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Forsmark site investigation

Drilling of the telescopic borehole KFM03A and the core drilled borehole KFM03B at drilling site DS3

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June 2004

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Summary

The major part of the deep boreholes drilled within the scope of the Forsmark site investigations are performed as telescopic boreholes, entailing that the upper 100 metres are percussion drilled with a diameter of c. 200-250 mm, whereas section 100-1000 m is core drilled with a diameter of approximately 76-77 mm. Performance of and results from drilling and measurements during drilling of the third deep borehole drilled by applying this technique are presented in this report. The borehole, which is denominated KFM03A, was drilled during the period March to June 2003, is 1001.19 m long and subvertical (inclined 85.75° from the horizon). KFM03A is of so called SKB chemical type, intended for detailed hydrogeochemical and microbiological investigations.

During percussion drilling of section 0-100 m with the diameter Ø 163 mm, the borehole was experienced as stable, low-fractured and as unsignificantly water yielding. Therefore, the percussion drilled part was reamed to its final diameter, 196 mm, and the borehole was left uncased, except for the part through the soil layer and a few metres into firm bedrock. When airlift pumping during the subsequent core drilling, a flat-dipping fracture zone at about 60-62 m, which after all appeared to exist, was activated. The zone, which eventually turned out to have a large water capacity, is hydraulically connected to the percussion boreholes HFM06 and HFM08 situated c. 150 m respectively 200 m away.

A relatively complicated flushing water/return water system was applied for the core drilling of section 102.05-1001.19 m, where the flushing water was prepared in several steps before use, and the return water was taken care of, as to permit drill cuttings to settle before the water was conducted to the recipient. During drilling, a number of technical and flushing water/return water parameters were registered in order to obtain a good control of the drilling process and to permit an estimation of the impact on the borehole and adjacent formation of flushing water and drilling debris during drilling. Because high-conductive fractures were encountered at depth, probably both drill cuttings and flushing water have been forced into the formation, mainly at c. 380 m.

A sampling- and measurement programme for percussion drilling and another programme for core drilling provided preliminary but current information about the geological and hydraulic character of the borehole directly on-site. It also served as a basis for extended post-drilling analyses. Drill cores from the core drilled part and the samples of drill cuttings from the percussion drilled section, together with later produced video images of the borehole wall (so called BIPS-images), constituted the most important part of the working material used for borehole mapping (so called Boremap mapping) performed after drilling. Also results of the Boremap mapping are presented in this report.

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

One experience from drilling KFM03A is that the quartz-rich bedrock in Forsmark is hard to drill, entailing rapid wearing of drill bits. A higher average fracture frequency in combination with a relatively high water yielding capacity, however prolonged the life-time of the drill bits. Other lasting impressions from the drilling are the water-yielding flat-dipping and/or sub-horizontal fracture zones encountered in the shallow part of the bedrock as well as deeper down.

In order to compensate for the missing drill core in the percussion drilled part of KFM03A from the rock surface to 100.34 m, a short borehole was core drilled all the way from the rock surface to 101.54 m drilling length. Also KFM03B is sub-vertical (inclined 85.30º from the horizon). By drilling KFM03B, the existence of the flat-lying fracture zone indicated at c. 60-62 m in KFM03A was verified.

Sammanfattning

De flesta djupa borrhål inom Forsmarks platsundersökning utförs som teleskopborrhål. Det innebär att de övre 100 metrarna hammarborras med ca 200-250 mm diameter, medan avsnittet 100-1000 m kärnborras med 76-77 mm diameter. Resultaten från det tredje djupborrhålet i Forsmark som har utförts med denna teknik redovisas i denna rapport. Borrhålet, som benämns KFM03A, borrades under perioden mars till juni 2003, är 1001.19 m långt och nästan vertikalt (lutar 85.75° från horisontalplanet). KFM03A är ett så kallat kemiprioriterat borrhål, vilket innebär att det planeras att utnyttjas för detaljerade kemiska och bakteriologiska undersökningar, varför all utrustning som används i borrhålet, både vid borrning och mätning, måste rengöras och desinficeras enligt speciella instruktioner.

Vid hammarborrning av avsnittet 0-100 m med diametern Ø 163 mm uppfattades borrhålet som stabilt och med låg sprickfrekvens och obetydlig vattenföring, varför borrhålet rymdes upp till slutdimensionen 196 mm utan att foderrörsbeklädas mer än genom jordlagren och ytterligare ca 10 m ner i berg. Under mammutpumpningen vid den efterföljande kärnborrningen aktiverades den flacka sprickzon, som trots allt visade sig finnas i borrhålet vid ca 60-62 m. Zonen, som så småningom visade sig ha en betydande vattenkapacitet, har hydraulisk kontakt med hammarborrhålen HFM06 och HFM08 belägna ca 150 m respektive 200 m därifrån.

För kärnborrningen av avsnittet 102.05-1001.19 m användes ett relativt komplicerat spol- och returvattensystem, där spolvattnet preparerades i olika steg före användning. Returvattnet ledes till ett system av containrar, så att borrkaxet kunde sedimentera i tre steg innan vattnet leddes vidare ut till havet.

Under borrningen registrerades ett antal borr- och spolvattenparametrar, så att god kontroll uppnåddes dels avseende borrningens tekniska genomförande, dels beträffande den påverkan av spolvatten och borrkax som borrhålet utsattes för. Eftersom högkonduktiva sprickzoner påträffades på större djup, har troligen både borrkax och spolvatten trängt ut i formationen i huvudsak vid ca 380 meter.

Ett mät- och provtagningsprogram för hammarborrningen och ett annat program för kärnborrningen gav preliminär information om borrhålets geologiska och hydrauliska karaktär direkt under pågående borrning samt underlag för fördjupade analyser efter borrning. Bland de insamlade proverna utgör borrkärnorna från den kärnborrade delen av borrhålet och borrkaxproverna från den hammarborrade delen, tillsammans med videofilm av borrhålsväggen (s.k. BIPS-bilder), arbetsmaterialet för den borrhålskartering (s.k. Boremap-kartering) som utförs efter borrning. Även resultaten från Boremapkarteringen av KFM03A och KFM03B finns redovisad 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 det färdiga borrhålet.

En erfarenhet från borrningen av KFM03A är att den kvartsrika berggrunden i Forsmark är svårborrad och att borrkroneslitaget är högt. Något högre sprickfrekvens i kombination med relativt hög vattenföring förbättrade dock borrkroneslitaget jämfört med de tidigare borrade teleskopborrhålen KFM01A och KFM02A. Andra bestående intryck är de flacka, delvis kraftigt vattenförande zoner som påträffades i både den hammarborrade delen av borrhålet och djupare ner.

För att kompensera för den uteblivna borrkärnan från bergytan ner till 100.34 m borrades ett kort kärnborrhål, KFM03B, 12 m väster om KFM03A. Även KFM03B är subvertikalt (lutar 85.30º från horisontalplanet) och har en längd av 101.54 m. Vid borrningen av KFM03B kunde förekomsten av den flacka sprickzon som påträffades vid ca 60-62 m i KFM03A, verifieras.

Contents

1	**Introduction**	9
2	**Objective and scope**	13
3	**Equipment and basic technical functions**	15
3.1	Percussion drilling equipment	15
3.2	Gap injection technique	16
3.3	Core drilling equipment	17
	3.3.1 The wireline-76 system	17
	3.3.2 Flushing/return water system – function and equipment	17
	3.3.3 Drilling monitoring system	22
	3.3.4 Equipment for deviation measurements	23
	3.3.5 Equipment for hydraulic tests, absolute pressure measurements and water sampling during drilling	24
4	**Execution**	25
4.1	Percussion drilling of borehole KFM03A, section 0-100 m	25
	4.1.1 Preparations	25
	4.1.2 Mobilization	25
	4.1.3 Drilling, measurements and sampling during drilling	26
	4.1.4 Finishing off work	27
	4.1.5 Nonconformities	27
4.2	Core drilling	27
	4.2.1 Preparations	27
	4.2.2 Mobilization	27
	4.2.3 Drilling, measurements and sampling during drilling	28
	4.2.4 Finishing off work	29
	4.2.5 Nonconformities	31
4.3	Data handling	32
	4.3.1 Performance	32
	4.3.2 Nonconformities	32
4.4	Environmental programme	32
	4.4.1 Performance	32
	4.4.2 Nonconformities	32
5	**Results**	33
5.1	Drilling progress	33
5.2	Geometrical and technical design of borehole KFM03A	34
5.3	Percussion drilling 0-100.34 m (KFM03A)	36
	5.3.1 Percussion drilling period	36
	5.3.2 Drilling	36
	5.3.3 Measurements while drilling	37
5.4	Core drilling 100.34-1001.19 m (KFM03A)	37
	5.4.1 Drilling	38
	5.4.2 Registration of drilling parameters	38
	5.4.3 Registration and sampling of flushing water and return water	41
	5.4.4 Registration of the groundwater level in KFM03A	47

5.4.5 Core sampling 47
5.4.6 Recovery of drill cuttings 48
5.4.7 Deviation measurements 48
5.4.8 Measurements of the length difference between the compressed drilling pipe string and as extended by its own weight 48
5.5 Hydrogeology 49
5.5.1 Hydraulic tests during drilling (wireline tests) 49
5.5.2 Absolute pressure measurments 50
5.5.3 Recovery measurements upon airflush cleaning 50
5.5.4 Groundwater sampling - groundwater quality 51
5.5.5 Groove milling 51
5.5.6 Consumables 52
5.6 Geometrical and technical design of borehole KFM03B 53
5.7 Core drilling 0.15-101.54 m (KFM03B) 55
5.7.1 Flushing water and return water flow rate - water balance 55

6 References 57

Appendix A Well Cad presentation of the percussion drilled part of borehole KFM03A. 59
Appendix B Well Cad presentation of the core drilled part of borehole KFM03A 61
Appendix C Well Cad presentation of the core drilled borehole KFM03B 69
Appendix D Water Composition 71
Appendix E Hydraulic tests 73
Appendix F Absolute pressure measurements 79

1 Introduction

Site investigations are currently being performed by SKB for location and safety assessment of a deep repository for high level radioactive waste /1/. The investigations are carried out in two Swedish municipalities, Östhammar and Oskarshamn. The investigation area in Östhammar is situated close to the Forsmark nuclear power plant /2/, see Figure 1-1.

Drilling is one important activity within the scope of the site investigations. Three main types of boreholes are produced: core drilled respectively percussion drilled boreholes in solid rock and boreholes drilled through unconsolidated soil. 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 core drilled boreholes in hard rock. So far, three sub-vertical and two inclined, approximately 1000 m long, cored boreholes have been terminated, whereas one inclined borehole is underway. The locations of the six drilling sites in question, DS1, DS2, DS3, DS4, DS5, and DS6, are illustrated in Figure 1-1.

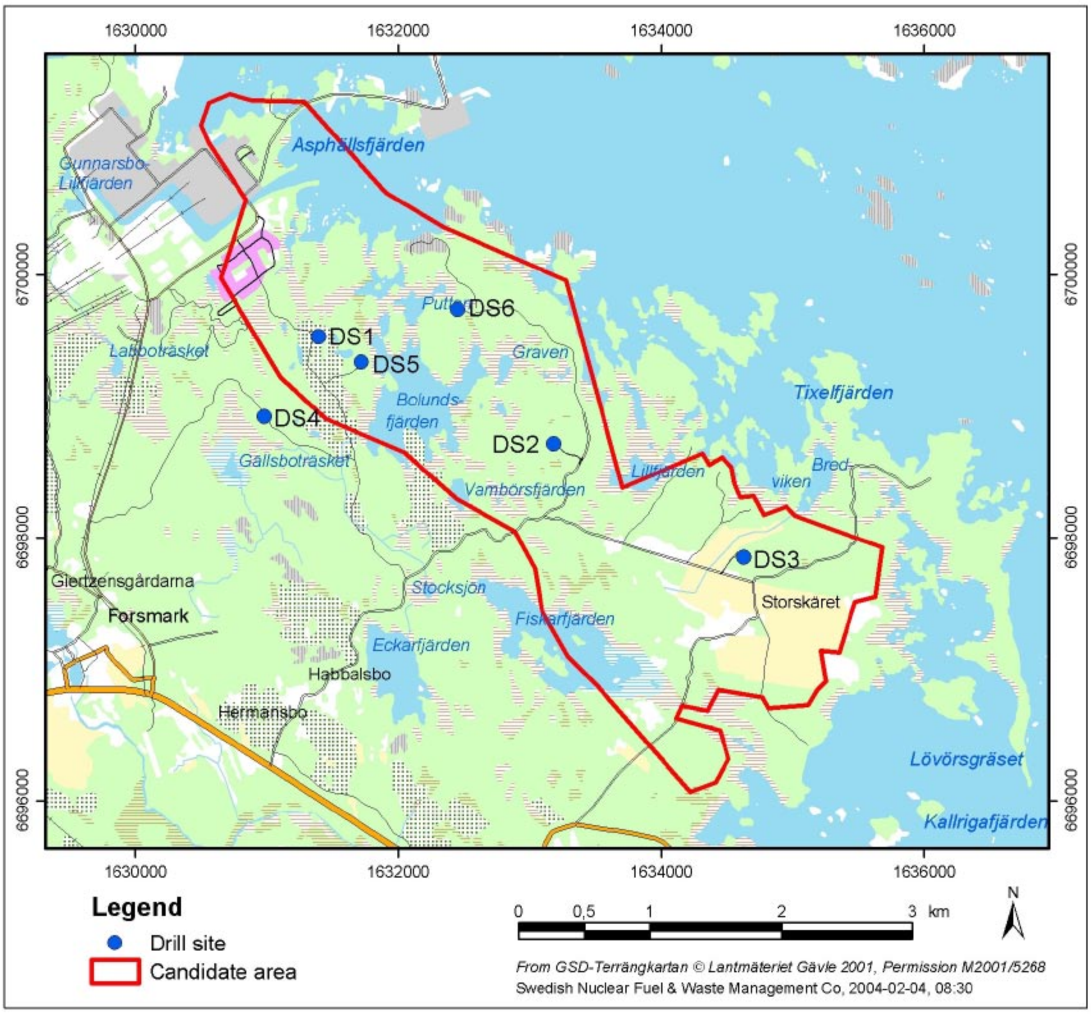


Figure 1-1. *The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drilling sites DS1-6 are marked with blue dots.*

By drilling the deep boreholes, so called telescopic drilling technique is applied, entailing that the upper 100 metres of the borehole are percussion drilled with a large diameter (≥200 mm), whereas the borehole section 100-1000 m is core drilled with a diameter of approximately 76-77 mm. This technical approach was adopted also when drilling the deep borehole presented in this report, KFM03A, which has a total drilling length of 1001.19 m (approximately equal to the vertical depth, as the borehole is near-vertical). Besides, borehole KFM03A is of so called SKB chemical type, implying that the borehole is prioritized for hydrogeochemical and microbiological investigations. A practical consequence of this is that all DTH (Down The Hole) equipment used during and/or after drilling must undergo severe cleaning procedures, see Chapter 4.

In order to compensate for the missing core in the borehole section 0-100 m, a shorter borehole, KFM03B, located c. 12 m W of KFM03A, see Figure 1-2, was core drilled all the way from the rock surface. Borehole KFM03B is inclined 85° from the horizontal plane and is 101.54 m long.

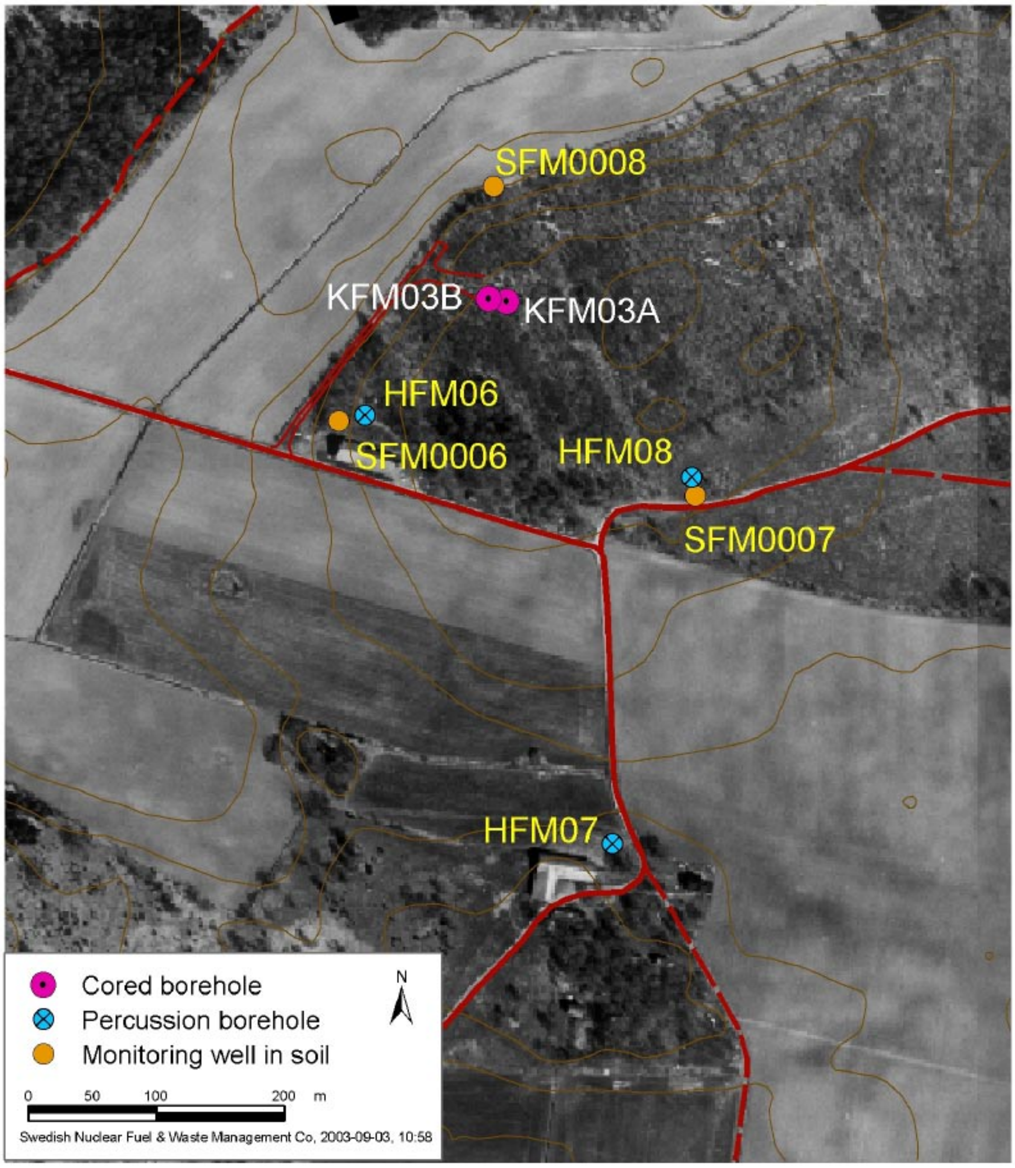


Figure 1-2. *Borehole locations at drilling site DS3. Besides the core drilled boreholes KFM03A and KFM03B, the drilling site incorporates a flushing water well (HFM06), two monitoring wells in solid rock (HFM07 and HFM08), and three monitoring wells in the unconsolidated overburden (SFM0006-08). The projections of inclined boreholes on the horizontal plane at top of casing are shown in the figure.*

Close to boreholes KFM03A and B at drilling site DS3, 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 approximately 144 m. The locations of all boreholes at drilling site DS3 are shown in Figure 1-2.

Drilling site DS3 is located in the south-eastern part of the candidate area, c. 6 km from the Forsmark power facilities. The area is characterized by open fields and pasture-land, quite different from the north-western, forested part of the candidate area. The coastline is situated about 7-800 m north of the drilling site (Figure 1-1).

In the present report, performance of and results from drilling and investigations made during and immediately after drilling of the telescopic borehole KFM03A and the core drilled borehole KFM03B at drilling site DS3 are presented.

Results from drilling of the flushing water well HFM06 and the two monitoring wells in hard rock, HFM07-08, have been reported separately /3/. So have the results from drilling of the three monitoring wells in regolith, SFM0006-08, /4/. Results from geological mapping of boreholes KFM03A and KFM03B (so called Boremap mapping) are treated in /5/.

Drilling of borehole KFM03A was performed in compliance with Activity Plan AP PF 400-03-16, Version 1.0, while drilling of borehole KFM03B was carried out according to Activity Plan AP PF 400-03-53, Version 1.0. Both Activity Plans refer to SKB MD 610.003, Version 1.0 (Method Description for percussion drilling), and SKB MD 620.003, Version 1.0 (Method Description for core drilling). The Activity Plans and Method Descriptions are SKB internal controlling documents.

Drillcon Core AB, Nora, Sweden, was engaged for the drilling commission. Two different drilling equipments were employed, a percussion drilling machine for drilling the upper c.100 metres of KFM03A, whereas core drilling of the remaining part (section 102.05-1001.19 m), as well as drilling of KFM03B was conducted with a wireline core drilling system.

Prior to drilling, a large number of preparative measures were taken at the drilling site. For example, the ground surface was levelled off and covered with a layer of coarse, draining gravel, so that a convenient working space was created. A cement slab, about 7 x 5 m in size and having an approximately 5 cm high bund along its perimeter, was cast around the collaring point. The slab serves as a firm platform for anchorage of the drilling machine while drilling, and provides a protection against any leaks of environmentally hazardous liquids, such as oil. The working area was also fenced in.

When preparations of the drilling site were terminated, the drilling equipment was mobilized, first the percussion drilling machine for drilling section 0-100 m, and later the core drilling equipment. Figure 1-3 illustrates when all core drilling equipment with accessories, e.g. barracks for monitoring system, core logging shelter, equipment repair, accommodation etc, are in place, and core drilling can start.

***Figure 1-3.** Investigation leader Lennart Ekman standing at drilling site DS3 with drill core shelter to the left and a plastic weather protection around the drilling machine.*

2 Objective and scope

The main objectives of drilling deep cored boreholes at the site investigation are the following:

- To provide rock samples from the ground surface to the borehole bottom. Percussion drilling through the overburden produces soil samples recovered to the surface by compressed air. These samples are collected with a frequency of one sample per metre. The same sampling frequency is applied for the drill cuttings produced when percussion drilling the upper c. 100 m of the solid rock. Below 100 m, the core drilling provides (in principle) continuous drill cores down to the borehole bottom. In order to compensate for the missing drill core in section 0-100 m in KFM03A, borehole KFM03B was drilled close to KFM03A. The rock samples collected during drilling are used for a lithological, structural and rock mechanical characterization as well as for determination of the retention and other transport properties of the bedrock from the rock surface to the full drilling depth.
- To render geophysical borehole investigations possible, e.g. TV logging, borehole radar logging and conventional geophysical logging as an aid for the geological/rock mechanical characterization.
- To allow hydraulic borehole tests (single hole tests as well as interference tests, in some cases performed as tracer tests) for characterization of the hydrogeological conditions of the bedrock.
- To make water sampling possible down to and below repository depth. High-class hydrogeochemical sampling/analysis demands special measures during and after drilling in order to keep the borehole clean. When these measures have been taken, the borehole is categorized as a borehole of chemical type. Only boreholes of this category are approved for advanced hydrogeochemical and microbiological characterization.
- To enable long-term hydraulic and hydrogeochemical monitoring at different levels of the bedrock.

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

Furthermore, a number of hydraulic tests and water samplings are normally performed during the drilling process, whereby a specifically designed test system, a so called wireline probe (WL-probe), is utilized.

3 Equipment and basic technical functions

Two types of drilling machines were used. The upper c.100 metres of KFM03A were drilled with a percussion drilling machine of type Puntel MX 1000. For core drilling of section 102.05-1001.19 m in KFM03A and of KFM03B (0-101.54 m), a Wireline-76 core drilling system, type Onram 2000 CCD, was engaged.

3.1 Percussion drilling equipment

The Puntel percussion machine is equipped with separate engines for transportation and power supplies. Water and drill cuttings were retrieved from the borehole by a 27 bars air-compressor, type Atlas-Copco XRVS 455 Md.

At drilling site DS3, the bedrock is covered by approximately 1 m of clayey-silty till with some boulder content. This layer was partly removed and replaced by a gravel filling. To achieve a borehole as straight as possible in this type of layers, the choice of drilling technique is important. In this case the NO-X technique was applied, following the principles and dimensions presented in Figure 3-1. The NO-X technique is described more in detail in SKB MD 610.003 (Method Description for percussion drilling). Figure 3-1 is a schematic diagram where the drilling depths presented are approximate. The true depths in the respective drilling sequences performed in KFM03A are presented in Section 5.2.

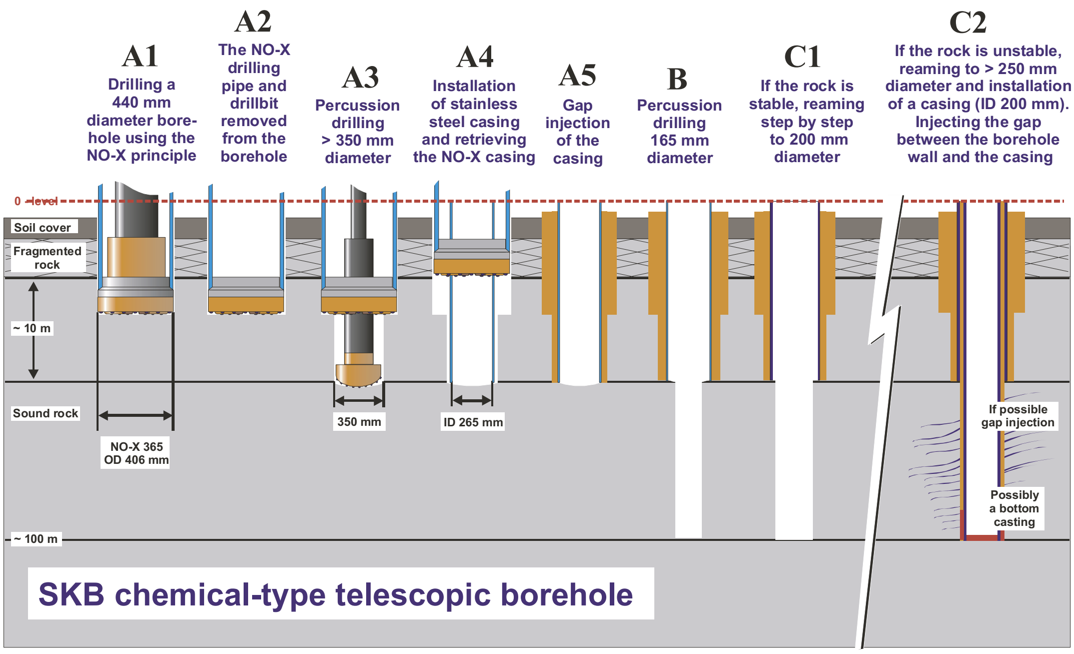


Figure 3-1. Schematic diagram showing the various stages of drilling the 0-100 m section of an SKB chemical-type telescopic borehole. The letters and numerals above each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB MD 620.003, Version 1.0.

