P-07-11

Forsmark site investigation

Drilling of flushing water well HFM33 and monitoring wells HFM34 and HFM35 at drill site DS11

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

April 2007

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

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Abstract

Three boreholes in solid rock, HFM33, HFM34 and HFM35, were drilled at drill site DS11 using percussion drilling technique. Borehole HFM33 was primarily aimed both as a flushing water well for the planned core drilling at DS11 and as a monitoring well for registration of the groundwater level during disturbed (during pumped) as well as undisturbed conditions. A third objective of borehole HFM33 was to investigate a minor lineament (ZFMNE0809) striking NW-SE just southwest of the drill site.

Borehole HFM33, which was drilled during the period April 26th to May 3rd, 2006, is 140.20 m long, inclined c. 59° to the horizontal plane and has in its upper part a diameter of c. 140 mm. A measurable groundwater inflow of 300 L/min was encountered at 136 m during drilling.

HFM34 and HFM35 were drilled with multiple objectives. Firstly, the boreholes were intended to investigate the Singö Deformation Zone in its shallow parts. Secondly, they were aimed at being used as monitoring wells, enabling long-term study of groundwater levels and groundwater-chemical composition.

HFM34 was drilled between May 24th and June 2nd, 2006. The borehole is 200.75 m long, inclined 59° to the horizontal plane and is drilled with the diameter c. 139 mm (in the upper part). Several small inflows, yielding in total 340 L/min, were encountered between 16–164 m during drilling.

Finally, the drilling period for HFM35 was June 6th to June 14th, 2006. Also HFM35 has a length of 200.75 m, is inclined 59° to the horizontal plane and is drilled with a start diameter of c. 138 mm. In this borehole several fractures with minor inflows were penetrated between 32–182 m. The final water yield of the borehole was 50 L/min.

Sammanfattning

Tre hammarborrhål, HFM33, HFM34 och HFM35, har borrats vid borrplats BP11. Borrhål HFM33 var 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 HFM33 var att undersöka ett mindre lineament (ZFMNE0809) med NV-SO-lig strykning strax sydväst om borrplatsen.

HFM33 borrades under perioden 26:e april till 3:e maj 2006. Borrhålet är 140,20 m långt, är ansatt ca 59° mot horisontalplanet och är borrat med startdiametern ca 140 mm. Under borrningen noterades ett grundvatteninflöde på 300 L/min vid 136 m.

HFM34 och HFM35 borrades i syfte att undersöka Singözonen samt för att användas som moniteringsbrunnar vid såväl störda som ostörda förhållanden. Borrningen av HFM34 utfördes under perioden 24:e maj till 2:a juni 2006, medan HFM35 borrades mellan den 6:e och den 14:e juni, 2006.

Såväl HFM34 som HFM35 är 200,75 m långa, är ansatta ca 59° mot horisontalplanet och borrade med en startdiameter av ca 139 mm respektive 138 mm. I HFM34 noterades under borrningen flera smärre inflöden mellan 16–164 m. Borrhålet ger totalt 340 L/min. Vid borrningen av HFM35 penetrerades flera sprickor med mycket små inflöden mellan 32–182 m. Borrhålets totala kapacitet är 50 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.

This document reports the results gained by drilling of a flushing water well, HFM33, and two monitoring wells, HFM34 and HFM35, at drill site DS11, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-06-027. Controlling documents for performance of this activity are listed in Table 1-1. Both activity plan, method descriptions and method instructions are SKB's internal controlling documents.

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-DS10 within or close to the candidate area. The majority of the cored boreholes drilled from these drill sites are inclined about 60° from the horizontal plane. 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.

Two new drill sites, DS11 and DS12, were built during the spring and autumn 2006, see Figure 1-1. One cored borehole, KFM11A, has been drilled at DS11 with the primary aim to investigate the bedrock northeast of the candidate area including the major Singö Deformation Zone, striking northwest-southeast. A last core drilled borehole, KFM12A, has recently been drilled at DS12, south-west of the candidate area. This borehole has investigated another major zone, the Forsmark Deformation Zone, which like the Singö Deformation Zone is striking northwest-southeast. All mentioned drill sites also include percussion drilled boreholes in bedrock and in soil.

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

Activity Plan	Number	Version
Hammarborrning av borrhål HFM33, HFM34 och HFM35	AP PF 400-06-027	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
Method Instructions	**Number**	**Version**
Rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Användning av kemiska produkter och material vid borrning och undersökning	SKB MD 600.006	1.0

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.*

Besides borehole KFM11A, drill site DS11 is also hosting the three percussion bore-holes in solid rock, HFM33, HFM34 and HFM35, presented in this report. The positions of the currently existing boreholes at drill site DS11 are displayed in Figure 1-2.

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 April 26th to May 3rd, 2006, (HFM33), May 24th to June 2nd, 2006 (HFM34), respectively June 6th to June 14th, 2006, (HFM35), in compliance with Activity Plan AP PF 400-06-027, Version 1.0.

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan number (AP PF 400-06-027). Only data in databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major revisions entail a revision of the P-report. Minor revisions are normally presented as supplements, available at *www.skb.se.*

Figure 1-2. *Borehole locations at drill site DS11.*

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.

Borehole HFM33 was drilled with multiple objectives. Firstly, the borehole was intended to account for supply of the clean flushing water needed for drilling the cored borehole KFM11A (and possibly other cored boreholes at DS11). Secondly, the borehole was aimed at being used as a monitoring well, enabling long-term study of groundwater levels and groundwater-chemical composition. A third objective was to characterize a minor lineament (ZFMNE0809) striking NW-SE just southwest of the drill site.

Also boreholes HFM34 and HFM35 were drilled with multiple aims. Firstly, they were intended to investigate the Singö Deformation Zone in its shallow parts. Secondly, the boreholes were aimed at being used as monitoring wells, enabling long-term study of groundwater levels and groundwater-chemical composition.

Boreholes HFM33, HFM34 and HFM35 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.

Besides the purpose of addressing the deformation zones to be investigated, one criterion for determining the positions of especially boreholes HFM34 and HFM35 was to locate them within the expected radius of influence of groundwater-level drawdown during core drilling at drill sites DS11.

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. Monitoring during the percussion and core drilling operations at drill site DS11 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 DS11, the boreholes discussed in this report will be used for long-term groundwater level monitoring and groundwater sampling.

3 Equipment

Drilling of borehole HFM33 at DS11 was carried out with a Comacchio 1500 S percussion drilling machine (Figure 3-1), whereas drilling of boreholes HFM34 and HFM35 was performed with a Nemek 407 RE DTH machine (Figure 3-2). Both machines were supplied with a variety of 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 Comacchio 1500 S 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 an Atlas-Copco XRVS 466 Md 27 bars diesel compressor. The DTH drill hammer was of type Secoroc 8", operated by a Driconeq 76 mm pipe string. All DTH-equipment was cleaned with a Kärcher HDS 1195 high-capacity steam cleaner.

Also the Nemek 407 RE drilling machine (Figure 3-2) 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.

Figure 3-1. *The Comacchio 1500 S drilling machine at HFM33, close to drill site DS11.*

Figure 3-2. The Nemek 407 RE drilling machine at drill site DS11.

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 HFM33, HFM34 and HFM35 only the borehole packer technique was applied.

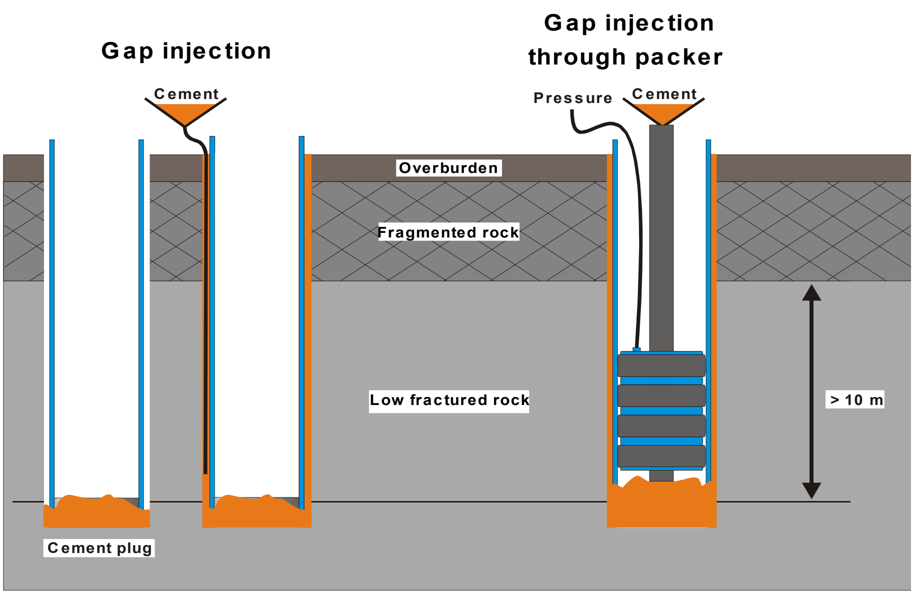


Figure 3-3. *Gap injection technique. In order to grout the gap between the borehole wall and the casing, different systems may be used. To the left, filling up a cement-water mixture with a flexible hose is shown. To the right, injection is performed through a borehole packer.*

3.3 Equipment for deviation measurements

After completion of drilling, a deviation measurement was carried out with a FLEXIT Smart Tool System, which is based on magnetic accelerometer technique. Azimuth and dip are measured at every third metre. The collaring point coordinates and the measured values are used for calculating the coordinates of the position of the borehole at every measurement point.

However, in connection with a major quality revision regarding orientation of all identified geological objects (fractures, fracture zones rock contacts etc) conducted by SKB during late autumn 2006 to winter/early spring 2007, the FLEXIT-method was judged as providing the most reliable results. The revision also led to changed routines for adjusting magnetic data, meaning that all available deviation measurements in the percussion drilled boreholes have been revised, including data from boreholes HFM33, HFM34 and HFM35.

Results from the deviation measurements stored in SKB's database Sicada are presented in Section 5.3.

4 Execution

Drilling of boreholes HFM33, HFM34 and HFM35 followed SKB MD 610.003, Version 1.0 (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 and a final function control.

4.3 Drilling and measurements during drilling of boreholes HFM33, HFM34 and HFM35

A TUBEX-system (an ODEX-variant) was applied for drilling through the overburden and some metres into solid bedrock (Figure 4-1).

