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Forsmark site investigation

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October 2006

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Summary

The percussion boreholes HFM25, HFM26 and HFM27 were drilled during the period September 5th to November 18th, 2005, with the purpose of investigating three different lineaments trending in a north-easterly direction. Borehole HFM25, which was drilled to a length of 187.50 m, addressed a lineament, that after interpretation of the results from drilling is believed to be a deformation zone which now is identified as a zone named ZFMNE062A, which also has been investigated by trenching. Practically no groundwater inflow was observed in HFM25. The purpose of drilling borehole HFM26 (202.70 m long) was to achieve a better understanding of a lineament today interpreted as a deformation zone named ZFMNE065, which earlier had been investigated by percussion borehole HFM18. A total groundwater yield of 5 L/min was observed in HFM26. Finally, the 127.50 m long borehole HFM27 was directed towards a lineament now known to correspond to a deformation zone named ZFMNE061. The maximum groundwater discharge from the borehole was 260 L/min.

Boreholes HFM29 (199.70 m) and HFM30 (200.75 m) were directed to penetrate two north-west trending lineaments. HFM29 was drilled between December 12th and December 19th, 2005, perpendicular to a lineament, later interpreted to be a deformation zone named ZFMNW0123, while borehole HFM30 was drilled from May 3rd to May 11th, 2006, and was addressing a lineament interpreted as a deformation zone named ZFMNW0017. Borehole HFM30 had a total groundwater inflow of 80 L/min, whereas HFM29 was almost dry.

From interpretation of reflection seismic data, a reflector called B8 was selected for further investigation by percussion borehole HFM31. The outcropping of reflector B8 might also be the origin of lineament ZFMNE1193. HFM31 was drilled between May 15th and May 19th, 2006, to a length of 200.75 m. A very minor groundwater inflow was observed.

The main aim of borehole HFM32 was to enable groundwater pressure monitoring down to a couple of hundred meters below lake Bolundsfjärden in order to establish if this is a recharge or a discharge area, an issue of considerable interest for the safety analysis. Borehole HFM32 was drilled between January 11th and January 14th, 2006, to 202.65 m borehole length. A groundwater yield of 290 L/min was obtained at maximum borehole length.

Short sections of so called “vuggy granite” were encountered in the deep, inclined core drilled borehole KFM08C. In order to investigate a possible vertical extension of this rock type and its conceivable association with an earlier identified steeply dipping fracture zone, percussion borehole HFM38 was drilled between June 14th and June 22nd, 2006, at a location right above a section of “vuggy granite” in KFM08C. The borehole was drilled to a length of 200.75 m and demonstrated a groundwater yield of 100L/min.

Sammanfattning

Tre hammarborrhål, HFM25, HFM26 och HFM27, borrades mellan den 5:e september och den 18:e november 2005 med syftet att undersöka tre lineament med nordostlig riktning. HFM25 ansattes mot ett lineament, som efter tolkning av resultaten från borrning tolkats vara en deformationszon som idag benämns ZFMNE062A. Lineamentet har tidigare blivit undersökt med dikesgrävning och geologisk kartläggning. Borrhål HFM25 uppvisade praktiskt taget inget grundvatteninflöde. Syftet med borrhål HFM26 var att öka kunskapen om ett lineament som idag tolkats vara en deformationszon benämnd ZFMNE065, som tidigare undersökts med hammarborrhål HFM18. Grundvatteninflödet till HFM26 uppmättes till 5 L/min. Slutligen borrades HFM27 mot ett lineament som idag tolkats motsvara en deformationszon benämnd ZFMNE061. I detta fall uppmättes ett grundvatteninflöde om hela 260 L/min.

Borrhål HFM29 som borrades mellan 12:e och 19:e december 2005, riktades mot ett lineament som idagsläget tolkats vare en deformationszon med beteckningen ZFMNW0123, medan borrhålet HFM30 borrades mellan 3 och 11 maj 2006 mot ett lineament nu tolkat som en deformationszon med beteckningen ZFMNW0017. Båda dessa zoner stryker i nordvästlig riktning. Borrhålet HFM30 visade ett totalt inflöde om 80 L/min, medan HFM29 var praktiskt taget torrt.

Från tolkning av reflektionsseismiska data valdes en reflektor benämnd B8 ut för undersökning med ett hammarborrhål, HFM31. Utgåendet av denna reflektor kan eventuellt vara ursprunget till ett lineament med beteckningen ZFMNE1193. HFM31 borrades mellan 15:e och 19:e maj 2006. Borrhålet gav obetydligt med vatten.

Huvudsyftet med hammarborrhål HFM32 var att penetrera berggrunden ner till 200–300 m för att möjliggöra monitering av grundvattentryck för att på så vis undersöka om denna del av kandidatområdet utgör ett in- eller ett utströmningsområde. Detta är en fråga av stor betydelse för säkerhetsanalysen. Detta borrhål utfördes mellan den 11:e och 14:e januari 2006 och gav totalt ett grundvatteninflöde om 290 L/min.

Ett antal korta sektioner av s k porös granit påträffades vid borrningen av det djupa, gradade kärnborrhålet KFM08C. För att undersöka om den porösa graniten eventuellt kunde ha en vertikal utbredning mot ytan, och eventuellt också stå i samband med en tidigare identifierad brantstående sprickzon, borrades mellan den 14:e och 22:a juni 2006 ett hammarborrhål med beteckning HFM38 rakt ovanför en sektion med porös granit i KFM08C. HFM38 borrades till 200,75 m längd och ett totalt grundvatteninflöde om 100 L/min uppmättes.

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.

In the present report, performance of and results from drilling the percussion boreholes HFM25, HFM26, HFM27, HFM29, HFM30, HFM31, HFM32 and HFM38 are presented. The borehole locations are displayed in Figure 1-1. 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.

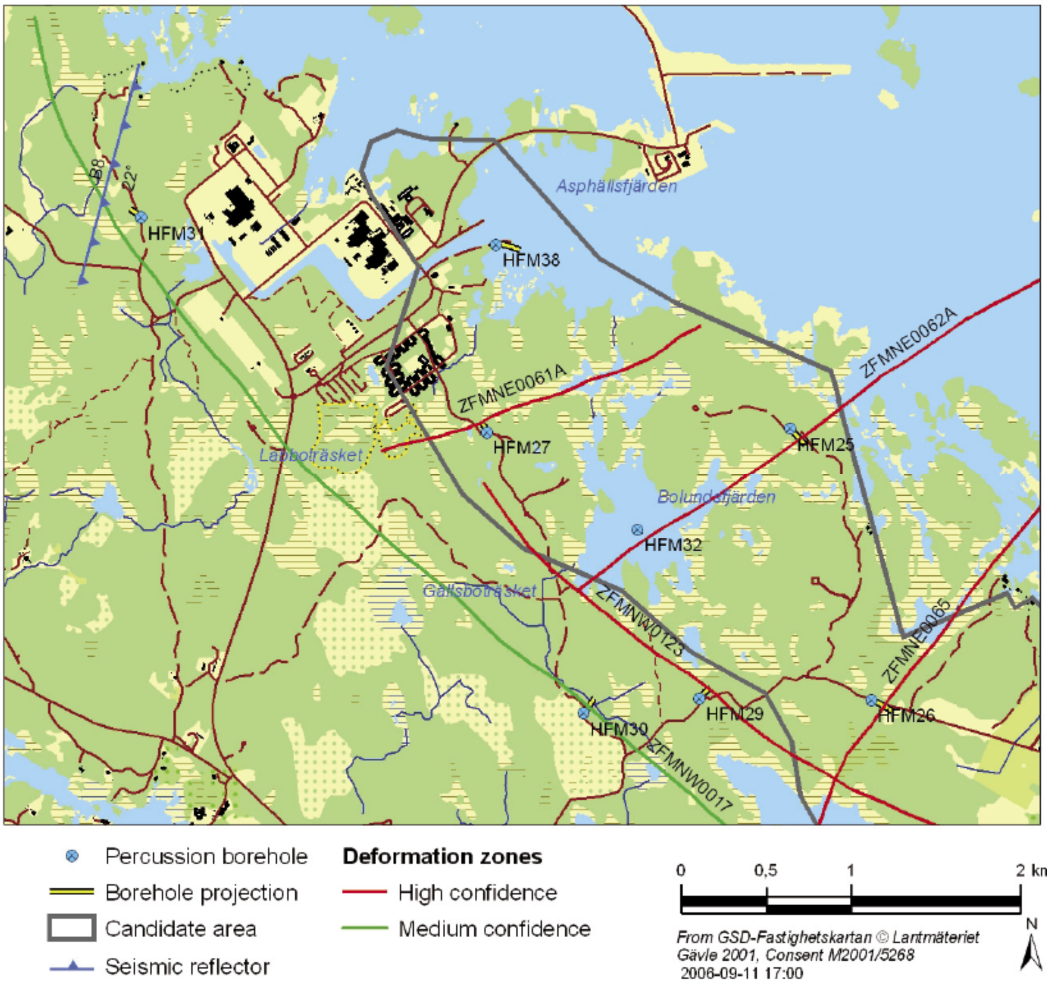


Figure 1-1. Borehole locations and lineaments addressed for borehole investigations.

Drilling of the eight boreholes was performed during the following periods:

- HFM25 between September 5th and 8th, 2005,
- HFM26 between November 14th and 18th, 2005,
- HFM27 between November 3rd and 10th, 2005,
- HFM29 between December 12th and 19th, 2005,
- HFM30 between May 3rd and 11th, 2006,
- HFM31 between May 15th and 19th, 2006,
- HFM32 between January 11th and 14th, 2006,
- HFM38 between June 14th and 22nd, 2006.

Controlling documents for performing the drilling 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 Systems Descriptions not included in the table below.

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

Activity plan	Number	Version
Hammarborrning av borrhål HFM25, HFM26 samt HFM27	AP PF 400-05-081	1.0
Hammarborrning av borrhål HFM29, HFM30 samt HFM31	AP PF 400-05-115	1.0
Hammarborrning av borrhål HFM32, Bolundsfjärden	AP PF 400-05-124	1.0
Hammarborrning av borrhål HFM38	AP PF 400-06-054	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för hammarborrning	SKB MD 610.003	1.0
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

2 Objectives and scope

Lineament investigations are fundamental for all work on structural geology. For the site investigations, it is of outmost importance to reveal whether a lineament reflects a structure in the bedrock, or merely a topographic anomaly, e.g. a glacier-induced depression in the soil layer or any other, similar surface-related phenomenon. For lineaments representing a zone of brittle deformation, it is essential to determine properties like lithological characteristics (including alteration), fracture frequency, rock mechanical parameters, hydraulic transmissivity and hydrogeochemical composition.

Boreholes penetrating the lineament make the necessary investigations for the above purposes possible. Whether core drilling or percussion drilling shall be applied, must be decided for each individual borehole. Percussion drilling is a rapid and hence cost-effective drilling method, which, in combination with advanced methods for borehole investigations in many cases offers an attractive solution for lineament investigations.

Of the eight percussion boreholes presented in this report, six were drilled in order to investigate lineaments. The aim of drilling the three percussion boreholes HFM25, HFM26 and HFM27 was to investigate three lineaments trending north-east /3/ and after investigation and analysis interpreted to represent deformation zones (see Figure 1-1):

- ZFMNE062A (borehole HFM25),
- ZFMNE065 (borehole HFM26). This lineament had earlier been investigated by borehole HFM18,
- ZFME061 (HFM27).

Boreholes HFM29 and HFM30 were addressing north-west trending lineaments /3/ also believed to be deformation zones after interpretation of data from the drilling:

- ZFMNW0123 (HFM29) and
- ZFMNW0017 (HFM30).

From interpretation of reflection seismic data, a reflector called B8 /4/ was selected for further investigation by percussion borehole HFM31. The outcropping of reflector B8 might also be the origin of lineament ZFMNE1193 /3/.

HFM32 was performed with the main aim of enabling groundwater pressure monitoring down to a couple of hundred metres below lake Bolundsfjärden in order to establish if this is a recharge or a discharge area, which is an issue of interest for the safety analysis.

Finally, short sections of so called “vuggy granite” were encountered in the deep, inclined core drilled borehole KFM08C. In order to investigate a possible vertical extension of this rock type and its conceivable association with an earlier identified steeply dipping fracture zone, percussion borehole HFM38 was drilled at a location right above a section of “vuggy granite” in KFM08C.

All the above named percussion boreholes are of so called SKB chemical type, implying that they 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.

All eight percussion drilled boreholes presented in this volume will also be used in the long-term groundwater level and hydrogeochemical monitoring programme.

3 Equipment

Drilling of percussion borehole HFM25, HFM26, HFM27 and HFM29, were carried out with a Nemek 710 DTH, percussion drilling machine (Figure 3-1), while drilling of the percussion boreholes HFM30, HFM31, HFM32 as well as HFM38 were performed with a Nemek 407 RE DTH percussion drilling 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 and the equipment used for measurements and sampling during drilling are briefly described.

3.1 Drilling system

The Nemek 710 TE drilling machine (Figure 3-1) 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 drill hammer was of type Secoroc 5", descended in the borehole by a Driconeq 76 mm pipe string.

The Nemek 407 RE drilling machine (Figure 3-2) is likewise equipped with separate engines for transportation and power supplies, and the same type of compressor and DTH-equipment including the pipe string was used as for the Nemek 710 machine.

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

Figure 3-1. *The Nemek 710 percussion drilling machine employed for drilling the percussion boreholes HFM25, HFM26, HFM27 and HFM29.*

Figure 3-2. *The Nemek 407 percussion drilling machine employed for drilling the percussion boreholes HFM30, HFM31, HFM32 and HFM38. Here establishing for drilling HFM32 at a small island in lake Bolundsfjärden.*

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 equipment. Two variants of gap injection with cement are illustrated in Figure 3-3. In the boreholes presented in this report only the borehole packer technique was applied.

3.3 Equipment for deviation measurements

Deviation measurements in HFM26 was performed with a Reflex EZ-shot (magnetic) camera (Figure 3-4), while a Flexit Multishot equipment (also magnetic) was used in HFM25, HFM27, HFM29, HFM30, HFM31, HFM32 and HFM38. Azimuth and dip were measured every third metre. The coordinates for the collaring and the measured values from the Reflex EZ- and Flexit instruments were used for calculating the coordinates for every measured point along the borehole.

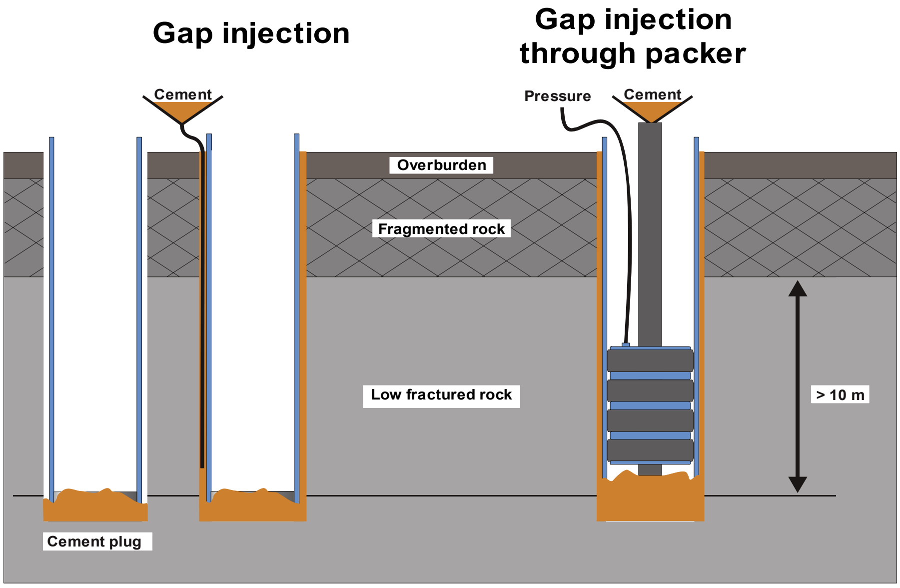


Figure 3-3. *Gap injection technique. In order to grout the gap between the borehole wall and the casing, different systems may be used. To the left, filling up a cement-water mixture with a flexible hose is shown. To the right, injection is performed through a borehole packer.*

Figure 3-4. *Deviation measurements in HFM26 were performed with a Flexit Multi-shot (magnetic) equipment.*

3.4 Equipment for measurements and sampling during positioning and drilling

The positioning of the borehole is first made with a GPS. The direction is made with a compass, while the dip is controlled by a graduated arc. The borehole is finally positioned and measured for determination of strike and dip with a theodolite (Figure 3-5).

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.

Figure 3-5. *Strike and dip for the borehole is measured with a GPS and a compass. The borehole is finally positioned and measured for strike and dip with a theodolite instrument.*

4 Execution

Drilling of boreholes HFM25, HFM26, HFM27, HFM29, HFM30, HFM31, HFM32 and HFM38 followed SKB MD 610.003 (Method Description for Percussion Drilling), see Table 1-1, 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´s internal controlling documents.

4.2 Mobilization

Mobilization onto and at the site started with preparation of the drilling 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 final function control.

4.3 Drilling and measurements during drilling of boreholes HFM25, HFM26, HFM27, HFM29, HFM30, HFM31, HFM32 and HFM38

For drilling through the overburden and between c six and 18 metres into solid bedrock, a TUBEX- system (an ODEX-variant) was applied (Figure 4-1).