3.2 Gap injection technique

For investigation of the groundwater conditions, especially the hydrogeochemical characteristics, of the cored part of a telescopic borehole, it is essential that the deeper groundwater is not mixed with surface water or groundwater from the shallow parts of the bedrock. Therefore, if groundwater is encountered in the borehole during percussion drilling of the telescopic borehole, it is essential to prevent this water to reach the deeper parts of the bedrock. This is achieved by cement grouting of the gap between the borehole wall and the casing. Also those parts of open, water yielding fractures, which are situated near and penetrated by the borehole, will in most cases be sealed by the injected agent during gap injection. Gap injection can be performed according to different techniques. Two variants are illustrated in Figure 3-2.

Borehole KFM03A was gap grouted at two occasions: 1) after installation of the $Ø_i$ 265 mm casing (A5 in Figure 3-1), and 2) after installation of the $Ø_i$ 200 mm, c. 12 m long casing (C2 in Figure 3-1). In both cases, gap injection through a hose was applied. Borehole KFM03B was gap grouted after installation of the 5 m long $Ø_i$ 78 mm casing. Also for KFM03B gap injection through a hose was applied.

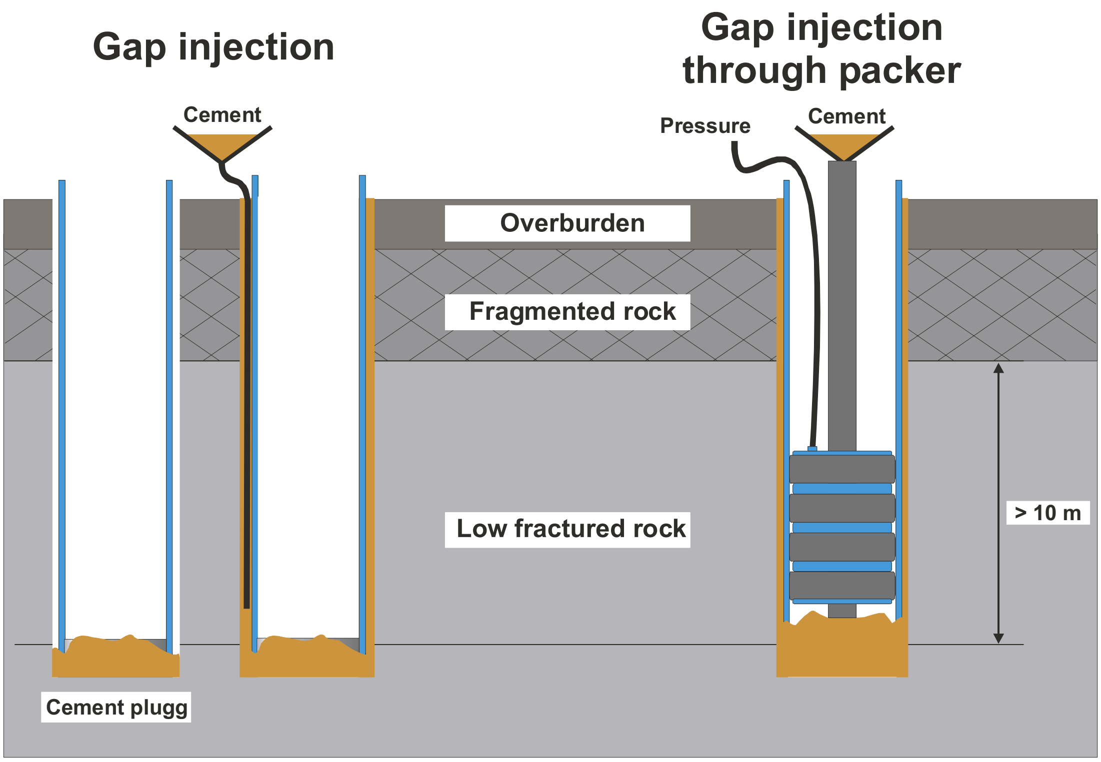


Figure 3-2. *Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer. Core drilling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

3.3 Core drilling equipment

3.3.1 The wireline-76 system

For drilling the cored part of borehole KFM03A and the entire part of borehole KFM03B, a wireline-76 system, type Hagby Bruk Onram 2000 CCD, was employed. The drilling process is operated by an electrically-driven hydraulic system supplied with a computer control. The drilling capacity for 76 mm holes is maximum c. 1500 metres. The drilling pipes and core barrel used belong to the Hagby WL76 triple-tube system. Technical specifications of the drilling machine with fittings are given in Table 3-1.

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 mm holes maximum approx. 1500 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

3.3.2 Flushing/return water system – function and equipment

Core drilling involves pumping of flushing water, which is conducted through the borehole tubing and the drill bit and, further, 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 drilling pipes. However, if the borehole has penetrated water conductive rock fractures, part of, and sometimes all of the return water from the borehole, including drill cuttings, may be forced into these fractures. This makes a correct characterization of the in situ hydraulic and hydrogeochemical conditions more difficult, due to partial or complete clogging by drill cuttings and due to the contribution of 'foreign' flushing water in the fracture system.

* In order to reduce these negative effects, SKB has developed a specially designed flushing water and return water system, which is applied to its full extent in telescopic boreholes. Regarding ordinary core drilled boreholes, the airlift pumping part of the system (see below) is not applicable. The equipment consists of the components shown in Figure 3-3. The system includes equipment for pumping, transport and storage of water. The flushing/return water system may be divided into:
* equipment for preparing the flushing water
* equipment for measuring flushing water parameters (flow rate, pressure, electrical conductivity and dissolved oxygene)
* equipment for airlift pumping while drilling (telescopic boreholes only)
* equipment for storage and discharge of return water.

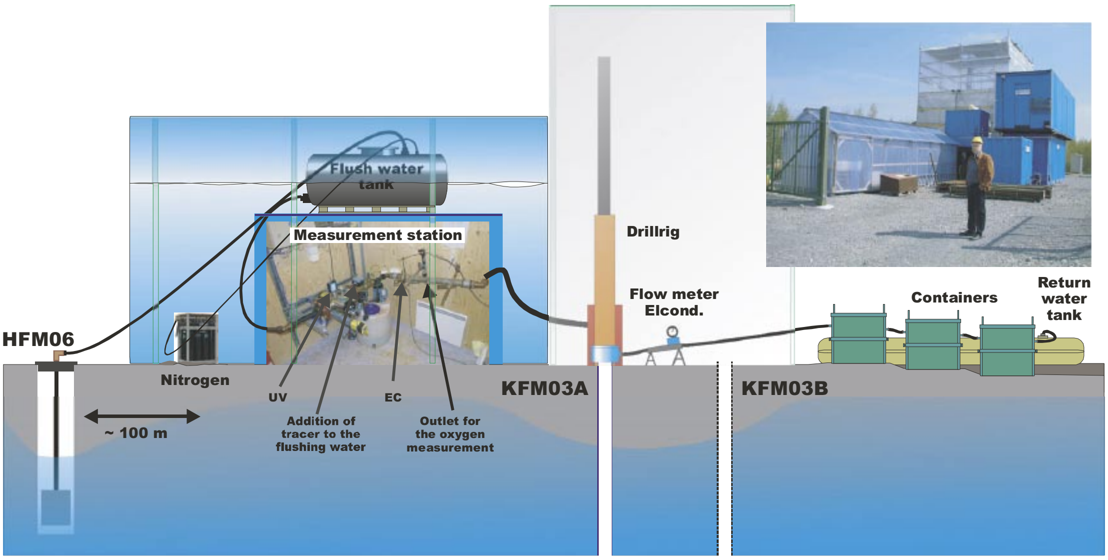


Figure 3-3. *Schematic illustration and photograph of the flushing/return water system when drilling KFM03A and KFM03B at DS3. The measurement station included the gauges and logger units for measurements of EC (electrical conductivity) and dissolved oxygen in the flushing water, the dosing feeder for labelling the flushing with a tracer, and the UV-radiation unit. For flushing water flow rate and pressure measurements, the drilling machine gauges were used.*

Preparation of the flushing water

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

The water well used for supply of flushing water for core drilling of KFM03A and KFM03B was a percussion drilled well in hard rock, HFM06 (see Figure 1-2), situated approximately 150 m from these boreholes. The water quality was analysed before use. The results of the analysis are presented in Section 5.4.3. The water quality was considered as good enough to serve as flushing water.

Besides the basic demands on the flushing water quality, which were fulfilled when drilling KFM03A and KFM03B, the flushing water was also prepared in three steps before use, in accordance with SKB MD 620.003 (Method description for core drilling).

1) The incoming water from the water well entered the 5 m^3 water tank illustrated in Figure 3-3. Nitrogen was bubbled through the water in the tank in order to expel oxygen which might be dissolved in the water. Expelled oxygen was discharged through a pressure reducing valve. Oxygen must be avoided in the flushing water because it is a critical parameter in the programme for hydrogeochemical characterization of the groundwater. The water was then stored under a positive nitrogen pressure (about 1 bar) until pumped further to the measurement station.
2) In the measurement station, the water from the tank was exposed to UV-radiation, whereby the microbe content in the water was radically reduced.
3) An organic tracer dye, Uranine, was added to the flushing water with a dosing feeder at a concentration of 0.2 mg/L before the water was pumped into the borehole, see Figure 3-4. 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 following flushing water parameters were measured on-line when pumping the flushing water into the borehole:

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

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

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

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

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

Airlift pumping while drilling

Airlift pumping during core drilling involves pumping of compressed air into the percussion drilled portion of the telescopic borehole, so that it emerges at a depth of about 100 m. As it expands in rising out of the borehole, it lifts the water up, to produce the airlift pumping effect. The resulting pressure drop entails transport of much of the mixture of water and drill cuttings from the bottom of the hole up to the surface, see Figure 3-4. The resulting return water is a mixture of flushing water, groundwater from fracture zones in the rock and drill cuttings. Some of the flushing water and drill cuttings will, however, be forced into the local fracture systems, and a minor part will be left in the borehole. The airlift pumping is continued throughout the drilling period.

The airlift pumping equipment in KFM03A consisted of the following main components, see Figure 3-4:

- Compressor, 12 bars/10 m³/min
- 100 m outer support casing, 98/89 mm diameter
- 100.5 m inner support casing, 84/77 mm diameter
- Expansion vessel (= discharge head)
- PEM hose: 20 bars, 28 mm diameter, 100 m
- Pressure sensor, 10 bars, instrumentation and data-logging unit
- Electrical supply cubicle, at least 16 A

- Two ejector tubes and one pumping nozzle
- Two PEM hose 20 bars, 40 mm diameter, 100 m
- Two - 22 mm diameter hoses at about 100 m
- One - 22 mm diameter hose at about 80 m

When installing the outer support casing and hoses, they were lowered into the borehole with a mobile crane. The ejector tube was fit to the outer support casing, about 200 mm above the bottom of the telescopic borehole. A 22 mm supply hose and a 40 mm return hose were connected to each ejector tube as shown in Figure 3-5. With this construction, the air leaving the ejector rises, reducing the pressure in the lower part of the ejector tube, helping to lift drill cuttings from the bottom of the hole.

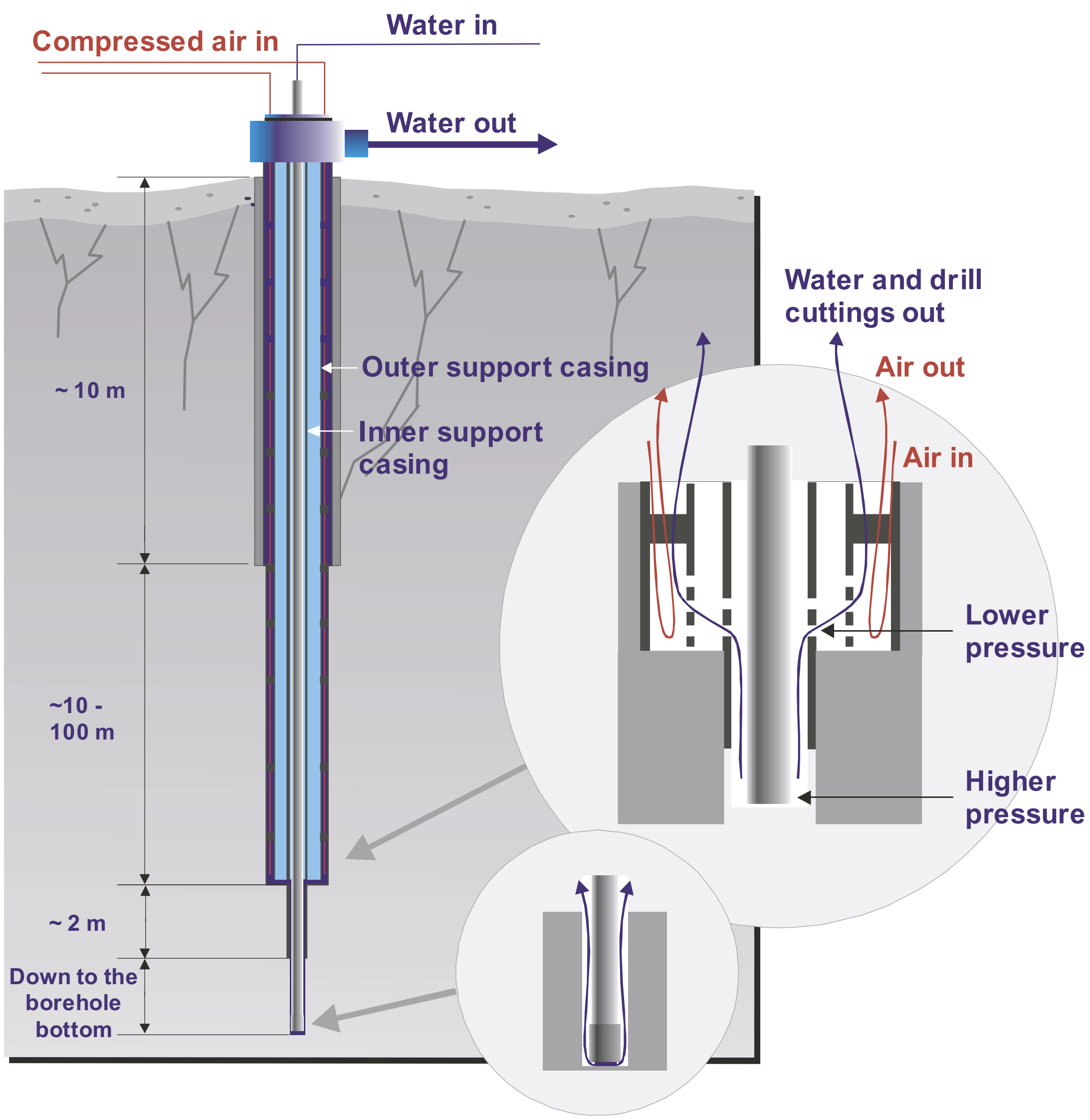


Figure 3-4. Airlift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air- and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole.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

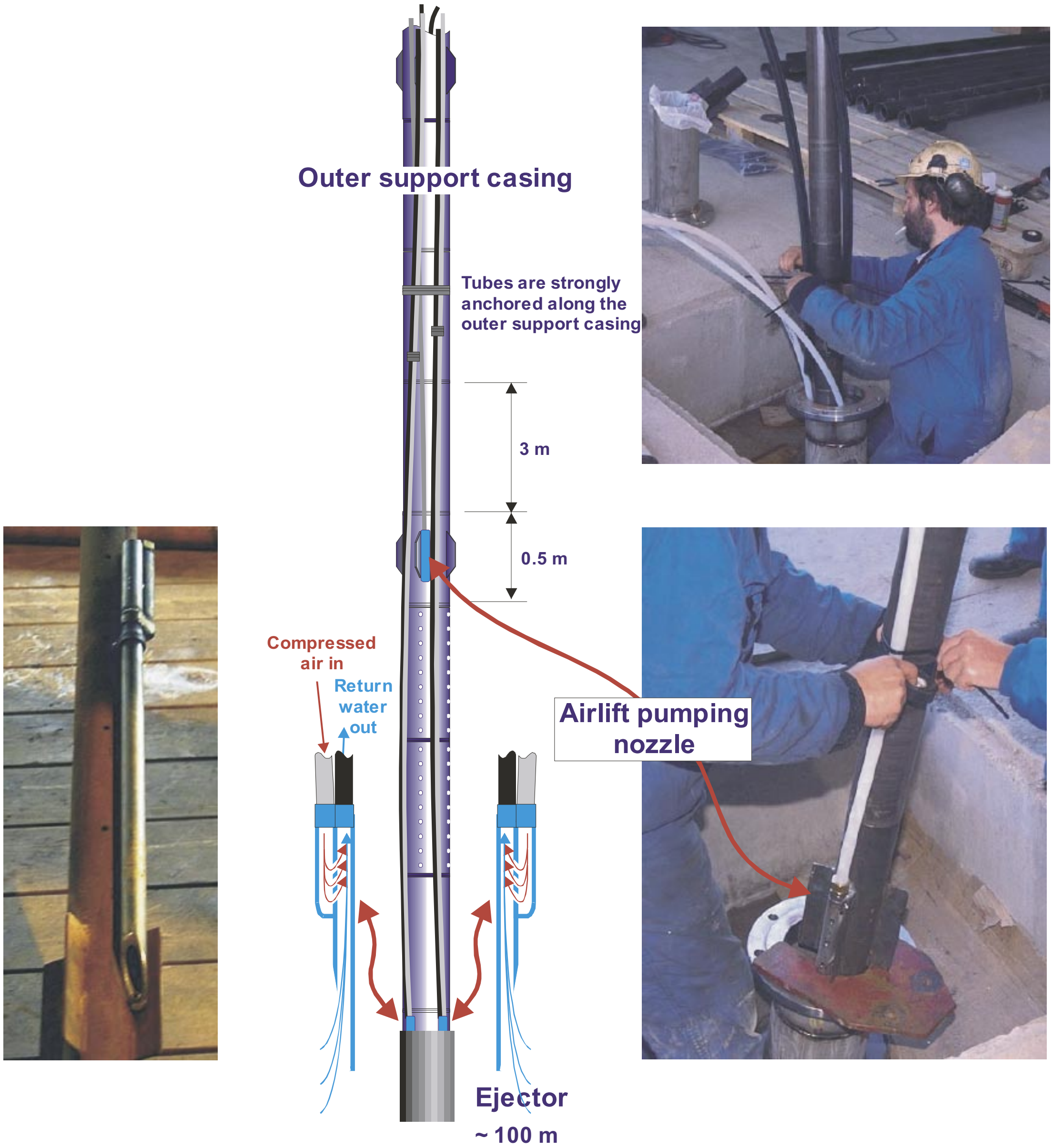


Figure 3-5. *Schematic representation of connection and installation of airlift pumping nozzle and ejector on the outer protective casing.*

Storage and discharge of return water

At the surface level, the return hose was connected to a return pipe between the discharge head and the first return water container, see Figures 3-3 and 3-6. The return water was discharged from the borehole via the expansion vessel and a flow meter to three containers, in which the drill cuttings separated out in three sedimentation steps. The cuttings were preserved in the containers for later weighing. 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 pumped from the containers via a 600 m long pipe string to the Baltic Sea. Intermittently, the return water was, after separation of drill cuttings stored in two elastic water tanks with an expansive capacity of up to 40 m^3 each, see Figure 3-3.

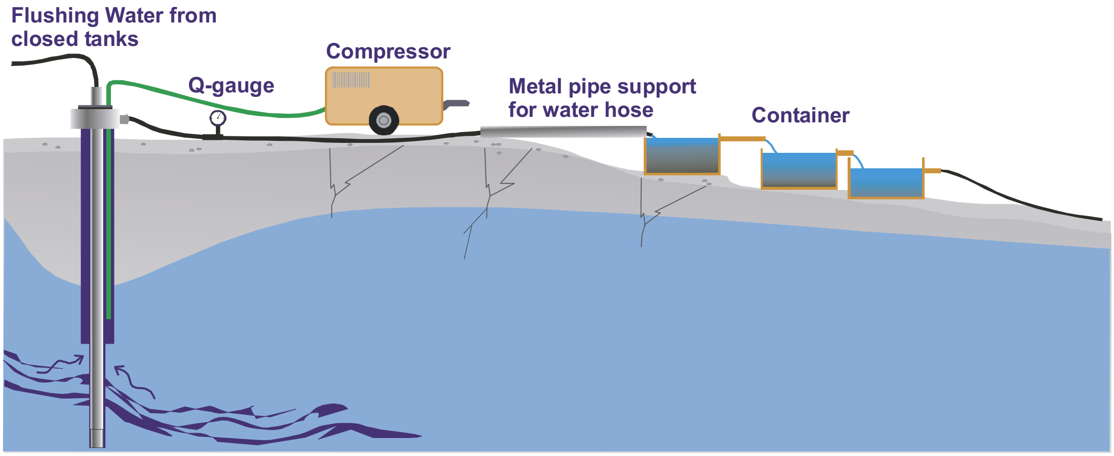


Figure 3-6. *Return water system. Airlift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in three stages in the containers (where it is preserved for later weighing), after which the water can be pumped to the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

The flow rate and electrical conductivity of the return water was measured and data stored in the data-logging system. Technical specifications of the measurement instrument are given in Table 3-3.

Flow rate data and other flushing water data were continuously stored in an automatic data-logging system, see Section 3.3.3. As a back-up and double-check, the total quantity of water supplied to the borehole was acquired by counting the number of filled water tanks used, multiplied by the tank volume.

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

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

3.3.3 Drilling monitoring system

The ONRAM 2000-CCD drilling machine is supplied with a computer based logging system integrated in the steering system (cf. Section 3.2.1). The parameters logged are those used for automatic operation of the drilling machine.

A log-file name, a time- or depth-interval and parameters to be logged are selected from a menu. The system produces files in ASCII-format, which can be transferred into several Windows programs for further analyses.

The following parameters are automatically registered: date, time, mode, status, rotation pressure (bar), feed force on drill bit (kp), feed force on cylinder (kp), feed pressure (bar), flushing water flow rate (L/min), flushing water pressure (bar), rotation speed (rpm), penetration rate (cm/min), drill length (cm), bit position (cm), feed position (1/10 mm), rod weight (kg) and rod pressure (bar). The parameter "mode" represents the current activity in the drilling cycle, whereas "status" gives an explanation to drill stops and also indicates when a drilling sequence is finished.

For the geoscientific data acquisition, the following technical parameters are of primary interest:

- time
- drill bit position
- penetration rate
- feed force
- rotation speed
- water pressure
- water flow.

However, during drilling of borehole KFM03A and KFM03B, the registration was extended to include also the following flushing water parameters:

- electric conductivity
- dissolved oxygen
- flow rate

as well as the return water parameters:

- flow rate
- electric conductivity.

The system is also provided with devises for convenient sampling of flushing water and return water for analysis of the uranine content.

Finally the level of the groundwater table in the borehole was registered.

3.3.4 Equipment for deviation measurements

Deviation measurements were made once during drilling of borehole KFM03A and again after termination of drilling, in order to check the straightness of the borehole. A deviation measurement was made also in KFM03B after completion of drilling. All measurements were performed with a Reflex MAXIBOR™ system, which is an optical, i.e. non-magnetic measurement system. Azimuth and dip are measured at every third metre. The collaring point coordinates and the measured values are used for calculating the coordinates of the position of the borehole at every measurement point.

3.3.5 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 specially designed for the wireline-76 system. The tool, which is denominated "the wireline probe" or "WL-probe", is described in SKB MD 321.002, Version 1.0 (Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wireline-borrning), which is an SKB internal controlling document.

4 Execution

4.1 Percussion drilling of borehole KFM03A, section 0-100 m

The performance of the percussion drilling followed Activity Plan AP PF 400-03-16, which refers to SKB MD 610.003 (Method Description for percussion drilling). The Activity Plan and Method Description are both SKB internal controlling documents. The percussion drilling operations included the following parts:

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

The four first items are treated in the present section (Section 4.1), whereas the last two items, together with the corresponding items for core drilling, are presented in Sections 4.3 and 4.4.

4.1.1 Preparations

The preparation stage included the contractor's service and function control of his equipment. The machinery was obliged to be supplied with fuel, oil and grease exclusively of the types stated in SKB MD 600.006, Version 1.0 (Instructions for the use of chemical products and construction materials in equipment for drilling and investigations). Finally, the equipment was cleaned in accordance with the cleaning instruction in SKB MD 600.004, Version 1.0 (Instruction for cleaning borehole equipment and certain surface equipment), for boreholes of SKB chemical type. Both instructions are SKB internal controlling documents.

4.1.2 Mobilization

Mobilization onto and at the site included preparation of the drilling site, and transport of drilling equipment, sampling pots for soil and drill cuttings, hand tools and other necessary outfit to the site. Furthermore, the mobilization included cleaning of all in-the-hole equipment at level two in accordance with SKB MD 600.004, lining up the machine and final function control.

4.1.3 Drilling, measurements and sampling during drilling

The percussion drilling started with drilling through the overburden while simultaneous casing driving and subsequent gap injection. These activities followed the principles described in Sections 3.1 and 3.2 (corresponding to A1-A5 in Figure 3-1). The length of the $Ø_i$ 265 mm casing was 11.83 m and the casing material used was SS2333 stainless steel.

The continued percussion drilling through solid rock was performed with a 163 mm drill bit to 100.34 m drilling length (corresponding to B in Figure 3-1).

For stabilization of the entire percussion drilled part, the borehole was reamed to Ø 196 mm with a special reamer bit to 100.29 m drilling length (i.e. 0.05 m of the pilot hole was left unreamed), and a SS2333 stainless steel $Ø_i$ 265 mm casing was installed to 11.83 m (corresponding to C2 in Figure 3-1). However, after installing the casing, the borehole was cleaned from drill cuttings by a “blow out” with the compressor working at maximum capacity during 30 minutes. This also served as a hydraulic capacity test of the borehole, since the recovery of the groundwater table was registered after the compressor had been turned off. The results were used as a rough capacity test of the percussion drilled part of the borehole,

In order to prevent leakage of water from the shallow water-yielding fractures penetrated by the borehole via the gap between the borehole wall and the casing, the gap was grouted using the packer technique illustrated in Figure 3-2. After grouting, the recharge of water into the borehole ceased completely.

Measurements and sampling while percussion drilling (and immediately after drilling) were performed according to a specific measurement/sampling programme. Concerning the section below the casing through the overburden down to 100.34 m, the measurements and sampling during and immediately after drilling were carried out in association with the Ø 163 mm drilling sequence. The measurement/sampling programme performed was in accordance with SKB MD 610.003 (Method Description for percussion drilling) and included:

1) Sampling of drill cuttings at every third metre. Each sample consisted of three individual samples collected one per metre. The samples were stored in a plastic bottle marked with a sample number. Ocular inspection and a preliminary description of the mineral content was made on-site as a basis for classification of the rock type.

2) Manual measurement of the penetration rate at every 20 cm.

3) Observation of the flow rate (if any) at every 20 cm. When a significant increase of the flow rate was noticed, it was measured using a graduated vessel and a stop-watch.

4) Observation of the water colour at every 20 cm.

5) Measurement of the electric conductivity of the groundwater at every three metres.

Analyses of drill cuttings from the soil layer respectively from the section of solid rock were performed as separate activities. The results of the analyses of the cuttings from the soil layer are integrated with the results from the mapping of Quaternary deposits /6/, whereas the analyses of cuttings from solid rock are presented in /5/. Results from the remaining measurements and observations are presented in Chapter 5.

4.1.4 Finishing off work

Finishing off work included measurements of the final diameter of the drill bit after reaming to Ø 196 mm. The borehole was secured with a lockable stainless steel flange. The drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

4.1.5 Nonconformities

Percussion drilling of borehole section 0-100.34 m in KFM03A was performed according to programme, i.e. without deviations.

