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Forsmark site investigation

Drilling of the telescopic borehole KFM05A at drilling site DS5

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December 2004

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

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Summary

The majority of the deep boreholes drilled within the scope of the Forsmark site investigation are performed as telescopic boreholes, entailing that the upper 100 m are percussion drilled with a diameter of c 200–250 mm, whereas section 100–1,000 m is core drilled with a diameter of approximately 77 mm. Performance of and results from drilling and measurements during drilling of the fifth deep borehole drilled by applying this technique are presented in this report. The borehole, which is denominated KFM05A, is 1,002.71 m long and drilled with a strike of 80.90° clockwise from north and with an inclination of 59.80° from the horizon. The vertical depth of the borehole bottom is c 823 m below the ground surface, and the borehole reaches about 568 m in the horizontal direction. KFM05A 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 164 mm, an unstable, fractured section was encountered at about 42 m, interpreted as a sub-horizontal fracture zone. This zone has a relatively low water yield, c 60 L/min. The entire percussion drilled part of the borehole was cased with a stainless steel casing, and the gap between the borehole wall and the casing was grouted. After these measures the inflow of groundwater to the percussion drilled part of the borehole ceased.

A relatively complicated flushing water/return water system was applied for the core drilling, 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 estimate of the impact on the borehole of flushing water and drilling debris during drilling. The conclusion after drilling was that only relatively small amounts of flushing water and drill cuttings penetrated the formation adjacent to the borehole.

A sampling- and measurement programme was applied during percussion drilling and another programme during 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. E.g. the 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), were used as working material for the borehole mapping (so called Boremap mapping) performed after drilling. Results of the Boremap mapping of KFM05A are presented in this report.

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

One experience from drilling KFM05A is that the quartz-rich bedrock in Forsmark is hard to drill, entailing rapid wearing of drill bits. Other lasting impressions from the drilling are the water-yielding sub-horizontal fracture zone encountered in the shallow part of the bedrock and the, on the other hand, a very low fracture frequency and low water-yielding capacity of the major part of the core drilled section of KFM05A.

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 100–1 000 m kärnborras ca 77 mm diameter. Resultaten från det femte djupborrhålet i Forsmark som har borrats med denna teknik redovisas i denna rapport. Borrhålet, som benämns KFM05A, är 1 002.71 m långt och är borrat i riktning 80.90° medsols från norr samt är ansatt med lutningen 59.80° från horisontalplanet. Vertikaldjupet för borrhålets botten är ca 823 m under markytan, och borrhålet når ca 568 m i horisontal-riktningen. KFM05A 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 164 mm påträffades ett instabilt, sprucket avsnitt vid ca 42 m, vilket tolkades som en subhorisontell sprickzon. Jämfört med ytliga, subhorisontella strukturer i andra delar av undersökningsområdet hade denna sprickzon en relativt blygsam vattenkapacitet, ca 60 L/min. Hela den hammarborrade delen av borrhålet kläddes in med rostfritt foderrör, varefter spalten mellan borrhålsvägg och foderrör cementinjekterades, så att allt vatteninflöde i denna del av hålet upphörde.

För kärnborrningen av avsnittet 100–1 002.71 m användes ett relativt komplicerat spol- och returvattensystem, där spolvattnet preparerades i olika steg före användning. Returvattnet leddes till ett system av containrar, så att borrkaxet kunde sedimentera i tre steg innan returvattnet pumpades vidare till recipient.

Under borrningen registrerades ett antal borr- och spolvattenparametrar för kontroll av dels borrningens tekniska genomförande, dels av den påverkan av spolvatten och borrkax som borrhålet utsattes för. Slutsatsen efter borrning var att endast relativt små mängder spolvatten och borrkax har trängt ut i formationen utanför borrhålet.

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 Boremap-karteringen av KFM05A 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 KFM05A är att den kvartsrika berggrunden i Forsmark är svårborrad och att borrkroneslitaget är högt. Andra bestående intryck är dels den ytliga subhorisontella, vattenförande sprickzonen som påträffades i KFM05A, liksom i hammar-borrade borrhål nära KFM05A, dels att, omvänt, sprickfrekvensen och vattenföringen i större delen av det kärnborrade partiet av borrhålet visade sig vara mycket låga.

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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 1,000 m long, cored boreholes have been drilled within the investigation area. A sixth deep borehole is also underway at DS6. The locations of the six drilling sites in question, DS1, DS2, DS3, DS4, DS5 and DS6, are illustrated in Figure 1-1.

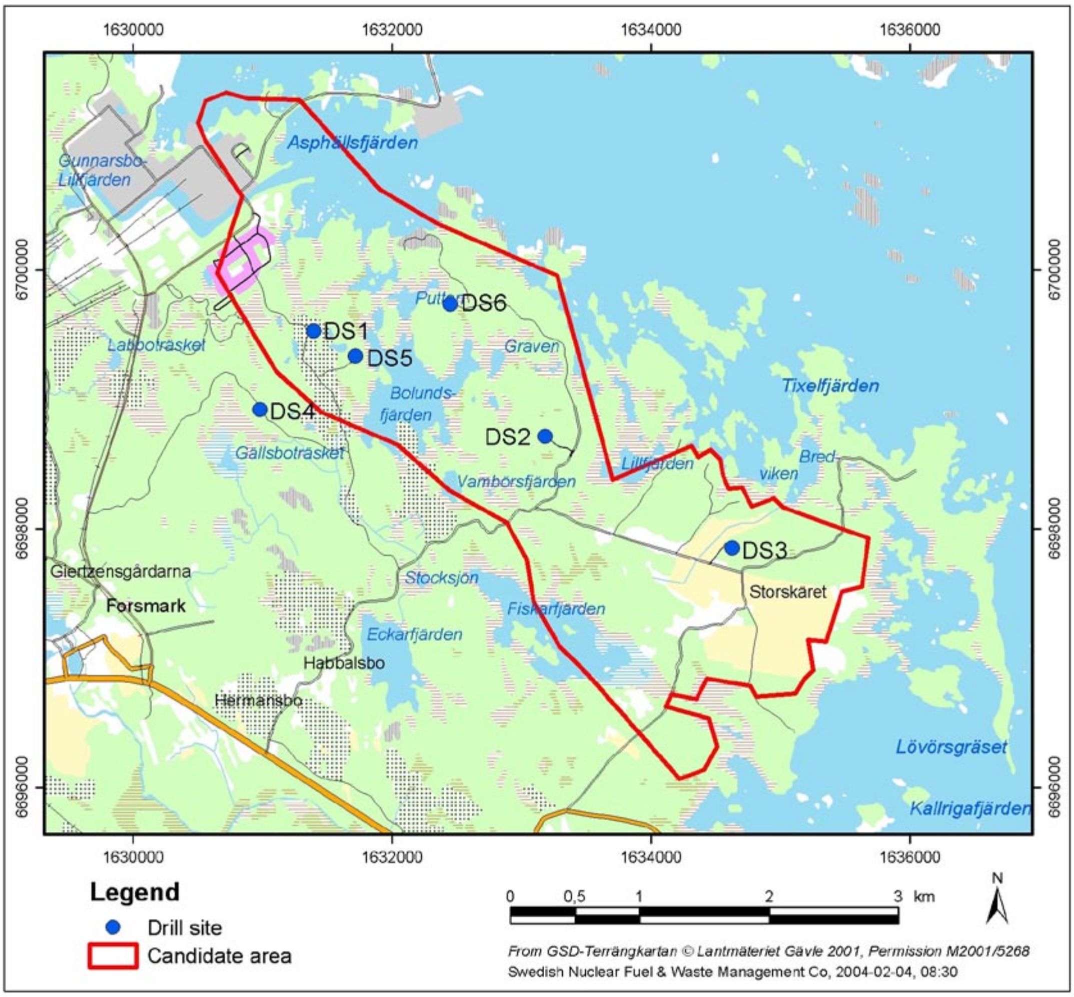


Figure 1-1. *The site investigation area at Forsmark including the candidate area selected for more detailed investigations. Drilling sites DS1-6 are marked with blue dots.*

By drilling the deep boreholes, so called telescopic drilling technique is applied, entailing that the upper 100 m of the borehole is percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section 100–1,000 m is core drilled with a diameter of approximately 77 mm. This technical approach was adopted also when drilling the borehole presented in this report, KFM05A, which has a total drilling length of 1,002.71 m. KFM05A is drilled with a strike of 80.90° clockwise from north and with an initial inclination at the collaring of 59.80° from the horizon. The vertical depth of the borehole bottom is c 823 m below the ground surface, and the borehole reaches about 568 m in the horizontal direction. Borehole KFM05A is of the 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 after drilling must undergo severe cleaning procedures, see Chapter 4.

Close to the deep borehole at drilling site DS5, 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 200 m. The locations of all boreholes at and close to drilling site DS5 are shown in Figure 1-2.

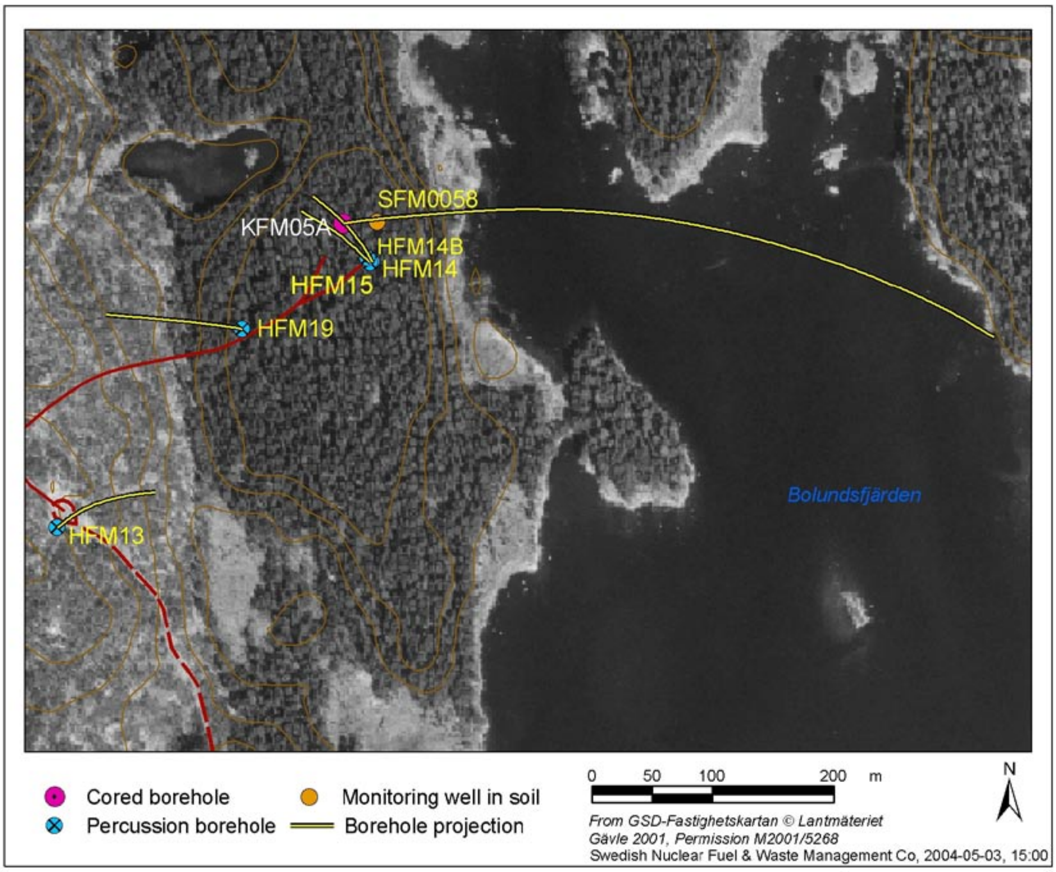


Figure 1-2. *Borehole locations at and near drilling site DS5. Besides the core drilled borehole KFM05A, the area incorporates a flushing water well (HFM13), three monitoring wells in solid rock (HFM14, HFM15 and HFM19), and one monitoring well in the unconsolidated overburden (SFM0058). HFM14B was drilled to enable investigations of a shallow open fracture, which in both HFM14 and 15 is covered by the casing pipe. The projection of inclined boreholes on the horizontal plane at the ground surface (top of casing) is shown in the figure.*

Drilling site DS5 is located in the north-western part of the candidate area, c 1.5 km from the Forsmark power facilities. The area is covered by forest and is characterized by small lakes tied off from the nearby Baltic Sea in, from a geological point of view, recent times. The present coastline is situated about 900 m north-east 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 KFM05A at drilling site DS5 are presented.

Drilling of borehole KFM05A was performed in compliance with a number of SKB controlling documents, which are presented in Table 1-1 below. Some of these documents are in Swedish, others are available also in English.

The two first method descriptions in Table 1-1 refer to a number of method instructions and measurement system descriptions, some only in Swedish, others also in English, see Table 1-2.

Table 1-1. SKB internal controlling documents for performance of the activity.

Activity Plans	Number	Version
Undersökningar i Forsmarksområdet. Borrning av teleskopborrhål KFM05A	AP PF 400-03-69	1.0
Method descriptions and instructions		
Metodbeskrivning för hammarborrning	SKB MD 610.003	2.0
Method Description for drilling cored boreholes	SKB MD 620.003	1.0
Metodbeskrivning för registrering och provtagning av spolvattenparametrar samt vägning av borrkax under kärnborrning	SKB MD 640.001	1.0
Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wireline-borrning	SKB MD 321.002	1.0

Table 1-2. Method instructions and Measurement System Descriptions (SKB internal controlling documents) referred to in Method descriptions SKB 610.003 and 620.003.

Method instructions and Measurement System Descriptions		
Instruktion för utsättning och ansättning av hammar- och kärnborrhål	SKB MD 600.002	1.0
Instruction for cleaning borehole equipment and certain surface equipment	SKB MD 600.004	1.0
Instruction for setting up at drilling sites	SKB MD 600.005	1.0
Instruction for the use of chemical products and construction materials in equipment for drilling and investigations	SKB MD 600.006	1.0
Instruction for flushing water management for core drilling	SKB MD 620.008	1.0
Instruktion för längdmarkering i kärnborrhål	SKB MD 620.009	1.0
Instruction for length calibration of core boreholes	SKB MD 620.010	1.0
Mätsystembeskrivning för övervakning av spolvattenparametrar	SKB MD 640.002–006	

Results from drilling of the flushing water well HFM013 and the two monitoring wells in hard rock, HFM14–15 (including HFM14B), have been reported separately /3/. Results from drilling of the flushing water well HFM019 and four other monitoring wells in hard rock, have also been reported separately /4/. Results from geological mapping of borehole KFM05A (so called Boremap mapping) are treated in /5/.

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 m, whereas core drilling of the remaining part (section 100.35–1,002.71 m) was carried out 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 leveled off for detailed fracture mapping before setting up the drilling site. For the first time during the site investigation the rock surface showed a highly fractured appearance with both steep and flat-lying fractures (Figure 1-3). Therefore, several additional, unplanned geological investigations /6/ had to be performed before the drilling site construction could continue.

With a delay of approximately one month, the site was covered with a layer of coarse, draining gravel, so that a convenient working space was created. A cement slab, about 11×5.5 m in size and having an approximately 5 cm high bund around its periphery, was cast around the actual borehole position. 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.

After preparation of the drilling site, the drilling equipment was mobilized, first the percussion drilling equipment for drilling of section 0–100 m (Figure 1-4), and later the core drilling equipment (Figure 1-5).

Figure 1-3. *The excavated area at drilling site DS5 with the highly fractured bedrock surface.*

Figure 1-4. *Percussion drilling of KFM05A on DS5, with percussion boreholes HFM14 (right) and HFM15(left) as well as HFM14B (yellow cap) in the foreground.*

Figure 1-5. *Core drilling outfit during mobilization on drilling site DS5.*

When drilling was completed, a preliminary groundwater level monitoring program in the open borehole started, and the borehole was equipped with a pressure transmitter called Minitroll (Figure 1-6). Monitoring data are collected by computer (Figure 1-7) or is transferred by GSM telephonic transmission. Later, when all other borehole investigations in KFM05A are finished, a permanent straddle-packer monitoring equipment will be installed, enabling long-term groundwater level monitoring in several isolated sections in KFM05A.

Figure 1-6. *The monitoring equipment was installed in KFM05A after the completed drilling program.*

Figure 1-7. *Results from the monitoring equipment is collected by a computer.*

2 Objective and scope

Siting of borehole KFM05A was primarily governed by a decision (SKB Decision 1019286) to investigate the dip and character of lineaments trending NNW-SSE through lake Bolundsfjärden. The main general objectives of drilling deep cored boreholes at the site investigation (applicable also to KFM05A) 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. The rock samples collected during drilling are used for a lithological, structural and rock mechanical characterization as well as determination of the 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 properties 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 after drilling are transferred to SICADA, may be used as supplementary data for geological and hydraulic characterization. DMS-data are described in this report.

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

3 Equipment and basic technical functions

Two types of drilling machines were used. The upper c 100 m were drilled with a percussion drilling machine of type Puntel MX 1000. For core drilling of section 100.35–1,002.71 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.

The bedrock at drilling site DS5 is covered by a layer of sandy-silty till with some boulder content. The thickness of the overburden varies between c 1–5 m at different parts of the site. After uncovering the bedrock surface, see Chapter 1, and after finishing of the geoscientific investigations made, the site was restored and the bedrock was again covered by soil. The till was also covered with a layer of coarse, draining gravel, so that a convenient, and well-drained working space was created. At the collaring, the total thickness of the natural and artificial overburden is c 6 m. This part had to be cased off with a solid pipe.

Due to the information gained from uncovering of the bedrock surface, which had shown that the shallow part of the bedrock is highly fractured at drilling site DS5, a decision was made to use a NO-X 280 system for penetration of the overburden and fractured bedrock. To achieve a borehole as straight as possible in this type of regolith, the choice of technique is important. In this case the NO-X technique was applied, following the principles and dimensions presented in Figure 3-1. In this case, the quality of the upper, outer casing is non-stainless, which is regarded as sufficient, because the casing is hydraulically isolated from the borehole by grouting, see Section 3.2. 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 KFM05A are presented in Section 5.2.

3.2 Gap injection technique

For investigation of 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 the gap between the borehole wall and the casing. Also open, water yielding fractures penetrated by the borehole will in most cases be sealed by the injected agent during gap injection. Gap grouting can be performed according to different techniques. Two variants are illustrated in Figure 3-2.

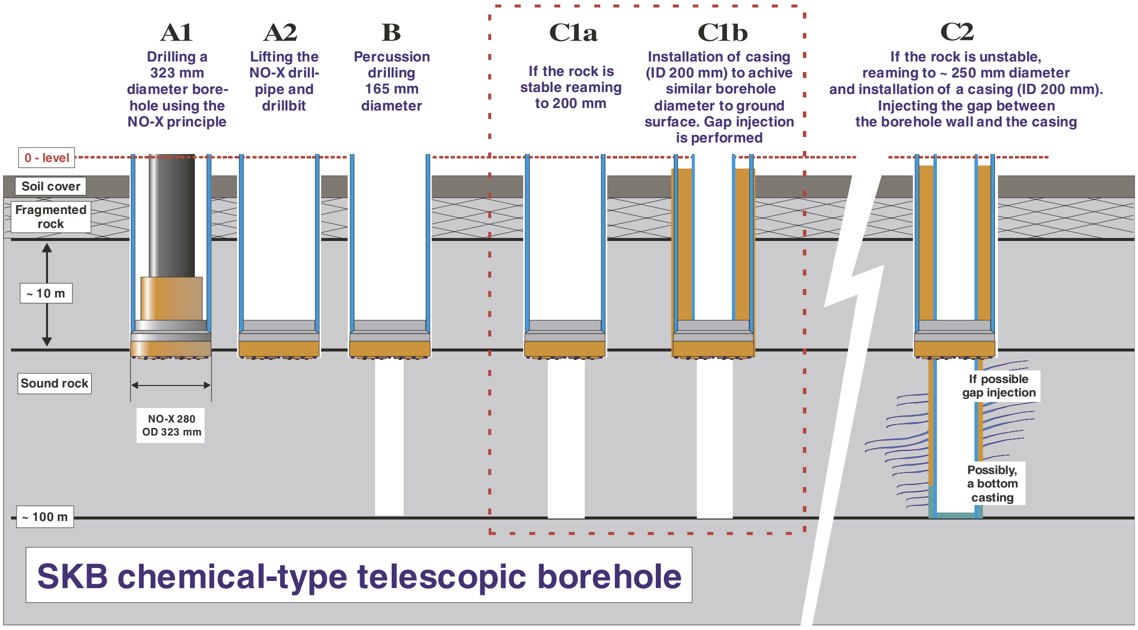


Figure 3-1. Schematic diagram showing the various stages of drilling the 0–100 m section of KFM05A (SKB chemical-type telescopic borehole). The letters and numerals over each stage refer to some of the operations described in Sections 3.4.1 and 3.4.2 in SKB MD 620.003.