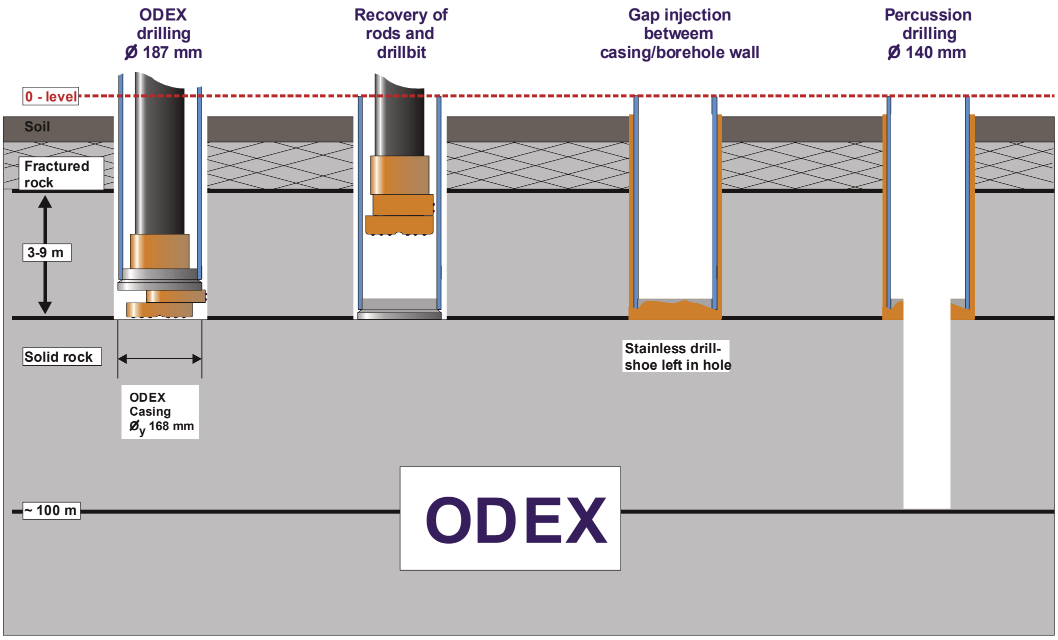


Figure 4-1. *The different steps included in the performance of the percussion drilled boreholes HFM25, HFM26, HFM27, HFM29, HFM30, HFM31, HFM32 and HFM38.*

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.

4.3.2 Gap injection

When the casing string had been firmly installed in borehole HFM25, HFM26, HFM27, HFM29, HFM30, HFM31, HFM32 and HFM38, 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 4-1. However, a diameter decrease of about 1 mm/100 m drilling 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 normally has to be grinded.

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.
- Collecting one sample per 3 metres drilling length of drill cuttings from the bedrock (Figure 4-2). 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. Later on logging of the boreholes with a BIPS camera resulted in a qualified mapping of the borehole walls which will be reported in /5/.
- 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).

***Figure 4-2.** Sampling of drill cuttings from the penetrated bedrock in HFM27.*

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 hydro geochemical 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. All documents and data 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 Plans were made.

5 Results

Below, a summary of the data acquired is presented.

5.1 Design of the percussion drilled boreholes HFM25, HFM26, HFM27, HFM29, HFM30, HFM31, HFM32 and HFM38

Administrative, geometric, and technical data for HFM25, HFM26, HFM27, HFM29, HFM30, HFM31, HFM32 and HFM38 are presented in Table 5-1. The technical design of the boreholes is illustrated in Figures 5-1, 5-2, 5-3, 5-4, 5-5, 5-6, 5-7 and 5-8.

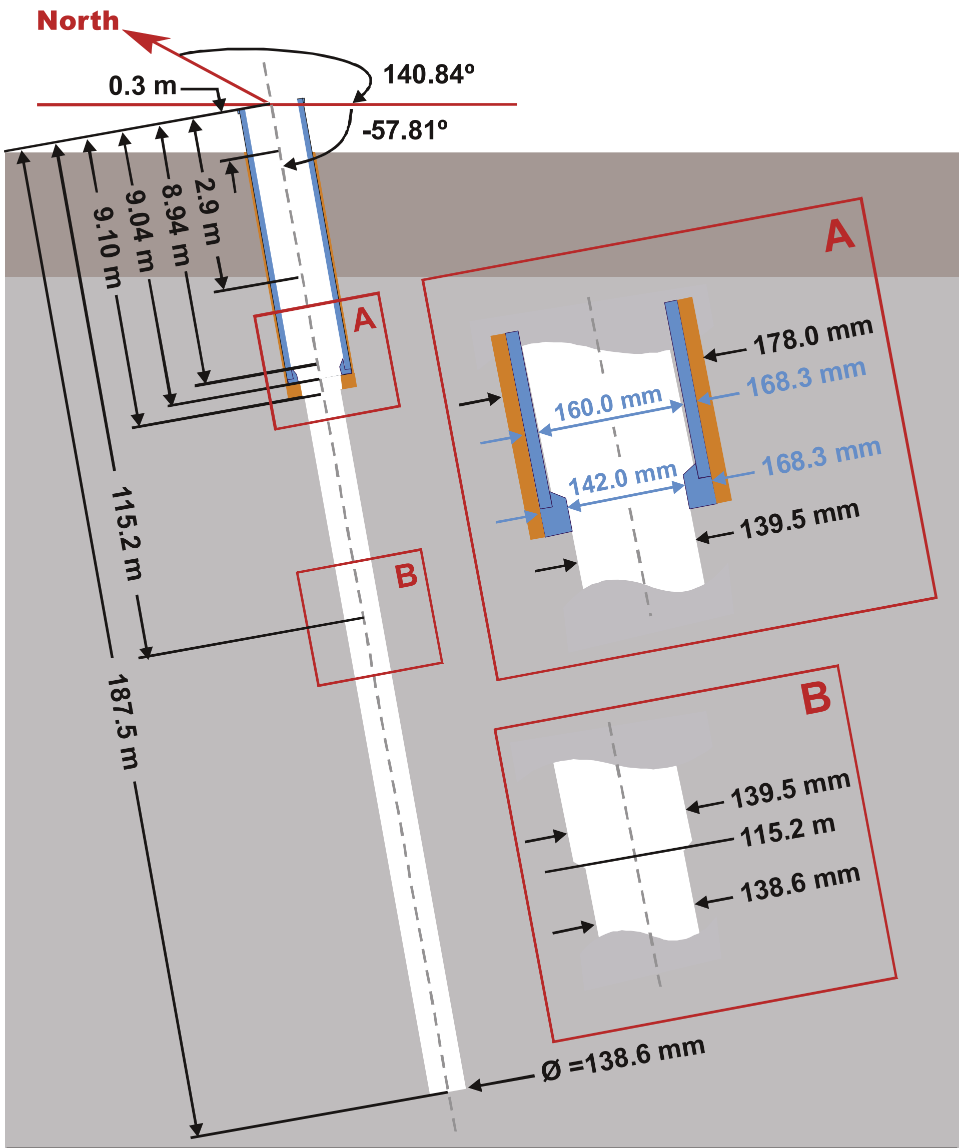
Table 5-1. Administrative, geometric and technical data for boreholes HFM25-HFM27, HFM29-HFM32 and HFM38.

Parameter	HFM25	HFM26	HFM27	HFM29
Drilling period	From 2005-09-05 to 2005-09-08	From 2005-11-14 to 2005-11-18	From 2005-11-03 to 2005-11-10	From 2005-12-12 to 2005-12-19
Borehole inclination (collaring point)	–57.81° (– = downwards)	–53.75° (– = downwards)	–67.83° (– = downwards)	–58.57° (– = downwards)
Borehole bearing	140.84°	112.42°	337.26°	29.95°
Borehole length	187.50 m	202.70 m	127.50 m	199.70 m
Borehole diameter	From 0.00 m to 9.10 m: 0.178 m	From 0.00 m to 12.03 m: 0.180 m	From 0.00 m to 12.03 m: 0.180 m	From 0.00 m to 9.03 m: 0.180 m
	From 9.10 m to 187.50 m: decreasing from 0.140 m to 0.139 m	From 12.03 m to 115.35 m: decreasing from 0.141 m to 0.140 m	From 12.03 m to 110.00 m: decreasing from 0.141 m to 0.140 m	From 9.03 m to 85.70 m: decreasing from 0.141 m to 0.140 m
		From 115.35 m to 202.70 m: decreasing from 0.140 m to 0.138 m	From 110.00 m to 127.50 m: decreasing from 0.140 m to 0.139 m	From 85.70 m to 199.70 m: decreasing from 0.140 m to 0.138 m
Casing length	9.04 m	12.03 m	12.03 m	9.03 m
Casing diameter	$Ø_o/Ø_i$ = 168 mm/160 mm to 8.94 m	$Ø_o/Ø_i$ = 168 mm/160 mm to 11.94 m	$Ø_o/Ø_i$ = 168 mm/160 mm to 11.94 m	$Ø_o/Ø_i$ = 168 mm/160 mm to 8.94 m
	$Ø_o/Ø_i$ = 168 mm/142 mm between 8.94 and 9.04 m	$Ø_o/Ø_i$ = 168 mm/143 mm between 11.94 and 12.03 m	$Ø_o/Ø_i$ = 168 mm/143 mm between 11.94 and 12.03 m	$Ø_o/Ø_i$ = 168 mm/143 mm between 8.94 and 9.03 m
Drill bit diameter	Start of drilling: 0.140 m End of drilling: 0.139 m	Start of drilling: 0.141 m End of drilling: 0.138 m	Start of drilling: 0.141 m End of drilling: 0.139 m	Start of drilling: 0.141 m End of drilling: 0.138 m
Collaring point coordinates (system RT90 2.5 gon V/ RHB70)	Northing: 6699616.18 m Easting: 1633039.37 m Elevation: 3.86 m.a.s.l.	Northing: 6698008.93 m Easting: 1633516.39 m Elevation: 2.73 m.a.s.l.	Northing: 6699595.26 m Easting: 1631245.94 m Elevation: 2.45 m.a.s.l.	Northing: 6698018.65 m Easting: 1632502.81 m Elevation: 4.47 m.a.s.l.

Parameter	HFM30	HFM31	HFM32	HFM38
Drilling period	From 2006-05-03 to 2006-05-11	From 2006-05-15 to 2006-05-19	From 2006-01-11 to 2006-01-14	From 2006-06-14 to 2006-06-22
Borehole inclination (collaring point)	–55.50° (– = downwards)	–69.23° (– = downwards)	–86.06° (– = downwards)	–54.45° (– = downwards)
Borehole bearing	28.81°	311.80°	116.15°	93.62°
Borehole length	200.75 m	200.75 m	202.65 m	200.75 m
Borehole diameter	From 0.00 m to 18.03 m: 0.180 m	From 0.00 m to 9.03 m: 0.180 m	From 0.00 m to 6.03 m: 0.175 m	From 0.00 m to 9.05 m: 0.180 m
	From 18.03 m to 122.25 m: 0.140 m	From 9.03 m to 122.25 m: decreasing from 0.141 m to 0.140 m	From 6.03 m to 106.60 m: decreasing from 0.141 m to 0.139 m	From 9.05 m to 122.25 m: decreasing from 0.141 m to 0.139 m
	From 122.25 m to 200.75 m: decreasing from 0.140 m to 0.139 m	From 122.25 to 200.75 m: decreasing from 0.140 m to 0.139 m	From 106.60 m to 169.65 m: decreasing from 0.139 m to 0.136 m	From 122.25 m to 200.75 m: decreasing from 0.139 m to 0.136 m
			From 169.65 m to 202.65 m: decreasing from 0.136 m to 0.132 m	
Casing length	18.03 m	9.03 m	6.03 m	9.05 m
Casing diameter	$Ø_o/Ø_i$ = 168 mm/160 mm to 17.94 m	$Ø_o/Ø_i$ = 168 mm/160 mm to 8.94 m	$Ø_o/Ø_i$ = 168 mm/160 mm to 5.94 m	$Ø_o/Ø_i$ = 168 mm/160 mm to 8.96 m
	$Ø_o/Ø_i$ = 168 mm/143 mm between 17.94 and 18.03 m	$Ø_o/Ø_i$ = 168 mm/143 mm between 8.94 and 9.03 m	$Ø_o/Ø_i$ = 168 mm/143 mm between 5.94 and 6.03 m	$Ø_o/Ø_i$ = 168 mm/143 mm between 8.96 and 9.05 m
Drill bit diameter	Start of drilling: 0.140 m End of drilling: 0.139 m	Start of drilling: 0.141 m End of drilling: 0.139 m	Start of drilling: 0.141 m End of drilling: 0.132 m	Start of drilling: 0.141 m End of drilling: 0.136 m
Collaring point coordinates (system RT90 2.5 gon V/ RHB70)	Northing: 6697930.95 m Easting: 1631819.57 m Elevation: 3.13 m.a.s.l.	Northing: 6700860.44 m Easting: 1629207.28 m Elevation: 6.07 m.a.s.l.	Northing: 6699015.04 m Easting: 1632137.07 m Elevation: 0.97 m.a.s.l.	Northing: 6700701.28 m Easting: 1631301.71 m Elevation: 2.21 m.a.s.l.

Technical data

Borehole HFM25



Drilling reference point

Northing:	6699616.177	(m), RT90 2,5 gon V 0:-15
Easting:	1633039.368	(m), RT90 2,5 gon V 0:-15
Elevation:	3.858	(m), RHB 70

