P-03-51

Forsmark site investigation

Drilling of a flushing water well, HFM05, and a groundwater monitoring well, HFM04, at drillsite DS2

Lars-Åke Claesson, Mirab Mineral Resurser AB
Göran Nilsson, GNC AB

May, 2003

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-03-51

Forsmark site investigation

Drilling of a flushing water well, HFM05, and a groundwater monitoring well, HFM04, at drillsite DS2

Lars-Åke Claesson, Mirab Mineral Resurser AB
Göran Nilsson, GNC AB

May, 2003

Keywords: AP PF 400-02-36, percussion drilling, flushing water well, monitoring well, soil, bedrock, DS2.

Contents

1 Introduction

SKB performs site investigations to locate a deep repository for high level radioactive waste /1/. The investigations are performed in two Swedish municipalities: Östhammar and Oskarshamn. The investigation area in Östhammar is situated close to the nuclear power plant at Forsmark /2/, see Figure 1-1.

Drilling is one important activity performed within the frame of the site investigations. Three main types of boreholes are produced: core drilled boreholes, percussion drilled boreholes in solid rock and boreholes drilled through unconsolidated soil. The initial phase of the investigations includes drilling of three, c 1000 m deep boreholes, one at each of the drillsites DS1, DS2 and DS3, see Figure 1-1. At these sites, also percussion drilled boreholes in solid rock and in soil have been produced.

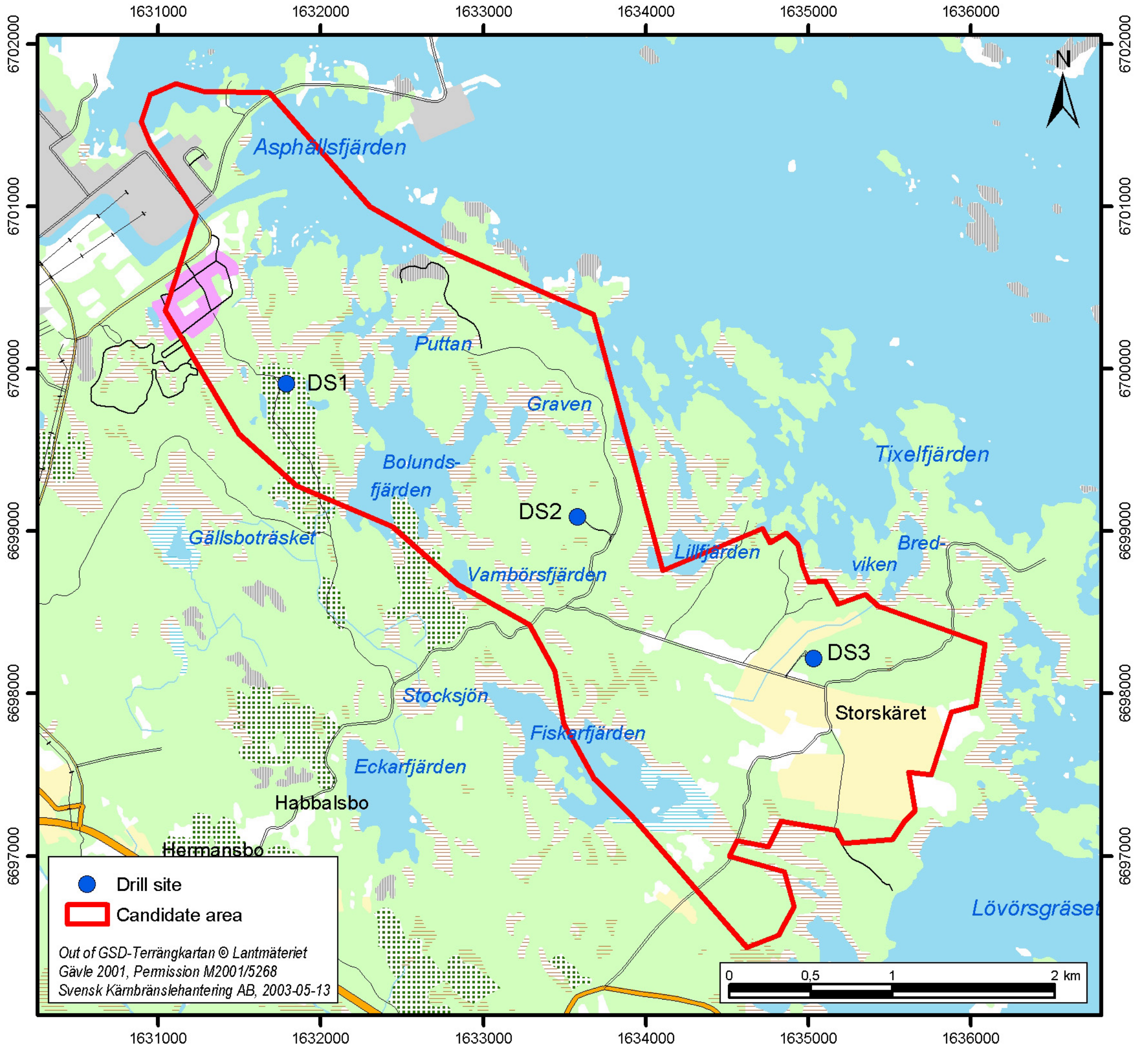


Figure 1-1. The investigation area at Forsmark including the candidate area selected for more detailed investigations. Drillsites DS1–3 are marked with blue dots.

At drillsite DS2, the deep cored borehole is named KFM02A, see Figure 1-2. The results from the drilling operations of this borehole are presented in /3/. Besides the deep borehole, altogether two percussion boreholes in solid rock with the depths 221.70 respectively 200.10 metres, as well as two boreholes through the soil layer were drilled at the drillsite (Figure 1-2). Results from drilling of the two monitoring wells in soil at drillsite DS2, SFM0004 and SFM0005 (Figure 1-2), are presented in /4/.

In the present report, performance of and results from drilling of the two percussion boreholes in solid rock, HFM04 and HFM05, at drillsite DS2 are dealt with. The report also treats investigations made during and immediately after the drilling operations including the results obtained.

Borehole HFM05 was produced for supply of the flushing water needed for drilling the deep cored borehole KFM02A, whereas borehole HFM04 was drilled to serve as a monitoring well, enabling long-term study of groundwater levels and groundwater-chemical composition. The drilling operations were performed by Sven Andersson in Uppsala AB, with support from SKB-personnel regarding measurements and tests during drilling. A Nemek 407 RE percussion drilling machine operated by a one-man drill crew was called in for the commission.

The drilling and measurement operations were performed according to Activity Plan AP PF 400-02-36 (SKB internal controlling document). The Activity Plan refers to SKB MD 610.003, Version 1.0 (Method Description for Percussion Drilling).

