P-07-43

Forsmark site investigation

Drilling of a flushing water well, HFM36, a groundwater monitoring well in solid bedrock, HFM37, and a groundwater monitoring well in soil, SFM0109

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

March 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

ISSN 1651-4416
SKB P-07-43

Forsmark site investigation

Drilling of a flushing water well, HFM36, a groundwater monitoring well in solid bedrock, HFM37, and a groundwater monitoring well in soil, SFM0109

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

March 2007

Keywords: AP PF 400-06-043, Percussion drilling, Monitoring well, DS12.

Summary

Two boreholes in solid rock, HFM36 and HFM37, were drilled at drill site DS12 using percussion drilling technique.

Borehole HFM36 was aimed both as a flushing water well for the planned core drilling at DS12 and, later, for monitoring of the groundwater level and for groundwater sampling. A third objective of borehole HFM36 was to characterize the Forsmark Deformation Zone in its shallow part. The goals of borehole HFM37 were to investigate a minor lineament striking NW-SE just south-west of the drill site, and to be used as a monitoring well.

Borehole HFM36, which was drilled during the period August 28th to September 4th, 2006, is 152.55 m long, inclined 59 degrees to the horizontal plane and is drilled with a diameter of c. 138 mm. A water inflow of 60 L/min was encountered during drilling.

Borehole HFM37 was drilled during the period August 7th to 16th, 2006. This borehole is 191.75 m long, inclined 59 degrees to the horizontal plane and has a diameter of c. 141 mm. A water yield of 12 L/min was observed during drilling.

Also percussion drilling of a soil borehole, SFM0109, was performed at DS12 with the purpose to be used for monitoring of the groundwater level in the regolith.

Sammanfattning

Två hammarborrhål, HFM36 och HFM37, har borrats vid borrplats BP12.

Borrhål HFM36 var avsett att användas både som spolvattenbrunn vid kärnborrningen vid borrplatsen och, senare, som moniteringsbrunn for registrering av grundvattennivån och för vattenprovtagning. Ett tredje syfte med HFM36 var att undersöka den ytligare delen av Forsmarkszonen.

Syftet med HFM37 var att undersöka ett lineament med strykning i nordväst-sydostlig riktning strax sydväst om borrplatsen samt att användas som moniteringsbrunn.

HFM36 borrades under perioden 28:e augusti till 4:e september 2006. Borrhålet är 152,55 m långt, är ansatt 59° mot horisontalplanet och borrat med diametern ca 138 mm. Under borrningen noterades ett vatteninflöde av 60 L/min.

HFM37 borrades under perioden 7:e till 16:e augusti 2006. HFM37 är 191,75 m långt, är ansatt 59° mot horisontalplanet och har en diameter av ca 141 mm. Vattenkapaciteten uppskattades under borrningen till totalt 12 L/min.

Även ett jordborrhål, SFM0109 utfördes med hammarborrningsteknik vid BP12. Borrhålet skall användas för monitering av grundvattennivån i jordlagren.

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 the drilling of a flushing water well, HFM36, and a monitoring well, HFM37, in solid rock as well as a monitoring well in soil, SFM0109, at drill site DS12. This is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-06-043. 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 inclined core drilled boreholes, drilled from drill sites DS4–DS10 within or close to the candidate area.

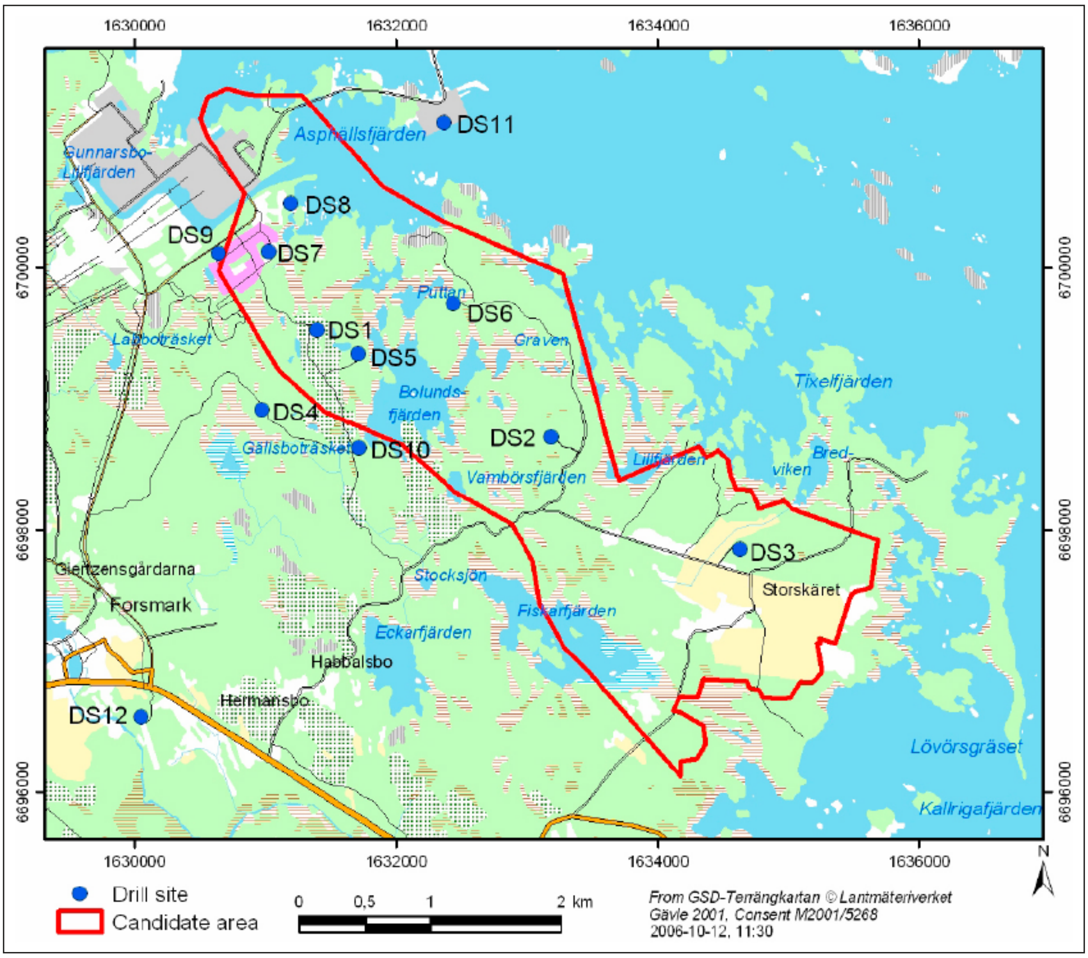


***Figure 1-1.** The investigation area at Forsmark including the candidate area selected for more detailed investigations. Drill sites DS1–12 are marked with blue dots.*

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

Activity plan	Number	Version
Hammarborrning av borrhål HFM36, HFM37 och jordborrhålet SFM0109	AP PF 400-06-043	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för hammarborrning	SKB MD 610.003	2.0
Metodbeskrivning för undersökningav borrkax vid hammarborrning	SKB MD 142.001	1.0
Metodbeskrivning för jordborrning	SKB MD 630.003	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
Metod 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

Two new drill sites, DS11 and DS12, were prepared during the spring and autumn 2006, see Figure 1-1. One cored borehole, KFM11A, and three percussion drilled boreholes, HFM33–35, were drilled at DS11 with the primary aim to investigate the bedrock to the north-east of the candidate area and a major deformation zone named the Singö Deformation Zone. The last core drilled borehole drilled during the site investigation, KFM12A, was drilled at DS12. This borehole was aimed at investigating the bedrock within and around another major deformation zone called the Forsmark Deformation Zone, which is striking NW-SE a few kilometres to the south-west of the candidate area. Drilling of the latter is reported in /3/.

All mentioned drill sites also include percussion drilled boreholes in bedrock and in soil, and at DS12 two percussion boreholes in solid rock, HFM36 and HFM37, with the borehole lengths 152.55 m respectively 191.75 m, and one percussion borehole through the soil layer, SFM0109, were drilled. The positions of the currently existing boreholes at drill site DS12 are displayed in Figure 1-2.

Drilling and measurements were carried out during the period August 28th to September 4th, 2006, (HFM36), August 7th to August 16th, 2006 (HFM37), respectively August 21st 2006, (SFM0109).