Drilling period

Drilling start date: 2005-09-05
Drilling stop date: 2005-09-08

rev 2005-10-28

Figure 5-1. *Technical data for borehole HFM25.*

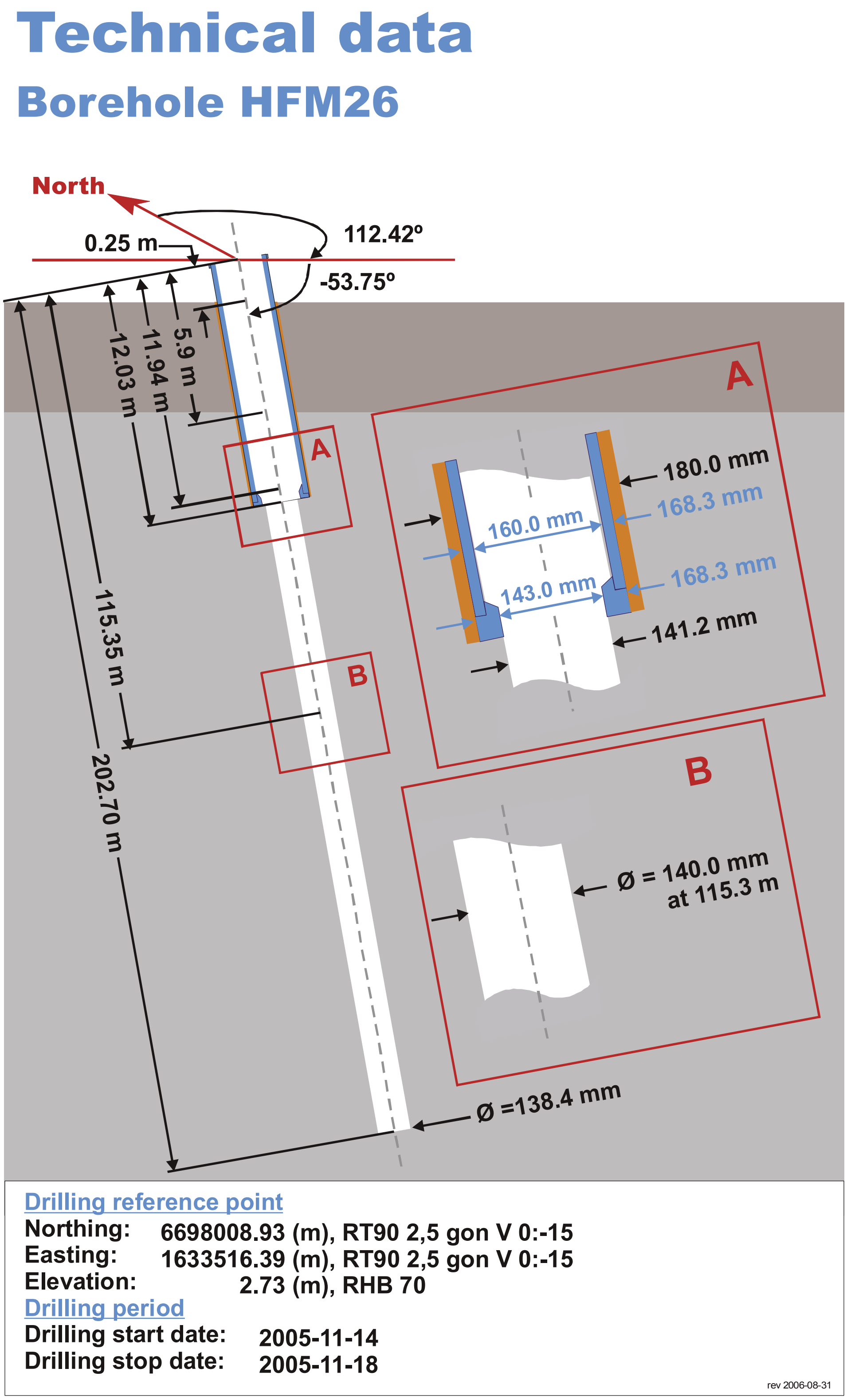


Figure 5-2. *Technical data for borehole HFM26.*

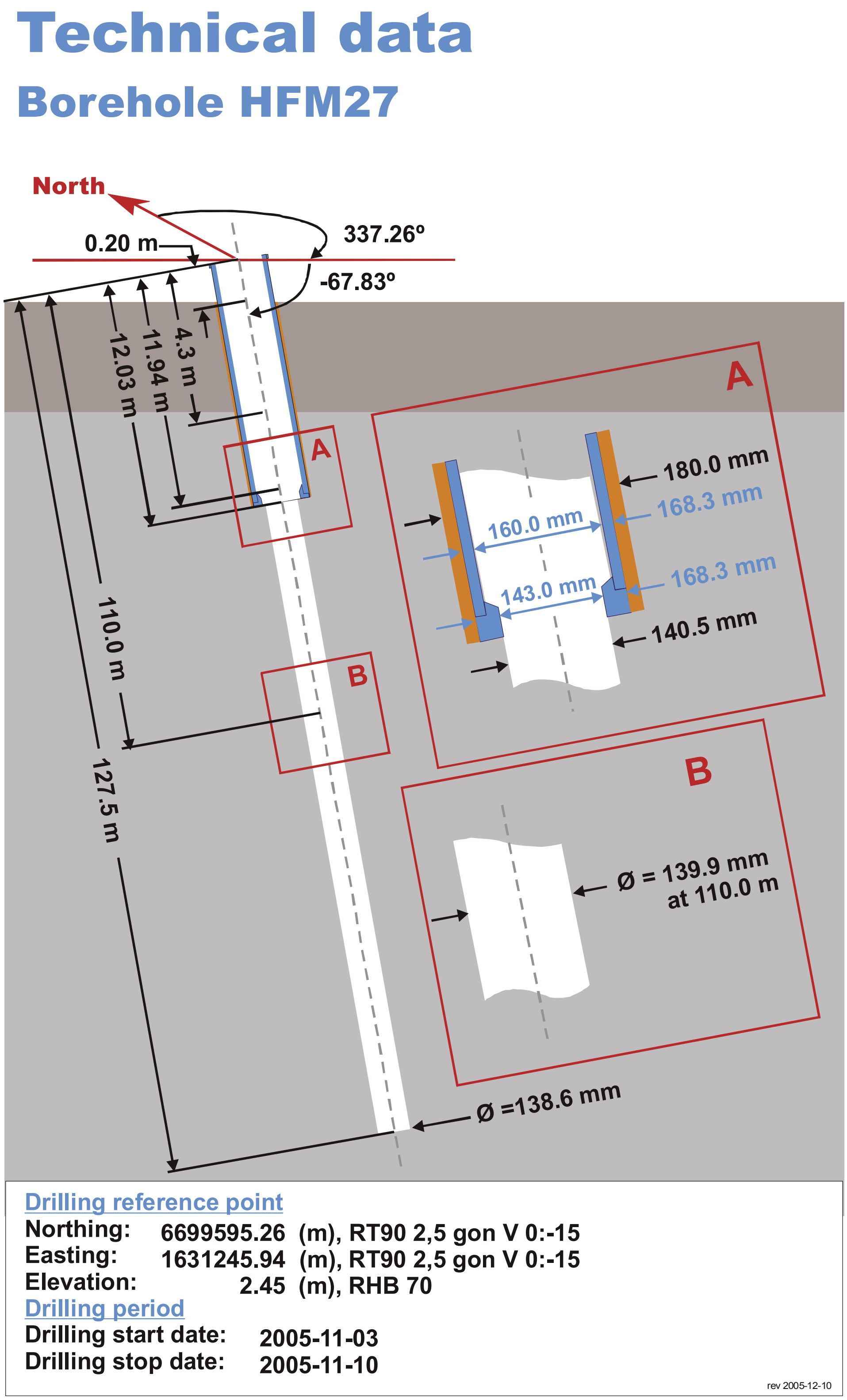
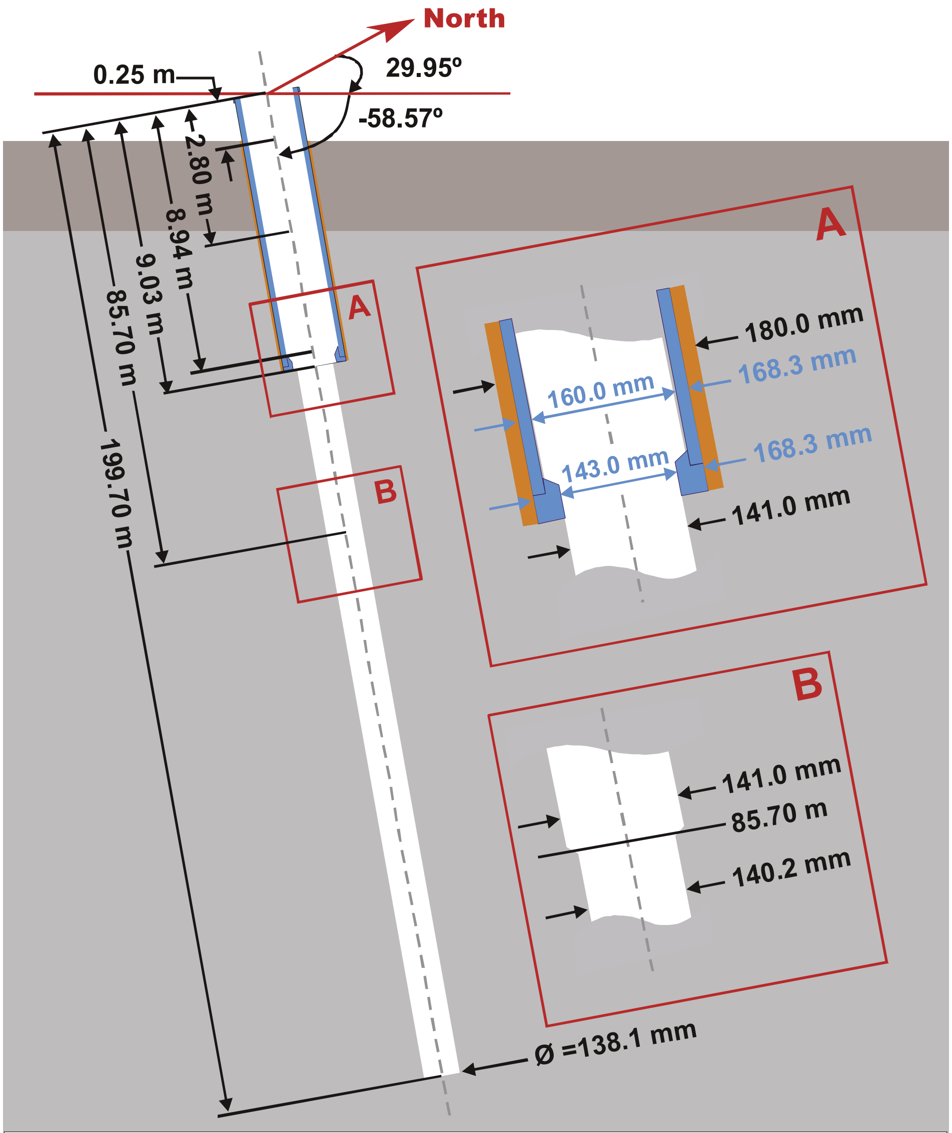


Figure 5-3. *Technical data for borehole HFM27.*

Technical data

Borehole HFM29



Drilling reference point

Northing:	6698018.65	(m), RT90 2,5 gon V 0:-15
Easting:	1632502.81	(m), RT90 2,5 gon V 0:-15
Elevation:	4.47	(m), RHB 70

Drilling period

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

rev 2006-02-20

Figure 5-4. *Technical data for borehole HFM29.*

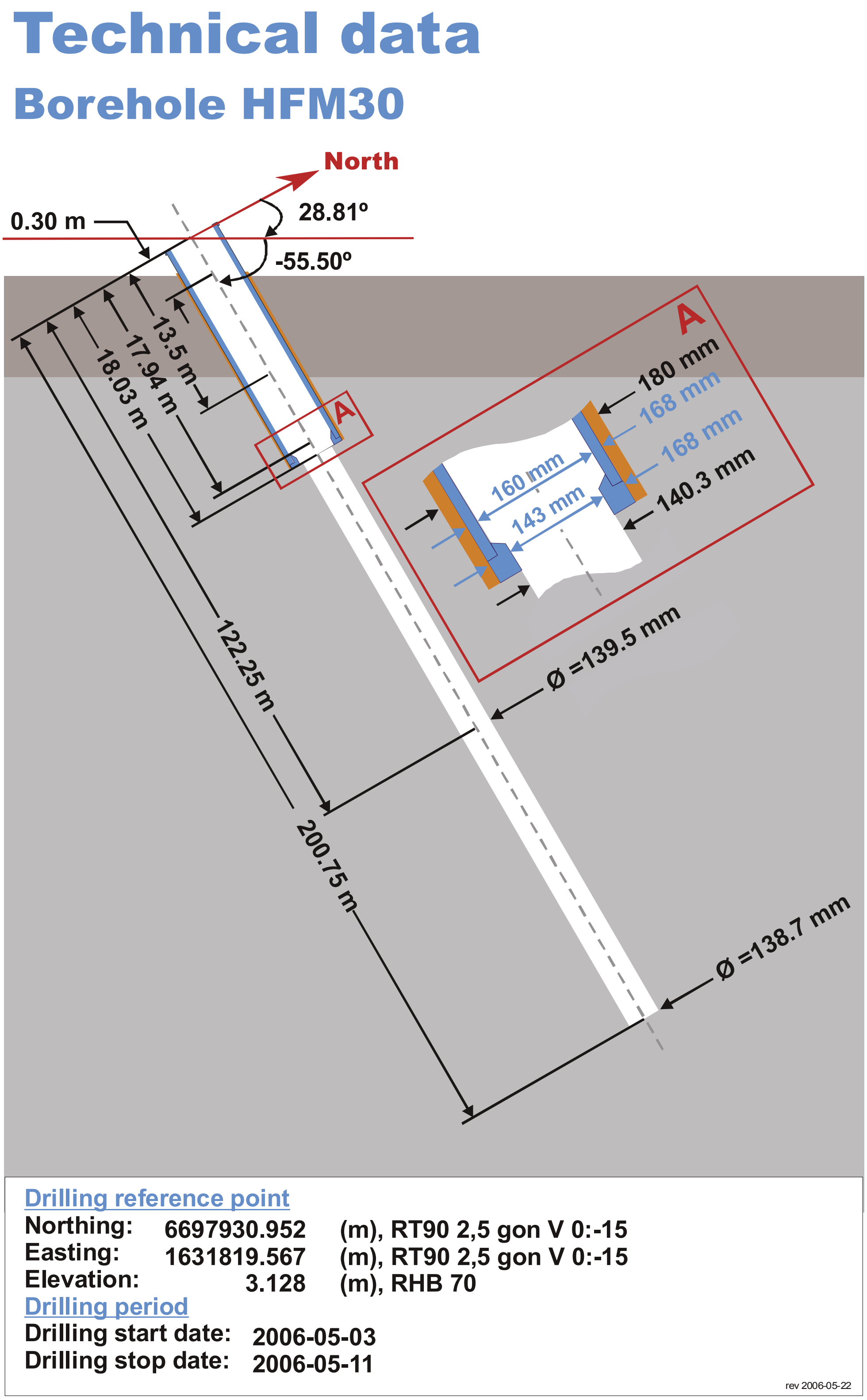


Figure 5-5. *Technical data for borehole HFM30.*

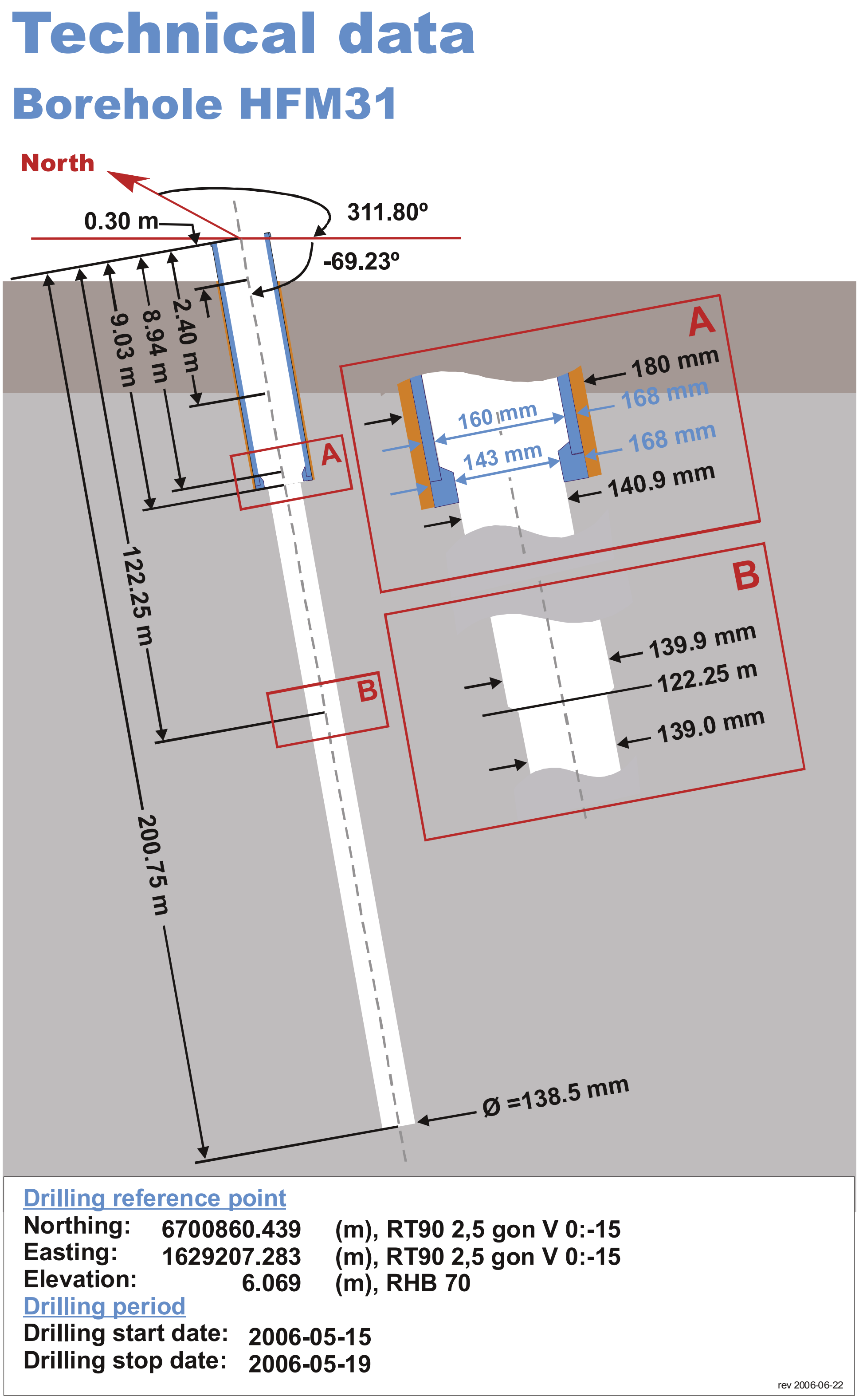
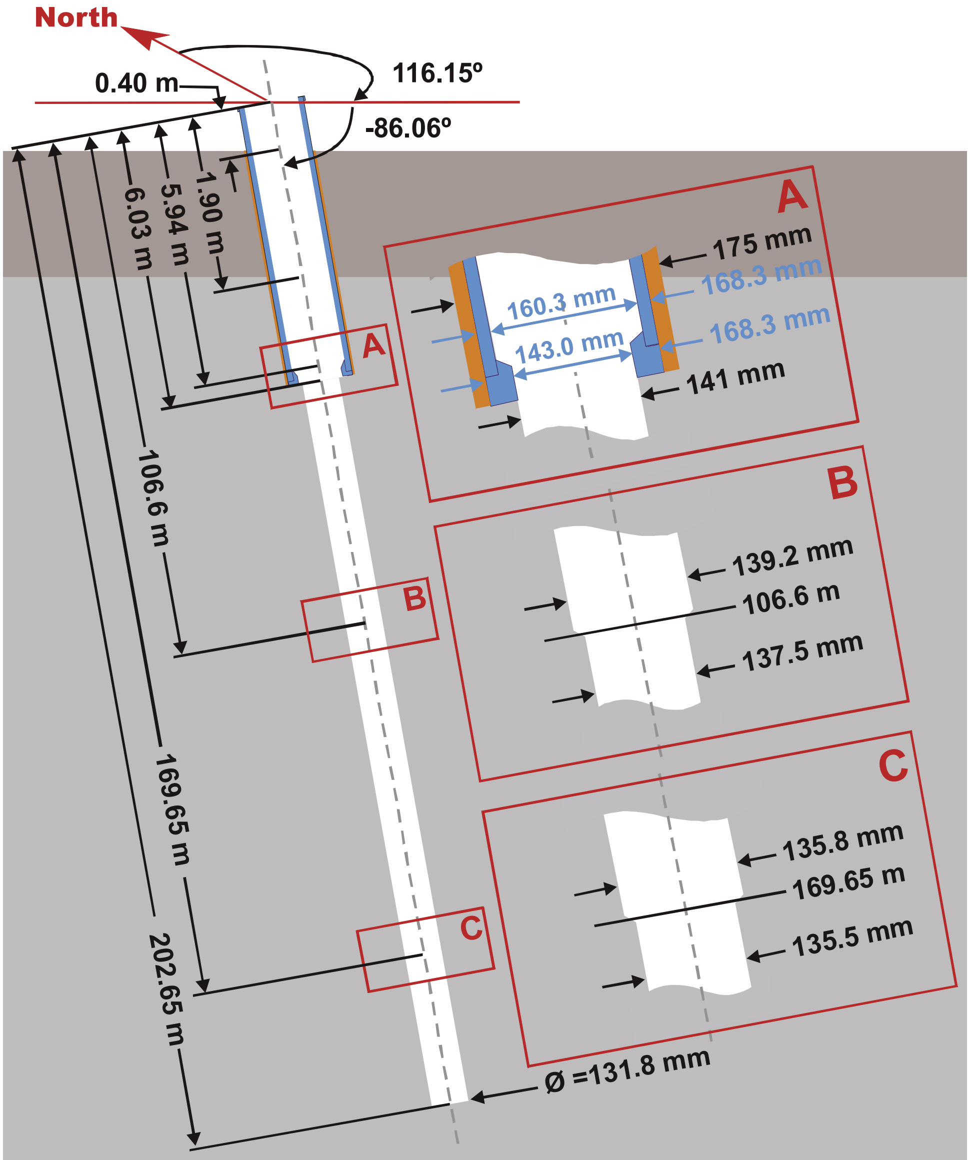


Figure 5-6. *Technical data for borehole HFM31.*

Technical data

Borehole HFM32



Drilling reference point

Northing:	6699015.036	(m), RT90 2,5 gon V 0:-15
Easting:	1632137.068	(m), RT90 2,5 gon V 0:-15
Elevation:	0.974	(m), RHB 70

Drilling period

Drilling start date: 2006-01-11
Drilling stop date: 2006-01-14

rev 2006-01-21

Figure 5-7. *Technical data for borehole HFM32.*

Technical data

Borehole HFM38

Drilling reference point

Northing:	6700701.28	(m), RT90 2,5 gon V 0:-15
Easting:	1631301.71	(m), RT90 2,5 gon V 0:-15
Elevation:	2.21	(m), RHB 70

Drilling period

Drilling start date:	2006-06-14
Drilling stop date:	2006-06-22

rev 2006-06-24

Figure 5-8. Technical data for borehole HFM38.