4.3.1 Drilling through the overburden

TUBEX is a system for simultaneous drilling and casing driving. The method is based on an arrangement 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 latter to follow the drill bit down the hole. In the Ejector-TUBEX system, which was applied here, 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 boreholes HFM33, HFM34 and HFM35, 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. Also the initial diameter of all three boreholes HFM33, HFM34 and HFM35 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 a 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) /3/.

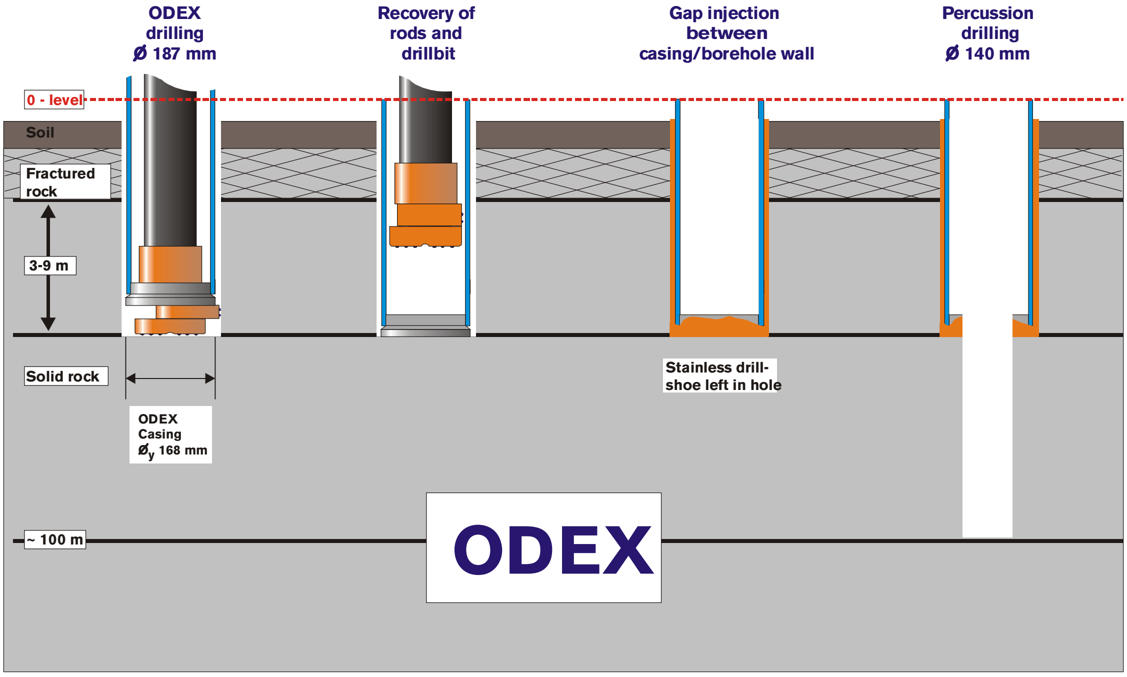


Figure 4-1. The different steps included in the performance of the percussion drilled boreholes HFM33, HFM34 and HFM35.

- 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 HFM33, HFM34 and HFM35

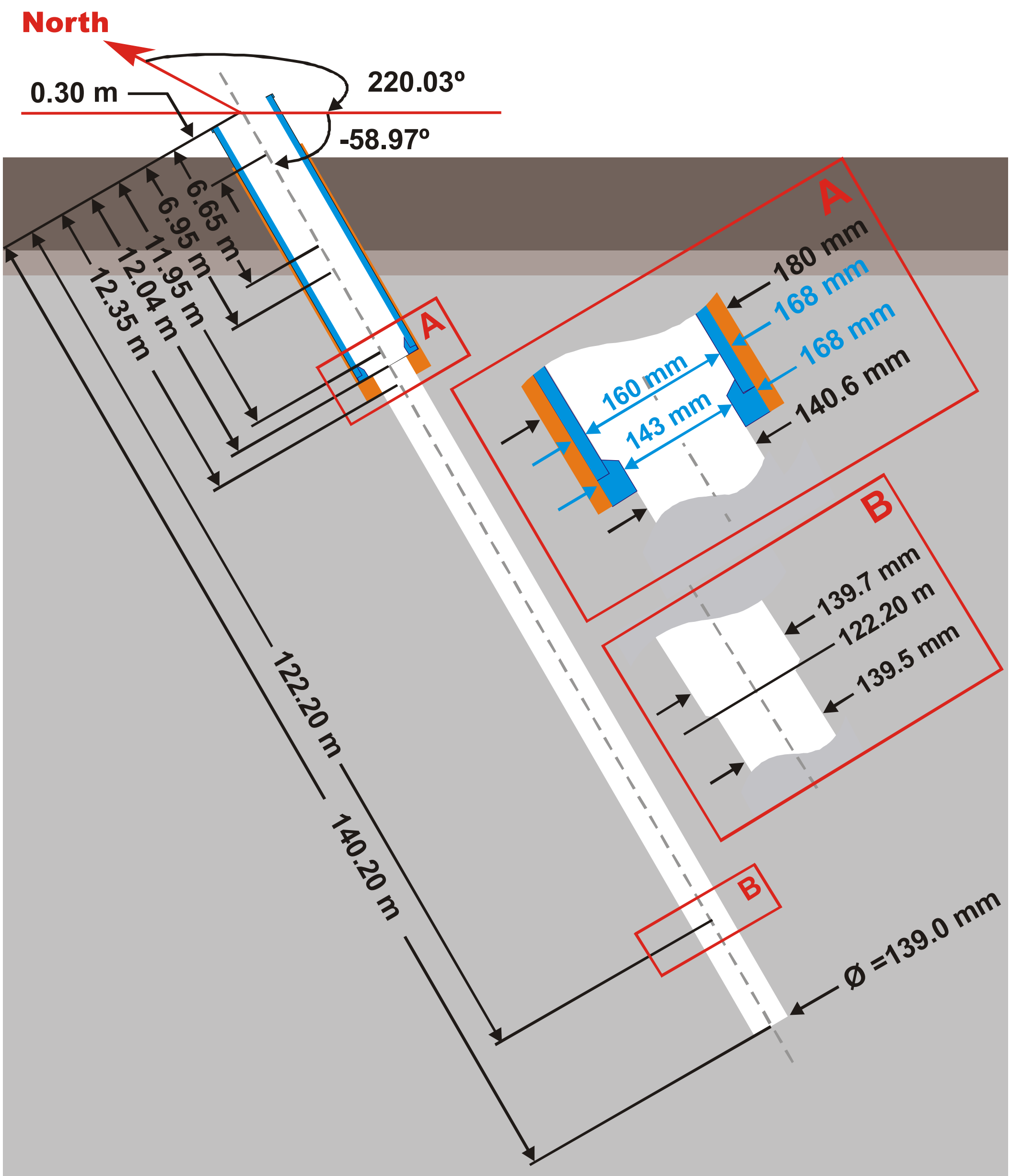
Administrative, geometric, and technical data for HFM33, HFM34 and HFM35 are presented in Table 5-1. The technical design of the boreholes is illustrated in Figures 5-1, 5-2, and 5-3.

Table 5-1. Administrative, geometric and technical data for boreholes HFM33, HFM34 and HFM35.

Parameter	HFM33	HFM34	HFM35
Drilling period	From 2006-04-26 to 2006-05-03	From 2006-05-24 to 2006-06-02	From 2006-06-06 to 2006-06-14
Borehole inclination (collaring point)	–58.97° (– = downwards)	–58.65° (– = downwards)	–59.19° (– = downwards)
Borehole bearing	220.03°	30.50°	32.96°
Borehole length	140.20 m	200.75 m	200.75 m
Borehole diameter	From 0.30 m to 12.35 m: 0.180 m From 12.35 m to 122.20 m: decreasing from 0.1406 m to 0.1397 m From 122.20 m to 140.20 m: decreasing from 0.1395 m to 0.1390 m	From 0.35 m to 12.08 m: 0.180 m From 12.08 m to 92.25m: decreasing from 0.1385 m to 0.1380 m From 92.25 m to 200.75 m: decreasing from 0.1377 m to 0.1368 m	From 0.30 m to 12.04 m: 0.180 m From 12.04 m to 122.25 m: decreasing from 0.1380 m to 0.1377 m From 122.25 m to 200.75 m: decreasing from 0.1374 m to 0.1356 m
Casing length	12.04 m	12.08 m	12.04 m
Casing diameter	$\varnothing_o/\varnothing_i$ = 168 mm/160 mm to 11.95 m $\varnothing_o/\varnothing_i$ = 168 mm/143 mm between 11.95 and 12.04 m	$\varnothing_o/\varnothing_i$ = 168 mm/160 mm to 11.99 m $\varnothing_o/\varnothing_i$ = 168 mm/143 mm between 11.99 and 12.08 m	$\varnothing_o/\varnothing_i$ = 168 mm/160 mm to 11.95 m $\varnothing_o/\varnothing_i$ = 168 mm/143 mm between 11.95 and 12.04 m
Drill bit diameter	Start of drilling: 0.1406 m End of drilling: 0.1390 m	Start of drilling: 0.1385 m End of drilling: 0.1368 m	Start of drilling: 0.1380 m End of drilling: 0.1356 m
Collaring point coordinates (system RT90 2.5 gon V/ RHB70)	Northing: 6701042.57 m Easting: 1632222.99 m Elevation: 2.62 m.a.s.l.	Northing: 6701325.06 m Easting: 1632470.21 m Elevation: 2.45 m.a.s.l.	Northing: 6701555.86 m Easting: 1632320.51 m Elevation: 1.90 m.a.s.l.

