P-05-278

Forsmark site investigation

Drilling of monitoring wells HFM23 and HFM28 at drill site DS9 as well as HFM24 and SFM0080 at drill site DS10

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

September 2006

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-05-278

Forsmark site investigation

Drilling of monitoring wells HFM23 and HFM28 at drill site DS9 as well as HFM24 and SFM0080 at drill site DS10

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

September 2006

Keywords: AP PF 400-05-073, AP PF 400-05-085, Percussion drilling, Monitoring well, DS9, DS10.

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.

A pdf version of this document can be downloaded from www.skb.se

Summary

Two boreholes in solid rock, HFM23 and HFM28, were drilled at drill site DS9 using percussion drilling technique. Borehole HFM23 was primarily aimed both as a flushing water well for the planned core drilling at DS9 and as a monitoring well during disturbed (pumped) and undisturbed conditions. A third objective of borehole HFM23 was to investigate a minor lineament north of the drill site.

Due to low water inflow to HFM23, another borehole, HFM28, was located close to HFM23, and was drilled almost vertically. However, the groundwater yield was insufficient also from this well. Both boreholes will though be used for monitoring of the groundwater level and for groundwater sampling.

Borehole HFM23, which was drilled during the period August 24th to September 1st, 2005, is 211.5 m long, inclined c. 58 degrees to the horizontal plane and has a diameter of c. 140 mm. No measurable water inflow was encountered during drilling. In order to improve the water yielding capacity, hydraulic fracturing at three levels was performed in the borehole, however resulting in a very limited capacity increase.

Borehole HFM28 was drilled during the period September 12th to 14th, 2005. This borehole is 151.2 m long, inclined c. 85 degrees to the horizontal plane and has a diameter of c. 140 mm. Also HFM28 was almost hydraulically non-transmissive.

A percussion borehole, HFM24, was drilled at drill site DS10 as well. The borehole was primarily aimed both as a flushing water well for the planned core drilling at the drill site and as a monitoring well during disturbed (pumped) and undisturbed conditions. Another aim of the borehole was to investigate a lineament. Borehole HFM24 was drilled during the period November 21st to 29th, 2005, and is 151.35 m long, inclined c. 60 degrees to the horizontal plane and has a diameter of c. 140 mm. A fracture zone encountered in section 46–52 m yielded 200 L/min. Also percussion drilling of a soil borehole, SFM0080, was performed at DS10.

Sammanfattning

Två hammarborrhål, HFM23 och HFM28, har borrats vid borrplats BP9. Borrhål HFM23 var ursprungligen avsett att användas både som spolvattenbrunn vid kärnborrningen vid borrplatsen och som moniteringsbrunn vid såväl störda (under pumpning) som ostörda förhållanden. Ett tredje syfte med HFM23 var att undersöka ett mindre lineament strax norr om borrplatsen. För att försök höja vattenkapaciteten i HFM23 gjordes hydraulisk spräckning på tre nivåer i borrhålet, vilket dock resulterade i en ytterst begränsad ökning av inflödet.

Då vatteninflödet inte räckte till för spolvattenförsörjning borrades HFM28 alldeles intill HFM23, men även detta borrhål visade sig vara nästintill torrt.

HFM23 borrades under perioden 24:e augusti till 1:a september 2005. Borrhålet är 211,5 m långt, är ansatt ca 58° mot horisontalplanet och är borrat med diametern ca 140 mm. Under borrningen noterades inget mätbart grundvatteninflöde.

HFM28 borrades under perioden 12:e till 14:e september 2005. HFM28 är 151,2 m långt, är ansatt ca 85° mot horisontalplanet och är borrat med diametern ca 140 mm. Inte heller i detta borrhål noterades något mätbart inflöde under borrningen.

Ett hammarborrhål, HFM24, har borrats även vid borrplats BP10. Borrhålet användes som spolvattenbrunn vid kärnborrningen vid BP10 och som moniteringsbrunn vid såväl störda (under pumpning) som ostörda förhållanden. HFM24 borrades under perioden 21:a till 29:e november 2005. Borrhålet är 151,35 m långt, är ansatt ca 60° mot horisontalplanet och är borrat med diametern 140 mm. En sprickzon vid 46–52 m ger ca 200 L/min.

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 /2/ is situated close to the nuclear power plant at Forsmark, see Figure 1-1.

Drilling is one important activity within the scope of the site investigations, rendering geoscientific characterization of the bedrock down to and beyond repository depth possible. Three main types of boreholes are produced: core drilled boreholes, percussion drilled boreholes in bedrock and boreholes drilled through the soil layer. The initial phase of the investigations included drilling of three, c. 1,000 m long subvertical cored boreholes inside the candidate area, at drill sites DS1, DS2 and DS3, see Figure 1-1. These boreholes were succeeded by several new core drilled boreholes, drilled from drill sites DS4–DS8 within or close to the candidate area. All cored boreholes drilled from these drill sites are inclined. Some are drilled within the rock domain characterizing the central part of the candidate area, whereas others are drilled towards the rock domains limiting this area.

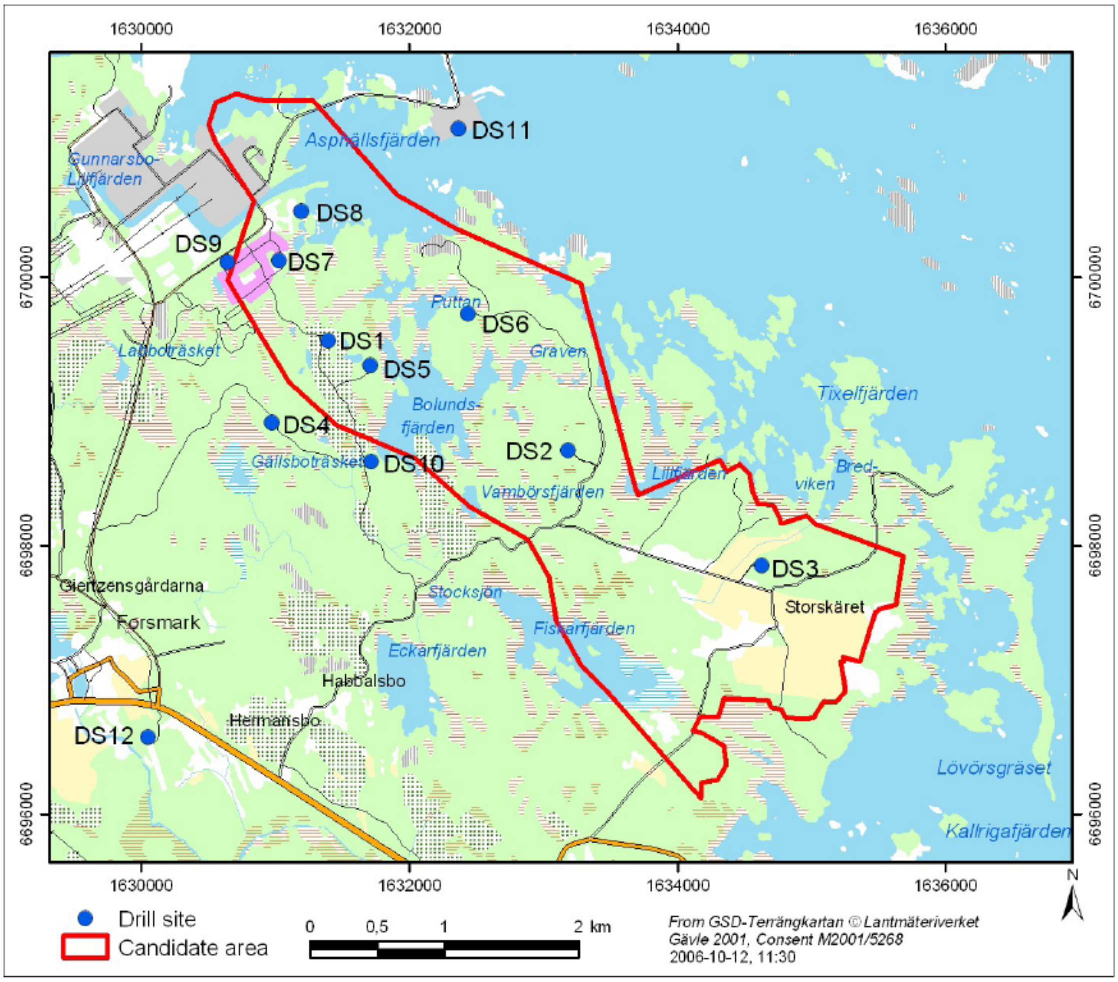


Figure 1-1. The investigation area at Forsmark including the candidate area selected for more detailed investigations. Drill sites DS1–12 are marked with blue dots.

Two new drill sites, DS9 and DS10, were built during the summer and autumn, 2005, see Figure 1-1. Two cored boreholes have been drilled at DS9 with the primary aim to investigate the bedrock at the planned location of a central shaft for the deep repository. Core drilling has also been completed at DS10. During the spring, 2006, two more drill sites were decided upon and laid out for drilling towards reginal deformation zones outside the candidate area. One deep borehole from each of these two drill sites has recently started.

All mentioned drill sites also incorporate percussion drilled boreholes in bedrock and in soil.

Besides boreholes KFM09A, KFM09B and KFM09C, drill site DS9 is also hosting two percussion boreholes in solid rock, HFM23 and HFM28, with the borehole lengths 211.50 m respectively 151.20 m, and a percussion borehole through the soil layer, SFM0049. Drilling of the latter is reported in /4/. A number of other, previously drilled soil boreholes are situated rather close to the drill site. The positions of the currently existing boreholes at drill site DS9 are displayed in Figure 1-2.

At drill site DS10, drilling of one semi-deep inclined cored borehole, KFM10A, has been completed. Drilling of the latter is reported in /5/.

Besides borehole KFM10A, also a percussion borehole in solid rock, HFM24, with the borehole length 151.35 m, and a percussion borehole through the soil layer, SFM0080, are situated at DS10. The positions of the three currently existing boreholes at drill site DS10 are displayed in Figure 1-3.