5.2 Consumables used in HFM25, HFM26, HFM27, HFM29, HFM30, HFM31, HFM32 and HFM38

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 5-2 and 5-3. The cement was of low alkalic type, consisting of white cement (Aalborg Portland CEM I, 52.5N) and, in HFM30, HFM31, HFM32 and HFM38, microsilica (920-D).

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 products are left in the borehole.

Table 5-2. Oil consumption.

Borehole ID	Hammer oil Preem Hydra 46	Compressor oil Schuman 46
HFM25	30 L	Not detected
HFM26	25 L	Not detected
HFM27	18 L	Not detected
HFM29	24 L	Not detected
HFM30	8 L	Not detected
HFM31	6 L	Not detected
HFM32	10 L	Not detected
HFM38	12 L	Not detected

Table 5-3. Consumption of cement grouting.

Borehole ID	Casing length	Cement volume (Aalborg Portland Cement/microsilica)	Grouting method
HFM25	9.04 m	71/0 kg	Borehole packer
HFM26	12.03 m	328.5/0 kg	Borehole packer
HFM27	12.03 m	292/0 kg	Borehole packer
HFM29	9.03 m	36.5/0 kg	Borehole packer
HFM30	18.03 m	50/22 kg	Borehole packer
HFM31	9.03 m	50/22 kg	Borehole packer
HFM32	6.03 m	25/6 kg	Borehole packer
HFM38	9.05 m	50/22 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 Figures 5-9 to 5-16.

Table 5-4 shows inclination and bearing at the collaring and at bottom of all boreholes determined from the deviation measurements. Furthermore, the "absolute deviation" at the borehole bottom is calculated. The "absolute deviation" is defined as the shortest distance between the real borehole bottom and an imaginary borehole bottom calculated following a straight line with the same inclination and bearing as that of the borehole collaring to full drilling length.

Table 5-4. Inclination and bearing of collaring and borehole bottom of the respective boreholes, indicating the borehole deviation. Also the absolute deviation is shown (se definition in text above).

Borehole	Borehole length	Collaring inclination and bearing	Borehole bottom inclination and bearing	Absolute deviation
HFM25	187.50 m	–57.81°/140.84°	38.27°/137.49°	33.00 m
HFM26	202.70 m	–53.75°/112.42°	42.12°/123.06°	29.51 m
HFM27	127.50 m	–67.83°/337.26°	67.13°/327.80°	3.87 m
HFM29	199.70 m	–58.57°/29.95°	71.58°/70.81°	36.98 m
HFM30	200.75 m	–55.50°/28.81°	62.84°/32.11°	17.65 m
HFM31	200.75 m	–69.23°/311.80°	61.97°/299.85°	15.02 m
HFM32	202.65 m	–86.06°/116.15	74.45°/170.14°	24.53 m
HFM38	200.75 m	–54.45°/93.62°	36.41°/109.06°	36.50 m

Title **PERCUSSION DRILLED BOREHOLE HFM25**

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Signed data**	
Borehole	HFM25	**Coordinate System**	RT90-RHB70
Diameter [mm]	139	**Northing [m]**	6699616.18
Length [m]	187.50	**Easting [m]**	1633039.37
Bearing [°]	140.84	**Elevation [m.a.s.l.]**	3.86
Inclination [°]	-57.81	**Drilling Start Date**	2005-09-05 14:00:00
Date of mapping		**Drilling Stop Date**	2005-09-08 12:15:00
		Plot Date	2006-09-26 21:12:20

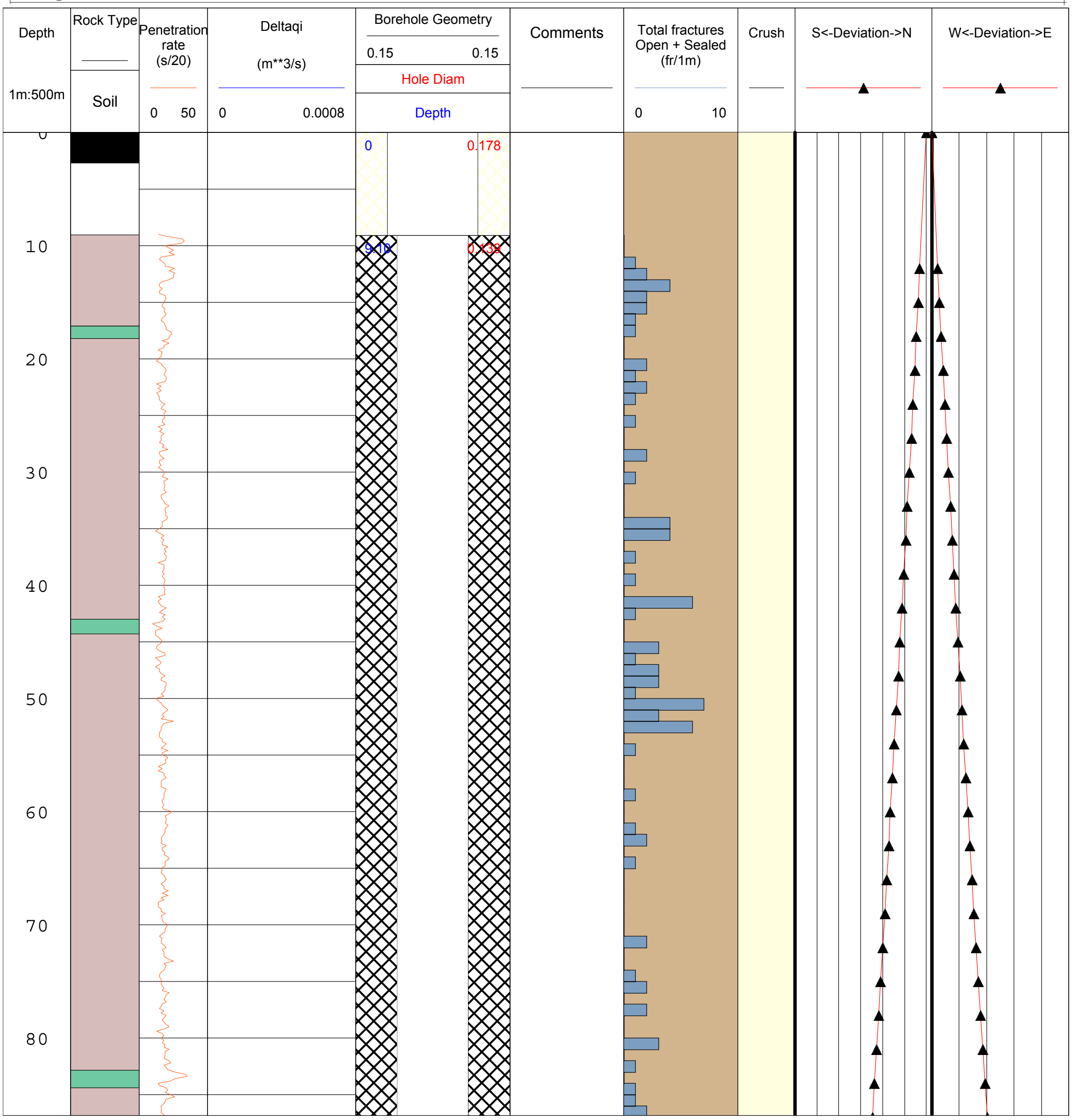
ROCKTYPE FORSMARK

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

SOIL

- **Soil**

Script Name



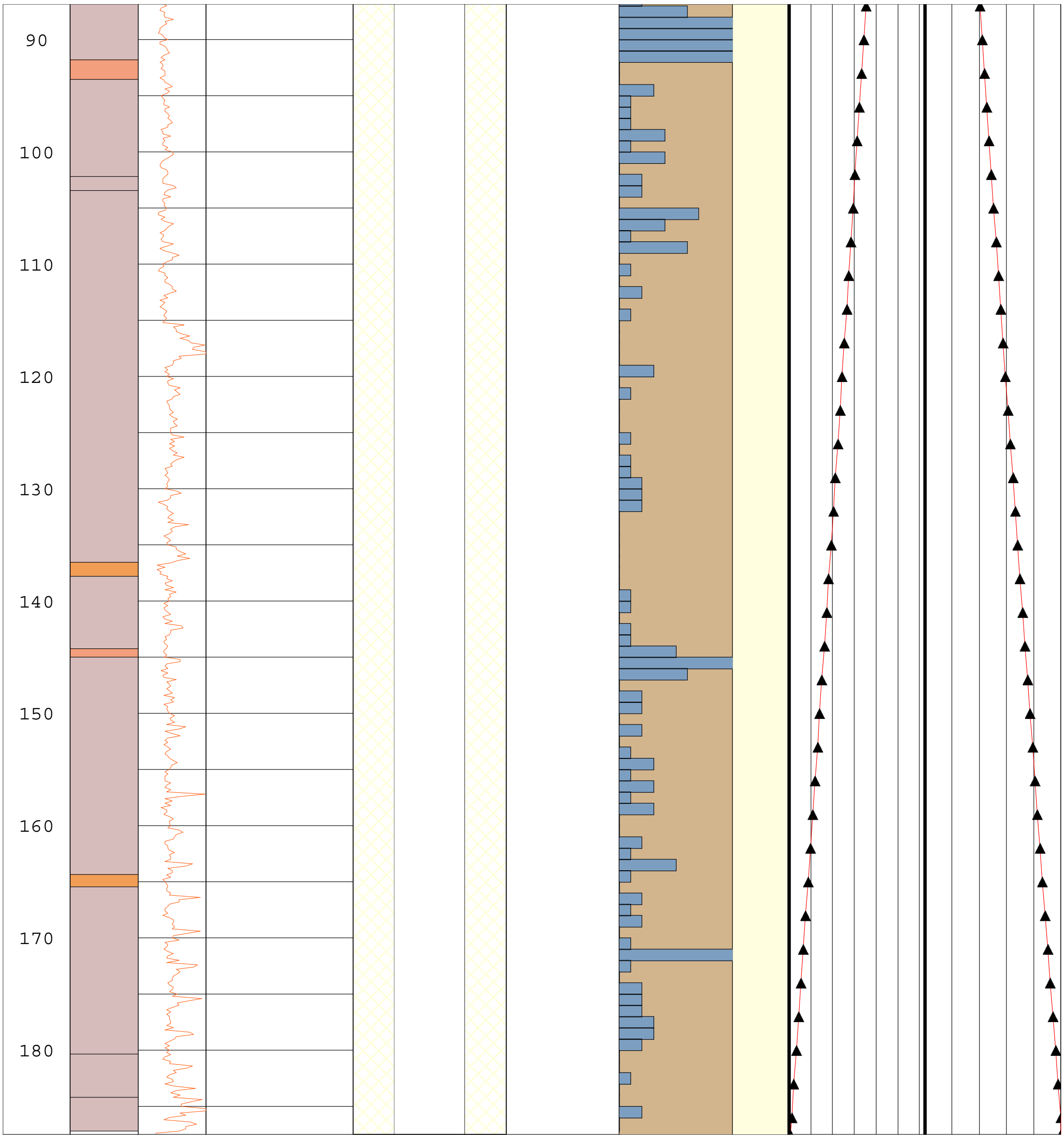


Figure 5-9. *Technical and geoscientific data acquired during drilling of borehole HFM25.*

Title PERCUSSION DRILLED BOREHOLE HFM26

Svensk Kärnbränslehantering AB		**Signed data**	
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM26	**Northing [m]**	6698008.93
Diameter [mm]	138	**Easting [m]**	1633516.39
Length [m]	202.70	**Elevation [m.a.s.l.]**	2.73
Bearing [°]	112.42	**Drilling Start Date**	2005-11-14 07:00:00
Inclination [°]	-53.75	**Drilling Stop Date**	2005-11-18 07:00:00
Date of mapping		**Plot Date**	2006-10-01 21:11:35