Technical data

Borehole HFM33



Drilling reference point

Northing: 6701042.57 (m), RT90 2,5 gon V 0:-15
Easting: 1632222.99 (m), RT90 2,5 gon V 0:-15
Elevation: 2.62 (m), RHB 70

Drilling period

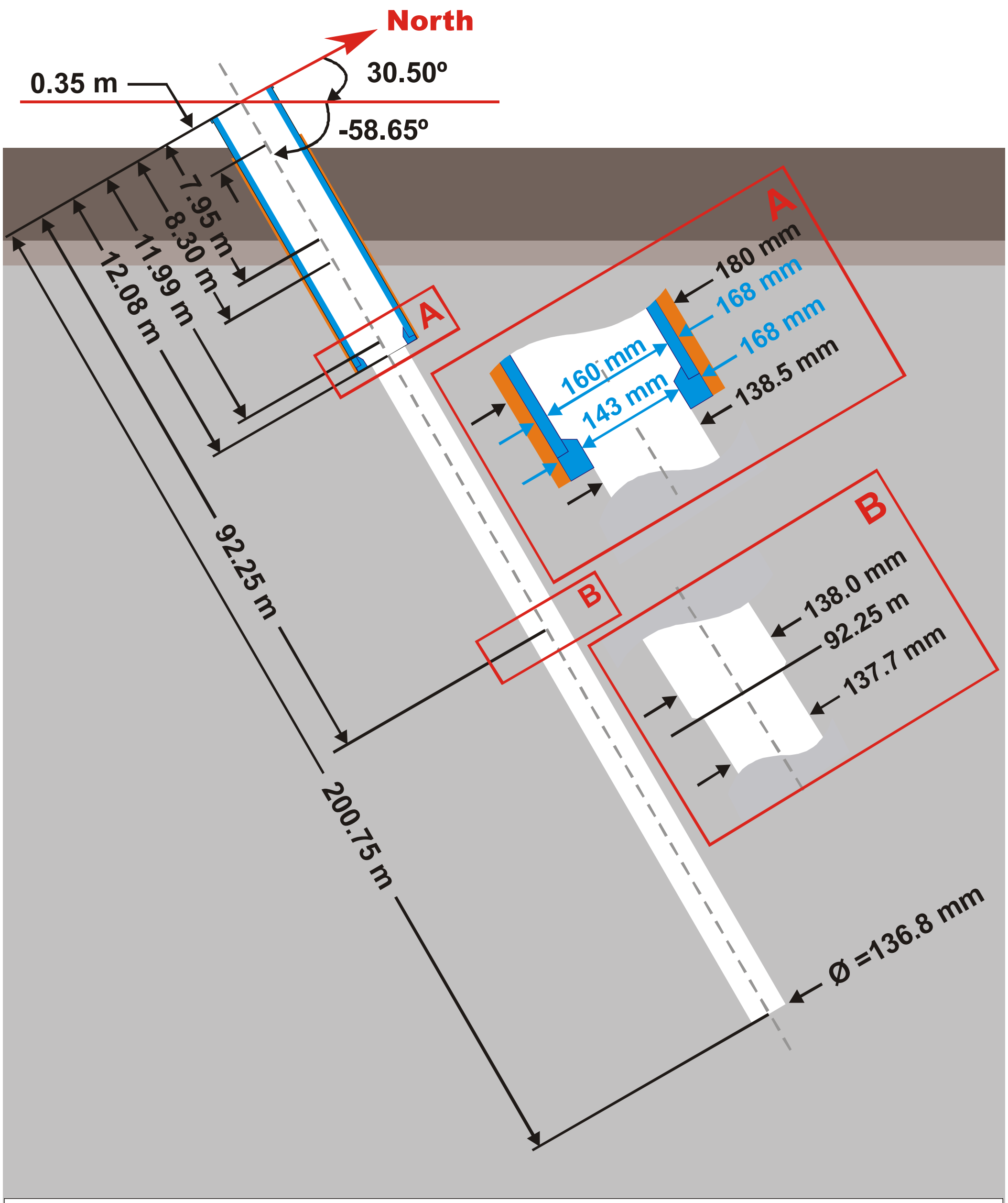
Drilling start date: 2006-04-26
Drilling stop date: 2006-05-03

rev 2006-06-28

Figure 5-1. Technical data for borehole HFM33.

Technical data

Borehole HFM34



Drilling reference point

Northing:	6701325.06	(m), RT90 2,5 gon V 0:-15
Easting:	1632470.21	(m), RT90 2,5 gon V 0:-15
Elevation:	2.45	(m), RHB 70

Drilling period

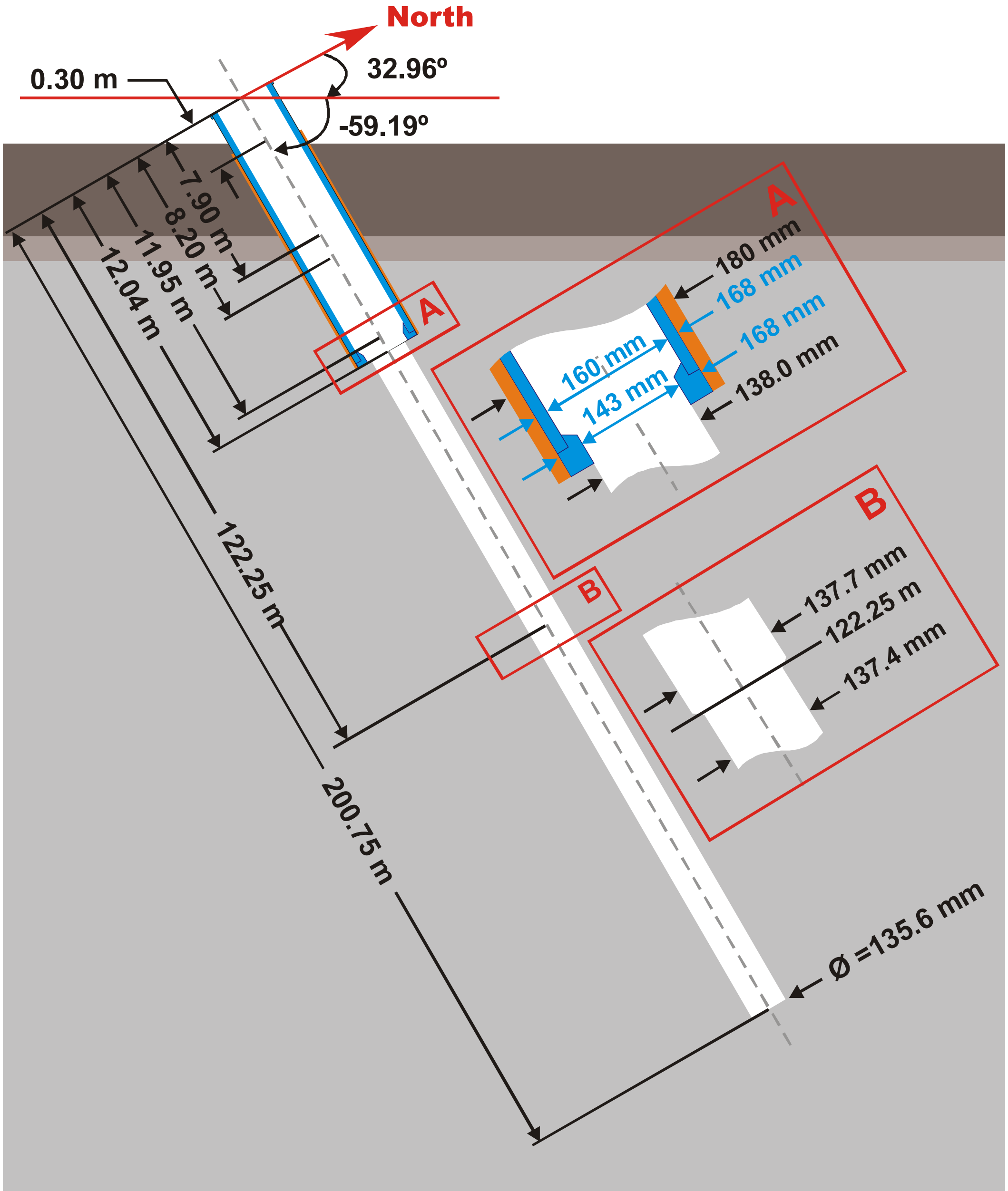
Drilling start date:	2006-05-24
Drilling stop date:	2006-06-02

rev 2006-06-28

Figure 5-2. *Technical data for borehole HFM34.*

Technical data

Borehole HFM35



Drilling reference point

Northing:	6701555.86	(m), RT90 2,5 gon V 0:-15
Easting:	1632320.51	(m), RT90 2,5 gon V 0:-15
Elevation:	1.90	(m), RHB 70

Drilling period

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

rev 2006-06-24

Figure 5-3. *Technical data for borehole HFM35.*

5.2 Consumables used up in HFM33, HFM34 and HFM35

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 microsilica (920-D) and white cement (Aalborg Portland CEM I, 52.5N) in proportions according to Table 5-2.

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.

5.3 Deviation measurements

The principal method applied for deviation measurements in percussion drilled boreholes is based on magnetic-accelerometer technique. For the three boreholes in this report, the FLEXIT Smart tool system was used. To ensure high quality measurements with the FLEXIT tool, the disturbances of the magnetic field must be small. A measuring station in Uppsala provides one-minute magnetic field values that are available on the Internet at *www.intermagnet.org* and gives sufficient information. The magnetic field variation during May 4^{th} , June 5^{th} and June $15^{th,}$ 2006, is seen in Figures 5-4, 5-5 and 5-6 respectively, and shows only minor disturbances when the FLEXIT surveys in HFM33, HFM34 and HFM35 were performed.

In the following a systematic description of the construction of the revised deviation data for the three percussion drilled boreholes HFM33–35 are given.

The principles of the equipment for deviation measurements were explained in Section 3.3. The quality control program for deviation measurements is mostly concentrated to the handling of the instrument as well as to routines applied for the performance. It is not possible to execute an absolute control measurement, as no long borehole is available with access both to the borehole collar and the borehole end.

Table 5-2. Oil consumption.

Borehole ID	Hammer oil Preem Hydra 46	Compressor oil Schuman 46
HFM33	10 L	Below detection limit
HFM34	8 L	Below detection limit
HFM35	8 L	Below detection limit

Table 5-3. Consumption of cement grouting.