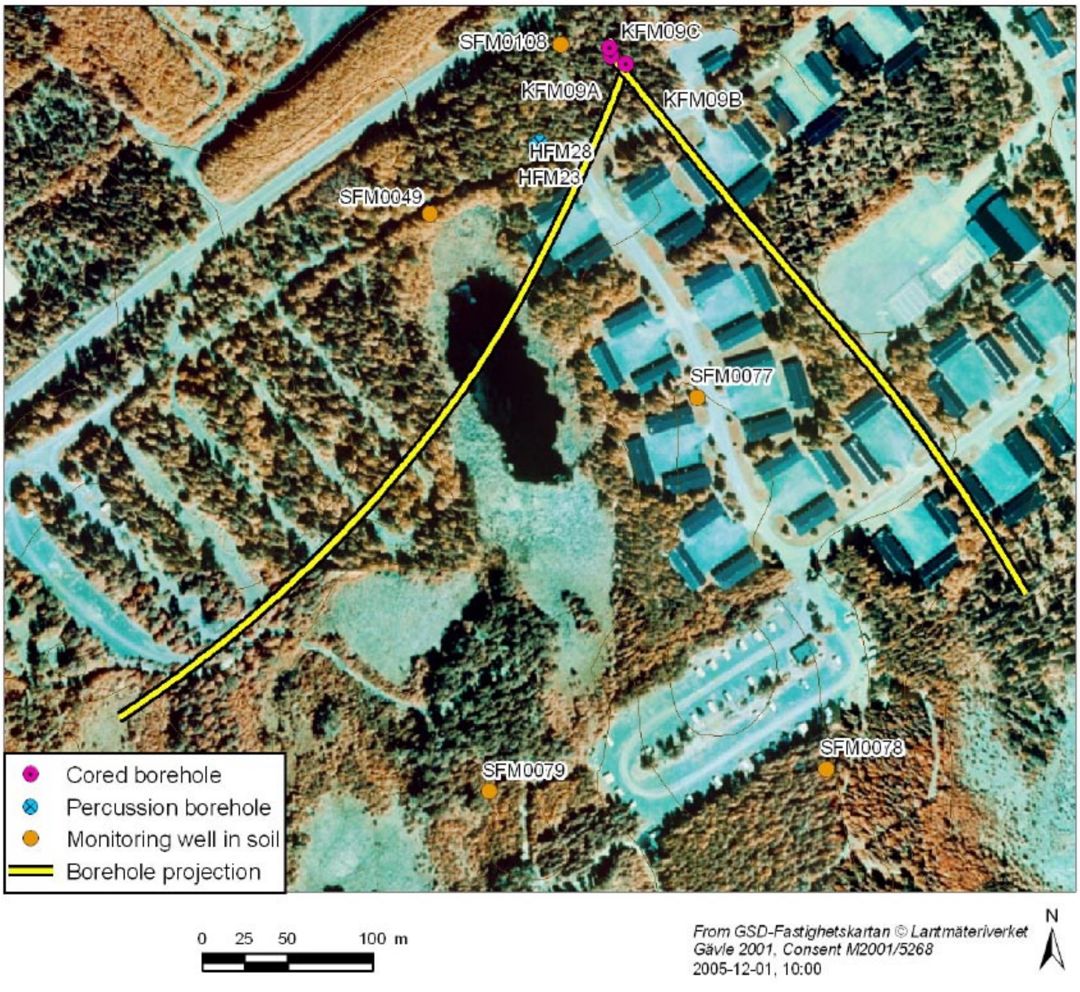


Figure 1-2. Borehole locations at drill site DS9.

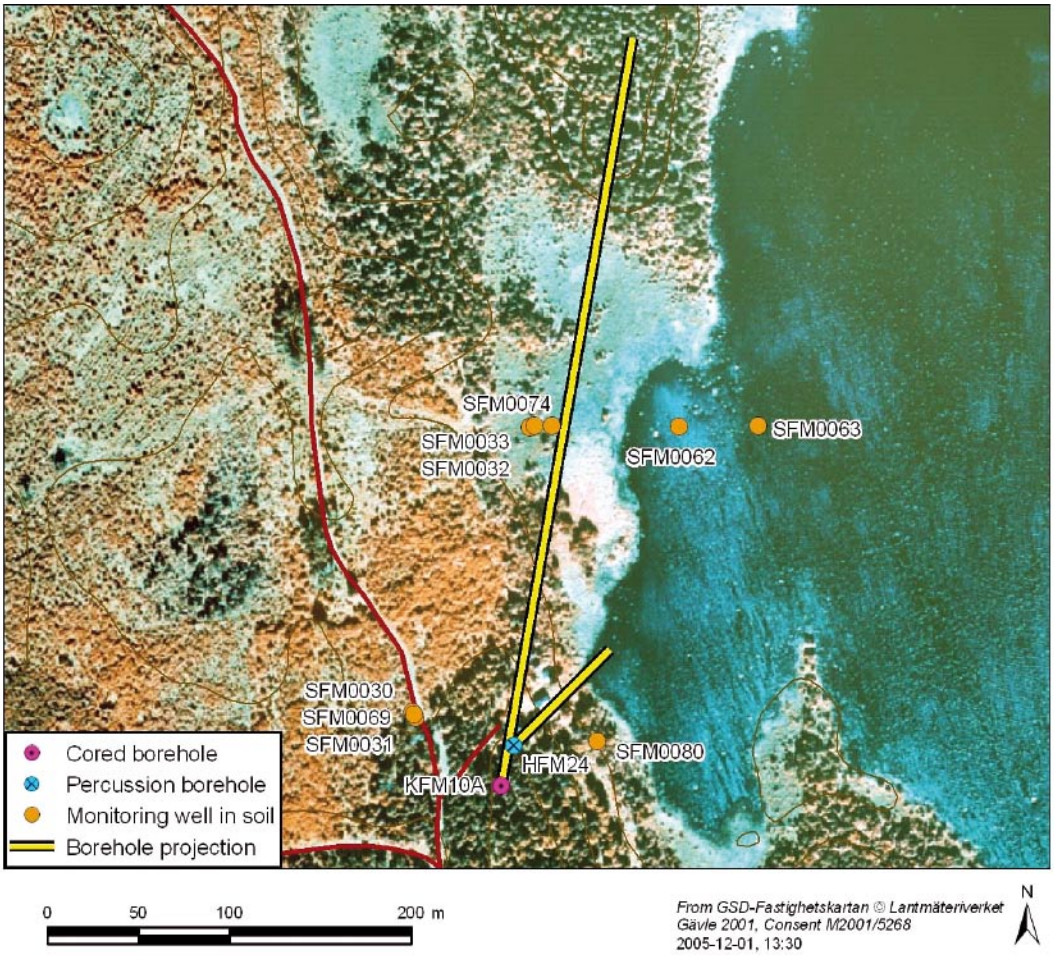


Figure 1-3. *Borehole locations at drill site DS10. Several monitoring wells in soil are drilled in the surroundings of DS10.*

In the present report, performance of and results from drilling of HFM23, HFM24, HFM28 and SFM0080 are presented. The report also treats investigations made during and immediately after drilling and the results obtained.

Sven Andersson in Uppsala AB was contracted for the drilling commission. Support was provided from SKB-personnel regarding measurements and tests during drilling.

Drilling and measurements were carried out during the period August 24th to September 1st, 2005, (HFM23), November 21st to November 29th, 2005 (HFM24), respectively November 30th 2005, (SFM0080), in compliance with Activity Plan AP PF 400-05-073, Version 1.0. Drilling of and measurements in HFM28 were carried out during the period September 12th to September 14th, 2005, according to Activity Plan AP PF 400-05-085, Version 1.0. Controlling documents for performing these activities are listed in Table 1-1. Both the activity plans and method descriptions, which are SKB's internal controlling documents, refer to method instructions and to measurement system descriptions not included in Table 1-1 below.

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

Activity plan	Number	Version
Hammarborrning av borrhål HFM23, HFM24 samt jordborrhål SFM0080	AP PF 400-05-073	1.0
Hammarborrning av borrhål HFM28	AP PF 400-05-085	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för hammarborrning	SKB MD 610.003	2.0
Metodbeskrivning för undersökning av borrkax vid hammarborrning	SKB MD 142.001	1.0
Metodbeskrivning för genomförande av hydrauliska enhålspumptester	SKB MD 321.003	1.0
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål	SKB MD 224.001	1.0
Metodbeskrivning för jordborrning	SKB MD 630.003	1.0

2 Objective and scope

Core drilling demands injection of relatively large amounts of flushing water through the drilling pipe string and drill bit for cooling the latter and for transportation of drill cuttings from the borehole bottom to the ground surface. During the entire core drilling period (comprising about one or two months when drilling a semi-deep borehole), the injection of flushing water exerts an influence on the groundwater levels and, possibly, the groundwater-chemical composition near the borehole. To enable observation of groundwater level- and groundwater chemical fluctuations due to the drilling operations, monitoring wells are drilled.

Boreholes HFM23 and HFM28 were drilled with multiple aims. Firstly, the boreholes were intended to account for supply of the clean flushing water needed for drilling the cored boreholes KFM09A and KFM09B (and possibly other cored boreholes at DS9). A too low inflow, however, disqualified HFM23 and HFM28 as flushing water wells. Secondly, the boreholes were aimed at being used as monitoring wells, enabling long-term study of groundwater levels and groundwater-chemical composition. A third objective was to characterize a minor lineament (XFM0428A0) striking NE-SW just north-west of the drill site.

The soil borehole SFM0049 close to drill site DS9 was drilled prior to establishment of the drill site with the purposes of monitoring the groundwater level in the soil layer and for groundwater sampling.

Also borehole HFM24 was drilled with multiple objectives, which were of the same character as those for the aforementioned boreholes: 1) to be used as flushing water well when drilling KFM10A (and possibly other core drilled boreholes at DS10), 2) to be used as monitoring well, and 3) to characterize a lineament (XFM0136A) striking NW-SE just northeast of the drill site.

The soil borehole SFM0080 close to drill site DS10 was drilled with the purposes of monitoring the groundwater level in the soil layer and for groundwater sampling.

Boreholes HFM23, HFM24 and HFM28 are of so called SKB chemical type, implying that the boreholes are prioritized for hydrogeochemical and bacteriological investigations. 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.

One criterion for determining the positions of boreholes HFM23, HFM24 and HFM28 was to locate them within the expected radius of influence of groundwater-level drawdown during core drilling at drill sites DS9 respectively DS10. The location of soil borehole SFM0049, which was drilled for monitoring purposes long before drill site DS9 was selected and prepared for deep drilling, turned out to be suitable also for monitoring of possible groundwater fluctuations related to the drilling at DS9. Also borehole SFM0080 was drilled prior to drill site DS10 was established.

Data gained during monitoring of undisturbed groundwater levels in the above mentioned boreholes will be part of the characterization of the groundwater conditions of the shallow part of the bedrock and of the soil layers. Monitoring during the percussion and core drilling operations at drill sites DS9 and DS10 is primarily part of the environmental control program for the drilling operations. However, also these data may be used for basic hydraulic characterization.

After completion of drilling and borehole investigations at DS9 and DS10, the boreholes discussed in this report will be used for long-term groundwater level monitoring and groundwater sampling.