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan number (AP PF 400-06-043). Only data in SKB's 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 data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

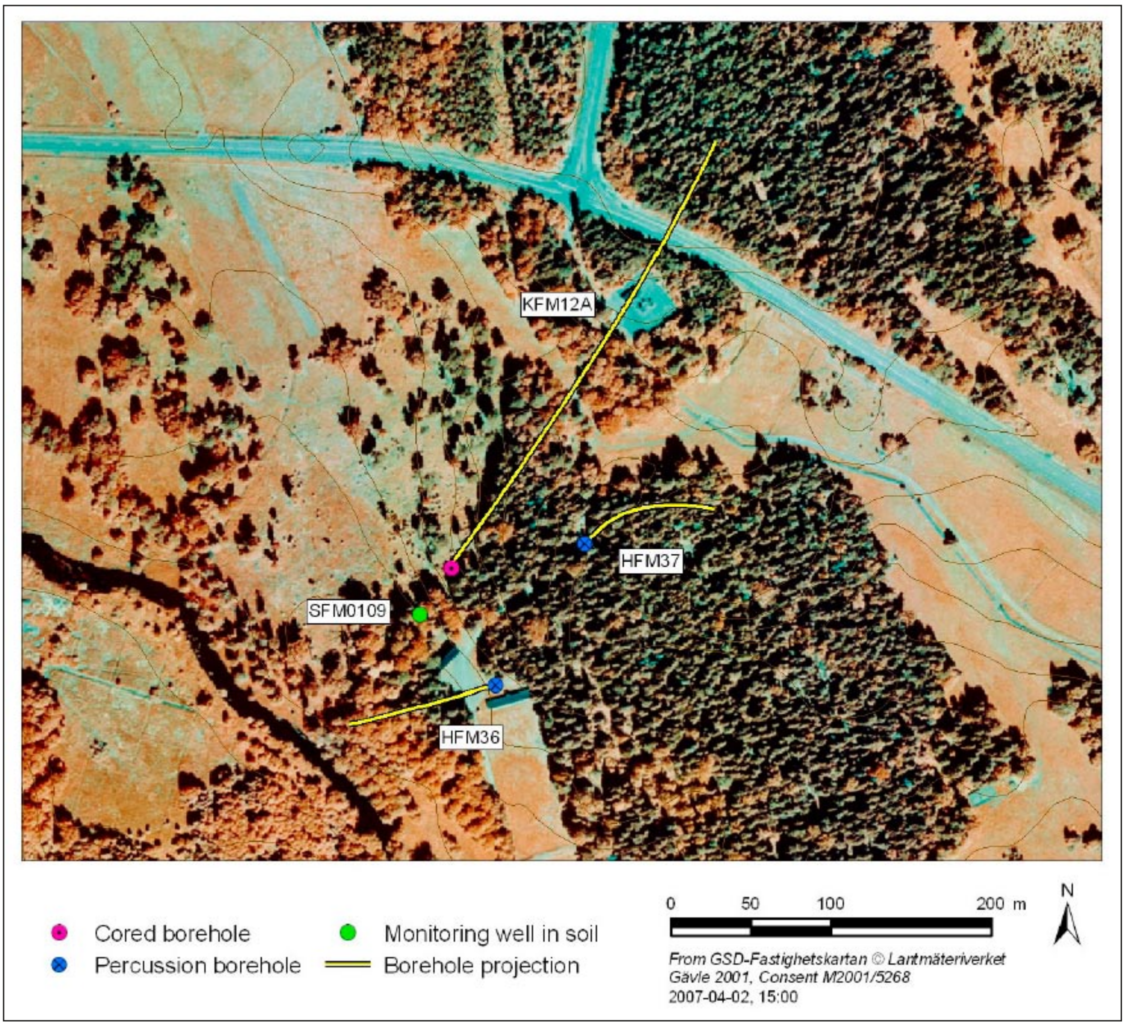


Figure 1-2. *Borehole locations at drill site DS12.*

2 Objective and scope

Core drilling demands injection of relatively large amounts of flushing water through the drill 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 site investigations the supply source for flushing water is normally a groundwater well drilled about 100–200 m into the bedrock in the immediate vicinity of the core drilled borehole to be drilled. 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, and later for long-term observations of the groundwater level and hydrochemical characteristics, monitoring wells are drilled.

Boreholes HFM36 and HFM37 were drilled with multiple aims. Firstly, one borehole, HFM36, was intended to account for supply of the clean flushing water needed for drilling the cored borehole KFM12A (and possibly other cored boreholes at DS12). 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 for HFM36 was to characterize the Forsmark Deformation Zone in its upper part, and a third objective for HFM37 was to investigate a minor lineament striking NW-SE just south-west of the drill site.

The soil borehole SFM0109 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.

Boreholes HFM36 and HFM37 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 boreholes HFM36 and HFM37 was to locate them within the expected radius of influence of groundwater-level drawdown during core drilling at drill site DS12.

Data gained during monitoring of the 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 DS12 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 DS12, the boreholes presented in this report will be used for long-term groundwater level monitoring and groundwater sampling.

3 Equipment

Drilling of boreholes HFM36, HFM37 and SFM0109 was carried out with a Nemek 407 RE DTH percussion drilling machine (Figure 3-1). The machine were supplied with various accessory equipment.

In this chapter short descriptions are given of the drilling system 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.

Figure 3-1. *The Nemek 407 percussion drilling machine employed for drilling the percussion boreholes HFM36, HFM37 and SFM0109 at drill site DS12. Here during drilling of HFM37.*

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.

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 3-2. In HFM36 and HFM37 only the borehole packer technique was applied.

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.

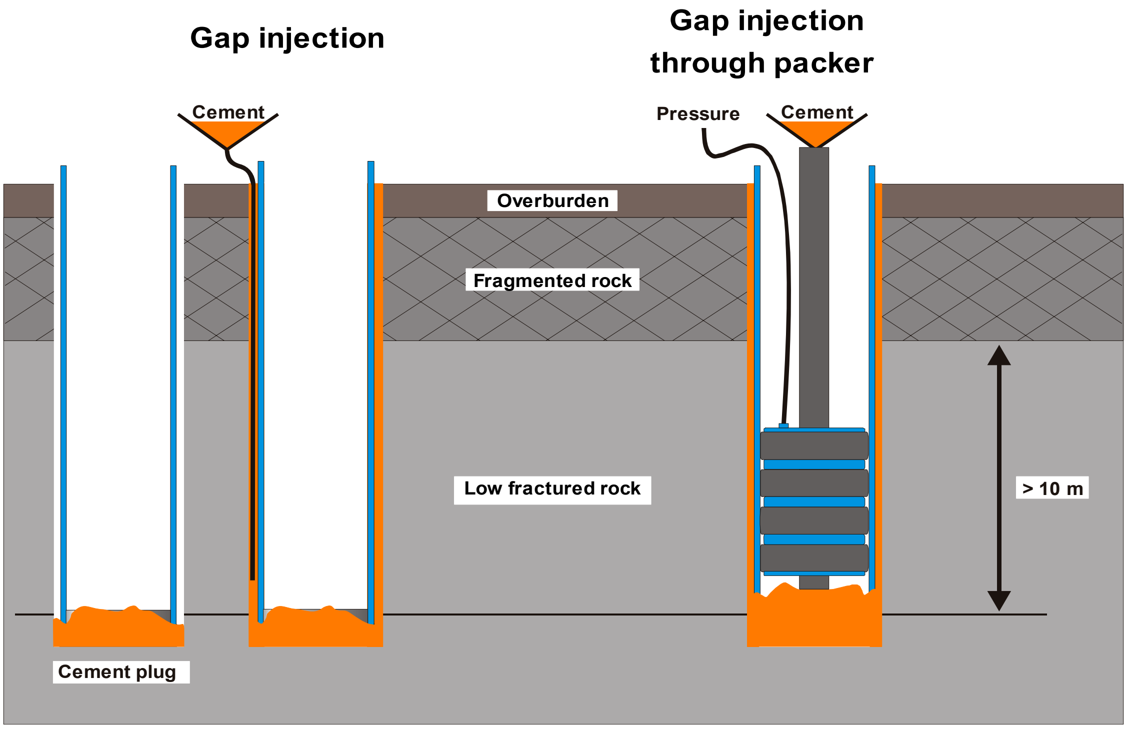


Figure 3-2. *Gap injection technique. In order to grout the gap between the borehole wall and the casing, different systems may be used. To the left, filling up a cement-water mixture with a flexible hose is shown. To the right, injection is performed through a borehole packer.*

However, 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 led to changed routines for adjusting magnetic data, entailing that all available deviation measurements in the percussion drilled boreholes have been revised, including data from boreholes HFM36 and HFM37.