Borehole KFM05A was gap grouted at two occasions: 1) after installation of the $Ø_y$ 324 mm casing (C1b in Figure 3-1), and 2) after installation of the $Ø_i$ 200 mm, 100 m long casing (C2 in Figure 3-1). In both cases gap injection through a packer was applied.

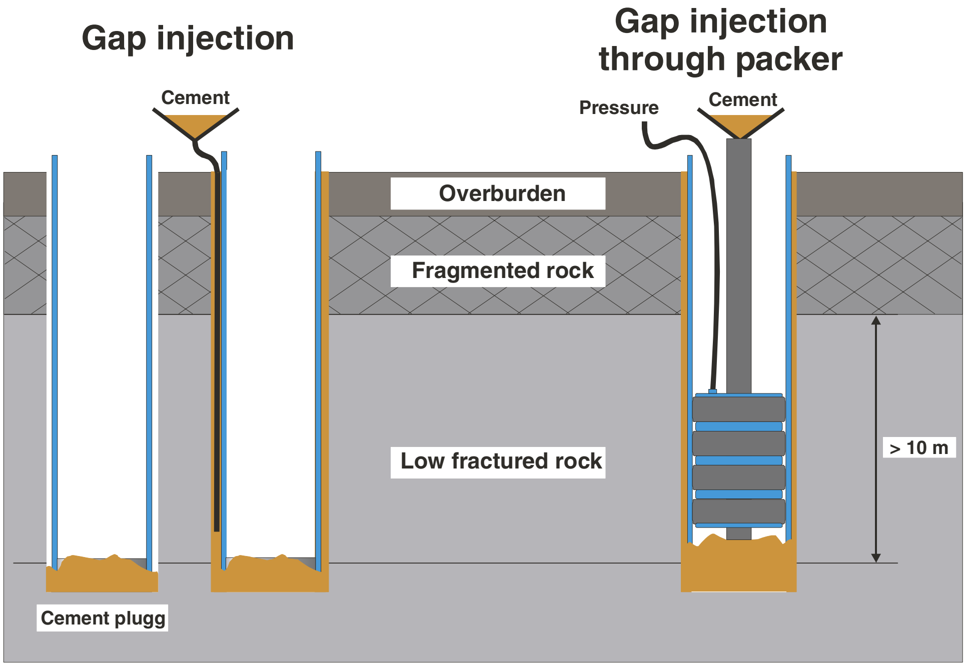


Figure 3-2. Gap injection techniques. In order to fill the gap between the borehole wall and the casing, different techniques may be applied. To the left, a flexible hose is lowered between the casing and the borehole wall, and to the right the grouting is performed through a borehole packer.

3.3 Core drilling equipment

3.3.1 The wireline-76 system

A Hagby Bruk Onram 2000 CCD wireline-76 system was employed for drilling the cored part of borehole KFM05A. 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 1,500 m. The drill 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 1,500 m	
Flush water pump	Bean	Max flow rate: 170 L/min Max pressure: 103 bars	
Submersible pump	Grundfos SQ	Max flow rate: 200 L/min	
Mobile electrical plant	P250HE with diesel engine Perkins GCD 325	250 KVA, 200 kW, 360 A	
Compressor	Atlas Copco GA75P-13	Max pressure: 12 bars Flow: > 5 L/sec	Electrically supplied
CCD-system	Dunfoss		Standard system modified for core drilling by the manufacturer

3.3.2 Flushing/return water system – function and equipment

Core drilling involves pumping of flushing water down the drill string, through the drill bit and 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. 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 oxygen) as well as return water parameters (flow rate and electrical conductivity),
- equipment for airlift pumping while drilling,
- equipment for storage and discharge of return water.

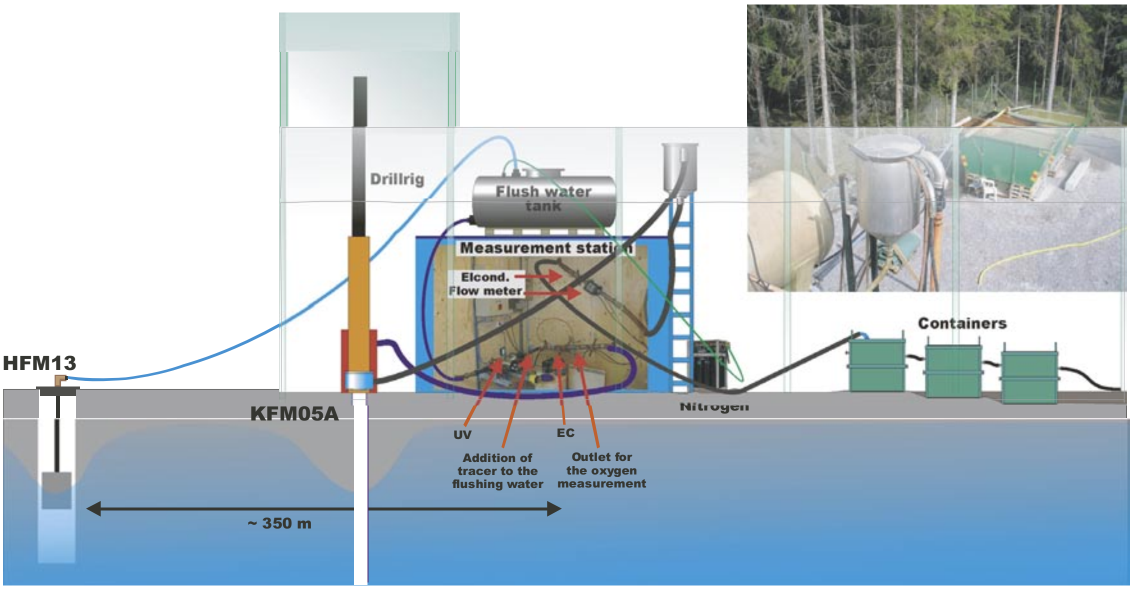


Figure 3-3. Schematic illustration (foreground) and photograph (background) of the flushing/ return water system when drilling KFM05A at DS5. The measurement station included the logger units and the UV-radiation unit. For flushing water flow rate and pressure measurements, the drilling machine gauges were used.

Preparing the flushing water

The quality of the flushing water must satisfy 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 which is to be expected in the aquifer penetrated by the telescopic borehole itself. Foreign substances, like oil and chemicals, must be avoided.

The water well used for the supply of flushing water for core drilling of KFM05A was a percussion drilled well in hard rock, HFM13A (see Figure 1-2), situated approximately 350 m from KFM05A. 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 satisfactory to serve as flushing water, however with one exception, see Section 5.4.3.

Besides these basic demands on the flushing water quality, which were fulfilled when drilling KFM05A, the flushing water was also prepared in three steps before use, in accordance with SKB MD 620.003 (Method Description for drilling cored boreholes).

1) Incoming water from the water well (HFM13) was pumped into the flush water tank (see Figure 3-3).

2) Nitrogen was bubbled through the water in the tank in order to expel oxygen which might be dissolved in the water (see Figure 3-3). Oxygen must be avoided in the flushing water because it is a critical parameter in the programme for hydrochemical characterization of the groundwater. The expelled oxygen was discharged through a pressure reducing valve, and the water was kept continuously under a positive nitrogen pressure (about 1 bar) until pumped down into the borehole.

3) In order to reduce the microbe content in the water from the flush water tank, it was exposed to UV-radiation by a UV-system placed inside the measurement station, see Figure 3-3.

4) After UV-radiation, an organic tracer dye, Uranine, was added with aid of a dosage equipment at a concentration of 0.2 mg/L, before the water was pumped into the borehole, see Figure 3-3. Labelling 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 during pumping the flushing water into the borehole:

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

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

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		

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

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 80–100 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 fractures and 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 KFM05A consisted of the following main components, see Figures 3-4 and 3-5:

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

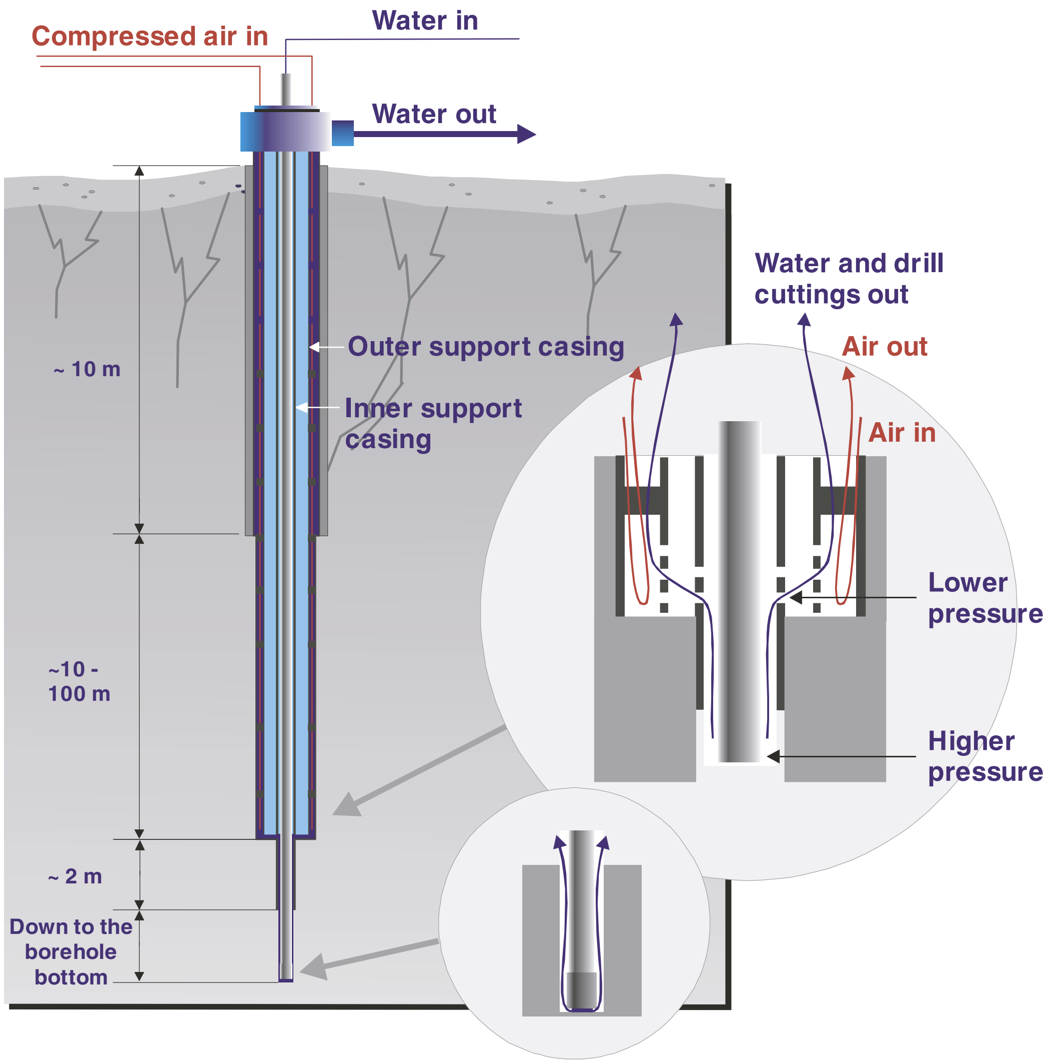


Figure 3-4. *Airlift pumping during core drilling of a telescopic borehole. Schematic representation, where the drilling depths are only approximate. The air and instrumentation hoses are secured to the outer support casing. The compressed air raises the flushing water and drill cuttings from the hole. 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.*

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 28 mm return hose were connected to the 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.

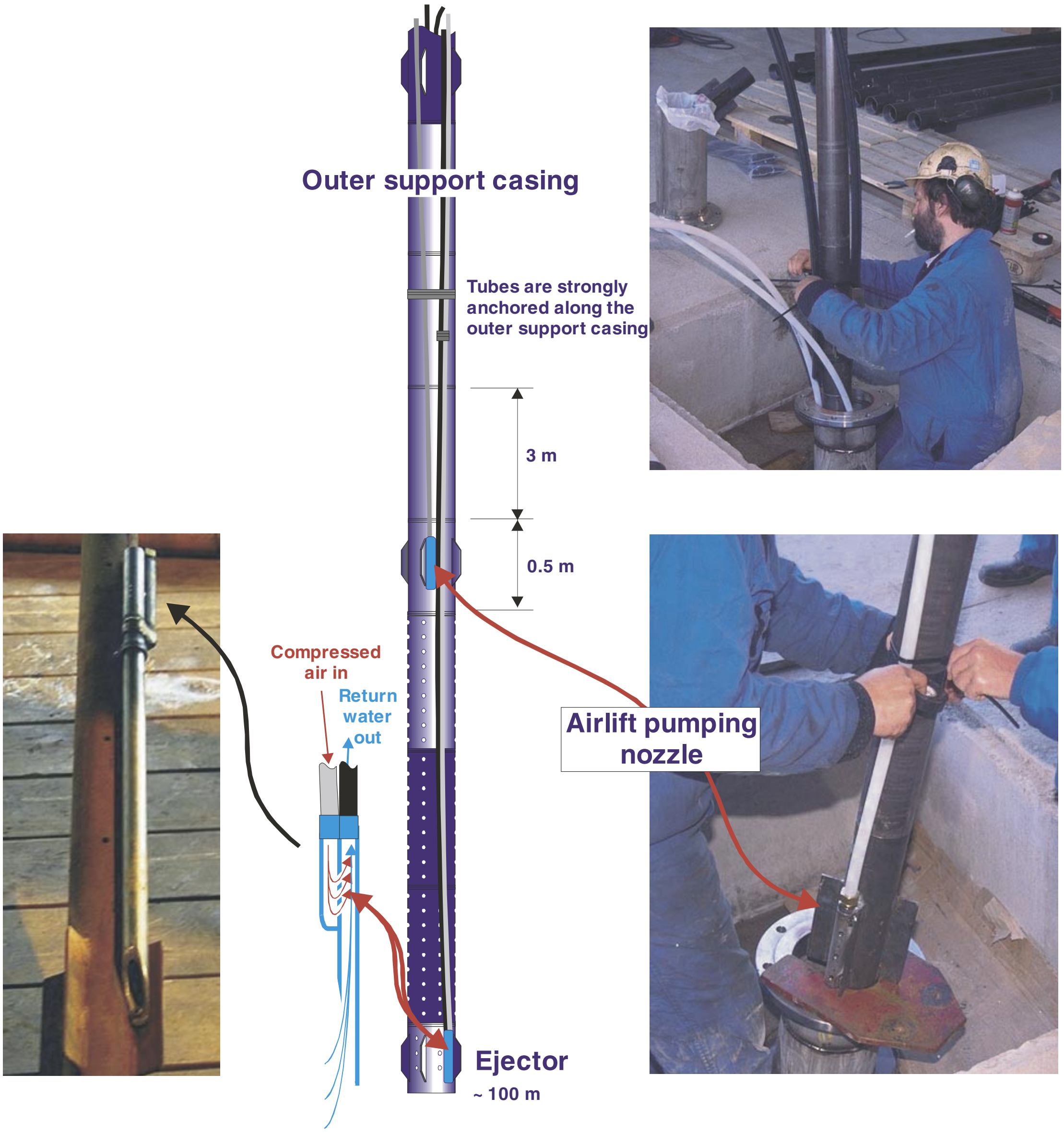


Figure 3-5. *Schematic representation of connection and installation of airlift pumping nozzle and ejector on the outer protective casing.*

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 1 km 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.

The flow rate and electrical conductivity of the return water was measured and data stored in the data-logging system. Technical specifications of the measuring devices 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	

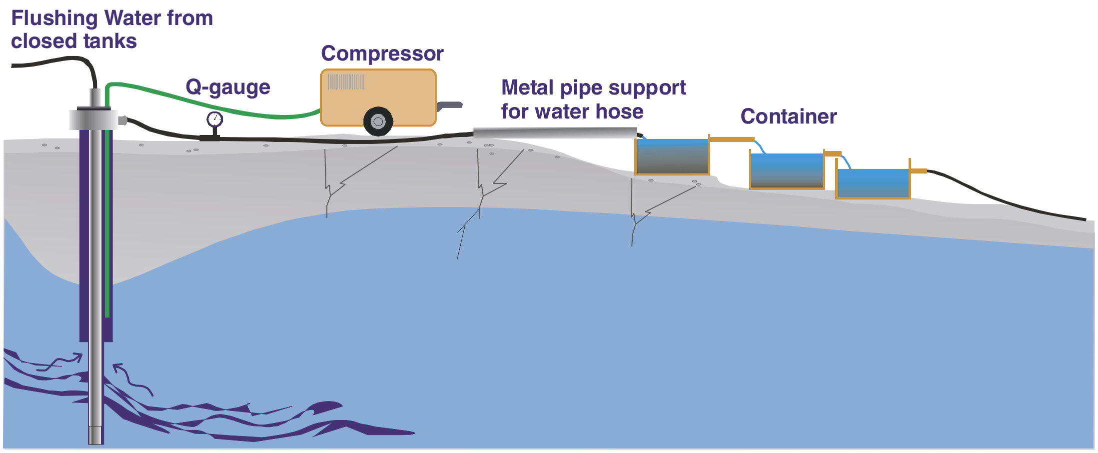


Figure 3-6. *Return water system. Airlift pumping raises the return water, consisting of flushing water, groundwater and drill cuttings, from the borehole. The cuttings separate out in three stages in the containers (where it is preserved for later weighing), after which the water can be pumped to the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

3.3.3 Drilling monitoring system

The ONRAM 2000-CCD drilling machine is supplied with a computer based logging system integrated in the steering unit (cf Section 3.3.1). Hence, the parameters logged are those used for automatic operation of the drilling process. During drilling of the previous telescopic boreholes, KFM01A to KFM04A, some quality problems regarding the core and the borehole wall had been observed. Therefore, an upgraded software and part of a new steering system was installed before start of drilling of borehole KFM05A.

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.

However, during drilling of borehole KFM05A, the registration was extended to include also the following flushing water parameters:

- electric conductivity,
- dissolved oxygen,

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 during drilling.

3.3.4 Equipment for deviation measurements

During drilling of borehole KFM05A, deviation measurement were made at one occasion during drilling in order to check the straightness of the borehole. After completion of drilling, a final deviation measurement was carried out. Both 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 (Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wireline-borrning).

4 Execution

4.1 Percussion drilling of borehole section 0–100 m

The performance of the percussion drilling followed Activity Plan AP PF 400-03-69, which refers to SKB MD 610.003 (Method Description for percussion drilling). The percussion drilling operations included the following items:

- 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 matters are treated in the present section (Section 4.1), whereas the last two points, 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 (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 (Instruction for cleaning borehole equipment and certain surface equipment), for boreholes of SKB chemical type.

4.1.2 Mobilization

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

4.1.3 Drilling, measurements and sampling during drilling

The percussion drilling started with drilling through the overburden during simultaneous casing driving and subsequent gap injection. These activities followed the principles described in Sections 3.1 and 3.2 (corresponding to A1–A2 and C1b in Figure 3-1). The length of the $Ø_y$ 324 mm casing was 12.25 m and the casing material used was non-stainless steel.

The continued percussion drilling through solid rock was performed with a 164 mm drill bit to 100.35 m drilling length (corresponding to B in Figure 3-1). The borehole section below the $Ø_y$ 324 mm casing turned out to be unstable. The fractured, unstable section showed a water yielding capacity of about 60 L/min at a drawdown of 70–80 m.

For stabilization of the entire percussion drilled part, the borehole was reamed to Ø 244 mm with a special reamer bit to 100.30 m drilling length (i.e. 0.05 m of the pilot hole was left unreamed), and a SS2333 stainless steel $Ø_i$ 200 mm casing was installed (corresponding to C2 in Figure 3-1). Before installing the casing, the borehole was cleaned from drill cuttings by a "blow out" with the compressor working at maximum capacity during 30 minutes. This also served as a hydraulic capacity test of the borehole, since the recovery of the ground-water table was registered after the compressor had been turned off. The results were used as a rough capacity test of the percussion drilled part of the borehole, used on-site i.e. for preparation of the gap injection of the casing, see below.