3 Equipment

Drilling of percussion borehole HFM23 at DS9 was carried out with a Nemek 407 RE DTH percussion drilling machine (Figure 3-1), whereas drilling of percussion boreholes HFM24 and SFM0080 at DS10 respectively HFM28 at DS9, were carried out with a Nemek 710 TE DTH machine (Figure 3-2). Both machines were supplied with various accessory equipment.

In this chapter short descriptions are given of the drilling systems and the technique and equipment for gap injection of the borehole casings. Besides, the instrumentation used for deviation measurements performed after completion of drilling as well as the equipment applied for measurements and sampling during drilling are briefly described.

3.1 Drilling system

The Nemek 407 RE drilling machine is equipped with separate engines for transportation and power supplies. Water and drill cuttings were discharged from the borehole by means of an Atlas-Copco XRVS 455 Md 27 bars diesel compressor. The air-operated DTH drilling hammer was of type Secoroc 5", descended in the borehole by a Driconeq 76 mm pipe string.

All DTH-components were cleaned with a Kärcher HDS 1195 high-capacity steam cleaner.

Figure 3-1. *The Nemek 407 percussion drilling machine employed for drilling the percussion borehole HFM23 at drill site DS9.*

Figure 3-2. *The Nemek 710 TE percussion drilling machine employed for drilling percussion boreholes HFM24 and SFM0080 at drill site DS10 as well as HFM28 at drill site DS9.*

Also the Nemek 710 TE drilling machine is equipped with separate engines for transportation and power supplies. The compressor used was of the same type as described above, a 27 bars diesel Atlas-Copco XRVS 455 Md, and the air-operated DTH drilling hammer was of type Secoroc 5", descended in the borehole by a Driconeq 76 mm pipe string. Cleaning of DTH-components was made with the above mentioned Kärcher HDS 1195 high-capacity steam cleaner.

3.2 Gap injection technique and equipment

In order to prevent surface water and shallow groundwater to infiltrate into deeper parts of the borehole, the normal procedure is to grout the gap between the borehole wall and the casing pipe with cement. The cement application may be performed by different technical approaches and equipments. Two variants of gap injection with cement are illustrated in Figure 3-3. In HFM23, HFM24 and HFM28 only the borehole packer technique was applied.

3.3 Equipment for deviation measurements

Deviation measurements in HFM23, HFM24 and HFM28 were performed with a Reflex EZ-shot (magnetic) camera. Azimuth and dip were measured every third metre. The coordinates for the collaring point and the measured values from the EZ-shot instrument were used for calculating the coordinates for every measured point along the borehole. The deviation measurements have shown that the inclied borehole HFM23 succesively deviates upwards, see Section 5.3. This causes a frictional resistance and the first deviation measurement in HFM23 could only be performed to 115 m when lowering with a wire. By manually pushing plastic pipes, the measuring probe reached 155 m. Finally, by using an electrical rig with steel tubes, the deviation probe was pushed to 204 m borehole lenght.

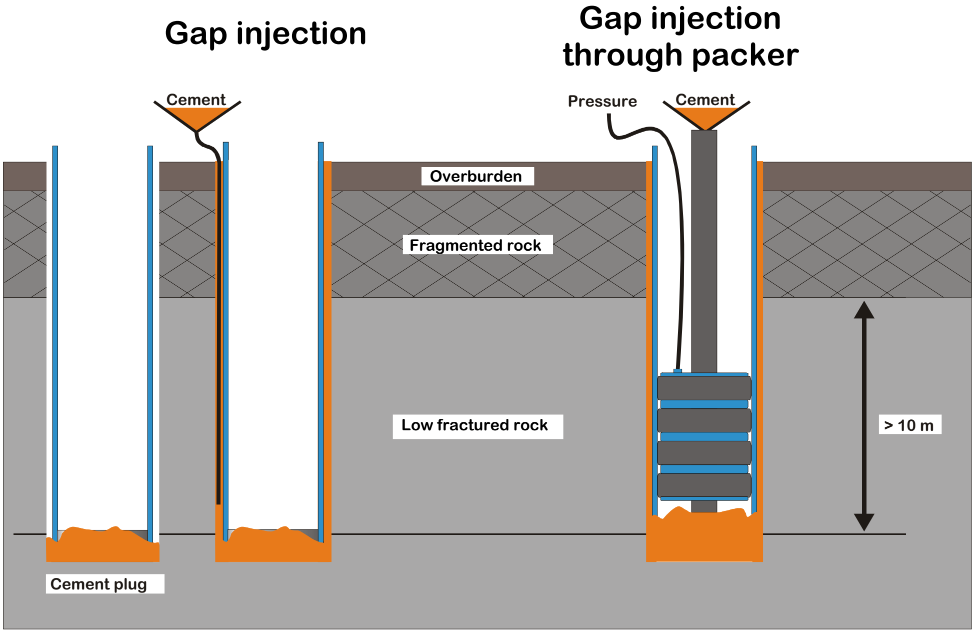


Figure 3-3. *Gap injection technique. In order to grout the gap between the borehole wall and the casing, different systems may be used. To the left, filling up a cement-water mixture with a flexible hose is shown. To the right, injection is performed through a borehole packer.*

3.4 Equipment for measurements and sampling during drilling

Flow measurements during drilling were conducted using measuring vessels of different sizes and a stop watch. Drilling penetration rate was measured 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. The electrical conductivity of the groundwater was measured by a Kemotron 802 field measuring devise.

4 Execution

Drilling of boreholes HFM23, HFM24 and HFM28 followed SKB MD 610.003, Version 2.0 (Method Description for Percussion Drilling), including the following items:

- preparations,
- mobilization, 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 preparations 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, part of the equipment was cleaned 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 (the remaining part of the equipment was cleaned on-site). SKB MD 600.004 and SKB MD 600.006 are both SKB internal controlling documents.

4.2 Mobilization

Mobilization onto and at the site started with preparation of the drill site and transport of drilling and accessory equipment to the site. The mobilization also comprised, on-site cleaning of all DTH-equipment at level two according to SKB MD 600.004, lining up the machine and making a control of the inclination with a graduated arc (Figure 4-1) and a final function control.

4.3 Drilling and measurements during drilling of boreholes HFM23, HFM24 and HFM28

A TUBEX- system (an ODEX-variant) was applied for drilling through the overburden and some metres into solid bedrock (Figure 4-2).

4.3.1 Drilling through the overburden

TUBEX is a system for simultaneous drilling and casing driving. The method is based on a system with a pilot bit and an eccentric reamer, which produces a borehole slightly larger than the external diameter of the casing tube. This enables the casing tube to follow the drill bit down the hole. In the Ejector-TUBEX system, the design of the discharge channels for the flushing medium, in this case compressed air, is such that the oxygen and oil contamination of the penetrated soil layers is reduced compared to conventional systems.

Figure 4-1. *Control of the inclination with a graduated arc.*

4.3.2 Gap injection

When the casing string had been firmly installed in boreholes HFM23, HFM24 and HFM28, the narrow gap between the borehole wall and the external wall of the casing was grouted with a cement/water-mixture according to the borehole packer technique illustrated in Figure 3-3.

4.3.3 Percussion drilling in solid rock

After the casing was set, 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 drilling step, the initial 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 drilling length is to be expected when drilling in the rock types prevailing

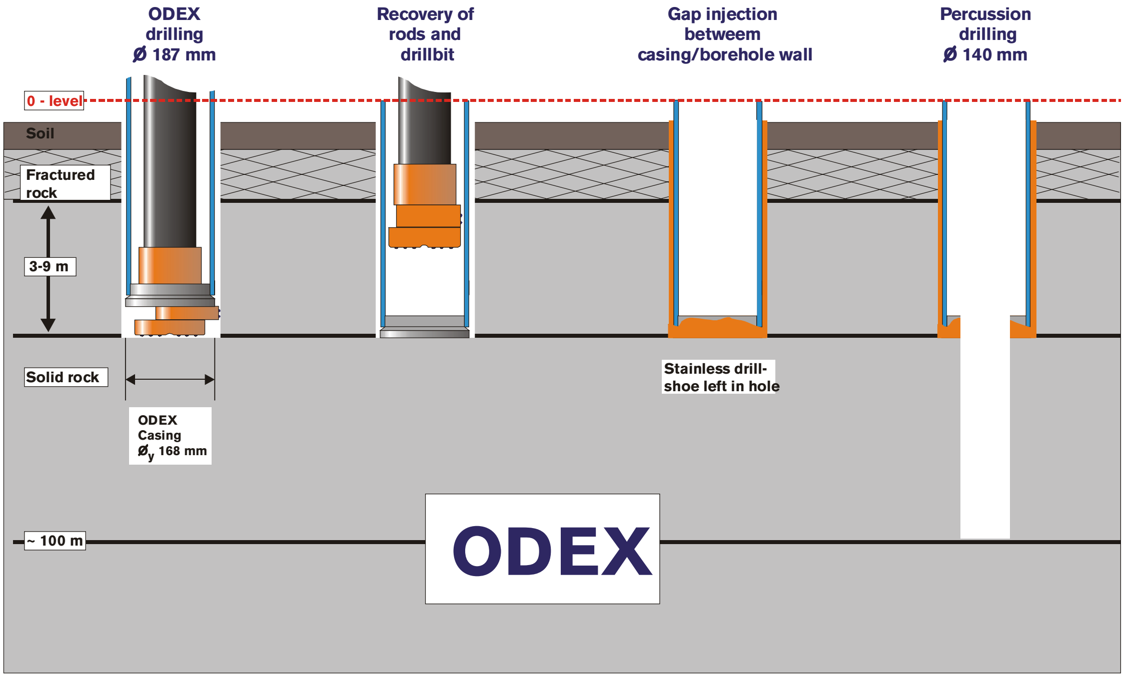


Figure 4-2. *The different steps included in the performance of the percussion drilled boreholes HFM23, HFM24 and HFM28.*

in the Forsmark area. For boreholes deeper then 100 metres, the drill bit normally has to be grinded. Also the initial diameter of all three boreholes HFM23, 24 and 28 is slightly less than 140 mm due to drilling with worn drill bits.

4.3.4 Sampling and measurements during drilling

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

- Collecting one soil sample per metre drilling length. Analysis and results will be reported separately.
- Collecting one sample per 3 metres drilling length of drill cuttings from the bedrock. Each major sample consists of three individual minor samples collected at every metre borehole length, stored in one plastic box marked with a sample number. As far as possible, mixing of the three individual samples was avoided. 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 later examined more thoroughly and interpreted together with a BIPS-log (so called Boremap mapping) /6/.
- Measurements of the penetration rate (one measurement per 20 cm drilling length). The time needed for the drill bit to sink 20 cm was recorded manually in a paper record.
- Performing one observation of discharged groundwater flow rate (if any) and water colour per 20 cm drilling 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 every 3 metres drilling length (noted in a paper record).