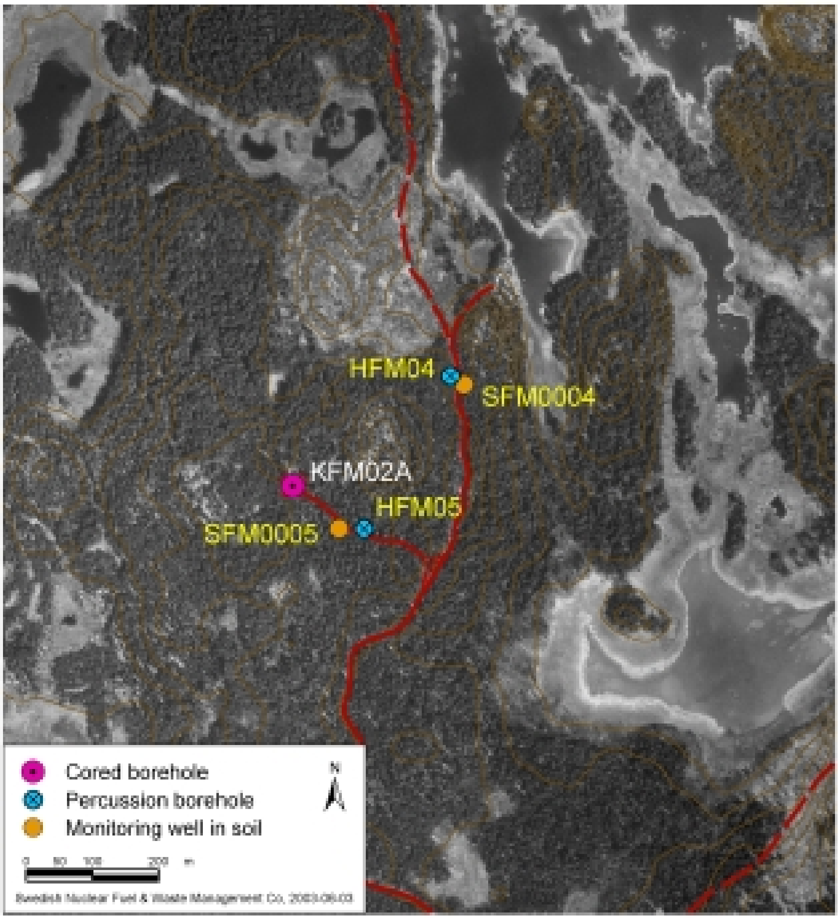


Figure 1-2. *Borehole locations at drillsite DS2. Besides the flushing water well and the monitoring well in hard rock, also two monitoring wells in unconsolidated soil were drilled.*

2 Objective and scope

Drilling of a 1000 m deep cored borehole is a time consuming procedure associated with extensive operations regarding e.g. water handling. At the SKB site investigations, drilling of deep cored boreholes is performed using a so called telescopic drilling technique, implying that the upper 100 m of the borehole is percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section 100–1000 m is core drilled with a diameter of approximately 76–77 mm.

Core drilling demands injection of relatively large amounts of flushing water through the drill string and drill bit for the purpose of cooling down the drill bit and for transportation of drill cuttings from the borehole bottom to the ground surface. At the SKB site investigations, an air-lift pump is installed in the upper, large-diameter part of the telescopic drilled borehole in order to enhance the recovery of flushing water and drill cuttings. During the entire drilling period (comprising several months) the air-lift pumping and, to a lesser extent, the injection of flushing water, entail some impact on the groundwater levels and, possibly, on the groundwater-chemical composition in the near-surrounding of the deep borehole. To enable observation of groundwater level fluctuations due to the operations in connection with drilling of a deep cored borehole, monitoring wells have to be drilled.

However, borehole HFM05 was drilled with the primary aim to, at a convenient distance (c 120 m) from the core drilled borehole KFM02A, account for the supply of relatively large amounts (c 5–50 L/min) of clean flushing water, whereas borehole HFM04 was drilled to serve primarily as a monitoring well. Such wells may be used for the study of groundwater levels and groundwater-chemical conditions under undisturbed as well as disturbed conditions.

Boreholes HFM04–05 are of so called SKB chemical type. The meaning of this is that the boreholes are prioritized for hydro-geochemical investigations (also including study of microorganisms, primarily bacteria, occurring in the groundwater). The practical consequence of this is that all DTH (Down The Hole)-equipment used during and/or after drilling must undergo severe cleaning procedures, see Section 4.1.

The strategy for setting out the monitoring well HFM04 was to locate it within the expected radius of influence of groundwater-level draw-down (approximately 300–400 m from borehole KFM02A) due to air-lift pumping during drilling. The location was also selected between geophysical anomalies in what was estimated to be homogeneous, low-fractured bedrock /5/.

Drilling of monitoring wells in the vicinity of a deep core drilled borehole should normally be performed prior to the start of drilling operations at the deep borehole, since the objective of the monitoring wells is to make the study of undisturbed as well as of disturbed groundwater conditions possible. However, due to practical/logistic reasons, drilling of borehole KFM02A was initiated one day after start of drilling the monitoring well HFM04 and 14 days before drilling of the flushing water well HFM05. Undisturbed conditions therefore have to be studied after completion of drilling of KFM02A.

Data gained during monitoring of undisturbed conditions will be part of the basic characterization of the groundwater conditions of the shallow part of the bedrock. Monitoring during the percussion and core drilling operations in KFM02A is primarily part of the environmental control program for these drilling operations. However, also these data may be used for basic characterization purposes. After completion of drilling and borehole investigations at DS2, boreholes HFM04 and HFM05 will be used for long-term groundwater level monitoring and groundwater sampling.

3 Equipment

Drilling of the two percussion boreholes in solid rock at drillsite DS2 was performed with a Nemek 407 RE DTH percussion drilling machine (Figure 3-1) supplied with various accessory equipment. In this chapter short descriptions are given of the drilling equipment, the technique and equipment for gap injection of the borehole casing and of the instrumentation used for deviation measurements performed after completion of drilling. Also the equipment used for measurements and sampling during drilling is briefly described.

3.1 Drilling equipment

The drilling machine was equipped with separate engines for transportation and power supplies. For uplifting of water and drill cuttings from the borehole, a 27 bar diesel air-compressor, type Atlas-Copco XRVS 455 Md was used. The DTH drillhammer was of type Secoroc 5", lowered into the borehole by a Driconeq 76 mm pipe string.

Figure 3-1. *The Nemek 407 percussion drilling machine engaged for drilling the two percussion boreholes in solid rock at drillsite DS2. Water and drilling debris is blown to the container. Photo Niclas Karlsson.*

A 254 mm (external diameter) temporary steel casing was driven through the soil layer and further through fractured rock and a certain distance into solid rock, see detailed description in Section 4.3. The gap between the borehole wall and the casing was grouted with cement, see Section 3.2.

Cleaning of all DTH-equipment was performed with a high-capacity steam cleaner of type Kärcher HDS 1195.

Recovered drill cuttings and groundwater were, for environmental reasons, not allowed to spread out on the ground surface, but was conducted to and collected in a steel container. After completion of drilling, the container was removed from the site and emptied at an approved deposit.

3.2 Gap injection technics and equipment

Grouting the gap between the borehole wall and the casing pipe with cement is performed in order to prevent surface water and shallow groundwater to infiltrate into deeper parts of the borehole. The cement application may be performed using different techniques and equipment. Two variants of gap injection with cement are illustrated in Figure 3-2. In boreholes HFM04 and HFM05 only the hose technique was applied.

