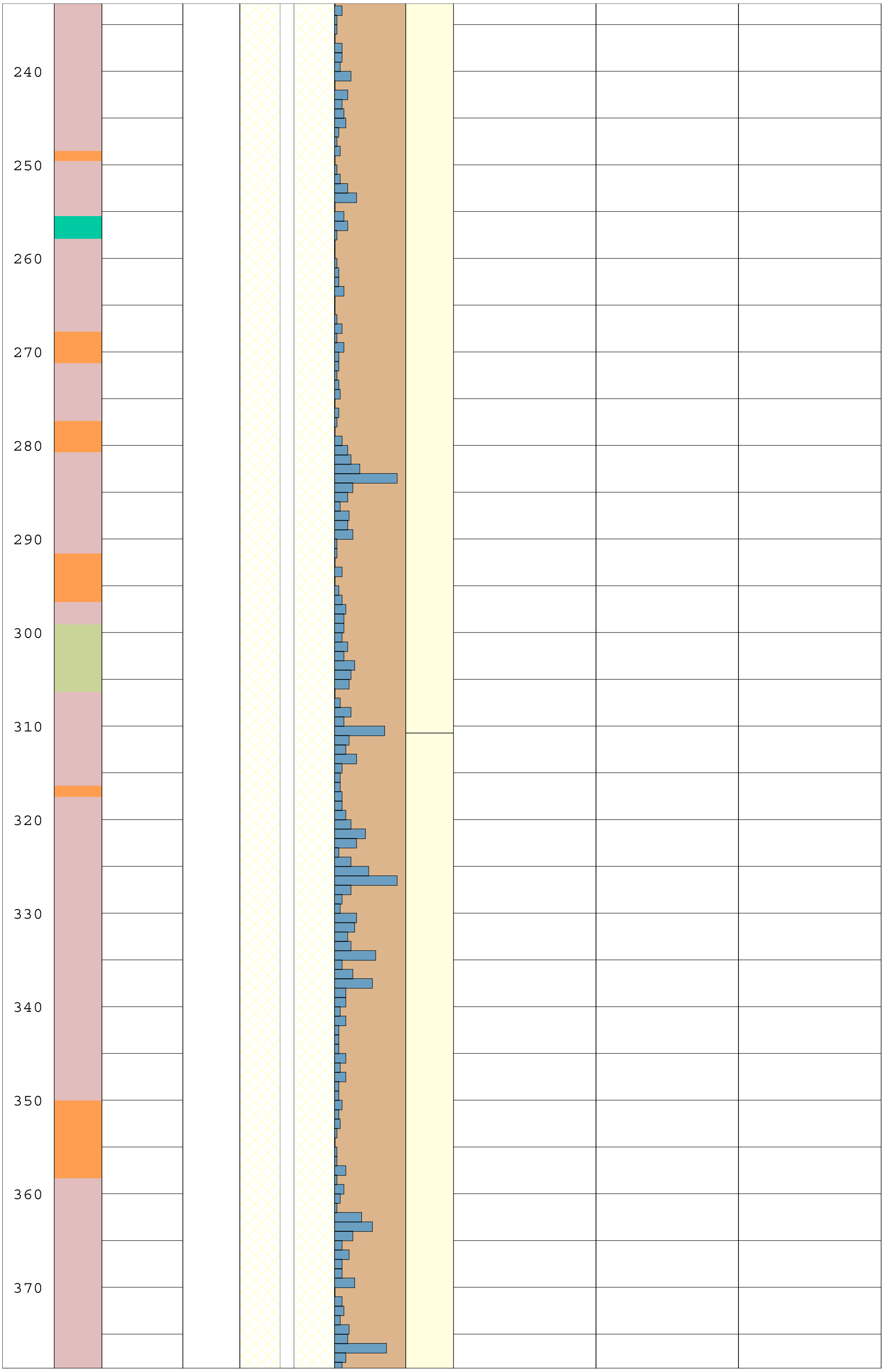
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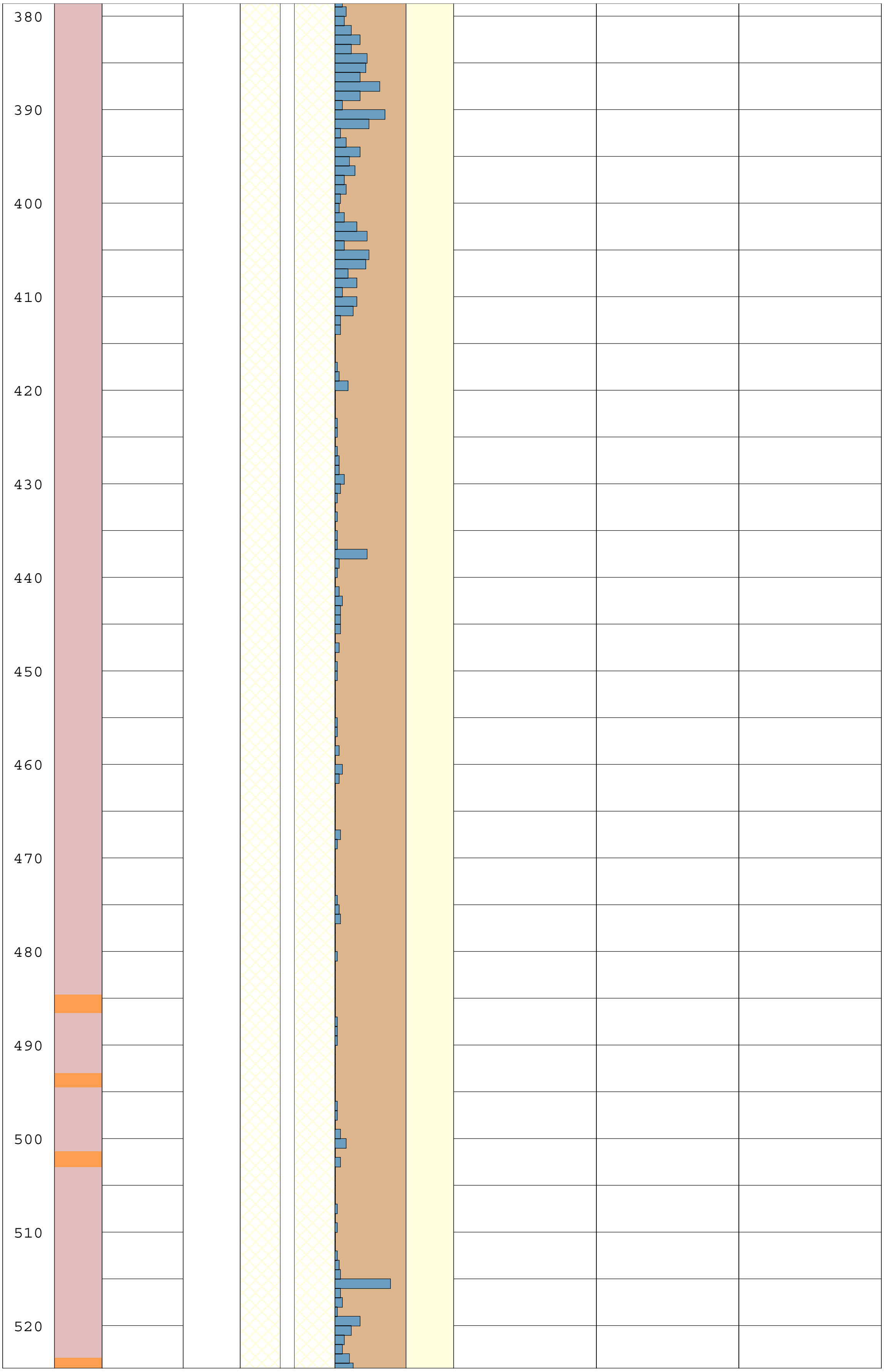
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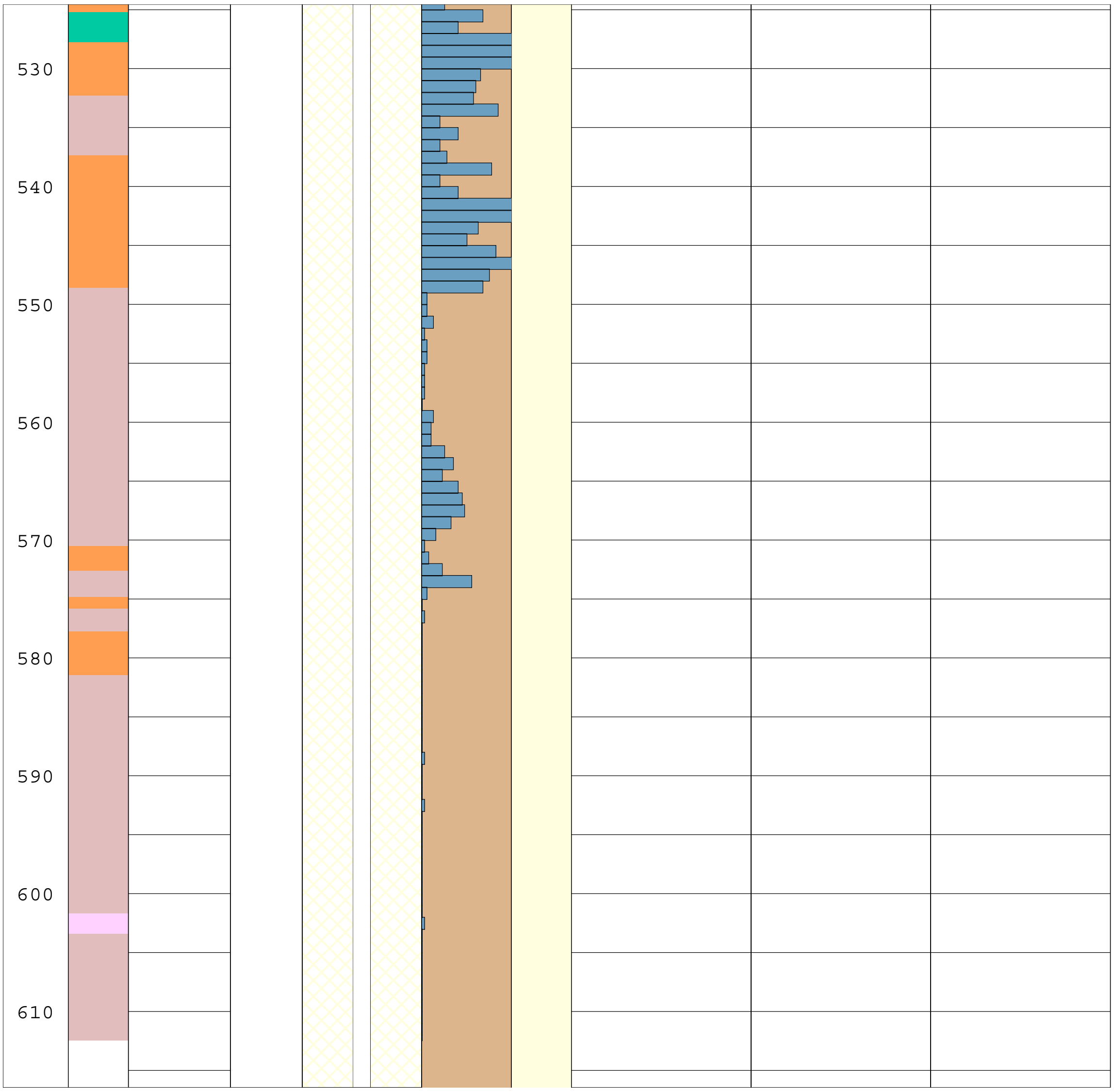
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Appendix C

Time series of absolute pressure measurements

Description of the parameters in the enclosed plots.

Channel	Parameter	Unit	Description
BA101	Pressure	kPa	Pressure of the water column in the telescopic section subtracted with the ambient air pressure.
MA61	Pressure-packer	kPa	Inflation pressure in packer.