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

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. By measuring the flow rate of the discharged groundwater, a rough estimate of the water yielding capacity of the borehole at maximum drawdown was achieved. The drilling pipes were then retrieved from the hole, and the diameter of the drill bit was measured. A deviation survey of the borehole completed the measurement programme during and immediately after drilling. The borehole was secured by a stainless steel lockable cap, mounted on the casing flange, which finishes off the casing. Finally, the equipment was removed, the site cleaned and a joint inspection made by representatives from SKB and the Contractor, to ensure that the site had been satisfactorily restored.

4.5 Data handling

Minutes with the following headlines: 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 and are traceable by the Activity Plan number.

4.6 Environmental control

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

4.7 Nonconformities

No departures from the Activity Plan were made.

5 Results

All data were stored in the SICADA database, where they are traceable by the Activity Plan number. Below, a summary of the data acquired is presented.

5.1 Design of the percussion drilled boreholes

5.1.1 Design of the percussion drilled boreholes HFM23, HFM24 and HFM28

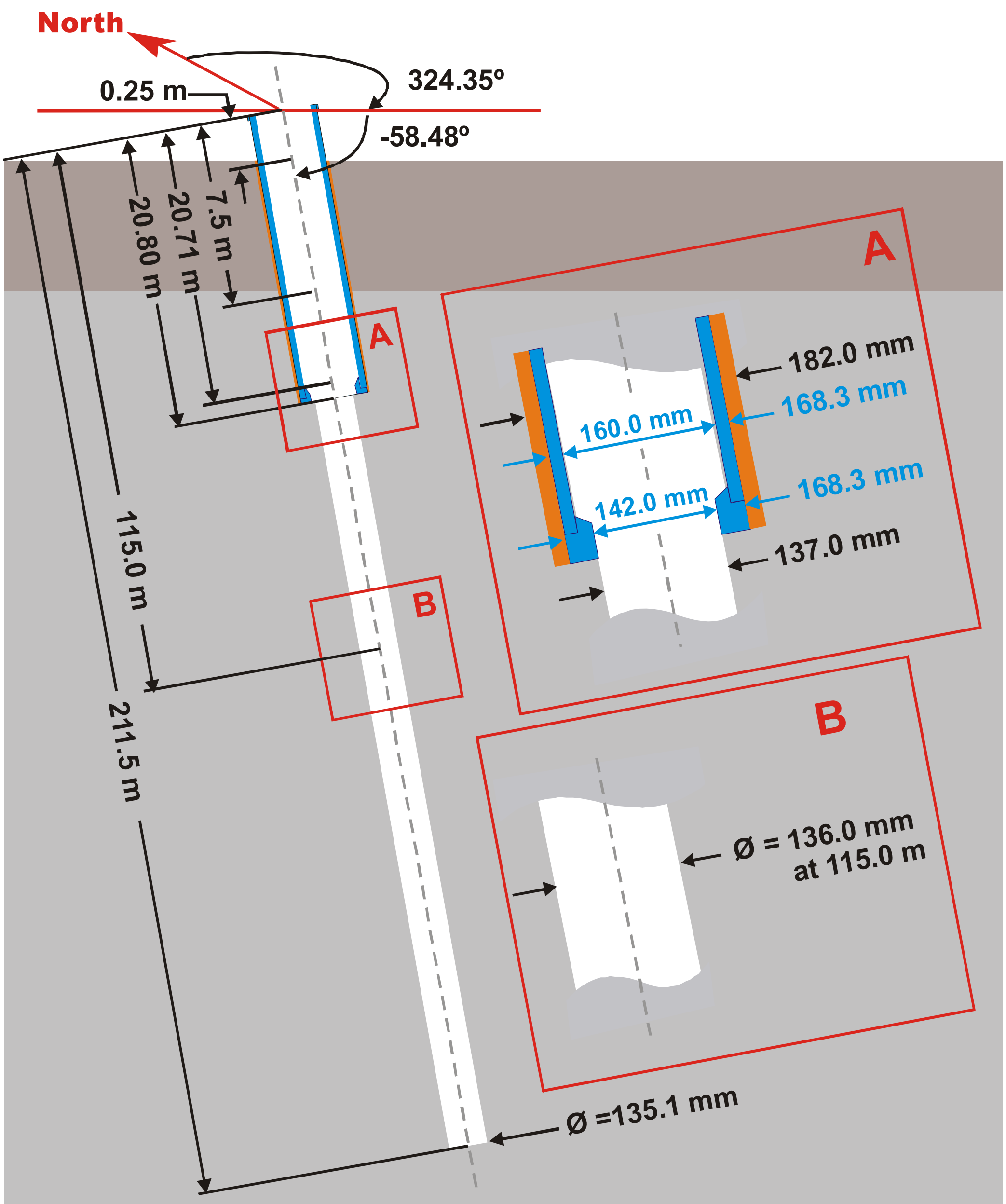
Administrative, geometric, and technical data for HFM23, HFM24 and HFM28 are presented in Table 5-1. The technical design of the boreholes is illustrated in Figures 5-1, 5-2, and 5-3.

Table 5-1. Administrative, geometric and technical data for boreholes HFM23, HFM24 and HFM28.

Parameter	HFM23	HFM24	HFM28
Drilling period	From 2005-08-24 to 2005-09-01	From 2005-11-21 to 2005-11-29	From 2005-09-12 to 2005-09-14
Borehole inclination (collaring point)	–58.48° (– = downwards)	–59.56° (– = downwards)	–84.76° (– = downwards)
Borehole bearing	324.35°	47.29°	146.78°
Borehole length	211.50 m	151.35 m	151.20 m
Borehole diameter	From 0.00 m to 20.80 m: 0.182 m	From 0.00 m to 18.03 m: 0.180 m	From 0.00 m to 12.10 m: 0.178 m
	From 20.80 m to 211.50 m: decreasing from 0.1370 m to 0.1351 m	From 18.03 m to 151.35 m: decreasing from 0.1397 m to 0.1377 m	From 12.10 m to 151.20 m: decreasing from 0.1383 m to 0.1351 m
Casing length	20.80 m	18.03 m	12.03 m
Casing diameter	$Ø_o/Ø_i$ = 168.3 mm/ 160.0 mm to 20.80 m	$Ø_o/Ø_i$ = 168.3 mm/ 160.0 mm to 18.03 m	$Ø_o/Ø_i$ = 168.3 mm/ 160.0 mm to 12.03 m
	$Ø_o/Ø_i$ = 168.3 mm/ 142.0 mm between 20.71 and 20.80 m	$Ø_o/Ø_i$ = 168.3 mm/ 143.0 mm between 17.94 and 18.03 m	$Ø_o/Ø_i$ = 168 mm/142.0 mm between 11.94 and 12.03 m
Drill bit diameter	Start of drilling: 0.1370 m End of drilling: 0.1351 m	Start of drilling: 0.1397 m End of drilling: 0.1377 m	Start of drilling: 0.1383 m End of drilling: 0.1351 m
Collaring point coordinates (system RT90 2.5 gon V/ RHB70)	Northing: 6700067.69 m Easting: 1630595.43 m Elevation: 4.250 m.a.s.l.	Northing: 6698662.37 m Easting: 1631719.64 m Elevation: 3.683 m.a.s.l.	Northing: 6700068.840 m Easting: 1630597.240 m Elevation: 4.266 m.a.s.l.

Technical data

Borehole HFM23



Drilling reference point

Northing: 6700067.686 (m), RT90 2,5 gon V 0:-15
Easting: 1630595.433 (m), RT90 2,5 gon V 0:-15
Elevation: 4.250 (m), RHB 70

Drilling period

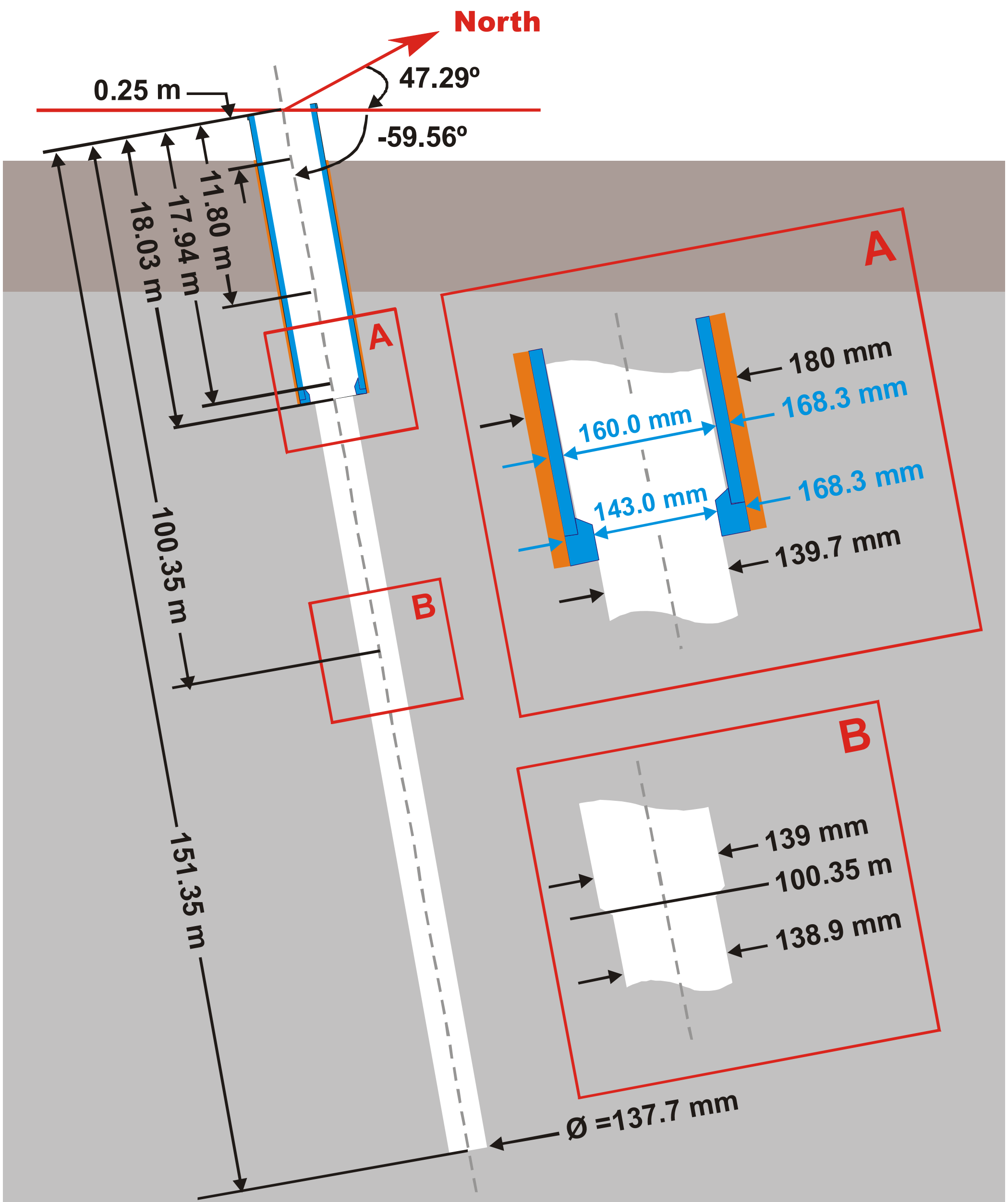
Drilling start date: 2005-08-24
Drilling stop date: 2005-09-01

rev 2005-10-28

Figure 5-1. *Technical data for borehole HFM23.*

Technical data

Borehole HFM24



Drilling reference point

Northing:	6698662.373	(m), RT90 2,5 gon V 0:-15
Easting:	1631719.641	(m), RT90 2,5 gon V 0:-15
Elevation:	3.683	(m), RHB 70