The bedrock in the Forsmark tectonic lens has proved to be relatively hard to drill, probably to a large extent depending on the high quartz content. As drilling site DS5 is located in the centre of the tectonic lens, the bedrock composition was assumed to be of similar character. However, the upper 200 m of the bedrock at DS5 is more fractured than previously observed within the candidate area. This resulted in longer life-time of the drill bits down to c 200 m than at greater depths. However, in average, the life-time was 27.3 drilled metres per drill bit in KFM05 A, which was almost exactly the same as in KFM01A. On the whole, core drilling in both KFM01A and KFM05A was more time consuming and costly than in average granitic rocks.

During, and immediately after drilling, a program for sampling, measurements, registration of technical and geoscientific parameters and some other activities was applied, as described in Section 4.2.3. The results are presented in Sections 5.4.2–5.4.11 below.

In order to prevent leakage of water from the 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 carried out in association with the Ø 164 mm drilling sequence. This programme was performed 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 consists of three individual samples collected one per metre. The samples were stored in a plastic bottle marked with a sample number. Ocular inspection and a preliminary description of the mineral content 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.

After completion of drilling with the Ø 164 mm drill bit, deviation measurements were made.

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 /7/, whereas the analysis of cuttings from solid rock is presented in /5/. Results from the remaining measurements and observations during drilling 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 244 mm. The borehole was secured with a lockable stainless steel flange. The drilling equipment was removed, the site cleaned and a joint inspection made by SKB and the contractor.

4.1.5 Nonconformities

The percussion drilling of borehole section 0–100 m in KFM05A was performed according to programme, i.e. without deviations.

4.2 Core drilling

The performance of the core drilling followed Activity Plan AP PF 400-03-69, which refers to SKB MD 620.003 (Method Description for drilling cored boreholes). 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 points 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, transport of drilling equipment, flushing water equipment, sampling boxes for drill cores, hand tools etc. Furthermore, the mobilization consisted of cleaning of all in-the-hole equipment at level two in compliance with SKB MD 600.004, lining up the machine and final function control of all equipment.

4.2.3 Drilling, measurements and sampling during drilling

The core drilling of borehole KFM05A was performed with two borehole dimensions. Section 100.35–110.10 m was drilled with a borehole diameter of 86.0 mm, whereas the main part of the borehole, section 110.10–1,002.71 m, was drilled with Ø 77.3 mm. The inner Ø 84/77 mm support casing 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 is resting on the bottom of the percussion drilled borehole.

The Ø 86 m section is normally only about 1–2 m long, which provides the sufficient stability for the inner support casing. In KFM05A this section was, however, drilled as long as almost 10 m. This was due to an unstable and fractured section between c 100 and 110 m, see Appendix B. The transition cone between the percussion drilled respectively the core drilled parts, see Figure 4-1, could in this way be prolonged, thereby stabilizing the fractured part of the borehole and preventing rock fragments from falling into the borehole.

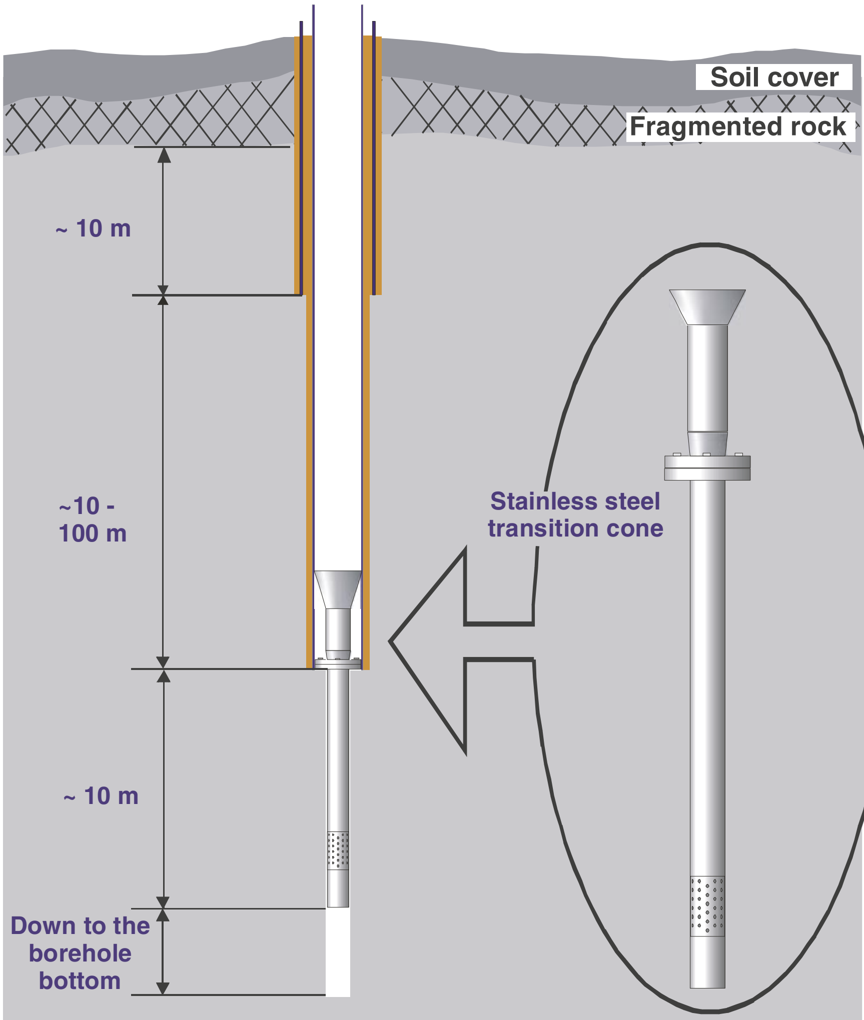


Figure 4-1. *Schematic illustration of the transition cone between the upper, wide section and the lower, slim part of a telescopic borehole. In KFM05A, the entire upper, percussion drilled part was cased.*

Core drilling with Ø 77.3 mm of the main part of the borehole serves many purposes, see 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 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 borehole KFM05A, 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, the 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 KFM05A 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 KFM05A.

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 constitutes 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.

Results of mapping of the drill core samples are presented in /5/, whereas the remaining measurements and registrations during core drilling are presented in Chapter 5 of 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. To control the microbe content variation during drilling of KFM05A, sampling was performed at several occasions both prior to and after cleaning of the flushing water system using 2% (by volume) Sodium Hypochlorite solution. The results of the study are presented in /8/.

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 borehole KFM05A.

Activity	Performance and frequency according to SKB MD 620.004	Performance and frequency during drilling of KFM05A
Registration of drilling- and flushing water parameters.	Described in Section 3.3.2. Registration during the entire drilling.	Technical problems with oxygen transducer. Some 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 measurement during drilling and one measurement after completion of drilling with the Maxibor system. An additional Maxibor measurement was made as well a measurement with Reflex EZ-AQ/EMS ™.
Measurements of the difference in length between the compressed drilling pipe string and as extended by its own weight.	Normally performed every 100 m.	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.	No pumping tests were made due to the very low hydraulic transmissivity along the core drilled part of the borehole below c 110 m.
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 sample was collected at about 122 m borehole length. Below this length the inflow of groundwater was extremely low. The sample was collected at open hole conditions, from water pumped to the ground surface. The WL-probe was not used.
Absolute pressure measurements.	Normally during natural pauses in drilling.	Three measurements performed.
Groove milling in the borehole wall, normally at each 100 m.	Normally performed after completion of drilling.	Seventeen grooves performed.
Collecting and weighing of drilling debris.	Drilling debris settled in containers weighed after finished drilling.	Not carried out for the percussion drilled part of the borehole. According to programme for the core drilled part.

Note: 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 were weighed after concluded drilling in order to give a measure of the drill cuttings recovery. However, weighing of the drill cuttings produced during percussion drilling and comparison with the weight of the theoretical volume was not carried out due to the high water flow. This caused a relatively large and uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations.

4.2.4 Finishing off work

The concluding work included the following items:

1) The borehole was flushed for about 10 hours during simultaneous airlift pumping in order to clean it from drilling debris adhered to the borehole walls, sedimented 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.

2) The drill string was pulled.

3) The inner support casing was removed with aid of a crane lorry.

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

5) The discharge head was removed.

6) Using the drill rig, a (prolonged) stainless steel transition cone was installed between the reamed and cased percussion drilled respectively the cored part of the borehole, as shown in Figures 4-1 and 5-4. The lower, pipe-shaped part of the cone is located at 100.02–110.00 m. The upper part of the cone fits tightly against the wall at 96.97 m in the percussion-drilled section of the borehole. Between 108.85 m and 109.40 m the transition cone is perforated in order to permit hydraulic testing of the fractured and water yielding section at c 100–110 m.

7) The borehole was again secured with the lockable stainless steel flange.

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

4.2.5 Nonconformities

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

4.3 Data handling

4.3.1 Performance

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

4.3.2 Nonconformities

None.

4.4 Environmental programme

4.4.1 Performance

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

4.4.2 Nonconformities

None.

5 Results

All data were stored in the SICADA database under field note no Forsmark 246. An overview of the drilling progress of borehole KFM05A is given in Section 5.1, whereas geometrical data and technical design are presented in Section 5.2.

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

- Section 5.3 (percussion drilling).
- Section 5.4 (core drilling).

Well Cad-presentations of borehole KFM05A are shown in:

- Appendix A (percussion drilled part).
- Appendix B (the complete drilled borehole). 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 KFM05A was produced during a period of approximately 5 months, including a pause during the Christmas holiday as well as up-dating of the steering system of the core drilling equipment, see Figure 5-1. The working environment was favourable in spite of the winter conditions, because the drill rig with water supply system was weather protected by a tent, resulting in more effective drilling and, hence, shorter drilling performance.

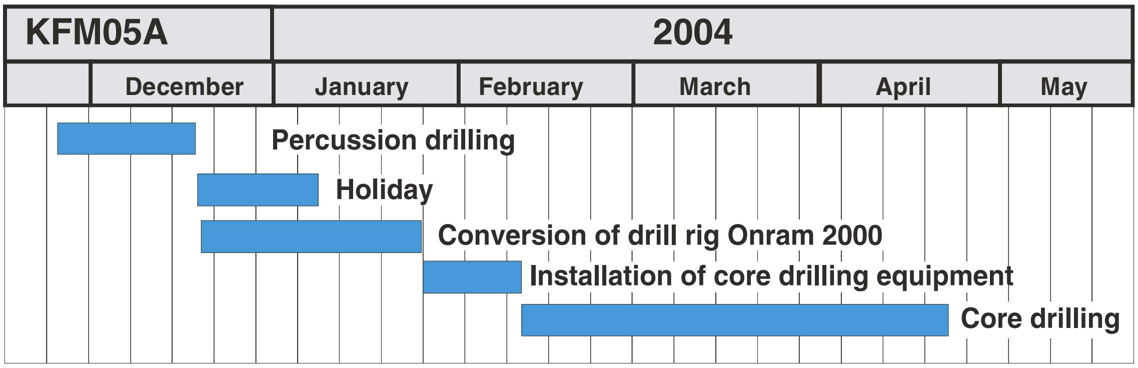


Figure 5-1. *Overview of the drilling performance of borehole KFM05A.*

5.1.1 Percussion drilling period

Percussion drilling per se is a rapid drilling method. However, the relatively complex approach applied for the drilling and especially the grouting sequences when drilling KFM05A, resulted in a rather long total working period.

The durations of the different operations included in the percussion drilling from 2003-11-23 to 2003-12-16 are presented in Figure 5-2.

5.1.2 Core drilling period

After percussion drilling of section 0–100.35 m and following the Christmas holiday, core drilling commenced. The progress of the core drilling from 2004-02-10 to 2004-04-22 is presented in Figure 5-3. 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.

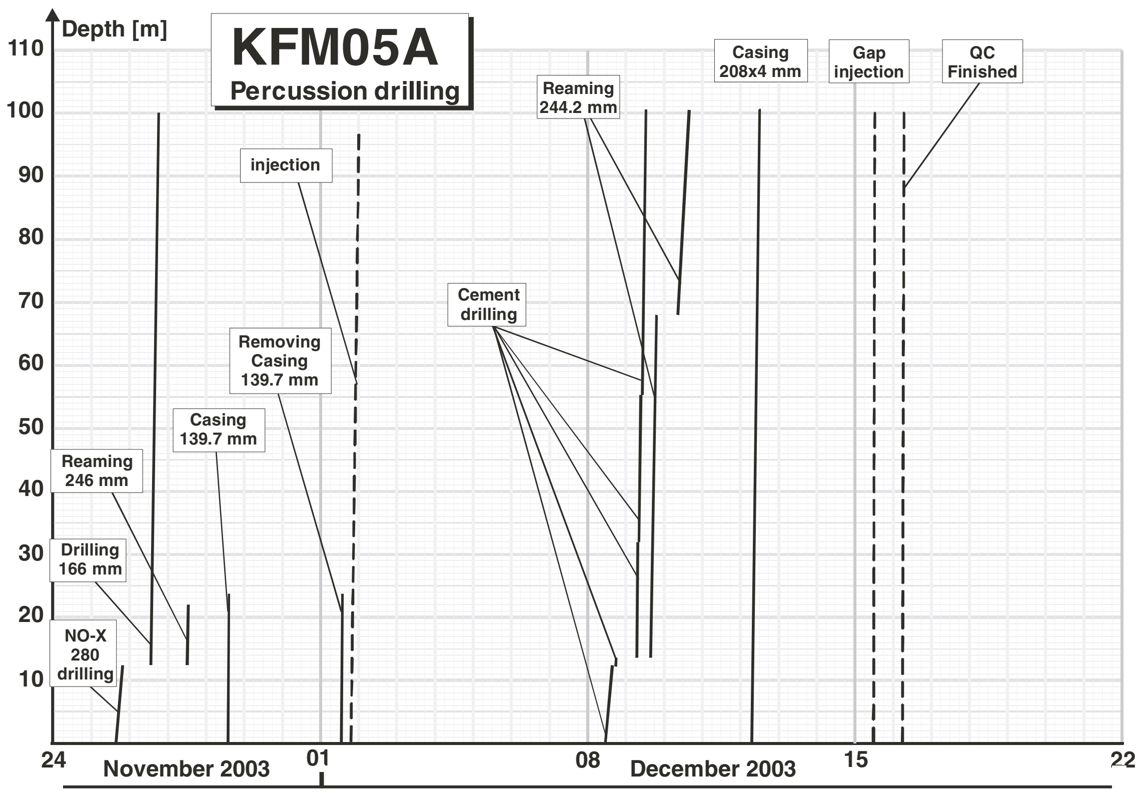


Figure 5-2. Percussion drilling progress (depth and activity versus calendar time).

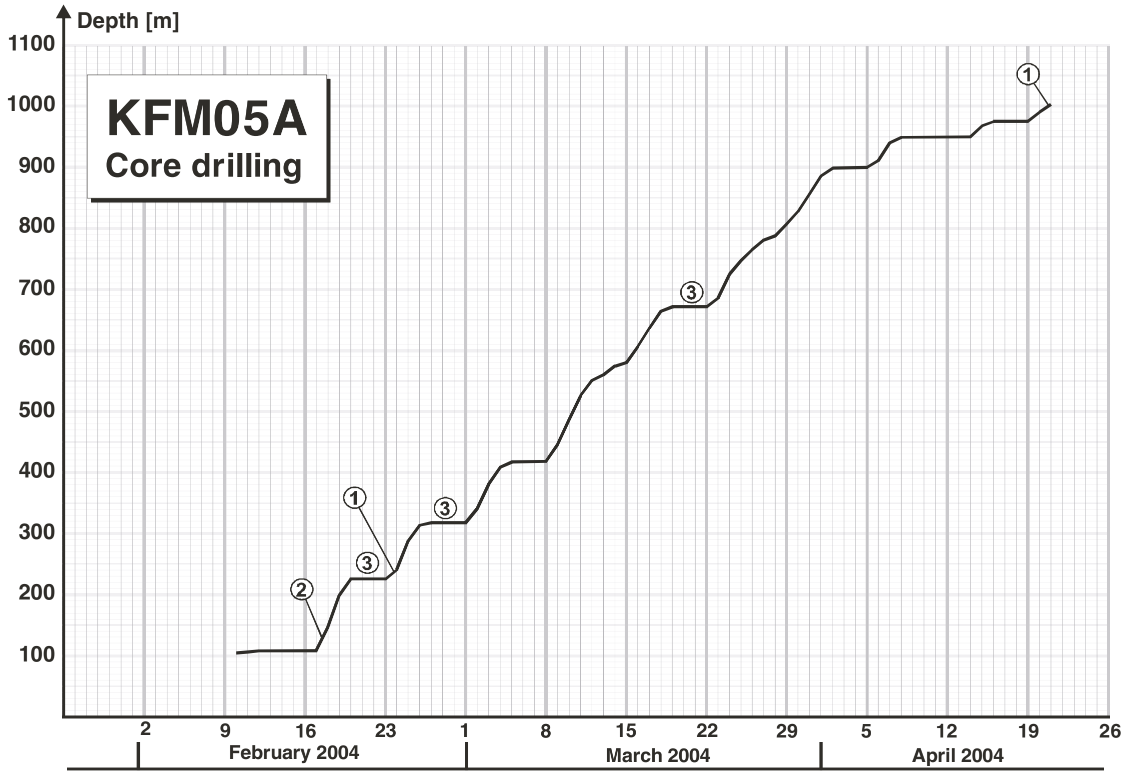


Figure 5-3. Core drilling progress (depth versus calendar time). ① Deviation measurement (Maxibor), ② Water sampling, ③ WL-tests.

5.2 Geometrical and technical design of borehole KFM05A

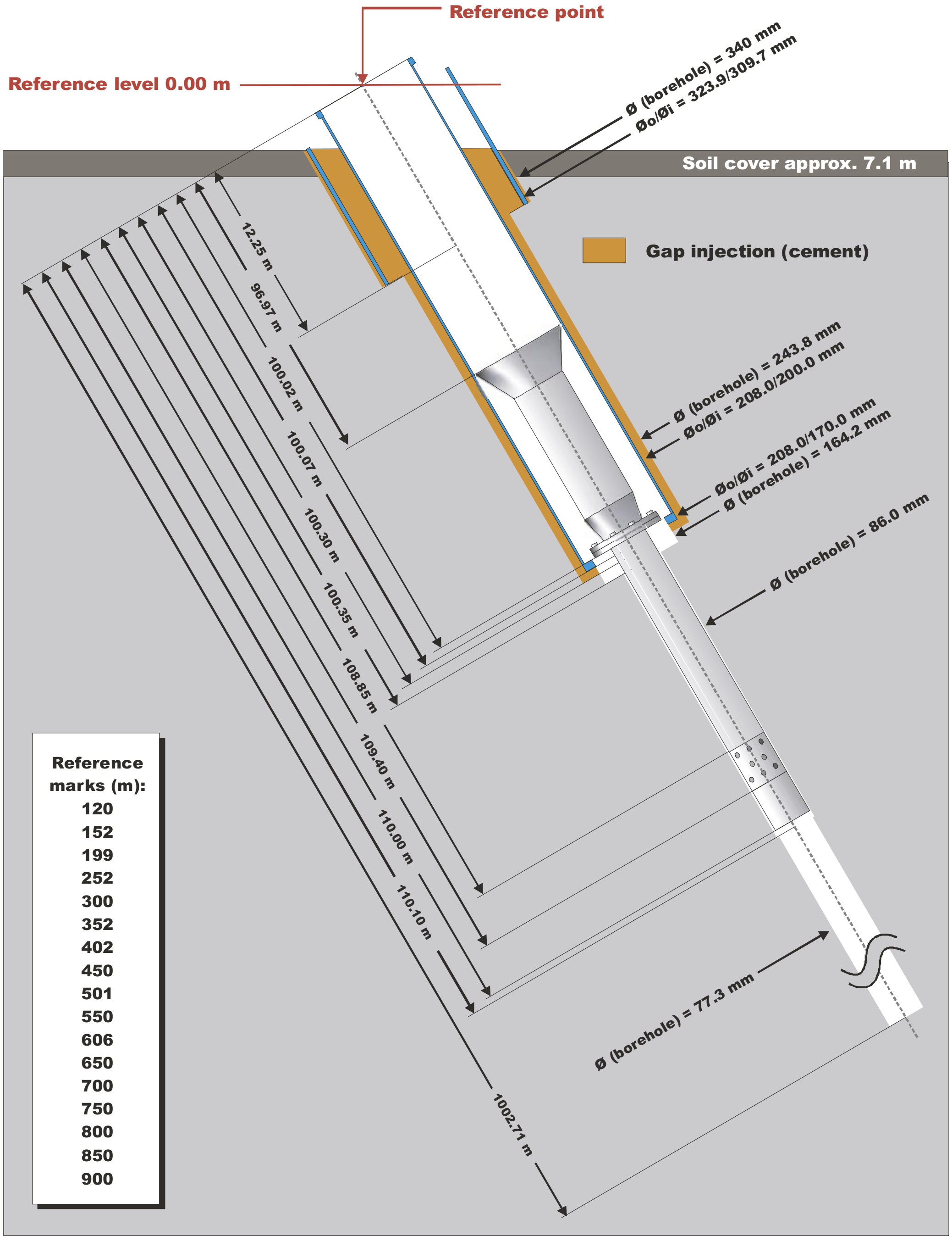
Administrative, geometric and technical data for the telescopic borehole KFM05A are presented in Table 5-1. The technical design is illustrated in Figure 5-4.