4.2 Core drilling

Core drilling of KFM03A was performed in compliance with Activity Plan AP PF 400-03-16, while core drilling of KFM03B was conducted according to Activity Plan AP PF 400-03-53. Both Activity Plans refer to SKB MD 620.003 (Method description for core drilling). The Activity Plans and Method Description are both SKB internal controlling documents. The core 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
- environmental control.

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

4.2.1 Preparations

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

4.2.2 Mobilization

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

4.2.3 Drilling, measurements and sampling during drilling

Core drilling of borehole KFM03A was performed in two dimensions. Section 100.34-102.05 m was drilled with a borehole diameter of 86.0 mm, whereas the main part of the borehole, section 102.05-1001.19 was drilled with Ø 77.3 mm. The inner Ø 84/77 mm support casing in KFM03A was fitted into the short Ø 86 mm borehole. In this way the casing was centralized in the borehole and fixed laterally. The outer Ø 98/89 mm support casing in KFM03A is resting on the bottom of the percussion drilled borehole.

Core drilling of borehole KFM03B was performed in four dimensions. Section 0.15 -0.78 m, through the overburden, was drilled with Ø 116.0 mm, section 0.78-5.00 m with Ø 101.0 mm, section 5.00-5.14 m with Ø 86.0 mm, and finally the main part of the borehole, section 5.14-101.54 m, with a borehole diameter of Ø 77.3 mm.

Core drilling with Ø 77.3 mm of the main part of the borehole serves many purposes, cf. Chapter 2. One of the most essential objectives is to provide (in principle) continuous rock samples, i.e. drill cores, down to the borehole bottom, which allows a lithological, structural and rock mechanical characterization of the bedrock. The drill cores may also be used for determination of retention and other transport properties of the rock and for the study of chemical characteristics of the pore water in the rock matrix.

Core drilling with a wireline system entails recovery of the core barrel via the drilling pipe string, inside which it is hoisted up with the wireline winch. During drilling of boreholes KFM03A and KFM03B, a 3 m triple tube core barrel was used. The nominal core diameter for the Ø 77.3 mm part of the borehole is 50.8 mm. Minor deviations from this diameter may, however, occur.

Like the percussion drilling, 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 KFM03A and KFM03B some deviations from this programme could not be avoided. In order to elucidate the nonconformities, the programme according to the Method Description is presented in Section 4.2.5, Table 4-1, together with the actual performance when drilling KFM03A and KFM03B.

A field log of the drill core is made during drilling, see Figure 4-1. Results from mapping of the drill core samples according to the Boremap method are presented in /5/ for both KFM03A and KFM03B, whereas the remaining measurements and registrations during core drilling are presented in Chapter 5 in the present report.

Besides the activities mentioned in Table 4-1, water samples were collected from different positions in the flushing water system, see Figure 3-3, in order to reveal if the content of microbes changed during transport through the vessels, pipes and hoses included in the system. The results of the study are presented in /7/.

Figure 4-1. *Field logging of the drill core is here made on-site by drilling manager Göran Nilsson.*

4.2.4 Finishing off work

The concluding work included the following items:

1) Borehole KFM03A was flushed for about 10 hours during simultaneous airlift pumping, 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. After finished flushing/air-lift pumping, the recovery of the groundwater table was registered as an estimate of the hydraulic conditions of the entire borehole. The results are presented in Chapter 5.

Since no airlift pumping was applied in borehole KFM03B, cleaning of the borehole was attempted by flushing at maximum capacity for about half an hour.

2) The drilling string was pulled.

3) The inner support casing was removed with aid of a crane lorry (relevant only for KFM03A).

4) The outer support casing was removed with the same crane lorry (only KFM03A).

5) The discharge head was removed.

6) Using the drill rig, a stainless steel transition cone was installed between the reamed and cased percussion drilled respectively the cored part of KFM03A, cf. Figure 4-2. The transition cone is located at 97.20-101.85 m.

7) The boreholes were secured with the lockable stainless steel flange.

8) The core drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

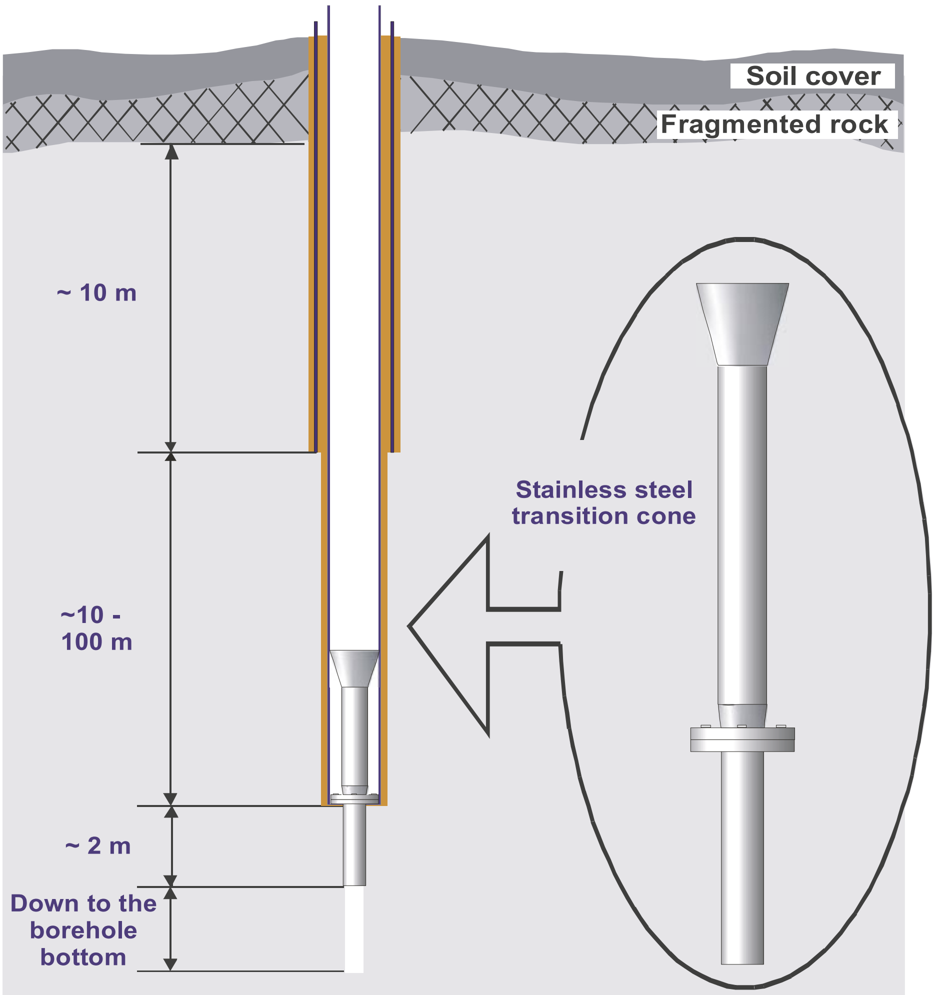


Figure 4-2. *Schematic illustration of the transition cone between the upper, wide section and the lower, slim part of a telescopic borehole. In KFM03A, the entire upper, percussion drilled part was cased.*

4.2.5 Nonconformities

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

Table 4-1. Programme for sampling, measurements, registrations and other activities during and immediately after core drilling according to SKB MD 620.003, and the actual performance during drilling of boreholes KFM03A and KFM03B.

Activity	Performance and frequency according to SKB MD 620.004	Performance and frequency during drilling of KFM03A and KFM03B
Registration of drilling- and flushing water parameters.	Described in Section 3.3.2. Registration during the entire drilling.	Technical problems with oxygen transducer. No measurements performed.
Registration of the groundwater level in the borehole during drilling.	Every 10th second.	According to programme.
Core sampling.	Continuous sampling of the entire drilled section.	According to programme.
Deviation measurements.	Normally performed every 100 m and after completion of drilling.	One measurements during drilling and one measurement after completion of drilling in KFM03A. After completion of drilling in KFM03B.
Measurements of the difference in length between the compressed drilling pipe string and as extended by its own weight.	Normally performed every 100 m.	Uncertain measurements made and rejected. Values presented in Figure 5-15 are from material properties of the drilling pipe string.
Hydraulic tests.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drilling pipe string should be controlled before each test.	Three measurements performed.
Water sampling.	Normally performed every 100 m, and also when penetrating larger conductive fractures/zones. The tightness of the drilling pipe string should be controlled before each test.	One measurements performed Two failed due to: technical problems with the test equipment.
Absolute pressure measurements.	Normally during natural pauses in drilling.	Five measurements performed.
Groove milling in the borehole wall, normally at each 100 m.	Normally carried out after completion of drilling.	Seventeen grooves performed. No grooves at 950 m due to technical problems.
Collecting and weighing of drilling debris.	Drilling debris settled in containers and weighed after finished drilling.	Not carried out for the percussion drilled part of borehole KFM03A. According to programme for the core drilled part. Not made for KFM03B.

The last item in Table 4-1 may be commented on. All drilling debris produced during drilling (percussion drilling as well as core drilling) was collected in the sedimentation containers of the return water system, see Figures 3-3 and 3-6 (except the finest fractions which stayed suspended in the discharge water from the third container). The collected drill cuttings from core drilling were weighed after concluded drilling in order to give a measure of the drill cuttings recovery. Weighing of the cuttings from percussion drilling was not carried out due to practical/logistic reasons. However, inspection during drilling indicated that the recovery of cuttings during percussion drilling was efficient.

4.3 Data handling

4.3.1 Performance

Minutes for several items with the following headlines were filled in by the field crew: Activities, Cleaning of the equipment, Drilling, Drillhole, Core drilling penetration rate, Deliverance of field material and Discrepancy report. The minutes were collected by the Activity Leader, who made a control of the information and had it stored in the SKB database SICADA /8/. Field Note numbers are presented in Chapter 5.

4.3.2 Nonconformities

None.

4.4 Environmental programme

4.4.1 Performance

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

4.4.2 Nonconformities

None.

5 Results

All data were stored in the SICADA database. Field Note numbers are Forsmark 100 and 123 (KFM03A) and 181 (KFM03B) /8/. An overview of the drilling progress of borehole KFM03A and KFM03B is given in Section 5.1, whereas geometrical data and technical design are presented in Section 5.2 (KFM03A) and Section 5.6 (KFM03B).

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

- Section 5.3 (percussion drilling of KFM03A)
- Section 5.4 (core drilling of KFM03A)
- Section 5.7 (core drilling of KFM03B).

Well Cad-presentations of borehole KFM03A and KFM03B are shown in:

- Appendix A (percussion drilled part of borehole KFM03A)
- Appendix B (core drilled part of borehole KFM03A)
- Appendix C (core drilled borehole KFM03B)

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

Borehole KFM03A was drilled during a period of slightly less than 4 months, see Figure 5-1. Since this was the third deep drilled borehole within the Forsmark site investigation programme, the technical constructions and working routines used were now smoothly running. Both the drill crew and the support organization were well trimmed after completion of boreholes KFM01A and KFM02A.

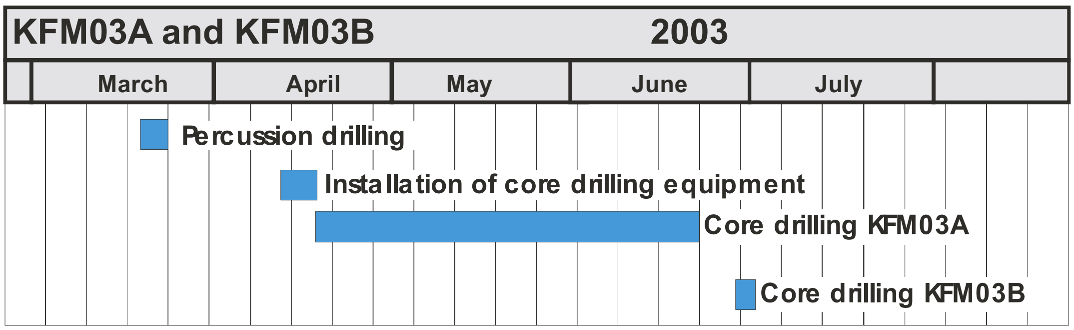


Figure 5-1. *Overview of the drilling performance of boreholes KFM03A and KFM03B.*

5.2 Geometrical and technical design of borehole KFM03A

Administrative, geometric and technical data for the telescopic borehole KFM03A are presented in Table 5-1. The technical design is illustrated in Figure 5-2.

Table 5-1. Administrative, geometric and technical data for borehole KFM03A.

Parameter	KFM03A
Borehole name	KFM03A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	March 18, 2003
Completion date	June 23, 2003
Percussion drilling period	2003-03-18 to 2003-03-28
Core drilling period	2003-04-16 to 2003-06-23
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Sven Andersson i Uppsala AB
Percussion drill rig	Puntel MX 1000
Core drill rig	ONRAM 2000 CCD
Position KFM03A at top of casing (RT90 2.5 gon V 0:-15 / RHB 70)	N 6697852.10 E 1634630.74 Z 8.29 (m.a.s.l.) Azimuth (0-360°): 271.52° Dip (0-90°): -85.75°
Position KFM03A at bottom of hole (RT90 2.5 gon V 0:-15 / RHB 70)	N 6697869.35 E 1634541.23 Z –988.18 (m.a.s.l.) Azimuth (0-360°): 300.65° Dip (0-90°): -82.74°
Borehole length	1001.19 m
Borehole diameter and length	From 0.00 m to 1.65 m: 0.440 m From 1.65 m to 11.86 m: 0.349 m From 11.86 m to 11.96 m: 0.248 m From 11.96 m to 100.29 m: 0.196 m From 100.29 m to 100.34 m: 0.163 m From 100.34 m to 102.05 m: 0.086 m From 102.05 m to 1001.19 m: 0.077 m
Casing diameter and length	$Ø_o/Ø_i$ = 273 mm/265 mm between 0.10 and 11.83 m $Ø_o/Ø_i$ =208 mm/200 mm between 0.00 and 11.96 m
Transition cone inner diameter	At 97.20 – 101.85 m: 0.190 m
Drill core dimension	100.34-102.05 m / Ø72 mm 102.05 –1001.19 m/ Ø51 mm
Core interval	100.34-1001.19 m
Average length of core recovery	3.35 m
Between 102.05-653.35 with 4½ m core barrel	3.83 m
Between 653.35-1001.19 with 3 m core barrel	2.78 m
Number of runs	269
Diamond bits used	21
Average bit life	42.8 m

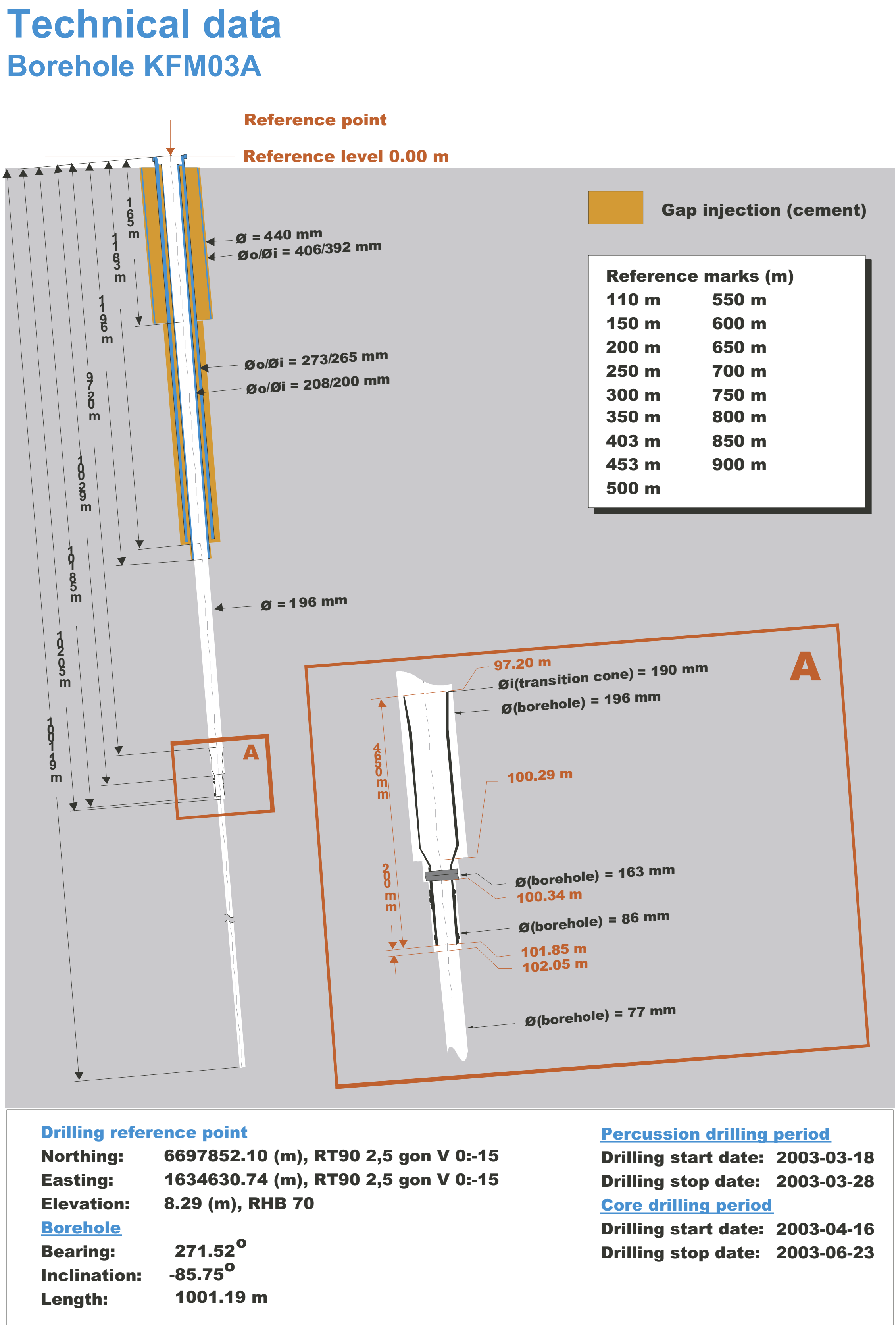


Figure 5-2. *Technical data of borehole KFM03A.*

5.3 Percussion drilling 0-100.34 m (KFM03A)

5.3.1 Percussion drilling period

The duration of the different operations included in the percussion drilling from March 18th 2003 to March 28th 2003 are presented in Figure 5-3. Percussion drilling of the upper 100 metres of KFM03A was finished after 10 days. The rapid performance was due to two reasons. Firstly, the thin overburden facilitated drilling with the NO-X technique. Secondly, the major part of the borehole was left uncased, se Section 5.3.2.

5.3.2 Drilling

As mentioned in Section 4.1.3, the upper part down to 11.83 m of the borehole was reamed, whereupon a 265 mm stainless steel casing was installed and the gap between the casing and borehole wall was cement grouted. During pilot drilling below casing to to 100.34 m, low water inflow was observed, and the borehole gave the impression of being stable, low-fractured and with a low water yielding capacity. Hence, it did not seem necessary to case the borehole below the already existing casing through the overburden. Borehole section 0-100.29 m was reamed to 196 mm. To avoid an edge at the transition in between the 265 mm casing and the 196 mm borehole, a 200 mm stainless steel casing was installed. The gap between the two casings respectively casing and borehole wall was cement grouted in the upper section 0-11.96 m.

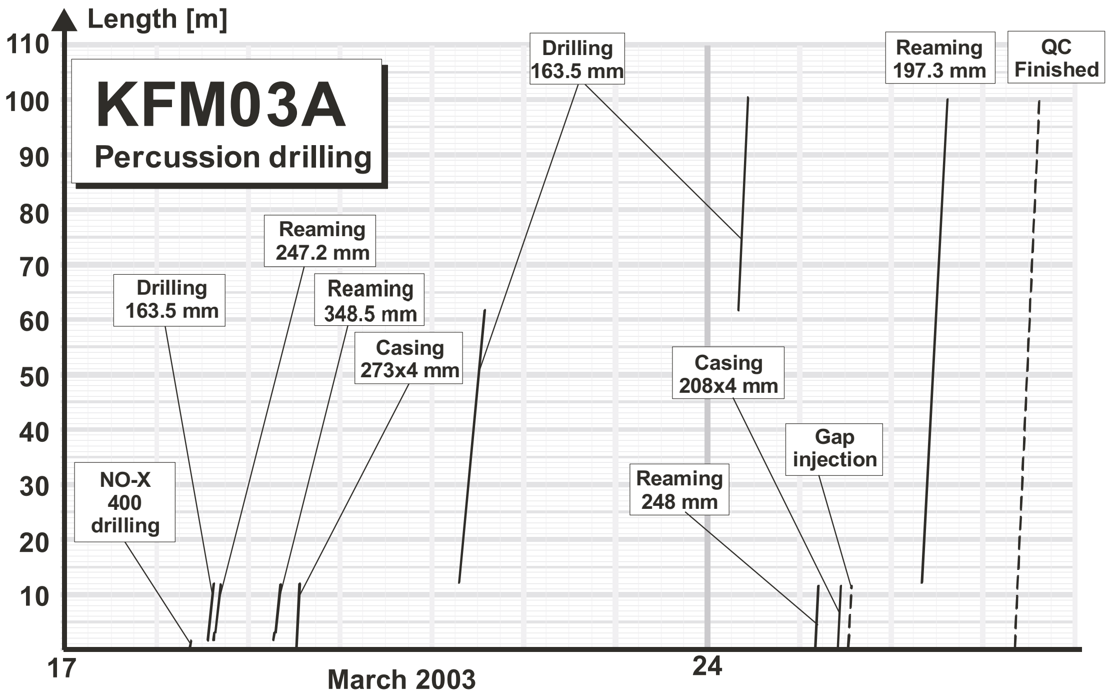


Figure 5-3. Percussion drilling progress.

5.3.3 Measurements while drilling

During, and immediately after drilling, a programme for sampling and measurements was applied, cf. Section 4.1.3. Below, the results of the deviation measurements made after completed percussion drilling of KFM03A (also displayed in the Well Cad-presentation in Appendix A) are commented on. The analyses of drill cuttings from the percussion drilled part of KFM03A are presented in /5/ (rock) and /6/ (soil).

Borehole deviation

The end (bottom) point of the percussion borehole deviates approximately 0.3 m upwards and 1.9 m to the left compared to an imagined straight line following the dip and strike of the borehole collaring point (inclination –85.75º and bearing 271.52º).

5.4 Core drilling 100.34-1001.19 m (KFM03A)

The progress of the core drilling period from April 16th 2003 to June 23rd 2003 is presented in Figure 5-4.

After percussion drilling of section 0-100.34 m and following a drilling stop at DS3, caused by the contractor´s finishing of the previously drilled borehole KFM02A, core drilling in KFM03A commenced as seen in Figure 5-1.

Figure 5-4 demonstrates that the pace of the drilling progress decreases versus time, due to that with increasing borehole length, retrieval of the core barrel, e.g. for change of drill bit, becomes more and more time consuming.

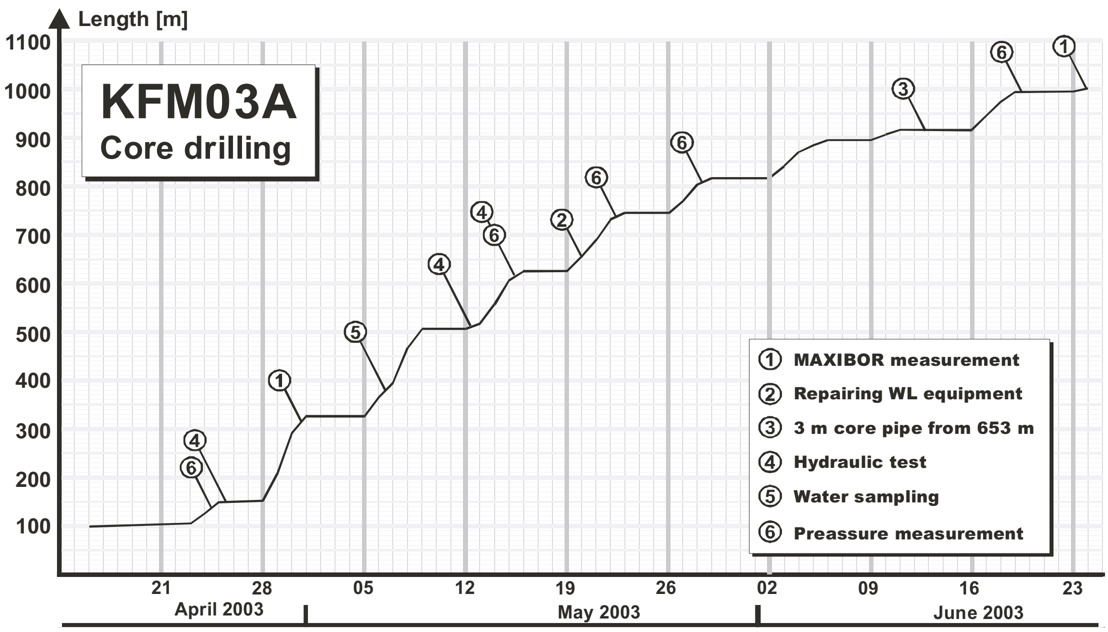


Figure 5-4. *Core drilling progress KFM03A (depth versus calendar time).*

5.4.1 Drilling

The bedrock in the Forsmark candidate area has proved to be surprisingly hard and difficult to drill, probably mostly depending on the high quartz content. However, the upper part of the bedrock at DS3 turned out to be more fractured and more permeable than observed in the previously drilled deep boreholes in the area. This entailed longer life-times of the drill bits consumed in the upper half of the borehole than at greater depths. In average, the drill bit life-time was 42.8 drilled metres in KFM03A, compared to 33.0 m in KFM02A. As a consequence, core drilling of KFM03A was more rapid than before in Forsmark, but still more time consuming and costly than in average granitic rocks.

During, and immediately after drilling, a programme for sampling, measurements, registration of technical and geoscientific parameters and some other activities was applied, as described in Section 4.2.3. The results are presented below. Boremap mapping of the drill core samples from KFM03A is presented in /5/.

5.4.2 Registration of drilling parameters

The letters CCD in the designation "Onram 2000 CCD" is an abbreviation for Computer Controlled Drilling. The Onram hydraulic driving device is supplied with built-in transmitters. The signals provide input to a trigger-unit, and a specific software controls the drilling operations. Additionally, the same data set is stored in a database, which forms one part of the drilling parameters collected for technical control and for geoscientific analyses. Additional drilling parameters are acquired by gauges for flushing and return water flow rate, flushing water pressure, electrical conductivity of flushing and return water and, finally, dissolved oxygen in the flushing water.

A selection of drilling parameters is presented in diagrams below. As regards the complete data set of drilling parameters for KFM03A, it is referred to SICADA, Field Note Nos. 100 and 123 /8/.

Drill bit position versus time

Figure 5-5 shows how the drilling proceeded versus time. Generally, drilling ran 24 hours a day from Monday to Thursday with a weekend stop from Thursday night to Monday morning. For the first time, a new 4.5 metres core barrel was developed and the contractor tested the equipment down to 653 m length. This is observed in Figure 5-5 where the weekly drilling lengths are significant higher down to that length, mainly due to fewer core recoveries, entailing a more efficient drilling. However, the drill core samples suffered from some quality problems, and drilling returned to the 3 m barrel. Figure 5-5 serves as a basis for Figure 5-3, with which it should be compared.