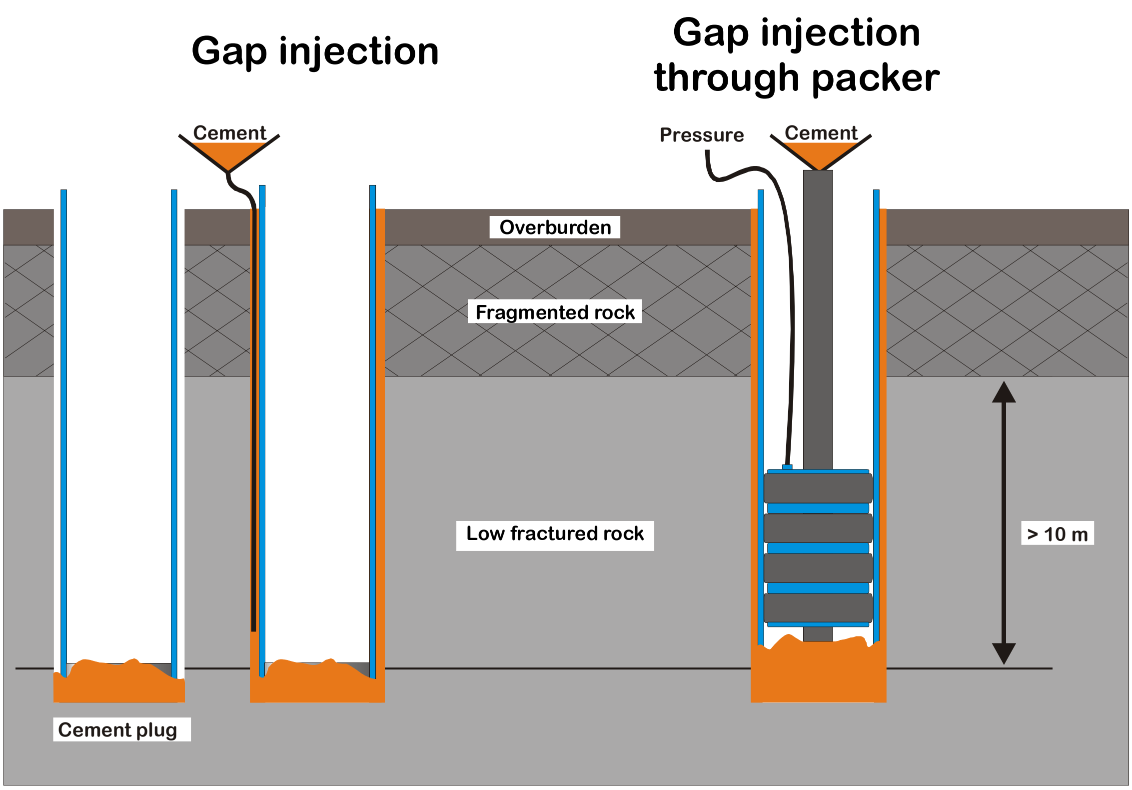


Figure 3-2. *Gap injection technique. In order to grout the gap between the borehole wall and the casing, different systems may be used. To the left, filling up a cement-water mixture with a flexible hose is shown. To the right, injection is performed through a borehole packer.*

3.3 Equipment for deviation measurements

Deviation measurements were performed in both boreholes using a Reflex EZ-shot (magnetic) equipment. Azimuth and dip was measured every third metre. The coordinates for the starting point and the measured values were used for calculating the coordinates for every measured point.

3.4 Equipment for measurements and sampling during drilling

Flow measurements during drilling were performed using measuring vessels of different sizes and a stop watch. Measurements of drilling penetration rate were accomplished with a carpenter´s rule and a stop watch.

Samples of soil and drill cuttings were collected in sampling pots and groundwater in small bottles. A field measuring devise was used for measurements of electrical conductivity of the groundwater.

4 Execution

The performance of the work followed SKB MD 610.003, Version 1.0 (Method Description for Percussion Drilling) and included the following items:

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

4.1 Preparations

The preparation stage included the Contractor's service and function control of his equipment. The machinery was obliged to be supplied with fuel, oil and grease exclusively of the types stated in SKB MD 600.006, Version 1.0 (Method Instruction for Chemical Products and Materials). Finally, the equipment was cleaned (Figure 4-1) in accordance with SKB MD 600.004, Version 1.0 (Method Instruction for Cleaning Borehole Equipment and certain Ground-based Equipment) at level two, used for SKB boreholes of chemical type.

4.2 Mobilisation

Mobilisation onto and at the site included first of all transport of drilling and accessory equipment to the drill site. Furthermore, the mobilisation comprised preparation of the drill site, cleaning of all DTH-equipment at level two according to SKB MD 600.004, Version 1.0, lining up the machine, and final control of function.

4.3 Drilling, measurements, and sampling during drilling

4.3.1 Drilling through the overburden

In normal Swedish terrain, the rock surface is often covered with a more or less thick stratum of unconsolidated rock material, e.g. till. The procedure of drilling a percussion borehole is in this case divided into two drill phases: 1) drilling through the overburden and 2) drilling in fractured and/or solid rock. The bedrock where boreholes HFM04 and

Figure 4-1. A high temperature steam cleaner is used for cleaning the drill pipes at level two according to SKB MD 600.004, Version 1.0, before start of Ejector-NO-X drilling. Photo Alf Sevastik.

HFM05 are situated is till covered, and hence drilling was performed according to these two phases. Figure 4-2 schematically illustrates the different steps carried out.

Drilling through the overburden may be accomplished using different technical approaches. In this case, so called Ejector-NO-X was applied. The prefix “ejector” indicates that the discharge channels for the flushing medium, in this case compressed air, are constructed in such a way that the oxygen and oil contamination of the penetrated soil layers is reduced compared to conventional systems. The NO-X system represents a method for concentric drilling and casing driving through the overburden. A circular pilot bit, attached to a DTH-hammer shank, and with large internal flushing holes and external flushing grooves, is connected to a symmetrical ring bit (reamer) with an internal bayonet coupling. The pilot bit and the ring bit are both rotating clockwise, thereby drilling a borehole with a diameter large enough to let the casing easily slip down into the reamed borehole. The ring bit is rotating freely against the casing shoe, which is welded to the lower end of the casing. The casing is non-rotating during drilling.

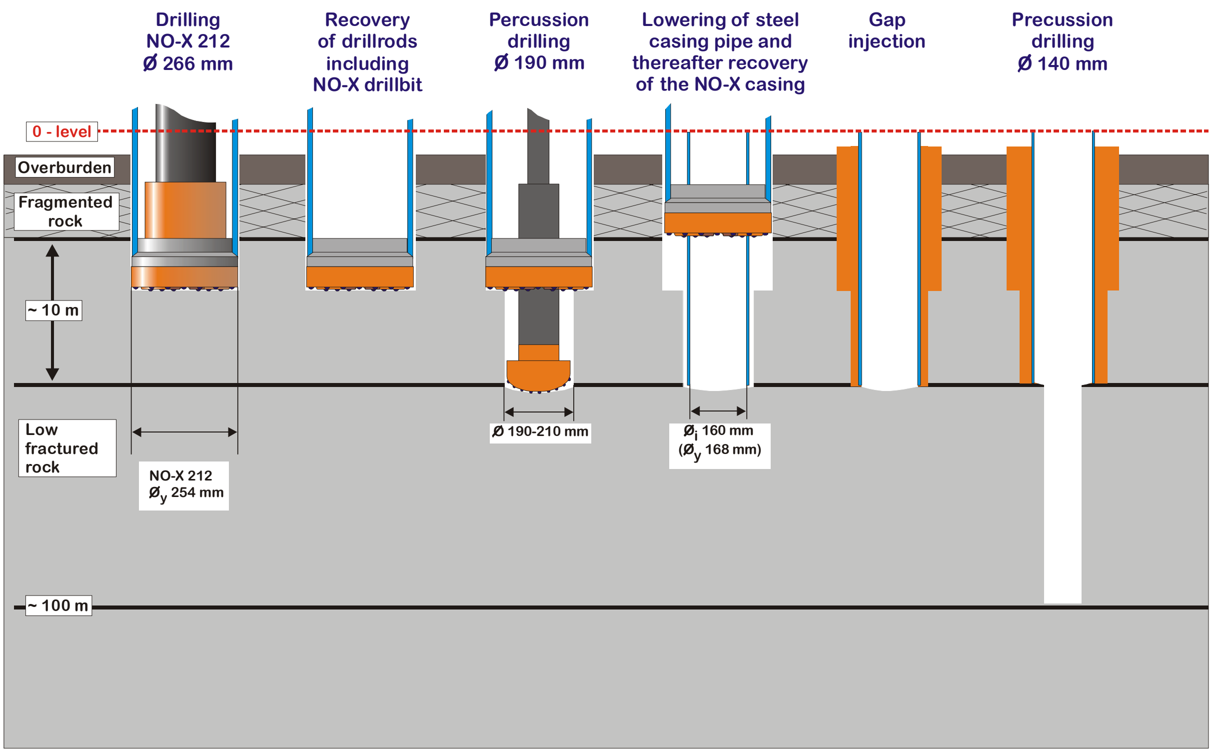


Figure 4-2. *The different steps included in the performance of the percussion drilled boreholes HFM04–05.*

Drilling through the overburden of boreholes HFM04–05 basically followed the principles for the Ejector-NO-X system. However, the method was to some extent applied in a non-conventional manner. During drilling of a borehole with the diameter 266 mm, a temporary steel casing with an outer diameter of 254 mm was driven through the till overburden and through fragmented rock a short distance into fresh, low-fractured rock, see Figure 4-2. The drillrods with the drillhammer and pilot bit were then retrieved from the borehole. A percussion drill bit was lowered into the borehole inside the temporary casing, and a borehole with a diameter of 190 mm was drilled about 10 m into high-quality, low-fractured rock.