MA62	Pressure-section	kPa	Pressure of the water column in the test section i.e. at depth in the borehole. Not corrected for ambient air pressure.

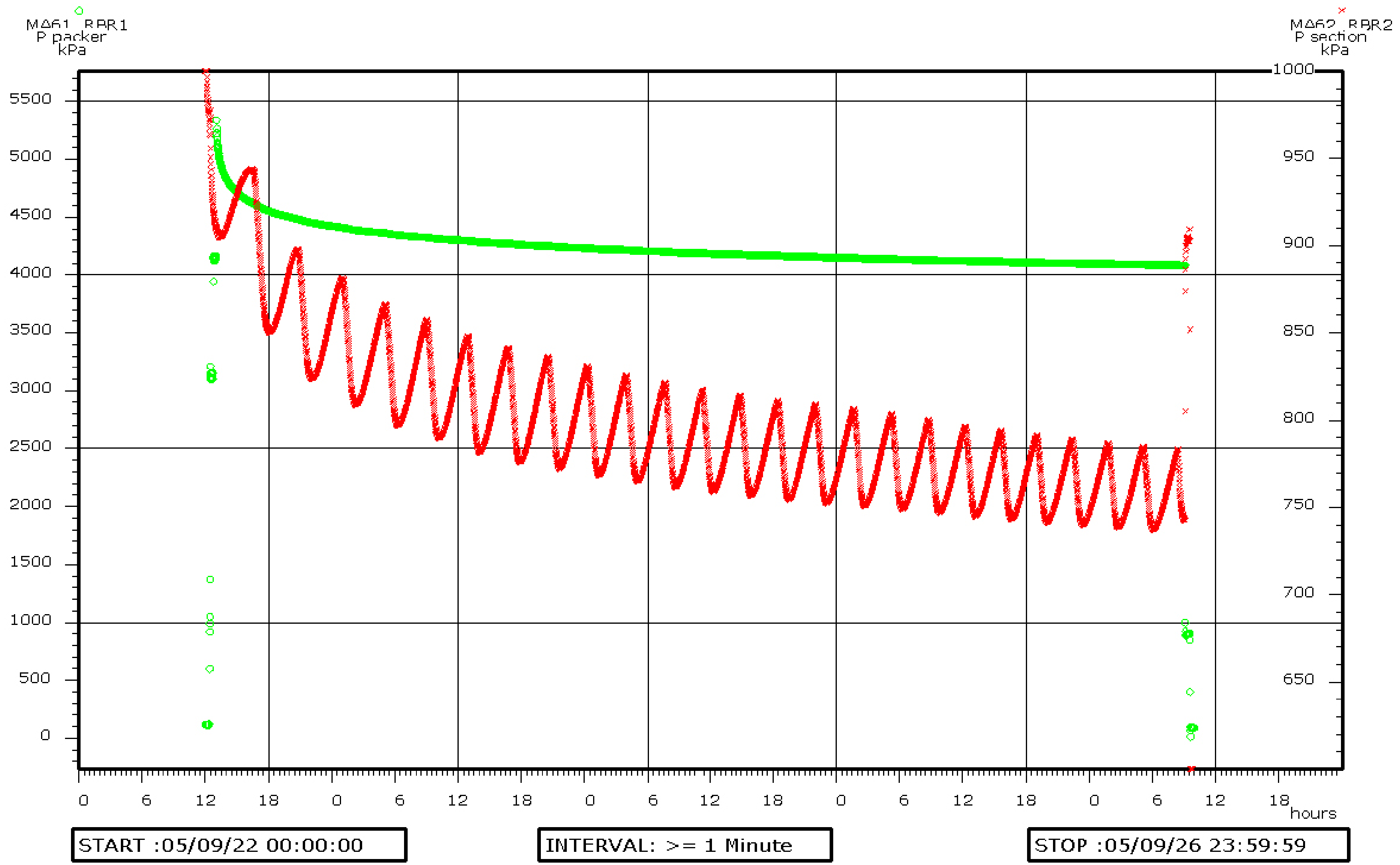