Borehole ID	Casing length	Cement weight/ volume (Aalborg Portland Cement/ microsilica)	Grouting method
HFM33	12.04 m	180 kg/200 L	Borehole packer
HFM34	12.08 m	72 kg/80 L	Borehole packer
HFM35	12.04 m	72 kg/80 L	Borehole packer

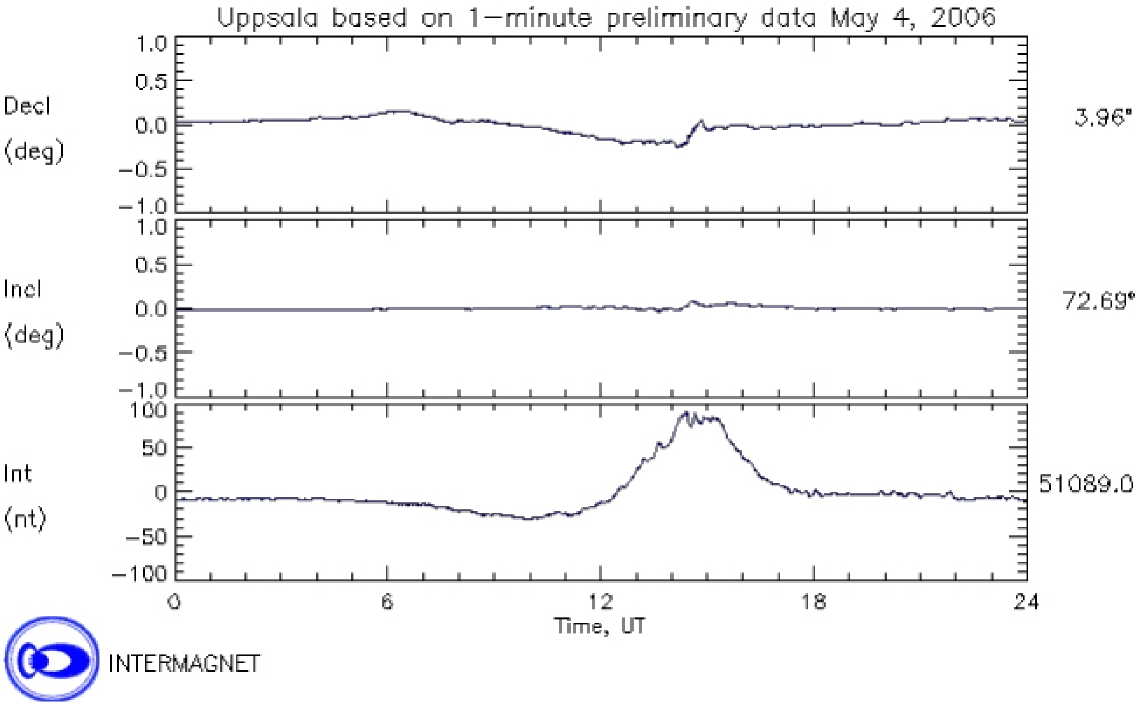


Figure 5-4. *Magnetic field variation during the FLEXIT survey performed on May 4th, 2006 in HFM33.*

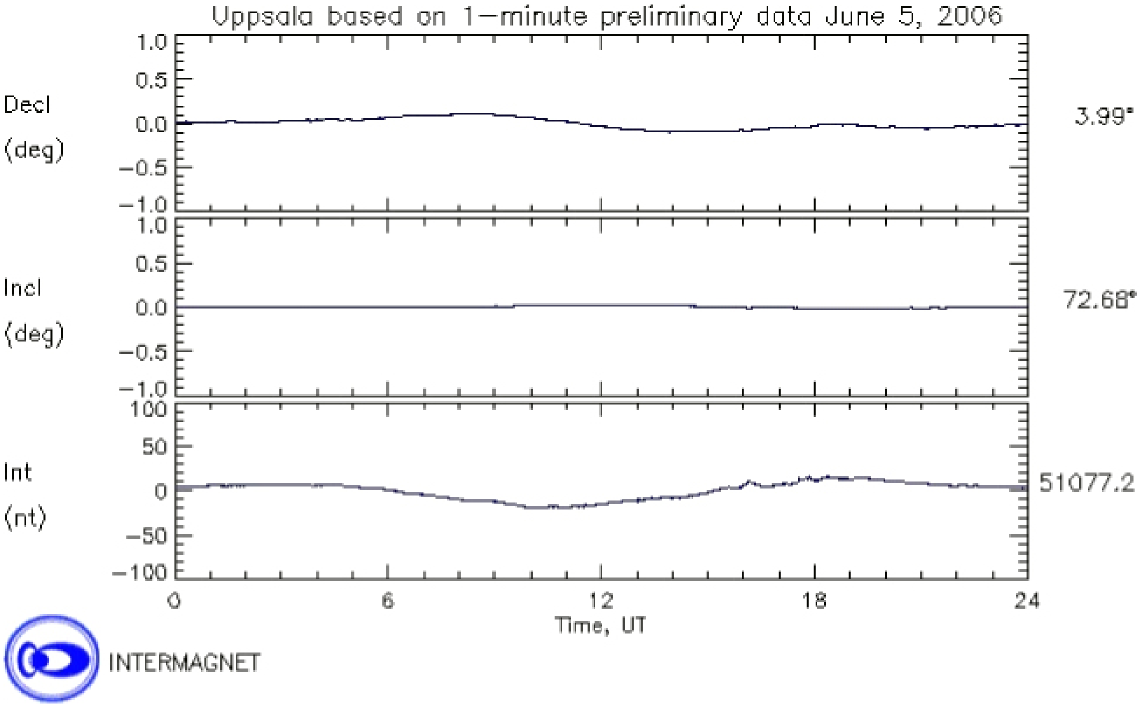


Figure 5-5. *Magnetic field variation during the FLEXIT survey performed on June 5th, 2006 in HFM34.*

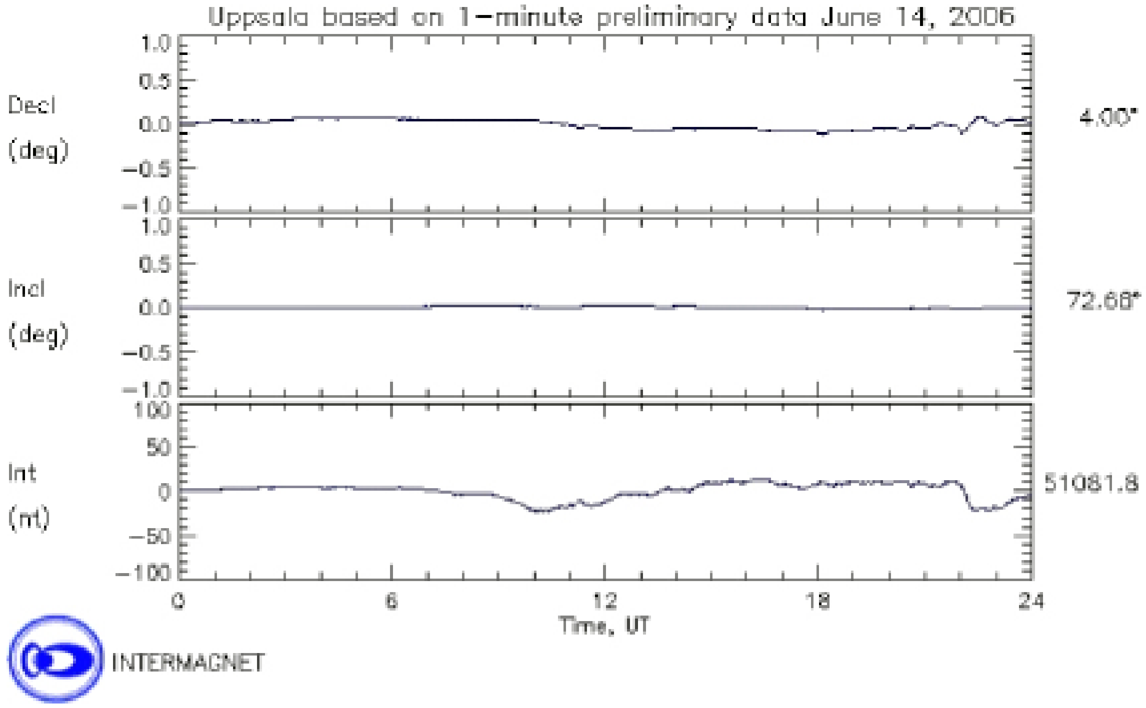


Figure 5-6. *Magnetic field variation during the FLEXIT survey performed on June 14th, 2006 in HFM35.*

The deviation data used for calculation of the borehole deviation file stored in Sicada are one FLEXIT-logging for each borehole. The deviation measurements were carried out every 3 m downwards, to 138 m borehole length in HFM33 and to 198 m borehole length in HFM34 and HFM35. These measurements were originally allotted the activity numbers 13116727, 13116729 respectively 13116731, see Table 5-4. However, the data files corresponding to these activities have an "Error-flag" in the column to the right, and are thus not to be used. The reason for that is that the deviation measurements in HFM33, 34 and 35 and the subsequent data processing were conducted prior to the major quality revision mentioned in Section 3.3. Hence, the quality routines established in connection with that revision were not applied at the time being.

However, all recommended quality routines were exercised in activities 13141388, 13141427 and 13141478, which are denoted an "F-flag" (Table 5-4). Hence, the corresponding data files are those that have been used for calculation of the deviation files stored in Sicada (activity code EG154 and activities 13142220, 13142277 respectively 13142278). All data files associated with these activities are assigned an "IC-flag". I.e. these files represent the deviation data accepted for further interpretation and modelling.

The EG154-activity also specifies the sections of the deviation measurements that have been used in the resulting calculation, see Table 5-5. The different lengths of the upper sections between bearing and inclination are due to the fact that magnetic-accelerometer measurements (bearing) are influenced by the 12 m steel casing, whereas inclinometer measurements (inclination) are unaffected by the presence of metal in the borehole.

A subset of the resulting deviation files and the estimated radius uncertainties are presented in Tables 5-6, 5-7 and 5-8.

Table 5-4. Activity data for the three deviation measurements approved for HFM33, HFM34 and HFM35 (from SICADA). The magnetic measurements were used for calculation of the final borehole deviation file. The “Flags” in the column to the right specify the status of the respective data files (see text below). E=abbrev. for “Error”, F=”File” and IC=”In use. Comment”.