Penetration rate

Borehole KFM03A was the third deep core drilled borehole within the scope of the Forsmark site investigation, and the contractor had gained experience regarding selection of those types of drill bits most appropriate for drilling in the hard Forsmark bedrock. For this reason, the penetration rate, see Figure 5-6, was in average higher than in KFM02A, especially towards greater depths /9/, and still higher than in KFM01A /10/. The high penetration rate may though partly be an effect of a high feed force being applied, se "Feed force" below.

However, the penetration rate in KFM03A displays a decreasing trend versus drilling length, which probably is due to the increasing frictional resistance of the return water flow conducted in the narrow gap between the borehole wall and the pipe string. This reduces the retrieval of drill cuttings and slows down the penetration rate, however not as much as in KFM01A, since the borehole diameter was increased from c. 76 mm, which was applied in KFM01A to 77.3 mm in KFM03A (and KFM02A).

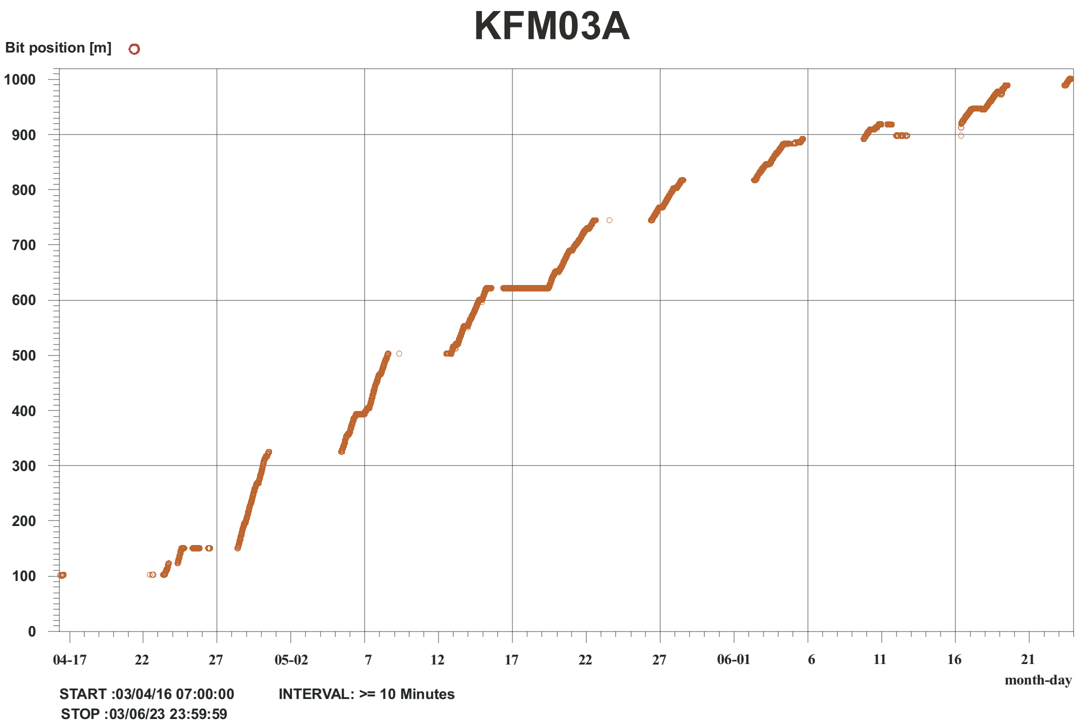


Figure 5-5. *Drill bit position versus time.*

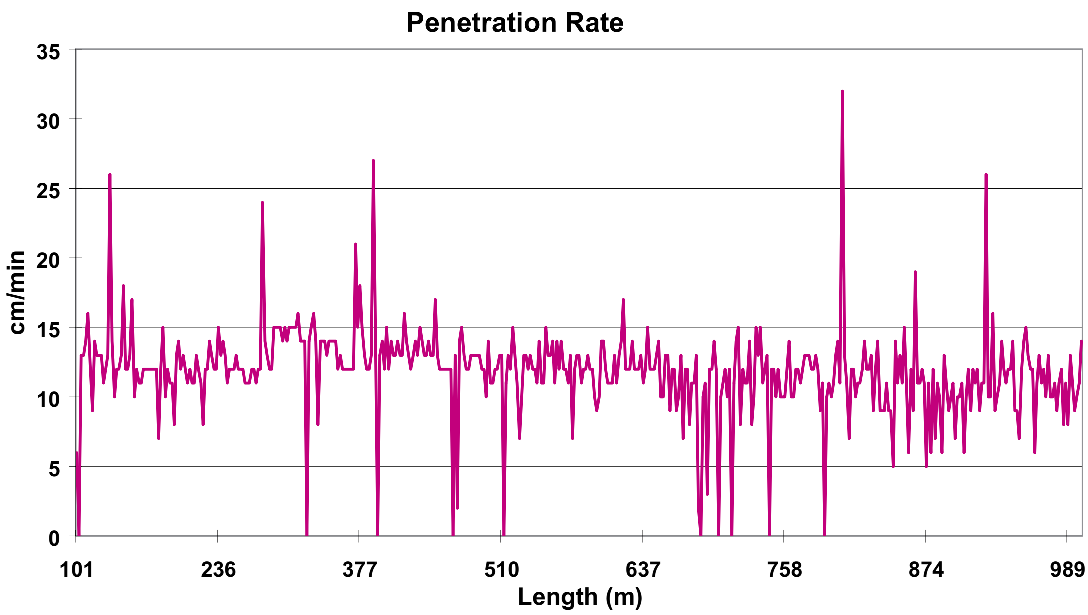


Figure 5-6. *Penetration rate during core drilling of KFM03A.*

Feed force

In Figure 5-7 the feed force is plotted versus borehole length. The average feed force applied in KFM03A was relatively high compared to that in KFM02A /9/ and slightly higher than in KFM01A /10/. A slow increasing trend versus depth is observed, which probably mainly is an effect of increasing frictional resistance of the return water flow.

A rapid feed force increase at about 650 m coincides with exchanging the 4.5 m core barrel to a 3 m barrel including use of a galvanized split tube from 653 m drilled length. A possible reason is that the new, unworn equipment at the beginning is "tighter" in the borehole, which increases the friction, because later on the feed force falls back and keeps its general trend. Decreases down to zero are due to the feed force being shut off.

However, regarding drilling parameters, another factor should be commented on. The drill core from KFM03A exposed quality deficiencies to a higher degree than earlier observed. Long sections of drill cores were helical, i.e. "corkscrew" shaped, and some fracture surfaces showed signs of rotation. When these phenomena had been fully recognized, steps were taken to overcome the problems. This resulted in that, by means of experiment, successive adjustments of several drilling parameters, e.g. feed force and rotation pressure, were made as well as extended drill bit tests. This had an effect on i.a. the penetration rate. Due to these measures, it is difficult to unambiguously connect the variations of for example penetration rate, feed force and rotation speed with specific geoscientific factors.

Rotation speed

From commencement of drilling, the rotation speed was 1000 rpm, see Figure 5-8, the same as applied during drilling of KFM02A. The rotation speed decreased at about 600 m drilling length, and more clearly around 650 m. These drops coincide with exchanging the core barrel mentioned above. Later, the rotation speed stabilizes at 900 rpm. See also the previous section regarding the drill core quality problems.

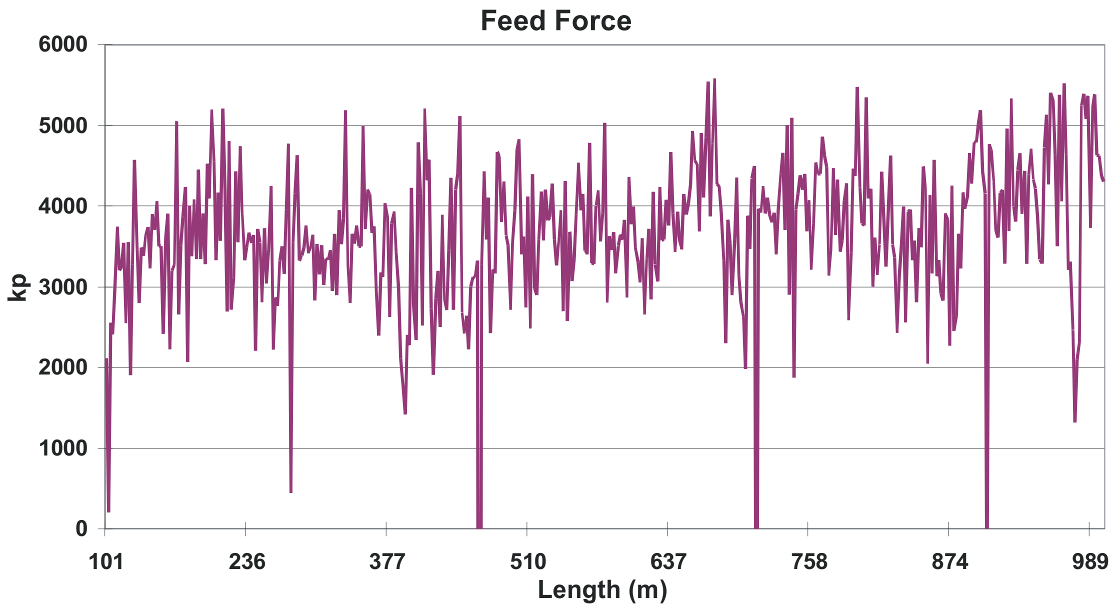


***Figure 5-7.** Feed force versus borehole length during drilling of borehole KFM03A.*

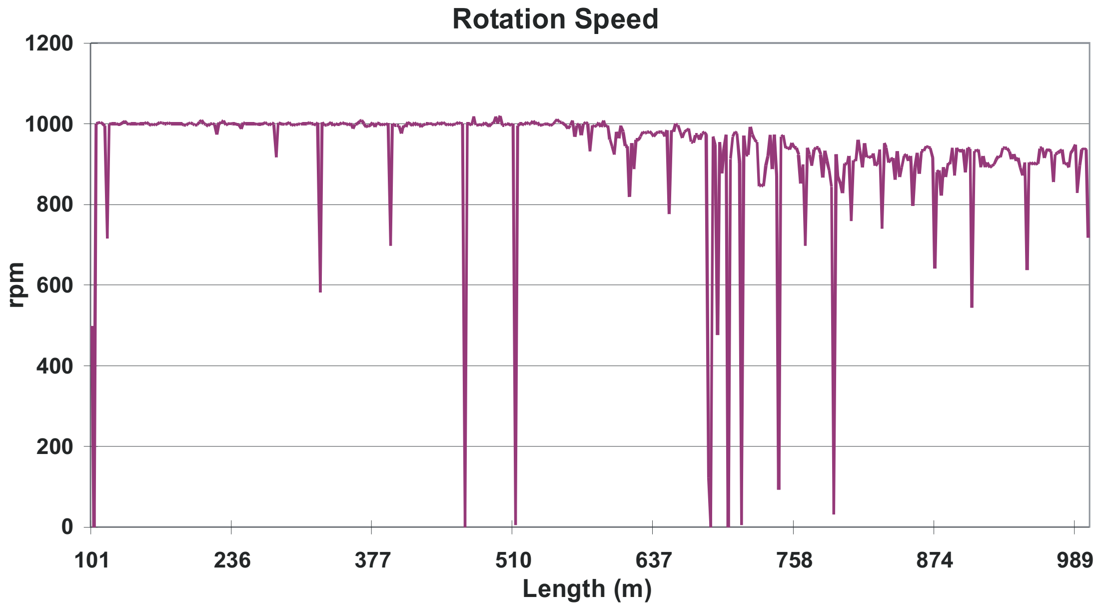


Figure 5-8. Rotation speed versus borehole length during drilling of borehole KFM03A.

5.4.3 Registration and sampling of flushing water and return water

Flushing water and return water flow rate - water balance

As borehole KFM03A is of SKB chemical type, it is important to estimate the amount of flushing water pumped into the borehole during drilling as well as the amount of return water recovered, to permit a water balance calculation. The flushing water flow rate was registered by a flow meter placed at the storage tank outlet leading into the measurement station, see Figure 3-3, and the return water by another flow meter mounted on-line with the discharge pipeline, see Figures 3-3 and 3-6.

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

Figure 5-9 illustrates the accumulated volume of flushing water and return water versus time during core drilling of borehole KFM03A, while Figure 5-10 displays the accumulated volumes of flushing water and return water from the entire drilling period, providing a return water/flushing water quotient of 3.87 (results from Uranine measurements are presented in the next section).

Figure 5-9 shows that the water quotient is exceeds 1.0 already from start, and that the difference in volume of flushing water and return water is steadily increasing, at first in a relatively linear way. By the end of drilling, the flow rate of the return water is obviously decreasing, while the flushing water flow rate keeps constant. In other words, the relative volume difference (water quotient) decreases. This may be due either to less efficient airlift pumping or that a negative hydraulic boundary was encountered by the long-lasting airlift pumping. Shorter duration of the airlift pumping and decreased drawdown by the end of drilling, see Figure 5-14, indicates that the former explanation is most plausible.

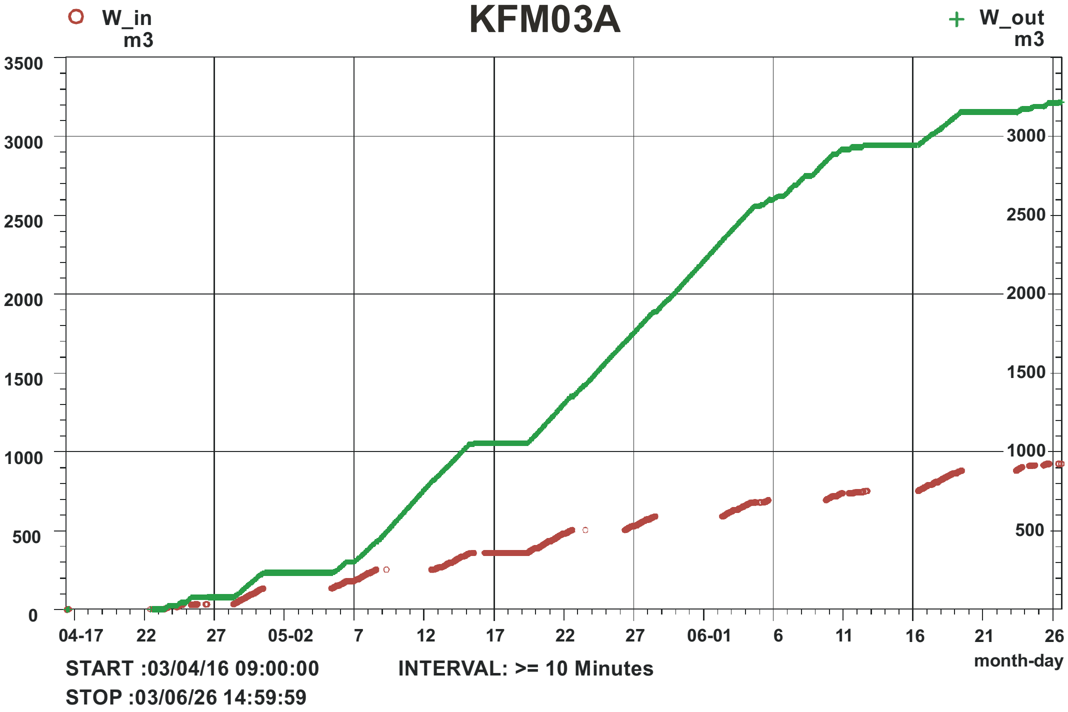


Figure 5-9. Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM03A.

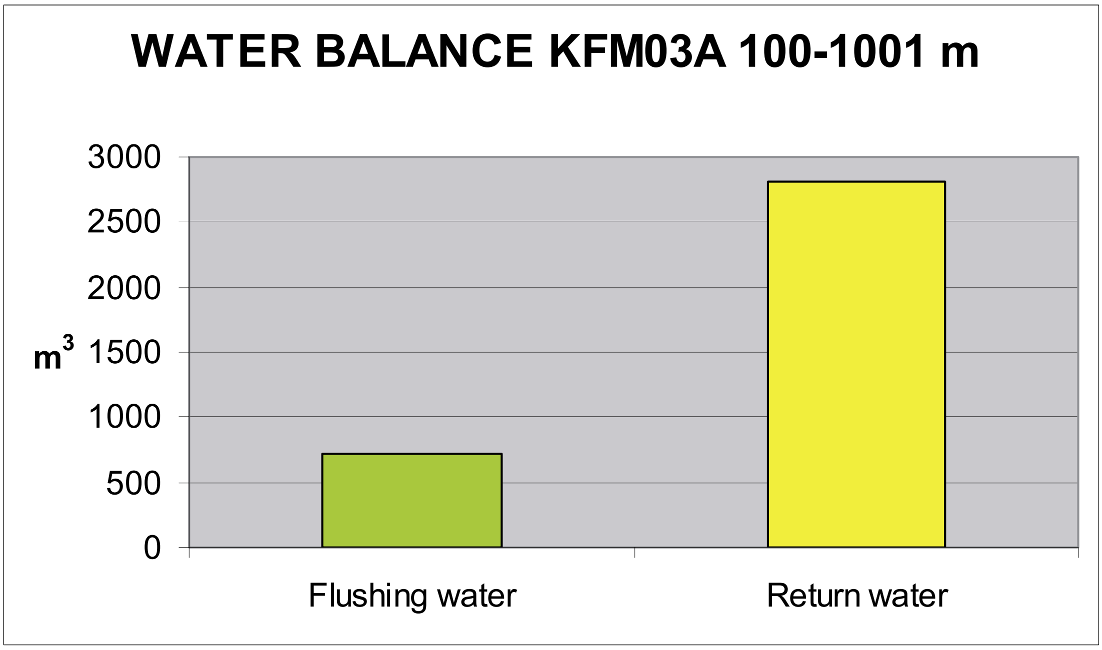


Figure 5-10. The accumulated volume of flushing water used during core drilling of KFM03A was 725 m³. During the same period, the total volume of return water was 2806 m³. The return water/flushing water quotient is then as high as 3.87, due to the large inflow of groundwater into the borehole.

Uranine content of flushing water and return water – mass balance

During the drilling period, sampling and analysis of flushing water and return water was performed systematically with a frequency of approximately one sample per 10-20 m drilling length, see Figure 5-11. Uranine was added to the flushing water by an automatic dosing feeder. The recommended Uranine concentration in the flushing water is 0.20 mg/L. As demonstrated by Figure 5-11, the feeder failed to maintain a stable and correct Uranine concentration. The average concentration for the entire drilling can be estimated at c. 0.10 mg/L, i.e. half of the recommended value.

Regarding the return water, the Uranine concentration is at first in the same range, but slightly lower, as in the flushing water. At c. 380 m drilling length, there is a significant concentration drop, and soon the Uranine content stabilizes at that low level. This indicates that the main part of the flushing water remains in the high-conductive fracture zone encountered at 380 m. Speeding up the return flow rate by airlift pumping (increased drawdown, see Figure 5-14), did not improve the Uranine recovery. Hence, it is probable that the main volume of return water reaching to the ground surface emerges from water yielding fractures in the upper part of the borehole, above 380 m.

A mass balance calculation of the accumulated volumes of flushing water and recovered flushing water in the return water suggests that about 106 m^3 flushing water was lost in the borehole. A conclusion that can be drawn from the Uranine budget calculations is that these are not fully reliable, and that a more frequent sampling is needed in order to obtain more correct information.

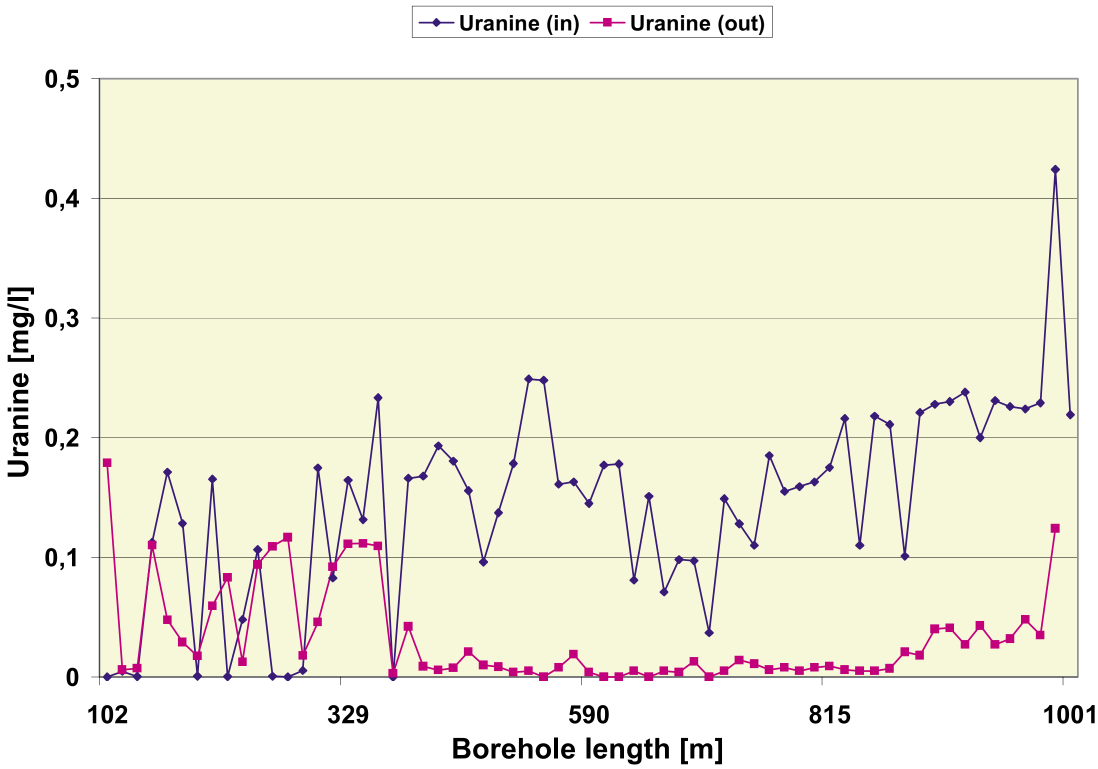


Figure 5-11. *Uranine content versus drilling length in flushing water and return water during drilling of borehole KFM03A.*

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM03A is exposed in Figure 5-12.

The drilling system WL-76, used for drilling of KFM03A, is constructed to give a large core dimension. This, however, entails that the gap dimension between the drilling string and the borehole wall becomes small, resulting in relatively high flushing water pressures to allow the flushing water flow rates needed. Therefore, in borehole KFM03A, the size of the drillbit and centralizers was increased with one mm compared to when drilling KFM01A, resulting in a borehole diameter of 77.3 mm. The increasing trend of the pressure versus drilling length reflects the augmented frictional resistance with increasing length of the drilling string. However, the increased borehole diameter resulted in a significantly lower flushing water pressure than during drilling of KFM01A /10/. The final pressure, i.e. that prevailing during drilling of the last 100 m, was in fact 20-30 bars lower than the final pressure during drilling of KFM01A, and in the same range as the final pressure in KFM02A.

The sudden drop in the pressure curve at c.380 m drilling length demonstrates that a high-conductive fracture zone is struck. During continued drilling between 380-650 m, the water pressure increases almost linearly. A minor pressure drop coincides with the exchange of core barrel mentioned before. From c.800 m the water pressure displays a smooth decrease, probably partly reflecting increased fracture frequency and higher transmissivity, and partly the experiments commented on earlier, which were made in order to improve the drill core quality.

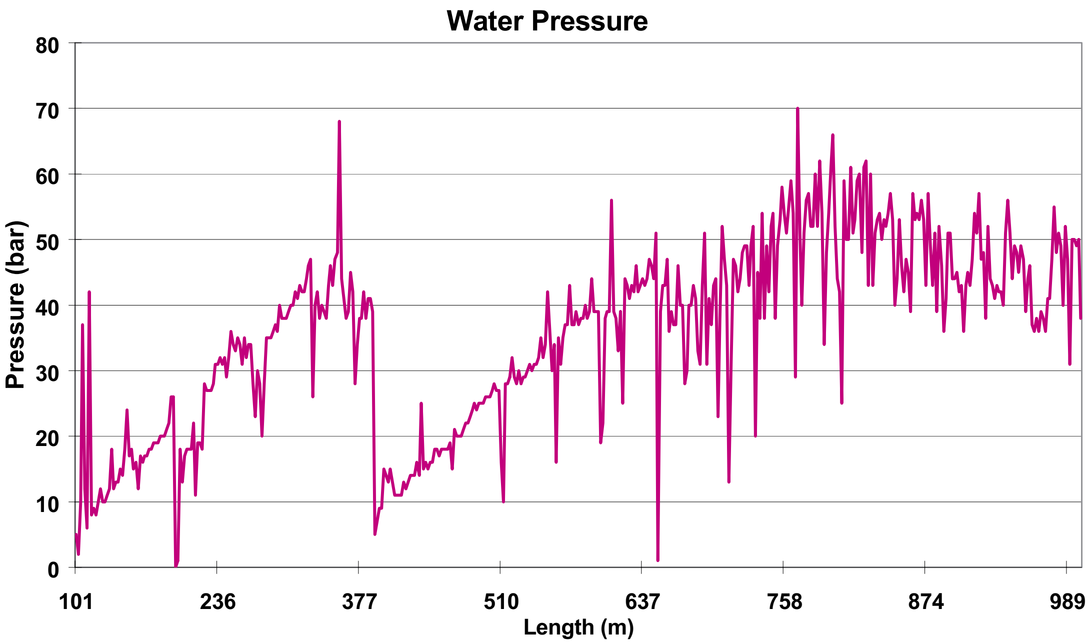


Figure 5-12. *Flushing water pressure versus drilling length when drilling KFM03A.*

Electric conductivity of flushing water

Flushing water was supplied from the c. 101 m deep percussion borehole HFM06, see Figure 1-2, with its major inflow at c. 40-70 m. A sensor for on-line registration of the electric conductivity (EC) of the flushing water, was placed in the measurement station, see Figure 3-3. The position of the sensor for registration of the electric conductivity (EC) of the return water was between the discharge head and the sedimentation containers, see Figure 3-3.

Figure 5-13 demonstrates a difference in electrical conductivity (salinity) of a couple of hundred units (mS/m) of the flushing water from HFM06 and that of the return water from KFM03A. This indicates a major inflow of formation water with a slightly higher salinity into KFM03A at a moderate depth. However, the true difference between flushing water and return water may possibly be larger than indicated by Figure 5-13. The high content of drilling debris and air-bubbles in the return water may cause artificially decreased EC-values. This is supported by the peaks observed in the return water diagram, which are due to the weekend drilling stops. At the end of every weekly drill shift, airlift pumping is stopped, whereupon formation water is recharging into the borehole during the weekend. When air flushing is restarted, the EC-value of the mixed return water is higher for a short moment, because of an increased content of formation water and a lower content of drill cuttings and air bubbles than before the weekend.