Drilling period

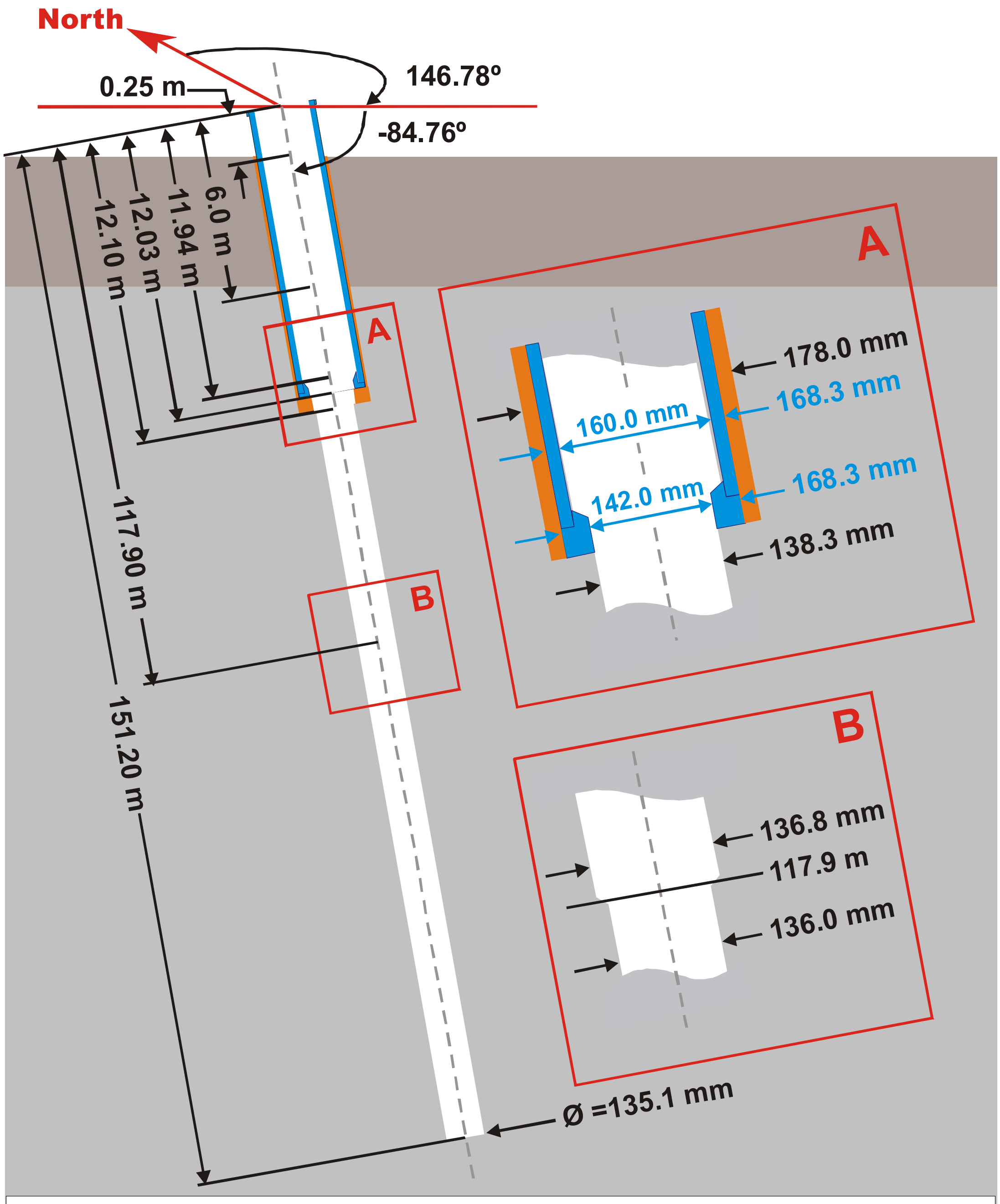
Drilling start date:	2005-11-21
Drilling stop date:	2005-11-29

rev 2006-04-11

Figure 5-2. *Technical data for borehole HFM24.*

Technical data

Borehole HFM28



Drilling reference point

Northing:	**6700068.840**	**(m), RT90 2,5 gon V 0:-15**
Easting:	**1630597.240**	**(m), RT90 2,5 gon V 0:-15**
Elevation:	**4.266**	**(m), RHB 70**

Drilling period

Drilling start date:	**2005-09-12**
Drilling stop date:	**2005-09-14**

rev 2006-09-04

Figure 5-3. *Technical data for borehole HFM28.*

5.1.2 Soil borehole SFM0080

The design of the groundwater monitoring well SFM0080 is illustrated in Figure 5-4. Table 5-2 displays the geometric characteristics of the well.

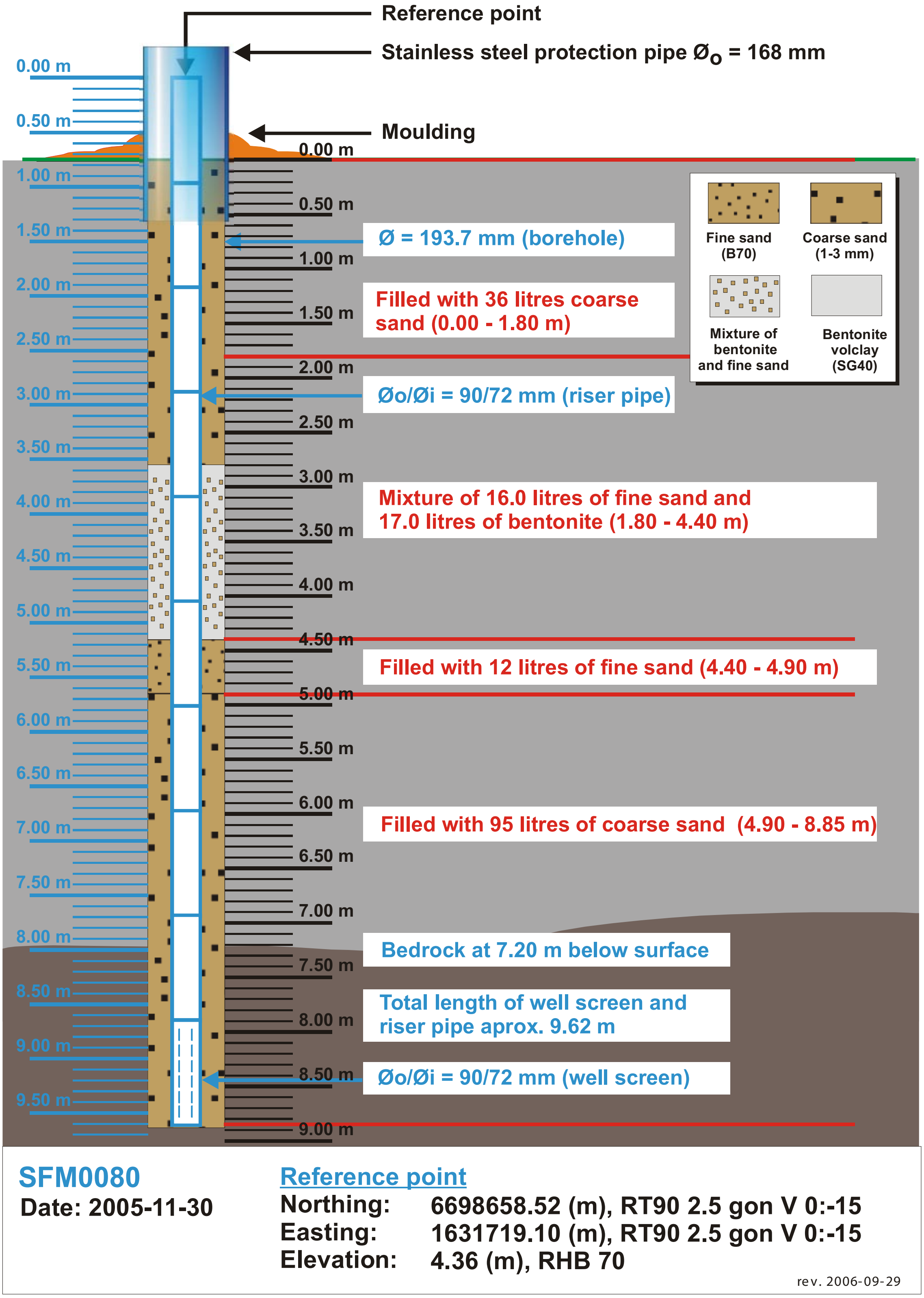


Figure 5-4. *The groundwater monitoring well installation in borehole SFM0080.*

Table 5-2. Geometric data for groundwater monitoring well SFM0080.

Drillhole ID	Incli-nation	Northing	Easting	Elevation m.a.s.l. (top of HDPE-pipe)	Total depth from ground level (m)	Screen length (m)	Screen pipe length includ-ing a well screen (m)	Screen pipe diameter ($Ø_o$/$Ø_i$, mm)
SFM0080	90°	6698658.52	1631719.10	4.36	8.85	1.00	9.62	90/72

5.2 Consumables used up in HFM23, HFM24 and HFM28

The amount of oil products consumed in the boreholes during drilling, and grout used for gap injection of the respective casings is reported in Tables 5-3 and 5-4. The cement was of low alkalic type, consisting of microsilica (920-D) and white cement (Aalborg Portland CEM I, 52.5N) in proportions according to Table 5-3.

Regarding contamination risks, albeit some amounts of hammer oil and compressor oil reach the borehole, they are, on the other hand, continuously retrieved due to the permanent air flushing during drilling. After completion of drilling, only minor remainders of the contaminants are left in the borehole.