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

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 HFM36 and HFM37 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 before mobilization 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, see Table 1-1.

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 HFM36 and HFM37

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 HFM36 and HFM37, 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 3-2.

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 at Forsmark, and normally the drill bit has to be grinded after about 100 m of drilling. The initial diameter of borehole HFM36 is slightly less than 140 mm due to drilling with a drill bit that was worn from start of drilling.

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, and is 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) /4/.
- 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 second and third items above were used as supporting data for the Boremap mapping mentioned above. The last two items gave on-site information about hydraulic and hydrogeochemical characteristics of the penetrated aquifers at the respective drill sites.

4.3.5 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 drill 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.

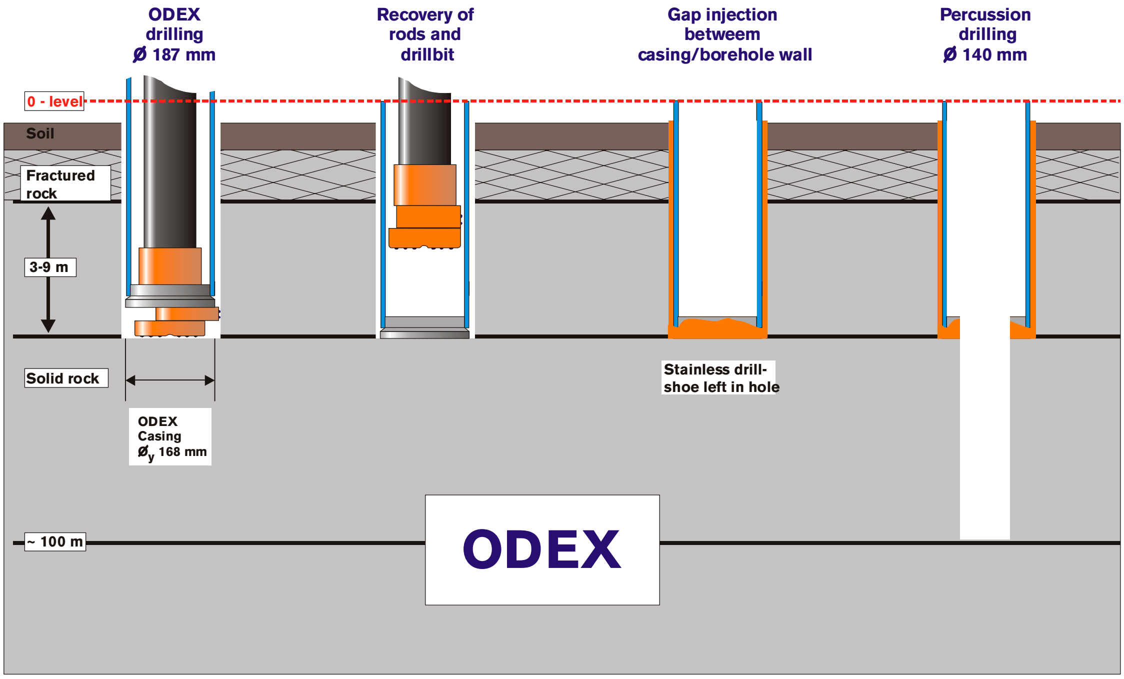


Figure 4-1. *The different steps included in the performance of the percussion drilled boreholes HFM36 and HFM37.*

4.4 Performance of soil borehole SFM0109

4.4.1 Drilling and sampling during drilling

Drilling through the overburden was performed using a variant of the TUBEX-system, called Ejector-TUBEX, see Section 4.3.1. During drilling, a temporary steel casing with the dimension 193.7 mm external and 165 mm internal diameter was simultaneously driven through the soil. When solid rock was indicated, drilling was continued almost one metre further, to ensure that the bedrock surface had been reached and not only compact till or a large boulder.

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

- One soil sample per metre.
- One sample of drill cuttings from the bedrock.
- One observation of groundwater flow (if any) and water colour per 20 cm and a measurement of the flow rate at each major flow change observed. Regarding the MWD flow rate parameter, see Section 4.3.4.
- Measurement of the electrical conductivity (EC) of the sampled groundwater (if any) at each 3 m.

The results from the last two items, preserved as field records, were used exclusively for the on-site decision of the design of the well screen and filter installation in the borehole.

4.4.2 Installation of well screen and screen filter

At completion of drilling, the temporary casing was driven approximately one metre into the bedrock. The results observed during drilling regarding soil depth and type, groundwater inflow etc were analysed on-site, and a decision was made about the design of the borehole installation. The well screen and screen filter were then assembled and the assembling documented. The installation was performed according to the design illustrated in Chapter 5.

The first part of the installation was to fill up a suitable amount of filter sand in the borehole, in order to cover the bedrock. The screen, connected to the riser pipes, was then descended in the borehole all the way down to the sand bed, where it was centralized in the borehole. During simultaneous lifting of the steel casing, the space between the plastic pipe and the inner casing wall was filled up with filter sand. In order to prevent surface water to infiltrate along the borehole, a bentonite sealing was installed at an appropriate level in the borehole. In the actual monitoring well, dry bentonite pellets were used. However, also a bentonite slurry may be suitable for this purpose.

4.4.3 Finishing off work

After installation of the screen, sand filter and sealing, the temporary casing was retrieved and the monitoring well secured with a stainless steel protective casing, which was driven a short distance into the ground around the upper part of the HDPE riser pipe. The casing was then moulded firmly to the ground. Supplied with a lockable stainless steel cover, this construction offers an effective protection against damage of the monitoring well.

Finally, the drilling machine was removed, the site cleaned, and a joint inspection of the drill site made by SKB and the Contractor.

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, where they 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 boreholes

5.1.1 The percussion drilled boreholes in bedrock, HFM36 and HFM37

Administrative, geometric, and technical data for HFM36 and HFM37 are presented in Table 5-1. The technical design of the boreholes is illustrated in Figures 5-1 and 5-2.

5.1.2 The percussion drilled soil borehole SFM0109

The design of the groundwater monitoring well SFM0109 is illustrated in Figure 5-3. Table 5-2 displays the geometric characteristics of the well.

Table 5-1. Administrative, geometric and technical data for boreholes HFM36 and HFM37.