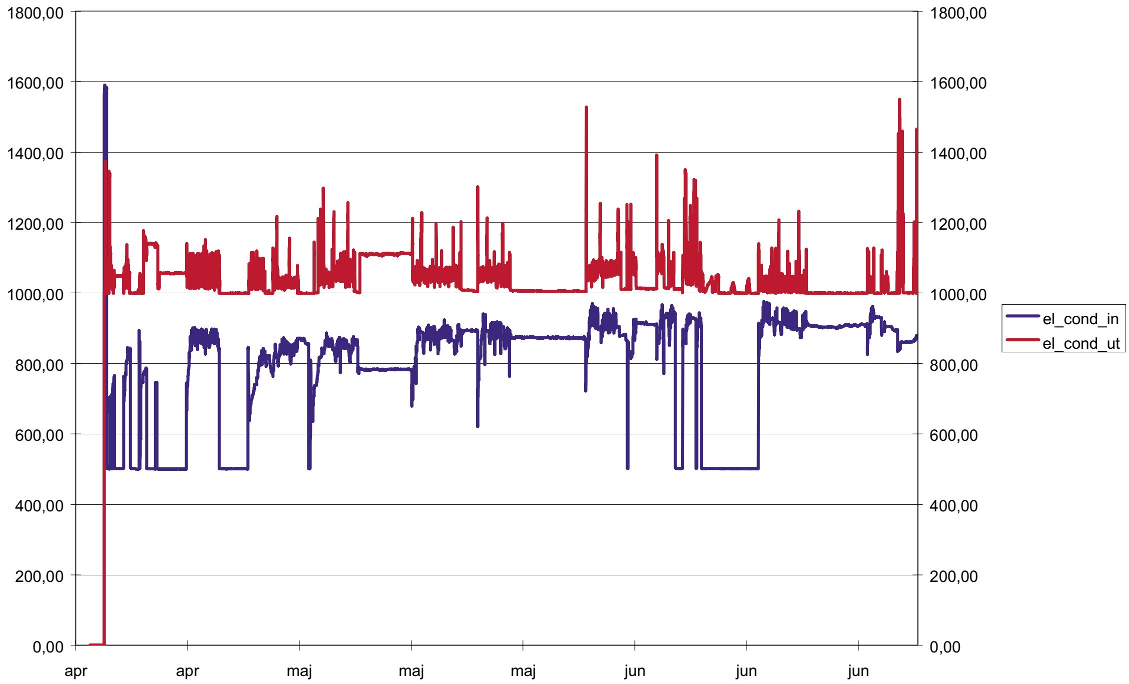


Figure 5-13. *Electrical conductivity in mS/m versus time of flushing water from HFM06 and return water from KFM03A.*

Content of dissolved oxygen in flushing water

The transmitter for measuring dissolved oxygen was out of function from start and could not be exchanged during the drilling period. Hence, no satisfactory readings were made.

Flushing water quality

The results from water analyses of flushing water from the supply well HFM06 are compiled in Appendix D. The flushing water was sampled prior to the core drilling and at a few occasions during the period of core drilling, for the following reasons:

- Initially, to check if the quality was satisfactory.

The main concern is the content of organic constituents, which should be low, preferably below 5 mg/L. The reason is that introduction of hydrocarbons may affect the microbiological flora in the borehole, which would obstruct a reliable characterization of the in situ microbiological conditions.

- To check the microbe content.
- To monitor the water composition.

The chemical composition of the flushing water is important when estimating the effect, or correcting for the effect of remaining flushing water in the water samples from borehole KFM03A.

The results concerning organic constituents, microbes and water composition are commented on below.

Organic constituents

The concentration of Total Organic Carbon (TOC) in the samples collected in HFM06 prior to core drilling was in the range 5.1-5.8 mg/L. These values were considered low enough and it was decided to use HFM06 as the flushing water well without further measures (e.g. using an active carbon filter system for reduction of organic substances as was applied when drilling KFM01A /10/).

Microbes

No check was conducted of the microbe content in the flushing water to KFM03A.

Water composition

The flushing water was sampled at four occasions during drilling and also prior to drilling, in connection with hydraulic testing of borehole HFM06 /11/ and /12/. Furthermore, one sample was collected in August 2003, i.e. after drilling. As shown in Appendix D, the composition of the water from HFM06 changes from time to time, possibly due to the pumping situation (different pumping flow rate, pumping intervals etc). Therefore, a conclusion from this is, that sampling should be performed more frequently, say twice a month during the drilling period.

5.4.4 Registration of the groundwater level in KFM03A

To enhance the recovery of drill cuttings from the borehole, air-flush (mammoth) pumping was applied during the entire drilling period. The effect of the pumping was checked by registration of the groundwater level in the borehole, below plotted versus borehole length (Figure 5-14).

The mammoth pumping was set to a drawdown of in average c. 15 m at the beginning of the drilling period, as vibrations in the drilling string appeared with increased drawdown. From about 400 m borehole length, the drawdown was increased to about 25 m. Drilling was performed continuously during Monday-Thursday. During the weekend stop of drilling and pumping, the groundwater table recovered due to recharge of groundwater into the borehole, resulting in the (positive) peaks in the diagram. When pumping was re-started, a simultaneous drawdown occurred. Minor drawdown variations versus time are observed in the diagram.

5.4.5 Core sampling

The average drill core length per run obtained when drilling KFM03A was 3.35 m. Due to the very low fracture frequency at depth, several 3 m and 4.5 m long, unbroken cores were recovered. Minerals in natural fractures were relatively well preserved. As mentioned, rotation marks on the drill core occurred, but with a rather low frequency. A preliminary on-site core logging was performed continuously.

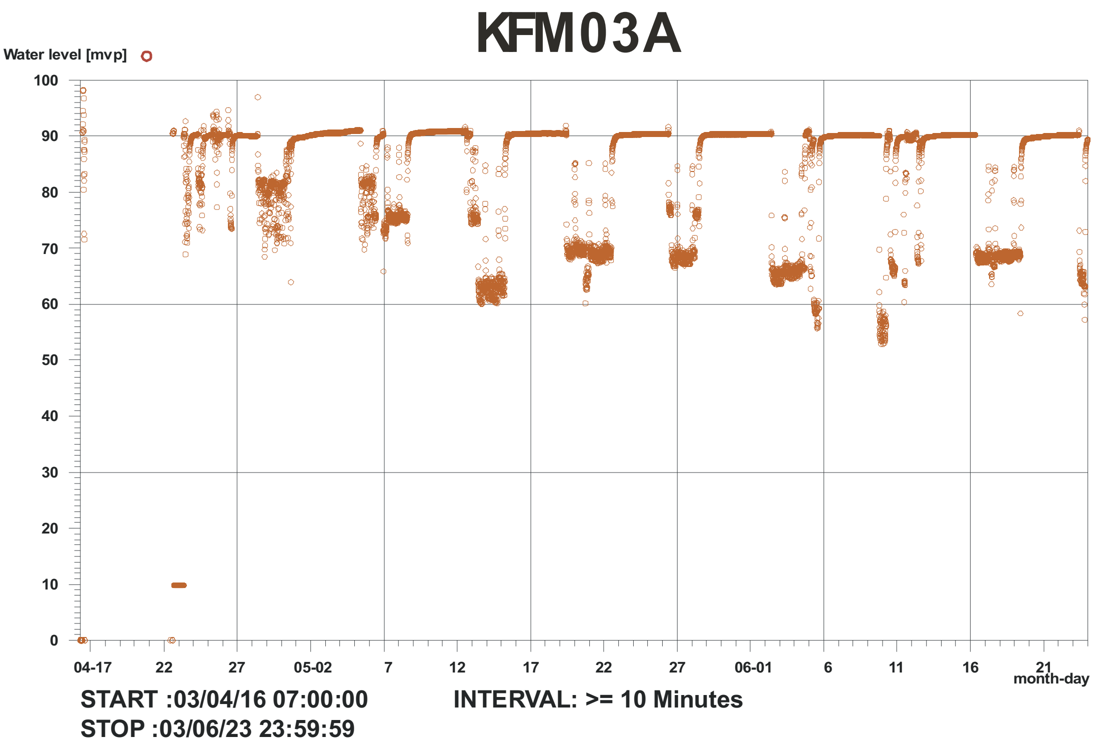


Figure 5-14. *Groundwater table in KFM03A during drilling.*

5.4.6 Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0-100 m) is 5 m^3. Weighing of drill cuttings and comparison with the weight of the theoretical volume was, however, not carried out due to practical/logistic reasons.

The theoretical difference in volume of the core drilled part of KFM03A and the drill core is calculated to be 2.350 m^3. This volume should correspond to the amount of drill cuttings produced during drilling. If a density of 2650 kg/m^3 (approximate figure for granitoids in the Forsmark area) is applied, the total weight of debris is estimated at 6229 kg. The calculated dry weight of the debris is then 3562 kg. The difference between estimated and calculated dry weight of debris is 2667 kg, which gives a recovery of 57 %.

The recovery figure could be commented on. The dwell time in the system is too short for sedimentation of the suspended finest fractions. No estimation was made of the amount of suspended material, but the true recovery is probably somewhat higher than 57 %. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

However, it is probable that relatively large amounts of drilling debris have been injected into the fracture system in the bedrock, in the main into the permeable sections with increased fracture frequency in the upper half of the borehole

5.4.7 Deviation measurements

The deviation measurements made in borehole KFM03A show that the deviation of the borehole is small (see Appendix B). The bottom of the borehole deviates 2 m upwards and 15 m to the right compared to an imagined straight line following the dip and strike of the borehole start point.

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

All length values used for measurements in the borehole and of the drill core emerge from registrations of the length of the drilling 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 of the pipe string, 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 inclination 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 5-15, which is based on load tests performed in the laboratory by the manufacturer of the drilling pipes.

As seen in the diagram, the maximum elongation at 1000 m length in a vertically drilled borehole is 180 mm. In inclined boreholes the elongation of the pipe string should theoretically be less.

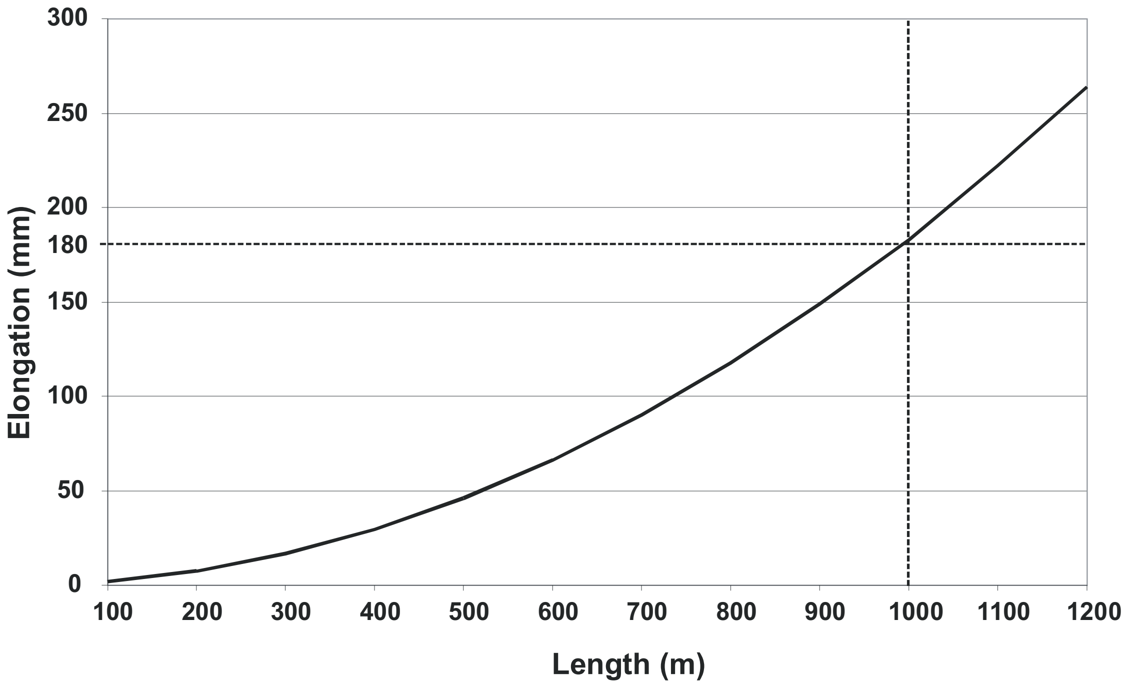


Figure 5-15. The diagram illustrates the elongation of the WL-76 drilling pipe string when hanging in a vertical water filled borehole. Values from a laboratory load tests of the drilling pipe string.

5.5 Hydrogeology

Measurements with the WL-probe are presented in the following sections.

5.5.1 Hydraulic tests during drilling (wireline tests)

Results from pumping tests and absolute pressure measurements from borehole KFM03A are presented in Table 5-2 and Table 5-3.

Pumping tests were performed in three different sections, but only two were successful. Absolute pressure measurements were performed in a total of five sections. Test diagrams are attached in Appendix E1-E5.

For the pumping tests the specific capacity (Q/s) and the hydraulic transmissivity (T_M) were calculated according to SKB MD 320.004, Version 1.0 “Analys av injections- och enhålspumptester” (SKB internal document).

Table 5-2. Pumping tests with WL-probe in KFM03A.

Tested Section (m)	Q/s (m^2/s)	T_{Moye} (m^2/s)	Comments
106.75 - 150.60	-	-	No drawdown in test section, probably due to a non-functioning test valve.
394.20 - 503.00	1.3E-06	1.7E-06	A drawdown of c. 180 kPa was generated in the section. Stable pressure and flowrate were obtained. The flow rate at the end of the test was very low (c. 1.4 L/min) which resulted in uncertain values of Q/s and T_M (due to possible leakage in the pipe string).
504.20 - 621.59	1.8E-07	2.4E-07	A drawdown of c. 230 kPa was generated in the section. Stable pressure and flowrate were obtained. The flow rate at the end of the test was very low (c. 0.25 L/min) which resulted in uncertain values of Q/s and T_M (due to possible leakage in the pipe string).

5.5.2 Absolute pressure measurements

Five absolute pressure measurements were performed, see Table 5-3.

Table 5-3. Absolute pressure measurements in KFM03A.

Test section (m)	Last pressure reading during test (kPa)	Test duration (h)	Borehole length to pressure sensor (m fr. Ref)
106.75 - 150.60	1088	13.2	107.73
504.20 - 621.59	5007	67	505.18
622.63 - 744.60	6186	90	623.61
744.20 - 817.69	7384	115	745.18
817.60 - 992.85	8076	68.7	818.58

5.5.3 Recovery measurements upon airflush cleaning

After completion of drilling at the final length (1001.19 m), the borehole was cleaned by airlift pumping in the section 0-100 m, causing a drawdown of 27 m. The recovery of the groundwater table was registered during the weekend and confirmed the high water yielding capacity of the borehole (Figure 5-16). From the diagram an inflow of >120 L/min can be estimated.

Prior to drilling start of KFM03A, the flushing water well HFM06 was drilled at drilling site DS3. During the period when drilling of KFM03A was ongoing, also percussion drilling of HFM07 and HFM08 (see Figure 1-2) at the drilling site was carried out. The pumping activities in KFM03A respectively in the two percussion drilled boreholes HFM06 and HFM08 at drilling site DS3, revealed hydraulic connections between all three boreholes at shallow levels.

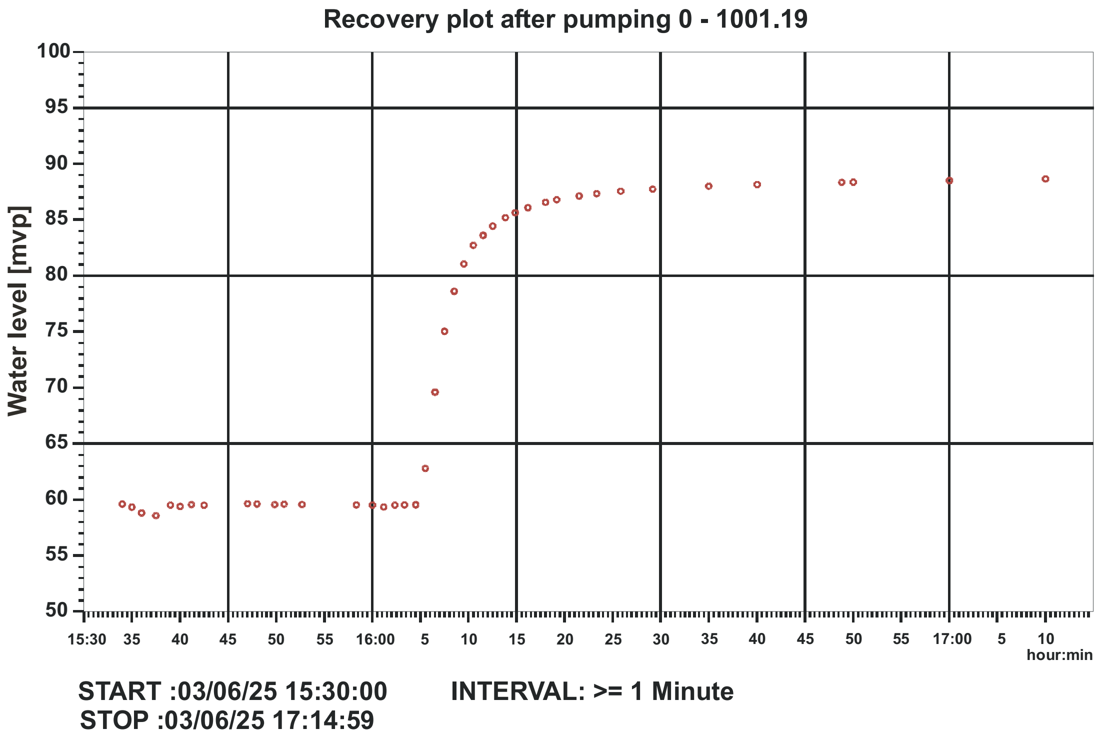


Figure 5-16. Recovery of groundwater table in section 0-1001.19 m of KFM03A.

5.5.4 Groundwater sampling - groundwater quality

A so called first strike WL-sample was collected from section 345-393 m. The flushing water content was quite low, only 9.5 %. Also isotopes were analysed. The results are presented in Appendix C.

5.5.5 Groove milling

After completion of drilling, borehole KFM03A will 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 5-17. Table 5-4 presents the reference levels selected for milling. The table reveals that milling was totally successful. After milling, the reference grooves were detected with the SKB level indicator (a calliper). A BIPS-survey provided the final conformation that the grooves exist.

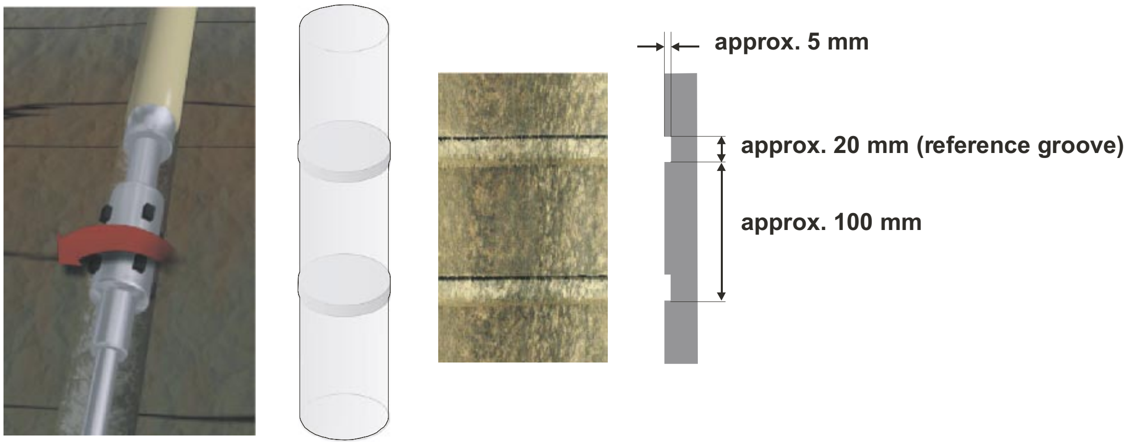


Figure 5-17. *Layout and design of reference grooves.*

Table 5-4. Compilation of length to the reference grooves. The positions of the grooves are determined from the length of the drilling pipes used at the milling process. The length is measured from the upper part of the upper two grooves.

Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS	Reference groove at (m)	Detection with the SKB level indicator	Confirmed from BIPS
110	Yes	Yes	550	Yes	Yes
150	Yes	Yes	600	Yes	Yes
200	Yes	Yes	650	Yes	Yes
250	Yes	Yes	700	Yes	Yes
300	Yes	Yes	750	Yes	Yes
350	Yes	Yes	800	Yes	Yes
403	Yes	Yes	850	Yes	Yes
453	Yes	Yes	900	Yes	Yes
500	Yes	Yes			

5.5.6 Consumables

The amount of oil products consumed during drilling in the percussion drilled borehole (0-100 m) and grout used for gap injections of the respective casings are reported in Table 5-5 and Table 5-6. Regarding hammer oil and compressor oil, these products are indeed entering the borehole but are, on the other hand, continuously retrieved from the borehole due to the permanent air flushing during drilling. After completion of drilling, only minor remainders of the products are left in the borehole.

The special type of thread grease (silicon based) used in this particular borehole was certified according to SKB MD 600.006, Version 1.0, Instruction for the use of chemical products and material during drilling and surveys (SKB internal controlling document). The experience from a technical point of view of the grease, is not satisfactory. Although expensive, the grease had low adhesion capacity to the threads and would therefore increase the risk of contamination in the borehole. Furthermore, the lubrication characteristics were not as good as for conventional lubricants.

Table 5-5. Oil and grease consumption.

Borehole ID	Hammer oil (percussion drilling) Preem Hydra 46	Compressor oil (percussion drilling) Schuman 46	Thread grease (core drilling) Üni Silkon L50/2
KFM03A	10 L	Not detected	5.4 kg

Table 5-6. Cement consumption when sealing the gap between the casing and the reamed borehole wall.

Borehole ID	Casing length (m)	Cement volume (Portland Standard Cement)	Grouting method	Remarks
KFM03A	0-11.86	440 kg/550 L	Hose	
KFM03A	11.96	25 kg		Bottom plug
KFM03A	0.10-11.96	300 kg/240 L	Hose	

5.6 Geometrical and technical design of borehole KFM03B

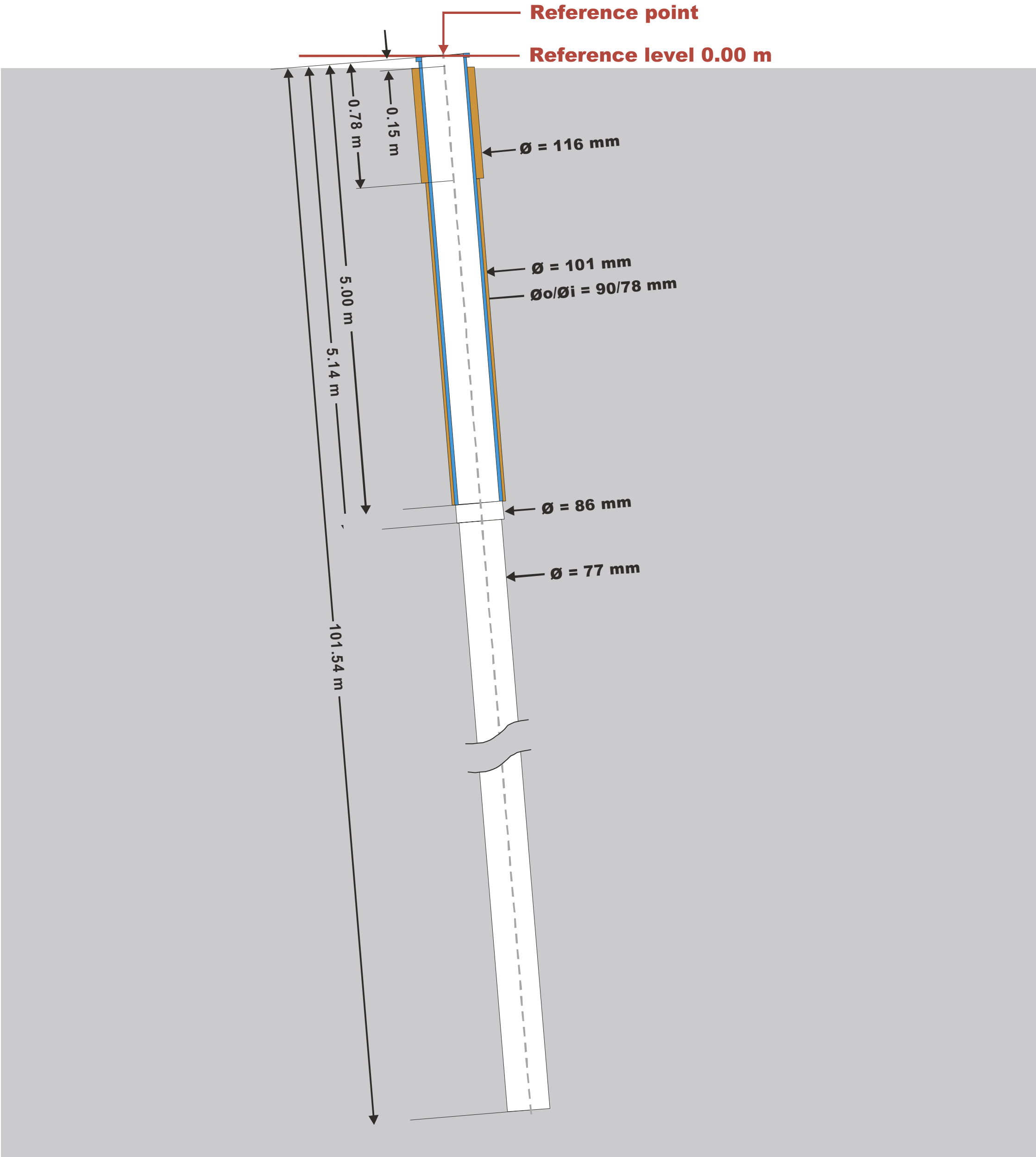
Administrative, geometric and technical data for the telescopic borehole KFM03B are presented in Table 5-7. The technical design of the borehole is illustrated in Figure 5-18.

Table 5-7. Administrative, geometric and technical data for borehole KFM03B.

Parameter	KFM03B
Borehole name	KFM03B
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	June 29, 2003
Completion date	July 02, 2003
Core drilling period	2003-06-29 to 2003-07-02
Contractor core drilling	Drillcon Core AB
Core drill rig	ONRAM 2000 CCD
Position KFM03A at top of casing (RT90 2,5 gon V 0:-15 / RHB 70)	N 6697844.20 E 1634618.98 Z 8.47 (m.a.s.l.)
	Azimuth (0-360°): 264.49° Dip (0-90°): -85.30°
Position KFM03B at bottom of hole (RT90 2,5 gon V 0:-15 / RHB 70)	N 6697843.82 E 1634609.70 Z –92.67 (m.a.s.l.)
	Azimuth (0-360°): 268.74° Dip (0-90°): -84.57°
Borehole length	101.54 m
Borehole diameter and length	From 0.15 m to 0.78 m: 0.116 m
	From 0.78 m to 5.00 m: 0.101 m
	From 5.00 m to 5.14 m: 0.086 m
	From 5.14 m to 101.54 m: 0.077 m
Casing diameter and length	$Ø_o/Ø_i$ = 90 mm/78 mm to 5.00 m Casing length from reference level 5.15 m.
Drill core dimension	0.78-5.14 m / Ø72 mm
	5.14 –101.54 m/ Ø51 mm
Core interval	0.78-101.54 m
Average core length retrieved in one run	2.67 m
Number of runs	36 from 5.14 m (77 mm)
Diamond bits used	3
Average bit life	32.1 m

Technical data

Borehole KFM03B



Drilling reference point

Northing: 6697844.20 (m), RT90 2,5 gon V 0:-15

Easting: 1634618.98 (m), RT90 2,5 gon V 0:-15

Elevation: 8.47 (m), RHB 70

Borehole

Bearing: 264.49°

Inclination: -85.30°

Length: 101.54 m

Percussion drilling period

Drilling start date:

Drilling stop date:

Core drilling period

Drilling start date: 2003-06-29

Drilling stop date: 2003-07-02

Figure 5-18. *Technical data of borehole KFM03B.*

5.7 Core drilling 0.15-101.54 m (KFM03B)

Core drilling of KFM03B was accomplished in one week (Figure 5-19). The thin layer of Quaternary deposits made soil drilling easy. After drilling and reaming, a stainless steel casing of c. 5 m length was installed and gap grouted, see Figure 5-18. Core drilling with 77 mm diameter was terminated after three shifts.