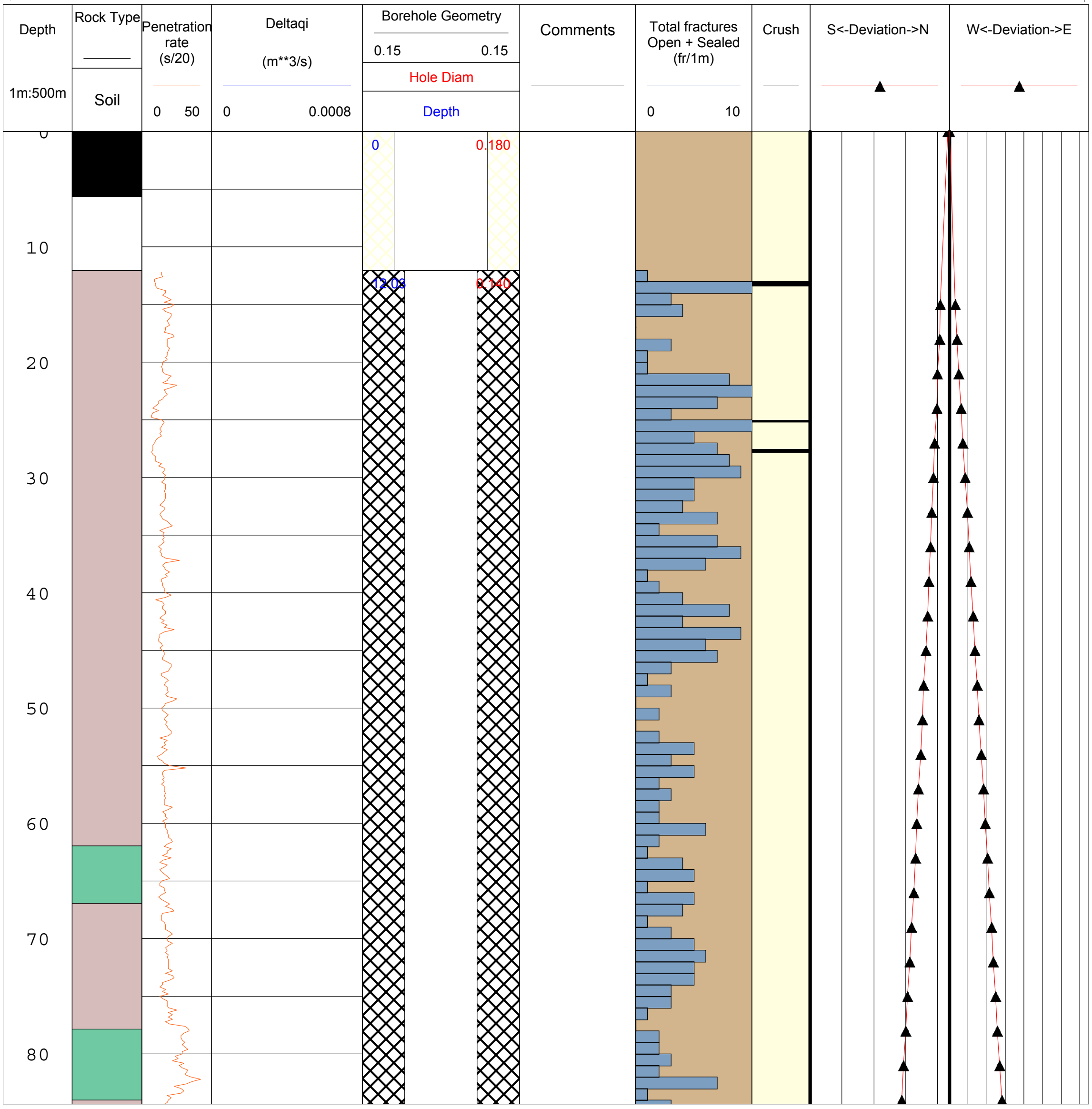
ROCKTYPE FORSMARK

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

SOIL

- **Soil**

Script Name



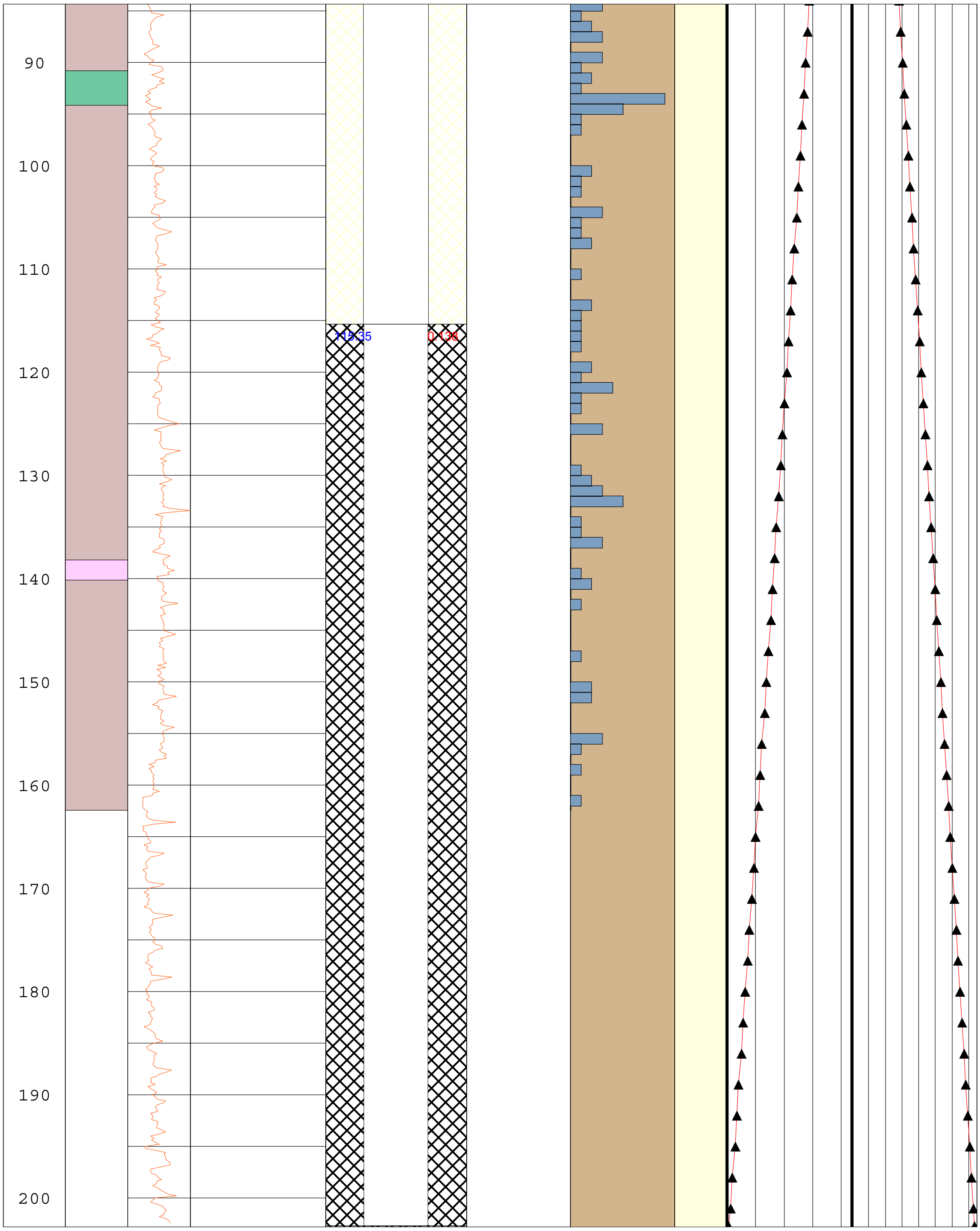


Figure 5-10. *Technical and geoscientific data acquired during drilling of borehole HFM26.*

Title **PERCUSSION DRILLED BOREHOLE HFM27**

Svensk Kärnbränslehantering AB

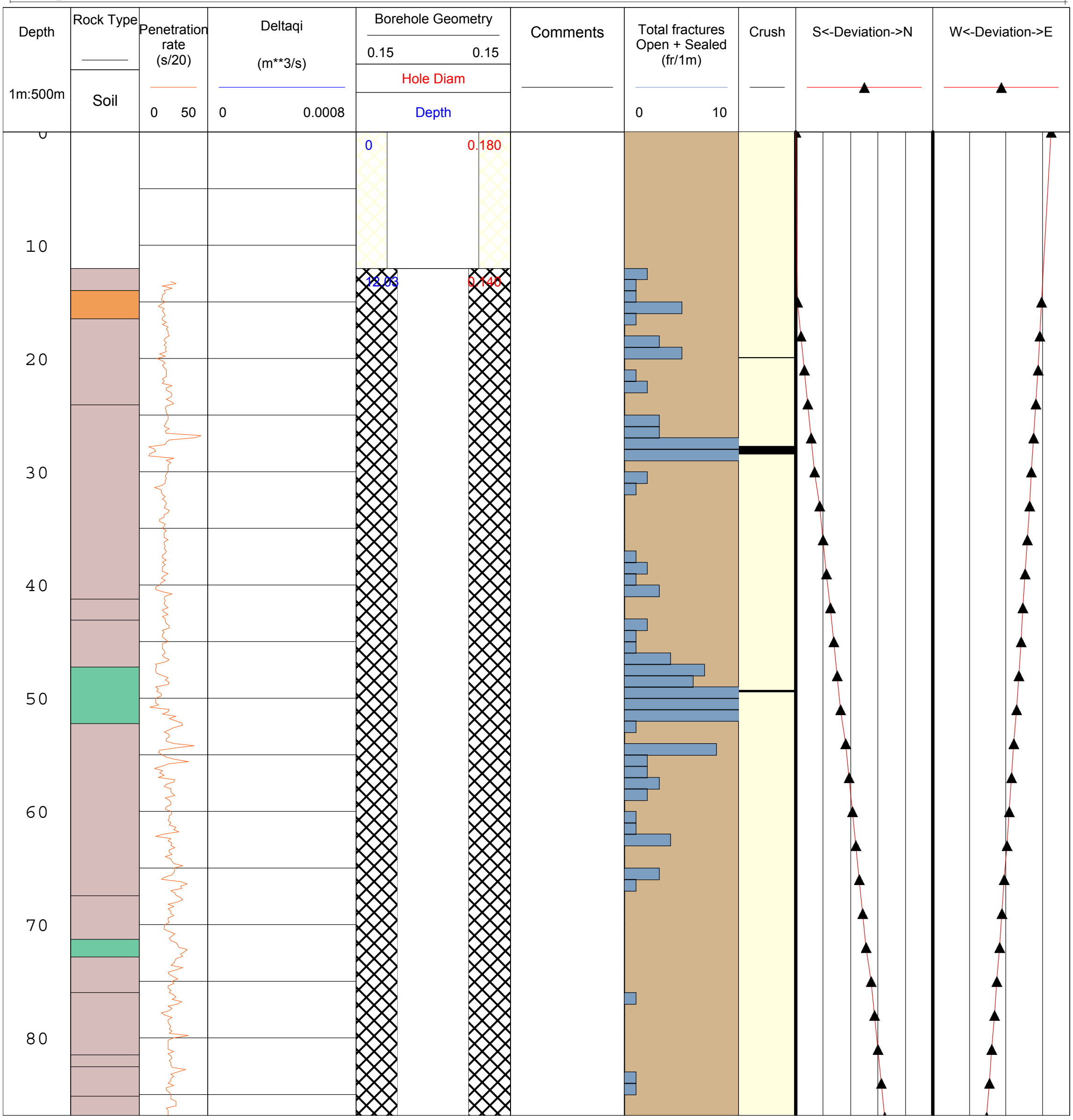
Site	FORSMARK	**Signed data**	
Borehole	HFM27	**Coordinate System**	RT90-RHB70
Diameter [mm]	139	**Northing [m]**	6699595.26
Length [m]	127.50	**Easting [m]**	1631245.94
Bearing [°]	337.26	**Elevation [m.a.s.l.]**	2.45
Inclination [°]	-67.83	**Drilling Start Date**	2005-11-03 16:00:00
Date of mapping		**Drilling Stop Date**	2005-11-10 19:00:00
		Plot Date	2006-09-26 21:12:20

ROCKTYPE FORSMARK

SOIL

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

Script Name



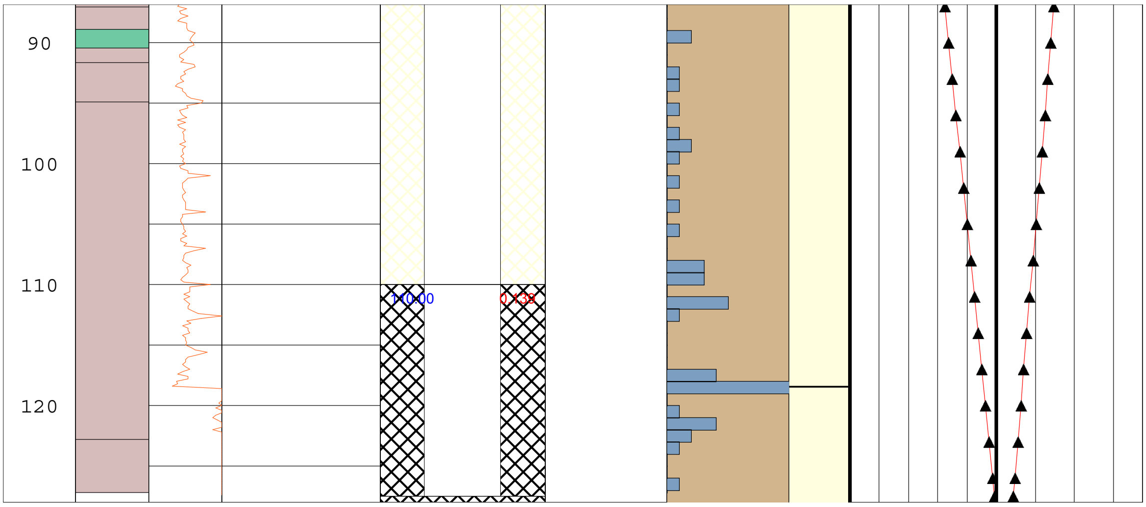


Figure 5-11. Technical and geoscientific data acquired during drilling of borehole HFM27.

Title **PERCUSSION DRILLED BOREHOLE HFM29**

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Signed data**	
Borehole	HFM29	**Coordinate System**	RT90-RHB70
Diameter [mm]	138	**Northing [m]**	6698018.65
Length [m]	199.70	**Easting [m]**	1632502.81
Bearing [°]	29.95	**Elevation [m.a.s.l.]**	4.47
Inclination [°]	-58.57	**Drilling Start Date**	2005-12-12 07:00:00
Date of mapping		**Drilling Stop Date**	2005-12-19 12:30:00
		Plot Date	2006-09-26 21:12:20

ROCKTYPE FORSMARK

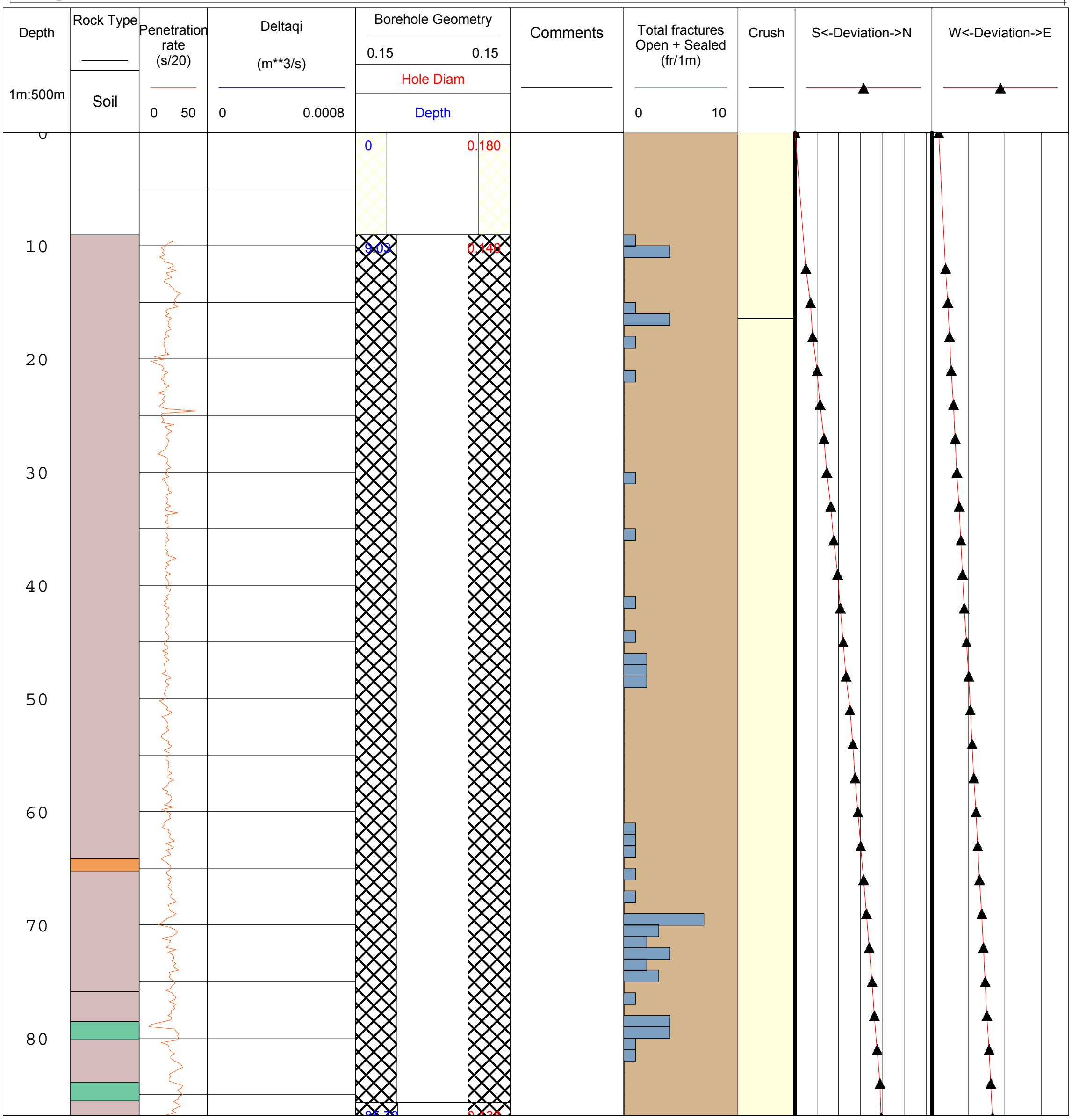
Pegmatite, pegmatitic granite

Granite to granodiorite, metamorphic, medium-grained

Amphibolite

SOIL

Script Name



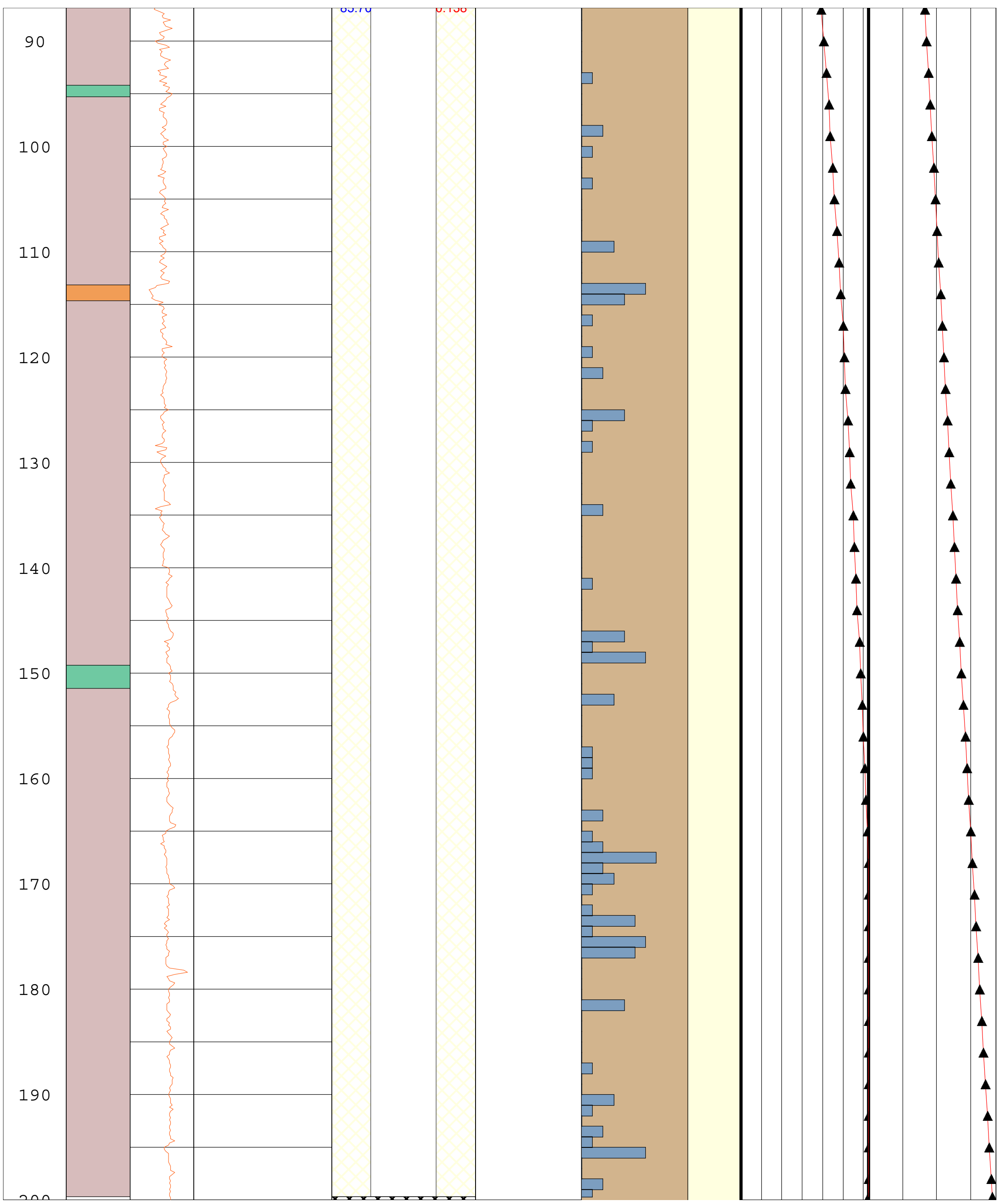


Figure 5-12. Technical and geoscientific data acquired during drilling of borehole HFM29.