Table 5-1. Administrative, geometric and technical data for borehole KFM05A.

Parameter	KFM05A
Borehole name	KFM05A
Location	Forsmark, Östhammar municipality, Sweden
Drill start date	November 23, 2003
Completion date	May 5, 2004
Percussion drilling period	2003-11-23 to 2003-12-16
Core drilling period	2004-02-10 to 2004-04-20
Contractor core drilling	Drillcon Core AB
Subcontractor percussion drilling	Sven Andersson i Uppsala AB
Percussion drill rig	Puntel MX 1000

Parameter	KFM05A
Core drill rig	ONRAM 2000 CCD
Position KFM05A at top of casing (RT90 2.5 gon V 0:–15 / RHB 70)	N 6699344.85 E 1631710.80 Z 5.53 (m a s l) Azimuth (0–360°): 80.90° Dip (0–90°): –59.80°
Position KFM05A at bottom of hole (RT90 2.5 gon V 0:–15 / RHB 70)	N 6699315.38 E 1632277.76 Z –817.52 (m a s l) Azimuth (0–360°): 100.36° Dip (0–90°): –51.98°
Borehole length	1,002.71 m
Borehole diameter and length	From 0.00 m to 12.25 m: 0.340 m From 12.25 m to 100.30 m: 0.244 m From 100.30 m to 100.35 m: 0.164 m From 100.35 m to 110.10 m: 0.086 m From 110.10 m to 1,002.71 m: 0.077 m
Casing diameter and length	$Ø_o/Ø_i$ = 324 mm/310 mm to 12.25 m $Ø_o/Ø_i$ = 208 mm/200 mm between 0.00 and 100.02 m Casing shoe $Ø_i$ = 170 mm between 100.02 and 100.07 m
Transition cone inner diameter	At 96.97 m: 0.195 m At 110.00 m: 0.080 m
Drill core dimension	100.35–101.90 m/Ø 72 mm 101.90–1,002.71 m/Ø 51 mm (as an extended transition cone had to be installed in section 101.90–110.10 m the borehole was reamed to Ø 86 mm)
Core interval	100.35–1,002.71 m
Average length of core recovery	2.66 m
Number of runs	339
Diamond bits used	33
Average bit life	27.3 m

Technical data
Borehole KFM05A



Drilling reference point

Northing:	6699344.85 (m), RT90 2,5 gon V 0:-15
Easting:	1631710.80 (m), RT90 2,5 gon V 0:-15
Elevation:	5.53 (m), RHB 70

Orientation

Bearing (degrees):	80.90°
Inclination (degrees):	-59.80°

Borehole

Length:	1002.71 m

Percussion drilling period

Drilling start date:	2003-11-23
Drilling stop date:	2003-12-16

Core drilling period

Drilling start date:	2004-02-10
Drilling stop date:	2004-04-20

Figure 5-4. *Technical data of borehole KFM05A.*

5.3 Percussion drilling 0–100.35 m

5.3.1 Drilling

As mentioned in Section 4.1.3, the upper 12.25 m of the borehole was cased and cement grouted. During pilot drilling to 100.35 m, highly fractured rock and an inflow of 60 L/min was observed. The fracturing was well in line with the results from the investigations made after uncovering of the bedrock surface at drilling site 5 and also in accordance with the results from the two percussion drilled boreholes nearby KFM05A /6/. When reaming the pilot drilled borehole, an instability was observed at 22 m, and it was judged as too hazardous to continue reaming. Therefore, the borehole was cement grouted and re-drilled with a pilot hole, whereupon the borehole section 0–100.30 m was reamed to 244 mm, and a 200 mm stainless steel casing was installed. Finally, the gap between the casing and borehole wall was cement grouted, so that the water inflow ceased completely.

5.3.2 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 KFM05A (also displayed in the Well Cad-presentation in Appendix A) are commented on. The analyses of drill cuttings from the percussion drilled part of KFM05A are presented in /5/ (rock) and /7/ (soil).

Borehole deviation

The end (bottom) point of the percussion borehole deviates approximately 0.4 m downwards and 2.5 m to the right compared to an imagined straight line following the dip and strike of the borehole collaring point (inclination –59.80º and bearing 80.90º).

5.4 Core drilling 100.35–1,002.71 m

5.4.1 Drilling

The bedrock in the Forsmark tectonic lens has proved to be relatively hard to drill, probably to a large extent depending on the high quartz content. As drilling site DS5 is located in the centre of the tectonic lens, the bedrock composition was assumed to be of similar character. However, the upper 200 m of the bedrock at DS5 is more fractured than previously observed within the candidate area. This resulted in longer life-time of the drill bits down to c 200 m than at greater depths. However, in average, the life-time was 27.3 drilled metres per drill bit in KFM05A, which was almost exactly the same as in KFM01A. On the whole, core drilling in both KFM01A and KFM05A was more time consuming and costly than in average granitic rocks.

During, and immediately after drilling, a program for sampling, measurements, registration of technical and geoscientific parameters and some other activities was applied, as described in Section 4.2.3. The results are presented in Sections 5.4.2–5.4.11 below.

Mapping of the drill core samples from KFM05A is presented in /5/.

5.4.2 Registration of drilling parameters

A selection of results from drilling parameter registration is presented in diagrams below. As regards the complete dataset of drilling parameters, it is referred to SICADA, field note no 246.

Drill bit position versus time

Figure 5.5 illustrates how 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. Furthermore, drilling was performed during two weekends, to compensate for the delayed drilling start. Figure 5-5 serves as a basis for Figure 5-3, with which it should be compared.

Penetration rate

The penetration rate, see Figure 5-6, was in average almost the same as during drilling of KFM01A /9/. Initially, the penetration rate started with c 10 cm/min, but in section 150–520 m it is increased to c 12 cm/min, whereupon in a 150 m section it fell back to c 10 cm/min. In the last 300 m of the borehole, the penetration rate varies around 10 cm/min, approximately corresponding to the increasing frictional resistance of the return water flow, which is 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 in KFM01A to 77.3 mm in KFM05A.

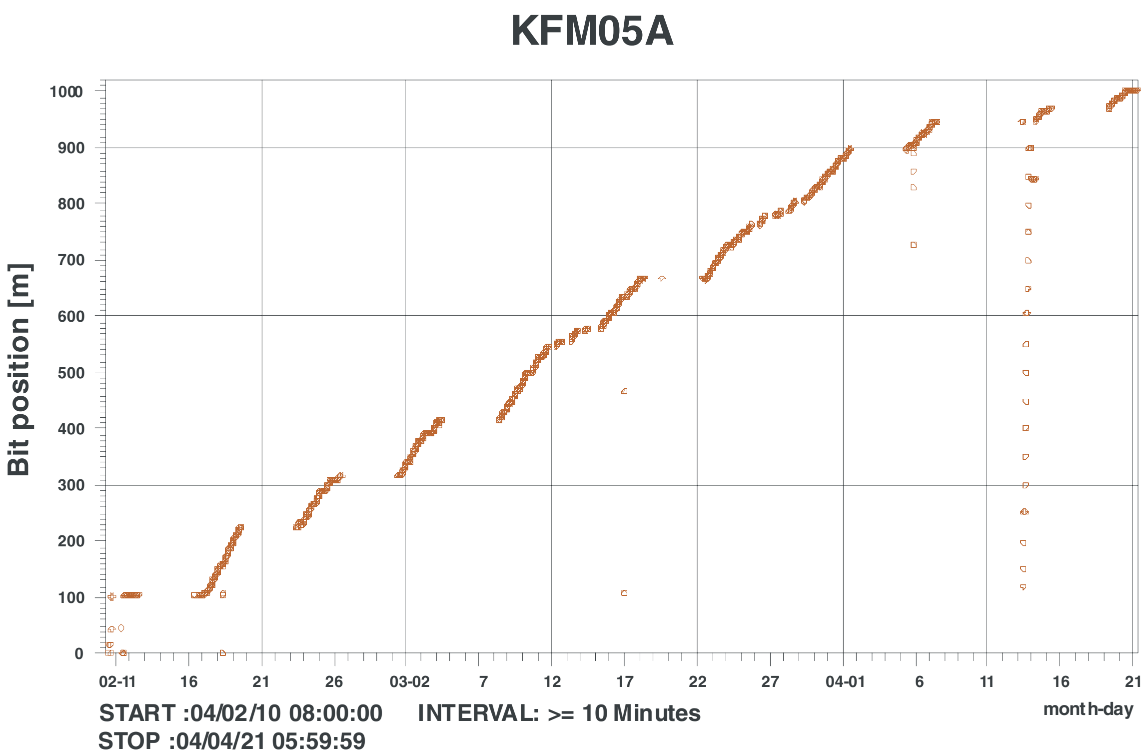


***Figure 5-5.** Drill bit position versus time.*

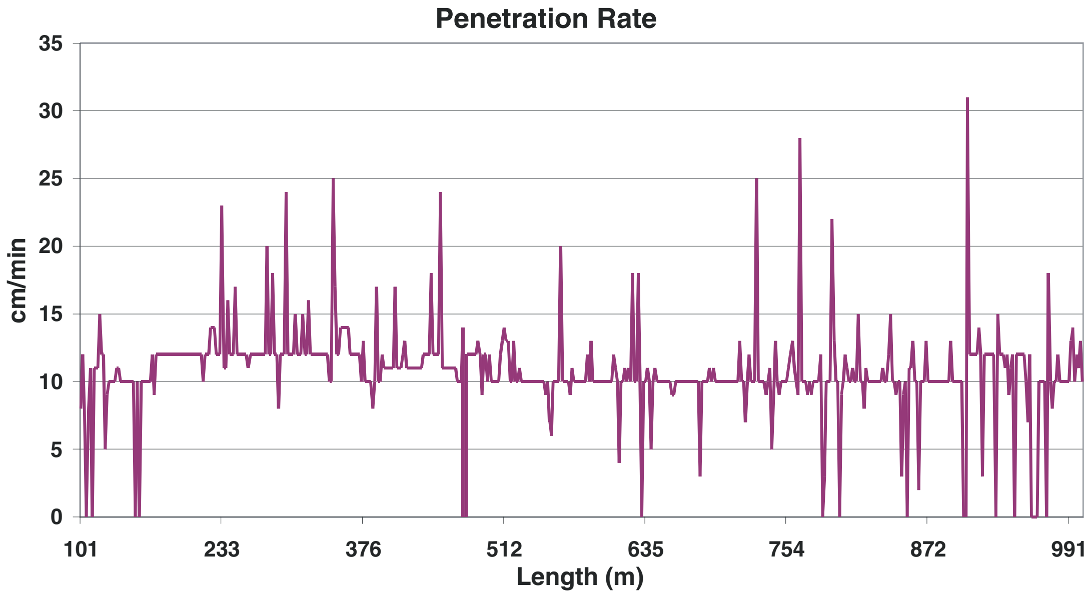


Figure 5-6. *Penetration rate during core drilling of KFM05A.*

Feed force

In Figure 5-7 the feed force is plotted versus borehole length. As the software for the steering system had been upgraded, resulting in a better control of the drilling parameters, the level of feed force when drilling KFM05A is significantly lower compared with the feed force registered when drilling the previous boreholes KFM01A to KFM04A.

The smooth undulation of the feed force is difficult to explain but could be an effect of different types of drill bits used.

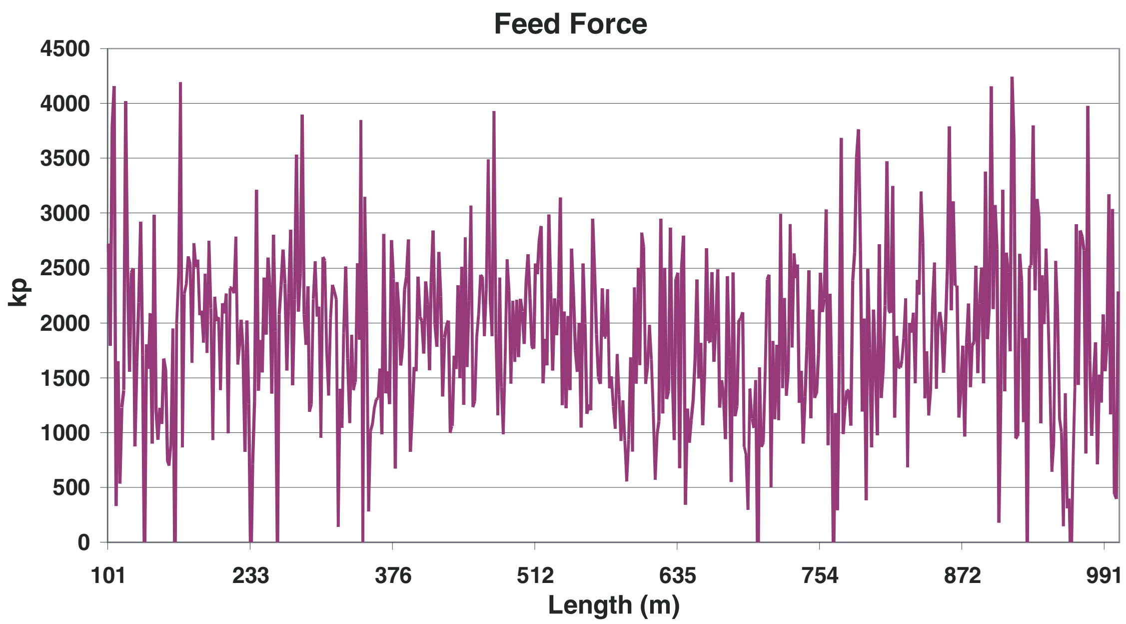


Figure 5-7. *Feed force versus borehole length during drilling of borehole KFM05A.*

Rotation speed

The rotation speed diagram, Figure 5-8, shows that the rotation speed normally varies between c 850–950 rpm. The sudden tops in the curve probably represent sharpening of the drill bit. This is significant below 700 m and is in accordance with shorter life-time of the drill bits at depth. The sudden drops in the curve represent drilling shut off.

5.4.3 Registration and sampling of flushing water and return water

Flushing water and return water flow rate – water balance

As borehole KFM05A 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 gauge in the measurement station, see Figure 3-3. The return water was measured by another flow meter, mounted on-line with the discharge pipeline, see Figures 3-3 and 3-6.

However, the return water is normally a mixture of flushing water and groundwater from the formation penetrated by the borehole. In order to estimate the amount of remaining flushing water in the formation and in the borehole after the drilling operations, 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, while Figure 5-10 displays the accumulated volumes of flushing water and return water from the entire drilling period, giving a return water/flushing water quotient of 3.21 (results from Uranine measurements are presented in the next section).

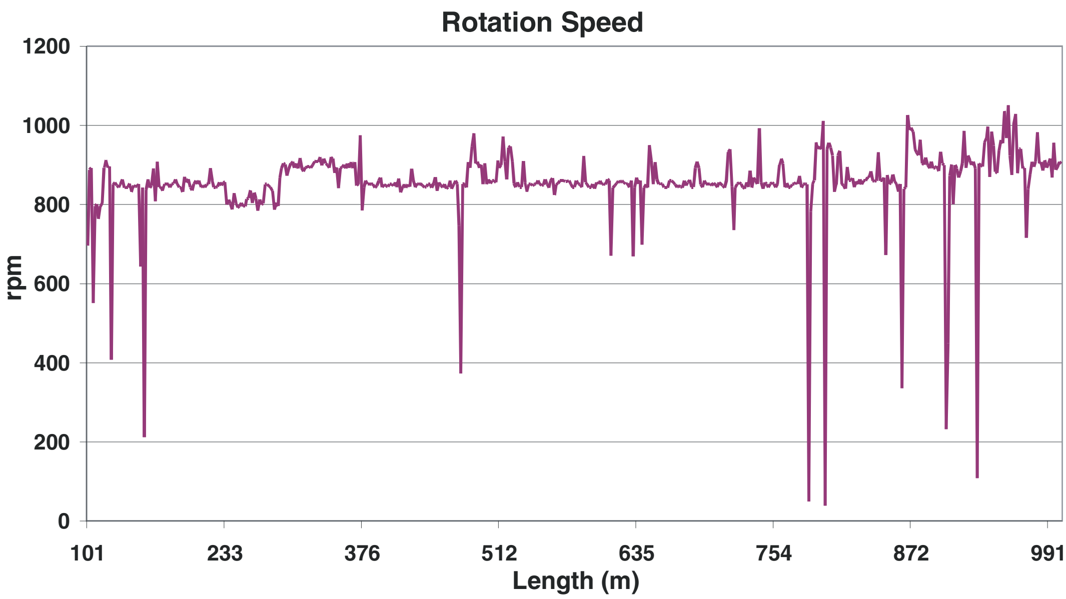


Figure 5-8. *Rotation speed versus borehole length during drilling of borehole KFM05A.*

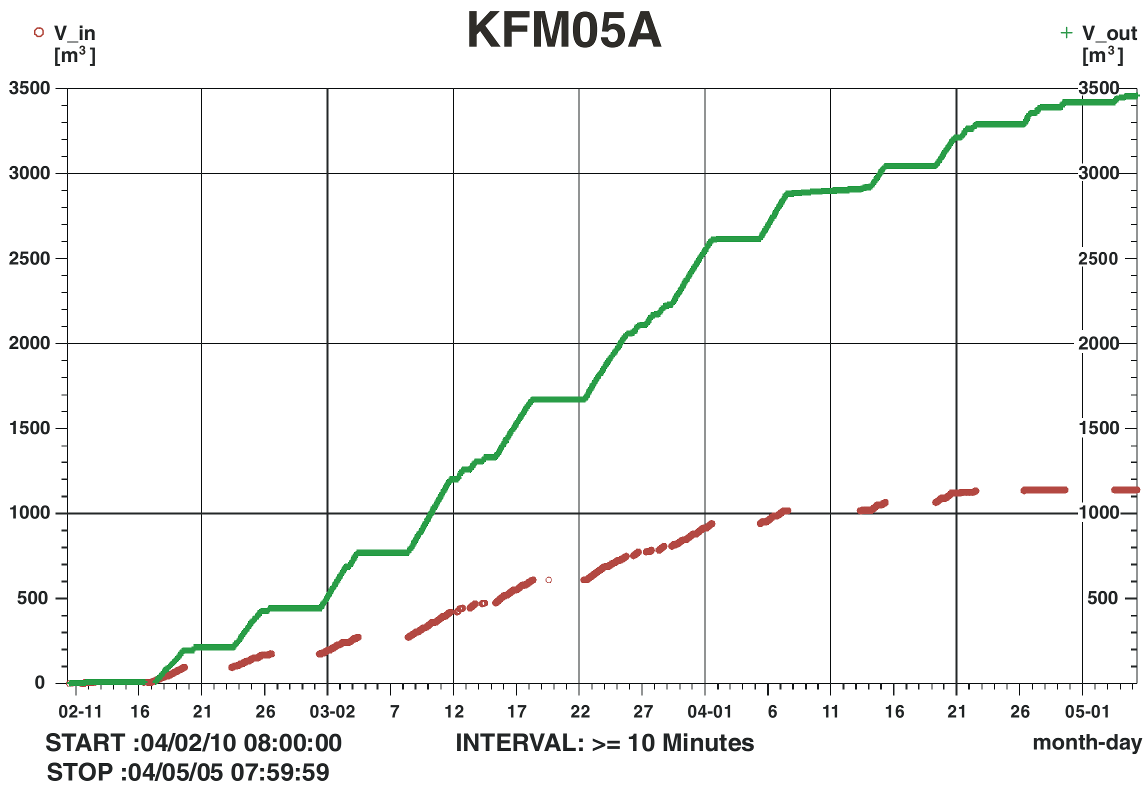


Figure 5-9. *Accumulated volumes of flushing water (red) and return water (green) versus time during core drilling of borehole KFM05A.*

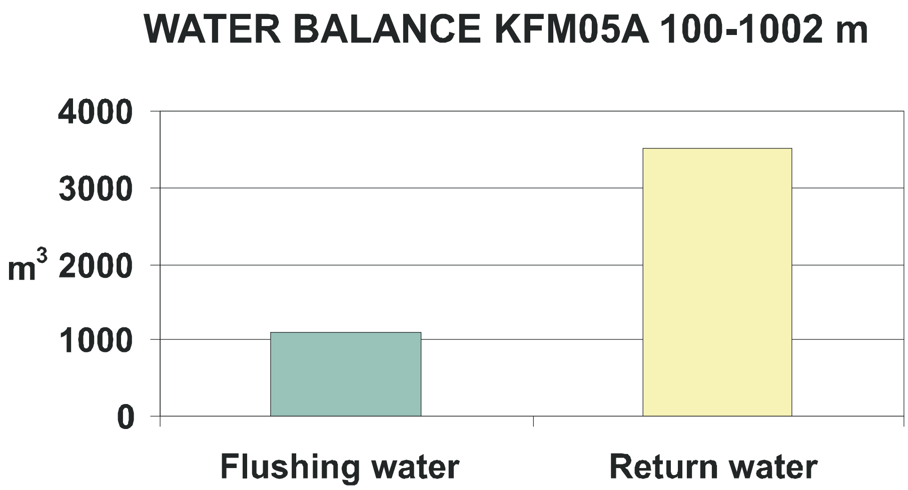


Figure 5-10. *The total volume of flushing water used during core drilling was 1,090 m³. During the same period, the total volume of return water was 3,500 m³. The return water/flushing water balance is then as high as 3.21, due to the large inflow of groundwater into the upper part of the borehole.*

However, in Figure 5-9 a loss of flushing water at shallow depths in the borehole is observed, as well as a significant excess of return water at depths exceeding c 350 m. This reflects the fact that when the drill bit position is close to water conductive fractures of the borehole, flushing water is forced into these fractures, because the flushing water pressure much exceeds that of the formation. When the drill bit has passed this section, the pressure gradient will eventually be reversed due to the air-lift pumping in the upper part of the borehole. If no other highly water conductive fractures are penetrated, where flushing water losses may occur, larger amounts of return water (groundwater and flushing water) are then extracted from the borehole than flushing water is supplied to it.