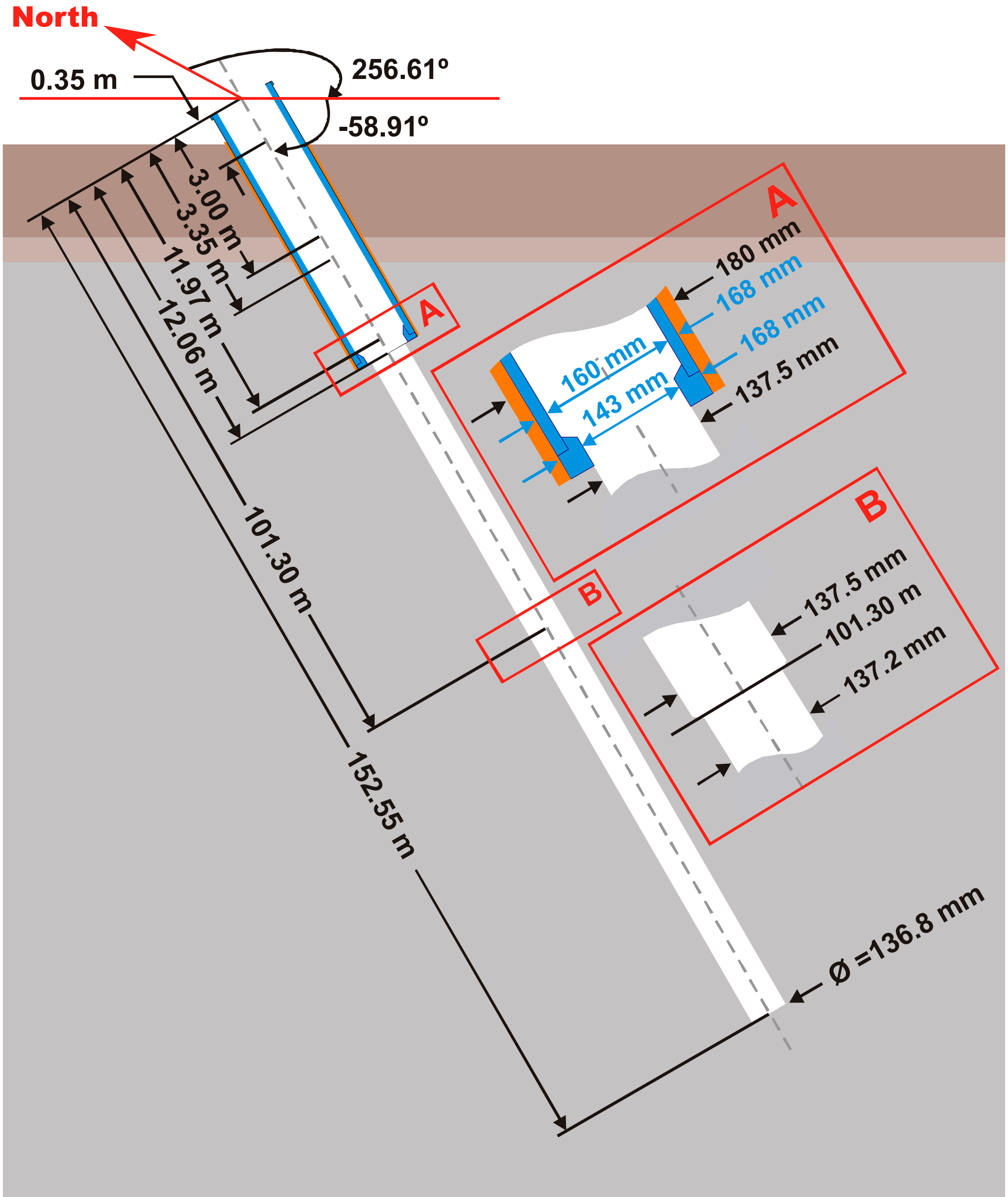
Parameter	HFM36	HFM37
Drilling period	From 2006-08-28 to 2006-09-04	From 2006-08-07 to 2006-08-16
Borehole inclination (collaring point)	–58.91° (– = downwards)	–59.15° (– = downwards)
Borehole bearing	256.61°	41.35°
Borehole length	152.55 m	191.75 m
Borehole diameter	From 0.00 m to 12.06 m: 0.180 m	From 0.00 m to 9.07 m: 0.1800 m
	From 12.06 m to 101.30 m: decreasing from 0.1375 m to 0.1372 m	From 9.07 m to 110.25 m: decreasing from 0.1410 m to 0.1395 m
	From 101.30 m to 152.55m: decreasing from 0.1372 m to 0.1368 m	From 110.25 m to 191.75 m: decreasing from 0.1395 m to 0.1385 m
Casing length	12.06 m	9.07 m
Casing diameter	Øo/Øi = 168 mm/160 mm to 12.06 m	Øo/Øi = 168 mm/160 mm to 9.07 m
Drill bit diameter	Start of drilling: 0.1375 m End of drilling: 0.1368 m	Start of drilling: 0.1410 m End of drilling: 0.1385 m
Collaring point coordinates (system RT90 2.5 gon V/RHB70)	Northing: 6696504.03 m Easting: 1630081.68 m Elevation: 8.415 m.a.s.l.	Northing: 6696592.43 m Easting: 1630137.37 m Elevation: 11.391 m.a.s.l.
Soil cover	2.57 m	2.96 m

Table 5-2. Geometric data for groundwater monitoring well SFM0109.

Drillhole ID	Incl.	Northing	Easting	Elevation m.a.s.l. (top of HDPE-pipe)	Total depth from ground level (m)	Bh diam. (mm)	Screen length (m)	Total pipe length (including a well screen and riser pipes) (m)	Screen pipe diameter (Øo/Øi, mm)
SFM0109	–89.43°	6696552.49	1630028.38	8.14	5.04	193.7	1.00	5.00	90/72

Technical data

Borehole HFM36



Drilling reference point

Northing: 6696504.03 (m), RT90 2,5 gon V 0:-15
Easting: 1630081.68 (m), RT90 2,5 gon V 0:-15
Elevation: 8.42 (m), RHB 70

Drilling period

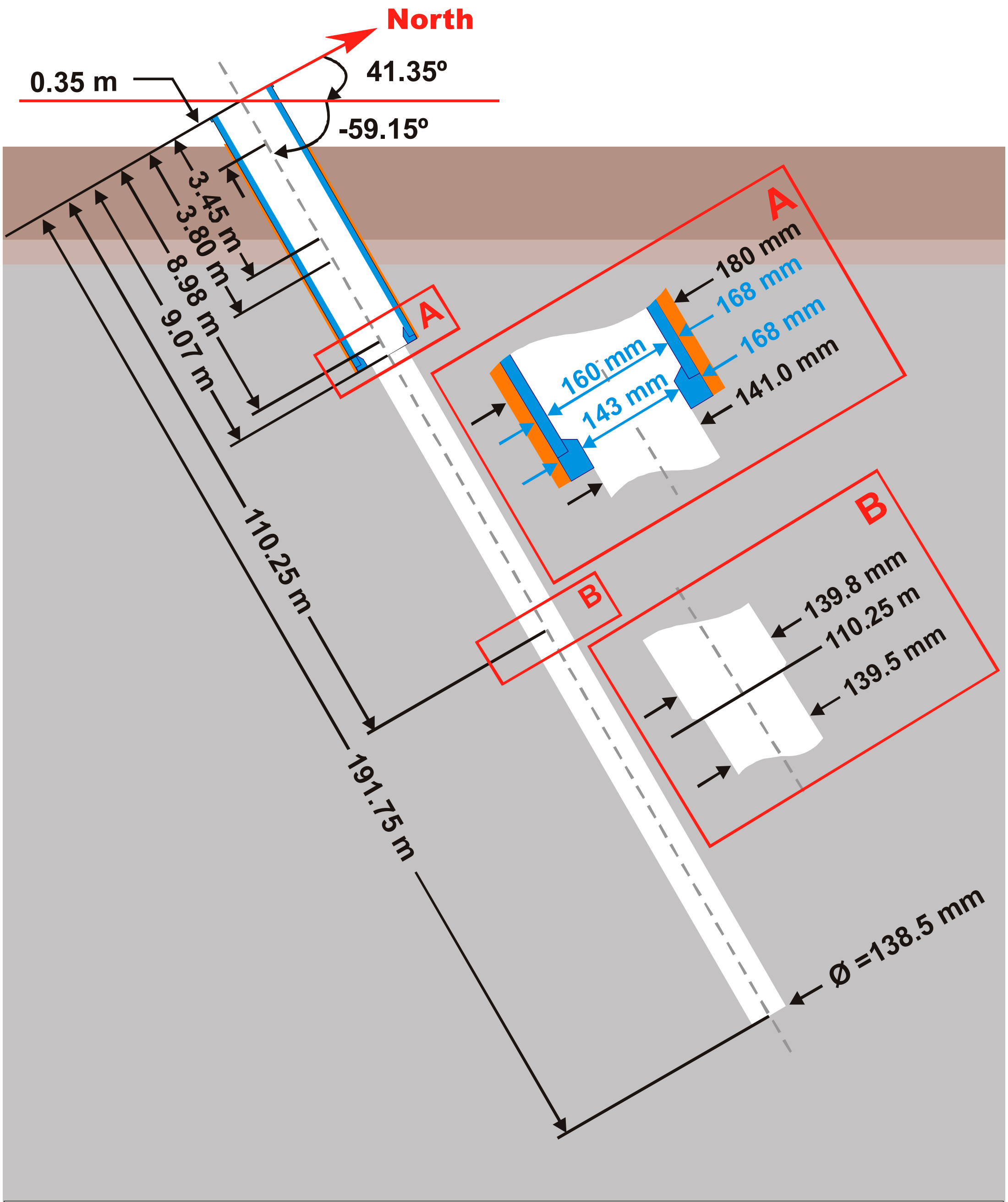
Drilling start date: 2006-08-28
Drilling stop date: 2006-09-04

rev 2006-10-04

Figure 5-1. *Technical data for borehole HFM36.*

Technical data

Borehole HFM37



Drilling reference point

Northing:	6696592.43	(m), RT90 2,5 gon V 0:-15
Easting:	1630137.37	(m), RT90 2,5 gon V 0:-15
Elevation:	11.39	(m), RHB 70