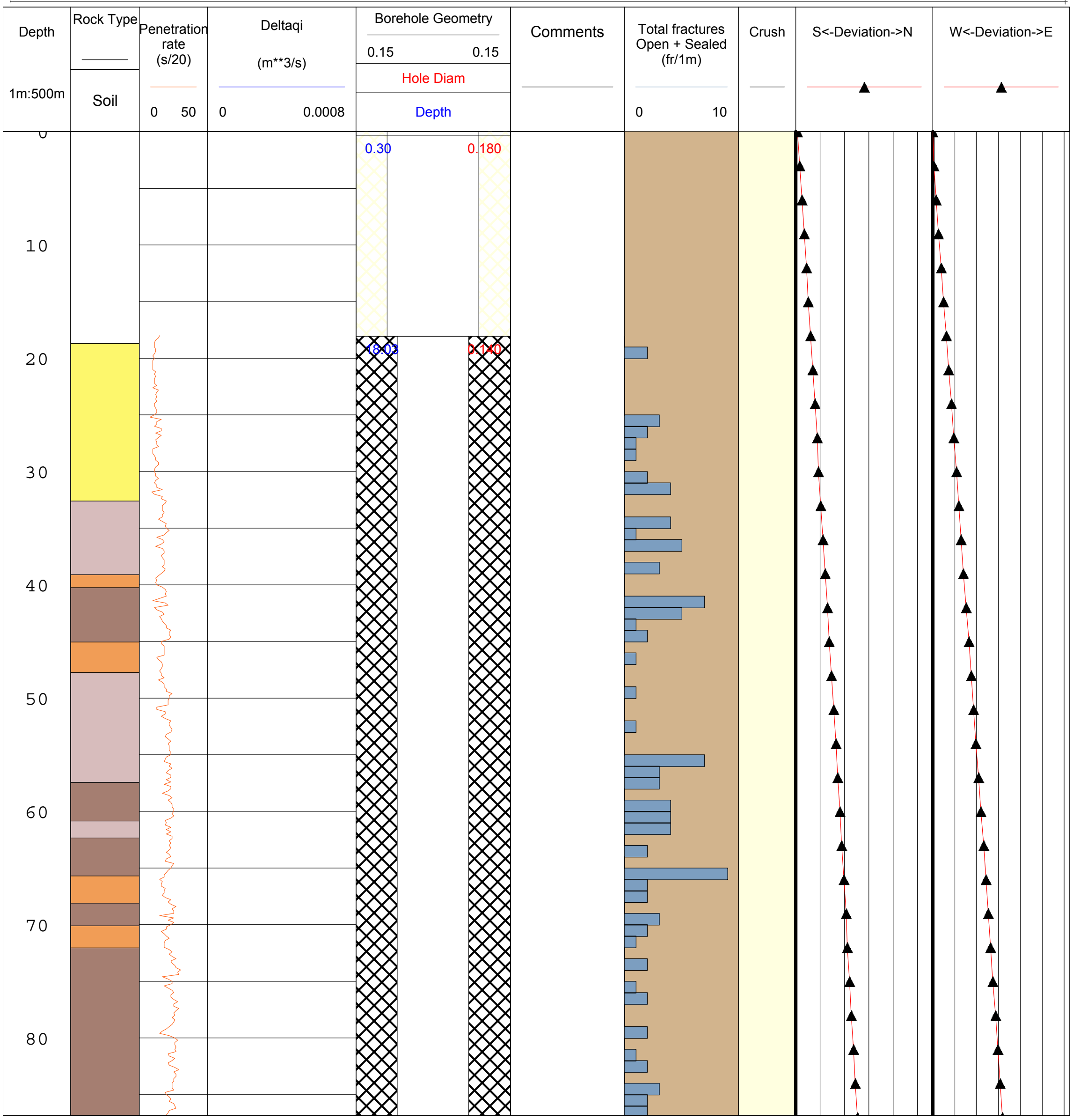
Title	PERCUSSION DRILLED BOREHOLE HFM30		
Svensk Kärnbränslehantering AB		**Signed data**	
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM30	**Northing [m]**	6697930.95
Diameter [mm]	139	**Easting [m]**	1631819.57
Length [m]	200.75	**Elevation [m.a.s.l.]**	3.13
Bearing [°]	28.81	**Drilling Start Date**	2006-05-03 16:00:00
Inclination [°]	-55.50	**Drilling Stop Date**	2006-05-11 12:00:00
Date of mapping		**Plot Date**	2006-09-26 21:12:20

ROCKTYPE FORSMARK

- **Granite, fine- to medium-grained**
- **Pegmatite, pegmatitic granite**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Tonalite to granodiorite, metamorphic**
- **Diorite, quarts diorite and gabbro, metamorphic**
- **Amphibolite**
- **Felsic to intermediate volcanic rock, metamorphic**

SOIL

Script Name



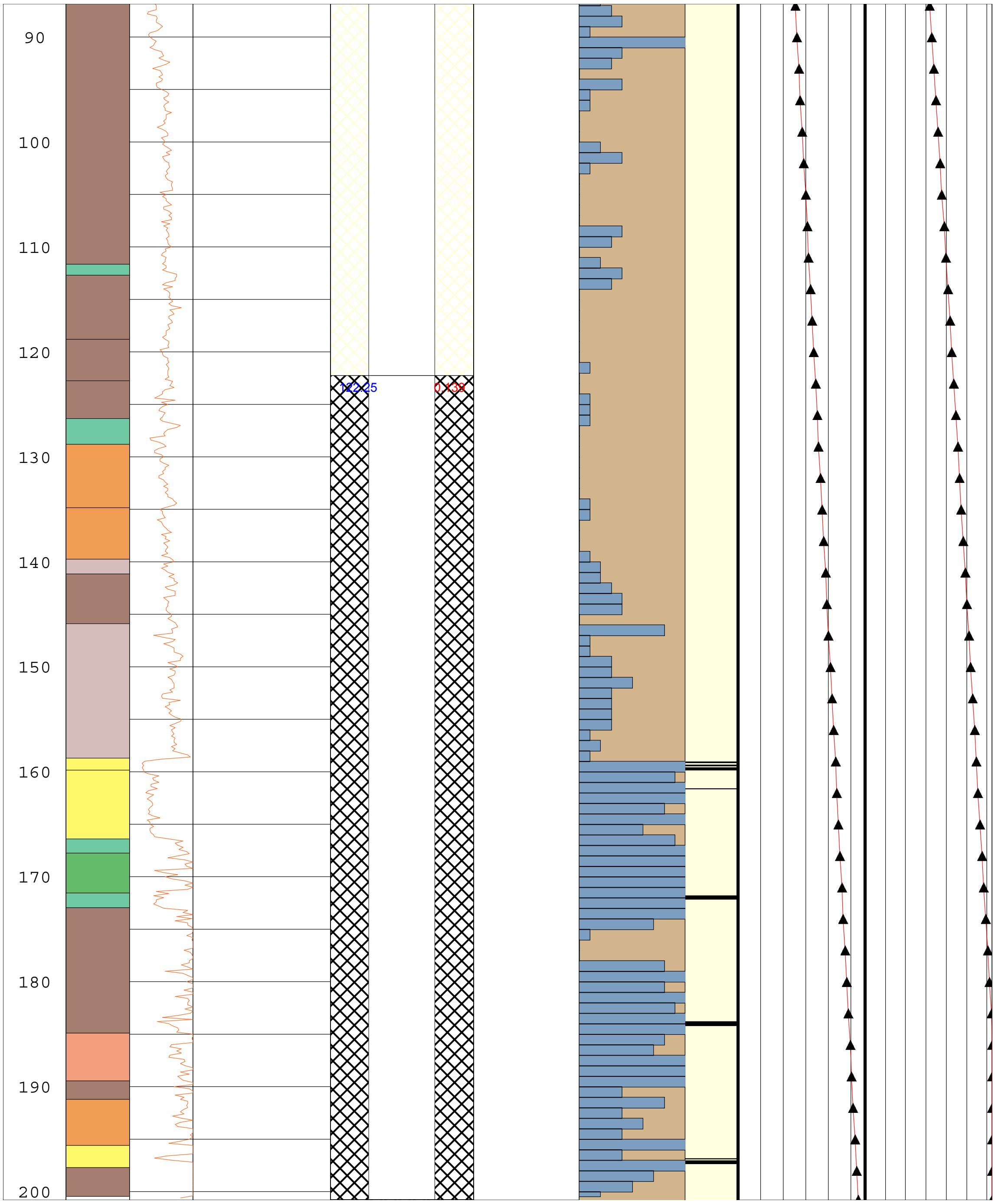


Figure 5-13. *Technical and geoscientific data acquired during drilling of borehole HFM30.*

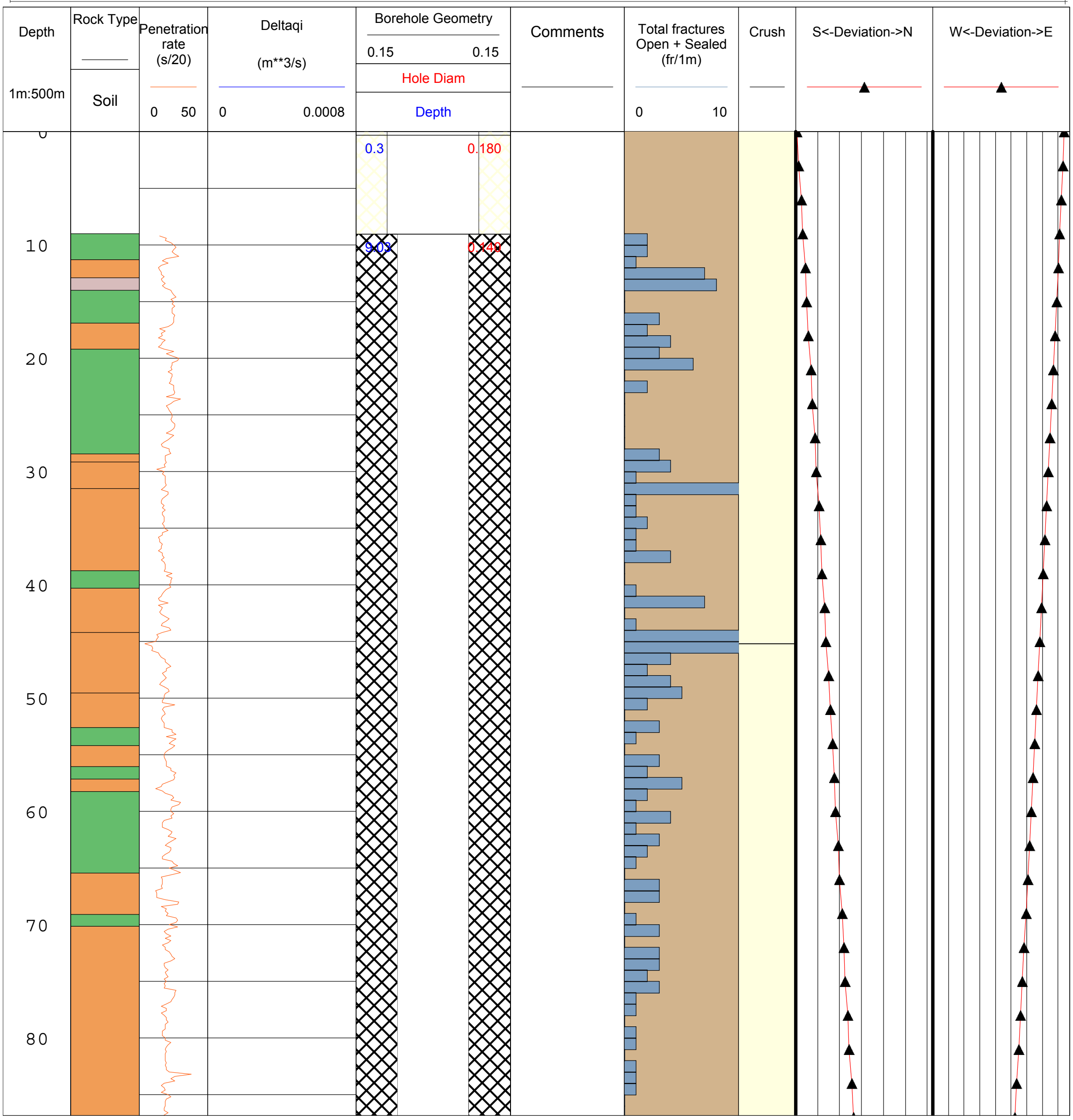
Title	PERCUSSION DRILLED BOREHOLE HFM31		
Svensk Kärnbränslehantering AB		Signed data	
Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	HFM31	Northing [m]	6700860.44
Diameter [mm]	139	Easting [m]	1629207.28
Length [m]	200.75	Elevation [m.a.s.l.]	6.07
Bearing [°]	311.80	Drilling Start Date	2006-05-15 08:30:00
Inclination [°]	-69.23	Drilling Stop Date	2006-05-19 10:00:00
Date of mapping		Plot Date	2006-09-26 21:12:20

ROCKTYPE FORSMARK

SOIL

- **Pegmatite, pegmatitic granite**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Diorite, quarts diorite and gabbro, metamorphic**
- **Amphibolite**

Script Name



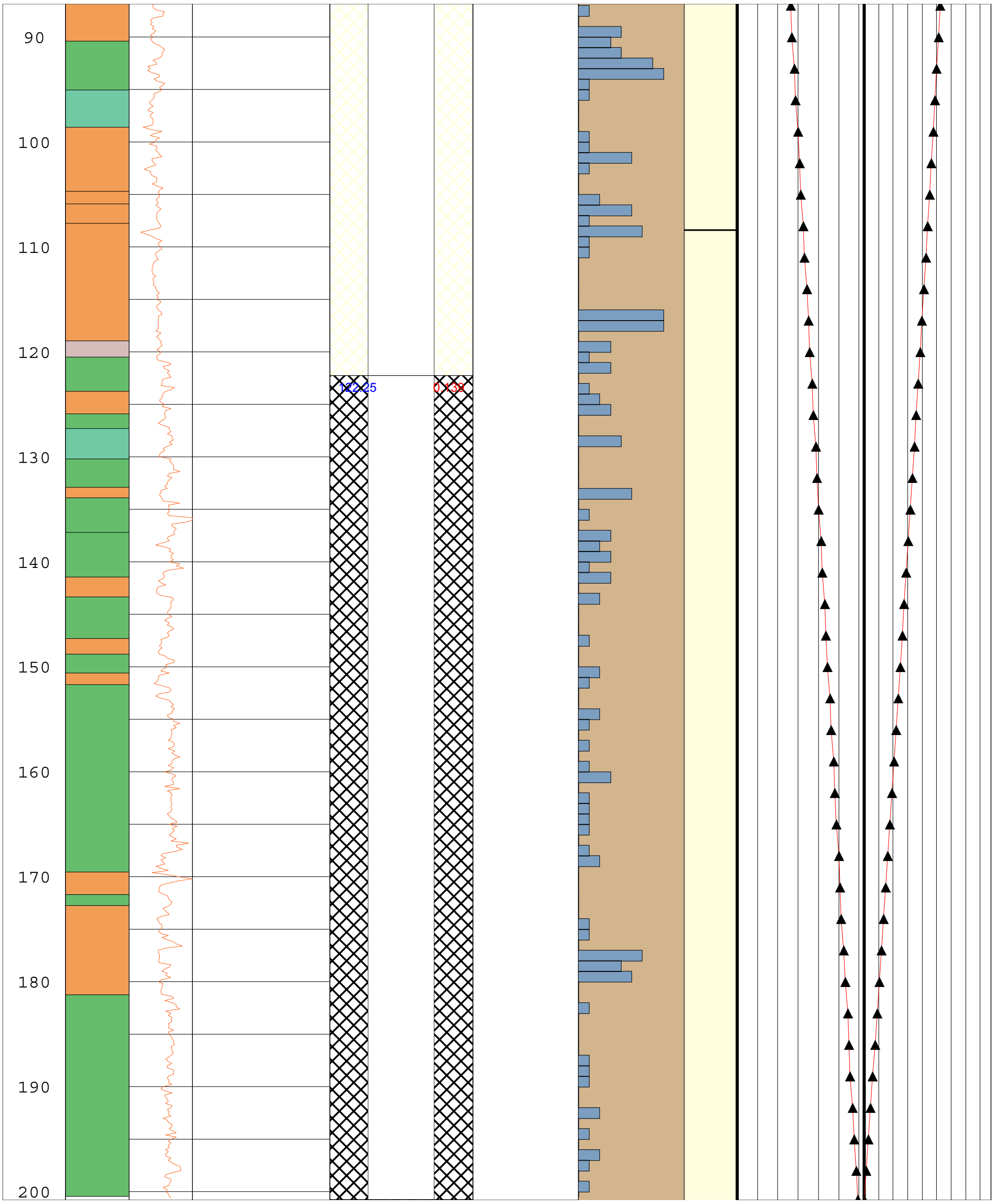


Figure 5-14. *Technical and geoscientific data acquired during drilling of borehole HFM31.*