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 every fourth hour during the drilling period, see Figure 5-11. Like in boreholes KFM02A,

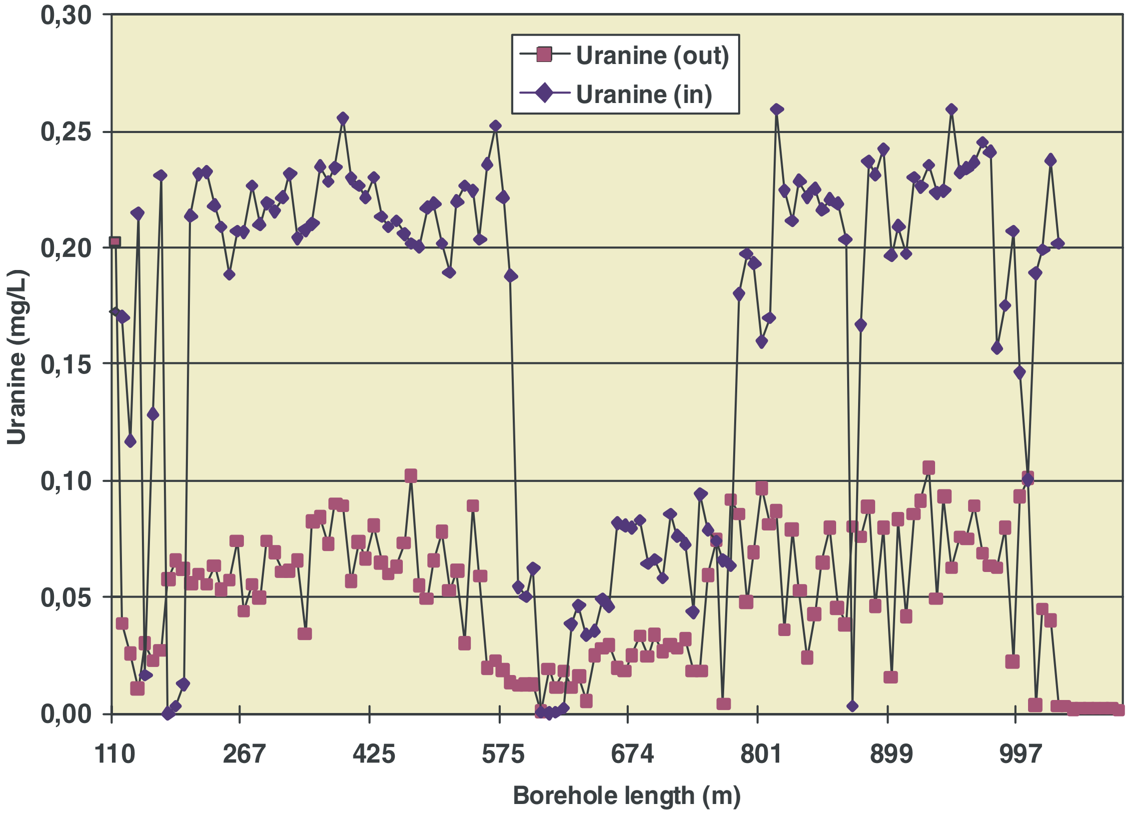


Figure 5-11. *Uranine content in the flushing water consumed and the return water recovered versus drilling length during drilling of borehole KFM05A. An automatic dosing equipment, controlled by a flow meter, accomplished the labelling with Uranine. During drilling between 600–750 m, malfunction caused irregular and erroneous dosage of Uranine. Hence, calculation of the amount of flushing water remaining in the formation is not fully reliable.*

KFM03A and KFM04A, a dosing feeder controlled by a flow meter was used for labelling the flushing water with Uranine. However, the flow meter malfunctioned during part of the drilling period.

A mass balance calculation of the accumulated volumes of flushing water and recovered flushing water in the return water indicates that the major part of the flushing water added to the borehole was recovered. A conclusion that can be drawn from the Uranine budget is that the increased sampling frequency compared to earlier boreholes resulted in more reliable calculations. According to notations in the log book, the amount of Uranine added to the borehole was 170 g. From the average Uranine concentration and the total volume of flushing water used, the amount of Uranine added is calculated to 186 g. The amount of Uranine recovered in the return water is calculated to 175 g.

Flushing water pressure

The flushing water pressure measured during drilling of borehole KFM05A is exposed in Figure 5-12. Like in boreholes KFM02A, KFM03A and KFM04A, the borehole diameter was 77.3 mm, i.e. increased c 1 mm compared to in borehole KFM01A. This resulted in lower flushing water pressure than in KFM01A, more like in KFM04A. The final water pressure was 10–20 bars higher than in KFM02A and KFM03A. One possible explanation may be that both KFM04A and KFM05A are more inclined than the previous boreholes, which makes the recovery of drill cuttings more difficult, demanding higher water pressures and increased flow rates.

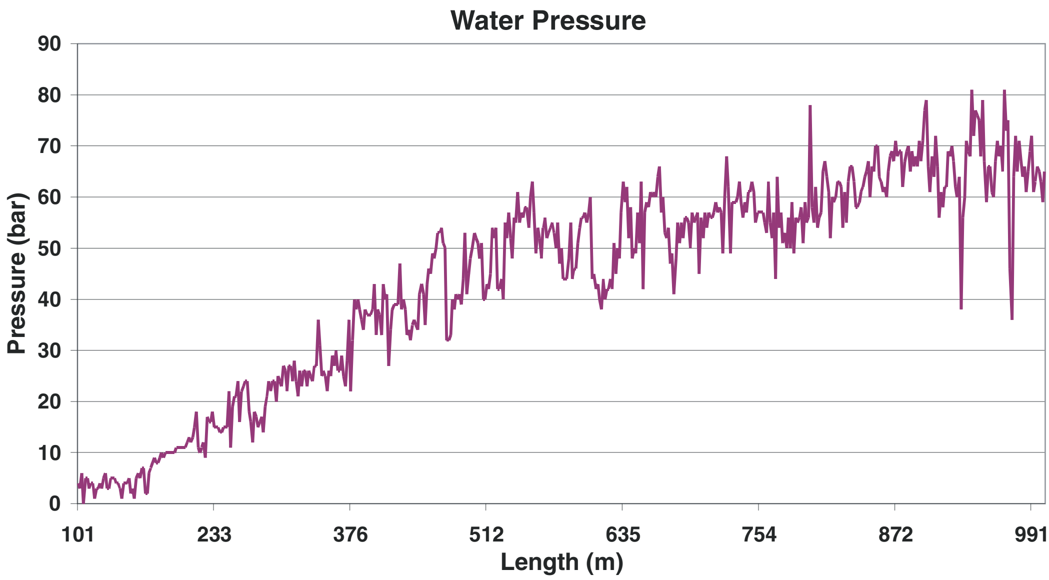


***Figure 5-12.** Flushing water pressure versus drilling length when drilling KFM05A.*

Electric conductivity of flushing water

Flushing water was supplied from percussion borehole HFM13. A sensor for on-line registration of the electric conductivity (EC) of the flushing water was placed in the measurement station, before the flushing water entered the borehole, see Figure 3-3.

The sensor for registration of the electric conductivity of the return water was positioned between the surge diverter (discharge head) and the sedimentation containers, see Figure 3-3.

The electrical conductivity (salinity) of the flushing water from the 175.6 m deep supply well HFM13 with its major inflow at c 162 m has from start a significantly increasing trend, but from 450 m it is almost constant during the drilling period which is observed in Figure 5-13.

The average electrical conductivity of the return water is almost constant during the drilling period, although a slightly decreasing trend may be observed. It is, however difficult to draw definite conclusions about the reason for that. One possible explanation is that the shallow groundwater inflow that dominates in KFM05A, is reactivated by the air flushing, entailing that the return water, i.e. flushing water mixed with increased amounts of shallow groundwater of lower salinity results in the decreasing salinity trend observed.

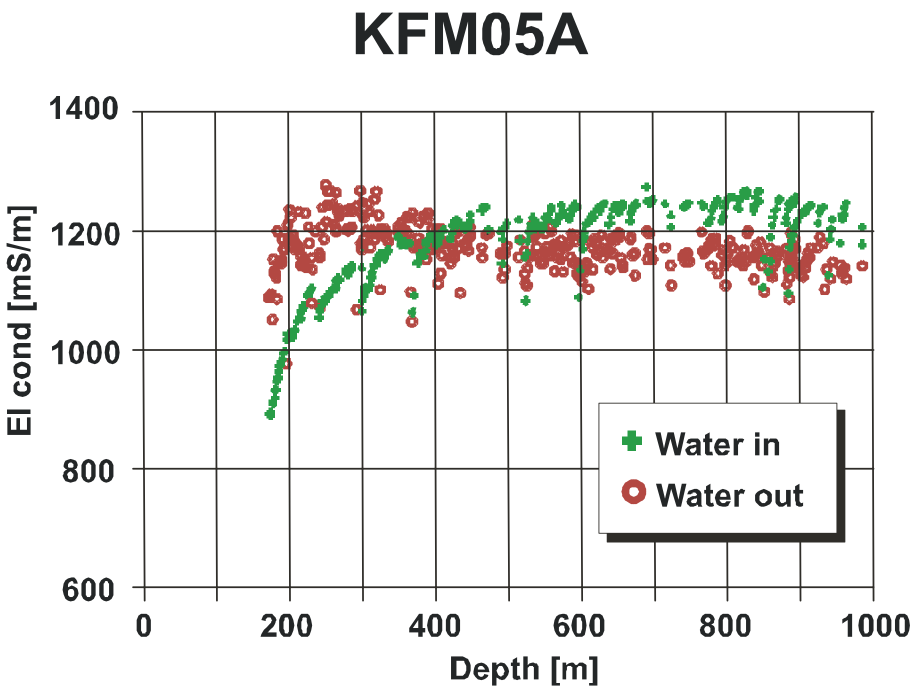


Figure 5-13. *Electrical conductivity of flushing water from HFM13 and return water from KFM05A. The amount of values in the dataset has been reduced as well as cleaned from outliers.*

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 chemical analyses of flushing water from the supply well HFM13 are compiled in Appendix C and reported in /11/. The flushing water was sampled prior to commencement of core drilling and at one occasion during 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 KFM05A.

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

Organic constituents

The concentration of Total Organic Carbon (TOC) in the samples collected in HFM13 prior to core drilling was in the range 3.8–6.0 mg/L. These values were considered as sufficiently low, and it was decided to use HFM13 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 /9/).

Microbes

The results from the control of the microorganism content in the flushing water used in KFM05A (Figure 5-14) are reported in /8/. The control was performed at three occasions during the drilling period: 1) initially after a thorough cleaning of the flushing water system, 2) when half of the borehole had been drilled, and before a renewed cleaning of the system, 3) when half the borehole was drilled but after the renewed cleaning of the system and 4) just before completion of the borehole. Contents below 1,000 cells/mL are considered acceptable, and this condition was generally met with, independently of the cleaning situation. This seems to prove that the flushing water system was sufficiently clean during the entire drilling period. Occasionally, the number of microbes was higher after the UV-system than before. This could be due to the fact that the sampling point after the UV-lamp is placed in the flow line after Uranine labelling. The Uranine vessel and the Uranine solution itself could possibly be a microbe source, although probably not a very serious one.

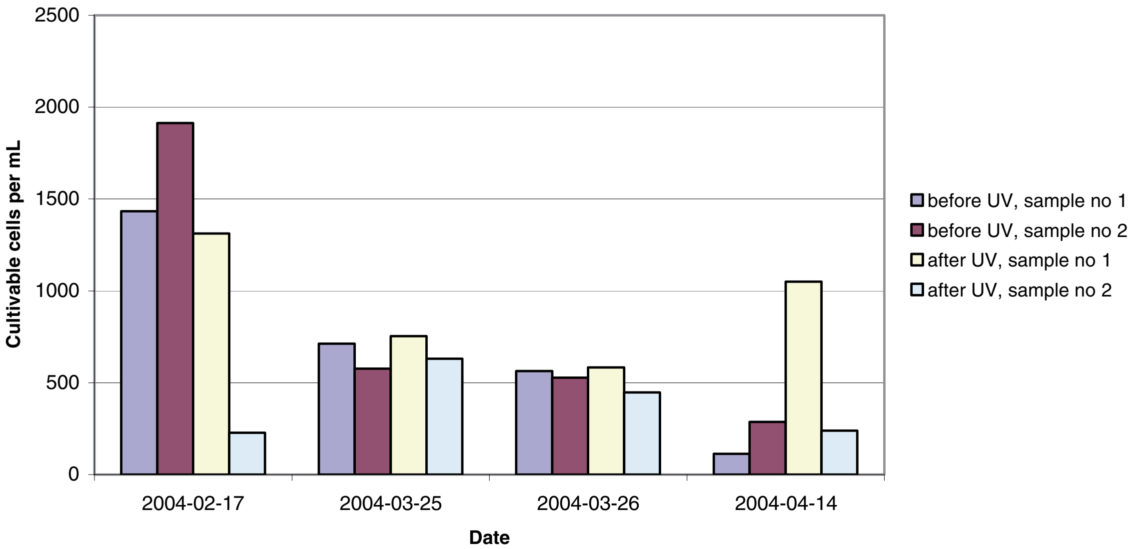


Figure 5-14. *Content of cultivable microbes in the flushing water at different occasions during drilling of KFM05A. Samples are collected before and after the UV-system. Two samples are collected at each sampling point and occasion.*

Chemical composition of flushing water

The flushing water was sampled at two occasions during drilling. As shown in Appendix C, the chemical composition of the groundwater from HFM13 changed slightly between the first and second sampling. Therefore, it could be concluded that the sampling aught to be conducted more frequently, say twice a month during the drilling period.

5.4.4 Groundwater sampling and analyses during drilling

Results from the only groundwater sample collected from KFM05A during the drilling period are presented in Appendix C. The flushing water content is unusually low for a sample being collected during drilling. Some of the isotope results were not yet reported from the consulted laboratory at the printing date but will be available in the database SICADA later on.

5.4.5 Registration of the groundwater level in KFM05A

To enhance the recovery of drill cuttings from the borehole, air-flush (mammoth) pumping was applied during the entire drilling period. The pumping capacity was checked by registration of the groundwater level in the borehole, below plotted versus borehole length (Figure 5-15).

From the beginning, the mammoth pumping was set at the maximum draw-down, but after the major inflow at 109 m, the drawdown was adjusted to approximately 35 m. Shortly before the end of drilling, the draw-down was again increased, to approximately 45 m. Drilling was performed continuously during Monday–Thursday. During the weekend stop of drilling and pumping, the groundwater table recovered rapidly due to recharge of groundwater into the borehole, resulting in the (positive) peaks in the diagram. This confirms that the total inflow of formation water in the upper part of the borehole (but below the upper cased and grouted parts) was high. When pumping was restarted, a simultaneous drawdown occurred.

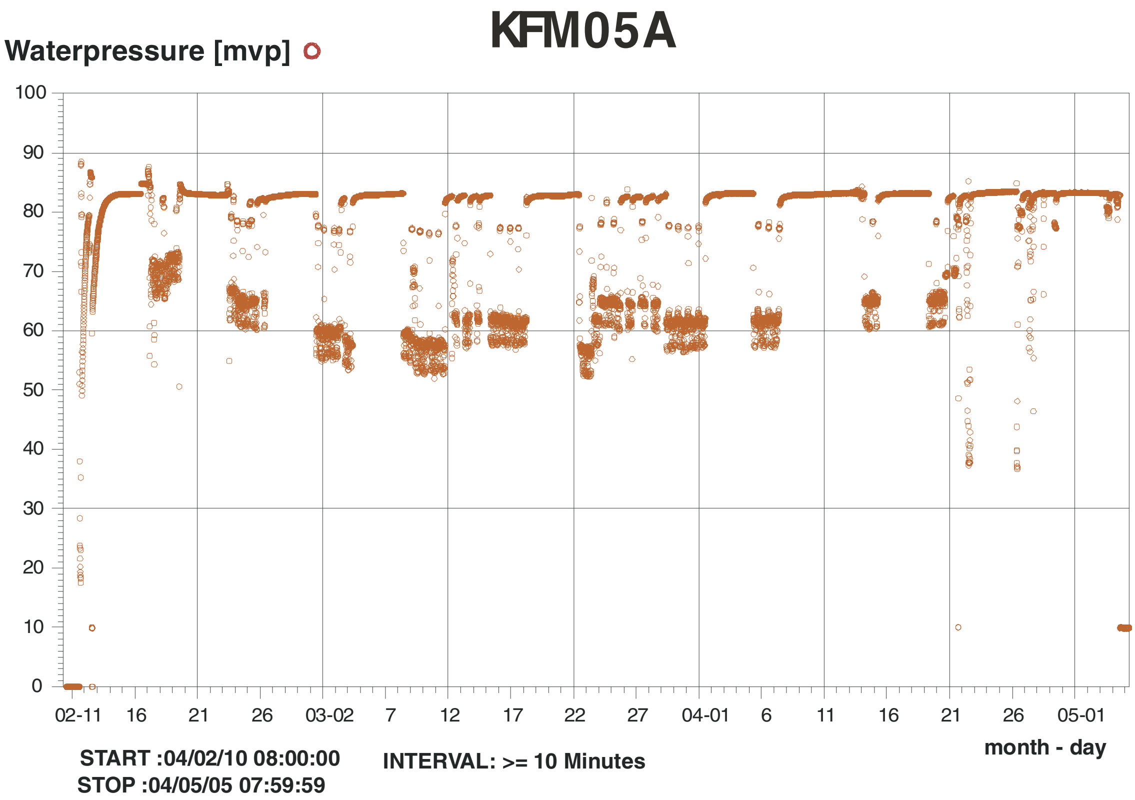


Figure 5-15. Variation of the level of the groundwater table in KFM05A during drilling.

5.4.6 Core sampling

The average drill core length per run obtained from the drilling was 2.66 m. Due to the very low fracture frequency at depth, approximately fourty 3 m long, unbroken cores were recovered. Fracture minerals were relatively well preserved. Rotation marks on the drill core occurred, but with a low frequency. A preliminary on-site core logging was performed continuously.