Idcode	Activity ID	Activity type code	Activity	Start date	Secup (m)	Seclow (m)	Flags
HFM33	13116727	EG157	Magnetic – accelerometer measurement	2006-05-04 12:50:00	3.00	138.00	E
HFM33	13141388	EG157	Magnetic – accelerometer measurement	2006-05-04 12:50:00	3.00	138.00	F
HFM33	13142220	EG154	Borehole deviation multiple measurements	2006-12-19 18:30:00			I C
HFM34	13141427	EG157	Magnetic – accelerometer measurement	2006-06-05 15:20:00	3.00	198.00	F
HFM34	13116729	EG157	Magnetic – accelerometer measurement	2006-06-05 15:20:00	3.00	198.00	E
HFM34	13142277	EG154	Borehole deviation multiple measurements	2006-12-19 18:40:00			I C
HFM35	13116731	EG157	Magnetic – accelerometer measurement	2006-06-14 17:40:00	3.00	198.00	E
HFM35	13141478	EG157	Magnetic – accelerometer measurement	2006-06-14 17:40:00	3.00	198.00	F
HFM35	13142278	EG154	Borehole deviation multiple measurements	2006-12-19 18:50:00			I C

Table 5-5. Content of the EG154 file (multiple borehole deviation intervals).

Idcode	Deviation activity Id	Deviation angle type	Approved secup (m)	Approved seclow (m)	Man_estim_ angle_uncert (degrees)
HFM33	13141388	Bearing	15.00	138.00	4.900
HFM33	13141388	Inclination	3.00	138.00	1.800
HFM34	13141427	Bearing	15.00	198.00	4.900
HFM34	13141427	Inclination	3.00	198.00	1.800
HFM35	13141478	Bearing	15.00	198.00	4.900
HFM35	13141478	Inclination	3.00	198.00	1.800

The calculated deviation (EG154-file) in borehole HFM33 shows that the borehole deviates upwards and to the right with an absolute deviation of 21 m compared to an imagined straight line following the dip and strike of the borehole start point.

The calculated deviation (EG154-file) in borehole HFM34 shows that the borehole deviates mostly upwards but is almost straight with an absolute deviation of 13 m compared to an imagined straight line following the dip and strike of the borehole start point.

Finally, the calculated deviation (EG154-file) in borehole HFM35 shows that the borehole deviates mostly upwards but is almost straight with an absolute deviation of 34 m compared to an imagined straight line following the dip and strike of the borehole start point.

The ”absolute deviation” is here defined as the shortest distance in space between a point in the borehole at a certain borehole length and the imaginary position of that point if the borehole had followed a straight line with the same inclination and bearing as of the borehole collaring.

Table 5-6. Deviation data and uncertainty data for the deviation measurements in HFM33A for approximately every 10 m borehole length calculated from EG154.

Idcode	Northing	Easting	Elevation	Length	Inclination	Bearing	Inclination_ uncertainty	Bearing uncertainty	Radius uncertainty
HFM33	6701042.57	1632222.99	2.62	0	–59.19	220.03	1.8	4.9	0.00
HFM33	6701036.69	1632217.81	–10.17	15	–57.77	222.77	1.8	4.9	0.67
HFM33	6701031.99	1632213.36	–20.28	27	–57.02	224.26	1.8	4.9	1.23
HFM33	6701027.39	1632208.65	–30.31	39	–56.54	226.46	1.8	4.9	1.79
HFM33	6701022.95	1632203.67	–40.29	51	–55.55	230.32	1.8	4.9	2.36
HFM33	6701018.69	1632198.25	–50.10	63	–54.28	232.72	1.8	4.9	2.95
HFM33	6701014.48	1632192.53	–59.78	75	–53.32	234.67	1.8	4.9	3.56
HFM33	6701010.37	1632186.55	–69.33	87	–52.24	235.87	1.8	4.9	4.18
HFM33	6701005.15	1632178.79	–81.06	102	–50.60	236.39	1.8	4.9	4.98
HFM33	6701000.99	1632172.38	–90.31	114	–50.25	237.17	1.8	4.9	5.64
HFM33	6700996.84	1632165.90	–99.52	126	–49.98	237.97	1.8	4.9	6.30
HFM33	6700991.99	1632158.11	–110.36	140.2	–49.59	238.18	1.8	4.9	7.08

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a minor discrepancy against the measured values seen in Borehole direction surveying (EG151).

Table 5-7. Deviation data and uncertainty data for the deviation measurements in HFM34 for approximately every 10 m borehole length calculated from EG154.

Idcode	Northing	Easting	Elevation	Length	Inclination	Bearing	Inclination uncertainty	Bearing uncertainty	Radius uncertainty
HFM34	6701325.06	1632470.21	2.45	0	–58.59	30.50	1.8	4.9	0.00
HFM34	6701331.79	1632474.15	–10.37	15	–58.68	30.22	1.8	4.9	0.67
HFM34	6701337.16	1632477.27	–20.63	27	–58.98	30.05	1.8	4.9	1.20
HFM34	6701342.51	1632480.36	–30.92	39	–59.11	29.85	1.8	4.9	1.72
HFM34	6701347.85	1632483.41	–41.23	51	–59.21	29.65	1.8	4.9	2.25
HFM34	6701353.26	1632486.47	–51.50	63	–58.26	29.50	1.8	4.9	2.78
HFM34	6701363.03	1632491.93	–69.26	84	–57.16	29.06	1.8	4.9	3.74
HFM34	6701368.78	1632495.15	–79.29	96	–56.19	29.42	1.8	4.9	4.30
HFM34	6701374.67	1632498.45	–89.22	108	–55.43	28.98	1.8	4.9	4.88
HFM34	6701382.19	1632502.59	–101.51	123	–54.59	28.95	1.8	4.9	5.62
HFM34	6701388.39	1632506.04	–111.19	135	–53.10	29.37	1.8	4.9	6.23
HFM34	6701394.74	1632509.62	–120.72	147	–51.90	29.73	1.8	4.9	6.85
HFM34	6701401.21	1632513.37	–130.10	159	–50.90	30.57	1.8	4.9	7.49
HFM34	6701407.83	1632517.25	–139.33	171	–49.29	30.15	1.8	4.9	8.15
HFM34	6701416.50	1632522.23	–150.52	186	–47.36	29.63	1.8	4.9	9.01
HFM34	6701425.27	1632527.18	–161.28	200.75	–46.59	29.41	1.8	4.9	9.87

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a minor discrepancy against the measured values seen in Borehole direction surveying (EG151).

Table 5-8. Deviation data and uncertainty data for the deviation measurements in HFM35 for approximately every 10 m borehole length calculated from EG154.

Idcode	Northing	Easting	Elevation	Length	Inclination	Bearing	Inclination uncertainty	Bearing uncertainty	Radius uncertainty
HFM35	6701555.86	1632320.51	1.90	0	–59.27	32.96	1.8	4.9	0.00
HFM35	6701562.46	1632324.87	–10.84	15	–57.24	33.76	1.8	4.9	0.68
HFM35	6701567.98	1632328.54	–20.85	27	–55.48	33.60	1.8	4.9	1.25
HFM35	6701573.77	1632332.42	–30.62	39	–53.70	33.98	1.8	4.9	1.85
HFM35	6701579.80	1632336.51	–40.15	51	–51.70	34.40	1.8	4.9	2.47
HFM35	6701586.00	1632340.72	–49.52	63	–51.03	33.83	1.8	4.9	3.12
HFM35	6701593.85	1632346.07	–61.12	78	–50.37	34.71	1.8	4.9	3.93
HFM35	6701600.16	1632350.45	–70.34	90	–49.85	34.62	1.8	4.9	4.59
HFM35	6701606.58	1632354.88	–79.47	102	–49.20	34.64	1.8	4.9	5.25
HFM35	6701614.69	1632360.53	–90.75	117	–47.77	34.76	1.8	4.9	6.10
HFM35	6701623.12	1632366.32	–101.73	132	–46.61	34.43	1.8	4.9	6.97
HFM35	6701629.97	1632370.97	–110.40	144	–46.00	33.85	1.8	4.9	7.68
HFM35	6701638.69	1632376.80	–121.13	159	–45.15	33.82	1.8	4.9	8.58
HFM35	6701647.52	1632382.71	–131.72	174	–44.67	34.04	1.8	4.9	9.49
HFM35	6701654.64	1632387.46	–140.13	186	–44.33	33.51	1.8	4.9	10.22
HFM35	6701663.51	1632393.21	–150.42	200.75	–44.15	32.42	1.8	4.9	11.12

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a minor discrepancy against the measured values seen in Borehole direction surveying (EG151).

5.4 Well Cad presentations

Technical as well as geoscientific results achieved during drilling are presented in the so called Well Cad plots in Figure 5-7, Figure 5-8 and Figure 5-9.

5.5 Hydrogeology

5.5.1 Observations during drilling

Usually. the shallow part of the bedrock in the Forsmark investigation area contains several water yielding fractures, resulting in large water-inflows in a majority of the existing percussion drilled boreholes in the area. At 11 m drilling length in borehole HFM33, an inflow of 3 L/min was encountered. The electrical conductivity of the groundwater (EC-value) amounted to c. 800 mS/m (see Figure 5-10). At 136 m drilling length, the accumulated water inflow suddenly increased to c. 400 L/min, corresponding to an EC-value increasing to c. 1,500 mS/m. After having penetrated this permeable fracture, the drilling speed decreased dramatically, as most of the compressed air had to be used for discharging the groundwater instead of supporting the drill hammer, and therefore drilling was interrupted at 140.20 m drilling length. After flushing the borehole and when the inflow from the permeable fracture had stabilised, an accumulated steady-state groundwater yield of c. 300 L/min with an EC-value of 1,550 mS/m was observed. This value indicates semi-deep bedrock groundwater conditions.

In borehole HFM34 (Figure 5-11) the first observed inflow at 18 m (85 L/min) is corresponding to an EC-value of c. 850 mS/m. Although there is a gradually increasing water inflow that finally ends with a capacity of c. 340 L/min, the EC-value remains almost constant at c. 800 mS/m, indicating inflow of sea water into the borehole.

The accumulated inflow to borehole HFM35 (Figure 5-12) at 53 m amounts to 10 L/min and corresponds to an EC-value of c. 700 mS/m. Further down the water yield is increasing step by step, and at 152 m drilling length the accumulated water inflow is twice as large. c. 20 L/min, and the EC-value is c. 800 mS/m. Finally, at 182 m the inflow increased to 50 L/min corresponding to an increase of the EC-value to c. 930 mS/m, indicating semi deep bedrock groundwater conditions, probably with a component of sea water.