Drilling period

Drilling start date:	2006-08-07
Drilling stop date:	2006-08-16

rev 2007-03-29

Figure 5-2. *Technical data for borehole HFM37.*

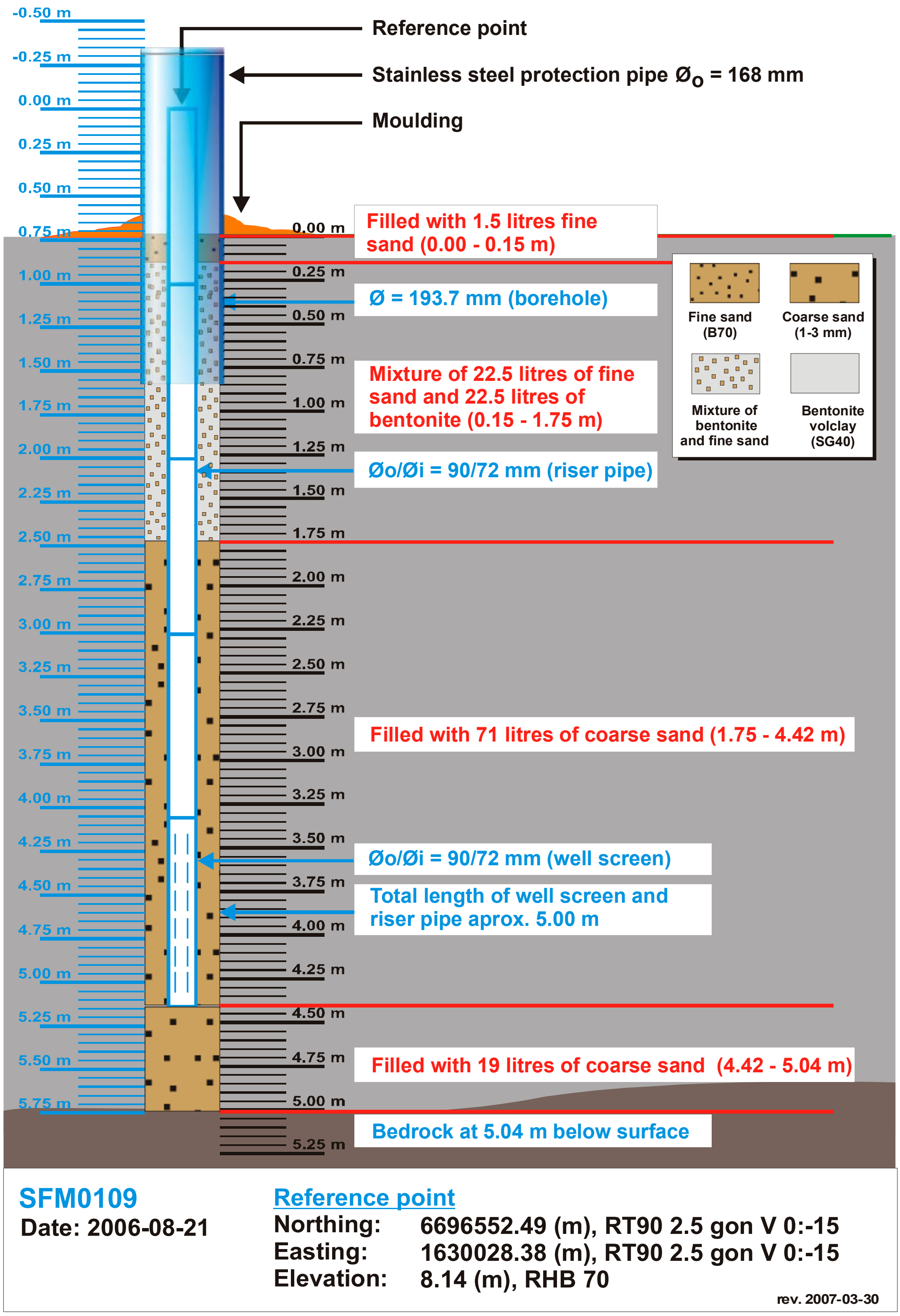


Figure 5-3. *The groundwater monitoring well installation in borehole SFM0109.*

5.2 Consumables used when drilling HFM36, HFM37 and SFM0109

The amount of oil products consumed during drilling of the boreholes HFM36, HFM37 and SFM0109, and amount of grout used for gap injection of the respective casings are 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 5-4.

Regarding contamination risks, albeit some amounts of hammer oil and possibly also compressor oil (although not in detectable amounts, see Table 5-3) 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 two boreholes in solid rock 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 Sept 4th, and Aug 16th 2006, is seen in Figures 5-4 and 5-5 respectively, and shows only minor disturbances when the FLEXIT surveys in HFM36 (between 1:00 and 2:05 PM) and in HFM37 (3:30 and 4:20 PM) were performed.

In the following a systematic description of the construction of the revised deviation data for both percussion drilled boreholes HFM36–37, are given.

Table 5-3. Oil consumption during drilling.

Borehole ID	Hammer oil Preem Hydra 46	Compressor oil Schuman 46
HFM36	10 L	Below detection limit
HFM37	5 L	Below detection limit
SFM0109	Not documented	Below detection limit

Table 5-4. Consumption of cement grouting.

Borehole ID	Casing length	Cement volume (Aalborg Portland Cement/microsilica)	Grouting method
HFM36	12.06 m	94 kg	Borehole packer
HFM37	9.06 m	138 kg/120 L	Borehole packer
SFM0109	c. 0.5 m	36 kg	Flexible hose

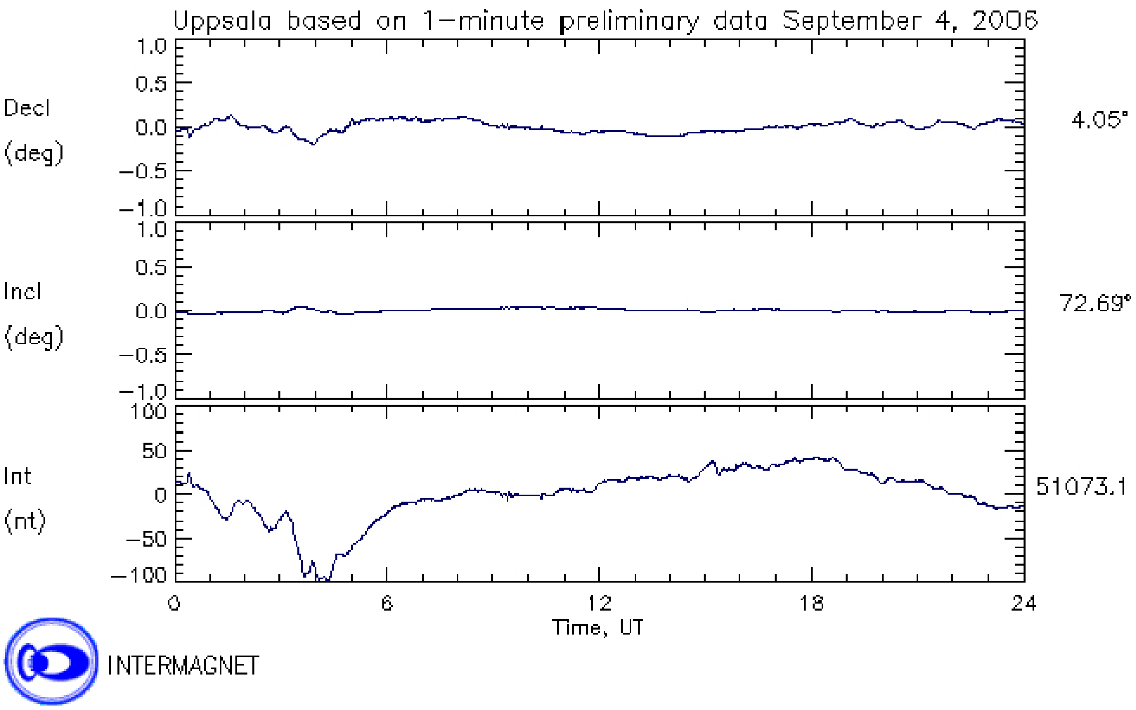


Figure 5-4. *Magnetic field variation during the FLEXIT survey performed on Sept 4th, 2006, in HFM36.*