5.7.1 Flushing water and return water flow rate - water balance

Figure 5-20 displays the accumulated volumes of flushing water and return water from the entire drilling period (results from Uranine measurements are presented in the next section). From Figure 5-20, the accumulated volumes of flushing water and return water at the end of the drilling period, gives a return water/flushing water quotient of 0.79.

Uranine content of flushing water and return water–mass balance

During the drilling period, sampling and analysis of flushing water and return water was performed systematically with a frequency of approximately one sample per 10-20 m drilling length, see Figure 5-21. The same dosage feeder as in KFM03A was used in KFM03B for adding the tracer. From the diagram a relatively high Uranine recovery is observed. The main loss occurred in the fracture zone at c. 55 m drilling length.

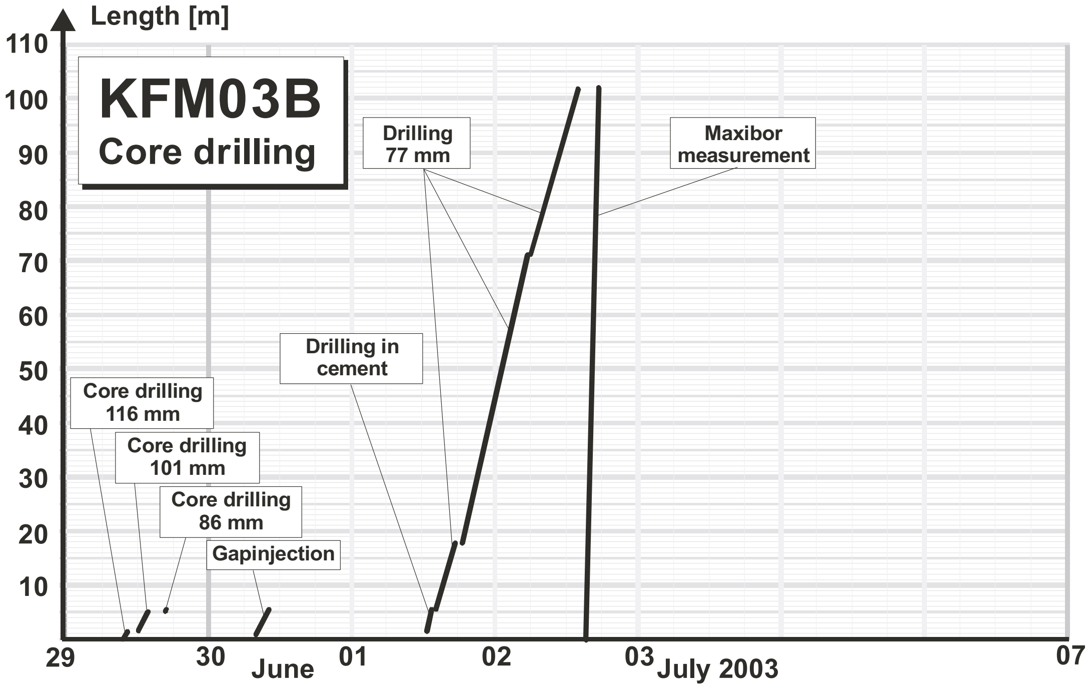


***Figure 5-19.** Core drilling period KFM03B (depth versus calendar time).*

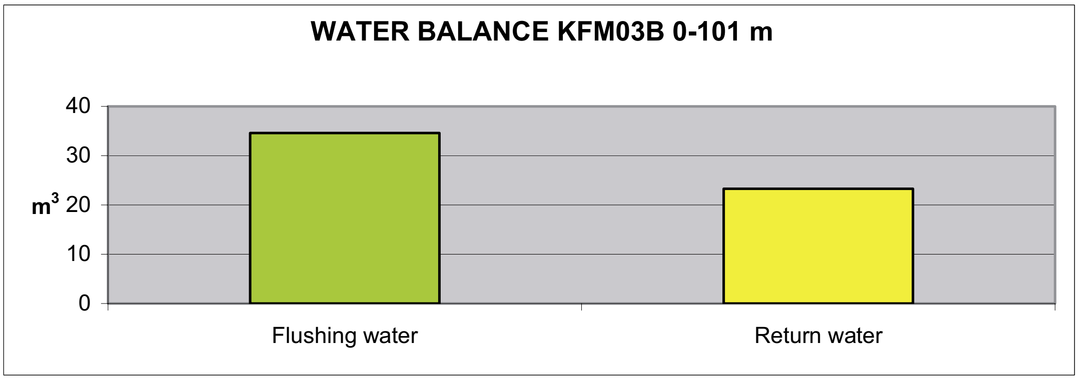


Figure 5-20. *The total volume of flushing water used during core drilling of KFM03B was 33 m³. During the same period, the total volume of return water was 26 m³. The return water/flushing water balance is then 0.79, i.e. below 1.0 due to a major flushing water loss in a fracture zone at approx. 55 m in the borehole.*

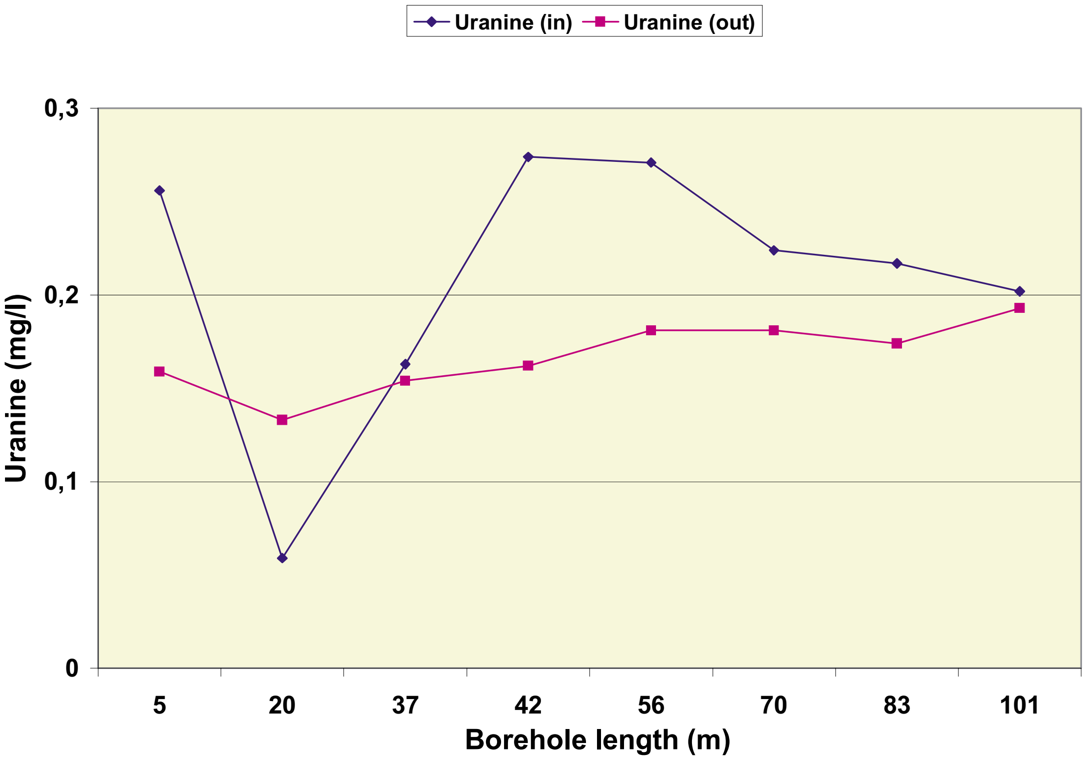


Figure 5-21. *Uranine content versus drilling length in flushing water and return water during drilling of borehole KFM03B.*

6 References

/1/ **SKB, 2001.** Site investigations. Investigation methods and general execution programme. SKB TR-01-29, Svensk Kärnbränslehantering AB.

/2/ **SKB, 2002.** Execution programme for the initial site investigations at Forsmark. SKB P-02-03, Svensk Kärnbränslehantering AB.

/3/ **SKB, 2003.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of a flushing water well, HFM06, and two groundwater monitoring wells, HFM07 and HFM08, at drilling site DS3. SKB P-03-58, Svensk Kärnbränslehantering AB

/4/ **SKB, 2003.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of monitoring wells SFM0006-SFM0008 in soil at drilling site DS3. SKB P-03-57, Svensk Kärnbränslehantering AB.

/5/ **SKB, 2003.** Petersson, J & Wängnerud, A. Site investigations at Forsmark. Boremap mapping of telescopic drilled borehole KFM03A and core drilled borehole KFM03B. SKB P-03-116, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2003.** Sohlenius, G, Rudmark, L and Hedenström, A. Forsmark site investigation. Mapping of unconsolidated Quaternary deposits. Field data 2002. SKB P-03-11, Svensk Kärnbränslehantering AB.

/7/ **SKB, 2003.** Pedersen, K & Kalmus, A. Forsmark site investigation. Control of microorganism content in flushing water used for drilling in KFM03A and KFM04A. SKB P-03-92, Svensk Kärnbränslehantering AB.

/8/ **SICADA.** Field note numbers 100, 123 and 181.

/9/ **SKB, 2003.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of the telescopic borehole KFM02A at drilling site DS1. SKB P-03-52, Svensk Kärnbränslehantering AB.

/10/ **SKB, 2003.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of the telescopic borehole KFM01A at drilling site DS1. SKB P-03-32, Svensk Kärnbränslehantering AB.

/11/ **SKB, 2003.** Nilsson, A-C. Forsmark site investigation. Sampling and analyses of groundwater in percussion drilled boreholes at drillsite DS 3. Results from the percussion boreholes HFM06 and HFM08. SKB P-03-49, Svensk Kärnbränslehantering AB.

/12/ **SKB, 2003.** Källgården, J, Ludvigson, J-E & Jönsson, S. Pumping tests and flow logging. Boreholes KFM03A (0-100m), HFM06, HFM07 and HFM08. SKB P-03-36, Svensk Kärnbränslehantering AB.

Well Cad presentation of the percussion drilled part of borehole KFM03A.

Title PERCUSSION DRILLED BOREHOLE KFM03A

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM03A	**Northing [m]**	6697852.10
Diameter [mm]	196	**Easting [m]**	1634630.74
Length [m]	100.34	**Elevation [m.a.s.l.]**	8.29
Bearing [°]	271.52	**Drilling Start Date**	2003-03-18 09:10:00
Inclination [°]	-85.74	**Drilling Stop Date**	2003-03-28 14:30:00
Date of mapping		**Plot Date**	2004-06-15 21:05:36

ROCKTYPE SOIL

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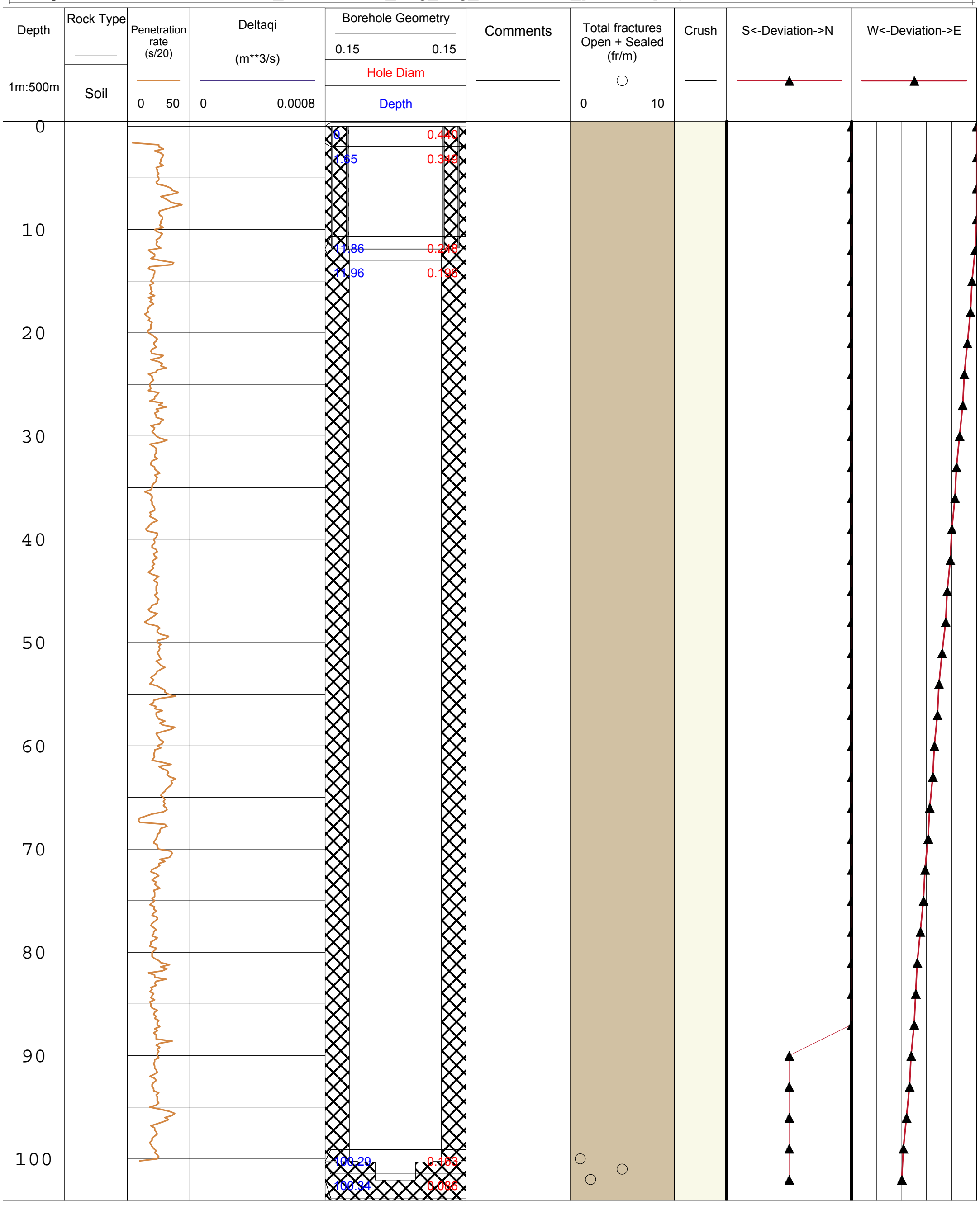


Well Cad presentation of the core drilled part of borehole KFM03A

Title KFM03A

Svensk Kärnbränslehantering AB

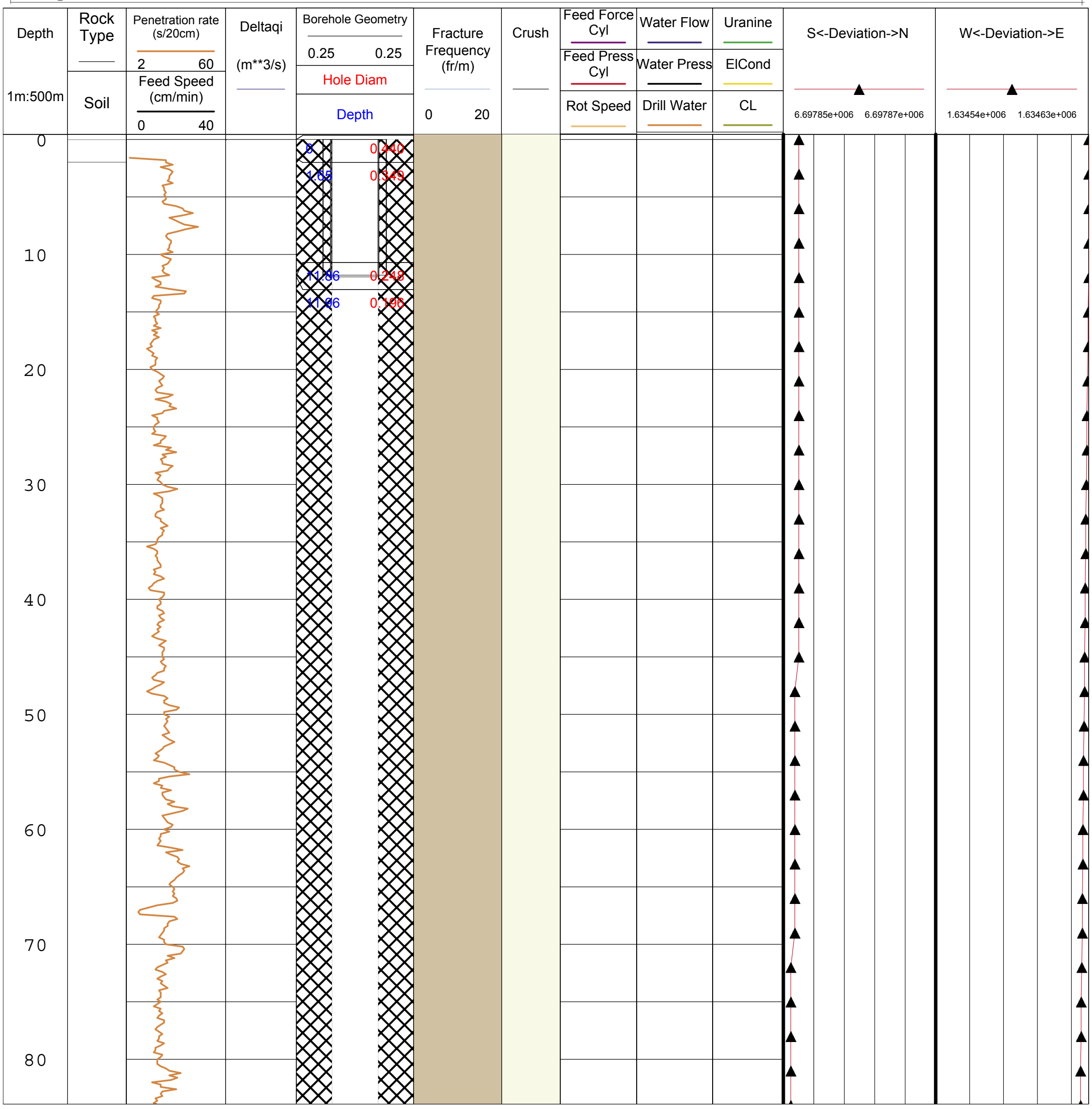
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM03A	**Northing [m]**	6697852.10
Diameter [mm]	77	**Easting [m]**	1634630.74
Length [m]	1001.19	**Elevation [m.a.s.l.]**	8.29
Bearing [°]	271.52	**Drilling Start Date**	2003-03-18 09:10:00
Inclination [°]	-85.74	**Drilling Stop Date**	2003-06-23 16:15:00
Date of mapping		**Plot Date**	2004-06-15 21:05:36

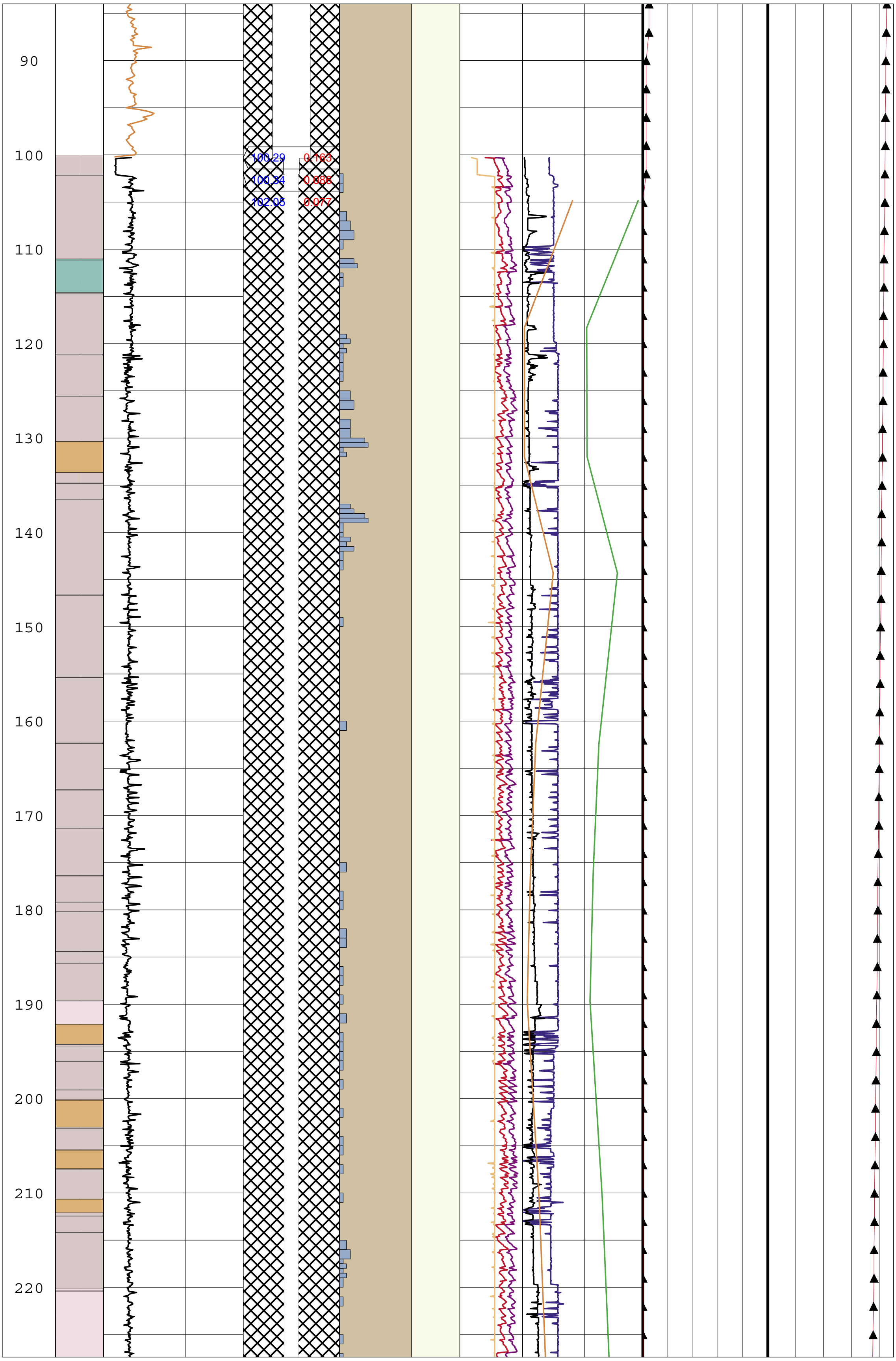
ROCKTYPE FORSMARK

- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite to granodiorite, metamorphic, medium-grained
- Tonalite to granodiorite, metamorphic
- Amphibolite