Again the drillrods, drillhammer and drill bit were retrieved, whereafter a stainless steel casing with the external/internal diameter 168/160 mm was applied. The casing was lowered into the borehole in 3 m-lengths, which were successively welded together.

4.3.2 Gap injection

When the casing string had been firmly installed in the borehole, the narrow gap between the borehole wall and the outer wall of the casing was grouted with a cement/water-mixture according to the hose technique illustrated in Figure 3-2.

4.3.3 Percussion drilling in hard rock

After stiffening of the grout, drilling could continue and was now performed to the full borehole length with conventional percussion drilling. Before start of drilling, the diameter of the drill bit was measured. In this last drill step the borehole diameter (approximately the same as the drill bit diameter) is normally 140 mm, see Figure 4-2. However, a diameter decrease of about 1 mm/100 m drill length is to be expected when drilling in the rock types prevailing in the Forsmark area. For boreholes deeper then 100 metres the drill bit has to be grinded.

4.3.4 Sampling and measurements during drilling

During drilling, a sampling and measurement program was performed, which included:

- Collecting of one soil sample per metre drill length. Analysis and results are reported in /6/.
- Collecting of one sample per 3 metre drill length of drill cuttings from the bedrock (Figure 4-3). Each sample consists of three individual samples taken at every metre borehole length, collected in one plastic box marked with a sample number. Effort is devoted to avoid mixing of the three individual samples. A first description of the material was made on-site including the mineral content and rock structure, which gave a preliminary classification of the rock type. These samples were examined and interpreted together with a BIPS-log (so called Boremap-mapping) and reported in /7/.
- Measurements of the penetration rate (one measurement per 20 cm drill length). The time needed for the drill bit to sink 20 cm was recorded manually in a paper record.
- Performing one observation of groundwater flow (if any) and water colour per 20 cm drill length and a measurement of the flow rate at each major flow change observed. The measured values were noted in a paper record.
- Measurements of the electrical conductivity of the groundwater (if any) at each 3 metre drill length (noted in a paper record).

The results from the third and fourth items were used as supporting data for the Boremap-mapping of the boreholes mentioned above. The last item gave on-site information about hydraulic and hydro-geochemical characteristics of the penetrated aquifers at the respective drillsites.

Figure 4-3. *Sampling of one sample per 3 metre drill length of drill cuttings from the bedrock. Photo Alf Sevastik.*

4.4 Finishing off work

Finishing off work included rinsing of the borehole from drill cuttings by a "blow out" with the compressor at maximum capacity during 30 minutes. The recovery of the groundwater table after rinsing was recorded, enabling a preliminary evaluation of the hydraulic conditions. The drillrods were then removed from the hole, and the diameter of the drill bit was measured as well as the deviation of the borehole. The borehole was secured by a stainless steel lockable cap, mounted on the casing. Finally, the equipment was removed, the site cleaned and a joint inspection was made by representatives from SKB and the Contractor, to ensure that the site had been satisfactorily restored.

4.5 Data handling

Minutes for the following items: Activities, Cleaning of equipment, Drilling, Borehole, Percussion drilling penetration rate, Deliverance of field material, and Discrepancy report were collected by the Activity Leader, who made a control of the information, and had it stored in the SKB database SICADA /8/.

4.6 Environmental control

A programme according to SKB's routine for environmental control was followed throughout the activity. A checklist was filled in and signed by the Activity Leader and finally filed in the SKB archive.

5 Results

All data were stored in the SICADA database for Forsmark. Field Note numbers are 58, 62, 70, 71 /8/.

Below, a summary of the data achieved during the drilling period is presented.

5.1 Borehole design

Administrative, geometric, and technical data for the percussion drilled boreholes HFM04–05 are presented in Table 5-1. The design of each borehole is illustrated in drawings in Figures 5-1 and 5-2.

Table 5-1. Administrative, geometric and technical data for boreholes HFM04–05.

Parameter	HFM04	HFM05
Drilling period	From 2002-11-19 to 2002-12-03	From 2002-12-04 to 2002-12-17
Borehole inclination (starting point)	–84.26° (– = downwards)	–84.96° (– = downwards)
Borehole bearing	336.87°	335.59°
Borehole length	221.70 m	200.10 m
Borehole diameter	From 0.00 m to 3.00 m: NO-X 215	From 0.00 m to 4.60 m: NO-X 215
	From 3.00 m to 12.10 m: 0.215 m	From 4.60 m to 11.87 m: 0.215 m
	From 12.10 m to 221.70 m: decreasing from 0.140 m to 0.138 m	From 11.87 m to 101.30 m: 0.136 m
		From 101.30 m to 200.10 m: 0.134 m
Casing length	12.12 m	11.87 m
Casing diameter	$\text{Ø}_o/\text{Ø}_i$ = 168 mm/160 mm to 12.10 m	$\text{Ø}_o/\text{Ø}_i$ = 168 mm/160 mm to 11.85 m
	$\text{Ø}_o/\text{Ø}_i$ = 168 mm/146 mm to 12.12 m	$\text{Ø}_o/\text{Ø}_i$ = 168 mm/146 mm between 11.85 and 11.87 m
	$\text{Ø}_o/\text{Ø}_i$ = 254 mm/244 mm between –0.220 and 2.720 m	
Drill bit diameter	Start of drilling: 0.140 m End of drilling: 0.138 m	Start of drilling: 0.136 m End of drilling: 0.134 m
Starting point coordinates (system RT90/RHB70)	Northing: 6698878.968 m Easting: 1633420.733 m Elevation: 3.873 m.a.s.l.	Northing: 6698647.275 m Easting: 1633289.721 m Elevation: 7.672 m.a.s.l.