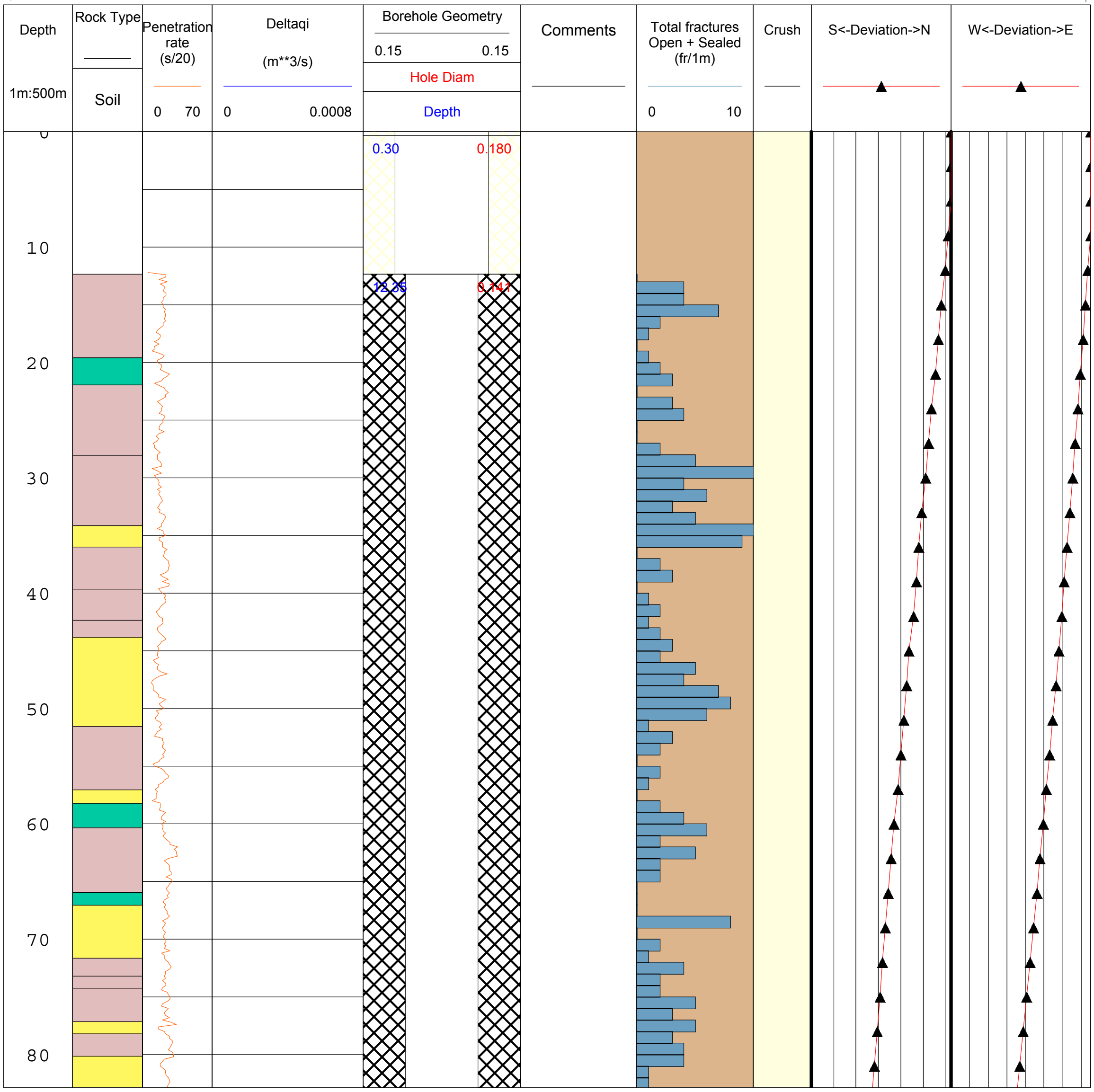
Title	PERCUSSION DRILLED BOREHOLE HFM33		
Svensk Kärnbränslehantering AB		**Signed data**	
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM33	**Northing [m]**	6701042.57
Diameter [mm]	139 (at bottom)	**Easting [m]**	1632222.99
Length [m]	140.20	**Elevation [m.a.s.l.]**	2.62
Bearing [°]	220.03	**Drilling Start Date**	2006-04-26 10:00:00
Inclination [°]	-58.97	**Drilling Stop Date**	2006-05-03 12:25:00
Date of mapping	2006-04-26 10:00:00	**Plot Date**	2007-03-18 22:13:40

ROCKTYPE FORSMARK

SOIL

- **Pegmatite, pegmatitic granite**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Amphibolite**
- **Felsic to intermediate volcanic rock, metamorphic**

Script Name



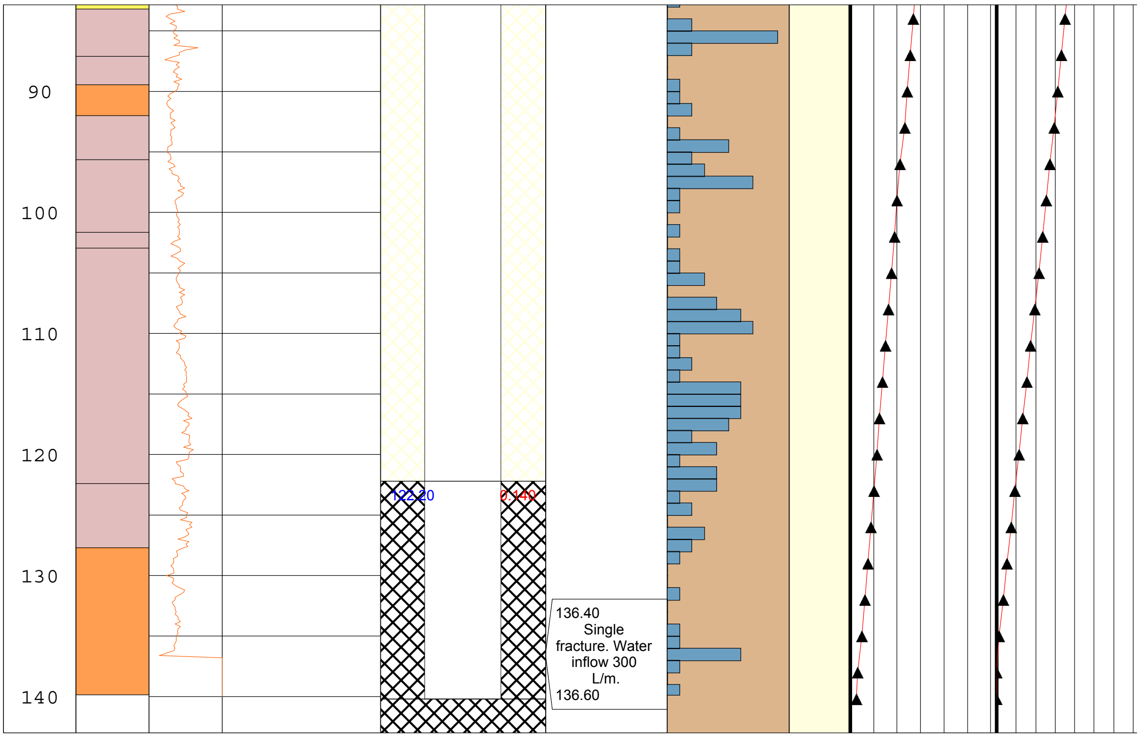


Figure 5-7. *Technical and geoscientific data acquired during drilling of borehole HFM33.*

Title **PERCUSSION DRILLED BOREHOLE HFM34**

Svensk Kärnbränslehantering AB

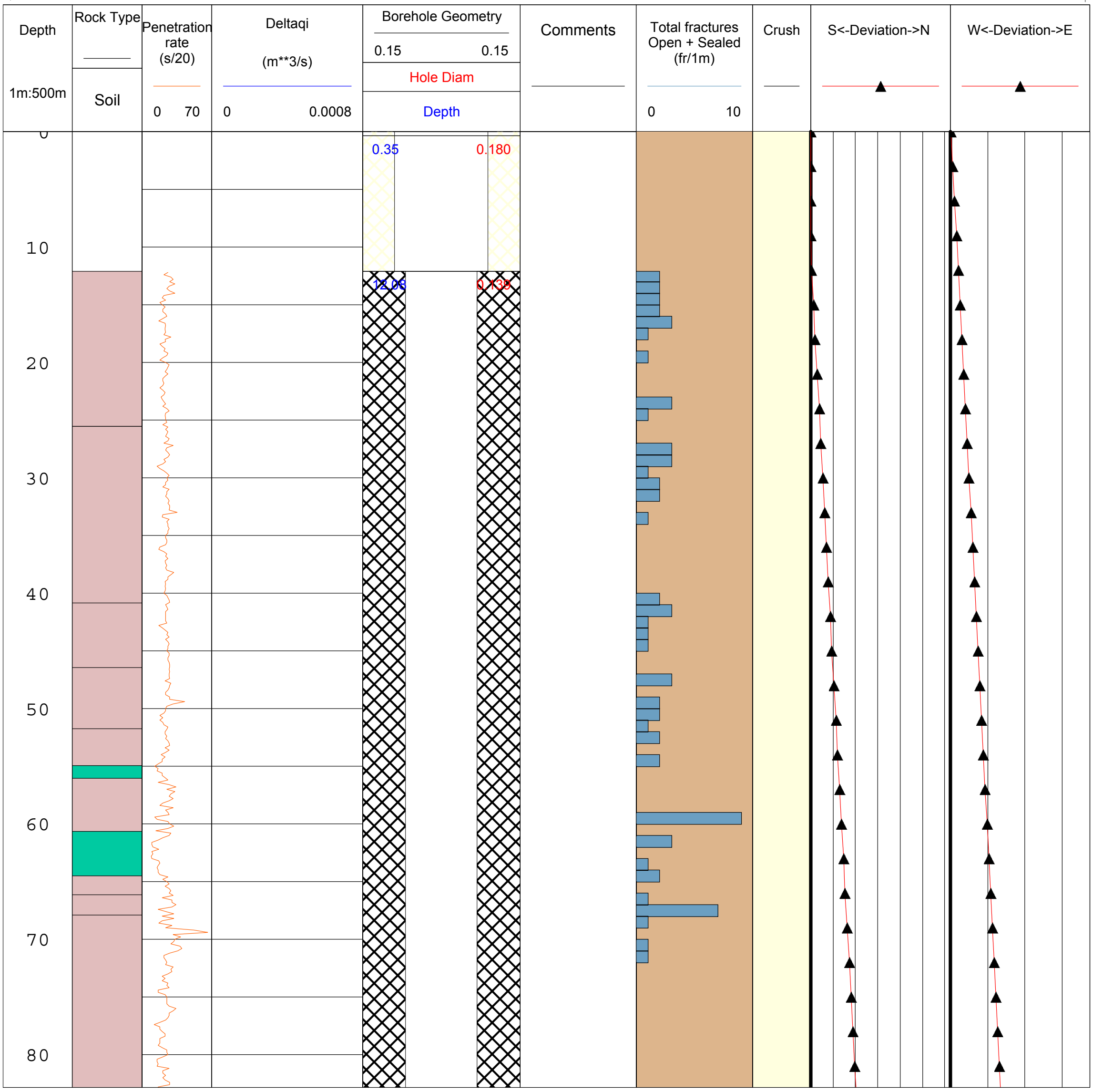
Site	FORSMARK	**Signed data**	
Borehole	HFM34	**Coordinate System**	RT90-RHB70
Diameter [mm]	137 (at bottom)	**Northing [m]**	6701325.06
Length [m]	200.75	**Easting [m]**	1632470.21
Bearing [°]	30.50	**Elevation [m.a.s.l.]**	2.45
Inclination [°]	-58.65	**Drilling Start Date**	2006-05-24 12:30:00
Date of mapping	2006-05-24 00:00:00	**Drilling Stop Date**	2006-06-02 12:00:00
		Plot Date	2007-03-18 22:13:40