5.4.7 Recovery of drill cuttings

The theoretical volume of the percussion drilled and reamed part of the borehole (0–100 m) is c 5 m^3. Weighing of drill cuttings and comparison with the weight of the theoretical volume was not carried out due to the relatively high water flow. This caused a relatively large and uncontrolled overflow of return water with suspended drill cuttings, making it difficult to obtain reliable results of drill cuttings estimations. However, it seems probable that the percussion drilled part was well cleaned from debris, since casing driving and gap grouting to full borehole length worked well, without obstruction from settled drill cuttings.

The theoretical difference in volume of the core drilled part of KFM05A and the drill core is calculated to be 2.406 m^3. This volume should correspond to the amount of drill cuttings produced during drilling. If a density of 2,650 kg/m^3 (approximate figure for granitoids in the Forsmark area) is applied, the total weight of the theoretical amount of debris is estimated at 6,376 kg. The calculated dry weight of the debris from the core drilling recovered and weighed in the containers is 3,223 kg. The difference between the theoretically produced and recovered dry weight of debris is 3,142 kg, which gives a recovery of 51%.

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 51%. It should also be observed, that weighing of the container including water and debris is associated with some uncertainty.

However, it seems plausible that drilling debris has been injected into the fracture system of the formation, especially in the permeable sections with increased fracture frequency above c 200 m in the borehole.

5.4.8 Deviation measurements

The deviation measurements made in borehole KFM05A with the Reflex Maxibor system indicated a larger deviation of KFM05A, both in the horizontal and the vertical plane, than observed for the previously drilled deep boreholes KFM01A–KFM04A. Independent results from difference flow logging by Posiva Oy indicated differences in elevation values (z-coordinate) compared to the Maxibor measurements. Therefore, a new Maxibor survey was carried out. However, now the results disagreed even more with those of the difference flow logging measurements.

Deviation measurements were now performed also with a Reflex EZ-AQ/EMS™ system. The results, which are presented in Appendix B, were well in accordance with the difference flow logging measurements. At present, these are the values regarded as the most reliable of the deviation measurement carried out and are stored in SICADA. The bottom of the borehole deviates 30 m upwards and 120 m to the right compared to an imagined straight line following the dip and strike of the borehole start point.

An investigation will be made about the dubious results from the Maxibor measurements.

5.4.9 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 inclinations of the borehole. The practical difficulties and uncertainties in the results however turned out to be considerable. Therefore it is recommended that the length error is determined from the diagram in Figure 5-16, 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 1,000 m length in a vertically drilled borehole is 180 mm. In inclined boreholes the elongation of the pipe string should theoretically be less.

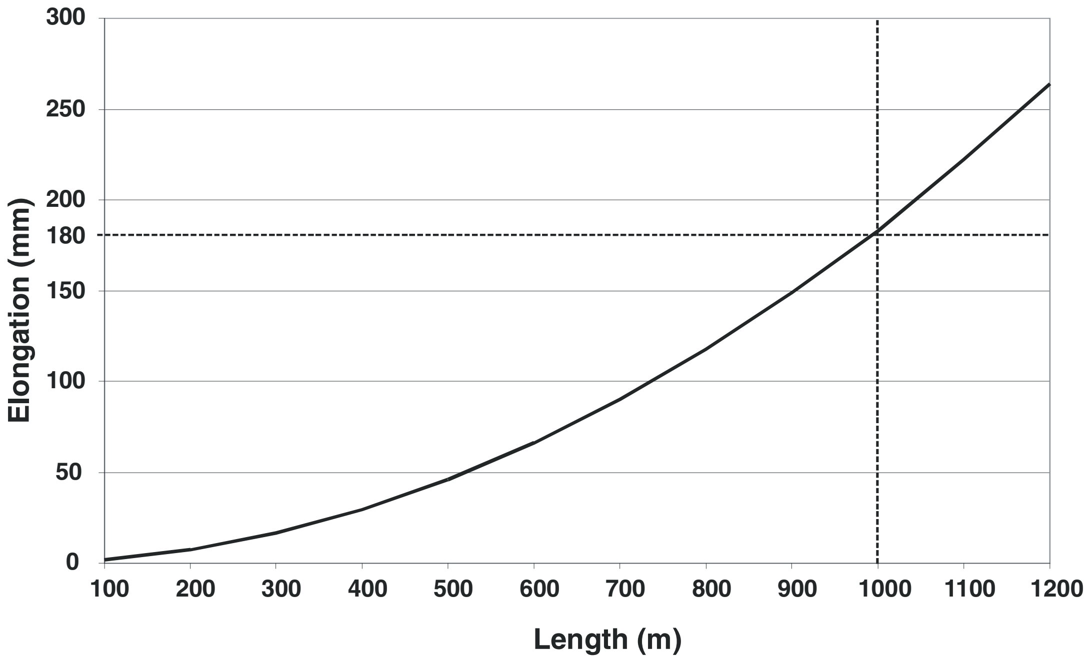


__Figure 5-16.__ The diagram illustrates the elongation of the WL-76 drilling pipe string when hanging in a vertical water filled borehole. Values from a laboratory load tests of the drilling pipe string.

5.4.10 Groove milling

After completion of drilling, borehole KFM05A will be used for 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 at certain levels with a specially designed tool. This was carried out after termination of 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 5-2 presents the reference levels selected for milling. The table also reveals that milling failed at certain levels. After milling, the reference grooves were detected with the SKB level indicator (a calliper). A BIPS-survey gave the final conformation of where the groove milling was successful and where it failed.

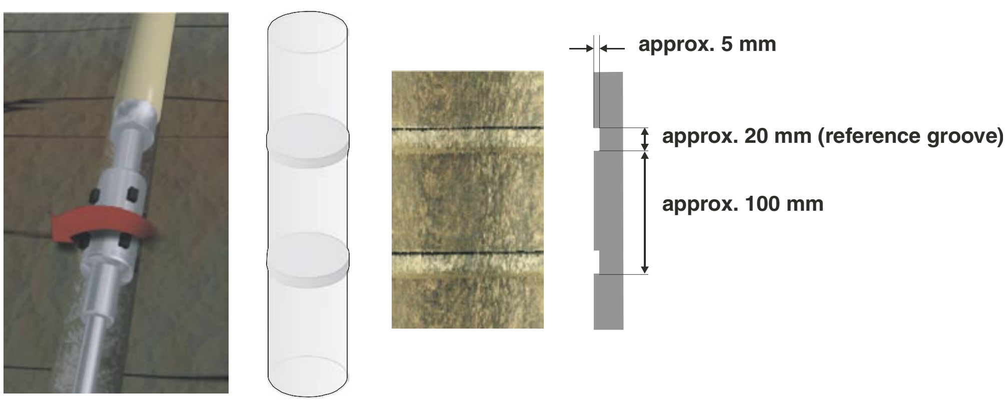


__Figure 5-17.__ Layout and design of reference grooves. The milling tool shown to the left.

Table 5-2. 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
120	Yes	Yes	550	Yes	Yes
152	Yes	Yes	606	Yes	Yes
199	Yes	Yes	650	Yes	Yes
252	Yes	Yes	700	Yes	Yes
300	Yes	Yes	750	Yes	Yes
352	Yes	Yes	800	Yes	Yes
402	Yes	Yes	850	Yes	Yes
450	Yes	Yes	900	No	Yes[1]
501	Yes	Yes			

[1] weak

5.4.11 Consumables

The amount of oil products consumed during drilling of the percussion drilled part of KFM05A (0–100 m), thread grease used during core drilling, and grout used for gap injections of the respective casings are reported in Tables 5-3 and 5-4. 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 during core drilling in this particular borehole was certified according to SKB MD 600.006, Instruction for the use of chemical products and material during drilling and surveys. The experience from a technical point of view of the grease, is not satisfactory. Although expensive, the grease had a low adhesion capacity to the threads, and the lubrication characteristics are not as good as for conventional lubricants.

Table 5-3. Oil and grease consumption.

Borehole ID	Hammer oil (percussion drilling) Preem Hydra 46	Compressor oil (percussion drilling) Schuman 46	Thread grease (core drilling) Unisilikon L50/2
KFM05A	15 L	Not detected	6.4 kg

Table 5-4. 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
KFM05A	12.25	5,819 kg/5,705 L	Hose	Stop pressure 7 bars. The entire borehole down to 100.35 m was cement grouted
KFM05A	100.07	1,499 kg/1,680 L	Packer	Gap injection

5.5 Hydrogeology

5.5.1 Hydraulic tests during drilling (wireline tests)

No pumping tests were performed due to the very low hydraulic transmissivity along the borehole. However, pumping tests and flow logging has been made in three percussion drilled boreholes HFM13, HFM14 and HFM15 at DS5 /10/.

Absolute pressure measurements were performed in three sections as specified in Table 5-5 and Appendix D.

Table 5-5. Absolute pressure measurement in KFM05A.

Test section (m)	Last pressure reading during test (kPa)	Test duration (h)	Borehole length to pressure sensor (m from ref)
104.7–223.84	971	86	105.68
224.2–316.03	2,017	98	225.18
590.9–669.08	5,020	96	591.88

5.5.2 Recovery monitoring after cleaning by airlift pumping

The recovery registration after the final cleaning of the borehole by airlift pumping, which caused a drawdown of 18 m, is displayed in the diagram of Figure 5-18. The recovery of the groundwater table was registered during a weekend and confirmed the high yielding capacity of the borehole. From the diagram an inflow of >200 L/min can be estimated.

Prior to drilling start of KFM05A, the flushing water well HFM13 was drilled c 350 m west of drilling site DS5. The pumping activities in KFM05A respectively in the two percussion drilled boreholes at drilling site DS5 revealed hydraulic connections between all three boreholes at shallow levels (<100 m).

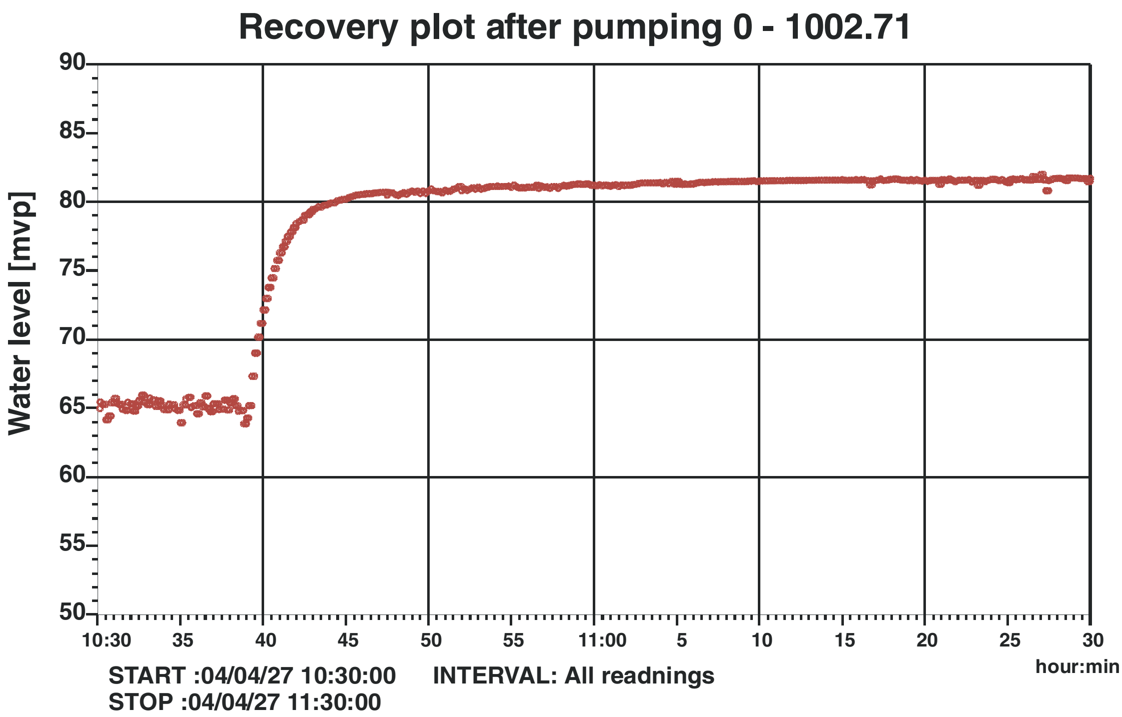


Figure 5-18. *Recovery of groundwater table in section 0–1,002.71 m of KFM05A.*

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 and Nilsson G. Forsmark site investigation. Drilling of a flushing water well, HFM13, two groundwater monitoring wells in solid rock, HFM14–15, and one groundwater monitoring well in soil, SFM0058, at and close to drilling site DS5. SKB P-04-85, Svensk Kärnbränslehantering AB.

/4/ **SKB, 2004.** Claesson L-Å and Nilsson G. Forsmark site investigation. Drilling of ive percussion boreholes, HFM11–12 and HFM 17–19, on different lineaments. SKB P-04-106, Svensk Kärnbränslehantering AB.

/5/ **SKB, 2003.** Petersson J and Wängnerud A. Site investigations at Forsmark. Boremap mapping of telescopic drilled borehole KFM05A. SKB P-report in progress, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2005.** Leijon B (ed). Forsmark site investigation. Investigations of superficial fracturing and block displacements at drill site 5. SKB P-report in progress, Svensk Kärnbränslehantering AB.

/7/ **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.

/8/ **SKB, 2004.** Hallbeck L, Pedersen K, Kalmus A. Site investigations in the Forsmark area. Control of microorganism content in flushing water used for drilling of KFM05A. SKB P-04-285, Svensk Kärnbränslehantering AB.

/9/ **SKB, 2003.** Claesson L-Å and Nilsson G. Forsmark site investigation. Drilling of the telescopic borehole KFM01A at drilling site DS1. SKB P-03-32, Svensk Kärnbränslehantering AB.

/10/ **SKB, 2004.** Ludvigson J-E, Jönsson S, Jönsson J. Forsmark site investigation. Pumping tests and flow logging. Boreholes HFM13, HFM14 and HFM15. SKB P-04-71, Svensk Kärnbränslehantering AB.

/11/ **SKB, 2004.** Nilsson D. Forsmark site investigation. Sampling and analyses of groundwater from percussion boreholes HFM09 to HFM19 and the percussion drilled part of KFM06A. SKB P-04-92, Svensk Kärnbränslehantering AB.

Well Cad presentation of the percussion drilled part of borehole KFM05A

Title PERCUSSION DRILLED BOREHOLE KFM05A

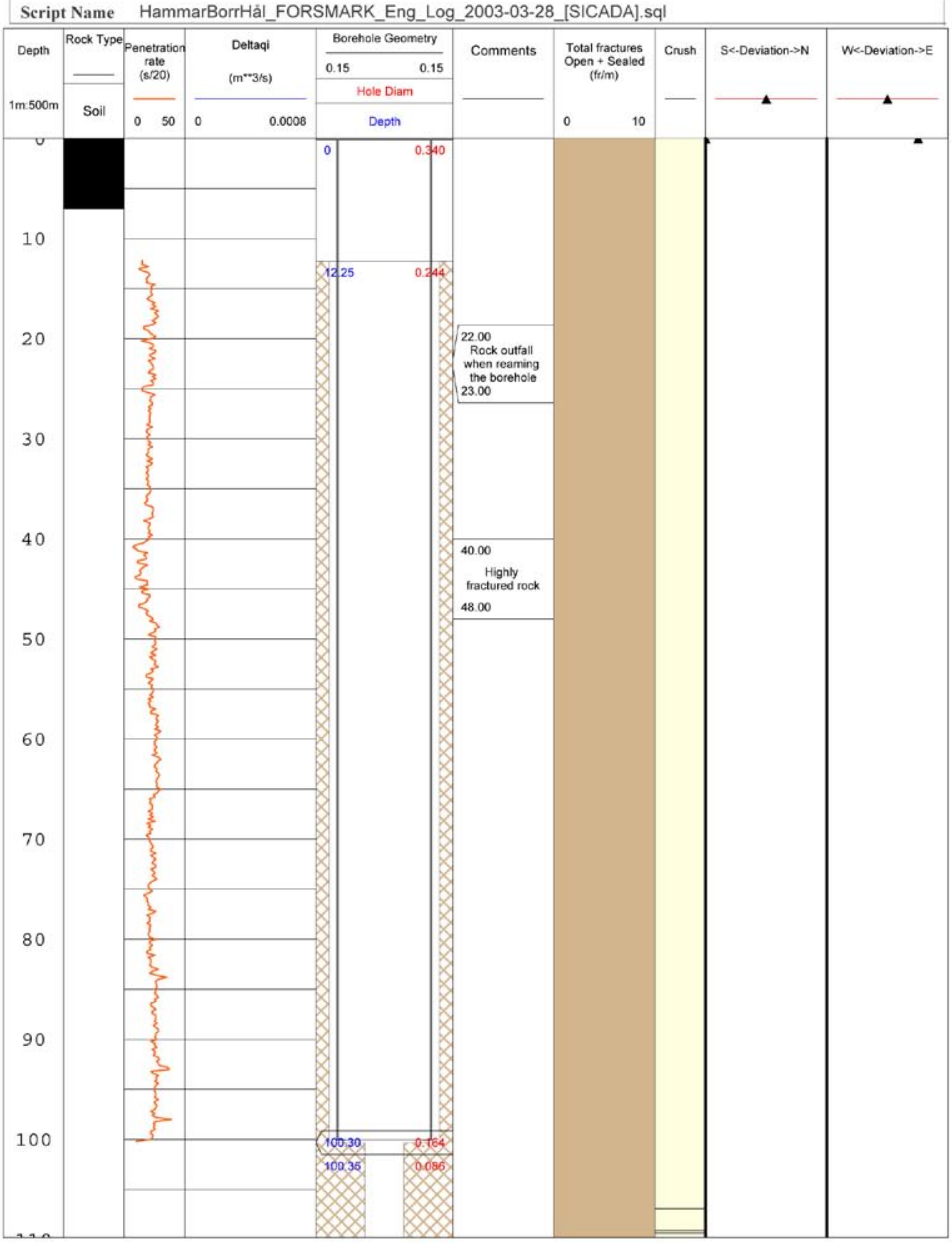
Svensk Kärnbränslehantering AB

Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	KFM05A	Northing [m]	6699344.85
Diameter [mm]	164	Easting [m]	1631710.80
Length [m]	100.35	Elevation [m.a.s.l.]	5.53
Bearing [°]	80.90	Drilling Start Date	2003-11-23 14:30:00
Inclination [°]	-59.80	Drilling Stop Date	2003-12-16 17:00:00
Date of mapping		Plot Date	2004-08-29 21:01:58