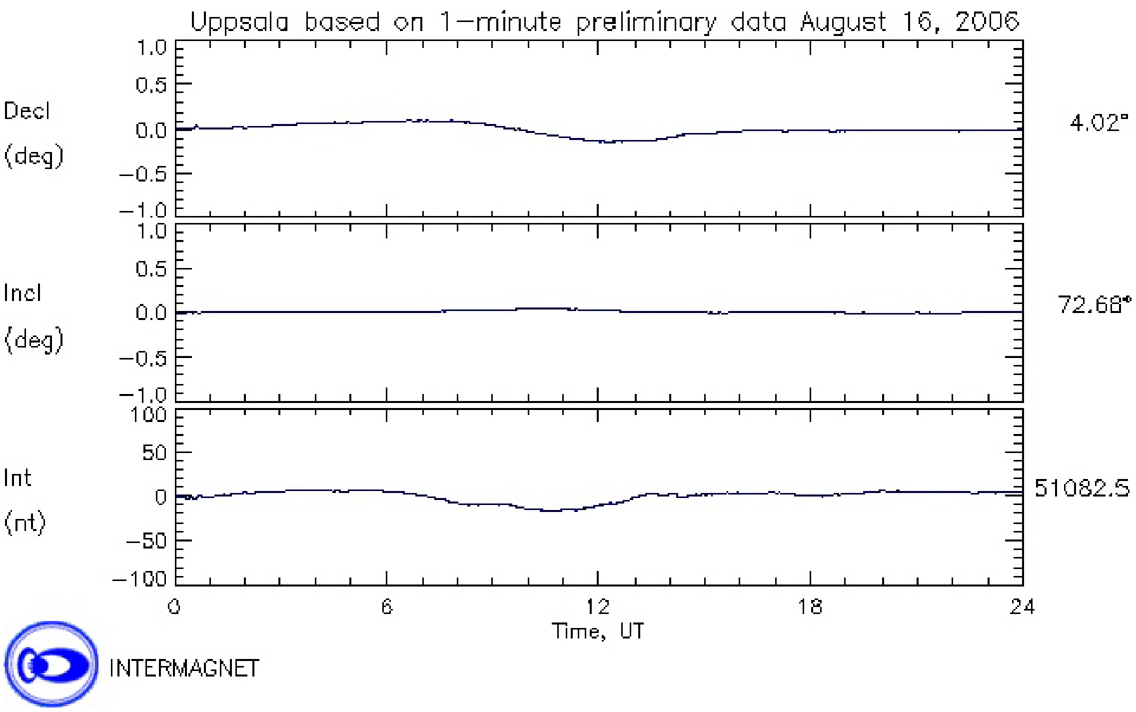


Figure 5-5. *Magnetic field variation during the FLEXIT survey performed on Aug 16th, 2006, in HFM37.*

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.

The deviation data used for calculation of the borehole deviation file stored in Sicada are one FLEXIT-logging for each borehole. The deviation measurements in both boreholes were carried out every 3 m downwards, to 150 m borehole length in HFM36 and to 189 m borehole length in HFM37. These measurements were originally allotted the activity numbers 13120325 respectively 13120327, see Table 5-5. 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 HFM36 and HFM37 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 13141428 and 13141482, which are denoted an "F-flag" (Table 5-5). 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 13142280 and 13142282). 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 5-6. The different length of the upper sections between the bearing and the inclination are due to the fact that the magnetic accelerometer measurement (bearing) is influenced by the 9 and 12 m steel casing, whereas inclinometer measurements (inclination) are unaffected by the presence of metal in the borehole.

Table 5-5. Activity data for both deviation measurements approved for HFM36 and HFM37 (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
HFM36	13120325	EG157	Magnetic – accelerometer measurement	2006-09-04 13:00:00	3.00	150.00	EF
HFM36	13141428	EG157	Magnetic – accelerometer measurement	2006-09-04 13:00:00	3.00	150.00	F
HFM36	13142280	EG154	Borehole deviation multiple measurements	2006-12-19 19:00:00			I C
HFM37	13120327	EG157	Magnetic – accelerometer measurement	2006-08-16 15:30:00	3.00	189.00	EF
HFM37	13141482	EG157	Magnetic – accelerometer measurement	2006-08-16 15:30:00	3.00	189.00	F
HFM37	13142282	EG154	Borehole deviation multiple measurements	2006-12-19 19:10:00			I C

Table 5-6. 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)
HFM36	13141428	BEARING	15.00	150.00	4.900
HFM36	13141428	INCLINATION	3.00	150.00	1.800
HFM37	13141482	BEARING	21.00	189.00	4.900
HFM37	13141482	INCLINATION	3.00	189.00	1.800

A subset of the resulting deviation file and the estimated radius uncertainty is presented in Tables 5-7 and 5-8.

The calculated deviation (EG154-file) in borehole HFM36 shows that the borehole deviates upwards but is laterally almost straight 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 HFM37 shows that the borehole deviates mostly to the right with an absolute deviation of 55 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 5-7. Deviation data and uncertainty data for the deviation measurements in HFM36 for approximately every 10 m borehole length calculated from EG154.

Idcode	Northing	Easting	Elevation	Length	Incl.	Bearing	Incl._ Uncertainty (degrees)	Bearing Uncertainty (degrees)	Radius_ Uncertainty (m)
HFM36	6696504.03	1630081.68	8.42	0	–59.01	256.61	1.8	4.9	0.00
HFM36	6696502.91	1630077.17	0.71	9	–58.72	255.13	1.8	4.9	0.40
HFM36	6696501.19	1630070.92	–9.39	21	–56.49	254.71	1.8	4.9	0.96
HFM36	6696499.34	1630064.36	–19.26	33	–54.36	253.68	1.8	4.9	1.54
HFM36	6696496.86	1630055.81	–31.34	48	–52.81	254.00	1.8	4.9	2.31
HFM36	6696494.83	1630048.73	–40.82	60	–51.68	254.05	1.8	4.9	2.94
HFM36	6696492.80	1630041.53	–50.20	72	–51.17	254.47	1.8	4.9	3.58
HFM36	6696490.80	1630034.21	–59.49	84	–50.38	254.89	1.8	4.9	4.23
HFM36	6696488.32	1630024.89	–70.98	99	–49.66	255.21	1.8	4.9	5.05
HFM36	6696486.32	1630017.32	–80.08	111	–48.92	255.29	1.8	4.9	5.72
HFM36	6696484.36	1630009.57	–89.02	123	–47.40	256.31	1.8	4.9	6.41
HFM36	6696481.95	1629999.60	–99.96	138	–46.04	256.81	1.8	4.9	7.28
HFM36	6696479.69	1629989.60	–110.29	152.55	–44.80	257.34	1.8	4.9	8.16

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

Table 5-8. Deviation data and uncertainty data for the deviation measurements in HFM37 for approximately every 10 m borehole length calculated from EG154.