ROCKTYPE FORSMARK

SOIL

- **Pegmatite, pegmatitic granite**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Amphibolite**
- **Felsic to intermediate volcanic rock, metamorphic**

Script Name



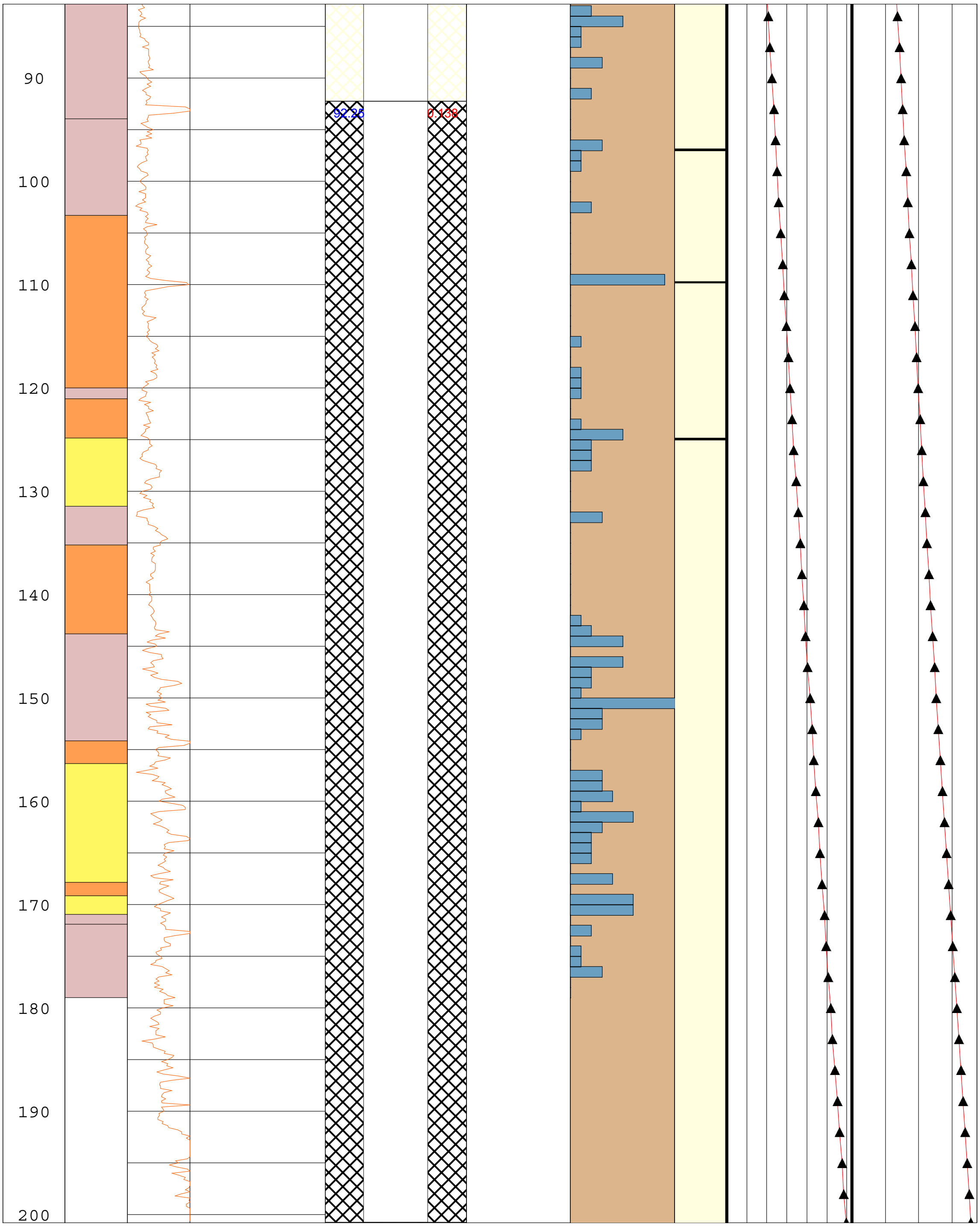


Figure 5-8. *Technical and geoscientific data acquired during drilling of borehole HFM34.*

Title	PERCUSSION DRILLED BOREHOLE HFM35		
Svensk Kärnbränslehantering AB		**Signed data**	
Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM35	**Northing [m]**	6701555.86
Diameter [mm]	136 (at bottom)	**Easting [m]**	1632320.51
Length [m]	200.75	**Elevation [m.a.s.l.]**	1.90
Bearing [°]	32.96	**Drilling Start Date**	2006-06-06 08:00:00
Inclination [°]	-59.19	**Drilling Stop Date**	2006-06-14 11:00:00
Date of mapping	2006-06-06 00:00:00	**Plot Date**	2007-03-18 22:13:40

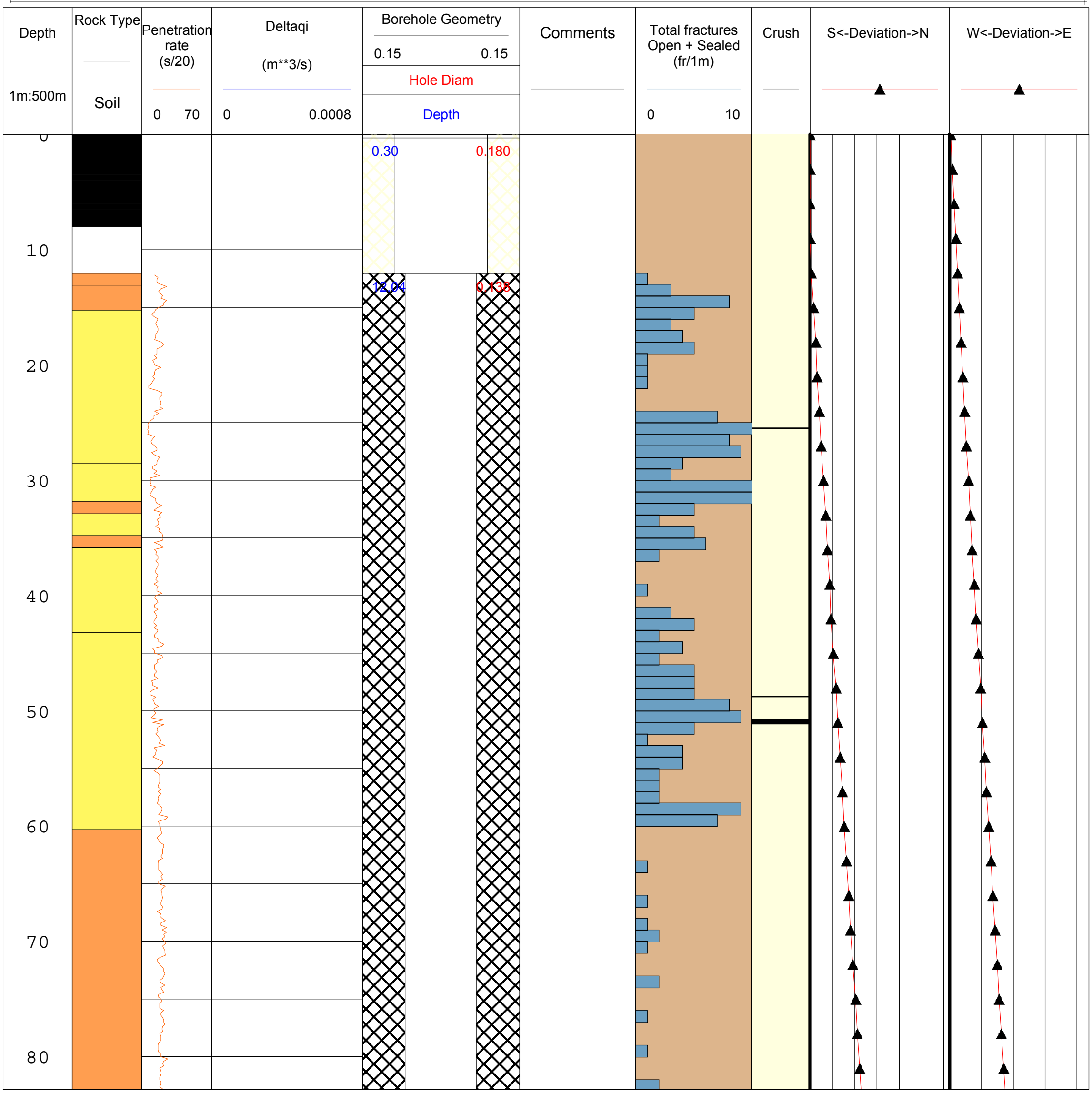
ROCKTYPE FORSMARK

- **Granite, fine- to medium-grained**
- **Pegmatite, pegmatitic granite**
- **Amphibolite**
- **Felsic to intermediate volcanic rock, metamorphic**