ROCKTYPE

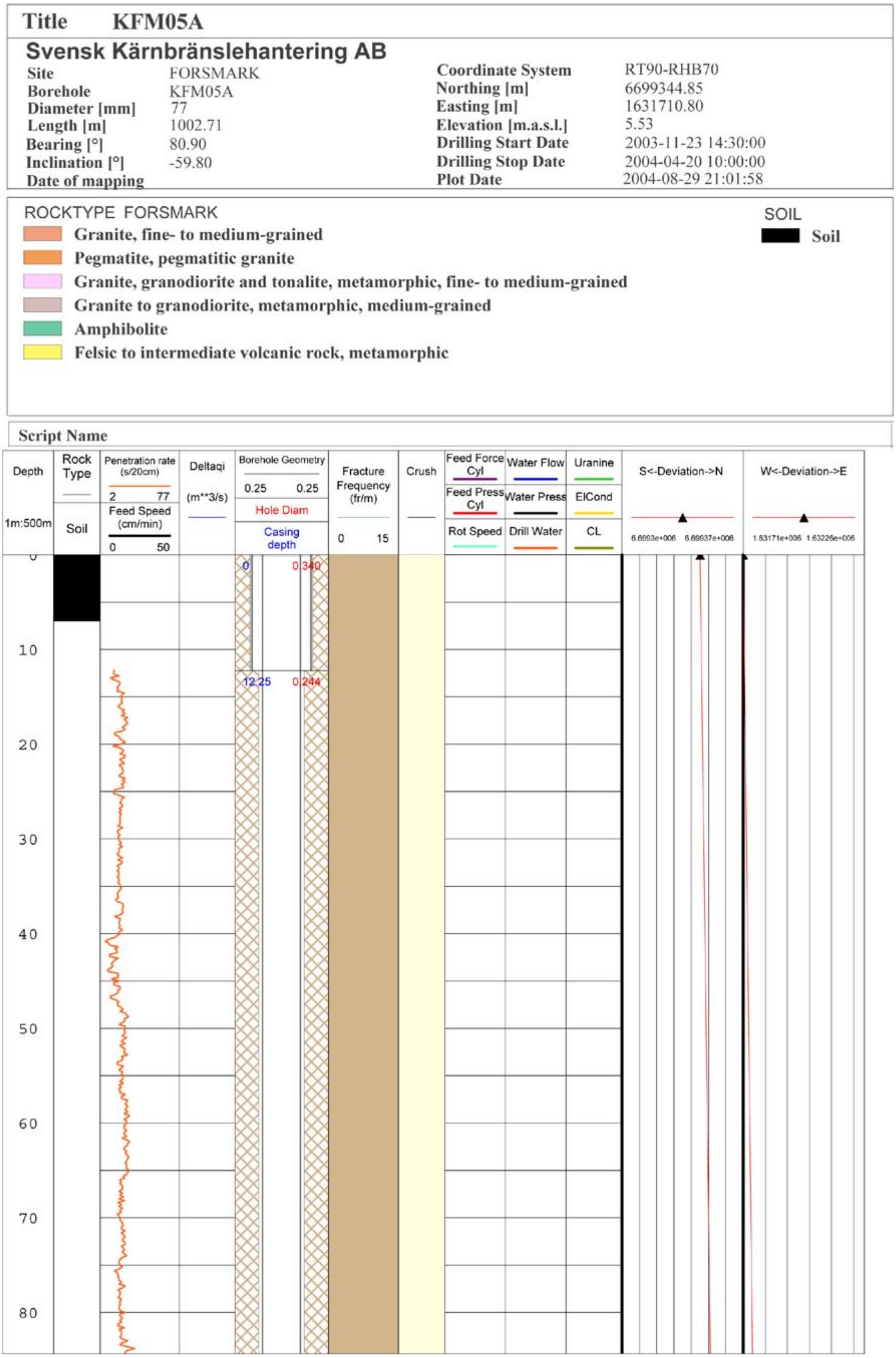
SOIL
Soil

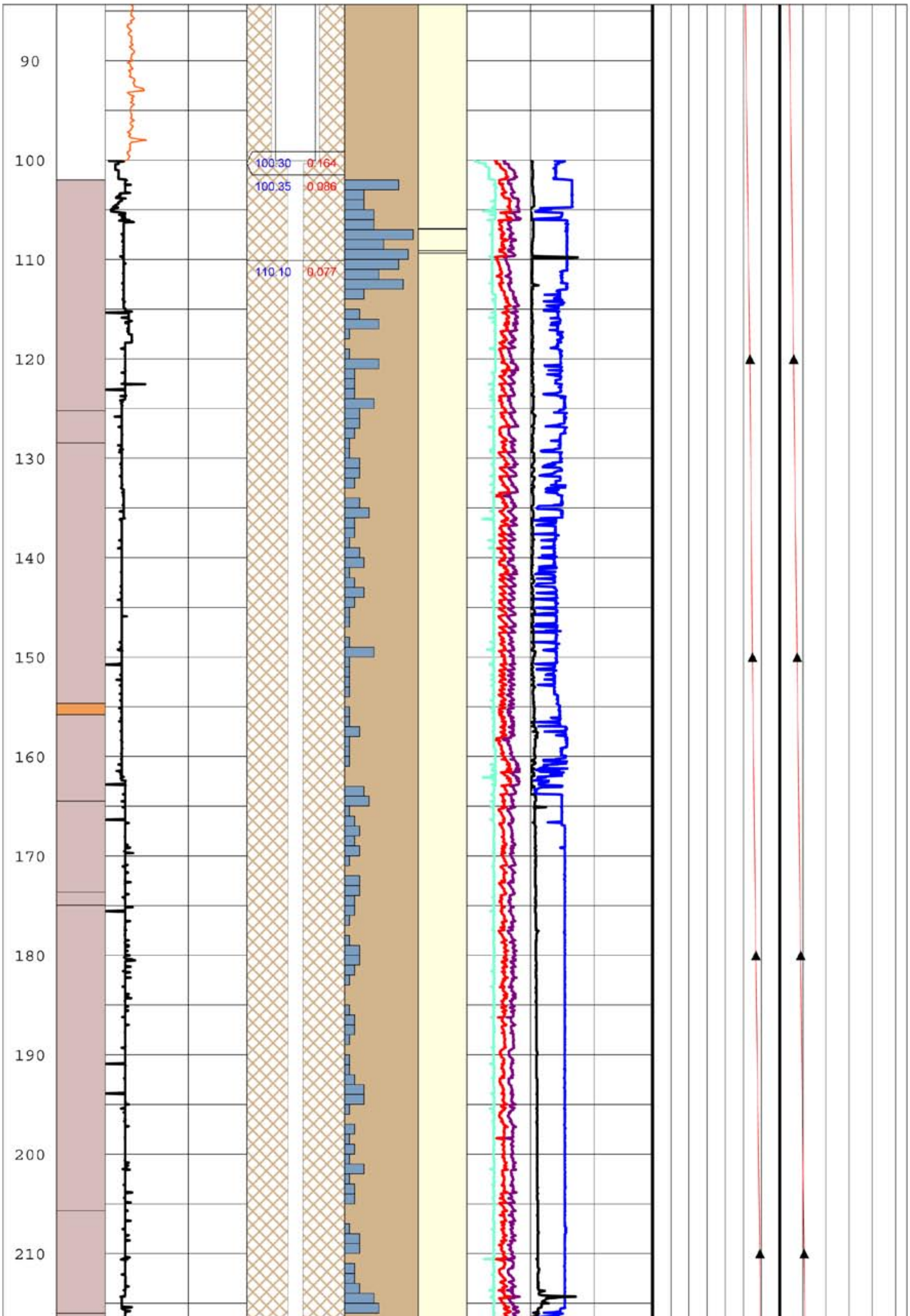
Script Name HammarBorrHål_FORSMARK_Eng_Log_2003-03-28_[SICADA].sql



Appendix B

Well Cad presentation of borehole KFM05A (entire borehole)

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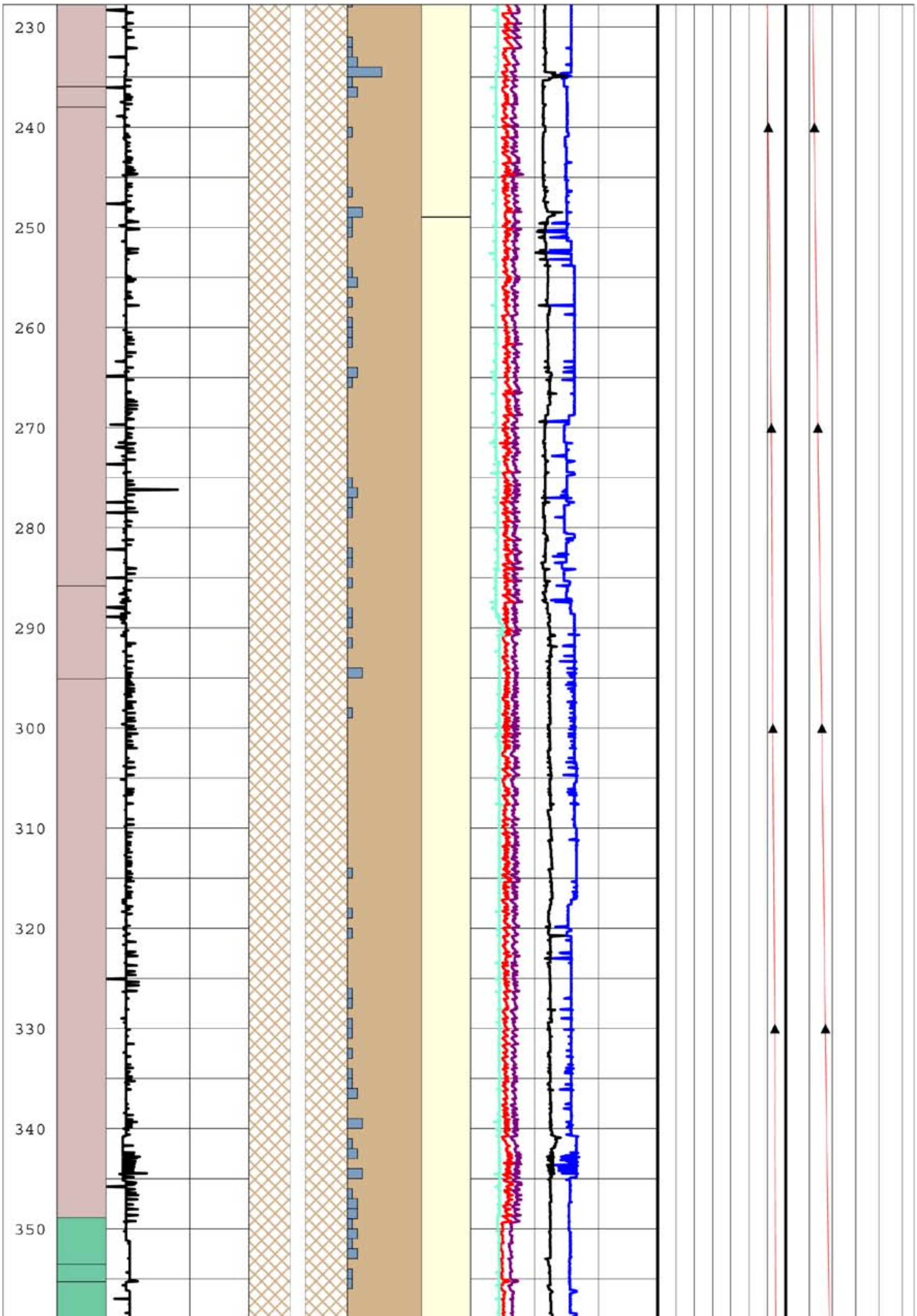
110
120
130
140
150
160
170
180
190
200
210
220
100.30 0.164
100.35 0.986
110.10 0.077



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310
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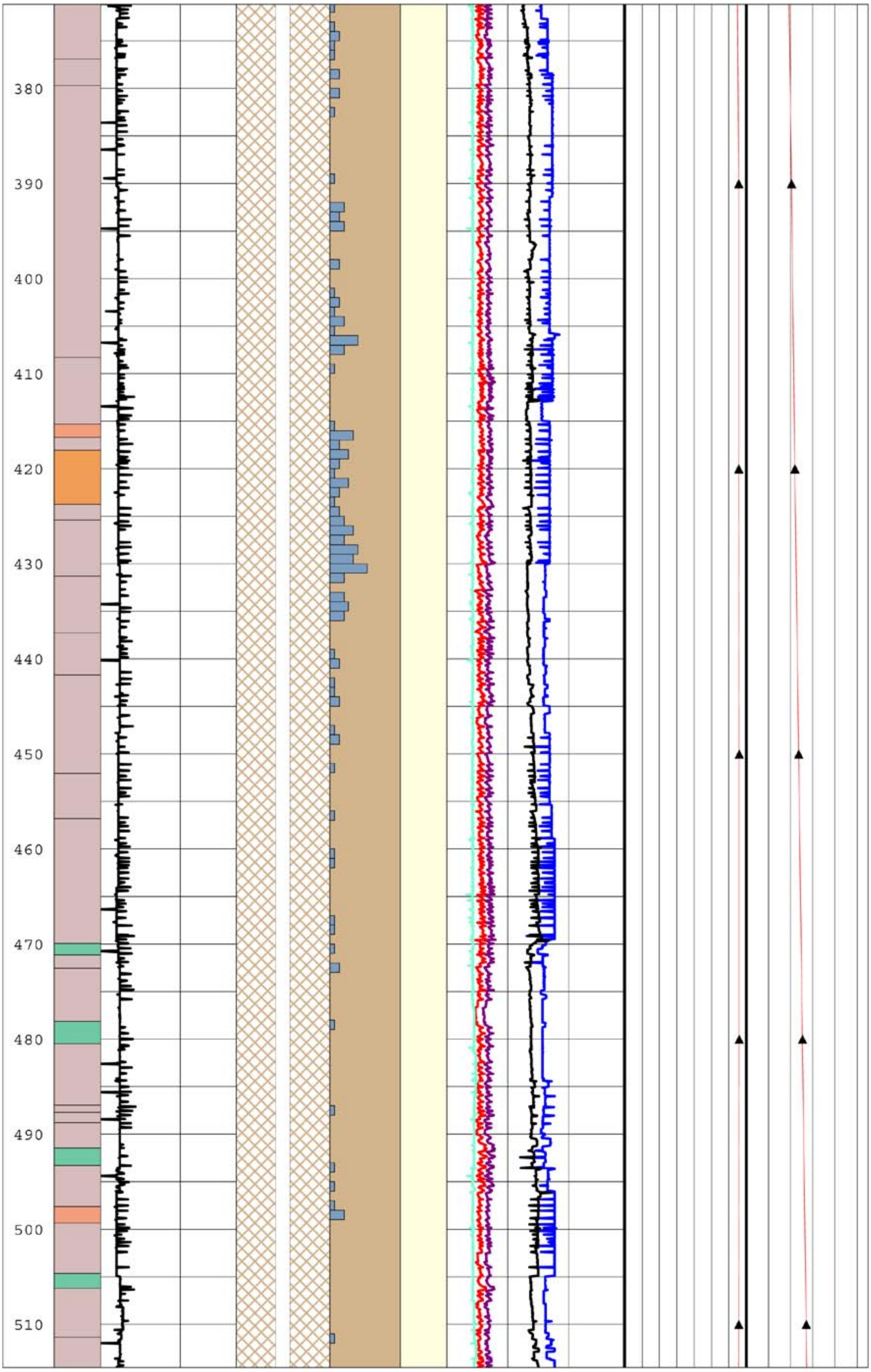
340
350
360
370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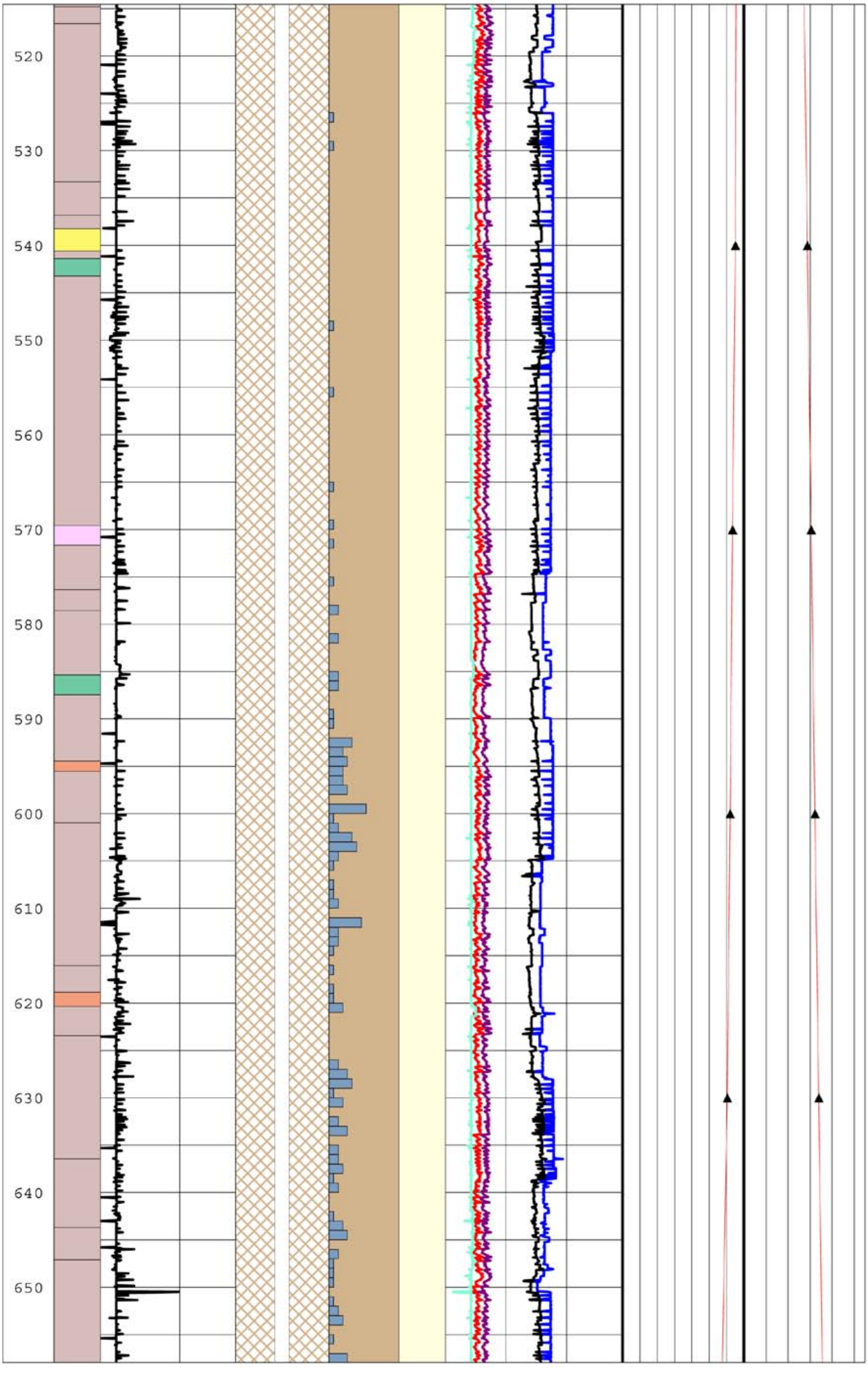
490
500
510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620
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640
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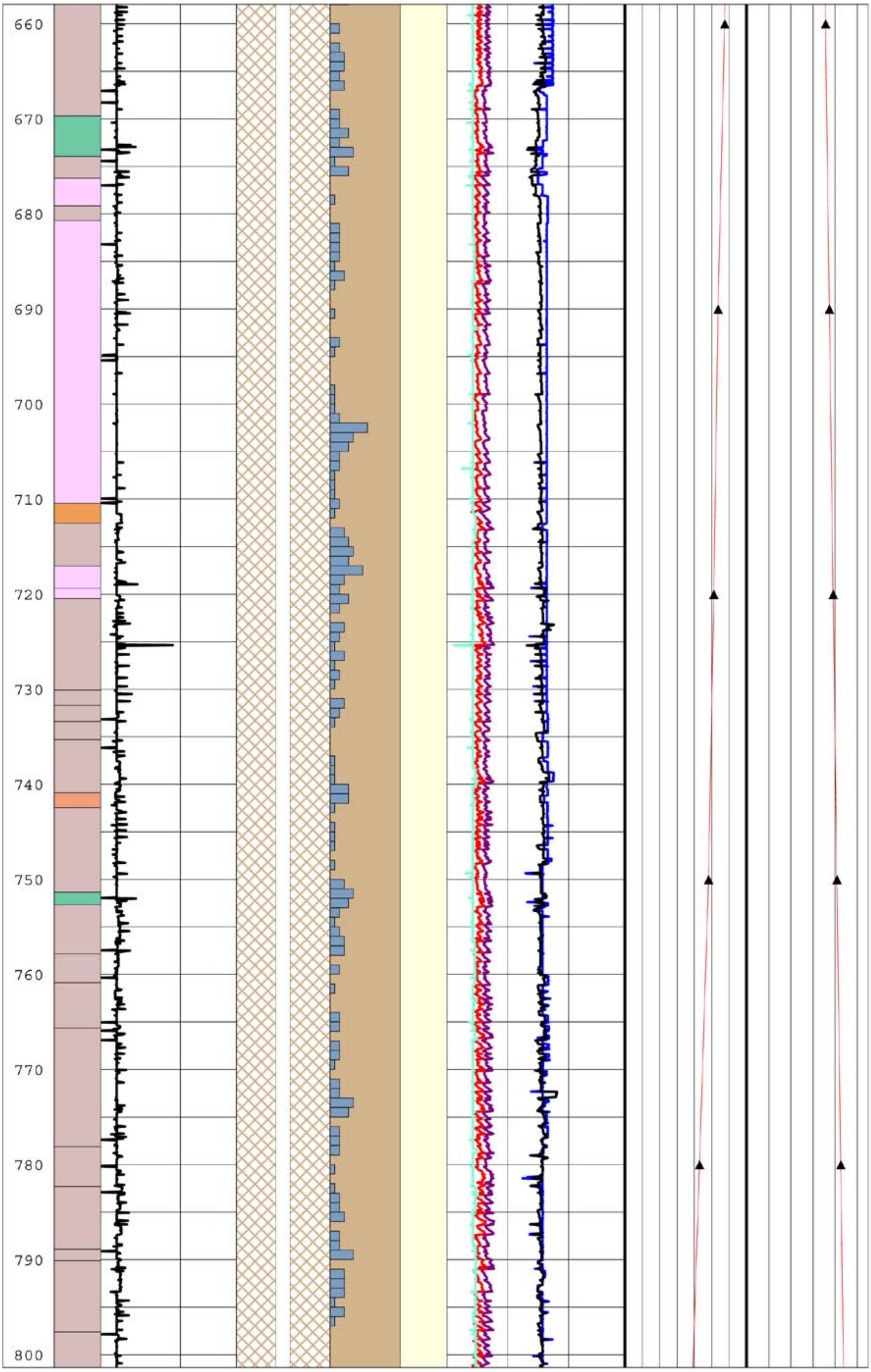
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790
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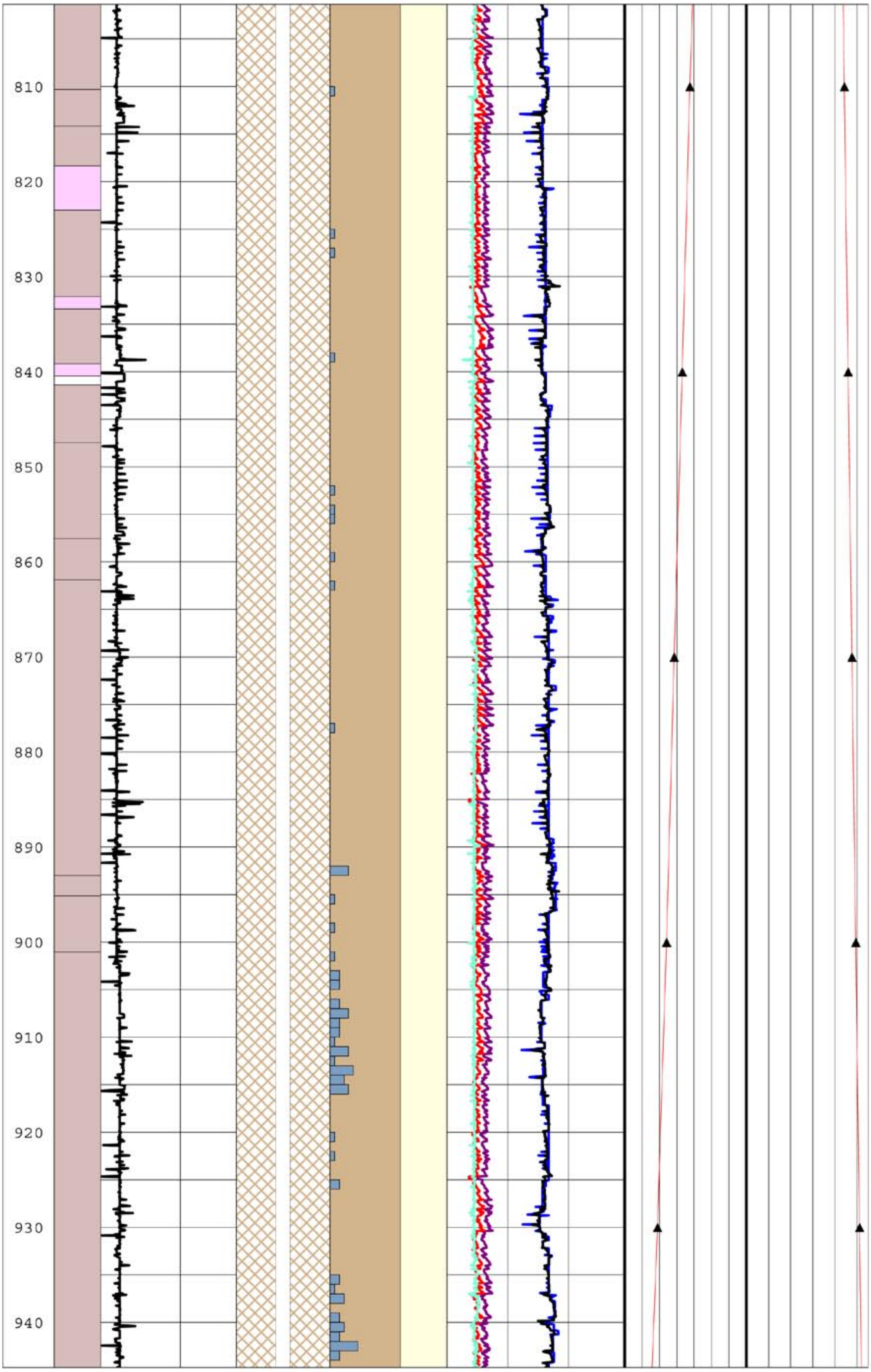
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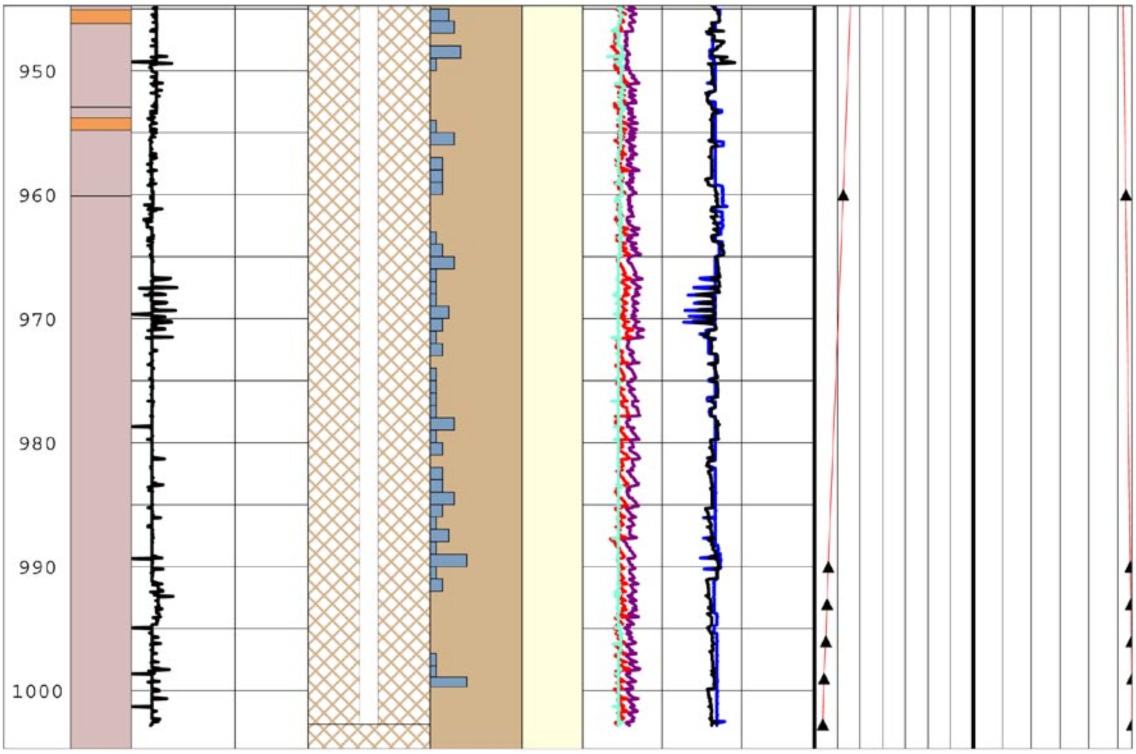
850
860
870
880
890
900
910
920
930
940