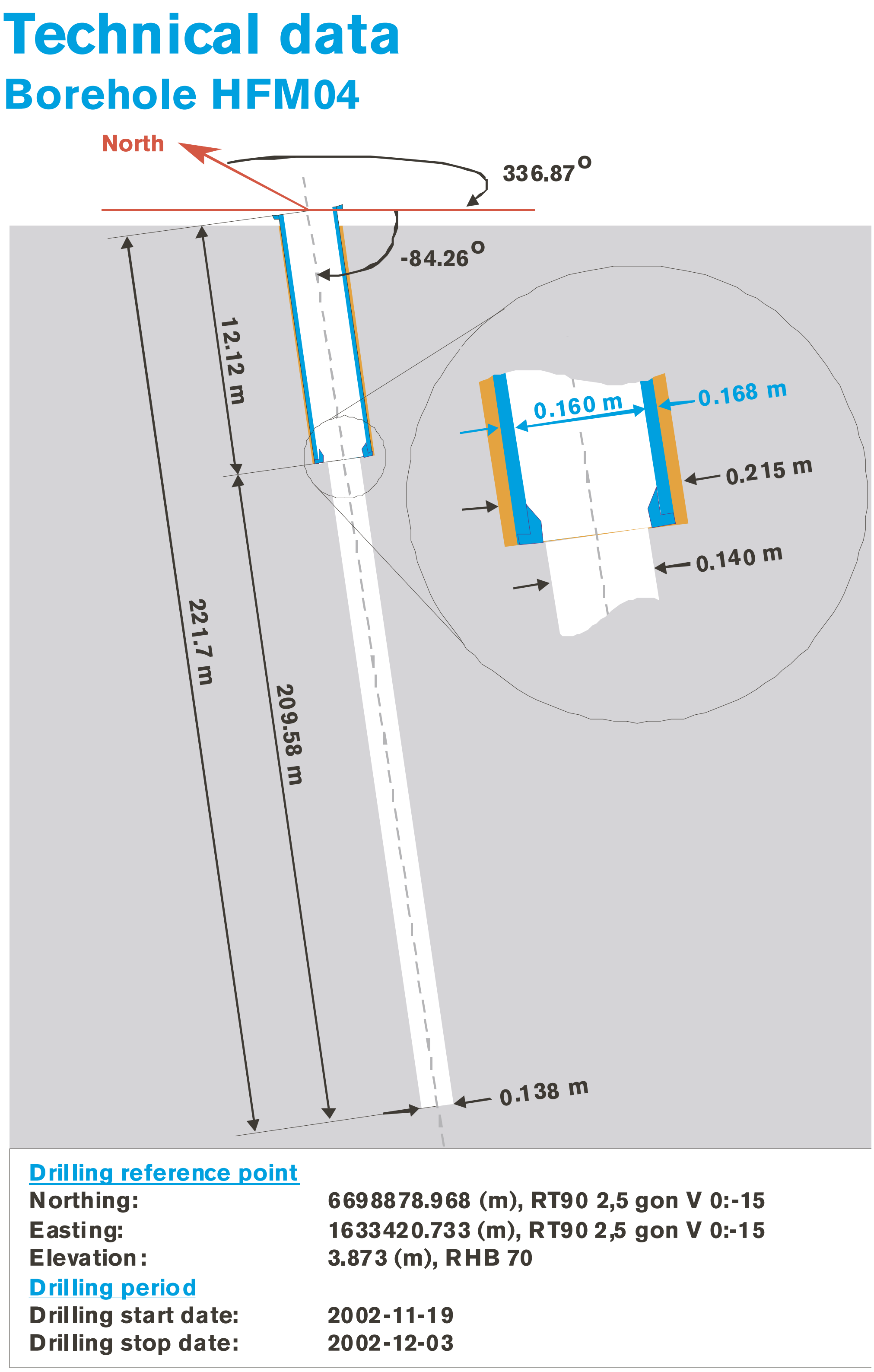
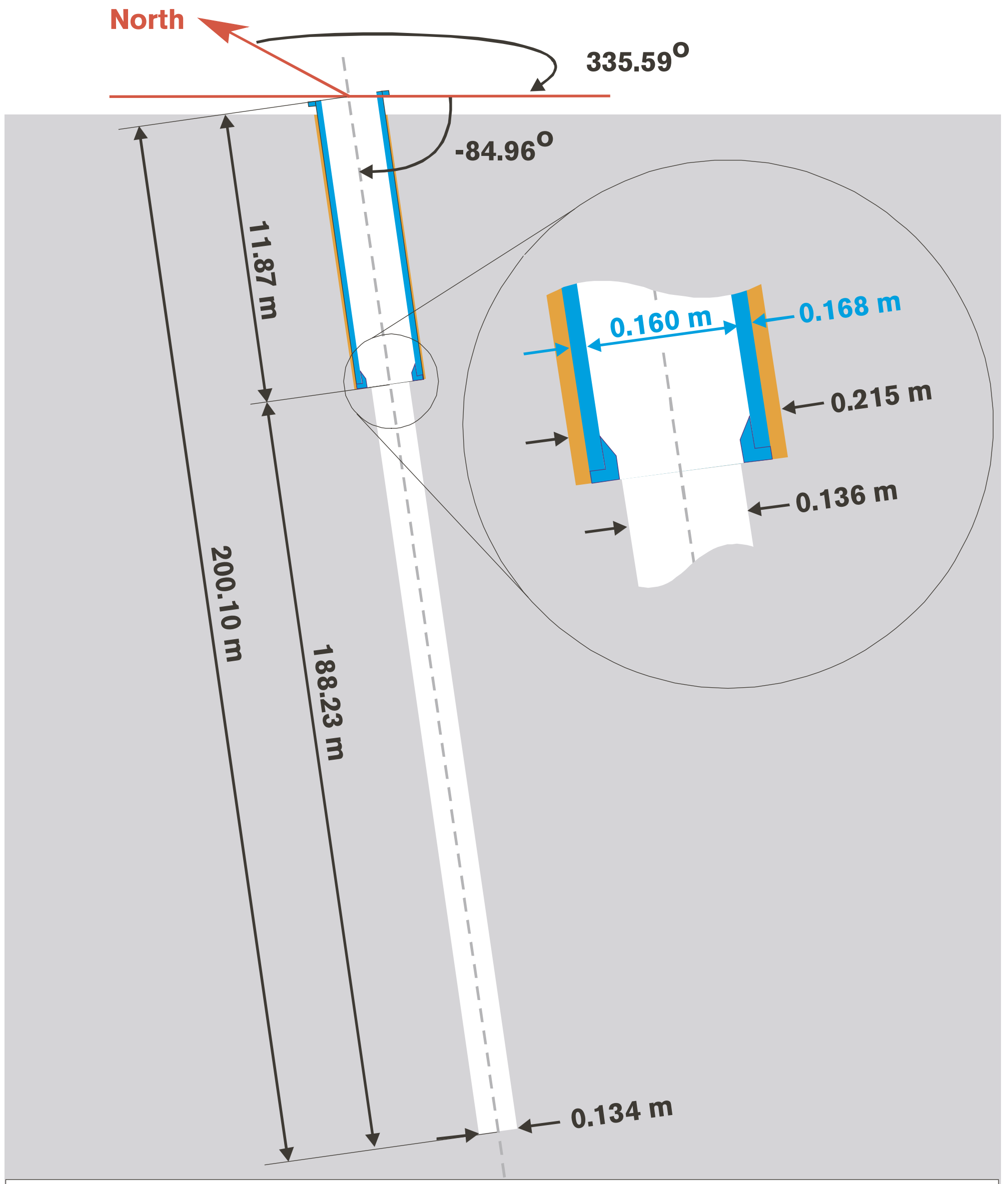


Figure 5-1. *Technical data for borehole HFM04.*

Technical data
Borehole HFM05



Drilling reference point	
Northing:	**6698647.275 (m), RT90 2,5 gon V 0:-15**
Easting:	**1633289.721 (m), RT90 2,5 gon V 0:-15**
Elevation:	**7.672 (m), RHB 70**
Drilling period	
Drilling start date:	**2002-12-04**
Drilling stop date:	**2002-12-17**

***Figure 5-2**. Technical data for borehole HMF05.*

5.2 Consumables used up during drilling

The amount of oil products consumed in each borehole during drilling and grout used for gap injection of the respective casings is reported in Tables 5-2 and 5-3. 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.

Table 5-2. Oil consumption.

Borehole ID	**Hammer oil** Preem Hydra 46	**Compressor oil** Schuman 46
HFM04	3 L	Not detected
HFM05	4 L	Not detected

Table 5-3. Consumption of cement grouting.

Borehole ID	**Casing length**	**Cement volume** (Portland Standard Cement)	**Grouting method**
HFM04	12.12 m	250 kg	Hose
HFM05	11.87 m	200 kg	Hose

5.3 Well Cad presentations

Technical as well as geoscientific results achieved during drilling are also presented in Figures 5-3 and 5-4.

The deviation measurements made in boreholes HFM04 and HFM05 (Figure 5-3 and 5-4) indicate that the deviation is quite normal, i.e. it follows the drill rotation (clockwise) and moves slighty upwards.

The end (bottom) point of HFM04 deviates 8 m upwards and 6 m to the right compared to an imagined straight line following the dip and strike of the borehole start point (inclination –84.3° and bearing 336.9°). The corresponding values for borehole HFM05 are 6 m upwards and 6.5 m to the right, compared to a straight line with the inclination –85.0° and bearing 335.6°.

Especially notable results are associated with a written comment in the Well Cad diagram. In borehole HFM04 (Figure 5-3), decreasing penetration rate in combination with a water inflow of 100 L/min (see the Deltaqi column) is interpreted as a flat fracture zone at approximately 60–63.5 m, and is commented as such in the diagram. The interpretation of the zone being flat dipping (Figure 5-5) is, however, not based on specific measurements during or after drilling of this first borehole at drillsite DS2 (the zone was immediately after drilling cased and gap injected), but is rather an overall assessment, based on results from all boreholes at the site, of the structural conditions prevailing in the shallow part of the bedrock.

Also in borehole HFM05 a fracture zone was revealed. This zone which is situated at a deeper level, 150.5–156.0 m (Figure 5-4), is associated with an increased fracture frequency and a very large inflow of groundwater, c 500 L/min.