Table 5-3. Oil consumption.

Borehole ID	Hammer oil Preem Hydra 46	Compressor oil Schuman 46
HFM23	7 L	Not detected
HFM24	22 L	Not detected
HFM28	Not documented	Not detected

Table 5-4. Consumption of cement grouting.

Borehole ID	Casing length	Cement volume (Aalborg Portland Cement/microsilica)	Grouting method
HFM23	20.80 m	55/22 kg	Borehole packer
HFM24	18.03 m	75/34.5 kg	Borehole packer
HFM28	12.10 m	25/11.5 kg	Borehole packer

5.3 Well Cad presentations

Technical as well as geoscientific results achieved during drilling are presented in the so called Well Cad plots in Figure 5-5, Figure 5-6 and Figure 5-7.

The deviation measurements made in boreholes HFM23, HFM24 and HFM28 are summarized in Table 5-5, expressed as “absolute deviation”. Absolute deviation is the radial distance, at equal length, between the deviated borehole and an imagined straight line following the dip and strike of the borehole collaring point.

HFM23, with the initial inclination –58.48° and bearing 324.35°, deviates mostly upwards. Two measurement attempts by, lowering with wire and manually pushing the probe failed, due to large frictional resistance. The deviation measuring probe in the final measurement was attached to steel pipes and pushed down with an electrical rig which made it possible to measure to 204 m borehole length.

The borehole shows an extraordinary deviation, and at c.162 m borehole length the inclination is zero (horizontal). Furthermore, at the final length 211.50 m, the borehole inclination is 9.35°, i.e. the borehole is climbing up. The absolute deviation at 211.50 m length is calculated to incredible 124.66 m.

Borehole HFM24 (initial inclination –59.56° and bearing 47.29°) has a moderate absolute deviation of 7.44 m, slightly to the right and upwards.

Finally, borehole HFM28 (inclination –84.76° and bearing 146.78°), also deviates slightly to the right an mostly upwards. The absolute deviation at 151.50 m length is calculated to 16.23 m.

Boreholes HFM23 and HFM28 are located close to each other. The boreholes are drilled with different drilling rigs and drilling crew, but with equal DTH, down the hole equipment. There is no simple explanation to the large difference between the borehole deviations in the two boreholes.

Table 5-5. Results from deviation measurements.

Borehole	Length (m)	Absolute deviation (m)	Remarks
HFM23	211.50	124.66	Total length of borehole is 211.50 m
HFM24	151.35	7.44	Total length of borehole is 151.35 m
HFM28	151.20	16.23	Total length of borehole is 151.20 m

Title **PERCUSSION DRILLED BOREHOLE HFM23**

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Signed data**	
Borehole	HFM23	**Coordinate System**	RT90-RHB70
Diameter [mm]	134	**Northing [m]**	6700067.69
Length [m]	211.50	**Easting [m]**	1630595.43
Bearing [°]	324.35	**Elevation [m.a.s.l.]**	4.25
Inclination [°]	-58.48	**Drilling Start Date**	2005-08-24 13:00:00
Date of mapping	2004-08-26 09:00:00	**Drilling Stop Date**	2005-09-01 14:00:00
		Plot Date	2006-09-05 21:10:45