950
960
970
980
990
1000

Appendix C

Water composition

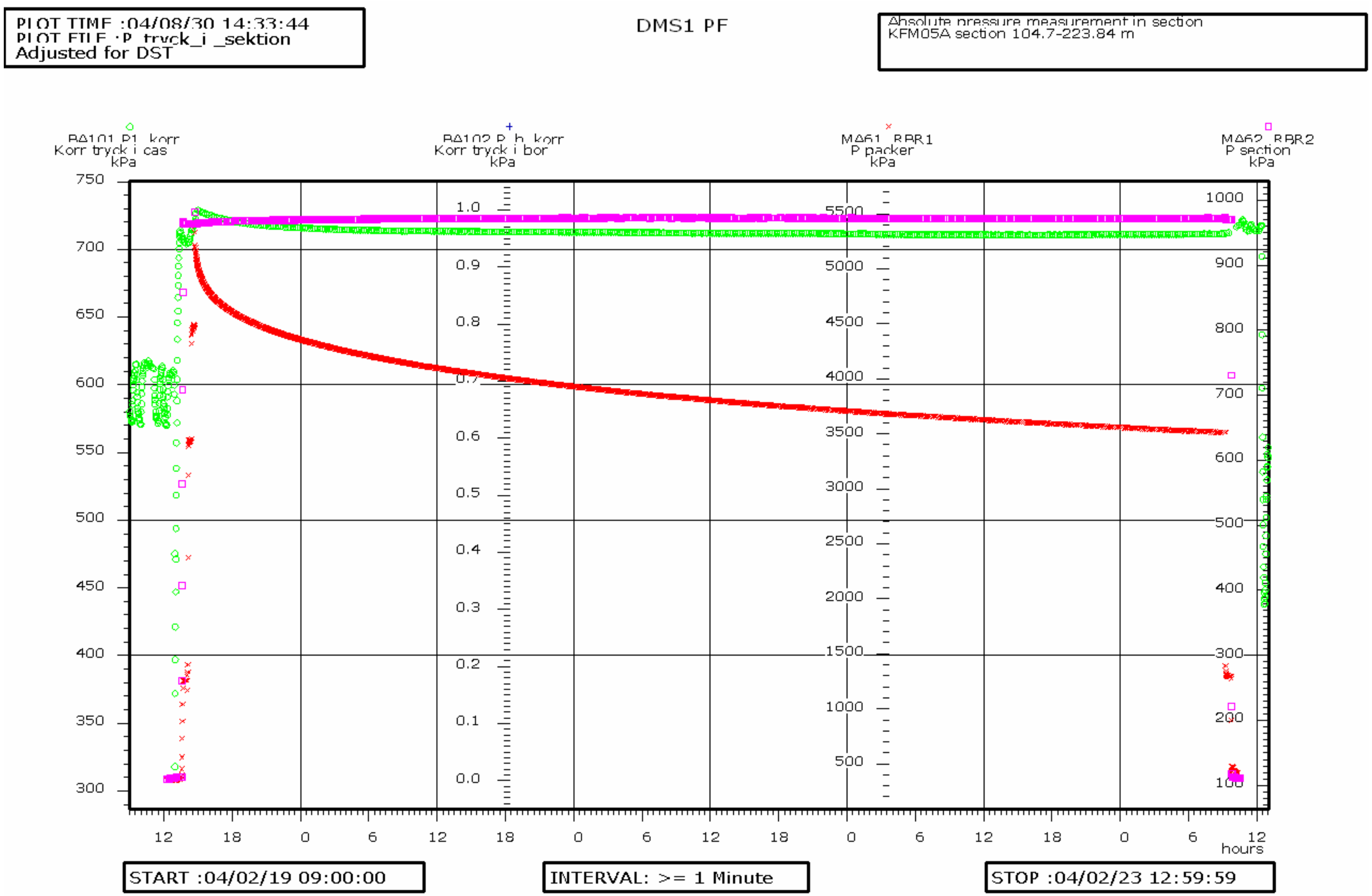
Date	ID code	Sample no	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO_3 mg/L	Cl mg/L	SO4 mg/L	SO_4_S mg/L	Br mg/L	F mg/L	Si mg/L	Li mg/L	Sr mg/L	TOC mg/L	pH no unit	Cond mS/m
2004-02-17	KFM05A	8332	1,710	46.9	862	197	127	4,370	486	160	13.5	–0.2	5.78	0.056	4.89	2.6	7.18	1,320
2004-02-25	HFM13	8339	1,380	24.4	718	156	170	3,810	414	123	11.8	–0.2	7.17	0.040	6.22	3.4	7.29	1,150
2004-03-24	HFM13	8367	1,560	30.5	802	180	172	4,180	473	137	20.8	1.6	7.06	0.045	6.4	2.8	7.42	1,250

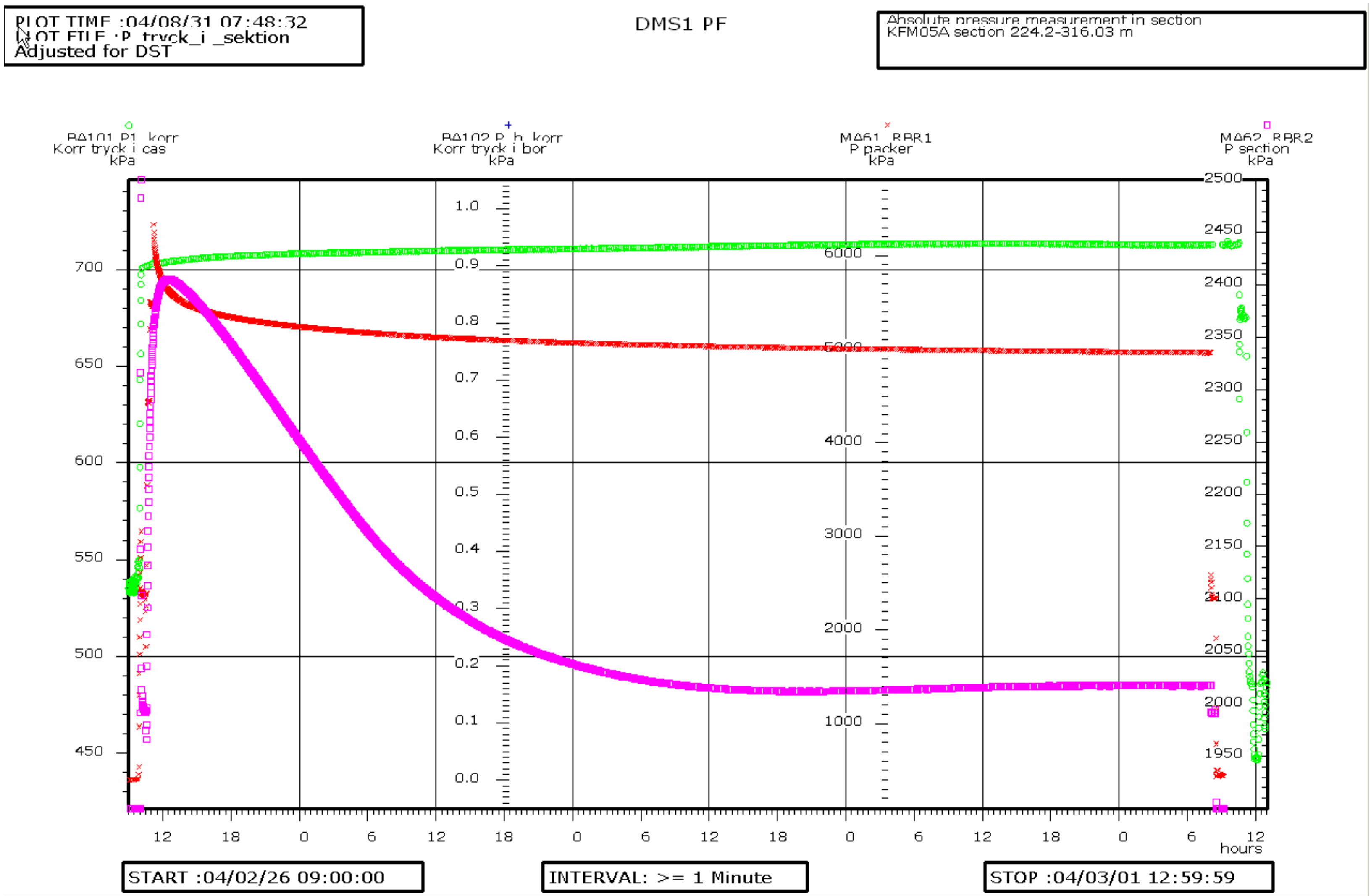
The sample from KFM05A has secup 0 m och seclow 121.6 m.

Date	IDCODE	Sample no	δ^2H ‰ SMOW	^3H TU	$\delta^{18}O$ ‰ SMOW	^{14}C pmC	$\delta^{13}C$ ‰ PDB	$^{10}B/^{11}B$ no unit	$\delta^{34}S$ ‰ CDT	$^{87}Sr/^{86}Sr$ no unit	Flushing water % mg/L
2004-02-17	KFM05A	8332	–64.2	1.50	–8.50	–	–	0.2365	–	–	5.3
2004-02-25	HFM13	8339	–71.1	1.90	–9.70	–	–	0.2414	25.0	0.719302	
2004-03-24	HFM13	8367	–68.4	–	–9.30	–	–	0.2360	24.8	0.719874	

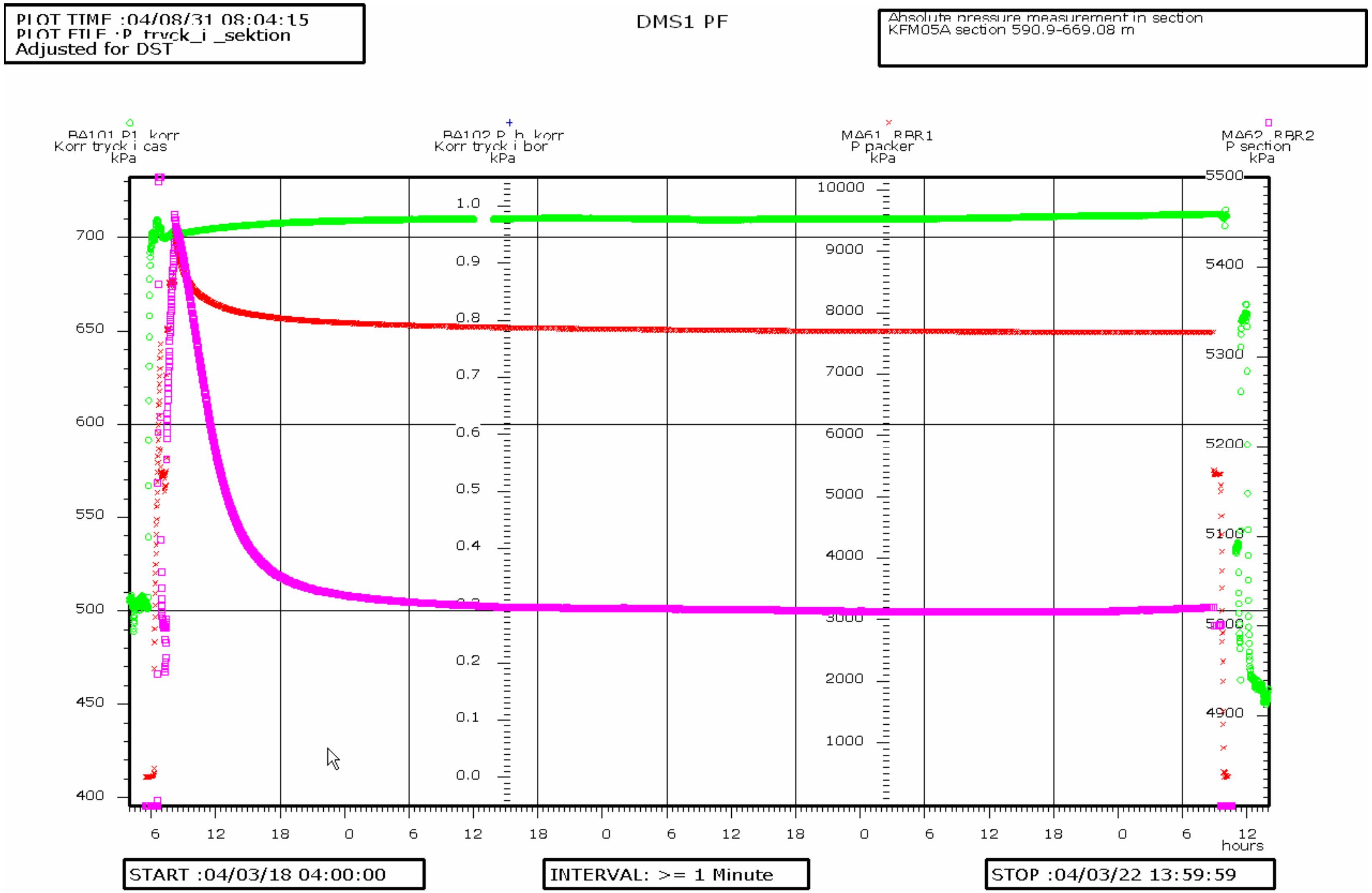
Appendix D

Absolute pressure measurements





PLOT TIME :04/08/31 07:48:32
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM05A section 224.2-316.03 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 :04/02/26 09:00:00
INTERVAL: >= 1 Minute
STOP :04/03/01 12:59:59


PLOT TIME :04/08/31 08:04:15
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PF
Absolute pressure measurement in section
KFM05A section 590.9-669.08 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 :04/03/18 04:00:00
INTERVAL: >= 1 Minute
STOP :04/03/22 13:59:59