SOIL

- **Soil**

Script Name



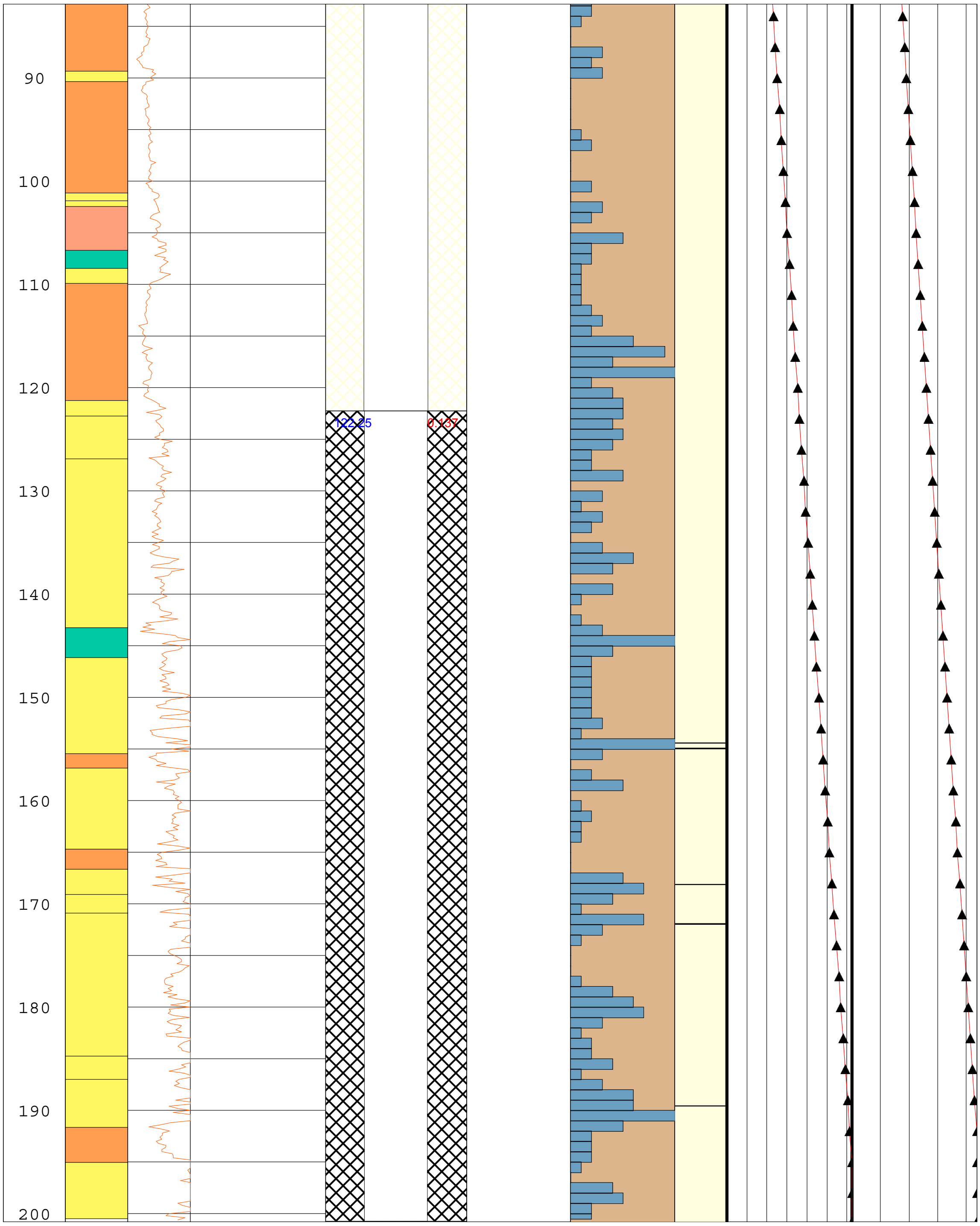


Figure 5-9. *Technical and geoscientific data acquired during drilling of borehole HFM35.*

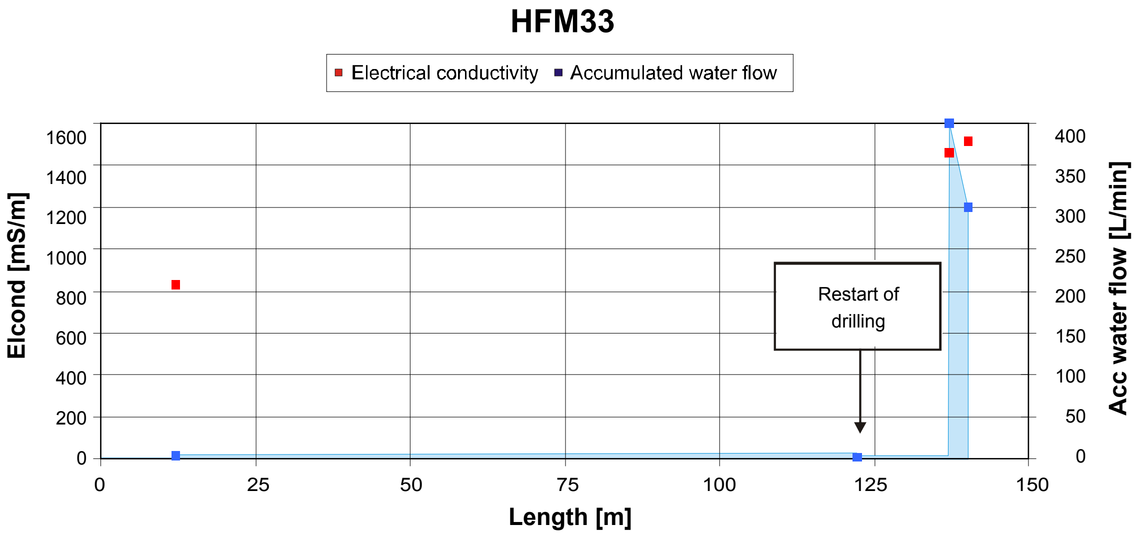


Figure 5-10. Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM33.

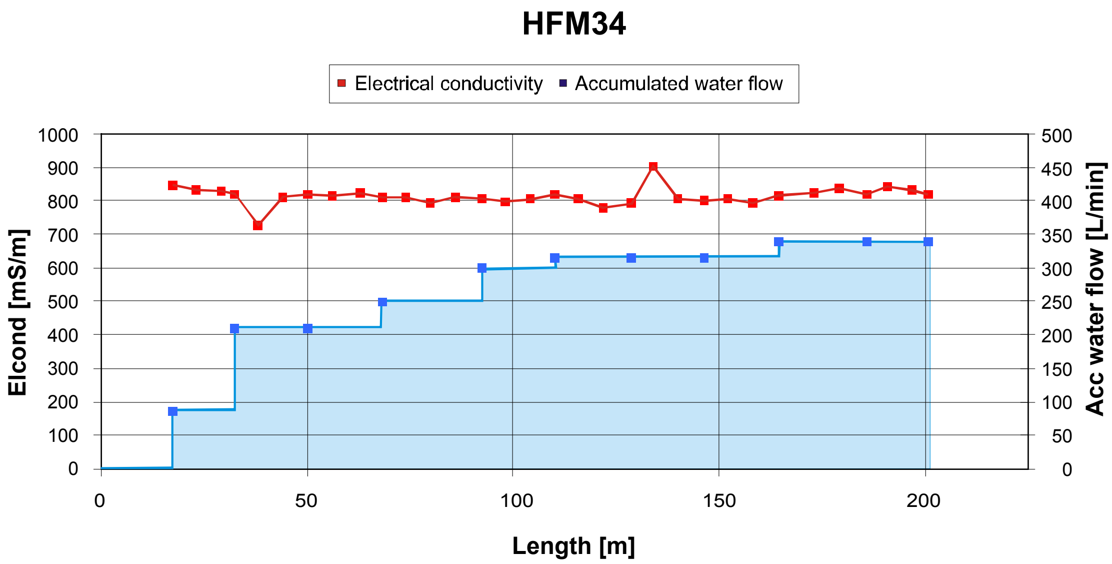


Figure 5-11. Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM34.

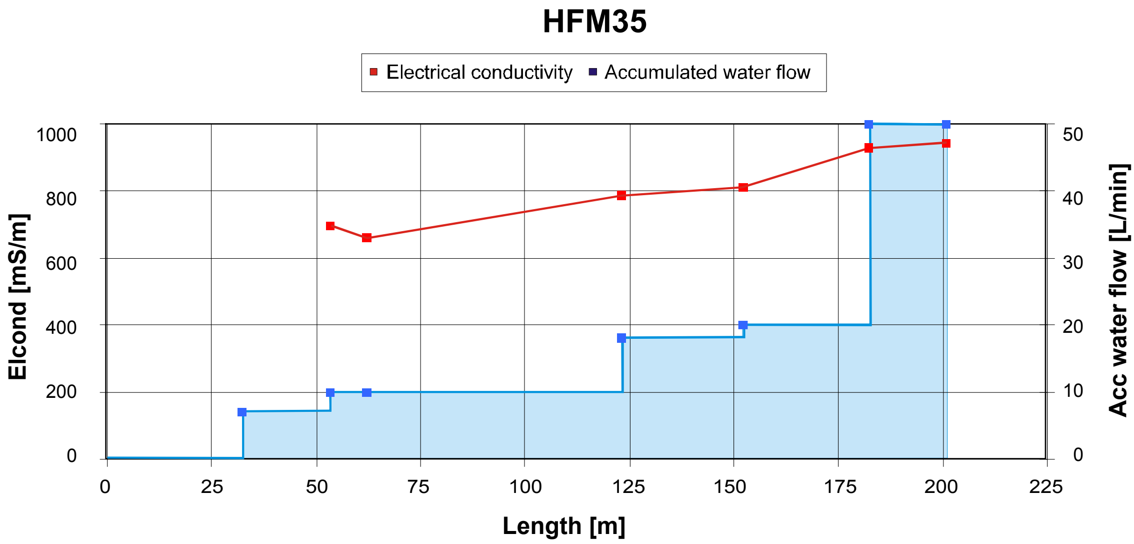


Figure 5-12. *Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM35.*

6 References

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/3/ **SKB, 2007.** Döse C and Samuelsson E. Forsmark site investigation. Boremap mapping of percussion boreholes HFM33-37. SKB P-report in progress, Svensk Kärnbärnslehantering AB.