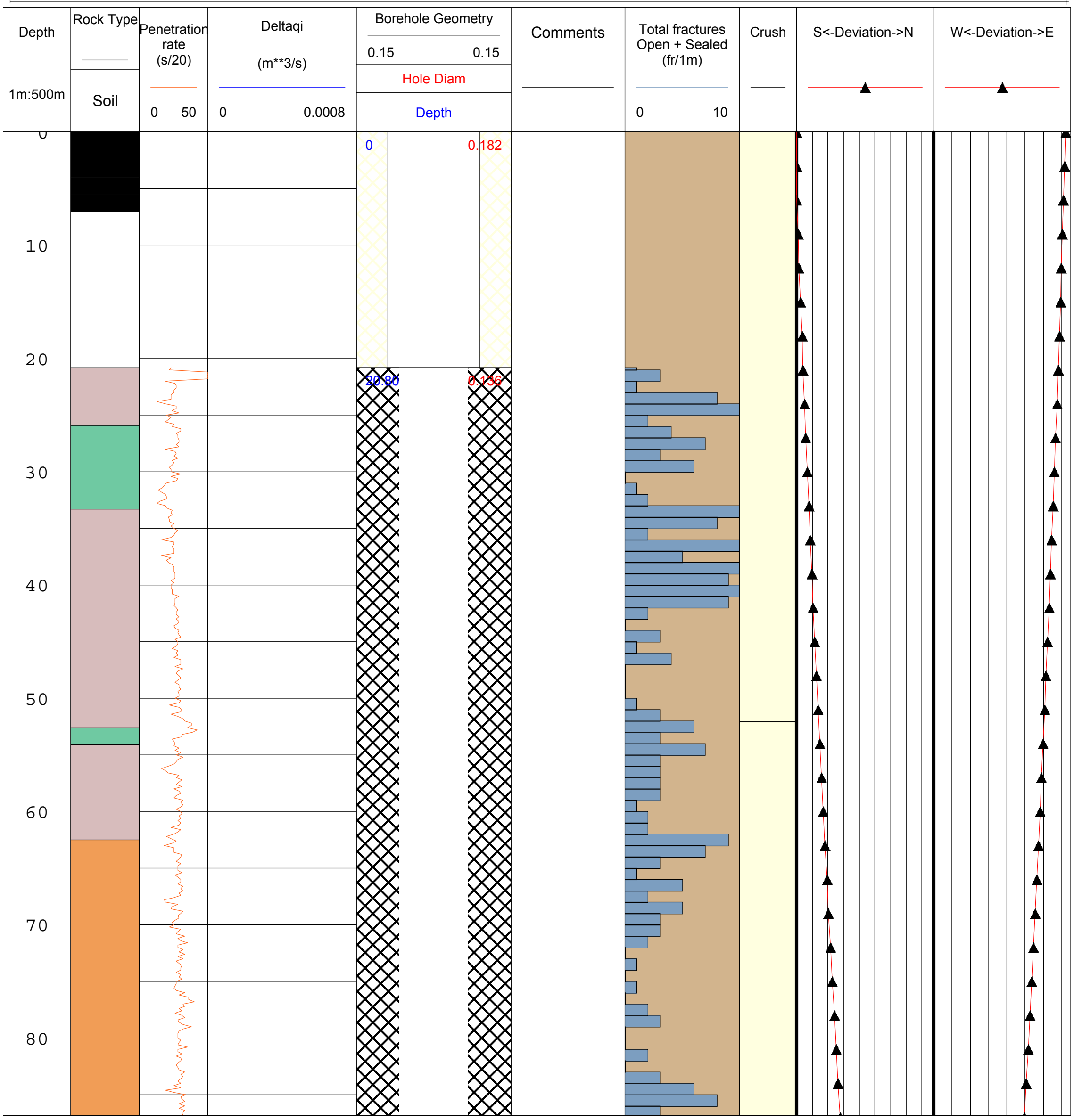
ROCKTYPE FORSMARK

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

SOIL

- **Soil**

Script Name



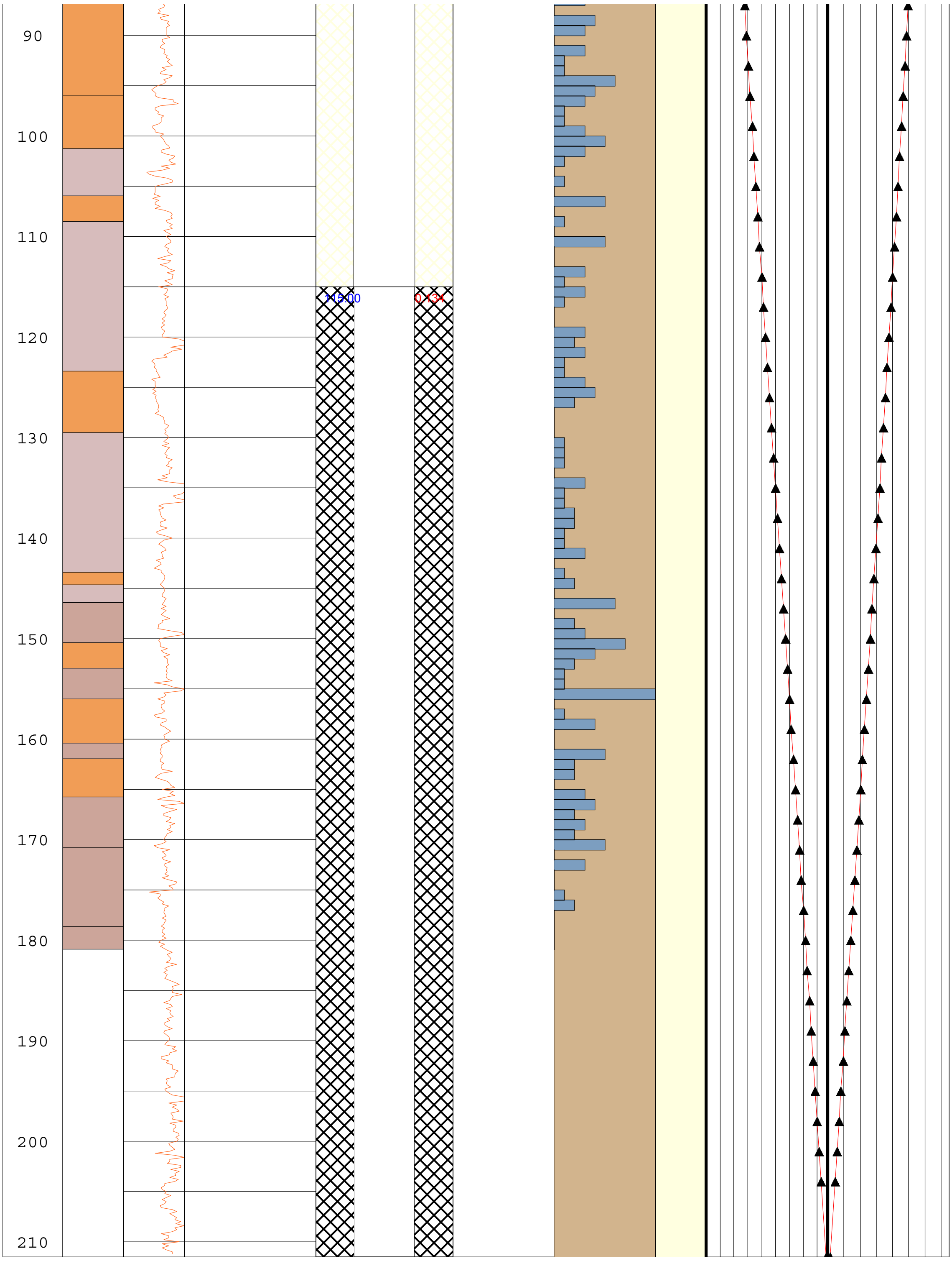


***Figure 5-5.** Technical and geoscientific data acquired during drilling of borehole HFM23.*

Title **PERCUSSION DRILLED BOREHOLE HFM24**

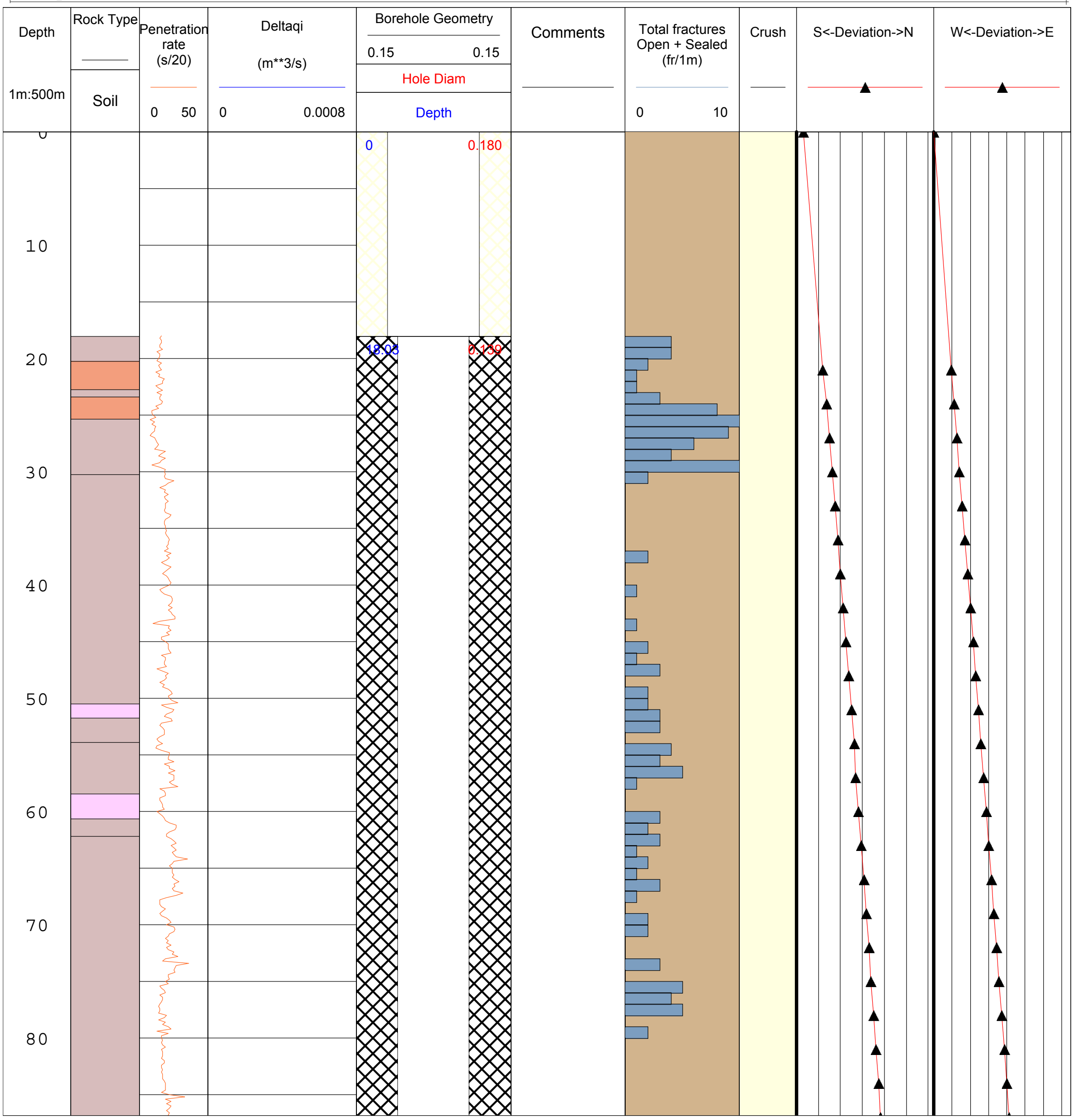
Svensk Kärnbränslehantering AB		**Signed data**	
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM24	**Northing [m]**	6698662.37
Diameter [mm]	138	**Easting [m]**	1631719.64
Length [m]	151.35	**Elevation [m.a.s.l.]**	3.68
Bearing [°]	47.29	**Drilling Start Date**	2005-11-21 10:00:00
Inclination [°]	-59.56	**Drilling Stop Date**	2005-11-29 11:00:00
Date of mapping	2005-11-21 00:00:00	**Plot Date**	2006-08-28 21:10:15

ROCKTYPE FORSMARK

SOIL

- **Granite, fine- to medium-grained**
- **Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained**
- **Granite to granodiorite, metamorphic, medium-grained**

Script Name



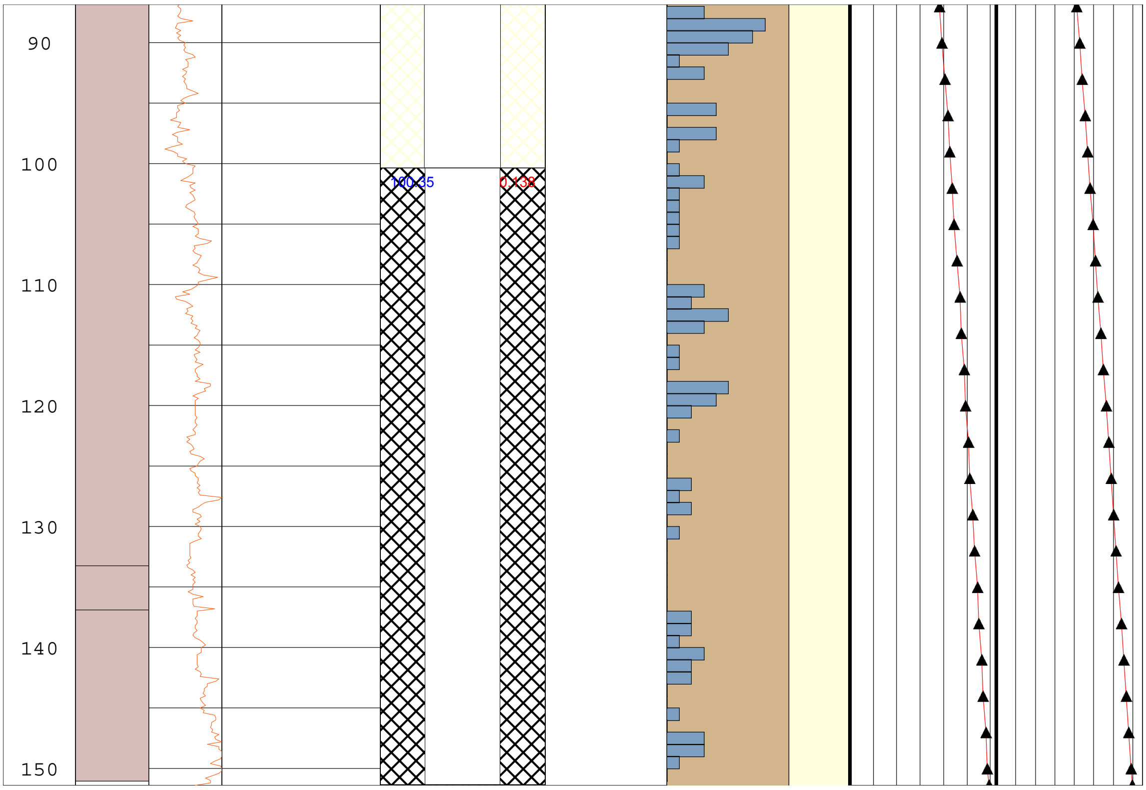


Figure 5-6. *Technical and geoscientific data acquired during drilling of borehole HFM24.*

Title **PERCUSSION DRILLED BOREHOLE HFM28**

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Signed data**	
Borehole	HFM28	**Coordinate System**	RT90-RHB70
Diameter [mm]	135	**Northing [m]**	6700068.84
Length [m]	151.20	**Easting [m]**	1630597.24
Bearing [°]	146.78	**Elevation [m.a.s.l.]**	4.27
Inclination [°]	-84.76	**Drilling Start Date**	2005-09-12 13:30:00
Date of mapping	2006-03-08 18:00:00	**Drilling Stop Date**	2005-09-14 19:00:00
		Plot Date	2006-09-24 21:10:11