SOIL

Script Name

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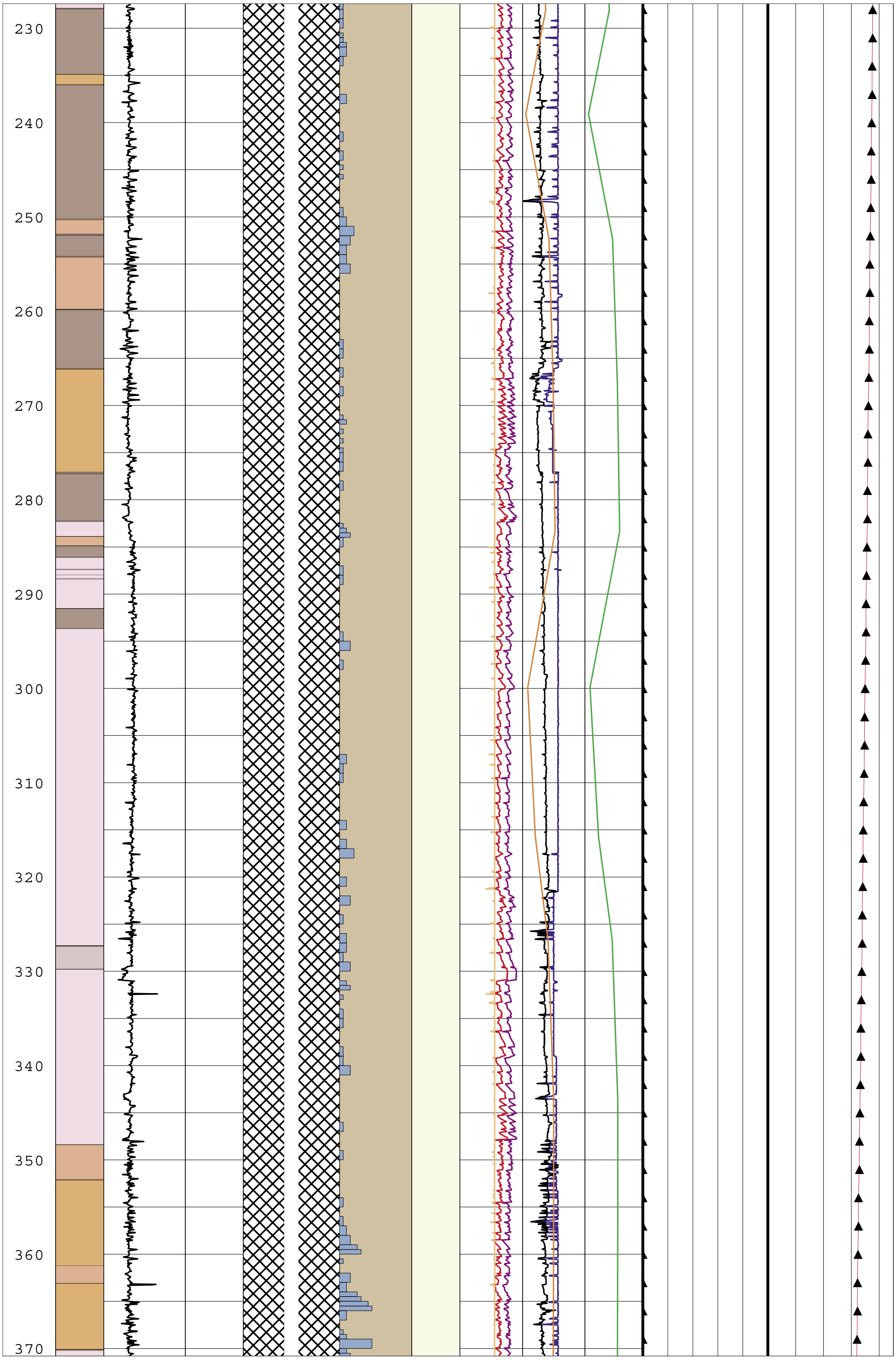
0.077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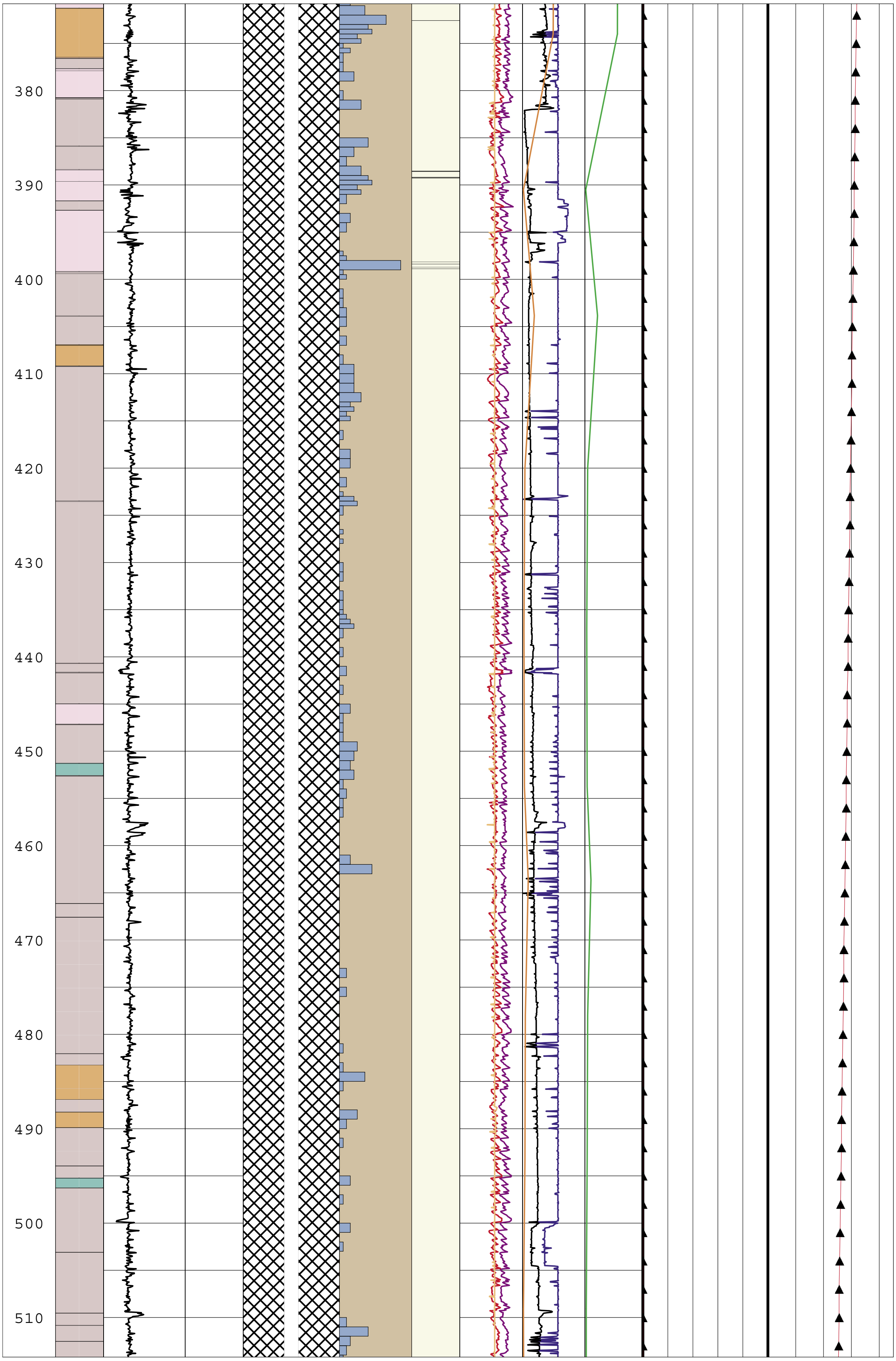
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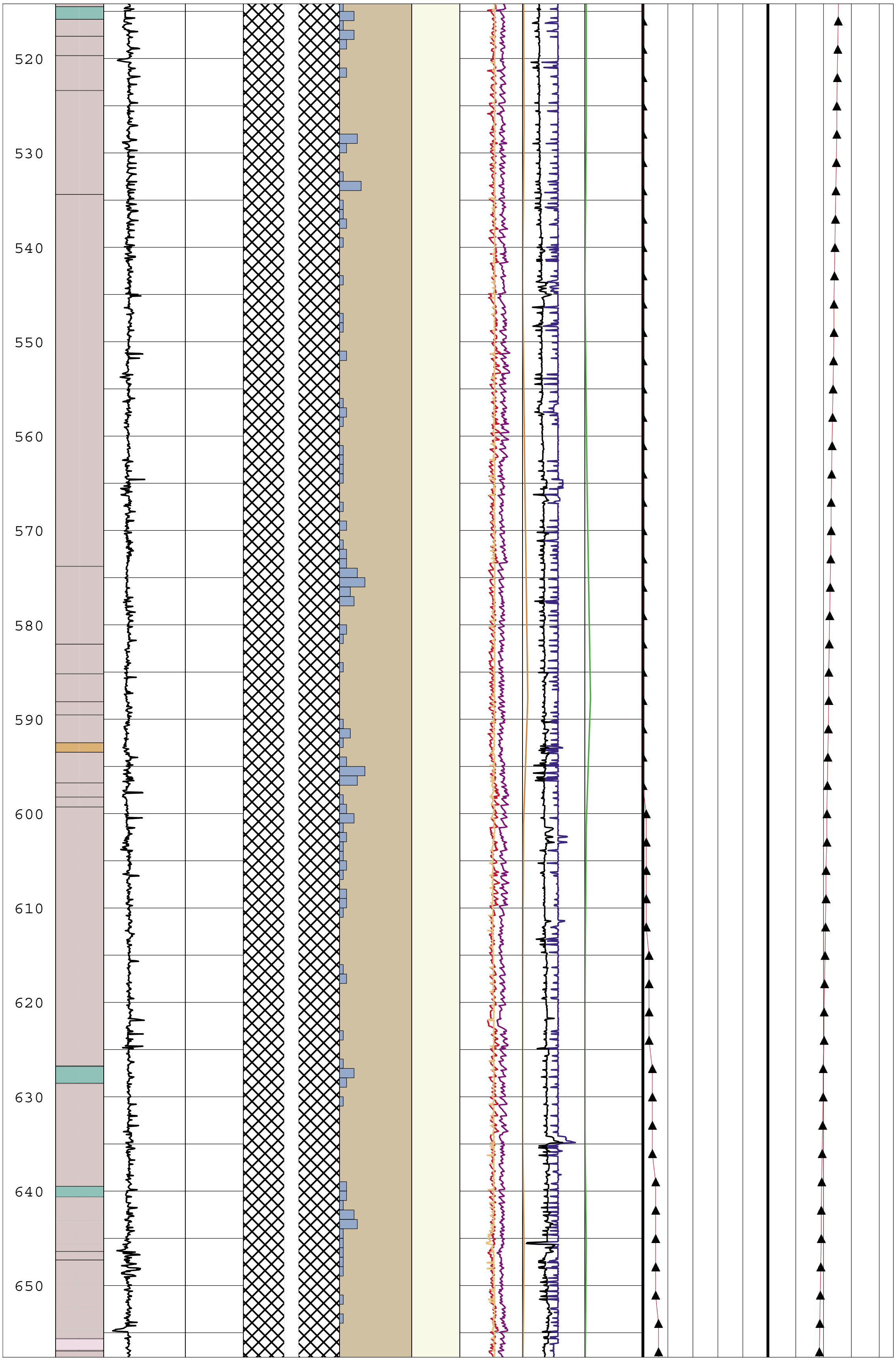
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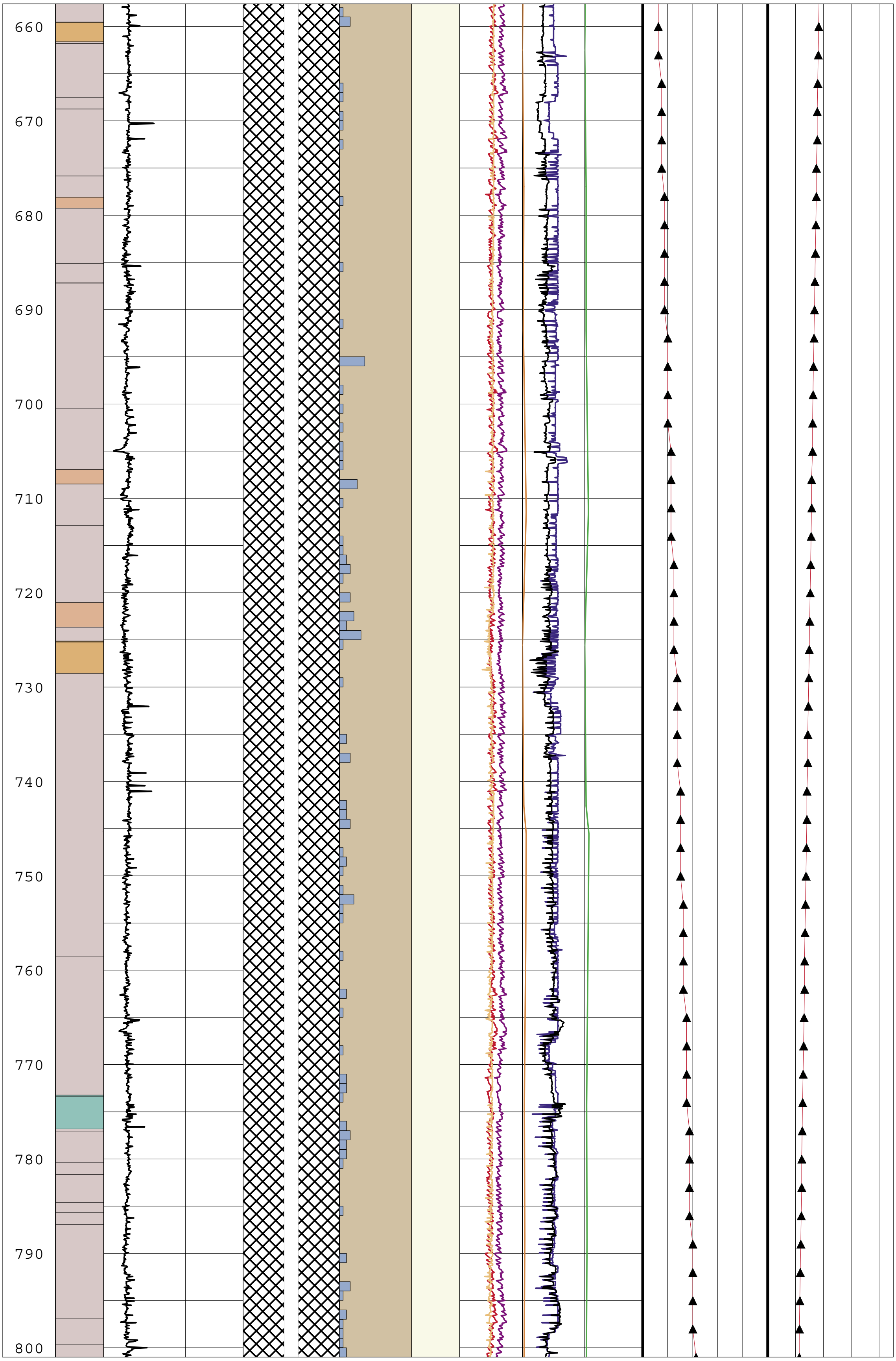
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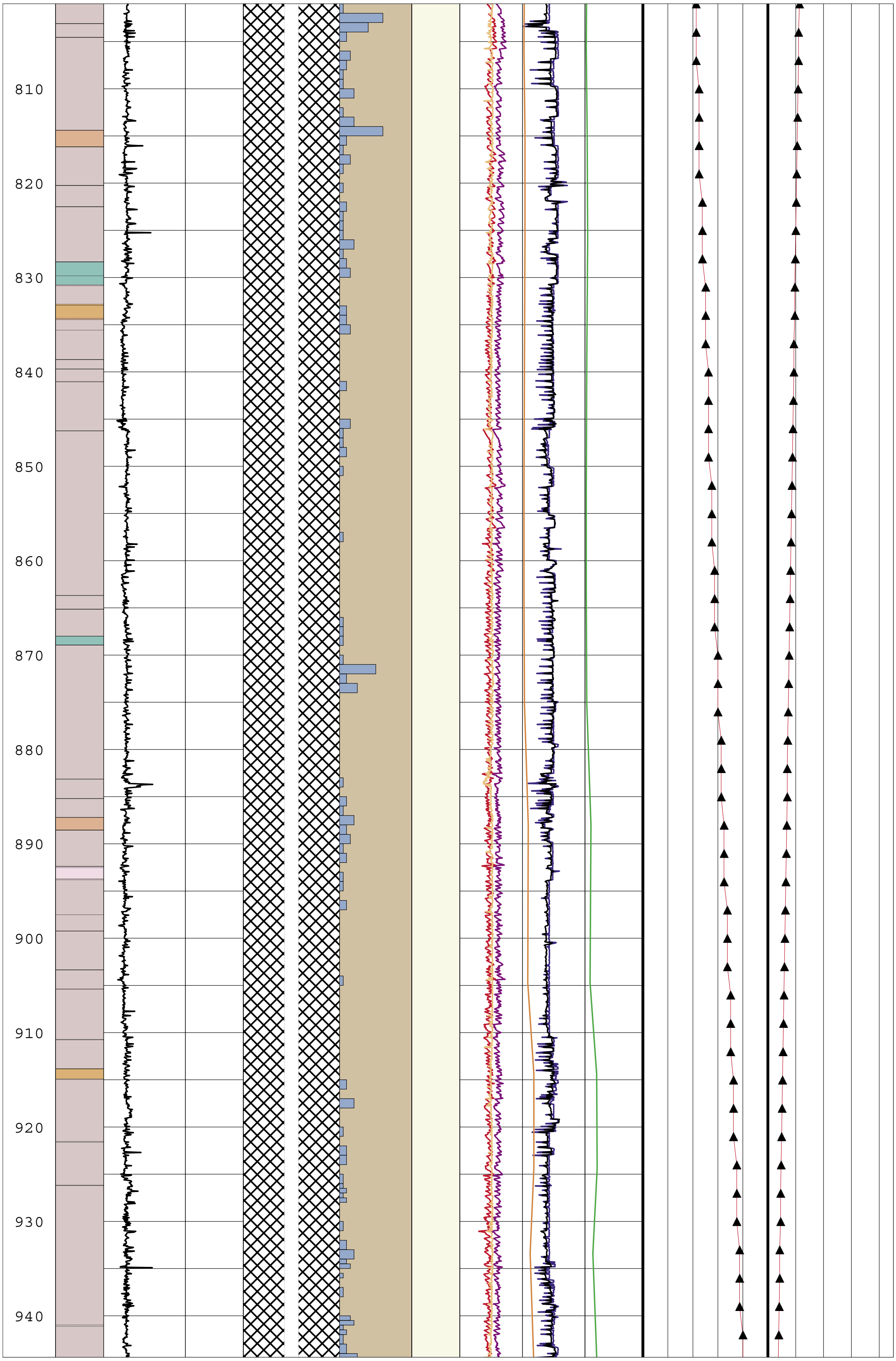
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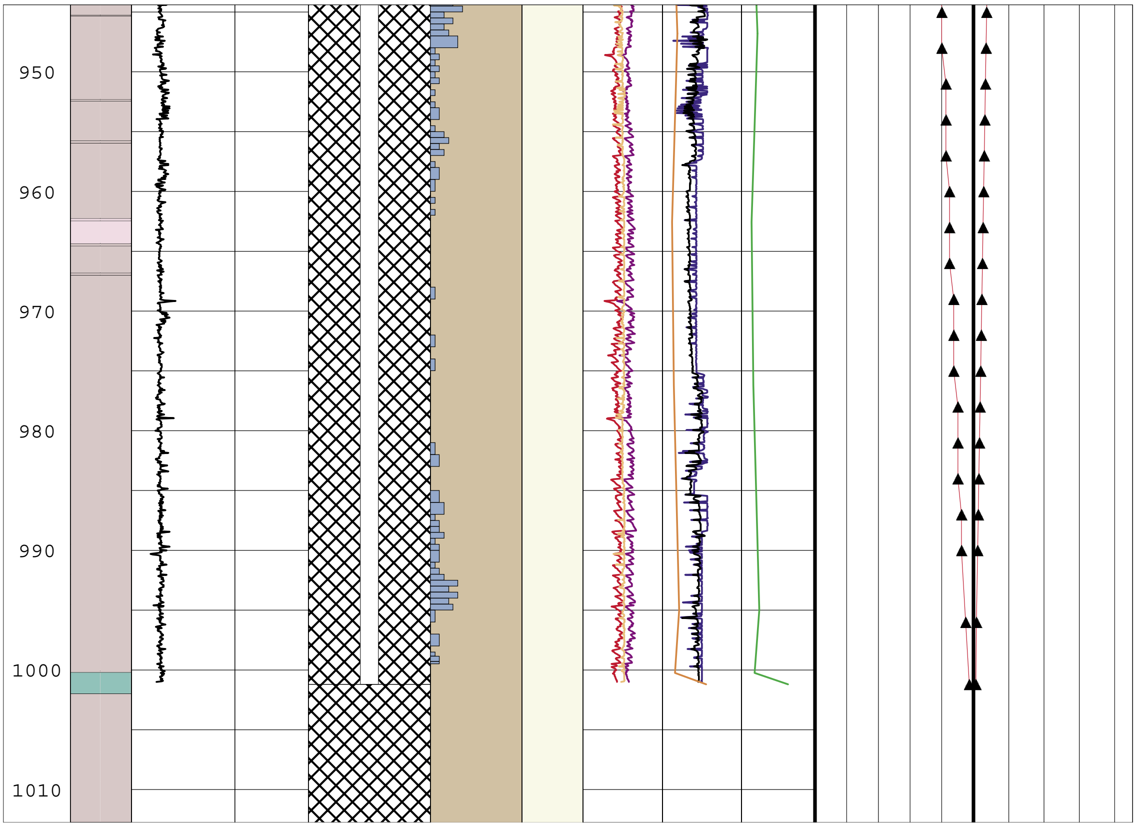
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1000
1010

Well Cad presentation of the core drilled borehole KFM03B

Title KFM03B

Svensk Kärnbränslehantering AB

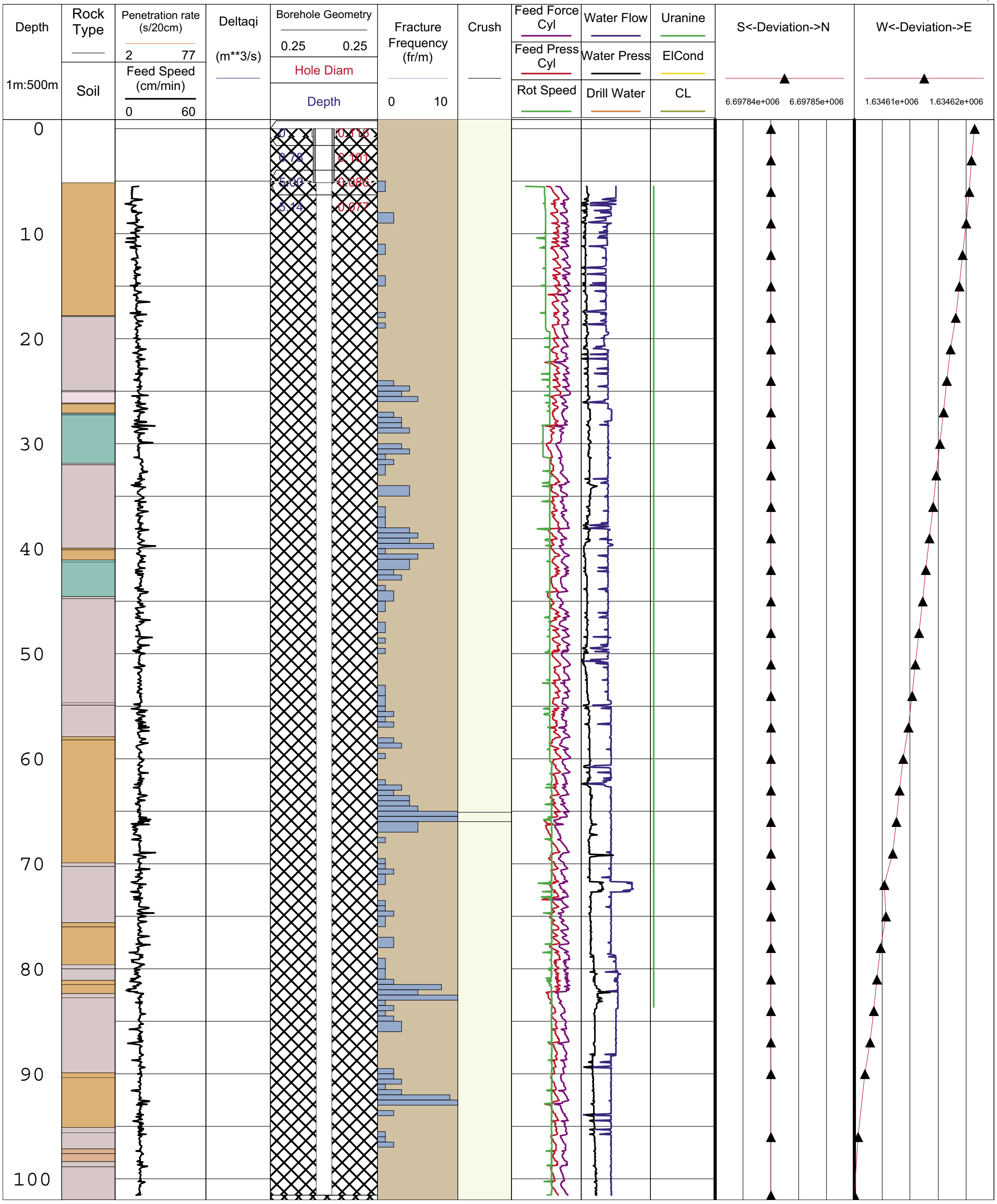
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	KFM03B	**Northing [m]**	6697844.20
Diameter [mm]	77	**Easting [m]**	1634618.68
Length [m]	101.54	**Elevation [m.a.s.l.]**	8.47
Bearing [°]	264.49	**Drilling Start Date**	2003-06-29 09:30:00
Inclination [°]	-85.30	**Drilling Stop Date**	2003-07-02 14:05:00
Date of mapping		**Plot Date**	2004-06-22 21:01:59

ROCKTYPE FORSMARK

SOIL

- **Granite, fine- to medium-grained**
- **Pegmatite, pegmatitic granite**
- **Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Amphibolite**

Script Name



Appendix D

Water Composition

IDCODE	SECUP	SECLOW	SAMPLE _NO	DATE	WATER_TYPE	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	SO_4-S (mg/L)	Br (mg/L	F (mg/L)	Si (mg/L)	Li (mg/L)
HFM06	0,00	110,70	4463	2003-01-21 11:55:00	Ground Water	384	17,6	73,3	20,4	231	476	135	44,1	1,87	1,70	5,03	0,010
HFM06	0,00	110,70	4464	2003-01-21 16:52:00	Ground Water	447	19,1	92,9	27,0	418	586	156	50,0	2,25	1,60	5,09	0,012
HFM06	0,00	110,70	4465	2003-01-21 21:50:00	Ground Water	519	21,4	125	37,2	404	797	173	55,5	3,02	1,48	5,21	0,015
HFM06	0,00	110,70	4618	2003-01-21 08:55:00	Ground Water	629	28,2	175	54,5	372	1110	208	71,6	3,71	1,80	4,73	0,017
KFM03A	346,65	393,65	4768	2003-05-06 22:30:00	Wire line sample	1930	45,7	844	205	145	x	x	149	19,5	x	6,70	0,047

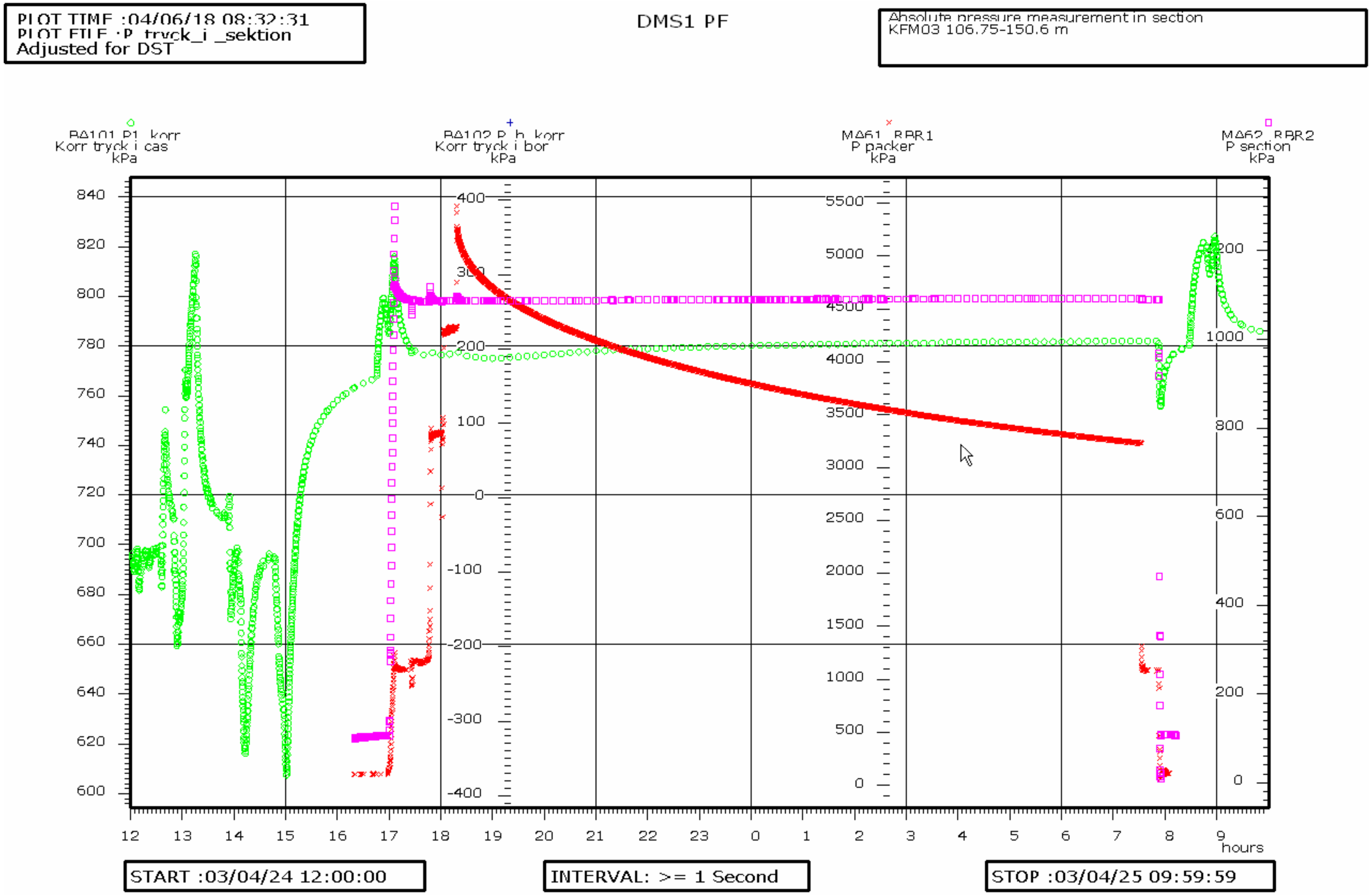
IDCODE	SECUP	SECLOW	SAMPLE _NO	DATE	WATER_TYPE	Sr (mg/L)	pH	TOC (mg/L)	I (mg/L)	El. Con (mS/m)	Flush water (%)
HFM06	0,00	110,70	4463	2003-01-21 11:55:00	Ground Water	0,43	7,65	5,7			
HFM06	0,00	110,70	4464	2003-01-21 16:52:00	Ground Water	0,60	7,58	5,8			
HFM06	0,00	110,70	4465	2003-01-21 21:50:00	Ground Water	0,85	7,57	5,1			
HFM06	0,00	110,70	4618	2003-01-21 08:55:00	Ground Water	1,25	7,57	5,1			
KFM03A	346,65	393,65	4768	2003-05-06 22:30:00	Wire line sample	7,06	7,55	1,9	0,036	1470	9,5