Title **PERCUSSION DRILLED BOREHOLE HFM32**

Svensk Kärnbränslehantering AB

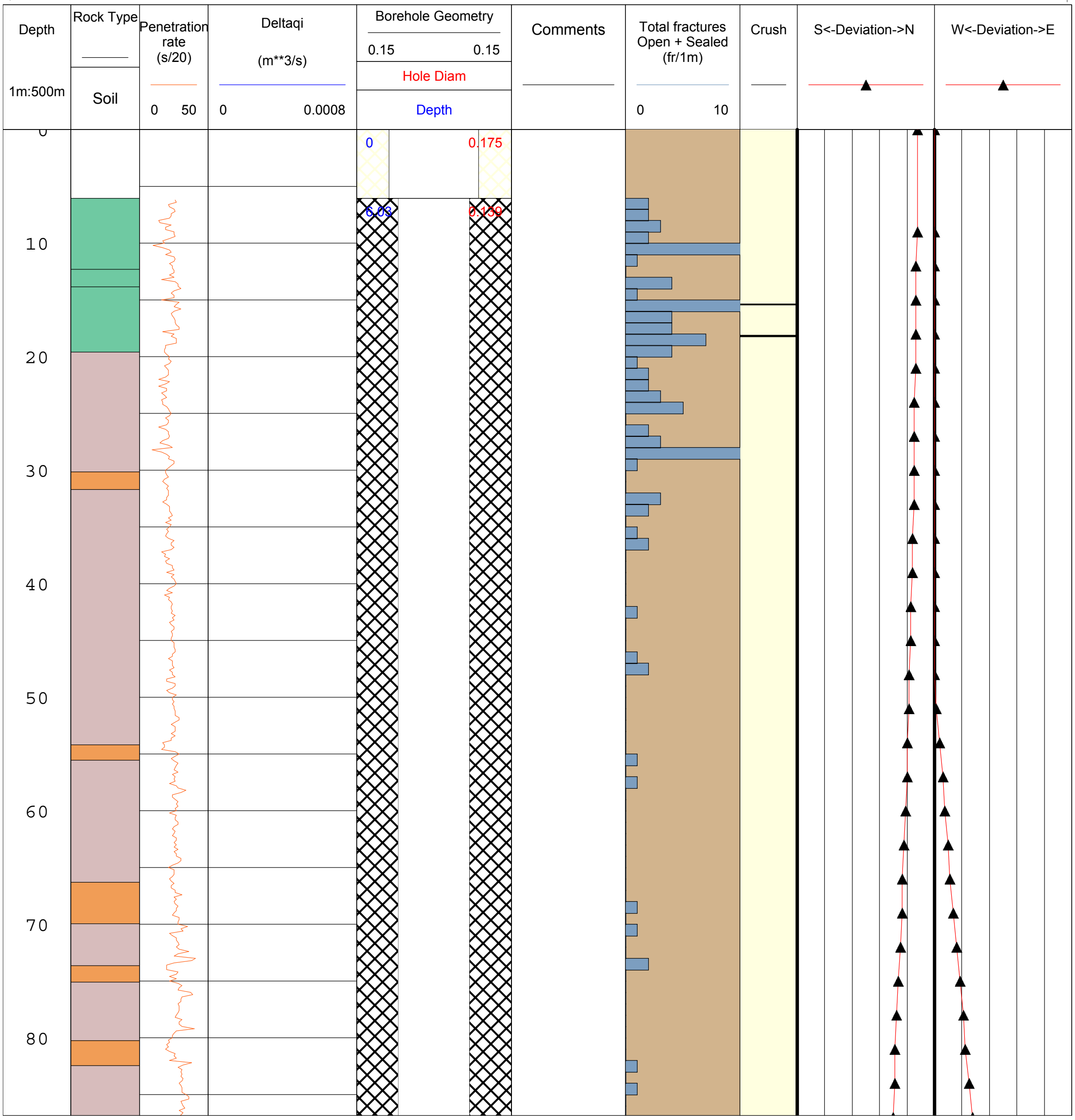
Site	FORSMARK	**Signed data**	
Borehole	HFM32	**Coordinate System**	RT90-RHB70
Diameter [mm]	132	**Northing [m]**	6699015.04
Length [m]	202.65	**Easting [m]**	1632137.07
Bearing [°]	116.15	**Elevation [m.a.s.l.]**	0.97
Inclination [°]	-86.05	**Drilling Start Date**	2006-01-11 08:30:00
Date of mapping		**Drilling Stop Date**	2006-01-14 16:00:00
		Plot Date	2006-09-26 21:12:20

ROCKTYPE FORSMARK

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

SOIL

Script Name



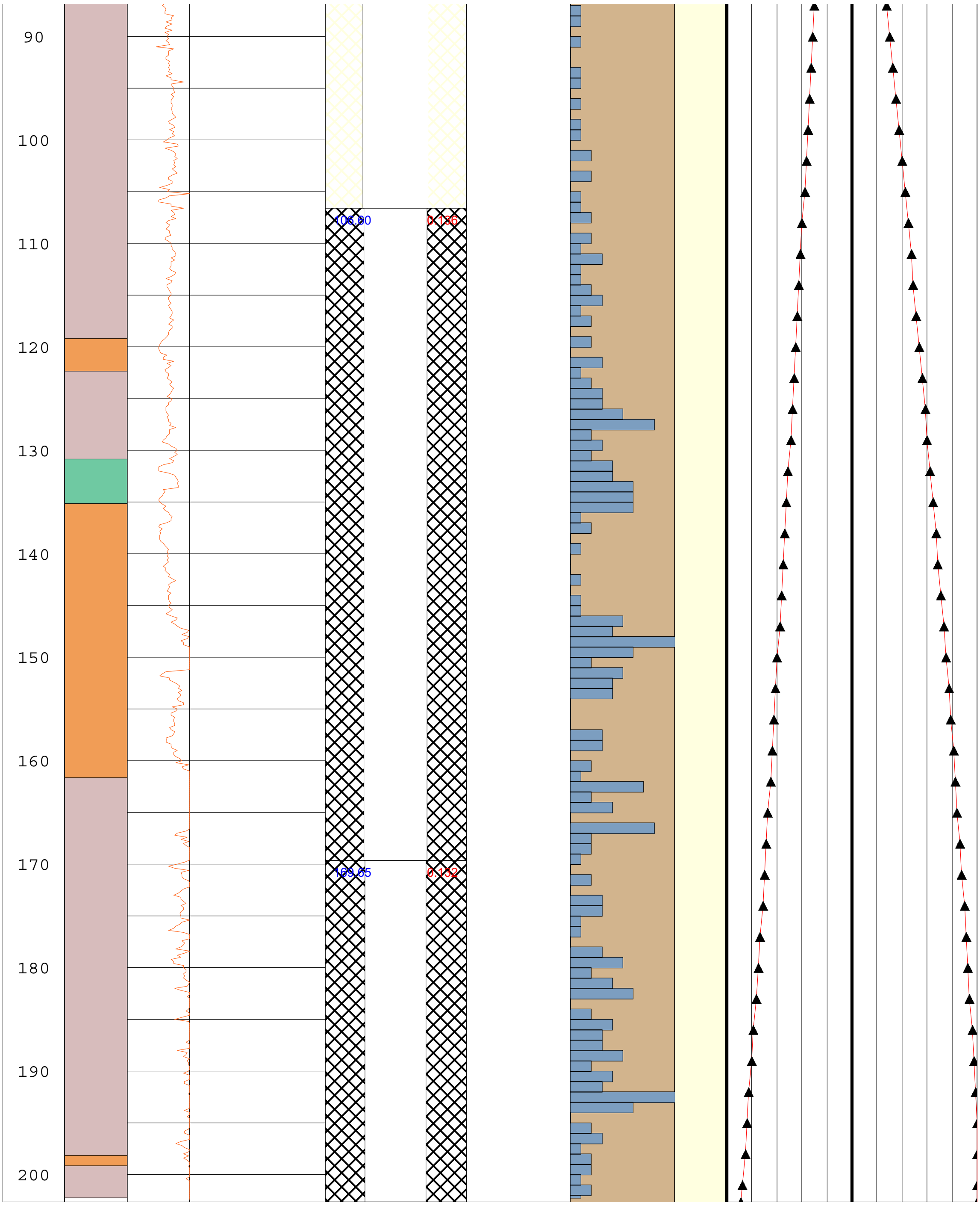


Figure 5-15. Technical and geoscientific data acquired during drilling of borehole HFM32.

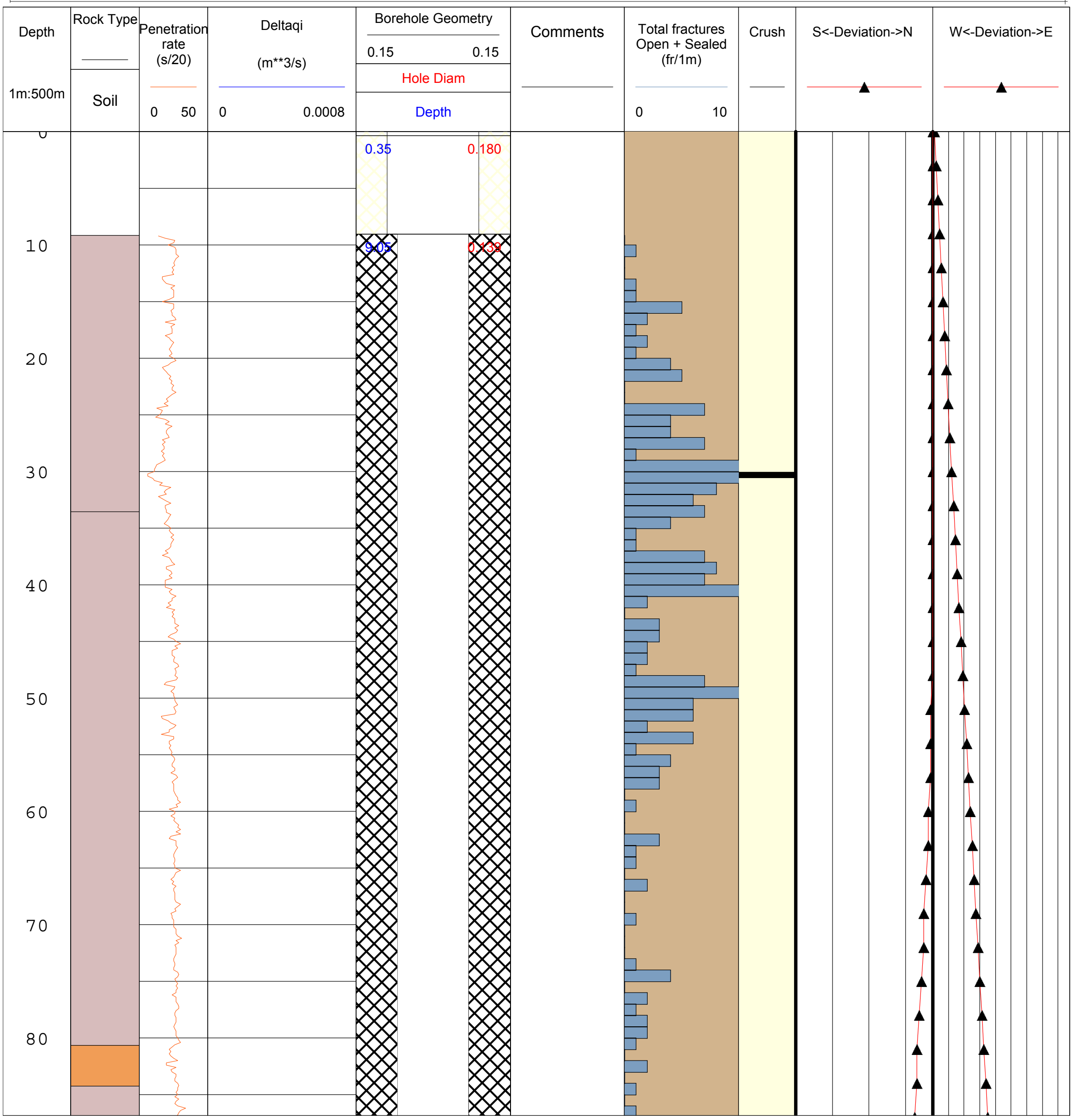
Title	PERCUSSION DRILLED BOREHOLE HFM38		
Svensk Kärnbränslehantering AB		**Signed data**	
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM38	**Northing [m]**	6700701.28
Diameter [mm]	136	**Easting [m]**	1631301.71
Length [m]	200.75	**Elevation [m.a.s.l.]**	2.21
Bearing [°]	93.62	**Drilling Start Date**	2006-06-14 16:00:00
Inclination [°]	-54.45	**Drilling Stop Date**	2006-06-22 12:00:00
Date of mapping		**Plot Date**	2006-09-26 21:12:20

ROCKTYPE FORSMARK

SOIL

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

Script Name



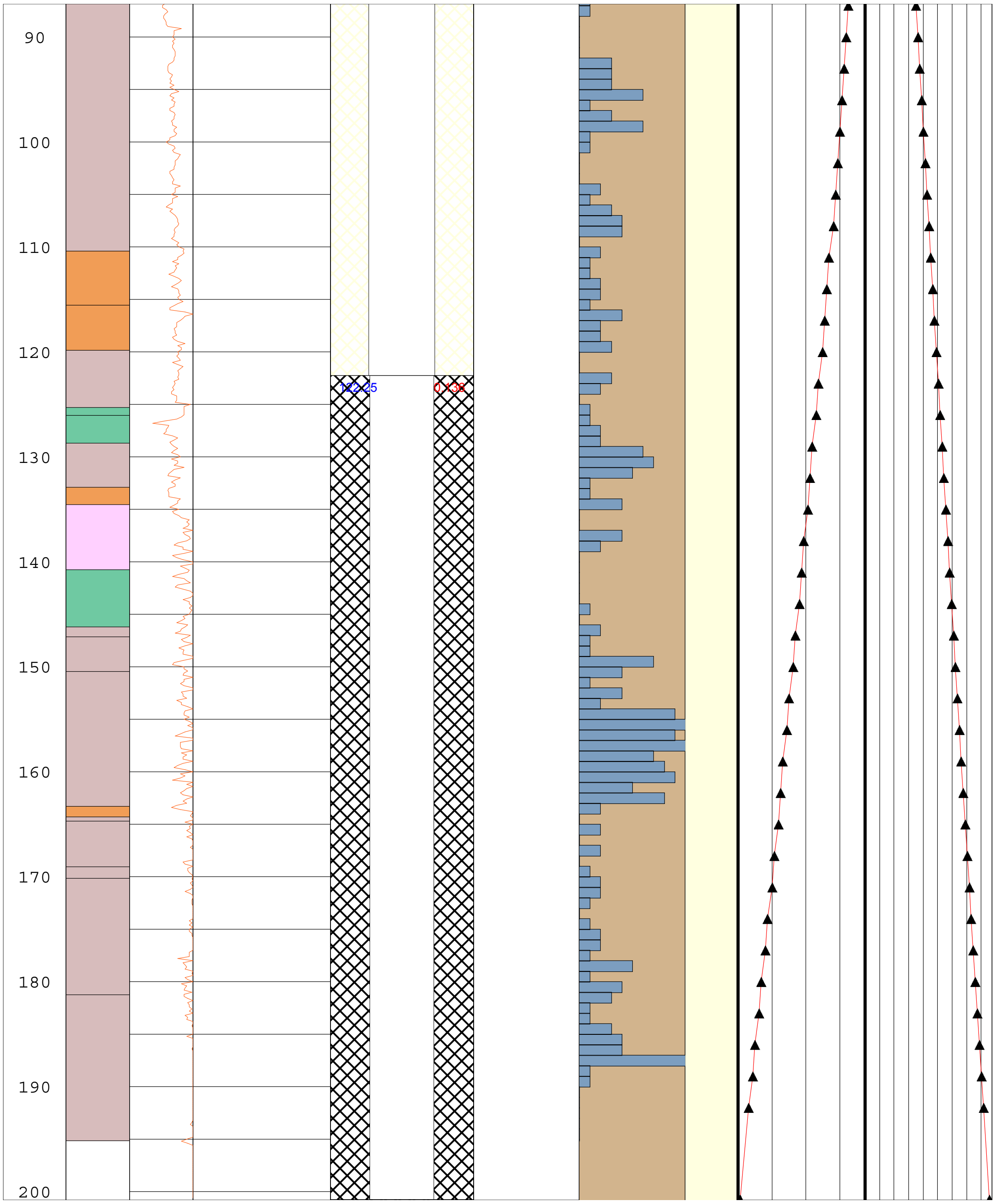


Figure 5-16. *Technical and geoscientific data acquired during drilling of borehole HFM38.*

5.4 Hydrogeology

5.4.1 Observations during drilling

No measurable amounts of groundwater were observed in borehole HFM25.