Idcode	Northing	Easting	Elevation	Length	Incl.	Bearing	Incl._ Uncertainty (degrees)	Bearing Uncertainty (degrees)	Radius_ Uncertainty (m)
HFM37	6696592.43	1630137.37	11.39	0	–59.17	41.35	1.8	4.9	0.00
HFM37	6696596.91	1630141.50	1.05	12	–60.06	44.84	1.8	4.9	0.52
HFM37	6696600.90	1630145.73	–9.44	24	–61.68	47.62	1.8	4.9	1.01
HFM37	6696604.50	1630149.99	–20.07	36	–63.10	53.41	1.8	4.9	1.49
HFM37	6696607.46	1630154.45	–30.81	48	–64.03	59.37	1.8	4.9	1.94
HFM37	6696609.86	1630159.04	–41.63	60	–64.62	64.91	1.8	4.9	2.38
HFM37	6696611.36	1630162.56	–49.77	69	–64.91	69.32	1.8	4.9	2.71
HFM37	6696612.95	1630167.39	–60.64	81	–65.03	73.66	1.8	4.9	3.14
HFM37	6696614.17	1630172.34	–71.50	93	–64.45	77.67	1.8	4.9	3.58
HFM37	6696614.91	1630176.17	–79.62	102	–64.08	79.78	1.8	4.9	3.91
HFM37	6696615.66	1630181.45	–90.37	114	–63.30	83.56	1.8	4.9	4.37
HFM37	6696616.15	1630186.86	–101.06	126	–62.90	85.90	1.8	4.9	4.84
HFM37	6696616.31	1630190.98	–109.07	135	–62.87	89.32	1.8	4.9	5.19
HFM37	6696616.26	1630196.43	–119.76	147	–62.97	91.94	1.8	4.9	5.65
HFM37	6696615.94	1630201.92	–130.42	159	–62.60	94.27	1.8	4.9	6.12
HFM37	6696615.37	1630207.50	–141.03	171	–61.65	97.24	1.8	4.9	6.61
HFM37	6696614.50	1630213.20	–151.56	183	–60.83	100.18	1.8	4.9	7.10
HFM37	6696613.67	1630217.41	–159.18	191.75	–60.46	101.63	1.8	4.9	7.47

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a 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 Figures 5-6 and Figure 5-7.

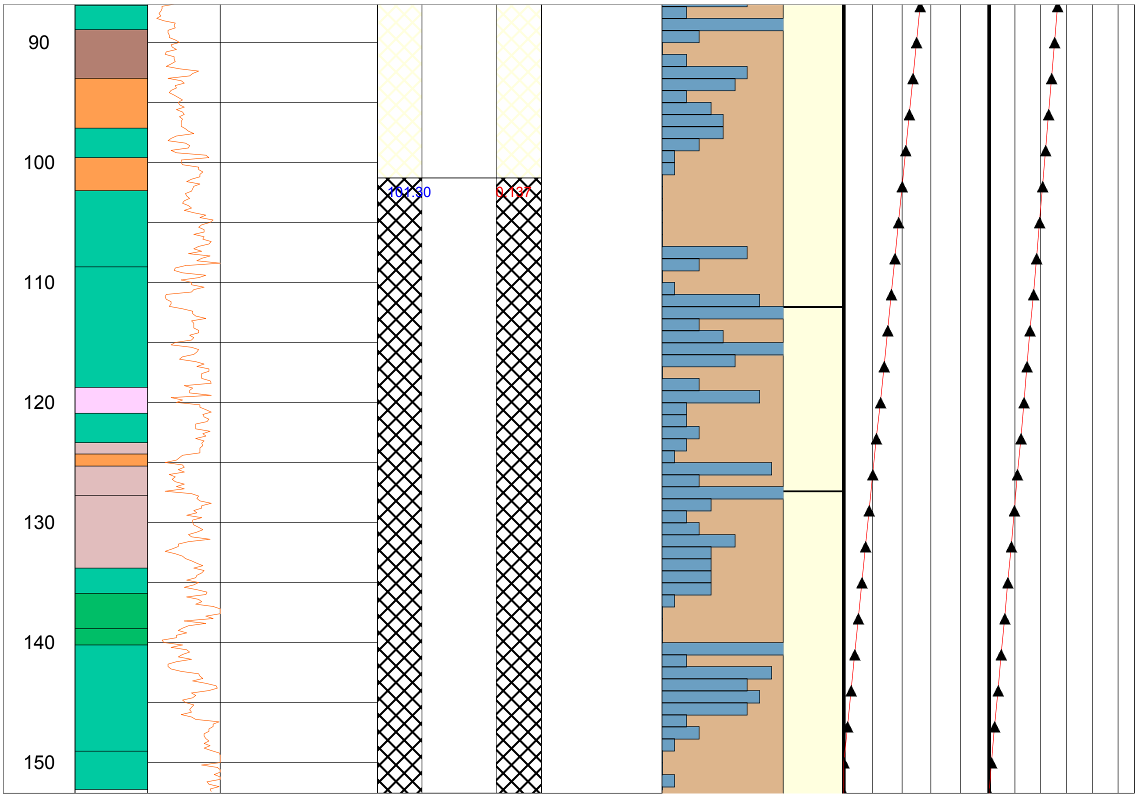


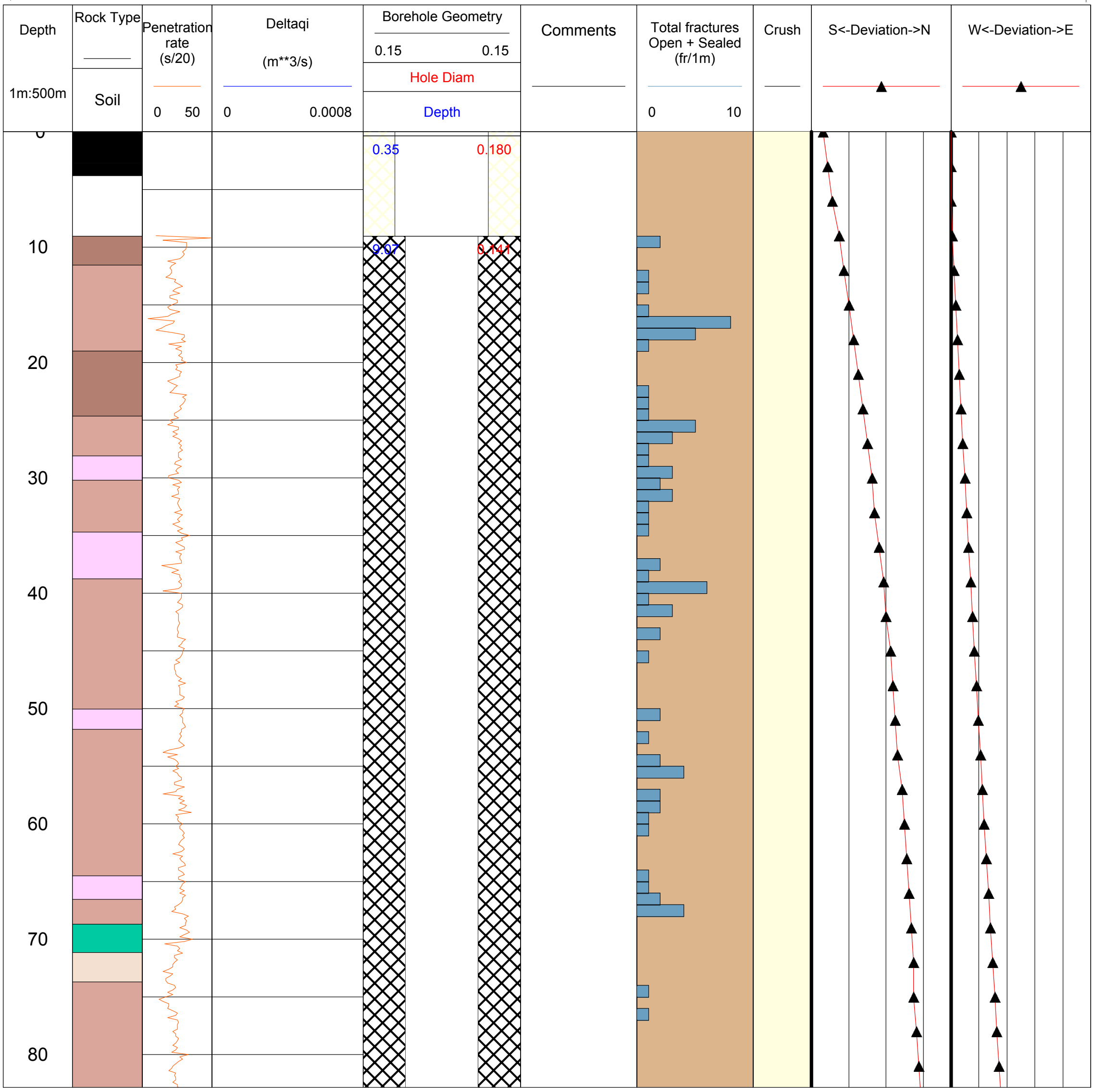
Figure 5-6. *Technical and geoscientific data acquired during drilling of borehole HFM36.*