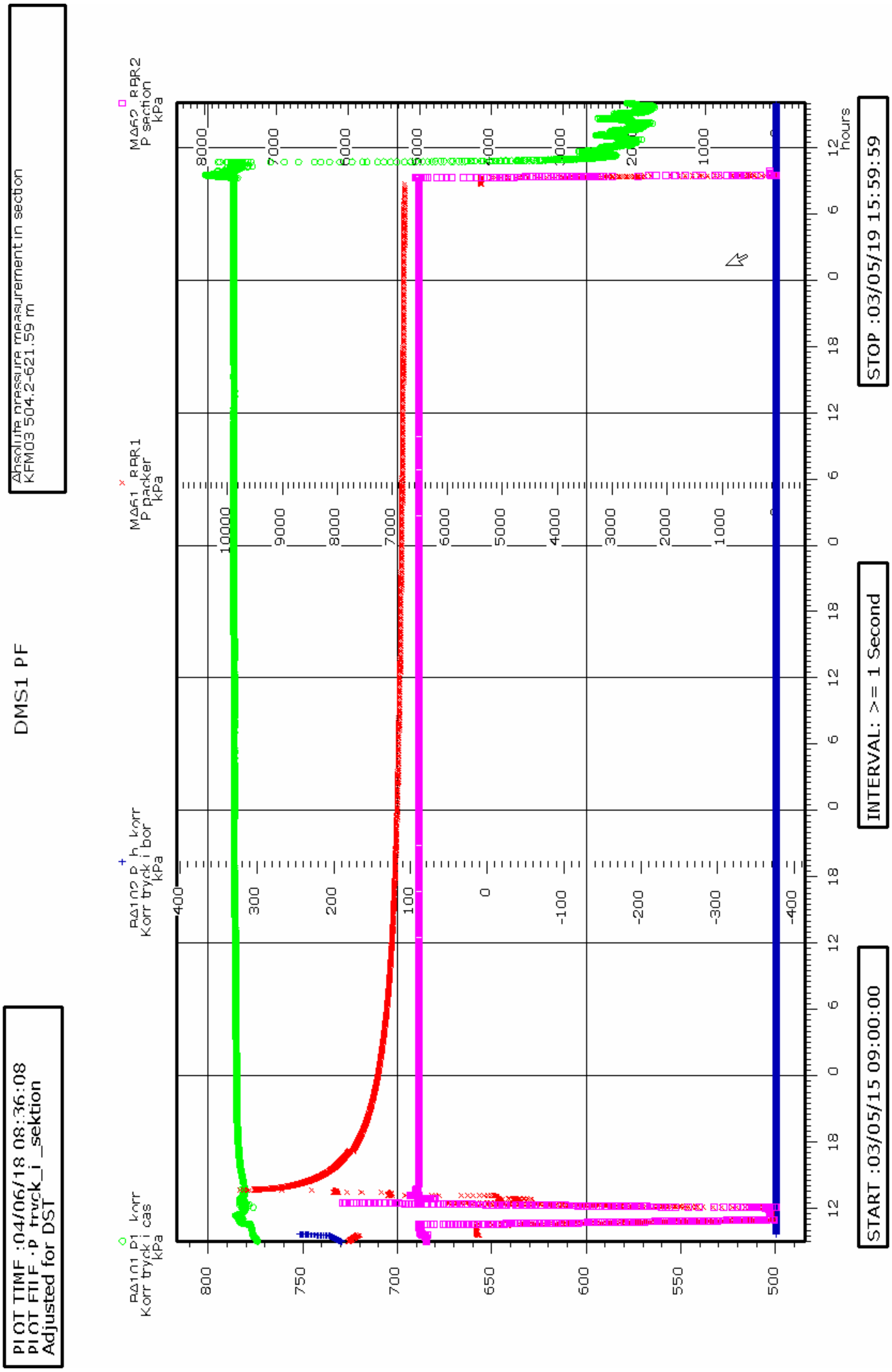
Isotop data

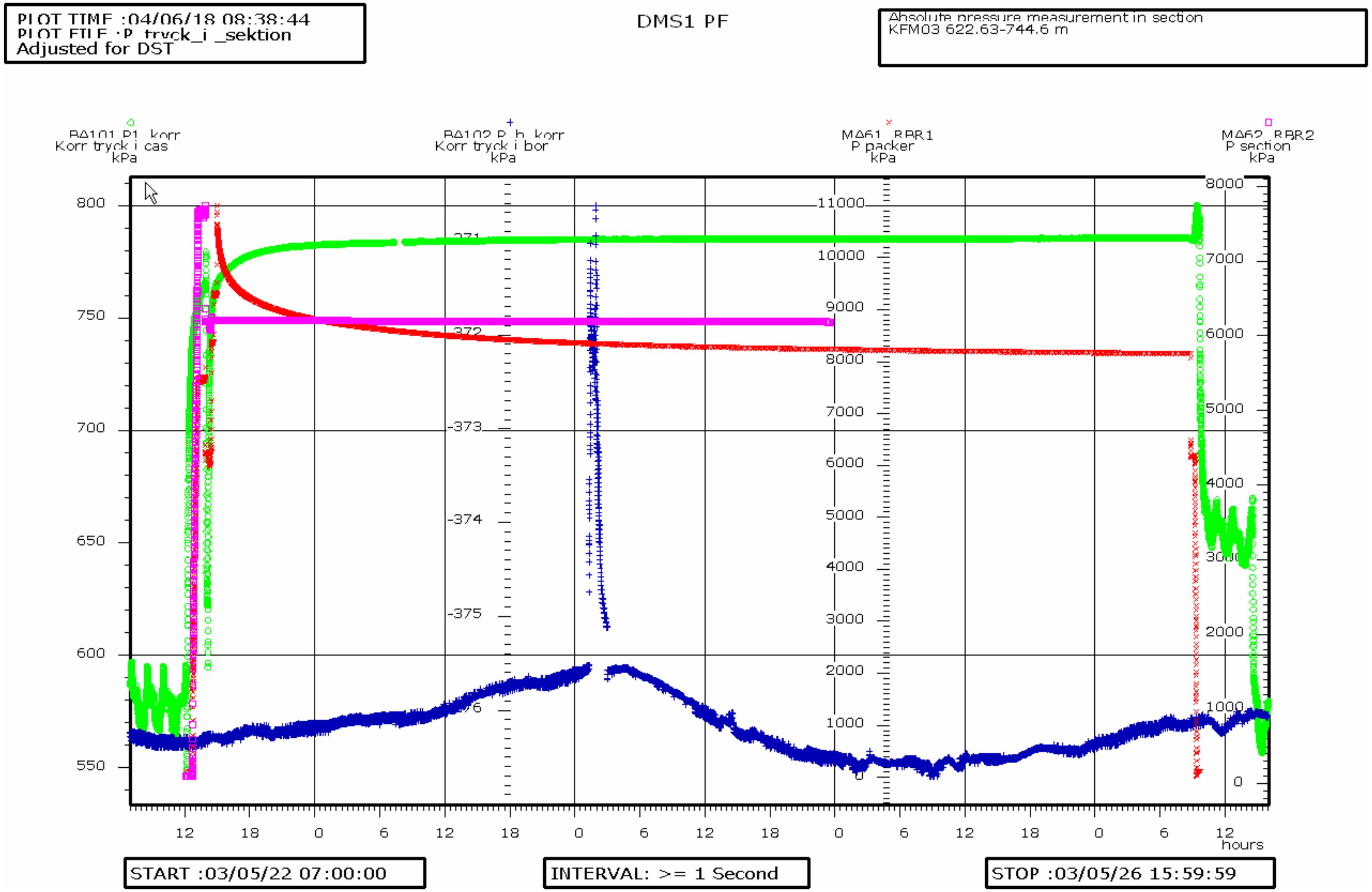
IDCODE	SECUP	SECLOW	SAMPLE _NO	DATE	WATER_TYPE	? D (SMOW)	Tr (TU)	? ^{18}O (SMOW)	^{14}C (pmC)	? ^{13}C (PDB)	AGE BP (years)	$^{10}B/^{11}B$	? ^{34}S (CDE)	? ^{37}Cl (SMOC)	$^{87}SR/^{86}SR$
HFM06	0,00	110,70	4463	2003-01-21 11:55:00	Ground Water	-82,6	6,40	-11,20	66,26	-11,98	3255	0,2403	12,3	0,11	0,720612
HFM06	0,00	110,70	4464	2003-01-21 16:52:00	Ground Water	-81,2	5,70	-11,10	64,70	-11,76	3447	0,2404	13,5	0,18	0,719862
HFM06	0,00	110,70	4465	2003-01-21 21:50:00	Ground Water	-80,3	5,10	-10,90	63,96	-11,76	3539	0,2400	14,6	0,45	0,719383
HFM06	0,00	110,70	4618	2003-03-06 08:55:00	Ground Water	-79,9	5,70	-10,60	61,06	-11,30	3911	0,2408	17,3	0,24	0,718808
KFM03A	346,65	393,65	4768	2003-05-06 22:30:00	Wire line sample	-77,9	-0,80	-9,30	36,33	-12,6	8080	0,2385	24,2	-0,23	0,718721

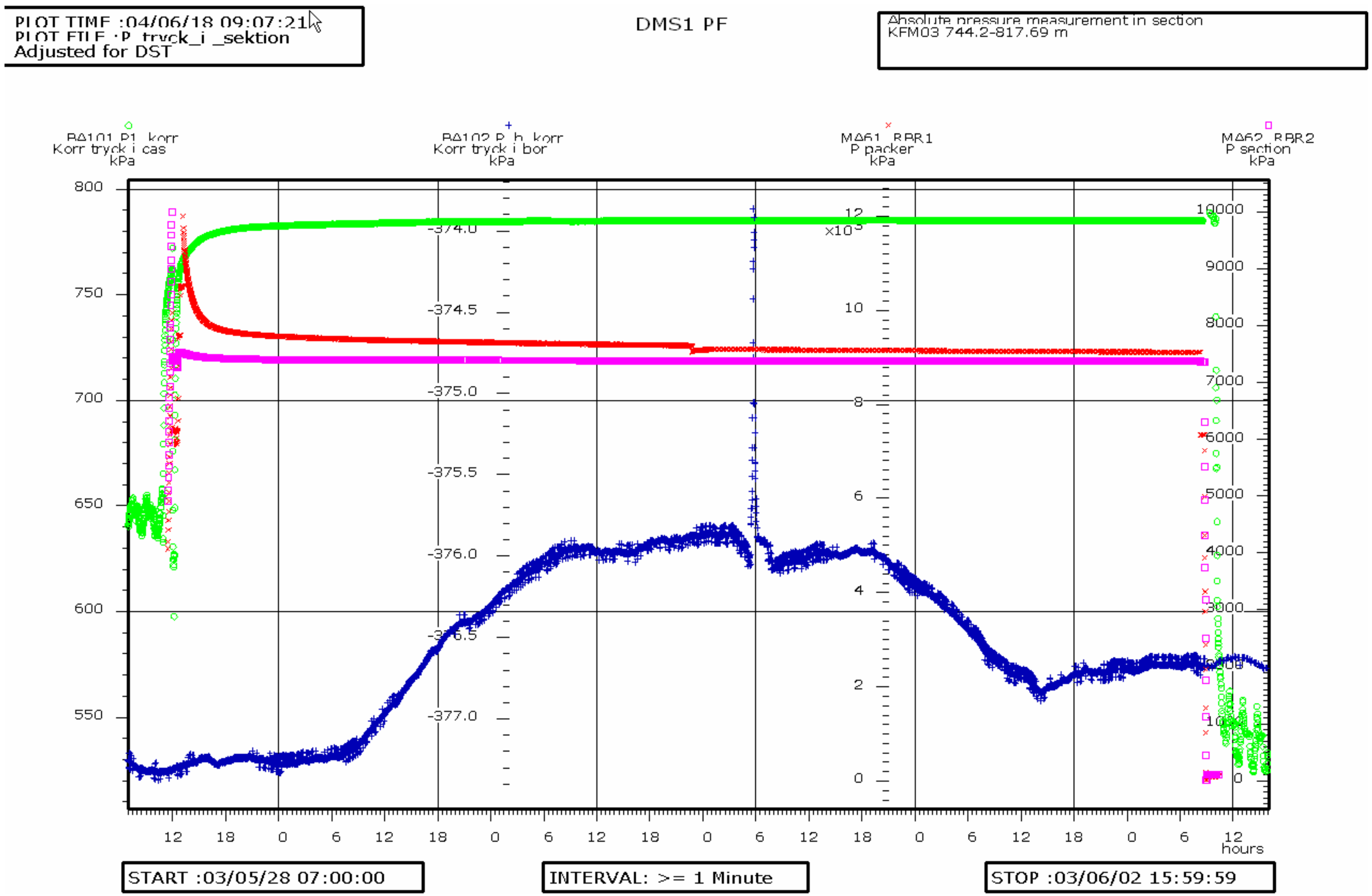
Appendix E

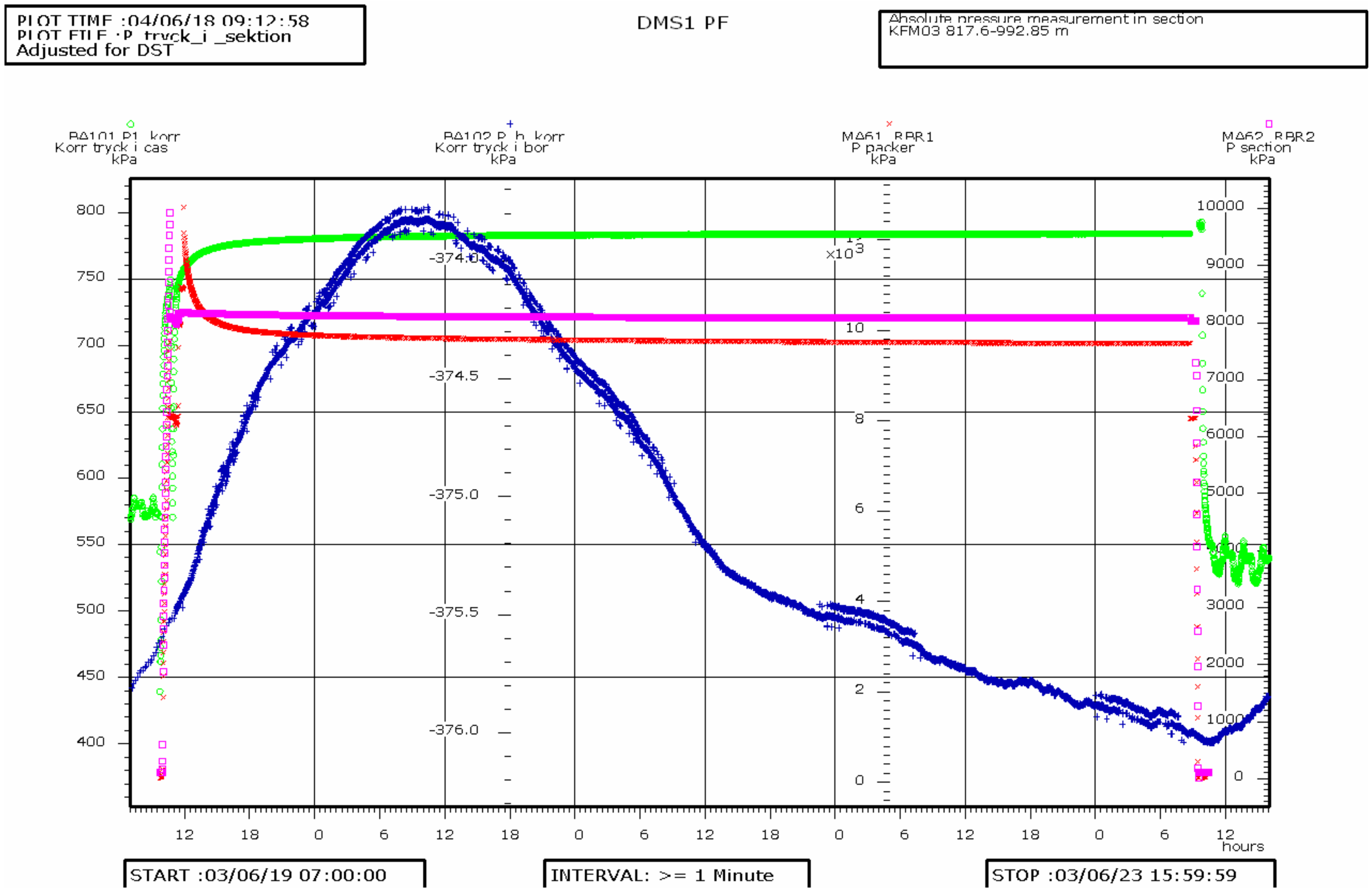
Hydraulic tests




PLOT TIME :04/06/18 08:36:08
PLOT FILE :P tryck_i_sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM03 504.2-621.59 m
RA101 P1 korr
Korr tryck i cas
kPa
RA102 P h korr
Korr tryck i bor
kPa
MA61 RBR1
P packer
kPa
MA62 RBR2
P section
kPa
hours
START :03/05/15 09:00:00
INTERVAL: >= 1 Second
STOP :03/05/19 15:59:59

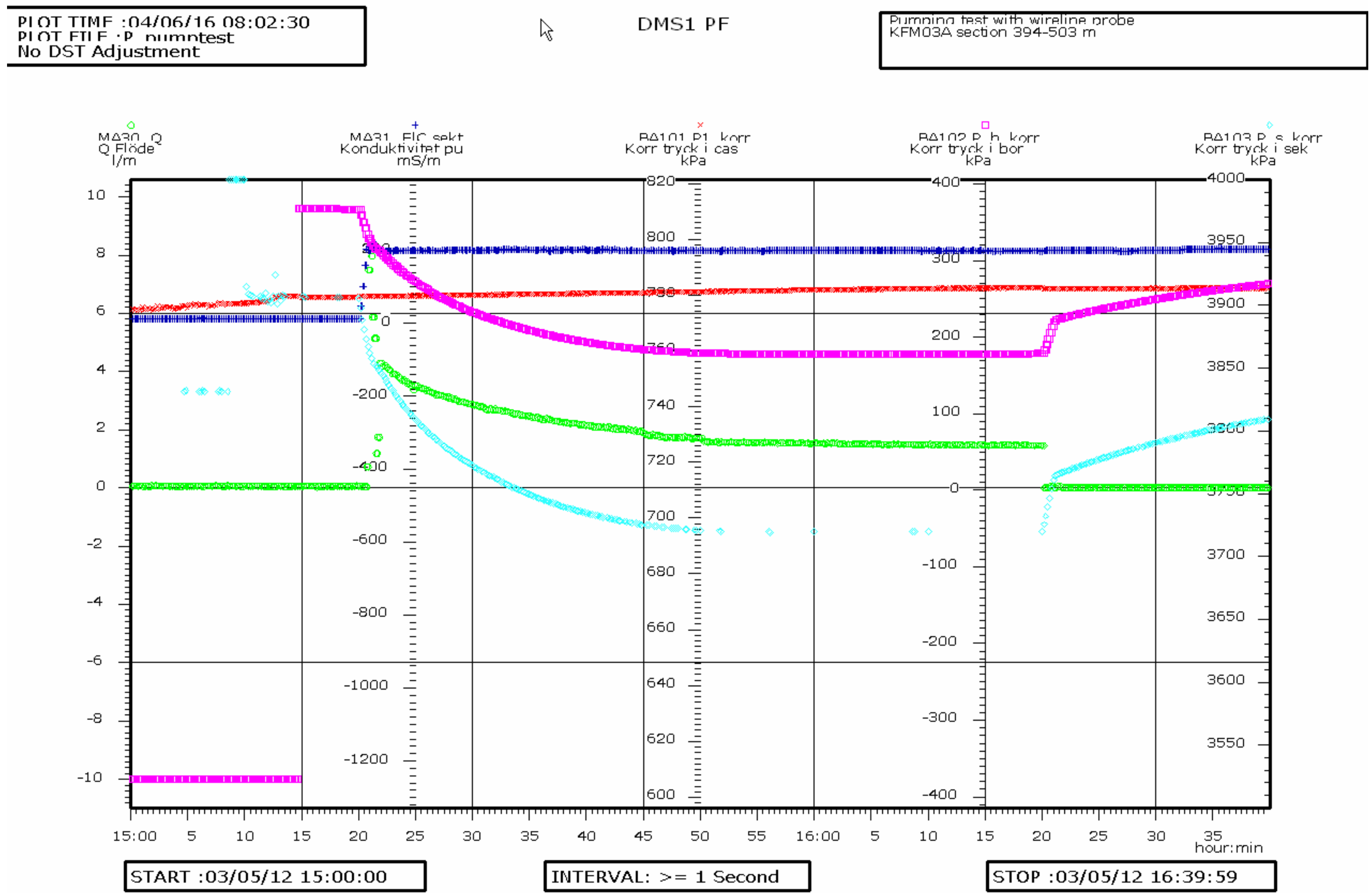

PLOT TIME :04/06/18 08:38:44
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM03 622.63-744.6 m
BA101 P1_korr
Korr tryck i cas
kPa
BA102 P_h_korr
Korr tryck i bor
kPa
MA61_RBR1
P packer
kPa
MA62_RBR2
P section
kPa
hours
START :03/05/22 07:00:00
INTERVAL: >= 1 Second
STOP :03/05/26 15:59:59

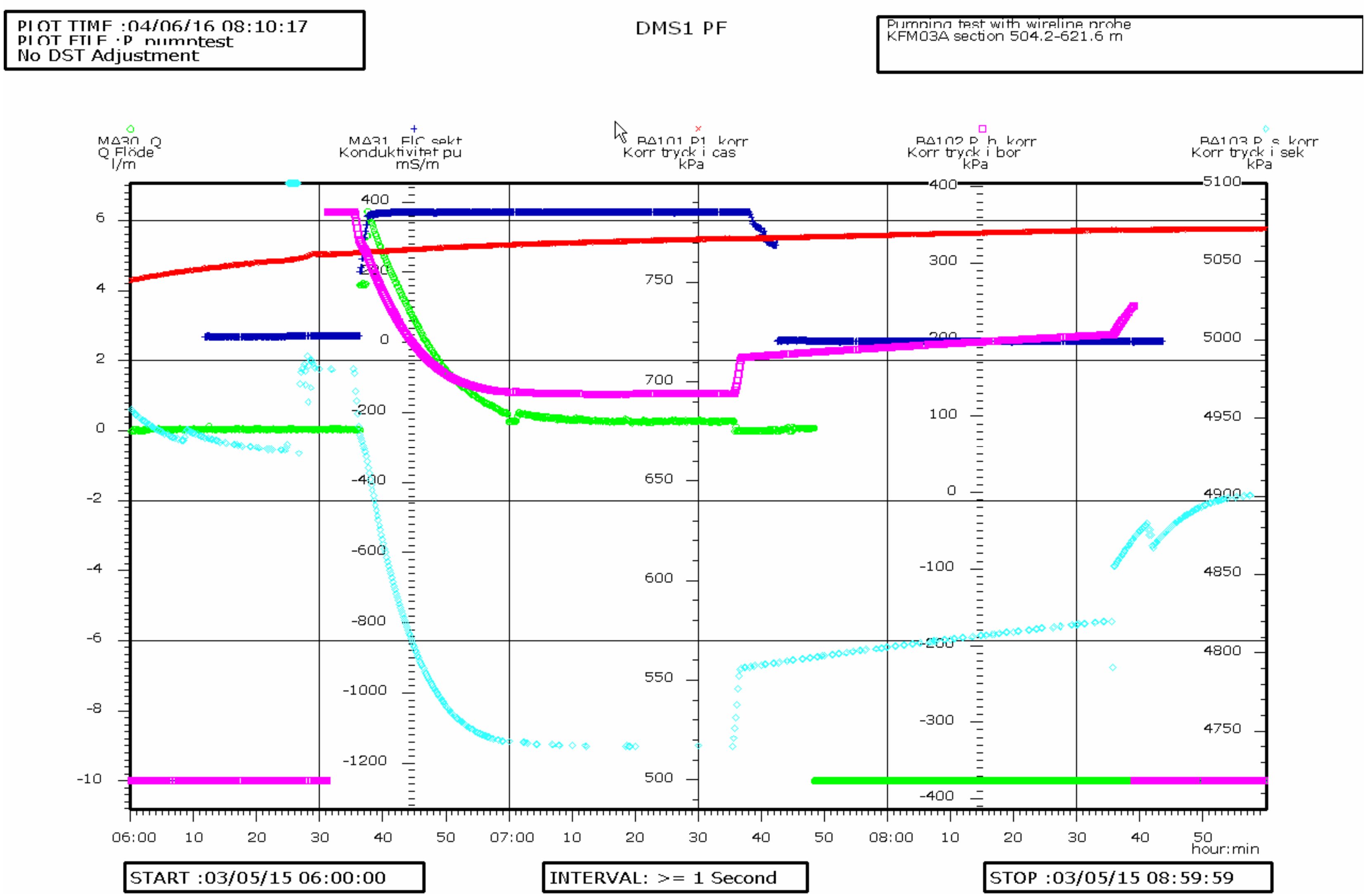

PLOT TIME :04/06/18 09:07:21
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM03 744.2-817.69 m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P_h_korr
Korr tryck i bor
kPa
MA61 RBR1
P packer
kPa
MA62 RBR2
P section
kPa
hours
START :03/05/28 07:00:00
INTERVAL: >= 1 Minute
STOP :03/06/02 15:59:59



PLOT TIME :04/06/18 09:12:58
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM03 817.6-992.85 m
BA101 P1_korr
Korr tryck i cas
kPa
BA102 P_h_korr
Korr tryck i bor
kPa
MA61_RBR1
P packer
kPa
MA62_RBR2
P section
kPa
hours
START :03/06/19 07:00:00
INTERVAL: >= 1 Minute
STOP :03/06/23 15:59:59

Absolute pressure measurements

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PLOT FILE :P_pumptest
No DST Adjustment
DMS1 PF
Pumping test with wireline probe
KFM03A section 504.2-621.6 m
MA30 Q
Q Flöde
l/m
MA31 EIC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P_h korr
Korr tryck i bor
kPa
BA103 P_s korr
Korr tryck i sek
kPa
hour:min
START :03/05/15 06:00:00
INTERVAL: >= 1 Second
STOP :03/05/15 08:59:59