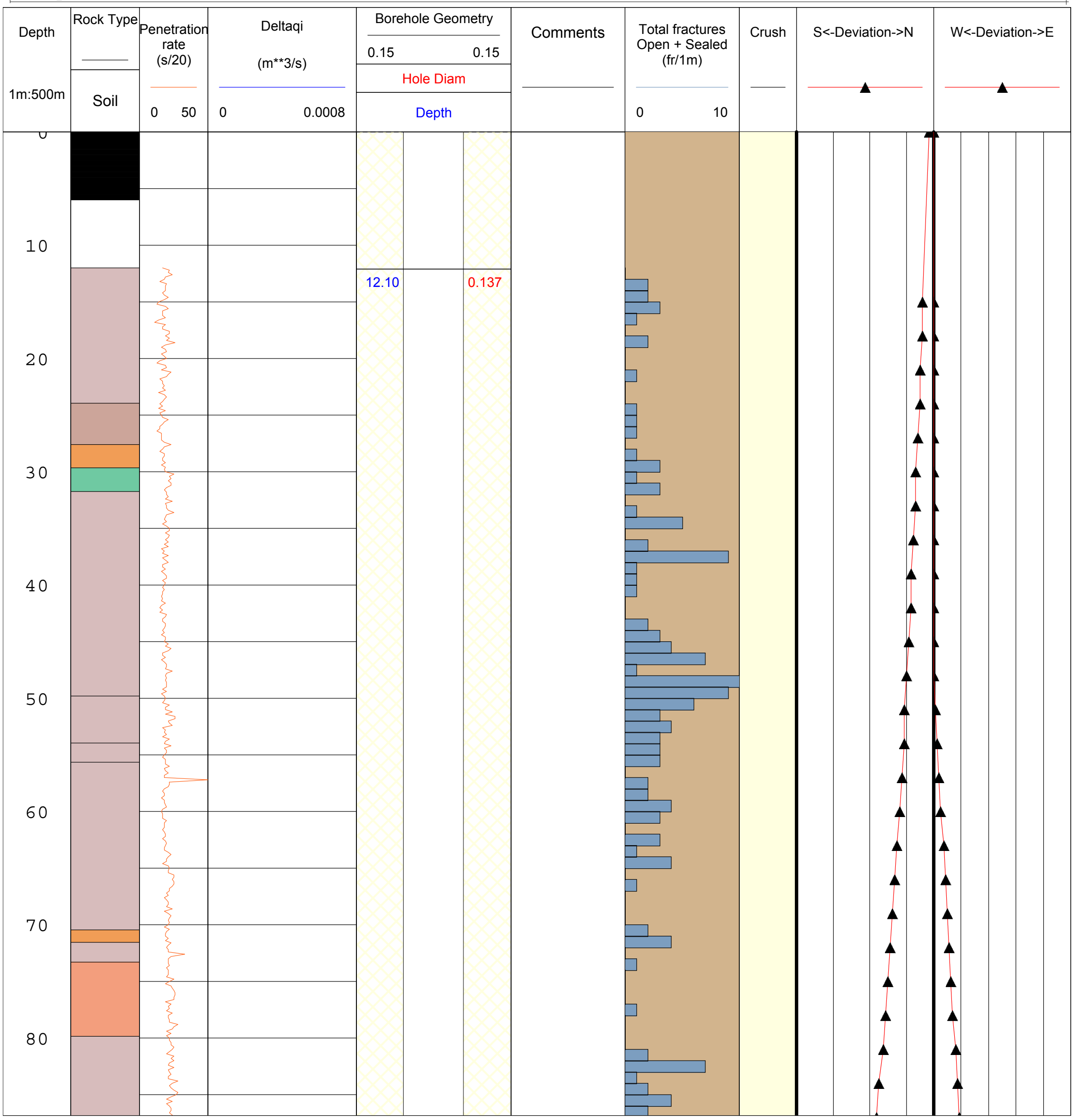
ROCKTYPE FORSMARK

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

SOIL

- **Soil**

Script Name



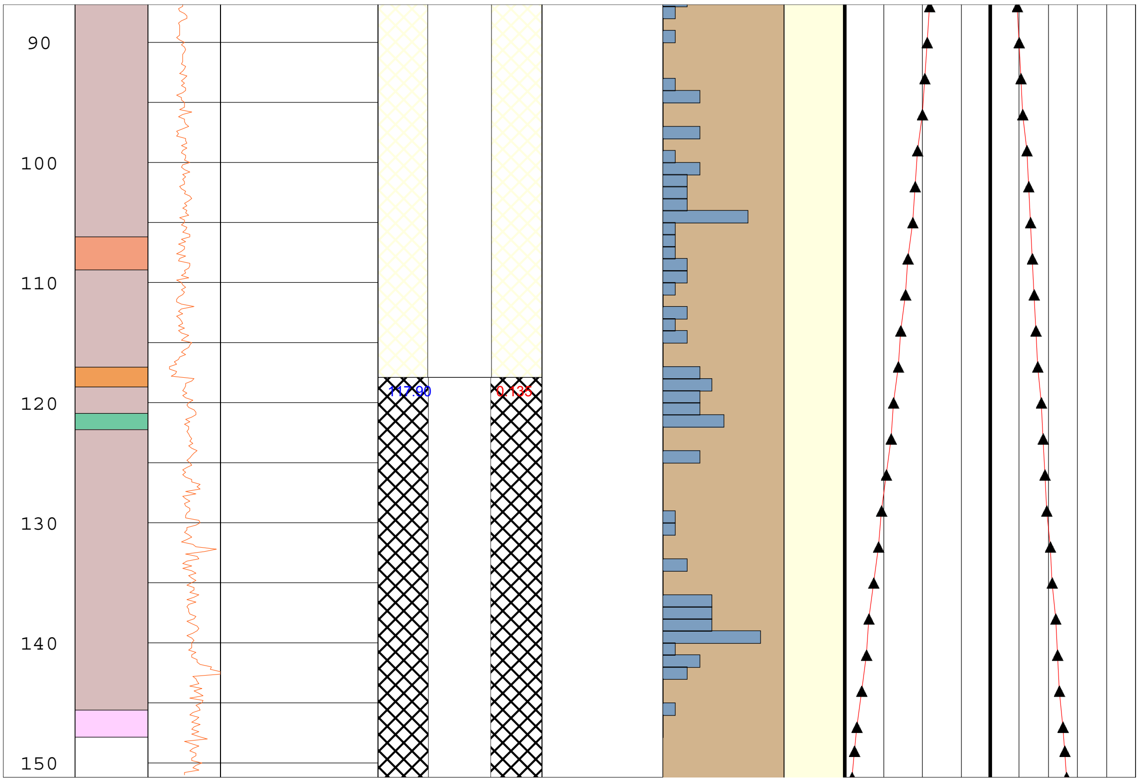


Figure 5-7. *Technical and geoscientific data acquired during drilling of borehole HFM28.*

5.4 Hydrogeology

5.4.1 Observations during drilling

Usually, the upper section of the bedrock in the Forsmark area contains several water yielding fractures, resulting in large water-inflows in most of the existing percussion drilled boreholes in the area. HFM23 and HFM28, located close to DS9, seem to be exceptions from the rule. During drilling and sampling in the boreholes, the low water-inflow was observed only as moist drilling debris. Still, a hydraulic connection between the boreholes appears, since the drilling performance of HFM28 caused an overflow in HFM23.

At 31 m drilling length in borehole HFM24, an inflow of 6 L/min was encountered. The electrical conductivity of the groundwater (EC-value) amounted to 10 mS/m (see Figure 5-8), indicating fresh water conditions. In section 46–52 m, the accumulated groundwater inflow increased stepwise to 100 L/min, whereupon the EC-value increased, first to to c. 210 mS/m and then slowly up to just above 230 mS/m at c. 90 m drilling lenght.

When drilling restarted at c.100 m, the accumulated water inflow rate increased to about 250 L/min during a period where the drilling length increased from 100 to 129 m. That discharge exceeded the aquifer capacity and steady-state conditions ensued at 200 L/min. Also the EC-values stabilized at c. 250 mS/m, which still indicates fresh water conditions.

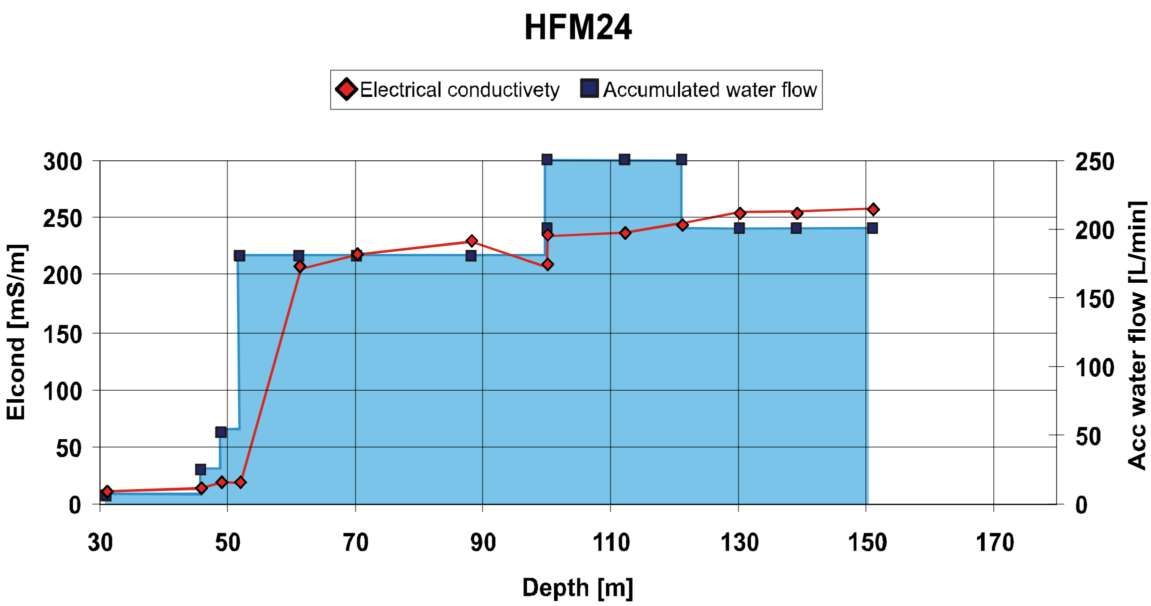


Figure 5-8. *Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM24.*

5.4.2 Hydraulic fracturing

The boreholes HFM23 and HFM28 were primarily aimed as flushing water wells for the planned core drilling at the drill site 9. However, due to very low water inflow, none of the boreholes have enough capacity to supply a drill site. One method commonly applied to increase the water yielding capacity of water wells is hydraulic fracturing. The principle of the method is to expose the rock volume below an inflated packer to a water pressure high enough to cause fracturing of the rock and/or widening of pre-existing fractures and to make the new fractures to be connected to water yielding fractures further away from the borehole.

In HFM28, hydraulic fracturing was performed at three levels, c. 30 m, c. 50 m and c. 75 m. The packer was inflated to c. 360 bars overpressure, whereupon water was pressed into the borehole section between the packer and the borehole bottom (150.50 m). With the packer at the 30 m level a pressure decrease was observed, but in the other sections no significant pressure changes were seen.

In HFM23, hydraulic fracturing was performed at two levels, c. 30 m and c. 38 m. No pressure decrease occurred during water injection, but when water was pressed into the respective sections in HFM23, an overflow in HFM28 was observed.

Finally, a pumping test showed that the hydraulic fracturing had not improved the water yielding capacity significantly. A water flow of c. 12 L/m was achieved from the two boreholes together, which is insufficient for supplying core drilling at drill site 9.

References

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

/2/ **SKB, 2001.** Execution programme for the initial site investigations at Forsmark. SKB P-02-03, Svensk Kärnbränslehantering AB.

/3/ **SKB, 2006.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of the core drilled boreholes KFM09A and KFM09B at drilling site DS9. SKB P-report in progress, Svensk Kärnbränslehantering AB.

/4/ **SKB, 2003.** Johansson, P-O. Forsmark: Drilling and sampling in soil. Installation of ground water monitoring wells and surface water level gauges. SKB P-03-64, Svensk Kärnbränslehantering AB.

/5/ **SKB, 2006.** Claesson, L-Å & Nilsson, G. Forsmark site investigation. Drilling of the telescopic drilled borehole KFM10A at drilling site DS10. SKB P-06-172, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2006.** Döse, C & Samuelsson, E. Forsmark site investigation. Boremap mapping of percussion boreholes HFM23-HFM32 and HFM38. SKB P-report in progress. Svensk Kärnbränslehantering AB.