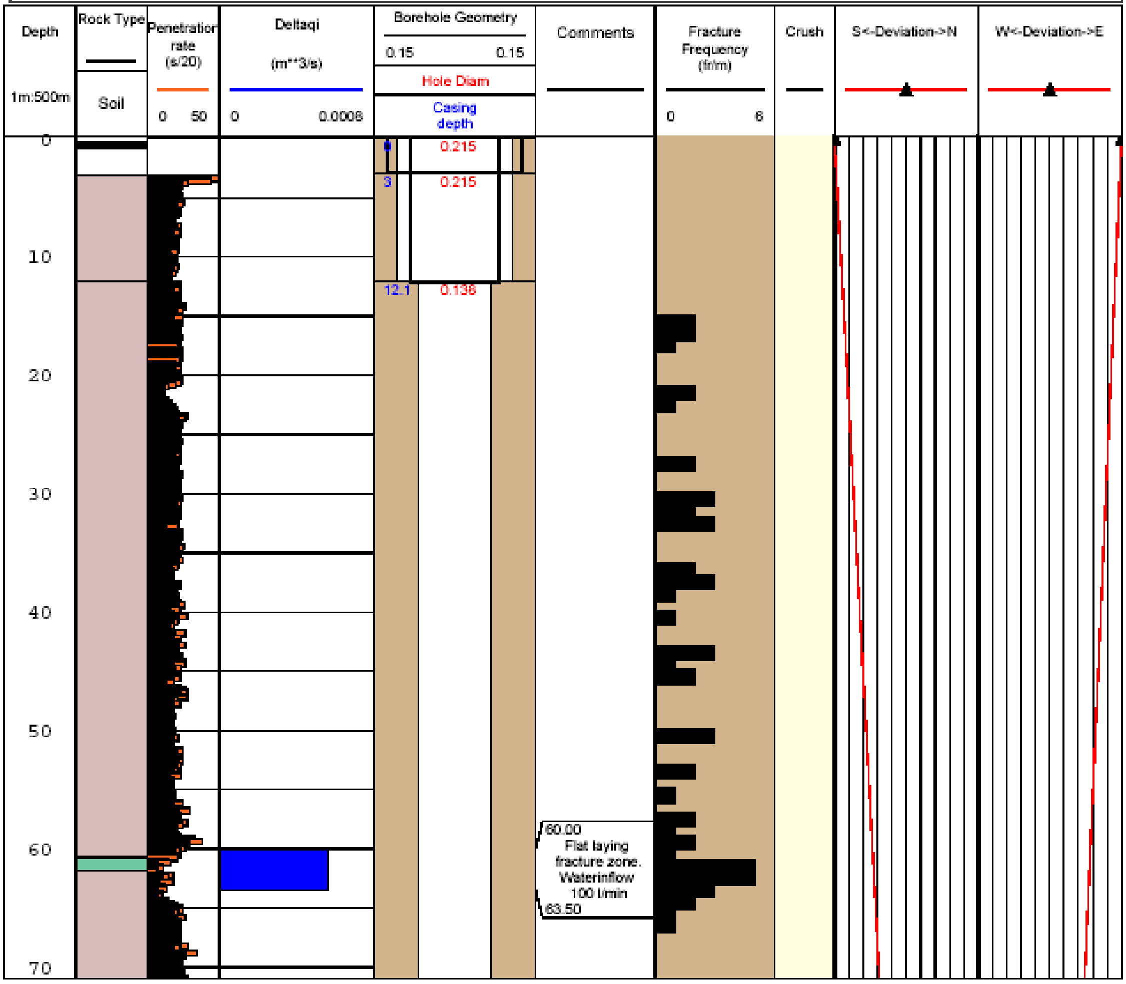
Significant hydraulic responses, supported by responses observed during the drilling of KFM02A when reaching 80 m depth, indicate that the fracture zone observed in HFM04 and HFM05 may be one and the same, Figure 5-5. These results imply that the inclination of the fracture zone outcropping a few hundred metres north of DS2 is subhorizontal (dipping approximately 30°), and the strike might be ENE-WSW.

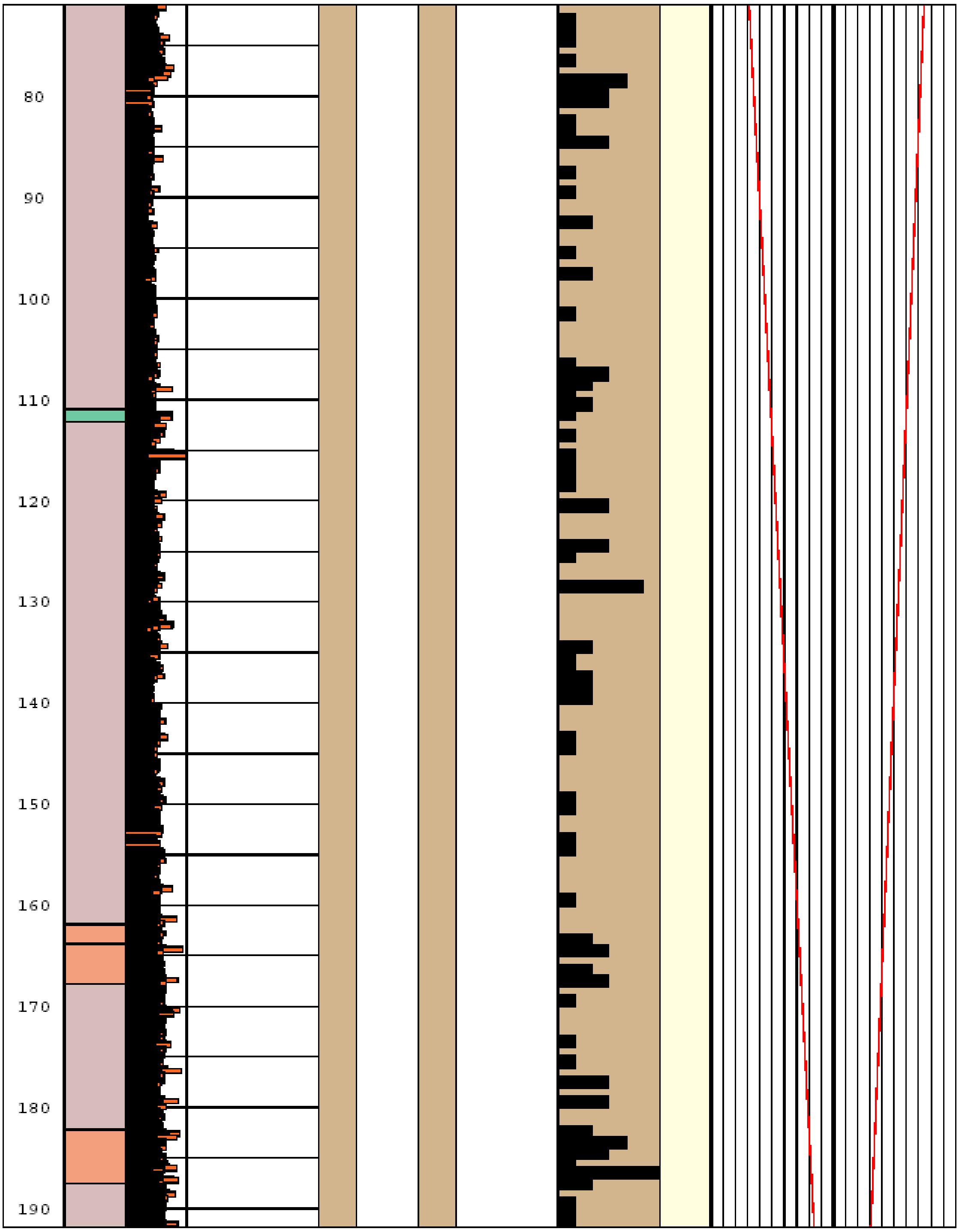
Title	PERCUSSION BOREHOLE HFM04		
Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	HFM04	Northing [m]	6698878.968
Diameter [m]	0.138	Easting [m]	1633420.733
Length [m]	221.7	Elevation [m.a.s.l.]	3.873
Bearing [°]	336.8747	Drilling Start Date	2002-11-19 13:00:00
Inclination [°]	-84.2567	Drilling Stop Date	2002-12-03 12:00:00
Remark		Plot Date	2003-05-27 23:25:30