Figure C-1. *Absolute pressure measurement in section 111.00–251.89 m in KFM09A.*

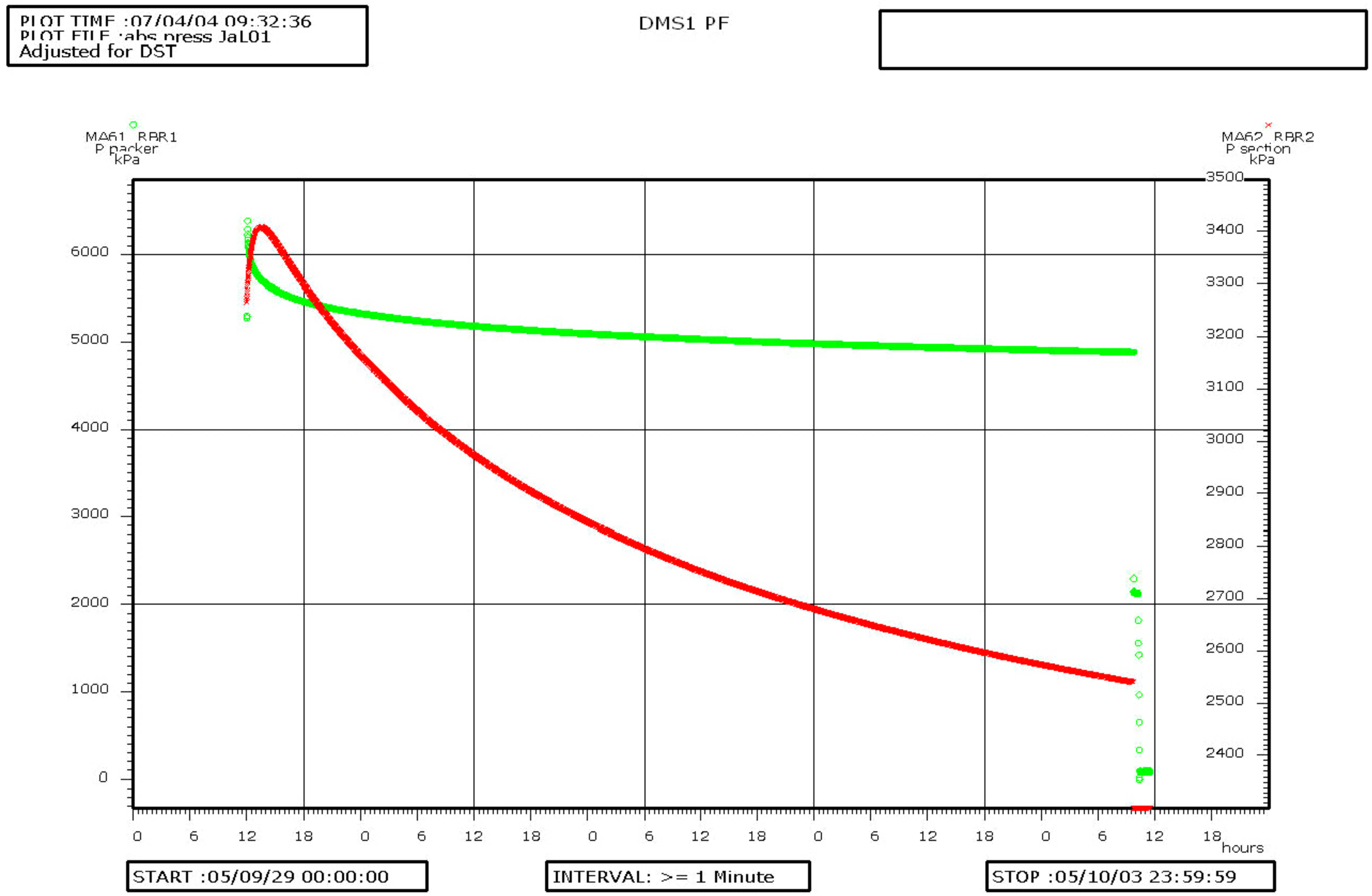

Figure C-2. *Absolute pressure measurement in section 250.20–400.81m in KFM09A.*