Title	PERCUSSION DRILLED BOREHOLE HFM37		
Svensk Kärnbränslehantering AB		Signed data	
Site	FORSMARK	Coordinate System	RT90-RHB70
Borehole	HFM37	Northing [m]	6696592.43
Diameter [mm]	139 (at bottom)	Easting [m]	1630137.37
Length [m]	191.75	Elevation [m.a.s.l.]	11.39
Bearing [°]	41.35	Drilling Start Date	2006-08-07 16:00:00
Inclination [°]	-59.15	Drilling Stop Date	2006-08-16 15:00:00
Date of mapping	2006-08-07 12:00:00	Plot Date	2007-04-15 23:55:01

ROCKTYPE FORSMARK
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granodiorite, metamorphic
- Tonalite to granodiorite, metamorphic
- Amphibolite

SOIL
- Soil

Script Name



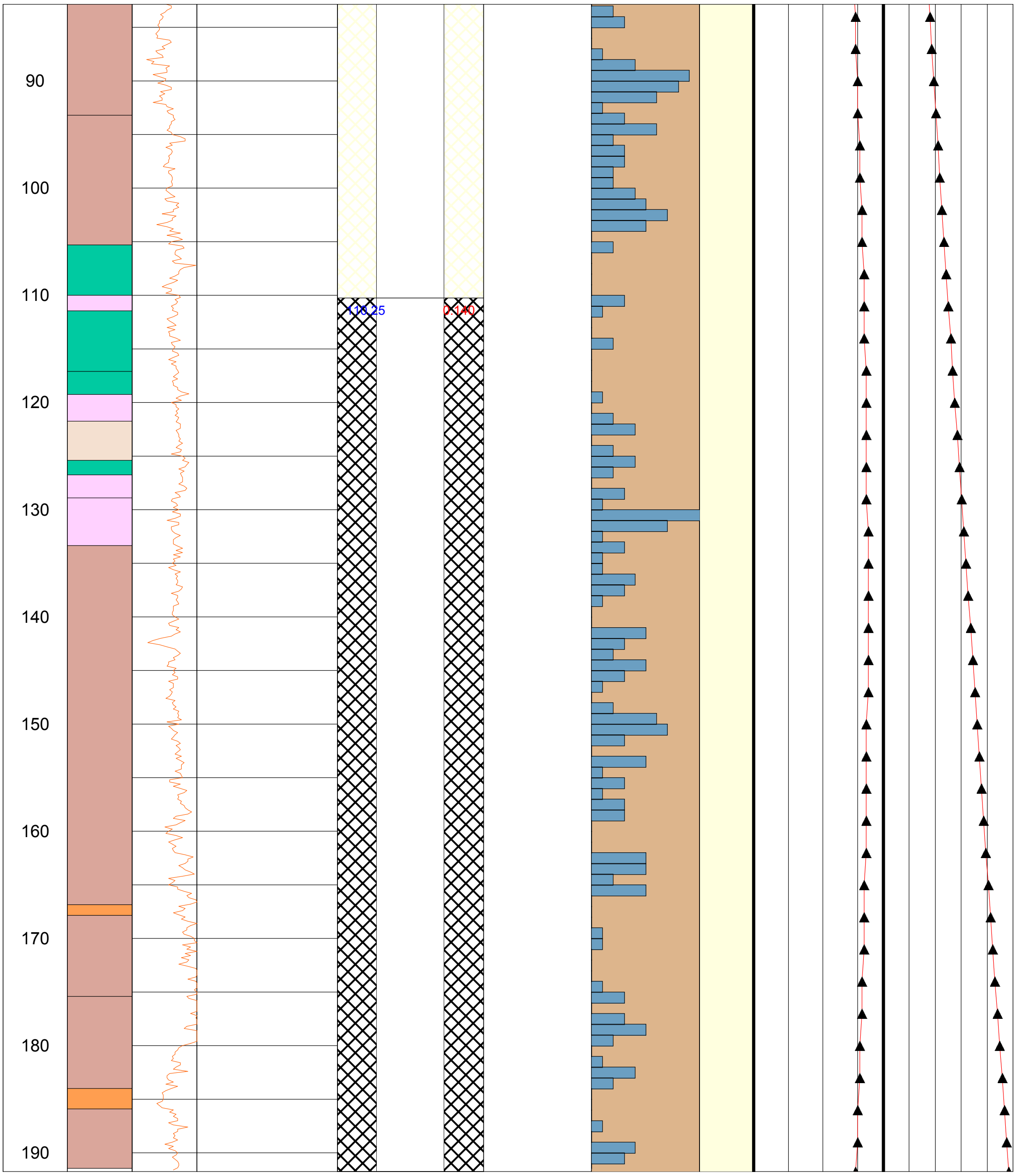


Figure 5-7. *Technical and geoscientific data acquired during drilling of borehole HFM37.*

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. HFM36 and HFM37, located at drill site DS12 about 3 km west of the candidate area, do not follow this pattern exactly, especially not HFM37. During drilling and sampling in borehole HFM37, a minor water-inflow was observed, appearing only as moist drilling debris, but after completed drilling the estimated accumulated water inflow increased to 12 L/min.

During casing driving in HFM36, a water yield of approximately 55 L/min was encountered at 11 m drilling length. The borehole was thereafter cased and cement grouted so that the inflow ceased completely. At 32 m drilling length, a new inflow of 18 L/min was observed. The electrical conductivity of the groundwater (EC-value) amounted to 690 mS/m (see Figure 5-8), indicating semi-saline conditions. The water inflow increased to 36 L/min at 89 m drilling length, but still with the EC-value varying around 700 mS/m. When drilling re-started at 101 m drilling length, the water yield had increased to 50 L/min, and further down the EC-values displayed an increasing trend. The final water inflow observed at 125 m drilling length amounted to 60 L/min, which was judged to be a sufficient capacity to supply core drilling of KFM12A with flushing water. Also the water quality was satisfactory for this purpose.

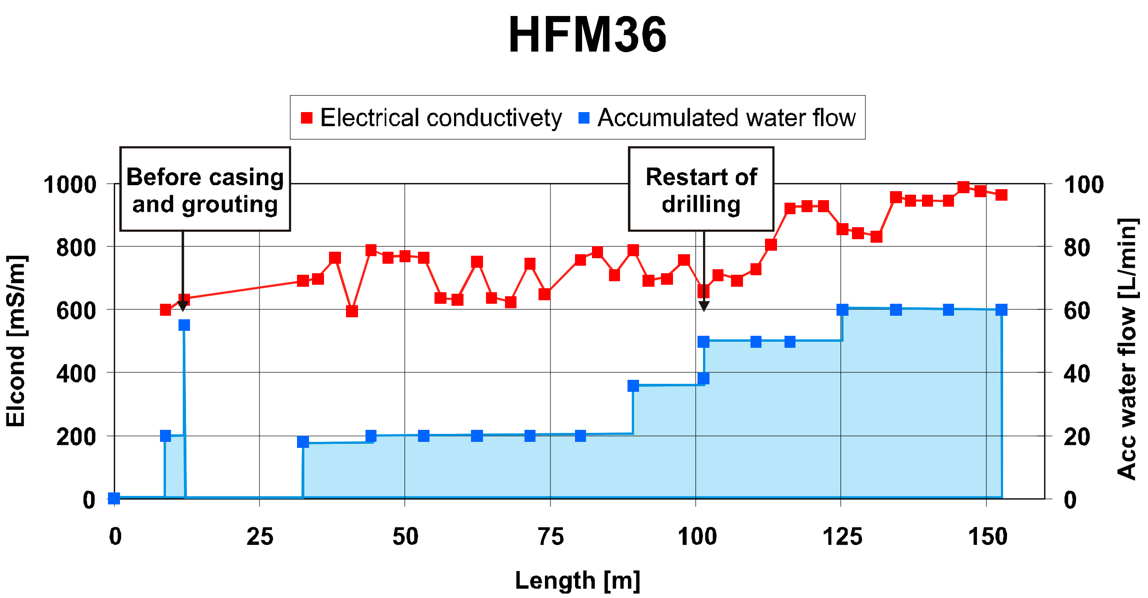


Figure 5-8. Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM36.

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 borehole KFM12A at drill site DS12. SKB P-07-46, Svensk Kärnbränslehantering AB.

/4/ **SKB, 2007.** Samuelsson, E & Döse, C. Forsmark site investigation. Boremap mapping of percussion boreholes HFM33–HFM37. SKB P-report in progress. Svensk Kärnbränslehantering AB.