ROCKTYPE FORSMARK
- Granite, fine- to medium-grained
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite

SOIL
- Soil

Script Name




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

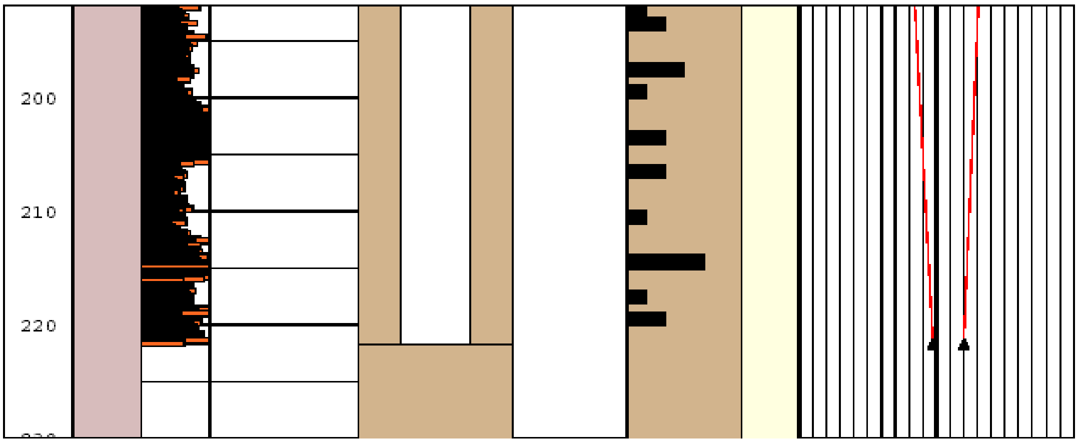


Figure 5-3. *Results achieved during drilling of borehole HMF04.*

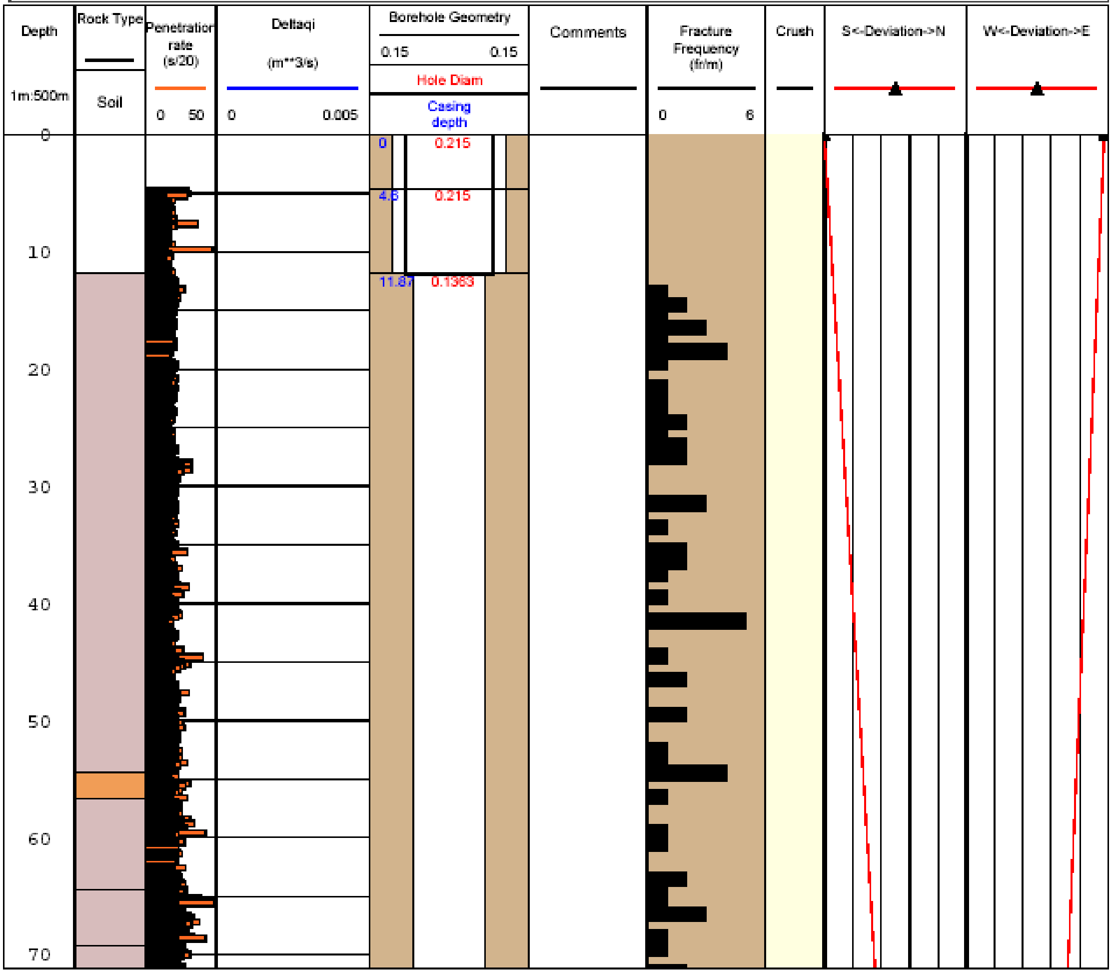
Title	PERCUSSION BOREHOLE HFM05		
Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	HFM05	Northing [m]	6698647.275
Diameter [m]	0.1341	Easting [m]	1633289.721
Length [m]	200.1	Elevation [m.a.s.l.]	7.672
Bearing [°]	335.5892	Drilling Start Date	2002-12-04 13:18:00
Inclination [°]	-84.9608	Drilling Stop Date	2002-12-16 17:36:00
Remark		Plot Date	2003-05-27 23:25:30