When drilling through the overburden in HFM26 (Figure 5-17), surface water inflow was observed, and as expected the groundwater was non-saline, indicated by an EC- value of c 70 mS/m.

At 60 m drilling length in borehole HFM26, an inflow of 2 L/min was encountered. When drilling restarted after a break at c 121 m, the accumulated water inflow rate increased to 5 L/min. Due to this limited inflow, a high degree of drilling debris contamination in the water samples could not be avoided, entailing that the EC-measurements are less reliable, and therefore not plotted.

In section 49–119 m in borehole HFM27 (Figure 5-18), the water inflow is gradually increasing from 3 to 40 L/min at the same time as the EC-value decreases slightly from c 500 to 400 mS/m. When flushing the borehole after drilling restarted the inflow of water increased temporarily to 96L/min. The results are thus indicating non-saline water conditions in the upper part of the borehole.

At 119 m drilling length, there is a significantly increasing water inflow corresponding to an increased EC-value to c 1,000 mS/m. As the accumulated water inflow rises to c 260 L/min, the EC-value is stabilized at c 1,200 mS/m, indicating semi-saline water conditions.

Borehole HFM29 yielded non-measurable amounts of groundwater.

The first inflow in HFM30 (Figure 5-19), 2 L/min, was observed at 15 m. When the accumulated water inflow rose to 12 L/min at 74 m drilling length, the EC–value displayed c 1,300 mS/m. Even though the water inflow was constant to 140 m drilling length, the EC-value decreased to 1,100 mS/m. At 140 m the accumulated groundwater inflow suddenly rose to 40 L/min, and was thereafter gradually increasing to 80 L/min at 200 m, corresponding to a moderately increasing EC-value that reached c 1,450 mS/min at the borehole end. The results are indicating semi-saline groundwater conditions in the borehole.

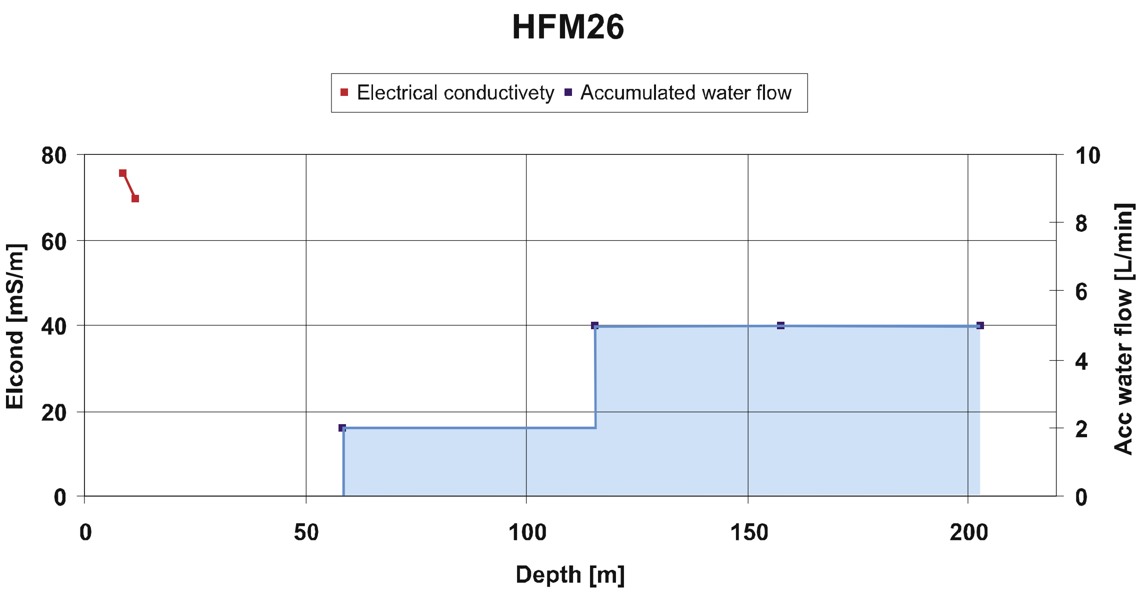


Figure 5-17. Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM26.

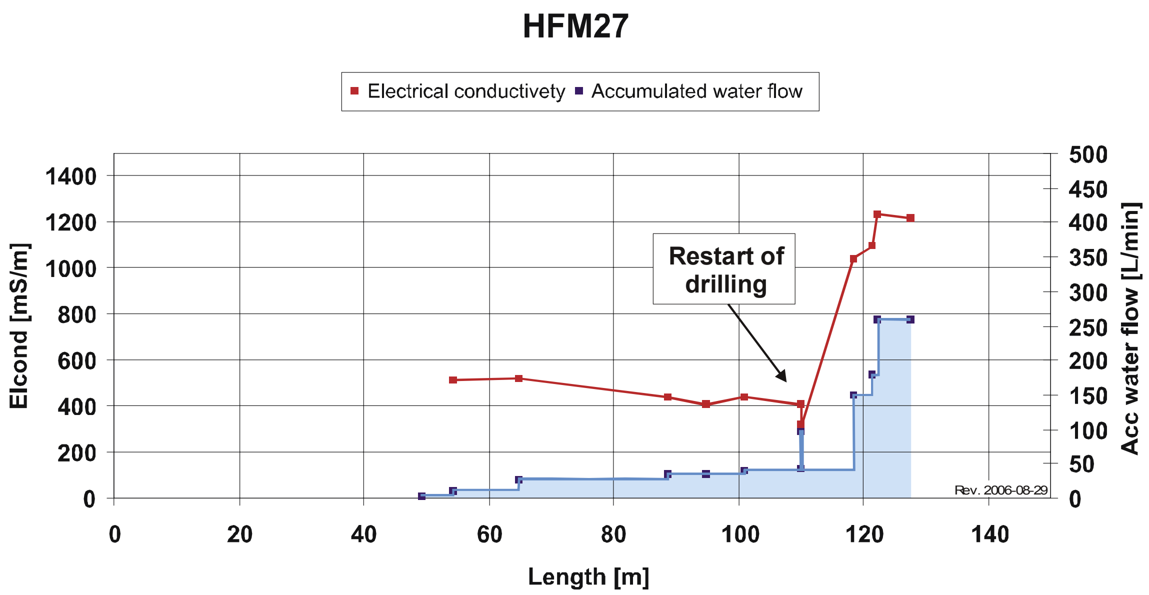


***Figure 5-18.** Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM27.*

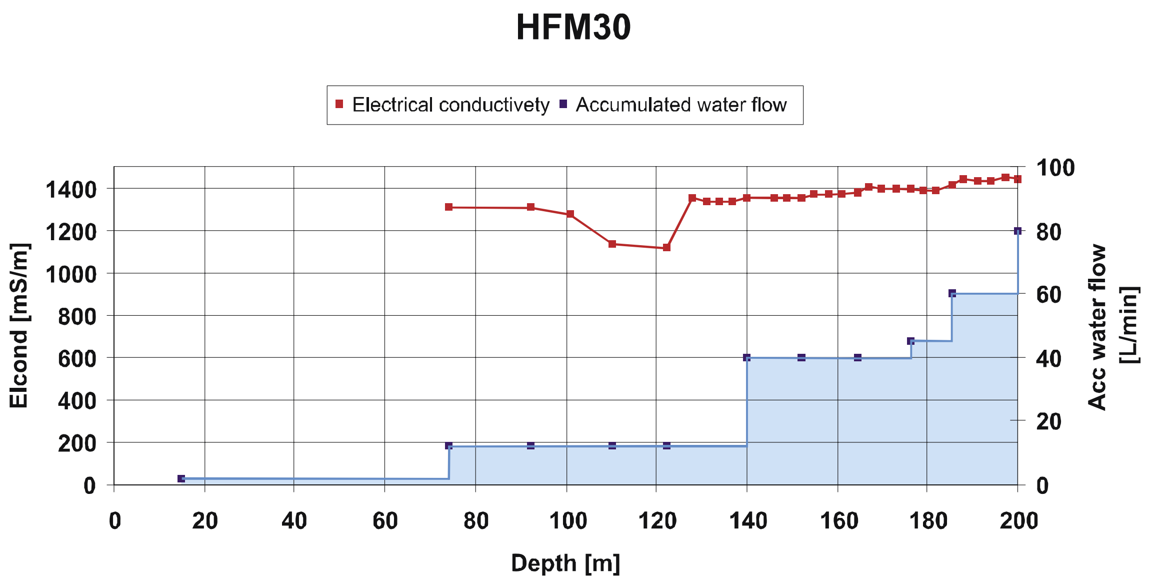


***Figure 5-19.** Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM30.*

Borehole HFM31 is to be regarded as non-yielding.

The first inflow in HFM32, 60 L/min (Figure 5-20), was encountered at 6 m, corresponding to an EC-value of c 700 mS/m. When drilling continued, the EC-value rose to c 1,200 mS/m. Further down, the inflow increased step-by-step until the accumulated water inflow reached 290 L/min at the final length (200.65 m). The EC-value was moderately increasing to c 1,300 mS/m, indicating semi-saline groundwater conditions in the entire borehole.

The first inflow in HFM38, 20 L/min (Figure 5-21), was encountered at 32 m, corresponding to an EC-value of c 1,000 mS/m. Further down the inflow increased step-by-step until the accumulated water inflow reached 100 L/min at the final length (200.75 m). The EC-value was moderately increasing to c 1,100 mS/m, except for the last ten metres, where the EC-value rose to c 1,200 mS/m, indicating semi-saline groundwater conditions in the entire borehole.

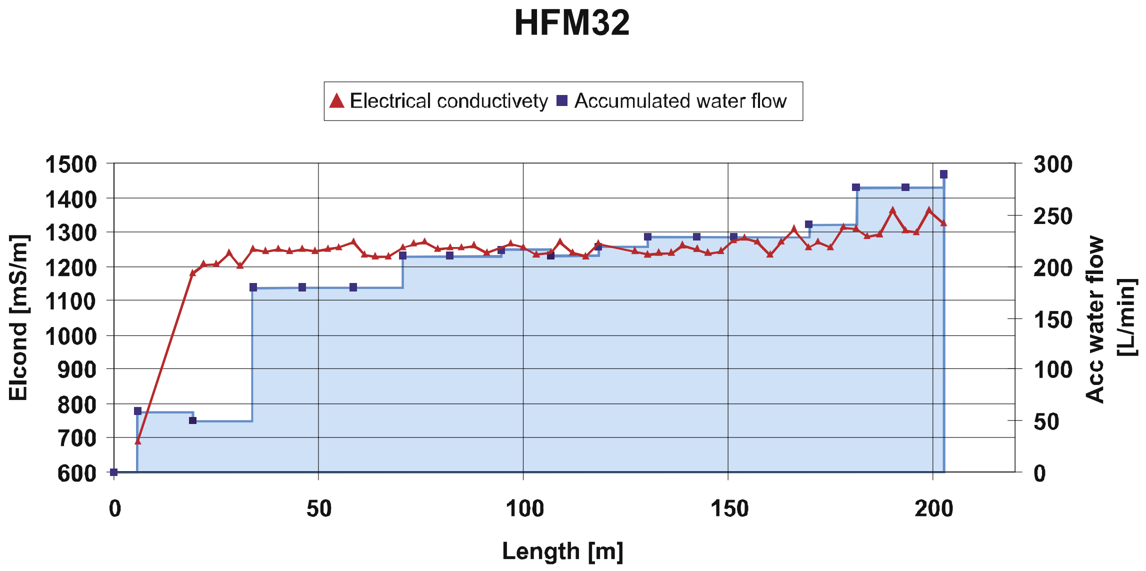


__Figure 5-20.__ Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM32.

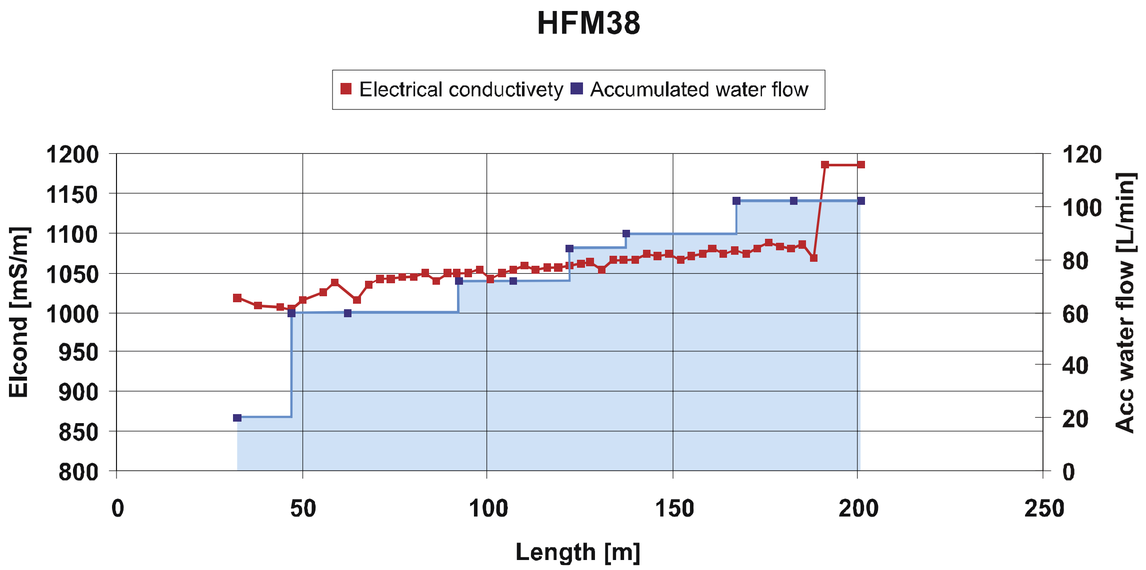


__Figure 5-21.__ Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM38.

5.4.2 Hydraulic responses

When drilling the percussion borehole HFM27, significant hydraulic responses were observed in HFM02, see Figure 5-22. The distance between the two boreholes is c 200 m. Borehole HFM02 is supplied with borehole packers, isolating three sections from each other. The groundwater level is monitored in each section. When a fracture zone discharging c 200 L/min at the bottom of HFM27 was penetrated, a drawdown of c 7 m was observed in upper section of HFM02.

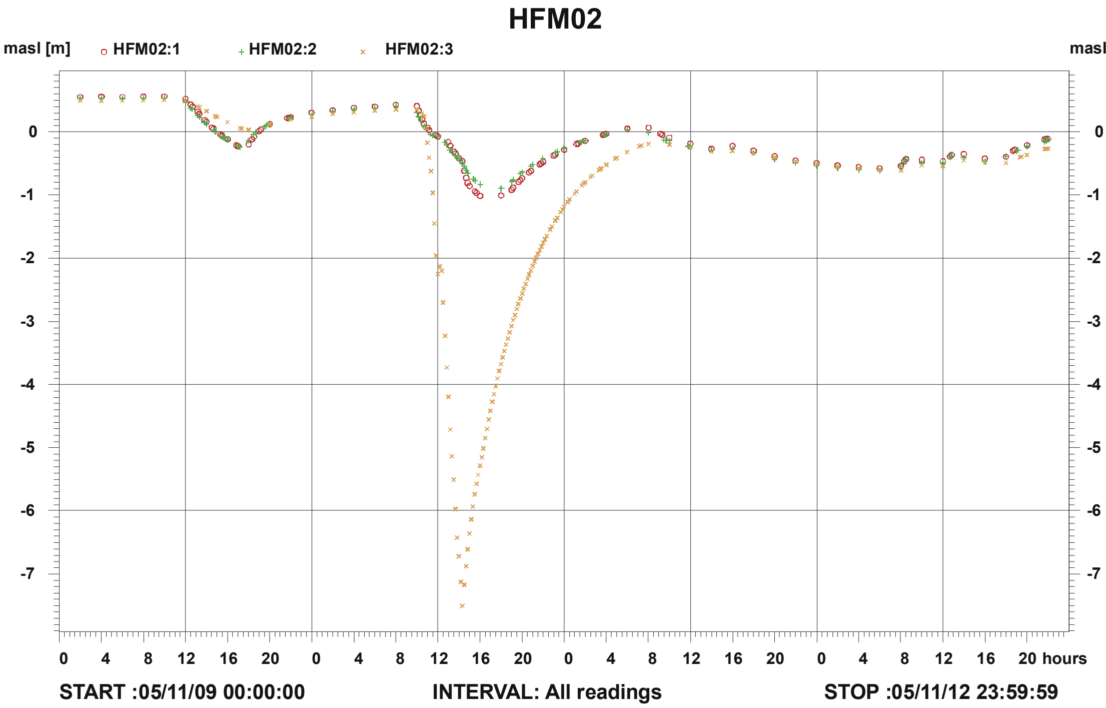


Figure 5-22. *Hydraulic responses in HFM02 when drilling HFM27.*

References

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