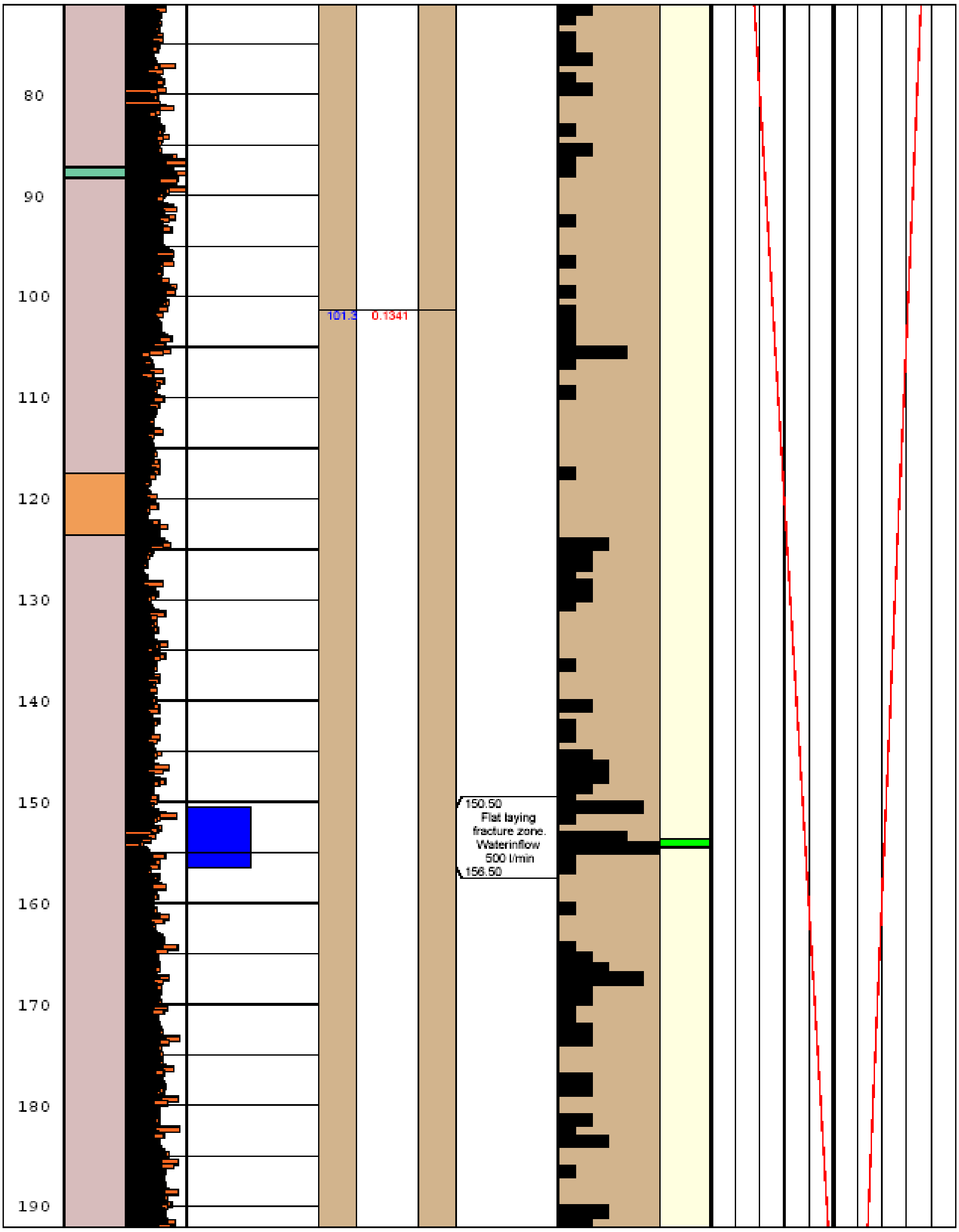
ROCKTYPE FORSMARK

SOIL

- Pegmatite, pegmatitic granite
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite

Script Name




80
90
100
110
120
130
140
150
160
170
180
190
101.3
0.1341
150.50
Flat laying fracture zone. Waterinflow 500 l/min
156.50

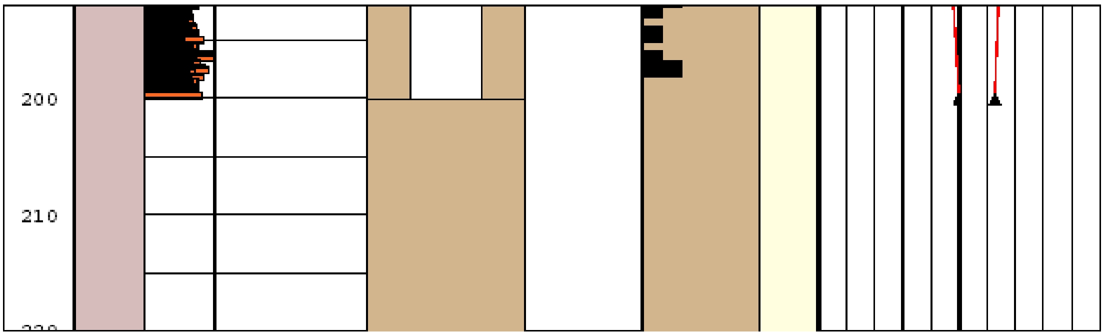


Figure 5-4. *Results achieved during drilling of borehole HMF05.*

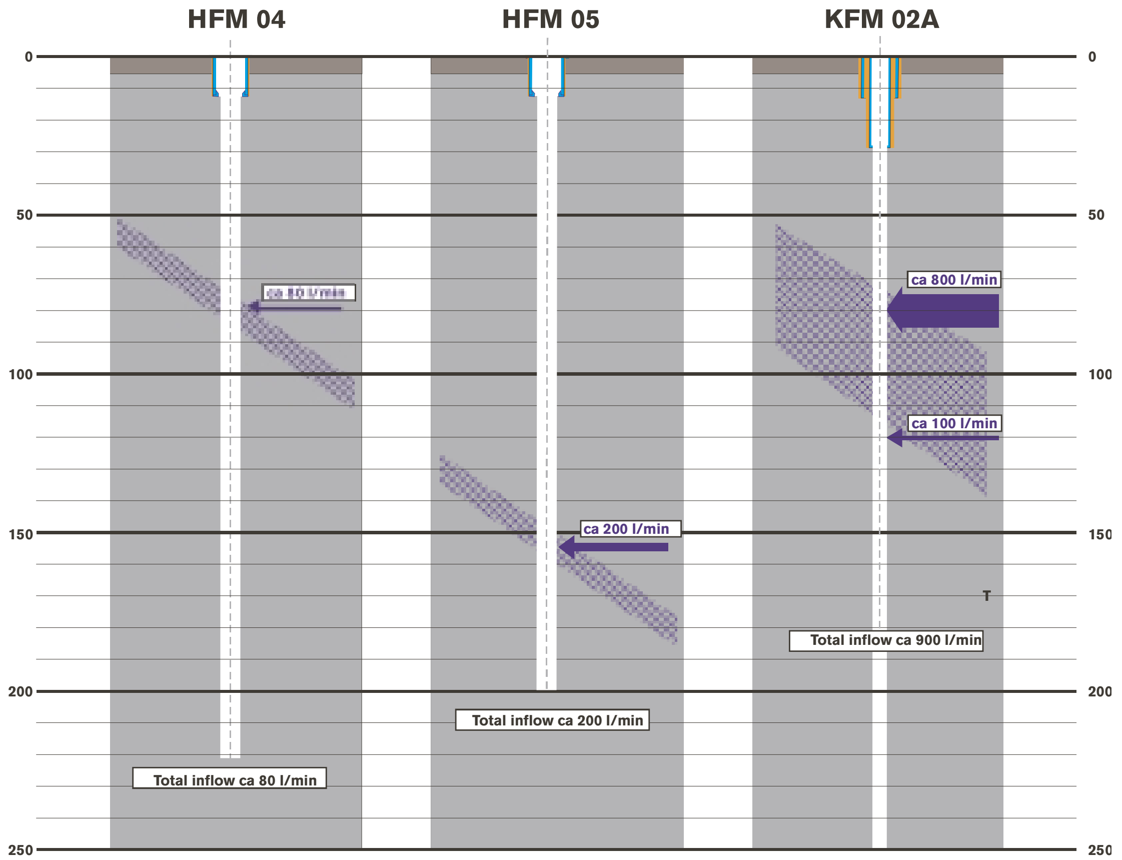


Figure 5-5. *Tentative, simplified interpretation of the structural conditions in the shallow part of the bedrock at drillsite DS2. Although evident proofs are not available, the fracture zone supposed to be penetrated by both HFM04 and HFM05 may also be intersected by borehole KFM02A.*

6 References

/1/ **SKB, 2001.** Platsundersökningar. Undersökningsmetoder och generellt genomförandeprogram. SKB R-01-10, Svensk Kärnbränslehantering AB.

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

/3/ **SKB, 2003.** Claesson L-Å & Nilsson G. Forsmark site investigation. Drilling of the telescopic borehole KFM02A at drillsite DS2. SKB P-03-52, Svensk Kärnbränslehantering AB.

/4/ **SKB, 2003.** Claesson L-Å & Nilsson G. Forsmark site investigation. Drilling of groundwater monitoring wells SFM0004-SFM0005 in soil at drillsite DS2. SKB P-03-50, Svensk Kärnbränslehantering AB.

/5/ **SKB 2002.** Thunehed H & Pitkänen T. Markgeofysiska mätningar inför placering av de tre första kärnborrhålen i Forsmarksområdet. SKB P-02-01.

/6/ **SKB, 2003.** Sohlenius G & Rudmark L. Forsmark site investigation. Mapping of unconsolidated Quarternary deposits 2002-2003. Stratigraphical and analytical data. SKB P-03-14.

/7/ **SKB, 2003.** Nordman C. Forsmark. Boremap mapping of percussion boreholes HFM01-03. SKB P-03-20.

/8/ **SICADA.** Field note numbers 58, 62, 70 and 71.